LOWER MINNESOTA RIVER
OXYGEN DYNAMICS ASSESSMENTS

July 17 - 24, 2006
August 31 - September 4, 2006

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HydrO$_2$ extends our sincere thanks to Ms. Cathy Larson, MCES, for her superb effort in coordination of this project, along with her support in the field. The assistance, advice, and input of local knowledge about the Minnesota River by Mr. Gary Rott, MPCA, and Mr. Scott Schellhaass, MCES, was invaluable. The logistical and field support provided by the numerous MCES and MPCA personnel listed above was essential to the success of the project and is truly appreciated by the partners of HydrO$_2$.

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DEFINITIONS

Reaeration (Ka): the transfer of oxygen from the atmosphere to the river.

Diffusion: the movement and mixing of oxygen molecules and, as it applies to the Minnesota River studies, the rate of transfer of oxygen across the air/water interface.

Total community oxygen metabolism (TCOM): diel (around-the-clock) measurement of oxygen gains and losses in the river from all sources and sinks in the air, water, and sediment.

Water-column production and respiration: oxygen gains and losses in the water column due mainly to the activities of floating algae or, in the case of respiration, the input of oxygen-demanding material from allochthonous sources.

Community substrate oxygen demand (CSOD): the loss of oxygen due to biochemical processes across all substrates, including sediment, rocks, logs, and aquatic plants.

Sediment oxygen demand (SOD): the loss of oxygen due to the decomposition of organic matter in the sediment bed (an important component of CSOD).

Autotrophic: as it applies to aquatic community production and respiration, a system that through photosynthesis produces more carbon than is consumed through respiration.

Heterotrophic: as it applies to aquatic community production and respiration, a system that through photosynthesis produces carbon in an amount insufficient to meet the respiration demands of the system and thereby depends on the import of carbon from allochthonous sources to meet these demands and support secondary productivity.

ABBREVIATIONS AND ACRONYMS

CSOD	**Community substrate oxygen demand**
DO	**Dissolved oxygen**
GPP	**Gross primary production**
Ka	**Reaeration**
MCES	**Metropolitan Council Environmental Services**
MPCA	**Minnesota Pollution Control Agency**
NPP	**Net primary production**
P:R	**Gross primary production : respiration**
R	**Respiration**
RM	**River mile**
SOD	**Sediment oxygen demand**
TCOM	**Total community oxygen metabolism**
USGS	**US Geological Survey**

SUMMARY

The oxygen dynamics studies provide a comprehensive assessment of the critical compartments associated with the dissolved oxygen regime of the lower Minnesota River during the periods of July 17-24 and August 31 - September 4, 2006. The parameters of primary interest that were measured throughout the study reach included

- Reaeration (Ka), which is the exchange rate of oxygen between the atmosphere and the river,
- Diel dissolved oxygen (DO) concentrations and DO percent saturation for assessment of total community oxygen metabolism (TCOM) and computation of community substrate oxygen demand (CSOD),
- Sediment oxygen demand (SOD), which is a measure of the bottom sediment consumption of dissolved oxygen from the water column,
- Gross primary production (GPP) by suspended phytoplankton in the water column,
- Respiration (R) associated with biological activity and chemical oxidation in the water column,
- Light transmission for delimiting the euphotic zone, defined as that portion of water column where one-percent or more of light is available for photosynthesis,
- Daily solar energy, and
- Chlorophyll-a for its potential relationship with water column production and respiration.

All of the above parameters and their associations proved to be critical considerations in evaluating the present and future DO regime of the lower Minnesota River.

Reaeration rate coefficients measured by both the noble gas krypton method and a comparable diffusion dome technique provided Ka rates throughout the study reach. Ka rates were considered typical for deep, slow moving waters at the flows investigated.

Sediment oxygen demand rates were measured and reported for the primary sediment types that are characteristic of the study reach as determined by sediment mapping. With one exception, the rates were low to moderate when compared to other SOD data bases. Receding flow between July and September appeared to have a notable influence on SOD rates at river miles 11.2 and 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.

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. Visible light is an essential requirement for this process. Light transmission profiles revealed that the euphotic zone was limited to a depth of about 2.5 to 3.0 feet in July and about 2.5 to 3.5 feet in September. More importantly, the depth of the euphotic zone was limited to an average of 20 and 31 percent of the water column during the respective study periods. With reduction in flow from July to September, clarity of the water improved slightly in the lower reach of the study area. 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 September study period, suggest that less viable forms of phytoplankton were aggregating in bottom water and settling to the sediments.

Even with declining concentrations, the magnitude of the chlorophyll-a values would indicate that the abundance of phytoplankton represented hypereutrophic conditions. However, study results relative to production-to-respiration (P:R) ratios show this not to be the case. Measured GPP rates demonstrated a significant decline occurred in production between July and September. Attendant respiration 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 to a heterotrophic state during the study period. P:R ratios were greater than one at two of six stations in July, while they were less than one at the other four stations in July and at all six stations in September. A ratio of one or greater

indicates that the photosynthetic processes of the phytoplankton community synthesized sufficient DO and organic carbon (carbohydrates) to meet or exceed the respiration demands in the water column, hence an autotrophic state. A ratio of less than one indicates that the process of photosynthesis yields insufficient DO and organic carbon to meet the demands of respiration, hence a heterotrophic state. This change, as reported, simply indicates a normal integral response to the effects of seasonal reduction in the solar energy and associated visible light regime.

Total daily solar radiation declined significantly during the study period. Solar radiation in terms of visible light energy per day during the July sampling period was more than twice the level encountered in the September sampling period. The slight improvement in the water clarity commensurate with flow reduction was not sufficient to offset the effects of seasonal reduction in total solar radiation. 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.

INTRODUCTION

Metropolitan Council Environmental Services (MCES), with the cooperation and participation of multiple partners, is developing a water quality model of the lower 40 miles of the Minnesota River. The segment of the river under focus meanders from Jordan, Minnesota, to the confluence of the Minnesota River with the Mississippi River. At issue are DO concentrations under summer low flow conditions and the river's ability to assimilate waste loads, specifically nutrients and oxygen-demanding components.

In the spring of 2004, MCES contracted with HydrO_2, Incorporated, Athens, Georgia, to conduct an assessment of oxygen dynamics at target flows of 1500 cubic feet per second (cfs), with an optional assessment at further reduced flows near 1000 cfs. With the field assessments being flow dependent, the contract spanned a three-year period, 2004-2006, in anticipation of potential weather and flow impacts on study scheduling. Such a strategy was indeed needed, as the initial target flow of 1500 cfs was not realized during the summers of 2004 and 2005. In consultation with the Minnesota Pollution Control Agency (MPCA) and HydrO_2, MCES amended the target flow of 1500 cfs to 2000 cfs for the final year of the contract. Suitable conditions prevailed during 2006 with the target flow of 2000 cfs coming in July. The comprehensive assessment of various oxygen dynamics rates was accomplished during July 17-24, 2006, at an average flow of 2220 cfs near Jordan, Minnesota. Following a temporary spike in flow immediately following the July effort, flows continued to recede and the second, but somewhat less intensive, survey was accomplished at an average flow of 966 cfs during the period August 31 - September 4, 2006.

In addition to assessing oxygen dynamics, MCES has an interest in nutrient inputs from point and nonpoint sources to the Minnesota River, including potential contributions from the sediment bed. To address this component of river nutrient loading, MCES acquired the assistance of the U.S. Army Engineer Research and Development Center's Eau Galle Aquatic Ecology Laboratory in Spring Valley, Wisconsin. Partitioning and flux of nutrients associated with river bed sediments were conducted using laboratory core analyses by the Eau Galle laboratory. In support of the assessment of sediment nutrient flux, MCES expressed interest in HydrO_2's capability for *in situ* measurement of sediment nutrient flux using the *in situ* chamber method associated with SOD measurements. To initially address concerns of maintaining the chamber-to-substrate seal over a long duration, incubation time requirements, and laboratory analytical capabilities that would govern the success of any future comprehensive *in situ* sediment nutrient flux study, HydrO_2 and MCES cooperated in a pilot study targeting only one station at which SOD measurements were already planned. This effort conducted in conjunction with the second oxygen dynamics assessment in September 2006 proved very successful, with results presented in Appendix E.

TASKS AND METHODS

The rates of various processes affecting DO concentrations in the lower Minnesota River were measured. Measured rates included the following:

- Reaeration rate coefficients
- Oxygen diffusion at the air/water interface
- Total community oxygen metabolism
- Gross and net primary production and respiration in the water column
- Sediment oxygen demand
- Community substrate oxygen demand

Measurements were conducted according to methods presented in the plan of study for the project (HydrO$_2$, 2004). Study tasks and methods are briefly described below along with salient statements regarding field conditions that affected the utility of, and deviation from, planned methods. Refer to the plan of study for more information on the methods.

Reaeration and Diffusion

Reaeration was measured in a reach from river mile (RM) RM-38.7 near Jordan to RM-18.9 using the non-radioactive krypton method in which noble (inert) krypton gas is injected via diffusers into the stream at the stream bottom in concert with a Rhodamine wt dye tracer. The gas and dye were injected near mid-stream offshore of the boat ramp at Highway 9, near Jordan. Monitoring for dye was conducted using an on-board flow-through fluorometer. Sampling for krypton and argon occurred at successive downstream dye and tracer gas plateaus using a specialized sampling device that avoids aeration of the sample.

Diffusion of oxygen at the air/water interface was measured at selected reaches from RM-38.7 to the confluence with the Mississippi River using the floating dome method originated by Copeland and Duffer (1963) and Hall (1970) as modified by HydrO$_2$ personnel. This method involves the simulation of oxygen deficits between the floating dome and water column that represents the oxygen deficit between the river and atmosphere. The transfer of oxygen between the dome and water is measured via sensors. The dome was floated through reaches where the krypton gas method was used for comparison, but most importantly, where the dome was the required method to overcome the obstacles of flow modulation and the effects of withdrawals and discharges prevalent throughout much of the river segment being studied. Significant flow modulation, withdrawals, and discharges precluded the effective use of a gas/tracer method.

Total Community Oxygen Metabolism

TCOM assessment was a cooperative effort involving MPCA and HydrO$_2$ personnel. It requires definition of the diurnal oxygen curve in conjunction with oxygen saturation deficits and measurement of oxygen diffusion to account for gain or loss of oxygen at the air/water interface. Data analysis for determination of total aquatic community GPP and R is accomplished using the diel curve method (Odum and Hoskins, 1958). The effectiveness of this method is dependent upon consistent water quality and hydrological conditions through the assessment period to assure a constant and accountable water history. The MPCA acquired the diel DO data through deployment of data logging sondes, while HydrO$_2$ measured reaeration and diffusion necessary for correction of DO rates of change. As will be discussed in the Results section of this report, the dynamic conditions in the lower half of the study reach, the apparent or presumed effect of various discharges and withdrawals, and sonde sensor malfunction confounded data interpretation, hampering assessment of TCOM at several stations during both periods.

Sediment Oxygen Demand

SOD measurements were conducted using the *in situ* chamber method developed by Murphy and Hicks (1986). Opaque chambers are set and sealed to the stream bottom by a diver and the decay rate of oxygen concentrations within the chambers is recorded over a time period sufficient to produce a regressed slope of the observed reduction in DO. Each chamber is corrected for water column respiration within each chamber to isolate the actual SOD. SOD measurements were conducted at all six stations during the July study, while only three stations were revisited during the September effort.

Water Column Production and Respiration

Measurements of GPP, NPP, and R rates within the water column were conducted in general accordance with the light-and-dark-bottle oxygen method (APHA, 1999). Delimiting of the euphotic zone was accomplished using a marine photometer for determination of the percent of total visible light transmitted through the water column. Filling and deployment of paired light and dark bottles at various depths and light percentages facilitate computation of primary production rates within the euphotic zone, as well as the respiration rate for the entire water column at the station. Continuous records of daily solar energy were acquired with a recording pyrheliometer and used for normalization of production rates per unit of solar energy. Non-composited chlorophyll-a samples were collected at each light bottle deployment depth and analyzed by MCES in order to assess chlorophyll-a distribution through the euphotic zone.

Community Substrate Oxygen Demand

CSOD represents the respiration associated with all substrates within a stream reach, not just the sediment bed. It is a calculated value derived from the results of the diel curve method for determining total community R appropriately corrected for atmospheric diffusion, followed by subtraction of water column R determined from the dark bottle method. With accurate accounting and partitioning of other oxygen demanding, producing, and accrual processes during the diel period, and application of stream reach average depth, CSOD can be estimated. Conversely, where the utility of the diel curve method is compromised by changes in history of the water, computation of CSOD is, likewise, flawed. Accordingly, computation of CSOD was limited to the uppermost stations of the study area.

DATA QUALITY STATEMENT

To collect the required set of information, several activities were conducted simultaneously on a daily basis within the defined reaches or at stations positioned through the lower 40 miles of the Minnesota River. Monitoring followed the standard operating procedures of HydrO$_2$ (2002) unless otherwise noted in the field notes.

Factors influencing data quality for reaeration measurements are stable flow conditions, efficiency of gas solubility and subsequent downstream mixing, assured sampling on the gas/dye concentration plateau, and laboratory analytical precision. Factors affecting accurate measurement of diffusion rates are flow stability, temperature control of the diffusion dome environment, and DO meter calibration and stability. The reaeration records and supporting data (stage recordings, dye concentrations curves, and gas analytical reports) subsequently following in this report reveal that these conditions prevailed throughout the field and analytical stages of this study unless otherwise noted. Likewise, the raw data in Appendix A reveal that the diffusion measurement was accompanied by stable flow and good temperature control of the dome environment. End calibration checks of the DO monitors revealed optimal performance without drift.

Factors affecting quality assurance of SOD rate measurements lie primarily with maintaining calibration of the DO monitoring equipment during the course of the measurements, which generally range between 90 and 280 minutes. Accuracy of the meter's measurement of DO concentration is assured through initial Winkler-method calibration of the instrument before deployment, followed by end calibration checks, again via the Winkler method, to assure that meter “drift” does not encumber the measurement of the SOD rate. As revealed in the raw field data, including calibration records, DO meter performance was optimal throughout the study. During the course of the measurements, performance characteristics within each chamber were closely monitored to assure chamber-to-substrate seal integrity and possible resuspension at the early stage of data recording. Where resuspension is identified in data analysis, rates are adjusted accordingly as noted in data analysis records. Resuspension of sediments during the course of these efforts was not a factor.

Diel DO monitoring for use in the TCOM assessment is dependent on the performance of sondes and their associated sensors. Data provided by the MPCA were obtained from multi-parameter sondes. Sonde performance characteristics were identified via pre- and post-calibration records. Reported GPP and R rates are limited to those sonde records that met the requirements of HydrO$_2$’s standard operating procedures.

STATION LOCATIONS

As previously stated, the study area was that portion of the Minnesota River from Highway 9 at the city of Jordan (RM-39.4) downstream to the river’s confluence with the Mississippi River. Reaeration and diffusion were measured through various reaches of the river. Other oxygen dynamic measurements were conducted at specific stations selected according to their position relative to various point source discharges or withdrawals, as well as earlier sediment bed mapping by the US Geological Survey (USGS) and MCES. Figure 1 presents an overall depiction of station locations along with influential point sources. Additional mapping of reaeration and diffusion-dome float reaches are presented in the Results section related to those efforts. Table 1 presents station GPS coordinates where SOD, GPP, R, and attendant parameters were measured. Sonde deployment was proximate to the Table 1 coordinates, generally within sight of the SOD stations.

River mile (RM) numbers were estimated based upon navigational aides. Following the initial first day reconnaissance, as well as subsequent fathometer cross-section recordings prior to chamber deployment, it was necessary to shift station locations upstream or downstream from those originally estimated in the plan of study for various reasons such as navigability upstream, suitable deployment slope for chambers, and avoidance of barge traffic.

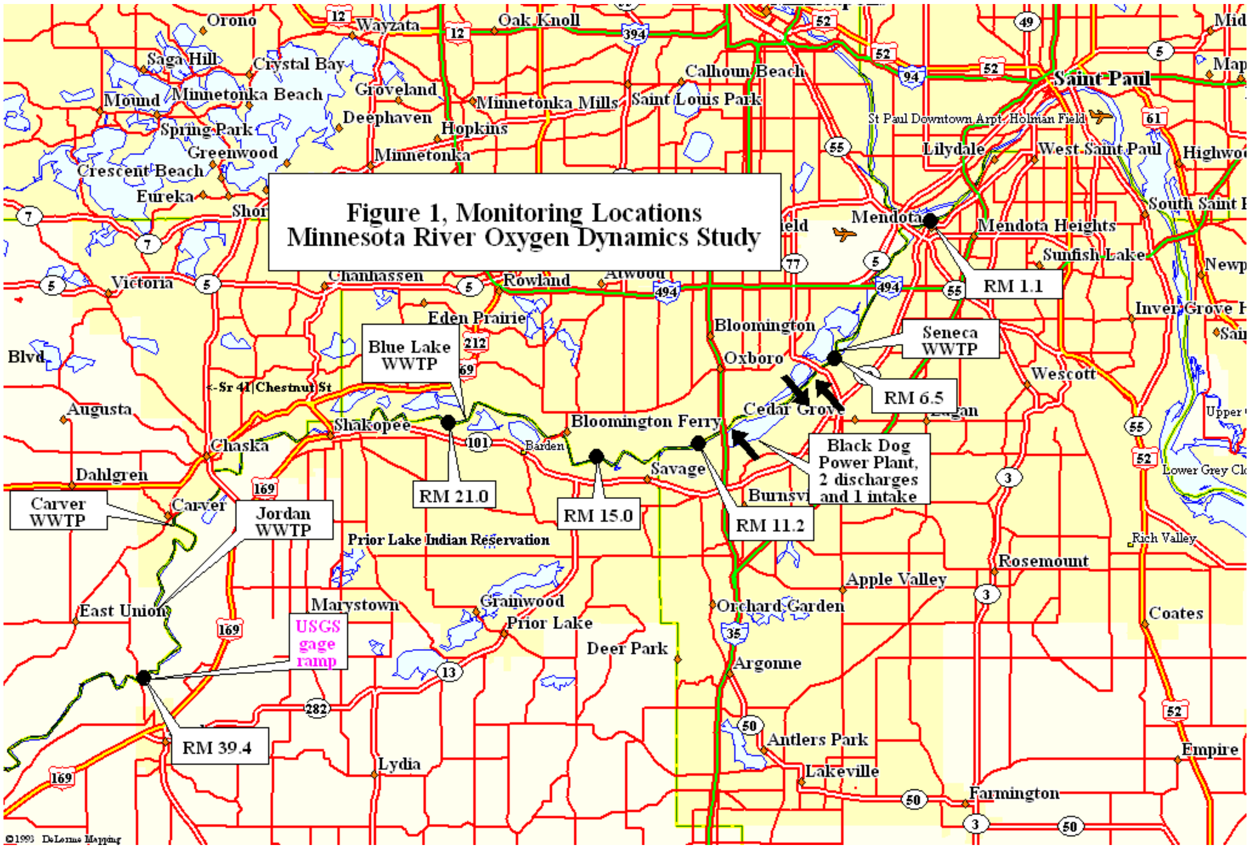

Figure 1, Monitoring Locations
Minnesota River Oxygen Dynamics Study

Table 1 – Station Descriptions	Latitude		Longitude	
	DEG	MIN	DEG	MIN
RM-39.4: Downstream of Hwy 9 Bridge near Jordan, MN; maximum depth – 17 feet; sharply incised off south bank and sloping upward toward north bank; depth at deployment site off north bank – 9 feet.	44	41.578	93	38.417
RM-21: Maximum depth – 16 feet; sharply incised off south bank and sloping upward toward north bank; depth at deployment site off north bank 6 – 9 feet (sloping); remnants of abandoned dredged navigation channel.	44	48.189	93	27.352
RM-15: Maximum depth 13 feet; generally uniform channel cross-section; depth at deployment site off south bank – 11 feet; dominant features of old dredged channel remain; current dredged channel begins at RM-14.7.	44	47.339	93	21.960
RM-11.2: Maximum depth – 11 feet; generally uniform channel cross-section; depth at deployment site off south bank – 11 feet; within currently maintained dredged channel.	44	47.650	93	18.305
RM-6.5: Upstream of Seneca WWTP discharge; maximum depth – 15 feet; sharp incision near banks, generally uniform center channel; depth at deployment site of north bank – 13 feet; within currently maintained channel.	44	49.832	93	13.384
RM-1: Downstream of airport discharges; maximum depth – 12 feet; generally uniform cross-section; depth at deployment site off south bank – 11 feet; within currently maintained channel.	44	53.380	93	09.942

RESULTS

Reaeration Rate Coefficients

Streeter and Phelps (1925) wrote: "In polluted streams the draft imposed upon the dissolved oxygen supply by the progressive satisfaction of the oxygen demand reduces the oxygen content below its saturation value; but as soon as this depression occurs, absorption of oxygen from the atmosphere follows." This process of oxygen absorption is commonly referred to as stream reaeration. Later Tsivoglou (1967) stated: "The ability of a flowing stream to obtain oxygen from the limitless resources of the atmosphere is the fundamental process by which a stream is able to purify itself once it has been polluted with organic waste." Knowing that DO is the driving force in the natural stream purification process, it becomes paramount to accurately quantify the rate of oxygen replenishment.

Reaeration rate coefficients were measured during both the July and September studies of the Minnesota River. Results are summarized in Table 2 and Figures 2 and 3. Reaeration rate coefficients were reported to the base e. The July study included the use of two different techniques for measuring reaeration rate coefficients. A noble gas tracer technique was used for the upper 19.8-mile segment of stream between river miles 38.7 and 18.9. The HydrO_2 technique represents an advancement of Tsivoglou's (1967) method. The computations and supporting documentation for the results in Table 2 can be found in Appendix A. In the lower segment of the river, an alternate diffusion dome technique was employed in both the July and September studies to measure reaeration rate coefficients. The diffusion dome technique can provide accurate measurements of reaeration rate coefficients even with the adverse effects from recirculation at the Black Dog Power Plant and the dynamic hydraulic control at the lock and dam downstream on the Mississippi River.

Table 2
Reaeration Rate Coefficient Data
Lower Minnesota River
Minneapolis, Minnesota
July 17-24 and August31-September 4, 2006

July 17-24, 2006 Study @ 2200 cfs

	River Reach (miles)	Wind Speed (meter/sec)	Ka @ 20 C (1/day)
Reaeration Rate Coefficients determined by Krypton Technique			
MR2-MR3	36.3-21.5	0.5	0.84 (3)
MR3-MR4	21.5-18.9	0.5	0.61(1)(3)
Reaeration Rate Coefficients determined by Diffusion Floats			
Float # 1	20.0-18.7	0.2	0.54 (1) (2)
Float # 6	21.0-18.7	0.6	0.53 (2)
Float # 2	15.5-14.6	0.8	0.52
Float # 3	12.0-10.0	0.9	1.17
Float # 4	8.8-8.6	2.6	1.16
Float # 5	7.4-6.5	1.0	0.42
Float # 7	5.0-0.0	1.2	1.04

(1) indicates comparison of krypton vs. dome techniques
(2) indicates comparison between lower and higher winds
(3) Indicates wind measured at fixed station , not on boat

August 31-September 4, 2006 Study @ 966 cfs

	River Reach (miles)	Wind Speed (meter/sec)	Ka @ 20 C (1/day)
Reaeration Rate Coefficients determined by Diffusion Floats			
Float # 6	39.6-38.7	0.3	1.34 (4)
Float # 7	19.2-15.9	0.5	0.16
Float # 3	16.0-15.7	0.6	0.46
Float # 4	10.3-10.2	0.9	0.31
Float # 5	9.4-9.2	1.4	1.65
Float # 1	4.5-2.8	1.3	0.31
Float # 2	1.1-0.9	2.1	0.58

(4) indicates heavy rain thoughout float

In order to provide confidence in the reaeration measurements, a single overlapping river segment, RM-21.5 – RM-18.9, was measured with both techniques (Table 2). A difference of 12% was noted between the two techniques with the dome method producing slightly lower results. This individual comparison is within the typical range of about 15% deviation experienced in technique comparisons over time. The length of the diffusion reach was somewhat shorter but characteristic of the overall reach measured. A more exact comparison was re-measured at a higher wind condition with almost the same Ka results, 0.54/day versus 0.53/day.

The wind plays a part in affecting the stream reaeration rate coefficients. The high river banks at low flow tend to orient the wind along the longitudinal axis of the river. Wind measurements reported in Appendix A were taken in the monitoring boat at a height of about four feet above the water surface. The only exception was for the krypton-based reaeration measurements, where MCES wind measurements at the river's edge at RM-3.5 were used.

A graphical presentation of the rate coefficient results for July (Figure 2) shows a riverine system flowing at about 2,200 cfs with low rate coefficients less than 1.2/day. The reaeration rate coefficients were even lower in September (Figure 3) as the Minnesota River was flowing at less than 1,000 cfs. It was expected that the Minnesota River at low flow would have low reaeration rate coefficients. This is typical of deep, slow moving waters. Stream reaeration is a direct function of the amount of turbulence and little turbulence was evident in the lower Minnesota River except in the area of Carver Rapids in the upper study reach.

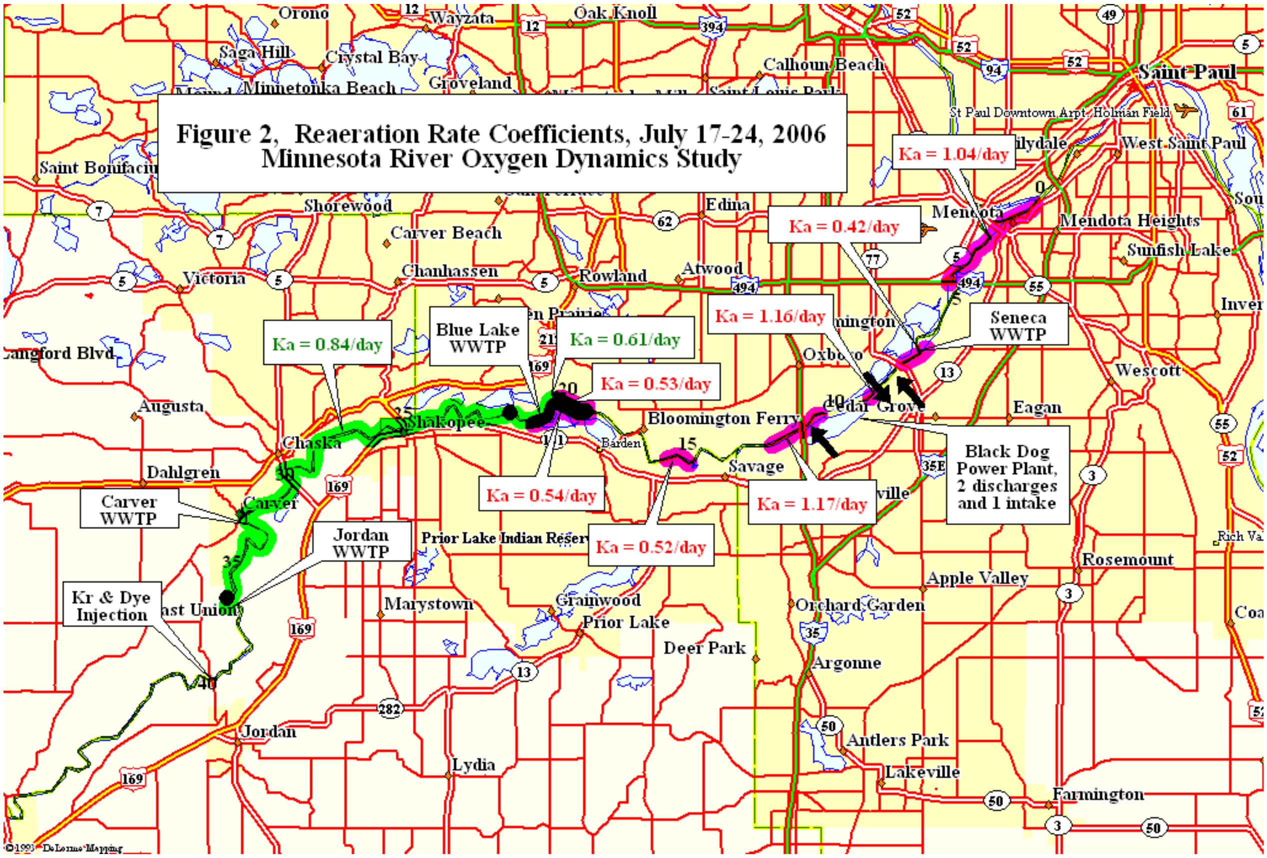

Figure 2, Reaeration Rate Coefficients, July 17-24, 2006
Minnesota River Oxygen Dynamics Study

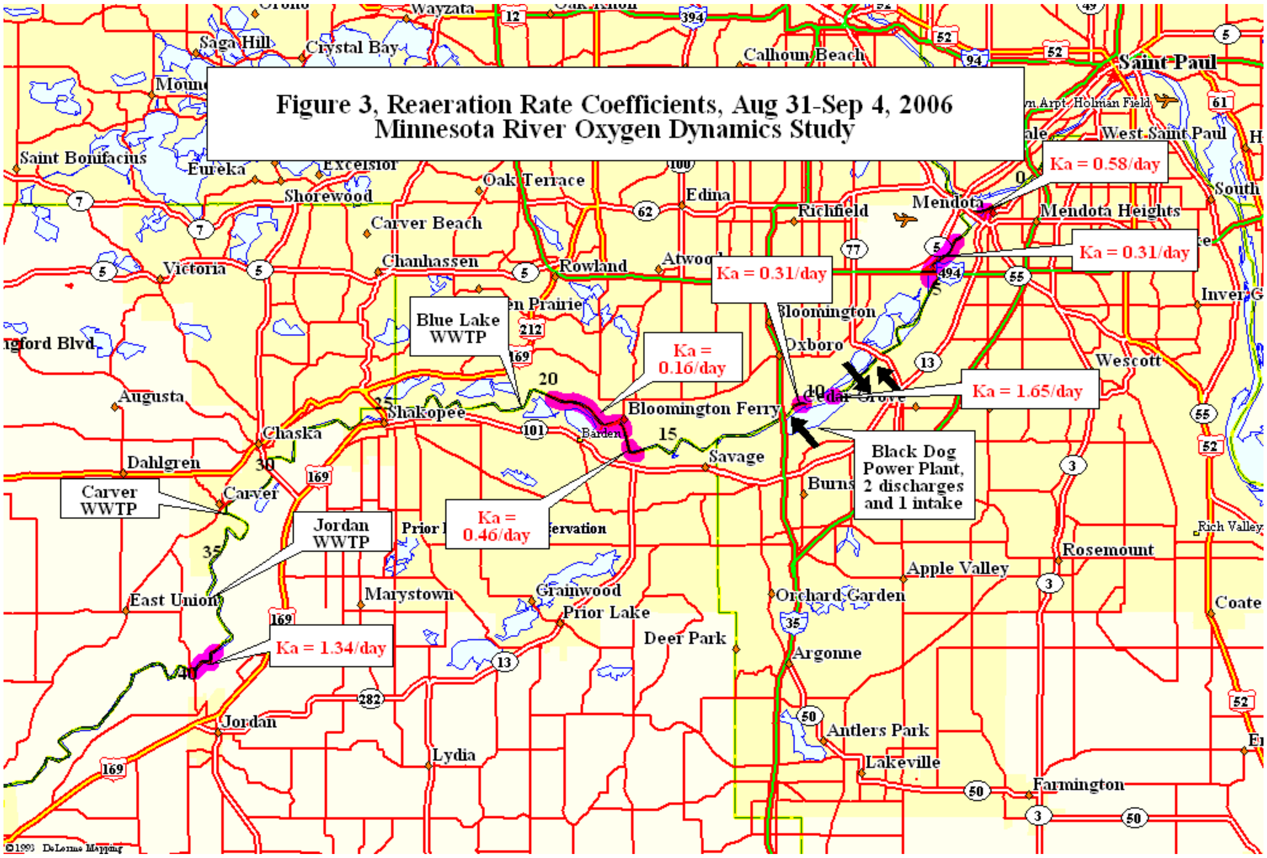

Figure 3, Reaeration Rate Coefficients, Aug 31-Sep 4, 2006
Minnesota River Oxygen Dynamics Study

Reaeration is typically thought of as a process that is a source of stream DO. Reaeration is computed as the rate coefficient multiplied by the water column DO deficit. A comparison of the reaeration results for the two Minnesota River studies revealed an unusual occurrence (Figure 4).

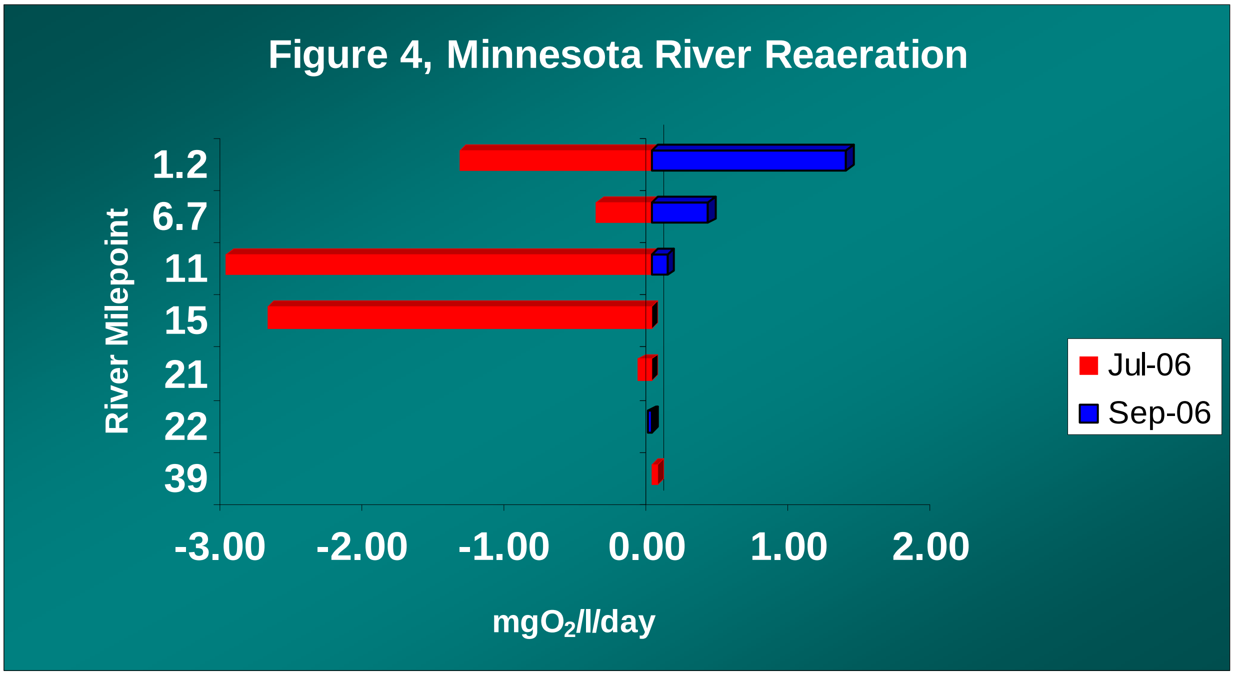

Figure 4, Minnesota River Reaeration

During the July study the river was supersaturated with DO in the lower reach. This supersaturated condition resulted in the reaeration process off gassing DO from the water column to the atmosphere. In the area from mile points 15 to 10, the river was losing as much as 1.8 mgO$_2$/L/day. In total contrast, during the September study, the lower portion of the river was experiencing a deficit of DO. Now the river was taking on oxygen from the atmosphere into the water column at a maximum rate of about 0.63 mgO$_2$/L/day.

In situ Sediment Oxygen Demand

SOD was measured at all six stations presented in Table 1 and Figure 1 during the July 2006 study. MCES requested that stations RM-21, RM-15, and RM-11 be revisited during the September 2006 study. Three replicate SOD chambers were deployed in contact with the sediments at each station. Additionally, a "blank" chamber (Rep. 0), identical in size and configuration but with a sealed bottom isolating the enclosed bottom water from sediment processes, was deployed alongside the sediment contact chambers and filled with bottom water for monitoring of water column respiration alone. Achievement of three replicate SOD rates was successful at all stations during both studies with two exceptions. In July at RM-21, river current eroded the chamber-to-substrate seal on one chamber. In July at RM-39.4, where all rates were rather negligible, the DO concentration in the Rep. 3 chamber showed no change even though maintenance of seal integrity throughout the deployment was confirmed by a diver. Accordingly, the results of these chambers were excluded from the data pool. All SOD rates are reported at the average water temperature measured during chamber deployment, as noted on the respective figures and tables in Appendix B.

Based on USGS and MCES sediment mapping of the lower 26 miles, the sediment bed is dominated by sand and sand/silt sediments with sparse areas of mixed sand, silt, and gravel. Diver observations during deployment of *in situ* SOD chambers were consistent with these findings. Diver observations of sediments at each sampling station are presented below (Table 3). As indicated, sand and silt were the dominant substrates upon which SOD rates were measured at all stations with the exception of RM-1 which exhibited a patchy mixture of sand, silt, and gravel. Diver-observed sediment characteristics at the repeat stations (RM-11.2, RM-15 and RM-21) exhibited slight modification between the two study periods. The sediment surface at RM-11.2 exhibited a thicker layer of soft unconsolidated material in September compared to July. In September, station RM-21 took on a characteristic of small pockets filled with loose floc similar to that exhibited at station RM-15 in July. Meanwhile, the silt pockets that were present at RM-15 in July became obscured and covered entirely with a soft layer. The observed increase in soft material (floc) at the sediment/water interface between the July and September studies likely reflects the settling of material from the water column as current velocities decreased with receding river flow.

STATION	**TABLE 3 DIVER-OBSERVED SEDIMENT CHARACTERISTICS**
RM-1	Chamber 1 – loose silt over sand gravel; silt approximately 2 inches thick Chamber 2 – loose silt (approx. 2") over sand with rocks (2-4" dia.) beneath sand Chamber 3 – loose silt over sand; silt approximately 2"
RM-6.5	2 inches loose silt over hard sand.
RM-11.2	¼" silt over approximately 2 inches silt/sand mix over firm sand; sediment more consolidated under chamber 2 (July 2006); soft floc (mud) 2-4 inches thick over sand (Sept. 2006).
RM-15	Coarse sand covered with silt in pockets; silt pockets cover approximately 75% of area; silt up to approximately 3 inches thick in pockets (July 2006); fluffy mud (silt) approximately 2-3 inches thick over sand (Sept. 2006)
RM-21	Silt ¼ – ½ inches thick over sand (July 2006); Small depressions (pockets) filled with loose floc over sand; floc is patchy (Sept. 2006)
RM-39.4	Sand and silt with thin unconsolidated floc at sediment surface

Tables 4 and 5 present the individual replicate and mean *in situ* SOD rates at each station for the July and September 2006 studies, respectively. Complete tabular and graphical presentation of data used for SOD rate calculations are presented in Appendix B. Table 6 provides a summary comparison of seasonal rates, along with information provided by Mr. Gary Rott, MPCA, from remotely deployed (no diver) chambers during a 1980 effort by Mr. Rott. Noteworthy in the summary of rates are several observations. First, during the July 2006 study, note the remarkably low mean rates of 0.216 gmO_2/m^2/day at RM-39.4 and 0.26 gmO_2/m^2/day at station RM-11.2, and the largest mean rate observed during all efforts of 4.01 gmO_2/m2/day at RM-21 during July. While the coefficient of variation at RM-21 reveals good replication, and diver observations indicated consistency in substrate character, the extremity of the RM-21 mean rate compared to all other stations was the factor supporting revisiting of this station in the second study. SOD measurements revealed a considerable reduction at RM-21 from 4.01 gmO_2/m^2/day in July to 1.51 gmO_2/m^2/day in September, while SOD at RM-11.2 increased from 0.26 to 1.73 gmO_2/m^2/day between the two studies. SOD at RM-15 reflected the previously noted change in substrate characteristics (increased deposition) between July and September with mean rates of 1.65 gmO_2/m^2/day in July and 2.75 gmO_2/m^2/day in September. SOD rates at stations RM-1 and RM-6.5 were relatively similar in July with means of 1.49 and 1.3 gmO_2/m^2/day, respectively.

Quite notable in Table 6 is the similarity of SOD rates measured by $HydrO_2$ in 2006 and the MPCA in 1980 at certain regions of the river where the $HydrO_2$ and MPCA stations were relatively proximate. Specifically warranting attention are comparisons of the following three pairs:

- $HydrO_2$ RM-6.5 and MPCA RM-7.2
- $HydrO_2$ (Sept) RM-11.2 and MPCA RM-10.9
- $HydrO_2$ (Sept) RM-21 and MPCA RM-21.5

Differences between the MPCA and $HydrO_2$ at other proximate locations could be a result of ineffective, unconfirmed chamber-to-substrate seals resulting from remote deployment (no diver) or simply may reflect changes in the sediment bed spatially and over time. Regardless, the similarity in rates over time provides some basis for the application of specific rate ranges within certain reaches of the study area.

Lastly, while the two extreme mean rates of 4.01 gmO_2/m^2/day at RM-21 and 0.21 gmO_2/m^2/day at RM-39.4 in 2006 may initially appear suspect, they should not be disregarded. Information to be presented later in this report regarding CSOD validates the apparent representativeness of these rates for the particular study period. In waterbodies where the sediment bed is the dominant component of SOD, CSOD and *in situ* chamber SOD rates are usually relatively close. In waterbodies where there are considerable “other” substrates (e.g., deadfall) in addition to the sediment bed where respiration can occur, then CSOD should exceed SOD. Computed CSOD at RM-39.4 for the July study was 0.27 gmO_2/m^2/day versus the mean *in situ* chamber SOD rate of 0.22 gmO_2/m^2/day. At RM-21 during July, CSOD was computed as 4.48 gmO_2/m^2/day versus the *in situ* chamber SOD rate of 4.01 gmO_2/m^2/day. Accordingly, CSOD appears to validate the observed chamber SOD rates in July at these two stations.

TABLE 4
Sediment Oxygen Demand (SOD) Rates
Replicates & Means
Lower Minnesota River
July 18-24, 2006

Station	Rep	Avg. Rate of Change (mg/L/min)	Adjusted Avg. /1 (mg/L/min)	SOD gmO2/m2/hr	Mean SOD gmO2/m2/hr *<gmO2/m2/day>*	*S* /2	CV (%) /3	Water Column R mg/L/min	Water Temp. (C)
RM-1	1	0.0041	0.0031	0.045	0.062	0.021	33.3	0.001	27
	2	0.0069	0.0059	0.085	*1.49*			0.001	
	3	0.0049	0.0039	0.056				0.001	
RM-6.5	1	0.0037	0.0025	0.036	0.054	0.02	36.4	0.0012	25.8
	2	0.0064	0.0052	0.075	*1.29*			0.0012	
	3	0.0047	0.0035	0.051				0.0012	
RM-11	1	0.0028	-0.0012	0.000	0.011	0.012	108	0.004	25
	2	0.0056	0.0016	0.023	*0.254*			0.004	
	3	0.0046	0.0006	0.009				0.004	
RM-15	1	0.0054	0.0049	0.071	0.069	0.004	6.3	0.0005	25.8
	2	0.0055	0.005	0.072	*1.65*			0.0005	
	3	0.0049	0.0044	0.064				0.0005	
RM-21	1	0.0142	0.0139	0.201	0.167	0.048	28.7	0.0003	25.8
	2	0.0095	0.0092	0.133	*4.00*			0.0003	
	3	Chamber seal eroded		0.000					
RM-39.4	1	0.0028	0.0008	0.012	0.009	0.004	47.1	0.002	28.7
	2	0.0024	0.0004	0.006	*0.21*			0.002	

/1 Adjusted average obtained by subtracting water column respiration from average rate of change in each chamber.

/2 S = standard deviation

/3 CV = coefficient of variation as percent

TABLE 5
Sediment Oxygen Demand (SOD) Rates
Replicates & Means
Lower Minnesota River
September, 2006

Station	**Rep**	**Avg. Rate of Change** (mg/L/min)	**Adjusted Avg. /1** (mg/L/min)	**SOD** gmO2/m2/hr	**Mean SOD** gmO2/m2/hr *<gmO2/m2/day>*	***S* /2**	**CV (%) /3**	**Water Column R** mg/L/min	**Water Temp.** (C)
RM-11	1	0.006	0.0053	0.077	0.072	0.004	5.75	0.0007	20.1
	2	0.0056	0.0049	0.071	*1.72*			0.0007	
	3	0.0054	0.0047	0.068				0.0007	
RM-15	1	0.0097	0.0079	0.114	0.115	0.0026	2.3	0.0018	22.5
	2	0.0096	0.0078	0.113	*2.76*			0.0018	
	3	0.01	0.0082	0.118				0.0018	
RM-21	1	0.0065	0.004	0.058	0.064	0.017	26.4	0.0025	22.9
	2	0.0082	0.0057	0.082	*1.52*			0.0025	
	3	0.006	0.0035	0.051				0.0025	

/1 Adjusted average obtained by subtracting water column respiration from average rate of change in each chamber.

/2 S = standard deviation

/3 CV = coefficient of variation as percent

Table 6

Minnesota River

Sediment Oxygen Demand Rates

July & September 2006 & September 1980

Station	**gmO2/m2/hr**		**gmO2/m2/day**		**gmO2/m2/day**	
	July	**September**	**July**	**September**	**MPCA Sept. 1980 ***	
RM-1	0.062		1.49		0.6	RM 0.5
RM-6.5	0.054		1.29		1.37	RM 7.2
RM-11	0.011	0.072	0.26	1.72	1.62	RM 10.9
RM-15	0.069	0.115	1.65	2.76	0.86	RM 15.3
RM-21	0.167	0.064	4	1.52	1.27	RM 21.5
RM-39.4	0.009		0.22		0	RM 24

* Courtesy of Gary Rott, MPCA from his 1980 SOD work using remotely deployed chambers.

Water Column Production and Respiration

Water column GPP, NPP, R, and attendant parameters of light transmission and chlorophyll-a were measured at all six stations during both the July and September 2006 studies (Tables 7-9). During the course of these deployments, continuous records of solar energy were obtained using a recording pyrheliometer to provide the opportunity to normalize production rates to a specific energy value, thereby allowing a comparison of rates obtained during the day-to-day varying energy regimes through the study periods.

Tables 8 and 9 present the observed GPP and R rates, solar energy values, and chlorophyll-a concentrations for the July and September 2006 studies. The following supporting data are presented in Appendix C:

- Percent light transmission profiles (Figure C-13)
- Light-and-dark-bottle raw data (Tables C-1 and C-2)
- Graphical presentations of GPP and NPP rates for the incubation period integrated through the euphotic zone and R rates integrated from surface to bottom (Figures C-1 through C-12)
- Daily solar energy records (Figures C-14 through C-25)

As evident by the chlorophyll values during both studies, but particularly during July where concentrations ranged from 110 to 150 ug/l chlorophyll-a, the Minnesota River is a hypereutrophic river if viewed from a limnological perspective. This, obviously, is not a new revelation for MCES and MPCA personnel with their long history of working on the river. However, in terms of water column P:R ratios measured with the enclosed bottle method, the upstream half of the study reach (RM-39.4 to RM-15) exhibited near autotrophic conditions, while the lower reach could clearly be described as a heterotrophic system using more carbon than produced via water column production. Only between RM-39.4 and RM-15 during the summer (July) period, did P:R approach or approximate 1.0 with ratios of 0.93, 1.15, and 1.2 at river miles 39.5, 21, and 15, respectively(Table 9). During July, in the downstream channelized reach of the river at miles 11.2, 6.5, and 1.0, where flow dynamics are confounded by influences of the Mississippi River, P:R ratios were well below 1.0 with values of 0.76 (RM-11.2), 0.36 (RM-6.5), and 0.65 (RM-1).

With river flow receding in September to around 1000 cfs, the entire study reach exhibited water column respiration exceeding production with the previously autotrophic upper reach of river (RM-39.4 – RM-15) becoming heterotrophic with P:R ratios of 0.65, 0.89, and 0.59 at river miles 39.4, 21, and 15, respectively. P:R was likewise reduced at RM-11.2, falling from 0.76 in July to 0.31 in September. P:R ratios at RM-1 and RM-6.5 remained consistent between the two study periods (Table 9).

The euphotic zone (that portion of the water column with 1% or greater visible light) changed little between the two studies (Figures C-13 and Table C-3, Appendix C). Generally, throughout the study reach, euphotic zone depth was slightly less than one meter during July. September saw slightly more light at each 0.5-foot (0.15-m) depth increment through the euphotic zone, but this resulted in minimal extension of total depth of the euphotic zone in comparison to the total depth at each station. The upstream stations (RM-15, RM-21, and RM-39.4) exhibited the most apparent increased euphotic zone depth but only by 0.15 to 0.30 meters. Reduced river flow resulting in a stilling of the water column is the most plausible factor affecting increased clarity of the water.

Obviously, at the latitude of the Minnesota River, daily solar energy exhibits a substantial reduction from late July to early September. During July 18-24, 2006, solar energy values ranged between 810-360 langleys per day. For the July study, water column production rates at each station for the photoperiod were calculated based on the mean energy value of 645 langleys per day. As evident in Table 8 and the pyrheliometer charts in Appendix C (Figures C14-C25), abundant sunshine prevailed through most of the July assessment with the exception of July 21, 2006, which was relatively cloudy (station RM-15; 360 langleys) (Table 9). Work was suspended on July 19, 2006, due to the passing of a severe weather front causing heavy clouds and rain through most of the day. During the September study, solar energy values were less than one-half of July values, ranging between 392-106 langleys per day (Table 9). September 3rd was the most sunlight-suppressed day of the September study due to an all-day rain event. Accordingly, a mean energy value of 253 langleys per day was used for calculation of water column production rates in September.

Chlorophyll-a concentrations, like solar energy, exhibited a marked reduction between the two study periods, with the exception of RM-39.4 where concentrations declined only 20 ug/L from 130 to 110 ug/L between July and September (Table 7). Interestingly, water column GPP per unit of available solar energy increased at five of the six stations in September versus July (Figure 5 and Tables 8 and 9). Only at station RM-15 did GPP/langley rates in July exceed those in September (Figure 5). NPP generally mimicked GPP responses (Figure 5). The exception was RM-39.4 during the very cloudy and rainy day of September 3, 2007, when NPP rates per unit of solar energy exhibited a marked reduction from July (Figure C-18, Appendix C). This suggests that the climatic conditions prevailing that day resulted in solar intensity marginally sufficient to meet the energy threshold required to stimulate photosynthesis.

Overall, due to over two times as much total energy during the day in July than in September, GPP rates were considerably greater throughout the study reach in July than September, with the exception of RM-1 where July and September rates were basically the same at approximately 6.5 gmO2/m2/day (Table 7). The observation that GPP rates per single unit of energy in the presence of reduced chlorophyll in September exceeded those of July (Figure 5), in contrast with the overall greater total GPP per photoperiod in July versus September (Table 7), is an illustration of the influence that environmental variables can have on water column primary production. Use of chlorophyll-a concentrations alone as the basis for adjusting production rates in model calibration should be done with extreme caution and with definitive, data-based supporting rational.

TABLE 7
Minnesota River
Water Column Gross Primary Production (GPP) & Respiration (R)
(as gmO2/m2/day)
July & September 2006

STATION	GPP - July	GPP - Sept	R - July	R - Sept.	P:R - July	P:R - Sept	Chl-a* (July)	Chl-a* (Sept)
RM-39.4	9.29	4.4	9.97	6.78	0.93	0.65	130	110
RM-21	7.22	5.19	6.21	5.84	1.16	0.89	110	75
RM-15	16.77	4.5	13.99	7.69	1.2	0.59	113	70
RM-11.2	7.93	4.33	10.44	14.4	0.76	0.31	113	73
RM-6.5	9.74	6.33	26.91	16.8	0.36	0.38	138	94
RM-1	6.45	6.58	9.9	9.38	0.65	0.7	145	71

***** Average Chlorophyll **a** concentrations determined from 3 to 4 discrete samples within the water column

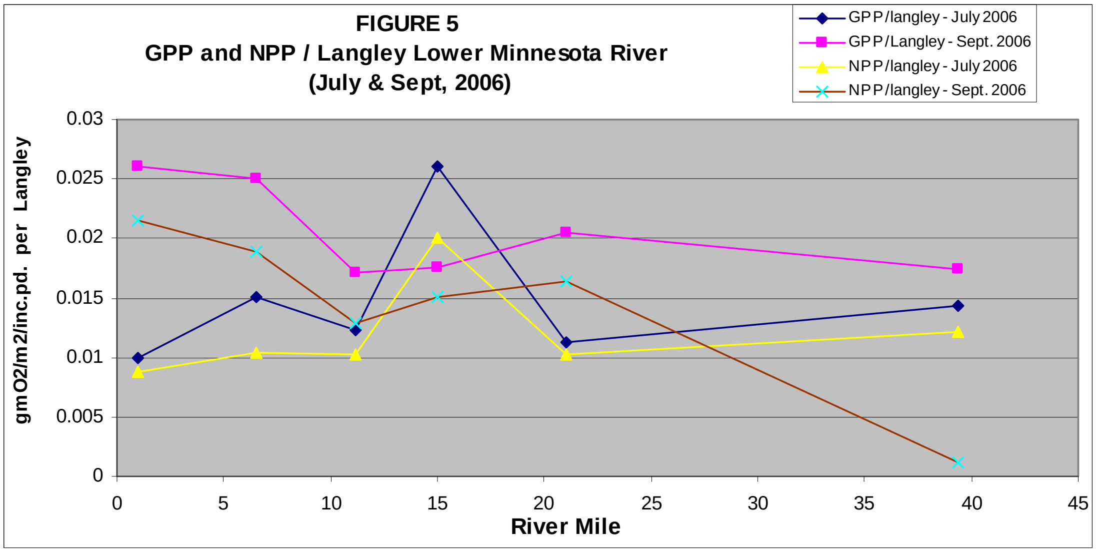
FIGURE 5
GPP and NPP / Langley Lower Minnesota River
(July & Sept, 2006)

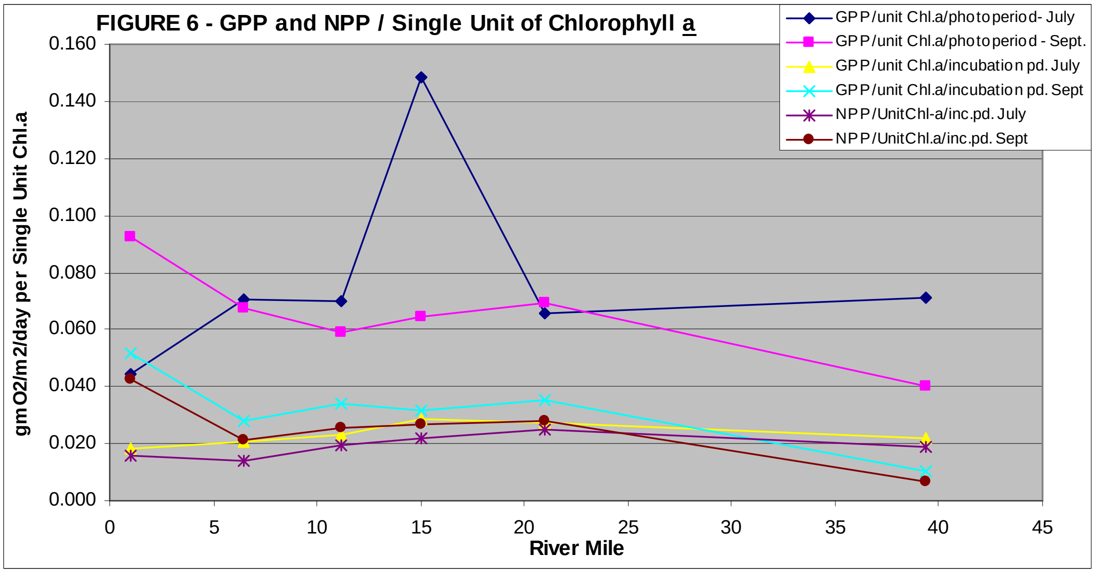
FIGURE 6 - GPP and NPP / Single Unit of Chlorophyll a

TABLE 8
Water Column Gross Primary Production (GPP) and Respiration (R)
Minnesota River, RM-39 to RM-1
July 2006

Station	**Date**	**Incubation Time/Period**	**Gross Primary Production and Respiration Rate per Incubation Period**		**GPP/Langley during Incubation Period***	**Langleys per Incubation Period and Day**		**GPP ** g 02/m2/day (Photoperiod 12 hrs)**	**R*** g 02/m2/day (24 hrs)**	**GPP: R Ratio**	**Chlorophyll-a ug/L**
			GPP gm02/m2	R gm02/m2		Incubation Period	Day				
RM-39.4	07/18/06	Light 3.1 hrs 1300-1605 Dark 4.5 hrs 1200-1730	2.88	1.87	0.0144	199	688	9.29	9.97	0.93	0.5' - 130 1.0' - 130 2..5' - 130
RM-21	07/20/06	Light 3.2 hrs 1115-1425 Dark 4.75 hr 1115-1600	3.00	1.23	0.0112	266	701	7.22	6.21	1.16	0.5' - 110 1.0' - 110 2.5' - 110
RM-15	07/21/06	Light 4.0 hrs 1250-1650 Dark 4.0 hrs 1250-1650	3.23	2.33	0.0260	124	360	16.77	13.99	1.20	0.5' - 120 1.0' - 110 2.5' - 110
RM-11.2	07/22/06	Light 2.4 hrs 1310-1535 Dark 4.0 hrs 1310-1710	2.63	1.74	0.0123	214	727	7.93	10.44	0.76	0.5' - 120 1.5' - 110 3.0' - 110
RM-6.5	07/23/06	Light 2.0 hrs 1250-1450 Dark 3.8 hrs 1450-1640	2.87	4.26	0.0151	189	810	9.74	26.91	0.36	0.5' - 130 1.0' - 130 2.5' - 140 12.0' - 150
RM-1	07/24/06	Light 3.5 hrs 1000-1330 Dark 4.0 hrs 1000-1400	2.63	1.65	0.010	265	582	6.45	9.9	0.65	0.5' - 150 1.0' - 140 2.0' - 140 10.0' - 150

* Calculated as follows: GPP g02/m2 divided by total langleys during incubation period

** Normalized to average solar energy (645 langleys/day) for the period July 18-24, 2006

*** Calculated as follows: R during incubation period (x 24 hrs)/incubation period (hrs)

TABLE 9
Water Column Gross Primary Production (GPP) and Respiration (R)
Minnesota River, RM-39 to RM-1
August 31 – September 03, 2006

Station	**Date**	**Incubation Time/Period**	**Gross Primary Production and Respiration Rate per Incubation Period**		**GPP/Langley during Incubation Period***	**Langleys per Incubation Period and Day**		**GPP ** g 02/m2/day (Photoperiod 12 hrs)**	**R*** g 02/m2/day (24 hrs)**	**GPP: R Ratio**	**Chlorophyll-a ug/L**
			GPP gm02/m2	R gm02/m2		Incubation Period	Day				
RM-39.4	09/03/06	4.0 hrs 1140-1540	1.13	1.13	0.0174	65	106	4.40	6.78	0.65	0.5' - 110 1.0’ - 110 2..5’ - 110 7.0’ - 110
RM-21	09/01/06	Light 3.2 hrs 1110-1420 Dark 4.6 hr 1110-1545	2.65	1.12	0.0205	129	342	5.19	5.84	0.89	0.5’ - 75 1.0’ - 79 3.0’ - 69 5.0’ -75
RM-15	09/02/06	Light 3.2 hrs 0940-1250 Dark 4.4 hrs 0940-1405	2.23	1.41	0.0178	125	171	4.50	7.69	0.59	0.5' - 69 1.5’ - 67 3.0’ - 72 11.0’ - 71
RM-11.2	09/01/06	Light 3.9 hrs 0900-1255 Dark 4.7 hrs 0900-1440	2.49	2.75	0.0171	146	342	4.33	14.04	0.31	0.5’ - 67 1.0’ - 69 3.0’ - 85 11.0’ - 70
RM-6.5	08/31/06	Light 3.0 hrs 1310-1610 Dark 3.8 hrs 1310-1700	2.63	2.66	0.0250	105	392	6.33	16.80	0.38	0.5’ - 92 1.5’ - 93 2.5’ - 96 13.0’ – 95
RM-1	08/31/06	Light 3.3 hrs 1115-1430 Dark 4.4 hrs 1115-1540	3.66	1.72	0.0260	141	392	6.58	9.38	0.70	0.5’ - 75 1.5’ - 83 3.5’ - 68 12.0’ - 56

* Calculated as follows: GPP g02/m2 divided by total langleys during incubation period

** Normalized to average solar energy (253 langleys/day) for the period August 31- September 03, 2006

*** Calculated as follows: R during incubation period (x 24 hrs)/incubation period (hrs)

Total Community Oxygen Metabolism and Community Substrate Oxygen Demand

TCOM is computed via the diel curve method (Odum and Hoskins, 1958). The diurnal oxygen curve is acquired for a 24-hour period and appropriately corrected for saturation deficits by accounting for atmospheric diffusion. Results provide the rate of GPP and R for the entire water body at selected stations. Multi-parameter data-recording sondes were deployed by the MPCA at all stations. Sondes were provided, calibrated, deployed, retrieved, and post-calibration checked by the MPCA with data downloaded and provided to $HydrO_{2.}$

The relationship between TCOM and CSOD is based on the use of the diel curve method to obtain total community production and respiration. First, the total oxygen budget (aquatic community GPP and R) is defined via the diel curve method. Second, using other techniques, the respiration demands of various components of the oxygen budget, excluding SOD, are partitioned. Through mathematical elimination, the remaining unmeasured oxygen demand represents CSOD. The basic premise of the diel curve method requires that the history of the water at each station remain generally consistent throughout the diel period of observation. This is evident in the equation associated with the diel curve method

$$\mathbf{Q = P - R + D + A}$$

where

Q = net rate of change in dissolved oxygen

P = rate of change in gross primary production

R = rate of change in respiration

D = rate of change in atmospheric diffusion

A = rate of change in oxygen due to accrual of drainage

If you cannot account for the assets or liabilities of accrual or other perturbations affecting water history, the analysis becomes flawed or not possible at all. As stated earlier in this report, application of the diel curve method was problematic at several of the downstream stations during both surveys. This was due to apparent hydrological and biological reasons that altered water history, as well as DO sensor malfunction in the sondes at stations RM-11 (July) and RM-15 (Sept). Data from stations RM-39.4 and RM-21 proved quite amenable to application of the diel curve method and subsequent computation of CSOD. Downstream stations RM-1 and RM-6.5 were affected by interruption of the typical diurnal oxygen curve. Flow oscillations associated with lock and dam operations in the Mississippi River and their known influence on the lower Minnesota River were the suspected cause of perturbations to the curves (Figures D-7 through D-10).

While diel curves in July at RM-11.2 and RM-15 (Figures D-5 and D-6) appear to provide reasonable fits to typical diurnal oxygen excursions and DO rates of change, poor relationships between community respiration (diel curve analysis) and water column respiration (via the dark bottles) proved problematic for CSOD computation at these two stations. Review of continuous recording sonde records at these two stations (Figures D-18 and D-19) reveals that DO saturation exceeded 100 percent, with progressive escalation greater than 100 percent saturation each day during the July study. This biologically driven phenomenon associated with photosynthesis by a rich phytoplankton community confounded determination of community respiration in the diel curve analysis, voiding any confidence in the use of the diel curves at RM-11.2 and RM-15 for CSOD computation

During the July 2006 study, sonde performance and stable water history at RM-39.4 and RM-21 allowed for development and analysis of diel curve rates of change. Sonde records for stations RM-39.4 (top and bottom) and RM-21, which provide the basis for computation of total community oxygen metabolism (GPP and R), are presented in Tables D-1 through D-4 (Appendix D). Diel oxygen rate-of-change curves resulting from analysis of these data are presented in Figures D-1 through D-4. The 24-hour windows associated with July 20-21, 2006, reveal a distinctly positive rate of change reflecting GPP during the daily photoperiod, followed by a relatively constant negative rate of change during the nighttime as a result of aquatic community respiration.

Sonde deployment in September was extended to two weeks by the MPCA to meet their requirements while continuing support of the second oxygen dynamics study. Preliminary analysis of the July data prior to the September effort revealed a vertically mixed water column as well as water history perturbations to the diel curve analysis at the lower stations. These observations affected the deployment strategy in September. Because of low flow related navigational impediments, focus for sonde deployment was limited to the river reach from just above the Blue Lake WWTP (approximately RM-22) to the confluence with the Mississippi River, with the expectations that the perturbations to water history would continue to be evident at the lower flow.

Development of diel oxygen rate-of-change curves for sondes deployed at river miles 1, 6.5, 11, 15, 21, and 22 confirmed these expectations. Rate-of-change curves for stations RM-11, 6.5, and 1 revealed erratic fluctuations (positive to negative) throughout the twenty-four hour period of analysis that inhibited confident estimation of total community GPP and R at these stations. As in July, lock and dam operation on the Mississippi River and perturbations to the water column created by barge tow prop-wash are suspected causes. DO sensor malfunction in the sonde at RM-15 negated diel curve analysis at this station, leaving only sonde deployments at RM-21 and RM-22 for development of total community GPP & R at these locations, which affected subsequent CSOD estimation.

In situ SOD chamber deployment along with light-and-dark-bottle measurement of water column respiration occurred between these two sonde deployment locations. Accordingly, total community respiration rates for RM-21 and RM-22 were averaged for computation of CSOD. Average depth for this reach at a river flow of 1000 cfs was estimated by review of stage differences at the Jordan gage. Such an approach to average depth at this downstream location is recognized as crude due to the changes in river morphology with progression downstream from RM-39 to RM-21 and thus affects the accuracy of the comparison. Based on these recognized qualifications, estimation of CSOD versus the *in situ* chamber SOD rates are presented in Table 10.

TABLE 10
CSOD and *In Situ* SOD
Minnesota River
July & September 2006

STATION	Mean Depth Meters	Community R* $gmO_2/m^2/day$	Water Column R $gmO_2/m^2/day$	CSOD $gmO_2/m^2/day$	CHAMBER SOD** $gmO_2/m^2/day$
RM-39.4 (July 2006)	3.2	10.37	9.97	0.40	0.22
RM-21 (July 2006)	2.70	10.69	6.21	4.48	4.01
RM-21/22 (Sept. 2006)	1.9	8.16	5.84	2.32	1.51

* Water Column R + CSOD = Total Community R

****** SOD is a component of CSOD.

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