Test Run Data Collection and Modeling Report

for the

Dissolved Oxygen Facility Environmental Testing

for the

Savannah Harbor Expansion Project

Contract# W912HN-15-D-0023
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EXECUTIVE SUMMARY

As part of the Savannah Harbor Expansion Project (SHEP), dissolved oxygen (DO) injection systems will be needed at two locations (Downriver Site and Upriver Site) on the Savannah River to offset potential decreases in DO due to navigation channel deepening. The Downriver Site, located on Hutchinson Island in Chatham County, Georgia, serves two diffuser sites, one on the Back River and one on the lower Front River. The Upriver Site is located farther upstream on the Savannah River in Effingham County, Georgia. The USACE started operating the Downriver Site in January 2019, while as of August 2019, the Upriver Site is still under construction. The systems will be operated seasonally from June 15 through September 30 during the warmest months of the year when DO concentrations in the river are generally at their lowest.

The purpose of this report is to document the data collection during the Test Run and the resulting oxygen effect (benefit) on the lower Front River and Back River.

The EIS required mitigation of 40,000 lbs/day in total, with the Upriver Site contributing 28,000 lbs/day and the Downriver Site contributing 12,000 lbs/day. The Settlement Agreement required the Test Run to be performed prior to the inner harbor deepening and the Startup Run to be performed after the completion of both sites (Upriver and Downriver) in the summer period. To quantify the oxygen benefit, a “weight of evidence” approach was conducted using both monitoring and modeling of the Savannah River.

The Test Run data collection period was from March 14 through May 12, 2019. The WCTE calculations for the Test Run period showed an average combined WCTE of approximately 98%. During the data collection period, there was no indication of effervescence. Observed data indicated the injected oxygen had at least a 40:1 dilution ratio and was well mixed within the water column.

During the Test Run period, the average operating plant load under normal conditions injected by the Downriver Plant was 13,385 pounds/day with a ± one (1) standard deviation range of 12,682 pounds/day to 14,089 pounds per day. The average load, 13,385 pounds/day, was greater than the required 12,000 pounds/day.

The approved 2015 SHEP Model was extended through December 2017 (2018 SHEP Model). Model results from the 2018 SHEP Model produced verification statistics that were similar to the 2015 SHEP Model calibration statistics. Starting with the 2018 SHEP Model, the 2019 SHEP Model was extended through the Test Run period, and three scenarios were setup using the 2019 SHEP Model to evaluate the DO injection system impact:

- 2019 SHEP Baseline Model: 2019 SHEP Model with the DO injection system turned off
- 2019 SHEP Actual Model: 2019 SHEP Model with the actual 15-min DO loads injected into lower Front River and Back River
- 2019 SHEP EIS Model: 2019 SHEP Model with DO injection system adjusted to match EIS terms; model injected 8,000 lbs/day of DO into lower Front River and 4,000 lbs/day of DO into Back River

The 2019 SHEP Model scenarios were evaluated utilizing different ways including direct time series, longitudinal profiles, and zonal analysis. Results from the scenarios indicated that the during the Test Run period, on average, the DO injection system produced an increase in DO concentrations by 0.1 mg/L to 0.3 mg/L.

Based on an analysis of both measured data and modeling results, the conclusion is that Downriver DO injection system operated as expected during the Test Run period.

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ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
BGA	Phycoerythin blue-green algae
CBOD	Carbonaceous biochemical oxygen demand
CBODU	Ultimate carbonaceous biochemical oxygen demand
DO	Dissolved oxygen
EFDC	Environmental Fluid Dynamic Code
Excel	Microsoft Excel
GaEPD	Georgia Environmental Protection Division
GPS	Geospatial positioning system
IA	Index of agreement
ID	Identification
MAE	Mean absolute errors
NH3	Ammonia
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OneDrive	Microsoft OneDrive
PCode	Parameter code
Plant	DO Injection Facility
PSU	Practical salinity unit
PVC	Polyvinyl chloride
SHEP	Savannah Harbor Expansion Project
SPCOND	Specific conductivity
QA/QC	Quality assurance/quality control
RCode	Remark code
RFU	Relative fluorescence units
RMSE	Root mean square error
TMDL	Total maximum daily load
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WASP	Water Quality Analysis Simulation Program
WCTE	Water Column Transfer Efficiency
WRDB	Water Resources Database

1.0 INTRODUCTION

As part of the Savannah Harbor Expansion Project (SHEP), dissolved oxygen (DO) injection systems will be needed at two locations (Downriver Site and Upriver Site) on the Savannah River to offset potential decreases in DO due to navigation channel deepening (***Figure 1-1***). The Downriver Site, located on Hutchinson Island in Chatham County, Georgia, serves two diffuser sites, one on the Back River and one on the lower Front River. The Upriver Site is located farther upstream on the Savannah River in Effingham County, Georgia. Together these systems are designed to deliver 40,000 lbs (28,000 lbs from the Upriver Site and 12,000 lbs from the Downriver Site) of DO per day to the Savannah River harbor and estuary. The USACE started operating the Downriver Site in January 2019, while as of August 2019, the Upriver Site is still under construction. The systems will be operated seasonally from June 15 through September 30 during the warmest months of the year when DO concentrations in the river are generally at their lowest.

The DO injection systems withdraw river water from the Savannah River, super-oxygenate the water, and then return the super-saturated water to the river. To super-oxygenate the water, high-purity oxygen gas generated on-site and injected into the river water using “Speece” cones, named after the inventor. This super-saturated water will mix with the ambient river water and result in elevated DO levels.

The purpose of these DO injection systems is to mitigate for the impacts due to harbor deepening. Since the requirement for the DO system is not to achieve a specific DO concentration level, demonstrating success will not be simple. The Settlement Agreement defines success as the DO systems performing as they are intended. Success will therefore require a combination of monitoring and modeling efforts, or in other words, multiple lines of evidence.

The objective of the Test Run data collection effort was to determine how well the injected oxygen was distributed throughout the estuary and if the DO system performed as intended. The Test Run data collection was performed from March 14, 2019 through May 12, 2019 around the Downriver Site diffuser sites on the Back River and the lower Front River. In addition to the data collected near the diffuser sites, flow and water quality data from United States Geological Survey (USGS) stations located upstream and downstream of the diffuser sites and United States Army Corps of Engineers (USACE) DO injection facility (Plant) data, which provided information on the operation of the Plant, were used for the analysis.

Data that were collected during the Test Run period were used to calculate the Water Column Transfer Efficiency (WCTE), or what percentage of oxygen injected remained in the river. DO is lost to the atmosphere from the river system when ambient DO levels were above 100% saturation (super-saturated). The WCTE approach was a site-specific approach and based on data collected in the lower Front River and the Back River. The procedure used to calculate the WCTE is presented in the WCTE Report (LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2019b).

The purpose of the Test Run modeling was to extend the 2015 SHEP Environmental Fluid Dynamics Code (EFDC) and the Water Quality Analysis Simulation Program (WASP) models (2015 SHEP Model) and utilize them in evaluating the Down River DO injection system (Tetra Tech, Inc., 2015). The 2015 SHEP Model, which simulated hydrodynamic and water quality conditions from January 1, 1997 through April 30, 2014, was calibrated to measured USGS data and reviewed and approved by the USACE. The model boundary conditions and bathymetric data were updated and extended to simulate the January 1, 2014 through December 31, 2017 period (2018 SHEP Model) and January 1, 2018 through June 30, 2019 period (2019 SHEP Model). The 2018 and 2019 SHEP Models were compared to measured data to confirm that they performed similarly to the 2015 SHEP Model. Several scenarios were developed using the 2019 SHEP Model to evaluate the DO injection system performance in the far-field, specifically how much the water column DO concentrations were increased in the lower Front River and Back River. The SHEP model will be extended in 2020 to simulate conditions during the Startup Run.

The data and model results from the Test Run were used to inform the Water Column Transfer Efficiency (WCTE) in order to determine if the systems performed as intended and delivered the required oxygen load to the river

(LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2019b). The WCTE was determined by measuring the amount of oxygen supplied from the Speece Cone System and comparing it to the DO that remained in the Savannah River or Estuary water column. An oxygen sensor and flow measuring device were installed on each Speece Cone discharge pipe to provide flow and oxygen measurements of the super-saturated water. The oxygen and flow sensors (Greyline Doppler Flow Meter) were hard-wired into the DO injection systems infrastructure by the construction contractor CDM and measure DO and flow within the DO injection system as Plant data. It was expected that the flow and oxygen discharging through the diffusers would completely mix with the ambient water; however, factors such as the occurrence of effervescence and/or a plume of super-saturated water reaching the surface could occur, both of which would allow oxygen to leave the water column and reduce the WCTE.

The Test Run data collection and modeling report were Tasks 07 and 08 of the contract between LG^2 Environmental Solutions, their sub consultant Tetra Tech, and the USACE Savannah District. Test Run data collection and quality assurance/quality control (QA/QC) followed the methodology documented in Appendix A and Appendix B of the *Work Plan* for *Dissolved Oxygen Facility Environmental Testing for the Savannah Harbor Expansion Project* (LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2019c). This report discusses the data collection procedures used by the field team for the Test Run data collection period, data QA/QC evaluations conducted by the QA/QC team on the Test Run data, the WCTE calculation results, and a summary of the hydrodynamic and water quality modeling done to evaluate the performance of the dissolved oxygen injection system at the Downriver Site.

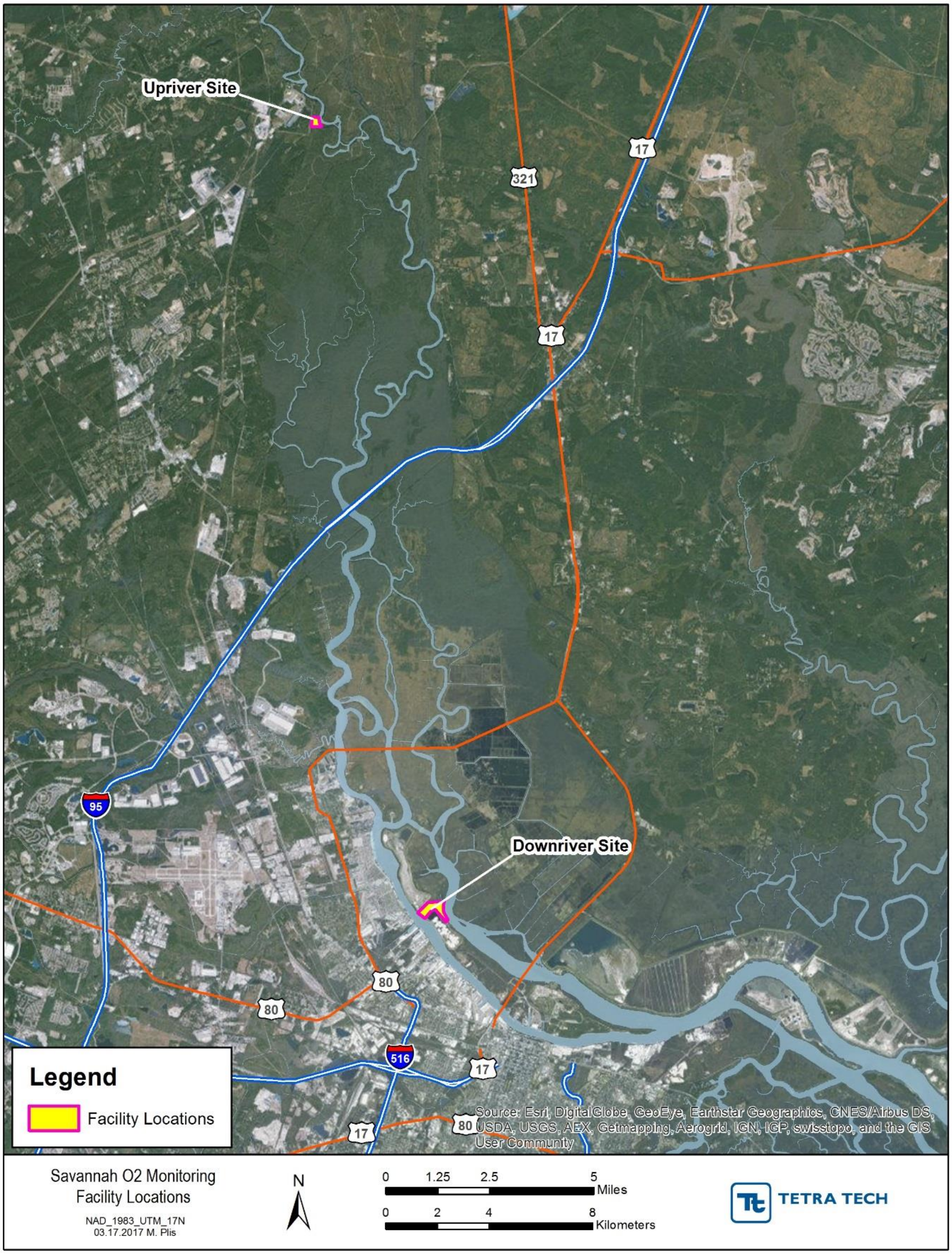


Figure 1-1 Dissolved oxygen injection facility locations

2.0 DATA COLLECTION PROCEDURES

The Test Run data collection effort consisted of four major data collection efforts which combined, provides a comprehensive description of how the lower Front River and Back River injected oxygen impacts the rivers' DO regime. These four efforts were:

- Platform data collection to gather continuous data around the Back River DO plume and at various depths.
- Semi-permanent buoys data collection to gather continuous lower Front River and Back River data upstream and downstream of the diffusers after the plume reached the surface.
- Profile and drift data collection to gather data approximately one hour before and after slack tides to show how the DO was mixed into the lower Front River and Back River systems and how it travels up and downstream.
- Dye studies to determine the diffuser dilution rates (at least 40:1) and how the DO plume traveled upstream and downstream.

Data collection procedures for the Test Run period followed the data collection procedures that were validated during the Background Data collection effort and were similar to the procedures used during the Water Column Transfer Efficiency (WCTE) study. The data collection effort provided the data necessary for the project to track and monitor the general movement and trends of the oxygen plume.

All data sondes and associated sonde sensors were prepared and calibrated in accordance with manufacturer's specifications by field team scientists trained by the manufacturer's technicians after having completed training classes. Periodically scientists were supported during the Test Run data collection task by the manufacturer's onsite field engineer. Preparation and maintenance of the data sondes were performed at the laboratory/work space provided by the USACE at the Army Corps Depot facility located on the east bank of the Savannah River on Hutchinson Island. The data sondes, according to manufacture specifications, are capable of accurately collecting data at a frequency of 1-seconds intervals.

2.1 PLATFORM MONITORING / DATA COLLECTION

A data sonde platform was deployed on the Back River from which sixteen (16) data sondes were installed and set to continuously monitor water quality conditions above the Back River diffuser pipe. The data sonde platform was fitted with three (3) (polyvinyl chloride) PVC down pipes on all four (4) corners of the platform set at fixed predetermined depths (surface, mid-depth, and bottom of water column). The data sondes were deployed in the PVC down pipes. Additional data sondes were placed in PVC down pipes located on the sides of the platform to monitor water quality constituents at variable depths in the water column between the corner fixed depth locations. Data from the platform-mounted sondes were collected from a central data logger installed on the platform and transmitted via cellular phone modem to a data management website. The platform-mounted sondes provided continuous data collected for the entire data collection event. ***Figure 2-1*** shows the location of the platform on the Back River. Additional information detailing the platform construction and deployment are located in the Background Data Collection Report (LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2019a).

The data sondes were delivered to the platform by the field team via project boats on March 13, 2019 during preparation for the Test Run data collection and were removed from service after completion of the Test Run data collection. The data sondes were set to recorded water quality measurements at 5-minute intervals for DO, DO saturation, salinity, conductivity, water temperature, and depth along with the date and time of each measurement. Several data sondes were outfitted with sensors to detect algae [phycoerythin blue-green algae (BGA) and chlorophyll *a*] in real-time through the in-vivo fluorometry technique. This method directly detected the fluorescence of specific pigments in living algal cells and determines relative algal biomass of BGA and chlorophyll *a*. The BGA pigment does not receive interference from chlorophyll a or turbidity. The BGA sensors were used to detect Rhodamine dye injected into the DO system pipes during planned dye injection events.

Data collected from platform sondes were transmitted to the data management website and retrieved using a proprietary data management software package and website (Xylem Eagle I/O). The field team viewed data recorded and transmitted to this website, which generated “dashboards” for the data sondes that displayed graphs and charts of the raw data. The visual aids allowed tracking of sonde performance and initiated team work between the field team and the QA/QC team to rectify any issues noted during data collection. ***Figure 2-2*** provides examples of the depth and DO timeseries data collected by the cluster of sondes located on the northeast corner of the platform for the Test Run study period.

The data sonde calibration intervals were determined by the manufacturer but could differ from typical recommendations depending on lengths of deployment, site conditions, and any anomalies interpreted from visual aids used to routinely review data (**APPENDIX K**). In cases where the visual review of data indicated that there was data drift or other potential data issues, the entire sonde would be replaced with a backup data sonde, and the particular sensor would be recalibrated according to the manufacturer’s specifications.

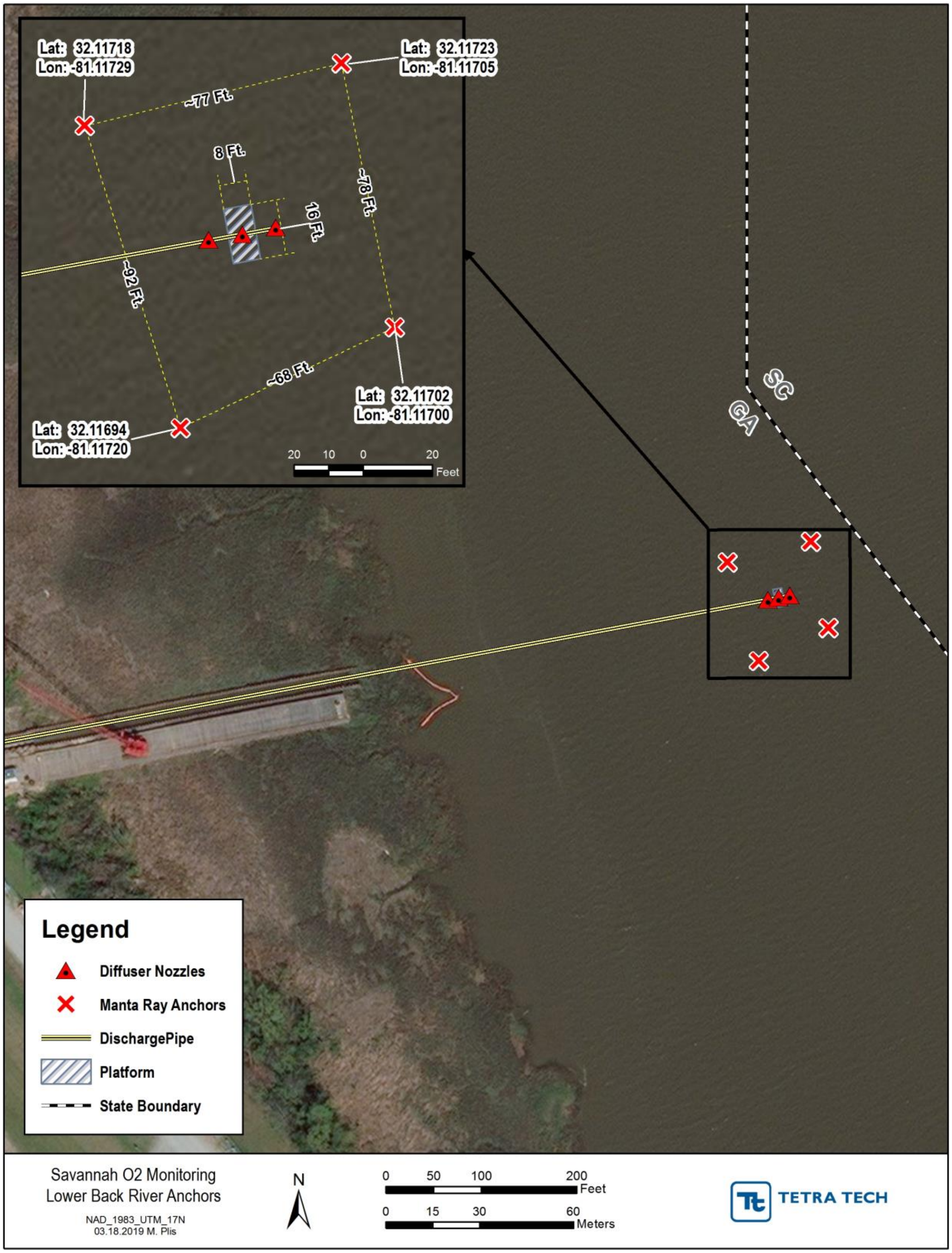


Figure 2-1 Location of platform on the Back River

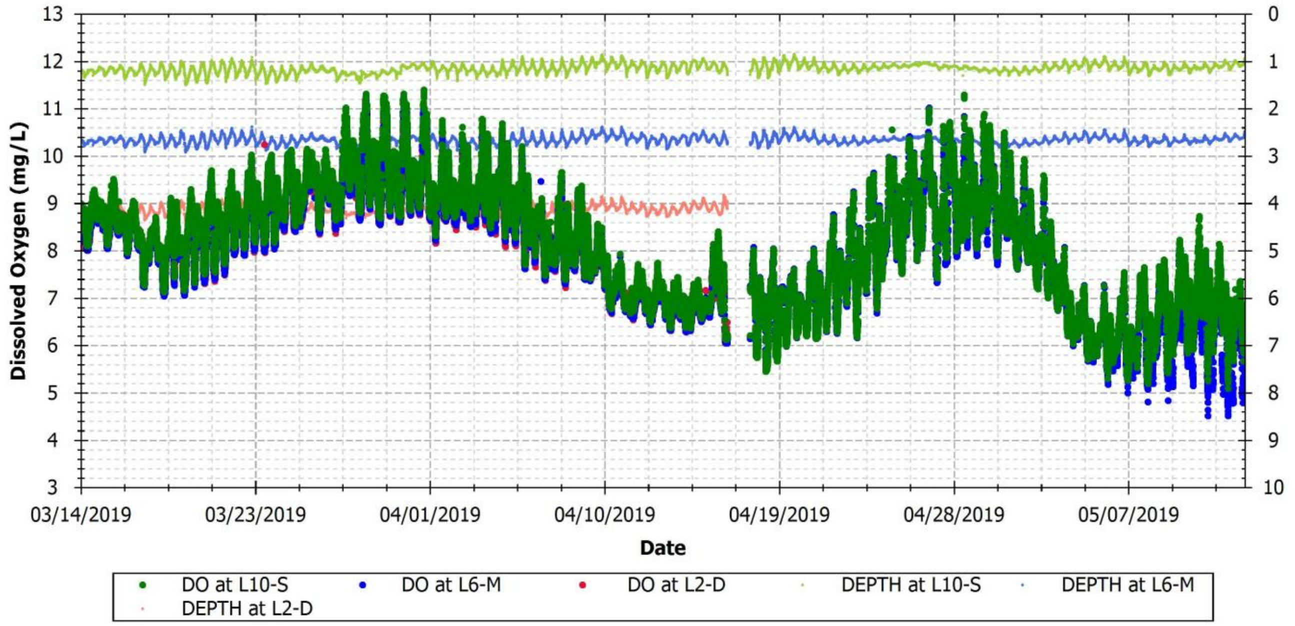


Figure 2-2 Back River northeast corner observed depth and DO

2.2 SEMI-PERMANENT BUOY MONITORING / DATA COLLECTION

Semi-permanent buoy data sondes were designed to be tethered in one (1) location and continuously collect and record data. The exact position of each individual semi-permanent buoy sonde was determined initially by near-field modeling for the Background Data collection period and were not moved for the Test Run data collection. Four (4) semi-permanent buoy sondes were installed near the water surface at four (4) separate locations around the Back River platform (***Figure 2-3***) to provide sentinel data outside the focused footprint of the fixed platform. During the Background Data Collection period only two (2) semi-permanent buoy sondes were installed on the Front River, however, a third semi-permanent buoy was added upstream of the north buoy during the Test Run Data Collection. The third buoy was added based on direction and orientation of the plume observed during the dye studies conducted during the Background Data Collection on the lower Front River. The three (3) semi-permanent buoy sondes installed upstream and downstream from the lower Front River diffuser pipe and diffusers, located outside of the navigational channel to avoid boat strikes, were used to provide constant sentinel data (***Figure 2-4***). Additional information detailing the buoy construction and deployment are located in the *Background Data Collection Report* (LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2019a).

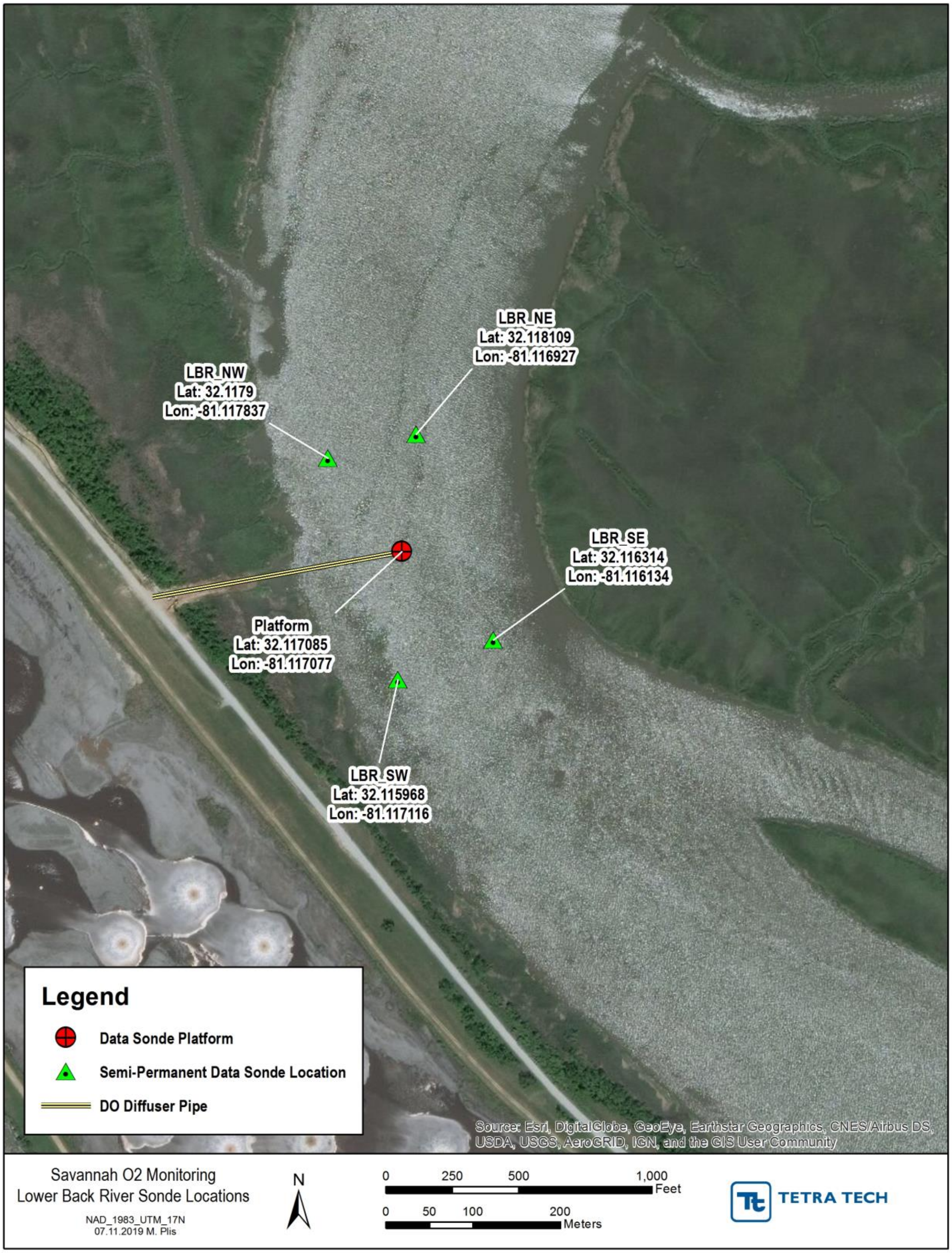


Figure 2-3 Location of semi-permanent buoys on the Back River

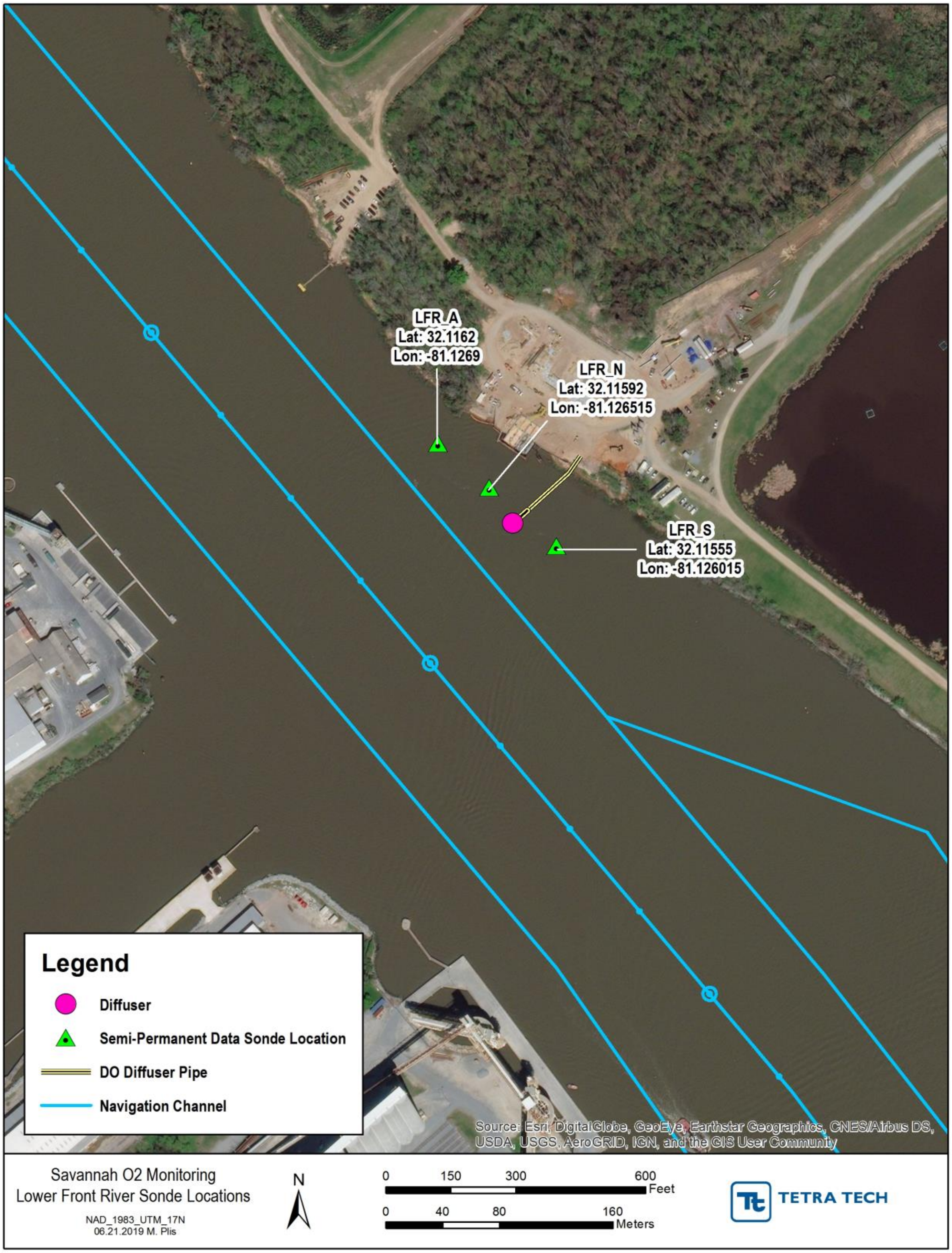


Figure 2-4 Location of semi-permanent buoys on the lower Front River

The data sondes were delivered to the semi-permanent buoys by the field team via project boats on March 13, 2019 during preparation for the Test Run data collection and were removed after completion of the Test Run data collection. The data sondes were set to recorded water quality measurements at 5-minute intervals for DO, DO saturation, salinity, conductivity, water temperature, and depth along with the date and time of each measurement. Several data sondes were outfitted with sensors to detect BGA and chlorophyll *a* in real-time through the in-vivo fluorometry technique.

The data stored were stored on each sonde's on board data logger and were downloaded frequently, approximately every three (3) days of deployment. The downloaded data, including geospatial positioning system (GPS) locations, were transferred to the QA/QC team, following the QA/QC procedures in Appendix B of the Work Plan. ***Figure 2-5*** provides an example of the depth and DO timeseries data collected by the Back River northeast buoy sonde and ***Figure 2-6*** provides an example of the depth and DO timeseries data collected by the lower Front River north buoy sonde.

The data sonde calibration intervals were determined by the manufacturer but could differ from typical recommendations depending on lengths of deployment, site conditions, and any anomalies interpreted from visual aids used to routinely review data (**APPENDIX K**). In cases where the visual review of data indicated that there was data drift or other potential data issues, the entire sonde would be replaced with a backup data sonde, and the particular sensor would be recalibrated according to the manufacturer's specifications.

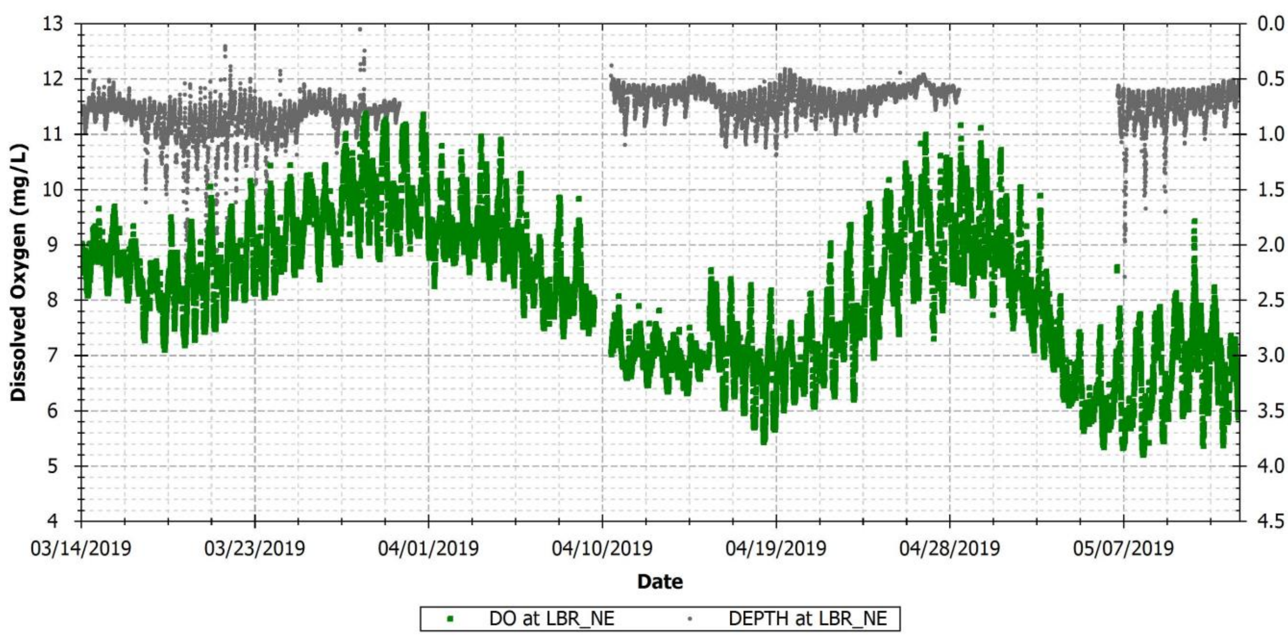


Figure 2-5 Back River northeast observed depth and DO

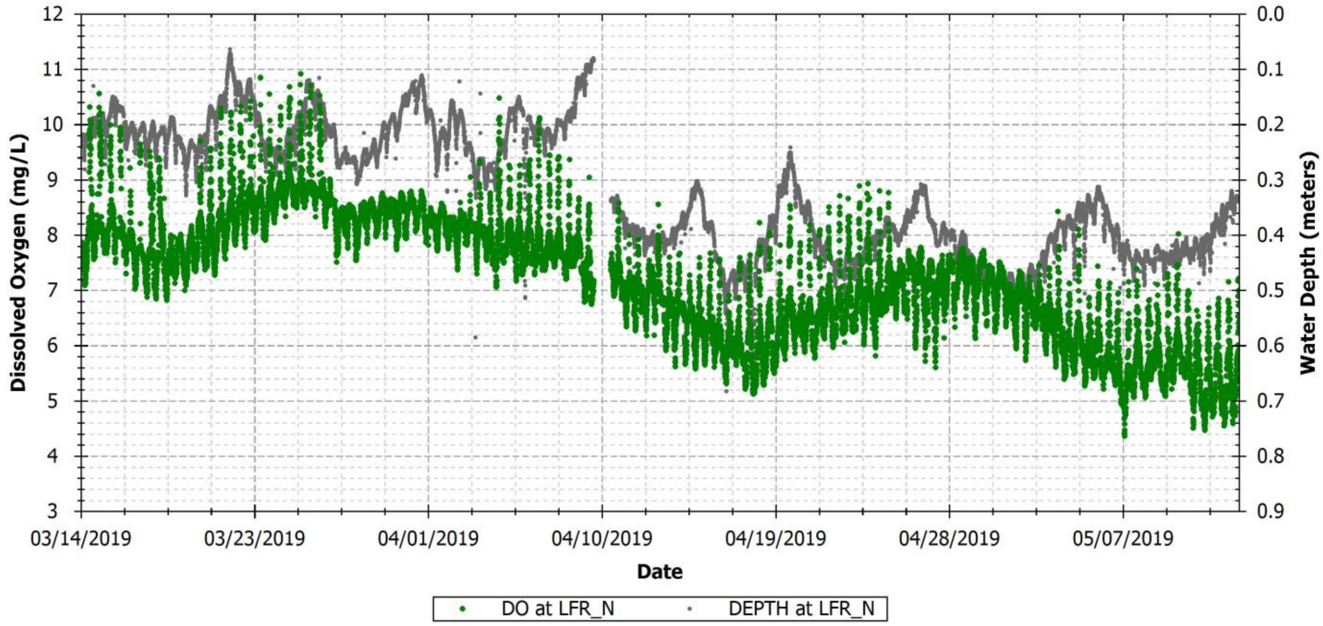


Figure 2-6 Lower Front River north observed depth and DO

2.3 PROFILE AND DRIFT DATA COLLECTION SCHEDULE

A data collection schedule was prepared prior to commencing the Test Run data collection that identified the dates, tidal conditions, and type of boat data collection that would occur on each river. This ensured that the study did not target specific conditions to meet a pre-determined conclusion. The data collection schedule conducted by the field team for the Test Run data collection is presented in ***Table 2-1***.

Table 2-1 Test Run data collection schedule

Date	Time[1]	Day	Tide	Back River			Lower Front River		
				Profile	Drift	Dye	Profile	Drift	Dye
3/14/2019	9:29	Thu	Low	●			●		
3/14/2019	15:08	Thu	High	●			●		
3/15/2019	10:35	Fri	Low		●			●	
3/16/2019	11:40	Sat	Low	●					
3/16/2019	17:33	Sat	High	●					
3/17/2019	12:41	Sun	Low				●		
3/18/2019	13:38	Mon	Low		●			●	
3/19/2019	8:16	Tue	High	●			●		
3/19/2019	14:30	Tue	Low	●			●		
3/20/2019	9:08	Wed	High					●	
3/20/2019	15:20	Wed	Low		●			●	

Date	Time[1]	Day	Tide	Back River			Lower Front River		
				Profile	Drift	Dye	Profile	Drift	Dye
3/21/2019	9:58	Thu	High	●			●		
3/21/2019	16:08	Thu	Low	●			●		
3/22/2019	10:46	Fri	High		●			●	
3/22/2019	16:55	Fri	Low						
3/23/2019	11:33	Sat	High	●					
3/24/2019	12:20	Sun	High				●		
3/25/2019	13:07	Mon	High		●			●	
3/26/2019	7:54	Tue	Low	●			●		
3/26/2019	13:57	Tue	High	●			●		
3/27/2019	8:48	Wed	Low		●			●	
3/27/2019	14:53	Wed	High		●			●	
3/28/2019	9:45	Thu	Low	●			●		
3/28/2019	15:59	Thu	High	●			●		
3/29/2019	10:43	Fri	Low		●	●			
3/30/2019	11:38	Sat	Low	●					
3/31/2019	12:29	Sun	Low				●		
4/1/2019	13:16	Mon	Low		●			●	
4/2/2019	13:59	Tue	Low	●			●		
4/3/2019	14:41	Wed	Low		●			●	
4/4/2019	9:13	Thu	High	●			●		
4/4/2019	15:20	Thu	Low	●			●		
4/5/2019	9:44	Fri	High		●			●	
4/6/2019	10:16	Sat	High	●					
4/7/2019	10:50	Sun	High				●		
4/8/2019	11:27	Mon	High		●			●	
4/9/2019	12:09	Tue	High	●			●		
4/10/2019	12:57	Wed	High		●			●	
4/11/2019	8:11	Thu	Low					●	●
4/12/2019	9:11	Fri	Low		●	●			
4/13/2019	10:15	Sat	Low	●					
4/14/2019	11:19	Sun	Low				●		
4/15/2019	12:18	Mon	Low		●				
4/17/2019	14:05	Wed	Low		●			●	
4/18/2019	8:47	Thu	High	●			●		

Date	Time[1]	Day	Tide	Back River			Lower Front River		
				Profile	Drift	Dye	Profile	Drift	Dye
4/18/2019	14:55	Thu	Low	●			●		
4/19/2019	9:35	Fri	High		●			●	
4/20/2019	10:22	Sat	High	●					
4/21/2019	11:07	Sun	High				●		
4/22/2019	11:52	Mon	High		●			●	
4/23/2019	12:37	Tue	High		●	●			
4/24/2019	13:24	Wed	High					●	●
4/25/2019	8:15	Thu	Low		●	●		●	
4/25/2019	14:15	Thu	High		●			●	
4/26/2019	9:08	Fri	Low		●				
4/26/2019	15:17	Fri	High					●	
4/27/2019	10:03	Sat	Low		●				
4/27/2019	16:23	Sat	High		●				
4/28/2019	10:57	Sun	Low	●					
4/29/2019	11:47	Mon	Low		●			●	
4/30/2019	12:35	Tue	Low	●			●		
5/1/2019	13:20	Wed	Low		●			●	
5/2/2019	14:03	Thu	Low	●			●		
5/3/2019	8:34	Fri	High		●			●	
5/4/2019	9:09	Sat	High	●					
5/5/2019	9:47	Sun	High				●		
5/6/2019	10:26	Mon	High		●			●	
5/6/2019	16:48	Mon	Low		●				
5/7/2019	11:08	Tue	High	●			●		
5/7/2019	17:33	Tue	Low				●		
5/8/2019	11:55	Wed	High					●	●
5/9/2019	12:48	Thu	High				●		
5/10/2019	13:47	Fri	High		●			●	
5/11/2019	14:53	Sat	High	●					
5/12/2019	9:57	Sun	Low	●					

[1] Tide predictions for NOAA Tide Predictions (Port Wentworth Bull Street Average)

2.4 PROFILE MONITORING / DATA COLLECTION

Profiling was conducted by the field team via project boats. Each data sonde recorded DO, DO saturation, salinity, specific conductivity, water temperature, BGA and chlorophyll *a*, along with the date, time, depth, and GPS locations of each measurement. The recording of measurements was performed using a hand-held device connected to the data sonde by a communication cable allowing “real-time” viewing of information logged by the data sondes. Profiling data was recorded at a frequency of two (2) seconds.

Profiling consisted of deploying a data sonde over the side of a project boat and lowering and raising it through the water column. Profiling data were collected in three different ways; (1) stationary profiles, (2) traveling profiles, and (3) combination profiles. Stationary profiles were collected in a static location (i.e. at each buoy and on the eastern and western sides of the platform) where the sonde was (1) held at the surface for approximately thirty (30) seconds to allow time for the sonde to stabilize when moving from air to water, (2) lowered slowly to bottom at a maximum rate of one (1) foot per second, and (3) slowly raised surface at a maximum rate of one (1) foot per second. Data collection was started and stopped at the beginning and end of each static profile thereby creating one data file for each static profile (file was minutes in length). Traveling profiles were collected with spatial, depth and temporal variability inside and outside of the plume. The project boat either drifted or motored in various ways around, through or within the DO plume while sometimes keeping the sonde at a static depth and other times conducting water column profiling. Data collection was started and stopped at the beginning and end of each traveling profile thereby creating one continuous data file for that traveling profile (files were typically hours in length). Combination profiles were collected with two sondes with spatial, depth, and temporal variability inside and outside of the plume. The project boat either drifted or motored in various ways around, through or within the plume while conducting water column profiling with one sonde and keeping the other sonde at a static deep depth within the water column.

For combination profiling the recording of measurements was performed in two ways (1) in real-time mode by using a hand-held device connected to one (1) of the data sondes by a communication cable (i.e. like stationary and traveling profiles) and (2) in deployment mode by setting the sonde to log data internally (i.e. like a semi-permanent buoy). The hand-held device was connected to the sonde being used for water column profiling allowing “real-time” viewing of information logged by the profiling sonde. The GPS coordinates of the hand-held device were recorded by the hand-held device. The static deep sonde was set to collect data in deployment mode without real-time viewing (blind recording). GPS coordinates were not recorded for the sonde in deployment mode but since data from both sondes were collected simultaneously the GPS position being recorded by the hand-held was also used to establish the GPS position for the deployment mode sonde. Data collection was started and stopped at the beginning and end of each combination profile thereby creating one continuous data file for each sonde used for that combination profile (files were hours in length).

Field notes and daily logs were prepared documenting the data collection times and locations, the field crew, the day’s weather conditions and any data collection issues (**APPENDIX K**). The downloaded data, including GPS locations, along with the field notes and daily logs, were transferred to the QA/QC team, following the QA/QC procedures in Appendix B of the Work Plan. Microsoft Excel (Excel) files contained raw data uploaded to the project Microsoft OneDrive (OneDrive) and provided in comma-delimited format. The raw data were reviewed and checked by the QA/QC team. ***Figure 2-7*** and ***Figure 2-8*** provide an example of the data collected for a traveling profile data collection run for the lower Front River, and ***Figure 2-9*** and ***Figure 2-10*** provide an example of the data collected for a traveling profile data collection run for the Back River.

Data sonde calibration intervals were determined by the manufacturer but could differ from typical recommendations depending on lengths of deployment, site conditions, and any anomalies interpreted from visual aids used to routinely review data (**APPENDIX K**). In cases where the visual review of data indicated that there was data drift or other potential data issues, the entire sonde would be replaced with a backup data sonde, and the particular sensor would be recalibrated according to the manufacturer’s specifications.

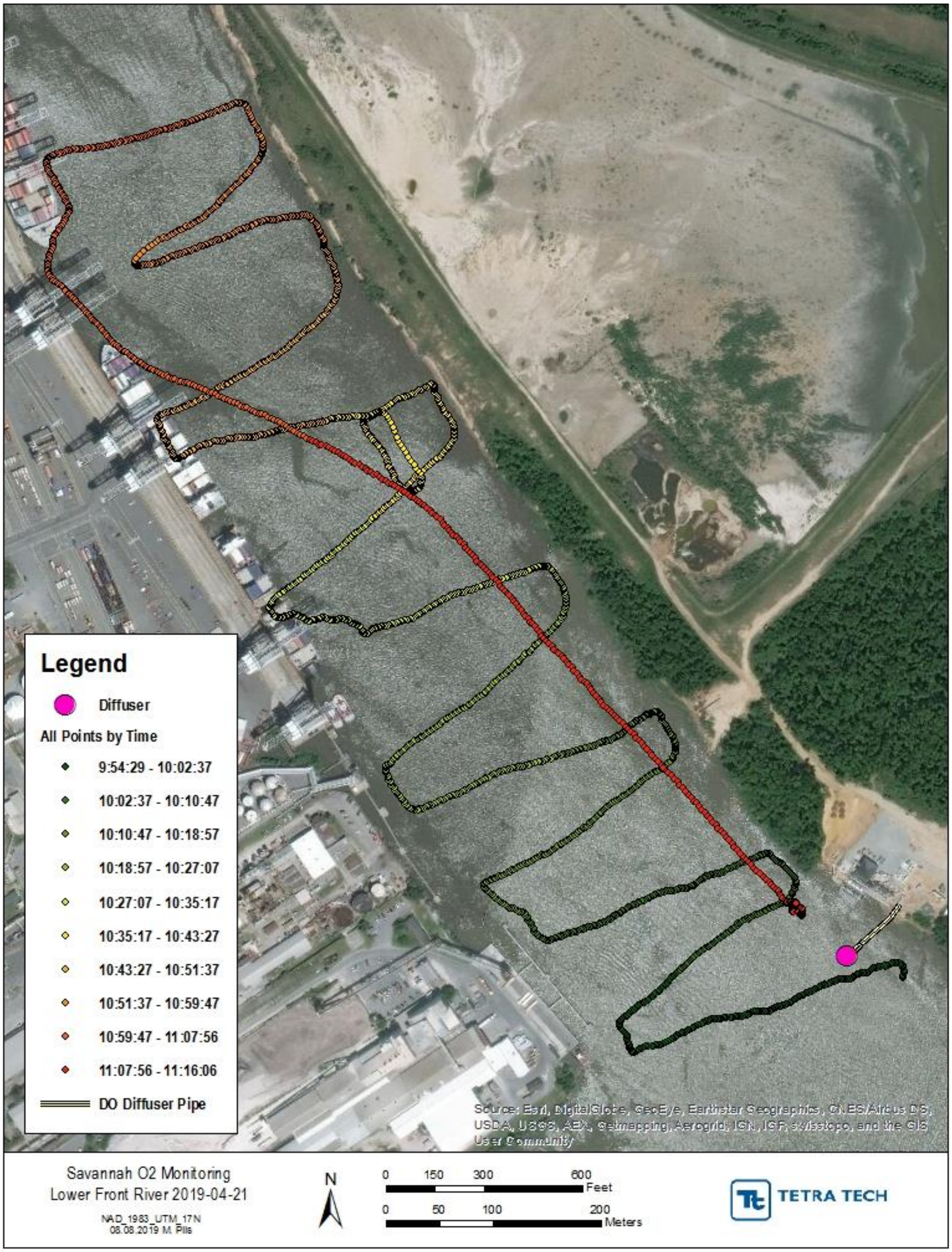


Figure 2-7 Front River April 21, 2019 flood tide traveling profile location map

Figure 2-8 Front River April 21, 2019 flood tide traveling profile period observations

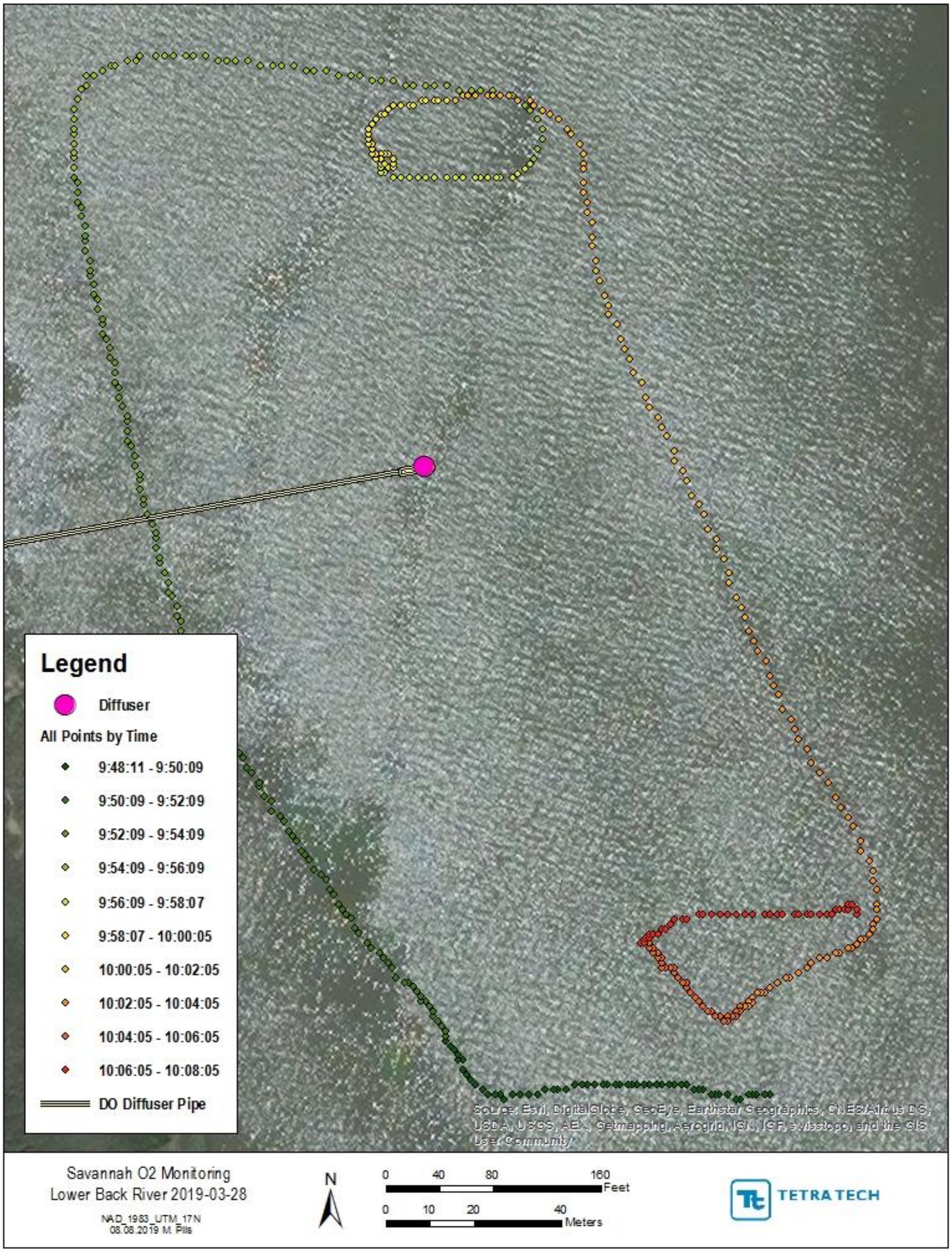


Figure 2-9 Back River March 28, 2019 ebb tide traveling profile location map

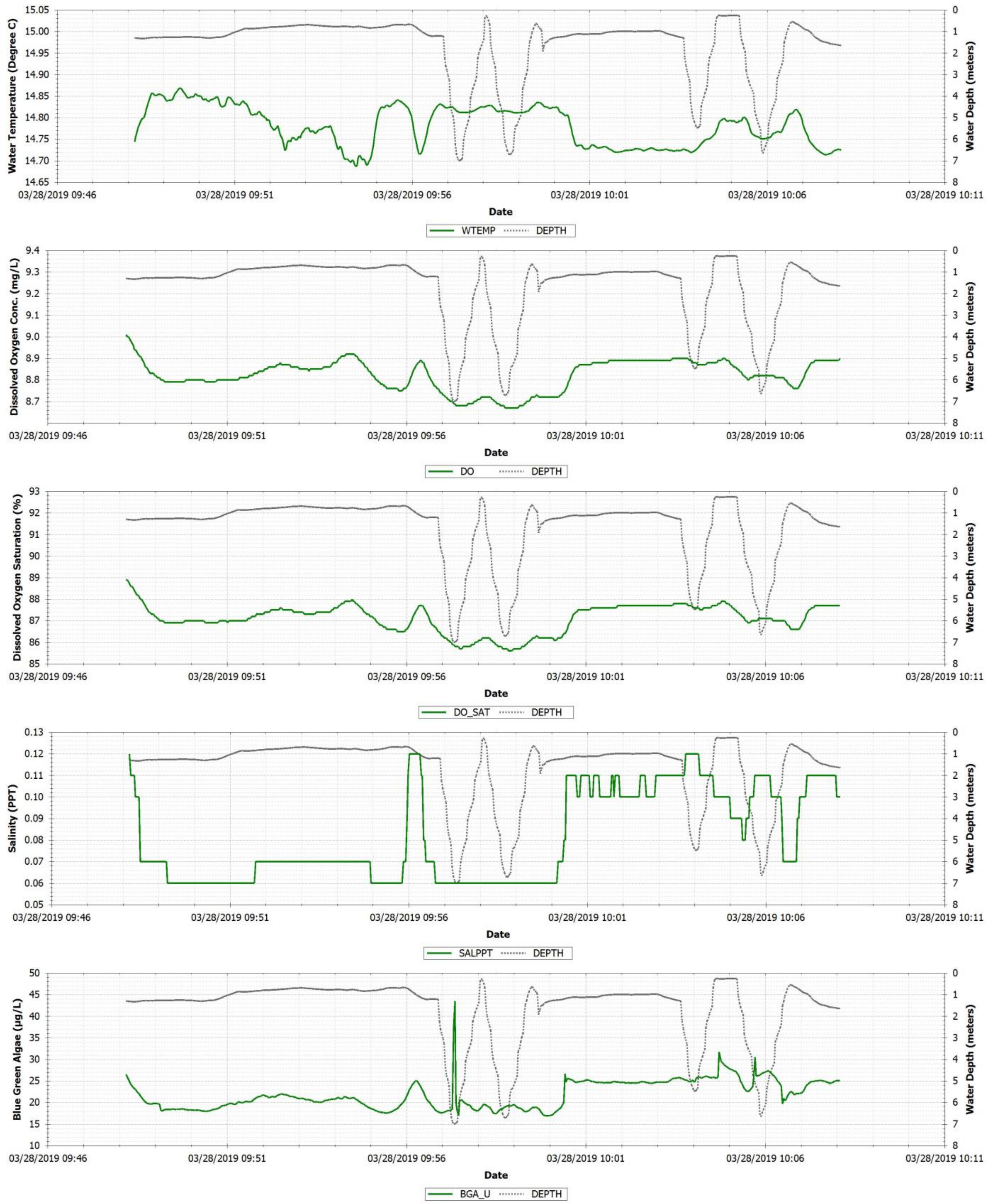


Figure 2-10 Back River March 28, 2019 ebb tide traveling profile period observations

2.5 DRIFT MONITORING / DATA COLLECTION

Drifting was conducted by the field team via project boats using multiple instruments deployed from a single boat. Up to four (4) data sondes were deployed from a boat with each deployed at four (4) different depth intervals. The four monitoring zones were relative to each due to the variable depths encountered during data collection, and were designated as surface, shallow, middle, and deep sondes. They were generally deployed at one-half (0.5) meter (surface), one (1) meter (shallow), three (3) meters (middle), and five (5) meters (deep) below the water surface. Data were collected simultaneously from all sondes in use for the duration of the drift event.

Drift data were collected with spatial and temporal variability inside and outside of the plume. The project boat either drifted or motored in various ways around, through or within the plume. Each data sonde recorded DO, DO saturation, salinity, conductivity, temperature, BGA, and chlorophyll *a* along with the date, time, and depth of each measurement. The recording of measurements was performed in two ways (1) in real-time mode by using a hand-held device connected to one (1) of the data sondes by a communication cable (i.e. like stationary and traveling profiles) and (2) in deployment mode by setting the sonde to log data internally (i.e. like a semi-permanent buoy). The hand-held device was usually connected to the shallow sonde allowing "real-time" viewing of information logged by the shallow sonde. The GPS coordinates of the hand-held device were recorded by the hand-held device. Typically, the surface, middle, and deep sondes were set to collect data in deployment mode without real-time viewing (blind recording). GPS coordinates were not recorded for the sondes in deployment mode. However, the water quality data from all sondes were collected simultaneously, therefore the GPS position recorded by the hand-held device was used to establish the GPS position for the deployment mode sondes. Data collection was started and stopped at the beginning and end of each drift thereby creating one continuous data file for each sonde used for that drift (files were typically hours in length).

Field notes and daily logs were prepared documenting the data collection times and locations, the field crew, the day's weather conditions and any data collection issues (**APPENDIX K**). The downloaded data, including GPS locations, were transferred to the QA/QC team, following the QA/QC procedures in Appendix B of the Work Plan. Excel files contained raw data uploaded to the project OneDrive and provided in comma-delimited format. The raw data were reviewed and checked by the QA/QC team. ***Figure 2-11*** and ***Figure 2-12*** provide an example of the data collected for a drifting data collection run for the lower Front River, and ***Figure 2-13*** and ***Figure 2-14*** provide an example of the data collected for a drifting data collection run for the Back River.

Data sonde calibration intervals were determined by the manufacturer but could differ from typical recommendations depending on lengths of deployment, site conditions, and any anomalies interpreted from visual aids used to routinely review data (**APPENDIX K**). In cases where the visual review of data indicated that there was data drift or other potential data issues, the entire sonde would be replaced with a backup data sonde, and the particular sensor would be recalibrated according to the manufacturer's specifications.

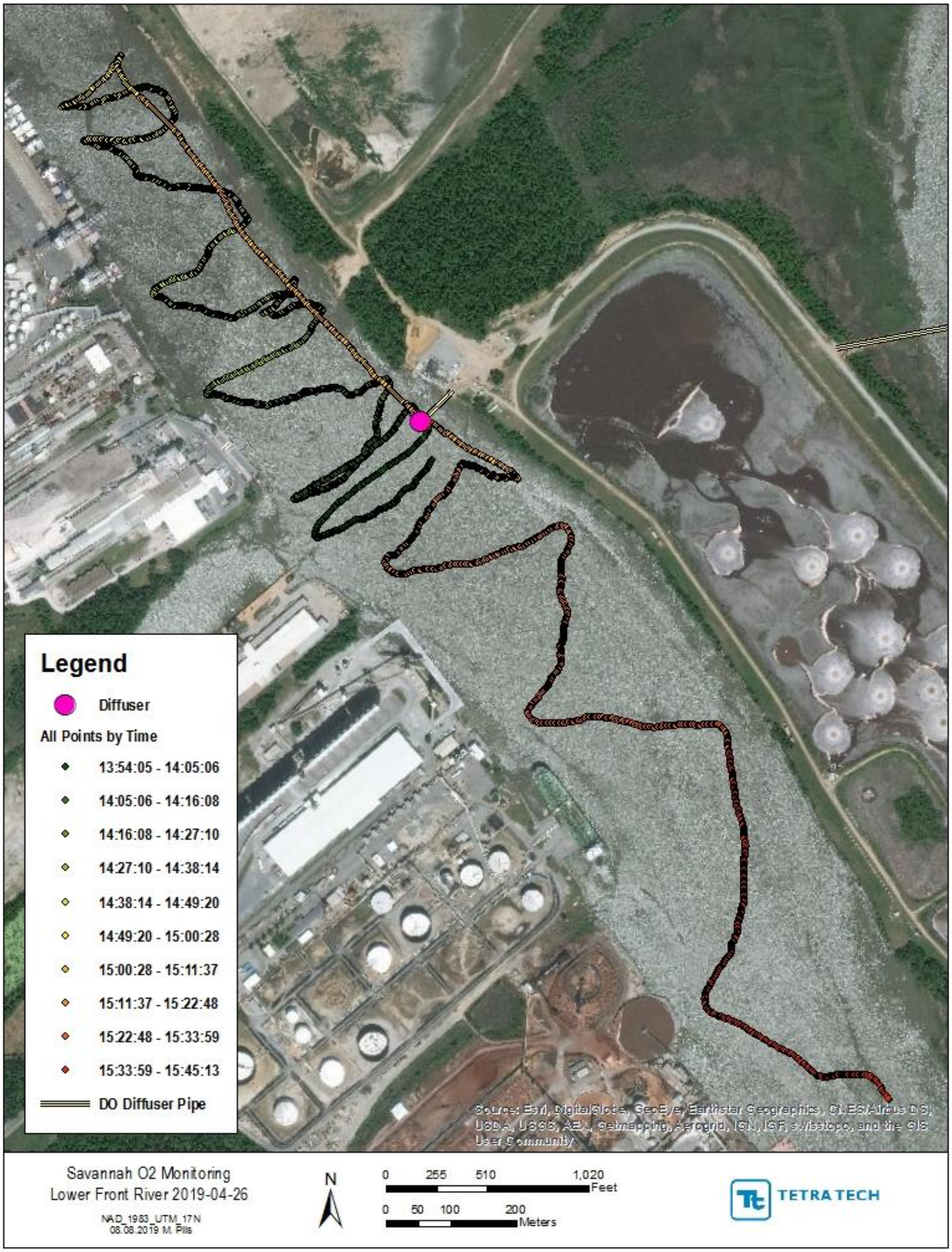


Figure 2-11 Front River April 26, 2019 flood tide drift location map

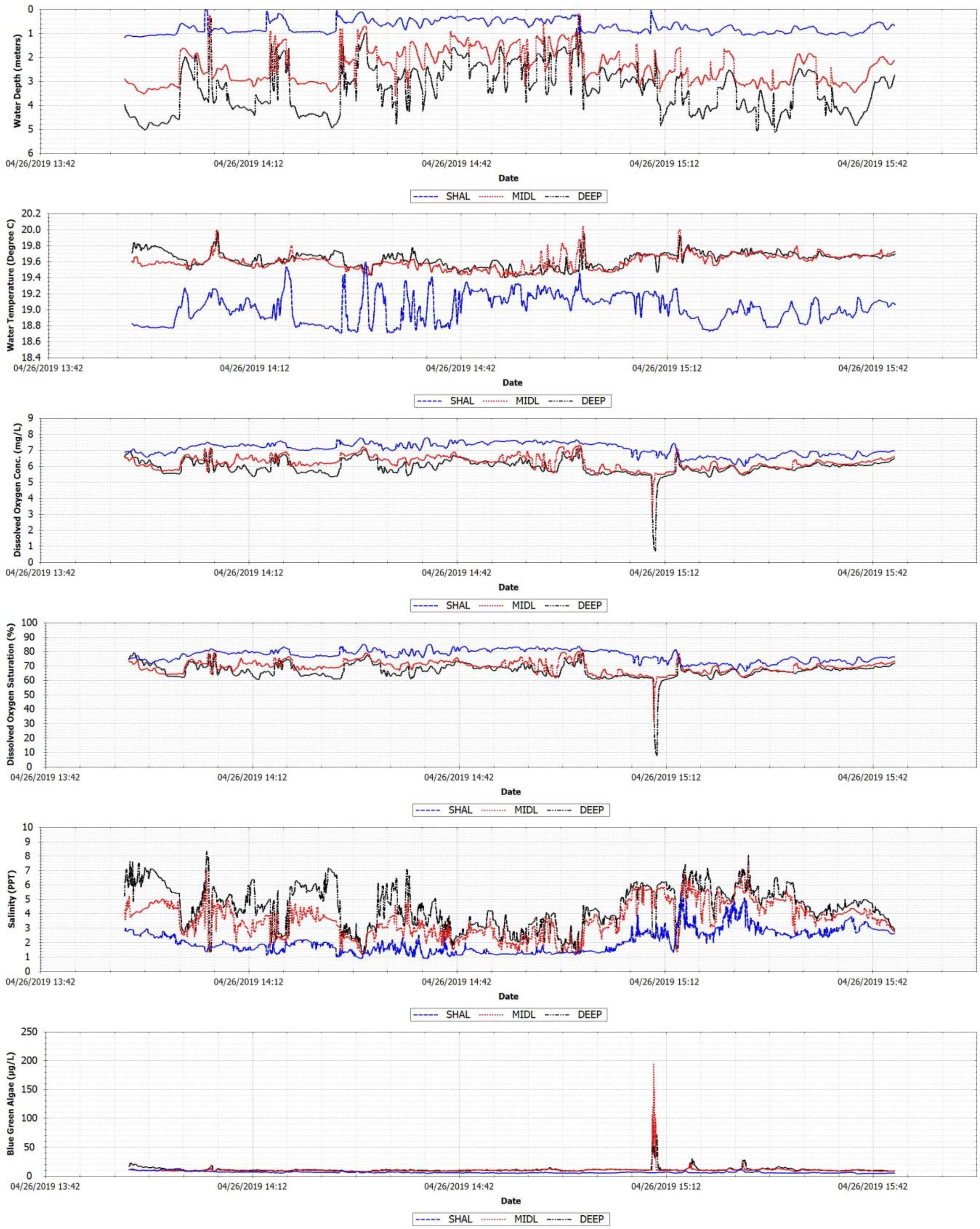


Figure 2-12 Front River April 26, 2019 flood tide drift observations

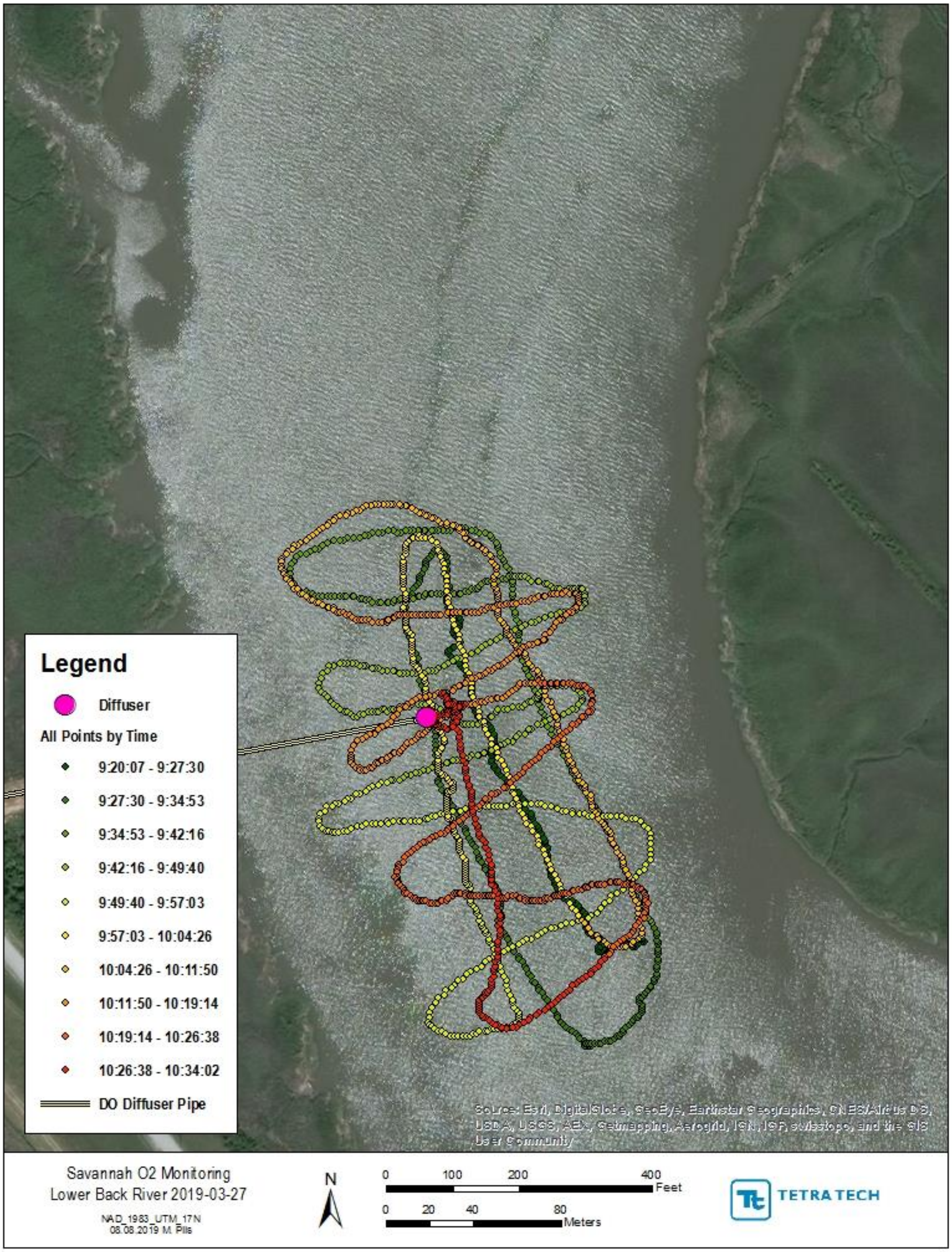


Figure 2-13 Back River March 27, 2019 ebb tide drift location map

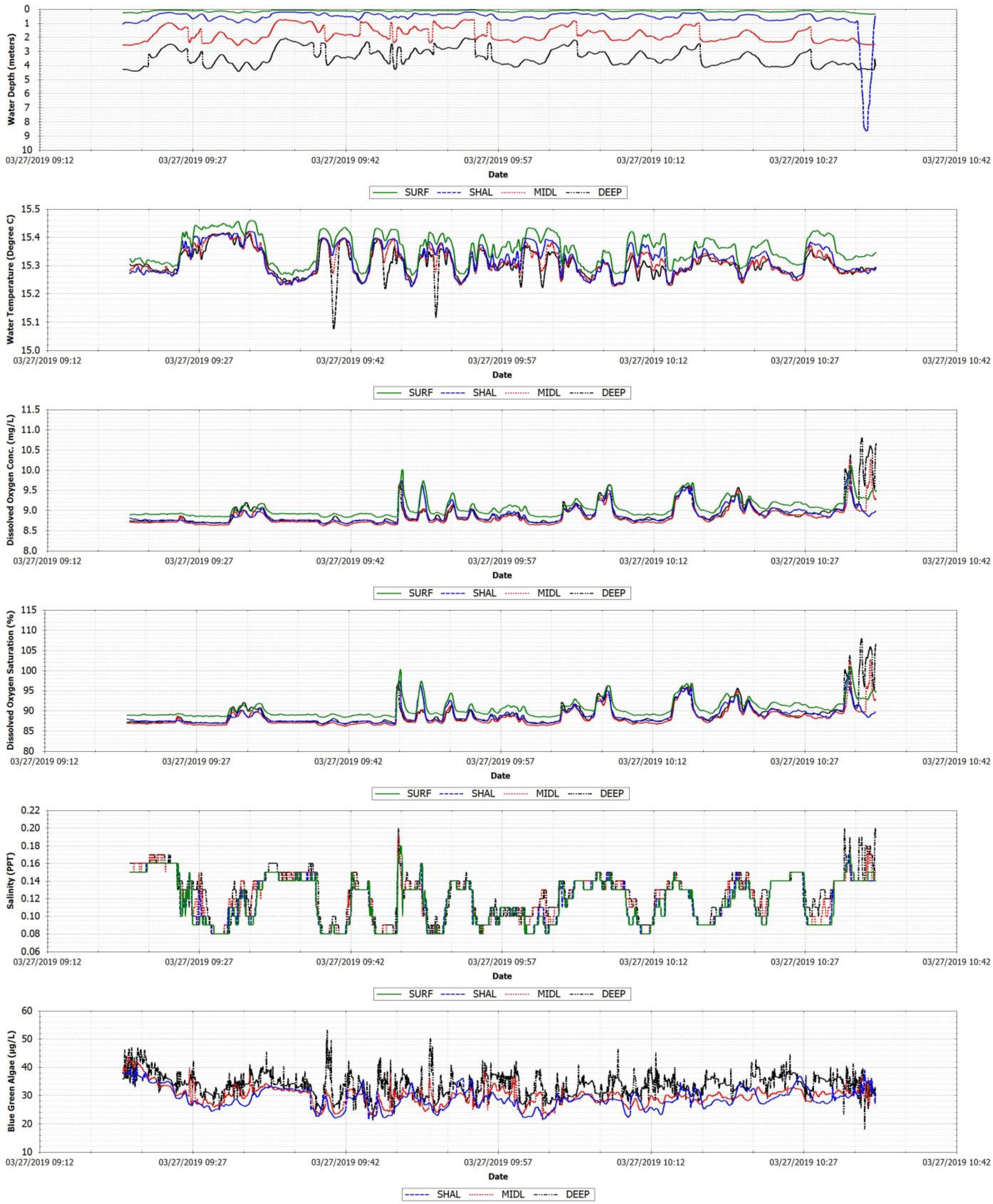


Figure 2-14 Back River March 27, 2019 ebb tide drift observations

2.6 DYE RELEASE AND MONITORING

During the Test Run data collection, Rhodamine dye releases were conducted in the Back River and lower Front River. Rhodamine WT is a fluorescent xanthene dye and is routinely used as a hydrologic tracer in surface water systems. The dye was injected into the Plant discharge pipes using a stainless-steel drum pump powered by a 120-volt electric motor head and fitted with an impeller capable of pumping containers empty of pumpable contents. The dye injection was regulated at the drum pump with a 1-inch ball valve and electronic flow meter to deliver the dye into the discharge pipe at approximately two (2) gallons per minute. ***Table 2-2*** provides the date, time, river, tide condition, dye strength, and dye volume used for the Test Run data collection dye releases. The table also provides the background dye concentration observed before the release dye. ***Figure 2-15*** shows an example of plume movement for ebb tide on the lower Front River and ***Figure 2-16*** shows an example of plume movement for ebb tide on the Back River.

The dye releases were used to visually confirm the direction and orientation of the DO plume, as well as the potential areal extent of the plume. This information was used by the data collection team to fine tune the data collection locations and data collection time.

Table 2-2 Test Run dye study information

Date	Time	River	Tide	Dye Strength (%)	Dye Volume (gallons)	Background Dye Concentration (BGA µg/L)
3/29/2019	11:02	Back	Low	20	16	20
4/11/2019	8:30	Front	Low	20	30	10
4/12/2019	9:45	Back	Low	20	30	20
4/23/2019	12:37	Back	High	2	30	10
4/24/2019	13:30	Front	High	4	30	10
4/25/2019	8:30	Back	Low	20	30	40
5/8/2019	10:30	Front	High	20	30	10

Dilution ratio dye studies were conducted April 23, 2019 and April 24, 2019 on the Back River and lower Front River, respectively. These dye studies used low concentrations of dye with intensive near field data collection to establish an estimated dilution ratio of the diffusers. Based on an estimated end-of-pipe dye concentration (i.e. calculated based on diffuser flow rate, dye flow rate, dye injection time, and dye concentration) and the maximum measured in-stream dye concentration, estimated diffuser dilution ratios were calculated ***Table 2-3***. The studies estimated a diffuser dilution ration of 50:1 on the Back River and 45:1 on the lower Front River.

Table 2-3 Diffuser dilution constituents

Constituent Description	April 23, 2019 Back River	April 24, 2019 Front River
Plant flow (GPM)	7,800	21,000
Dye flow (GPM)	1.67	2
Rhodamine injection true concentration (%)	2	4
BGA sensor concentration to true Rhodamine concentration (ratio)	5:1	5:1
BGA background Dye concentration (µg/L)	10	10
End of pipe dye concentration (BGA µg/L)	21,384	19,068
Maximum measured instream concentration (BGA µg/L)	425	426
Dilution Ratio	50:1	45:1

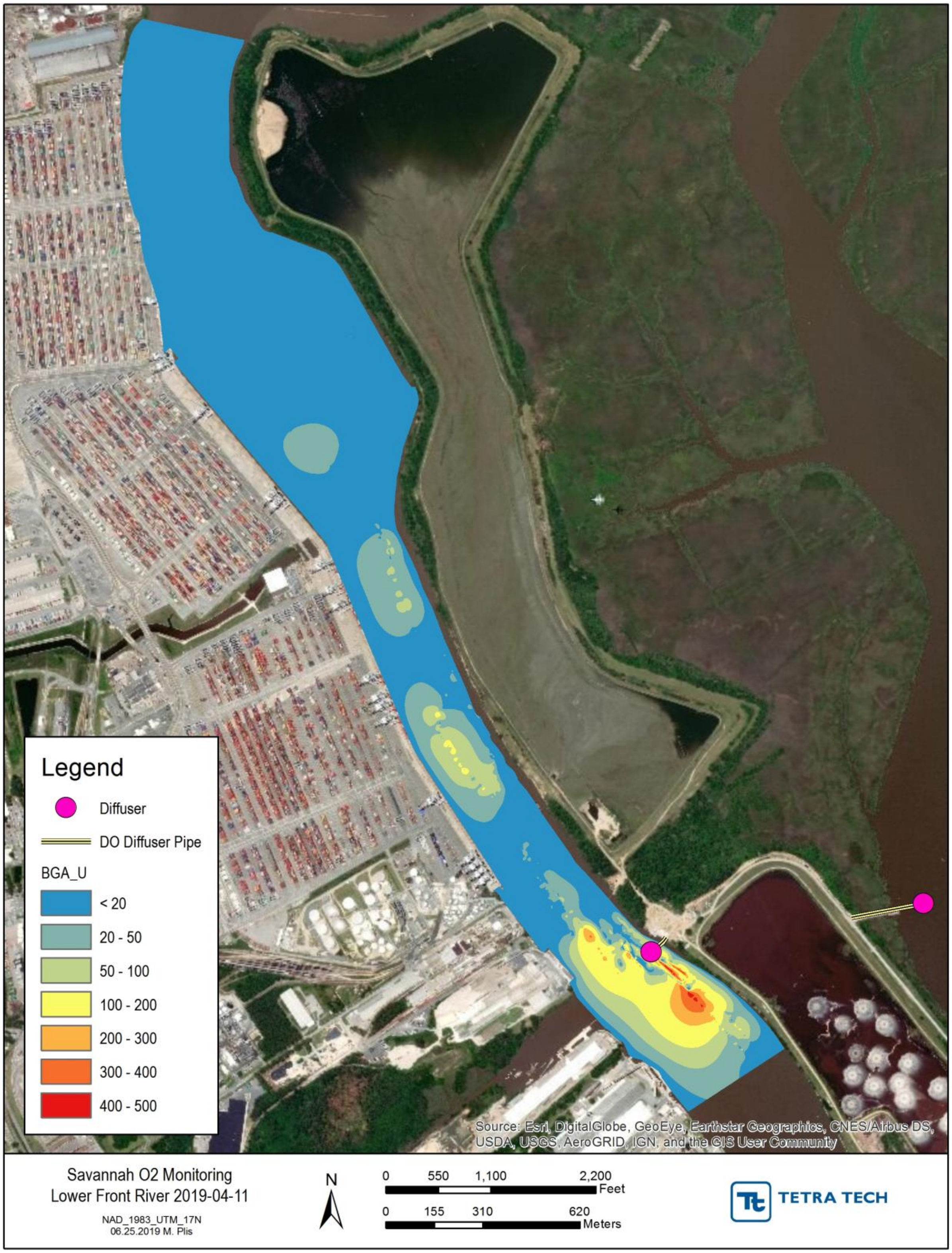


Figure 2-15 Front River April 11, 2019 ebb tide dye drift raster interpolation

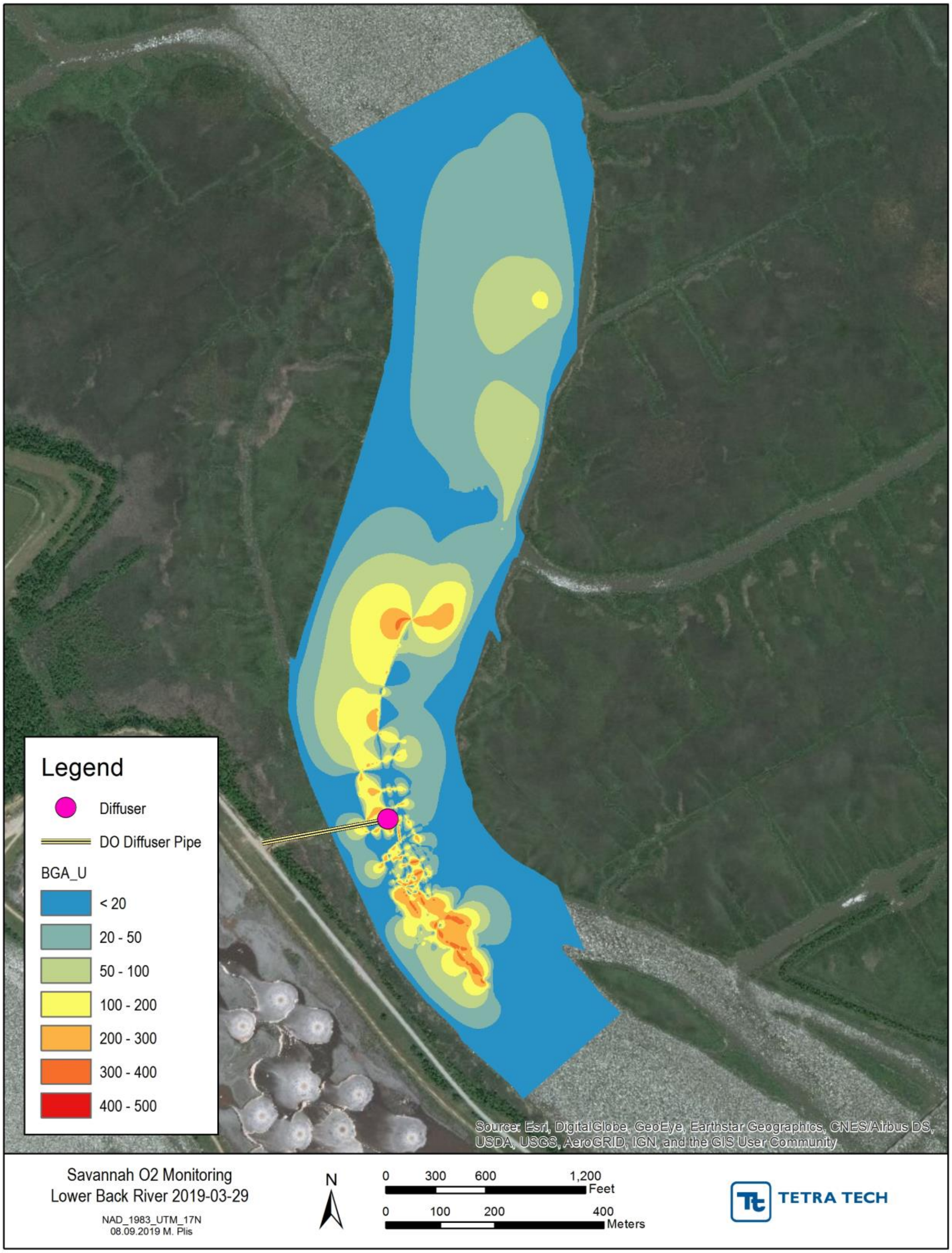


Figure 2-16 Back River March 29, 2019 ebb tide dye drift raster interpolation

3.0 DATA QAQC

The QA/QC team conducted a review of all of the data collected during the Test Run data collection effort. During this effort, they followed the QA/QC procedures outlined in Appendix B of the Work Plan (LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2019c).

All the data collected for Test Run data collection were downloaded by the QA/QC team through various web interfaces. The QA/QC team personnel conducting the downloads were responsible for documenting the date and time the data were received and confirming that all necessary pieces were transferred. This information was documented in a chain of custody form for data directly transferred to the QA/QC team from the field team and an access log for USGS data. These forms served as the first check point during the process of data review. All the downloaded data were stored on Tetra Tech's internal server as raw data files in the file and format received via the download. The access logs and chain of custody form were reviewed to ensure all data collected for the Test Run data collection were obtained by the QA/QC team.

A project database was created for Test Run data collection data. All the raw data files were modified to make them compatible for importing into the project database storage and post-processing tool, Water Resources Database (WRDB). WRDB consists of a set of linked relational database tables which contain the data for a given project. The user interface provides a set of Microsoft Windows-based forms, reports, graphs, and auxiliary programs to ease data entry and viewing.

The QA/QC team maintained data processing logs, like the access logs and chain of custody form, to document and track the modification and processing of the data files. The raw data files were duplicated and converted to Excel workbooks. This was done to ensure that the raw data files were not altered. The duplicated files were used for all further data processing needs. General data modification and processing before importing the data into WRDB included:

1) Removing blank rows and columns
2) Assigning parameter codes (PCode) to the various constituents
   - PCode is a required field in WRDB
   - PCodes are short identifiers provided for the parameter name
3) Identifying remark codes (RCodes) if they existed in the raw data files
   - RCodes is an optional field in WRDB
   - RCodes were used to abbreviate the comment provided by the field personnel
4) Assigning station identification (ID)
   - A unique identifier was used to identify the data from the different data sources and the location

During the process of importing data to WRDB, the total number of records in the modified file and the actual number of records imported into the WRDB database were checked. This QA/QC record count check was included in the data processing logs and compared to the access logs and chain of custody forms to ensure that all data collected for Test Run data collection was processed and imported into the WRDB database.

After the data were imported into the WRDB database the data were plotted to visually check for consistency. When potentially inconsistent data were identified, field personnel and field notes were reviewed to determine if the data were valid or if they should be removed (i.e., sonde was not in the water when the data were collected). After review of the potentially inconsistent data, the data processing workbooks were updated to separate the verified inconsistent data from the accepted data. Accepted data were re-imported into WRDB and were maintained in tables separate from the raw data previously imported. Inconsistent data were not deleted and are maintained in the following three locations:

1) Raw data files,
2) Raw data imported into WRDB, and
3) Verified inconsistent data in the data processing workbooks.

The approach for handling inconsistent data allowed for current and future analysis on both raw/original data and reviewed/cleaned data. The discussion in the following sections provides examples of data QA/QC for each type of data collected. **APPENDIX J** provides more detailed documentation of data QA/QC and focuses on the access of data, QA/QC checks performed on the received data, data manipulations, and the quality and volume of data obtained for each data source.

3.1 PLATFORM DATA

During the QA/QC check, unique observations and some inconsistencies in the data of the system were identified in the measured platform data and were separated from the consistent data in the processed data files and project database.

Based on the header information for specific conductivity (SPCOND) on the *.dat file downloaded from datalogger using Campbell Scientific LoggerNet 4.5, the units were reported as mS/cm. It was confirmed by Xylem that the units for SPCOND were mS/cm. The SPCOND concentrations for all continuously deployed sondes varied between 0.3 mS/cm and 12,045 mS/cm, with an average concentration of 1,923 mS/cm. To verify the range of SPCOND, two USGS monitoring stations located upstream (USGS 021989793) and downstream (USGS 0219897945) of the platform were evaluated. USGS 021989793 is located 1.42 miles upstream of the platform and USGS 0219897945 is located 2.45 miles downstream of the platform. During the period from March 14, 2019 through May 12, 2019, the USGS 0219897945 SPCOND varied between 304 µS/cm and 15,200 µS/cm with an average concentration of 4,614 µS/cm. At USGS 021989793, SPCOND varied between 88 µS/cm and 6,080 µS/cm, with an average concentration of 906 µS/cm. Based on the comparison, it was determined that the SPCOND concentrations from the data sondes at the platform were in µS/cm, not mS/cm as stated by Xylem. This correction did not impact the quality of the data.

On April 16, 2019, the field team determined that one of the platform anchors dislodged and the anchor line wrapped around the diffuser. All of the platform sondes were removed while the anchor was reset. The sondes were redeployed on April 17, 2019, but the deep and variable depth sondes (L1-D, L2-D, L3-D, L4-D, L13-V, L14-V, L15-V, and L16-V) were not redeployed to reduce the overall drag on the platform.

Of the 1,611,622 platform raw data points collected, greater that 90% were retained after the QA/QC check. **APPENDIX A** presents plots of the processed and accepted data collection data at each corner and side of the platform.

3.2 SEMI-PERMANENT BUOY DATA

The semi-permanent buoy data were reviewed in timeseries plots to identify any sample dates and times which contained observed values which were inconsistent with the observed values sampled before and after the inconsistent values. Comparison of the inconsistent dates and times to field notes revealed that the inconsistent data were strongly correlated to times when the field crew was at a buoy retrieving the data. As an example, ***Figure 3-1*** and ***Figure 3-2*** present the depth and DO timeseries respectively at the lower Front River north buoy. The data points in red were identified as being inconsistent. All of the inconsistent data points were associated with beginning and ending times of the intermittent data retrievals.

All of the buoy sondes were removed from the water for calibrated on April 9, 2019 around mid-day. A storm prevented the field team from redeploying the sondes immediately after recalibration. The sondes were redeployed around mid-day on April 10, 2019.

The buoy data for LBR_NE, LBR_SE, and LFR_A were periodically missing depth data throughout the Test Run period due to a problem with the sondes' pressure transducers. The data were considered acceptable since it was known that the sampled depth was near the surface. Additionally, even though depth was missing, the other sampled constituents were in range and trending with the constituent observations when depths were being recorded.

As part of the missing depth data investigation, the field team replaced the LBR_SE sonde on April 4, 2019. Between April 4, 2019 and April 6, 2019, the replaced sonde showed a discontinuity in comparison to depths recorded before the missing period began and the depths recorded after April 6, 2019 (***Figure 3-3***). The QA/QC theorizes that upon deployment an air bubble became lodged between the sonde's pressure transducer (the instrument used to measure water depth) and the water column. When the field team downloaded data on April 6, 2019, the air bubble likely became dislodged and the sonde subsequently started recording depth in range with depths recorded earlier during the Test Run.

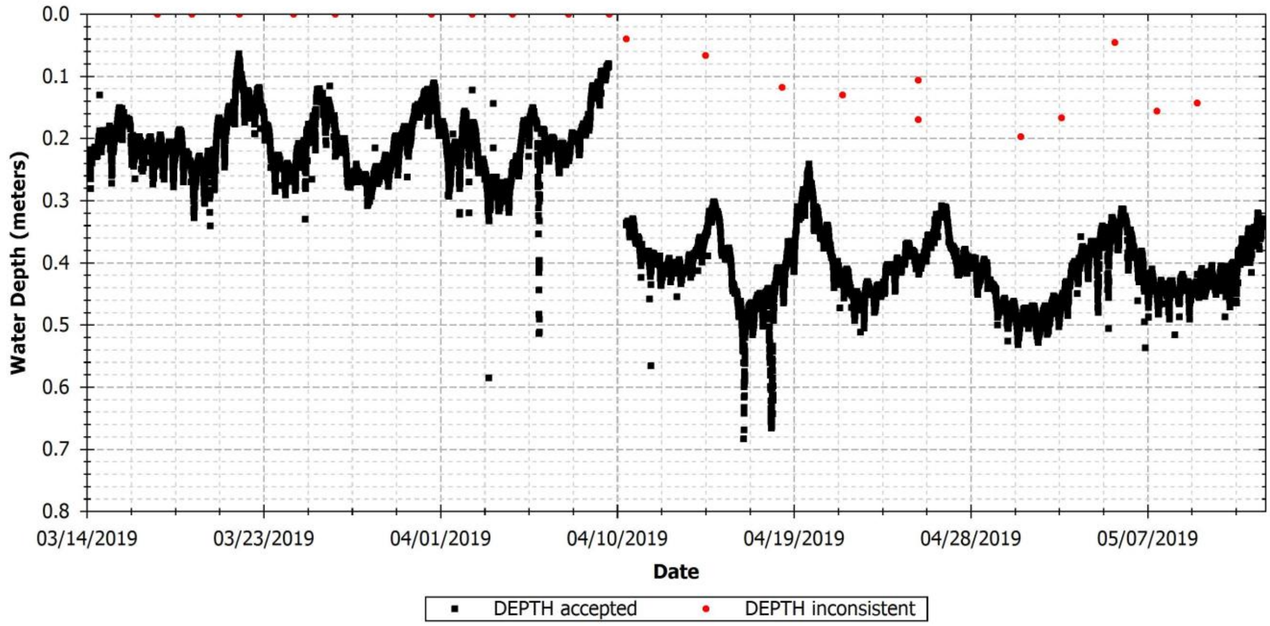


Figure 3-1 Lower Front River north QA/QC data depth

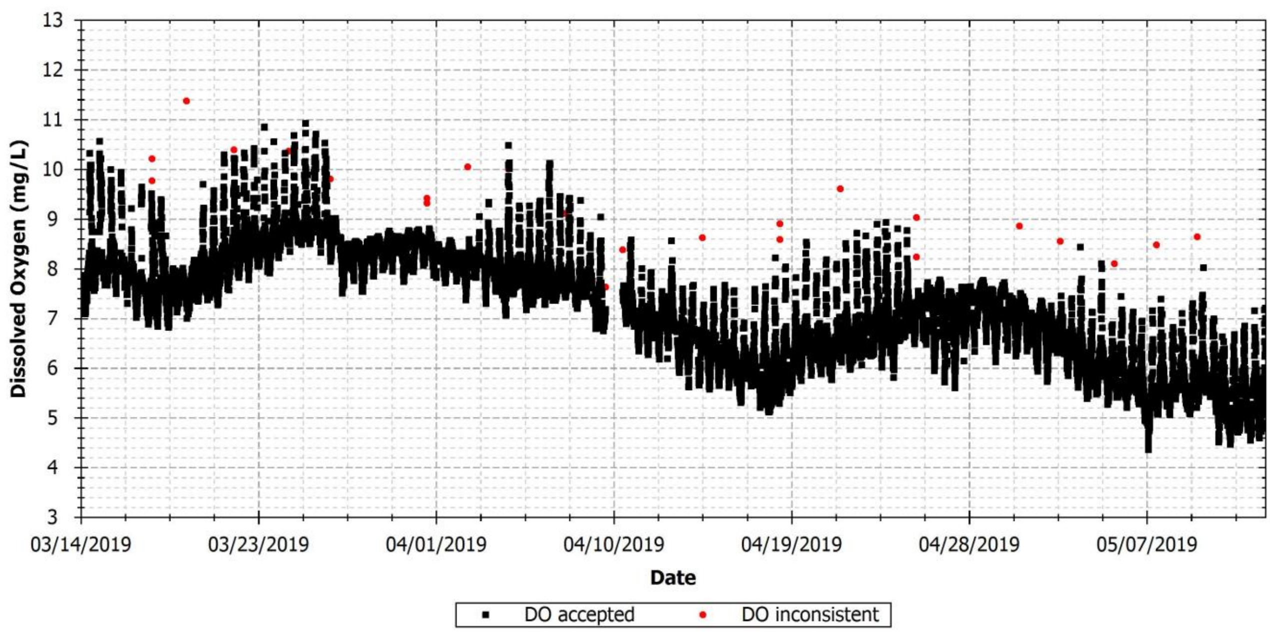
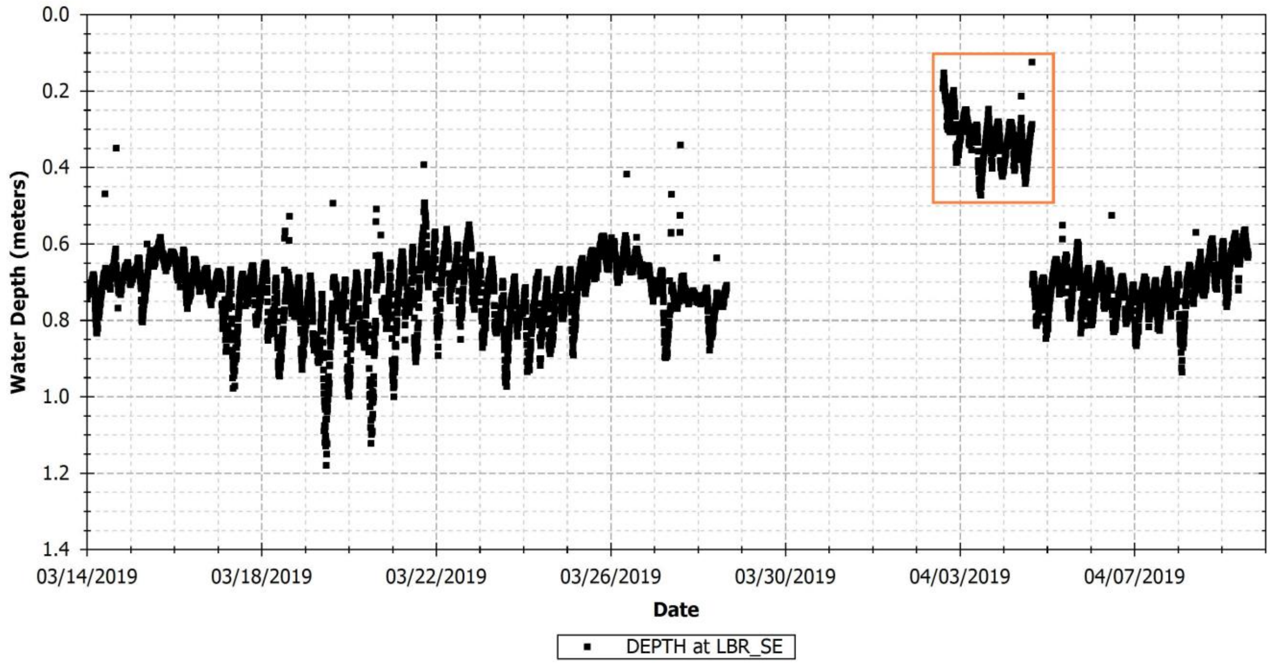


Figure 3-2 Lower Front River north QA/QC data DO



Note: orange box identifies the period of time where depth sensor may have been cushioned by an air bubble

Figure 3-3 Back River southeast QA/QC data depth

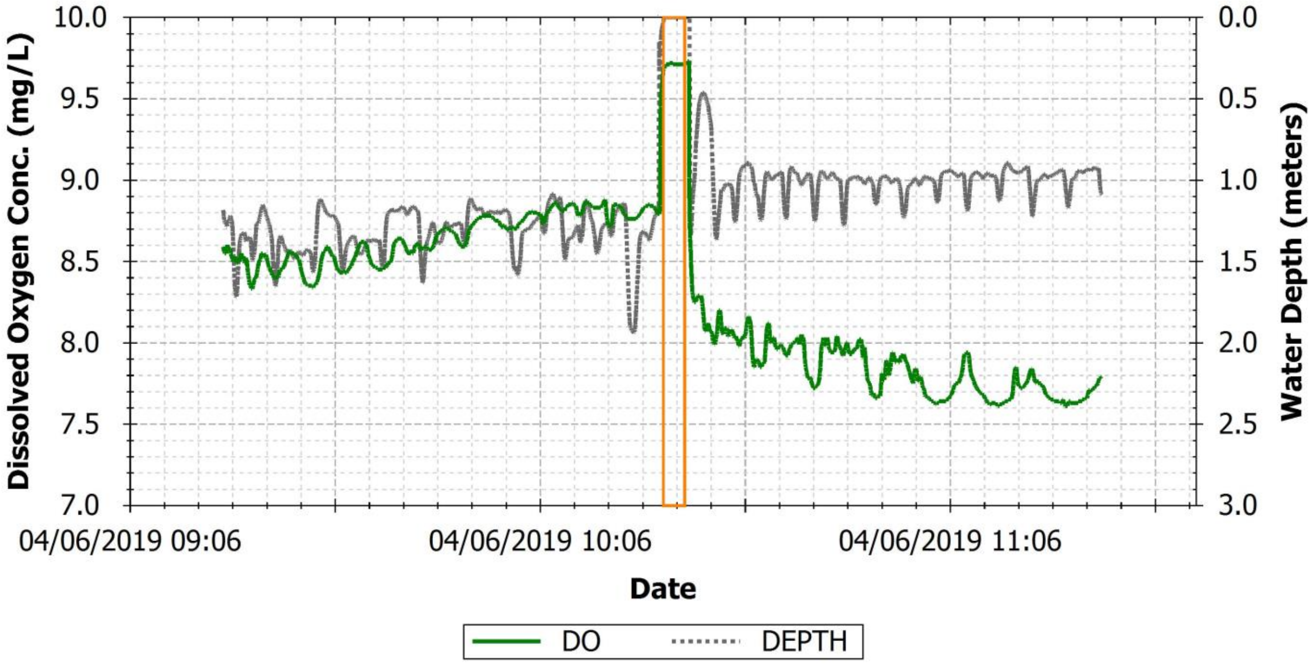
Of the 1,169,398 buoy raw data points collected, greater that 90% were retained after the QA/QC check. **APPENDIX B** presents plots of the processed and accepted data collection data at each semi-permanent buoy collected during the Test Run.

3.3 PROFILE DATA

The profile data were reviewed in timeseries plots to identify any sample dates and times which contained observed values which were inconsistent with the observed values sampled before and after the inconsistent values. The identified inconsistent dates and times were frequently correlated to times when the sondes were out of the water or at the water surface. As an example, ***Figure 3-4*** and ***Figure 3-5*** present the location map and depth and DO timeseries respectively of the LBR_040619_001 travelling profile. The orange polygon and box identify a period of time where the sondes were likely out of the water as the boat was travelling nearly twenty (20) miles per hour from one data collection location to another data collection location.

Note: orange polygon identifies the period of time where boat was traveling over 20 miles per hour and the sonde was out of the water

Figure 3-4 LBR_040619_001 travelling profile location map QA/QC



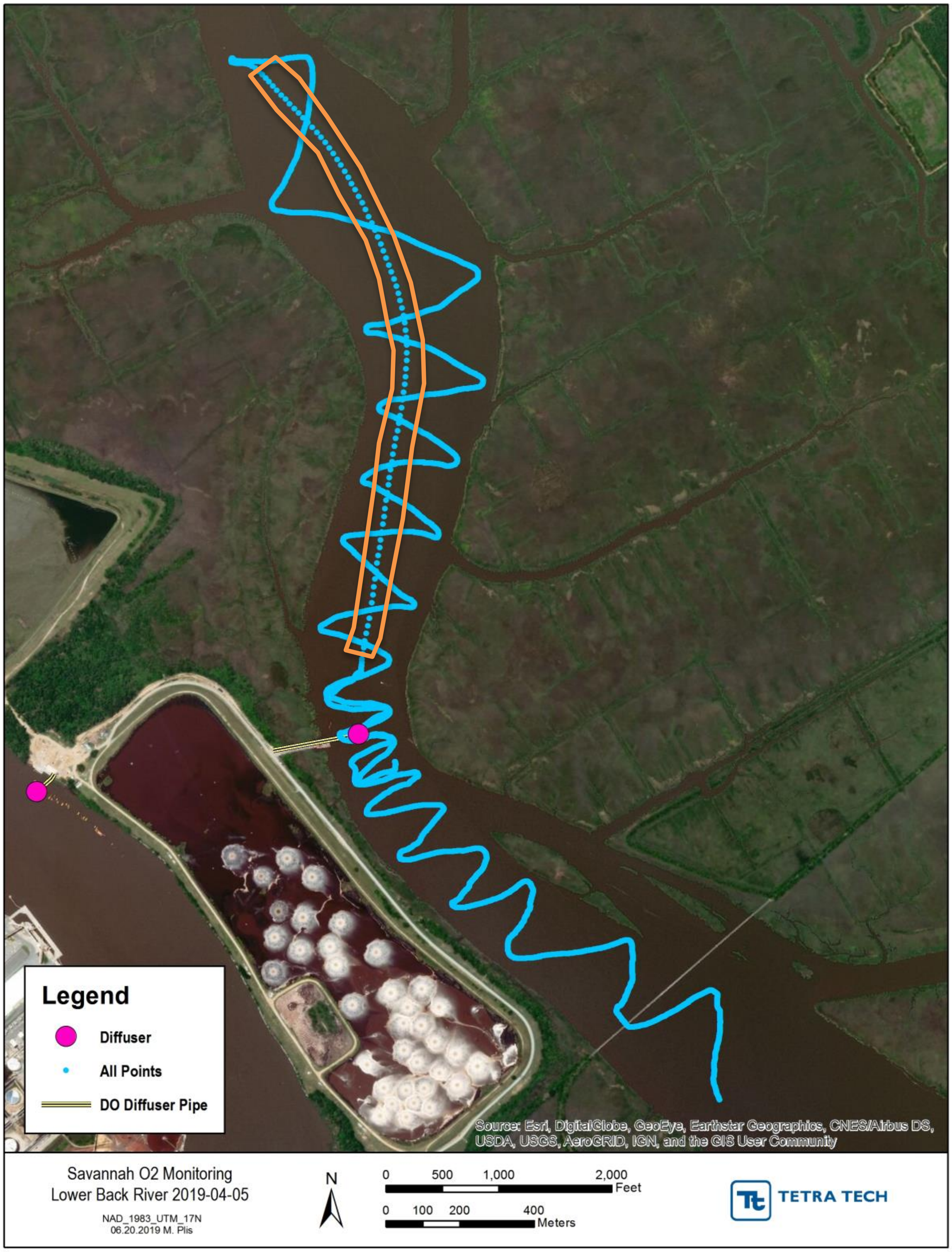
Note: orange box identifies the period of time where boat was traveling over 20 miles per hour and the sonde was out of the water

Figure 3-5 LBR_040619_001 travelling profile QA/QC depth and DO

Of the 4,448,970 profile raw data points collected, greater that 90% were retained after the QA/QC check. **APPENDIX C** presents plots of the processed and accepted data collection for each profile collected during the Test Run.

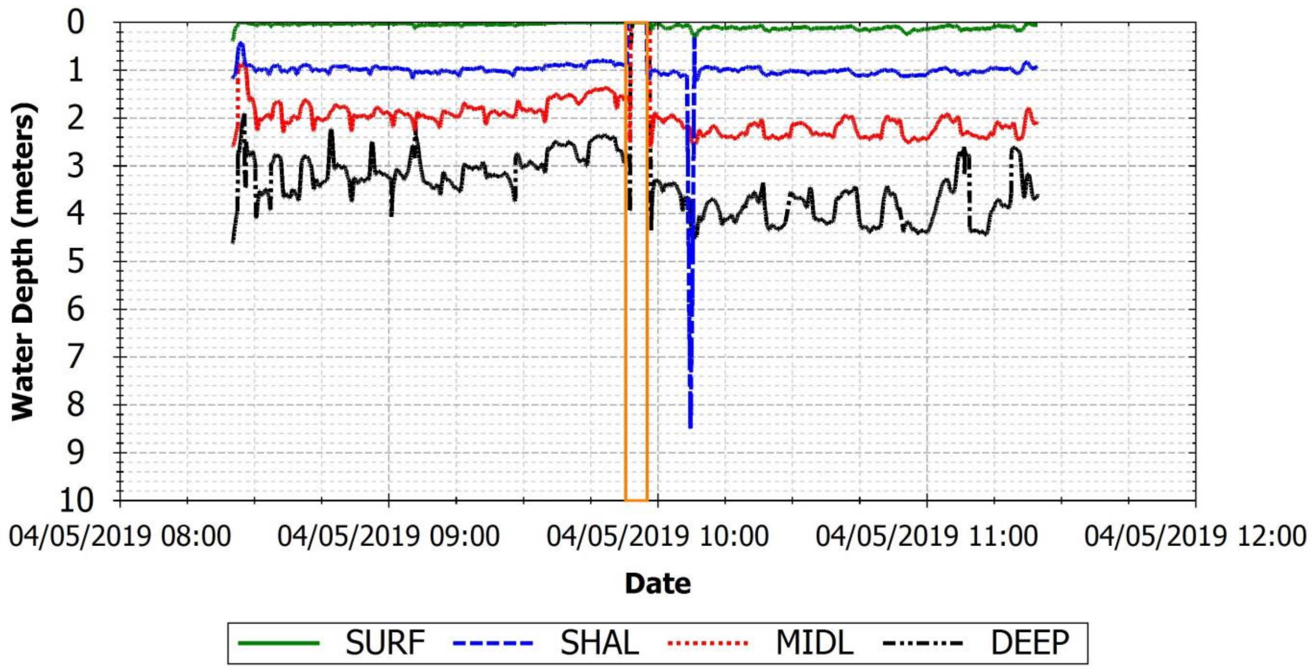
3.4 DRIFT DATA

The drift data were reviewed in timeseries plots to identify any sample dates and times which contained observed values which were inconsistent with the observed values sampled before and after the inconsistent values. The identified inconsistent dates and times were correlated to times when the sondes were likely out of the water or at the surface. As an example, ***Figure 3-6***, ***Figure 3-7*** and ***Figure 3-8*** present the location map, depth and DO timeseries respectively for the Back River, April 5, 2019 flood tide drift. The orange box identifies a period of time where all of the sondes were likely out of the water and the boat was traveling at a speed greater than 20 miles per hour from one data collection location to another data collection location.



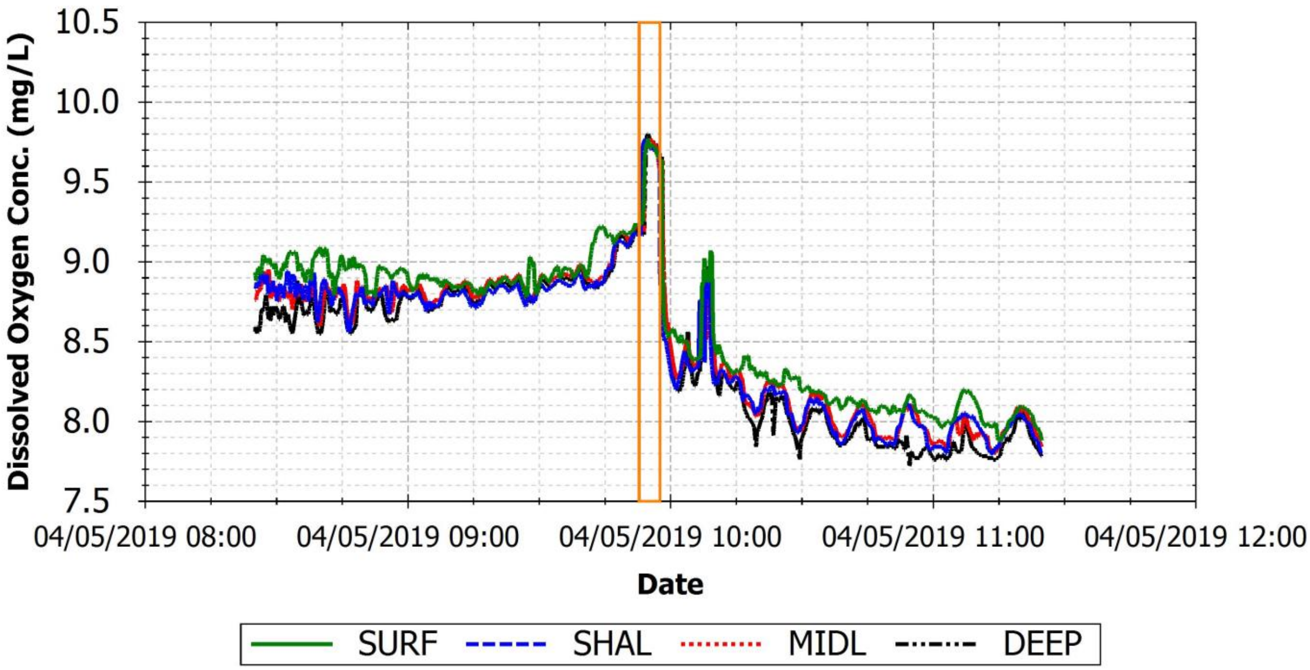
Note: orange polygon identifies the period of time where boat was traveling over 20 miles per hour and all sondes were out of the water

Figure 3-6 LBR_040519_HT_D1 drift location map QA/QC



Note: orange box identifies the period of time where boat was traveling over 20 miles per hour and all sondes were out of the water

Figure 3-7 LBR_040519_HT_D1 drift QA/QC depth



Note: orange box identifies the period of time where boat was traveling over 20 miles per hour and all sondes were out of the water

Figure 3-8 LBR_040519_HT_D1 drift QA/QC DO

Of the 13,741,688 drift raw data points collected, greater that 90% were retained after the QA/QC check. **APPENDIX D** presents plots of the processed and accepted data collection data for each drift collected during the Test Run.

3.5 USGS DATA

All of the USGS data was provisional and were assumed to carry the normal amount of uncertainty. **APPENDIX E** presents plots of the Test Run study data collection data at each USGS location.

3.6 USACE PLANT DATA

After completion of the Test Run, an independent QA/QC was performed on the Plant operational data (flows and loads), and the QA/QC data was provided the team. **APPENDIX F** presents timeseries plots of the Plant data during the Test Run study data collection and a table presenting daily flow rate and oxygen loads to the lower Front River and Back River diffusers.

3.7 DYE DATA

Dye data were included as a reported constituent (BGA) in the data that were downloaded, processed, and QA/QC'd as previously discussed for the platform data (**Section 3.1**), semi-permanent buoy data (**Section 3.2**), profile data (**Section 3.3**), and drift data (**Section 3.4**). Dye was measured and reported through the surrogate parameter BGA. Timeseries plots of dye response (reported as BGA µg/L) are provided throughout **APPENDIX A**, **APPENDIX B**, **APPENDIX C**, and **APPENDIX D** in the plots developed for those data types. **APPENDIX G** provides maps showing the boat data collection extent with data point coloring rendered based on shallow sample dye response (reported as BGA µg/L) and a GIS raster (one [1] square meter grid) that was created with the ArcGIS topo-to raster-tool. The topo to raster tool interpolated the profile and drift data measured dye response (reported as BGA µg/L) in areas where data collection did not occur and provides a visualization for the size and extent of the plume based on the data collected at the time and immediately following dye release.

4.0 DATA ANALYSIS

In an effort to evaluate the Downriver plant and the impact of the injected oxygen on both the lower Front River and Back River, the QA/QC data collected during the Test Run period were analyzed to determine: 1) if data collected showed the presence of the oxygen injection, 2) how long the oxygen was staying in the water column, and 3) if mixing of the oxygen is occurring in the water column. This section provides several examples of the data analyses that helped to answer these questions, and includes analyses of supporting data that were not collected or reviewed as part of the Test Run data collection effort.

4.1 PLANT DATA

Figure 4-1 shows the total net DO load injected into the lower Front River and Back River during the Test Run period. This information was provided by the USACE. The average operating plant load under normal conditions was 13,385 pounds/day with a ± one (1) standard deviation range of 12,682 pounds/day to 14,089 pounds per day. The average load, 13,385 pounds/day, was greater than the required 12,000 pounds/day.

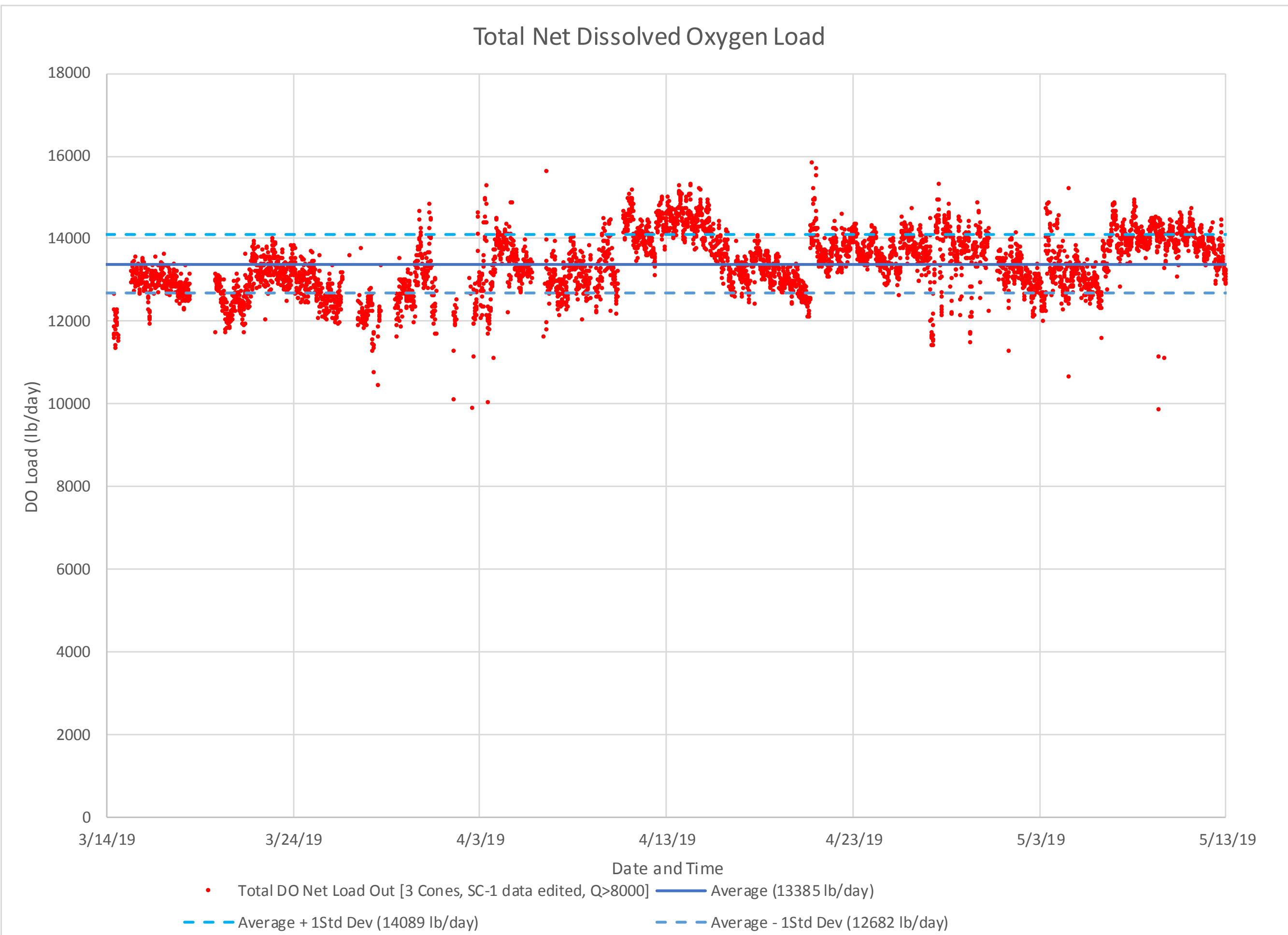


Figure 4-1 Plant total net DO load to the lower Front River and Back River for Test Run period

4.2 USGS HISTORICAL FLOW AND DO DATA

Hourly freshwater flows from the USGS station 02198500 Savannah River near Clyo, GA were obtained from January 1, 2010 through July 31, 2019 period (***Figure 4-2***). Statistical analyses were performed on measurements collected during the Test Run days (March 14 through May 12) of every year from 2010 through 2019 (***Table 4-1***). Based on the results, 2019 is a high flow year, with 2014 and 2016 also showing high flow periods, therefore, DO data from 2014 and 2016 were compared to 2019.

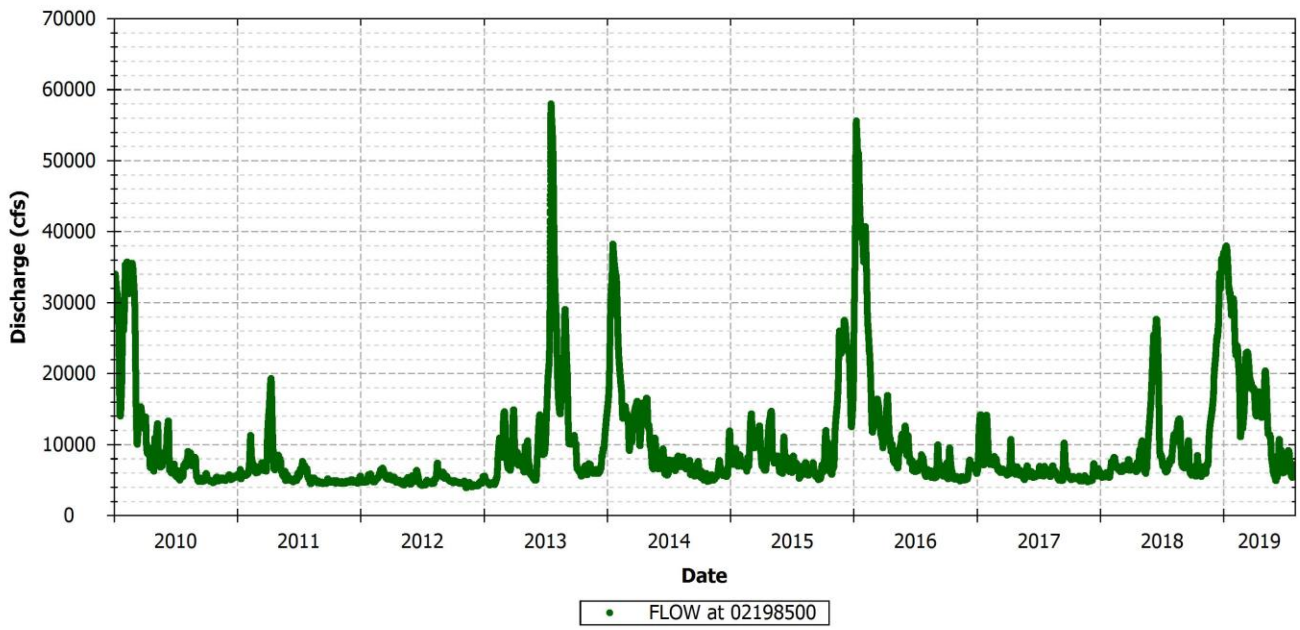


Figure 4-2 Hourly freshwater flows at Clyo

Table 4-1 Statistical analysis of the freshwater flows at USGS station 02198500, Savannah River near Clyo during the Test Run days

Flow (cfs)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Average	10,840	9,439	4,990	8,374	**13,480**	9,786	**10,725**	6,447	7,451	**16,844**
10th %tile	6,790	6,389	4,500	6,560	**10,000**	6,770	**7,399**	5,800	6,480	**14,000**
50th %tile	10,900	7,510	5,030	7,850	**14,000**	9,850	**10,600**	6,190	6,900	**17,000**
75th %tile	13,200	11,600	5,270	8,890	**15,400**	11,700	**12,425**	6,413	7,860	**18,500**
90th %tile	14,600	16,600	5,480	11,020	**16,000**	13,500	**15,000**	6,840	9,370	**20,000**

15-minute DO concentrations were then obtained from USGS stations 021989793 Little Back River at Hog Island and 0219897945 Back River downstream of US 17, located upstream and downstream of the Back River diffuser respectively, and USGS stations 021989715 Savannah River at Garden City and 021989773 Savannah River at USACE Dock, located upstream and downstream of the lower Front River diffuser respectively.

The DO concentrations were evaluated for years 2014, 2016, and 2019 during the Test Run days of March 14 through May 12 at the USGS stations located on the Back River (***Table 4-2*** and ***Table 4-3***) and lower Front River

(***Table 4-4*** and ***Table 4-5***). The statistical analyses on the DO concentrations in the Back River indicated there was an average increase of 0.8 mg/L to 1.4 mg/L (2019 vs. 2014 and 2016) due to the injection of the oxygen loads by the Plant (***Table 4-2*** and ***Table 4-3***). In the lower Front River, the increase in DO concentrations caused by the Plant was in the range of 0.2 mg/L to 1.1 mg/L (2019 vs. 2014 and 2016) (***Table 4-4*** and ***Table 4-5***).

Table 4-2 Statistical analysis of the DO concentrations at USGS station 021989793, Little Back River at Hog Island during the Test Run days

DO (mg/L)	2014	2016	2019	Delta (2019 - 2014)	Delta (2019 - 2016)
Average	7.41	6.80	8.19	0.78	1.39
10^{th} %tile	6.00	5.70	6.60	0.60	0.90
50^{th} %tile	7.40	7.00	8.30	0.90	1.30
75^{th} %tile	8.20	7.30	9.10	0.90	1.80
90^{th} %tile	8.50	7.60	9.60	1.10	2.00

Table 4-3 Statistical analysis of the DO concentrations at USGS station 0219897945, Back River downstream of US 17 during the Test Run days

DO (mg/L)	2014	2016	2019	Delta (2019 - 2014)	Delta (2019 - 2016)
Average	6.96	6.38	7.82	0.86	1.44
10^{th} %tile	5.60	5.03	6.00	0.40	0.97
50^{th} %tile	7.00	6.50	7.80	0.80	1.30
75^{th} %tile	7.70	7.00	8.80	1.10	1.80
90^{th} %tile	8.20	7.40	9.50	1.30	2.10

Table 4-4 Statistical analysis of the DO concentrations at USGS station 021989715, Savannah River at Garden City during the Test Run days

DO (mg/L)	2014	2016	2019	Delta (2019 - 2014)	Delta (2019 - 2016)
Average	6.69	5.81	6.90	0.21	1.09
10^{th} %tile	5.30	4.10	5.40	0.10	1.30
50^{th} %tile	6.70	6.00	7.00	0.30	1.00
75^{th} %tile	7.50	6.60	7.80	0.30	1.20
90^{th} %tile	8.20	7.00	8.30	0.10	1.30

Table 4-5 Statistical analysis of the DO concentrations at USGS station 021989773, Savannah River at USACE Dock during the Test Run days

DO (mg/L)	2014	2016	2019	Delta (2019 - 2014)	Delta (2019 - 2016)
Average	6.49	5.71	6.81	0.31	1.09
10th %tile	5.40	4.10	5.50	0.10	1.40
50th %tile	6.50	6.00	6.80	0.30	0.80
75th %tile	7.20	6.30	7.70	0.50	1.40
90th %tile	7.50	6.60	8.10	0.60	1.50

Figure 4-3 shows the 15-minute DO concentrations at the USGS station 021989793 at Hog Island and the concentrations appeared to be higher during the Test Run period in 2019 in comparison to the same period of time in earlier years. In addition, average DO concentrations during the Test Run period were elevated in 2019 compared to 2018 (***Figure 4-4***). The elevated DO concentrations in 2019 were due to the injection of oxygen by the Plant.

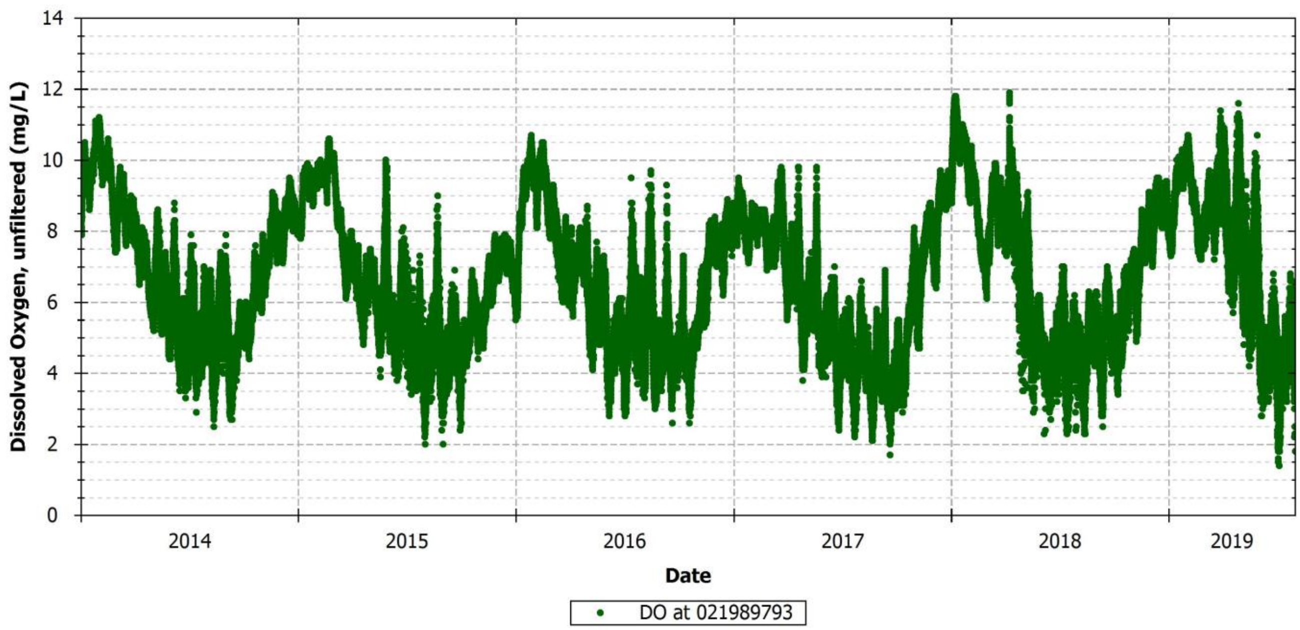


Figure 4-3 15-minute DO concentrations at USGS station 021989793, Little Back River at Hog Island, near Savannah, GA

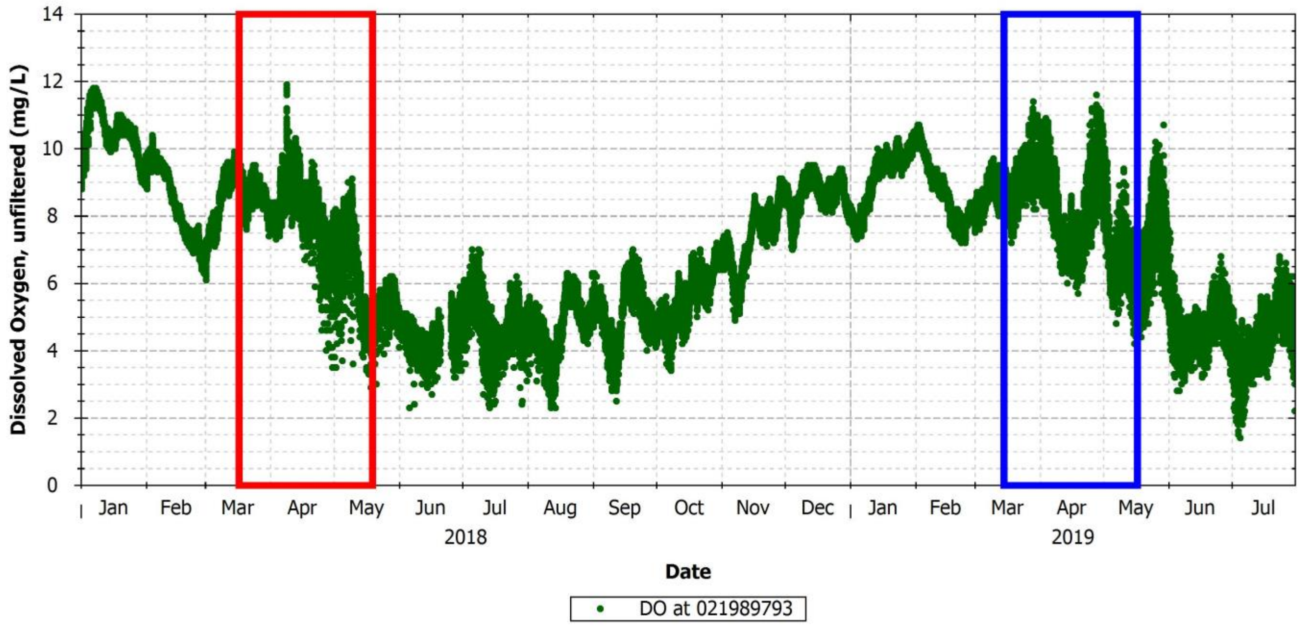


Figure 4-4 15-minute DO at USGS station 021989793 during the years 2018 and 2019

4.3 LONG-TERM DYE DATA

The Back River dye study conducted on April 12, 2019 showed that dye remained present in the water column near the Back River diffusers for several days following the initial dye release (***Figure 4-5***). The released dye was registered by the platform sondes on subsequent ebb and flood tidal swings. The dye study also showed that the water column was fully vertically mixed because the shallow and deep sondes reported approximately the same value for dye concentration.

USGS data upstream of the Back River diffuser (Hog Island) detected elevated dye concentrations following dye releases that occurred during the WCTE study (***Figure 4-6***). Spikes in dye concentrations occurred after the dye releases on March 29, April 23, and April 25, 2019. Dye remained in Back River for over one (1) month following last dye release on April 25, 2019 before returning to background conditions around five (5) relative fluorescence units (RFU) (***Figure 4-6***). Dye injected into the lower Front River on April 11, 2019 during the Test Run caused increases in dye concentrations in the Middle River on that date (***Figure 4-7***). Other high dye concentrations in the Middle River were likely a result of water from the Back River entering the Middle River during certain tidal conditions.

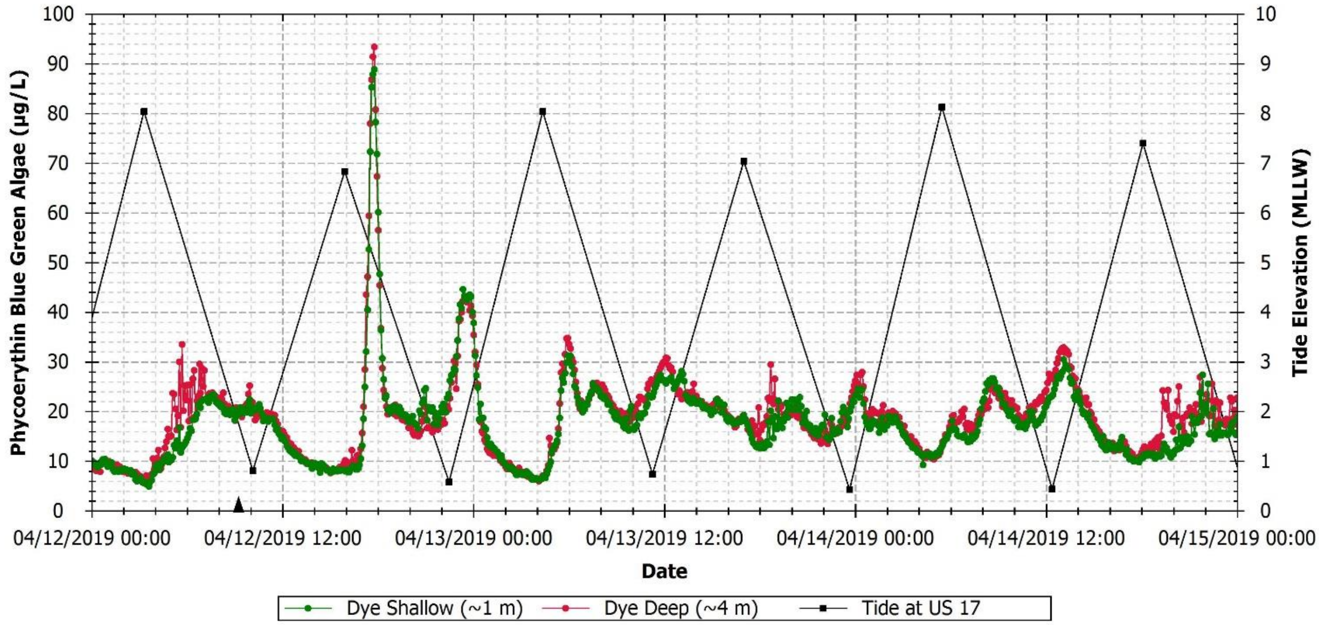


Figure 4-5 Back River platform three-day dye response

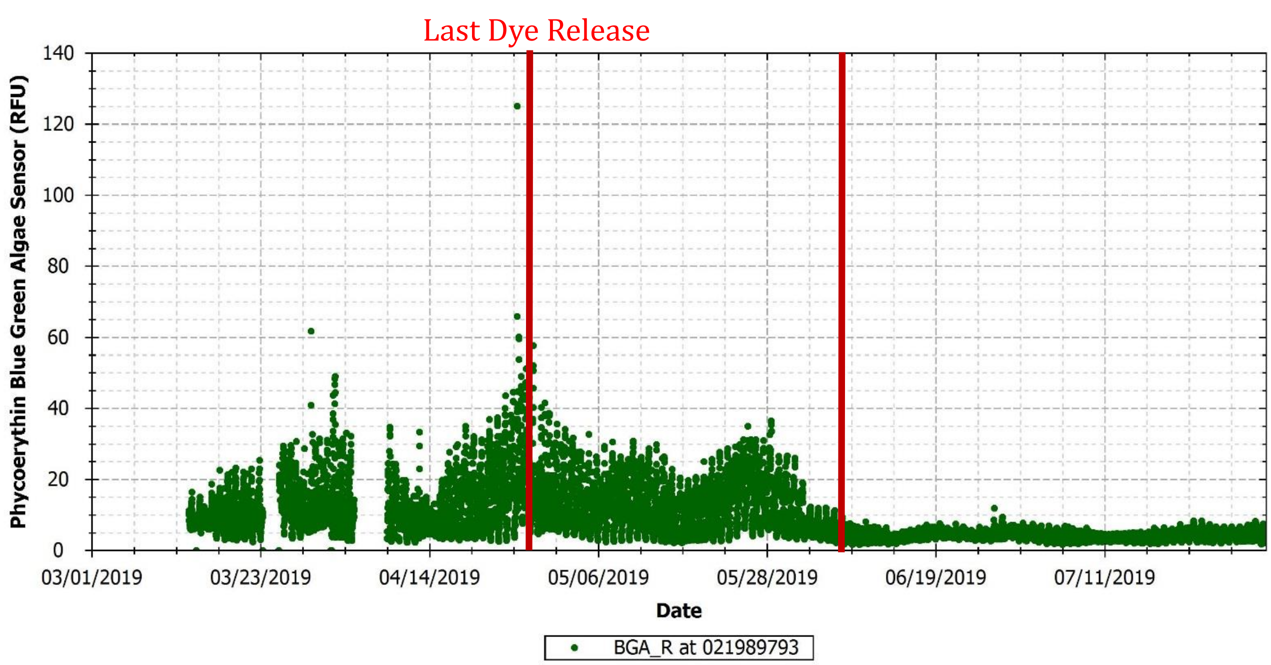


Figure 4-6 Back River upstream USGS dye March through July 2019

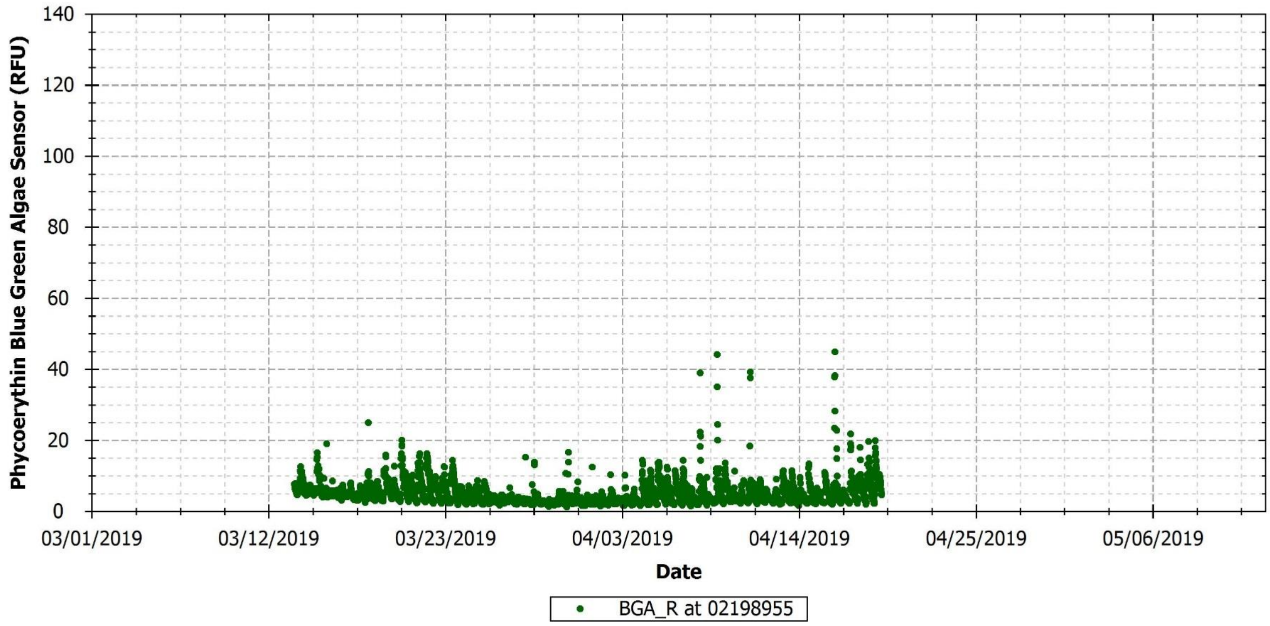


Figure 4-7 Middle River USGS dye March through July 2019

4.4 USGS DYE CROSS-SECTION DATA

Cross-sectional profiling was conducted by USGS field personnel during the April dye releases on April 12, 2019 and April 25, 2019 in the Back River and April 11, 2019 in the lower Front River. The cross-sectional profile data included measured water temperature, discharge, gage height, specific conductance, phycoerythin fluorescence, and depth to bottom. Phycoerythin fluorescence (RFU) measures red-orange fluorescence and was used to measure the concentration of dye in the water, similar to BGA. The profiles were collected at three (3) USGS continuous monitoring stations: 02198955 (Middle River at Fish Hole at Port Wentworth), 021989793 (Little Back River at Hog Island), and 0219897945 (Back River downstream of US 17). Profile data were collected vertically throughout the water column, and data collected at depths from 0 to 3 feet were defined as shallow, 4 to 5.5 feet as middle, and 6 to 19 feet as deep.

Three (3) cross-sectional profiles were taken in the Back River on the day of the April 12, 2019 dye release: two (2) at USGS station 021989793, and one (1) at USGS stations 0219897945. Prior to the dye release at 9:45 am, RFU concentrations in the Back River were typically less than 10 RFU (***Figure 4-8***). Approximately one (1) hour after dye release, the dye had traveled upstream to USGS station 021989793 and the plume spanned approximately half of the channel cross-section (***Figure 4-9***). The dye was close to background conditions when the cross-sectional data were collected at USGS station 0219897945, indicating that the plume had not moved downstream when sampling occurred (***Figure 4-10***). The phycoerythin fluorescence data showed that the water column was well mixed (***Figure 4-8*** through ***Figure 4-10***).

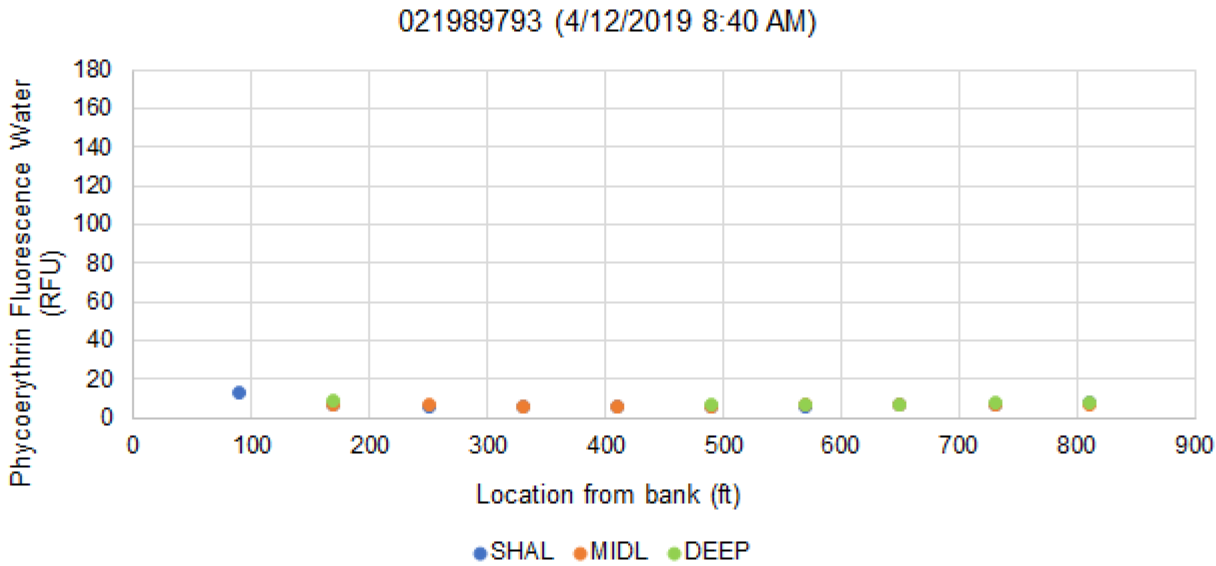


Figure 4-8 Cross-sectional profile starting at April 12, 2019 8:40 AM at USGS station 021989793

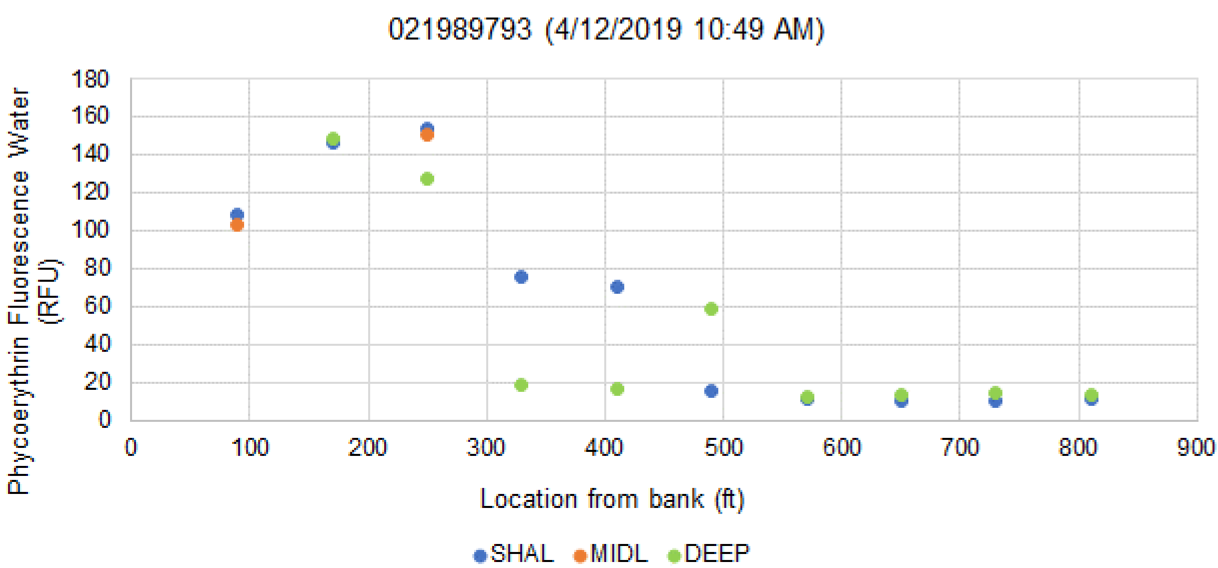


Figure 4-9 Cross-sectional profile starting at April 12, 2019 10:49 AM at USGS station 021989793

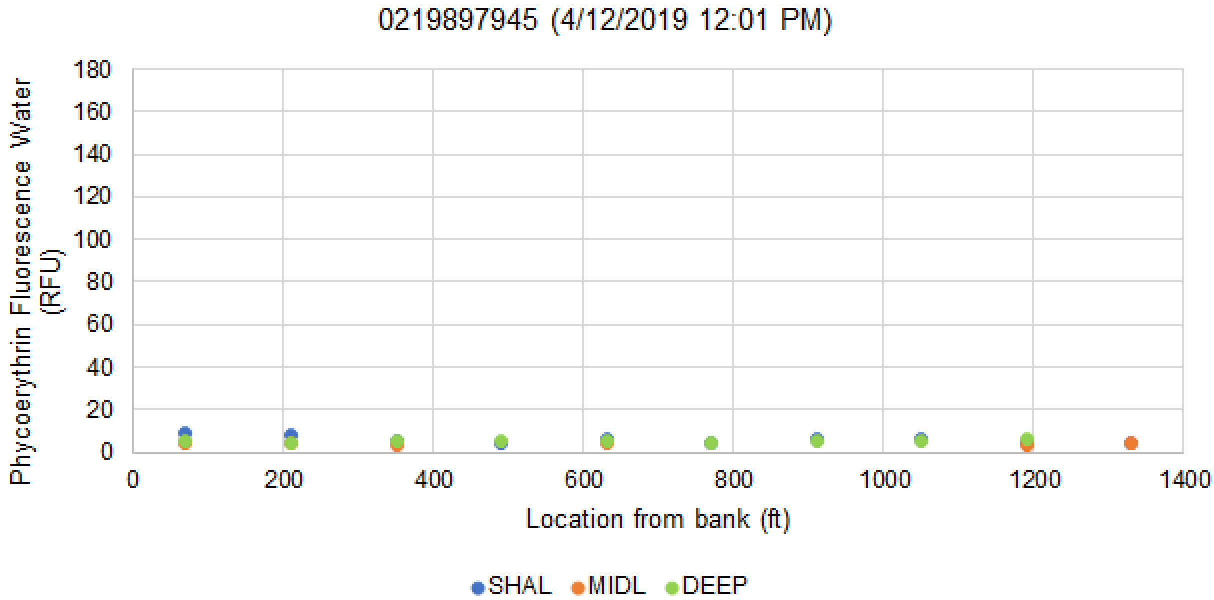


Figure 4-10 Cross-sectional profile starting at April 12, 2019 12:01 AM at USGS station 0219897945

Two (2) cross-sectional profiles were taken in the Back River on the day of the April 25, 2019 dye release at USGS station 021989793. The first cross-sectional profile was collected approximately 10 minutes prior to the dye release and concentrations were at background conditions (around 10 RFU) (***Figure 4-11***). Similar to the April 12, 2019 dye release, dye was detected at the station approximately one (1) hour after the dye release throughout the water column (***Figure 4-12***). The plume spanned approximately two-thirds of the channel cross-section, and the dye was detected on the opposite bank from the April 12, 2019 study (***Figure 4-12***).

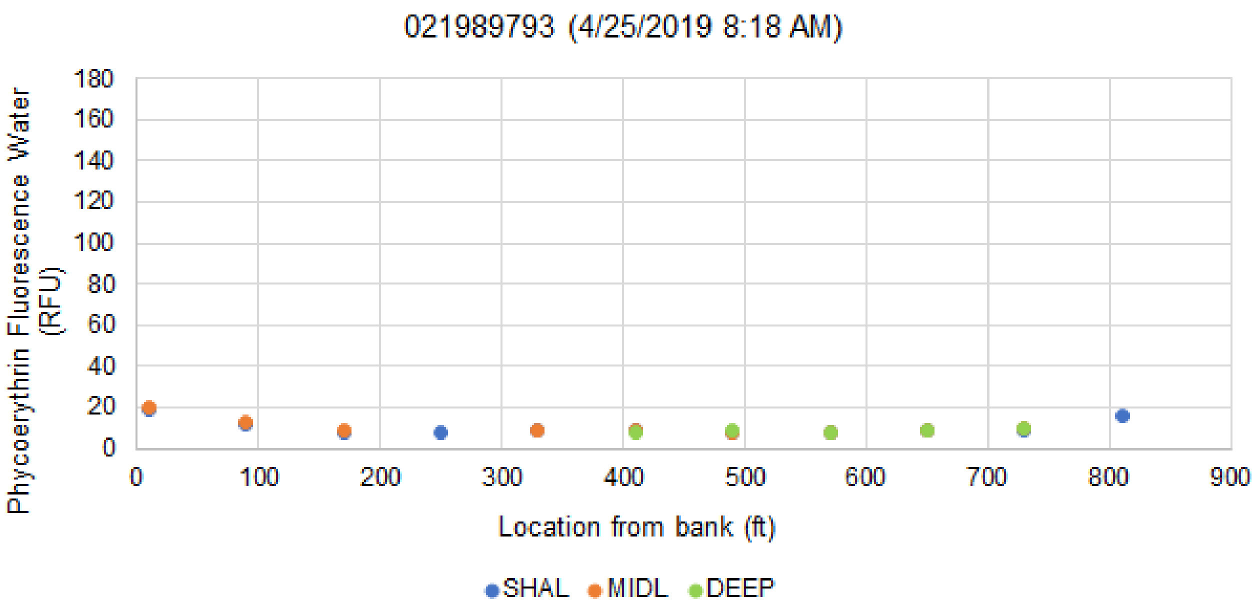


Figure 4-11 Cross-sectional profile starting at April 25, 2019 8:18 AM at USGS station 021989793

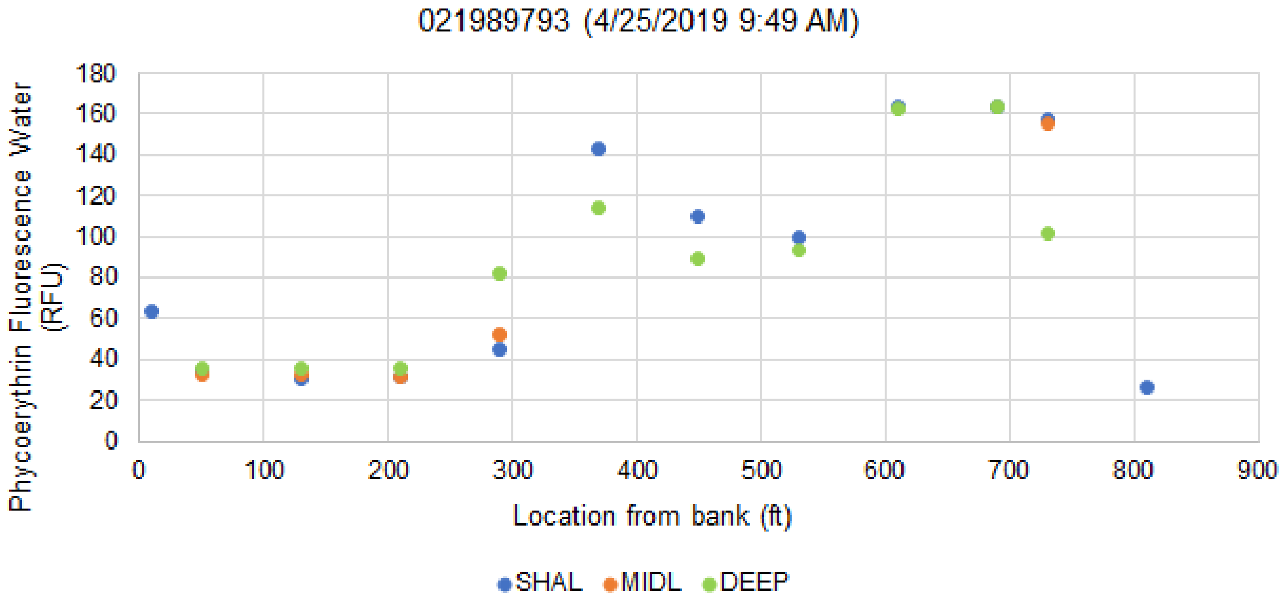


Figure 4-12 Cross-sectional profile starting at April 25, 2019 9:49 AM at USGS station 021989793

4.5 USGS DO ANALYSIS

The USGS stations located upstream and downstream of the diffusers show the presence of the DO plume in the Back River when the Plant was operating during the Test Run (yellow boxes) (***Figure 4-13*** and ***Figure 4-14***). The plant was operated for seven (7) days following the end of the Test Run (May 13, 2019 through May 19, 2019), and the evidence of the plume was still visible during these periods and remained present until early June. DO saturation in June and July were approximately 30% lower (blue boxes) when the Plant was not operating.

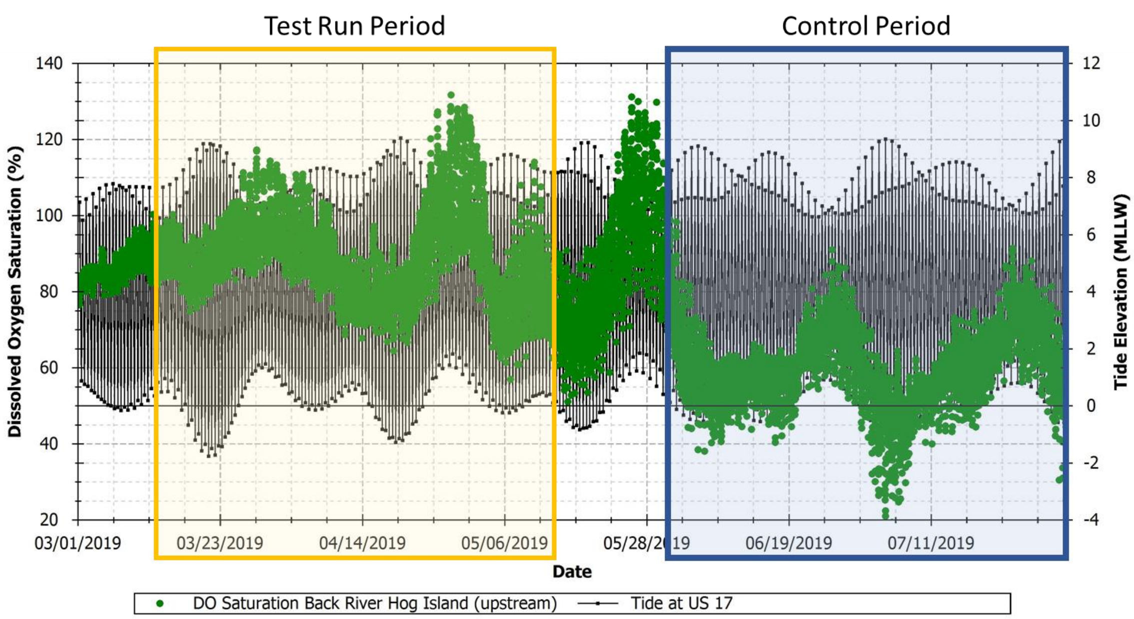


Figure 4-13 Back River upstream USGS DO saturation March through July 2019

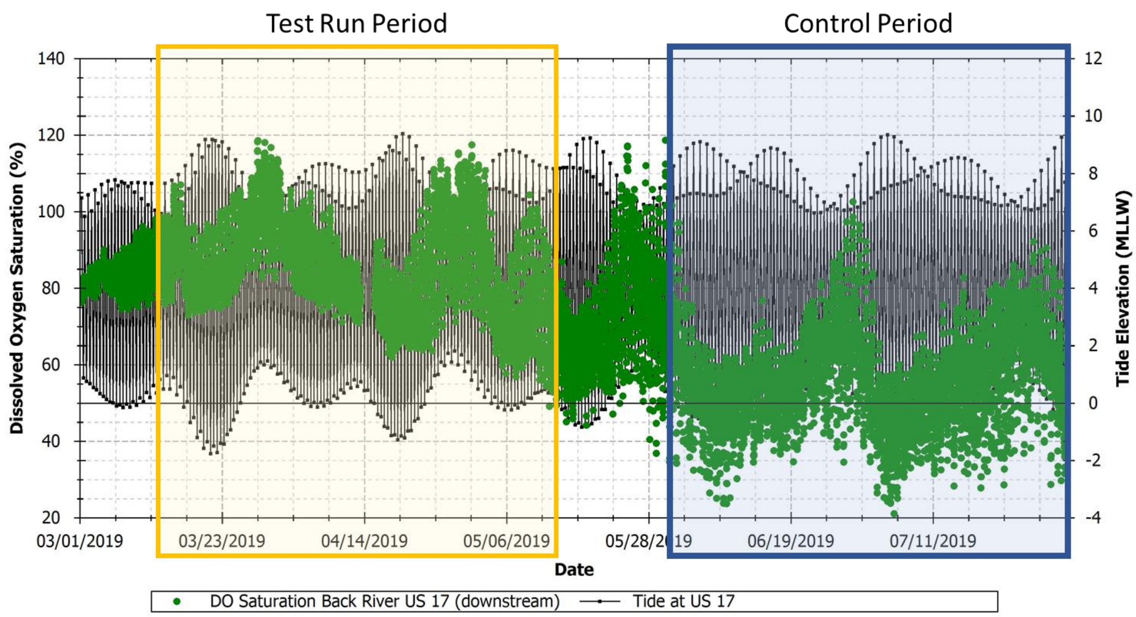


Figure 4-14 Back River downstream USGS DO saturation March through July 2019

4.6 BUOY DO DATA

At the north buoy (upstream of the lower Front River diffuser) periods of elevated DO saturation were clearly visible at the beginning of flood tide indicating that the sonde was measuring the DO plume (***Figure 4-15***). The yellow box in the figure identifies a period of time on March 18, 2019 and March 19, 2019 that the Plant was off for maintenance. During this period the elevated DO saturation values at the beginning of flood tide were not present and the DO saturation values were overall lower during this period as compared to the periods when the Plant was operating.

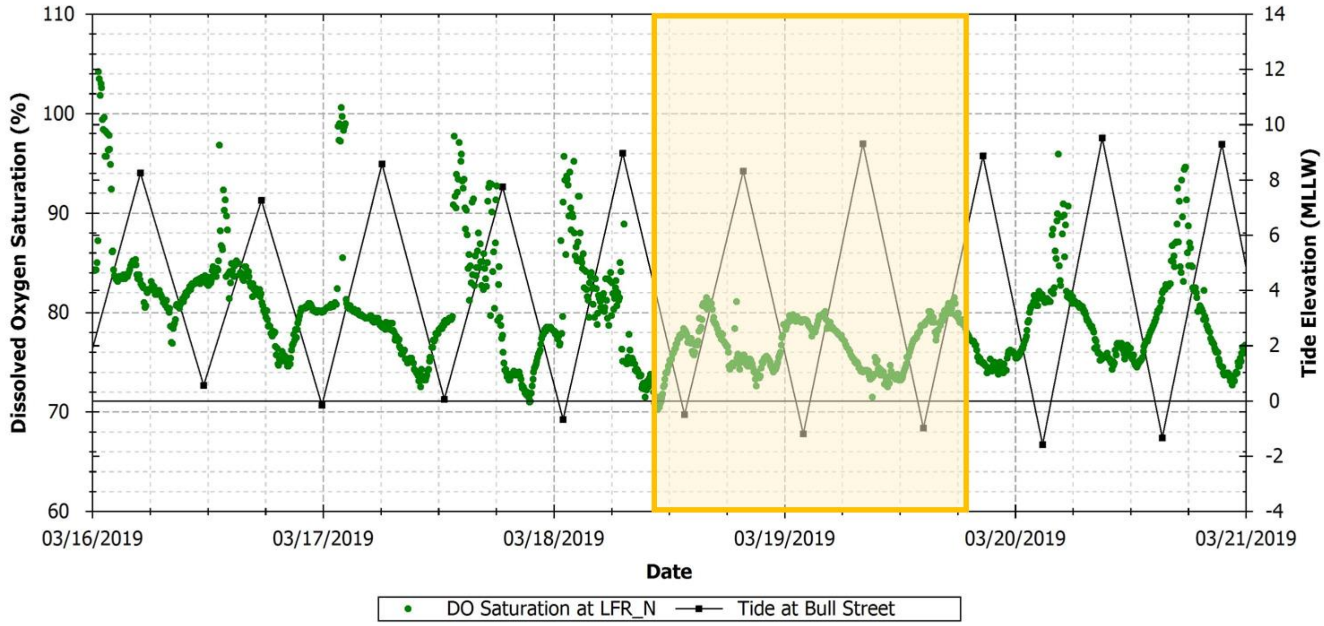


Figure 4-15 Lower Front River north buoy plume interception and Plant maintenance

4.7 DRIFT AND PROFILE DATA

During drift monitoring on the Back River, when all three sondes intersected the dye plume DO saturation values increased (***Figure 4-16***). This provided confirmation that drift data collection intercepted the plume on the Back River and DO plume was measurable. The DO saturation and dye data also showed that the water column was well mixed as both DO saturation and dye were only slightly stratified.

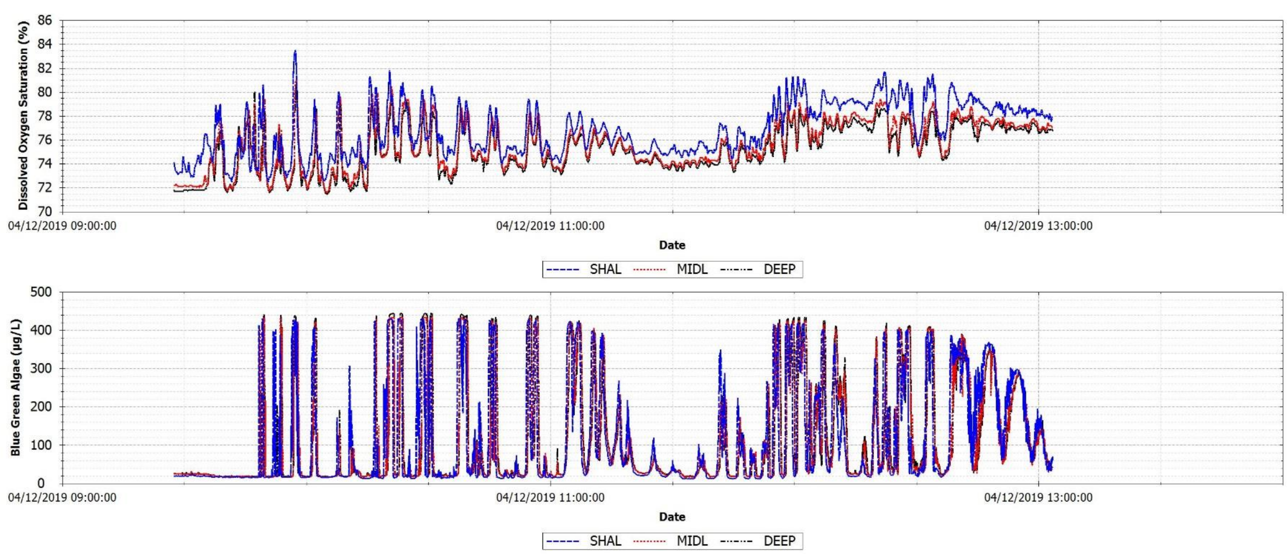


Figure 4-16 Back River April 12, 2019 drift data collection

During the April 23, 2019 Back River dye release, drift profiles were collected over a two (2) mile longitudinal length of the river, beginning at the diffuser. Dye concentrations and DO saturation values both decreased with distance from the diffuser as the plume mixed with the ambient water (***Figure 4-17***). Further from the diffuser, dye and higher DO saturation values were predominantly detected in deeper water, indicating that the plume was traveling along the bottom of the water column and that DO was not being lost to the atmosphere.

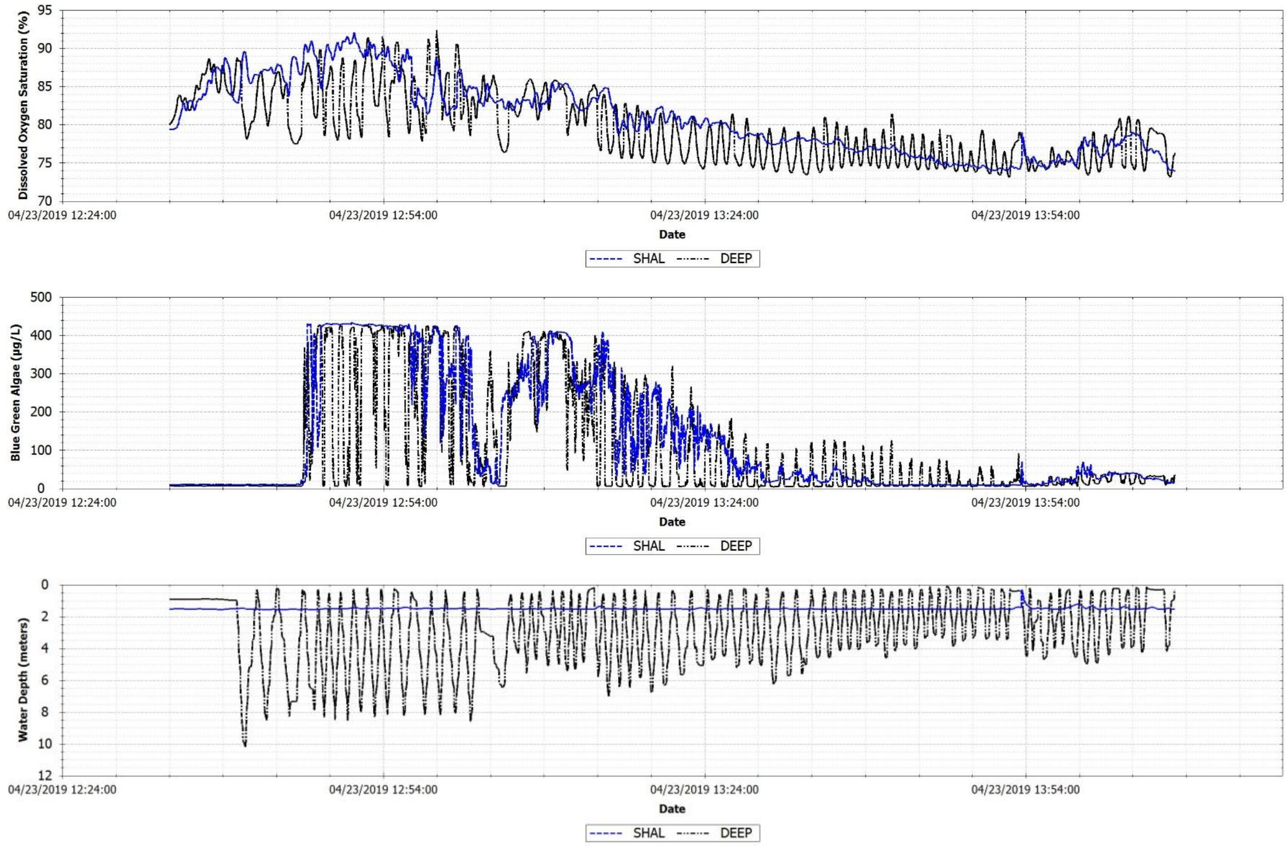


Figure 4-17 Back River April 23, 2019 combination profile

During drift monitoring on the lower Front River, when all three sondes intersected the dye plume, DO saturation values increased (***Figure 4-18***). This provided confirmation that drift data collection intercepted the plume on the lower Front River. The data also showed that DO saturation was well mixed in the water column.

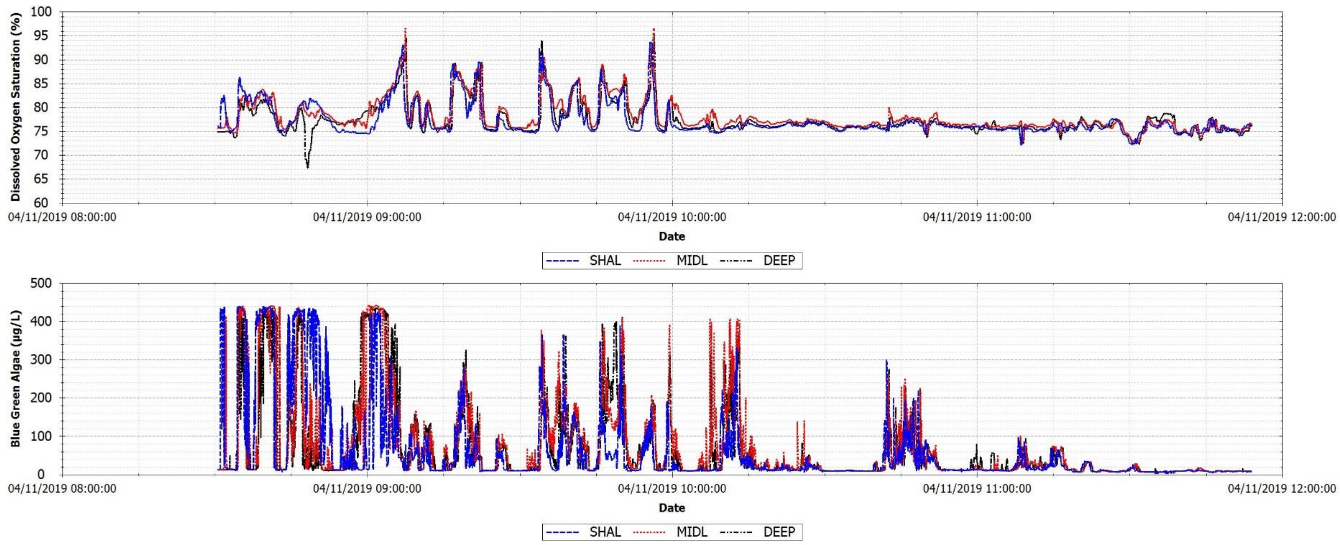


Figure 4-18 Lower Front River April 11, 2019 drift data collection

4.8 STATIONARY PROFILE DATA

Stationary profiles were collected near the semi-permanent buoys and on both sides of the platform on profiling days. These profiles were used to verify the stability of DO saturation, DO concentration, temperature, and salinity values being collected by the deployed semi-permanent buoy and platform sondes. ***Table 4-6*** presents a ten (10) measurement example of the values collected by the profile sonde at a depth similar to the depth of the buoy measurements in comparison to values obtained by semi-permanent buoy sondes at the time closest to the time the profile was measured. The full comparison in provided in **APPENDIX J**. ***Table 4-7*** presents a single profile measurement example of the values collected by the profile sonde at a depth similar to the depth of the platform measurements in comparison to values obtained by platform sondes at the time closest to the time the profile was measured. The full comparison in provided in **APPENDIX J**. Comparing the values collected by side-by-side indicate good agreement (typically less than ±5%) and verified that sondes could be deployed for long periods of time with little to no calibration drift.

Table 4-6 Profile and semi-permanent buoy comparison

Location	Tide	Date	Time	Depth (m)		DO Saturation (%)		DO (mg/L)		Salinity (PPT)		Temperature (°C)	
				Pro	Buoy	Pro	Buoy	Pro	Buoy	Pro	Buoy	Pro	Buoy
LFR_A	Ebb	3/26/2019	8:32	0.39	0.49	88.3	88.2	8.78	8.77	0.12	0.12	15.62	15.61
LFR_A	Flood	3/26/2019	14:01	0.45	0.83	90.3	89.2	8.88	8.82	0.91	0.57	15.89	15.78
LFR_A	Ebb	3/28/2019	10:19	0.44	0.73	83.3	82.9	8.42	8.32	0.71	0.74	14.68	15.02
LFR_A	Flood	3/28/2019	15:45	0.61	0.54	88.2	88.1	8.74	8.65	0.53	0.52	15.63	16.11
LFR_A	Ebb	3/31/2019	13:00	0.38	0.25	87.2	87.1	8.49	8.47	0.60	0.59	16.49	16.52
LFR_A	Ebb	4/2/2019	14:33	0.66	0.70	83.1	82.9	8.26	8.22	0.86	1.02	15.44	15.49
LFR_A	Flood	4/4/2019	9:32	0.64		77.6	77.7	7.77	7.72	2.29	1.66	14.72	15.21
LFR_A	Ebb	4/4/2019	15:38	0.63		83.4	83.2	8.30	8.27	0.24	0.24	15.54	15.61
LFR_A	Flood	4/9/2019	12:20	0.51		72.3	75.4	6.82	7.07	1.11	1.01	17.86	18.17
LFR_A	Flood	4/18/2019	9:23	0.48	0.43	59.1	59.1	5.41	5.34	1.41	1.27	19.27	19.98

Table 4-7 Profile and platform comparison

Location	Tide	Date	Time	Depth (m)		DO Saturation (%)		DO (mg/L)		Salinity (PPT)		Temperature (°C)	
				Pro	Buoy	Pro	Buoy	Pro	Buoy	Pro	Buoy	Pro	Buoy
L9-S	Ebb	3/14/2019	9:40	1.30	1.19	86.10	90.24	8.46	8.81	0.05	0.07	16.19	16.50
L12-S	Ebb	3/14/2019	9:40	1.30	1.21	86.10	84.42	8.46	8.23	0.05	0.07	16.19	16.56
L13-V	Ebb	3/14/2019	9:40	1.94	1.86	85.70	84.18	8.43	8.23	0.05	0.08	16.17	16.43
L8-M	Ebb	3/14/2019	9:40	2.66	2.79	84.60	84.81	8.32	8.29	0.05	0.09	16.15	16.41
L5-M	Ebb	3/14/2019	9:40	2.66	2.85	84.60	83.77	8.32	8.18	0.05	0.09	16.15	16.48
L15-V	Ebb	3/14/2019	9:40	3.64	3.37	84.60	83.40	8.32	8.14	0.05	0.09	16.15	16.52
L1-D	Ebb	3/14/2019	9:40	4.20	4.29	84.40	84.49	8.31	8.26	0.05	0.10	16.14	16.42
L4-D	Ebb	3/14/2019	9:40	4.43	4.34	84.40	83.43	8.30	8.16	0.05	0.10	16.13	16.38
L12-S	Flood	3/14/2019	15:48	1.13	1.12	95.70	95.59	9.11	9.02	0.88	0.80	17.48	17.92
L9-S	Flood	3/14/2019	15:48	1.18	1.19	95.50	96.45	9.09	9.12	0.88	0.81	17.45	17.81
L13-V	Flood	3/14/2019	15:49	1.64	1.82	94.00	95.66	8.98	9.04	0.89	0.81	17.32	17.85
L8-M	Flood	3/14/2019	15:49	2.77	2.71	93.10	96.35	8.89	9.10	0.89	0.81	17.29	17.87
L5-M	Flood	3/14/2019	15:49	2.87	2.85	92.90	95.32	8.88	9.00	0.89	0.81	17.28	17.88
L15-V	Flood	3/14/2019	15:49	3.29	3.36	91.80	95.28	8.78	8.99	0.89	0.82	17.23	17.91
L4-D	Flood	3/14/2019	15:49	4.19	4.16	91.60	95.17	8.76	8.98	0.89	0.82	17.24	17.90
L1-D	Flood	3/14/2019	15:49	4.27	4.28	91.60	95.92	8.76	9.05	0.89	0.82	17.24	17.91

5.0 WATER COLUMN TRANSFER EFFECIENCY

The WCTE calculation estimated the percentage of oxygen supplied by the Speece Cone System that remained in the Savannah River and Estuary water column. Ideally, the flow and oxygen discharged by the Plant through the diffusers would be completely mixed with the ambient water; however, if the plume of super-saturated water reached the surface, oxygen could escape the water column and reduce the WCTE. Therefore, the WCTE calculation needed two pieces of information: (1) the mass of oxygen injected and (2) the mass of oxygen lost to the atmosphere.

Initially, the occurrence of effervescence was considered a possible source of oxygen loss to the atmosphere; however, no indication of effervescence was noted during the fourteen (14) days of WCTE or during the sixty (60) days of Test Run data collection. During the three (3) months of data collection, the injected oxygen experienced an estimated dilution of at least 40:1 and was well mixed within the water column, which likely prevented effervescence from occurring.

The load of oxygen supplied by the Speece Cone System was determined by an oxygen sensor and flow measuring devices that were installed on each Speece Cone discharge pipe. These sensors provided flow and oxygen concentration measurements of the DO super-saturated water that was discharged into the water column.

The monitoring data collected during both the WCTE data collection (February 2019) and Test Run data collection (March to May 2019) were used to estimate the mass of oxygen released to the atmosphere across the air-water interface when conditions were present that allowed for a plume of super-saturated water to reach the water column surface. DO was available for release, or transfer, to the atmosphere when the DO saturation at the air-water interface was greater than 100%. The evaluation used all of the QA/QC data listed in **Section 3.0** in this report to estimate when excess DO was near the water surface and evaluated the daily length of time and area of the excess DO plume. The methods used to calculate WCTE are contained in the Water Column Transfer Efficiency Report (LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2019b). **APPENDIX H** provides maps showing the Daily Intermittent DO Loss Area, a table of the Daily Continuous DO Loss Area, and information used in the WCTE calculations.

The QA/QC team calculated WCTE and provided results to USACE on a continual weekly basis throughout the Test Run period. After the completion of the Test Run, the WCTE results were updated with the QA/QC'd Plant data.

Table 5-1 and ***Table 5-2*** present average inputs tabulated across river specific DO loss areas and the resulting Daily River DO Loss and WCTE for the lower Front River and Back River respectively. ***Table 5-3*** presents the river specific Plant loads, river specific WCTE, and the downriver systems combined WCTE results. ***Figure 5-1*** presents the results for the WCTE calculations for the Test Run period in comparison to the Back River predicted tidal and lunar cycles. In the figure, the orange line shows the daily WCTE results for the Back River diffuser, the blue line shows the daily WCTE results for the Front River diffuser, and the green line shows the daily WCTE results for the Back River and lower Front River combined WCTE. The Test Run average combined WCTE was approximately 98%. During the Test Run period, the average operating plant load injected by the Downriver Plant under normal conditions was 13,385 pounds/day.

Table 5-1 Test Run Front River daily WCTE calculation inputs and outputs summary

Date	DO Loss Area (m^2)	Final Daily River Time (min)	Area weighted average Excess Oxygen (mg/L)	Depth (m)	Ka (1/day)	KL (m/day)	Daily River DO Loss (pounds/day)	Daily Plant DO Load (pounds/day)	Front River WCTE
3/14/2019	86	45	0.313	1.5	0.485	0.7	0.001	5,978	100.0%
3/15/2019	404	100	0.304	1.5	0.517	0.8	0.015	9,697	100.0%
3/16/2019	21	25	0.287	1.5	0.478	0.7	0.000	9,375	100.0%
3/17/2019	35	65	0.121	1.5	0.340	0.5	0.000	9,386	100.0%
3/18/2019	0	0	0.000	1.5	0.309	0.5	0.000	4,263	100.0%
3/19/2019	0	0	0.000	1.5	0.511	0.8	0.000	1,638	100.0%
3/20/2019	233	60	0.402	1.5	0.408	0.6	0.005	8,883	100.0%
3/21/2019	209	85	0.319	1.5	0.372	0.6	0.005	9,170	100.0%
3/22/2019	42	17	0.138	1.5	0.568	0.9	0.000	9,554	100.0%
3/23/2019	42	17	0.463	1.5	0.398	0.6	0.000	9,608	100.0%
3/24/2019	71	105	0.257	1.5	0.394	0.6	0.002	9,377	100.0%
3/25/2019	128	148	0.240	1.5	0.432	0.6	0.005	9,140	100.0%
3/26/2019	1,329	110	0.423	1.5	0.424	0.6	0.060	9,015	100.0%
3/27/2019	0	0	0.000	1.5	0.552	0.8	0.000	8,950	100.0%
3/28/2019	0	0	0.000	1.5	0.384	0.6	0.000	8,289	100.0%
3/29/2019	0	0	0.000	1.5	0.315	0.5	0.000	8,742	100.0%
3/30/2019	0	0	0.000	1.5	0.352	0.5	0.000	9,073	100.0%
3/31/2019	76	60	0.577	1.5	0.594	0.9	0.004	8,084	100.0%
4/1/2019	0	0	0.000	1.5	0.551	0.8	0.000	7,212	100.0%
4/2/2019	0	0	0.000	1.5	0.585	0.9	0.000	9,244	100.0%
4/3/2019	184	60	0.236	1.5	0.278	0.4	0.002	9,226	100.0%
4/4/2019	340	86	0.731	1.5	0.397	0.6	0.019	9,666	100.0%
4/5/2019	21	5	0.315	1.5	0.431	0.6	0.000	9,350	100.0%
4/6/2019	42	20	0.170	1.5	0.308	0.5	0.000	9,068	100.0%
4/7/2019	21	15	0.079	1.5	0.309	0.5	0.000	9,034	100.0%
4/8/2019	0	0	0.000	1.5	0.462	0.7	0.000	9,027	100.0%
4/9/2019	0	0	0.000	1.5	0.421	0.6	0.000	8,763	100.0%
4/10/2019	0	0	0.000	1.5	0.410	0.6	0.000	9,751	100.0%
4/11/2019	0	0	0.000	1.5	0.507	0.8	0.000	9,939	100.0%
4/12/2019	0	0	0.000	1.5	0.608	0.9	0.000	9,782	100.0%
4/13/2019	0	0	0.000	1.5	0.512	0.8	0.000	10,250	100.0%
4/14/2019	0	0	0.000	1.5	0.707	1.1	0.000	10,220	100.0%
4/15/2019	0	0	0.000	1.5	0.887	1.3	0.000	9,889	100.0%
4/16/2019	0	0	0.000	1.5	0.410	0.6	0.000	8,352	100.0%
4/17/2019	0	0	0.000	1.5	0.354	0.5	0.000	9,421	100.0%
4/18/2019	0	0	0.000	1.5	0.493	0.7	0.000	9,684	100.0%
4/19/2019	0	0	0.000	1.5	0.905	1.4	0.000	9,460	100.0%
4/20/2019	0	0	0.000	1.5	0.746	1.1	0.000	9,543	100.0%
4/21/2019	0	0	0.000	1.5	0.515	0.8	0.000	9,938	100.0%
4/22/2019	0	0	0.000	1.5	0.310	0.5	0.000	10,038	100.0%

Date	DO Loss Area (m^2)	Final Daily River Time (min)	Area weighted average Excess Oxygen (mg/L)	Depth (m)	Ka (1/day)	KL (m/day)	Daily River DO Loss (pounds/day)	Daily Plant DO Load (pounds/day)	Front River WCTE
4/23/2019	21	5	0.152	1.5	0.337	0.5	0.000	10,113	100.0%
4/24/2019	0	0	0.000	1.5	0.418	0.6	0.000	10,008	100.0%
4/25/2019	0	0	0.000	1.5	0.390	0.6	0.000	10,057	100.0%
4/26/2019	0	0	0.000	1.5	0.756	1.1	0.000	9,937	100.0%
4/27/2019	0	0	0.000	1.5	0.435	0.7	0.000	9,738	100.0%
4/28/2019	0	0	0.000	1.5	0.456	0.7	0.000	9,946	100.0%
4/29/2019	0	0	0.000	1.5	0.461	0.7	0.000	9,762	100.0%
4/30/2019	0	0	0.000	1.5	0.401	0.6	0.000	8,362	100.0%
5/1/2019	0	0	0.000	1.5	0.432	0.6	0.000	9,494	100.0%
5/2/2019	0	0	0.000	1.5	0.498	0.7	0.000	9,166	100.0%
5/3/2019	0	0	0.000	1.5	0.415	0.6	0.000	9,433	100.0%
5/4/2019	0	0	0.000	1.5	0.354	0.5	0.000	9,296	100.0%
5/5/2019	0	0	0.000	1.5	0.604	0.9	0.000	9,260	100.0%
5/6/2019	0	0	0.000	1.5	0.372	0.6	0.000	9,348	100.0%
5/7/2019	0	0	0.000	1.5	0.493	0.7	0.000	9,965	100.0%
5/8/2019	0	0	0.000	1.5	0.514	0.8	0.000	10,122	100.0%
5/9/2019	0	0	0.000	1.5	0.548	0.8	0.000	9,684	100.0%
5/10/2019	0	0	0.000	1.5	0.496	0.7	0.000	9,886	100.0%
5/11/2019	0	0	0.000	1.5	0.499	0.7	0.000	9,920	100.0%
5/12/2019	0	0	0.000	1.5	0.472	0.7	0.000	9,732	100.0%

Note Daily River DO Loss and resulting WCTE values are actual calculated loss (summed from individual areas) and not based on averages as presented in table

Table 5-2 Test Run Back River daily WCTE calculation inputs and outputs summary

Date	DO Loss Area (m^2)	Final Daily River Time (min)	Area weighted average Excess Oxygen (mg/L)	Depth (m)	Ka (1/day)	KL (m/day)	Daily River DO Loss (pounds/day)	Daily Plant DO Load (pounds/day)	Back River WCTE
3/14/2019	289	160	0.067	1.5	0.625	0.9	0.004	2,443	100.0%
3/15/2019	204	201	0.151	1.5	0.629	0.9	0.009	3,707	100.0%
3/16/2019	372	195	0.128	1.5	0.643	1.0	0.014	3,592	100.0%
3/17/2019	0	0	0.000	1.5	0.474	0.7	0.000	3,538	100.0%
3/18/2019	0	0	0.000	1.5	0.478	0.7	0.000	1,574	100.0%
3/19/2019	0	0	0.000	1.5	0.689	1.0	0.000	777	100.0%
3/20/2019	168	75	0.098	1.5	0.579	0.9	0.002	3,530	100.0%
3/21/2019	153	70	0.129	1.5	0.567	0.8	0.002	3,631	100.0%
3/22/2019	105	62	0.090	1.5	0.740	1.1	0.001	3,744	100.0%
3/23/2019	168	182	0.067	1.5	0.602	0.9	0.003	3,609	100.0%
3/24/2019	189	320	0.210	1.5	0.593	0.9	0.017	3,663	100.0%
3/25/2019	3,277	557	0.190	1.5	0.616	0.9	0.489	3,557	100.0%

Date	DO Loss Area (m^2)	Final Daily River Time (min)	Area weighted average Excess Oxygen (mg/L)	Depth (m)	Ka (1/day)	KL (m/day)	Daily River DO Loss (pounds/day)	Daily Plant DO Load (pounds/day)	Back River WCTE
3/26/2019	92,793	613	0.210	1.5	0.540	0.8	14.792	3,473	99.6%
3/27/2019	92,884	810	0.721	1.5	0.670	1.0	83.416	3,369	97.5%
3/28/2019	92,884	1,095	0.942	1.5	0.491	0.7	107.968	3,057	96.5%
3/29/2019	92,884	990	0.702	1.5	0.433	0.6	64.162	3,723	98.3%
3/30/2019	92,884	960	0.628	1.5	0.496	0.7	63.804	3,964	98.4%
3/31/2019	92,884	1,050	0.696	1.5	0.725	1.1	112.976	3,645	96.9%
4/1/2019	92,884	480	0.214	1.5	0.682	1.0	14.959	3,054	99.5%
4/2/2019	92,884	375	0.379	1.5	0.739	1.1	22.391	3,675	99.4%
4/3/2019	7,353	271	0.237	1.5	0.428	0.6	0.465	3,786	100.0%
4/4/2019	73,239	345	0.270	1.5	0.544	0.8	8.536	3,895	99.8%
4/5/2019	189	181	0.352	1.5	0.612	0.9	0.017	3,857	100.0%
4/6/2019	147	65	0.082	1.5	0.491	0.7	0.001	3,833	100.0%
4/7/2019	189	154	0.235	1.5	0.465	0.7	0.007	3,872	100.0%
4/8/2019	189	230	0.142	1.5	0.613	0.9	0.009	3,885	100.0%
4/9/2019	21	30	0.025	1.5	0.612	0.9	0.000	3,770	100.0%
4/10/2019	42	5	0.138	1.5	0.589	0.9	0.000	4,189	100.0%
4/11/2019	0	0	0.000	1.5	0.647	1.0	0.000	4,238	100.0%
4/12/2019	0	0	0.000	1.5	0.775	1.2	0.000	4,179	100.0%
4/13/2019	0	0	0.000	1.5	0.660	1.0	0.000	4,298	100.0%
4/14/2019	0	0	0.000	1.5	0.884	1.3	0.000	4,247	100.0%
4/15/2019	0	0	0.000	1.5	1.099	1.6	0.000	4,089	100.0%
4/16/2019	0	0	0.000	1.5	0.592	0.9	0.000	3,333	100.0%
4/17/2019	0	0	0.000	1.5	0.552	0.8	0.000	3,682	100.0%
4/18/2019	0	0	0.000	1.5	0.666	1.0	0.000	3,606	100.0%
4/19/2019	0	0	0.000	1.5	1.128	1.7	0.000	3,525	100.0%
4/20/2019	0	0	0.000	1.5	0.963	1.4	0.000	3,590	100.0%
4/21/2019	0	0	0.000	1.5	0.692	1.0	0.000	3,727	100.0%
4/22/2019	189	46	0.096	1.5	0.509	0.8	0.001	3,733	100.0%
4/23/2019	189	346	0.307	1.5	0.532	0.8	0.025	3,639	100.0%
4/24/2019	189	503	0.640	1.5	0.591	0.9	0.083	3,540	100.0%
4/25/2019	1,443,125	1,140	0.659	1.5	0.532	0.8	1,324.021	3,658	63.8%
4/26/2019	1,443,125	1,200	0.551	1.5	0.932	1.4	2,040.559	3,791	46.2%
4/27/2019	1,443,125	930	0.872	1.5	0.592	0.9	1,592.466	3,734	57.4%
4/28/2019	1,443,125	1,170	0.647	1.5	0.614	0.9	1,540.298	3,821	59.7%
4/29/2019	1,443,125	1,275	0.813	1.5	0.646	1.0	2,219.005	3,839	42.2%
4/30/2019	1,443,125	1,365	0.722	1.5	0.563	0.8	1,839.029	3,370	45.4%
5/1/2019	1,443,125	990	0.591	1.5	0.598	0.9	1,160.489	3,824	69.6%
5/2/2019	388,815	281	0.469	1.5	0.702	1.1	82.598	3,745	97.8%
5/3/2019	42	10	0.049	1.5	0.599	0.9	0.000	3,871	100.0%
5/4/2019	0	0	0.000	1.5	0.514	0.8	0.000	3,831	100.0%
5/5/2019	0	0	0.000	1.5	0.828	1.2	0.000	3,738	100.0%

Date	DO Loss Area (m^2)	Final Daily River Time (min)	Area weighted average Excess Oxygen (mg/L)	Depth (m)	Ka (1/day)	KL (m/day)	Daily River DO Loss (pounds/day)	Daily Plant DO Load (pounds/day)	Back River WCTE
5/6/2019	0	0	0.000	1.5	0.580	0.9	0.000	3,708	100.0%
5/7/2019	0	0	0.000	1.5	0.679	1.0	0.000	3,932	100.0%
5/8/2019	21	45	0.295	1.5	0.700	1.0	0.000	3,978	100.0%
5/9/2019	42	107	0.103	1.5	0.753	1.1	0.001	3,871	100.0%
5/10/2019	17,498	152	0.137	1.5	0.660	1.0	0.552	4,026	100.0%
5/11/2019	84	33	0.102	1.5	0.697	1.0	0.000	4,049	100.0%
5/12/2019	0	0	0.000	1.5	0.658	1.0	0.000	3,909	100.0%

Note Daily River DO Loss and resulting WCTE values are actual calculated loss (summed from individual areas) and not based on averages as presented in table

Table 5-3 Test Run combination WCTE results

Date	Front River Daily Plant DO Load (pounds/day)	Front River WCTE	Back River Daily Plant DO Load (pounds/day)	Back River WCTE	River Combination WCTE
3/14/2019	5,978	100.0%	2,443	100.0%	100.0%
3/15/2019	9,697	100.0%	3,707	100.0%	100.0%
3/16/2019	9,375	100.0%	3,592	100.0%	100.0%
3/17/2019	9,386	100.0%	3,538	100.0%	100.0%
3/18/2019	4,263	100.0%	1,574	100.0%	100.0%
3/19/2019	1,638	100.0%	777	100.0%	100.0%
3/20/2019	8,883	100.0%	3,530	100.0%	100.0%
3/21/2019	9,170	100.0%	3,631	100.0%	100.0%
3/22/2019	9,554	100.0%	3,744	100.0%	100.0%
3/23/2019	9,608	100.0%	3,609	100.0%	100.0%
3/24/2019	9,377	100.0%	3,663	100.0%	100.0%
3/25/2019	9,140	100.0%	3,557	100.0%	100.0%
3/26/2019	9,015	100.0%	3,473	99.6%	99.9%
3/27/2019	8,950	100.0%	3,369	97.5%	99.3%
3/28/2019	8,289	100.0%	3,057	96.5%	99.0%
3/29/2019	8,742	100.0%	3,723	98.3%	99.5%
3/30/2019	9,073	100.0%	3,964	98.4%	99.5%
3/31/2019	8,084	100.0%	3,645	96.9%	99.0%
4/1/2019	7,212	100.0%	3,054	99.5%	99.9%
4/2/2019	9,244	100.0%	3,675	99.4%	99.8%
4/3/2019	9,226	100.0%	3,786	100.0%	100.0%
4/4/2019	9,666	100.0%	3,895	99.8%	99.9%
4/5/2019	9,350	100.0%	3,857	100.0%	100.0%
4/6/2019	9,068	100.0%	3,833	100.0%	100.0%
4/7/2019	9,034	100.0%	3,872	100.0%	100.0%
4/8/2019	9,027	100.0%	3,885	100.0%	100.0%
4/9/2019	8,763	100.0%	3,770	100.0%	100.0%

Date	Front River Daily Plant DO Load (pounds/day)	Front River WCTE	Back River Daily Plant DO Load (pounds/day)	Back River WCTE	River Combination WCTE
4/10/2019	9,751	100.0%	4,189	100.0%	100.0%
4/11/2019	9,939	100.0%	4,238	100.0%	100.0%
4/12/2019	9,782	100.0%	4,179	100.0%	100.0%
4/13/2019	10,250	100.0%	4,298	100.0%	100.0%
4/14/2019	10,220	100.0%	4,247	100.0%	100.0%
4/15/2019	9,889	100.0%	4,089	100.0%	100.0%
4/16/2019	8,352	100.0%	3,333	100.0%	100.0%
4/17/2019	9,421	100.0%	3,682	100.0%	100.0%
4/18/2019	9,684	100.0%	3,606	100.0%	100.0%
4/19/2019	9,460	100.0%	3,525	100.0%	100.0%
4/20/2019	9,543	100.0%	3,590	100.0%	100.0%
4/21/2019	9,938	100.0%	3,727	100.0%	100.0%
4/22/2019	10,038	100.0%	3,733	100.0%	100.0%
4/23/2019	10,113	100.0%	3,639	100.0%	100.0%
4/24/2019	10,008	100.0%	3,540	100.0%	100.0%
4/25/2019	10,057	100.0%	3,658	63.8%	90.3%
4/26/2019	9,937	100.0%	3,791	46.2%	85.1%
4/27/2019	9,738	100.0%	3,734	57.4%	88.2%
4/28/2019	9,946	100.0%	3,821	59.7%	88.8%
4/29/2019	9,762	100.0%	3,839	42.2%	83.7%
4/30/2019	8,362	100.0%	3,370	45.4%	84.3%
5/1/2019	9,494	100.0%	3,824	69.6%	91.3%
5/2/2019	9,166	100.0%	3,745	97.8%	99.4%
5/3/2019	9,433	100.0%	3,871	100.0%	100.0%
5/4/2019	9,296	100.0%	3,831	100.0%	100.0%
5/5/2019	9,260	100.0%	3,738	100.0%	100.0%
5/6/2019	9,348	100.0%	3,708	100.0%	100.0%
5/7/2019	9,965	100.0%	3,932	100.0%	100.0%
5/8/2019	10,122	100.0%	3,978	100.0%	100.0%
5/9/2019	9,684	100.0%	3,871	100.0%	100.0%
5/10/2019	9,886	100.0%	4,026	100.0%	100.0%
5/11/2019	9,920	100.0%	4,049	100.0%	100.0%
5/12/2019	9,732	100.0%	3,909	100.0%	100.0%

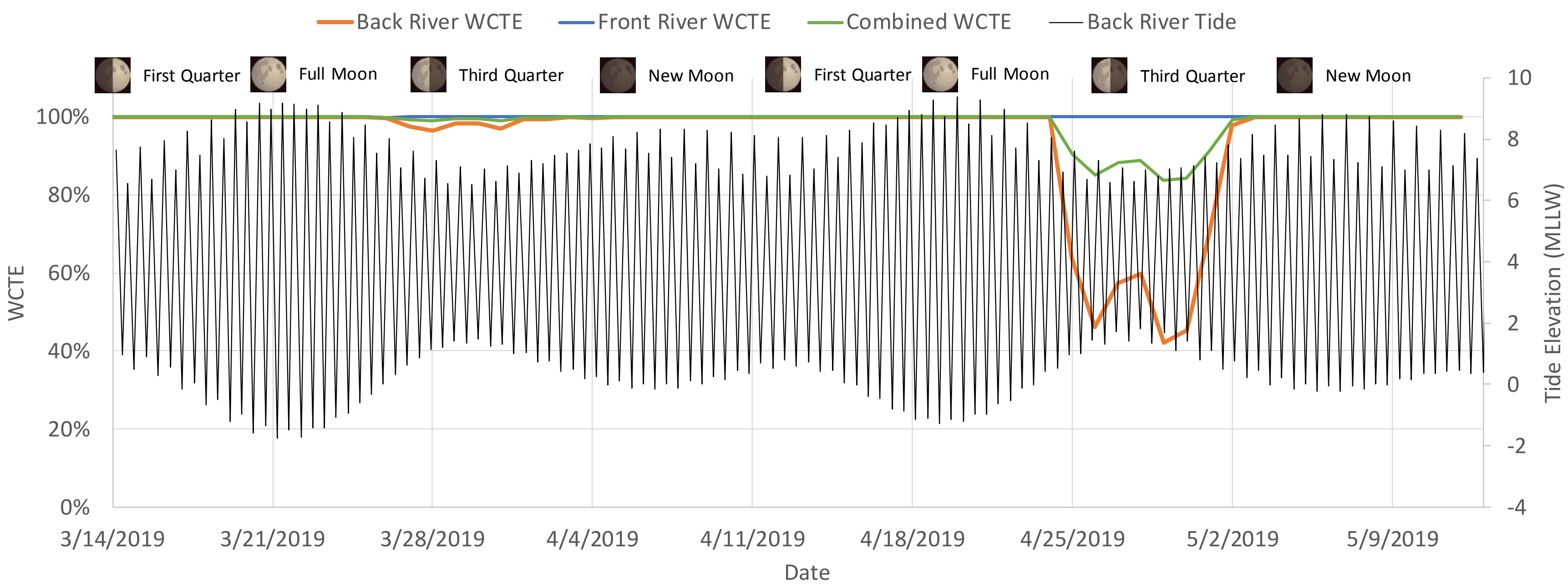


Figure 5-1 Test Run WCTE results in comparison to tidal and lunar cycles

6.0 2018 AND 2019 SHEP MODELS

6.1 MODEL BACKGROUND

A mechanistic modeling approach using the Environmental Fluid Dynamics Code (EFDC) and Water Quality Simulation Program (WASP) models has historically been used to simulate the circulation, transport, and biochemical processes impacting hydrodynamics and water quality in the Savannah River and Harbor. The EFDC model simulates the hydrodynamic transport (flows, water depths, velocities, etc.) and salinity exchange between the ocean and the river in the Savannah River system. The WASP model simulates relevant water quality processes impacting DO in the system (DO loading, sediment oxygen demand, etc.). Details about the EFDC and WASP models and their algorithms can be found in Tetra Tech (2015).

Tetra Tech currently maintains multiple EFDC hydrodynamic and WASP water quality models of the Savannah River and Harbor. These models were developed iteratively over a nearly 15-year period to evaluate impacts to water quality from a variety of sources, including the proposed SHEP navigational and mitigation features. A description of the models is provided below. All of the models, with the exception of the 2010 SHEP model, were developed by Tetra Tech.

- **2006 Savannah Harbor Expansion Project (SHEP) Model**
  - Used to develop the SHEP Environmental Impact Statement
  - Simulated hydrodynamic and water quality conditions from January 1, 1997 through December 31, 2003
  - Evaluated and approved by agencies and stakeholders
- **2010 SHEP Model**
  - Developed by U.S. Environmental Protection Agency and used to develop the 2010 DO Total Maximum Daily Load
  - Used 2006 SHEP Model as baseline
  - Revised model grid to better represent DO in Savannah River and Harbor
  - Evaluated and approved by agencies and stakeholders
- **2015 SHEP Model**
  - Simulated hydrodynamic and water quality conditions from January 1, 1997 to April 30, 2014
  - Calibrated baseline model
  - Evaluated and approved by agencies and stakeholders
- **2015 SHEP Without-project**
  - Used 2015 SHEP model as baseline
  - Bathymetry modified to meet authorized depth throughout navigation channel
- **2015 SHEP With-project (WP)**
  - Used 2015 SHEP Without-project model as baseline
  - Included all proposed SHEP navigational and mitigation features
- **2015 SHEP With-project WP V2**
  - Used 2015 SHEP WP model as baseline
  - Included the reduced width dredging template from the Area Works Final Project Design, template was obtained from the plan sheets for Middle and Little Back River
- **2015 SHEP WP McCoy's Cut (MC)**
  - Used the 2015 SHEP WP V2 model as baseline
  - Developed three models to represent in a stand-alone fashion individual project features from the McCoy's Cut Area Works Final Project Design
    - **2015 SHEP WP MC1**: 2015 SHEP WP V2 + 2600 ft extension of the dredging template on Middle River
    - **2015 SHEP WP MC2:** 2015 SHEP WP V2 + increased depth of the dredging template at the mouth of Union Creek on Little Back River
    - **2015 SHEP WP MC3:** 2015 SHEP WP + complete closure of Rifle and McCombs Cuts

- **2015 SHEP WP V3**
  - Used 2015 SHEP WP V2 model as baseline
  - Included all three project features from the McCoy's Cut Area Works Final Project Design: 1) 2,600 ft extension of the dredging template on Middle River, 2) increased depth of the dredging template at the mouth of Union Creek on Little Back River, and 3) complete closure of Rifle and McCombs Cuts
- **2018 SHEP Model**
  - Used 2015 SHEP model as baseline
  - Simulated hydrodynamic and water quality conditions from January 1, 2014 through December 31, 2017
  - Updated the navigational channel bathymetry using the May 2018 bathymetric survey performed by the USACE Savannah District
  - Updated the Downriver and Upriver site bathymetry using the bathymetric survey conducted by Bottom Line Echo Company during 2017 to support development of the Computational Fluid Dynamics near-field models (LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2017)
- **2019 SHEP Model**
  - Used 2018 SHEP model as baseline
  - Simulated hydrodynamic and water quality conditions from January 1, 2018 through June 30, 2019
  - Updated the navigational channel bathymetry using the March 2019 bathymetric survey performed by the USACE Savannah District
  - Updated the McCoys Cut area and Rifle Cut bathymetry using the September 2018 bathymetric survey performed by the USACE Savannah District
  - Removed tidal gate representation from the model
  - Closed Rifle and McCombs Cuts in the model
  - Added the DO injection system to assist with the Test Run data collection evaluations
  - Developed three scenario models to assist in evaluating DO injection system
    - **2019 SHEP Model Baseline**: No DO loads injected
    - **2019 SHEP Model Actual**: Actual 15-min DO loads injected into Front River and Back River
    - **2019 SHEP Model EIS**: DO loads injected at loads identified in EIS, 8,000 lbs/day into Front River and 4,000 lbs/day into Back River

6.1.1 Model Update

The 2018 and 2019 (2018/2019) SHEP Models were developed to evaluate the levels of DO in the Savannah River and Estuary during the Background, WCTE, and Test Run data collection periods. These models used the 2015 SHEP Model as the baseline model and updated the bathymetry and boundary conditions to reflect the extended simulation periods. The models used the same data processing methodologies, setup assumptions, and calibration parameters as the 2015 SHEP Model setup. The 2015 SHEP model development methodologies and calibration are extensively detailed in Tetra Tech (2015). The 2018 SHEP Model was developed to verify the model performance against the calibrated 2015 SHEP Model and to better represent hydrodynamics and water quality for the Test Run period.

The 2018/2019 SHEP Model computational grids start on the Savannah River at River Mile 61.0 near Clyo, Georgia, at USGS station 02198500, and extend approximately 25 miles offshore from Jones/Oyster bed Island. The offshore portion covers the navigational channel of Savannah Harbor. The modeled area includes the Savannah River, the Front River, the Middle River, the Little Back River, the Back River, the South Channel, and the offshore portions in the Atlantic Ocean. In addition, the grid includes 15 marsh cell boxes located outside of the channels which represent the large marsh areas directly connected to the Savannah River and Harbor. ***Figure 6-1*** shows the spatial coverage of the boundary and data sources used in the 2018 and 2019 SHEP Model setup.

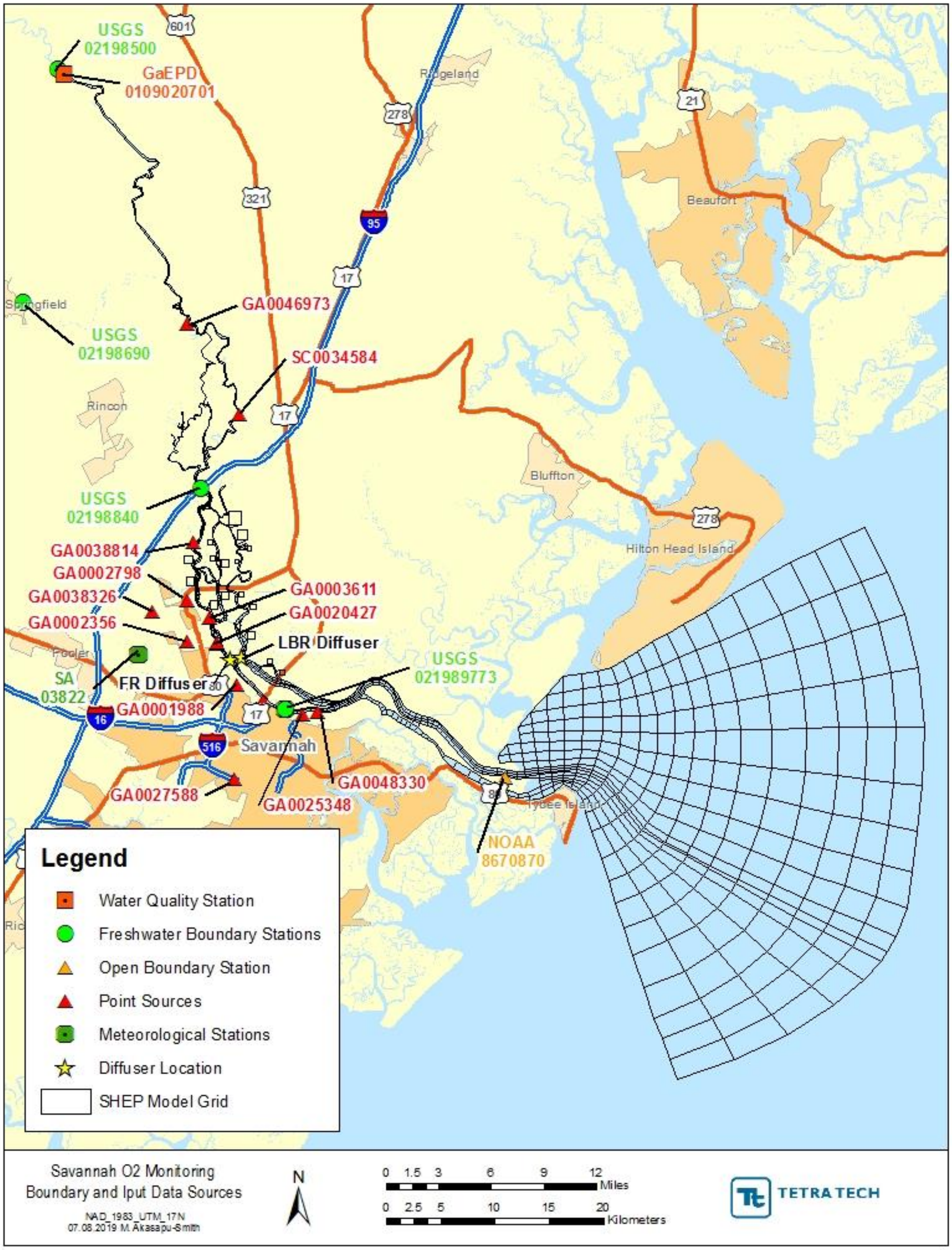


Figure 6-1 Location of boundary and input data sources used in the 2018 and 2019 SHEP Models setup

All major SHEP features that were constructed prior to the Test Run were included in the 2019 SHEP model. This included the removal of the tidal gates, Rifle and McCombs Cuts closures, entrance channel dredging, and the Downriver Site DO injection system. Although the 2019 SHEP model runs from January 1, 2018 through June 30, 2019, model setup began immediately after the Test Run data collection period ended on May 12, 2019. Therefore, the model boundaries (freshwater flow, open boundary water surface elevations, meteorological inputs, etc.) for the period May 13, 2019 through June 30, 2019 used placeholder data and these boundaries may be updated in the future using measured data. Placeholder data consisted of the long term daily and/or monthly values for each boundary.

6.1.2 Meteorological

Precipitation measured by USGS at the USACE Dock at Savannah (021989773) and station pressure, air temperature, wind speed, and wind direction, relative humidity, solar radiation, and cloud cover measured by National Climatic Data Center Surface Airways station at Savannah (03822) were used to generate the meteorological time series for the 2018/2019 SHEP Models. The 2018/2019 SHEP Models used the same methodology as the 2015 SHEP Model to review the quality of meteorological conditions and fill gaps in the data (Tetra Tech, Inc., 2015).

6.1.3 Open Water Boundaries

The 6-minute water surface elevation data measured by National Oceanographic and Atmospheric Administration (NOAA) at station 8670870 at Fort Pulaski were used to generate the tidal boundary condition at the open ocean boundary of the 2018/2019 SHEP Models. Because the open boundary is located approximately 19 miles east of Fort Pulaski, it was necessary to adjust the phase of the measurements in order to provide appropriate boundary conditions to the model. The discussion on the adjustment methodology can be found in the modeling report for 2015 SHEP Model (Tetra Tech, Inc., 2015).

Hourly temperature data measured by NOAA at station 8670870 at Fort Pulaski were used to generate the open ocean boundary for temperature at a 6-hour timestep.

Salinity data collected by SABSOON at station R2, for the period 2005 through 2007 (time when salinity data were collected), were used to generate the open ocean boundary condition for salinity. Measured salinity in the offshore area at the SABSOON station remained fairly constant and averaged 35.12 practical salinity units (PSU) with a small standard deviation of 0.78 PSU; therefore, a constant value of 35.12 PSU was used for the open ocean boundary condition (Tetra Tech, Inc., 2015).

The open water DO boundary conditions were calculated assuming 100% DO saturation (Tetra Tech, Inc., 2015). The DO saturation concentrations were computed as a function of salinity and temperature using a state equation (Chapra, 2008). The DO open boundary was calculated using an average of concentration of 35.12 PSU and the measured NOAA station 8670870 Fort Pulaski water temperature time series.

No measured data were available to define the concentrations of carbonaceous biochemical oxygen demand (CBOD) and ammonia (NH3) at the open boundaries. Constant concentrations of CBOD and NH3 were provided based on the values previously specified in the total maximum daily load (TMDL) model and were maintained the same as in 2015 SHEP Model (USEPA, April 2010).

6.1.4 Marsh Loads

CBOD marsh loads were included in the model to quantify the exchange of organic material between marshes and the open water and to better represent the complex ecological interactions occurring in the highly productive marsh areas. The 2018/2019 SHEP Models used the CBOD marsh loading rates developed for the 2010 TMDL model, which were also used in the 2015 SHEP Model (USEPA, April 2010; Tetra Tech, Inc., 2015). The CBOD loading rates provided at the fifteen (15) marshes can be found in Tetra Tech (2015). To address seasonality of the marsh loads, a 2003 research paper was used that measured dissolved inorganic carbon in tidal freshwater marshes and the adjacent estuary in Virginia (Neubaer, 2003). The percentages were derived from the referenced study and were applied to the CBOD loading rates to develop the monthly loads for CBOD from the marsh areas in the 2018 and 2019 SHEP WASP7 Models. This same seasonal variation was also used in the 2010 TMDL WASP model (USEPA, April 2010).

6.1.5 Freshwater Boundaries

Daily average flow data collected at USGS station 02198500 on the Savannah River near Clyo, GA were used to represent the upstream freshwater boundary in the 2018/2019 SHEP Models (Tetra Tech, Inc., 2015). Daily average flow data collected at USGS station 02198690 on the Ebenezer Creek at Springfield, GA were used to define the freshwater flow boundary conditions for the tributaries of the Savannah River. Data were not available at all of the tributaries, so the USGS station 02198690 flows were area-weighted to approximate freshwater flow conditions at all of the boundaries. The following tributaries were represented in the 2018/2019 SHEP Models:

- Union Creek
- Dandee Canal
- Pipe Makers Canal
- St. Augustine Creek
- Black Creek
- Ebenezer Creek
- Sweigoffer Creek
- Mill Creek

Information on the methodology used for area-weighting the flows can be found in the modeling report developed for the 2015 SHEP Model (Tetra Tech, Inc., 2015).

The 15-minute temperature data from the USGS station 02198840 were processed to provide a 6-hour timestep time series for the 2018/2019 SHEP Model. The temperature data used to develop the freshwater boundary were complete with no data gaps. The processing methodology can be found in the modeling report developed for 2015 SHEP Model (Tetra Tech, Inc., 2015).

A combination of data collected by Georgia Environmental Protection Division (GaEPD) at station 0109020701 near Clyo, GA and USGS station 02198840 were used to provide freshwater boundary conditions for DO to the 2015 SHEP model. The DO measurements at USGS station 0109020701 were available between one to three times a month from January 2000 through December 2010, and at a 15-minute frequency at USGS station 02198840 from August 26, 2013 to April 30, 2014. The freshwater water quality boundary conditions developed for the 2015 SHEP Model for DO were applied as monthly averages for the 2018/2019 SHEP Models.

There were limited measurements of CBOD and NH3 data at GaEPD station 0109020701 at Clyo, GA, and the data were insufficient to develop freshwater boundary conditions for the models. GaEPD developed a riverine hydrodynamic and water quality model (GaEPD-RIV1 Model) for the Savannah River from Thurmond Dam to Clyo for the 2010 SHEP Model simulation period. This model was used to simulate the transport of oxygen demanding substances from the upper watershed to the Savannah Harbor, and the model outputs were used to provide flow, DO, temperature, CBOD (fast and slow), and NH3 boundary conditions for the calibrated and 2010 TMDL model (USEPA, April 2010). Because of the lack of measured data, the 2018/2019 SHEP Model used the monthly averaged CBOD and NH3 GaEPD-RIV1 simulated values for the freshwater boundaries. The data were generated using a multi-annual monthly average of the GaEDP-RIV1 simulation, and the multi-annual averages were repeated for each year of the 2015 SHEP and the 2018/2019 SHEP Models. For more information on the water quality boundary conditions developed for 2015 SHEP Model, refer to the modeling report developed for 2015 SHEP Model (Tetra Tech, Inc., 2015).

6.1.6 Bathymetry

In order to represent channel conditions in each model, the bathymetric data was updated using the best available data. For areas where recent bathymetric data were not available, bathymetry from the 2015 SHEP Model was used in the 2018 SHEP Model. For information on the 2015 SHEP Model bathymetric data sources and processing methodologies, refer to the modeling report developed for 2015 SHEP Model (Tetra Tech, Inc., 2015).

The following bathymetry sources were used to update the bathymetry of the 2018 SHEP Model:

- USACE navigational channel bathymetry (2018): The navigation channel bathymetry for the 2018 SHEP Model grid was updated with May 2018 bathymetric survey data collected by the USACE Savannah District (***Figure 6-2***). The bathymetric survey extended from the outer channel dredging to 0.3 miles downstream of the N. Coastal Highway past Port Wentworth.
- Downriver and Upriver Sites bathymetry: The Downriver and Upriver Sites bathymetry were updated using the Bottom Line Echo Company bathymetric survey data collected in February 2017 (LG2 Environmental Solutions, Inc. and Tetra Tech, Inc., 2017) (***Figure 6-3*** and ***Figure 6-4***). At the Downriver Site, this survey only collected data in the Back River.

The 2018 SHEP Model bathymetry was used as the 2019 SHEP Model bathymetry baseline. The following bathymetry sources were used to update the bathymetry of the 2019 SHEP Model:

- USACE navigational channel bathymetry (2019): The 2019 SHEP Model navigation channel bathymetry was updated with March 2019 bathymetric data collected by the USACE Savannah District (***Figure 6-5***).
- McCoys Cut area bathymetry: The McCoys Cut area and Rifles Cut bathymetry was updated with September 2018 bathymetric survey also collected by the USACE Savannah District (***Figure 6-6***).

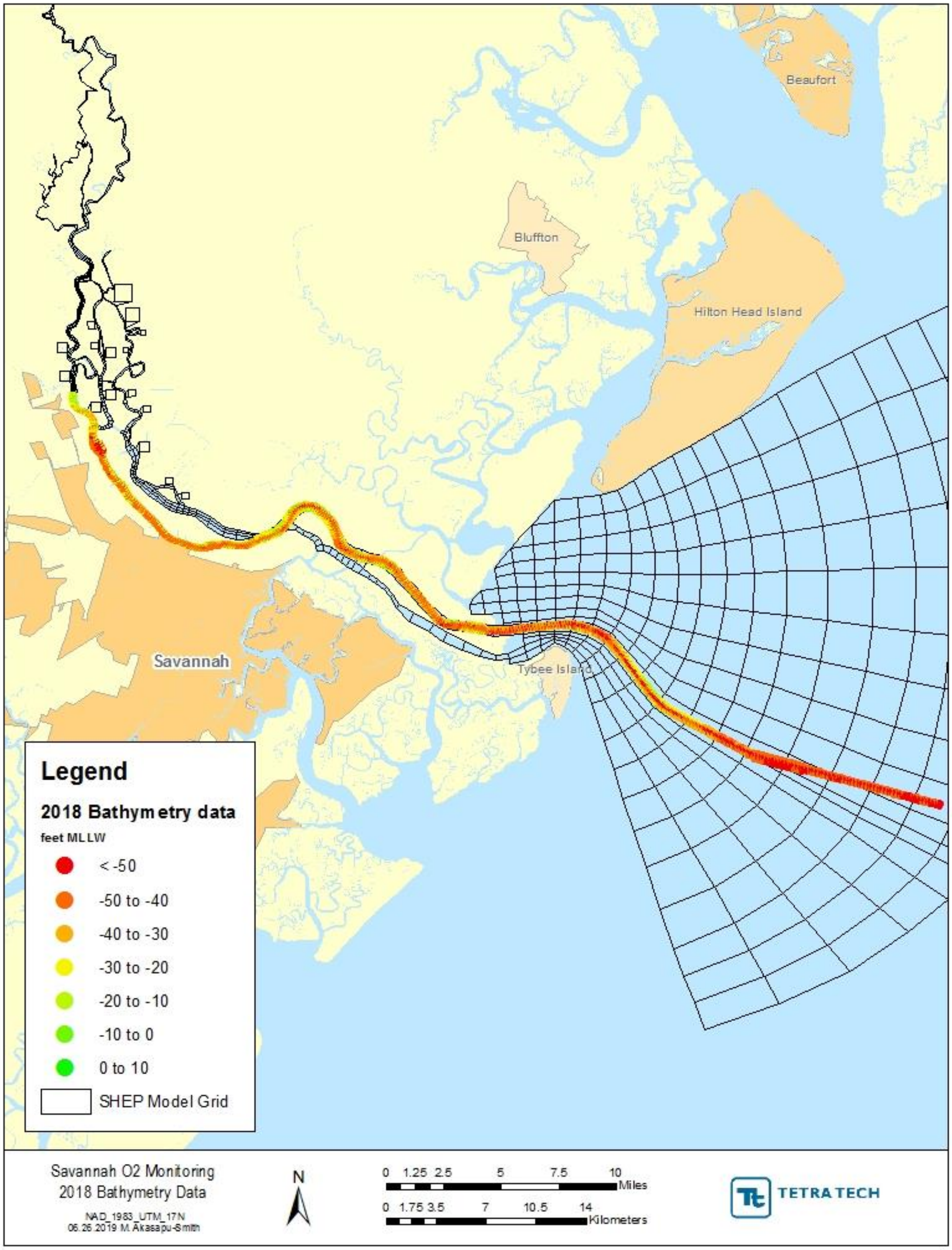


Figure 6-2 Data coverage of the navigational channel from the May 2018 bathymetry survey

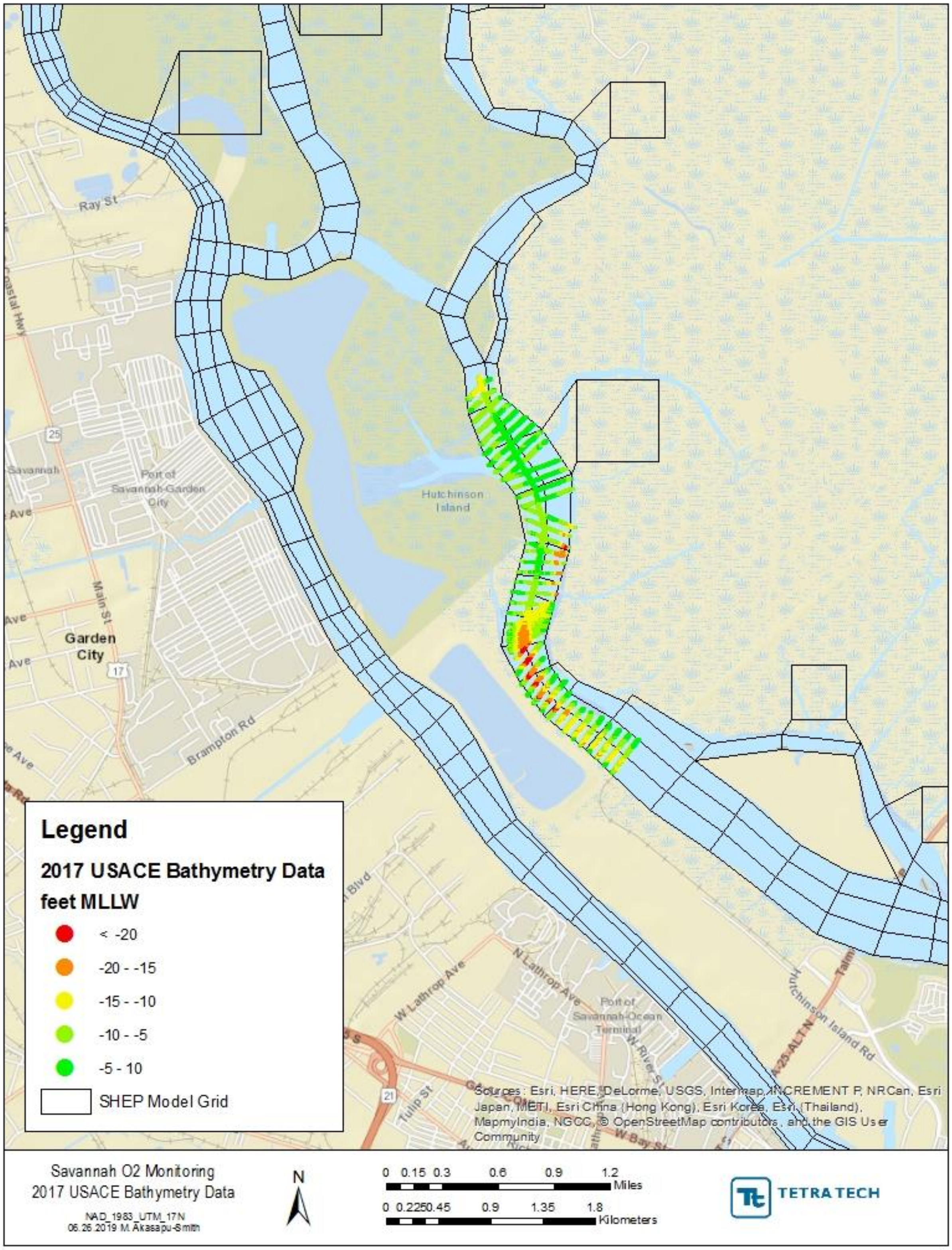


Figure 6-3 Data coverage of the Back River from the February 2017 Downriver Site bathymetry survey

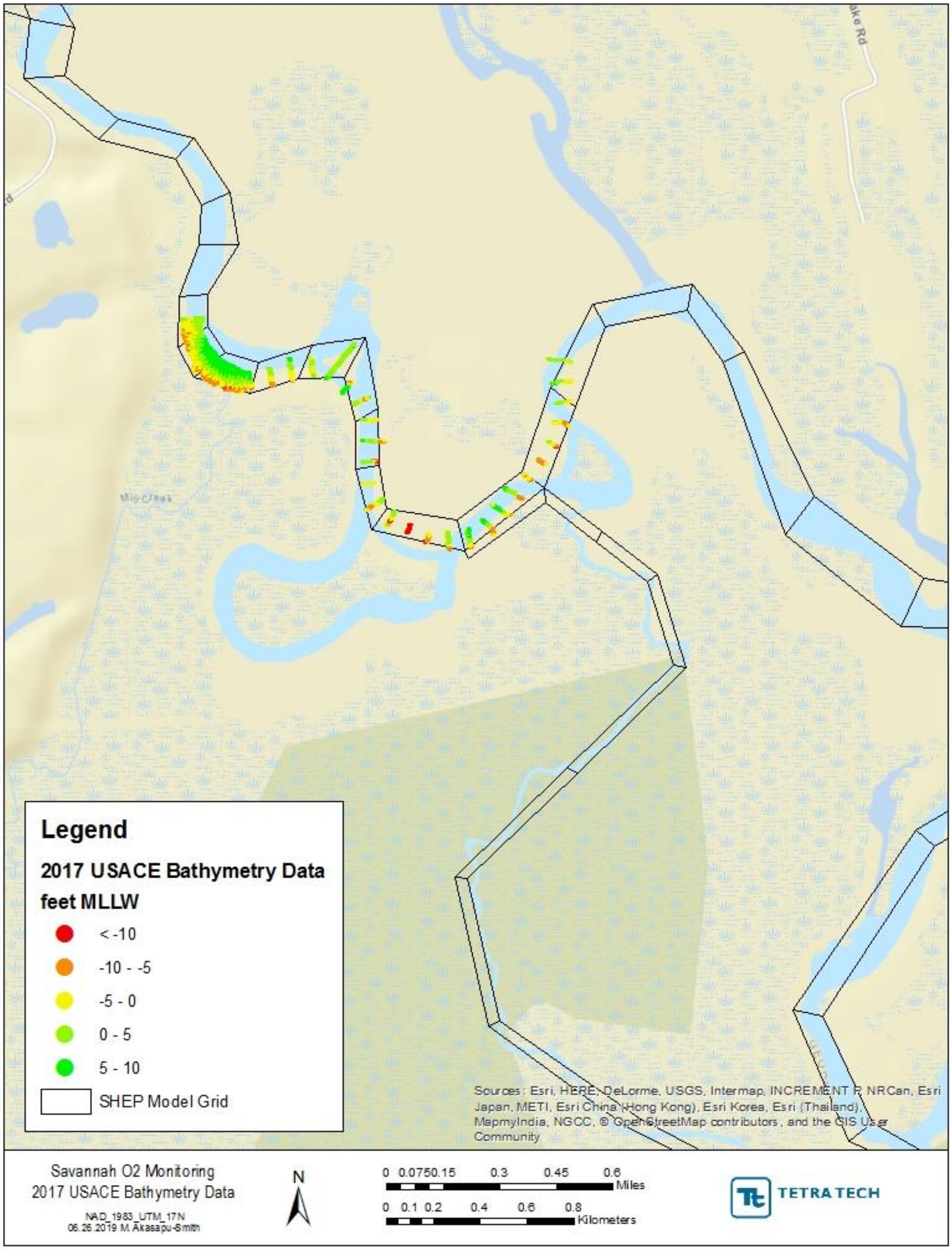


Figure 6-4 Data coverage of the Savannah River from the February 2017 Upriver Site bathymetry survey

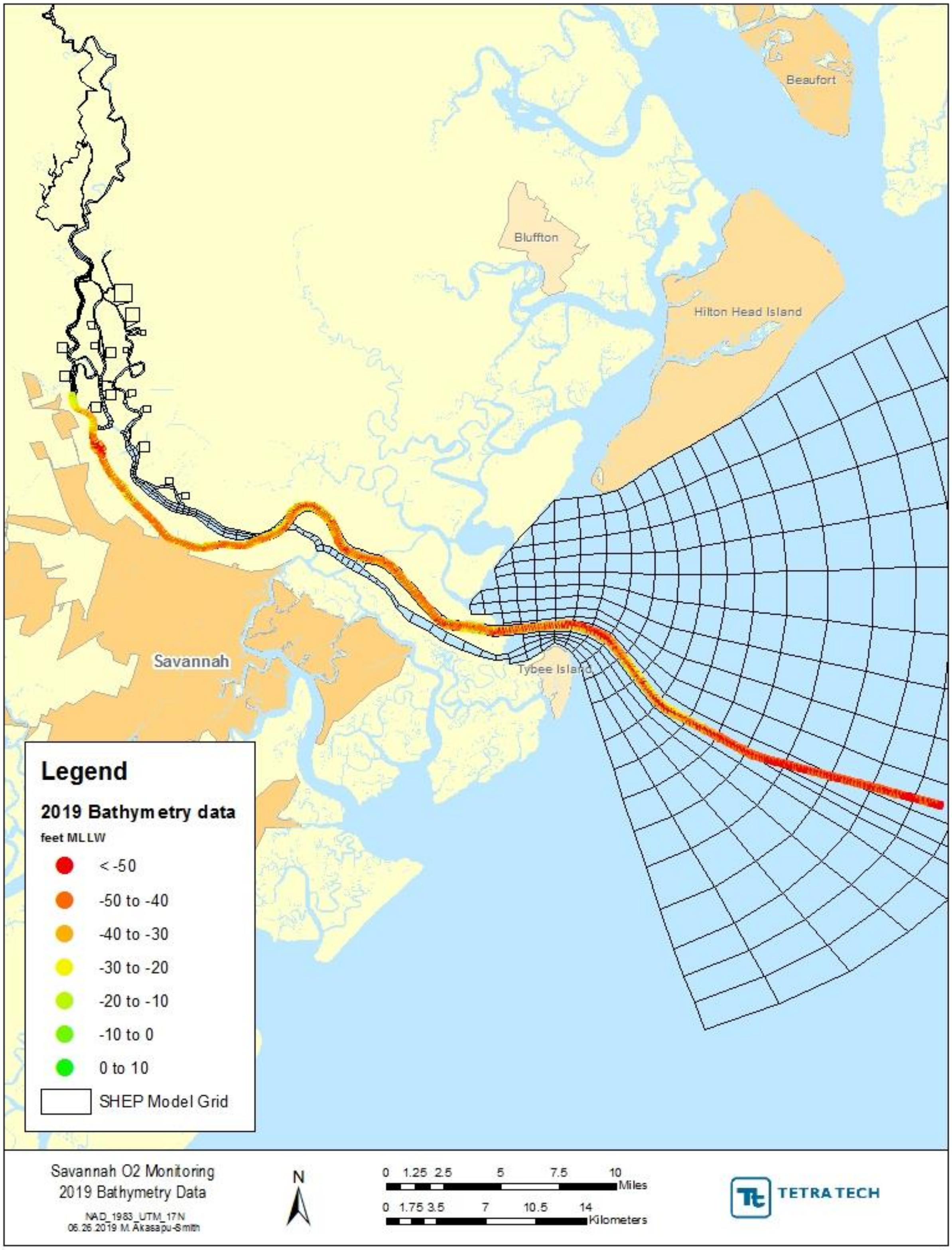


Figure 6-5 Data coverage of the navigational channel from the March 2019 bathymetry survey

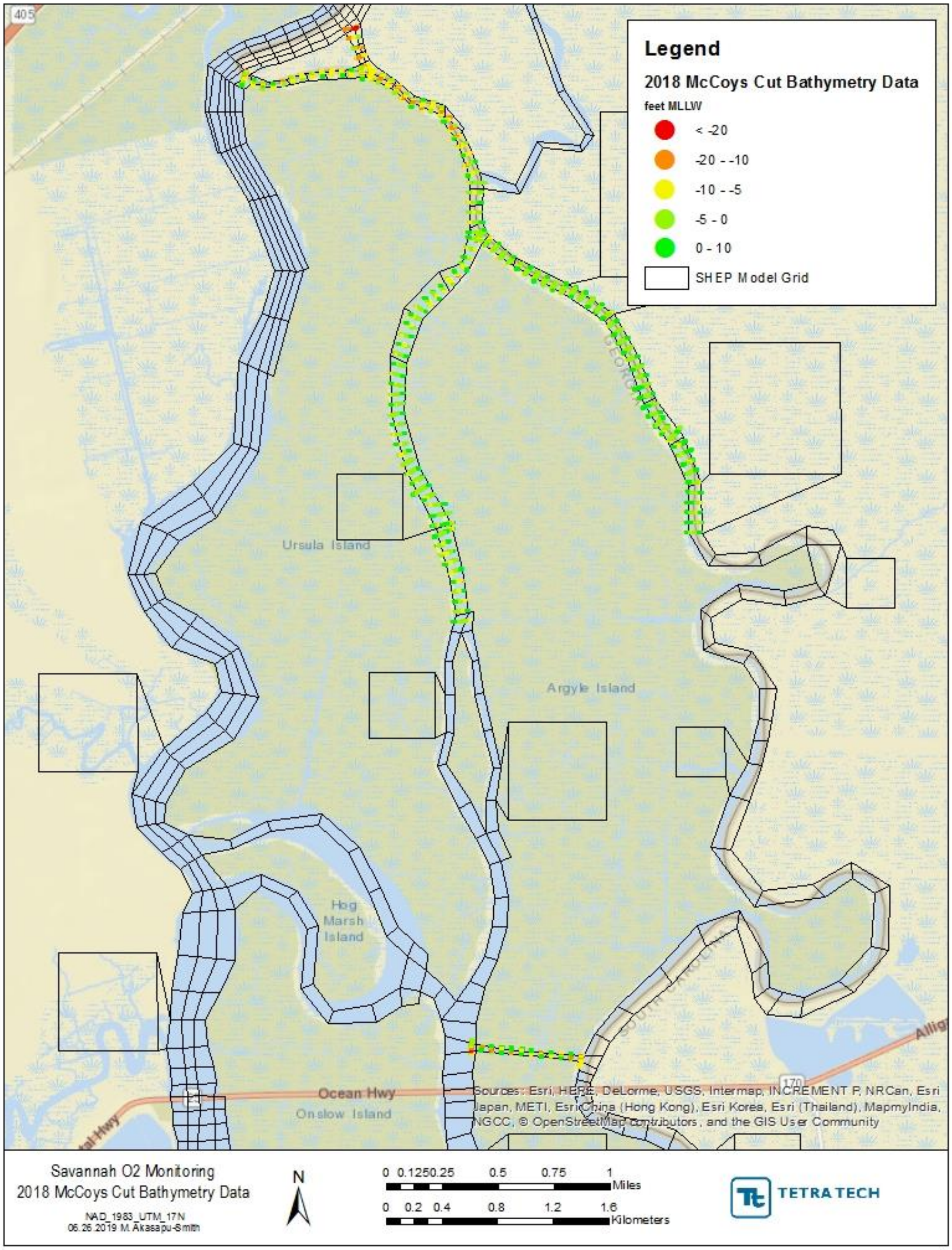


Figure 6-6 Data coverage of the McCoys Cut area from the September 2018 bathymetry survey

6.1.7 Point Sources

Flows and water quality data (temperature, DO, ultimate carbonaceous biochemical oxygen demand [CBODU], and NH3) for the fourteen (14) National Pollutant Discharge Elimination System (NPDES) point source discharging to the SHEP grid domain were obtained from GaEPD in the form of Discharge Monitoring Reports (DMRs). The data were provided at a monthly timestep from January 1, 2014 through April 30, 2019. ***Table 6-1*** presents the point source facilities included in the 2018/2019 SHEP Models and gives the NPDES number, facility name, facility type and permitted flow.

Data were not available for all required model constituents for all point sources. To fill in data gaps, the 2018/2019 SHEP Models used the same methodology as the 2015 SHEP Model (Tetra Tech, Inc., 2015). When data gaps were present for three months or less, the data available before and after the gaps were averaged and supplied to the model. When data gaps were present for three months or more, the facility's long-term monthly averages were supplied. If no data were available for the constituent, which typically occurred for water temperature, assumed concentrations based on typical concentrations (default values) were supplied. For more information on point source input development and assumptions, refer to the modeling report developed for 2015 SHEP Model (Tetra Tech, Inc., 2015).

Table 6-1 Summary of NPDES Point Source discharges in the 2018/2019 SHEP Models

NPDES Number	Facility Name	Agency	Facility Type	Permitted Flow (MGD)	Data Available	Frequency of DMR
GA0001988	International Paper Company	GaEPD	IND	-	January 1, 2014 – April 30, 2019	Daily
GA0002356	PCS Nitrogen Fertilizer LP	GaEPD	IND	-	January 1, 2014 – April 16, 2019	Daily
GA0002798	Weyerhaeuser Company-Port Wentworth	GaEPD	IND	-	January 1, 2014 – February 28, 2019	Daily
GA0003611	Savannah Sugar Refinery	GaEPD	IND	-	February 1, 2016 – April 1, 2019	Monthly
GA0020427	Savannah Travis Field WPCP	GaEPD	MUN	1.50	No data available	
GA0020443	Savannah Wilshire WPCP	GaEPD	MUN	4.50	January 1, 2014 – April 30, 2019	Daily
GA0025348	Savannah President Street WPCP	GaEPD	MUN	27.00	January 1, 2014 – April 30, 2019	Daily
GA0027588	USA Hunter AFB STP	GaEPD	FED	1.25†	January 1, 2014 – April 30, 2019	Daily
GA0031038	Garden City WPCP	GaEPD	MUN	2.00	January 1, 2014 – April 30, 2019	Daily
GA0038326	Savannah Crossroads WPCP	GaEPD	MUN	3.00	January 1, 2014 – April 30, 2019	Daily

NPDES Number	Facility Name	Agency	Facility Type	Permitted Flow (MGD)	Data Available	Frequency of DMR
GA0038814	City of Port Wentworth	GaEPD	MUN	2.00	November 1, 2017 – April 30, 2019	Daily
GA0046973	Georgia Pacific-Savannah River Mill	GaEPD	IND	-	January 1, 2014 – April 30, 2019	Daily
GA0048330	Engelhard Corporation-Chatham	GaEPD	IND	-	January 1, 2014 – April 30, 2019	Daily
SC0034584	Beaufort-Jasper Water and Sewer Authority Hardeeville WWTP	SCDHEC	MUN	0.60	January 1, 2014 – April 30, 2018	Daily

†Daily average limit

6.1.8 Withdrawals

The 2015 SHEP Model included seven (7) surface water withdrawals, three (3) of which do not currently withdraw surface water from the Savannah River. Six (6) of the facilities represented in the 2018/2019 SHEP Models are in Georgia. Daily withdrawal data were provided for those facilities by GaEPD from January 1, 2014 through January 31, 2019:

- 051-0115-01 (Savannah I and D)
- 051-0114-01 (Georgia Pacific [Fort James Operating Company])
- 025-0192-06 (Savannah Acid Plant LLC [Kemira, Inc.])
- 025-0192-03 (Weyerhaeuser near Port Wentworth Mill [Willamette Industries, (Port Wentworth)], stopped withdrawing water on June 20, 2016)
- 025-0192-08 (Weyerhaeuser Company, permit revoked September 2010)
- 025-0192-07 (International Paper Corporation, permit revoked 2010).

Using the daily water withdrawal data, a monthly time series was developed for the 2018/2019 SHEP Models using the same methodologies to fill data gaps as the 2015 SHEP Model (Tetra Tech, Inc., 2015). The three discontinued surface water withdrawals, 025-0192-03, 025-0192-08, and 025-0192-07, had withdrawals of 0 MGD in the 2018/2019 SHEP Models.

One facility, the Beaufort and Jasper W and Surface Airway 07WS005, was located in South Carolina. Data were not provided for this facility, so the long-term monthly averages from the time series developed for 2015 SHEP Model were used to extend the timeseries to June 30, 2019.

6.1.9 DO Injection System

The intake location of the Plant on the lower Front River was represented as a withdrawal in the 2019 SHEP EFDC Model. The Plant flow intake was assumed to match the Plant outflow, which was measured. The Plant inflow was calculated by summing the 15-minute Plant flows to Back River and lower Front River (Section 3.6).

After the completion of Test Run data collection effort, the Plant data were independently reviewed. The data consisted of information on the flow distribution of the super-oxygenated water to the Back River and lower Front River, and the total raw, gross, and net DO loads (***Figure 6-7*** and ***Figure 6-8***). The total raw DO load was the load associated with the background DO concentration at the intake location, the total gross DO load was the total

DO load from the USACE Plant, and total net DO load was the difference between the total raw DO load and total gross load. Using the total raw DO load and the total flow from the reviewed plant data, a DO concentration time series was developed to include in the 2019 SHEP WASP Model at the intake location (***Figure 6-9***).

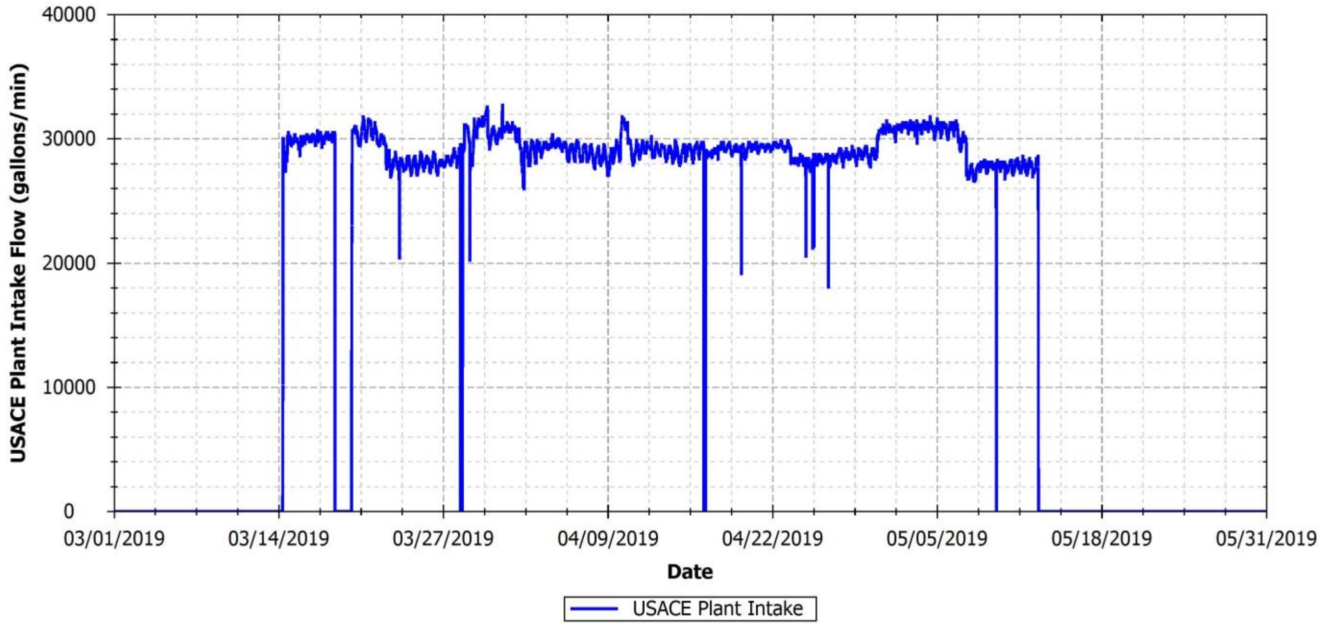


Figure 6-7 USACE Plant flow intake time series at lower Front River

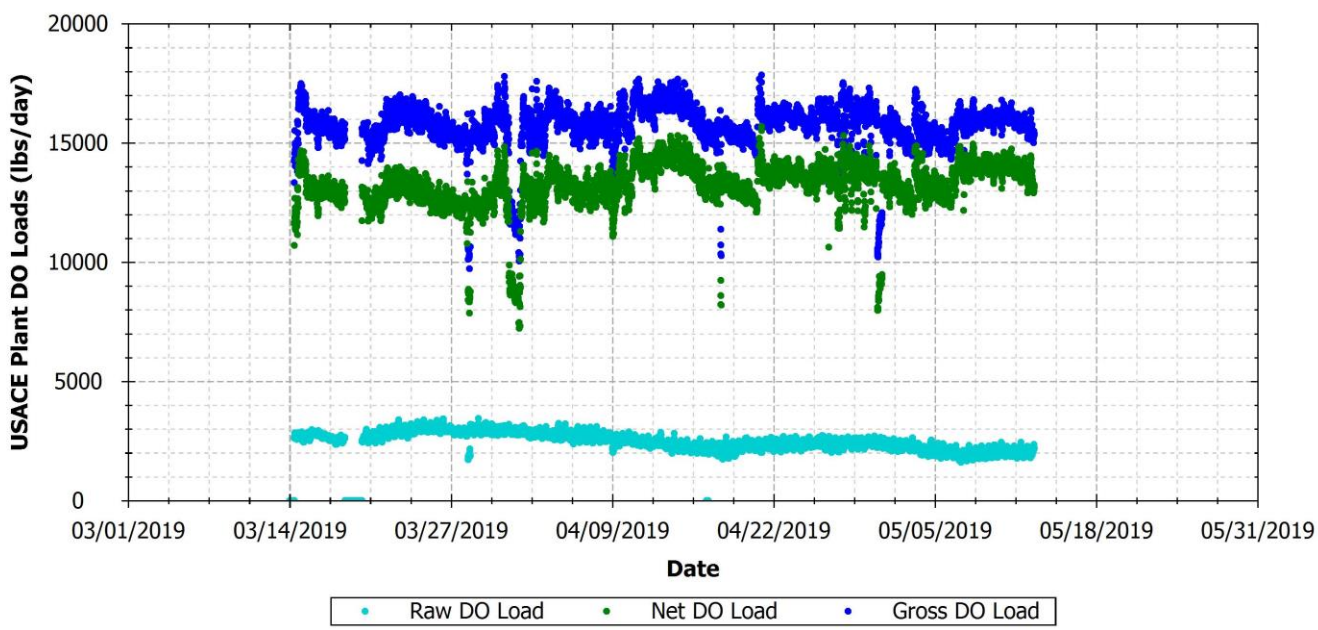


Figure 6-8 USACE Plant DO raw, net, and gross loads

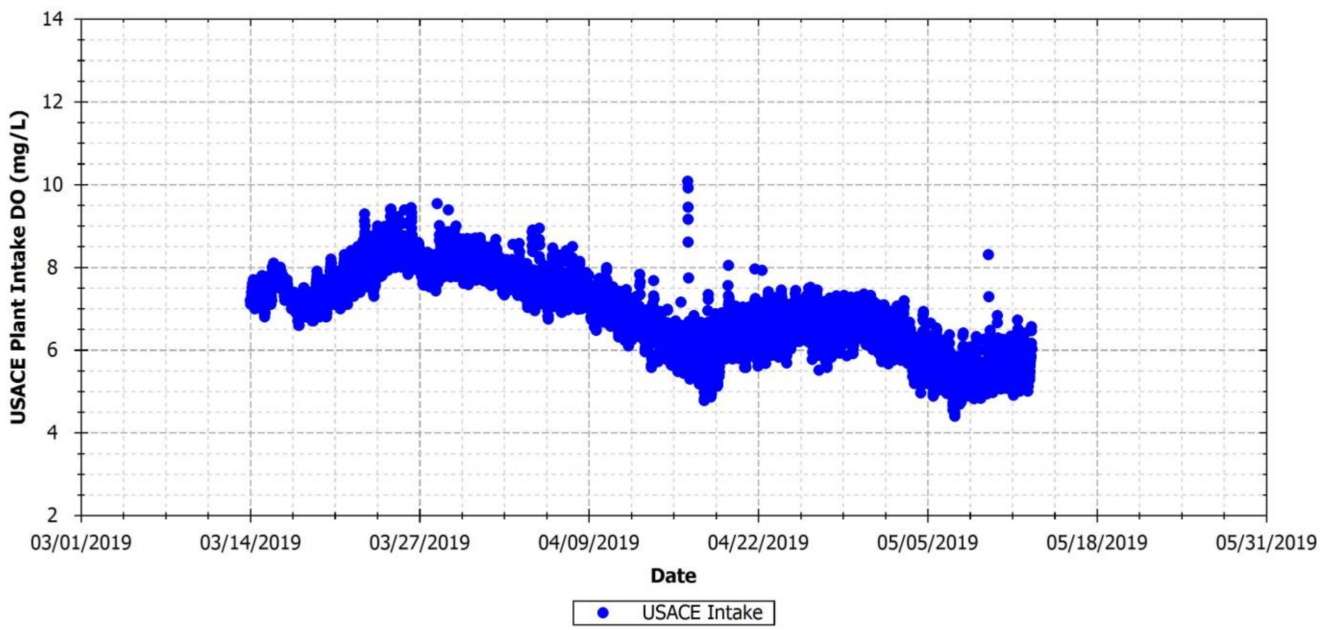


Figure 6-9 Raw DO intake time series

The flows, temperatures, salinity, and DO concentrations from the Back River and lower Front River diffusers were represented as point sources in the 2019 SHEP Model. The 15-minute Plant data for the Test Run period from March 14, 2019 through May 12, 2019 were provided by USACE after they were independently reviewed. The reviewed Plant data, which consisted of information on the flow distribution of the super-oxygenated water to the Back River and lower Front River, and the total raw, gross, and net DO loads, were used to develop the Plant discharge representation in the model. The reviewed Plant flows were converted from gallons/min to cubic meters/second to include in the 2019 SHEP EFDC Model (***Figure 6-10***).

The 15-minute raw Plant data were used to develop temperature time series for the Back River and lower Front River diffuser locations. The raw Plant data consisted of temperatures from the four Speece Cones. The water temperatures from the four Speece Cones were flow-weighted using the Speece Cone flows to calculate a composite water temperature time series from the Plant. The temperatures were converted from degree Fahrenheit to degree Celsius to include in the 2019 SHEP EFDC Model (***Figure 6-11***).

Salinity, CBOD, and NH3 were not measured at the Plant intake location. Therefore, to represent the concentrations from the Plant flow, modeled salinity concentrations at the intake location were applied at the Back River and lower Front River diffusers locations in the 2019 SHEP EFDC Model and modeled CBOD and NH3 concentrations were applied at the diffuser locations in the 2019 SHEP WASP Model.

Using the total gross DO load and the flow distribution to the Back River and lower Front River from the reviewed Plant data, a DO concentration time series was developed and included in the 2019 SHEP WASP Model (***Figure 6-12***).

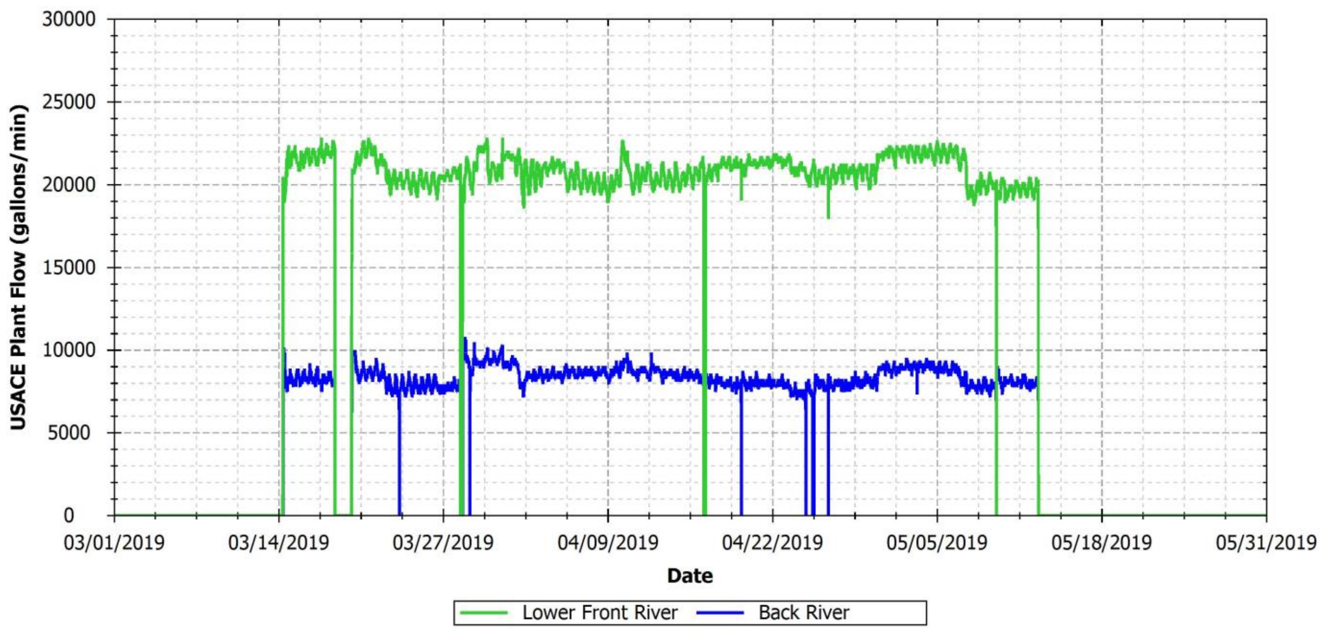


Figure 6-10 USACE Plant flow input time series

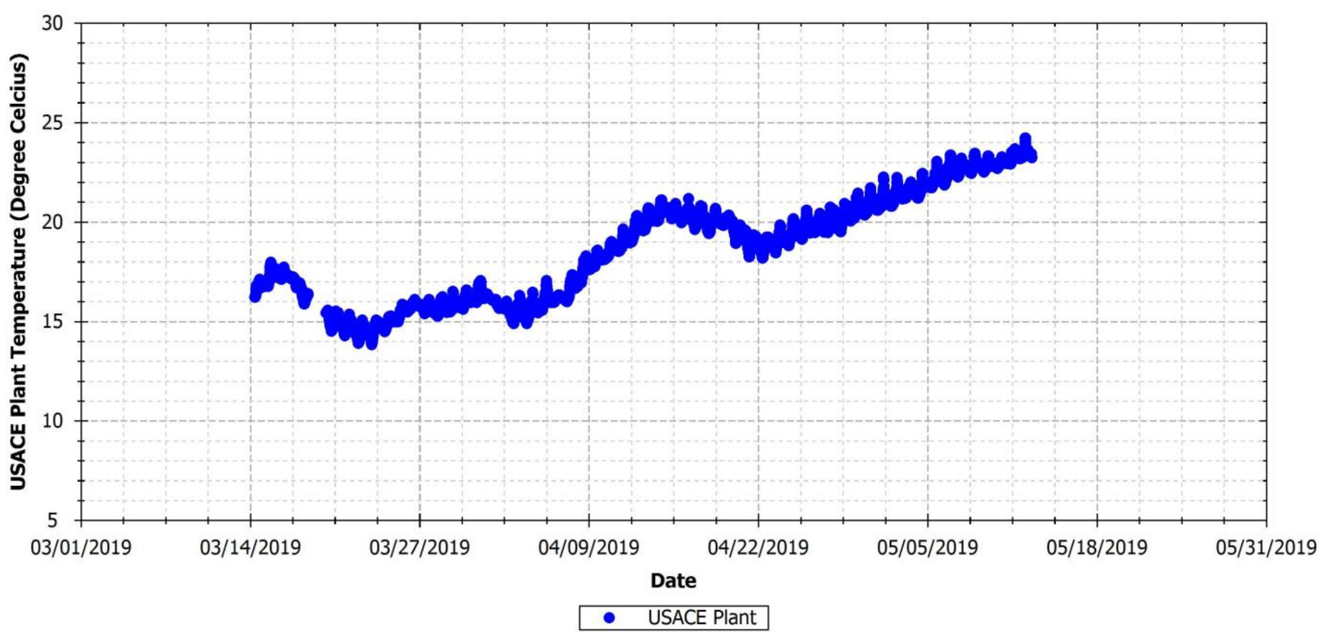


Figure 6-11 USACE Plant temperature time series

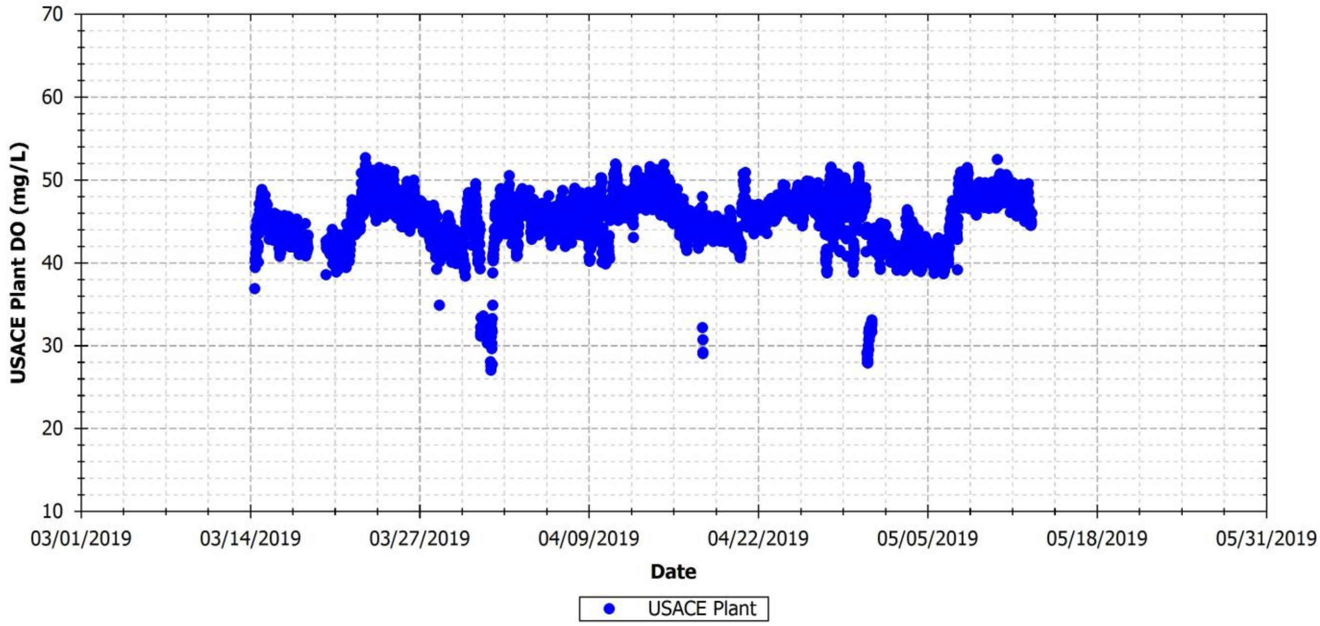


Figure 6-12 USACE Plant DO concentrations time series

6.1.10 2018 SHEP Model Verification

The 2018 SHEP Model was run from January 1, 2014 through December 31, 2017 with the period from January 1, 2014 through April 30, 2014 overlapping with the 2015 SHEP Model. To verify the model performance of the 2018 SHEP Model, results from the model were compared to measured data. The verification statistics were then compared to the calibration statistics from the 2015 SHEP Model to ensure that 2018 SHEP Model performance was similar to the 2015 SHEP Model performance. The 2019 SHEP Model was not used for model verification since several mitigation projects (closure of Rifles Cut, McCombs Cut, and opening of tidal gate) were under construction and the model did not represent this bathymetry during the construction periods. The 2019 SHEP Model bathymetry, which included all projects that were completed by March 14, 2019, only represented conditions during the Test Run.

The following goodness-of-fit statistics were evaluated for the 2015 SHEP Model calibration and the 2018 SHEP Model verification:

- Correlation coefficient, R^2: a measure of the degree of linear correlation between the trends of two time-series, in this case the series of observations and model predictions.
- Mean absolute error (MAE) and root mean squared error (RMSE): an estimate of the average deviation of the model predictions from the observations
- Normalized root mean squared error (NRMSE): an estimate of the relative importance of the errors with respect to the observations
- Index of agreement (IA): evaluation of the global agreement between the predictions and the observations

The dimensionless correlation coefficient can range from -1 to 1, with negative values indicating that the observed and predicted values tend to vary inversely. Values close to -1 or 1 indicate that the values vary similarly, although they may vary numerically (Stow, 2003). The MAE, RMSE, and NRMSE constitute indicators of model prediction accuracy (Stow, 2003), and the smaller their values, the higher the agreement between the observations and the model predictions. Values of the IA range between 0 and 1, with values close to 1 indicating a close numerical match between the two time-series. A value of zero indicates that the model predicts individual observations no better than the average of the observations.

The calibration statistics for the 2015 SHEP Model were computed using measured data from January 1, 2013 through April 30, 2014 at key locations throughout the Savannah River (Tetra Tech, Inc., 2015). For an analysis of the calibration results and statistics, please see the 2015 SHEP Model report. Verification statistics for the 2018 SHEP Model were calculated from January 1, 2014 through December 31, 2017 at the same key stations. ***Figure 6-13*** shows the spatial coverage of the verification stations used for the 2018 SHEP Model verification. The calibration and verification statistics for water surface elevation, salinity, water temperature, flow, velocity, and DO are provided in **APPENDIX I**.

The 2015 SHEP Model calibration and 2018 SHEP Model verification hydrodynamic statistics were very similar, indicating that the 2018 SHEP Model performed as well as the 2015 SHEP Model (**APPENDIX I)**. Water surface elevations for both models had R^2 values ranging between 0.90 and 0.99, with an average R^2 of 0.96. The MAE and RMSE differed between the two models by 1 cm and 2 cm, respectively. The R^2 and IA values for flows and velocities were also high, typically greater than 0.88 and 0.96, respectively. The differences in the two correlation values between the models were normally less than 0.02. The average IA for water temperature for the 2015 SHEP and 2018 SHEP Models was 0.99. The average R^2 was slightly higher for the verification period, 0.99, as compared to the calibration period, 0.97. The average MAE and RMSE were also very similar and varied between the two models by 0.05 °C and 0.07 °C, respectively. For salinity, the average R^2 and IA were slightly lower during the verification period compared to the calibration period, but the MAE and RMSE performed slightly better during the verification period.

The 2015 SHEP Model DO calibration statistics and the 2018 SHEP Model DO verification statistics were also similar (***Table 6-2*** through ***Table 6-3***). Two of the USGS comparison stations, 021989715 Savannah River at Garden City and 021989773 Savannah River at USACE Dock, are located on the lower Front River in close proximity to the diffuser. USGS 021989715 is located 0.2 miles upstream of the lower Front River diffuser, and USGS 021989773 is located 3.7 miles downstream of the diffuser. Calibration and verification statistics were very similar at these two stations. The R^2 was on average 0.04 points lower in the verification run and the IA was on average 0.03 points lower. In addition, two USGS comparison stations, 021989793 Little Back River at Hog Island and 0219897945 Back River downstream of US 17, are located immediately upstream and downstream of the Back River diffuser. At these locations, the 2018 SHEP Model verification results were slightly better than the 2015 SHEP Model calibration results. The R^2 was on average 0.07 point higher in the verification run and the IA was on average 0.04 points higher as.

The results from the 2018 SHEP Model verification show that the model is performing very similar to the 2015 SHEP Model and can be used to evaluate the far-field impacts of the DO injection system.

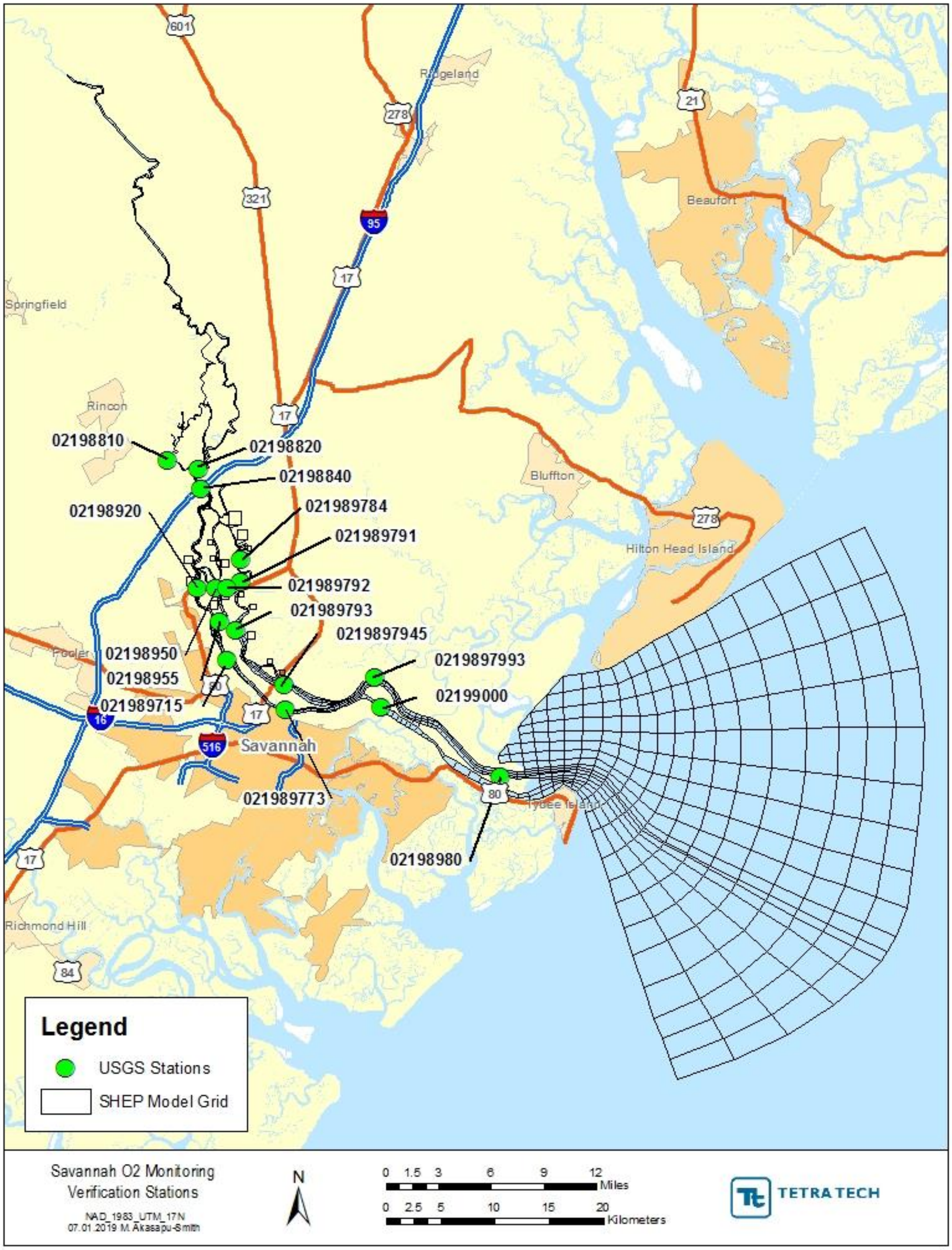


Figure 6-13 Location of verification stations

Table 6-2 2015 SHEP Calibration Statistics at select stations for DO from January 1, 2013 through April 30, 2014

Station	Measured (mg/L)				Simulated (mg/L)				R^2	Mean Abs Error (mg/L)	RMS Error (mg/L)	Norm RMS Error (mg/L)	Index of Agrmt
	Mean	Median	5% tile	95% tile	Mean	Median	5% tile	95% tile					
02198840	8.43	9.00	4.50	10.50	8.47	9.03	5.14	10.64	0.94	0.33	0.40	0.05	0.98
02198920	7.68	8.30	4.20	10.50	8.02	8.60	4.98	10.61	0.89	0.54	0.73	0.09	0.96
02198950	7.66	8.20	4.40	10.30	8.08	8.67	5.19	10.80	0.93	0.54	0.66	0.08	0.97
02198955	7.82	8.10	6.10	9.30	8.70	9.00	7.41	9.69	0.82	0.88	0.98	0.12	0.75
021989715	6.76	7.30	3.40	9.80	8.00	8.55	5.26	10.55	0.91	1.25	1.39	0.18	0.87
021989773	6.27	7.10	3.20	9.40	7.08	7.52	4.68	10.05	0.90	0.88	1.03	0.15	0.93
021989792	7.57	8.20	4.20	10.20	8.26	8.97	5.37	10.86	0.94	0.73	0.85	0.11	0.95
021989793	8.64	8.70	6.90	10.50	9.15	9.21	7.48	11.07	0.79	0.62	0.73	0.08	0.89
0219897945	8.02	8.20	6.40	9.70	8.23	8.37	6.69	10.05	0.67	0.54	0.64	0.08	0.89
0219897993	6.93	7.50	3.60	9.50	7.21	7.65	4.39	10.22	0.89	0.58	0.70	0.10	0.97

Table 6-3 2018 SHEP Verification Statistics at select stations for DO from January 1, 2014 through December 31, 2017

Station	Measured (mg/L)				Simulated (mg/L)				R^2	Mean Abs Error (mg/L)	RMS Error (mg/L)	Norm RMS Error (mg/L)	Index of Agrmt
	Mean	Median	5% tile	95% tile	Mean	Median	5% tile	95% tile					
02198840	7.81	7.70	6.00	10.20	7.63	7.75	5.80	9.67	0.71	0.60	0.76	0.10	0.91
02198920	6.44	6.90	2.40	9.80	6.88	7.11	4.11	9.47	0.76	0.92	1.19	0.17	0.91
02198950	6.53	6.70	3.40	9.70	7.10	7.30	4.44	9.78	0.79	0.82	1.06	0.15	0.92
02198955	5.62	5.90	1.80	9.40	6.71	6.74	4.28	9.48	0.80	1.22	1.52	0.24	0.86
021989715	5.68	6.00	2.30	9.40	7.11	7.43	4.46	9.92	0.88	1.49	1.72	0.26	0.84
021989773	5.37	5.50	2.30	9.10	6.22	6.44	3.61	9.25	0.85	1.00	1.25	0.21	0.91
021989792	6.60	6.80	4.00	9.70	7.33	7.59	4.82	9.93	0.73	0.96	1.19	0.17	0.88
021989793	6.61	6.90	3.90	9.70	7.04	7.29	4.28	9.93	0.75	0.84	1.07	0.15	0.91
0219897945	6.07	6.40	3.20	9.30	6.26	6.52	3.52	9.36	0.84	0.63	0.83	0.13	0.95
0219897993	5.98	6.20	3.30	9.10	6.32	6.55	3.87	9.21	0.84	0.61	0.80	0.13	0.95

6.1.11 2019 SHEP Model Comparison

To evaluate the 2019 SHEP Model predictions, modeled results were compared to measured data collected during the WCTE and Test Run data collection periods. The WCTE study time period was from February 14, 2019 through February 27, 2019 and the Test Run time period from March 14, 2019 through May 12, 2019.

Figure 6-14 and ***Figure 6-15*** presents the comparison for the WCTE and Test Run periods between daily average simulated surface DO with the daily average measured data at USGS stations 021989793 and 0219897945, located upstream and downstream of the Back River diffuser respectively. The 2015 SHEP Model was calibrated to data predictions at both of these stations, and the 2019 SHEP Model results follow the general trends of the measured data at the USGS stations. Model outputs were also compared to the semi-permanent buoy data collected on both the lower Front River and Back River. The 2019 SHEP Model also follows the general DO trends measured at these stations (***Figure 6-16*** and ***Figure 6-17***). It captures most of the diurnal variability on the lower Front River, although it does not fully capture the magnitudes of variability on the Back River. At the diffuser, the model shows the same trends compared to the surface platform sonde data (***Figure 6-18***). However, the 2019 SHEP Model captures both the overall trends and diurnal variability measured in the bottom platform sondes (***Figure 6-19***).

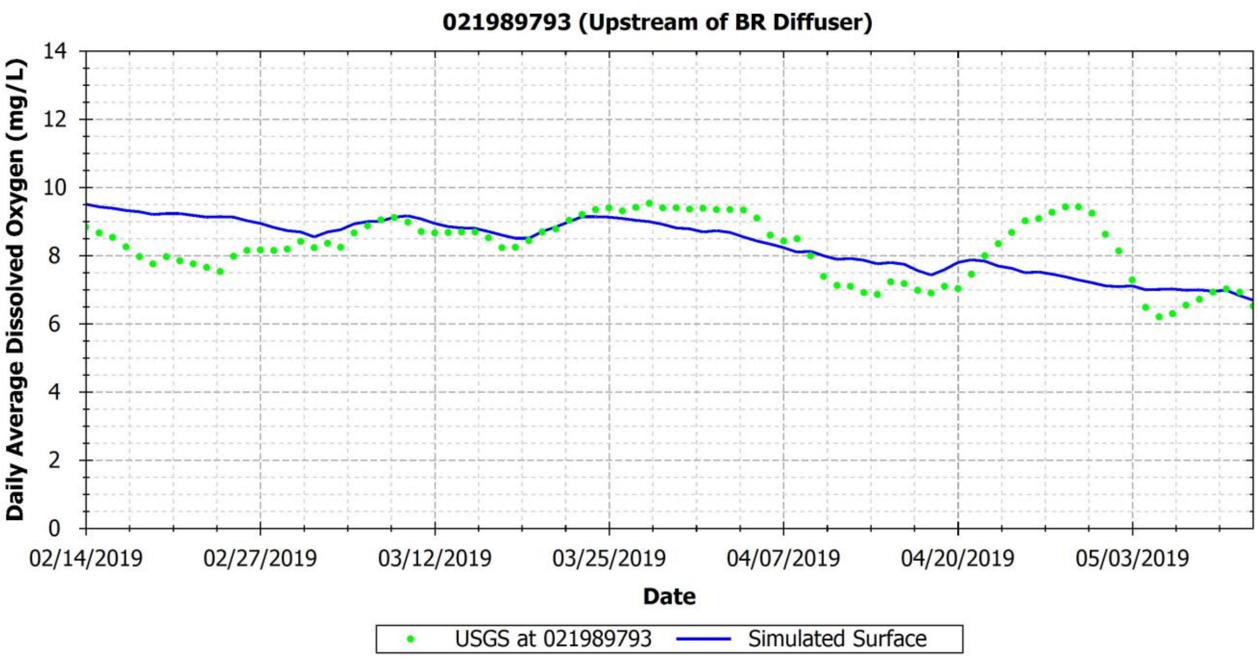


Figure 6-14 Daily average comparison for surface DO at USGS 021989793, Little Back River at Hog Island near Savannah, GA

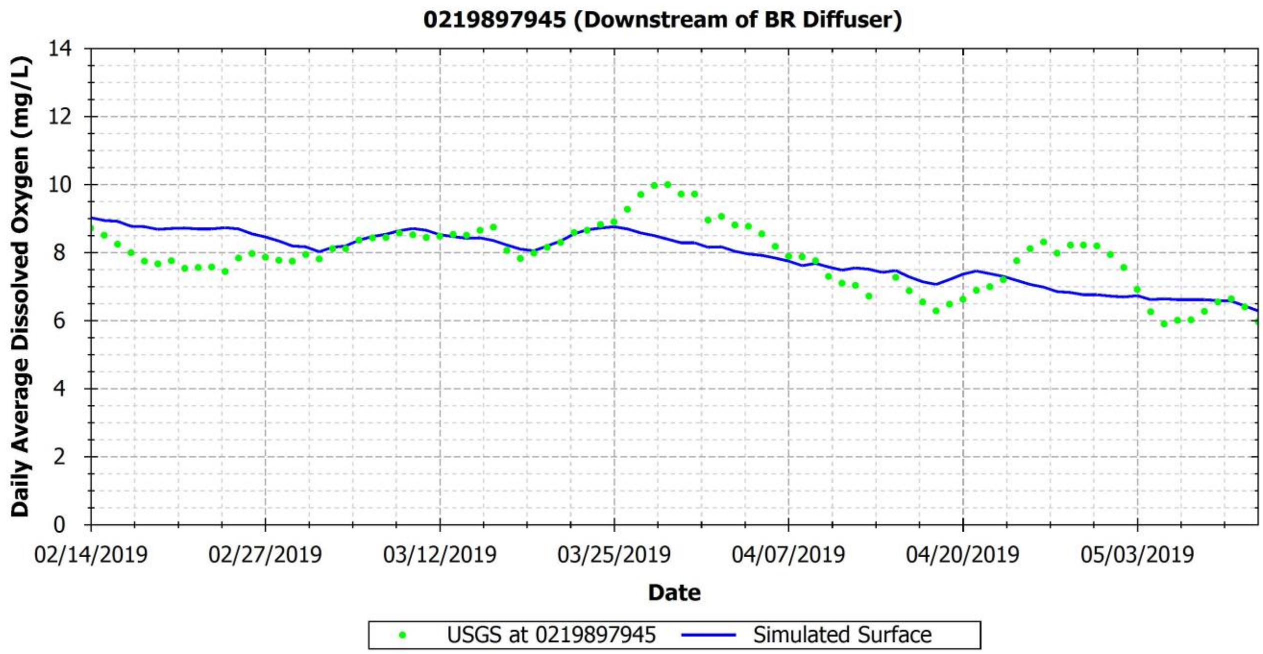


Figure 6-15 Daily average comparison for surface DO at USGS 0219897945, Back River 0.4 miles downstream US17 near Savannah, GA

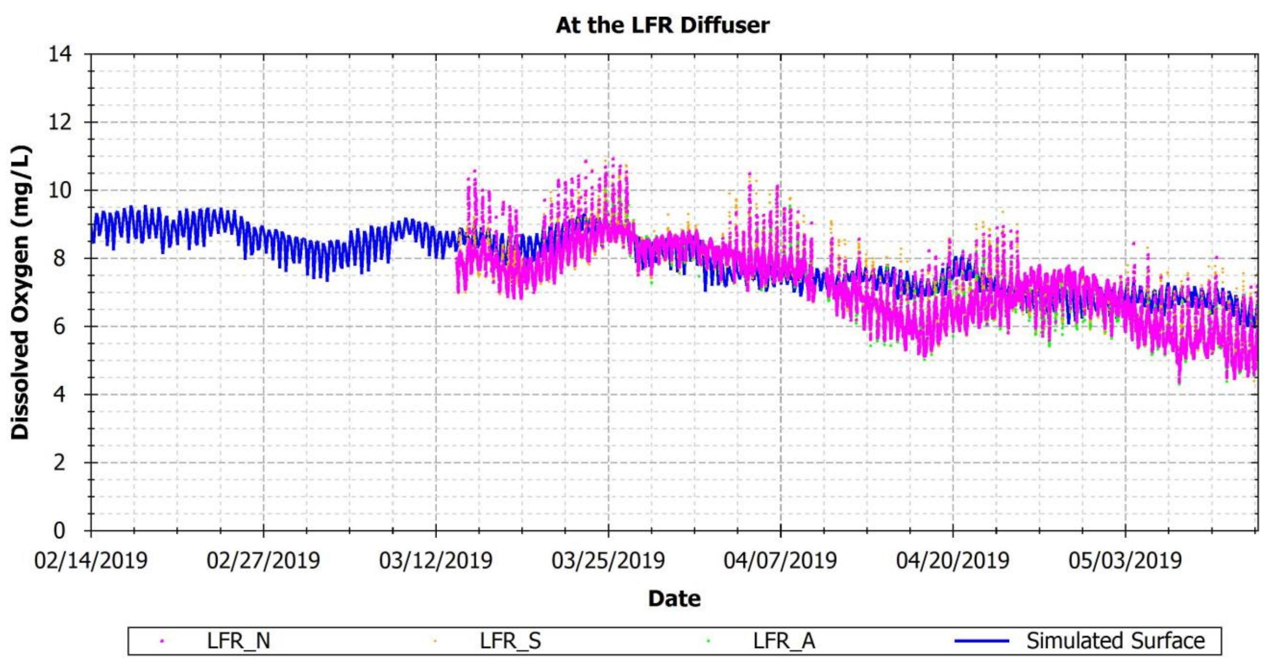


Figure 6-16 2019 SHEP simulated surface DO comparison with data collected at lower Front River semi-permanent buoy

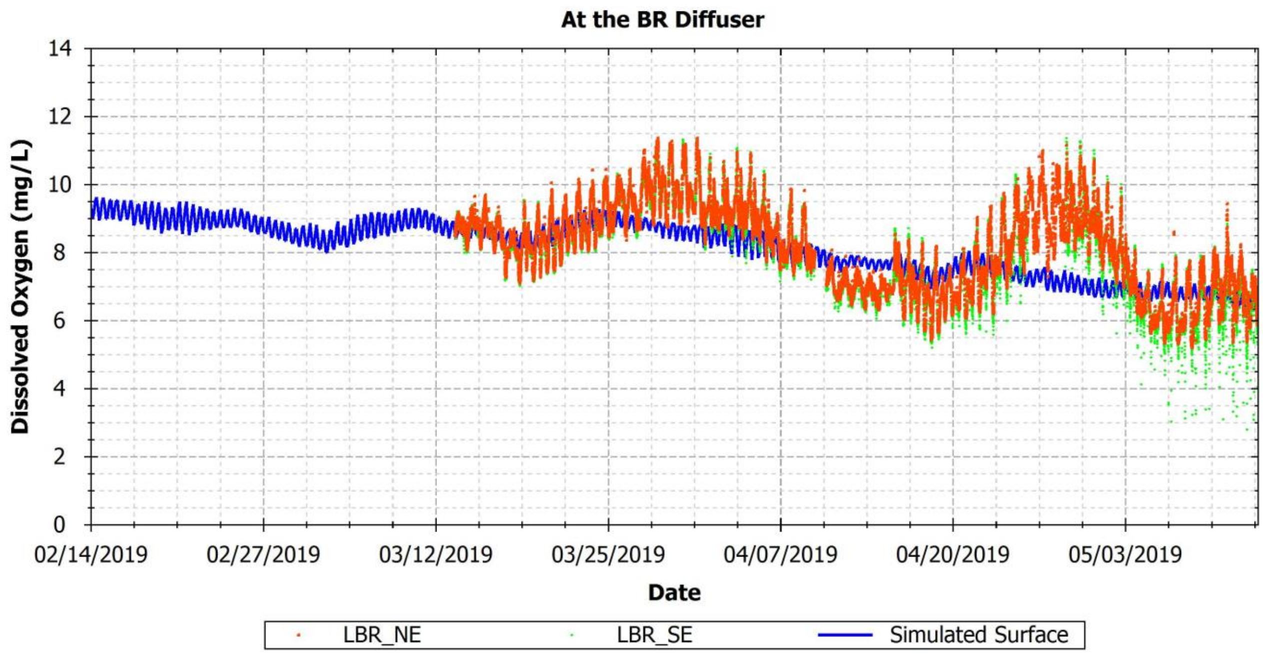


Figure 6-17 2019 SHEP simulated surface DO comparison with data collected at Back River semi-permanent East buoy

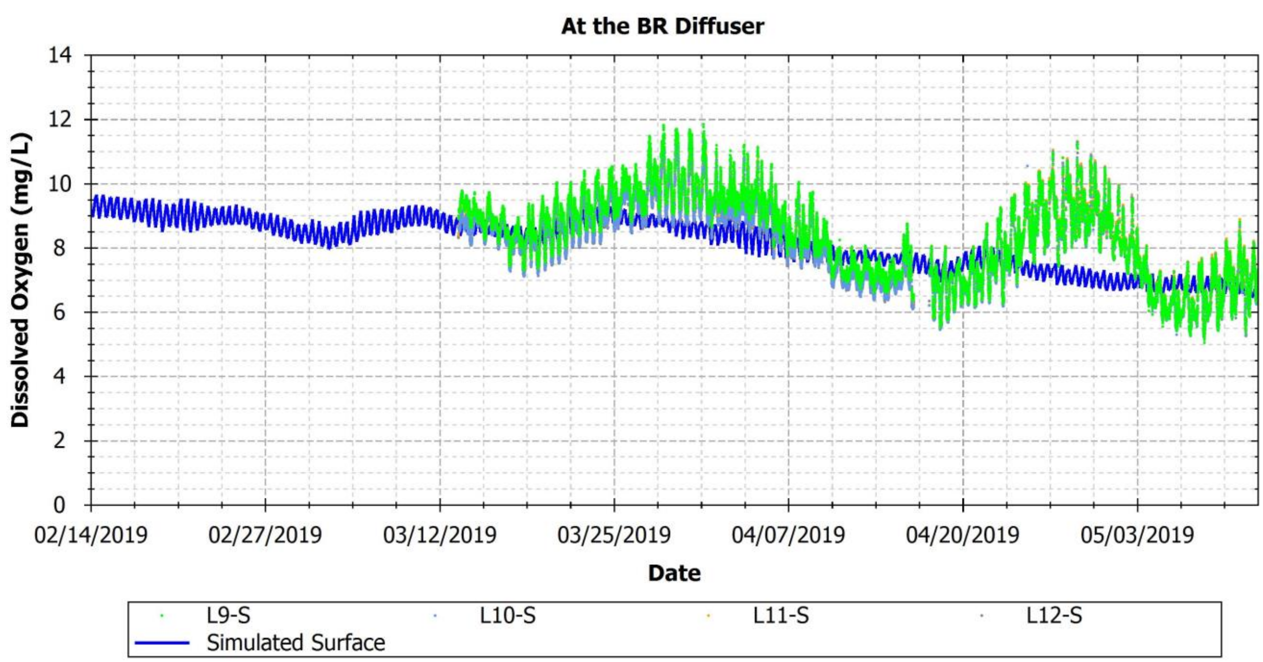


Figure 6-18 2019 SHEP simulated surface DO comparison with data collected at the surface sondes on Back River Platform

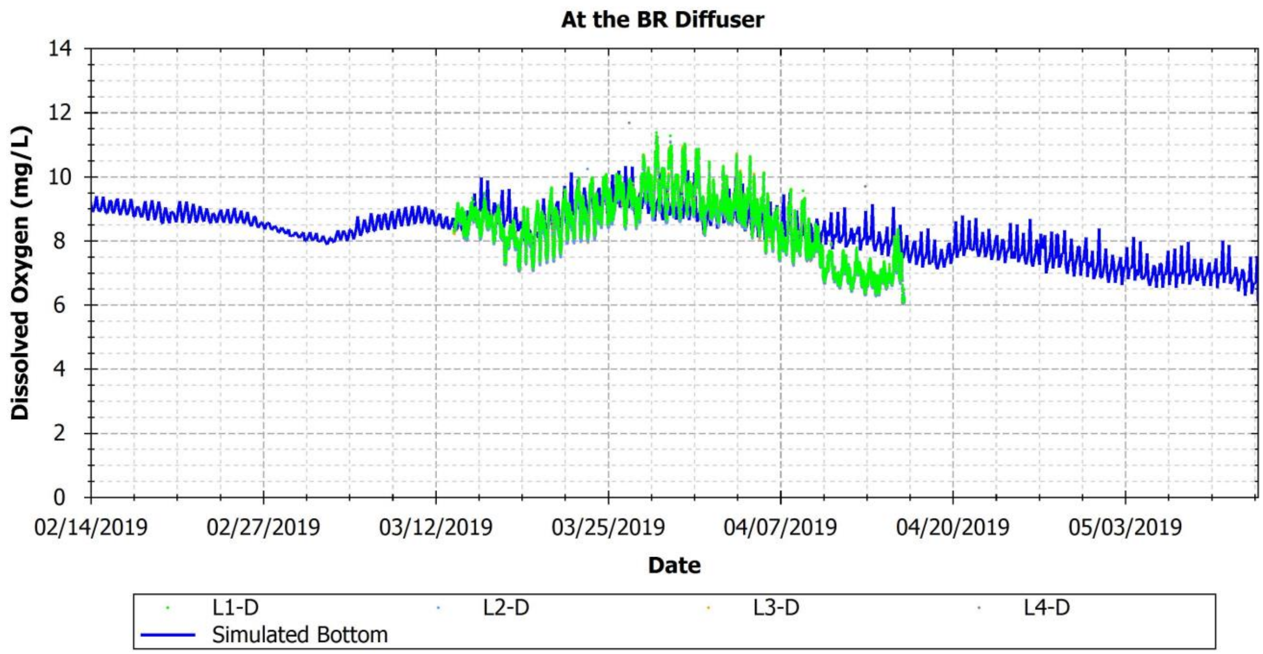


Figure 6-19 2019 SHEP simulated bottom DO comparison with data collected at the deep sondes on Back River Platform

6.2 DOWNRIVER PLANT ANALYSIS

The 2019 SHEP Model was used to assess if the downriver DO injection system operated as designed during the Test Run and assess the far-field impacts to DO concentrations in the system. To evaluate the DO injection system impacts, three scenarios were developed and analyzed:

- 2019 SHEP Baseline Model: 2019 SHEP Model with the DO injection system turned off
- 2019 SHEP Actual Model: 2019 SHEP Model with the actual 15-min DO loads injected into lower Front River and Back River
- 2019 SHEP EIS Model: 2019 SHEP Model with DO injection system adjusted to match EIS terms; model injected 8,000 lbs/day of DO into lower Front River and 4,000 lbs/day of DO into Back River

6.2.1 Time Series Analysis

When DO is injected into the lower Front River and Back River, DO concentrations in the bottom layers are frequently 1.55 mg/L or greater than DO concentrations in the 2019 SHEP Baseline Model (***Figure 6-20*** and ***Figure 6-21***). The 2019 SHEP Actual Model DO concentrations were typically slightly higher than the 2019 SHEP EIS Model concentrations because a greater DO load was injected into the Savannah River than required throughout most of the Test Run.

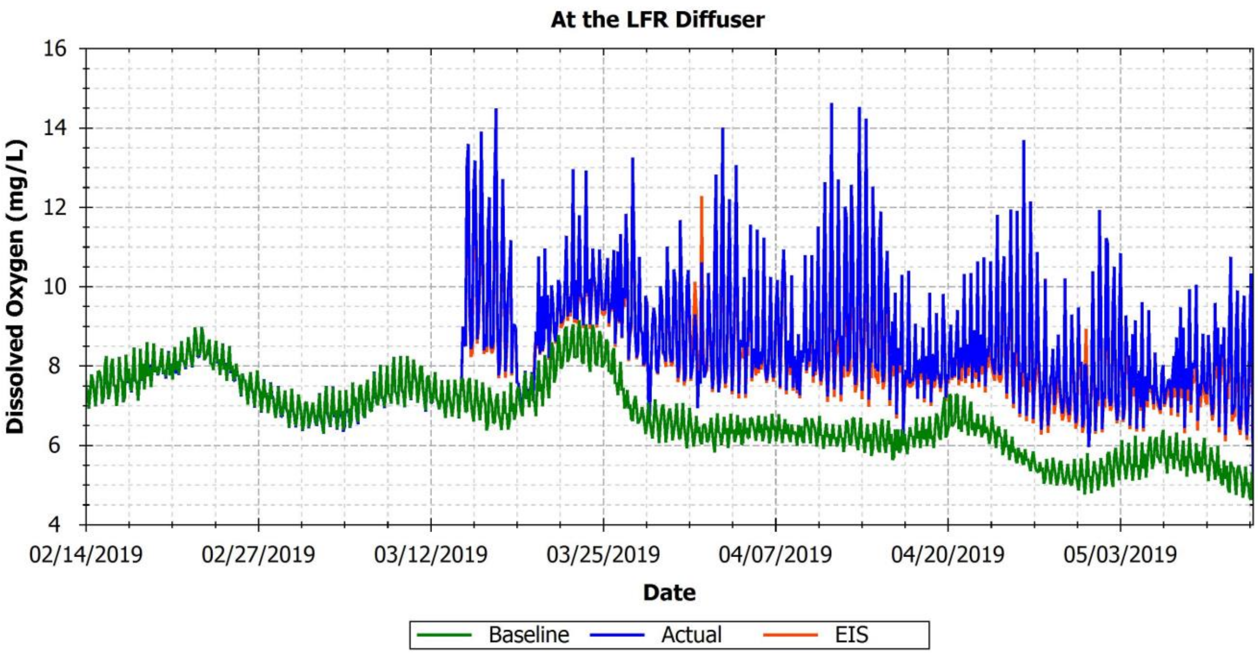


Figure 6-20 Simulated bottom DO concentrations at the lower Front River diffuser

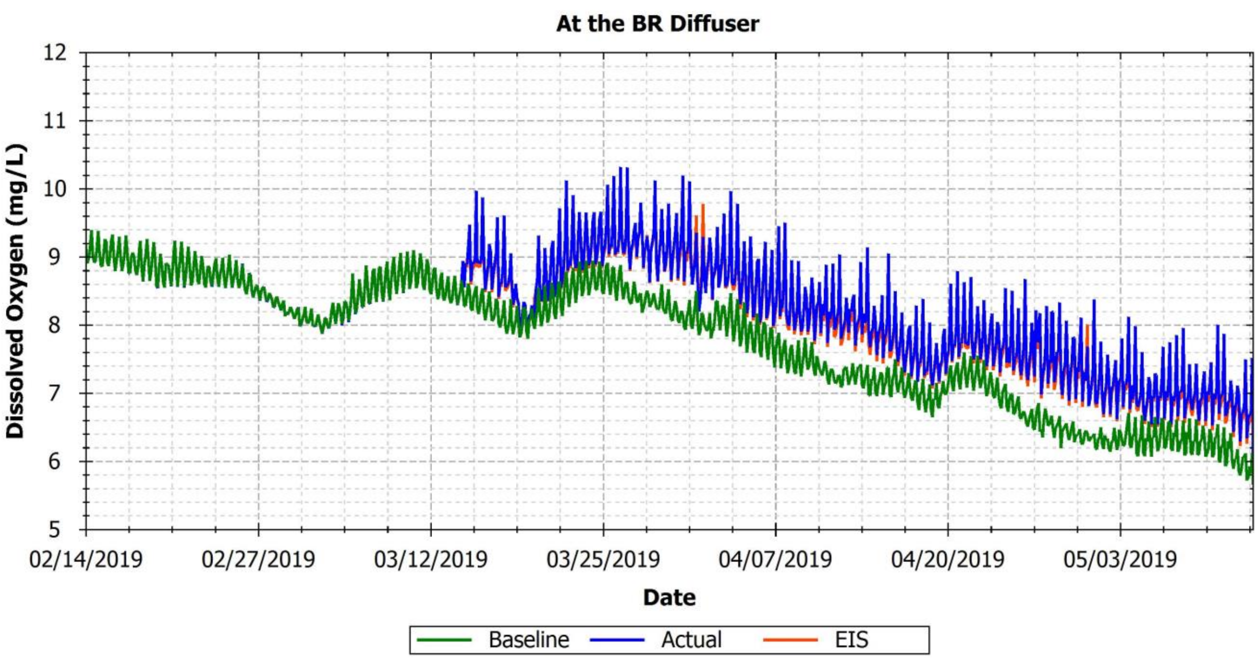


Figure 6-21 Simulated bottom DO concentrations at the Back River diffuser

The simulated surface DO results from the three model scenarios were analyzed at key USGS locations located upstream and downstream of the lower Front River and Back River diffusers and at the diffusers. There was a minimal difference in the DO concentrations at USGS 021989715, located 0.2 miles upstream of the lower Front River diffuser (***Figure 6-22***). Downstream of the lower Front River diffuser, at USGS 021989773, located in the close proximity of the diffuser, the surface DO concentrations in the 2019 SHEP Actual and EIS Model scenarios were typically 0.03 mg/L higher than the 2019 SHEP Baseline Model (***Figure 6-23***). The increase of 0.10 mg/L to 0.15 mg/L was observed in surface DO concentrations in the Back River, located immediately upstream and downstream of the diffuser (***Figure 6-24*** and ***Figure 6-25***). At the downstream Back River location, the surface DO concentrations in the 2019 SHEP Actual and EIS Model scenarios increased by approximately 0.14 mg/L compared to the 2019 Baseline Model. The increases in DO concentrations are lower in the lower Front River due to the higher freshwater flows that increase the flushing of the system as compared to the Back River.

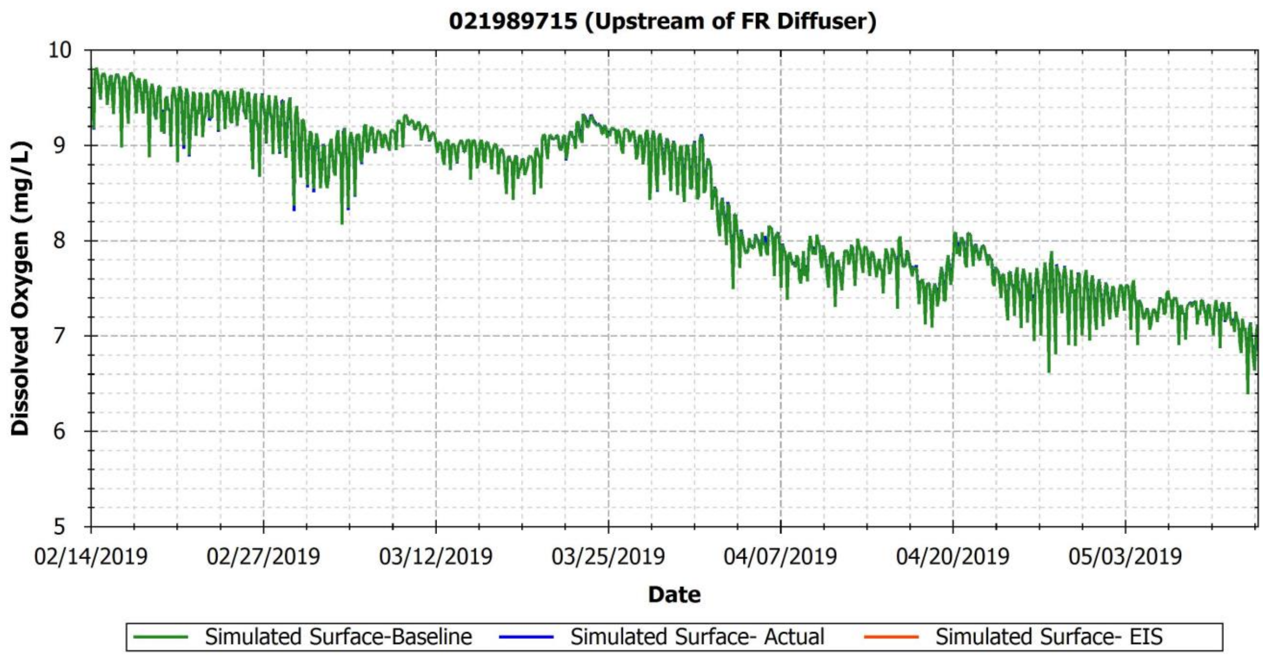


Figure 6-22 Simulated surface DO concentrations at the USGS station 021989715 Savannah River at Garden City

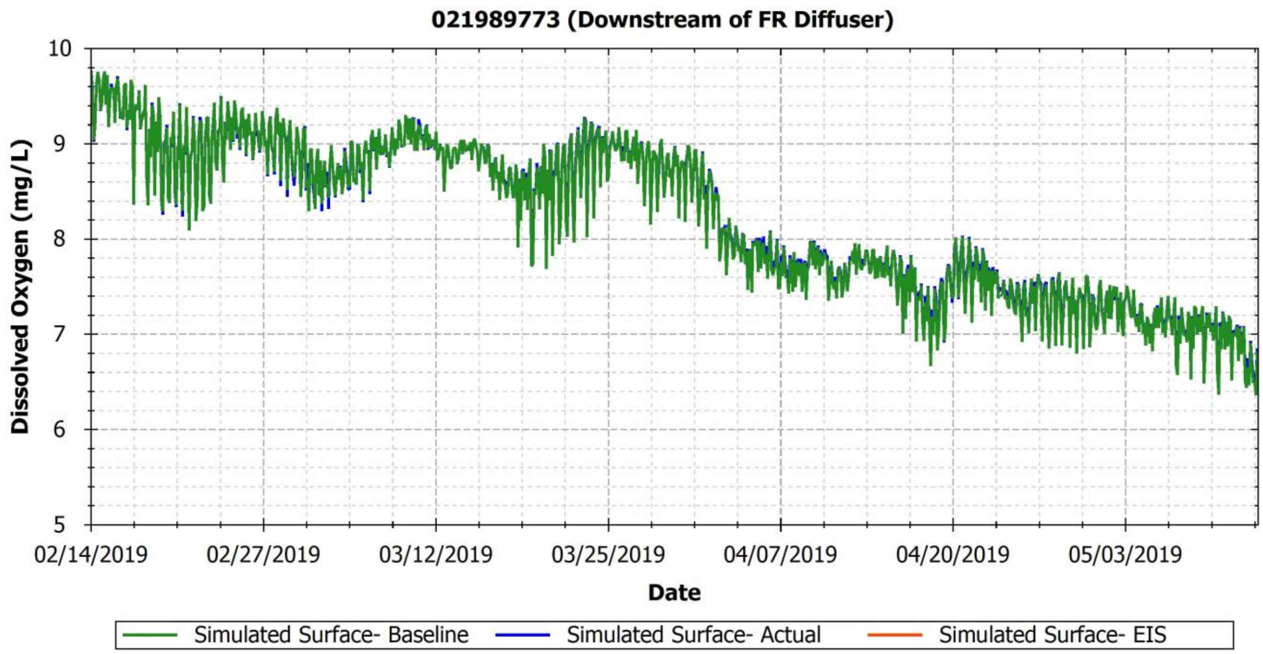


Figure 6-23 Simulated surface DO concentrations at the USGS station 021989773 Savannah River at USACE Dock

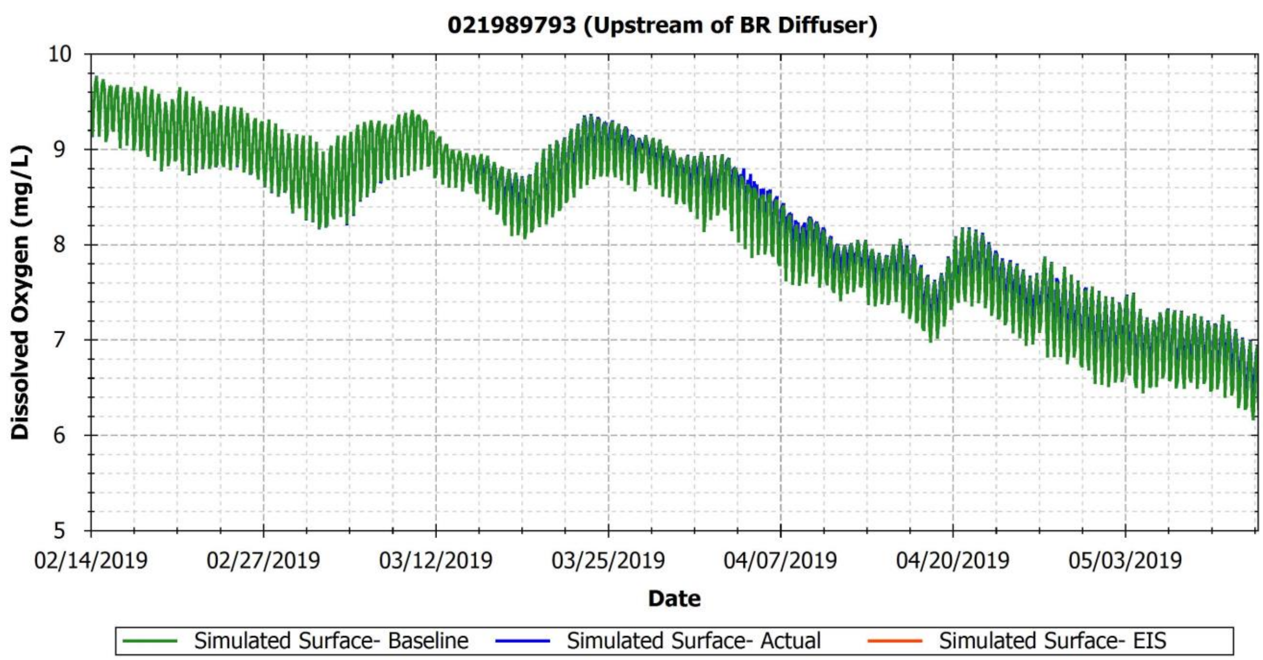


Figure 6-24 Simulated surface DO concentrations at the USGS station 021989793 Little Back River at Hog Island near Savannah

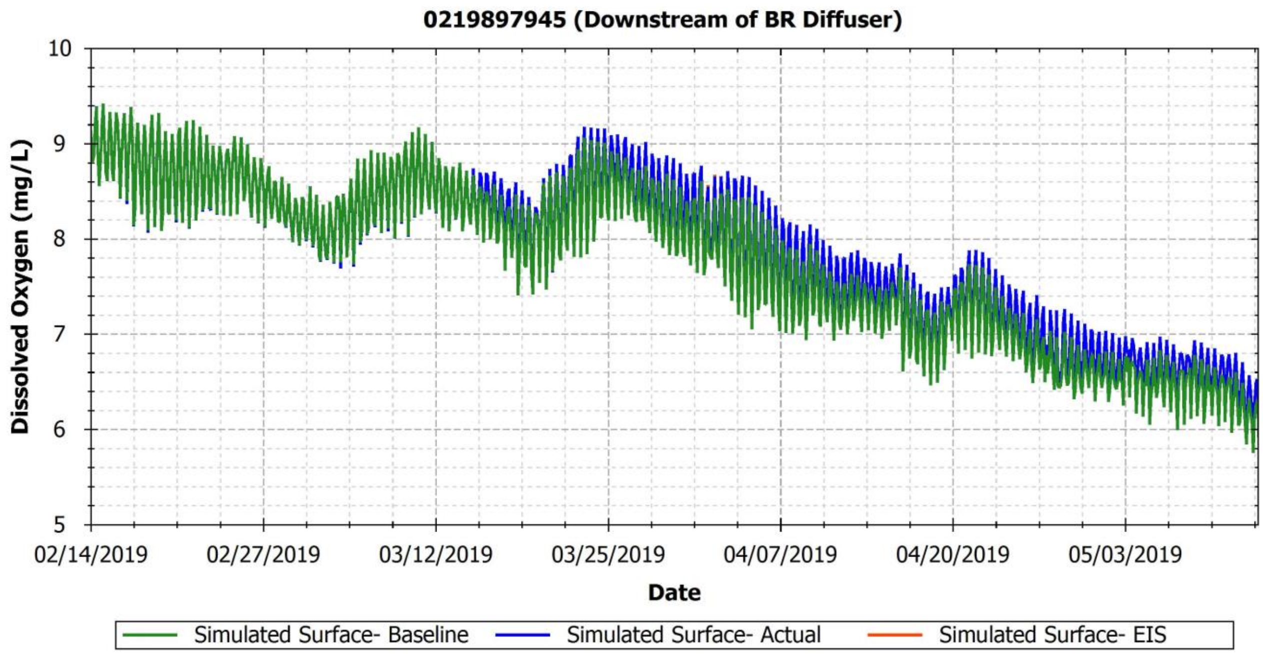


Figure 6-25 Simulated surface DO concentrations at the USGS station 0219897945 Back River 0.4 miles downstream US17 near Savannah

6.2.2 Longitudinal Profile Analysis

The changes in DO in the navigational channel due to the DO injection system were evaluated throughout lower Front River and Back River using longitudinal profiles. The profiles used all of the modeled outputs during the Test Run period from March 14, 2019 through May 12, 2019. They were created for the 10th, 50th, and 90th percentiles for both the bottom and surface layers for all three 2019 SHEP Model scenarios.

In the surface layer of lower Front River, the impacts of the DO injection system were greater downstream of the diffusers compared to the upstream channel (***Figure 6-26***). The DO concentrations were slightly elevated in the both the 2019 SHEP Actual and EIS Models from the diffuser to the mouth of the Savannah River at Fort Pulaski. The maximum surface DO delta increase in the 2019 SHEP Actual Model for the 10th percentile occurred at river mile 9.95 and was 0.10 mg/L (***Table 6-4***). In the bottom layer of the lower Front River, the DO impacts are greater upstream of the diffuser, likely due to the strength of the ebb tides (***Figure 6-27***). The maximum bottom DO delta increase in the 2019 SHEP Actual Model for the 10th percentile, 0.15 mg/L, occurred at river mile 19.54, approximately 3.2 miles upstream of the lower Front diffuser (***Table 6-4***).

In the Back River, the DO injection system increased DO concentrations from around river mile 9.0 to the confluence with the lower Front River at river mile 0.0 (***Figure 6-28*** and ***Figure 6-29***). In the surface layer, the maximum DO delta occurred upstream of the diffuser in the 10th percentile and downstream of the diffuser in the 90th percentile. The maximum surface DO delta increase in the 2019 SHEP Actual Model for the 10th percentile occurred at river mile 5.08, 0.7 miles upstream of the diffuser, and was 0.22 mg/L (***Table 6-4***). In the bottom layer of the Back River, the maximum DO delta increase in the 2019 SHEP Actual Model occurred at the diffuser in all percentiles (10th, 50th, 90th), and was 0.68 mg/L, 0.82 mg/L, and 0.73 mg/L, respectively (***Table 6-4***).

Table 6-4 Max deltas along the longitudinal profile for Front River and Back River

Location	Max Delta (mg/L)		
	10th %tile	50th %tile	90th %tile
Front River (Surface layer)	Actual – Baseline		
	0.10	0.09	0.07
	EIS – Baseline		
	0.09	0.09	0.07
Front River (Bottom layer)	Actual – Baseline		
	0.15	0.11	0.07
	EIS – Baseline		
	0.14	0.11	0.07
Back River (Surface layer)	Actual – Baseline		
	0.22	0.19	0.19
	EIS – Baseline		
	0.20	0.16	0.18
Back River (Bottom layer)	Actual – Baseline		
	0.68	0.82	0.73
	EIS – Baseline		
	0.61	0.72	0.68

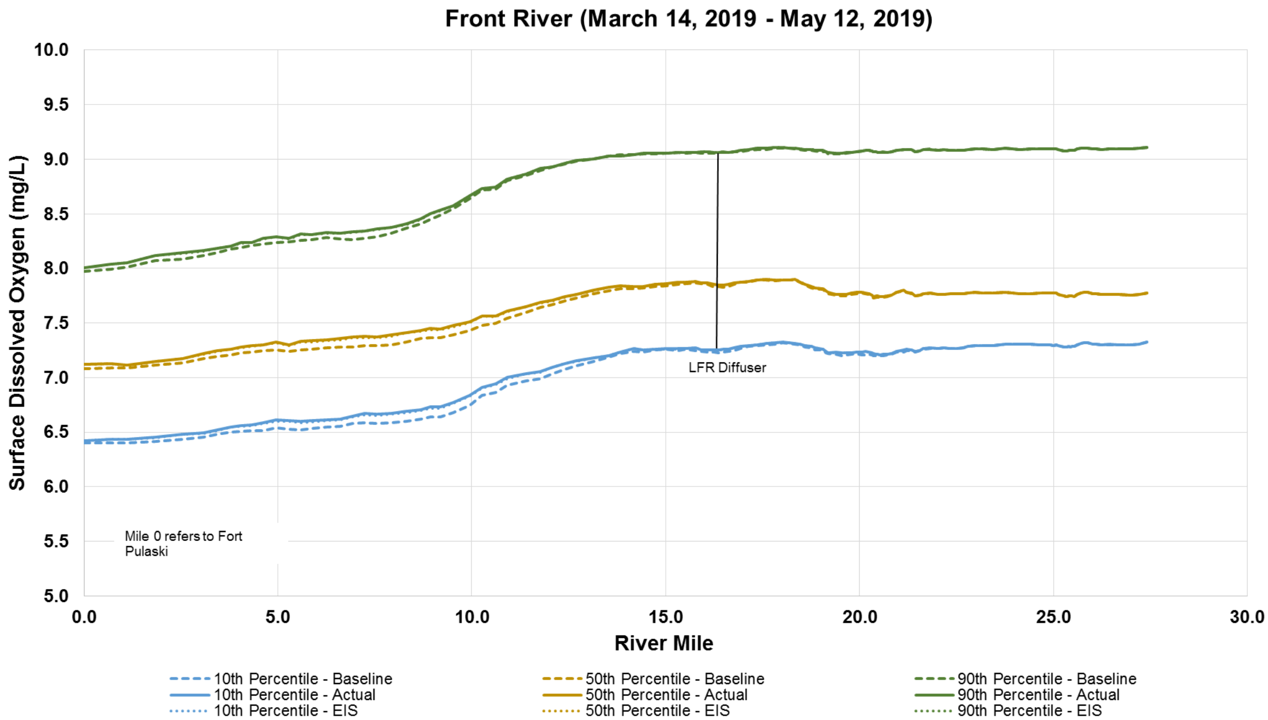


Figure 6-26 Surface DO longitudinal profile plot for the 2019 SHEP Model scenarios along the lower Front River

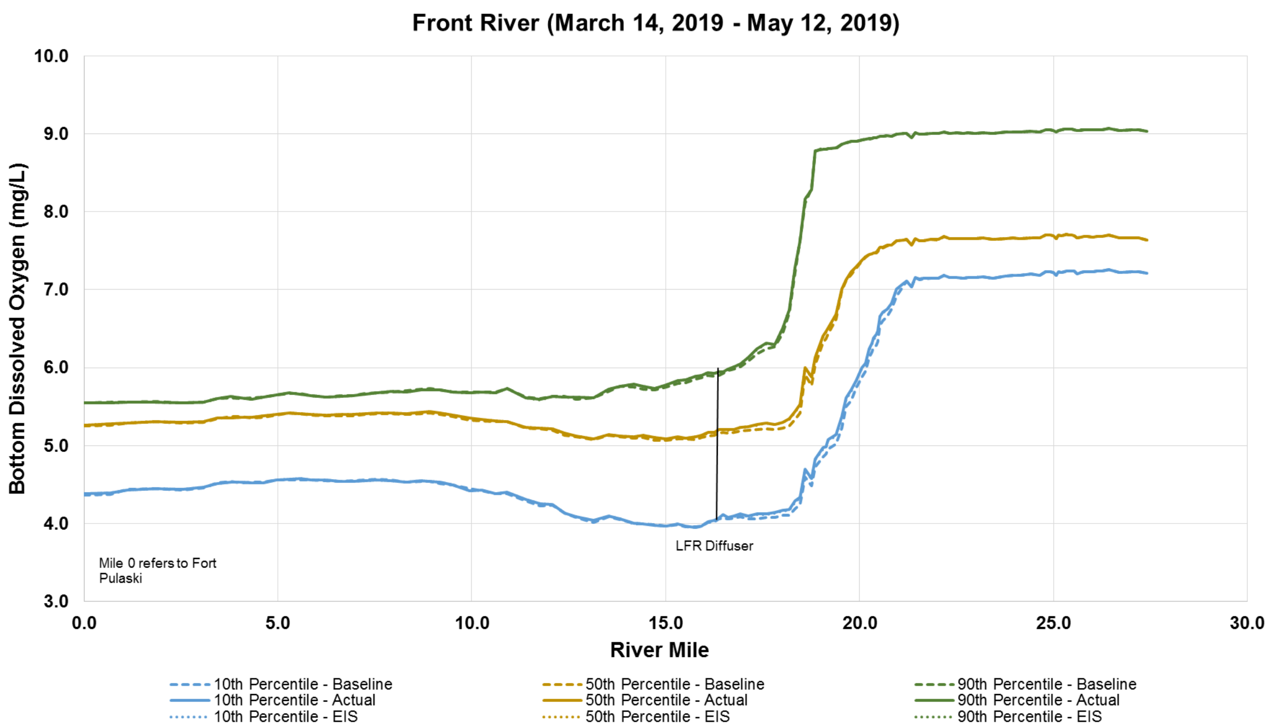


Figure 6-27 Bottom DO longitudinal profile plot for the 2019 SHEP Model scenarios along the lower Front River

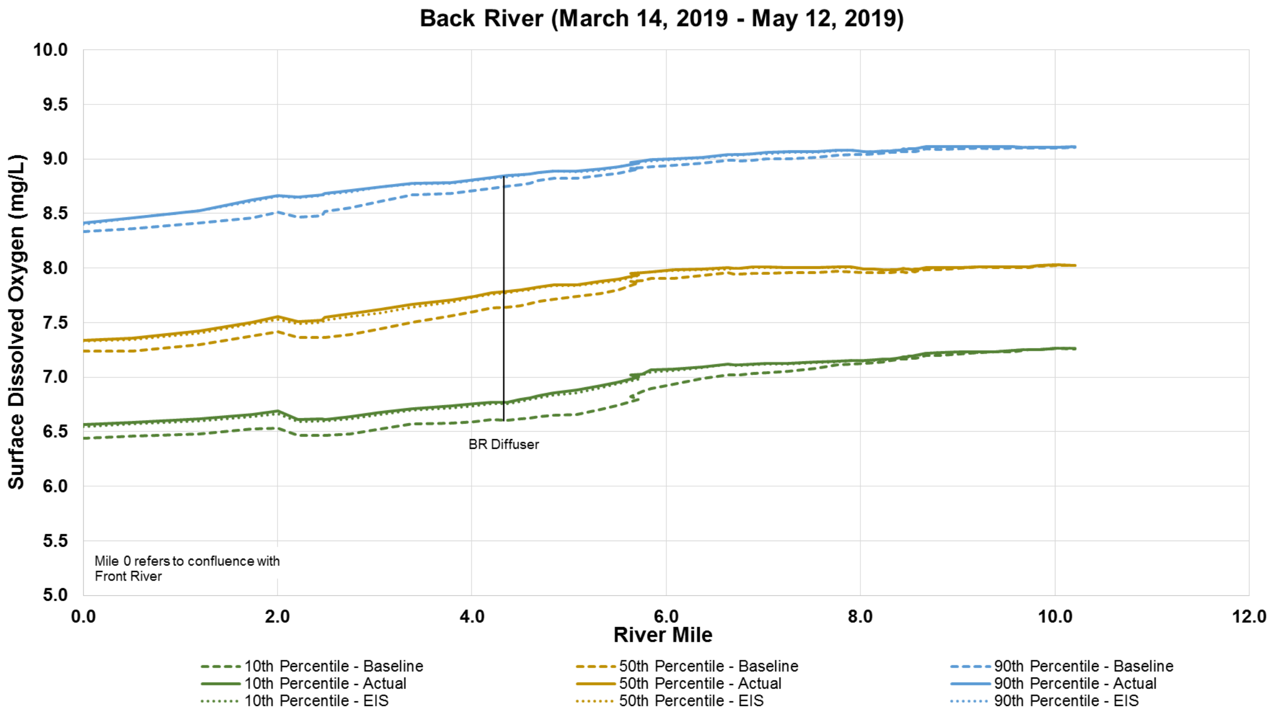


Figure 6-28 Surface DO longitudinal profile plot for the 2019 SHEP Model scenarios along the Back River

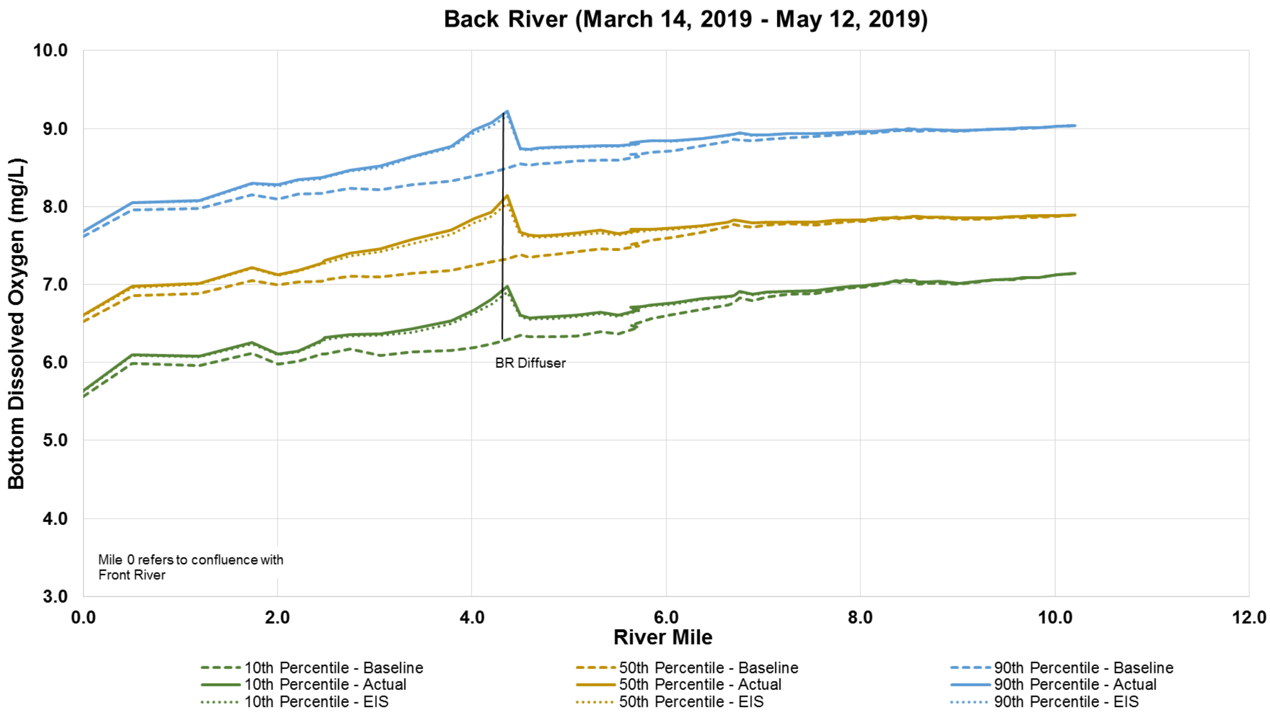


Figure 6-29 Bottom DO longitudinal profile plot for the 2019 SHEP Model scenarios along the Back River

6.2.3 DO Zonal Analysis

Potential changes in DO resulting from the DO injection system were investigated by calculating the changes in the bottom half water column DO concentrations at different locations of the Savannah River and Harbor for all three 2019 SHEP Model scenarios. The bottom half water column DO concentrations were evaluated regionally using the spatial zones defined in the *2010 Draft Revised Total Maximum Daily Load (TMDL) for Dissolved Oxygen in Savannah Harbor* report (USEPA, April 2010) and *2010 Oxygen Injection Design Report Savannah Harbor Expansion Project Savannah, Georgia* report (Tetra Tech, Inc., 2010). The zonal analysis was used to evaluate the DO TMDL targets and discharger permit limits (USEPA, April 2010).

The Front River diffuser is located in spatial zone FR05 and the Back River diffuser is located in the spatial zone BR03 (highlighted in ***Table 6-5*** and ***Table 6-6***). The results for 1^{st} percentile simulated DO concentrations indicate that the simulated DO concentrations from the 2019 SHEP Actual Model were 0.16 mg/L higher than DO concentrations simulated by the 2019 SHEP Baseline Model in the FR05 zone and by 0.29 mg/L in the BR03 zone (***Table 6-5***). The simulated DO concentrations in the 2019 SHEP Baseline and 2019 SHEP EIS Model runs are similar because the differences in the EIS DO loads and actual DO loads were relatively small. The results from the DO zonal analysis indicate that the DO injection system positively impacted the DO in the bottom half of the water column by increasing the concentrations by 0.1 mg to 0.2 mg/L in the 50^{th} percentile, and by 0.1 mg/L to 0.3 mg/L in the 1^{st} percentile (***Table 6-5*** and ***Table 6-6***). In addition, the Upriver Site was not operational during the Test Run. Once operational, an additional 28,000 pounds of DO will be delivered to the system and there should be an increase in DO concentrations in all zones.

Table 6-5 Summary of DO differences by zone in the bottom half of layers between 2019 SHEP Baseline and 2019 SHEP Actual models

Zones	2019 SHEP Baseline (mg/L)			2019 SHEP Actual (mg/L)			Relative Difference (mg/L)		
	1st %tile	50th %tile	99th %tile	1st %tile	50th %tile	99th %tile	1st %tile	50th %tile	99th %tile
FR01	4.96	6.05	6.64	4.97	6.07	6.67	0.01	0.02	0.03
FR02	5.07	6.21	7.31	5.12	6.26	7.36	0.05	0.05	0.05
FR03	4.69	5.89	7.15	4.73	5.95	7.19	0.04	0.06	0.04
FR04	4.56	5.83	7.89	4.66	5.93	7.99	0.10	0.10	0.10
FR05†	4.58	5.90	8.20	4.74	6.09	8.36	0.16	0.19	0.16
FR06	4.20	5.83	8.75	4.28	5.95	8.77	0.08	0.12	0.02
FR07	4.77	7.06	9.10	4.90	7.08	9.10	0.13	0.02	0.00
FR08	5.86	7.58	9.15	5.96	7.59	9.15	0.10	0.01	0.00
FR09	6.87	7.66	9.15	6.89	7.66	9.15	0.02	0.00	0.00
FR10	7.03	7.69	9.16	7.03	7.69	9.16	0.00	0.00	0.00
FR11	7.04	7.68	9.16	7.04	7.68	9.16	0.00	0.00	0.00
MR01	5.57	7.48	9.25	5.82	7.52	9.25	0.25	0.04	0.00
MR02	6.10	7.69	9.26	6.24	7.72	9.26	0.14	0.03	0.00
MR03	6.73	7.94	9.34	6.78	7.95	9.34	0.05	0.01	0.00
MR04	6.92	7.81	9.21	6.93	7.81	9.21	0.01	0.00	0.00
MR05	6.91	7.69	9.18	6.91	7.69	9.18	0.00	0.00	0.00
MR06‡	NA	NA	NA	NA	NA	NA	NA	NA	NA
LBR01	7.01	7.85	9.27	7.01	7.85	9.27	0.00	0.00	0.00
LBR02	6.92	7.92	9.28	6.92	7.92	9.29	0.00	0.00	0.01
LBR03	6.60	7.79	9.18	6.66	7.81	9.20	0.06	0.02	0.02
BR01	5.46	6.68	8.18	5.54	6.79	8.32	0.08	0.11	0.14
BR02	5.88	7.15	8.64	6.10	7.38	8.89	0.22	0.23	0.25
BR03†	6.13	7.51	9.02	6.42	7.72	9.15	0.29	0.21	0.13
SCh01	6.07	7.16	8.07	6.12	7.20	8.12	0.05	0.04	0.05
SCh02	5.80	6.94	8.01	5.83	6.99	8.04	0.03	0.05	0.03
SR	7.12	7.69	9.18	7.12	7.69	9.18	0.00	0.00	0.00
StbR	6.45	7.47	9.07	6.48	7.49	9.07	0.03	0.02	0.00

†FR05 and BR03 are the spatial zones where the lower Front River diffuser and Back River diffusers are located respectively

‡MR06 (McCoombs Cut) was removed from the 2019 SHEP Model to represent the complete closure of McCoombs Cut

Table 6-6 Summary of DO differences by zone in the bottom half of layers between 2019 SHEP Baseline and 2019 SHEP EIS models

Zones	2019 SHEP Baseline (mg/L)			2019 SHEP EIS (mg/L)			Relative Difference (mg/L)		
	1st %tile	50th %tile	99th %tile	1st %tile	50th %tile	99th %tile	1st %tile	50th %tile	99th %tile
FR01	4.96	6.05	6.65	4.97	6.07	6.67	0.01	0.02	0.03
FR02	5.07	6.21	7.32	5.11	6.26	7.36	0.04	0.05	0.05
FR03	4.69	5.90	7.16	4.73	5.95	7.18	0.04	0.06	0.03
FR04	4.56	5.84	7.90	4.65	5.92	7.98	0.09	0.09	0.09
FR05†	4.58	5.90	8.21	4.73	6.08	8.35	0.15	0.18	0.15
FR06	4.20	5.83	8.75	4.28	5.94	8.77	0.08	0.11	0.02
FR07	4.77	7.07	9.11	4.89	7.08	9.10	0.12	0.02	0.00
FR08	5.86	7.59	9.15	5.95	7.59	9.15	0.09	0.01	0.00
FR09	6.87	7.66	9.16	6.89	7.66	9.15	0.02	0.00	0.00
FR10	7.03	7.69	9.17	7.03	7.69	9.16	0.00	0.00	0.00
FR11	7.04	7.69	9.16	7.04	7.68	9.16	0.00	0.00	0.00
MR01	5.57	7.48	9.26	5.79	7.51	9.25	0.22	0.03	0.00
MR02	6.10	7.69	9.26	6.25	7.72	9.26	0.15	0.03	0.00
MR03	6.73	7.95	9.34	6.77	7.94	9.34	0.04	0.00	0.00
MR04	6.92	7.81	9.22	6.93	7.81	9.21	0.01	0.00	0.00
MR05	6.91	7.69	9.18	6.91	7.69	9.18	0.00	0.00	0.00
MR06‡	NA	NA	NA	NA	NA	NA	NA	NA	NA
LBR01	7.01	7.85	9.27	7.01	7.85	9.27	0.00	0.00	0.00
LBR02	6.92	7.93	9.29	6.92	7.92	9.29	0.00	0.00	0.01
LBR03	6.60	7.80	9.19	6.65	7.81	9.20	0.05	0.02	0.02
BR01	5.46	6.68	8.19	5.53	6.77	8.31	0.07	0.09	0.13
BR02	5.88	7.16	8.65	6.08	7.36	8.87	0.20	0.21	0.23
BR03†	6.13	7.51	9.02	6.38	7.70	9.14	0.25	0.19	0.12
SCh01	6.07	7.17	8.08	6.11	7.20	8.11	0.04	0.04	0.04
SCh02	5.80	6.95	8.01	5.83	6.98	8.03	0.03	0.04	0.02
SR	7.12	7.69	9.18	7.12	7.69	9.18	0.00	0.00	0.00
StbR	6.45	7.48	9.07	6.48	7.49	9.07	0.03	0.02	0.00

†FR05 and BR03 are the spatial zones where the lower Front River diffuser and Back River diffusers are located respectively

‡MR06 (McCoombs Cut) was removed from the 2019 SHEP Model to represent the complete closure of McCoombs Cut

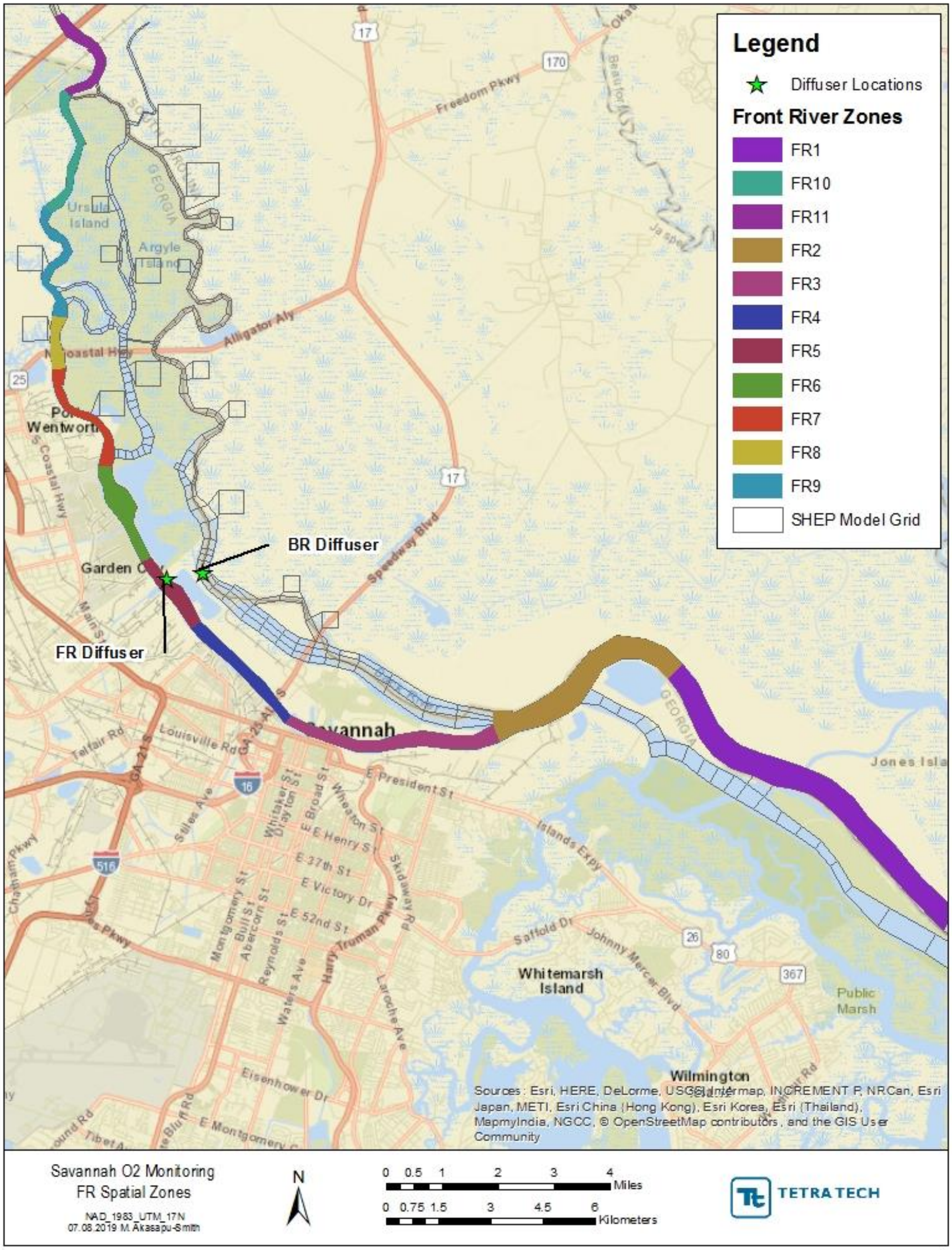


Figure 6-30 Location Front River (FR) DO Spatial zones

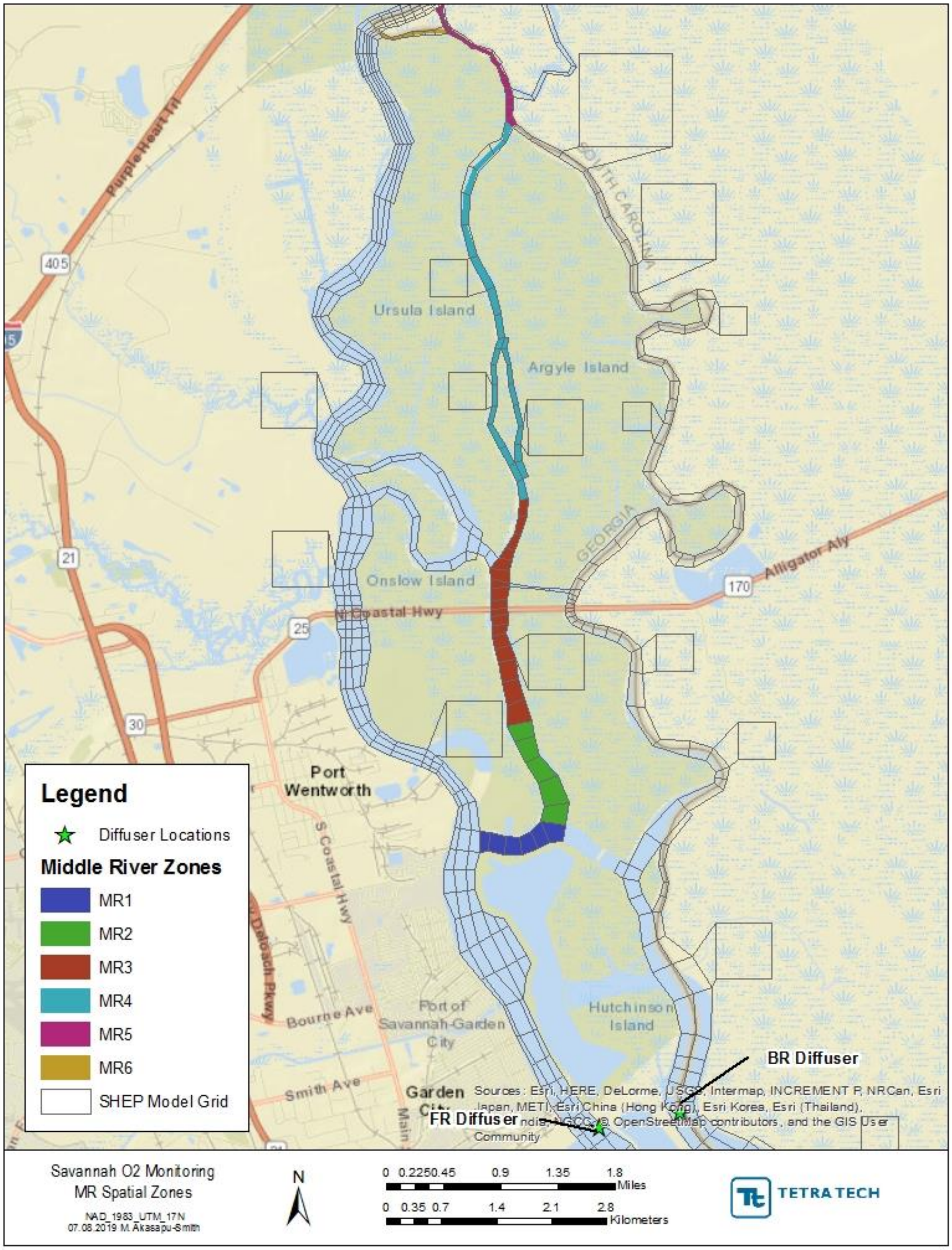


Figure 6-31 Location Middle River (MR) DO Spatial zones

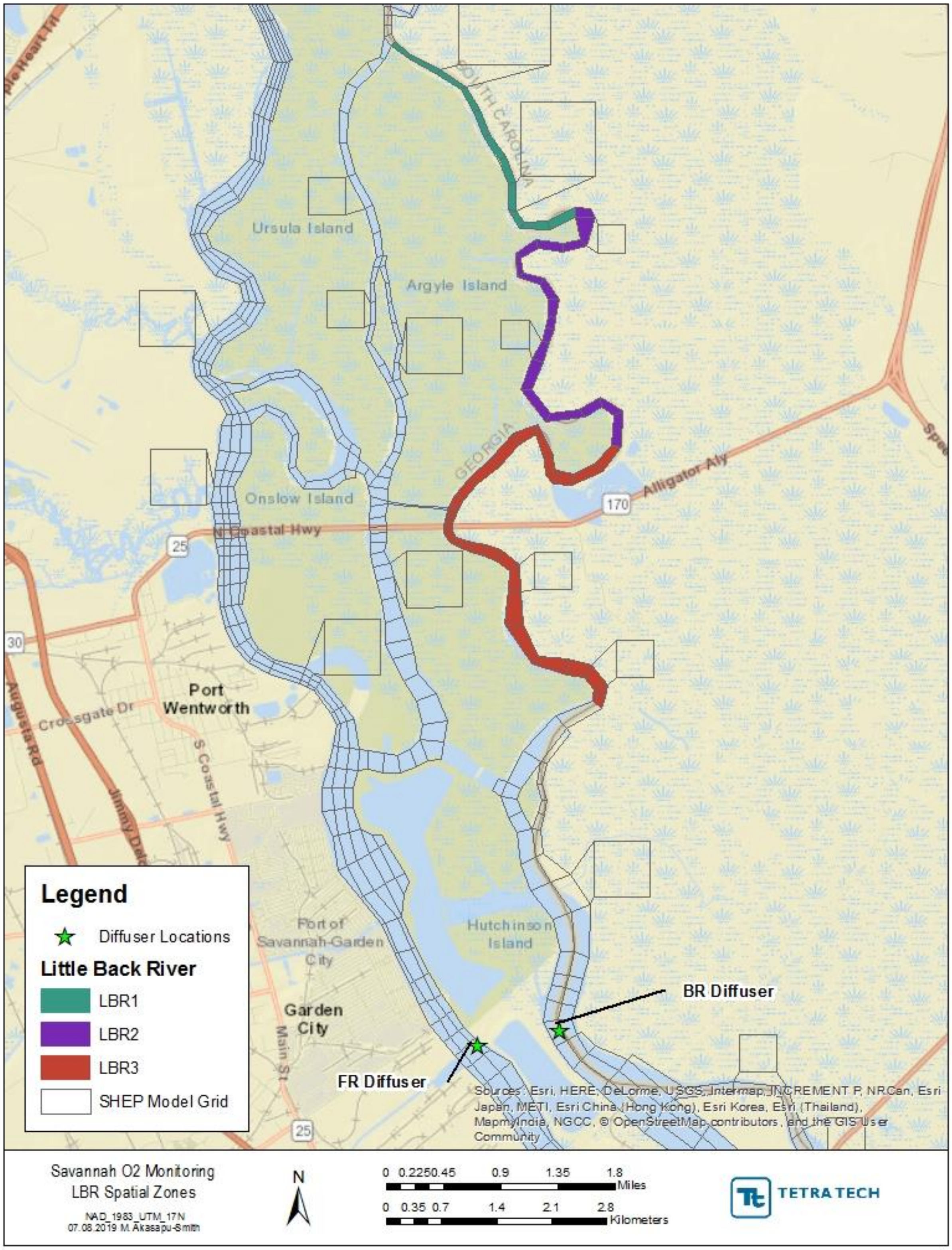


Figure 6-32 Location Little Back River (LBR) DO Spatial zones

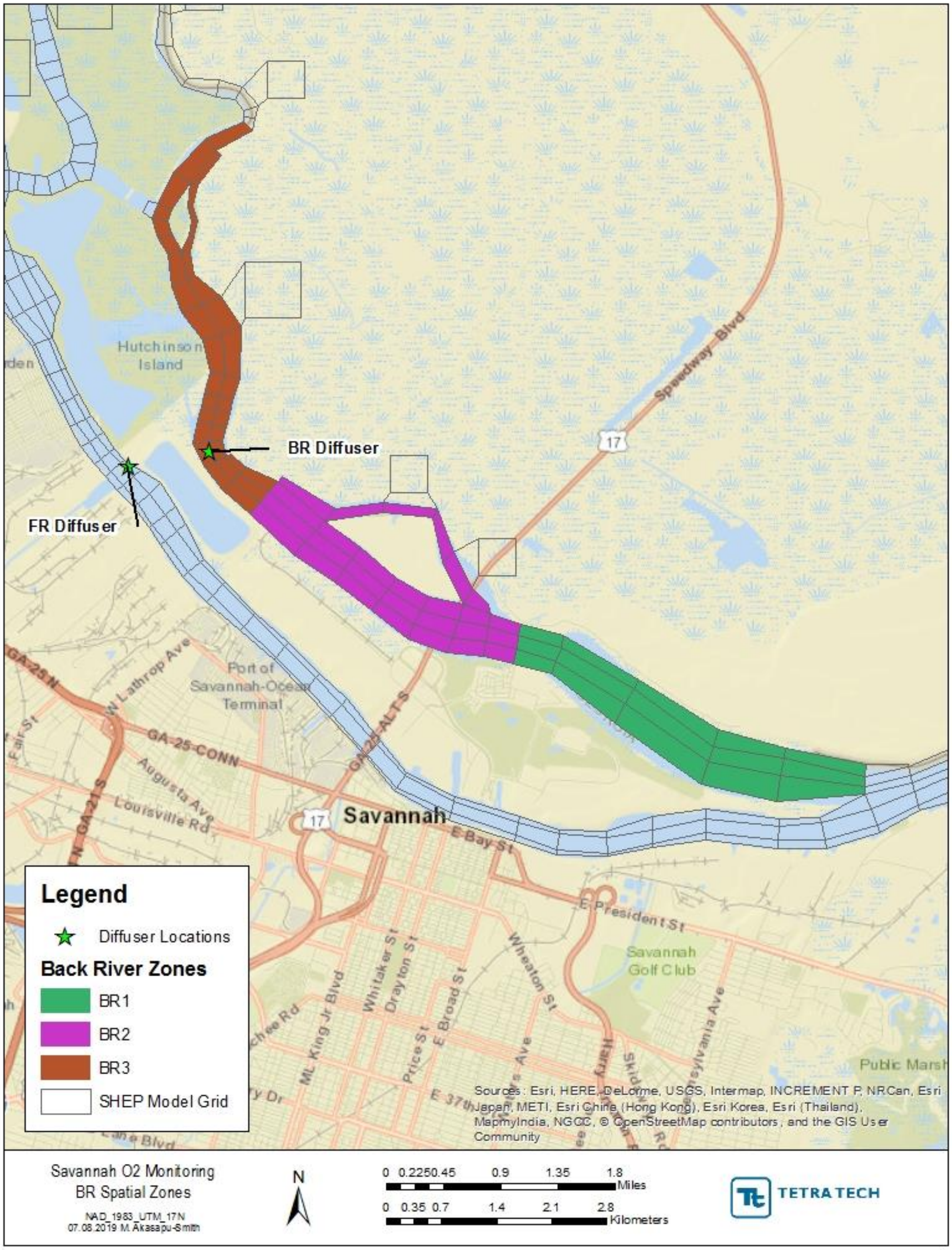


Figure 6-33 Location Back River (BR) DO Spatial zones

Figure 6-34 Location South Channel (SCh) DO Spatial zones

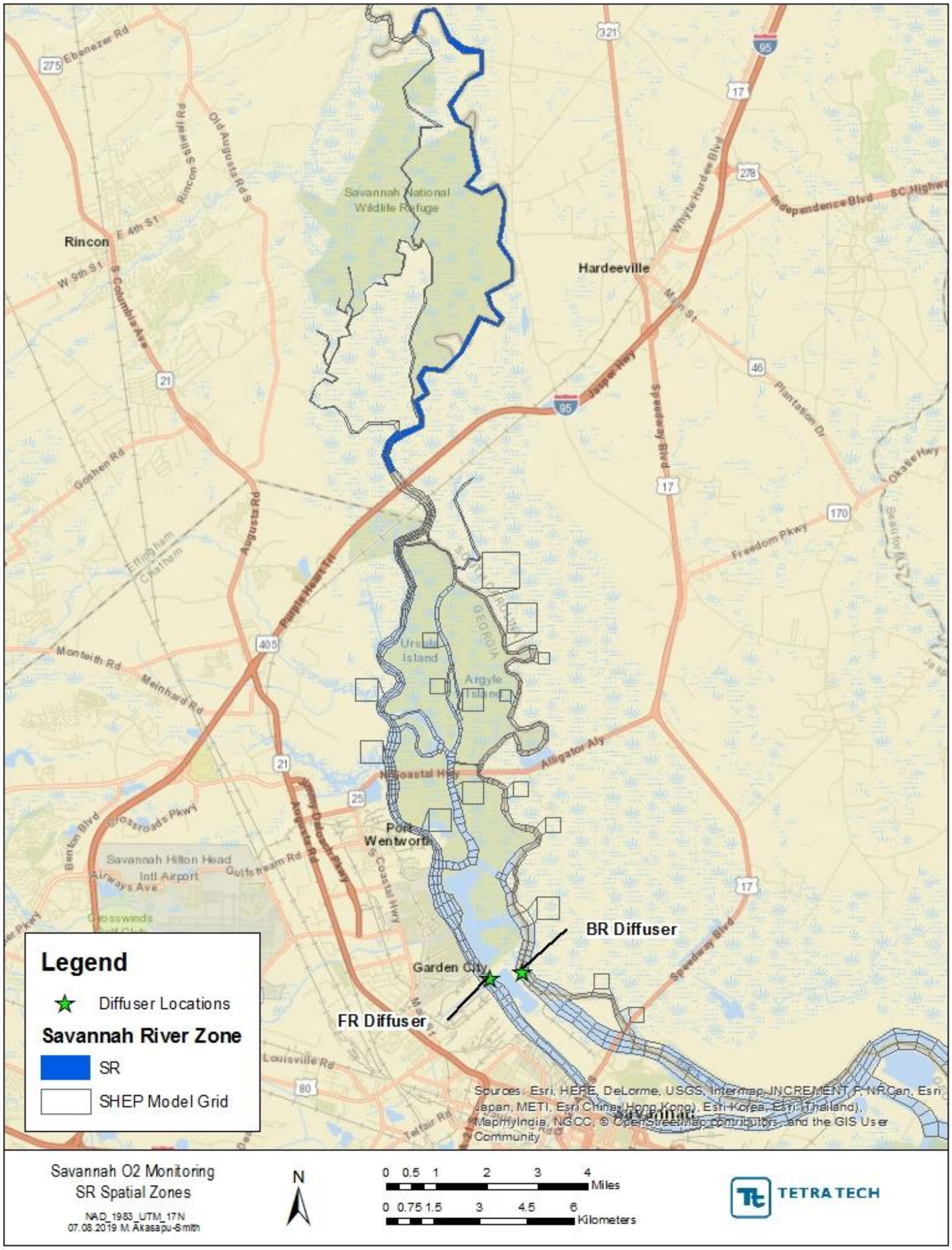


Figure 6-35 Location Savannah River (SR) DO Spatial zones

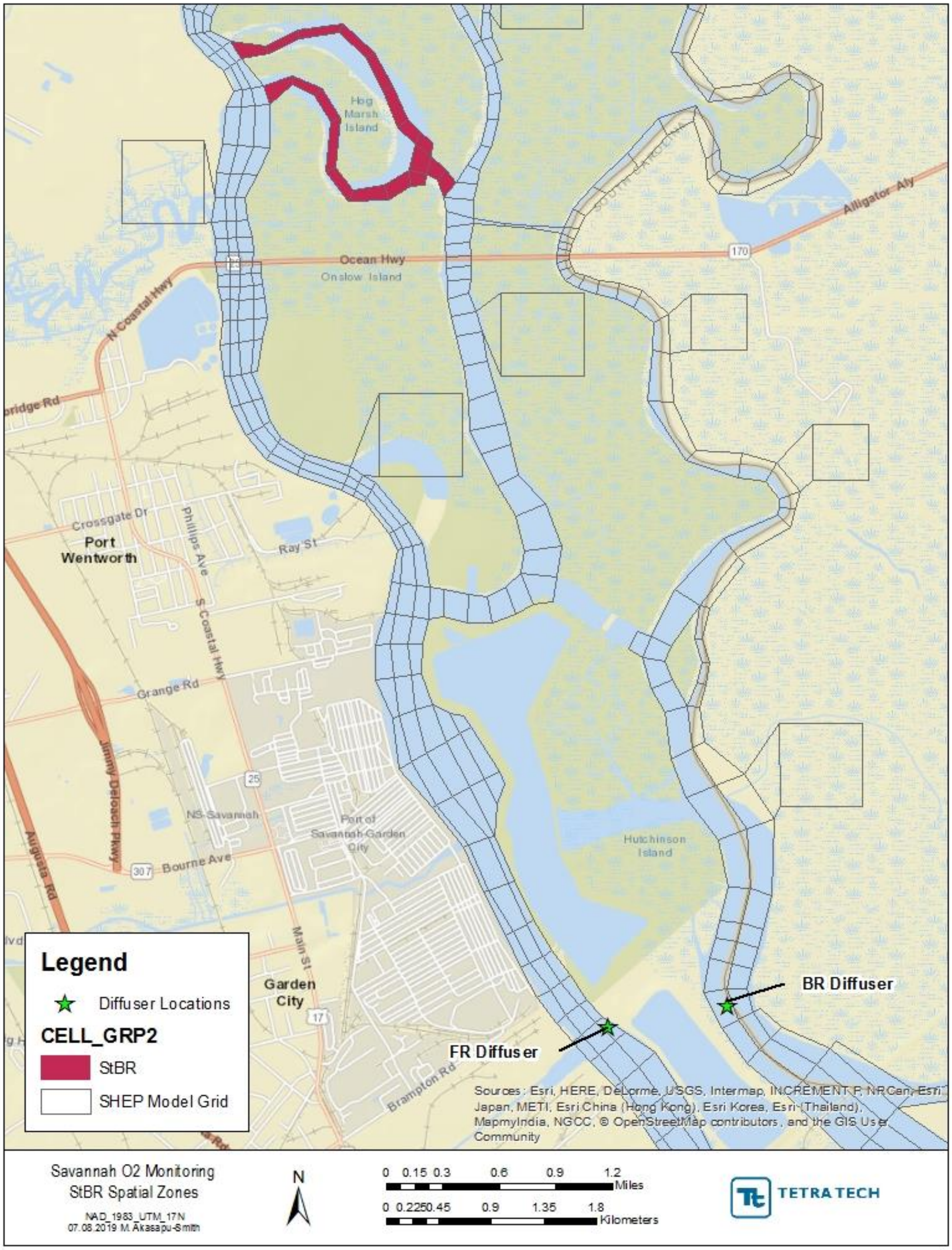


Figure 6-36 Location Steamboat River (StBR) DO Spatial zones

7.0 CONCLUSIONS

The objective of the Test Run data collection effort was to determine how well the injected oxygen was distributed throughout the estuary and if the DO system performed as expected. The Test Run data collection was performed for a 60-day period from March 14, 2019 through May 12, 2019 around the Downriver diffuser sites on the lower Front River and the Back River. In addition to the data collected near the diffuser sites, flow and water quality data from USGS stations located upstream and downstream of the diffuser sites, and USACE DO injection facility data which provided information on the operation of the Plant were used for the analysis.

During the Test Run data collection period, the field team successfully conducted monitoring on the lower Front River and Back River by collecting data from platform sondes, semi-permanent buoy sondes, profiling sondes and drift sondes. The acceptance rates for the monitoring data were 99.5% for platform data, 99.8% for semi-permanent buoy data, 98.9% for profile data, and 96.6% for drift data. The overall data acceptance rate for the data collected were greater than 90%. The field team also conducted seven (7) dye studies during this period. The dye studies were used to visually confirm the direction and orientation of the DO plume, as well as the potential area extent of the plume. This information was also used by the field team to adjust the data collection locations and data collection times.

The data collected were analyzed and were able to show the following: 1) showed the presence of the DO injection, 2) that the DO was staying within the water column, and 3) that mixing of the DO is occurring within the water column.

Data collected during the Test Run data collection period were used to calculate the WCTE. The WCTE calculations for the Test Run period showed an average combined WCTE of approximately 98% for the lower Front River and Back River. During the Test Run data collection, two neap tide conditions occurred at the end of March and April of 2019. Extended periods of super-saturated DO were observed in the Back River during the neap tides due to lower tidal flushing which allowed the injected DO loads to accumulate in the river. This resulted in a larger loss of oxygen to the atmosphere and a lower WCTE number. The lower Front River WCTE was not impacted by the neap tides due to the large freshwater flows that continually flushed the system.

The approved 2015 SHEP Model was updated and extended through December 2017 (2018 SHEP Model). When the model results were compared to measured USGS data, the 2018 SHEP Model produced verification statistics that were similar to the 2015 SHEP Model calibration statistics. Using the 2018 SHEP Model as the baseline, the 2019 SHEP Model was updated and extended through the Test Run period and the model results were able to capture the general trends and magnitudes of measured DO on both the lower Front River and the Back River. The 2019 SHEP Model was therefore able to show the impacts of the DO injection in the system, and three scenarios were setup using the 2019 SHEP Model to evaluate the DO injection system impact:

- 2019 SHEP Baseline Model: 2019 SHEP Model with the DO injection system turned off
- 2019 SHEP Actual Model: 2019 SHEP Model with the actual 15-min DO loads injected into lower Front River and Back River
- 2019 SHEP EIS Model: 2019 SHEP Model with DO injection system adjusted to match EIS terms; model injected 8,000 lbs/day of DO into lower Front River and 4,000 lbs/day of DO into Back River

Results from the 2019 SHEP Model scenarios indicate that the during the Test Run period, on average, the DO injection system increased surface DO concentrations by 0.02 mg/L at the Front River diffuser and by 0.14 mg/L at the Back River diffuser, and by 2.35 mg/L and 0.75 mg/L in the bottom layers at the lower Front River diffuser and Back River diffusers, respectively. The maximum 10th percentile DO concentration increase in the Front River surface layer occurred at river mile 9.95, 6.4 miles downstream of the diffuser, and was 0.10 mg/L, while in the bottom layer it occurred at river mile 19.54, 3.2 miles upstream of the diffuser, and was 0.15 mg/L. The maximum 10th percentile DO concentration increase in the Back River surface layer occurred at river mile 5.08, 0.7 miles upstream of the diffuser, and was 0.22 mg/L, while in the bottom layer it occurred at the diffuser and was 0.68 mg/L. In addition, the DO in the bottom half of the water column in previously used regional spatial zones showed an increase of 0.16 mg/L (1st percentile and 99th percentile) in the Front River zone (FR05) by the diffuser, and an increase of 0.29 mg/L (1st percentile) and 0.13 mg/L (99th percentile) in DO in the Back River zone (BR03) by the diffuser.

Based on an analysis of both measured data and modeling results, the conclusion is that Downriver DO injection system operated as expected during the Test Run period.

8.0 BIBLIOGRAPHY

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