DYE DISPERSION AND FISH MOVEMENT IN RESPONSE TO INCREASED WINTER INFLOW AT SPRING LAKE, A BACKWATER OF THE MISSISSIPPI RIVER NEAR SAVANNA, ILLINOIS

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February 2006

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Abstract

Dye dispersion and fish movement were monitored during February 2005 by U.S. Army Corps of Engineers, Rock Island District, Water Quality and Sedimentation Section personnel following an increase in inflow to Spring Lake, a backwater of the Mississippi River near Savanna, Illinois. An environmental enhancement project for the lake was completed in 1999 as part of the Upper Mississippi River System Environmental Management Program. The project included construction of a gated inlet in the perimeter levee of the lake to allow for the inflow of oxygenated water during winter periods of low dissolved oxygen. The results from a similar dye study performed in 2002 indicated that with a 25 cm (10 in) gate opening, reoxygenation of the lake occurs slowly, with the dispersal pattern favoring the deeper portions of the lake north and east of Silo Island. The primary purpose of the present study was to determine how inflowing oxygenated water disperses, both temporally and spatially, throughout the lake during the winter under ice cover while utilizing a gate opening of 91 cm (3 ft). A single slug injection of Rhodamine WT dye was dispensed in the inlet structure and tracked over a period of thirteen days as it dispersed throughout the lake.

An additional objective of the study was to track the movement of 20 radio-tagged centrarchids in response to the increased inflow. Iowa Department of Natural Resources, Bellevue Fish Research and Management Station and U.S. Army Corps of Engineers, Rock Island District, Water Quality and Sedimentation Section personnel used conventional pole and line ice fishing methods in order to procure the centrarchids required for the study. Fish movement was determined during three tracking events over an 11-day period.

The results from the 2005 study were similar to the 2002 study in that the dye dispersal pattern again favored the deeper portions of the lake north and east of Silo Island. However, unlike in 2002, dye was eventually detected in samples collected from the sub-basin of the lake west of Silo Island. As anticipated, with the larger gate opening, the dye traveled through the lake in a shorter period of time. A comparison of dye analysis results from samples collected on the sixth day following injection during both studies show that the dye traveled more than twice the distance during 2005 compared to that observed in 2002. The dye traveled 1,125 m (3,691 ft) to site 7 in 2002, for an average velocity of .22 cm/sec while in 2005 it traveled 2,375 m (7,792 ft) to site 16 for an average velocity of .46 cm/sec.

Movement of radio-tagged black crappies and a bluegill indicated the fish were not adversely impacted by the increased gate opening. The velocity in the vicinity where most fish were located throughout the study (site 7) increased from 0.16 cm/sec (prior to increasing the gate opening) to 0.45 cm/s (after increasing the gate opening). The 0.29 cm/s increase in velocity was apparently insufficient to cause the fish to disperse from the area.

Introduction

In the 1986 Water Resources Development Act, Congress authorized the creation of the Upper Mississippi River System-Environmental Management Program (UMRS-EMP), a multi-element program designed to protect, restore, and balance the resources of the UMRS. A major element of the program includes the construction of Habitat Rehabilitation and Enhancement Projects, or HREPs, for the purpose of preserving and improving fish and wildlife habitat on the UMRS. Spring Lake is a 1,335 ha (3,300 ac) HREP

backwater lake located on the Mississippi River, river kilometers 852.0 to 857.6 (river miles 532.5 to 536.0) near Savanna, Illinois. A cross dike divides the lake into upper and lower portions. The lower portion of the lake is bounded by the natural riverbank and a perimeter levee. A breach in the downstream end of the perimeter levee allows for connectivity with the Mississippi River. Environmental improvements to the lake include construction of a gated inlet on the perimeter levee of the lower lake and a pump station on the cross dike (see Figure 1). Construction of the project was completed in 1999. The inlet structure contains two 1.5 m (5 ft) by 1.5 m (5 ft) gates. The purpose of the inlet structure is to allow oxygenated river water into the lake during the winter to help prevent fish kills. The gates are closed during other times of the year in order to prevent sediment from entering the lake.

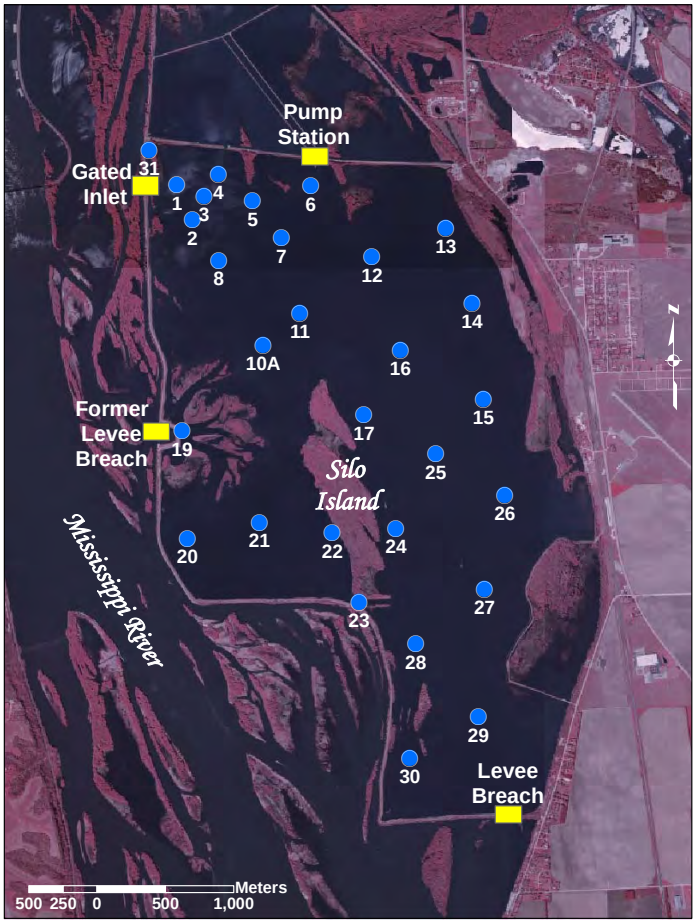

Figure 1. Spring Lake features and sampling site locations.

A fish kill occurred in both the upper and lower portions of Spring Lake during January 2001. During this time, one gate was open 15 cm (6 in) and low dissolved oxygen (DO) concentrations were recorded by an *in-situ* water quality monitoring instrument deployed in the lower lake near site 23. In an effort to prevent future fish kills, a dye study was performed during February 2002 for the purpose of determining how inflowing oxygenated water disperses both spatially and temporally throughout the lower lake. At the time of the study, the south gate of the inlet structure was open 25 cm (10 in). The results of this study, reported by Bierl (2002), indicated that with a 25 cm (10 in) gate opening, reoxygenation of the lake occurred slowly, with the dispersal pattern favoring the deeper portions of the lake north and east of Silo Island. Dye was not detected in the sub-basin of the lake west of Silo Island by day 10 following dye injection, when the study was terminated due to an early thaw. The 2002 study suggested that a larger gate opening would allow for a more rapid dispersion of oxygenated water throughout the lake, possibly including the sub-basin west of Silo Island. The primary objective of the present study was to investigate these issues under a gate opening of 91 cm (3 ft), again using Rhodamine WT dye to track the inflowing water. One concern of a larger gate opening is that an increase in water velocity could possibly impact over-wintering centrarchids, which prefer areas with little or no velocity (Palesh and Anderson, 1990; Sheehan et al., 1990; Knights et al., 1995; and Gent et al., 1995). In order to address this concern, fish response was monitored by tracking centrarchids fitted with radio transmitters.

Methods

Fish Telemetry

Iowa Department of Natural Resources, Bellevue Fish Research and Management Station (IDNR) and U.S. Army Corps of Engineers, Rock Island District, Water Quality and Sedimentation Section (USACE)

personnel used conventional pole and line ice fishing methods in order to procure the centrarchids required for the fish radio-telemetry portion of the study. The targeted species included black and white crappie (*Pomoxis sp.*) and bluegill (*Lepomis macrochirus*). Previous studies performed by IDNR fishery research biologists suggested that a minimum fish size of about 198 g (7 oz) would be required for the transmitter to not influence fish behavior. IDNR and USACE personnel, with the assistance of local anglers, obtained 10 black crappie (*Pomoxis nigromaculatus*) and one bluegill on January 25, 2005. The following day, 9 black crappie were caught. All fish were caught in the upper part of the lake in the vicinity of sampling sites 5 and 7 (see Figure 1) and ranged in size from 196 g (6.9 oz) to 675 g (23.8 oz).

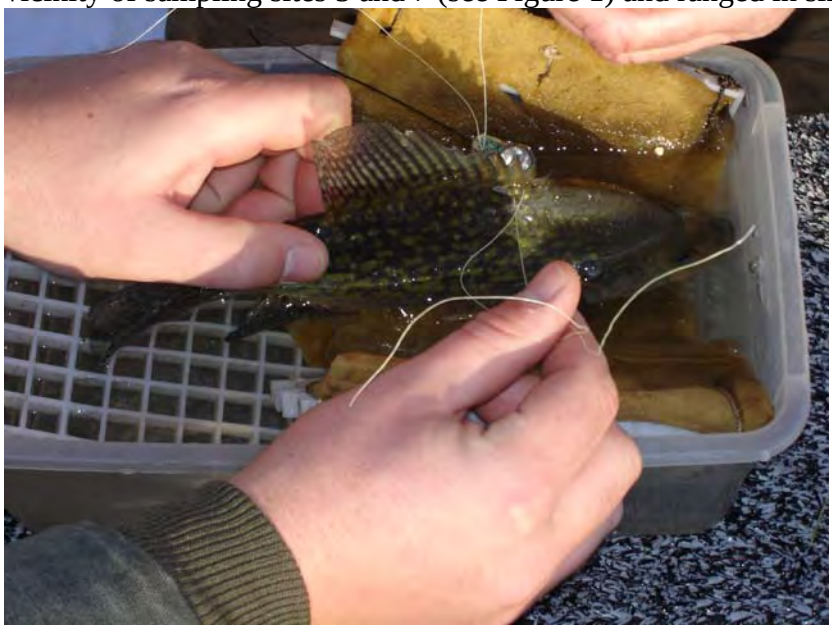

Figure 2. Attaching transmitter to a black crappie.

The fish were immediately fitted with externally placed transmitters and released at the capture location. The transmitters were attached at two locations just below the base of the dorsal fin spines (see Figure 2). The transmitters were body implant types that were modified for external placement by tying braided fishing line (Firewire) to the body of the transmitter in two locations and using epoxy to hold it in place. The free ends of the line were drawn with a needle through the musculature at the base of the dorsal fin, one at a point anterior to a spine and the other at a point posterior to the spine. The two lines were then pulled tight around the spine and were tied off. The process was then repeated at a second dorsal fin spine. The transmitters, models F1540 and F1580 obtained from Advanced Telemetry Systems, Inc (ATS), weighed 2.0 (.07 oz) and 3.6 gm (.13 oz), respectively, and operated in the 49 MHz bandwidth (49.054 MHz – 49.890 MHz). Fish were tracked by airboat and then by foot (see cover photo) during three tracking events using an ATS receiver (model R2000) and a hand-held loop antenna. Fish location was recorded with a Trimble Pro XR Global Positioning System (GPS).

Dye and Water Quality Monitoring

The results of the 2002 dye study were reviewed by USACE personnel in order to determine the location of the sampling points for the present study. The sampling points remained the same, with the exception of two sites being eliminated because shallow water depth in the vicinity of these sites made it difficult to obtain a representative sample. Site 10 was moved to the southeast to a deeper area and redesignated as site 10A. The locations of the 29 sampling sites are shown in Figure 1.

On January 28, 2005, USACE personnel deployed YSI model 6600 multiparameter sondes equipped with probes for measuring DO, pH, temperature and chlorophyll at sites 1, 5, 7, 19, 24, 29 and 31. Two sondes were deployed at site 5, the deepest site, at points 3 ft (0.91 m) and 7 ft (2.13 m) from the bottom, in order to determine if stratification was present. The sondes deployed at sites 1 and 31 were moved to sites 14 and 16 on February 2, 2005, in an effort to capture the plume as it moved through the lake. USACE personnel drilled holes in the ice at 29 Spring Lake sampling sites on January 31st and February 1st. GPS was used to locate the sampling sites using the coordinates from the 2002 study. Test holes were drilled in the ice in the vicinity of the old site 10 in order to locate an area with sufficient sampling depth. The

new site, 10A, was located approximately 450 m (1,476 ft) to the southeast of the old site. An airboat allowed for quick and safe transit between sites. Water depth, ice thickness and snow depth were determined at each site. At selected sampling sites, DO, temperature, pH and velocity measurements were taken. DO, pH and temperature measurements were initially taken with a YSI model 600 XL multiparameter sonde. Following dye injection, a YSI Model 58 meter was utilized to measure DO and temperature and an Oakton pHTestr2 was used for measuring pH. A Sontek FlowTracker hand-held ADV (Acoustic Doppler Velocimeter) was used for velocity measurements. Blank samples for dye analysis were collected at sites 1, 5, 15, 21 and 28 in order to determine background fluorescence. Orange spray paint and a wire stake vinyl flag were used to mark the ice near each sampling site (see Figure 3). A discharge measurement was taken within the lake, approximately 15 m (49 ft) from the gated inlet structure, according to the methods described for measurements under ice cover in USGS (1969). At this time, the gate on the north side of the inlet structure was open 20 cm (8 in). At 4:00 p.m. on January 31st, U.S. Fish and Wildlife Service, Upper Mississippi River National Wildlife and Fish Refuge, Savanna District (USFWS) personnel increased the gate opening to 91 cm (3 ft). A discharge measurement was taken at the same location on February 1st to determine the flow volume resulting from the new gate opening.

Figure 3. Dye sampling site identifiers.

The fluorescent dye used for the study was a 20 percent solution of Rhodamine WT manufactured by Crompton and Knowles. The dye delivery system was as described in Bierl (2002), with the following modifications which accelerated the injection of the dye: the Tygon tubing was replaced with a larger diameter, weighted garden hose and the slotted nozzle at the end of the tubing was eliminated. On the morning of February 1st, the garden hose was lowered into the north gate well of the inlet structure until it was positioned at the level of the gate opening. In order to facilitate the assimilation of the dye with the inflowing river water, 7 liters (1.8 gal) of dye was mixed with 90 liters (23.8 gal) of river water in the refuse container. This helped reduce the viscosity of the dye and equilibrate the temperature of the dye with that of the inflowing river water. Dye was immediately visible on the lake side of the water control structure (see Figure 4) following release of the dye, which commenced at 9:16 a.m. By 9:44 a.m., all of the dye had been dispensed. At no time was a dye plume observed on the river side of the perimeter levee.

Figure 4. Dye entering Spring Lake at the water control structure.

The first round of sampling commenced at site 1 at 10:26 a.m., followed by sites 31, 2, 3, and 4. The sampling instrumentation and methods were as described in Bierl (2002). Staff gage readings on the outside of the gated inlet structure (583.35' NGVD) and lower lake side of the pump station (583.20' NGVD) were recorded. Three more sampling events were performed on February 1st. Sampling commenced at sites 1-5, 8 and 31 at 12:21 p.m. and at sites 1-8 and 31 at 2:49 p.m. and 5:42 p.m. Two sampling events were performed on February 2nd. Sites 1-13 and 31 were sampled commencing at 8:45 a.m. and at 2:36 p.m. Sites 1-19, 24-26 and 31 were sampled on February 4th and all sites were sampled on the February 7th, 10th and 14th collection dates. The sites selected for sampling during each event were based on dye analysis results from prior events, along with a review of the results from the 2002 study. In general, the sites closest to the inlet structure were sampled first, followed by those farther away. DO, temperature and velocity readings were taken at selected sites. Staff gage readings were taken at the inlet structure and pump station on all sampling dates.

Dye Analysis

Dye standards were prepared according to the guidelines given in Wilson et al. (1986). A Turner Designs Model 10-AU fluorometer was used for sample analysis. The fluorometer was calibrated with dye standards according to instructions given in the manufacturer's user's manual. Water samples were stored in the dark and allowed to come to room temperature prior to analysis. All samples and blanks were analyzed with a Turner Designs Model 10-AU fluorometer. Time was recorded for each analysis and sample temperature was recorded at a minimum of at the beginning and end of each analysis session. All Rhodamine WT dye concentrations were within the linear range of the fluorometer; therefore, no samples required dilution. Some samples were reanalyzed following additional settling because there were concerns that suspended matter may have affected the results. Increased turbidity in the inflow, due to snow-melt runoff following unusually high air temperatures on February 5th and 6th, most likely contributed to the increased suspended matter content of some samples collected after February 6th.

Results and Discussion

Initial Conditions

The results from field measurements taken on January 31st and February 1st, prior to the impact of the increased gate opening are shown in Table 1. Water depths at sampling sites ranged from 0.32 m (1.05 ft) at site 20 to 2.60 m (8.53 ft) at site 5. Only six sites had a water depth greater than 1 m (3.28 ft). Unlike the 2002 study, all sites were snow and ice covered. Ice thicknesses ranged from 17 cm (6.7 in) at site 1 to 36 cm (14.2 in) at site 3. Snow depths ranged from 1 cm (0.4 in) at sites 8, 10A, 11 and 17 to 8 cm (3.1 in) at site 28. Unusually low DO concentrations measured in the water entering the gated inlet on February 1st prompted a switch in DO meters. DO concentrations determined prior to this point were determined to be invalid because of a faulty probe. Immediately prior to injecting the dye, DO (13.44 mg/L), temperature (0.0°C) and pH (7.99) measurements were taken where water entered the gated inlet. Valid DO measurements were taken in the inlet and at sites 10A through 17. DO concentrations at sites within the lake, ranged from 6.72 mg/L at site 11 to 17.19 mg/L at site 17, with an average concentration of 13.01 mg/L. Temperature values within the lake ranged from 0.08°C at site 1 to 2.80°C at sites 11 and 14. Values for pH were similar throughout the lake, ranging from 7.65 at site 30 to 8.08 at site 8. According to Smart and Laidlaw (1977), pH values within this range should have little effect on Rhodamine WT fluorescence.

A cursory review of all velocity measurements taken during the study revealed that several of the readings were unexpectedly high. An ADV relies on suspended particulate matter to reflect an acoustic signal in order to measure velocity. As the concentration of the suspended matter decreases, the strength of the

reflected acoustic signal decreases and approaches the ambient noise level of the instrument. According to the FlowTracker user's manual, for best operating conditions the signal-to-noise ratio (SNR) should be greater than 10 dB; however, the instrument can operate reliably with SNRs as low as 2-3 dB. The lack of suspended particulate matter in the water column at several Spring Lake sites resulted in a number of erroneous velocity measurements. An in-depth review of the raw velocity data (each velocity value is the mean of 40 individual velocity measurements taken by the ADV over a 40-second period) suggested that low SNRs could be responsible for many of the erroneous readings. Also, many of the erroneous values had a relatively high standard error of velocity. These two quality control measures (SNR and standard error of velocity) were used to filter the velocity results in order to obtain a more reliable data set. The erroneous values were determined using the following criteria: mean SNR less than or equal to 3 dB or mean standard error of velocity greater than or equal to 0.7 cm/s. Filtering the data set resulted in approximately 25 percent of all velocity measurements taken during the study to be considered invalid.

With the exception of site 1 (6.69 cm/s) near the inlet structure, velocity readings throughout the lake were less than 1 cm/s (see Table 1) prior to increasing the gate opening. A dredged channel extends from the inlet structure to site 1. Apparently, the velocity of the inflow drops markedly once it leaves the confines of the dredged channel and enters the main basin of the lake. The discharge into the lake from the inlet structure was calculated to be 0.34 m^3s (12.02 cfs) with a gate opening of 20 cm (8 in).

Multiparameter Sonde Data

The DO, temperature and pH results from sondes deployed at sites 1, 5, 7, 14, 16, 19, 29 and 31 are displayed in Figures 6-13. The sonde deployed at site 24 malfunctioned; therefore, no usable data were collected here. In general, the measurements recorded by the sondes did not indicate any dramatic changes in water quality that can be attributed to the increased gate opening. Noticeable changes were slight, at best.

At site 1, the monitoring site closest to the inlet structure, the DO and temperature values decreased slightly following the increase in gate opening, whereas pH values remained relatively stable (see Figure 6). Sondes were deployed at points 0.91 m (3.00 ft) and 2.13 m (7.00 ft) from the bottom at Site 5, the deepest site. As seen in Figure 7, stratification was most noticeable with DO. Differences between DO concentrations measured by the upper and lower sondes were generally about 4 mg/L, with the exception of a DO spike near the surface on February 5th. The differences in temperature and pH values throughout the deployment were less noticeable. DO concentrations started to increase about the time when the initial impact from the increased gate opening would have reached the site; whereas, temperature and pH values remained relatively constant throughout the deployment. The time window of initial water quality impact from increased gate opening was estimated from the results of the dye analyses. The beginning of the time window coincided with the last sampling time dye was not detected at the site (minus 17 hours to account for the time difference between when the gate opening was increased to the time the dye was injected) and the end of the window coincided with the time dye was first detected at the site (again, minus 17 hours). As displayed in Figure 8, the results from the sonde deployed at site 7 were similar to those seen at site 5, in that the pH remained relatively constant throughout the deployment and a DO spike was observed on February 5th. The main difference between the two sites was seen with temperature. The temperature fluctuations at site 7 were noticeably greater than at site 5. This could be explained by the shallower depth, and therefore smaller volume of water at site 7, which would be more susceptible to temperature changes. The site 14 results are shown in Figure 9. DO concentrations were supersaturated and pH values changed little throughout the deployment. A pronounced diurnal pattern was seen in the temperature values at this site. A noticeable diurnal pattern was also seen with temperature at site 16 (see Figure 10). A sharp drop in temperature was noted on February 7th. All three parameters began to decline on February 9th. The results from site 19 are displayed in Figure 11. The DO concentrations were

considerably lower and the temperature values noticeably higher at this site. This was the only site where DO concentrations below 5 mg/L and temperature values above 4.0°C were measured. Similar conditions were observed at Spring Lake during a water quality study performed by USACE personnel on March 13, 2003, when nearly all sites throughout the lake exhibited supersaturated DO concentrations and temperature values below 2.5°C, while at site 19, values of 3.26 mg/L and 4.2°C, respectively, were measured. It is theorized that this site is influenced by a spring. The DO concentrations from site 29 (see Figure 12) suggest that this sensor was not functioning properly. The DO generally decreased throughout the deployment, approaching zero on February 14th. The wide swing in temperature values suggest this probe may have also malfunctioned. As shown in Figure 13, no dramatic differences were seen in DO, temperature or pH at site 31 during the 3-day deployment. It is possible that the small inflections in the DO and temperature curves at 0700 on February 1st were due to the increased inflow to the lake.

In addition to measuring DO, temperature and pH, the multiparameter water quality sondes deployed at sites 1, 5, 7, 14, 16, 19 and 31 were fitted with a chlorophyll probe in an effort to measure Rhodamine WT dye. The chlorophyll probes were calibrated with Rhodamine WT dye. A two-point calibration process was utilized. The chlorophyll probe functions in essentially the same manner as a Rhodamine WT dye probe, in that they are both optical fluorescence sensors; however, the wavelength of the excitation light and the emission filter for the sensors differ. Previous studies performed by USACE staff suggested that the chlorophyll probe could be used for detecting Rhodamine WT dye, although at relatively high concentrations. These studies also indicated that the chlorophyll probe was sensitive to sunlight. This was determined by placing a sonde fitted with a chlorophyll probe in a Rhodamine WT dye solution and alternatively exposing the probe to sunlight and darkness. Even though the concentration of the dye remained constant, the probe's response was dampened when it was exposed to sunlight. In an effort to address this effect, the sondes deployed in the present study were fitted with black plastic shades (see Figure 5). The results from the chlorophyll probes are displayed in Figures 14-20. Where applicable, the Rhodamine WT dye results from samples analyzed with a fluorometer are included on the figures. Site 1 was the only location where detection of the Rhodamine WT dye by the chlorophyll probe was clearly evident (see Figure 14). The only measurement to capture the dye was taken at 10:01 on February 1st, 45 minutes after the initiation of dye injection. The corresponding fluorometer analysis dye concentration from a sample collected close to this time was 16.6 µg/L at 10:26. The chlorophyll probe did not detect any dye at 12:21, when the next dye sample was collected. The fluorometer analysis dye concentration from this sample was 0.879 µg/L. Unfortunately, the sonde was programmed to only take a measurement every hour in order to conserve battery power. A 15-minute (or less) measurement frequency would have been more effective at capturing the passage of dye at site 1. The chlorophyll probe at site 19 appears to be the only one that was impacted by sunlight. As seen in Figure 19, a diurnal pattern is evident, with high values generally seen during darkness and lower values seen during sunlight hours. It cannot be determined when the dye may have passed this site based on the chlorophyll data.

Figure 5. Sonde fitted with plastic shade to reduce exposure to sunlight.

The results from the chlorophyll probe measurements from all sondes indicate that the probe could be

useful for detecting Rhodamine WT dye, but only at relatively high concentrations and only if the probes response to sunlight is addressed. The results suggest that the Rhodamine WT dye detection limit of the chlorophyll probe is within the range of 7.74 to 16.6 µg/L, which is too high to be practical for many dye study applications.

Physicochemical Data Collected during Dye Tracking

On February 1st, following an increase in gate opening to 91 cm (3 ft), the discharge into the lake increased from 0.34 m^3s (12.02 cfs) to 1.06 m^3s (37.39 cfs). Velocity measurements taken at dye sampling sites are shown in Table 2. Following an increase in the gate opening, the velocity at site 1 increased from 6.69 cm/s to 20.97 cm/s and remained above 15.18 cm/s for the duration of the study. Velocity measurements at other lake sites were below 1 cm/s, with the following seven exceptions: 1.09 cm/s at site 5 on Feb 7th, 1.86 cm/s at site 17 on Feb 14th, 1.08 cm/s at site 19 on Feb 10th, 3.40 cm/s at site 23 on Feb 7th, 2.79 cm/s at site 28 on Feb 14th, 4.68 cm/s at site 29 on Feb 7th and 6.54 cm/s at site 29 on Feb 14th. These measurements may have been impacted by relatively low SNR values, or in some cases it was observed that the pressure of the airboat on the ice forced water up through the sampling hole; thus making it difficult to get a representative velocity measurement.

With the exception of site 1, sites where dye was observed showed no clear trend when comparing velocity measurements taken prior to and following the gate change. The validity of the velocity data and the non-presence of dye at some sites limited this comparison to the following sites: 3, 6, 7, 8, 11, 13, 14, 16, 24, 26 and 31. Of these eleven sites, six (sites 6, 7, 14, 24, 26 and 31) experienced higher velocities after the gate opening was increased and five (sites 3, 8, 11, 13 and 16) experienced lower velocities. The average change in velocity seen at these eleven sites was an increase of 0.021 cm/s. Therefore, it appears that other than site 1, the increased gate opening had a relatively minor impact on velocity throughout the lake. These results are similar to those reported in the 2002 study, where velocities decreased markedly beyond the inlet channel that extends to site 1.

Staff gages on the river side of the water control structure and the lower lake side of the pump station indicated that the water level of the river was higher than the lake for the duration of the study. The head differences on February 1st, 2nd, 4th, 7th, 10th and 14th were 4.6 cm (0.15 ft), 3.7 cm (0.12 ft), 4.3 cm (0.14 ft), 13.4 cm (0.44 ft), 14.9 cm (0.49 ft), and 18.9 cm (0.62 ft), respectively. The average daily river stage during the study (3.68 m or 12.07 ft), as measured at the Sabula, Iowa gage, was 10.67cm (0.35 ft) above the 25-year daily average for the month of February (3.57 m or 11.72 ft). The average daily river stage during the 2002 dye study was 3.42 m (11.22 ft). The stage remained relatively stable from February 1st – 6th, increased 13.12 cm (0.43 ft) on February 7th, an additional 14.94 cm (0.49 ft) on February 8th, and then varied little until an increase of 11.58 cm (0.38 ft) on February 14th.

DO measurements taken when dye samples were collected ranged from 5.27 mg/L at site 19 to 25.71 mg/L at site 6, both on Feb 4th. As discussed previously, low DO concentrations were also measured at site 19 by the sonde deployed there. Most DO concentrations throughout the lake were supersaturated and only two measurements were below 10 mg/L. Temperature values ranged from -0.01°C at site 1 on Feb 7th to 3.1°C at site 12 on Feb 4th.

Dye Analysis Data

Background fluorescence was determined by analyzing blank samples. The results from the analysis of blank samples collected on January 31st and February 1st are given in Table 3. The fluorescence values for the five blank samples ranged from 0.069 µg/L at site 21 to 0.130 µg/L at site 28. Additional blank samples were collected from water entering the gated inlet on February 10th and 14th after a noticeable

increase in inflowing water turbidity was observed. The fluorescence values from these samples were 0.158 and 0.137 µg/L, respectively. It is surmised that these higher fluorescence values may have been due to increased suspended algal chlorophyll in the inflow. Upon reanalysis following additional settling, the fluorescence values of these samples decreased to 0.133 and 0.116 µg/L, respectively. Based on these results, several dye samples collected after the inflow turbidity increased were reanalyzed following additional settling. Included were dye samples collected on February 7th, 10th and 14th.

Dye sampling was performed on ten occasions over a 13-day period (February 1st – 14th). Pertinent sample collection data and all dye analysis results are given in Table 3. The length of time required for completing each sampling event ranged from 17 minutes (first sampling event on February 1st) to $4^1/_2$ hours (February 10th sampling event). Utilizing the results from the blank analyses and following an initial review of the dye analysis results, it was determined that a fluorescence value greater than or equal to 0.145 µg/L would indicate the presence of Rhodamine WT dye. The highlighted concentrations in Table 3 are those where dye was detected. According to Johnson (1984), Rhodamine WT fluorescence decreases approximately five percent for every 2°C increase in temperature. The maximum temperature differential at the time of analysis was relatively small (2.3°C); therefore, temperature corrections were not made. The fluorescence values ranged from 0.032 µg/L at site 20 on February 14th to 101.0 µg/L at site 4 during the third sampling event on February 1st. Apparently, the highest dye concentration was not measured at site 1 because the densest portion of the plume had moved beyond this site before the first sample could be taken. The locations where dye was detected in Table 3 are shown on orthophotos of Spring Lake in Figures 21 through 23. The photos are positioned sequentially for the ten sampling events and include the time elapsed from initial injection of the dye to the beginning of each sampling event. The last photo is a cumulative map, showing all sites where dye was detected at some point during the study.

Dye was detected at site 1 during the first six sampling events, was not found here during event seven, and then reappeared during events eight and nine. It is surmised that the reappearance of dye at site 1 may have been due to the rise in water level that occurred between events seven and eight, which may have flushed dye out of a small bay in the lake where site 31 is located. By sampling event two (elapsed time 3 hours), the dye was also detected at site 3. During sampling events three (elapsed time 5½ hours) and four (elapsed time 8½ hours), dye was present at sites 1, 3 and 4. After one day (sampling event five), the dye was detected at sites 1-5 and 31. At this point during the 2002 study the dye was present at only sites 3 and 4. During event six, at the 1¼ day mark, dye was detected at one additional site (7). By day 3 (sampling event seven), dye was not detected at site 1, but was additionally detected at sites 6, 8 and 11. The dye was no longer detected at sites 2, 3 and 4 during sampling event eight (elapsed time 6 days) but it reappeared at site 1 and was detected for the first time at sites 12 and 16. At this point during the 2002 study, site 7 was the farthest point from the injection site where dye was detected. During sampling event nine on day 9, the dye was detected at the most sampling points (sites 1, 5-17, 24-26, 28 and 31). On the final sampling event, day 13, dye was for the first time detected in the sub-basin of the lake west of Silo Island, appearing at sites 22 and 23. Dye was not detected in this area of the lake during the 2002 study. Other sites where dye was detected during event ten include 5, 13-15, 24-26, 28 and 31. The cumulative map indicates that over the course of the study, dye was detected at 23 of the 29 sites. During both the 2002 and present study, samples were collected on the sixth day following dye injection. Comparison of dye analysis results from these sampling events show that the dye traveled more than twice the distance during 2005 compared to that observed in 2002. The dye traveled 1,125 m (3,691 ft) in 2002, for an average velocity of .22 cm/sec while in 2005 it traveled 2,375 m (7,792 ft) for an average velocity of .46 cm/sec.

As observed in 2002, the primary route of the dye in 2005 was to the east side of Silo Island. However, unlike in 2002, dye was detected in the sub-basin west of Silo Island in 2005, albeit not until the last

sampling event. The area west of the upper part of Silo Island is relatively shallow. A significant amount of sediment deposition has occurred here due to previous levee failures. Much of this area is above the normal lake level and is covered with willow trees, thus, isolating it from the main basin of the lake. On the final sampling event, dye was detected adjacent to Silo Island at sites 22 and 23. Since dye was not detected at sites 19, 20 and 21, it is presumed that the dye traveled along the west side of Silo Island from site 10A to sites 22 and 23.

Fish Telemetry Data

One objective of the study was to determine if an increase in water velocity caused by a larger gate opening would adversely impact over-wintering centrarchids, which prefer areas with little or no velocity. This objective was accomplished by tracking the movement of centrarchids fitted with radio transmitters to determine if they would leave the area where they were captured/released in response to the increased inflow. Twenty fish were caught and released below the cross dike on January 25th and 26th (see Figure 24). Fish were identified according to the last three digits of their transmitter frequency and whether they were a black crappie ("C") or a bluegill ("B"). For example, the fish labeled "164B" was a bluegill fitted with a transmitter emitting a radio signal with a frequency of 49.164 MHz. The fish were monitored during three tracking events: January 31st-February 2nd; February 4th; and February 10th - 11th. Nineteen of twenty fish were located during each tracking event. Fish 761C was never found. The objective of the first tracking event was to determine initial fish location. The second and third tracking events were performed following the increase in gate opening. Figures 24-28 show the location of the fish during each tracking event by date. During the first tracking event, sixteen fish were located on January 31st. The position of some fish on this date was estimated when late in the day the GPS unit lost battery power. Fish 084C and 631C were found on February 1st and fish 194C was found on February 2nd. Although some fish were located after the increase in gate opening, it is unlikely the area where they were found was yet impacted by the increased inflow, except for perhaps fish 194C. The fish remained relatively close to the area where they were captured/released. The farthest distance traveled was approximately 1,200 m (3,937 ft) by fish 631C (see Figure 26). The second tracking event occurred on the fourth day (February 4th) following the increase in gate opening. The fish still remained relatively close to the area of capture/release, except for fish 751C. This black crappie traveled over 1,800 m (5,906 ft) to the east side of the lake; however, by the third tracking event six days later, it had returned to the vicinity where it was originally captured/released (see Figure 27). The third tracking event was performed on the tenth and eleventh days following the increase in gate opening. Again, the fish were located relatively close to the area of capture/release. The farthest distance traveled was approximately 900 m (2,953 ft) by fish 831C (see Figure 28).

Based on the distance traveled from the capture/release site, the telemetry data indicate the fish were not adversely impacted by the increase in gate opening. Initial concerns that the fish may be "flushed" from the lake did not materialize. In fact, the fish that traveled the furthest distance from its capture/release site eventually returned to the area, suggesting that the increased inflow was not the reason for its initial departure from the area. The velocity at site 7, in the vicinity where most of the fish were located throughout the study, increased from 0.16 cm/sec on January 28th to 0.45 cm/s on February 14th. The 0.29 cm/s increase in velocity was apparently not sufficient to cause the fish to disperse from the area.

Physicochemical Data Collected during Fish Telemetry

Water quality and velocity measurements were taken on several instances when fish were located. These data are shown in Table 4. DO concentrations were more than sufficient to support aquatic life, ranging from 9.88 – 19.60 mg/L, with an average value of 13.39 mg/L. Temperature values ranged from 0.0 – 2.7°C, with an average value of 1.0°C. These overwintering environmental conditions were compared to

those described by Knights et al. (1995), in their study of overwintering bluegills and black crappies in the Mississippi River in Minnesota. They partitioned backwater areas into five distinct habitat types according to DO, temperature and velocity. They found that the most selected habitat type had current velocities $\leq$ 1 cm/s and temperature values $\leq$ 1°C. They further stated that although this habitat type had the highest selection ranking of the five habitat types defined, fish movement patterns suggested that if DO concentrations were adequate, fish preferred areas with higher temperature values. Utilizing the quality control criteria discussed previously, nearly half the velocity measurements made while locating fish were considered invalid. All velocity measurements where fish were located were below 1 cm/s. Values ranged from 0.17 – 0.84 cm/s, with an average velocity of 0.40 cm/s. These results are in agreement with the findings of Knights et al. (1995), who reported that bluegills and black crappies avoided areas with velocities greater than 1 cm/s.

Conclusions

With a gate opening of 91 cm (3 ft) in 2005, inflowing water dispersed throughout Spring Lake faster and more completely than was observed during a similar study in 2002 when the inlet structure gate was open only 25 cm (10 in). With the larger gate opening in 2005, the inflow to the lake was measured at 1.06 m^3s (37.39 cfs), which is comparable to the value predicted (1.33 m^3s or 47 cfs) prior to construction utilizing a culvert rating program (U.S. Army Corps of Engineers, 1993). The dispersal pattern still favored the deeper portions of the lake north and east of Silo Island; however, unlike in 2002, dye was eventually detected in samples collected from the sub-basin of the lake west of Silo Island. A comparison of dye analysis results from samples collected on the sixth day following injection during both studies show that the dye traveled more than twice the distance during 2005 compared to that observed in 2002. The dye traveled 1,125 m (3,691 ft) to site 7 in 2002, for an average velocity of .22 cm/sec while in 2005 it traveled 2,375 m (7,792 ft) to site 16 for an average velocity of .46 cm/sec. In both studies the velocity of the inflow dropped markedly once it exited the dredged channel near site 1 and entered the main basin of the lake. In 2002, the velocity measured at site 1 was 3.353 cm/s, while in 2005 it ranged from 15.18 to 20.97 cm/s. Velocities measured at other sites throughout the lake were nearly all below 1 cm/sec. The use of a Doppler current meter in 2005 resulted in several velocity readings being considered invalid due to low SNRs caused by insufficient suspended particulate matter in the water column. It is recommended for future studies, if utilizing a Doppler current meter, the bottom should be disturbed to suspend particulate matter, or a seeding material added to the water column if low SNRs are encountered.

Multiparameter water quality sondes fitted with a chlorophyll probe were not practical for measuring Rhodamine WT dye at the detection levels required for the present study. The chlorophyll probe functions in essentially the same manner as a Rhodamine WT dye probe; however, the results from the deployments at Spring Lake indicate the probe could be useful for detecting Rhodamine WT dye, but only at relatively high concentrations and only if the probes response to sunlight is addressed. The results suggest that the dye detection limit of the chlorophyll probe is within the range of 7.74 to 16.6 µg/L, which is too high to be practical for many dye study applications.

Movement of radio-tagged centrarchids (black crappies and a bluegill) indicated the fish were not adversely impacted by the increased gate opening. Initial concerns that the fish may be "flushed" from the area did not materialize. In fact, the fish that traveled the furthest distance from its capture/release site eventually returned to the area. The velocity at site 7, in the vicinity where most fish were located throughout the study, increased from 0.16 cm/sec on January 28th to 0.45 cm/s on February 14th. The 0.29 cm/s increase in velocity was apparently insufficient to cause the fish to disperse from the area.

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Acknowledgements

The author wishes to thank Ed Britton, Manager and Russ Engelke, Assistant Manager for the Savanna District of the Upper Mississippi River National Wildlife and Fish Refuge, and staff for their cooperation and assistance with this study. The efforts of IDNR staff (Gene Jones, John Pitlo, Caleb Schnitzler, Mike Steuck and Denny Weiss) in obtaining the fish required for the telemetry study is greatly appreciated. A special thanks goes to citizen conservationist "Tiger" Steuck for his relentless efforts in locating the "honey hole" where most of the fish for the study were caught. Finally, I thank fellow USACE employees Dr. Clint Beckert, Dan McBride, Brad Palmer, Anna Denton and Christine Martinson for their assistance in the field, laboratory and/or preparation of this report.

Table 1. Field Data Collected on January 31, 2005 or February 1, 2005 prior to Impact of the Increased Gate Opening, including the Sites where Blank Samples were Collected.

Site Number	Time	Water Depth (m)	Ice Thickness (cm)	Snow Depth (cm)	D.O. (mg/L)	Water Temp. (°C)	pH	Velocity (cm/s)	Comments
Inlet**	0857	-	-	-	13.44*	0.0*	7.99*	-	-
1	1442	0.650	17	4	***	0.08	7.96	6.69	Blank collected
2	1452	0.580	27	3	-	-	-	-	-
3	1506	0.670	36	5	***	0.23	7.96	0.76	-
4	1520	0.815	25	5	-	-	-	-	-
5**	0721	2.600	29	5	***	1.48	7.71	****	Blank collected
6**	0750	0.670	26	3	***	1.70	7.91	0.15	-
7**	0759	1.040	30	3	-	-	-	****	-
8**	0809	0.640	30	1	***	1.40	8.08	0.93	-
10A**	1118	0.380	24	1	16.23	0.6	-	-	-
11**	1057	0.670	26	1	6.72	2.8	-	0.56	-
12**	1033	0.540	27	3	9.20	2.3	-	0.26	-
13**	1145	0.660	29	2	14.92	2.3	-	0.41	-
14**	1631	0.730	28	3	11.80	2.8	-	0.16	-
15**	1615	0.750	29	3	14.96	2.0	-	0.60	Blank collected
16**	1600	0.610	28	2	13.02	2.5	-	0.20	-
17**	1545	0.450	25	1	17.19	2.6	-	0.52	-
19	1303	1.380	24	2	-	-	-	-	-
20	1253	0.320	24	2	-	-	-	-	-
21	1224	0.365	23	6	***	0.34	7.74	-	Blank collected
22	1214	0.660	26	4	-	-	-	-	-
23	1156	2.450	23	3	***	2.01	7.75	0.12	-
24	1143	0.720	25	5	***	2.13	7.81	0.60	-
25	1131	0.370	23	4	***	0.84	7.67	-	-
26	1117	0.590	21	6	***	1.65	7.78	0.03	-
27	1103	0.620	21	2	***	1.18	7.74	0.31	-
28	1047	1.040	28	8	***	1.09	7.80	0.08	Blank collected
29	1033	0.990	19	2	***	1.05	7.86	0.52	-
30	1015	0.700	29	4	***	1.78	7.65	0.08	-
31	1421	1.900	35	3	-	-	-	-	-

* Measurement taken from where water flowed into the gated inlet structure.

** Data collected on February 1, 2005, prior to impact of increased gate opening.

*** Measurement determined to be invalid due to malfunctioning DO probe.

**** Measurement determined to be invalid due to poor quality control data.

Table 2. Velocity Measurements Taken at Dye Sampling Sites

Date	Time	Site	Velocity (cm/s)	Mean SNR (dB)	Mean Standard Error (cm/s)
1/31/05	1442	1	6.69	4.2	0.2
2/2/05	0845	1	20.97	15.9	0.2
2/4/05	1259	1	17.88	10.7	0.1
2/7/05	0945	1	17.45	25.6	0.3
2/10/05	0922	1	15.54	19.2	0.1
2/14/05	0908	1	15.18	22.6	0.4
2/2/05	0910	2	0.42	8.3	0.3
1/31/05	1506	3	0.76	12.4	0.5
2/4/05	1242	3	0.22	13.7	0.1
2/10/05	0943	4	0.87	3.7	0.1
2/7/05	1011	5	1.09	8.7	0.1
2/1/05	0750	6	0.15	18.3	0.0
2/2/05	0941	6	0.14	7.1	0.0
2/4/05	1204	6	0.45	8.4	0.0
1/28/05	1233	7	0.16	23.2	0.1
2/14/05	1002	7	0.45	3.4	0.0
2/1/05	0809	8	0.93	28.5	0.1
2/2/05	0954	8	0.31	7.5	0.0
2/4/05	1115	8	0.14	3.8	0.0
2/2/05	1002	10A	0.15	24.8	0.0
2/4/05	1055	10A	0.64	25.0	0.1
2/1/05	1057	11	0.56	9.0	0.1
2/4/05	1045	11	0.24	13.7	0.0
2/10/05	1052	11	0.70	5.0	0.3
2/1/05	1033	12	0.26	18.4	0.0
2/4/05	1035	12	0.25	8.1	0.0
2/1/05	1145	13	0.41	17.4	0.0
2/2/05	1024	13	0.30	7.9	0.1
2/4/05	1026	13	0.30	13.4	0.1
2/10/05	1113	13	0.25	9.4	0.1
2/1/05	1631	14	0.16	12.4	0.3
2/4/05	1008	14	0.19	4.8	0.5
2/7/05	1122	14	0.24	7.0	0.1
2/14/05	1048	14	0.82	17.6	0.1
2/1/05	1615	15	0.60	19.7	0.1
2/4/05	0956	15	0.21	5.7	0.1

Table 2 (Cont.). Velocity Measurements Taken at Dye Sampling Sites

Date	Time	Site	Velocity (cm/s)	Mean SNR (dB)	Mean Standard Error (cm/s)
2/1/05	1600	16	0.20	27.9	0.0
2/4/05	0936	16	0.20	8.8	0.1
2/7/05	1136	16	0.05	33.8	0.0
2/1/05	1545	17	0.52	26.2	0.1
2/4/05	0926	17	0.70	9.3	0.0
2/14/05	1122	17	1.86	4.1	0.4
1/28/05	1034	19	0.19	9.4	0.1
2/4/05	1105	19	0.20	11.0	0.0
2/7/05	1153	19	0.79	11.3	0.1
2/10/05	1146	19	1.08	10.9	0.1
2/7/05	1208	21	0.83	18.7	0.1
2/14/05	1149	21	0.30	10.0	0.1
2/10/05	1212	22	0.40	16.3	0.0
1/31/05	1156	23	0.12	13.9	0.0
2/7/05	1222	23	3.40	4.8	0.1
2/10/05	1228	23	0.87	9.0	0.1
1/28/05	1010	24	0.07	20.0	0.1
1/31/05	1143	24	0.60	20.9	0.1
2/4/05	0855	24	0.89	7.4	0.6
2/14/05	1236	24	0.66	5.9	0.1
2/4/05	0914	25	0.24	9.0	0.0
2/7/05	1300	25	0.26	9.8	0.1
1/31/05	1117	26	0.03	26.8	0.1
2/4/05	0841	26	0.71	5.4	0.1
2/14/05	1256	26	0.87	7.0	0.4
1/31/05	1103	27	0.31	28.9	0.0
1/31/05	1047	28	0.08	11.7	0.1
2/14/05	1207	28	2.79	6.8	0.1
1/28/05	0940	29	0.17	9.1	0.1
1/31/05	1033	29	0.52	16.3	0.1
2/7/05	1240	29	4.68	14.3	0.1
2/14/05	1222	29	6.54	9.0	0.1
1/31/05	1015	30	0.08	19.3	0.1
1/28/05	1138	31	0.14	7.0	0.3
2/2/05	0855	31	0.22	7.0	0.1
2/4/05	1305	31	0.21	5.8	0.1
2/14/05	0842	31	0.09	14.7	0.1

Table 3. Sample Collection and Analysis Results for Field Blanks and Rhodamine WT Dye Sampling Events 1, 2, 3 and 4 on 2/1/05 and 5 and 6 on 2/2/05.*

Site Number	Collection Date	Collection Time	Blank (µg/L)
1**	1/31/05	1444	0.070
5**	2/1/05	0721	0.077
15**	2/1/05	1615	0.110
21**	1/31/05	1224	0.069
28**	1/31/05	1047	0.130

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/1/05	1026	16.6
2	2/1/05	1034	0.077
3	2/1/05	1040	0.075
4	2/1/05	1043	0.069
31	2/1/05	1032	0.092

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/1/05	1221	0.879
2	2/1/05	1232	0.078
3	2/1/05	1236	28.6
4	2/1/05	1239	0.066
5	2/1/05	1243	0.091
8	2/1/05	1249	0.072
31	2/1/05	1226	0.080

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/1/05	1449	0.405
2	2/1/05	1459	0.070
3	2/1/05	1502	18.2
4	2/1/05	1505	101.0
5	2/1/05	1512	0.089
6	2/1/05	1516	0.111
7	2/1/05	1521	0.070
8	2/1/05	1526	0.068
31	2/1/05	1455	0.096

* Highlighted concentrations indicate dye was detected.

** Field blank sample.

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/1/05	1742	0.224
2	2/1/05	1751	0.077
3	2/1/05	1753	9.75
4	2/1/05	1756	19.0
5	2/1/05	1800	0.076
6	2/1/05	1803	0.079
7	2/1/05	1807	0.077
8	2/1/05	1811	0.076
31	2/1/05	1746	0.085

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/2/05	0845	0.179
2	2/2/05	0910	1.11
3	2/2/05	0918	8.13
4	2/2/05	0925	6.50
5	2/2/05	0933	1.75
6	2/2/05	0941	0.079
7	2/2/05	0948	0.073
8	2/2/05	0954	0.072
10A	2/2/05	1002	0.064
11	2/2/05	1009	0.062
12	2/2/05	1018	0.058
13	2/2/05	1024	0.038
31	2/2/05	0855	7.74

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/2/05	1436	0.283
2	2/2/05	1501	1.53
3	2/2/05	1509	2.34
4	2/2/05	1518	1.95
5	2/2/05	1525	1.09
6	2/2/05	1536	0.120
7	2/2/05	1543	7.85
8	2/2/05	1550	0.070
10A	2/2/05	1555	0.055
11	2/2/05	1607	0.061
12	2/2/05	1613	0.056
13	2/2/05	1618	0.085
31	2/2/05	1457	1.89

Table 3 (Cont.). Sample Collection and Analysis Results for Rhodamine WT Dye Sampling Events 7 (2/4/05) and 8 (2/7/05).*

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/4/05	1259	0.115
2	2/4/05	1249	0.550
3	2/4/05	1242	0.147
4	2/4/05	1234	0.429
5	2/4/05	1220	0.444
6	2/4/05	1204	3.50
7	2/4/05	1129	0.948
8	2/4/05	1115	1.54
10A	2/4/05	1055	0.041
11	2/4/05	1045	9.11
12	2/4/05	1035	0.059
13	2/4/05	1026	0.076
14	2/4/05	1008	0.044
15	2/4/05	0956	0.063
16	2/4/05	0936	0.053
17	2/4/05	0926	0.046
19	2/4/05	1105	0.066
24	2/4/05	0855	0.067
25	2/4/05	0914	0.115
26	2/4/05	0841	0.064
31	2/4/05	1305	2.46

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/7/05	0945	0.209**
2	2/7/05	0955	0.099
3	2/7/05	1000	0.095
4	2/7/05	1005	0.112**
5	2/7/05	1011	0.515**
6	2/7/05	1039	0.344**
7	2/7/05	1044	0.198**
8	2/7/05	1049	0.171**
10A	2/7/05	1055	0.055
11	2/7/05	1100	0.293**
12	2/7/05	1108	0.575**
13	2/7/05	1112	0.088
14	2/7/05	1122	0.102
15	2/7/05	1131	0.065
16	2/7/05	1136	1.29**
17	2/7/05	1143	0.053
19	2/7/05	1153	0.057**
20	2/7/05	1202	0.037
21	2/7/05	1208	0.066
22	2/7/05	1214	0.127
23	2/7/05	1222	0.105
24	2/7/05	1254	0.076
25	2/7/05	1300	0.033
26	2/7/05	1308	0.075
27	2/7/05	1247	0.114
28	2/7/05	1230	0.102
29	2/7/05	1240	0.141**
30	2/7/05	1234	0.126
31	2/7/05	0938	0.517**

* Highlighted concentrations indicate dye was detected.

** Sample reanalyzed after allowing suspended material to settle out.

Table 3 (Cont.). Sample Collection and Analysis Results for Rhodamine WT Dye Sampling Events 9 (2/10/05) and 10 (2/14/05).*

Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)	Site Number	Collection Date	Collection Time	Dye Conc. (µg/L)
1	2/10/05	0922	0.191**	1	2/14/05	0908	0.123**
2	2/10/05	0934	0.114	2	2/14/05	0916	0.040
3	2/10/05	0939	0.079	3	2/14/05	0921	0.074
4	2/10/05	0943	0.133**	4	2/14/05	0926	0.067
5	2/10/05	1002	0.378**	5	2/14/05	0936	0.327**
6	2/10/05	1016	0.164**	6	2/14/05	0954	0.126**
7	2/10/05	1023	0.161**	7	2/14/05	1002	0.080
8	2/10/05	1028	0.160**	8	2/14/05	1014	0.058
10A	2/10/05	1034	0.207**	10A	2/14/05	1019	0.116
11	2/10/05	1052	0.246**	11	2/14/05	1025	0.074
12	2/10/05	1101	0.147**	12	2/14/05	1031	0.125**
13	2/10/05	1113	1.45**	13	2/14/05	1039	0.254**
14	2/10/05	1120	0.358**	14	2/14/05	1048	0.388**
15	2/10/05	1124	1.21**	15	2/14/05	1103	0.407**
16	2/10/05	1130	0.282**	16	2/14/05	1109	0.077
17	2/10/05	1135	0.265**	17	2/14/05	1122	0.118**
19	2/10/05	1146	0.091**	19	2/14/05	1132	0.091**
20	2/10/05	1158	0.046	20	2/14/05	1143	0.032
21	2/10/05	1204	0.086	21	2/14/05	1149	0.085
22	2/10/05	1212	0.044**	22	2/14/05	1155	0.191**
23	2/10/05	1228	0.071**	23	2/14/05	1201	0.721**
24	2/10/05	1315	0.352**	24	2/14/05	1236	0.272**
25	2/10/05	1325	2.83**	25	2/14/05	1250	0.229**
26	2/10/05	1332	0.146**	26	2/14/05	1256	0.969**
27	2/10/05	1309	0.091	27	2/14/05	1231	0.088
28	2/10/05	1238	0.155**	28	2/14/05	1207	0.531**
29	2/10/05	1250	0.124	29	2/14/05	1222	0.114
30	2/10/05	1243	0.075**	30	2/14/05	1214	0.132**
31	2/10/05	0902	0.326**	31	2/14/05	0842	0.226**

* Highlighted concentrations indicate dye was detected.

** Sample reanalyzed after allowing suspended material to settle out.

Table 4. Water Quality and Velocity Measurements Taken at Fish Location Sites

Fish	Date	Dissolved Oxygen (mg/L)	Temperature (°C)	Velocity (cm/s)	Mean SNR (dB)	Mean Standard Error (cm/s)
054C	2/10/05	10.88	0.6	*	3.7	1
084C	2/1/05	11.68	2.5	0.59	15.8	0.1
084C	2/4/05	15.48	0.9	*	7.3	0.7
084C	2/11/05	11.12	0.1	*	2	2.6
143C	2/4/05	15.56	2.0	*	15.3	0.7
143C	2/10/05	-	-	0.22	2	0.1
154C	2/10/05	11.28	0.7	0.42	9.4	0.1
164B	2/10/05	12.38	0.7	0.54	12.3	0.1
173C	2/11/05	9.88	0.9	0.19	8.7	0
194C	2/2/05	15.54	0.5	*	3.7	1.5
194C	2/4/05	16.02	1.2	0.39	20.6	0
194C	2/10/05	11.38	0.4	0.17	5.7	0
210C	2/4/05	16.35	1.0	*	1	0
210C	2/10/05	11.24	0.2	*	2.1	0.5
491C	2/10/05	-	-	*	3.2	2
631C	2/1/05	11.08	2.7	0.37	7.1	0.1
711C	2/4/05	19.60	1.7	0.36	19.9	0.1
711C	2/10/05	11.18	0.3	*	5.2	1.8
721C	2/11/05	11.98	0.0	*	2.2	0.9
751C	2/4/05	18.09	1.3	0.19	4.8	0.5
751C	2/10/05	11.38	0.6	*	6.7	0.9
770C	2/10/05	-	-	0.84	21	0.1
810C	2/11/05	12.08	0.8	0.44	17.7	0
851C	2/10/05	-	-	0.40	17.3	0.1
890C	2/4/05	17.07	0.9	0.31	22.6	0
890C	2/10/05	-	-	*	2.9	0

Minimum	9.88	0.0	0.17
Maximum	19.60	2.7	0.84
Average	13.39	1.0	0.40

* Invalid velocity reading due to a mean SNR less than or equal to 3 dB and/or mean standard error of velocity greater than or equal to 0.7 cm/s.

Figure 6. Multiparameter Sonde Water Quality Data from Site 1.

Figure 7. Multiparameter Sonde Water Quality Data from Site 5.

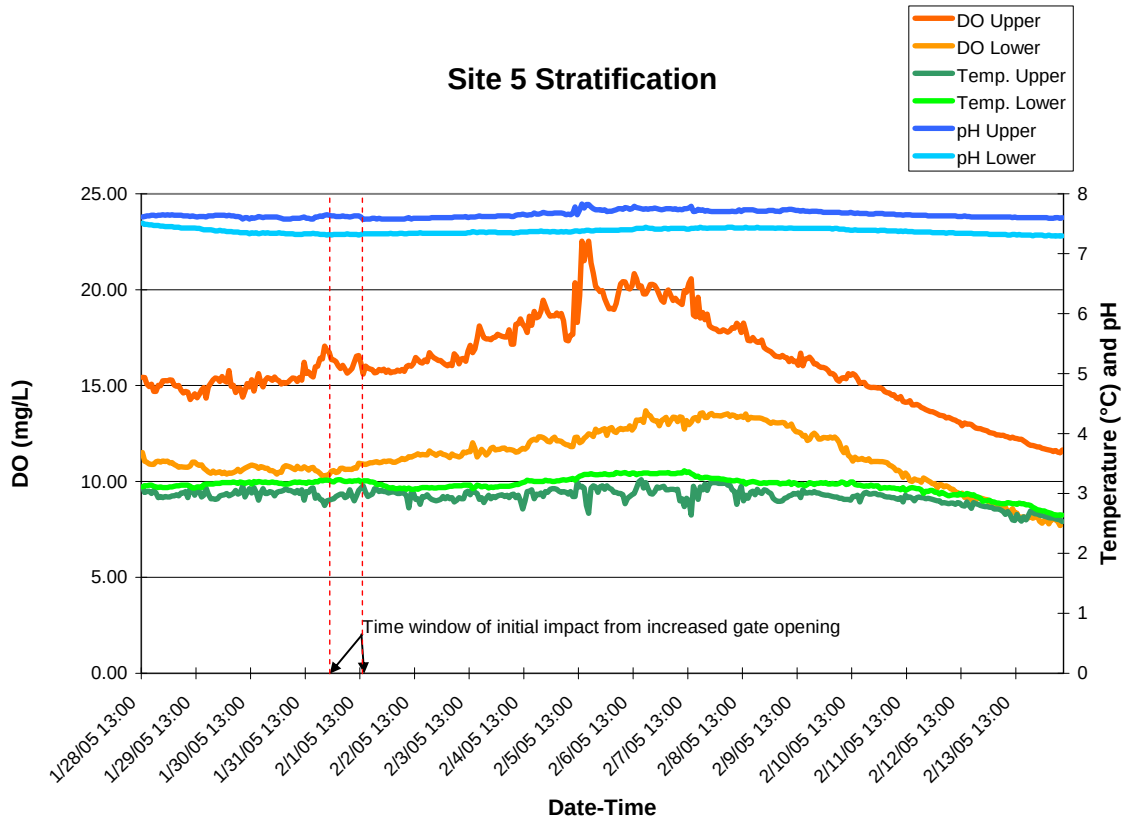


Figure 8. Multiparameter Sonde Water Quality Data from Site 7.

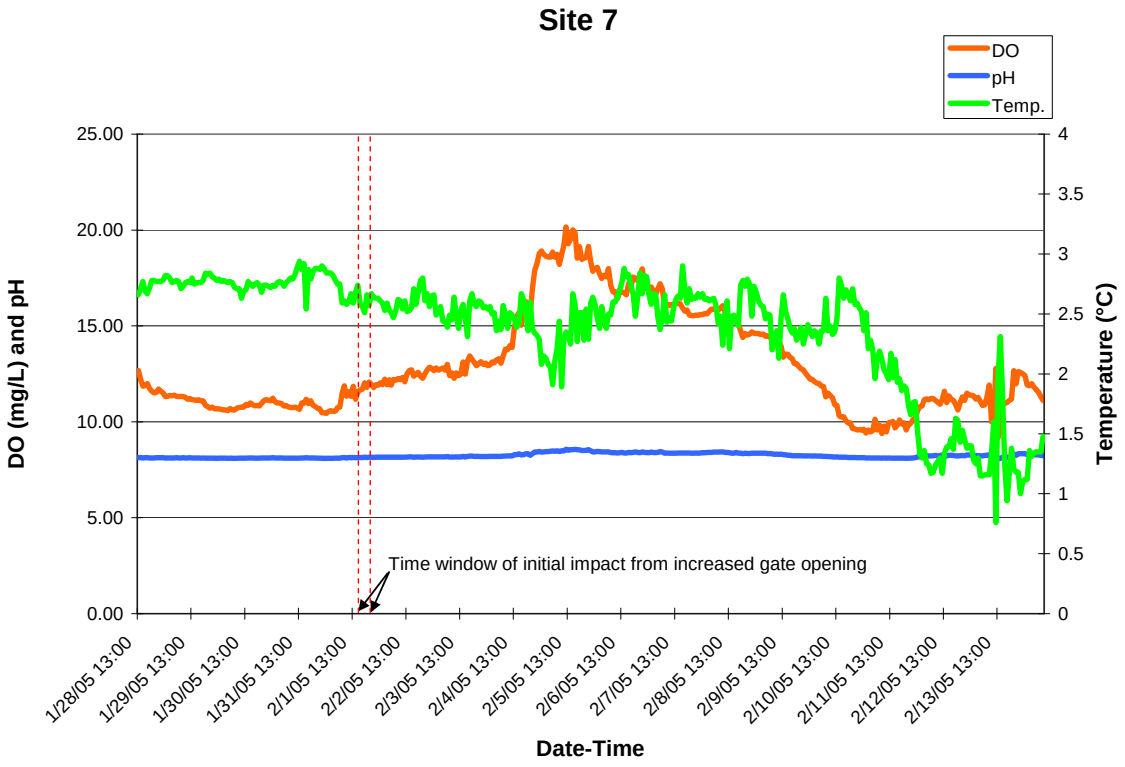


Figure 9. Multiparameter Sonde Water Quality Data from Site 14.

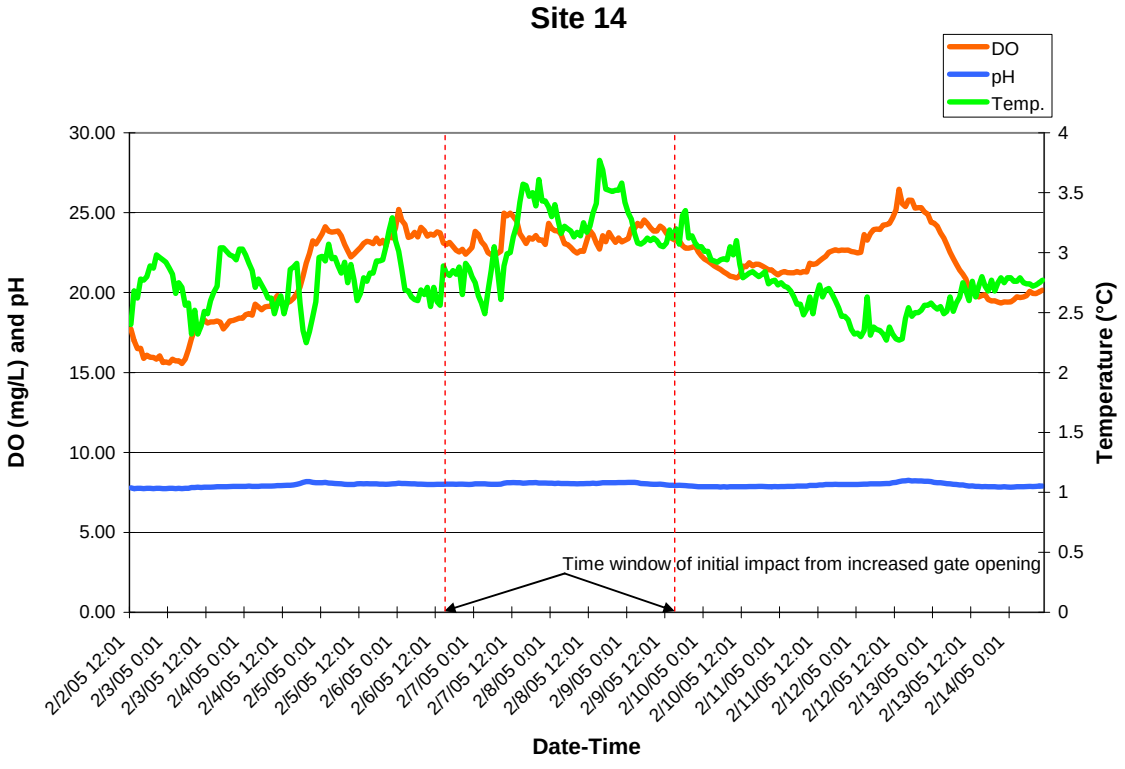


Figure 10. Multiparameter Sonde Water Quality Data from Site 16.

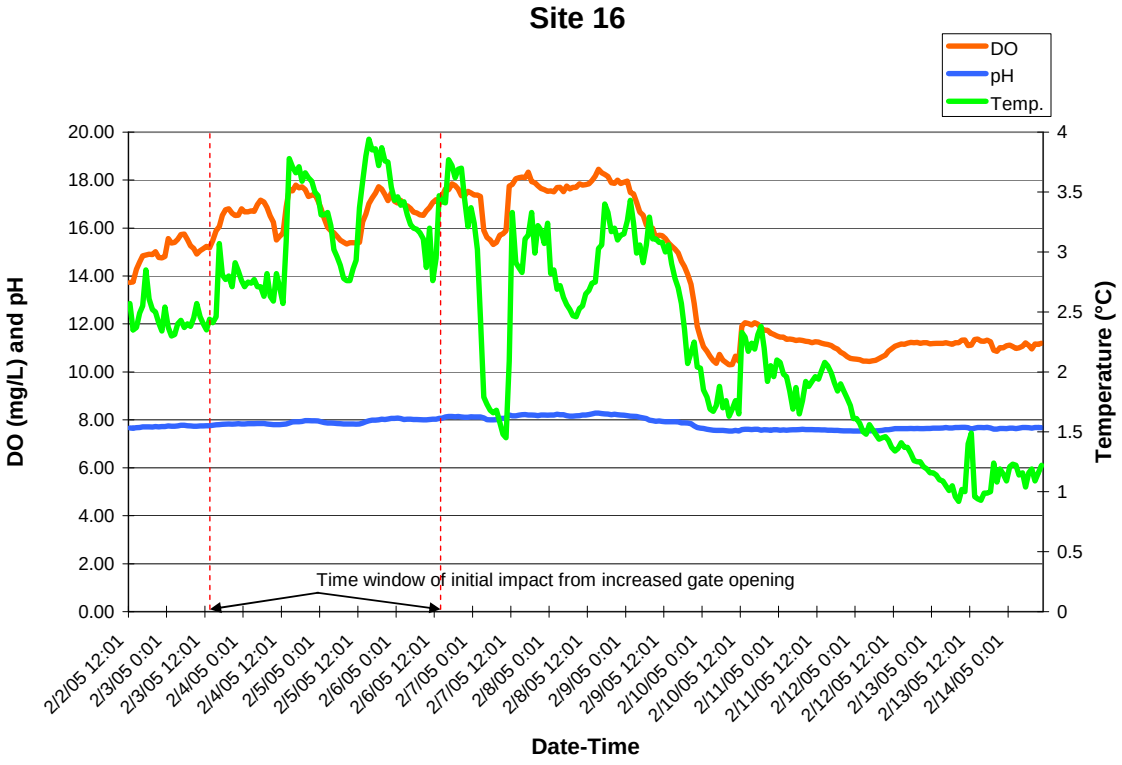


Figure 11. Multiparameter Sonde Water Quality Data from Site 19.

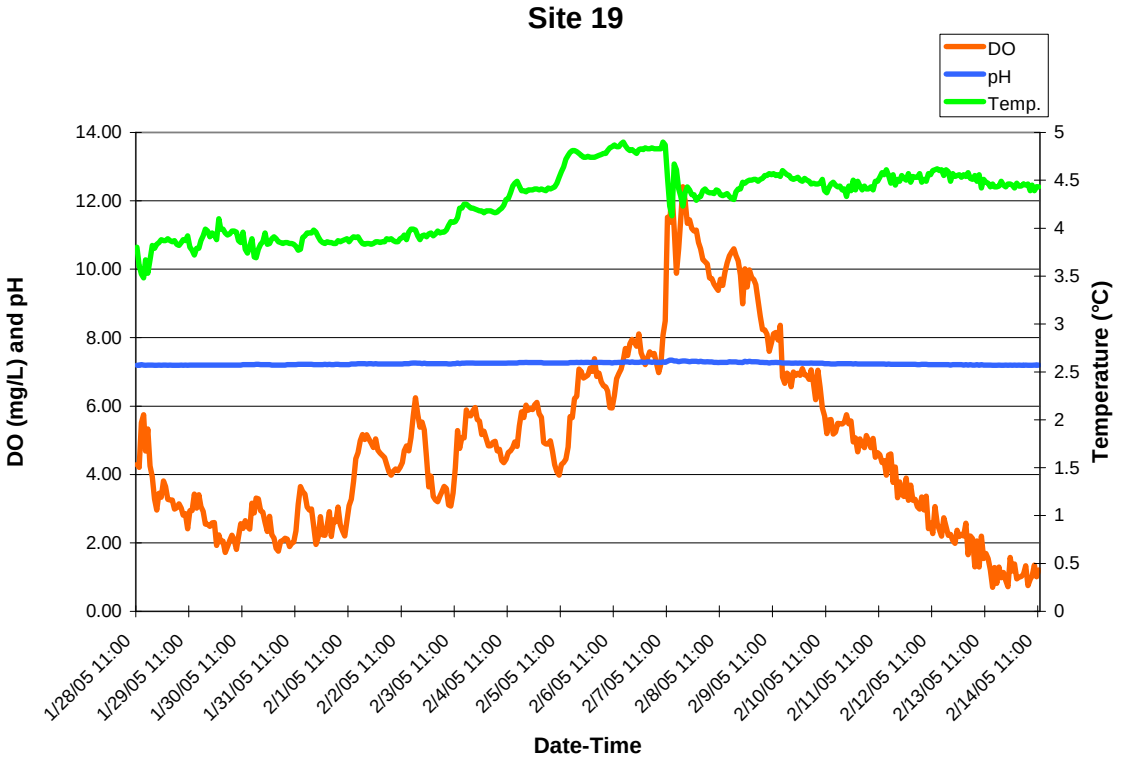


Figure 12. Multiparameter Sonde Water Quality Data from Site 29.

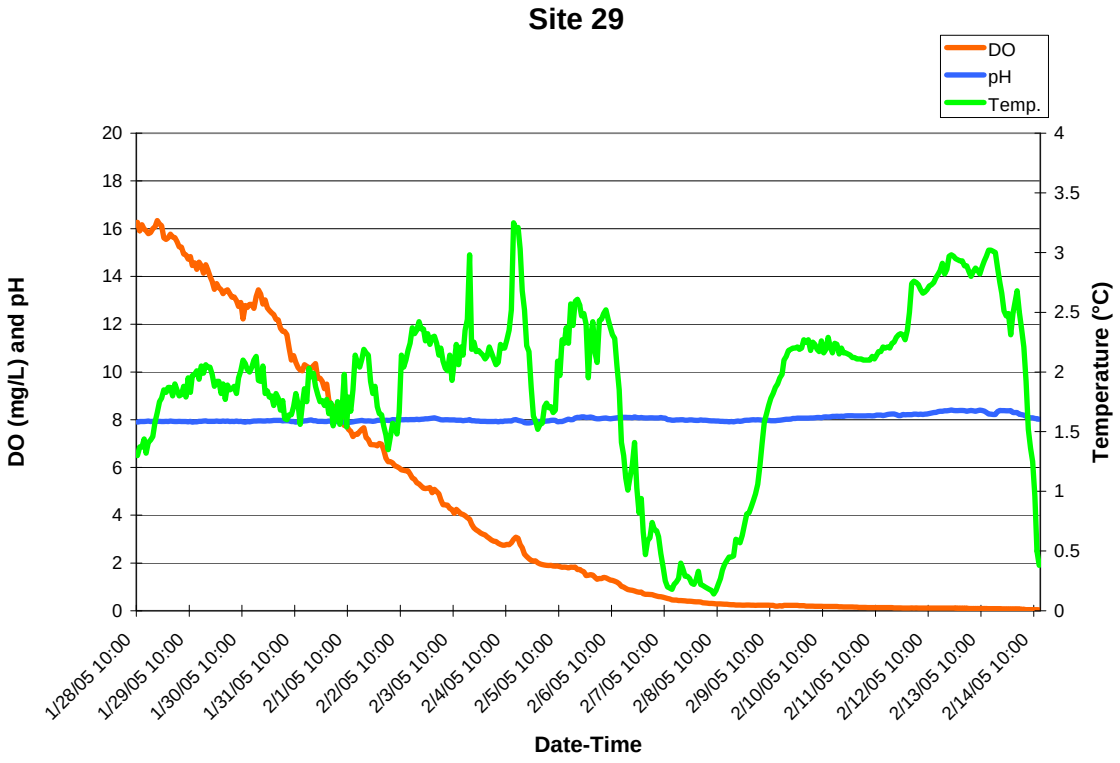


Figure 13. Multiparameter Sonde Water Quality Data from Site 31.

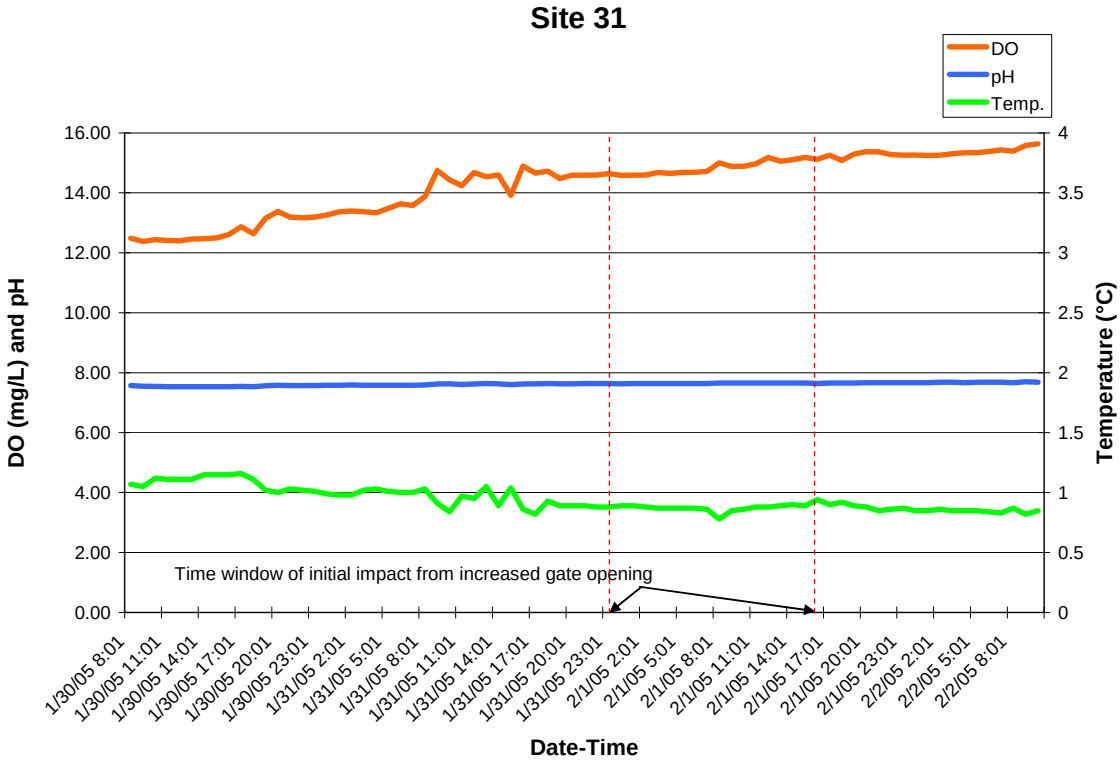


Figure 14. Field and Laboratory Rhodamine WT Concentration Comparisons from Site 1.

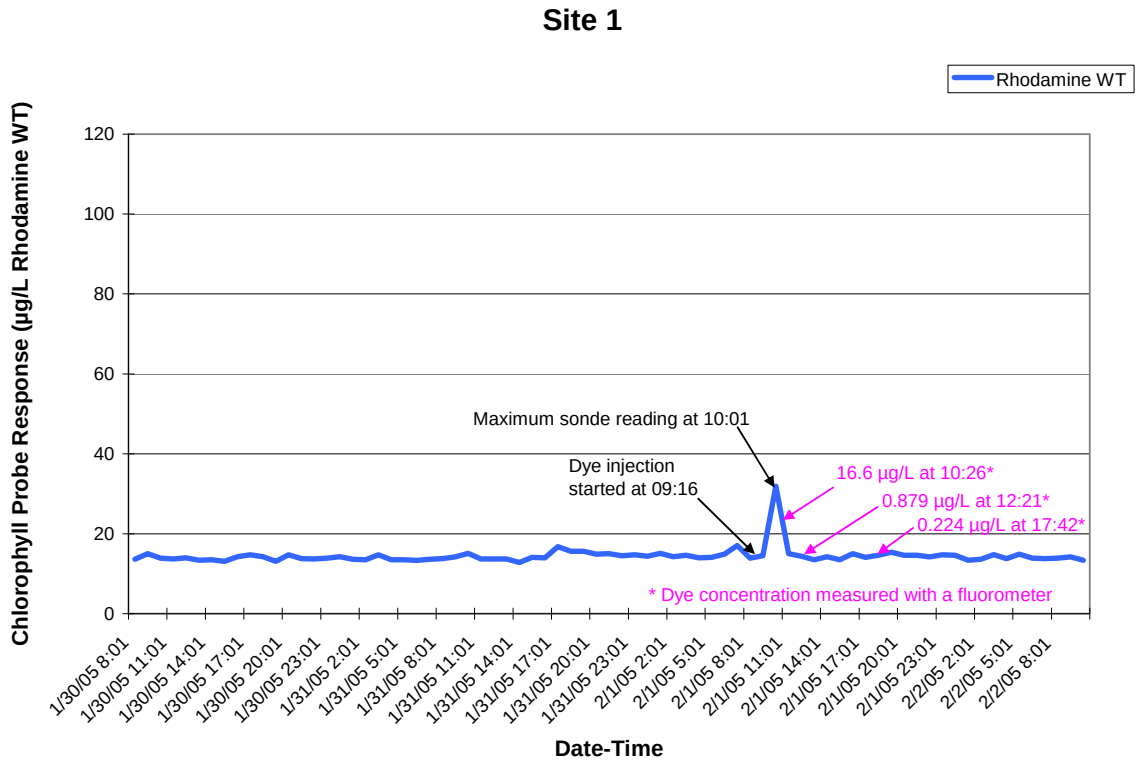


Figure 15. Field and Laboratory Rhodamine WT Concentration Comparisons from Site 5.

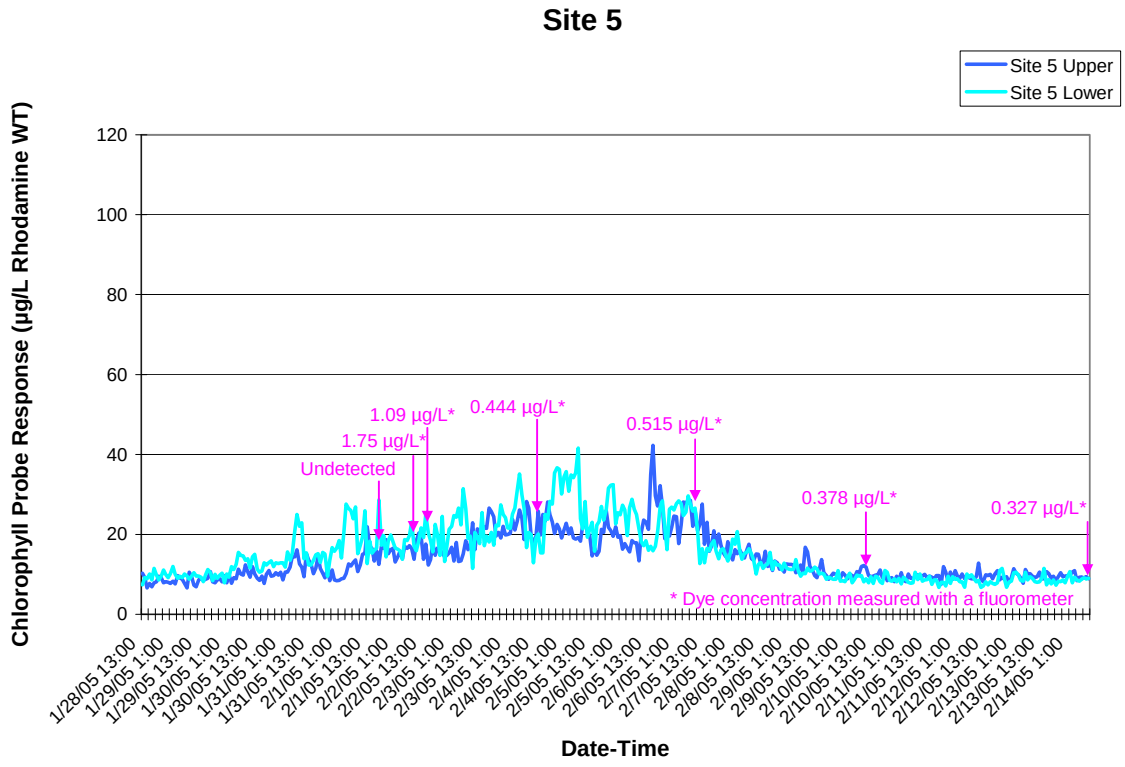


Figure 16. Field Measured Rhodamine WT Concentrations from Site 7.

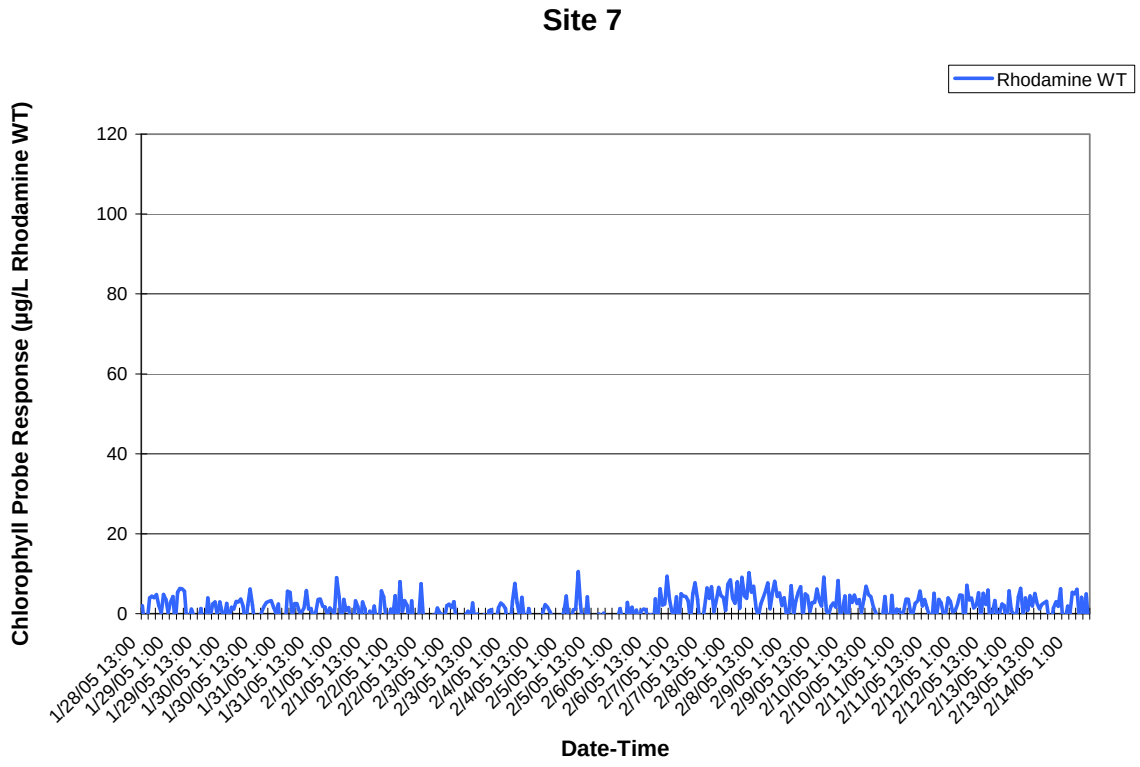


Figure 17. Field and Laboratory Rhodamine WT Concentration Comparisons from Site 14.

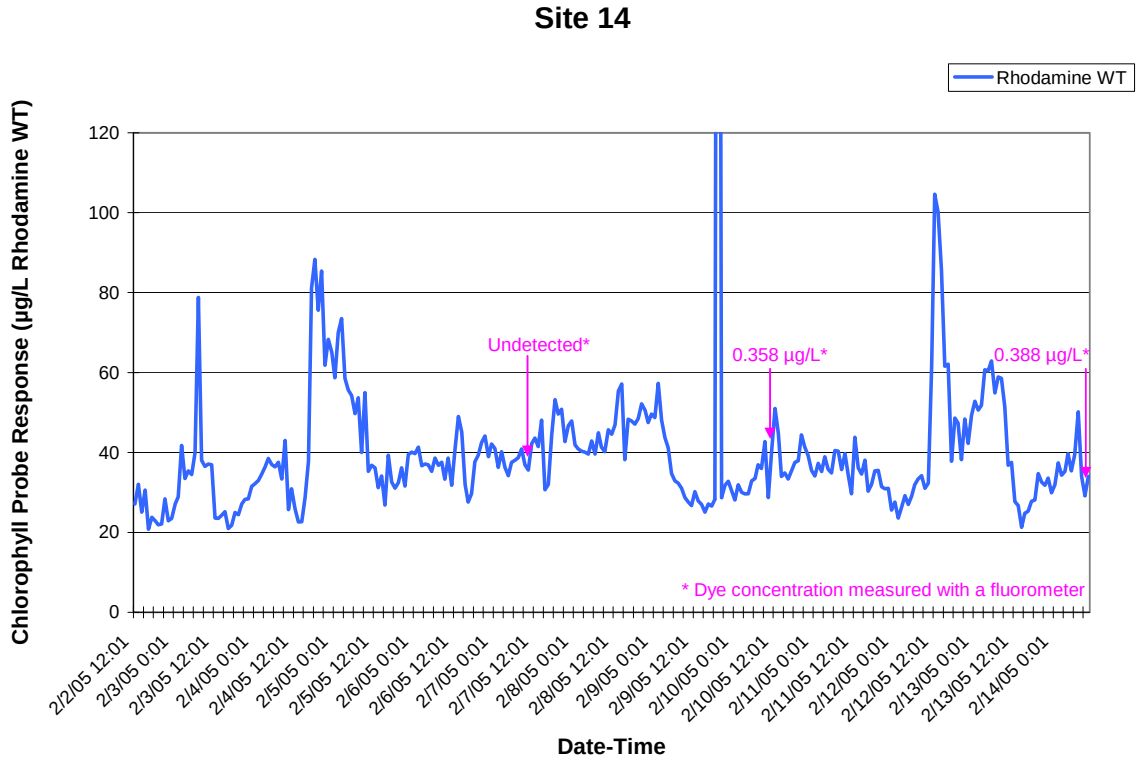


Figure 18. Field and Laboratory Rhodamine WT Concentration Comparisons from Site 16.

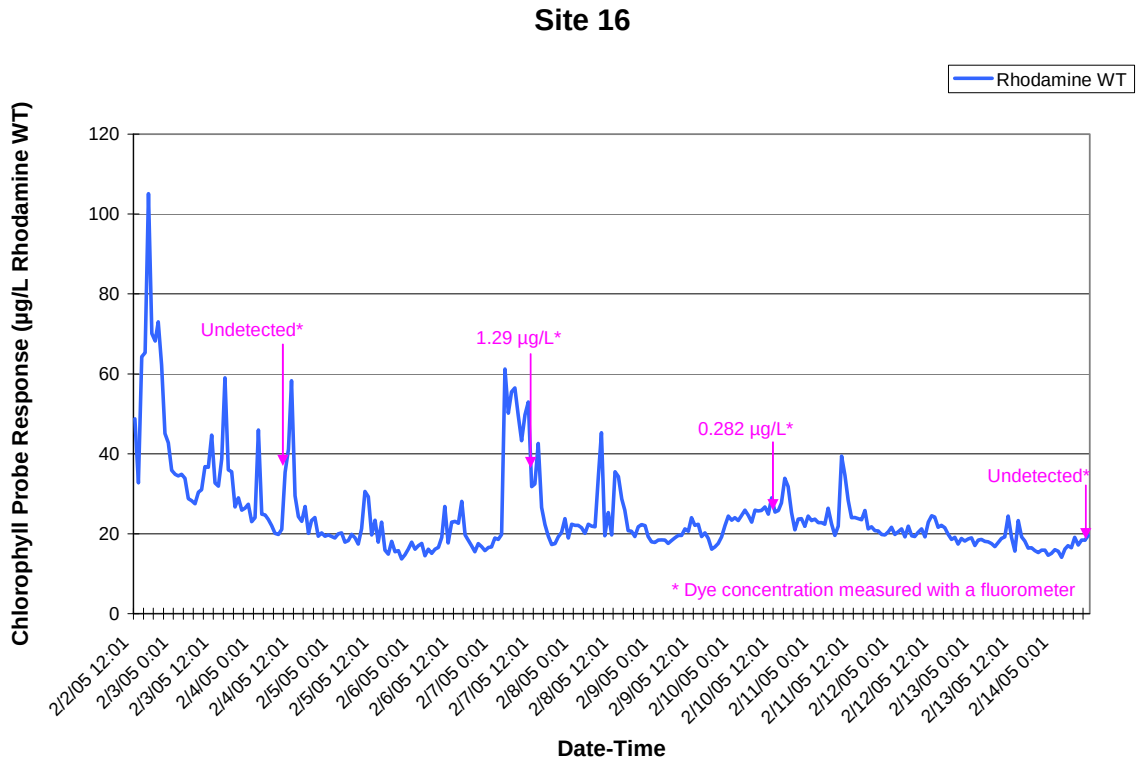


Figure 19. Field Measured Rhodamine WT Concentrations from Site 19.

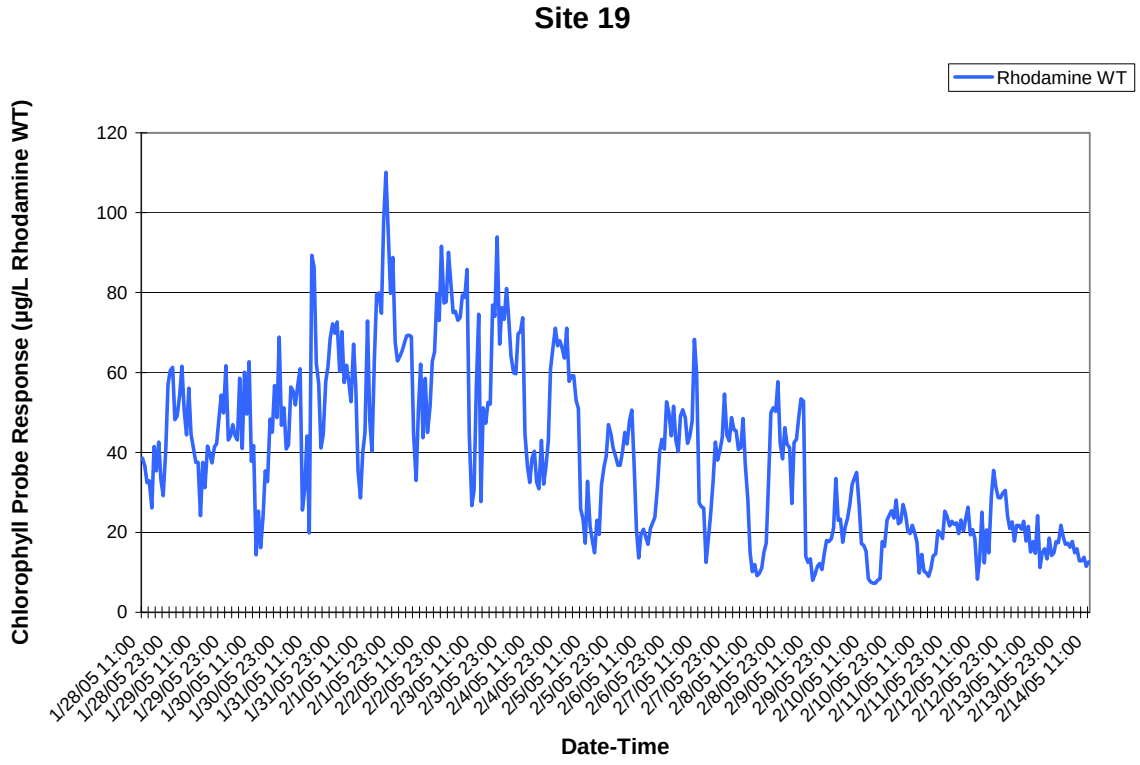


Figure 20. Field and Laboratory Rhodamine WT Concentration Comparisons from Site 31.

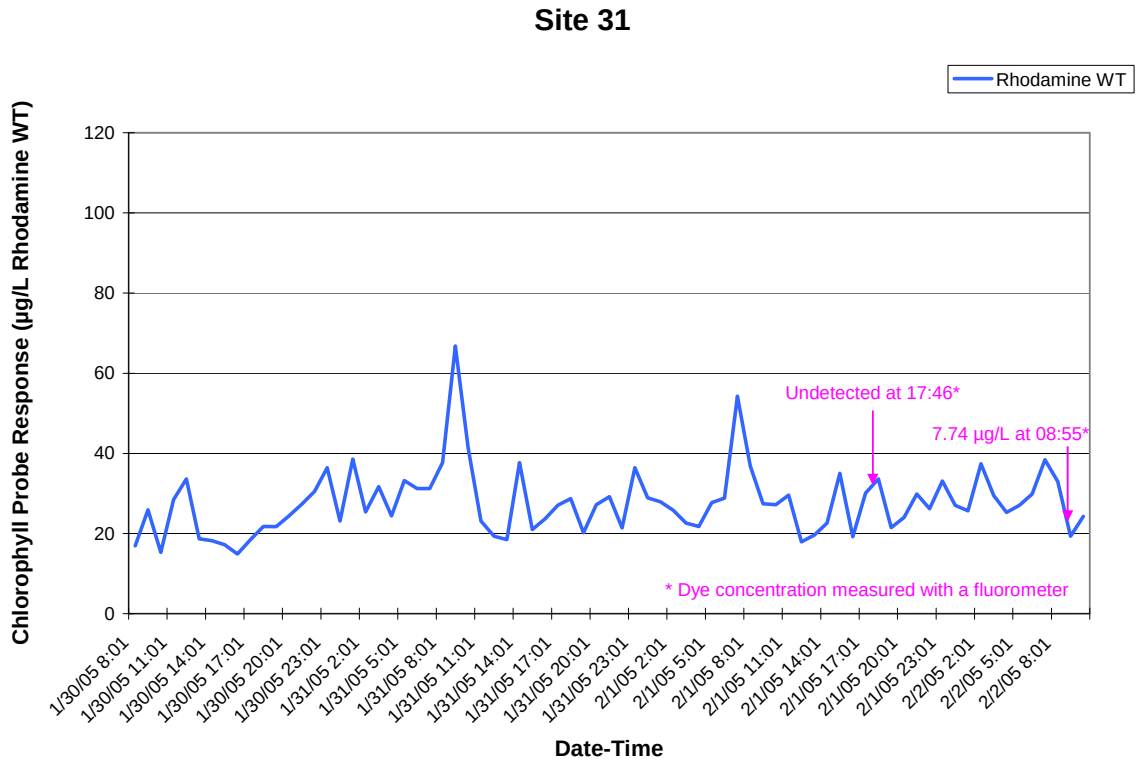


Figure 21. Spring Lake Dye Dispersion, February 1, 2005.

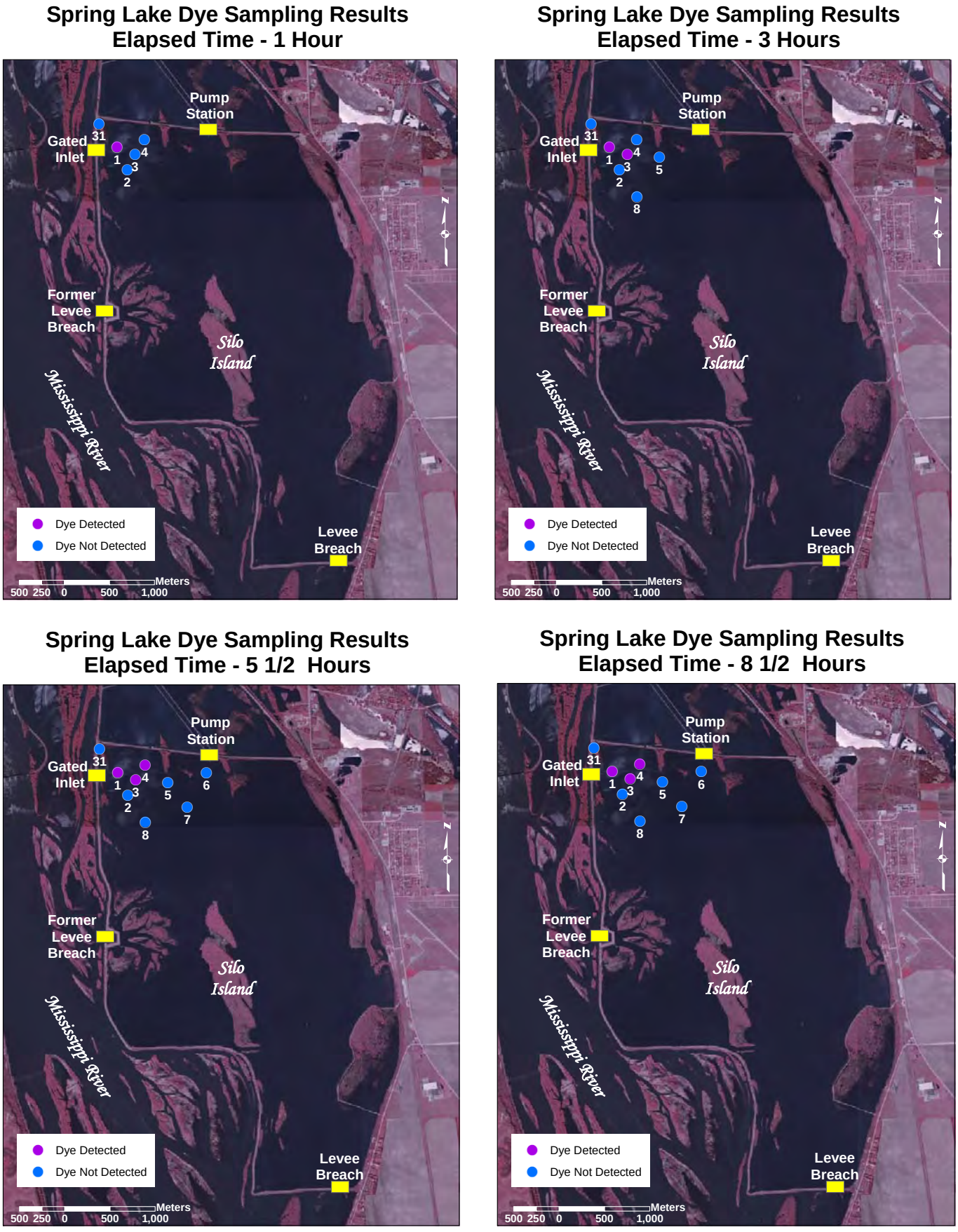


Figure 22. Spring Lake Dye Dispersion, February 2, 4 and 7, 2005.

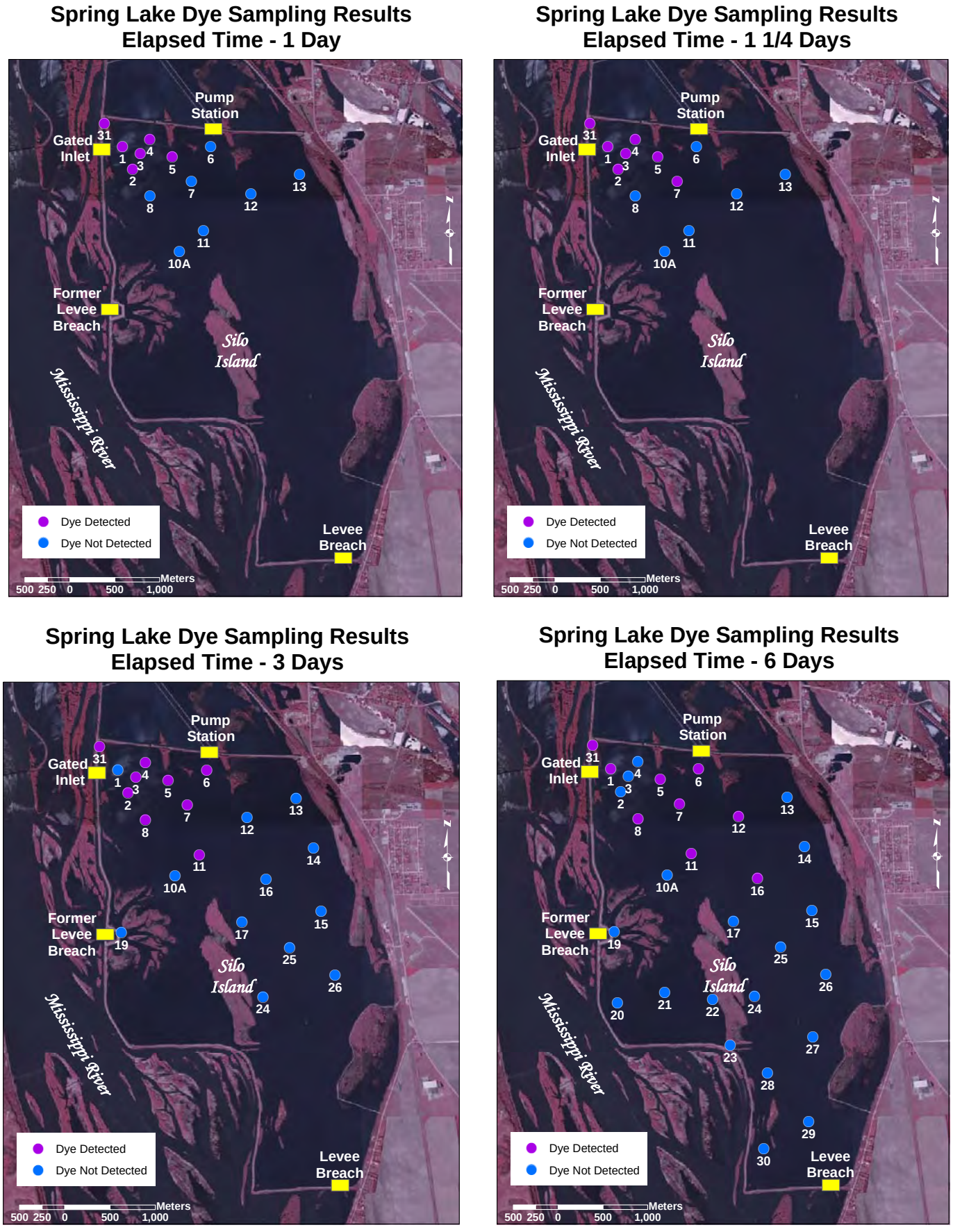
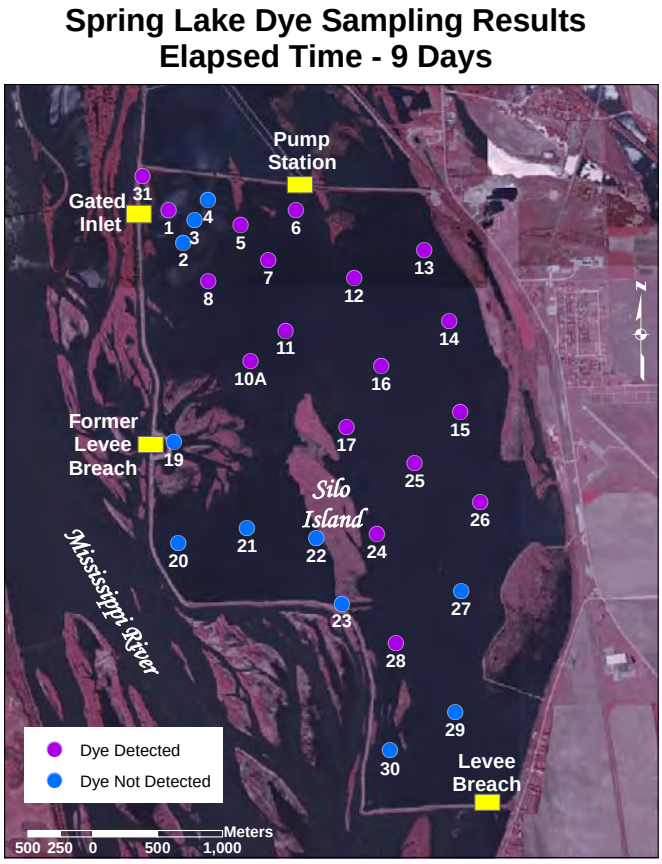
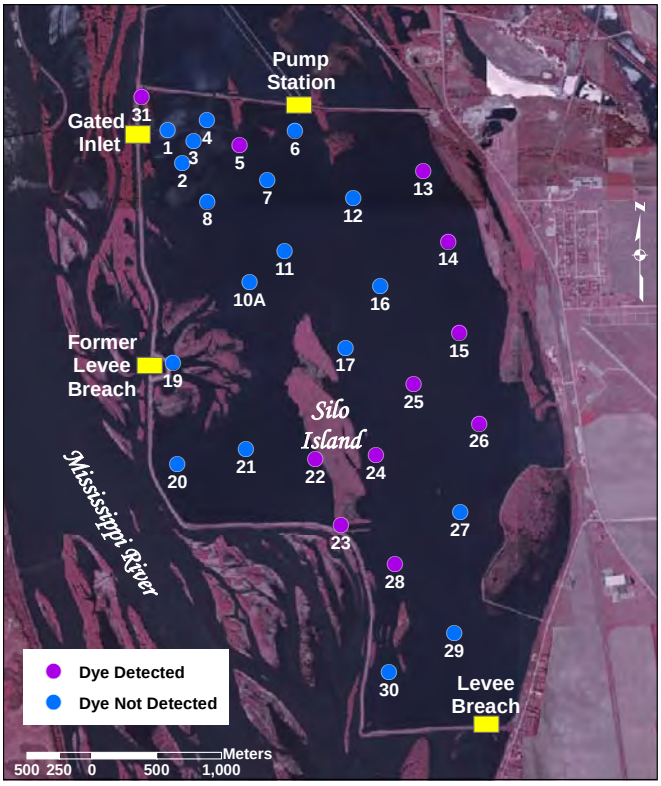


Figure 23. Spring Lake Dye Dispersion, February 10 and 14, 2005 and a Cumulative Map of all Sites where Dye was Detected.





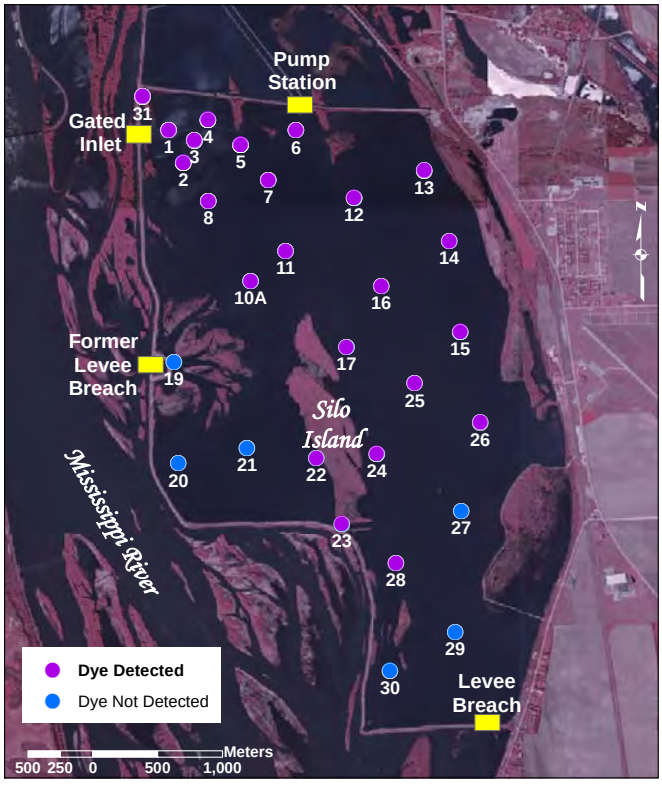


Figure 24. Location of Fish Capture Sites and Movement of Fish 054C, 074C and 084C on Specified Dates in 2005.

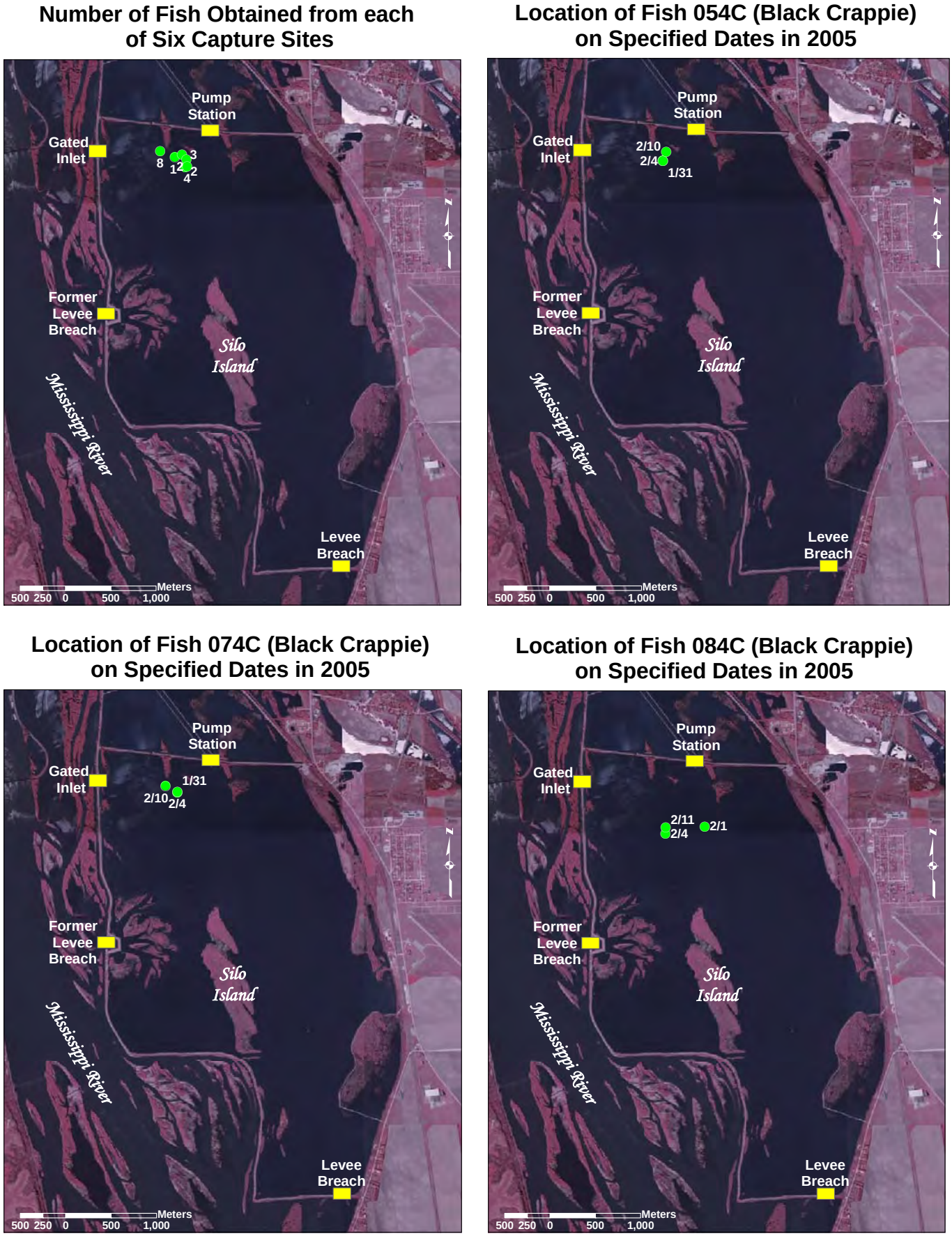


Figure 25. Location of Fish 143C, 154C, 164B and 173C on Specified Dates in 2005.

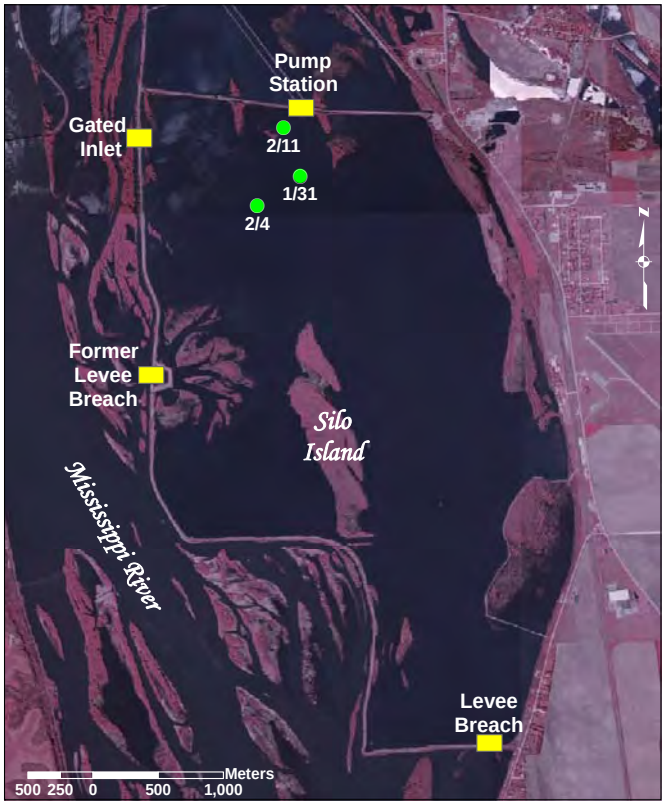
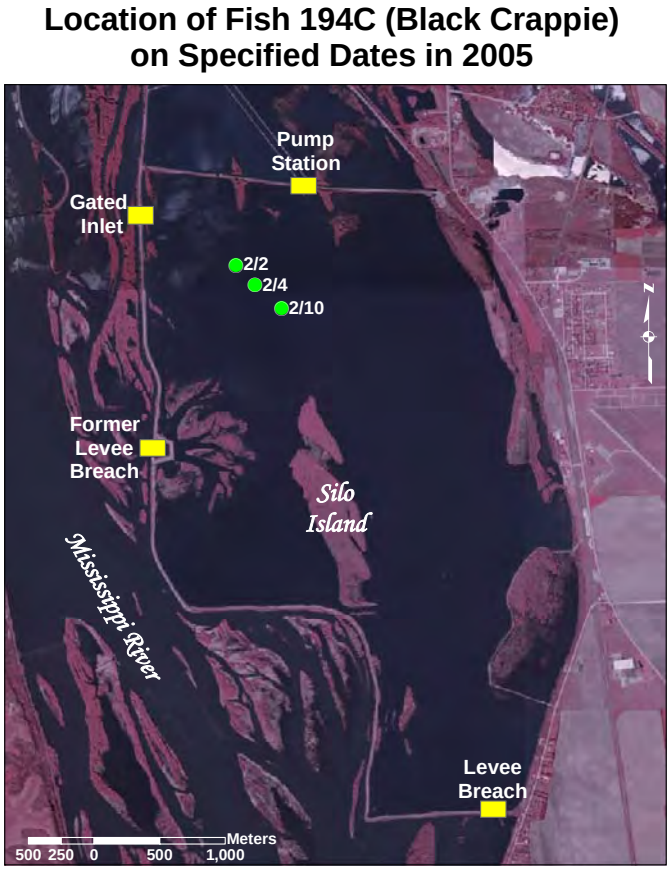


Figure 26. Location of Fish 194C, 210C, 491C and 631C on Specified Dates in 2005.



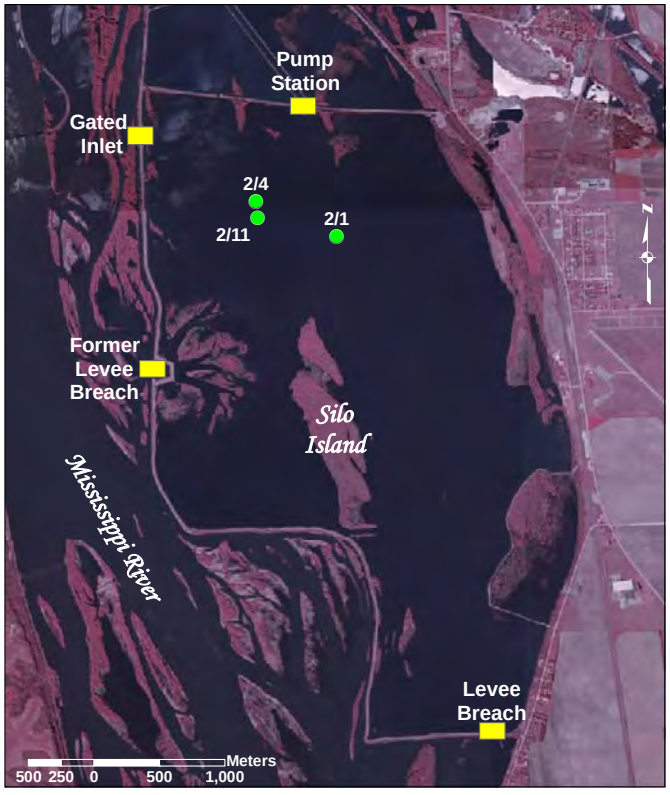
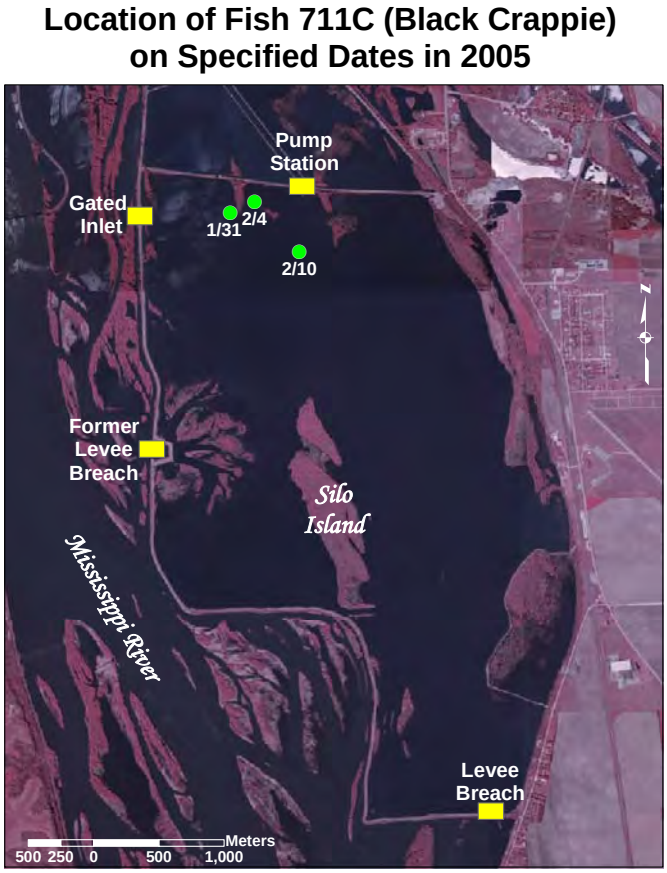
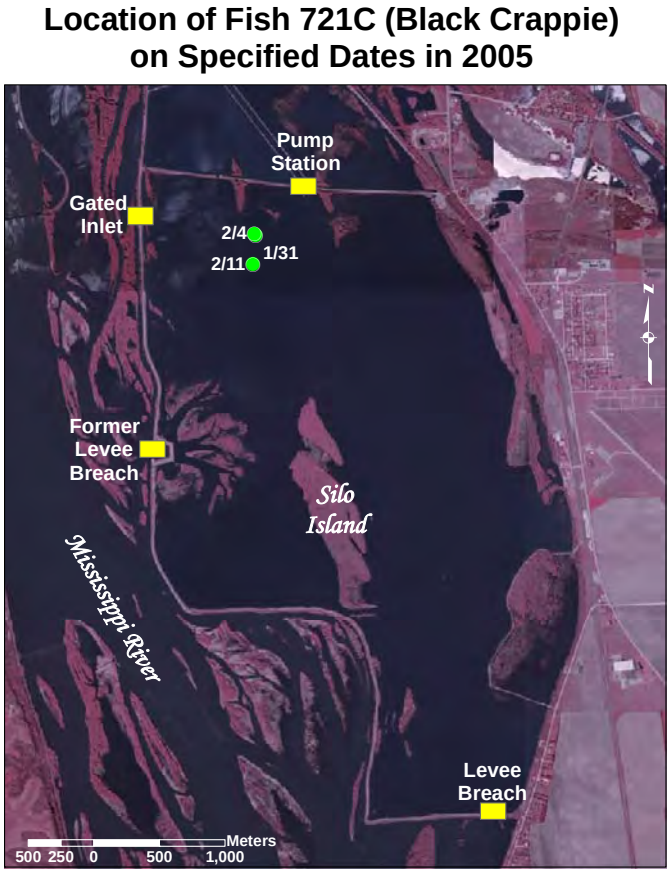


Figure 27. Location of Fish 711C, 721C, 751C and 770C on Specified Dates in 2005.





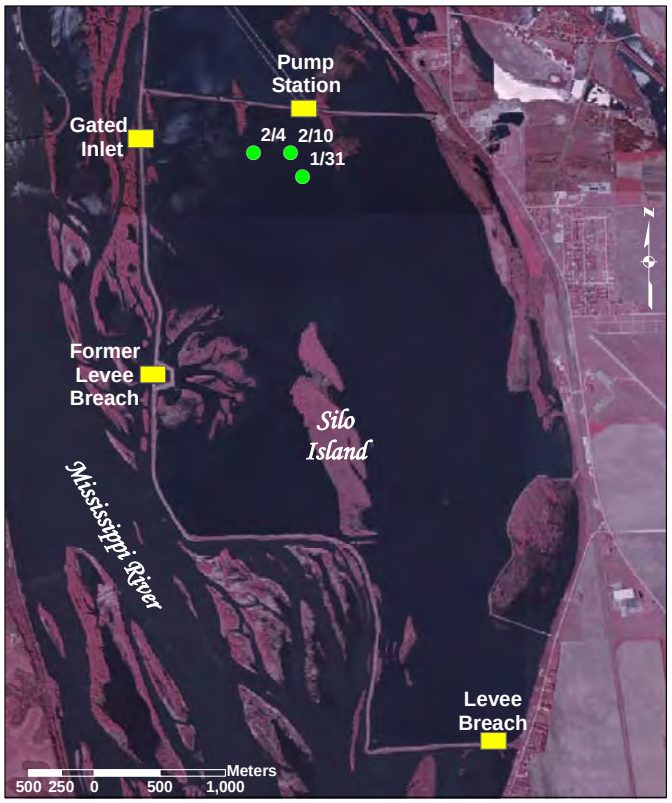


Figure 28. Location of Fish 810C, 831C, 851C and 890C on Specified Dates in 2005.