Lower Minnesota River Model (LMRM)
Technical Meeting #7, June 7, 2007
Notes by Cathy Larson, Metropolitan Council

Twenty-six people, representing 11 organizations, attended the meeting. The groups represented were the Met Council, Carver County, EQB, HydrO_2 (consultant), MDNR, MPCA, NWA, PLSL Watershed District, U of M, USACE, and USGS. The meeting featured updates on modeling and research from the USA-ERDC, results of special river studies in summer 2006 from the MPCA and HydrO_2, and notes on modeling transparency and turbidity from Dr. Robert Megard, UM. Following are notes from the seven presentations:

Project Update (Cathy Larson, Met Council)

- An electronic or printed copy of the presentation is available upon request.
- Accomplishments. Since our initial planning session in February 2003, we have accomplished almost every monitoring objective recommended by the group. Many of the same cast of characters returned to St. Paul to present their results. We've completed the following over the past four years (Bravo, we did it!!):
  - Three years of specially designed river, effluent, and stream monitoring to gather data for the model, including continuous monitoring at Jordan and a meteorological station at Fort Snelling (MCES)
  - Field studies of ground-water inflows, sediment-bed characteristics, water-column mixing, and representative sampling (USGS)
  - Gaging station at Fort Snelling (USGS)
  - Research on nutrient bioavailability, phosphorus dynamics, sediment characteristics & fluxes, and nutrient & sediment budgets (USA-ERDC)
  - Two oxygen dynamics assessments (HydrO_2)
  - Two synoptic sonde surveys (MPCA)
- Budget. We owe thanks to our sponsors for supporting this work. The following six major sponsors have committed a total of $945,962 in funds and services to the LMRM project: Met Council, USACE, MPCA, USGS, LMRWD, and MAC. This does not include staff time for project management and other normal responsibilities.
- Schedule. The schedule is unchanged. The three-year monitoring program to support the model ended on September 30, 2006. Monitoring will continue at pre-LMRM levels. No special field activities are planned. The project has evolved from work in the field and lab to work on the computer: data evaluation, report writing, and modeling. Model calibration will continue through this year, with the goal of a fully tested model by the end of 2007. Final reports for the various projects will be completed this year and next.
- Next Meeting. Our next meeting will be held this fall (likely November). USA-ERDC will return to present the water-quality calibration of the CE-QUAL-W2 model and final results of the nutrient and sediment research. We invited Xcel Energy to present the results of the Black Dog environmental studies. MCES plans to run model projections next year, so this would be a good time to start discussing management scenarios to test.

CE-QUAL-W2 Modeling Update (Drs. David Smith and Barry Bunch, USA-ERDC)

- An electronic or printed copy of the presentation is available upon request.
- Dave presented the calibration results for the hydrodynamic models of water years 2004-2006. We are starting to develop the water-quality models, which will be presented this fall.
- In the model, the river is broken into a number of cells. In each cell, equations are solved that approximate water movement and quality while keeping a balance sheet on mass. At this time, the Lower Minnesota River Model is composed of 11,322 cells: 102 longitudinal segments from Jordan to the mouth by 111 vertical layers from top to bottom. CE-QUAL-W2 is a two-dimensional model with no lateral segments; results are laterally averaged. Segment lengths vary from 18.9 to 2321.4 meters, and layers are 0.2 m deep. This is a very fine scale that might be collapsed to improve execution time (3-4 days per year).
- The slope of the river changes near Savage and the beginning of the navigation channel. For this reason, the model is broken into two branches: Jordan to Savage and Savage to the mouth.
- Dave presented plots and statistics to compare model-calculated results with field-measured data for flow, stage, and temperature. Some of the key data sets for comparison are the continuous records at Savage (stage),

I35W bridge (temperature), and Fort Snelling (stage, flow, and temperature), but Dave looked at data from various sources, including MCES grab measurements. Stage readings at mid-Pool 2 provided a good substitute for Fort Snelling before the new station was deployed.

- The statistics included mean error, root mean square error, and absolute mean error. CE-QUAL-W2 has been applied to hundreds of systems, so ERDC has a good handle on what to expect for model performance.
- WY2004 (including the preceding three-month low-flow period): Stage prediction improves as you move downstream. Temperature prediction might be improved, especially in winter, but is reasonable. Flow prediction is excellent.
- WY2005 (better data): Stage prediction improves as you move downstream. Flow prediction is excellent. Temperature prediction is excellent.
- WY2006 (including late summer low flows): Again, stage predictions improve as you move downstream. Temperature predictions are good but some issues with ice formation are still occurring.
- The statistics for temperature would improve if the ice periods were removed. Summer is the critical period for low DO and eutrophication, which are priority issues for the LMR model.
- In the field, we did not witness many occurrences of vertical differences in temperature during the three years. Dave presented temperature profiles for select dates, which showed mixed results. The better test will be DO, where we measured vertical differences more often.
- Overall, ERDC is pleased with the hydrodynamics calibration and considers it nearly complete. They are ready to start work on the water-quality model as soon as MCES delivers the data inputs.
- Barry announced that we are proceeding with two optional tasks: adding variable stoichiometry (as in the Upper Mississippi River-Lake Pepin model) and enhancing sediment deposition and resuspension (to match the Minnesota River Basin Model). ERDC and MCES are scoping a third option: incorporating the Corps' NAVSED model to study the effects of barge traffic.
- Also on the table is modeling the historical years 1988-1991, which was in the original scope. Unlike the past three years, this historic period includes flows near the 7Q10 (weekly flows with a one-in-ten year occurrence), which is the regulatory flow against which waste load allocations and effluent limitations are determined. However, there was less data collected in 1988-1991 to support the model (e.g., no continuous data at Jordan and no flow at Ft Snelling). ERDC and MCES will weight these factors, the effort ("not trivial"), and others in their decision whether to model these years. We welcome feedback on this issue.

Nutrient and Sediment Research Update (Bill James, USA-ERDC)

- An electronic or printed copy of the presentation is available upon request. Note: SRP is soluble reactive phosphorus, also known as orthophosphate (PO_4) or dissolved inorganic phosphorus (DIP).
- In 2005 and 2006, MCES collected water and sediment samples from the lower Minnesota River and delivered them to the Eau Galle Aquatic Ecology Laboratory for analysis. An interim report on the 2005 results is posted on the LMRM Web site: www.metrocouncil.org/environment/Water/LMRM. Bill presented preliminary results for 2006 and compared them to 2005. Final results will be available later this year.
- Sediment Characteristics. In each of the past two field seasons, 24 sediment samples were collected from the lower 26 miles of the Minnesota River to analyze sediment characteristics, and 12 samples were collected to measure nutrient release rates in the lab. Sampling was stratified by river reach (miles 0-12 and 12-26) and sample type (60% sand-silt, 30% silt, and 10% sand) according to the sediment-bed map developed by the USGS and MCES. The samples represented a wide range of sediment characteristics. Moisture content (%) increased with the percent of silt and clay, while sediment density (g/mL) decreased. Total phosphorus (mg/g) increased with moisture, silt, and clay content (%). Concentrations of loosely- and iron-bound P (labile forms that readily become bioavailable under the right conditions) increased with total P concentrations. Concentrations of these two labile forms were significantly higher in 2006, possibly due to lower flows.
- Diffusive Flux. Mean P release rates under both oxic and anoxic conditions were higher in the 2006 sediment cores (oxic, 3.1 mg/m2/day; anoxic, 16.7 mg/m2/day). Individual cores displayed a wide range of rates, with anoxic rates roughly 3-4 times greater than oxic rates. P release rates showed the strongest relationship to iron-bound P concentrations. Did the settling of algae under low flow conditions fuel P release in summer 2006?
- Suspended Phosphorus. Bill examined the relationships of flow to TSS, chlorophyll, and various forms of suspended phosphorus in 2005 and 2006. As flows decreased, chlorophyll and particulate P concentrations increased. The composition of the suspended phosphorus also changed at lower flows, with increasing concen-

trations of labile forms (loosely-bound, iron-bound, and labile organic P). A shift from allochthonous generation of inorganic material from the greater watershed at higher flows to autothonous production of algae in the river at low flows may have occurred, increasing the portion of labile forms of suspended phosphorus.

- Equilibrium Studies. Eau Galle also studied equilibrium processes between P in water and P attached to suspended solids. One test attempts to find the SRP concentration at which phosphorus stops adsorbing to particles and starts to desorb. This is called the equilibrium phosphorus concentration (EPC). The results for 2006 were very different from 2005. In 2005, the EPC was similar to ambient SRP concentrations (means of 0.117 and 0.116 mg/L, respectively), suggesting that suspended solids were controlling SRP concentrations in the river. In 2006, the mean EPC was higher than mean river SRP concentrations (0.172 and 0.035 mg/L, respectively). Bill suspects this was due to higher algal levels in 2006 as the lysing of algal cells can interfere with EPC measurements. The EPC results from 2005 are probably the best to apply.
- Budgetary Analysis. Bill has just started work on the nutrient and sediment budgets for 2006. He presented a couple three-dimensional plots of TP and SRP by date and river mile during the late summer low-flow period. SRP concentrations were nearly zero at Jordan in late summer but increased to greater than 0.1 mg/L at Fort Snelling. Chlorophyll concentrations went the opposite direction, decreasing from Jordan to Fort Snelling. "A lot of things are going on." Bill will have more to present this fall.

Monitoring Highlights, 2006 (Cathy Larson, MCES)

- An electronic or printed copy of the presentation is available upon request.
- While river flows did not dip very far below normal last summer, they decreased below the 2000-cfs target set for special low-flow studies and monitoring. They fell below 2000 cfs at Jordan in late July and below 1000 cfs in early September. We completed the following work in summer 2006:
  - Seven weeks of intensive monitoring (more sites, more often) by MCES from July 24 to Sept 15.
  - Two assessments of oxygen dynamics by $HydrO_2$ on July 17-24 and Aug 31-Sept 4.
  - Two synoptic sonde surveys by the MPCA on July 18-24 and Aug 30-Sept 13.
- The special studies were covered in depth by the USA-ERDC, MPCA, and $HydrO_2$ at the meeting, so I just presented a few slides on algae.
- The Lower Minnesota River was hypereutrophic during June-September, 2006. At Jordan, viable chlorophyll-a concentrations were greater than 60 ug/L in 14 of 18 samples, greater than 150 ug/L in four samples, and a maximum of 270 ug/L in mid-August. Concentrations were lower at Fort Snelling, especially during the low-flow period; however, even here, 14 of 18 samples contained levels above 60 ug/L (maximum 180 ug/L).
- Phytoplankton biomass (mg/m^3) displayed a small peak in late July 2006; however, levels were higher in spring and much higher the previous fall. We saw a similar pattern in water year 2004: very high biomass peaks in fall and spring with a smaller peak in late summer.
- Blue-green algae increased to as much as 20% of the phytoplankton biomass at Fort Snelling in summer 2006, but they but did not dominate the algal community as they did on occasion in summer 2003, when there was a greater mix of algae. Diatoms dominated all samples in summer 2006.
- The LMRM monitoring program covered two low-flow periods: July-September, 2003 and 2006. However, flows did not reach the 7Q10 statistic of ~300 cfs in either summer, as they did in summer 1988.
- Special thanks were given to individuals who participated on the low-flow monitoring teams at MCES and MPCA, especially Scott Schellhaass, Tim Pattock, and Gary Rott.

Synoptic Sonde Surveys (Gary Rott, MPCA)

- Gary presented charts and photos from his report on the two sonde surveys, which will be posted at the LMRM Web site: www.metrocouncil.org/environment/Water/LMRM. The surveys were done in conjunction with the oxygen-dynamics assessments.
- A portion of the old dredged channel from Shakopee (RM 25.6) to Blue Lake WWTP (RM 20.5) is returning to its natural shape. Their boat's hull hit bottom around mile 22.5.
- Sondes were placed at various locations to continuously record DO, pH, temperature, and conductivity for a period of time. Lessons learned from the first survey in July benefited the design of the second survey in September. At most locations, two sondes were deployed: one at the center of the photic zone and one midway between this point and the river bed. The photic zone was generally only two to three feet.

- In both surveys, DO concentrations decreased as the river moved downstream. In July algal activity resulted in supersaturated conditions and diurnal DO fluctuations of approximately 4 mg/L at the upstream sites to 1.5 mg/L near the mouth. In September, pH also consistently decreased from the upstream to downstream sites, which may be explained by decreasing algal activity. In both surveys, temperature increased noticeably after the Black Dog Generating Plant's cooling-lake outfalls.
- Cloud cover was a factor in DO concentrations, with the highest concentrations recorded on clear days and levels dropping off on cloudy days.
- In July there was little difference in DO between the upper and lower sondes at Jordan, but there was a wide difference at Fort Snelling, especially during the day. The river appears more mixed at the upstream sites than near the mouth.
- Gary showed photographs of thick biological growth on the equipment during the July survey. Below six feet, however, nothing grew on the chains. Less growth was noted in September.
- MCES is required to super aerate the effluent at the Seneca WWTP during the summer when the weekly average flow falls below 1200 cfs. On four days in September 2006, the MPCA measured some apparent oxygen losses near the end of the outfall pipe. Bank-to-bank mixing occurred within a mile or so downstream.
- Gary compared data collected by the MPCA on 8/30/06 to data collected by the USGS on 8/21/03 under similar field conditions. DO concentrations fell below 5 mg/L at miles 8.5 and 3.5 in the earlier study. DO concentrations were higher in the MPCA study, possibly due to higher levels of algae.
- Algal health appeared to decline as the river approached the mouth, as evidenced by an increasing portion of as pheophytin-a to total chlorophyll-a from Jordan to Fort Snelling.
- Q: Did we collect enough data to understand the river at 7Q10? A: Yes, Gary expects reaeration and algae to drive DO at 7Q10, not the WWTPs.

Oxygen Dynamics Assessment (Philip Murphy and Mark Koenig, HydrO$_2$)

- An electronic or printed copy of the presentation is available upon request. HydrO$_2$ completed their final report, which will be posted at the LMRM Web site: www.metrocouncil.org/environment/Water/LMRM. Some of the following notes were taken from the summary in HydrO$_2$'s final report.
- In their assessment of oxygen dynamics, HydrO$_2$ measured various rates in order to complete a budget of oxygen sources and sinks. Measurements included reaeration rate coefficients, sediment oxygen demand rates, water-column production and respiration, and community oxygen metabolism.
- Field measurements help put bounds on rates applied in the model and improve model defensibility. For example, HydrO$_2$ compared measured reaeration rate coefficients from their many studies to values predicted by five formulas commonly applied in water-quality models. There was poor agreement.
- Reaeration is the exchange of oxygen between the river and atmosphere. HydrO$_2$ applied two techniques for measuring reaeration: krypton gas tracer and diffusion dome. The gas technique could not be applied in the lower reaches due to interference by discharges and intakes. Side-by-side runs in the Lower Minnesota River and other streams demonstrate that the two techniques yield comparable results.
- The reaeration rate coefficient ranged from 0.4 to 1.2 per day in the July survey and from 0.2 to 1.7 per day in the September survey. These values are typical of slow-moving deep water.
- The role of reaeration in the oxygen budget in July was very surprising: it was a sink not a source of oxygen to the river. HydrO$_2$ personnel had not seen this in previous work. Because the river was supersaturated with oxygen due to algal activity, reaeration allowed some of this excess gas to escape to the atmosphere up to a maximum of 1.8 mgO$_2$/L/day at miles 11 and 15. Conditions were more typical of rivers in September, where reaeration served as a source of oxygen up to a maximum of 0.63 mgO$_2$/L/day at miles 1.2 and 6.7.
- Sediment oxygen demand (SOD) rates measure biological and chemical oxygen-consuming processes in the river bed. With one exception, the rates were low to moderate (less than 3 gmO$_2$/m^2/day) in the lower Minnesota River compared to other SOD studies. Receding flow between July and September appeared to have a notable influence on SOD rates at RM-11.2 and RM-15, where rates increased as flow receded. This was consistent with the diver-observed increase in soft substrate at the sediment-water interface in September. The SOD rates ranged from 0.21 to 4.00 gmO$_2$/m^2/day at six sites in July and from 1.52 to 2.76 gmO$_2$/m^2/day at three sites in September 2006.
- In the lower Minnesota River, light attenuation through the water column is a major factor affecting DO metabolism. Gross primary production is not possible without the benefit of photosynthesis, and visible light is an

essential requirement for this process. Light transmission profiles revealed that the euphotic zone was limited by suspended material to a depth of about 2.5 to 3.0 feet in July and about 2.5 to 3.5 feet in September.

- Concentrations of chlorophyll-a indicated an abundance of phytoplankton throughout the study reach, but it was in a declining mode from July to September. The chlorophyll data, particularly for the latter study period, suggests that less viable forms of phytoplankton were aggregating in bottom water and settling to the sediments. While phytoplankton numbers were high, their net effect on DO concentrations was often negative.
- A significant decline occurred in gross primary production (GPP) between July and September. Attendant respiration (R) also decreased but to a lesser extent. When GPP and R rates are viewed in terms of P:R ratios, the metabolism of the water column was progressing from an autotrophic (P:R > 1) to a heterotrophic (P:R < 1) state during the study period. This change, as reported, simply indicates a normal integrate response to the effects of seasonal reduction in the solar energy and associated visible light regime.
- The restricted depth of the euphotic zone in the study reach coupled with a decline in solar energy appeared as the factors limiting the GPP potential of the phytoplankton community. With significant reduction in the river flow and a commensurate expansion of the euphotic zone to greater depths during the annual peak period of solar radiation, a significant increase would likely occur in the phytoplankton GPP and water column R rates.
- Community substrate oxygen demand (CSOD) represents respiration across all substrates, not just the sediment bed. Due to the complex hydrodynamics of the lower reach, CSOD could only be measured near Shakopee and Jordan. As expected, CSOD exceeded SOD at the two sites, providing additional confirmation of the SOD rates.

Physical and Statistical Models for River Transparency and Turbidity (Dr. Robert Megard, U of M)

- An electronic or printed copy of the presentation is available upon request. Once completed, Dr. Megard plans to submit his research for publication.
- In part for the Lake Pepin TMDL Study, Bob has been working on statistical and physical models to describe hydrologic optics in the Mississippi River and improve our understanding of transparency, turbidity, and the role of suspended sediment. In theory, relationships developed for the Mississippi River could be applied to rivers all over the world because the underlying physics are the same. Bob has worked mainly with data from ERDC-Eau Galle and MCES, which includes data from the Minnesota and St. Croix Rivers.
- This work is based on the Lambert-Bouger Law on light attenuation in water. Total attenuance is the sum of partial attenuators, including the water itself, dissolved organic carbon, organic suspensoids (phytoplankton, zooplankton, detritus, etc.) and inorganic suspensoids (soil particles).
- Using measurements of dissolved organic carbon, total suspended solids, volatile suspended solids, and chlorophyll, Bob has developed a nonlinear equation relating algal organic solids, non-algal organic solids, inorganic solids, and dissolved organic carbon to Secchi transparency. He considers the Secchi disk the "most reliable optical device." Other findings follow.
- Suspended solids and transparency are lowest in winter.
- Suspended solids have the same effect on transparency in the Minnesota and Mississippi Rivers.
- Concentrations of inorganic suspended solids usually exceed those of organics; however, non-algal organic suspended solids have the biggest effect on light attenuation in the three rivers. Inorganics may scatter light, but organics may both scatter and absorb light.
- Bob is also working on relationships between turbidity and suspended solids and between Secchi transparency and turbidity.
- MCES may send additional data for the lower Minnesota River for Bob to explore, although the current formulas should apply. This is timely because we will be working heavily on the water-quality models in the upcoming months, and light is bound to be an important factor. Barry Bunch said the CE-QUAL-W2 model can easily be adapted to Bob's light formulations.

Web Site for the Lower Minnesota River Model

These notes and other documents are posted at www.metrocouncil.org/environment/Water/LMRM.