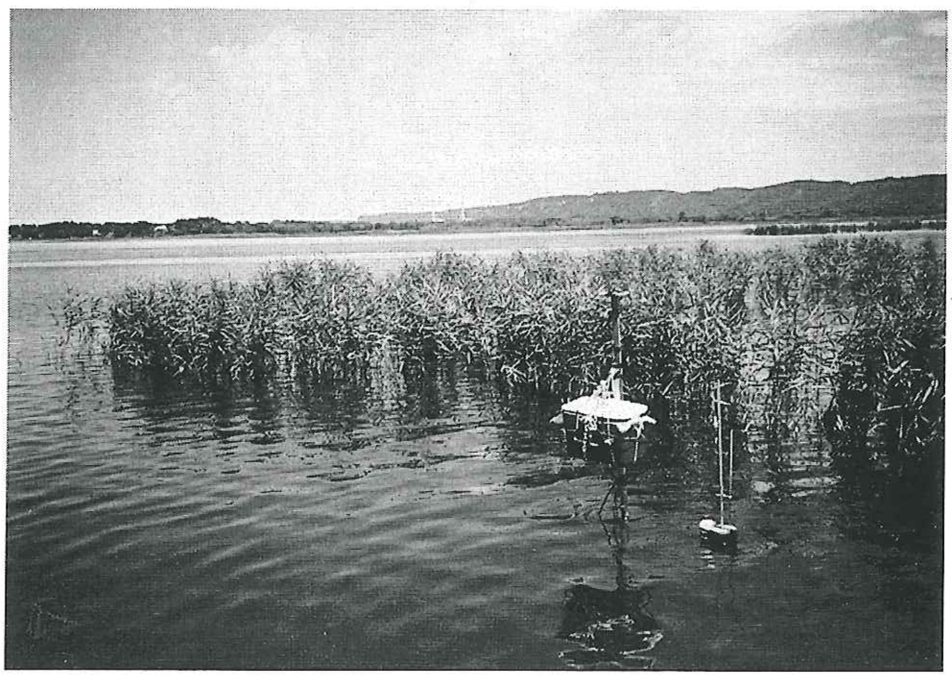
# Continuous Monitoring of Dissolved Oxygen, Temperature, and Light Penetration at Weaver Bottoms, Pool 5, Mississippi River, during July and August, 1986-95



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**October 1996**

## ABSTRACT

Short term continuous water quality monitoring surveys were conducted in the northern and southern portion of Weaver Bottoms during July and August from 1986 to 1995, except 1987. The primary focus of this work was to define diurnal changes in water temperature and dissolved oxygen and to measure underwater light penetration in response to a major habitat rehabilitation project constructed at Weaver Bottoms in late 1986 and 1987. Average daily temperature fluctuations ranged from about 2 to 4°C. Average daily maximum temperatures reached 29°C during heat waves with a maximum hourly average of 32°C recorded during July 1995. Average daily diurnal dissolved oxygen ranged from 1 to 10 mg/L and was influenced by solar radiation, water temperature, river flow, submersed macrophyte density or algae biomass. Dissolved oxygen concentrations normally exceeded 5 mg/L with the exception of August of 1988 during low flow conditions. Light penetration decreased at both monitoring sites during the 10-year study and was attributed to increased algae during low flow periods and increased suspended solid concentrations following the summer drought of 1987-89. The loss of aquatic vegetation in Weaver Bottoms in the late 1980's may have contributed to increased wind-induced sediment resuspension which negatively effected light penetration. In addition, increased hydraulic residence time, due to the reduction main channel inflows to Weaver Bottoms, may have enhanced phytoplankton production and the retention of both external and internal sources of other suspended solids. Large changes in river flows combined with a system-wide decline in aquatic vegetation masked water quality changes directly attributable to hydraulic modifications associated with the Weaver Bottoms Rehabilitation Project.


## INTRODUCTION

Continuous measurements of dissolved oxygen (DO), water temperature, and surface and underwater light were collected at two sites in Weaver Bottoms, Pool 5, Upper Mississippi River during short term periods (7-8 days) in July and August of 1986 through 1995, except 1987. The purpose of this work was to define diurnal fluctuations in DO and water temperature and daily changes in surface and underwater light conditions. This monitoring activity was undertaken to help evaluate potential water quality changes attributable to side channel closures and island creations (Figure 1) associated with the Weaver Bottoms Rehabilitation Plan (U.S. Corps of Engineers, 1986). This plan was implemented in August of 1986 and completed in the spring of 1988.

## STUDY AREA

Weaver Bottoms is a 4000 acre backwater complex in Minnesota bordering the right descending bank of the central portion of Pool 5 of the Upper Mississippi River. This backwater area is hydraulically influenced by inflows from the Mississippi River and Whitewater River. In addition, the old Zumbro River discharges into the northwest end of Weaver Bottoms, but its contribution is relatively minor. The average hydraulic residence time (volume/inflow) within Weaver Bottoms increased about three fold (1 to 3 days) after channel closures reduced inflows from the Mississippi River in late 1986 (Davis et al. 1991).

Continuous water quality measurements were made in upper (Site 1) and lower (Site 2) portions of Weaver Bottoms during the study period. In addition, the Mississippi River main channel boarder (Site 3) was sampled once during the study period.

Site 1 was sampled in July and represents water quality conditions of a large open water area located in the northern portion of Weaver Bottoms (Figure 1). This area is characterized by small emergent beds of <u>Phragmites communis</u> with water depths of about 1.0 to 1.3 m at control pool elevation. The density of these beds have decreased dramatically since the construction and operation of Lock and Dam 5 in the mid 1930s. The density and size of the beds also appeared to show a general declined over the 10-year study period. Submerged aquatic plants were sparse at this location in 1986 and were absent by 1990. Small patches of sago pondweed (<u>Potamogeton pectinatus</u>) and <u>Myriophyllum sp.</u> recolonized the area starting in 1992. Since 1992, sago pondweed has increased in density at this site. Water was usually turbid at this site and was influenced by inflow from the Mississippi River and wind-induced sediment resuspension. Water current normally flowed in a southerly direction at about 1 to 2 cm/s.

However, greater wind-induced currents were obvious during days with moderate to heavy winds. Bottom substrate at this site consisted of silt and clay.

Measurements at Site 2 were collected in August at the southern end of Weaver Bottoms immediately adjacent to the main channel levee. The depth was about 0.5 to 0.75 m. In 1986, a dense bed of wild celery (Vallisneria americana) was present in the area. Very few aquatic plants were present during the 1988 survey and were not observed at this site between 1989 and 1995. Algae blooms were occasionally observed at this location, especially during periods with reduced river flow. Water current was quite variable and generally ranged from undetectable (<0.6 cm/s) to 4 cm/s. Bottom substrate at this site was mainly sand to silty-sand. Turbid inflows from the Whitewater River may influence this site, especially on days with moderate winds from the northwest. Wind-induced resuspension of sandy bed sediments was evident at this site during periods of strong winds from the northwest as indicated by sand deposits on the underwater sensors.

## METHODS

Continuous DO and temperature measurements were made using a Yellow Springs Instruments (YSI) Model 56 or 57 meter and probe. DO and temperature data collected in 1986 were recorded with the strip chart recorder of the YSI 56 unit. A Li-Cor model 1000 data logger was used to log hourly average DO and temperature measurements after 1986. A YSI thermistor was used to measure water temperature when the data loggers were utilized.

The thermistor was checked yearly by comparing it to a certified reference thermometer. The accuracy of the temperature readings were approximately +/- 0.5°C. DO calibration was performed using the air calibration technique utilizing ambient air pressure (Wisconsin Department of Natural Resources, 1983). Ambient or station air pressure was normally determined in the field with a barometer. The field barometer was lab-calibrated by adjusting sea level corrected measurements obtained from the National Weather Service at the La Crosse Municipal Airport (650 ft msl) to true local pressure. Field barometric pressure readings had an accuracy of about +/-2 mm of mercury.

The accuracy of DO measurements with the YSI equipment is reported to be about 0.3 mg/L (YSI, 1983). Field measurements of DO calibration drift were determined at the end of each monitoring period. If the DO drift (error) exceeded 0.4 mg/L, the recorded DO data were adjusted using a linear error correction over the monitoring period.

Surface and underwater light measurements were collected using Li-Cor models 190SA and 192SA quantum sensors, respectively, and recorded electronically with a Li-Cor model 1000 data logger. The light sensors represent a flat cosine corrected response for photosynthetically active radiation (PAR), (ie. 400-700 nm wavelengths). Surface PAR measurements represent hourly integrated values. Light cells were calibrated yearly by Li-Cor, Inc.

Light extinction coefficients and the depth at which 1% of surface light penetrated were based on the following formula:

$$Iz = Io \times e^{-kz}$$

where Iz = the light intensity at depth z
Io = the light intensity at the surface
e = the base of natural logarithms
k = the extinction coefficient
z = depth

Extinction coefficients were based on integrated light energy ($mols/hr/m^2$) recorded between 1000 and 1400 hours (DST). Surface PAR measurements were determined about 1.5 meters above the water or ground surface in areas unobstructed by local vegetation. Underwater PAR sensors were mounted to a stake at mid-depth between 1986 and 1990. Corrections for daily water depth changes were based on USCOE stage level readings collected at the tailwater of Lock and Dam 4 and the pool elevation at Lock and Dam 5. Daily water depth estimates at the monitoring site were calculated assuming a linear slope to the water surface between these two stage levels. Fouling of the underwater cell by periphyton, invertebrates and other debris was determined by measuring the sensor response before and after cleaning at the end of the monitoring period. If the difference exceeded 5%, an adjustment in the data was performed using a linear error correction over the monitoring period. After 1990, the underwater PAR sensor was mounted to a floating device at approximately 0.5 m below the water surface. This latter technique avoided the need for stage level corrections to determine the sensor depth.

River flow data were obtained from the USGS gaging station at Winona, Minnesota located about 20 miles downstream. There are no major tributaries entering the river between Weaver Bottoms and the gaging station. Monthly total suspended solids (TSS) and inorganic nitrogen data were available from Wisconsin Department of Natural Resources and Minnesota Pollution Control Agency for Lock and Dams 4 and 5, respectfully. This information was obtained from U.S. EPA's Storage and Retrieval System (STORET). Data on wind velocity at Weaver Bottoms were recorded with a Young model 05106 wind monitor and were available from a separate study (Sullivan and Anderson, 1994).

Strip chart and electronically logged data were transferred to a Lotus 123 (Lotus Development Corp.) spreadsheet for the determination of basic statistics and graphical analysis. Continuous monitoring data has been stored on a personal computer (IBM compatible) hard disk. Backup copies are available on 3 1/2 in. disks. An example of a typical spreadsheet is included in Appendix A. A listing of Lotus spreadsheet files by date and site is included in Table 1. Hourly average temperature and DO data and hourly integrated surface PAR measurements are illustrated in Appendix B.

## RESULTS and DISCUSSIONS

### Mississippi River Flow and General Water Quality Trends

Temporal changes in Mississippi River flow and water quality are important factors influencing Weaver Bottoms since the river is the dominant source of water for Weaver Bottoms. Mississippi River flows were substantially above normal during the May-September period of 1986 and 1993 (Figure 2a). In contrast, the 1987 to 1989 flows were substantially below normal. The July flows in 1988 approached the 10-year frequency of reoccurrence based on low flow duration data for the Winona gaging station (Arntson and Lorenz, 1987).

The low flow conditions present in the late 1980's resulted in greater hydraulic residence times in the Mississippi River pools. The reduction in pool flushing rates enhanced phytoplankton production and was particular apparent in Lake Pepin (Pool 4) during the summer of 1988 (Heiskary and Vavricka, 1993). Total suspended solid concentrations (Figure 2b) in the Mississippi River were reduced during low flows as a result of smaller suspended loads from the tributaries. The low flow periods also contributed to reduced inorganic nitrogen concentrations (Figure 2c) because of lower nitrogen loadings from nonpoint source inputs and utilization by aquatic macrophytes and algae within the riverine system. TSS and inorganic nitrogen concentrations increased markedly at Lock and Dam 5 in 1990 after the 1987-1989 summer drought and likely reflected nonpoint source inputs to Pool 5 from the Whitewater and Zumbro River watersheds. TSS concentrations at Lock and Dam 4 showed a general increasing trend after 1989. The reason for this latter response has not been determined. Possible factors include increased TSS loads from lower Pool 4 tributary inflows (Chippewa or Buffalo Rivers) or increased sediment resuspension in lower Pool 4.

### Water Temperature

Average daily water temperature fluctuations (max-min) in Weaver Bottoms ranged from 1.7 to 4.1°C (Table 2) during the short term, continuous monitoring surveys in July and August. Warmest water temperatures were recorded at Site 1 during July of 1988 and 1995 during heat waves (Figure 3c). Average daily maximum temperatures reached 29°C during these periods. The maximum hourly average exceeded 32°C on July 14, 1995 (Appendix B), a day when the 100-year record maximum air temperature (42.2°C or 108°F) was recorded at La Crosse, Wisconsin (National Weather Service, La Crosse, WI). Coldest hourly average water temperature (15.5°C) was recorded in August of 1986 (Appendix B) after passage of a major cold front.

**Dissolved Oxygen**

Average daily diurnal (max-min) DO data were quite variable and ranged from 1 to 10 mg/L during the July and August surveys (Table 2). Daily variation in DO were influenced by solar radiation, water temperature, macrophyte density or algae biomass. The magnitude of daily fluctuations in DO over the ten-year period are illustrated in Figure 3e,f. High river flows, such as that found during the July 1993 survey, dampened algal photosynthetic activity and resulted in reduced diurnal DO "swings" (Appendix B). This was likely in response to reduced hydraulic residence time (ie. increased flushing) and increased dilution of riverine phytoplankton concentrations. The greatest diurnal DO variation was recorded at Site 2 in August 1986 when this site was influenced by a dense macrophyte bed dominated by wild celery. Phytoplankton blooms were observed at Site 2 in August of 1989 and 1992 and resulted in a relatively large average diurnal DO fluctuation (about 7 mg/L) and high DO saturation (>140%), (Table 2). Photosynthetic activity, as reflected by DO saturation or diurnal DO data, did not show substantial changes at Site 2 over the ten-year period, even though primary production changed from a macrophyte dominated community to one influenced primarily by phytoplankton.

DO levels were lowest at Site 2 in August of 1988 during low flow and at Site 1 in July of 1993 during high flow conditions (Figures 3a,b,e,f). The reason for this response during low flow was not determined, but may have been related to high turbidity observed during the initial monitoring period in August of 1988. It is possible that the turbid conditions contributed to reduced photosynthesis and increased biochemical oxygen demand during this period. In addition, thermal stratification may have been greater during the low flow period which would have restricted re-oxygenation of bottom waters. No serious DO depletions (below 2 mg/L) were observed during the study period. DO concentrations fell below Wisconsin's and Minnesota's water quality standard of 5 mg/L during short term periods at Site 1 in July of 1986, 1994 and 1995 and were likely related to typical diurnal DO fluctuations associated with macrophytes and algae in a productive backwater (Appendix B). More pronounced DO depletion occurred during the August 1988 survey at Site 2 when concentrations were less than 5 mg/L for about 30% of the time (Table 2). All other monitoring periods at Sites 1 and 2 had DO concentrations exceeding the standard.

**Light**

Average surface PAR measurements exhibited moderate variation during the continuous monitoring periods (Figure 4a,b) and reflect changes in cloud cover. July measurements were normally greater than August since the latter data were recorded nearer the summer solstice.

Light penetration (Figure 4c,d) and underwater light energy (Figure 4e,f) decreased substantially at both sites between 1986 and 1990 as determined from light extinction measurements (Table 2). The average theoretical compensation depth (1% of surface PAR) declined 50% at Site 1 and 78% at Site 2 over this four-year period. The reduction in light penetration in Weaver Bottoms during this period was consistent with spring measurements (May and early June) made by the author at Lock and Dams 8 and 9. This response was attributed to increased algae concentrations and other suspended matter between 1986 and 1990. The low flow period of 1987 to 1989 promoted phytoplankton production as a result of decreased pool flushing times. High TSS concentrations in the river in 1990 following the summer drought in the late 1980's (Figure 2a,b) resulted in turbid conditions and low light penetration. Since 1990, light penetration and underwater light energy have shown moderate fluctuations at both sites and are still well below values found in 1986 (Figure 4c,d,e,f).

The loss of submergent and emergent vegetation within Weaver Bottoms in the late 1980s (Davis et al. 1991) may have negatively influenced light penetration. Macrophyte beds can restrict wind-induced sediment resuspension by retarding wave height and advective water currents. The impact of wind-induced sediment resuspension on light penetration was measured in Weaver Bottoms as part of a separate study near Site 1 (Sullivan and Anderson, 1994). A re-evaluation of this data by the author revealed a 10 mph increase in average wind speed from one day to the next, resulted in a corresponding decrease in light penetration by about 0.4 m (Figure 5). The decline in light penetration at Site 2 between 1986 and 1988 (Figure 4e) was primarily due to the loss of the dense wild celery bed at this site which had previously restricted the inflows of turbid water or retarded wind-induced sediment resuspension in this area.

Submerged aquatic plants have decreased throughout the Upper Mississippi River between 1987 and 1989 (Carl Korschgen, National Biological Survey, personal communication). The specific reason for the decline has not been established, but is believed to be related to water quality changes associated with the summer drought of 1987-89 (Figure 2a and 3a). Potential factors include increased phytoplankton or periphyton biomass which contributed to increased competition for light and inorganic nitrogen, and reduced available nitrogen concentrations in bed sediments following years of moderate to heavy vegetation growth in the mid-1980s.

Hydraulic modifications of the main channel inflows to Weaver Bottoms increased in the mean hydraulic residence time of this backwater area about 200% (Davis et al. 1991). This change may have resulted in increased suspended solids retention within Weaver Bottoms. The sources of these solids could include tributary and main channel inflows, sediment resuspension or high phytoplankton populations. High suspended solids concentration would contribute to reduced light penetration. This would be most evident when main channel suspended solids concentrations were lower than Weaver Bottoms. This was reflected in the August 1992 light penetration data (Table 2) when main channel light penetration was 1.25 m greater (165%) than Site 2. A similar condition was documented during the August survey of 1996 (unpublished data).

## CONCLUSIONS AND RECOMMENDATIONS

Mississippi River flows changed substantially during the summer study period. River flows were above normal in 1986, fell to low levels in 1987 to 1989 and returned to normal to high levels between 1990 to 1995.

Water temperatures fluctuated about 3°C daily based on short term continuous monitoring surveys in July and August. Maximum temperatures were recorded during the July of 1988 and 1995 during heat waves when average daily maximum temperatures reached 29°C.

Largest diurnal DO fluctuation was greatest in a wild celery bed in August of 1986 where the average daily swing (max-min) was 10 mg/L. High diurnal DO fluctuations (about 7 mg/L) were also recorded when algae blooms were present. Minimum DO levels were normally above the 5 mg/L water quality standard, the only major exception occurred during the low flow period in August of 1988 when DO concentrations dropped below the standard for about 30% of the time.

Light penetration decreased dramatically over the study period. Light penetration was greatest in 1986 in a wild celery bed and lowest in 1990 when sediment resuspension and nonpoint source sediment inputs were high. Light penetration has decreased as a result of several factors. Increase phytoplankton concentrations were observed during the low flow periods of 1988 and 1989. Total suspended solids measured in the river increased over time and was particularly high in 1990. The loss of aquatic vegetation in Weaver Bottoms in the late 1980's may have resulted in reduced sediment stability and allowed for an increase in sediment resuspension. The loss of submerged vegetation was not unique to Weaver Bottoms and has been reported for other Mississippi River pools.

The large variation in river flows over the last ten years, in combination with a system-wide decline of aquatic vegetation, masked water quality changes directly attributable to the Weaver Bottoms Rehabilitation Program. A longer monitoring period will be necessary to effectively evaluate the impact of the hydraulic modifications on Weaver Bottoms.

## REFERENCES

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Yellow Springs Instruments, Inc., 1983. Instruction Manual YSI Model 57 Dissolved Oxygen Meter. Yellow Springs, Ohio.

Table 1. Lotus 123 spreadsheet files containing continuous water quality monitoring data for Weaver Bottoms, Pool 5, Upper Mississippi River.

| Year | Period | Site No. | File Name |
|---|---|---|---|
| 1986 | July 16-24 | 1 | WEVJUL86.WK1 |
| | Aug. 21-29 | 2 | WEVAUG86.WK1 |
| 1988 | July 14-21 | 1 | WEVJUL88.WK1 |
| | Aug. 18-25 | 2 | WEVAUG88.WK1 |
| 1989 | July 12-20 | 1 | WEVJUL89.WK1 |
| | Aug. 16-24 | 2 | WEVAUG89.WK1 |
| 1990 | July 12-20 | 1 | WEVJUL90.WK3 |
| | Aug. 14-22 | 2 | WEVAUG90.WK3 |
| 1991 | July 9-17 | 1 | WEVJUL91.WK3 |
| | Aug. 15-23 | 2 | WEVAUG91.WK3 |
| 1992 | July 11-18 | 1 | WEVJUL92.WK3 |
| | Aug. 19-28 | 2 | WEVAUG92.WK3 |
| | Aug. 19-28 | 3 | MN14892.WK3 |
| 1993 | July 12-16 | 1 | WEVJUL93.WK3 |
| | Aug. 13-20 | 2 | WEVAUG93.WK3 |
| 1994 | July 18-25 | 1 | WEVJUL94.WK3 |
| | Aug. 15-23 | 2 | WEVAUG94.WK3 |
| 1995 | July 11-19 | 1 | WEVJUL95.WK3 |
| | Aug. 17-25 | 2 | WEVAUG95.WK3 |

Table 2. Summary of dissolved oxygen, water temperature, surface and underwater light penetration measurements collected at Weaver Bottoms, Pool 5, Upper Mississippi River during short term monitoring periods in July and August, 1986 and 1988-95. Data are averages (Avg.) and standard deviations (SD) of selected parameters. Note: current velocity measurements represent grab samples at the start and end of the monitoring period.

| Parameter | 1986 Site 1 July 16-24 | | 1986 Site 2 Aug. 21-29 | | 1988 Site 1 July 14-21 | | 1988 Site 2 Aug. 18-25 | | 1989 Site 1 July 12-20 | | 1989 Site 2 Aug. 16-24 | | 1990 Site 1 July 12-20 | | 1990 Site 2 Aug. 14-22 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) |
| Dissolved Oxygen (mg/l) | | | | | | | | | | | | | | | | |
| Avg. Daily Maximum | 12.1 | (1.3) | 16.3 | (2.2) | 9.3 | (1.2) | 8.7 | (2.4) | 12.6 | (2.7) | 15.8 | (2.5) | 12.4 | (4.2) | 14.5 | (4.4) |
| Avg. Daily Minimum | 5.1 | (0.5) | 6.2 | (0.7) | 6.0 | (0.6) | 4.6 | (2.0) | 6.4 | (1.0) | 8.6 | (1.1) | 6.7 | (1.2) | 7.8 | (1.8) |
| Avg. Daily Max-Min | 6.9 | (1.4) | 10.0 | (2.6) | 3.0 | (0.9) | 5.2 | (1.3) | 6.9 | (3.2) | 6.7 | (2.5) | 6.8 | (3.4) | 6.2 | (3.2) |
| Average | 8.4 | (2.3) | 11.5 | (3.6) | 7.6 | (1.0) | 6.6 | (1.9) | 9.6 | (2.5) | 11.9 | (2.4) | 9.0 | (2.0) | 10.9 | (3.5) |
| Avg. % Saturation | 103 | (29) | 132 | (44) | 97 | (18) | 81 | (30) | 121 | (33) | 141 | (30) | 112 | (44) | 133 | (41) |
| % Values less than 5.0 | 3.6 | | 0 | | 0 | | 30 | | 0 | | 0 | | 0 | | 0 | |
| Calibration Error (mg/l) @ | 0.1 | | -0.1 | | -0.1 | | -0.2 | | 0.2 | | -1.4 | | -0.5 | | -0.2 | |
| Water Temperature (C) | | | | | | | | | | | | | | | | |
| Avg. Daily Maximum | 26.1 | (0.8) | 23.5 | (1.9) | 29.2 | (1.6) | 26.1 | (1.4) | 27.6 | (1.4) | 25.6 | (1.2) | 26.7 | (2.4) | 26.7 | (1.7) |
| Avg. Daily Minimum | 23.5 | (0.6) | 19.2 | (2.2) | 26.7 | (1.6) | 22.5 | (2.5) | 24.6 | (1.1) | 22.3 | (0.7) | 23.3 | (1.8) | 23.2 | (1.8) |
| Avg. Daily Max-Min | 2.6 | (0.6) | 3.9 | (2.4) | 1.7 | (0.4) | 2.7 | (1.4) | 2.7 | (1.1) | 2.9 | (1.0) | 4.1 | (1.4) | 3.3 | (1.8) |
| Average | 24.7 | (1.1) | 21.3 | (2.3) | 27.7 | (1.6) | 24.3 | (2.3) | 26.0 | (1.2) | 23.9 | (1.1) | 24.7 | (1.8) | 24.6 | (1.7) |
| Light Data | | | | | | | | | | | | | | | | |
| Avg. Daily PAR (mols/m²/d)# | 49.3 | (9.5) | 26.5 | (12.9) | 38.7 | (8.4) | 24.4 | (10.8) | 47.7 | (9.3) | 31.1 | (9.5) | 46.8 | (7.9) | 24.1 | (13.8) |
| Extinction Coeff. (1/m) | 2.6 | (0.5) | 1.5 | (1.5) | 3.52 | (0.47) | 3.67 | (1.43) | 4.34 | (0.66) | 6.12 | (1.43) | 5.38 | (1.39) | 6.71 | (1.14) |
| 1% Compensation Depth (m) | 1.8 | (0.3) | 3.2 | (0.7) | 1.33 | (0.18) | 1.59 | (0.84) | 1.09 | (0.16) | 0.81 | (0.24) | 0.90 | (0.16) | 0.71 | (0.14) |
| Current Velocity (cm/s) | 1.5 | | ND - 1.5 | | 0.9 | | ND - 1.5 | | 1.5 - 2.4 | | 3.0 - 4.0 | | 0.6 - 2.1 | | ND - 2.4 | |
| River Discharge at Winona (cfs) | 54000 | (3300) | 45670 | (2460) | 7730 | (850) | 11100 | (2400) | 12570 | (1820) | 12400 | (960) | 30700 | (3580) | 20300 | (8200) |

Table 2. Continued.

| Parameter | 1991 Site 1 July 9-17 | | 1991 Site 2 Aug. 15-23 | | 1992 Site 1 July 11-18 | | 1992 Site 2 Aug. 19-28 | | 1992 Above MN-14* Aug. 19-28 | | 1993 Site 1 July 12-16 | | 1993 Site 2 Aug. 13-20 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) |
| Dissolved Oxygen (mg/l) | | | | | | | | | | | | | | |
| Avg. Daily Maximum | 12.4 | (1.8) | 14.0 | (3.5) | 8.9 | (1.8) | 19.4 | (4.3) | 14.1 | (1.4) | 6.5 | (0.1) | 10.6 | (1.0) |
| Avg. Daily Minimum | 7.2 | (0.7) | 9.1 | (1.1) | 5.8 | (0.3) | 11.7 | (2.3) | 9.7 | (0.6) | 5.5 | (0.1) | 7.2 | (0.2) |
| Avg. Daily Max-Min | 5.0 | (1.9) | 5.1 | (3.1) | 2.7 | (0.8) | 7.9 | (3.0) | 4.4 | (1.2) | 1.0 | (0.1) | 3.4 | (1.1) |
| Average | 9.5 | (2.0) | 11.2 | (2.4) | 7.1 | (1.5) | 15.1 | (4.1) | 11.8 | (1.8) | 6.0 | (0.3) | 8.4 | (1.2) |
| Avg. % Saturation | 118.6 | (27.6) | 133.0 | (32.2) | 83.3 | (18.8) | 175.2 | (51.9) | 137.4 | (23.1) | 68.3 | (4.6) | 98.7 | (16.0) |
| % Values less than 5.0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| Calibration Error (mg/l) @ | -0.75 | | -0.5 | | -0.1 | | -4.5 | | -0.7 | | 0.1 | | -0.6 | |
| Water Temperature (C) | | | | | | | | | | | | | | |
| Avg. Daily Maximum | 27.6 | (1.4) | 25.1 | (1.3) | 23.8 | (1.1) | 24.1 | (2.0) | 23.5 | (0.9) | 22.5 | (0.9) | 26.4 | (1.0) |
| Avg. Daily Minimum | 24.5 | (0.9) | 21.6 | (1.2) | 21.1 | (0.9) | 20.6 | (1.4) | 21.5 | (0.8) | 21.0 | (0.4) | 23.4 | (0.6) |
| Avg. Daily Max-Min | 3.5 | (1.5) | 3.6 | (1.3) | 2.6 | (0.7) | 3.3 | (1.1) | 1.9 | (0.3) | 1.7 | (0.9) | 2.9 | (1.1) |
| Average | 25.9 | (1.4) | 23.4 | (1.7) | 22.3 | (1.3) | 22.1 | (2.0) | 22.4 | (1.1) | 21.6 | (0.7) | 24.5 | (1.1) |
| Light Data | | | | | | | | | | | | | | |
| Avg. Daily PAR (mols/$m^2$/d)# | 50.3 | (8.8) | 37.1 | (12.6) | 33.5 | (14.3) | 36.6 | (13.0) | 36.6 | (13.0) | 36.5 | (22.8) | 27.5 | (9.9) |
| Extinction Coeff. (1/m) | 3.75 | (0.88) | 3.50 | (0.31) | 3.40 | (0.57) | 6.18 | (0.37) | 2.91 | (1.68) | 4.12 | (0.48) | 3.65 | (0.46) |
| 1% Compensation Depth (m) | 1.24 | (0.27) | 1.33 | (0.12) | 1.39 | (0.26) | 0.75 | (0.04) | 1.99 | (0.88) | 1.13 | (0.12) | 1.28 | (0.16) |
| Current Velocity (cm/s) | 0.9 - 1.8 | | 2.1 | | ND - 1.2 | | ND | | ND | | | | 3.3 | |
| River Discharge at Winona (cfs) | 55600 | (4140) | 34070 | (3430) | 18980 | (1240) | 34840 | (9400) | 34840 | (9400) | 130000 | (1400) | 64890 | (3760) |

Table 2. Continued.

| Parameter | 1994 Site 1 July 18-25 | | 1994 Site 2 Aug. 15-23 | | 1995 Site 1 July 11-19 | | 1995 Site 2 Aug. 17-25 | |
|---|---|---|---|---|---|---|---|---|
| | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) | Avg. | (SD) |
| Dissolved Oxygen (mg/l) | | | | | | | | |
| Avg. Daily Maximum | 10.4 | (2.0) | 14.4 | (2.8) | 12.9 | (4.2) | 14.5 | (3.7) |
| Avg. Daily Minimum | 5.8 | (1.0) | 8.9 | (0.6) | 6.1 | (1.8) | 7.7 | (1.0) |
| Avg. Daily Max-Min | 3.9 | (0.6) | 6.0 | (2.4) | 5.9 | (2.2) | 7.0 | (3.0) |
| Average | 8.0 | (2.0) | 11.3 | (2.3) | 9.0 | (3.5) | 10.7 | (3.1) |
| Avg. % Saturation | 110.3 | (28.4) | 79.2 | (16.3) | 115.7 | (44.7) | 134.0 | (41.2) |
| % Values less than 5.0 | 4.1 | | 0 | | 7.9 | | 0 | |
| Calibration Error (mg/l) @ | -0.5 | | -0.5 | | -0.5 | | -0.8 | |
| Water Temperature (C) | | | | | | | | |
| Avg. Daily Maximum | 25.6 | (0.8) | 24.4 | (1.4) | 29.1 | (2.5) | 27.9 | (0.4) |
| Avg. Daily Minimum | 23.4 | (0.6) | 21.1 | (1.2) | 26.2 | (2.5) | 24.4 | (1.0) |
| Avg. Daily Max-Min | 2.2 | (0.6) | 3.5 | (1.5) | 2.5 | (0.7) | 3.4 | (1.2) |
| Average | 24.5 | (1.0) | 22.5 | (1.6) | 27.5 | (2.5) | 26.0 | (1.3) |
| Light Data | | | | | | | | |
| Avg. Daily PAR (mols/m²/d)# | 41.7 | (7.8) | 34.3 | (9.2) | 44.8 | (10.3) | 40.2 | (10.6) |
| Extinction Coeff. (1/m) | 7.78 | (1.31) | 3.88 | (0.58) | 6.18 | (1.91) | 4.01 | (0.83) |
| 1% Compensation Depth (m) | 0.61 | (0.10) | 1.22 | (0.21) | 0.81 | (0.23) | 1.18 | (0.22) |
| Current Velocity (cm/s) | | | | | | | | |
| River Discharge at Winona (cfs) | 35990 | (2400) | 29800 | (1680) | 51470 | (1485) | 53420 | (10180) |

ND - Not Detected
@ - Instrument calibration drift at the end of the monitoring period.
# - Photosynthetic active radiation (PAR) measured in the 400-700 nm wavelength spectrum.
* - Site located in the Mississippi River upstream of MN-14 and adjacent to Site 2.

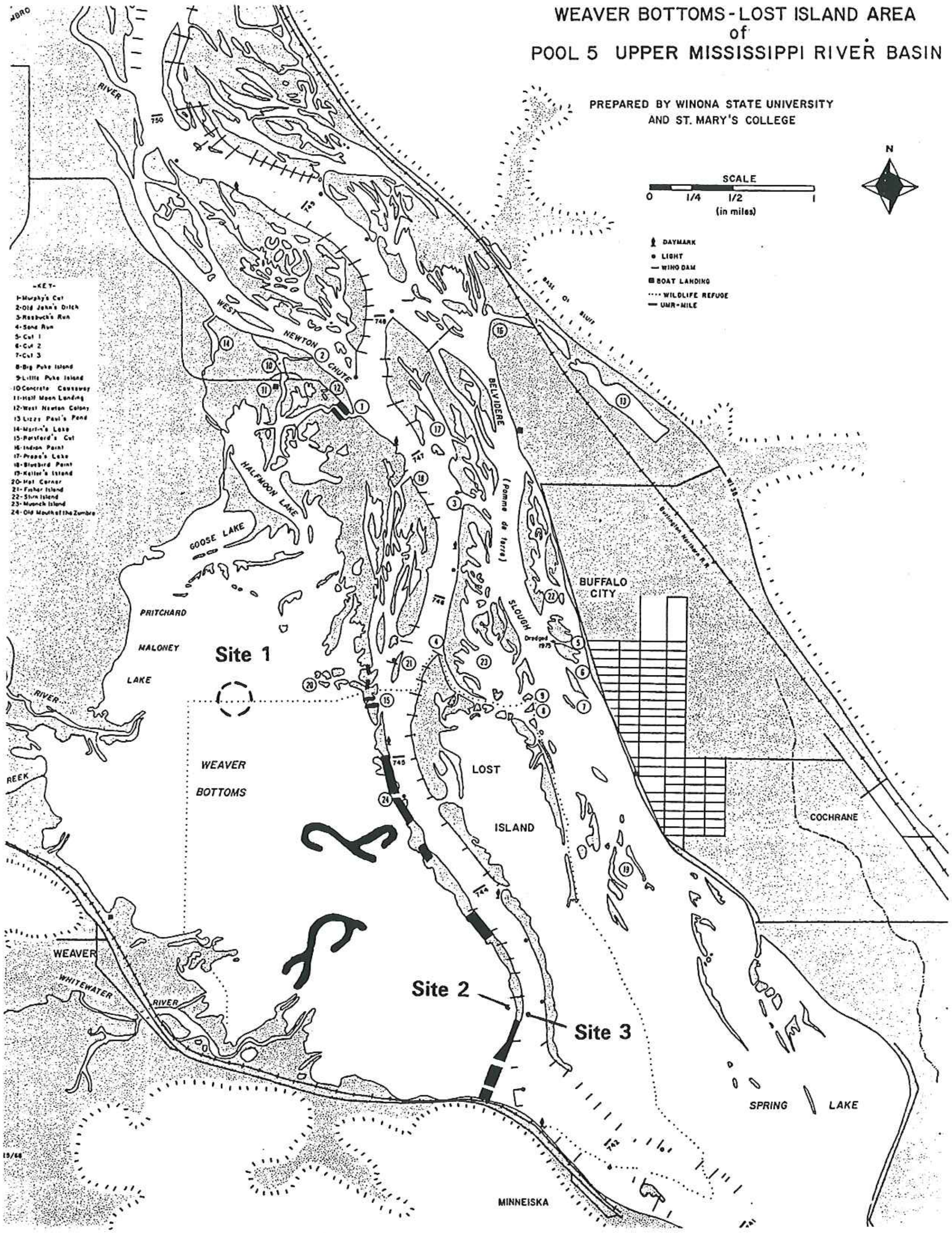



Figure 1. Weaver Bottoms study area. Darkened areas represent new islands and closing structures created as part of the Weaver Bottoms Rehabilitation Program. Modified map from Nielsen et al. 1978.

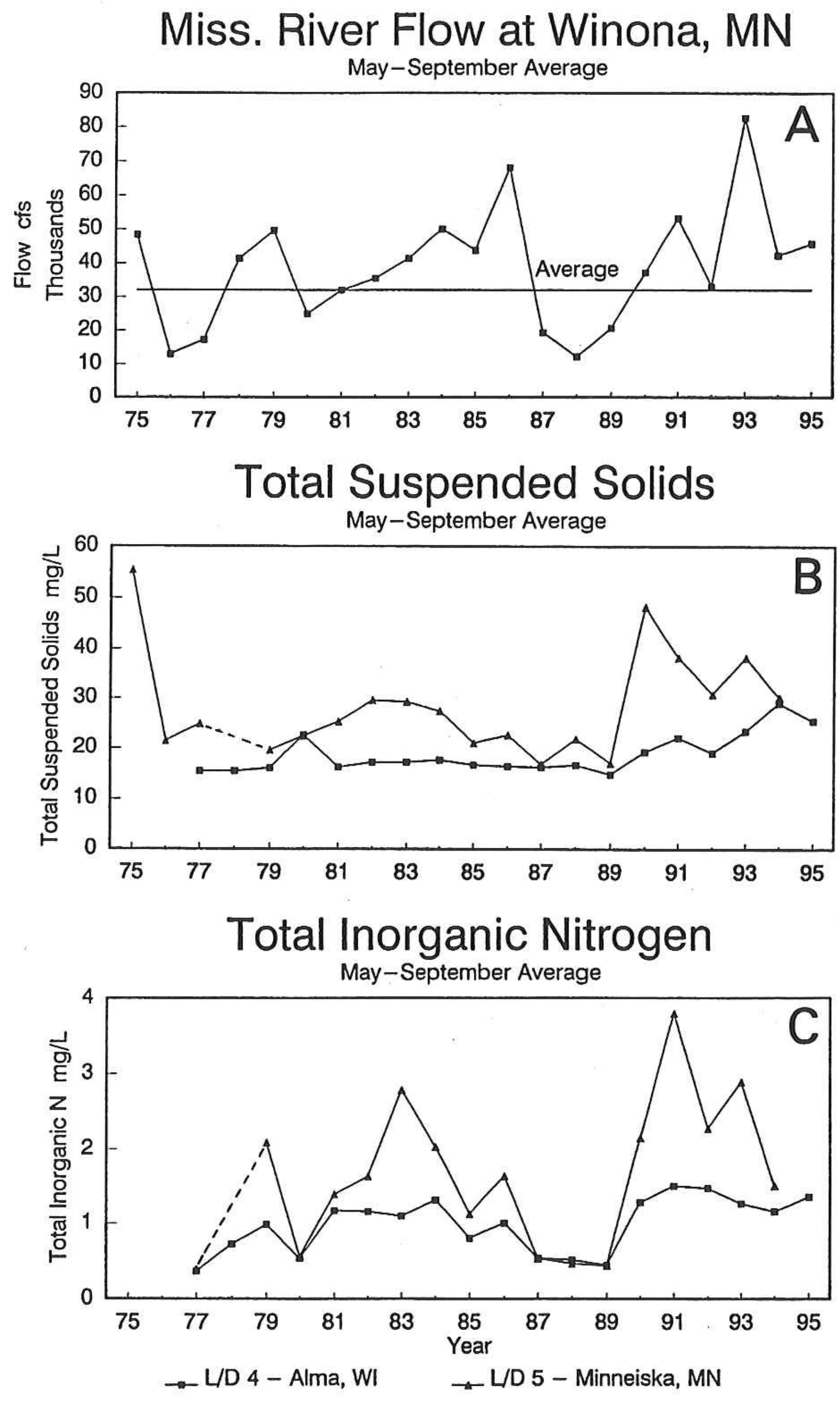



Figure 2. **A**. Summer average river flow for the USGS gaging station at Winona, Minnesota. **B**. Summer average total suspended solid concentrations for Wisconsin Department of Natural Resources' (WDNR) monitoring station at Lock and Dam 4 and Minnesota Pollution Control Agency's (MPCA) station at Lock and Dam 5 available from U.S. EPA's STORET data base. **C**. Summer average total inorganic nitrogen concentrations at Lock and Dam 4 and 5 collected by WDNR and MPCA. Water quality data reflect monthly grab samples.

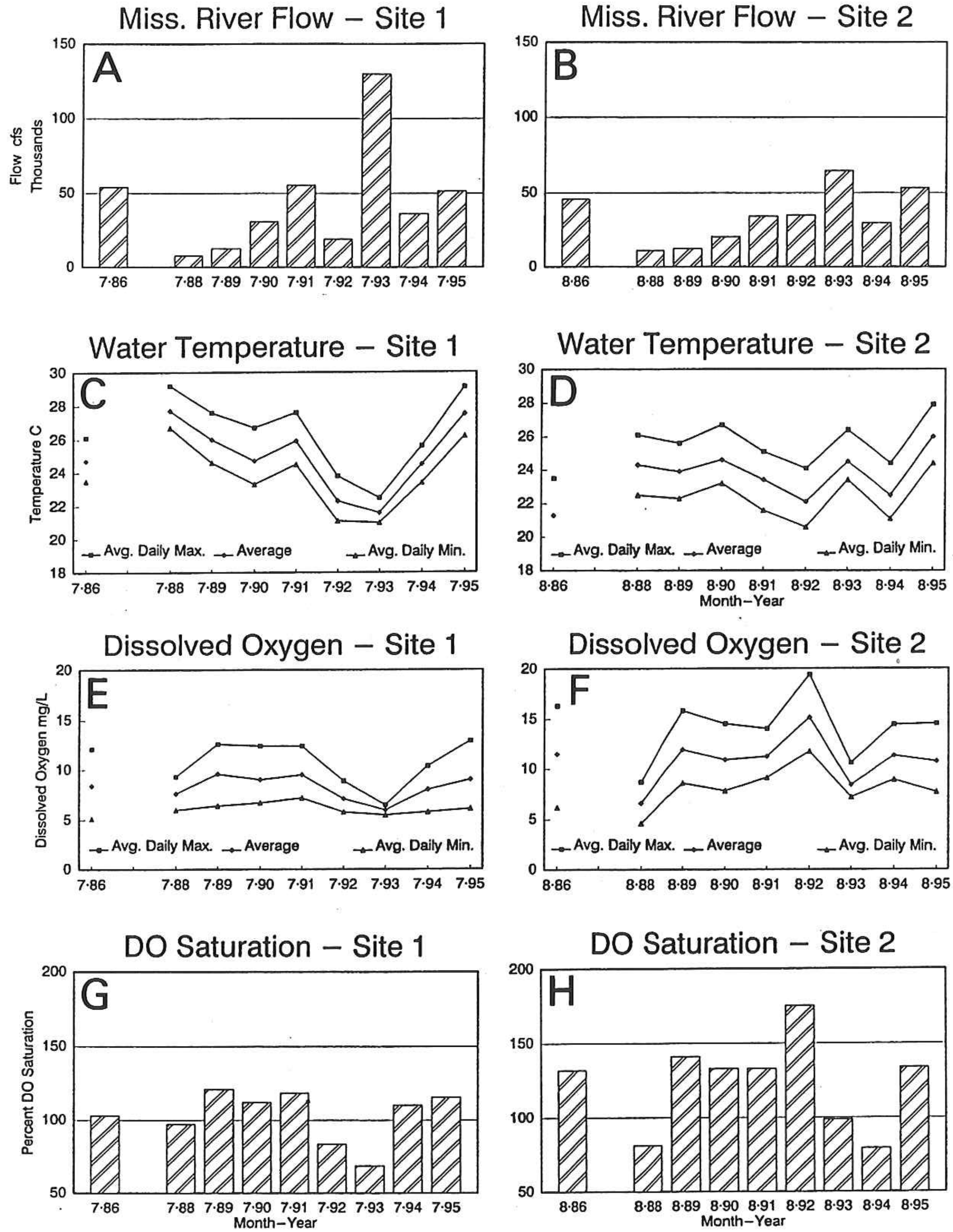



Figure 3. **A.** Average river flow at Winona, MN (USGS data) during the July monitoring period at Site 1 and during August (**B**) at Site 2. **C.** Average daily maximum, average daily, and average daily minimum water temperature during the July monitoring period at Site 1 and during August (**D**) at Site 2. **E.** Average daily maximum, average daily and average daily minimum dissolved oxygen (DO) during the July monitoring period at Site 1 and during August (**F**) at Site 2. **G.** Average DO saturation during the July monitoring period at Site 1 and during August (**H**) at Site 2.

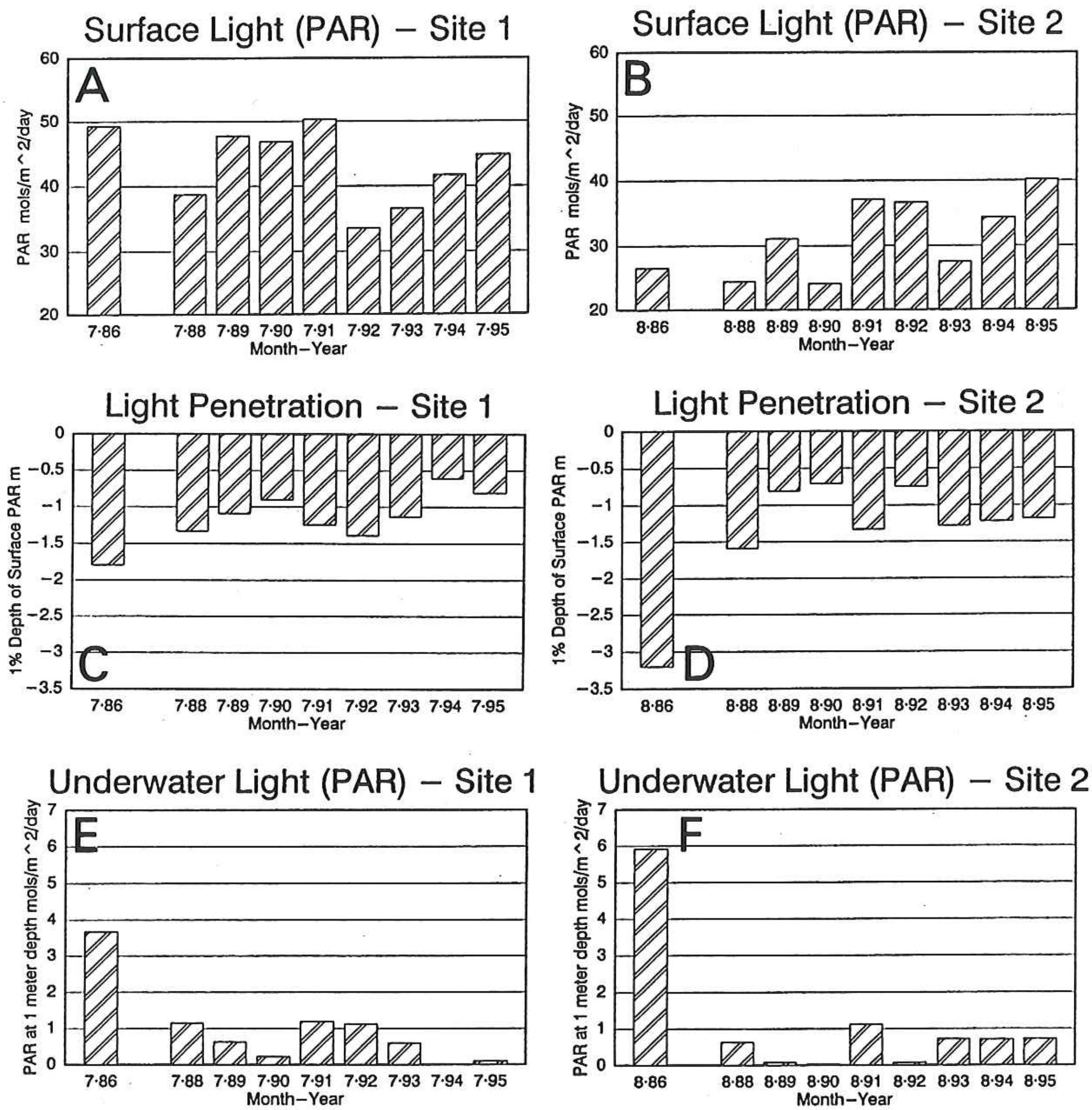



Figure 4. **A.** Average surface photosynthetically active radiation (PAR) measurements during the July monitoring period at Site 1 and during August (**B**) at Site 2. **C.** Average depth of underwater light penetration (1% of surface PAR) during the July monitoring period at Site 1 and during August (**D**) at Site 2. E. Average light energy (PAR) at 1 meter depth during the July monitoring period at Site 1 and during August (**F**) at Site 2.

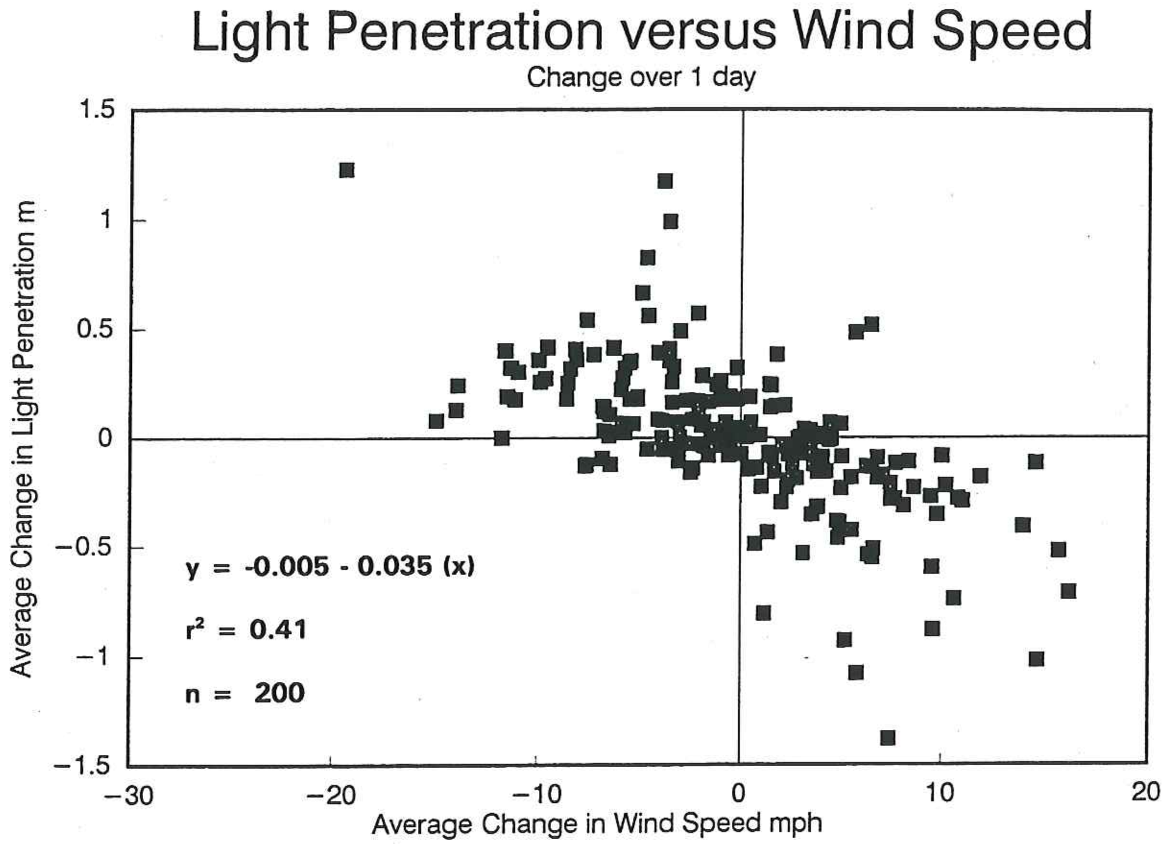


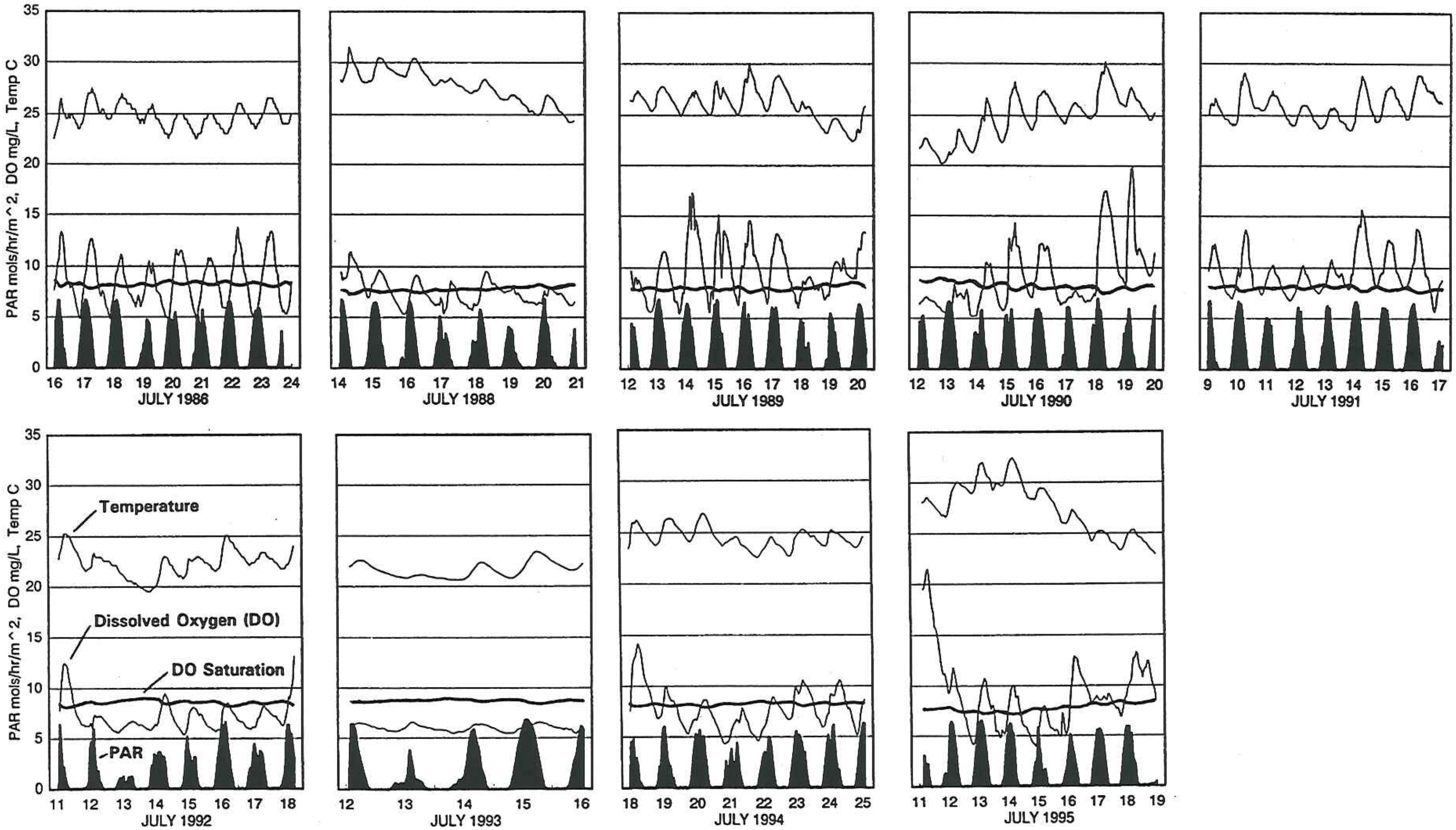

Figure 5. The relationship between the change in light penetration and change in wind speed over 1 day at Weaver Bottoms, Pool 5, Upper Mississippi River. Light penetration measurements reflect the 1% depth of surface photosynthetically active radiation (PAR). Light and wind speed data reflect the average of mid-day measurements (1000 - 1400 hrs) collected at Site 1 between April 7 and November 9, 1994.

# Appendix A. Example Lotus Spreadsheet - July 1990

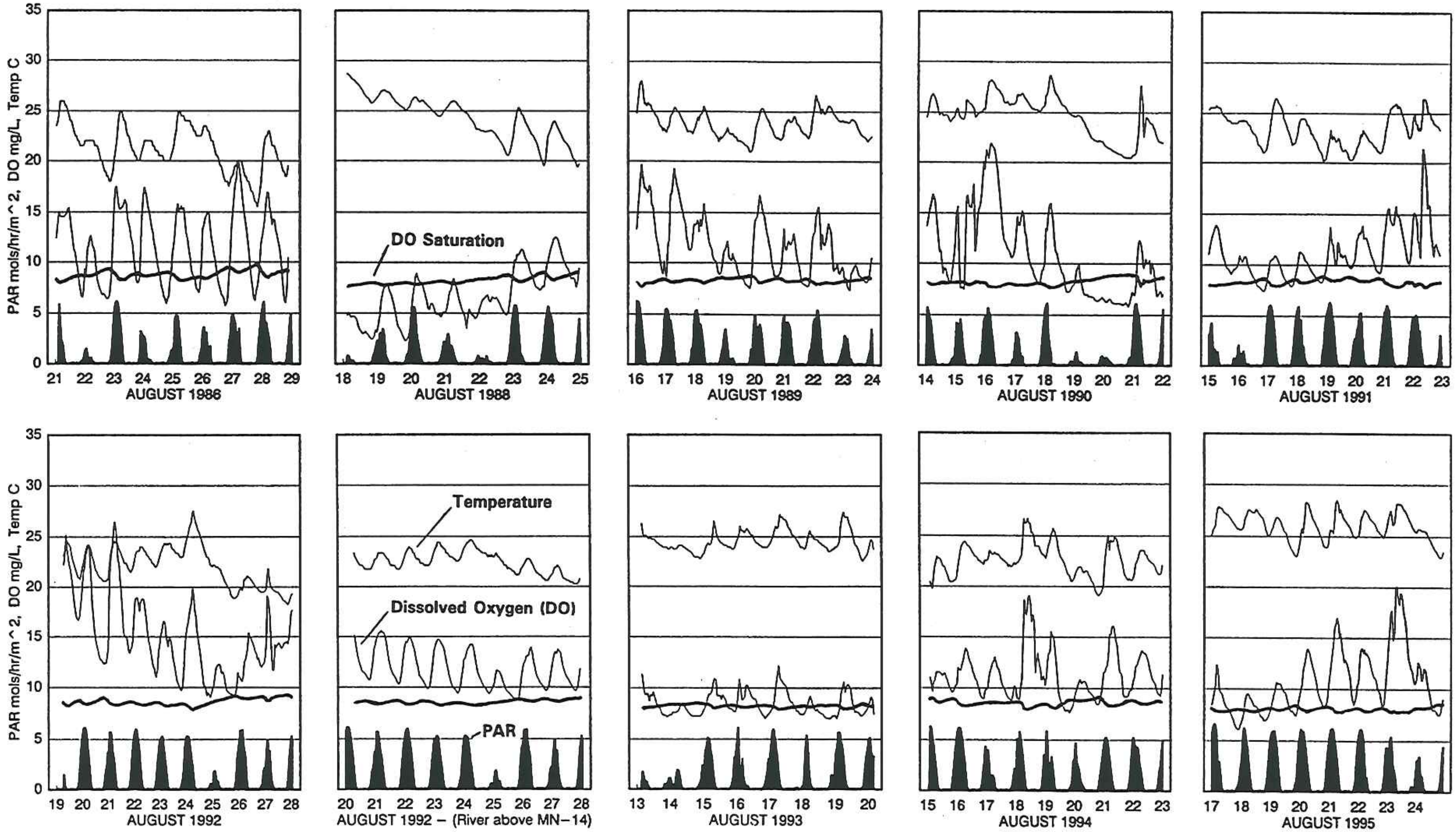
WEAVER BOTTOMS SITE 1. CONTINUOUS MONITORING DATA BY WDNR-LAX. J. SULLIVAN. DO METER YSI 57WQ WITH 100FT CABLE.
NEW LICOR USED WITH OLD PAR SENSORS. FINAL DO DRIFT -0.5 MG/L. THERMISTOR 4 USED.
LIGHT CORRECTION APPLIED DUE TO PROBE FOULING (SEE BELOW).

| | DATE | TIME | Io | Iz | DEPTH m | EXT/M | 1% EST. | LIGHT ADJUST | ADJUST 1 % DEPTH | 1% DEPTH 10-2PM | EXT/M 10-2PM | DO mg/l | CORR. FACTOR | CORR. DO mg/l | TEMP C | AVG LIGHT Io MOL/M/SQ | SUM LIGHT Io MOL/M/SQ | AVG LIGHT Iz MOL/M/SQ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | | 1200 | | | | | | | | -0.59 | 7.81 | | | | | | | |
| | | 1300 | | | | | | | | | | | | | | | | |
| | 900712 | 1400 | 4.6640 | 0.0036 | .92 | 7.80 | -0.59 | 1.00 | -0.59 | | | 6.4 | 0.0 | 6.40 | 21.7 | | | |
| | 900712 | 1500 | 4.0630 | 0.0034 | .92 | 7.71 | -0.60 | 1.00 | -0.60 | | | 6.6 | 0.0 | 6.56 | 21.8 | | | |
| | 900712 | 1600 | 5.1700 | 0.0049 | .92 | 7.56 | -0.61 | 1.00 | -0.61 | | | 6.7 | 0.0 | 6.67 | 22.0 | | | |
| | 900712 | 1700 | 5.2730 | 0.0047 | .92 | 7.64 | -0.60 | 1.01 | -0.61 | | | 6.7 | 0.0 | 6.75 | 22.3 | | | |
| | 900712 | 1800 | 4.3260 | 0.0032 | .92 | 7.85 | -0.59 | 1.01 | -0.59 | | | 6.9 | 0.0 | 6.93 | 22.6 | | | |
| | 900712 | 1900 | 2.6670 | 0.0017 | .92 | 8.03 | -0.57 | 1.01 | -0.58 | | | 7.0 | 0.0 | 7.05 | 22.7 | | | |
| | 900712 | 2000 | 1.1430 | 0.0006 | .92 | 8.30 | -0.55 | 1.01 | -0.56 | | | 7.0 | 0.0 | 7.06 | 22.7 | | | |
| | 900712 | 2100 | 0.1446 | 0.0000 | .92 | 8.78 | -0.52 | 1.01 | -0.53 | | | 6.9 | 0.0 | 6.95 | 22.4 | | | |
| | 900712 | 2200 | | | | | | | | | | 6.8 | 0.0 | 6.81 | 22.1 | | | |
| | 900712 | 2300 | | | | | | | | | | 6.7 | 0.0 | 6.76 | 21.8 | | | |
| | 900713 | 0 | | | | | | | | | | 6.7 | 0.0 | 6.69 | 21.7 | | | |
| | 900713 | 100 | | | | | | | | | | 6.6 | 0.0 | 6.68 | 21.5 | | | |
| | 900713 | 200 | | | | | | | | | | 6.6 | 0.0 | 6.61 | 21.4 | | | |
| | 900713 | 300 | | | | | | | | | | 6.5 | 0.0 | 6.53 | 21.3 | | | |
| | 900713 | 400 | | | | | | | | | | 6.2 | 0.0 | 6.22 | 21.0 | | | |
| | 900713 | 500 | | | | | | | | | | 6.1 | 0.0 | 6.12 | 20.9 | | | |
| | 900713 | 600 | 0.0401 | 0.0000 | .98 | 9.00 | -0.51 | 1.03 | -0.53 | | | 6.1 | 0.0 | 6.14 | 20.7 | | | |
| | 900713 | 700 | 0.5279 | 0.0002 | .98 | 8.09 | -0.57 | 1.03 | -0.59 | | | 6.0 | 0.0 | 6.01 | 20.3 | | | |
| | 900713 | 800 | 1.5970 | 0.0005 | .98 | 8.23 | -0.56 | 1.03 | -0.58 | | | 5.7 | 0.0 | 5.77 | 20.2 | | | |
| | 900713 | 900 | 2.8970 | 0.0008 | .98 | 8.31 | -0.55 | 1.03 | -0.57 | | | 5.7 | 0.0 | 5.70 | 20.3 | | | |
| | 900713 | 1000 | 4.2200 | 0.0010 | .98 | 8.53 | -0.54 | 1.03 | -0.56 | | | 5.5 | 0.1 | 5.59 | 20.3 | | | |
| | 900713 | 1100 | 5.3480 | 0.0014 | .98 | 8.41 | -0.55 | 1.04 | -0.57 | | | 5.6 | 0.1 | 5.62 | 20.4 | | | |
| 13 | 900713 | 1200 | 6.1070 | 0.0021 | .98 | 8.14 | -0.57 | 1.04 | -0.59 | -0.60 | 7.71 | 5.8 | 0.1 | 5.81 | 20.6 | | | |
| | 900713 | 1300 | 6.5910 | 0.0033 | .98 | 7.76 | -0.59 | 1.04 | -0.62 | | | 5.6 | 0.1 | 5.65 | 20.9 | | | |
| | 900713 | 1400 | 6.6910 | 0.0034 | .98 | 7.75 | -0.59 | 1.04 | -0.62 | | | 5.7 | 0.1 | 5.79 | 21.4 | | | |
| | 900713 | 1500 | 6.4180 | 0.0037 | .98 | 7.60 | -0.61 | 1.04 | -0.63 | | | 5.7 | 0.1 | 5.80 | 21.1 | | | |
| | 900713 | 1600 | 5.8030 | 0.0040 | .98 | 7.43 | -0.62 | 1.04 | -0.65 | | | 5.8 | 0.1 | 5.89 | 21.2 | | | |
| | 900713 | 1700 | 4.8820 | 0.0054 | .98 | 6.95 | -0.66 | 1.05 | -0.69 | | | 6.7 | 0.1 | 6.82 | 21.4 | | | |
| | 900713 | 1800 | 3.6730 | 0.0091 | .98 | 6.12 | -0.75 | 1.05 | -0.79 | | | 8.3 | 0.1 | 8.34 | 21.7 | | | |
| | 900713 | 1900 | 2.3650 | 0.0089 | .98 | 5.69 | -0.81 | 1.05 | -0.85 | | | 7.8 | 0.1 | 7.85 | 21.7 | | | |
| | 900713 | 2000 | 1.0940 | 0.0026 | .98 | 6.16 | -0.75 | 1.05 | -0.79 | | | 7.0 | 0.1 | 7.07 | 22.6 | | | |
| | 900713 | 2100 | 0.1900 | 0.0005 | .98 | 6.08 | -0.76 | 1.05 | -0.80 | | | 7.2 | 0.1 | 7.28 | 23.5 | | | |
| | 900713 | 2200 | | | | | | | | | | 7.2 | 0.1 | 7.32 | 23.6 | | | |
| | 900713 | 2300 | | | | | | | | | | 7.4 | 0.1 | 7.47 | 23.3 | | | |
| | 900714 | 0 | | | | | | | | | | 7.2 | 0.1 | 7.29 | 23.0 | 3.7 | 58.4 | 0.0029 |
| | 900714 | 100 | | | | | | | | | | 7.0 | 0.1 | 7.07 | 22.8 | | | |
| | 900714 | 200 | | | | | | | | | | 6.8 | 0.1 | 6.89 | 22.4 | | | |
| | 900714 | 300 | | | | | | | | | | 7.3 | 0.1 | 7.42 | 22.2 | | | |
| | 900714 | 400 | | | | | | | | | | 7.7 | 0.1 | 7.85 | 21.9 | | | |
| | 900714 | 500 | | | | | | | | | | 7.1 | 0.1 | 7.19 | 21.8 | | | |
| | 900714 | 600 | 0.0083 | 0.0000 | 0.98 | 6.05 | -0.76 | 1.07 | -0.81 | | | 6.0 | 0.1 | 6.13 | 21.6 | | | |
| | 900714 | 700 | 0.2306 | 0.0012 | 0.98 | 5.35 | -0.86 | 1.07 | -0.92 | | | 5.2 | 0.1 | 5.35 | 21.5 | | | |
| | 900714 | 800 | 0.9960 | 0.0042 | 0.98 | 5.58 | -0.83 | 1.07 | -0.88 | | | 5.1 | 0.1 | 5.20 | 21.3 | | | |
| | 900714 | 900 | 2.2800 | 0.0122 | 0.98 | 5.34 | -0.86 | 1.07 | -0.92 | | | 5.1 | 0.1 | 5.23 | 21.3 | | | |
| | 900714 | 1000 | 3.4880 | 0.0166 | 0.98 | 5.46 | -0.84 | 1.07 | -0.91 | | | 5.2 | 0.1 | 5.27 | 21.5 | | | |
| | 900714 | 1100 | 3.6330 | 0.0135 | 0.98 | 5.71 | -0.81 | 1.08 | -0.87 | | | 5.1 | 0.1 | 5.24 | 21.8 | | | |
| 14 | 900714 | 1200 | 3.1890 | 0.0140 | 0.98 | 5.54 | -0.83 | 1.08 | -0.90 | -0.90 | 5.10 | 5.2 | 0.1 | 5.27 | 22.2 | | | |
| | 900714 | 1300 | 3.4180 | 0.0174 | 0.98 | 5.39 | -0.85 | 1.08 | -0.92 | | | 5.9 | 0.1 | 6.06 | 22.9 | | | |
| | 900714 | 1400 | 2.4300 | 0.0126 | 0.98 | 5.37 | -0.86 | 1.08 | -0.93 | | | 6.5 | 0.1 | 6.60 | 23.5 | | | |

| SUM LIGHT Iz MOL/M/SQ | MIN DO mg/l | MAX DO mg/l | DO MAX MINUS MIN | AVG DO mg/l | MIN TEMP C | MAX TEMP C | TEMP MAX MINUS MIN | AVG TEMP C | TEMP DEG F | DO SAT MG/L | % SAT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 71.0 | 8.7 | 73.4 |
| | | | | | | | | | 71.3 | 8.7 | 75.4 |
| | | | | | | | | | 71.5 | 8.7 | 76.9 |
| | | | | | | | | | 72.2 | 8.6 | 78.4 |
| | | | | | | | | | 72.7 | 8.6 | 81.0 |
| | | | | | | | | | 72.9 | 8.5 | 82.5 |
| | | | | | | | | | 72.8 | 8.6 | 82.5 |
| | | | | | | | | | 72.3 | 8.6 | 80.8 |
| | | | | | | | | | 71.8 | 8.6 | 78.8 |
| | | | | | | | | | 71.3 | 8.7 | 77.7 |
| | | 7.1 | | 6.8 | | 22.7 | | 22.2 | 71.0 | 8.7 | 76.7 |
| | | | | | | | | | 70.8 | 8.7 | 76.4 |
| | | | | | | | | | 70.5 | 8.8 | 75.4 |
| | | | | | | | | | 70.3 | 8.8 | 74.3 |
| | | | | | | | | | 69.9 | 8.8 | 70.5 |
| | | | | | | | | | 69.6 | 8.9 | 69.1 |
| | | | | | | | | | 69.2 | 8.9 | 69.0 |
| | | | | | | | | | 68.5 | 9.0 | 67.0 |
| | | | | | | | | | 68.3 | 9.0 | 64.1 |
| | | | | | | | | | 68.5 | 9.0 | 63.5 |
| | | | | | | | | | 68.5 | 9.0 | 62.3 |
| | | | | | | | | | 68.8 | 8.9 | 62.9 |
| | | | | | | | | | 69.1 | 8.9 | 65.3 |
| | | | | | | | | | 69.7 | 8.9 | 63.8 |
| | | | | | | | | | 70.5 | 8.8 | 66.0 |
| | | | | | | | | | 69.9 | 8.8 | 65.7 |
| | | | | | | | | | 70.2 | 8.8 | 67.0 |
| | | | | | | | | | 70.5 | 8.8 | 77.7 |
| | | | | | | | | | 71.1 | 8.7 | 95.6 |
| | | | | | | | | | 71.0 | 8.7 | 90.0 |
| | | | | | | | | | 72.7 | 8.6 | 82.6 |
| | | | | | | | | | 74.4 | 8.4 | 86.7 |
| | | | | | | | | | 74.5 | 8.4 | 87.3 |
| | | | | | | | | | 74.0 | 8.4 | 88.4 |
| 0.0469 | 5.6 | 8.3 | 2.7 | 6.5 | 20.2 | 23.6 | 3.5 | 21.4 | 73.5 | 8.5 | 85.9 |
| | | | | | | | | | 73.0 | 8.5 | 82.9 |
| | | | | | | | | | 72.4 | 8.6 | 80.3 |
| | | | | | | | | | 72.0 | 8.6 | 86.0 |
| | | | | | | | | | 71.4 | 8.7 | 90.4 |
| | | | | | | | | | 71.2 | 8.7 | 82.7 |
| | | | | | | | | | 70.8 | 8.7 | 70.1 |




Appendix B. Continuous measurements of water temperature (°C), dissolved oxygen (DO, mg/L), DO saturation (mg/L), and photosynthetically active radiation (PAR, mols/hr/m$^2$) at Weaver Bottoms, Pool 5, Upper Mississippi River. Data collected at Site 1 during July 1986, 1988-1995. Temperature and DO data represent hourly averages. PAR values are surface hourly totals.




Appendix B (Continued). Continuous measurements of water temperature (°C), dissolved oxygen (DO, mg/L), DO saturation (mg/L), and photosynthetically active radiation (PAR, mols/hr/m$^2$) at Weaver Bottoms, Pool 5, Upper Mississippi River. Data collected at Site 2 during August 1986, 1988-1995 and at a main channel border site (above MN-14) in August 1992. Temperature and DO data represent hourly averages. PAR values are surface hourly totals.