Continuous Dissolved Oxygen and Temperature Monitoring in Pool 8 of the Upper Mississippi River during January and February 2004

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Introduction

Water temperature and dissolved oxygen (DO) are important factors that influence habitat conditions for aquatic organisms. Severe dissolved oxygen depletion can develop in shallow backwaters that receive little inflow from the Mississippi River especially during periods of ice and snow cover. These conditions may lead to a deterioration of habitat for fish and can results in localized fishkills (winterkill) during periods of prolonged snow cover. Periods of ice cover without snow, can lead to DO supersaturation in shallow backwater areas as a result of plant photosynthetic activity which may also negatively impact fish (gas bubble disease), especially where escape routes to deeper water are unavailable.

Winter water temperature is a critical factor influencing aquatic habitat for fish, especially centrarchids, which prefer warmer temperatures found in the subsurface waters of backwaters, sloughs and other aquatic areas where water currents are low. Main channel and side channel water temperatures are about 0°C during January and February, but bottom waters in backwater areas may approach 4° C or warmer if influenced by groundwater inflows. Although this temperature range is small, these conditions may have a pronounced influence on the ability of a backwater area to provide suitable habitat to over-wintering fish and other aquatic organisms with low temperature intolerance.

Recent advancements of continuous, portable temperature and dissolved oxygen monitoring equipment have greatly facilitated the ability to make remote water quality measurements during periods of ice cover. Although numerous short-term deployments of continuous monitoring has been conducted during summer periods in backwater areas of the Mississippi River in the reach bordering Wisconsin (Sullivan 1996, 2001 and Kimber et al. 1995), very few measurements have been conducted during winter. The objectives of this work were to test the performance of this equipment during winter conditions, obtain water quality information to assess habitat conditions for aquatic life in off channels areas of the river, and evaluate the response of DO or water temperature to climatic and hydrologic factors.

Methods

Continuous measurements of DO and water temperature were collected at five backwater or isolated locations within Pool 8 of the Upper Mississippi River during the winter of 2004 (Figure 1). Dissolved oxygen and temperature were electronically recorded at hourly intervals at remote locations using Aqua 2002 data loggers obtained from BioDevices, Inc. The logging units were attached to small metal posts or were or suspended from the bottom using a simple flotation device to keep the units at a fixed monitoring depth. All units were deployed under about 1 ft (0.3 m) of ice in mid-January and were retrieved in late February prior to ice-out.

Field deployment consisted of drilling three, 7-in (17.8 cm) diameter holes in a triangular pattern in close proximity to one another. Care was taken to avoid drilling completely through the ice to avoid disturbing bed sediments. The hole was opened with an ice chisel and then the ice was removed manually by hand or with a ice fishing strainer. The units at sites A to C (Figure 2) were secured to a small board using two hose clamps (see cover photo). The board was mounted to a 3-ft (0.9 m) long fence post using a single bolt drilled through the board's center and through the upper portion of the fence post. This allowed the unit to be swiveled into a horizontal position below the bottom of the ice after the fence post was pushed into the sediment for stability. The unit was mounted at approximately mid-depth which provided about 0.6 to 1 ft (0.2 to 0.3 m) of clearance between the unit and the bottom of the ice. The fence post was tethered to a small diameter log that was allowed to freeze in the hole to mark the sampling site and aid in equipment retrieval.

The monitoring units were deployed at sites D and E by tethering the units on a nylon rope between a small anchor and seining float. The ropes were adjusted to suspend the units at approximately mid-depth. At site E an additional unit was also deployed 0.5-ft (0.1 m) off the bottom.

Sample location was determined using a Lowrance Globallnav 12 hand-held GPS receiver in autonomous mode. Position coordinates were recorded to the nearest ± 20 m in UTM units using the 1927 North American Datum (Table 1). Water and ice depth measurements were recorded to the nearest 0.1 ft (3 cm) using a metal disk attached to a fiberglass measuring tape. Field measurements of DO and water temperature were made using a YSI model 55 or 57 DO/temperature meter. Velocity measurements were determined using a Marsh McBirney model 201D current meter.

Pre- and post- DO calibration was performed using an air-saturated tap water at ambient air pressure (WDNR, 1983). If post calibration DO measurements indicated a drift greater than 0.4 mg/L, a DO correction was applied assuming a linear error adjustment over the course of the deployment period. Temperature accuracy was checked using a certified reference thermometer by immersing the sensors in a 0.0 °C ice bath for thirty minutes. Temperature values were adjusted if the temperature error exceeded the reported instrument error of ±0.1 °C. A summary of Aqua 2002 post calibration information for each data logger is presented in Table 1.

River flow at Lock and Dam 8, Pool 8 stage and main channel border river temperature at Brownsville, Minnesota were obtained from the U.S. Corps of Engineers (http://www.mvp-wc.usace.army.mil/projects/lock_dam.shtml). Air temperature and snow depth data were obtained from the National Weather Service for the La Crosse Airport (http://www.crh.noaa.gov/arx/).

Monitoring Site Descriptions

Site A was in the north lobe of an isolated wetland south of Stoddard, Wisconsin (Figure 2a). The area is bounded by the Burlington RR embankment on the east, Coon Creek delta on the south, wooded hillside on the west and low lying floodplain on the north. The area receives no direct inflow from the Mississippi River or Coon Creek during normal to low river stages. The village of Stoddard's municipal wastewater treatment plant discharges secondary wastewaters at the north end.

Site B was in an isolated slough and backwater complex between Bluff Slough and the Mississippi River main channel just west of the south side of La Crosse Wisconsin (Figure 2b). The monitoring site was at a constriction separating three small sloughs. Forested floodplains cover the shoreline areas. Sandbars at the southern end of the sloughs prevent water exchange with the river during normal to low river stages.

Site C was in a dead-end slough west of Running Slough about a mile north of Goose Island (Figure 2c). The shoreline contains scattered trees and grasses with the exception of the southeast end that adjoins Running Slough. Although current velocity was not detected (< 0.02 ft/s), lateral mixing with Running Slough was expected due to its close proximity to the monitoring site.

Site D was in an isolated abandoned channel ¾ miles north of the Root River delta (Figure 2d). The shoreline is comprised of a floodplain forest and open areas with grasses. Current velocity was not detected. Lateral mixing with a flowing channel lying immediately east of the site was expected.

Site E was at the south end of Lawrence Lake, a shallow floodplain lake on the west side of the Mississippi River main channel (Figure 2e). Current velocity was not detected but limited mixing with the river was expected during fluctuations in river stage. This site was previously monitored by the Department's Onalaska field station as part of the federal Long Term Resource Monitoring Program on the river (Jim Fischer, Wisconsin DNR, personal communications).

Results and Discussion

Winter climate and hydraulic conditions

Ice formation in backwaters of Pool 8 occurred late and thickness sufficient for supporting ice fishing was not present until early to mid-December, 2003. Snow depths reported at the La Crosse Airport reached 3 in. (7.6 cm) on December 16 but had disappeared by December 26. The next significant snowfall occurred during late January and early February (Figure 3a). These conditions resulted in a period of snow-free ice that persisted for approximately 4 weeks (December 26, 2004 to January 24, 2005). Snow depths exceeding 2 in. (5 cm) occurred during late January through late February.

Coldest air temperatures occurred during late January to early February. Average daily air temperatures during the study period remained below freezing until February 18 (Figure 3b). Average air temperatures increased several degrees in the latter half of February with the approach of the spring thaw.

River temperatures reported by the U.S. Army Corps of Engineers for the main channel border stage gaging site at Brownsville, MN were found to be reading high by an average of 1.9 °C. This finding was based on a comparison of Brownsville temperature data to grab measurements collected by the author at the same time 9 miles downstream at Lock and Dam 8 as part of other monitoring efforts. The Brownsville temperature measurements were adjusted downward 1.9 °C to provide better representation of main channel river temperatures during the period of continuous monitoring deployment. The reason for the higher temperature measurements at Brownsville were not explored but were assumed to be due to thermistor error since higher readings were observed during other periods of the year as well. Adjusted river temperatures at Brownsville gradually decreased from approximately 0.5 °C in mid-January to 0 °C in early to mid-February (Figure 3c). River temperatures appeared to show a slight increase at the termination of the monitoring period in late February.

Pool 8 river stage at Brownsville exhibited a net increase of 0.2-ft (6 cm) during the monitoring period (Figure 3d). The change in stage was gradual with the exception of two moderate fluctuations of 0.15 to 0.2 ft (4.6-6 cm) that occurred in late January and February that were related to changes in river flow (Figure 3e). River flows measured at LD 8 followed a similar pattern described for stage and increased from 9,000 to 14,000 cfs during the monitoring period. Winter flow conditions were below normal and represent flow durations of approximately 75 to 95% based on flow-duration tables provided by the US Corps of Engineers for Lock and Dam 7.

Temperature

Pre- and post-temperature calibration checks in ice water indicated five of the six units were reading slightly higher than the reported sensor accuracy (± 0.1°C) by 0.1 to 0.2 °C (Table 1). A post-deployment temperature adjustment was made to ensure consistent measurements at 0 °C and to facilitate temperature comparisons between monitoring sites.

Initial mid-depth water temperature measurements during mid-January ranged from about 0.5 to 3.0 °C at sites A to D (Figure 4). Coldest waters were found at sites C and D and were likely influenced by mixing and circulation of colder flowing waters associated with main channel inflows delivered by secondary and tertiary side channels. Temperature measurements at sites C and D were slightly warmer than the river temperatures at Brownsville (Figure 3c) but in general followed a similar temporal trend over the deployment period. However, sites C and D did exhibit greater diurnal fluctuations, which were more typical of the backwater or isolated sites (A, B and E).

Warmest water temperatures occurred at isolated or backwaters sites that received little to no mixing with side channel inflows from the river (Figure 4a,b,e). The influence of groundwater inflows at these sites was not determined. However, a spatial survey of upper Lawrence Lake (north of site E) indicated bottom and mid-depth temperatures of 5 °C and suggests groundwater inflows may be important in this backwater lake. Springs are apparent in the western portion of the lake (Jim Fischer, Wisconsin DNR, personal communication). Air temperature changes (Figure 3b) were an important factor influencing water temperatures especially at the isolated or backwater sites that did not mix with flowing side channels.

Moderate diurnal temperature fluctuations of 0.5 to 1 °C were apparent from the onset of deployment beginning on January 15 to January 23 (Figure 4). These changes occurred during a period of bare ice and were mainly attributed to solar heating. Diurnal temperature fluctuation decreased greatly at all sites following the accumulation of 2 in. (5 cm) of snow on January 24 (Figure 3a) and remained low for the duration of the monitoring period. The exception was site D that continued to yield a small diurnal change of 0.2 to 0.3 °C which may indicate a greater influence of daily air temperature fluctuations and solar heating at this location (Figure 4d). This site was likely influenced by side channel inflows from a portion of the river channel that had little ice cover during the monitoring period and the dirunal pattern may reflect temperature fluctuations of the main channel.

Dissolved Oxygen

Post-DO calibration indicated sensor drift ranging from –0.2 to 1.8 mg/L. Three of the six monitoring units had calibration drifts exceeding 0.4 mg/L and were adjusted as previously described. The calibration error on the remaining three units was less than 0.2 mg/L (Table 1).

Initial DO concentrations exceeded saturation levels at all locations during mid- to late January. Highest DO concentrations were found at the isolated or backwater sites (A, B and E) and ranged from about 20 to 35 mg/L (Figure 5). These concentrations yield DO saturation values of approximately 150 to 260% at 2 °C and 750 mm Hg pressure. Highest DO concentrations occurred at site A (Stoddard Wetland) which had substantial algae (phytoplankton) as indicated by a pronounced greenish-brown turbidity in the water column during initial data logger deployment. Water clarity at site B and E was very high and the bottom was visible. Vertical DO profiles collected during mid-January indicated greatest DO concentrations in the bottom waters at sites C, D and E suggesting photosynthetic activity associated with sub-surface phytoplankton, benthic algae, live submersed aquatic macrophytes or attached algae. Green submersed aquatic plant tissues and filamentous algae were observed on the bottom in Lawrence Lake on January 21.

Marked diurnal fluctuations in DO were only apparent at site A and ranged from about 3 to 7 mg/L (Figure 5a). This response was likely a result of greater phytoplankton concentrations at this site as previously discussed. The diurnal fluctuations diminished greatly in late January, presumably as a result of snow accumulation on ice and the resultant decreased in light availability for photosynthesis.

Dissolved oxygen concentrations fell dramatically at the isolated or backwater sites (A, B and E) in late January to early February in response to snow cover and decreased photosynthetic activity, plant respiration and sediment oxygen demand (Figure 5). By early February, monitoring sites A and B and the bottom sample at site E indicated hypoxic to anoxic conditions. The bottom waters at site E exhibited some recovery of DO at the termination of the monitoring period in late February (Figure 5e). Small decreases in DO were also apparent at sites influenced by mixing with flowing side channels (C and D) but the magnitude of these changes was noticeably less and the minimum DO concentrations at these sites were substantially greater as compared to the backwater or isolated sites. Winter main channel and side channel DO concentrations do not normally fall to low levels as a result of aeration below dams, reduced ice and snow cover, reduced sediment oxygen demand and oxygenated inflows from tributary streams.

The influence of snow cover on the rate of oxygen depletion was evaluated by plotting DO concentrations by time (day) for a 10 day period from January 26 to February 4 (Figure 6). This time period followed the onset of snow accumulation (Figure 3a). Since DO depletion followed a linear response, linear regression (slope determination) was used to calculate the average depletion rate at each site. Highest rates of oxygen depletion occurred in the isolated or backwater sites (A, B and E) and ranged from 1.36 to 2.68 mg/L/day (Figure 6a). The Stoddard Wetland area (Site A) experienced the highest depletion rate and was likely a result of a higher initial DO, increased respiratory demand due to algae, and greater sediment oxygen demand (shallower water). Further, this site may have also been influenced by residual biochemical oxygen demand associated with municipal wastewater discharges to this area. The rate of oxygen depletion at sites influenced by the river (Sites C and D) were an order of magnitude lower and ranged from 0.18 to 0.26 mg/L/day (Figure 6b).

Influence of Fluctuating River Stage

The deployment of two continuous monitoring units (2.5 and 5 ft depths) near the mouth of Lawrence Lake (Site E) provided an opportunity to assess the influence of rising (inflow) or falling (outflow) river stages on this large backwater lake (Figure 1). Cold, oxygenated inflows from the river (south) would be expected during periods of quickly rising stage. During rapidly falling stages, the site would expected to be influenced by outflowing waters upstream (north) of the site.

River stages at Brownsville, Minnesota exhibited a gradual increasing trend between mid-January and the end of February (Figure 7). The net change was only about 0.2 ft (6 cm) and represented an average rate of change of less that 0.01 ft/day (0.3 cm/day). The overall influence on temperature or DO concentrations associated with this slow rate of rise was likely minimal and not measurable.

Although the net change in river stage during the monitoring period was low, a moderate fluctuation of 0.08 to 0.11 ft/day occurred over several days in late January and February, respectively (Figure 7). Mid-depth temperatures exhibited an inverse response to the stage level fluctuation with a maximum temperature decrease of about 0.5 to 0.7° C (Figure 7a). This response was more noticeable during the February stage fluctuation when air temperatures were more stable (Figure 3b). This cooling was likely associated with cold water inflows from the main channel during the initial rise in stage.

Measurements of near-bottom water temperatures in Lawrence Lake during moderate stage fluctuations yielded a more complicated response. Bottom temperatures generally exceeded mid-depth temperatures by about 0.5 to 2° C (Figure 7a). Minimum bottom temperatures seemed to lag behind minimum surface temperatures by several days and may reflect delayed cooling and reduced vertical mixing due to thermal stratification.

The response of DO concentrations to moderate fluctuations in pool stage was even less clear than that described for temperature. Mid-depth DO did not appear to be influenced by the initial stage increase in late January but rose about 4 mg/L during the late February rise in stage (Figure 7b). Mid-depth DO decreased 4 to 6 mg/L during periods of rapidly falling stages in late January and February (Figure 7b). This latter response may reflect mixing of bottom waters, containing lower DO, into the overlaying water during these periods including the flushing of low DO waters from upper Lawrence Lake. Such mixing seemed evident during the stage decrease in late February when small increases in bottom DO were observed (1 to 2 mg/L). This response wasn't noticed during the fall in stage in late January and may have been masked by higher bottom DO concentration and moderate DO fluctuation during this period.

Summary and Conclusions

Continuous dissolved oxygen and temperature monitoring was conducted in six backwater or isolated areas of Pool 8 of the Upper Mississippi River during January and February 2004. The units were relatively easily deployed under ice. Three of the six monitoring units indicated post-deployment DO calibration error ranging from 0.5 to 1.8 mg/L. Adjusted DO measurements were made assuming a linear error correction over the deployment interval. Pre- and post-temperature calibration measurements in an ice bath indicated the six sensors were reading high by 0.1 to 0.3 °C. A temperature adjustment was made on five of the six units where the error exceeded 0.1 °C.

Temperature measurements in backwater areas influenced by mixing with flowing side channels were slightly warmer (0.2 to 1 °C) than that found in the main channel as derived from data collected by the US Army Corps of Engineers at the Brownsville, MN gage. Backwater or isolated sites removed from the influence of flowing water were 1 to 3 °C warmer than the main channel. Diurnal temperature fluctuations of 0.5 to 1 °C were apparent during the initial monitoring period in mid-January and were likely driven by solar heating, which was facilitated by the absence of snow cover on ice.

Mid-January DO concentrations exceeded saturation levels at all locations. Highest DO concentrations were found in shallow backwater or isolated areas that exhibited greater photosynthetic activity and were not influenced by mixing with flowing secondary or tertiary side channels. Dissolved oxygen concentrations at sites influenced by mixing with flowing side channels were more stable and had concentrations that were closer to saturated levels.

Dissolved oxygen concentrations decreased dramatically (1.4 to 2.7 mg/L/day) at backwater and isolated sites that were removed from the influence of flowing water following snow accumulation on ice during late January and early February. The DO depletion rate was about ten-fold less at backwater sites where mixing was apparent with flowing side channels. The rapid decline in DO was attributed to greater respiratory demand associated with algae, macrophytes and sediment oxygen demand in the shallow, isolated backwater areas. Residual biochemical oxygen demand associated with treated municipal wastewater effluent may have been an additional factor contributing the DO depletion at one isolated site.

Moderate, short-term winter stage level fluctuations of approximately 0.1 ft/day (3 cm/day) influenced DO and temperature measurements at the mouth of a large backwater lake. Rising stage resulted in a 0.5 to 0.7 °C decrease at mid-depth and was likely associated with the inflow of colder main channel waters. The response of bottom temperature measurements were not as apparent and appeared to show a lag effect due to delayed cooling and reduced vertical mixing associated with thermal stratification. The response in DO concentrations to stage level fluctuation was more difficult to define. The most obvious response was a large decrease in mid-depth DO concentrations of 4-6 mg/L at the mouth of the lake during a period of rapidly falling stage. This may have reflected mixing of hypoxic bottom waters into overlying waters as the backwater drained or flushing of low DO waters from the upper portion of the lake.

References

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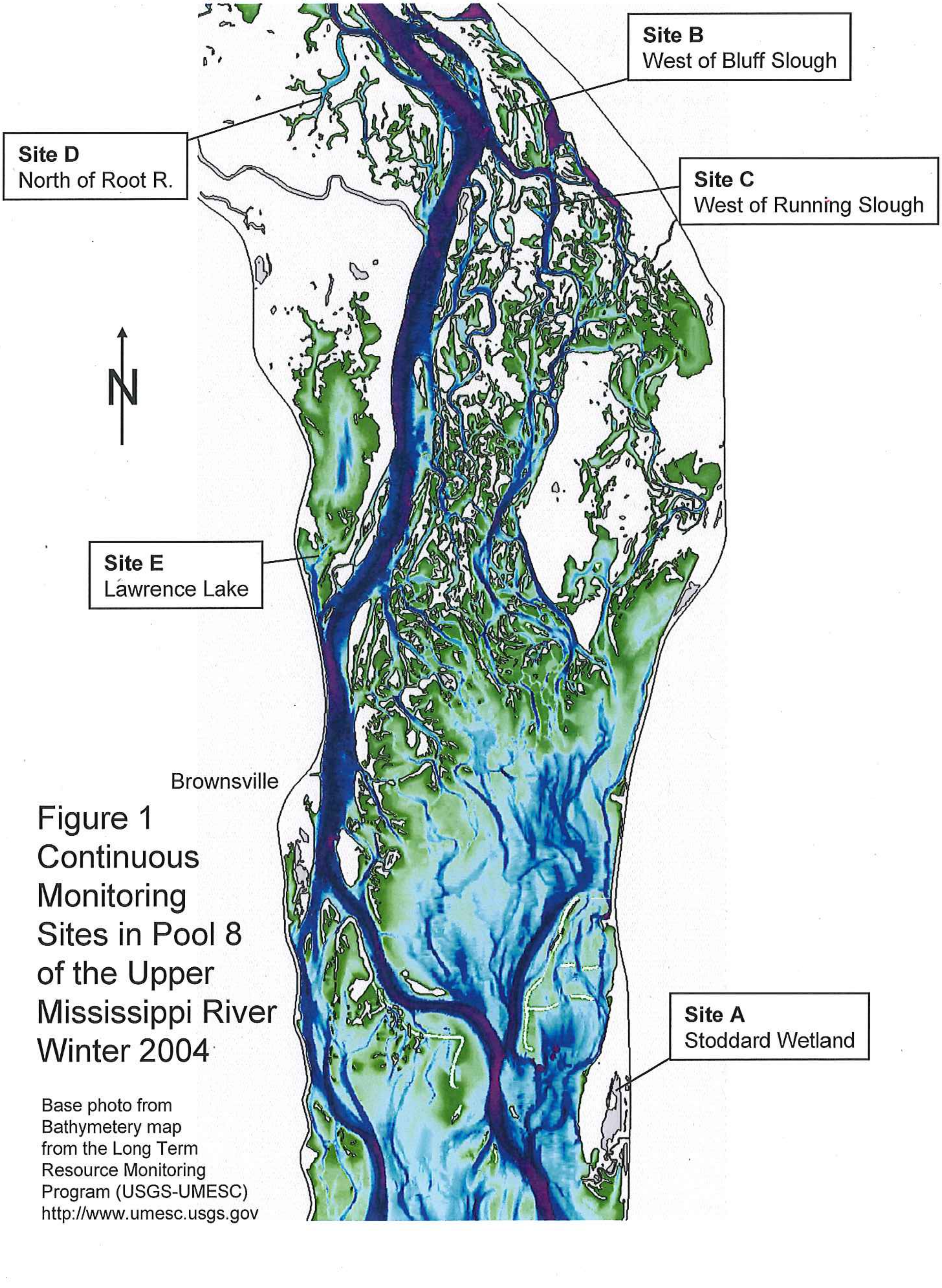

Figure 1
Continuous
Monitoring
Sites in Pool 8
of the Upper
Mississippi River
Winter 2004

Base photo from
Bathymetery map
from the Long Term
Resource Monitoring
Program (USGS-UMESC)
http://www.umesc.usgs.gov

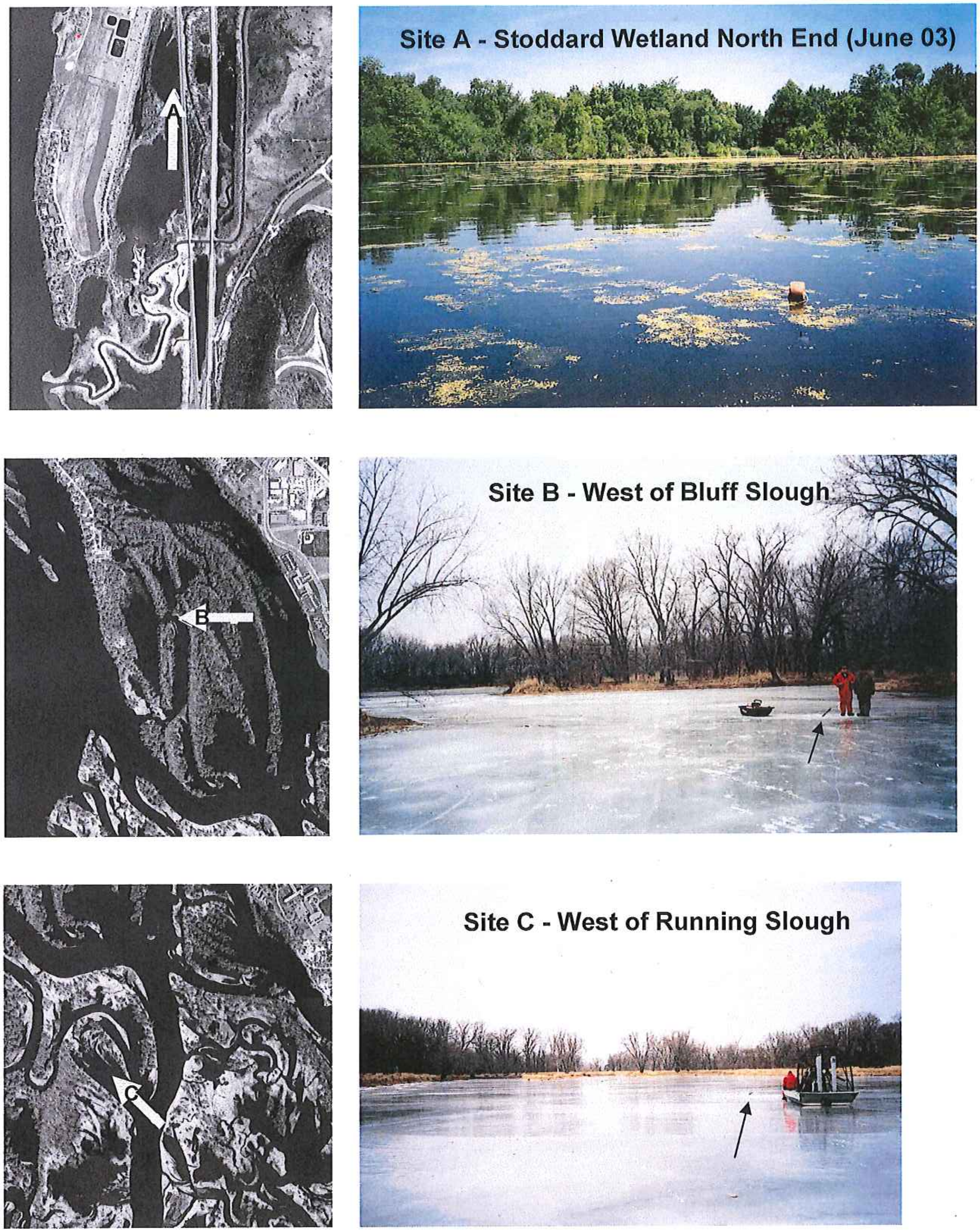

Figure 2. Continuous dissolved oxygen and water temperature monitoring sites (arrow) in Pool 8 during the winter of 2004. Arrow on aerial photo indicates direction of field photo.

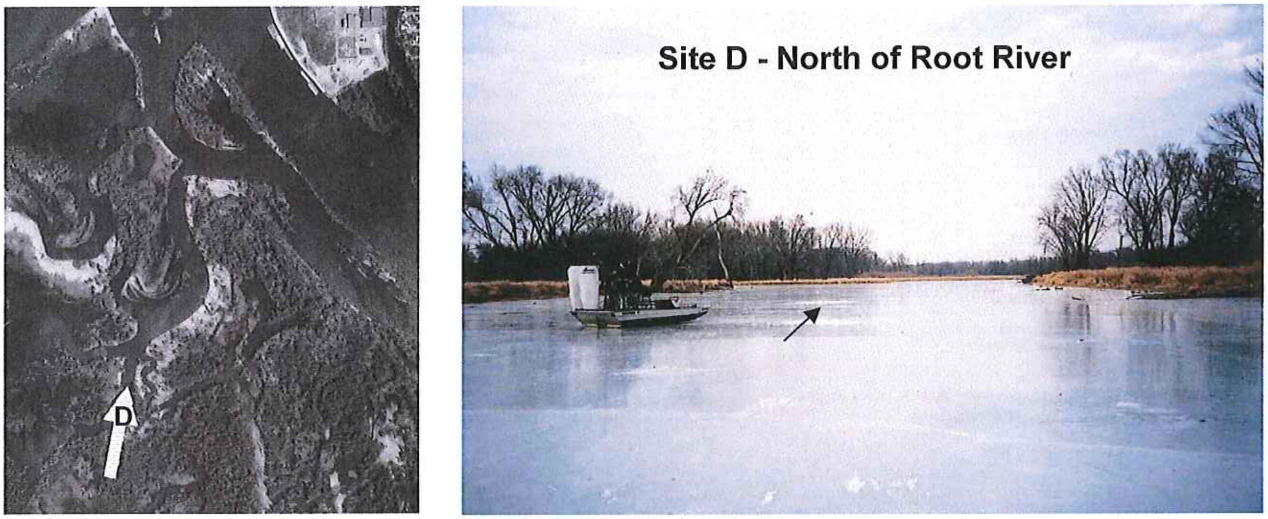

Figure 3 - Continued.

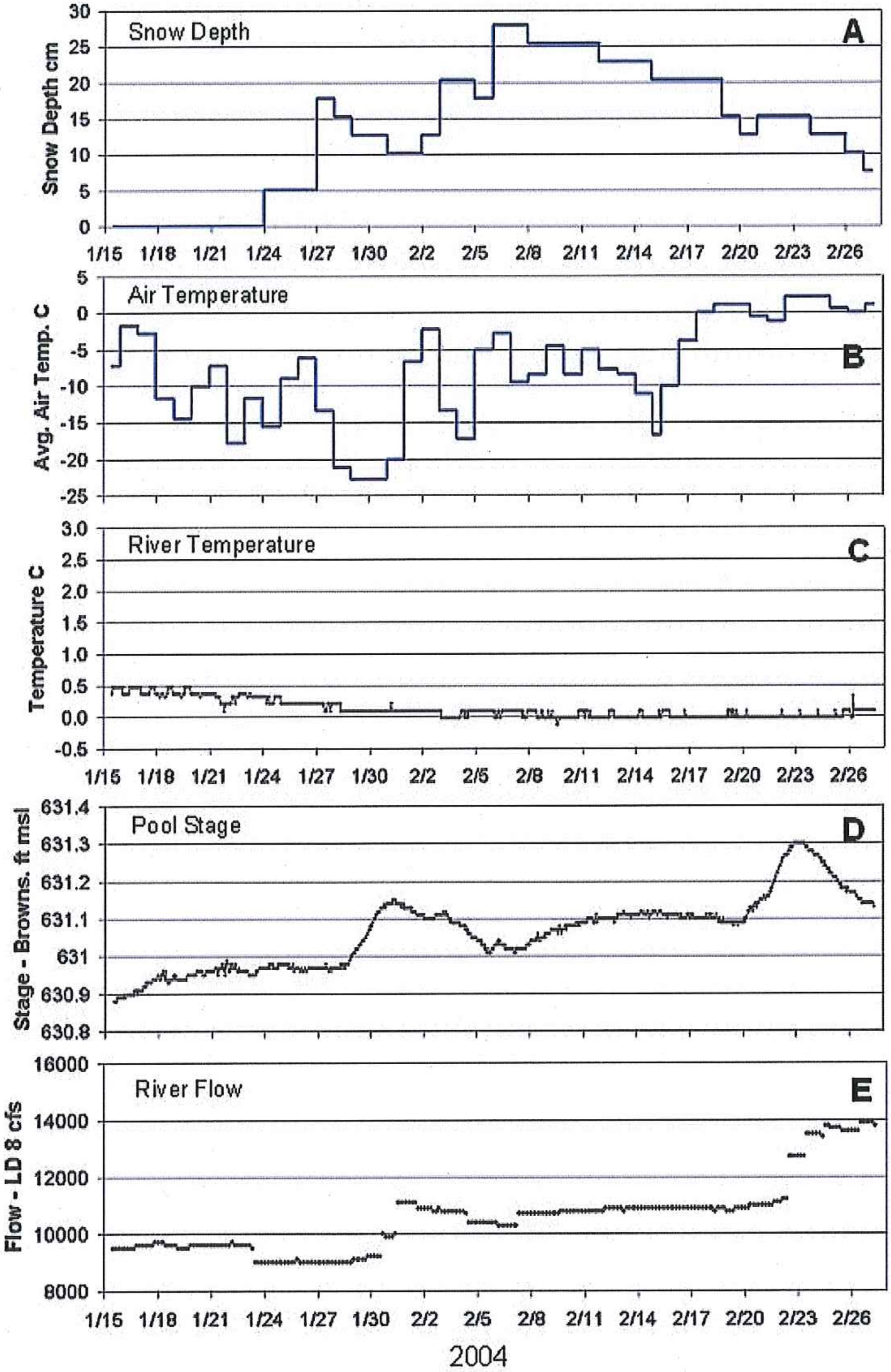

Figure 3. A. Snow depth from National Weather Service, La Crosse, Airport. B. Average daily air temperature from National Weather Service. C. River temperature at Brownsville, MN. D. Pool 8 stage (elevation) at Brownsville, MN. E. River flow at Lock and Dam 8.

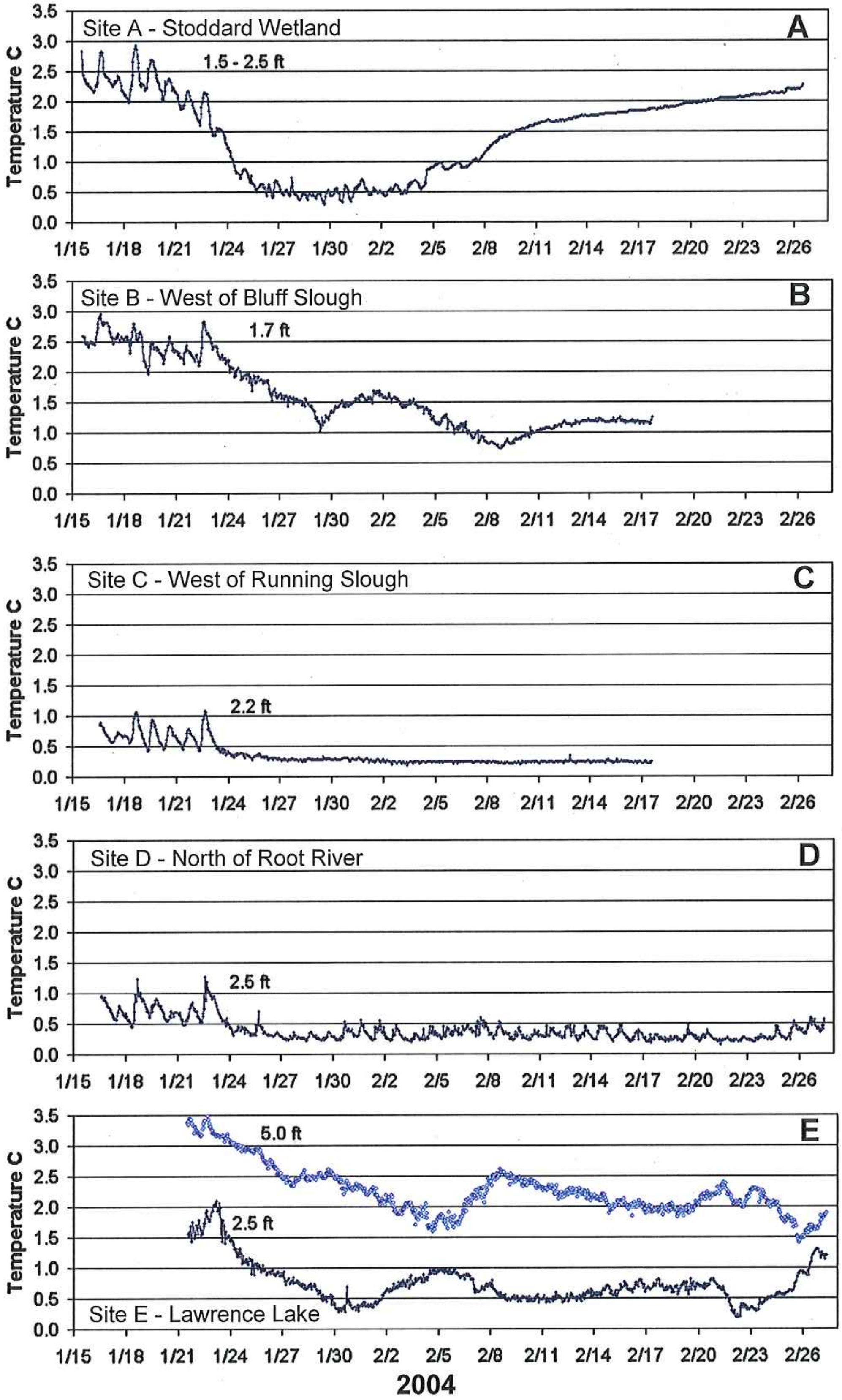

Figure 4. Hourly water temperature measurements made in backwater or isolated areas of Pool 8 of the Mississippi River during January to February 2004. Depth in figure indicates the approximate depth of deployment.

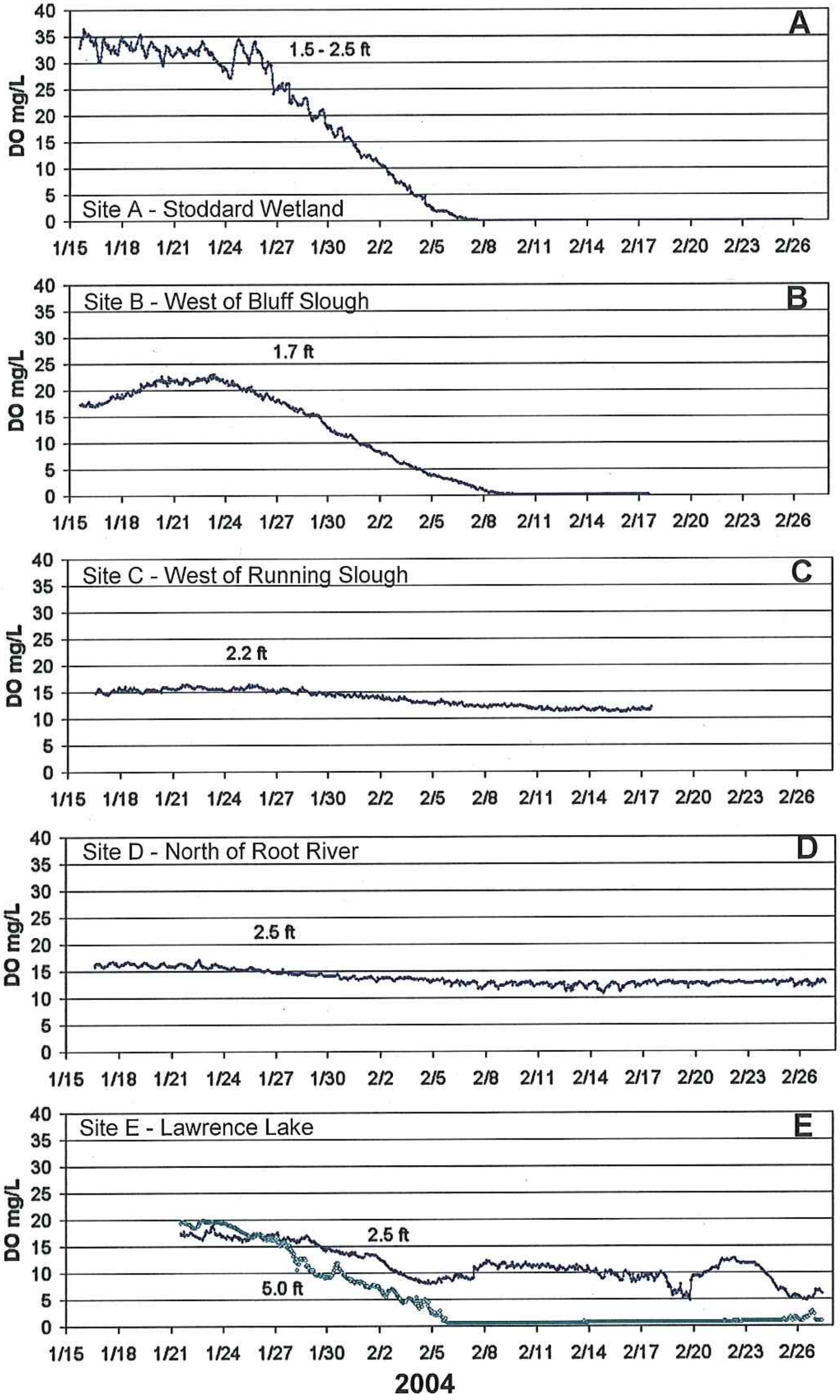

Figure 5. Hourly dissolved oxygen (DO) measurements made in backwater or isolated areas of Pool 8 of the Mississippi River during January to February 2004. Depth in figure indicates the approximate depth of deployment.

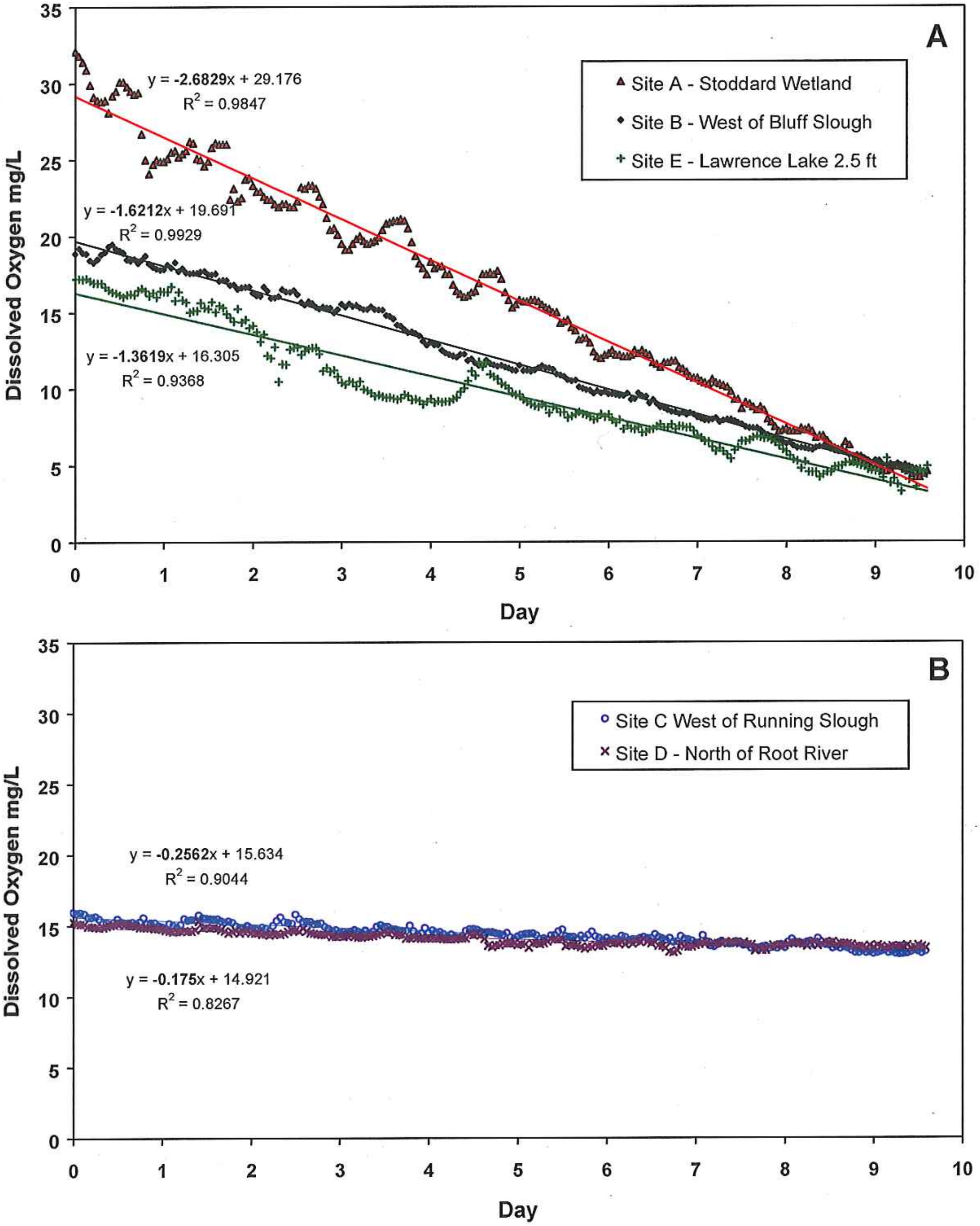

Figure 6 **A**. Dissolved oxygen depletion rates determined from hourly mid-depth DO measurement collected in three backwater or islolated areas of Pool 8 of the Mississippi River during January 26 to February 4, 2004. **B**. Similar measurements made in backwater sites that were influenced by mixing with flowing side channels of the river.

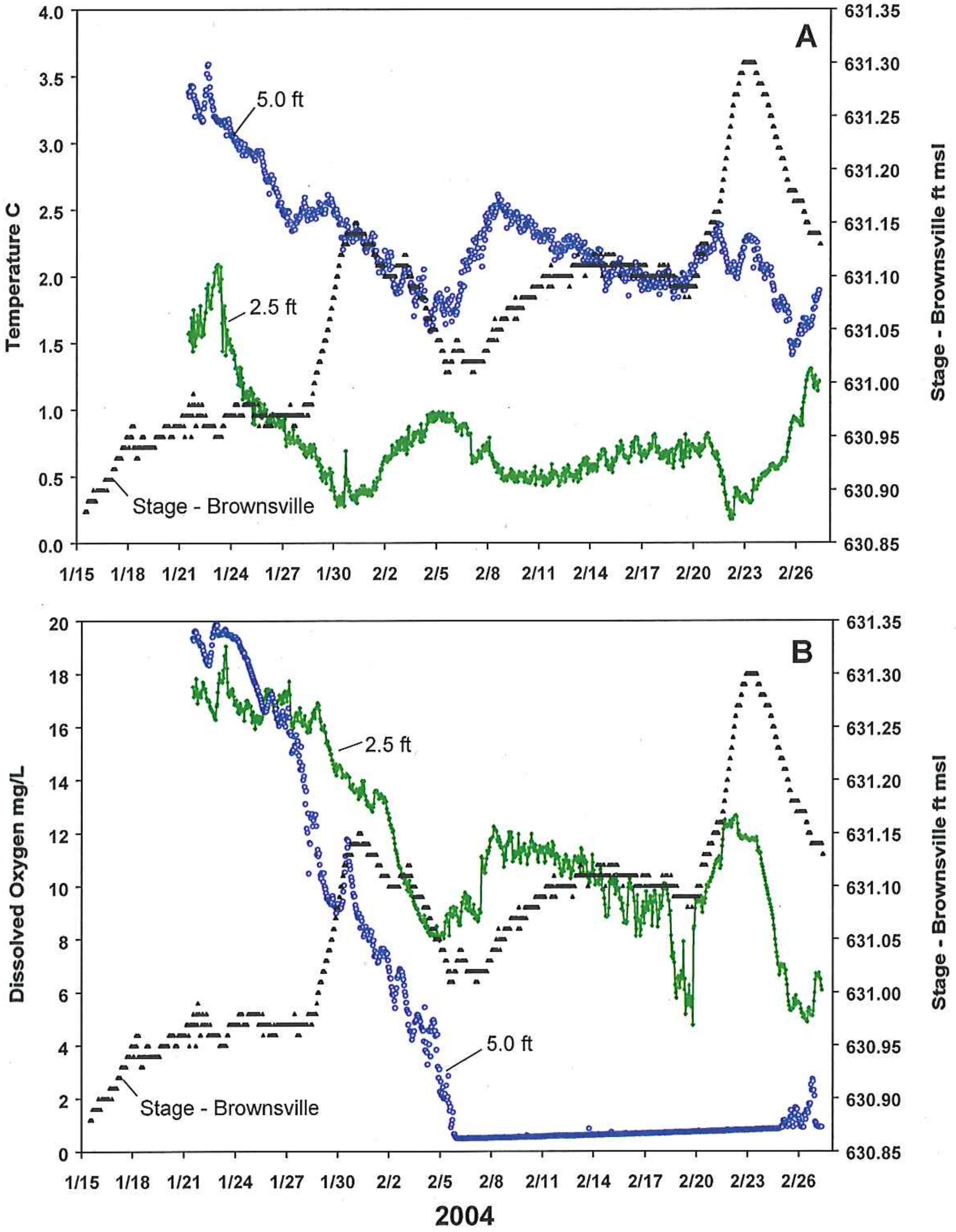

Figure 7. **A**. Hourly water temperature measurements collected at two depths at the mouth of Lawrence Lake and stage levels at Brownsville, MN in Pool 8 of the Mississippi River during January and February 2004. **B**. Similar measurements for dissolved oxygen.

Table 1. Continuous dissolved oxygen and temperature monitoring site data and calibration information colleced during field surveys in Pool 8 of the Mississippi River during January and February 2004.

Site	Easting[1] m	Northing[1] m	Install Date	Aqua Unit No.	Ice Depth ft	Water Depth ft	Sensor Depth ft	Initial Ice Clearance ft	Comments and calibration notes
Site A Stoddard Wetland	643472	4834771	01/15/2004	ML2-WDNR	0.9	3	1.5[a]	0.6	Mounted horizontally on metal post. Off metal post along RR track, 40 ft from E. shore DO drift -0.2 mg/L Temp error 0.1 C
Site B West of Bluff Slough	641983	4848306	01/15/2004	131-LTRM	1	3.8	1.7	0.7	Mounted horizontally on metal post. 40 ft from north shore boards and logs. Coordinates are approximate DO drift 0.1 mg/L Temp error 0.28 C
Site C West of Running Slough	642322	4846895	01/16/2004	132-LTRM	1.3	3.9	2.2	0.9	Mounted horizontally on metal post. 115 ft from south shore. DO drift 1.8 mg/L Temp. error 0.16 C
Site D North of Root River	639344	4848437	01/16/2004	134-LTRM	1.2	3.7	2.5	1.3	Suspended from bottom on rope & float 58 ft from off-shore exposed stump on SE bank DO drift 0.5 mg/L Temp. error 0.23 C
Site E Lawrence Lake	639328	4842152	01/21/2004	CK-WDNR 133-LTRM	1.1 1.1	5.5 5.5	2.5 5	1.4 3.9	Suspended from bottom on rope & float 2.5 ft DO drift -0.1 mg/L Temp. error 0.28C 5 ft DO drift 0.8 mg/L Temp. error 0.28C

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[1] Datum = NAD 27

[a] Sensor re-deployed to 2.5 ft on February 4.