WINTER WATER CIRCULATION PATTERNS IN MUD LAKE FOLLOWING INLET MODIFICATION - AN ADAPTIVE MANAGEMENT STUDY OF A BACKWATER HABITAT RESTORATION PROJECT IN POOL 11 OF THE MISSISSIPPI RIVER

By

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Rock-filled upper inlet of the Mud Lake portion of the Pool 11 Islands HREP (Courtesy of Scott Gritters, Iowa DNR).

Winter Water Circulation Patterns in Mud Lake following Inlet Modification - An Adaptive Management Study of a Backwater Habitat Restoration Project in Pool 11 of the Mississippi River

Abstract

A habitat restoration project for Mud Lake, a backwater in Pool 11 of the Mississippi River, was completed in 2005 as part of the Upper Mississippi River Restoration program. The project included creation of deep-water dredged channels in the backwater adjacent to the Mississippi River navigation channel to provide overwintering habitat for centrarchids and associated species. U.S. Army Corps of Engineers, Rock Island District (USACE) personnel performed a dye study during March 2014 in the backwater in response to Iowa Department of Natural Resources (IDNR) fish telemetry data, which indicated that newly created dredged channels were underutilized by overwintering fish, and velocity data that indicated Mississippi River main-channel flow was entering the backwater area from the dredged channel outlet at the downstream end of the project. The results from the 2014 study verified that flow was entering the dredged channel "outlet" (also referred to as the lower inlet) and also indicated velocities exceeded those preferred by overwintering fish; thus, prompting a modification in the fall of 2015 to reduce flow entering the upper inlet of the backwater. The modification consisted of filling the upper inlet with rock. A subsequent dye study was performed during February 2016 to determine the effectiveness of the modification in reducing flow through the upper inlet and to ascertain its impact on flow entering the lower inlet.

The primary purposes of the two dye studies were to determine how inflowing water disperses both temporally and spatially throughout the backwater complex during winter under ice cover and to measure velocity, a critical factor in the selection of overwintering areas utilized by centrarchids. For the 2016 study, a slug injection of Rhodamine WT dye was dispensed downstream from the upper inlet of the backwater, followed immediately by an additional dye injection in the lower inlet. The dye was tracked for more than 48 hours as it dispersed throughout the backwater complex. The results of the study showed that a significant reduction in velocities occurred in the upper portion of the project following closure of the upper inlet. Velocities entering the project through the lower inlet, however, still remain high, suggesting that implementation of additional adaptive management measures may be necessary.

Introduction

The Pool 11 Islands Habitat Rehabilitation and Enhancement Project (HREP) under the Upper Mississippi River Restoration program includes two distinct backwater enhancement areas: Mud Lake and Sunfish Lake (see Figure 1). All work related to the present study was performed in Mud Lake, which is located on the Mississippi River (river miles 587.6 to 589.4), approximately five miles upstream from L/D 11 and the City of Dubuque, Iowa. Construction of the Mud Lake project commenced in August 2004 and was completed in July 2005 (USACE, 2014). The project area consists of Mud Lake at the upstream portion of the backwater area and Zollicoffer Slough at the downstream portion, with the mouth of Leisure Creek forming a depositional area between the two water bodies (see Figure 2). The recommended plan for the project included construction of a 3,038 m sediment deflection embankment to protect the backwater complex from sediment accretion /resuspension and mechanically dredging 8.8 ha of deep channels for fish overwintering habitat (USACE, 2001). Dredged material was used to construct the deflection embankment and an island near the lower portion of the project which was adjacent to a channel connecting Zollicoffer Slough with the main dredged channel.

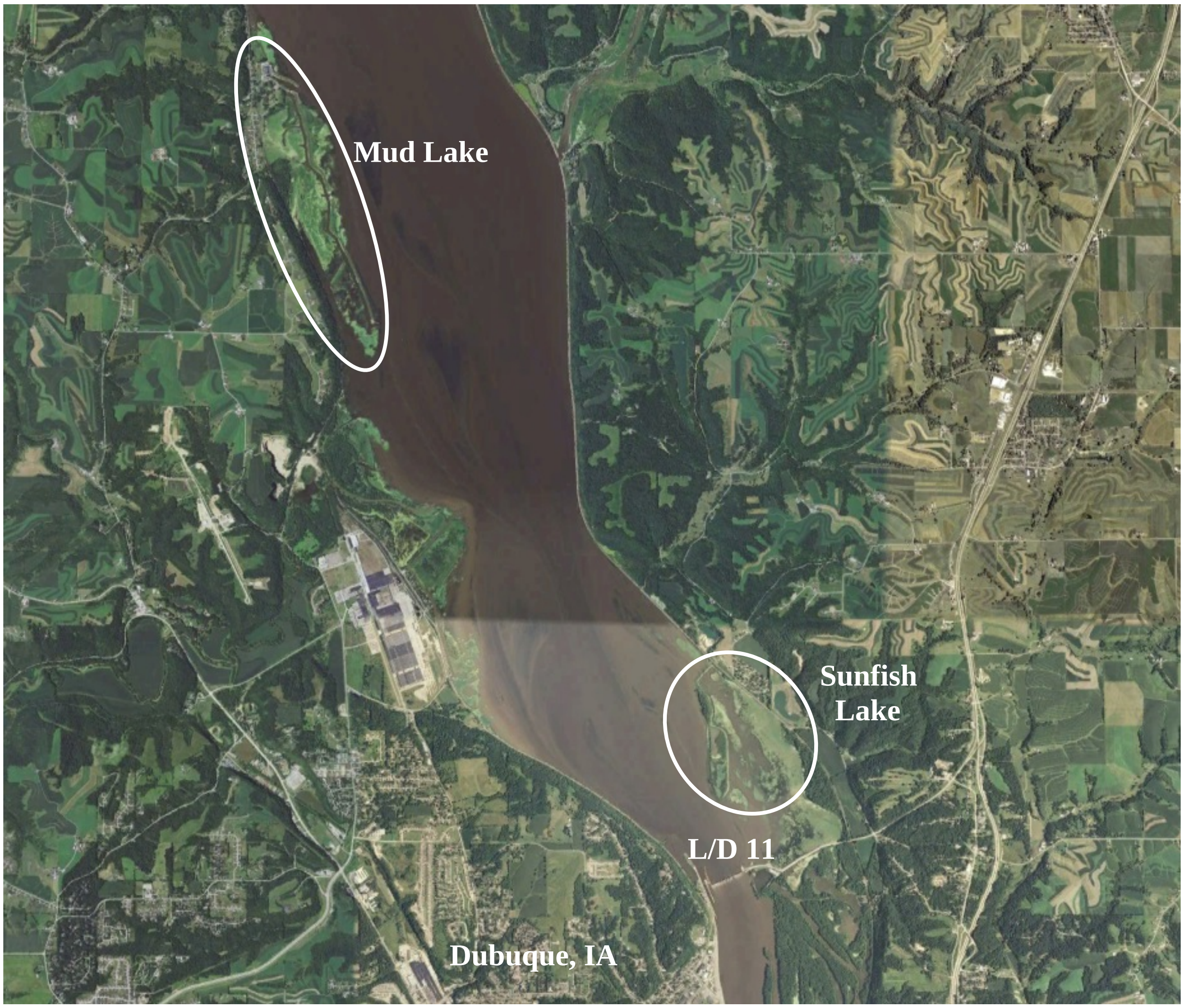

Figure 1. Location map for Mud Lake and Sunfish Lake in the Pool 11 Islands HREP.

As part of the original design process for the Mud Lake project, a two-dimensional hydrodynamic model (RMA-2) was utilized to evaluate various alternatives for the project. The recommended alternative included two notched rock weirs in the deflection embankment: one at the upper end and one near the middle. The primary purpose of the weirs was to allow oxygenated main channel flow into the backwater area during the winter months to help assure sufficient dissolved oxygen (DO) concentrations to support overwintering fish. A DO mass balance performed during project design indicated an inflow of 1.09 cm/sec would be necessary to maintain a DO of 5 mg/L in the backwater. The RMA-2 model was used to size the inlets for the required inflow.

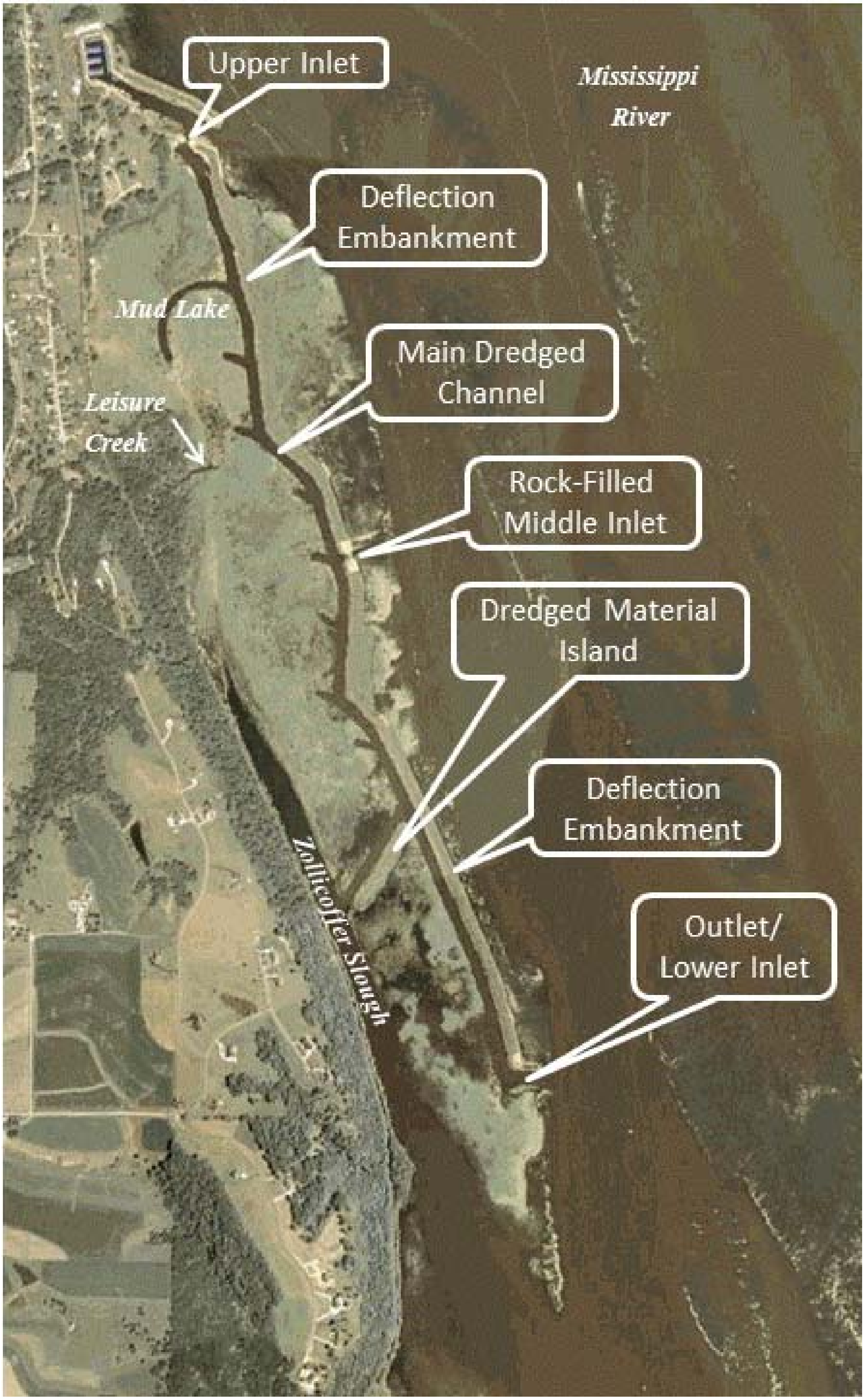

Figure 2. Mud Lake HREP project features.

Following project construction, both USACE and Iowa Department of Natural Resources (IDNR) personnel measured velocities in the dredged channels that were excessive for overwintering centrarchids. In 2006, adaptive management measures were incorporated to reduce the inflow. The opening in the middle of the deflection embankment was completely filled with rock, while the opening at the upper end was partially filled. This change resulted in a significant reduction in velocity in the dredged channels during ensuing winters; however, IDNR fish telemetry studies have indicated the HREP is still underutilized by overwintering centrarchids and velocities continue to be excessive. According to Scott Gritters (IDNR, personal communication, April 2, 2014), at the start of winter, centrarchids in the HREP prefer to stage in areas with zero flow.

In addition to issues involving velocity magnitude, velocity direction has also been a concern. A study performed jointly by IDNR and Wisconsin Department of Natural Resources (WDNR) staff on February 22, 2008 indicated Mississippi River main-channel flow enters the backwater area from the lower inlet. This was also verified by USACE in a 2014 dye study (Bierl, 2016).

In response to the persistent high velocities and underutilization of the project area by overwintering fish, another adaptive management modification was completed in the fall of 2015, which entailed filling the upper inlet with rock. The present study was performed in February 2016 in order to better define velocities and circulation patterns in the backwater complex following the project modification.

Methods

Information gathered and lessons learned by USACE personnel during the 2014 dye study were incorporated when possible during the 2016 study. Most of the 2016 initial sampling sites were the same as those utilized in 2014. Sample site locations were determined by utilizing Google Earth Pro software. Historical imagery was viewed in order to select a recent image (September 22, 2011) that provided the best view of the dredged channels and other deep areas in the backwater complex, which were readily recognized as areas devoid of emergent vegetation. The software pointer was placed on the location of each proposed sampling site and the geographical coordinates were recorded and converted with Corpscon software to NAD83 IL West State Plane, US Survey Feet for entry as waypoints into the GPS unit (see Table 1). Most of the sampling sites were located in dredged channels, while some were located in Zollicoffer Slough. For the 2016 study, most of the 2014 sites were used; sites outside the flow path or with insufficient depth were eliminated. In this initial exercise, 18 sampling locations were identified (see Figure 3). Once dye tracking commenced, additional sampling sites were identified in order to locate the leading edge of the dye at various times.

The fluorescent dye used for the study was a 20 percent solution of Rhodamine WT manufactured by Crompton and Knowles. Determination of the amount of dye required was according to the methods described in Bierl (2016) however, to account for additional dye fluorescence decay which may have occurred during storage, it was conservatively estimated that four liters of dye would be sufficient for the upper inlet injection and two liters for the lower inlet injection.

Figure 3. Mud Lake HREP dye sampling locations.

Table 1. Sampling Site Coordinates.

Site	Easting	Northing	Site	Easting	Northing
1	2152897.203	2167844.339	14.12	2153331.844	2162791.305
3	2153169.360	2166899.202	14.2	2153355.334	2162711.972
4	2152619.255	2166795.296	14.23	2153371.198	2162672.730
4.12	2152570.925	2166735.029	14.25	2153368.914	2162633.614
4.25	2152530.382	2166686.375	14.5	2153547.219	2162318.718
4.5	2152491.568	2166574.450	14.7	2153678.673	2162061.122
4.65	2152489.179	2166488.204	15	2154633.913	2162339.758
4.75	2152507.271	2166405.982	15.5	2154788.225	2162026.958
5	2152547.010	2166255.457	16	2154417.932	2161699.895
5.75	2153196.911	2163017.568	17	2153921.584	2161471.158
6	2153312.427	2166215.378	17.5	2154112.597	2160999.381
7	2153118.734	2166252.224	18	2154974.044	2161582.403
10.75	2153954.312	2164783.071	19	2154812.588	2160580.960
11	2153998.700	2164656.402	20	2155535.254	2160067.644
11.25	2154042.780	2164464.787	21	2154550.354	2159840.956
11.75	2154099.078	2164324.410	22	2154841.205	2158913.044
13	2154151.498	2164140.046	24	2155375.382	2157469.093
13.25	2154117.442	2163450.135	29	2155404.990	2160475.182
13.5	2154466.259	2162707.304	30	2155259.558	2160882.430
13.55	2154523.741	2162580.388	31	2155131.934	2161230.705
13.65	2154561.392	2162492.135	36	2153253.339	2166545.730
13.75	2154601.156	2162413.391	316	2153190.926	2166839.800
14	2153234.078	2162917.643	326	2153211.606	2166760.061

* Coordinates are NAD83 IL West State Plane, US Survey Feet.

Waypoints stored on a GPS (Trimble TSC1 datalogger/Pro XR receiver) were used to locate the 18 sampling sites on the first day of the study (February 15, 2016). The sites were marked with orange spray paint, holes were drilled through the ice and measurements were taken. Site 19 was found to have insufficient water depth to allow for collection of a representative water sample; thus, this site was eliminated from further study. At the remaining sites, water depth, ice thickness, snow depth, dissolved oxygen (DO), water temperature, pH and velocity (magnitude and direction) were recorded. DO and water temperature values were measured at the surface (10 cm below the bottom of the ice), mid-depth (1/2 the water depth) and bottom (10 cm above the bottom) with a YSI Pro ODO Meter. A Sontek FlowTracker ADV was used for taking velocity measurements at the surface. An Extech Instruments pH100 meter was used to measure pH. At selected sites, a depth integrated water sample was collected and analyzed for background fluorescence with a Turner Designs Model 10-AU fluorometer.

Figure 4. Dye delivery apparatus.

Figure 5. Dye sampling apparatus.

Water samples were collected with a 2.8 m length of ½-inch diameter EMT conduit with back-to-back #0 conduit hangers fastened near one end (see Figure 5). A 40 ml, amber glass vial with silicon septum screw cap was snapped into place in the conduit hanger. The narrow opening of the cap (following removal of the silicon septum) allowed the bottle to fill relatively slowly; thus, allowing for sample collection throughout the depth profile. The sampling apparatus was lowered into the hole until it approached the bottom and was then raised at the same rate to allow for a depth-integrated sample. Following collection, a portion of the sample was poured into a 13 mm cuvette and immediately analyzed for the presence of dye with the fluorometer. This process helped assure the temperature of all samples was similar; thus, minimizing the impact of temperature variation on dye concentration. According to Johnson (1984), Rhodamine WT fluorescence decreases approximately five percent for every 2°C increase in temperature. In order to prevent cross-contamination, the sampling apparatus, ice auger, and chisel were rinsed with non-dye tainted river water after each sample containing dye was collected.

On the morning of February 16, 2016, water collected from just below the upper inlet was mixed with Rhodamine WT dye in a 151 liter plastic drum fitted with a spigot and a one meter discharge tube (see Figure 4). In order to facilitate assimilation of the dye with the inflow, four liters of dye were mixed with 106 liters of river water. This dilution reduced the viscosity of the dye and equilibrated the temperature of the dye with that of the inflowing river water in order to allow for more complete mixing. A slug injection of the dye immediately below the upper inlet commenced at 0828 hours and was completed by 0853 hours.

A second dye injection, in the lower inlet, commenced at 0931 hours and was completed by 0946 hours. Here, two liters of dye were mixed with 61 liters of river water. During this injection, the dye froze in the valves of the delivery apparatus, thus necessitating their removal along with the attached tubing. The dye was then poured slowly from the opening in the drum into the hole in the ice.

Following injection of dye at the upper and lower inlets on the morning of February 16, 2016, tracking commenced. Based on velocities measured the preceding day, dye injected in the lower inlet was tracked first. At most sites, at least one measurement was taken before the dye was detected; thus, giving a good indication as to when the leading edge of the dye plume had arrived. At others, dye was detected on the first measurement; therefore, it was difficult to estimate how much time had lapsed since the leading edge of the dye plume had passed. Tracking was done by a single team during daylight hours for approximately 48 hours. Because the team was only on site during the day and they were tracking dye on multiple fronts, sampling sites were added as needed in an effort to locate the leading edge of the dye before it arrived at the next established sampling point.

Determination of when the leading edge of the dye reached a particular sampling site was usually readily apparent but occasionally was less evident. During these instances, three factors were considered in order to make a determination: the background fluorescence on February 15, 2016; the initial post-injection fluorescence value at a particular site; and whether consecutive readings at a particular site were stable, rising or falling. At site 13, for example, the background fluorescence on February 15, 2016 was 1.40 µg/L; however, six readings taken on February 17, 2016 were all below 1.00 µg/L. It wasn’t until February 18, 2016 that a reading of 18.9 µg/L indicated dye had reached the site, although the leading edge had likely passed.

Results and Discussion

The Mississippi River elevation rose slightly, less than 0.2 feet, during the course of the study and stayed within the normal navigation pool limits as measured at the Lock and Dam 11 Pool gage (see Figure 6). The 8:00 a.m. river elevations on February 15 and 18, 2016 were 606.57’[1] and 606.75’ upstream at the Lock and Dam 10 Tailwater gage. The respective measurements downstream at the Lock and Dam 11 Pool gage were 602.87’ and 602.90’. Water levels during the 2016 dye study were slightly less than those measured during the March 10-12, 2014 study (see Figure 7). The interpolated water surface elevations at River Mile 589.3, at the upper inlet, may not exactly reflect water levels in the backwater due to the berm and inlet structures.

Field data collected on February 15, 2016 are given in Table 2. The winter of 2013/2014 was one of the coldest on record; thus, ice thickness during the 2014 dye study was greater than during the 2016 dye study. Ice thickness ranged from 30 to 66 cm during the 2014 study and from 18 to 44 cm during the 2016 study. In light of the thinner ice conditions during 2016, an attempt was made to sample a site located outside of a dredge cut (site 19), downstream from the dredged material island; however, conditions still precluded collection of a representative water sample.

[1] All river elevations reference the MSL 1912 datum.

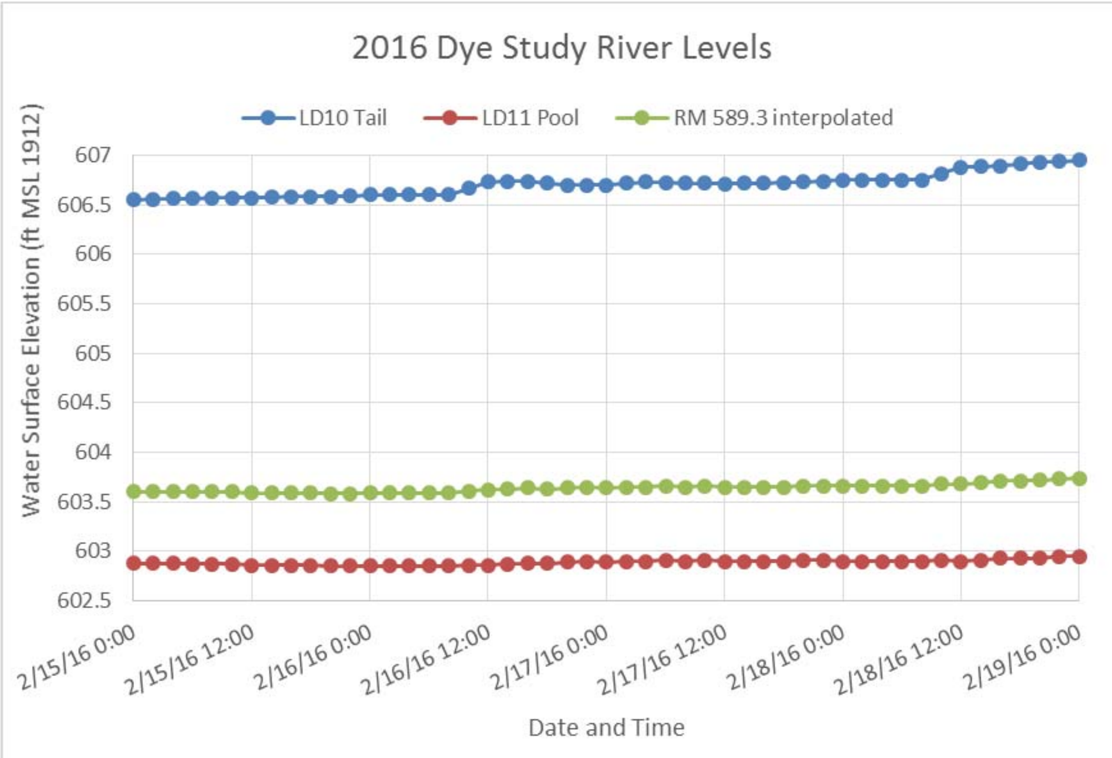

Figure 6. Mississippi River elevations during the 2016 dye study.

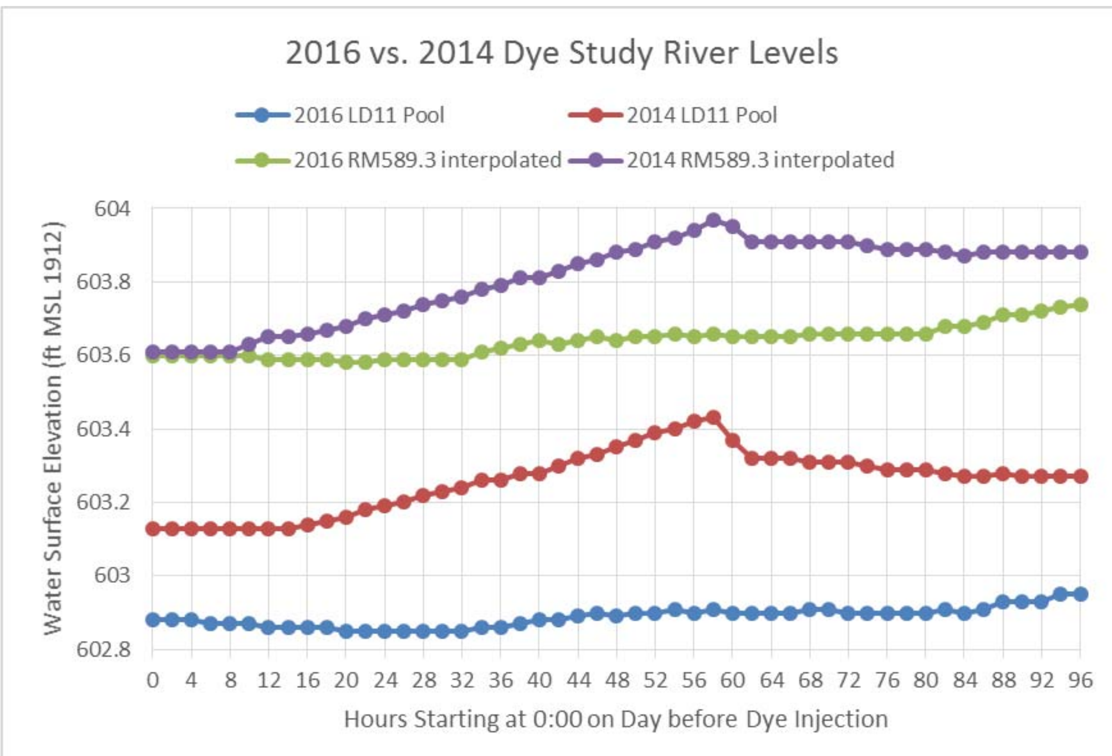

Figure 7. Mississippi River elevations during the 2014 and 2016 dye studies.

The average water depth of sites located in dredged channels was 1.69 m, with the deepest area (2.04 m) located in the middle of the main dredged channel at site 11 and the shallowest area (1.34 m) at site 20, near the dredged channel outlet. Snow was present at all sites with depths ranging from 3 cm at several locations to 8 cm at site 22. All DO values in the backwater area exceeded 13 mg/L, with concentrations ranging from 13.56 to 22.36 mg/L. DO stratification was minimal where water velocity was the highest (sites 18 and 20) and it varied at the remaining sites. Surprisingly, the most prominent stratification occurred in the main dredged channel at site 3, where the surface DO was 15.45 mg/L and the bottom DO was 22.36 mg/L. The velocity here was 1.01 cm/s, while several sites with lower velocity did not exhibit as prominent stratification.

A similar stratification pattern was seen with water temperature, where the sites with the highest velocity (18 and 20) had the least stratification and it varied at the remaining sites. Water temperature ranged from 0.0 to 2.0°C, with the greatest stratification (1.6°C) at site 22. Sites 3, 13, and 15 had the next highest difference between the surface and bottom temperatures (1.4°C). The pH of surface measurements taken throughout the backwater complex ranged from 7.89 at site 22 to 8.69 at site 13. Sample fluorescence (dye) blanks were collected at sites 1, 5, 13, 14, 15, 16, 17, 20 and 21 in order to determine background concentrations, which ranged from 0.775 to 1.40 µg/L.

The most significant change in velocity following closure of the upper inlet occurred at sites 1, 3 and 6 located in the upper third of the main dredged channel. The velocity at these sites during the 2014 dye study ranged from 5.20 to 6.17 cm/s, while the 2016 values at these sites were significantly lower, ranging from 1.00 to 1.10 cm/s. Another noticeable difference between the pre- and post-2015 modification velocity measurements was in the lower inlet. Velocities at sites 18 and 20 were 3.02 and 3.60 cm/s in 2014 and 6.31 and 6.04 cm/s respectively, in 2016. In addition, the flow entering the lower inlet extended farther up the main dredged channel in 2016. During the 2014 study, the flow at site 15 was moving in the downstream direction; while during 2016, flow here was in the upstream direction, continuing to approximately site 13.5. Difficulty obtaining a repeatable velocity measurement at site 13 indicated an eddy may have been present. One velocity measurement here indicated a slight upstream flow while another indicated a slight downstream flow. Thus, this site was likely where the flow paths from the upper and lower inlets met.

Figures 8 and 9 display the general magnitude and direction of flow during the 2014 and 2016 studies. Flow moving along the dredged-material island splits upon entering Zollicoffer Slough, with some coursing downstream and some upstream. Unlike in 2014, the velocity at site 21 was less than the velocity at site 17 during 2016. Similar to 2014, lower velocities were measured in the dredged channel in Mud Lake (0.14 cm/s at both sites 4 and 5), in a short dredge cut off of the main dredged channel (0.22 cm/s at site 7) and at site 14 in Zollicoffer Slough (0.10 cm/s).

Table 2. Field data collected on February 15, 2016, prior to dye dispersal.

Site*	Time	Water Depth (m)	Ice (cm)	Snow (cm)	D.O. (mg/L)	Water Temp. (°C)	Velocity (cm/s)	pH	Dye Blank (µg/L)
1S	0956	1.74	41	4	14.95	0.2	1.10	8.06	1.15
M					14.67	0.4			
B					16.78	1.3			
3S	1030	1.71	41	5	15.45	0.4	1.01	8.02	
M					15.94	0.6			
B					22.36	1.8			
4S	1047	1.76	41	5	15.17	0.6	0.14	7.96	
M					19.58	1.0			
B					20.24	1.3			
5S	1100	1.80	41	5	16.28	0.7	0.14	8.14	1.11
M					17.47	0.7			
B					18.12	0.9			
6S	1134	1.67	41	3	15.70	0.5	1.00	8.09	
M					15.95	0.8			
B					20.70	1.8			
7S	1118	1.65	43	3	16.56	0.7	0.22	8.16	
M					16.63	0.7			
B					16.36	1.9			
11S	1151	2.04	39	5	16.73	0.7	0.81	8.12	
M					17.53	1.4			
B					18.64	1.8			
13S	1205	1.99	38	5	18.97	0.6	0.26**	8.69	1.40
M					17.04	1.3			
B					17.89	2.0			
14S	1250	1.38	44	4	16.40	0.5	0.10	8.17	0.911
M					16.63	0.7			
B					22.19	1.5			
14.7S	1308	1.81	44	4	14.92	0.2	0.80	8.06	
M					15.25	0.3			
B					15.68	0.6			
15S	1457	1.57	43	3	14.13	0.1	0.71	7.95	0.855
M					14.09	0.1			
B					16.97	1.5			
16S	1514	1.54	18	5	13.82	0.1	5.42	7.93	0.798
M					13.80	0.2			
B					14.98	0.8			
17S	1321	1.31	44	3	14.40	0.2	1.23	7.95	0.855
M					14.40	0.2			
B					15.63	0.6			
18S	1445	1.47	33	3	13.64	0.0	6.31	7.92	
M					13.60	0.0			
B					13.62	0.0			
20S	1417	1.34	28	3	14.11	0.0	6.04	8.00	0.775
M					14.11	0.1			
B					14.16	0.1			
21S	1338	2.56	44	5	15.39	0.2	0.82	8.56	0.801
M					17.37	0.3			
B					16.35	1.1			
22S	1402	3.20	44	8	13.56	0.1	0.58	7.89	
M					14.92	0.5			
B					14.75	1.7			

* "S" readings taken at 10 cm under the ice, "M" at 1/2 water depth, "B" at 10 cm off of bottom.
** Average of two measurements.

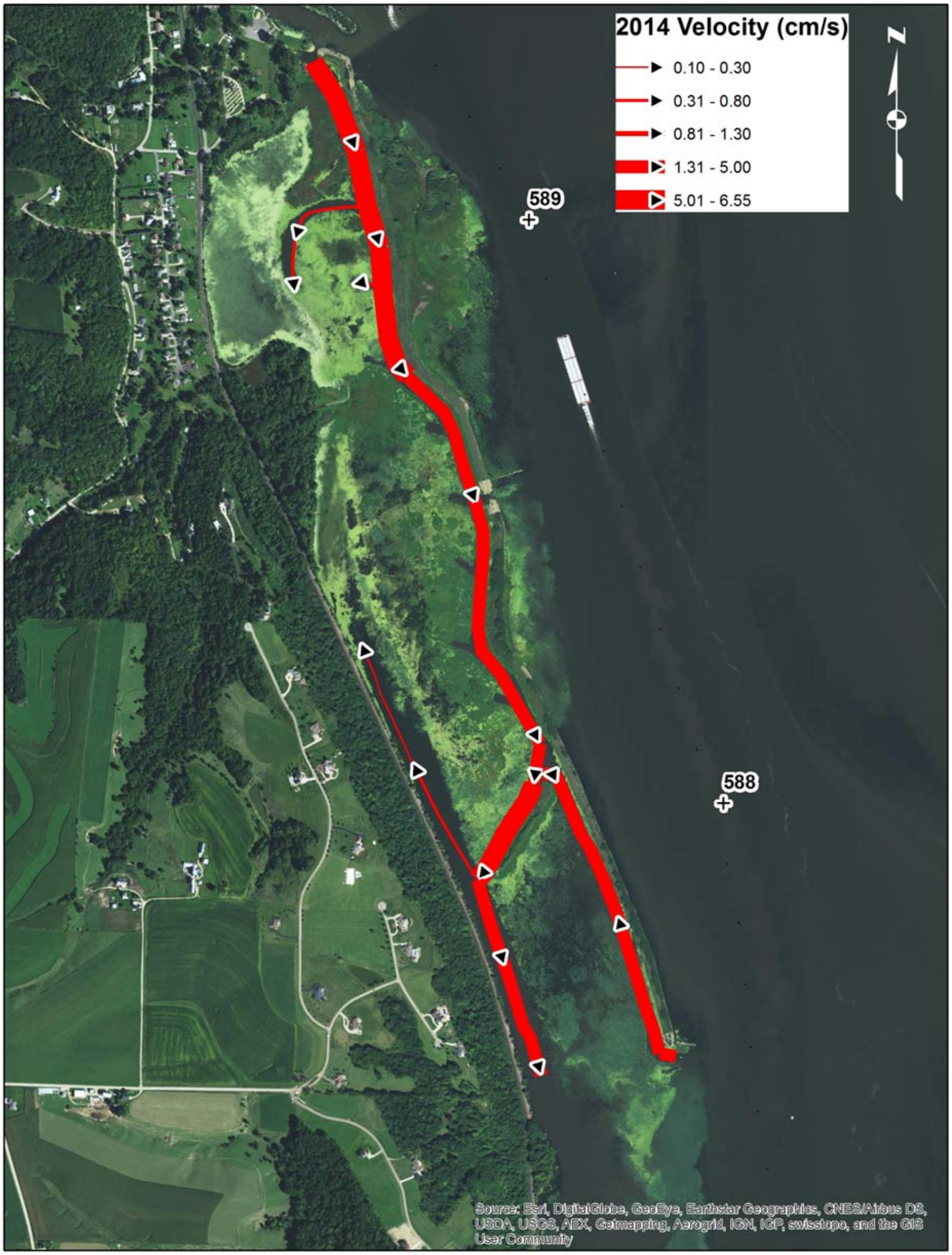

Figure 8. Mud Lake HREP velocities on March 10, 2014.

Figure 9. Mud Lake HREP velocities on February 15, 2016.

The lower inlet dye injection tracking results are shown in Table 3. The dye injection in the lower inlet commenced at 0931 hours on February 16, 2016. The leading edge of the dye had already passed site 20 at 1010 hours when a reading of 36.7 µg/L was taken. The dye quickly moved up the main dredged channel, passing sites 29, 30, 31 and 18 before arriving at site 15.5, next to the dredged material island, at 1306 hours. From here, the majority of the flow moved along the island towards Zollicoffer Slough, but unlike during the 2014 dye study, a smaller portion continued up the main dredged channel to the vicinity of site 13.5.

Once the dye passed site 16, along the dredged material island, it entered Zollicoffer Slough. Here, a majority of the dye flowed downstream, while a smaller portion traveled upstream. The leading edge of the dye had already passed the farthest downstream Zollicoffer Slough site (24) within 24 hours, while it took more than 48 hours to arrive at site 5.75, which was the farthest upstream site located in Zollicoffer Slough. The approximate elapsed time (hours) the dye took to reach selected sampling sites is given in Figure 10.

The dye injected in the upper inlet flowed at a much slower pace than the lower inlet injection. The upper inlet dye injection tracking results are shown in Table 4. The upper inlet injection commenced at 0828 hours on February 16, 2016 and the dye took more than ten hours to reach site 316, at the junction of the curved dredged channel. By comparison, during the 2014 study the dye traveled this distance in approximately 1.5 hours, indicating closure of the upper inlet was successful in reducing velocities in this portion of the project. When tracking resumed in the main dredged channel the following day, the leading edge of the dye had already passed site 6 by 0816 hours and site 11 by 1626 hours but was detected at site 11.75 at 1653 hours. As the dye flowed from the main dredged channel into the curved dredged channel it slowed again. The leading edge of the dye had passed site 4 by 0835 hours and reached site 4.25 at approximately 1724 hours, and site 4.65 the following day at 0842 hours.

Table 3. Lower inlet injection Rhodamine WT dye tracking results.

Site	Date	Time	Dye (µg/L)*	Site	Date	Time	Dye (µg/L)*
20	2/16/2016	10:10	36.7	17.5	2/16/2016	16:05	1.40
29	2/16/2016	10:22	0.820	21	2/17/2016	8:56	1.84
29	2/16/2016	10:27	0.819	22	2/17/2016	9:03	3.54
29	2/16/2016	10:32	0.944	24	2/17/2016	9:14	1.73
29	2/16/2016	10:37	1.02	17	2/16/2016	14:47	0.870
29	2/16/2016	10:42	>100	17	2/16/2016	14:57	1.19
30	2/16/2016	10:55	1.16	17	2/16/2016	15:02	1.07
30	2/16/2016	10:59	0.943	17	2/16/2016	15:07	1.19
30	2/16/2016	11:03	1.09	17	2/16/2016	15:12	1.14
30	2/16/2016	11:07	1.01	17	2/16/2016	15:17	1.21
30	2/16/2016	11:11	1.26	17	2/16/2016	15:22	1.17
30	2/16/2016	11:16	1.30	17	2/16/2016	16:14	0.957
31	2/16/2016	11:42	0.828	17	2/16/2016	16:26	1.04
31	2/16/2016	11:47	1.14	17	2/16/2016	17:21	0.944
31	2/16/2016	11:52	0.936	17	2/17/2016	9:26	1.45
31	2/16/2016	11:57	0.701	14.7	2/17/2016	9:36	4.79
31	2/16/2016	12:02	7.40	14	2/17/2016	9:44	0.918
18	2/16/2016	12:17	0.769	14	2/17/2016	17:57	0.832
18	2/16/2016	12:22	0.803	14	2/18/2016	10:14	3.30
18	2/16/2016	12:27	0.793	14.5	2/17/2016	9:56	4.05
18	2/16/2016	12:33	1.38	14.25	2/17/2016	10:10	2.30
15.5	2/16/2016	12:51	1.05	14:12	2/17/2016	10:24	0.864
15.5	2/16/2016	12:56	1.18	14:12	2/17/2016	18:06	2.39
15.5	2/16/2016	13:01	1.03	14.2	2/17/2016	10:34	1.10
15.5	2/16/2016	13:06	1.23	14.2	2/17/2016	10:43	1.05
15.5	2/16/2016	13:11	2.88	14.2	2/17/2016	10:51	0.933
16	2/16/2016	13:27	1.13	14.23	2/17/2016	10:40	1.44
16	2/16/2016	13:32	1.18	14.23	2/17/2016	10:55	1.60
16	2/16/2016	13:37	1.11	5.75	2/18/2016	10:24	1.21
16	2/16/2016	13:42	1.20	15	2/16/2016	16:33	3.52
16	2/16/2016	13:47	1.04	13.75	2/16/2016	16:42	1.83
16	2/16/2016	13:52	1.03	13.75	2/17/2016	18:27	1.39
16	2/16/2016	13:57	1.13	13.65	2/16/2016	16:53	1.08
16	2/16/2016	14:02	1.10	13.65	2/16/2016	16:58	1.14
16	2/16/2016	14:07	1.88	13.65	2/16/2016	17:03	1.05
17.5	2/16/2016	15:35	0.870	13.65	2/16/2016	17:08	0.982
17.5	2/16/2016	15:55	1.05	13.65	2/16/2016	17:13	0.901
17.5	2/16/2016	16:00	1.21	13.65	2/16/2016	17:43	0.827

* Shaded concentrations indicate dye was detected.

Figure 10. Mud Lake HREP Rhodamine WT dye travel times (hours).

Table 4. Upper inlet injection Rhodamine WT dye tracking results.

Site	Date	Time	Dye (µg/L)*	Site	Date	Time	Dye (µg/L)*
3	2/16/2016	17:51	8.09	11	2/17/2016	12:29	0.879
6	2/16/2016	18:05	0.427	11	2/17/2016	13:34	0.815
6	2/17/2016	8:16	43.7	11	2/17/2016	13:39	0.798
36	2/16/2016	18:15	0.386	11	2/17/2016	16:26	20.1
326	2/16/2016	18:25	0.449	10.75	2/17/2016	13:29	12.0
316	2/16/2016	18:35	1.54	11.25	2/17/2016	16:42	14.4
7	2/17/2016	8:26	0.790	11.75	2/17/2016	16:53	1.10
7	2/17/2016	12:17	3.22	11.75	2/17/2016	16:58	1.35
4	2/17/2016	8:35	2.34	13	2/17/2016	16:33	0.699
5	2/17/2016	8:42	0.835	13	2/17/2016	17:33	0.977
5	2/17/2016	11:29	0.721	13	2/17/2016	17:38	0.977
5	2/17/2016	17:12	0.864	13	2/17/2016	17:43	0.929
5	2/18/2016	8:15	0.677	13	2/17/2016	17:48	0.950
4.5	2/17/2016	11:41	0.774	13	2/17/2016	18:35	0.990
4.5	2/17/2016	17:19	0.820	13	2/18/2016	8:53	18.9
4.5	2/18/2016	8:23	3.25	13.25	2/18/2016	9:03	12.6
4.25	2/17/2016	11:52	0.961	13.5	2/18/2016	9:14	8.04
4.25	2/17/2016	12:10	0.880	13.75	2/18/2016	9:24	1.11
4.25	2/17/2016	17:24	1.58	13.65	2/18/2016	9:29	1.26
4.12	2/17/2016	12:01	1.74	13.55	2/18/2016	9:41	1.92
4.75	2/18/2016	8:35	0.847	15	2/18/2016	9:51	1.25
4.65	2/18/2016	8:42	1.18	18	2/18/2016	10:04	0.978

* Shaded concentrations indicate dye was detected.

Conclusions and Recommendations

A Rhodamine WT dye study was performed during February 2016 in Mud Lake, the site of a backwater rehabilitation project on the Mississippi River in Pool 11 near Dubuque, Iowa. The study was performed to determine the effectiveness of a modification to reduce flow through the upper inlet into the backwater.

Discrete water quality samples collected just prior to the dye study did not reveal adverse effects to dissolved oxygen levels in the project area due to the flow reduction. Concentrations were generally supersaturated, similar to those observed in the 2014 dye study. However, continuous DO monitoring during the critical winter months will better assess the impacts of the flow modification on DO levels in the project area. If over-summering habitat is also a concern, continuous DO monitoring during the summer months is also recommended to ensure adequate DO levels for fish year-round.

The results from the study indicate post-2015 modification velocities in the upper portion of Mud Lake under ice are considerably lower than pre-2015 modification values. A considerable portion of the project, however, is still subject to relatively high velocities from flow entering the lower inlet. It is imperative that additional adaptive management measures be investigated in order to determine if the area currently provides a viable overwintering site for fish.

Radiotelemetry and/or creel studies are two options for making this determination. If overwintering fish continue to underutilize the area, it may be necessary to evaluate new adaptive management strategies for reducing or redirecting flow.

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