Savannah River at Risk^{SM}

Final Report

February 2006 – January 2008

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1. INTRODUCTION

Southeastern Natural Sciences Academy (SNSA) conducted a 24-month study within the Savannah River Basin (SRB). The goal of this research was to characterize the effects of the urban corridor on Savannah River water quality under baseline and storm event conditions, with special attention to dissolved oxygen and carbon dynamics. The study was designed to identify source and sink areas for key inorganic and organic constituents.

The study included continuous monitoring, monthly chemical and biological sampling and also incorporated major stochastic events to evaluate the impact of storms. This research was designed to estimate the annual mass flux by employing a network of fixed water quality monitoring stations within and downstream of the urban river reach. Also included were Butler Creek and Horse Creek, listed respectively on Georgia and South Carolina 303(d) lists, and Stevens Creek (SC). The study was designed to identify source and sink areas for key inorganic and organic constituents. This was employed to estimate the current loadings from natural and anthropogenic sources into the urban corridor and downstream areas.

1.1. Savannah River Background Information

Savannah River flows for approximately 312-miles from its headwaters in the Blue Ridge Mountains to the Atlantic Ocean near Savannah, Georgia. The river forms much of the border between Georgia and South Carolina, bisecting three distinct physiographic regions - the Appalachian Plateau, Piedmont Province and Coastal Plain. The Savannah River Basin (Figure 1-1) receives drainage from approximately 10,600 square miles of watershed located in North Carolina, Georgia, and South Carolina.

Near the headwaters, the Seneca and Tugaloo Rivers join and are impounded to form Lake Hartwell. Below Hartwell Dam, the river is further regulated by Richard B. Russell and J. Strom Thurmond dams and their associated impoundments. These three impoundments stretch 120 river miles (USACE 1996), and are primarily constructed for flood control and hydroelectric power generation. Beginning approximately 13 miles below Thurmond Dam, three additional features impact river flow: Stevens Creek Reservoir and Dam; Augusta Diversion Dam and Augusta Canal; and New Savannah Bluff Lock & Dam (NSBLD). The Savannah River becomes a free flowing river below NSBLD. Flow patterns have also been influenced by down-river dredging, 26 miles of channelization, and navigation cuts (Hale and Jackson, 2003). Dredging operations from River Mile 21.3 (RM, measured from the mouth of the Savannah River) up to

RM 204.4 (just above New Savannah Bluff Lock & Dam) ended in 1979 due to a lack of barge traffic around Augusta.

1.2. Urban Corridor

This study extends the length of the metropolitan Augusta urban corridor from RM 208 to 179 (Figure 1-1). The corridor lies within Richmond and Columbia Counties in Georgia and Edgefield and Aiken Counties in South Carolina. The urban corridor begins near the Fall Line RM 208, immediately below Stevens Creek Dam. Just downstream is the Augusta Diversion Dam (RM 207), which diverts a portion of the river flow into the Augusta Canal. Three small hydroelectric projects use water supplied by the Canal to generate electricity. The Augusta Raw Water Pumping Station uses water from the Canal to power hydromechanical turbines that pump water from the river to a treatment plant that supplies Augusta's potable water needs. The pumping station turbines return water to river within the last mile of the shoals (~RM 203).

The river is regulated downstream by New Savannah Bluff Lock & Dam, just above RM 187. Between the Augusta Diversion Dam and New Savannah Bluff Lock & Dam water level and current velocities are modified by the pool effect. Historic peak flows in the Augusta corridor prior to construction of impoundments were between 200,000 to 300,000 cubic feet per second (cfs), but today rarely exceed 40,000 cfs (USACE 1996). Flow remains rather constant seasonally, but varies widely throughout the day due to hydroelectric production schedules. Two USGS gauges, located within the urban corridor, provided flow data from the past 50+ years. Since Thurmond Dam operation began, peak flows have been greatly reduced and low flows have increased causing an overall dampened hydrograph (Hale and Jackson, 2003).

There are four creeks within the urban corridor, Reed Creek and Rae's Creek, which flow into the Augusta Canal, Horse Creek on the South Carolina side, and Butler Creek on the Georgia side. Several municipal industrial river water withdrawals and NPDES wastewater discharges exist within the corridor, as well as a major NPDES thermal discharge from a coal/natural gas-fired power plant.

There is minimal connectivity between the river and the floodplain within the urban corridor due to an extensive levee system on the Georgia side. Some interaction with Black Gum Swamp on the South Carolina side occurs near RM 190.

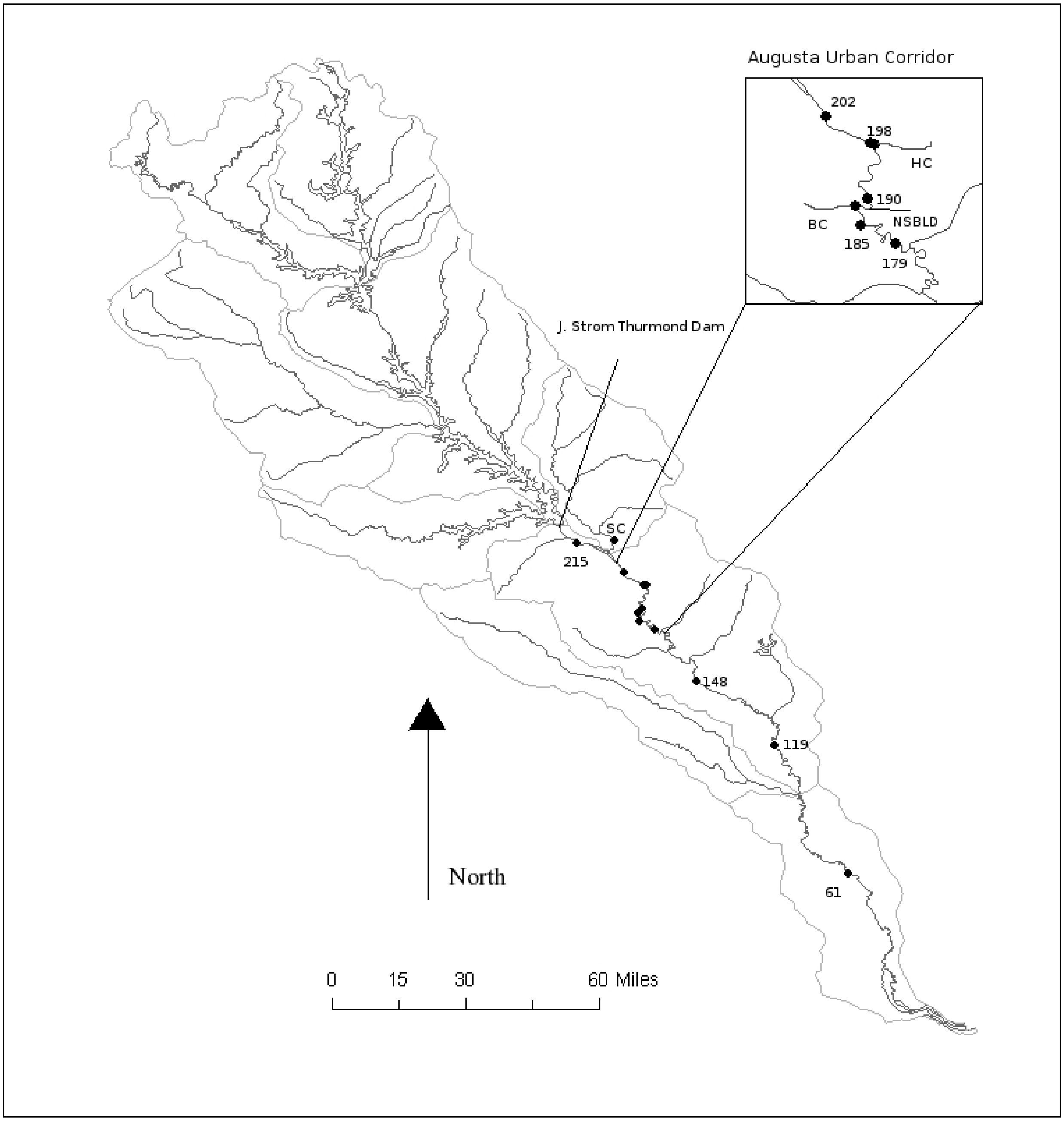

Figure 1-1. Savannah River Basin Map

2. METHODS

2.1. Study Sites

Nine study sites were selected on the mainstem Savannah River and three major tributaries, including Stevens Creek (Edgefield County) and Horse Creek (Aiken County) in South Carolina, and Butler Creek (Richmond County) in Georgia (Table 2-1). Study sites were selected based on several criteria including accessibility, safety, security, and proximity to major source inputs (e.g., creeks, municipal/industrial discharges, etc.). Stations at RM 119 and RM 61 were added in August and September 2006, respectively, to better understand downstream watershed effects on mainstem water quality.

Table 2-1. Savannah River at Risk sampling stations

River Mile or Tributary	Description	Latitude	Longitude
215	7 miles below Thurmond Dam	33.5959109	-82.1461363
Stevens Creek	4.2 upstream of mouth	33.6064540	-82.0258880
202	Just below Augusta Shoals	33.5027653	-81.9906723
198	I520 bridge	33.4634678	-81.9268230
Horse Creek	0.4 miles upstream of mouth	33.4619200	-81.9205050
190	2.5 miles upstream of New Savannah Bluff Lock & Dam	33.3839097	-81.9317347
Butler Creek	just upstream of levee, 0.2 miles upstream of mouth	33.3730430	-81.9481890
185	2.5 miles downstream of New Savannah Bluff Lock & Dam	33.3453000	-81.9410000
179	8.5 miles downstream of New Savannah Bluff Lock & Dam	33.3179140	-81.8909290
148	1 mile downstream of USGS Gage 021973269	33.1514072	-81.7547337
119	0.25 miles upstream of USGS Gage 02197500	32.9403800	-81.5019190
61	0.5 miles downstream of USGS Gage 02198500	32.5247390	-81.2623880

NOTE: River Mile (RM) designations in this report are referenced to National Oceanographic and Atmospheric Administration nautical charts 11514 and 11515

2.1.1. Site Descriptions

RM 215

Hydrology at RM 215 is highly influenced by hydropower discharges from the USACE's J. Strom Thurmond Dam, located approximately seven miles upstream. This section of the river is also referred to as the Stevens Creek pool, as it is impounded by SCE&G's Stevens Creek Dam, located approximately seven miles downstream (RM 208). Depending on the magnitude, duration, and timing of generation at both dams, water velocities ranged from 0.4 to 2 ft/sec and depths fluctuated an average of two feet daily, with a mean cross-sectional depth of approximately 11 feet. The river channel was relatively wide with a bed consisting primarily of course sand. Fallen trees and limbs (snags) were common along the banks.

Stevens Creek

The Stevens Creek drainage basin (HUC 03060107) includes approximately 772 square miles in McCormick, Greenwood, Saluda, and Edgefield counties in South Carolina. The mouth of Stevens Creek is located at RM 218, just upstream of the Stevens Creek Dam. The SNSA research station on Stevens Creek was located approximately four miles upstream from its confluence with the River. Releases from Thurmond and Stevens Creek Dams can affect water depth and velocity in Stevens Creek several miles upstream of its mouth. This eight mile section experienced daily flow reversals and average daily water level fluctuations of two feet. Sediments in this section consisted primarily of sand and silt, with numerous snags along the banks and within the channel.

RM 202

The station at RM 202 was located approximately five miles below the Augusta Diversion Dam (ADD) at the base of the shoals and at the upstream limit of the Augusta Pool, which extends approximately 15 miles downstream to New Savannah Bluff Lock and Dam (NSBLD). Hydrology at RM 202 was influenced greatly by the ADD, which, during low flows, diverted up to 75% of the river flow into the Augusta Canal (FERC, 2006). Water levels here were held relatively constant by NSBLD, with pool level fluctuations averaging less than one foot daily. Mean cross-sectional depths were typically 10 - 18 feet, with measured velocities ranging from 0.28 -1.36 ft/second. This station is immediately below the most downstream river island, and a majority of the water flows through a channel on the South Carolina side of the river. The streambed was predominantly composed of bedrock and course sand on the South Carolina side, and by coarse sand and silt on the more stagnant Georgia side.

RM 198

This station was located in the Augusta Pool just upstream of Horse Creek and the Sand Bar Ferry Bridge (HWY 28). At this location, most of the remaining water from the Augusta Canal was returned to the river. Mean cross-sectional depths ranged from 13 -18 feet with velocities between 0.3 – 1.11 ft/sec. The river channel was relatively wide with a bed consisting primarily of course sand. Because velocities in this section were relatively low, many of the shallow areas were covered by submerged aquatic vegetation, but the banks were lined with emergent vegetation and trees. This was one of only two sites within the study where emergent and submerged vegetation was present throughout the entire year. Within this section, the river was bordered by heavy development on both sides. Recent residential development on the South Carolina side between RMs 202 and 196 resulted in the removal of most riparian vegetation, with numerous lengths of rip-rapped banks. The Georgia side has been developed for some time, with the Riverwalk, City Marina, and several residential developments.

Horse Creek

Horse Creek drains approximately 165 square miles in Aiken County, South Carolina. Much of the area is rural but some urban areas also feed the creek. The Horse Creek station was located approximately 0.37 miles upstream of the confluence with the river. Mean cross-sectional depth at the station was approximately four feet with velocities up to 1.8 ft/sec. The stream bottom consisted primarily of course sand, with densely vegetated banks and numerous snags. Aiken County, South Carolina's Horse Creek Wastewater Plant discharge (NPDES No. SC0024457) is located just downstream of the mouth of Horse Creek.

RM 190

The RM 190 station was the last station in the pool section of the Savannah River, was located approximately 3 miles upstream of NSBLD. Cutgrass (*Zizianopsis miliacea*) and water hyacinth (*Eichhornia crassipes*) were the primary aquatic plants inhabiting the shallow stream margins. Mean cross-sectional depth ranged from 15-18 ft. with velocities between 0.4-1.02 ft/sec. Bottom substrate consisted primarily of course sand.

Butler Creek

Butler Creek drains roughly 165 square miles of predominantly urban areas in Augusta, Georgia, and joins the Savannah River approximately 0.25 miles downstream of NSBLD. The sampling station was located just upstream of the Augusta levee gates which is below the confluence of Butler Creek and Phinizy Ditch. Phinizy Ditch drains the 3,000 acre Phinizy Swamp, and also receives water from the City of Augusta's J.B. Messerly Wastewater Treatment Plant (NPDES No. GA0037621) and Levee Ditch. Levee Ditch receives drainage from urban, agricultural, aggregate mining, and industrial sources. At this sampling location, it was often evident that complete mixing of the two sources had not occurred but the sample methodology (left, center, and right thirds) allowed for equal sampling of the sources which made up the composite sample. The bottom substrate at this sampling location consisted of silt and detrital material.

RM 185

The RM 185 station was located two miles below NSBLD, the first station within the free flowing section of the Savannah River. This section experienced daily average water level fluctuations of approximately 1 foot due to operations at NSBLD. The station was located in the thalweg of an outside meander bend adjacent to a bank armored by rip-rap. Interaction with the floodplain began in this reach and continued to the Savannah Harbor. Mean cross-sectional depths ranged from 10 to 18 feet with velocities between 1.6 and 2.2 ft/sec. Bottom substrate consisted primarily of course sand.

RM 179

The RM 179 station was located approximately six miles downstream of NSBLD. This was the first station downstream of the Augusta Urban Corridor, located approximately three miles downstream of the a pulp and paper mill discharge. The channel at this station was relatively narrow, with mean cross-sectional depths of 15-18 feet and water velocities that averaged 1.3 – 2.3 ft/sec. Like most of the free-flowing section, the bed consisted of course sand, with numerous snags along the banks. Wing dikes in this section directed flow into the main channel to prevent sedimentation and bank erosion.

RM 148

The RM 148 station was located approximately one mile downstream of Plant Vogtle nuclear electric plant, and was the third station in the free-flowing section of the river. This station was downstream from the mouth of Upper Three Runs Creek, located on the Department of Energy's Savannah River Site. Mean cross-sectional depths at this site ranged from 7 to 11 feet with velocities between 1.8 and 2.1 ft/sec. The bed material consisted primarily of coarse sand.

RM 119

The RM 119 station was located just upstream of the Highway 301 bridge and USGS Station No. 02197500. The sonde at this station was tethered to a wing dike on the SC side of the river in a relatively straight reach. Mean cross-sectional depths and velocities at this site were 8.9 feet and 2.26 ft/sec, respectively. Snags were common in this section, with black willows (*Salix nigra*) lining the shallower margins of the channel. This station was added in July 2006.

RM 61

The RM 61 station was located 0.4 miles below Georgia Highway 119. The sonde at this station was tethered to the rail bridge timber crib. Snag habitat was common in this reach. Mean cross-sectional depth and velocity at this site was 9.6 ft and 2 ft/sec, respectively. This station was added in September 2006.

2.2. Hydrology

Discharge data from several USGS stations located at or near SNSA stations were obtained for the study period (Table 2-2). Also, hourly and daily average discharge and water level data from USACE's Thurmond Dam were obtained for comparison to the SNSA station at RM 215. Discharge measurements were also made by SNSA using a boat-mounted 1.5 MHz acoustic doppler current profiler (SonTek Mini-ADP River Surveyor System).

Table 2-2. USGS Station Locations

USGS Staion #	Station Name	Nearest River Mile
02196690	Horse Creek at Clearwater, SC	
02196999	Savannah River above NSBL&D	187
02197000	Savannah River at Augusta, GA	187
021973269	Savannah River near Waynesboro, GA	150
02197500	Savannah River at Burton's Ferry Bridge near Millhaven, GA	120
02198500	Savannah River near Clyo, GA	60

2.3. Climate

Climate data for the study period were obtained from the NOAA National Climatic Data Center for the weather station at Bush Field Airport in Augusta, GA. These data included daily total precipitation, min/mean/max temperature, average wind speed and direction, barometric pressure, and min/max relative humidity.

2.4. Light Profiles

Water column light attenuation was measured using Photosynthetically Active Radiation (PAR) sensors connected to a LiCor logger. Two sensors were used to measure the upwelling and downwelling PAR at the surface and at one-foot intervals. Light attenuation (K_d) was calculated using the following equation:

$$I_z = I_o - e^{-kz}$$

and

$$K_d = \frac{\ln I_o - \ln I_z}{z}$$

where

I = light intensity

z = depth

k = extinction coefficient

A separate, on-board sensor was used to used to correct for incident radiation variations. Data from incremental (1-foot) measurements for each profile were averaged over the entire depth to produce aver water column K_d values. Light attenuation was also measured using a Secchi disk according to Lind (1985).

2.5. Continuous Water Quality Monitoring

SNSA deployed continuous water quality monitors (sondes) at all 12 study sites using eleven YSI Model 6600 EDS sondes and one Hach Hydrolab Series 4a sonde on the dates listed in Table 2-3. All sondes were equipped with probes that measured temperature, dissolved oxygen (saturation and concentration), pH, conductivity, and turbidity (Table 2-4). Each sonde was programmed to record data at 15-minute intervals and deployed at or near mid-depth in the thalweg (Figure 2-1). Sondes were checked at regular intervals (~2 weeks) to download data and clear deployment systems of excessive aquatic vegetation. Sondes were retrieved for post-check and recalibration and redeployed at two-month intervals, according to the Project Quality Assurance Plan (SNSA 2008). All data that passed our QA/QC protocols were used and are presented within this document without correction for sensor drift or other correction factors.

Table 2-3. Deployment dates for continuous monitors

Site	Initial Deployment Date
RM 215	1/4/2006
Stevens Creek	1/14/2006
RM 202	12/23/2005
RM 198	12/23/2005
Horse Creek	1/19/2006
RM 190	1/10/2006
Butler Creek	1/26/2006
RM185	12/22/2005
RM 179	2/14/2006
RM 148	1/5/2006
RM 119	8/8/2006
RM 61	9/6/2006

Table 2-4. Continuous monitoring parameters

Parameter	Sensor Type	Range	Accuracy	Resolution	Method
Temperature	thermistor	-5 to 45 °C	±-0.15 °C	0.01 °C	170.1
Dissolved Oxygen	Rapid Pulse - Clark type polarographic	0 to 500% air saturation	±2% of reading or ±2% of air saturation	0.1% air saturation	4500-O-G
Specific Conductance	4-electrode cell with autoranging	0 to 100 mS/cm	±0.5% of reading + 0.001 mS/cm	0.001 mS/cm to 0.1 mS/cm (range dependent)	120.1
pH	Glass combination electrode	0-14 units	±0.2 units	0.01 units	150.2
Turbidity	Optical, 90° scatter, with mechanical cleaning	0 to 1,000 NTU	±5% of reading or 2 NTU	0.1 NTU	180.1

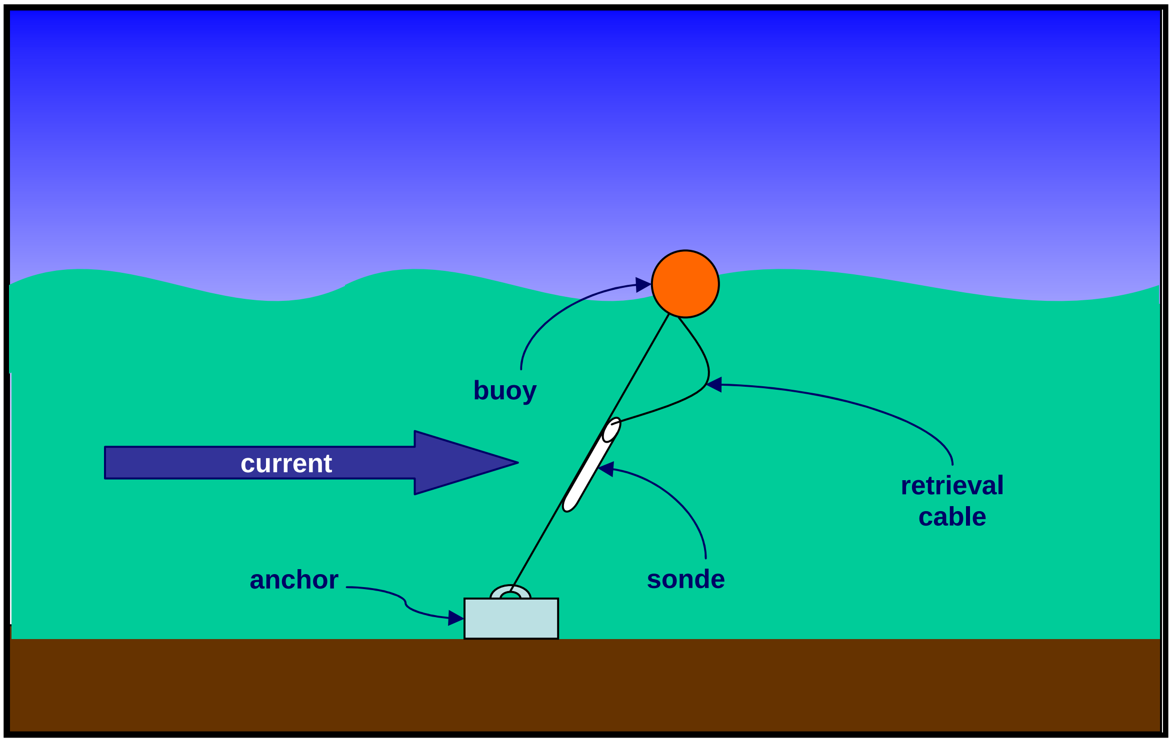

Figure 2-1. Diagram of continuous monitoring deployment system

2.6. Discrete Water Quality Sampling

In order to better understand chemical processes in the River, SNSA employed a Lagrangian approach to our monthly, discrete sampling scheme. The goal of this scheme was to sample the same mass of water as it traveled downstream through each monitoring station. Results from continuous water quality monitors were used to develop correlations for discharge and travel time between each sampling location. Because the RM 215 and Stevens Creek sites were located upstream of Stevens Creek Dam and Augusta Diversion Dam, respectively, they were not included in the Lagrangian scheme.

Water samples were collected using a US-D96-A1 collapsible bag sampler developed by the

Federal Interagency Sedimentation Project (Davis 2001). This device allowed for the collection of flow-weighted, depth-integrated samples. Based on depth and water velocity, the device was lowered and raised at a constant rate to collect approximately three liters of water. A total of approximately 20 L of water was collected at each sampling location, with approximately one-third of the total volume collected at the right, center, and left thirds of the transect. The US-D96-A1 did not collect water at velocities below 1.5 – 2.0 ft/sec. At sites where water velocities were below this threshold, depth-integrated samples were collected with an electric pump. Fecal coliform samples were collected at the same time. Each 20L carboy containing samples was placed on ice for transport to the SNSA lab. For each sampling event, a duplicate and field blank were included for QA/QC purposes.

Water samples were homogenized in the lab using a 37 L polyethylene churn splitter. Water samples were then either poured directly into sample containers or filtered through a 0.45 µm cellulose acetate filter using a peristaltic pump for total and dissolved constituent analysis, respectively.

2.7. Sediment Sampling

Sediment samples were collected using a stainless steel Wildco Petite Ponar. At each station, sediment samples were collected at three locations (right, center, & left) within the stream cross section, homogenized in a stainless steel pan, and distributed into glass jars supplied by the contract laboratory. All sediment collection equipment was thoroughly washed with a 2% solution of Micro-90, triple rinsed with tapwater, followed by a final rinse with deionized water. Cleaned sediment sampling equipment was wrapped in aluminum foil or polyethylene bags to avoid contamination during transport from the SNSA lab to the sampling location. Sediment samples were analyzed for metals, mercury, herbicides, pesticides, and PCBs.

All chemistry analyses (water and sediment) were performed by Shealy Environmental Services, Inc. (NELAC No. E87653) in West Columbia, SC. Fecal coliform tests were performed by Microbac Laboratories, Inc. (A2LA #1814-01) in New Ellenton, SC. Aqueous and Sediment sample anayltes and methods are listed in Table 2-5.

Table 2-5. Aqueous and sediment sample parameters and methods

Aqueous Sample Analyte	Filtration*	Method
Alkalinity	F	SM 2320B
Ammonia – Nitrogen	U	350.1
BOD, 5 day	U	SM 5210 B
Carbonaceous BOD, 5 day	U	SM 5210B
Chemical Oxygen Demand	U	SM 5220 D
Chloride	F	300.0
Dissolved Organic Carbon	F	SM5310 B
Fecal Coliform Bacteria	U	SM 9221 C E
Nitrate + Nitrite – Nitrogen	U	353.2
Nitrite-Nitrogen	F	353.2
Ortho – Phosphate	F	365.1
pH	U	SM 4500-H+ B
Sulfate	B	300.0
Total Dissolved Solids	U	SM 2540 C
Total Inorganic Carbon	F	SM5310 B
Total Kjeldahl – Nitrogen	U	351.2
Total Organic Carbon	U	SM5310 B
Total Phosphorus	U	365.1
Total Suspended Solids	U	SM 2540 D
Total Volatile Suspended Solids	U	SM2540D/160.4
Mercury	B	245.1
Aluminum	B	200.8
Arsenic	B	200.8
Cadmium	B	200.8
Calcium	B	200.8
Chromium	B	200.8
Copper	B	200.8
Iron	B	200.8
Lead	B	200.8
Magnesium	B	200.8
Manganese	B	200.8
Nickel	B	200.8
Potassium	B	200.8
Selenium	B	200.8
Sodium	B	200.8
Zinc	B	200.8

* F = Filtered, U = Unfiltered, B = Both

Sediment Sample Analyte	Method
Mercury	7471A
Arsenic	6010B
Cadmium	6010B
Calcium	6010B
Chromium	6010B
Copper	6010B
Iron	6010B
Lead	6010B
Magnesium	6010B
Manganese	6010B
Nickel	6010B
Potassium	6010B
Selenium	6010B
Sodium	6010B
Zinc	6010B
Total Organic Carbon	Walkley-Black
Herbicides	
2,3,4-TP (Silvex)	8151A
2,4,5-T	8151A
2,4-D	8151A
2,4-DB	8151A
Dalapon	8151A
Dicamba	8151A
Dichloroprop	8151A
Dinoseb	8151A
MCPA	8151A
MCPP	8151A
Pesticides	
4,4’-DDD	8081A
4,4’-DDE	8081A
4,4’-DDT	8081A
Aldrin	8081A
alpha-BHC	8081A
alpha-Chlordane	8081A
beta-BHC	8081A
delta-BHC	8081A
Dieldrin	8081A
Endosulfan I	8081A
Endosulfan II	8081A
Endosulfan sulfate	8081A
Endrin	8081A
Endrin aldehyde	8081A
Endrin ketone	8081A
gamma-BHC (Lindane)	8081A
gamma-Chlordane	8081A
Heptachlor	8081A
Heptachlor epoxide	8081A
Methoxychlor	8081A
Toxaphene	8081A
PCBs	
Aroclor 1016	8082
Aroclor 1221	8082
Aroclor 1232	8082
Aroclor 1242	8082
Aroclor 1248	8082
Aroclor 1254	8082
Aroclor 1260	8082

2.8. Biological Sampling

No standard method currently exists for sampling macroinvertebrates in nonwadeable streams. In an effort to minimize researcher sampling bias and standardize sampling effort, SNSA investigated aquatic macroinvertebrate communities using Hester-Dendy samplers. Results from this method alone typically show good overall representation of the macroinvertebrate community in nonwadeable streams (Blocksom and Flotermersch, 2005) and result in decreased processing time compared to other sampling techniques.

In this study, Hester-Dendy samplers were deployed in two pairs at each sampling location. Each sampler consisted of 14 square 7.6 cm masonite plates with a total surface area of 0.16 m^2. The plates were variably spaced by 3 mm washers, yield eight 3 mm spacings, one 6 mm spacing, two 9 mm spacings, and two 12 mm spacings. The depth at which the samplers were deployed was standardized to 1 foot below the water surface at each location by suspending each sampler set from a float. After a deployment period of approximately 30 days, the samplers were retrieved and processed. Processing consisted of disassembling and cleaning the sampler plates of all material. After cleaning, the material was passed through a #30 (0.6 mm) sieve. Material remaining in the sieve was washed back into a container and macroinvertebrates were separated from organic material and preserved in ethanol for subsequent identification.

3. RESULTS

3.1. Hydrology

Daily flow rates within the river were largely regulated by the USACE’s Thurmond Dam. From January 2006 through January 2008, flows were below average for all months compared to long term monthly averages (1954 – 2005), with September and October of both 2006 and 2007 at or near record low flows (Figure 3-1). Figure 3-2 shows discharge data from the USGS gauge at RM 187 (02197000) from January 1, 2006 through January, 31 2008.

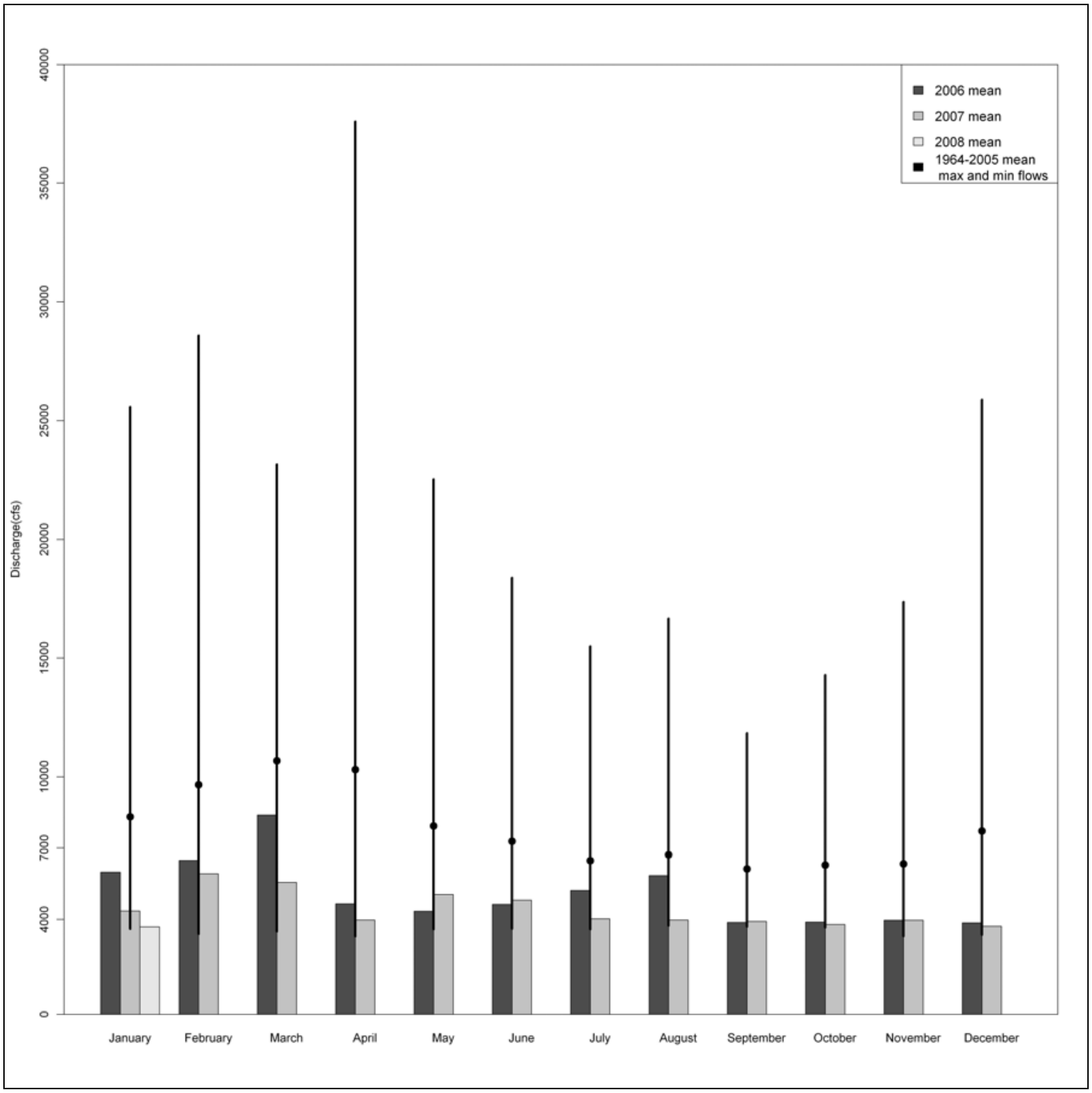

Figure 3-1. Thurmond Dam Discharge

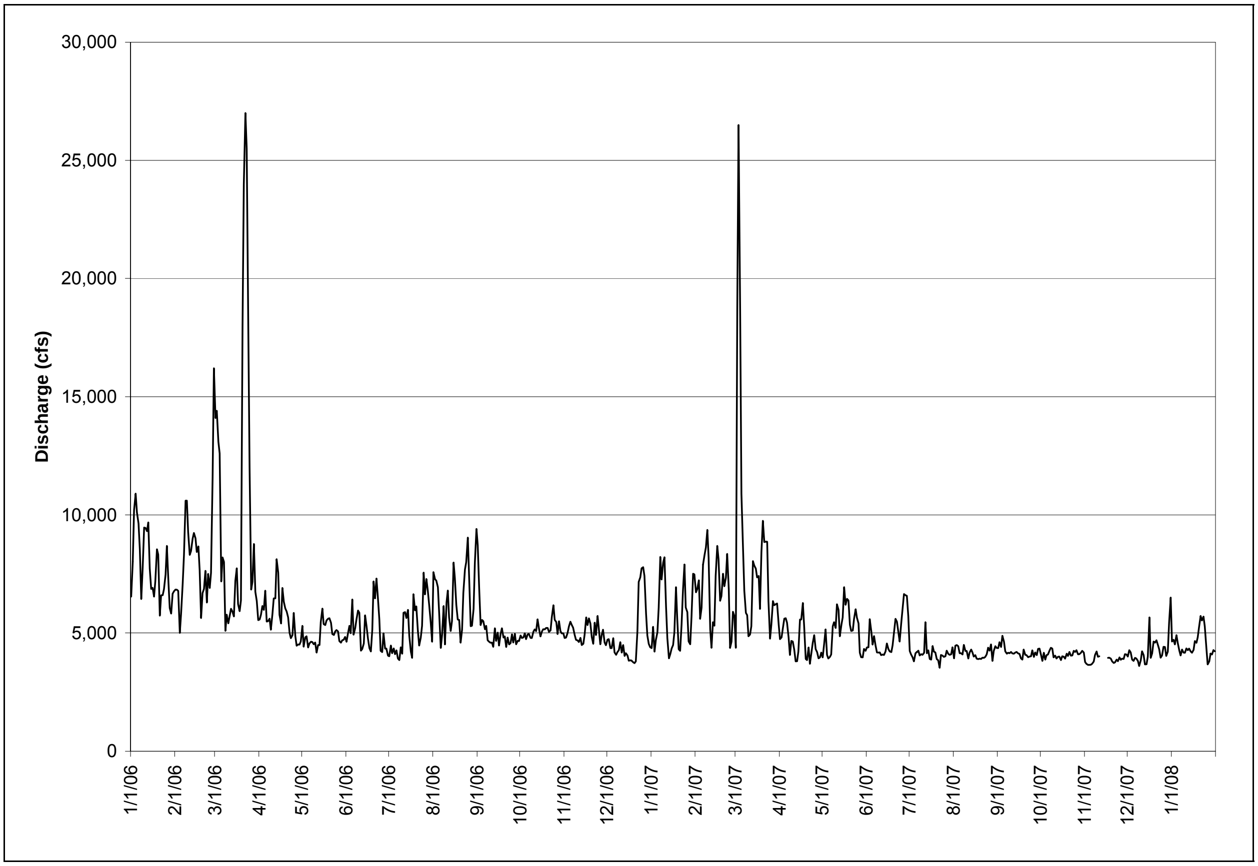

Figure 3-2. Daily average discharge from January 2006 - January 2008 at USGS gauge 02197000 (RM 187).

The data indicated that, on average, discharge increased from RM 187 to RM 61 (Figure 3-3). During the study period, mean discharge increased by 11.3% from RM187 (5,538 cfs) to RM148 (6,165 cfs), 15.3% from RM 187 to 119 (6,385 cfs), and 24.8% from RM 187 to RM 61 (6,910 cfs) (Figure 3-3). In addition, during low flows, discharge was 21.2% higher at RM 61 (4,280 cfs) when compared to RM 187 (3,530 cfs), 10.5% higher at RM 119 (3,900 cfs) when compared to RM 187, and 10.2% higher at RM148 (3,890 cfs) when compared to RM187 (Figure 3-3). During the highest flows of the study period, the data may have indicated a loss of water (i.e. floodplain inundation) as the flows at RM 187 (27,000 cfs) were 20.4% higher than RM 148 (21,500 cfs), 21.5% higher than RM 119 (21,200 cfs), and 35.6% higher than RM 61 (17,400 cfs) (Figure 3-3). Flow duration curves for the study period are provided in Figure 3-4.

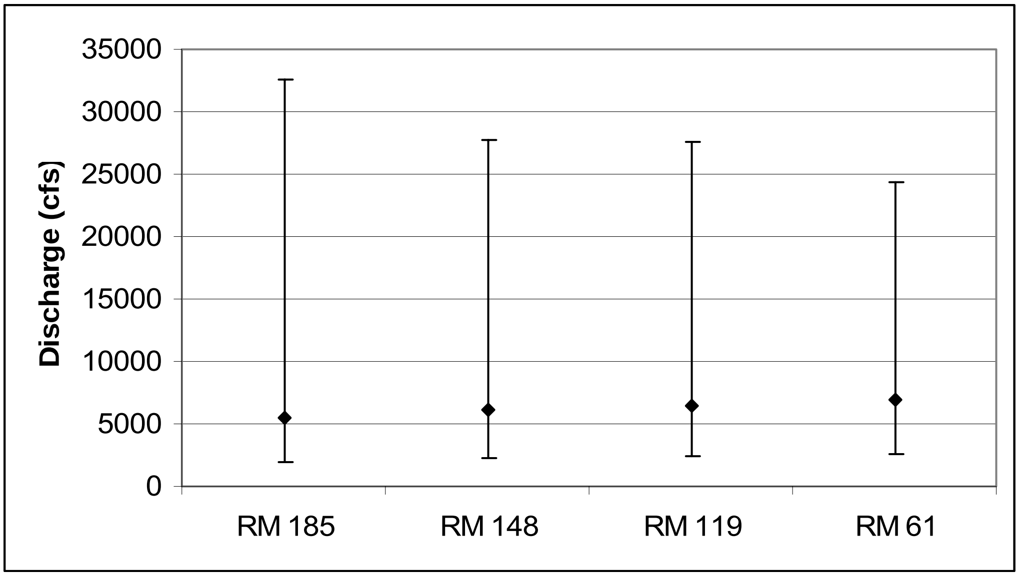

Figure 3-3. Mean, minimum, maximum discharge from USGS gauges at RMs 187, 148, 119, and 61 from January 2006 - January 2008.

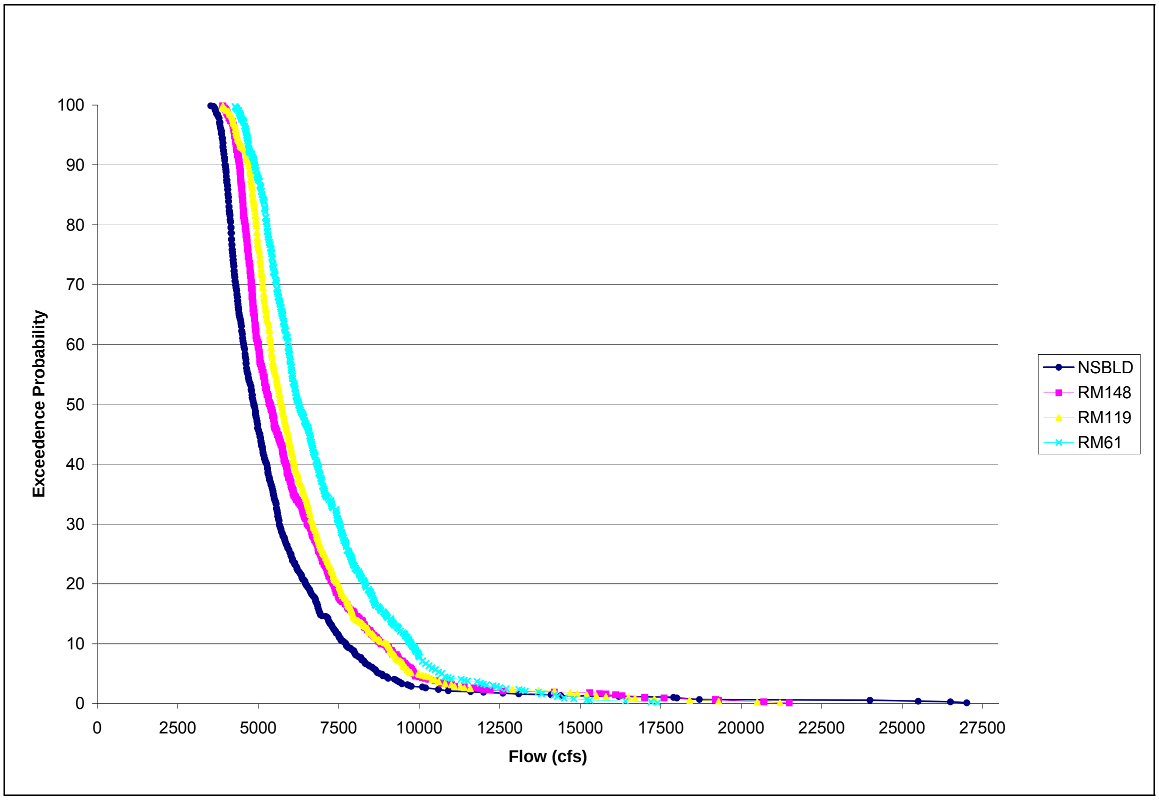

Figure 3-4. Combined flow duration curves at four Savannah River locations from January 2006 to January 2008.

Data from RMs 187, 119, and 61 during a low-flow periods in 2006 (October 17, 2006 through October 23, 2006) and 2007 (November 16 through December 8, 2007) represent stable flow conditions, and were important for quantifying additional flows to the river below RM 187. Additional flows to the river were assumed to be the sum of surface water and groundwater contributions. Since each of the trends were fairly linear (indicating steady flows over that time segment), accounting for flood routing was not necessary for this analysis. Flows at sequential USGS gauges were compared by integrating the area under the discharge curve using KaleidaGraph (Synergy Software, 2000).

Results for October 2006 indicated that the total volume of water increased by 18.4% (754 cfs) between RM 187 and RM 119, and increased by 11.1% (540 cfs) between RM 119 and RM 61 for this period (Figure 3-5). In the November/December 2007 analysis, total volume increased by 3.74% (147 cfs) between RM 187 and RM 119, and increased by 5.49% (224 cfs) between RM 119 and RM 61 (Figure 3-6).

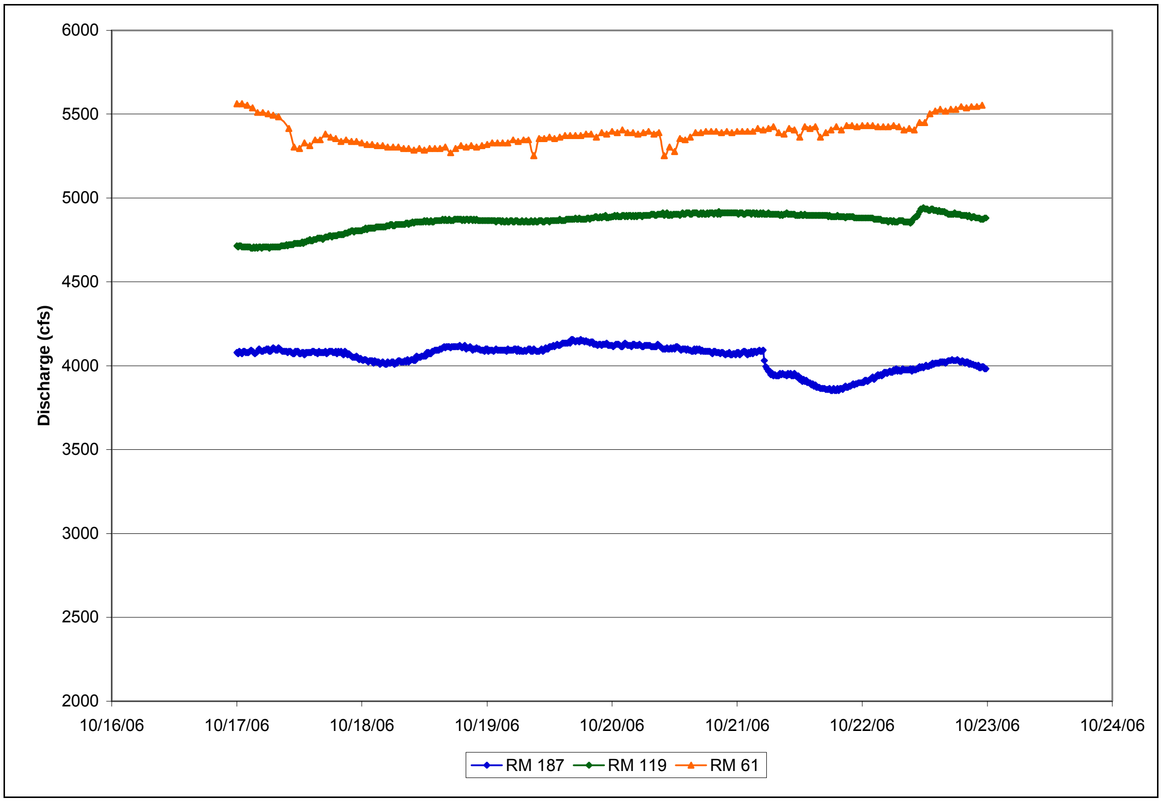

Figure 3-5. Continuous discharge from USGS gauges at RM 187, 119, and 61 (October 16 – 23, 2006).

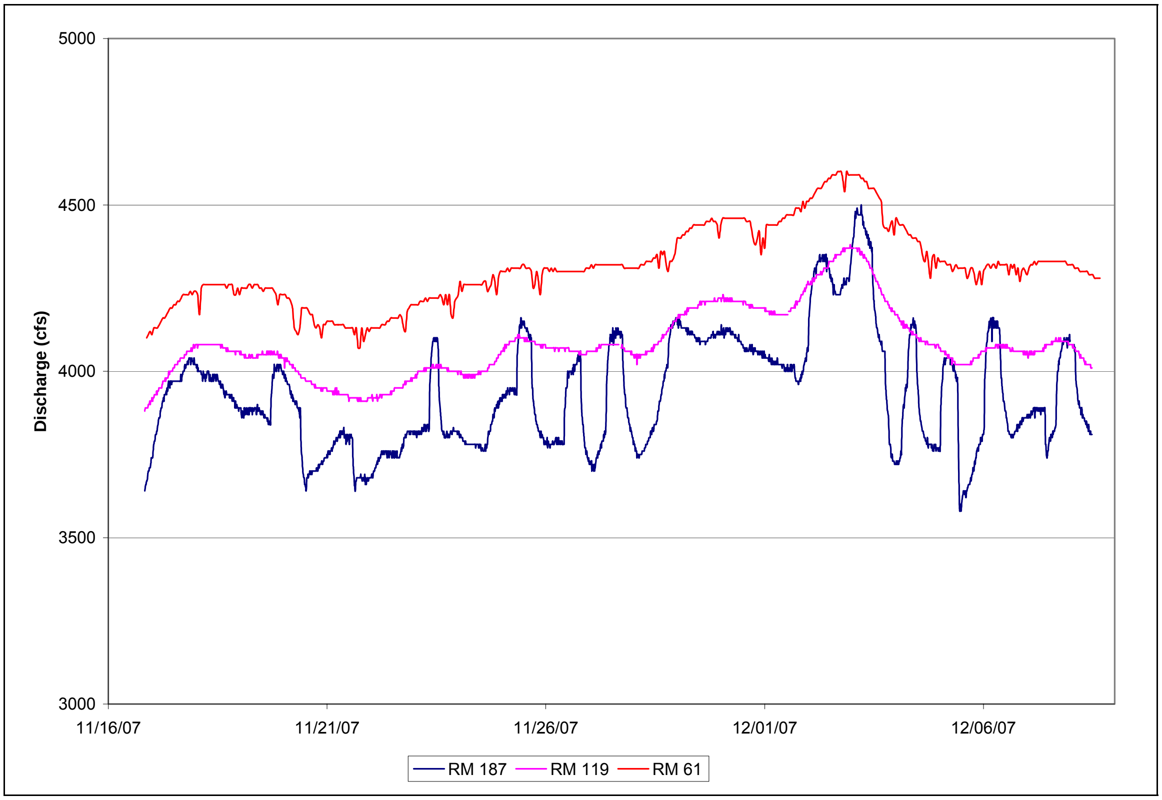

Figure 3-6. Continuous discharge from USGS gauges at RM 187, 119, and 61 (November 16 – December 8, 2007)

Data reported by Cooney et al. (2002) for the 1998-2002 water years showed that Upper Three Runs (UTR) Creek and Lower Three Runs (LTR) Creek could contribute an average of 345 cfs to the river, with a maximum of 619 cfs and a minimum of 188 cfs. Our calculated increases in discharge from RM 187 to 119 during the 2007 low-flow period (147 cfs) could have been accounted for by flows from both UTR and LTR. However, since a drought existed within the Savannah basin in 2006 and 2007, flows from UTR and LTR probably accounted for much less than the increases calculated for this reach for the 2006 period (754 cfs).

Brier Creek enters the Savannah River at RM 102.5. The mean daily discharge at the USGS gauge on Brier Creek (02198000) for the 2006 integration period was 119 cfs, or 22% of the calculated 540 cfs increase between RM 119 to RM 61. In the 2007 integration period, mean discharge at the Brier Creek gauge was approximately 100 cfs, or 44% of the 224 cfs increase calculated for this reach. These data indicate that ungauged sources between RM 187 and RM 61 may contribute a significant amount of water to the reach.

3.1.1. Acoustic Doppler Profiles

Discharge data used for calculating mass fluxes were obtained from either measured values using an Acoustic Doppler Profiler (ADP) or from nearby USGS gauging stations. Since discharge within the Urban Corridor reach of the river (RM 215 to RM 190) was regulated by several dams, it was not possible to correlate water levels within that reach to discharges reported at the gauge at NSBLD (USGS Station 02196999). Therefore, discharge was measured during chemistry sampling events in this reach. Flows were also measured in the creeks. In addition to discharge, several other parameters were obtained with the instrument, including the depth and wetted width, bathymetry, and instantaneous flow rates throughout the water column. Examples of each river cross section, creeks, and Augusta canal where the ADP was used are compiled within Appendix A.

3.2. Climate

Daily precipitation totals are presented in Figure 3-7. Of the 762 days, 580 (76.1 %) had no precipitation, 14 (1.8%) had 0-0.01 in., 117 (15.4%) had 0.01-0.5 in., 26 (3.4 %) had 0.5-1.0 in., 15 (2 %) had 1.0-1.5 in., 2 (0.3 %) had 1.5-2.0 in., and 8 (1 %) had greater than 2 in. Total precipitation for the 761 days (1/1/06 – 1/31/08) was 78.04 in. Monthly precipitation totals and historic precipitation averages for Augusta, GA are presented in Figure 3-8. The data indicated a significant precipitation deficit throughout the study period, compared to long-term averages. Drought conditions developed and persisted during the study period, with moderate to extreme drought conditions in the upper SRB, and moderate drought in the middle SRB.

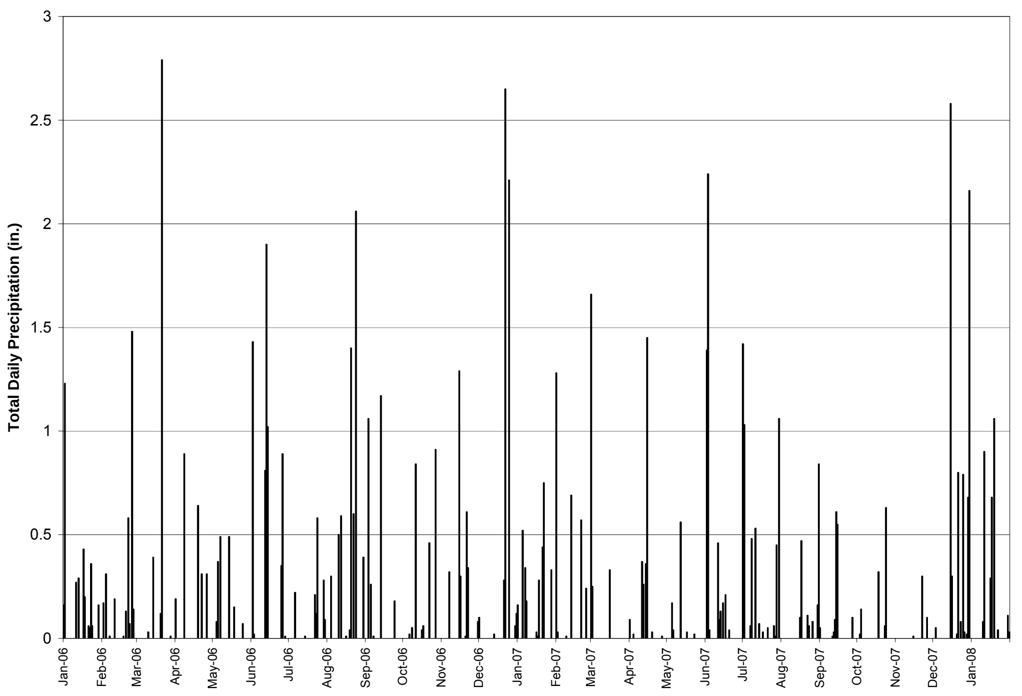

Figure 3-7. Total daily precipitation from Bush Field in Augusta, GA from January 2006 through January 2008 (NOAA, 2008).

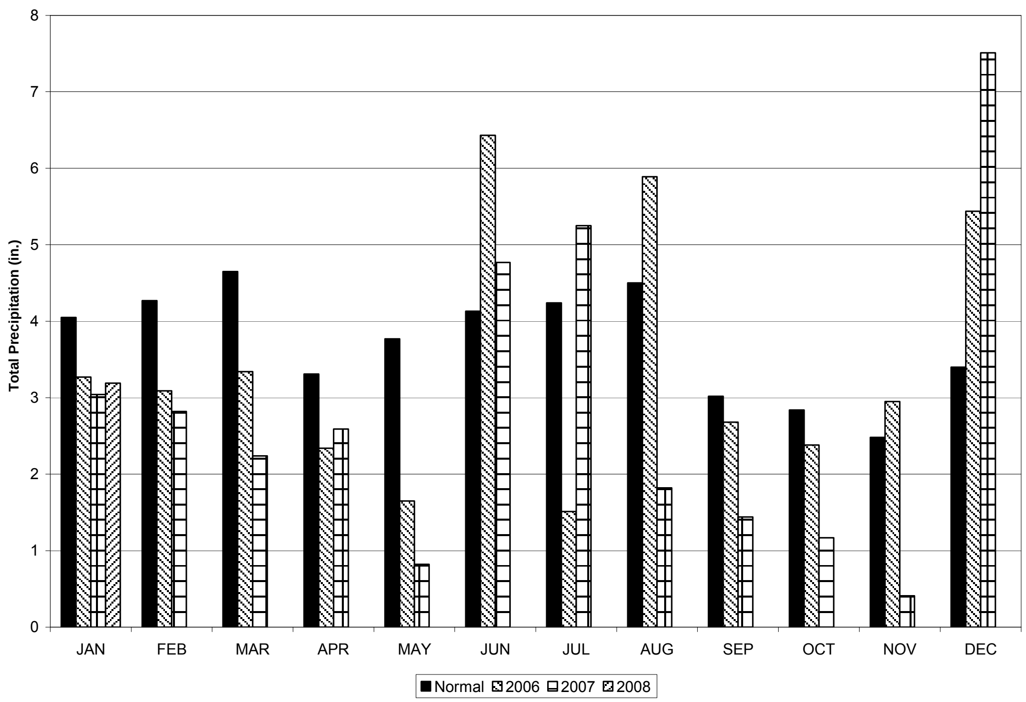

Figure 3-8. Monthly precipitation totals and long term averages (1971 – 2000) from Bush Field in Augusta, GA (NOAA, 2008).

3.3. Light profiles

Average light attenuation decreased through the Augusta pool and increased downstream of NSBLD (Figure 3-9). Figure 3-10 shows the percentage of surface light at the bottom of each profile location for all stations during the May 2007 sampling date. This figure indicates that less than 1% of the surface light reached the channel bottom at Stevens Creek, Butler Creek, and RM 61.

Light attenuation decreased from RM 215 to RM 198 and steadily increased to RM 61. Highest attenuation was observed within the creeks (SC, HC, BC). The attenuation rate at RM 61 was nearly as high as the rates for the creeks. Average secchi depth at each study site is presented in Figure 3-11.

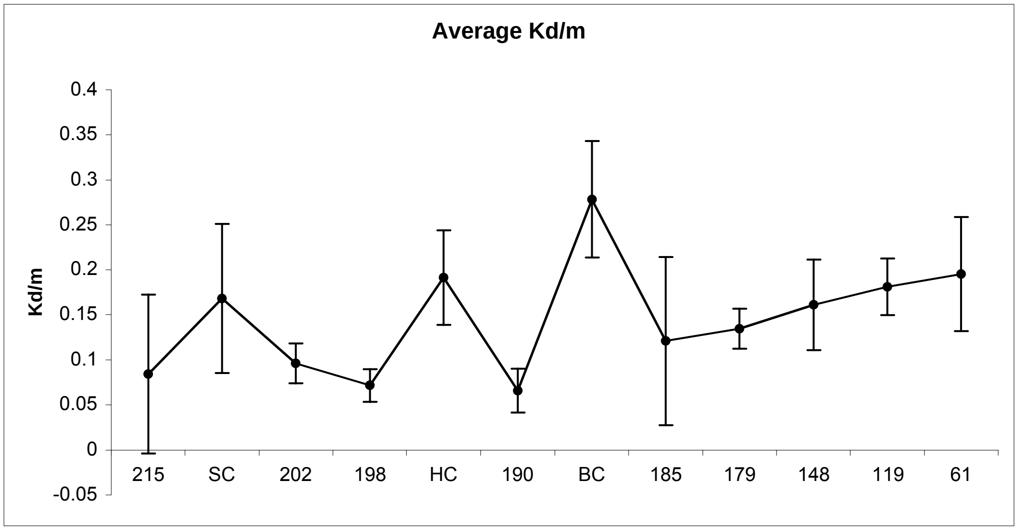

Figure 3-9 Average water column light attenuation (Kd/m) for 2007 (error bars are 1 standard deviation).

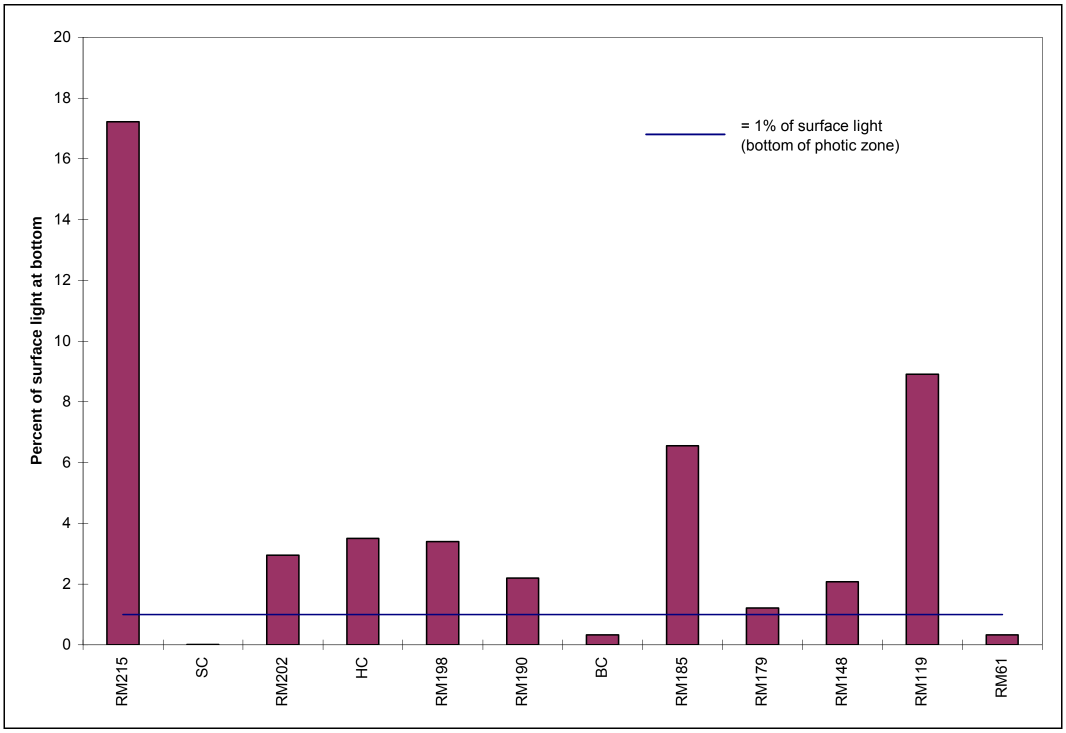

Figure 3-10. Percentage of surface light reaching the lowest depth at each sampling location (May 2007).

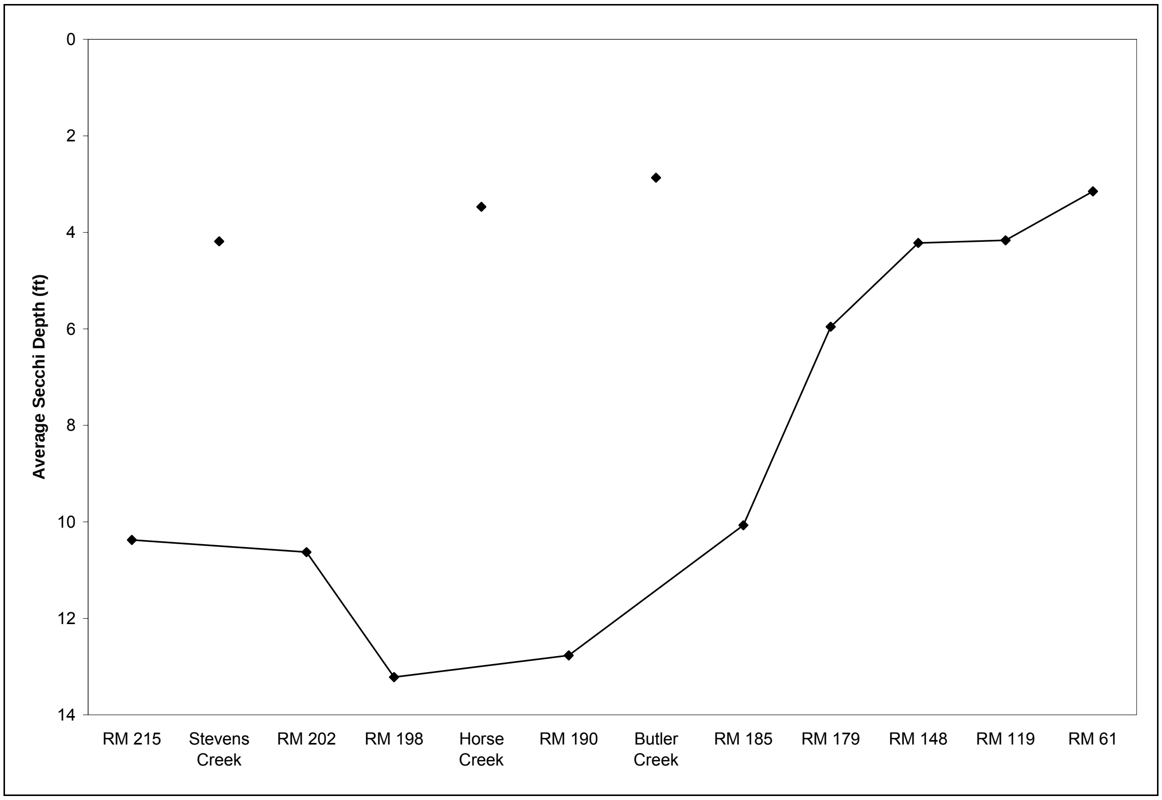

Figure 3-11. Average secchi depth at study sites

3.4. Continuous Monitoring

Individual sonde data statistics are presented in box plot format in this section (January 2006 – January 2008). Data for these figures were compiled from all available data that passed our QC protocols according to the project QAPP (SNSA 2008), so not all sample sizes are exactly equal. The box plots depict median, 25% and 75% quartiles, and 95% confidence intervals. Since installation and monitoring at two stations (RM 119 and RM 61) began later in 2006, a second set of box plots for each parameter is provided for January 2007 to January 2008, when all station were being monitored simultaneously. For all box plots, outliers (values outside of 95% CI) were removed for clarity.

Several problems were encountered that limited continuous datasets. Excessive vegetation buildup on deployment rigs caused accelerated fouling on sondes. Dissolved oxygen probe membranes and pH probe bulbs were punctured on several occasions, often by debris. During low-flow periods, some sondes periodically rested on the stream bottom, which also caused accelerated fouling and unrepresentative readings. The rigs were adjusted to compensate for lower flows, as needed.

3.4.1. Temperature

Water temperature increased from RM 215 to RM 202, remained relatively stable from RM 202 to RM 119, and increased again at RM 61 (Figure 3-12). Increase in temperature from RM 215 to RM 202 was due to warming of the thermally sheltered hypolimnetic lake water. Increased suspended sediment concentrations and increased water staining (tannins) were likely responsible for the temperature increase from RM 185 to 61. A strong correlation existed between monthly average temperature at RM215 and the zone of withdrawal within the lake. Highest average temperature variability was observed within the creeks. This was a result of seasonal temperature variability, smaller water volume (compared to the river), and high suspended sediment concentrations.

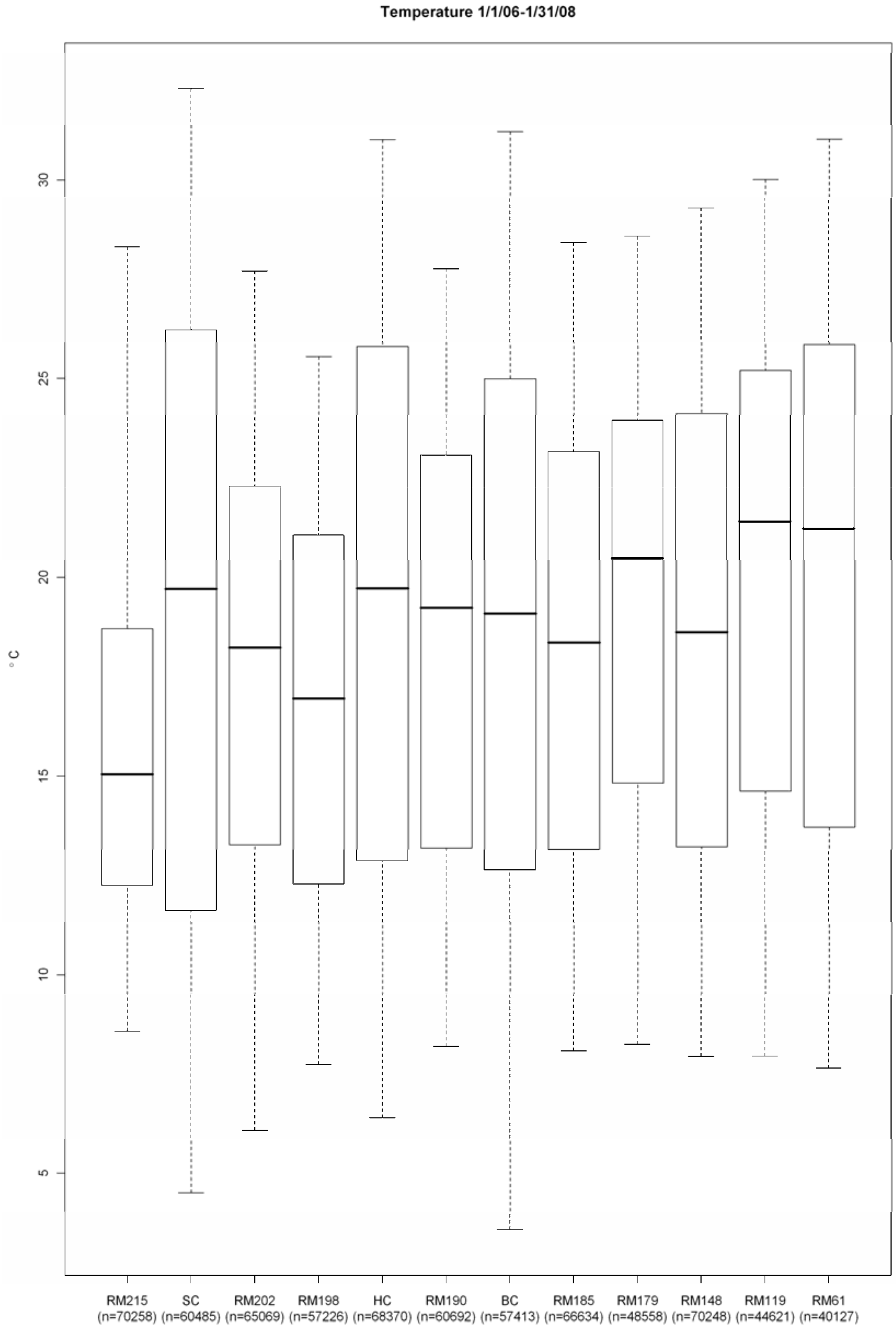

Figure 3-12. Temperature statistics from all stations from January 2006 through January 2008.

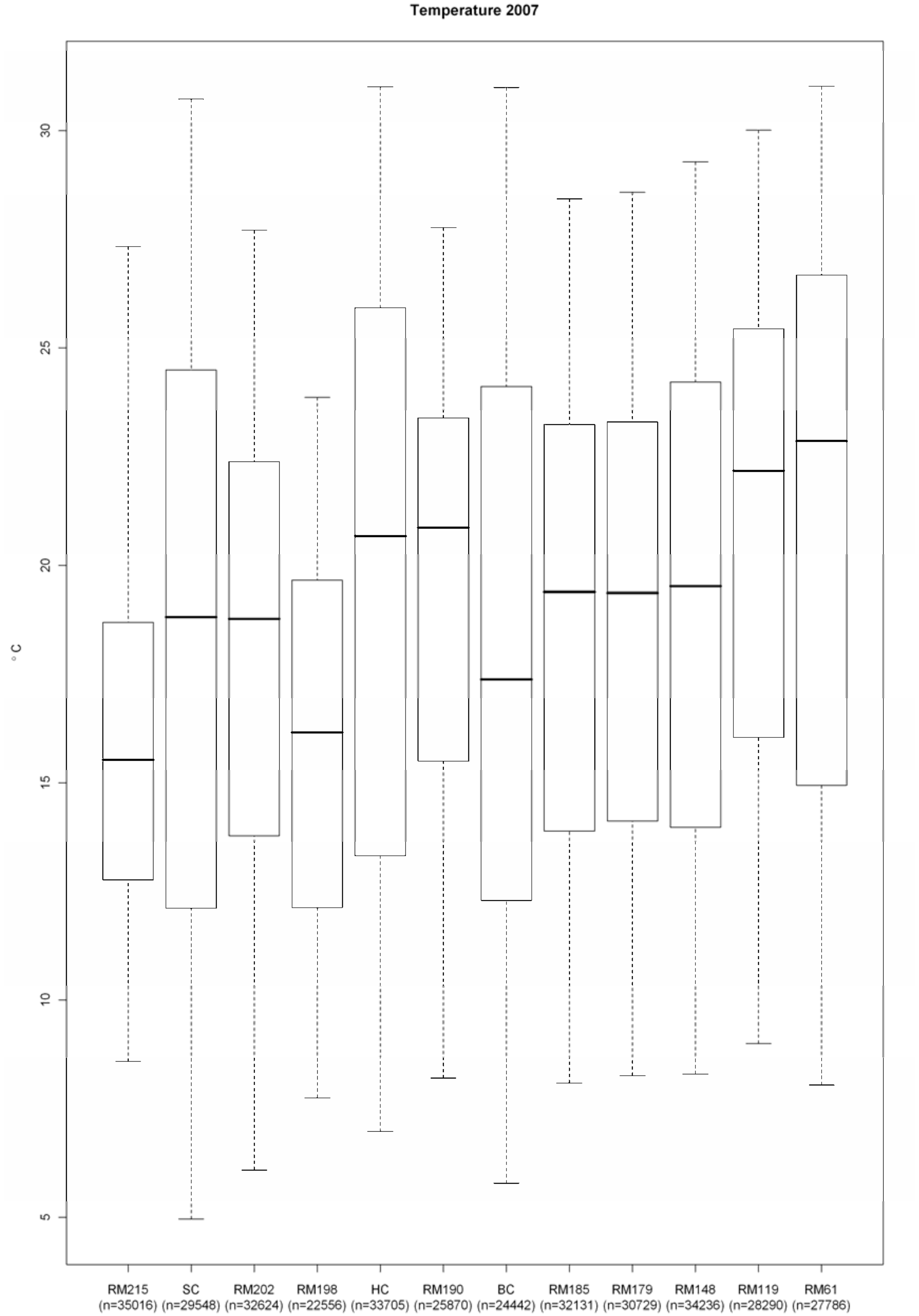

Figure 3-13 Temperature statistics from all stations 2007.

3.4.2. Specific Conductance

Specific conductance increased by 128% from RM 215 (46 uS/cm) to RM 61 (105 uS/cm) (Figure 3-14). Approximately 59% of this increase occurred within the RM 215 to RM 185 reach, with the remainder added within the RM 185 to RM 61 reach. Much of this increase was observed by RM 179 (below the urban corridor), where specific conductance averaged 110 uS/cm. Average specific conductance at RM 185 and RM 61 was 73 uS/cm and 105 uS/cm, respectively. RM 119 had the highest average specific conductance (117 uS/cm) of all mainstem river stations, and Butler Creek had the highest specific conductance (889 uS/cm) of all stations. Highest variability was within the creeks. Specific conductance in the lower reach of the river was generally highest in late summer and early fall during periods of low rainfall and river flow.

Historical Comparisons

Average monthly specific conductance values measured by SNSA in 2007 were compared to historical data (1972 – 2001) available from USGS for its sampling station at RM 61 (02198500). Monthly average specific conductance from 2007 was generally higher than historical monthly averages, especially during the warmer months, but was within the range of measurements taken in the past (Figure 3-16).

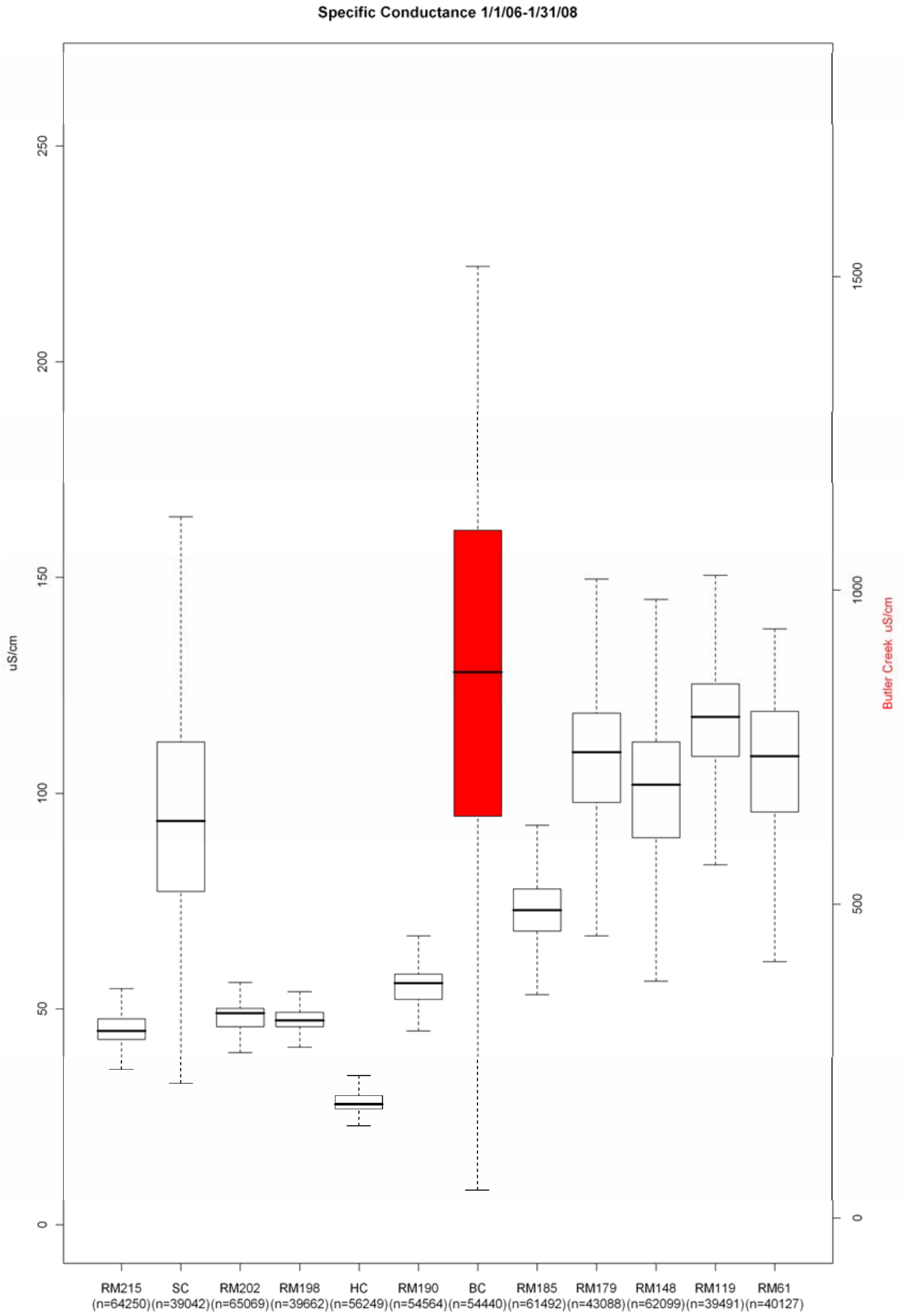

Figure 3-14. Specific conductance statistics from all stations from January 2006 through January 2008.

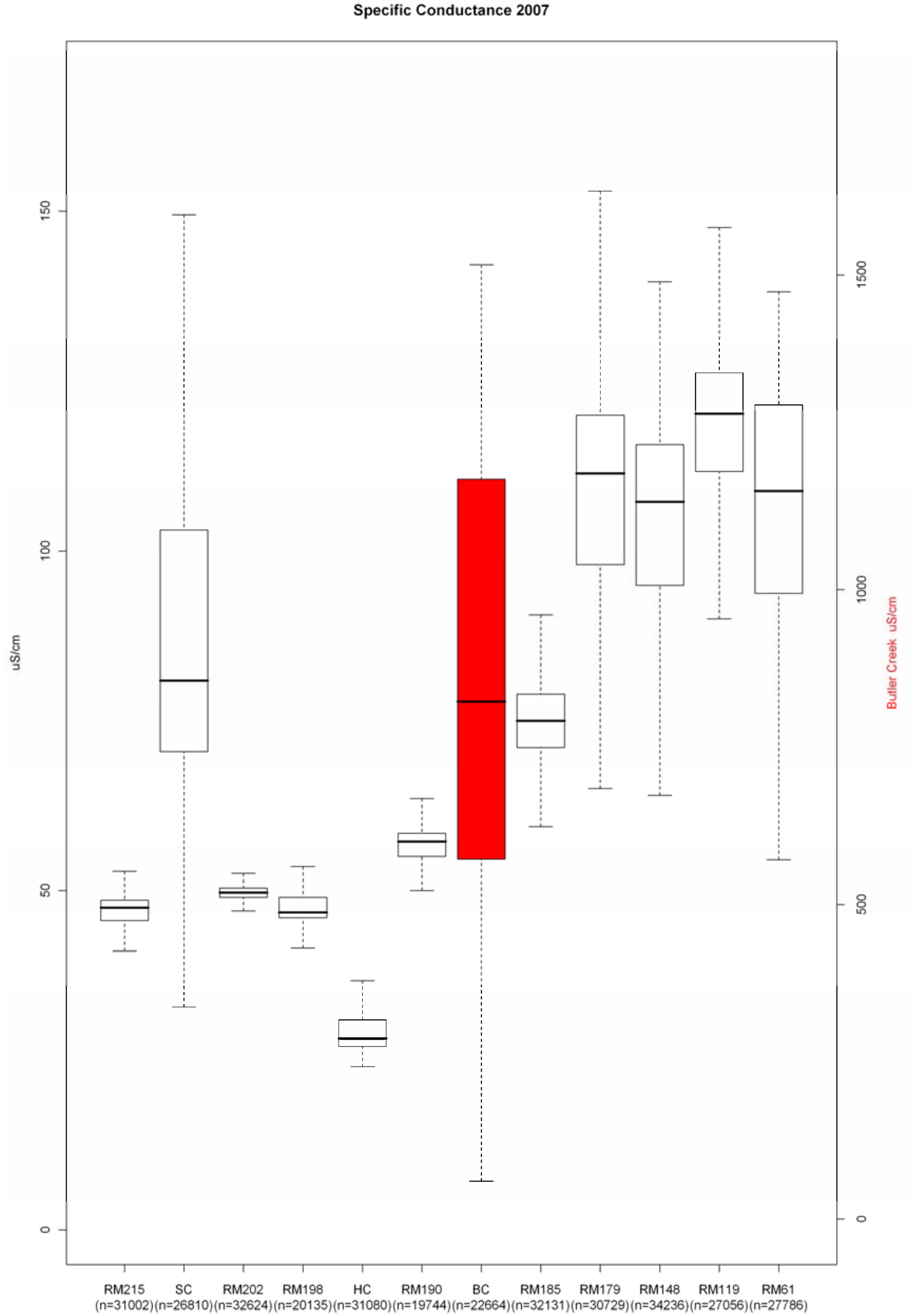

Figure 3-15 Specific conductance statistics from all stations 2007.

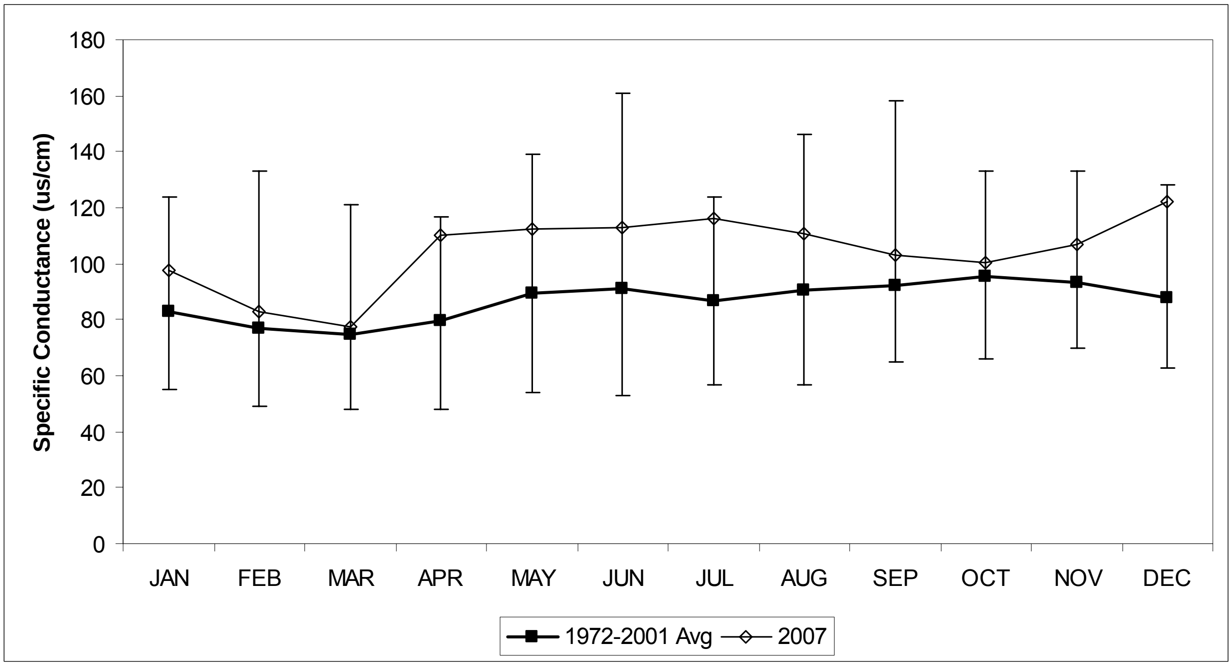

Figure 3-16. Comparison of long-term mean/min/max specific conductance data (USGS 02198500) to 2007 mean monthly data for RM 61.

3.4.3. Dissolved Oxygen

Dissolved oxygen (mg/L) increased from RM 215 to RM 202, decreased slightly at RM 190, increased at RM 185, decreased steadily to RM 119, and increased slightly at RM 61 (Figure 3-17, Figure 3-18). Overall, DO was higher and was less variable at RM 61 than RM 215(Figure 3-19, Figure 3-20). DO was lowest in Stevens Creek and Butler Creek. Dissolved oxygen saturation was above 100% at RM 202 and RM 187 for much of the study period.

Dissolved Oxygen and Water Quality Standards

Georgia and South Carolina standards for dissolved oxygen specify a daily average of 5.0 mg/L and an instantaneous minimum of 4.0 mg/L. Continuous monitoring data that was below these standards is summarized in Table 3-1 and Table 3-2. Dissolved oxygen concentrations were below both daily average and instantaneous minimum standards for significant periods of time at the Stevens Creek and Butler Creek monitoring stations. Additionally, there were at least 31 days in 2006 and 2007 when daily average DO concentrations were below 5.0 mg/L at RM 215.

Historical Comparisons

Average monthly dissolved oxygen concentrations measured by SNSA in 2007 were compared to historical data available from USGS for its sampling station at RM 61 (02198500). Monthly average dissolved oxygen concentrations from 2007 fell within the range of historical measurements, with the exception of July (Figure 3-21). Additionally, eight of twelve months in 2007 had higher average dissolved oxygen concentrations than the 30-year average.

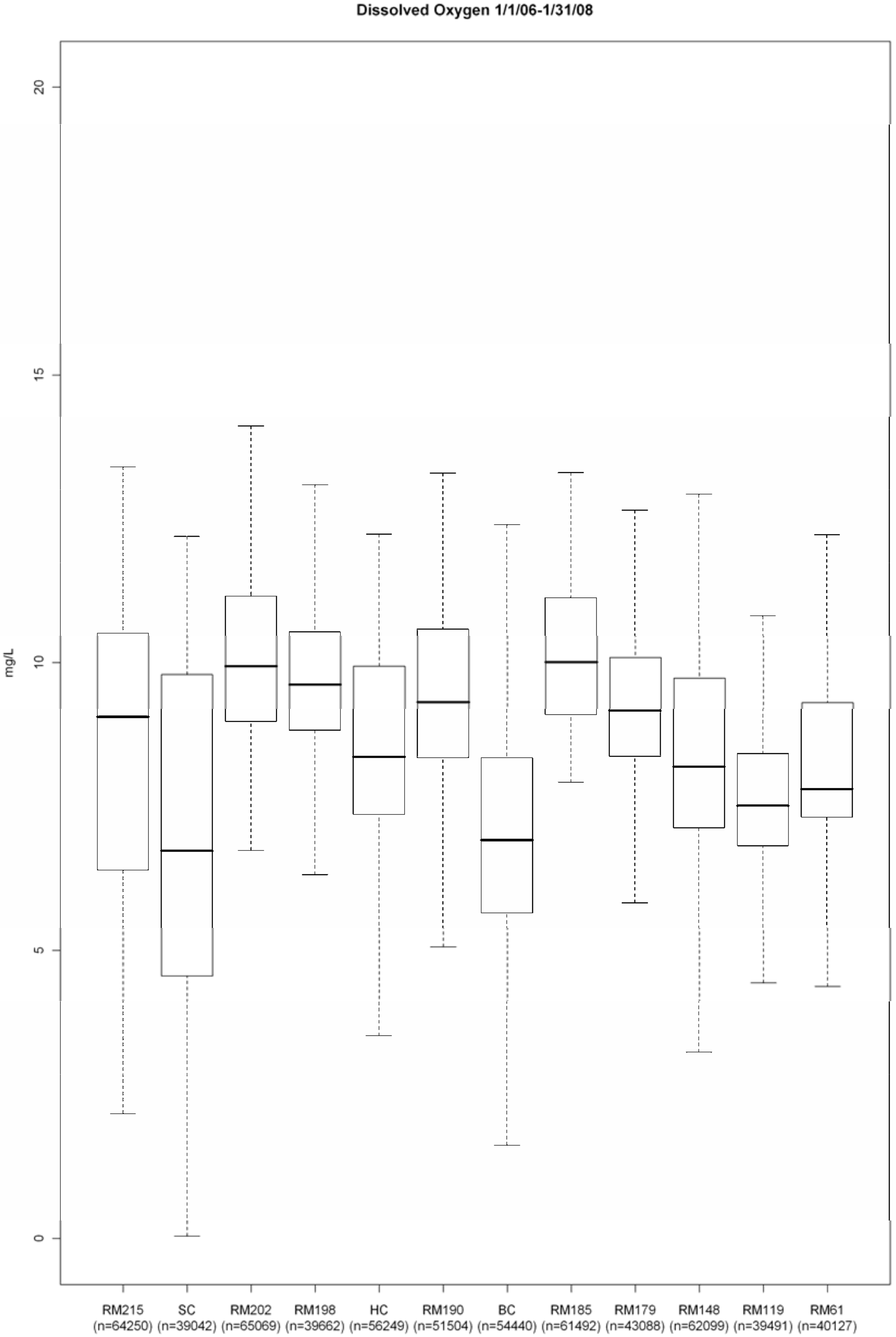

Figure 3-17. Dissolved oxygen statistics from all stations from January 2006 through January 2008.

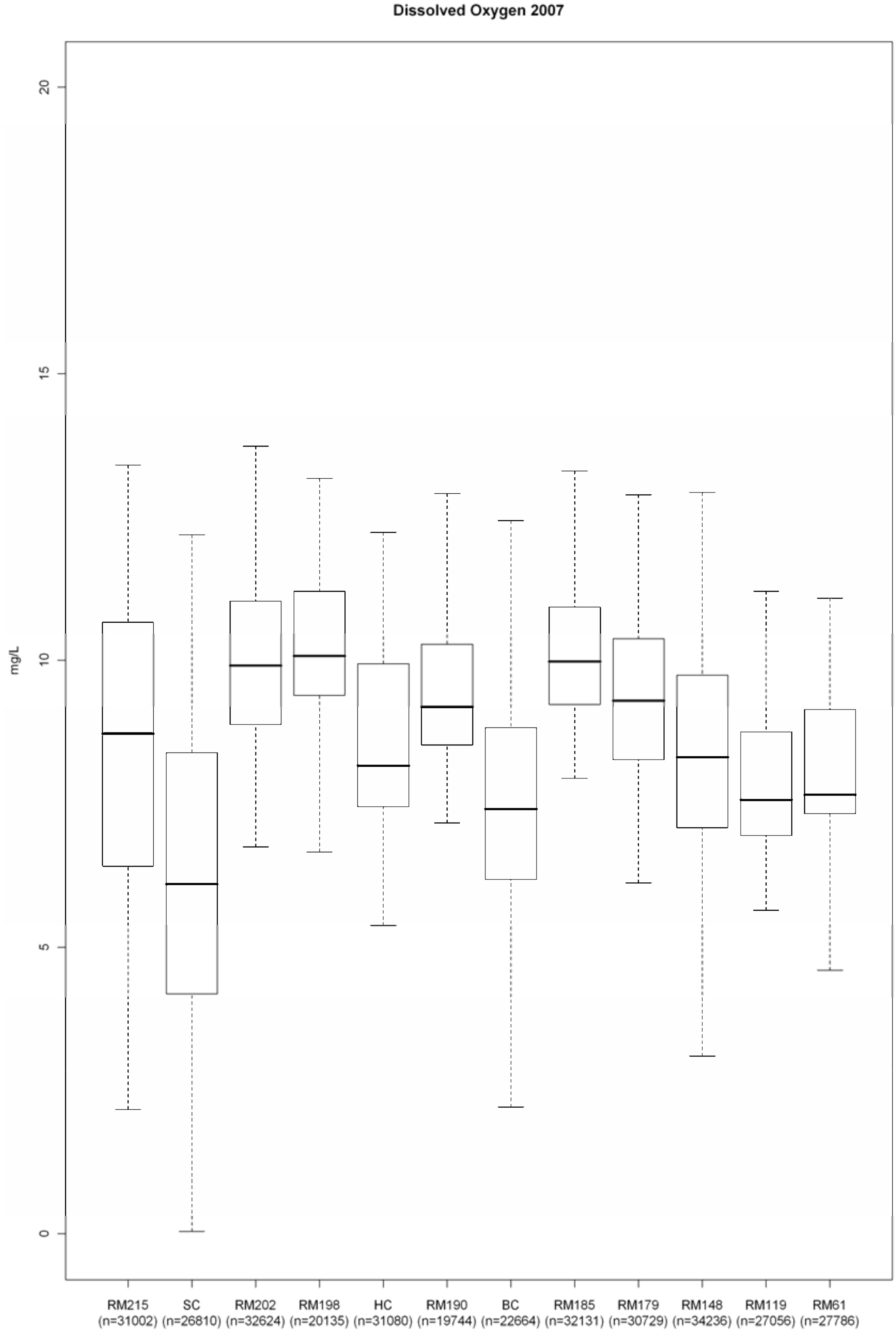

Figure 3-18 Dissolved oxygen statistics from all stations 2007.

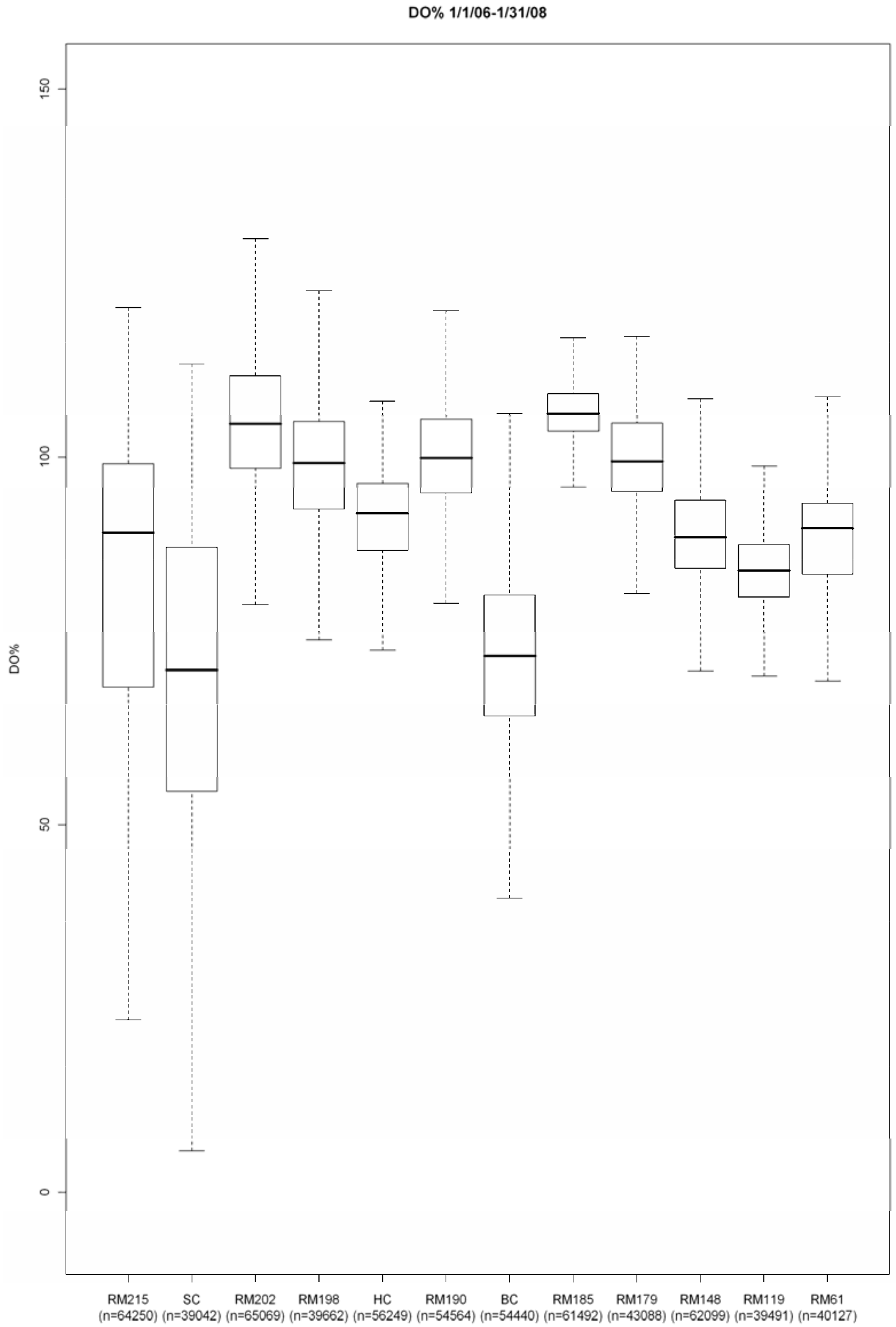

Figure 3-19. Dissolved oxygen percent saturation statistics from all river stations from January 2006 through January 2008.

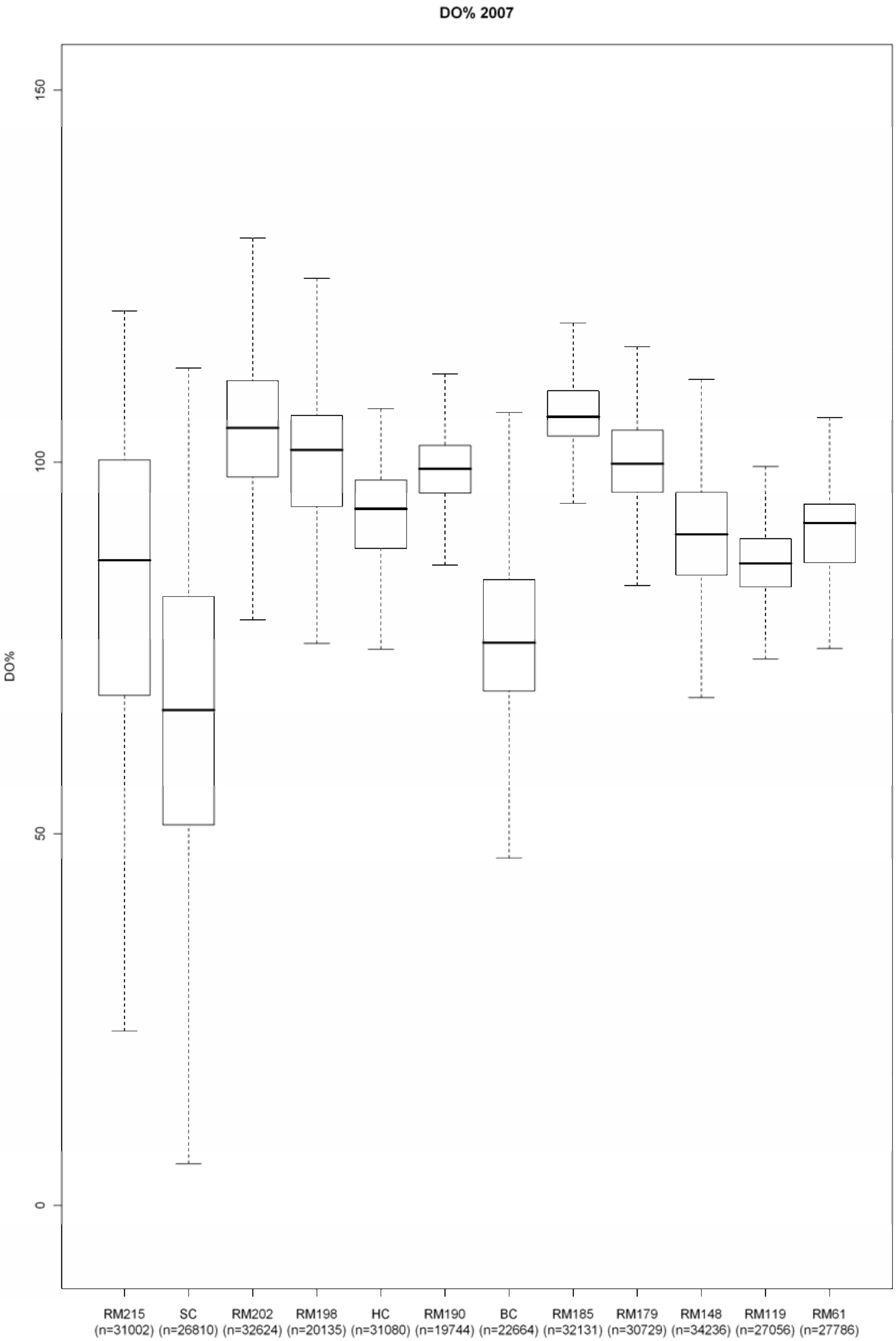

Figure 3-20 Dissolved Oxygen percent saturation statistics from all river stations 2007.

Table 3-1. Summary of daily average dissolved oxygen concentrations below state standards

Station	Month-Year	# Days < 5.0 mg/L	Days Sampled
RM 215	Aug-06	15	31
	Sep-06	8	30
	Oct-06	2	27
	Sep-07	6	30
Stevens Creek	Apr-06	13	30
	May-06	11	15
	Apr-07	1	30
	May-07	25	31
	Jun-07	28	28
	Jul-07	8	8
	Aug-07	25	25
	Sep-07	7	7
	Oct-07	4	28
Butler Creek	May-06	1	28
	Jun-06	18	30
	Jul-06	8	26
	Aug-06	30	31
	Sep-06	14	19
	Jun-07	13	16
	Sep-07	5	18

Table 3-2. Summary of instantaneous dissolved oxygen concentrations below state standards

Station	Month-Year	# Samples < 4.0 mg/L	Hours	Total # Samples
RM 215	Aug-06	6	1.5	2975
	Sep-06	15	3.75	2879
	Sep-07	294	73.5	2878
Stevens Creek	Apr-06	252	63	2879
	May-06	428	107	1477
	May-07	1497	374.25	2970
	Jun-07	1270	317.5	2752
	Jul-07	599	149.75	976
	Aug-07	1895	473.75	2648
	Sep-07	760	190	934
Butler Creek	Jun-06	355	88.75	2877
	Jul-06	88	22	2597
	Aug-06	1876	469	2975
	Sep-06	848	212	1824
	Jun-07	105	26.25	1573
	Sep-07	367	91.75	1823

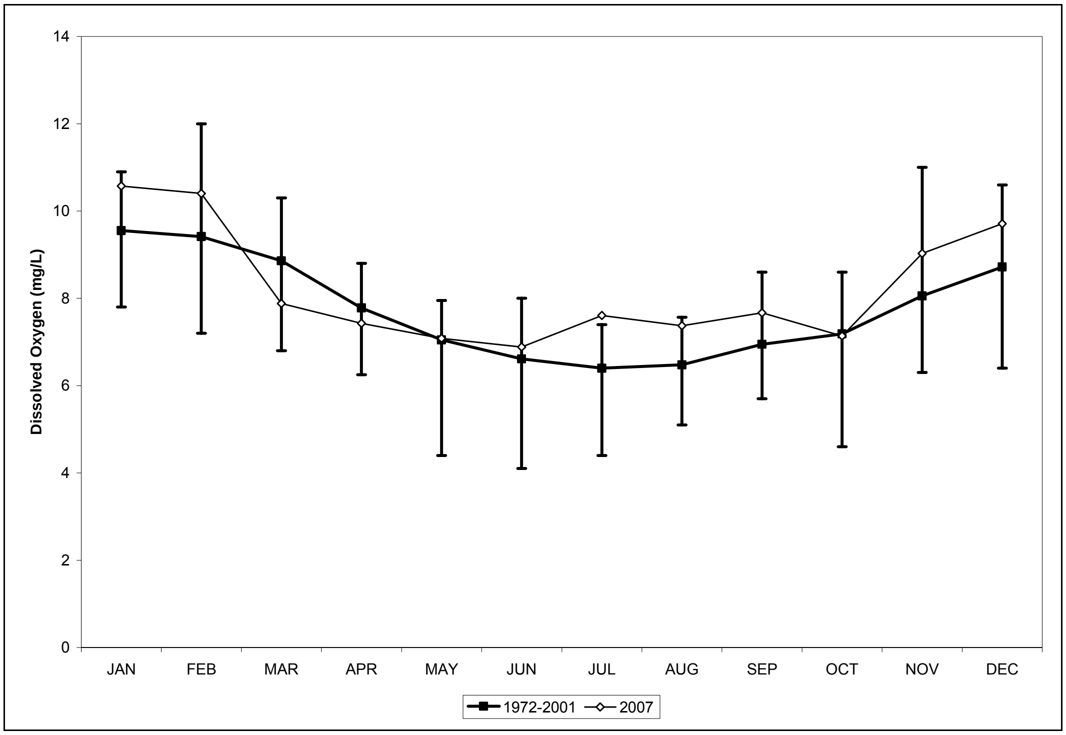

Figure 3-21. Comparison of long-term mean/min/max dissolved oxygen data (USGS 02198500) to 2007 data for RM 61.

3.4.4. pH

In general, pH increased from RM 215 to a maximum at RM 202 (Figure 3-22, Figure 3-23). The lowest pH was within Horse Creek. Highest variability was at RM 215 and lowest was RM 61.

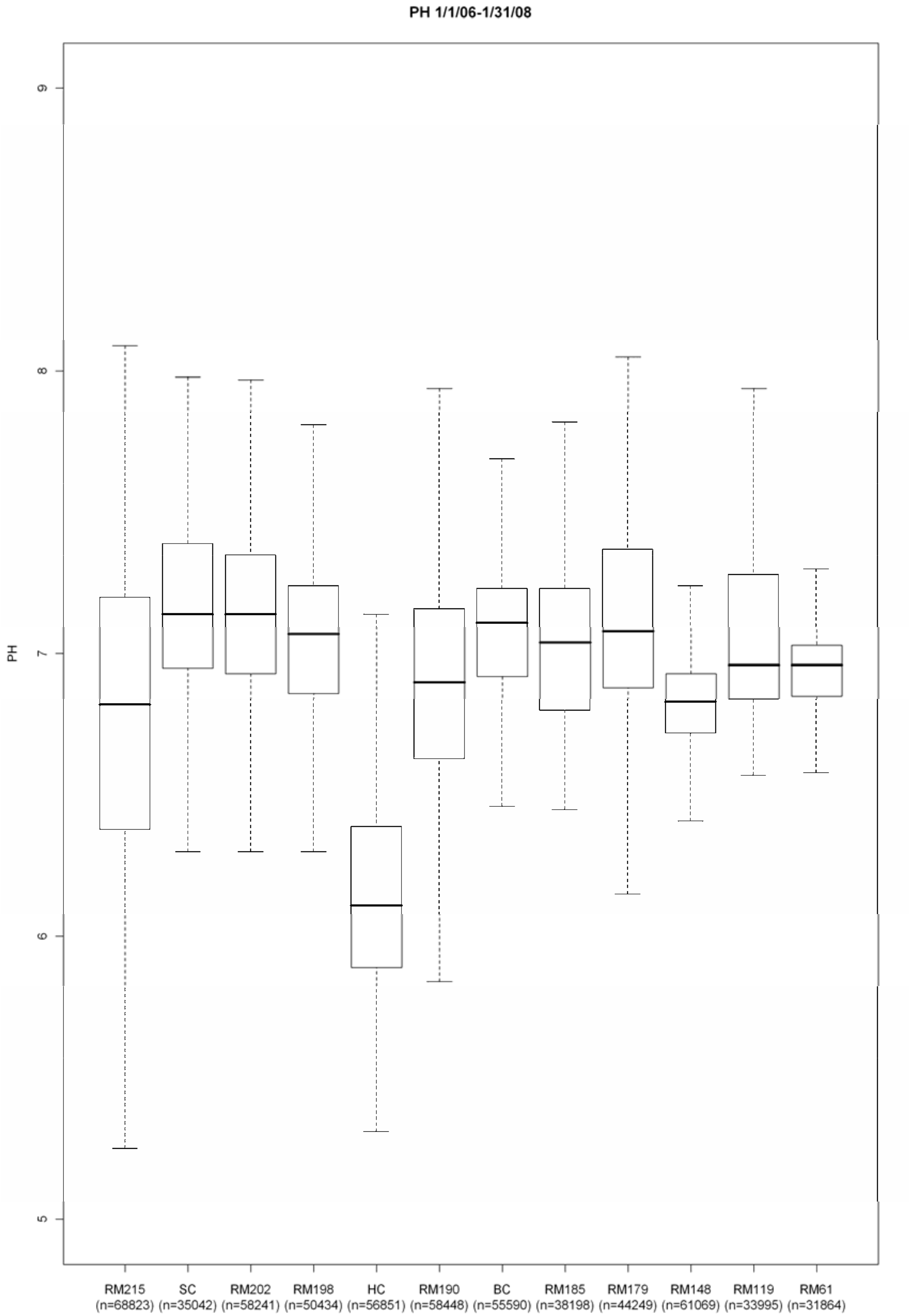

Figure 3-22. pH statistics from all stations from January 2006 through January 2008.

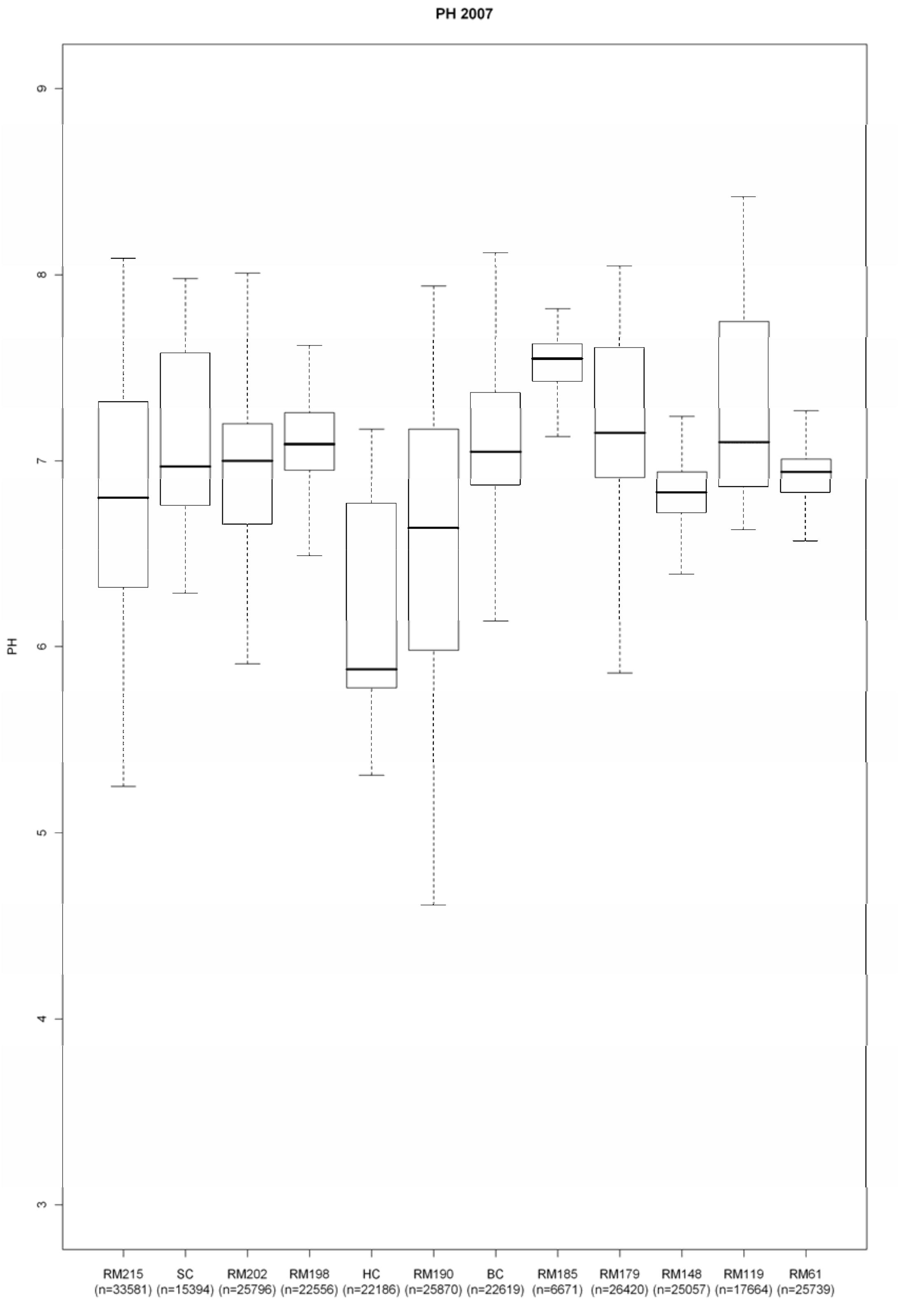

Figure 3-23. pH statistics from all stations 2007.

3.5. Discrete Water Quality Sampling

3.5.1. Eularian perspective

Sampling events were conducted over the entire hydrograph (Figure 3-24). The USACE's artificial pulse in March 2006 and a natural pulse in March 2007 were the highest flow events during the study period, with each event peaking at approximately 30,000 cfs. Most mainstem samples were collected at flows between 4,000 and 6,000 cfs. As shown, several sampling events coincided with significant rain events (March, June, and August).

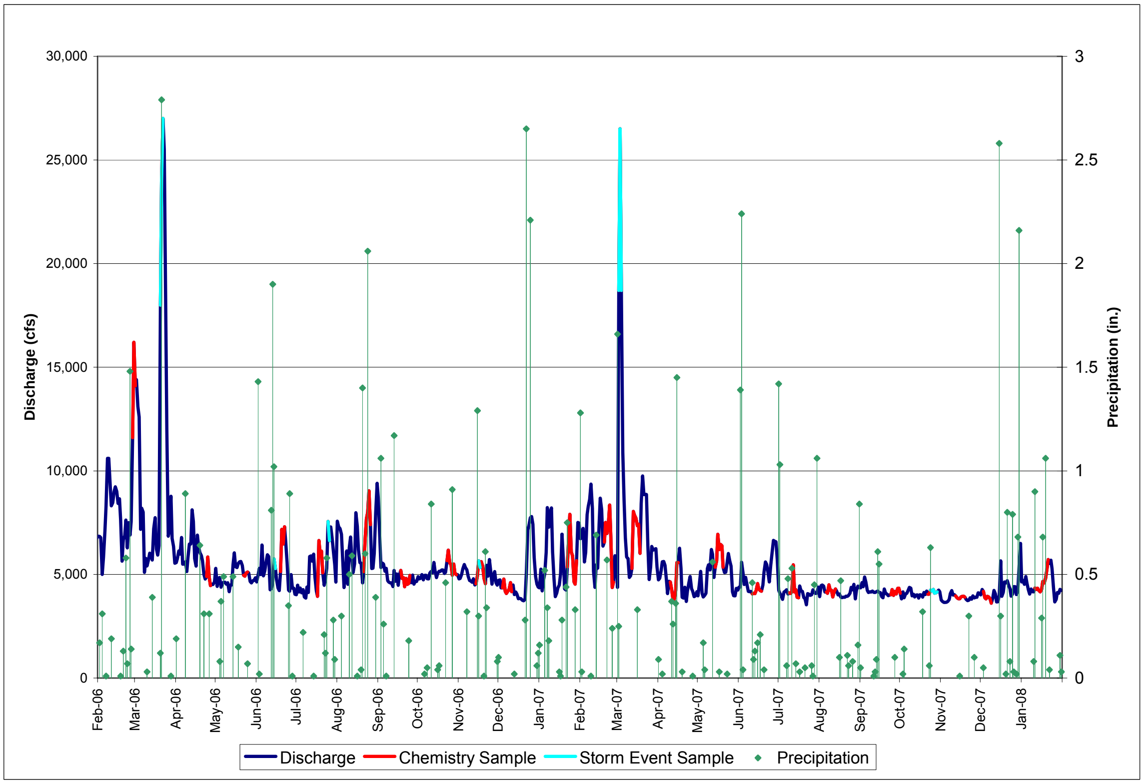

Figure 3-24. Chemistry sampling events, Savannah River Discharge (USGS 02197000), and precipitation (NOAA, 2008).

Figure 3-25 shows median, 25% and 75% quartiles, 95% confidence intervals, and outliers (3*Inter Quartile Range) of each individual sampling site from February 2006 through January 2008; results for all constituents are reported in mg/L. Tabular statistical summaries of these data are provided in **Appendix B**.

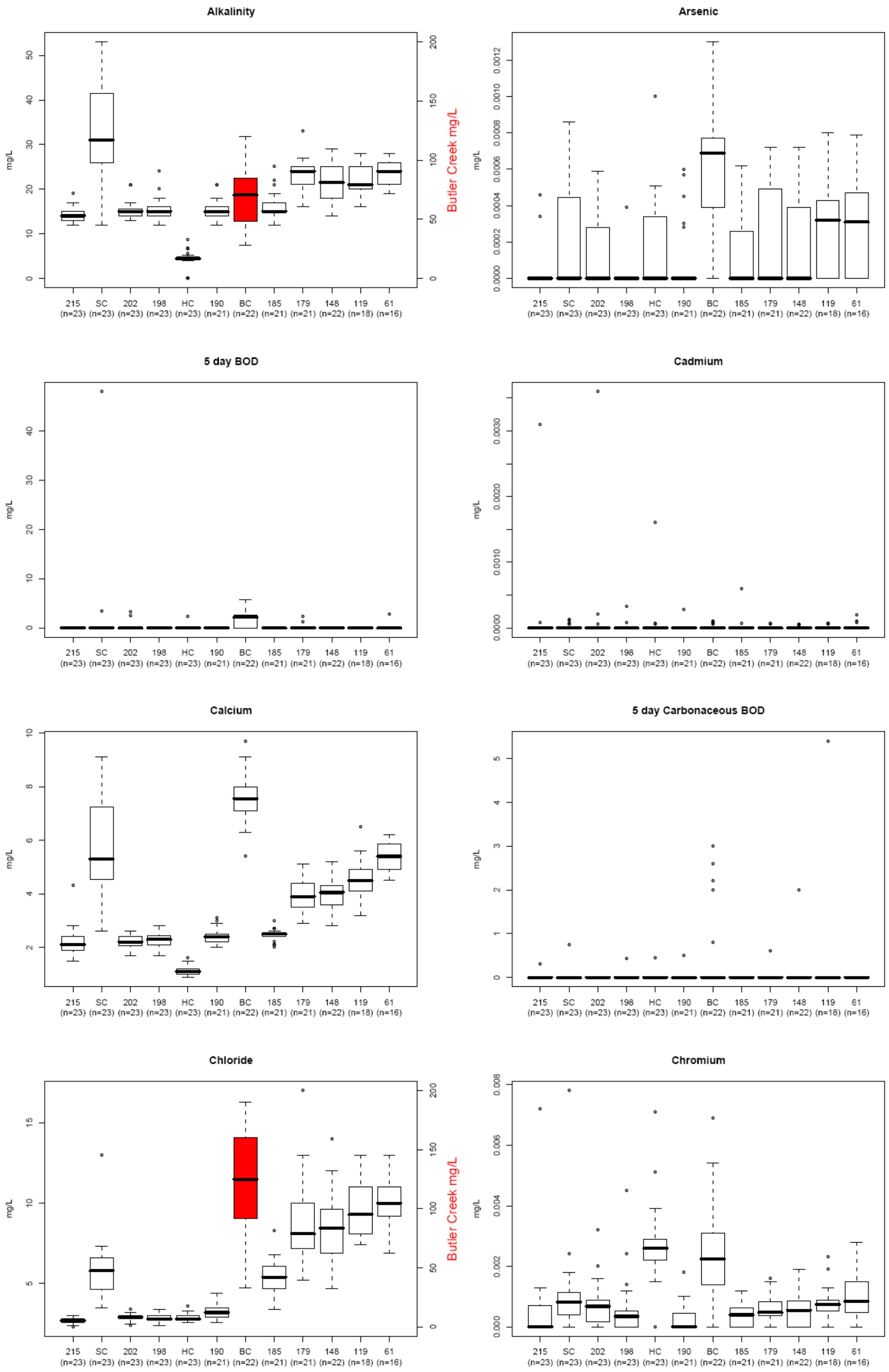

Figure 3-25. Boxplots of Water Chemistry Analytes

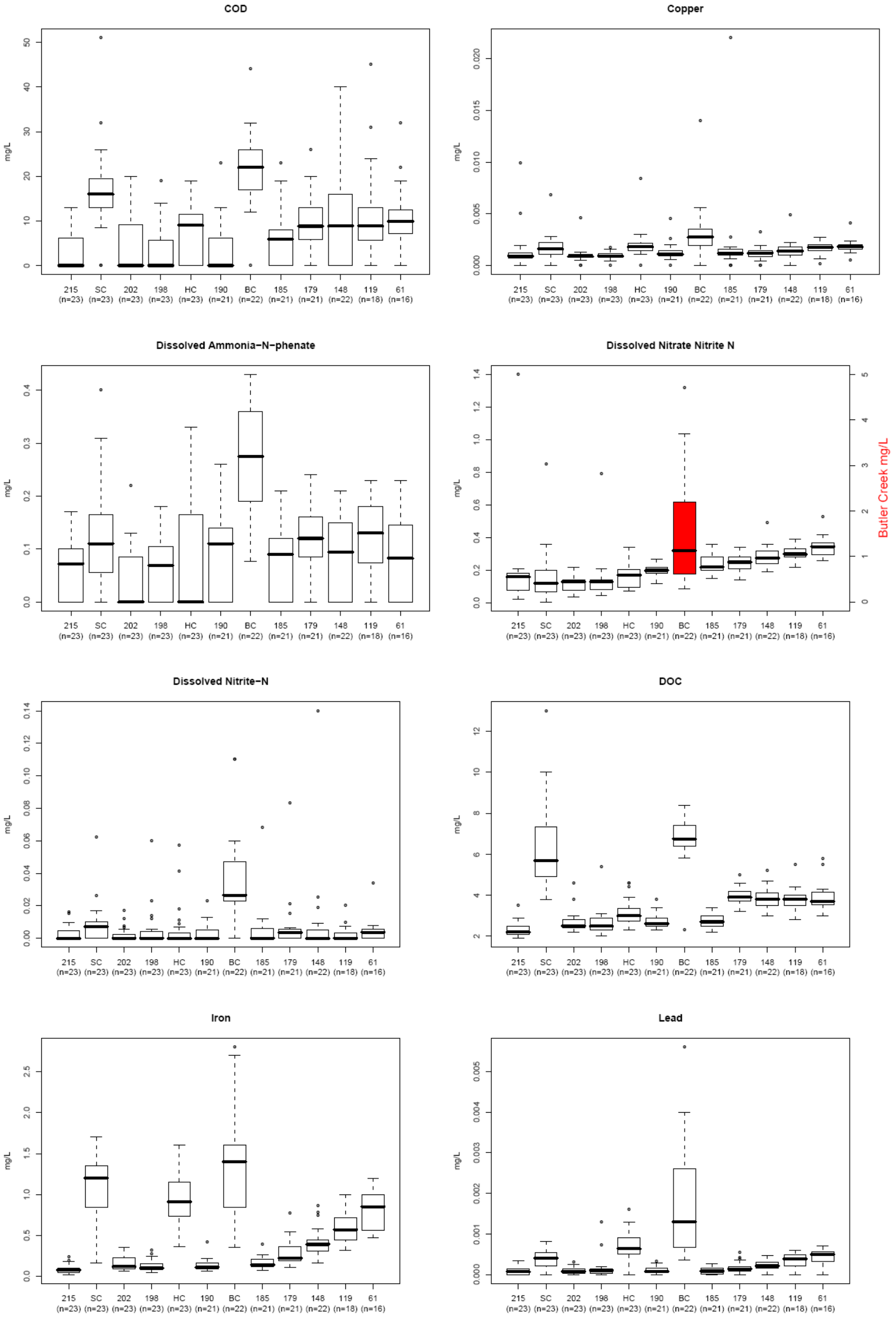

Figure 3-25 (Cont.).

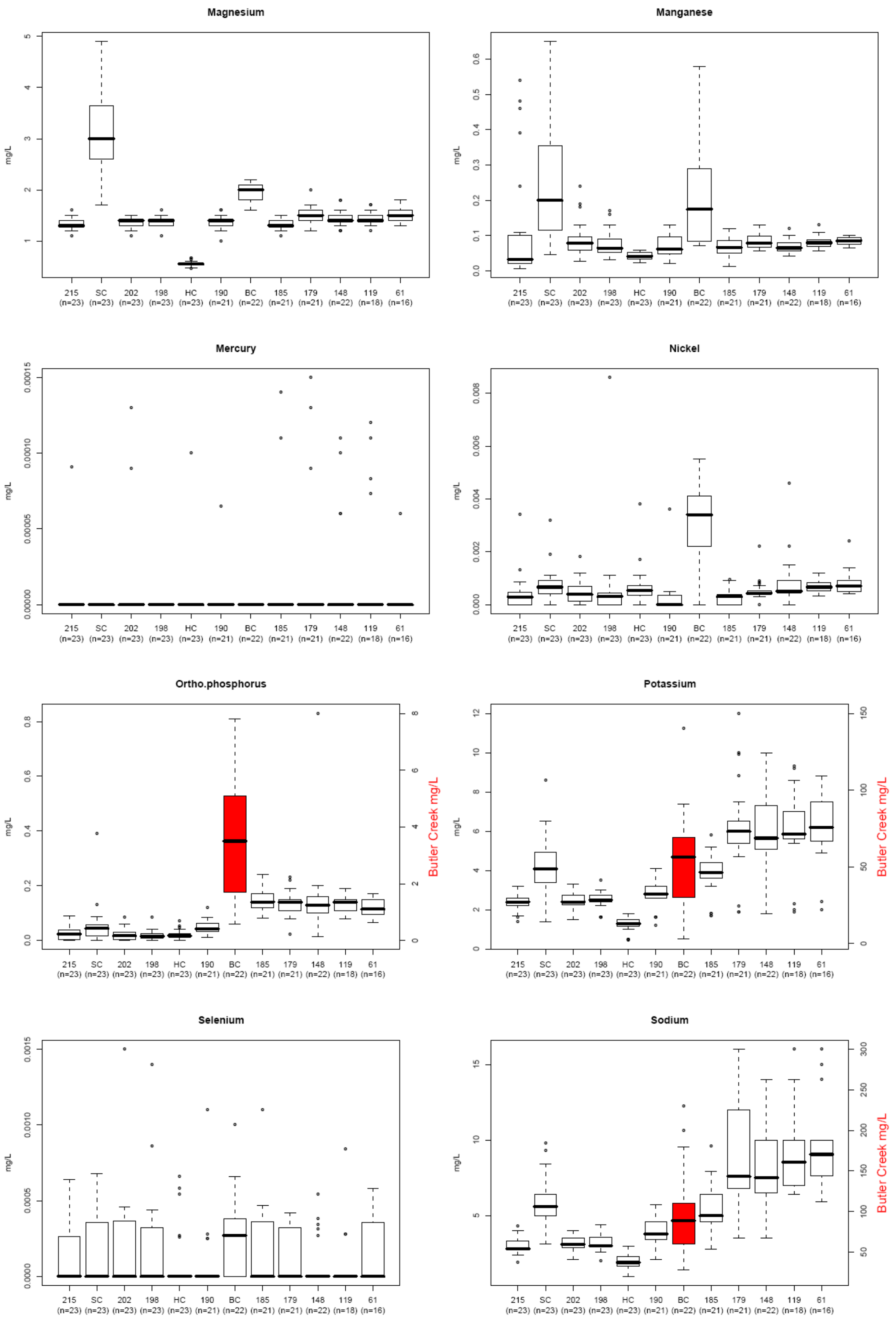

Figure 3-25 (Cont).

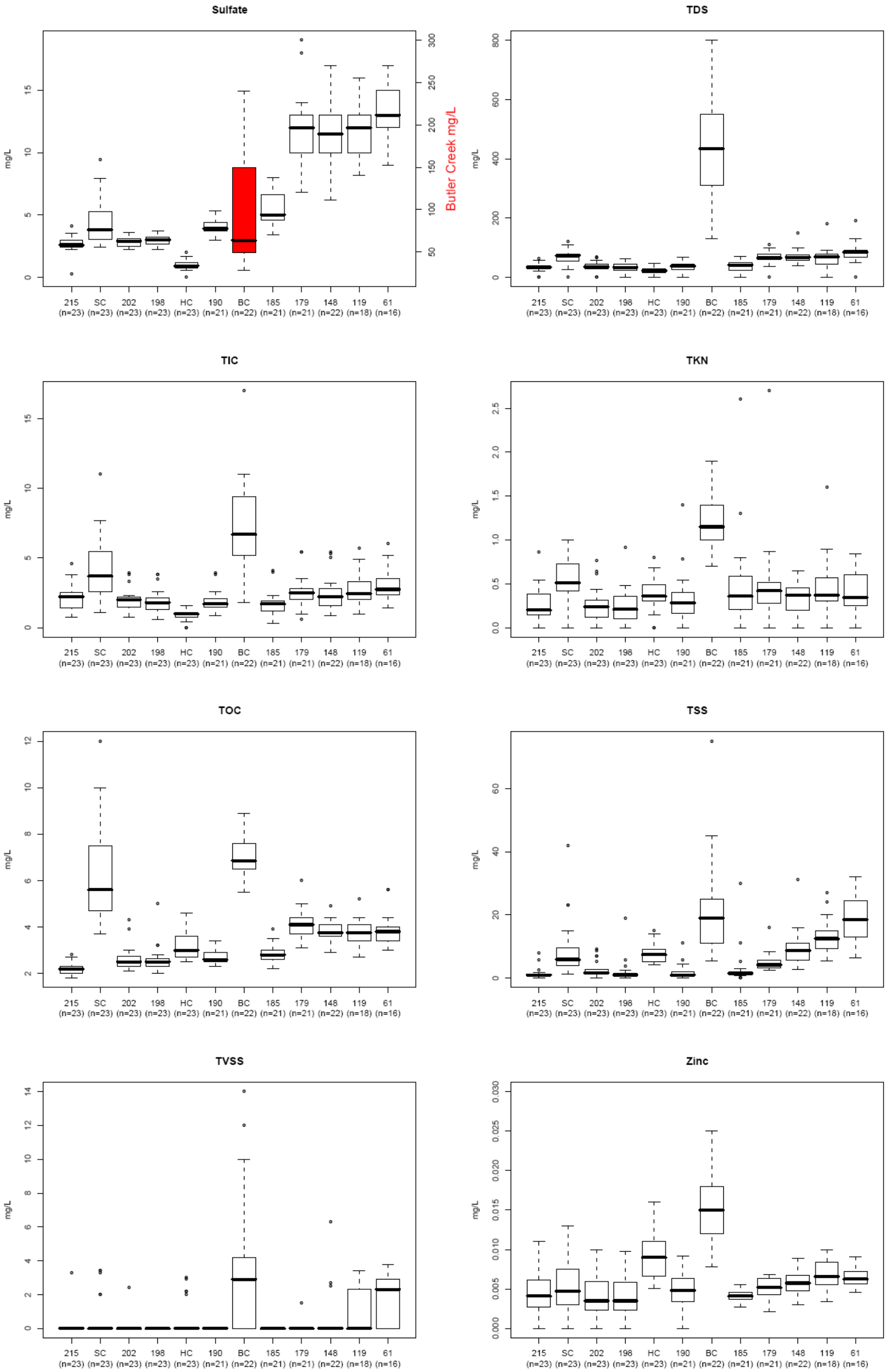

Figure 3-25 (Cont.).

Individual constituent data from each stations (shown above), coupled with conductivity data, can be used to calibrate conductivity measurements, which can lead to further understanding of the system in terms of mass flux dynamics. Specific conductance data showed a steady increase with decreasing RM. To calculate the percent contribution of individual ions to the overall conductivity, the following equation was used:

$$\sum \mathit{cations} = \sum \mathit{anions}\ (meq/L) = \mathit{electrical\ conductivity}\ (uS/cm)/100$$

(from Appelo and Postma, 1993).

Results from this analysis are shown in Table 3-3. Specific conductance at RM 148 at the time of sampling was 109 uS/cm and the calculated conductance from the chemistry data was 125 uS/cm (% difference = 13.0). In addition, the electroneutrality of the solution calculated by the chemistry data had an error of 11%. Although these results were not within the preferred 5% error (Appelo and Postma, 1993), the results remain quite useful, especially in light of the fact that some species were deemed negligible even though concentrations were >0 and no charge was attributed to organic acids (a portion of the DOC concentration). Using this equation, the majority of ions were accounted for and over half of the increase was due to sodium (~18%) and sulfate (~37%).

Table 3-3. Individual constituents responsible for conductivity increase from RM 215 to RM 148.

	River Mile 215 (mg/L)	**River Mile 148 (mg/L)**	**Difference (meq/L)**	**Percent cont. to total conductivity change**
Alkalinity (HCO_3^-)	16	26	0.1667	13.28
Arsenic	0	0	neg.	
Cadmium	0	0.000047	neg.	
Calcium	1.9	3.6	0.0848	6.76
Chloride	2.5	8.5	0.1692	13.49
Chromium	0	0	neg.	
Copper	0.0017	0.0049	neg.	
Iron	0.02	0.44	0.0150	1.20
Lead	0.00017	0.0002	neg.	
Magnesium	1.2	1.2	neg.	
Manganese	0.013	0.058	0.0016	0.13
Nickel	0	0.0046	neg.	
Ortho-phosphorus ($H_2PO_4^-$)	0.04	0.13	neg.	
Potassium	2.3	7.6	0.1356	10.80
Selenium	0.00053	0.00034	neg.	
Silicon	4.3	3.7	neg.	
Sodium	3.4	14	0.4611	36.75
Sulfate	2.4	13	0.2207	17.59
Zinc	0.0028	0.006	neg.	
neg. = negligible				100%

Table 3-4 shows the chemistry sample results that were in excess of state standards (n = 37).

Table 3-4. Chemistry Sample results in excess of state/federal clean water limits

				Georgia[1]		**South Carolina**[2]	
Site	**Date**	**Constituent**	**Result (µg/L)**	**Chronic**	**Acute**	**Chronic**	**Acute**
RM 215	8/22/2006	Copper	15	5.0	7.0	2.9	3.8
	8/22/2006	Mercury	0.13	0.012	1.4	0.91	1.6
Stevens Creek	8/21/2006	Cadmium	0.23			0.1	0.53
	8/21/2006	Copper	6.8			2.9	3.8
RM 202	8/22/2006	Copper	3.4	5.0	7.0	2.9	3.8
	5/22/2006	Copper	4.2	5.0	7.0	2.9	3.8
	3/2/2007	Copper	4.6	5.0	7.0	2.9	3.8
	7/26/2006	Copper	36	5.0	7.0	2.9	3.8
	12/5/2006	Lead	0.83	1.2	30	0.54	14
	8/22/2006	Mercury	0.092	0.012	1.4	0.91	1.6
Horse Creek	3/2/2007	Copper	3.7			2.9	3.8
	7/26/2006	Copper	55			2.9	3.8
	7/18/2006	Lead	0.6			0.54	14
	7/26/2006	Lead	0.81			0.54	14
	3/21/2006	Lead	1.1			0.54	14
Butler Creek	6/15/2006	Copper	5	5.0	7.0		
	5/24/2006	Lead	1.5	1.2	30		
	3/14/2007	Lead	1.5	1.2	30		
	3/2/2007	Mercury	0.16	0.012	1.4		
RM 185	8/23/2006	Copper	21	5.0	7.0	2.9	3.8
	3/21/2006	Lead	0.89	1.2	30	0.54	14
	10/26/2006	Mercury	0.084	0.012	1.4	0.91	1.6
	7/12/2007	Mercury	0.088	0.012	1.4	0.91	1.6
	8/23/2006	Mercury	0.12	0.012	1.4	0.91	1.6
RM 179	10/26/2006	Mercury	0.095	0.012	1.4	0.91	1.6
	2/21/2007	Mercury	0.14	0.012	1.4	0.91	1.6
RM 148	2/22/2007	Mercury	0.07	0.012	1.4	0.91	1.6
	10/27/2006	Mercury	0.084	0.012	1.4	0.91	1.6
	8/24/2006	Mercury	0.1	0.012	1.4	0.91	1.6
RM 119	10/28/2006	Mercury	0.07	0.012	1.4	0.91	1.6
	3/16/2007	Mercury	0.075	0.012	1.4	0.91	1.6
	1/21/2008	Mercury	0.078	0.012	1.4	0.91	1.6
	3/3/2007	Mercury	0.13	0.012	1.4	0.91	1.6
RM 61	9/25/2006	Mercury	0.06	0.012	1.4	0.91	1.6
	4/16/2007	Mercury	0.06	0.012	1.4	0.91	1.6
	6/18/2007	Mercury	0.11	0.012	1.4	0.91	1.6
	12/10/2007	Zinc	40	65	65	37	37

[1] South Carolina Regulation 61-68

[2] Georgia DNR EPD Regulation 391-3-6-.03

3.5.2. Lagrangian perspective

Mass flux rates were calculated for several Lagrangian sampling excursions and are shown in Figure 3-26 through Figure 3-30. This was accomplished by multiplying the constituent concentration by the average discharge during the 1-hour sample collection window.

One drawback to sampling an individual mass of water was that advective waves and surface waves travel at different speeds. Since the surface wave was bounded by the atmosphere on one side and the density difference between the water and air was large, the surface wave can travel at much higher speeds than advective waves . This makes it difficult to close the water balance on each Lagrangian sample.

Despite the potential confounders with the Lagrangian sampling methodology, several generalizations can be made resulting from this analysis. As previously shown, the shoals caused DO supersaturation throughout the entire first year of study so some decrease in DO mass flux was expected due to atmospheric loss (aeration). The increase in mass likely resulted from the additional water influent from the Augusta Canal. DO mass flux remains relatively stable from RM 185 through RM 61 throughout the study (Figure 3-31).

Three instances were observed where decreases in DO mass flux rates were calculated for the reach between RM 148 and RM 119 (Figure 3-26, Figure 3-28, Figure 3-29). For two of these instances, chloride mass flux rate increased while during the third instance, the rate remained the same. In August, the DO mass flux rate decreased by 20.6% while the chloride mass flux rate increased by 21.7%. In December, the DO rate decreased by 3.8% while the chloride rate increased by 11.1%. In October, the DO rate decreased by 16.0% but the chloride rate decreased by 0.1%. Since Upper Three Runs was located within the RM 148/RM 119 reach and had nearly 50% of its ionic charge load as sodium chloride, the chloride mass rate should have increased through the RM148/RM119 reach if UTR flows were continuous despite the river flow rates. Divergence from such a pattern may have indicated errors in sampling, so the October data may not be accurate. Conversely, the decreased DO rates in August and December may signify significant losses during those time periods. The August data seems plausible since microbial activity should have been at a maximum during that time of year but cause for the decreased rate during December is unknown.

Dissolved organic carbon (DOC) generally increased with decreasing RM (Figure 3-32). January through April DOC increased from RM 179 to RM 61, which is likely a result of decreased respiration due to lower temperatures (Figure 3-32). However, DOC decreased or remained the same from RM 179 to RM 61 from May through December 2007 (Figure 3-32). This observation was likely a result of in-stream bacterial processing of organic loads.

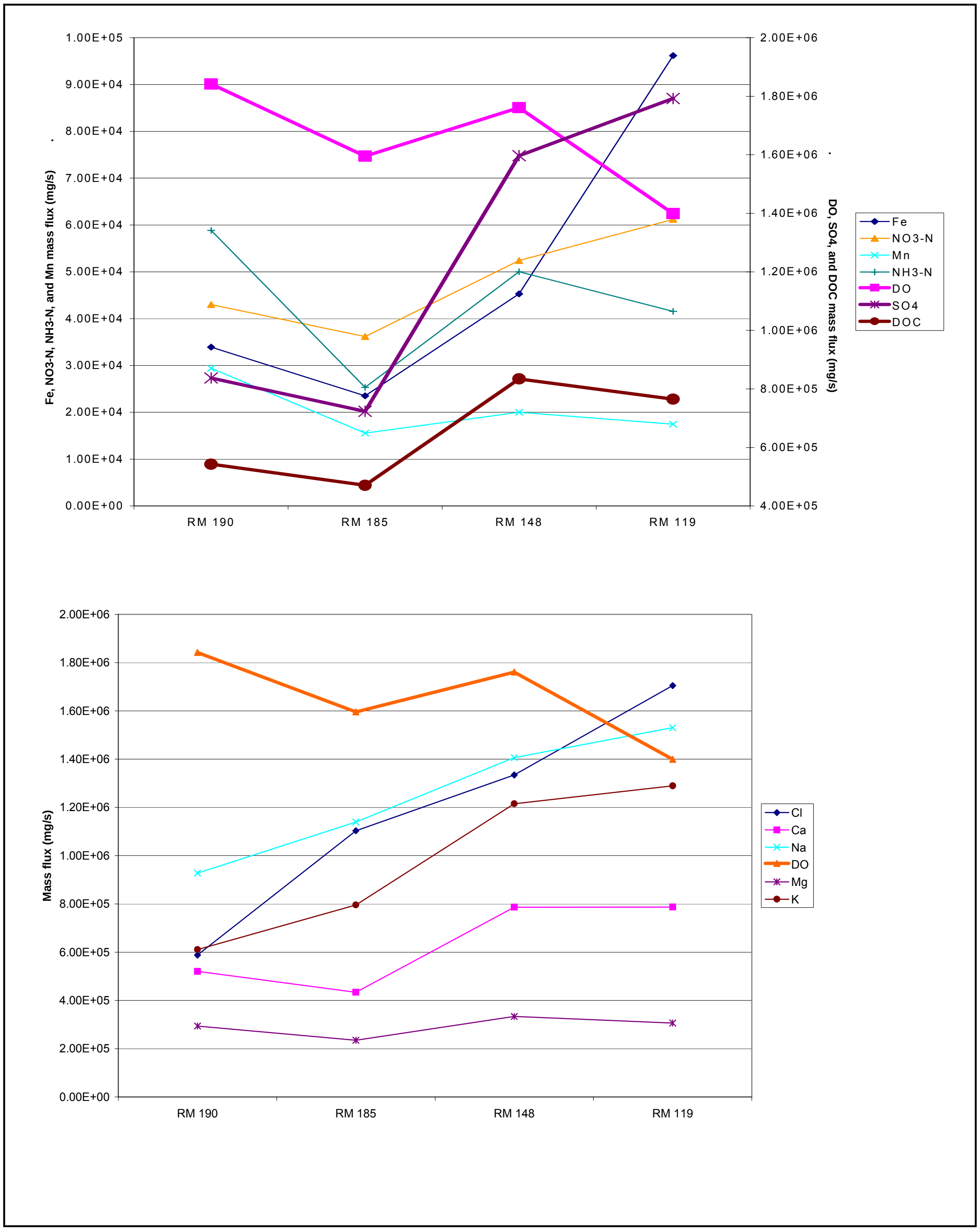

Figure 3-26. Lagrangian mass flux results for August 2006.

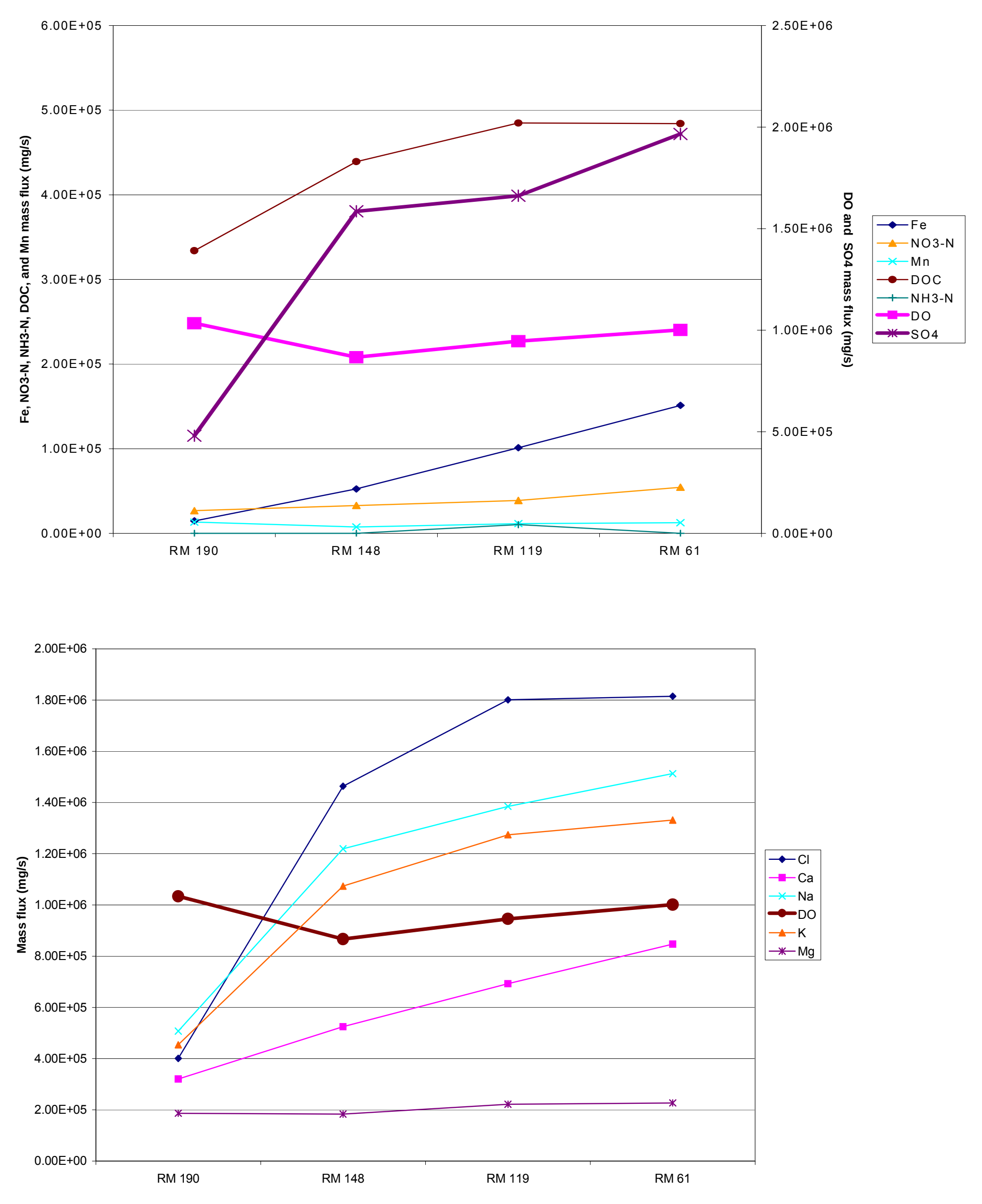

Figure 3-27. Lagrangian mass flux results for September 2006.

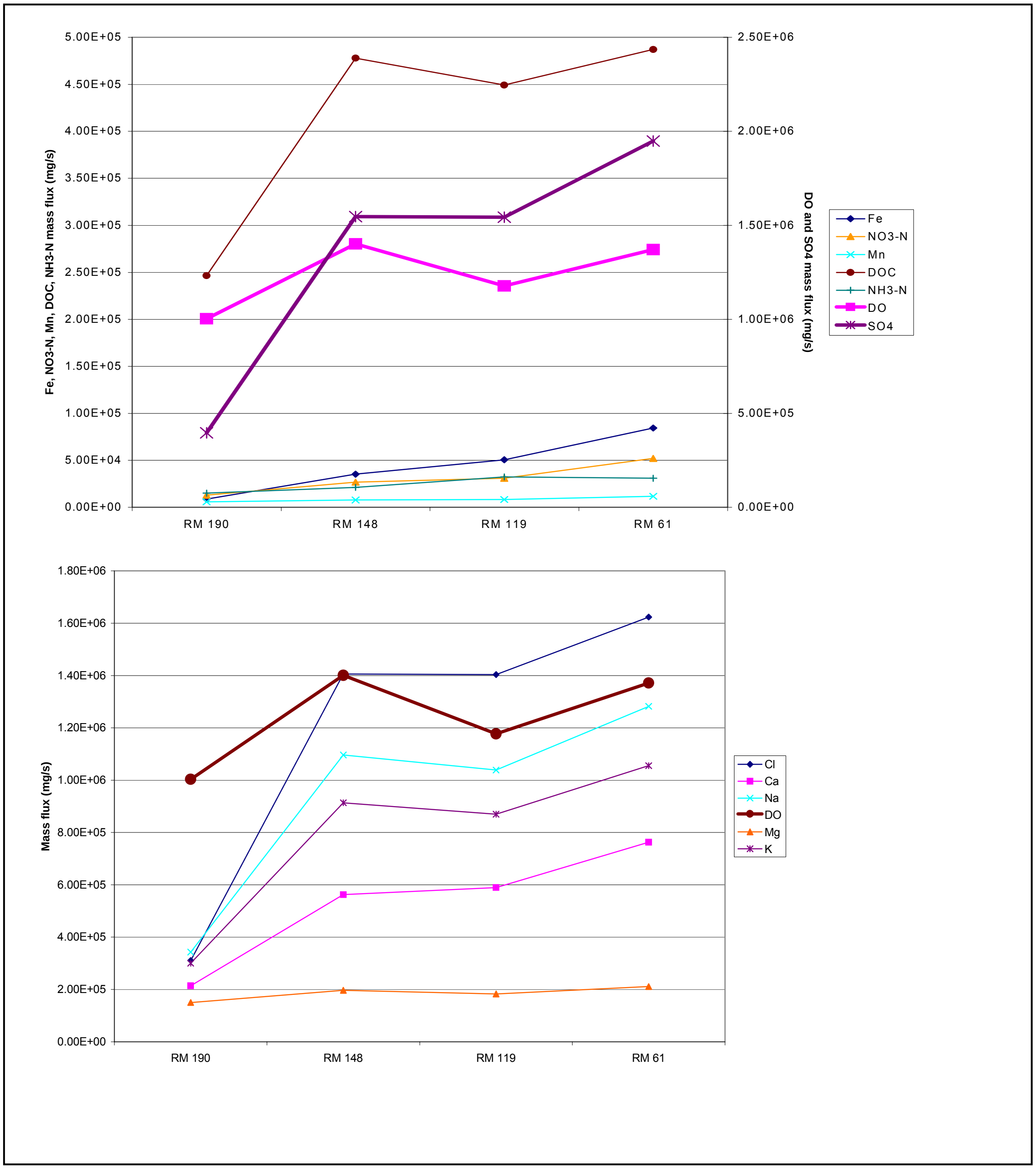

Figure 3-28. Lagrangian mass flux results for October 2006.

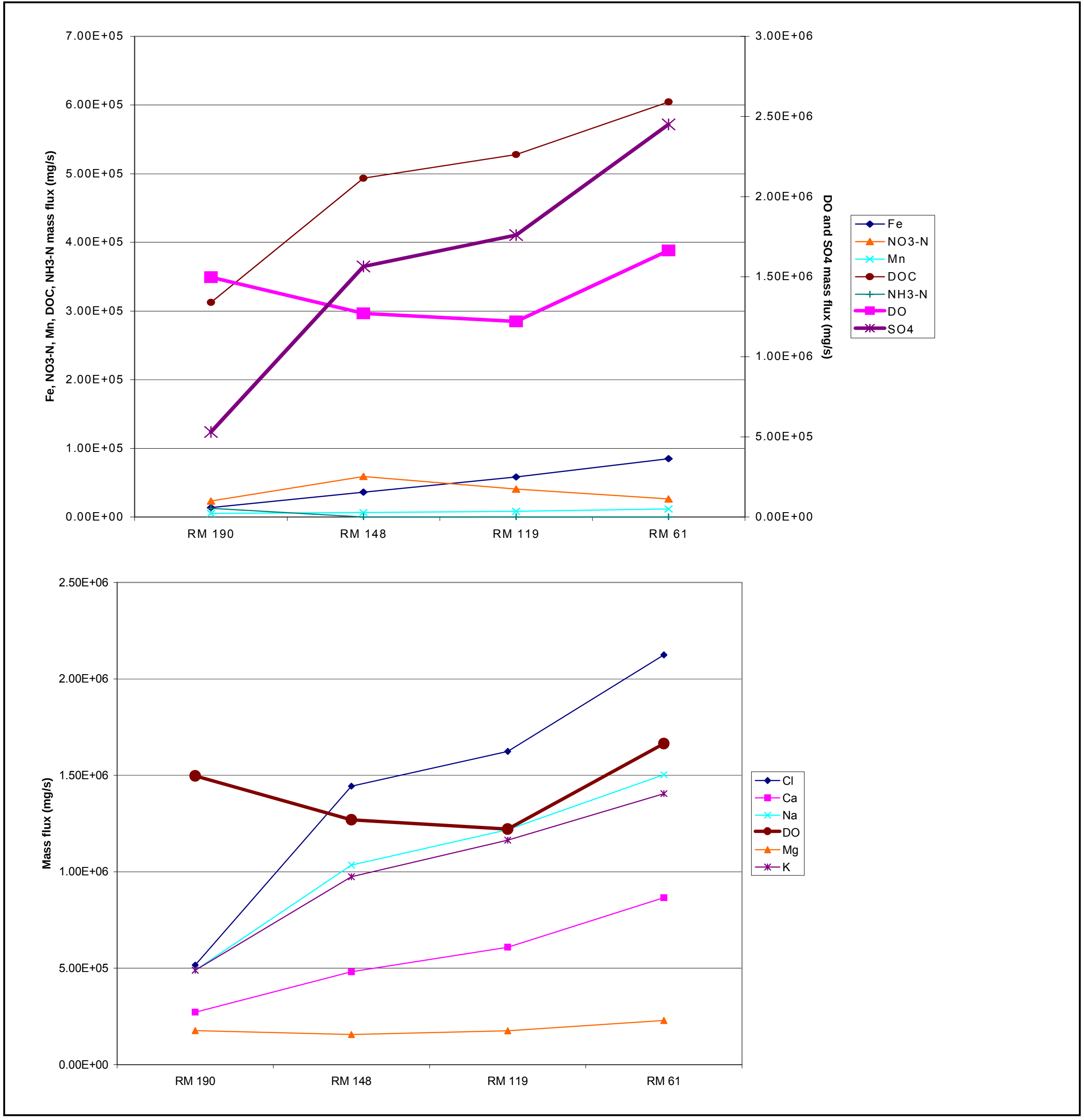

Figure 3-29. Lagrangian mass flux results for December 2006.

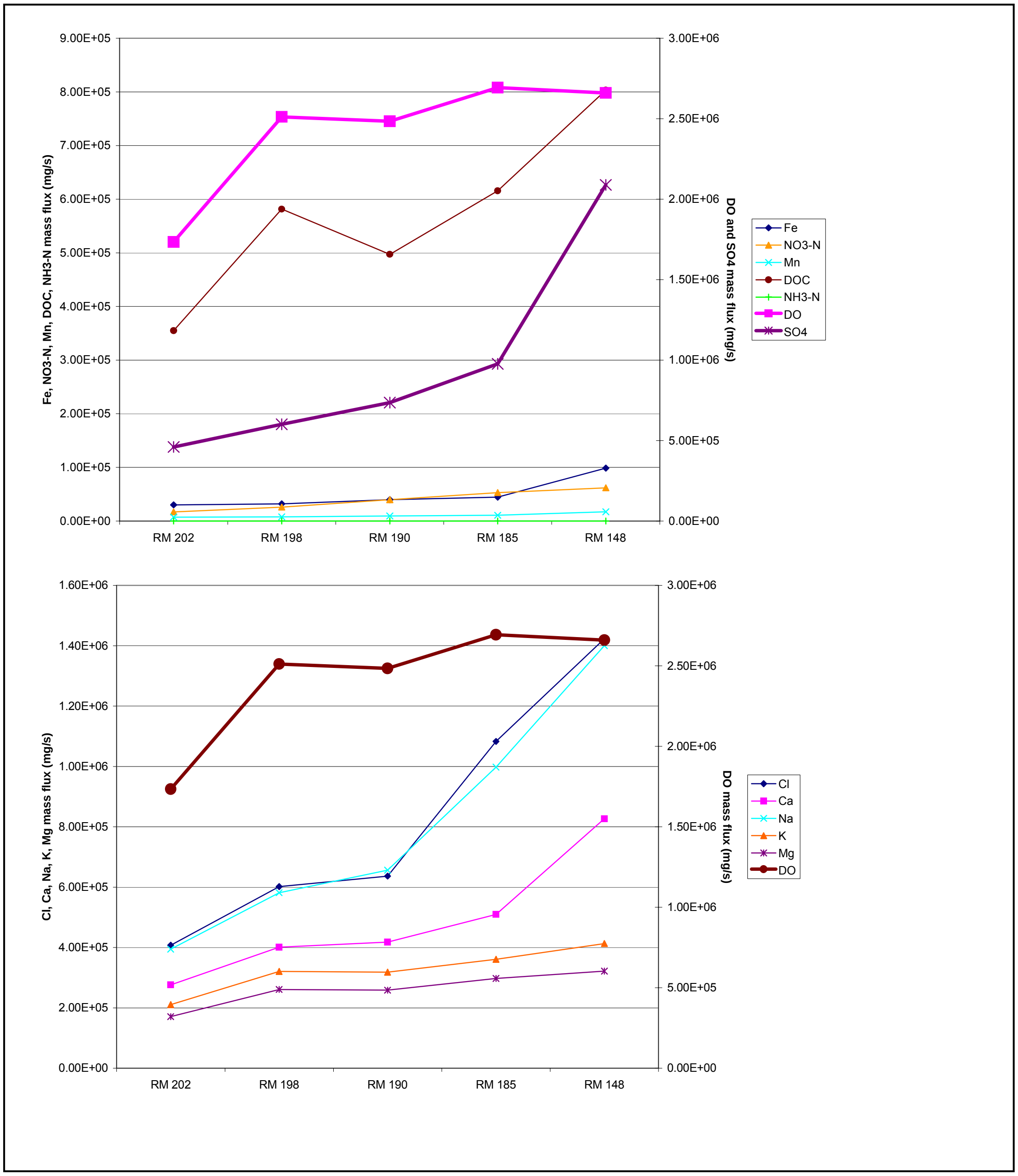

Figure 3-30. Lagrangian mass flux results from February 2007.

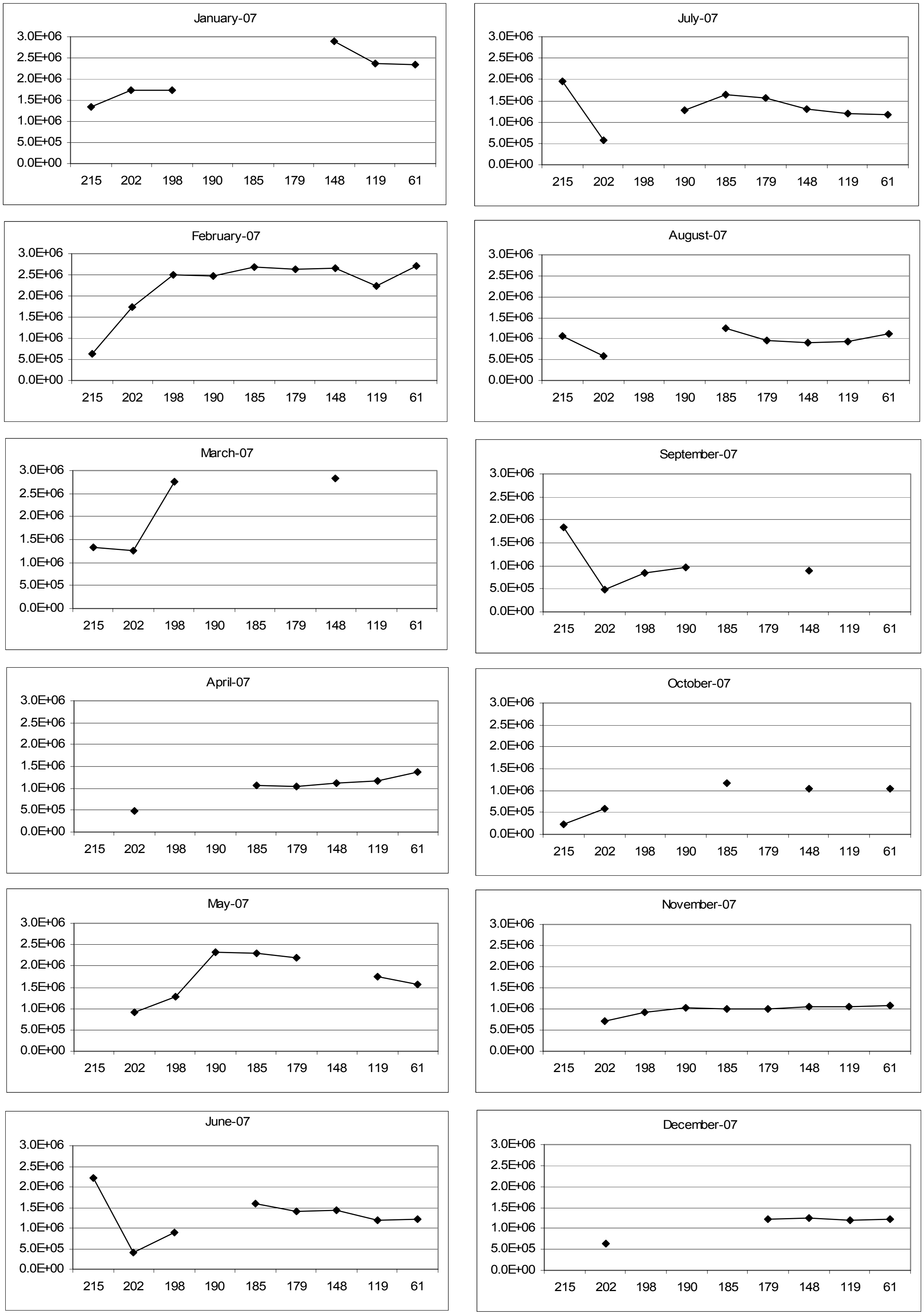

Figure 3-31. Lagrangian Dissolved Oxygen mass (mg/sec) January 2007 through December 2007.

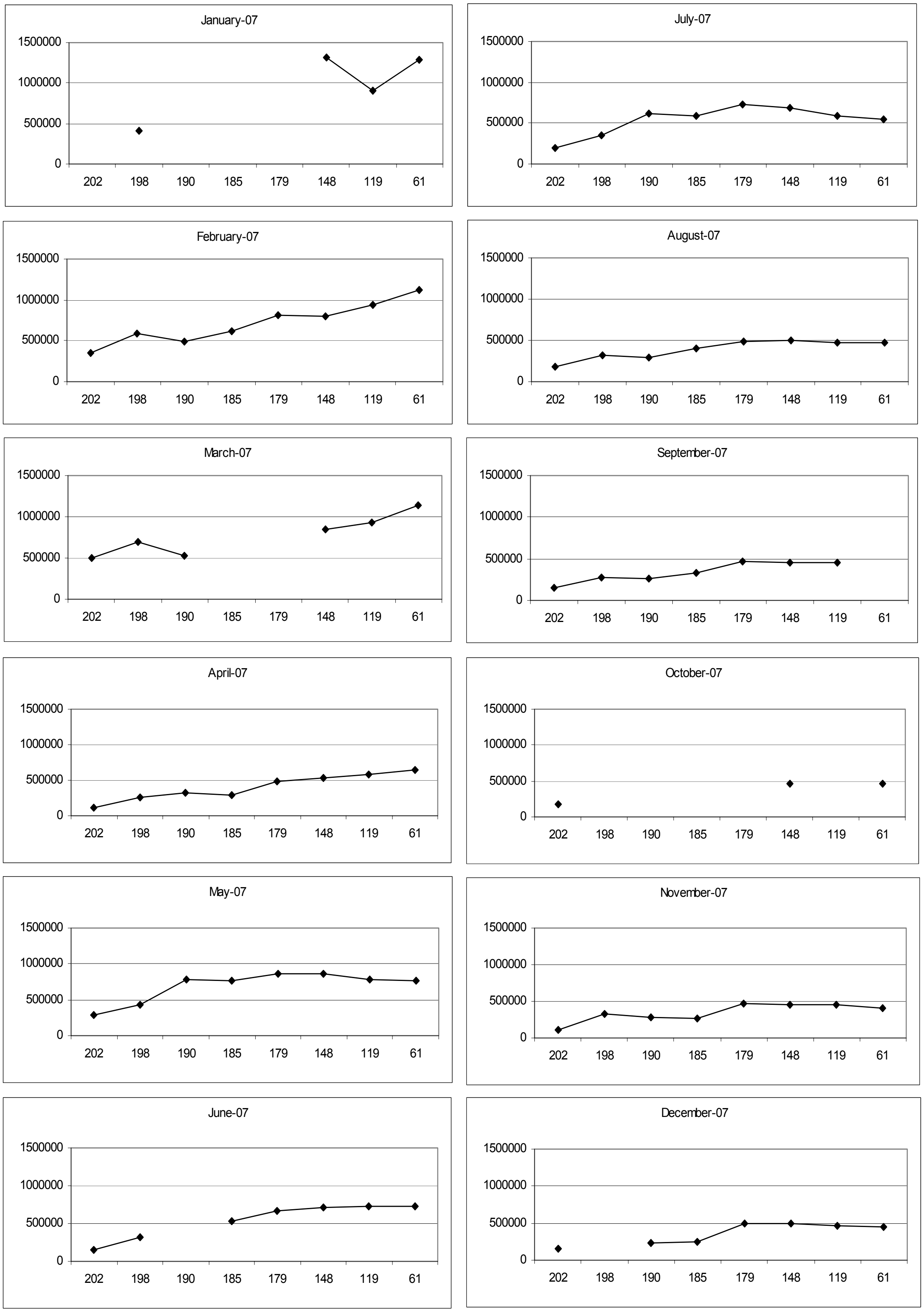

Figure 3-32. Lagrangian dissolved organic carbon mass flux (mg/sec) January - December 2007.

3.5.3. Annual Mass Flux

The annual mass flux (kg/year) for each analyte is presented in Table 3-5. Annual mass flux was calculated by multiplying constituent concentrations (mg/L) by discharge (ft^3/sec) measured during the sampling window, resulting in individual sample mass flux rates (mg/sec). These rates were averaged for each site and converted to annual mass flux (kg/year) estimations.

It should be noted that the calculations for RM 202, 190, 185, and 148 included data from the March 2007 flood pulse, which resulted in large mass fluxes of material. As a result, the annual mass flux estimates for these sites are likely skewed high relative to the other stations that were not sampled during the 2007 pulse.

Table 3-5. Estimated annual mass flux

	RM 215	SC	RM 202	RM 198	HC	RM 190	BC*	RM 185	RM 179	RM 148	RM 119	RM 61	
	(n=12)	(n=7)	(n=14)	(n=11)	(n=25)	(n=11)	(n=27)	(n=9)	(n=9)	(n=25)	(n=21)	(n=16)	
Alkalinity	7.99E+07	1.49E+07	5.96E+07	6.42E+07	4.77E+05	9.16E+07	5.83E+06	9.49E+07	1.08E+08	1.31E+08	1.15E+08	1.29E+08	kg/year
Aluminum	1.52E+05	2.22E+05	1.14E+07	4.04E+05	3.12E+04	1.43E+07	2.77E+01	1.30E+07	5.72E+05	3.45E+06	1.46E+06	1.91E+06	kg/year
Arsenic	2.78E+02	1.69E+02	2.40E+03	1.57E+02	2.44E+01	3.67E+03	4.88E-02	3.74E+03	1.81E+03	1.20E+03	1.51E+03	1.43E+03	kg/year
BOD, 5 day	0.00E+00	0.00E+00	7.48E+06	0.00E+00	8.24E+03	9.93E+06	1.49E+05	8.11E+06	0.00E+00	1.89E+06	9.63E+05	9.02E+05	kg/year
Cadmium	1.50E+01	0.00E+00	0.00E+00	0.00E+00	8.62E+00	0.00E+00	1.52E-03	4.26E+01	0.00E+00	4.72E+01	4.91E+01	1.16E+02	kg/year
Calcium	1.31E+07	2.79E+06	1.32E+07	1.02E+07	1.66E+05	2.00E+07	6.37E+02	1.95E+07	1.87E+07	2.42E+07	2.41E+07	2.92E+07	kg/year
CBOD, 5 day	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.54E+06	5.09E+06	4.30E+04	0.00E+00	0.00E+00	6.69E+05	2.16E+06	0.00E+00	kg/year
Chloride	1.58E+07	3.07E+06	1.34E+07	1.30E+07	4.27E+05	2.27E+07	9.80E+06	2.90E+07	4.00E+07	4.63E+07	4.98E+07	5.42E+07	kg/year
Chromium	5.95E+03	7.33E+02	4.56E+04	3.41E+03	6.70E+02	6.21E+04	2.55E-01	6.73E+04	2.87E+03	7.86E+03	5.54E+03	5.18E+03	kg/year
COD	1.16E+07	7.63E+06	1.08E+08	9.10E+06	1.39E+06	1.80E+08	1.88E+06	1.54E+08	3.61E+07	6.82E+07	6.87E+07	6.07E+07	kg/year
Copper	5.16E+03	1.11E+03	1.84E+04	4.15E+03	3.76E+02	2.70E+04	2.77E-01	2.67E+04	7.22E+03	1.29E+04	8.78E+03	1.06E+04	kg/year
Dissolved Aluminum	1.22E+05	6.90E+04	4.58E+05	1.29E+05	3.65E+03	3.35E+05	3.24E+00	3.07E+05	1.94E+05	1.93E+05	1.70E+05	1.57E+05	kg/year
Dissolved Ammonia	2.99E+05	2.26E+04	3.83E+05	3.08E+05	1.26E+04	6.46E+05	2.33E+04	3.00E+05	5.24E+05	5.54E+05	5.65E+05	4.88E+05	kg/year
Dissolved Arsenic	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E-02	0.00E+00	2.81E+02	3.36E+02	1.48E-01	3.54E+02	kg/year
Dissolved Cadmium	2.34E+01	3.68E+00	1.44E+02	0.00E+00	4.57E+00	2.76E+01	4.99E-04	0.00E+00	2.73E+01	1.45E+02	6.96E+01	5.22E+01	kg/year
Dissolved Calcium	1.27E+07	2.78E+06	1.00E+07	1.02E+07	1.57E+05	1.75E+07	6.01E+02	1.69E+07	1.85E+07	2.19E+07	2.27E+07	2.92E+07	kg/year
Dissolved Chloride	1.32E+07	3.13E+06	1.18E+07	1.31E+07	4.08E+05	2.24E+07	9.54E+06	2.97E+07	3.98E+07	4.40E+07	4.97E+07	5.47E+07	kg/year
Dissolved Chromium	3.01E+03	3.98E+02	9.70E+03	9.20E+02	7.00E+06	7.24E+03	7.51E-02	7.52E+03	1.81E+03	3.66E+03	1.92E+03	1.26E+03	kg/year
Dissolved Copper	5.13E+03	9.34E+02	1.13E+04	4.07E+03	2.67E+02	8.89E+03	1.66E-01	8.90E+03	5.45E+03	7.16E+03	5.72E+03	6.61E+03	kg/year
Dissolved Iron	1.69E+05	3.55E+05	9.63E+05	4.05E+05	4.99E+04	9.03E+05	3.10E+01	8.98E+05	5.61E+05	9.36E+05	8.66E+05	9.61E+05	kg/year
Dissolved Lead	9.56E+01	1.32E+02	1.43E+03	2.13E+02	3.76E+01	7.99E+02	2.78E-02	6.42E+02	5.29E+02	7.19E+02	4.68E+02	4.51E+02	kg/year
Dissolved Magnesium	7.61E+06	1.44E+06	5.48E+06	6.02E+06	7.67E+04	9.18E+06	1.57E+02	8.86E+06	7.10E+06	8.43E+06	7.42E+06	7.98E+06	kg/year
Dissolved Manganese	4.86E+05	5.51E+04	1.00E+06	2.32E+05	4.29E+03	1.01E+06	1.36E+01	8.27E+05	3.10E+05	1.89E+05	1.01E+05	5.60E+04	kg/year
Dissolved Mercury	0.00E+00	2.26E+01	1.78E+01	0.00E+00	8.27E-01	0.00E+00	8.14E-01	5.28E+01	1.07E+02	6.53E+01	1.61E+02	7.38E+01	kg/year
Dissolved Nickel	1.09E+03	6.32E+02	5.17E+03	7.68E+02	7.81E+01	4.50E+03	2.12E-01	5.06E+03	1.31E+03	6.41E+03	2.13E+03	3.49E+03	kg/year
Dissolved Nitrate-Nitrite	6.79E+05	1.00E+05	4.93E+05	5.54E+05	2.64E+04	1.23E+06	1.18E+05	1.40E+06	1.23E+06	1.55E+06	1.68E+06	1.88E+06	kg/year
Dissolved Nitrite	2.37E+04	4.69E+03	5.42E+03	2.63E+04	6.90E+02	1.28E+04	3.04E+03	3.98E+04	6.21E+04	5.09E+04	1.62E+04	2.59E+04	kg/year
Dissolved Potassium	1.16E+07	1.84E+06	1.00E+07	1.04E+07	1.75E+05	1.85E+07	4.29E+03	2.03E+07	2.65E+07	3.01E+07	3.14E+07	3.37E+07	kg/year
Dissolved Selenium	7.63E+02	1.09E+02	2.09E+03	8.86E+02	1.41E+01	2.18E+02	1.64E-02	1.56E+03	4.87E+02	4.29E+02	5.23E+02	1.13E+03	kg/year
Dissolved Silicon	2.44E+07	3.49E+06	1.69E+07	1.88E+07	3.13E+05	2.77E+07	4.52E+02	2.62E+07	1.91E+07	2.52E+07	2.29E+07	2.30E+07	kg/year
Dissolved Sodium	1.65E+07	2.77E+06	1.23E+07	1.39E+07	2.66E+05	2.40E+07	8.06E+03	2.99E+07	4.24E+07	4.75E+07	4.65E+07	5.11E+07	kg/year
Dissolved Sulfate	1.64E+07	3.41E+06	1.43E+07	1.42E+07	1.69E+05	2.86E+07	7.15E+06	3.54E+07	5.97E+07	6.30E+07	6.18E+07	7.26E+07	kg/year
Dissolved Zinc	2.67E+04	3.36E+03	6.56E+04	1.93E+04	1.40E+03	2.83E+04	9.39E-01	2.78E+04	2.07E+04	3.26E+04	2.96E+04	3.83E+04	kg/year
DOC	1.35E+07	3.16E+06	3.66E+07	1.20E+07	5.76E+05	2.94E+07	5.93E+05	2.82E+07	1.92E+07	2.71E+07	2.09E+07	2.24E+07	kg/year
Iron	6.31E+05	7.04E+05	2.06E+07	7.25E+05	1.52E+05	2.56E+07	1.28E+02	2.39E+07	1.30E+06	7.13E+06	3.99E+06	4.65E+06	kg/year
Lead	2.98E+02	3.00E+02	1.51E+04	8.16E+02	1.46E+02	2.23E+04	1.71E-01	2.08E+04	1.15E+03	5.09E+03	2.45E+03	2.64E+03	kg/year
Magnesium	7.94E+06	1.46E+06	8.01E+06	6.03E+06	8.46E+04	1.17E+07	1.69E+02	1.10E+07	7.24E+06	9.59E+06	8.01E+06	8.30E+06	kg/year
Manganese	9.16E+05	8.35E+04	3.90E+06	3.18E+05	6.90E+03	7.66E+06	1.98E+01	7.49E+06	4.12E+05	1.08E+06	5.50E+05	4.84E+05	kg/year
Mercury	1.69E+01	0.00E+00	1.57E+02	0.00E+00	7.54E-01	2.73E+02	0.00E+00	0.00E+00	1.60E+02	7.79E+01	1.50E+02	2.01E+01	kg/year
Nickel	2.79E+03	6.34E+02	2.42E+04	4.30E+03	1.67E+02	2.87E+04	2.93E-01	3.15E+04	2.32E+03	7.26E+03	4.09E+03	5.06E+03	kg/year
Ortho-phosphorus	4.63E+04	1.58E+04	1.21E+05	6.81E+04	3.55E+03	1.90E+05	3.00E+05	7.23E+05	6.42E+05	8.21E+05	7.77E+05	6.52E+05	kg/year
Phosphorus	5.91E+04	2.11E+04	6.85E+05	6.94E+04	4.42E+03	9.28E+05	3.75E+05	1.32E+06	6.24E+05	9.22E+05	1.32E+06	7.30E+05	kg/year
Potassium	1.24E+07	1.84E+06	1.18E+07	1.04E+07	1.86E+05	1.94E+07	4.26E+03	2.16E+07	2.68E+07	3.15E+07	3.26E+07	3.41E+07	kg/year
Selenium	7.07E+02	1.99E+02	1.67E+03	8.08E+02	8.66E+00	4.30E+02	2.11E-02	1.88E+03	6.28E+02	4.73E+02	6.29E+02	8.03E+02	kg/year
Silicon	2.55E+07	3.51E+06	2.15E+07	1.68E+07	3.20E+05	3.12E+07	4.56E+02	2.93E+07	1.91E+07	2.82E+07	2.33E+07	2.33E+07	kg/year
Sodium	1.71E+07	2.78E+06	1.48E+07	1.38E+07	2.85E+05	2.46E+07	8.19E+03	3.14E+07	4.26E+07	5.07E+07	4.89E+07	5.13E+07	kg/year
Sulfate	1.66E+07	3.21E+06	1.68E+07	1.39E+07	1.89E+05	2.92E+07	7.37E+06	3.61E+07	5.99E+07	6.36E+07	6.14E+07	7.09E+07	kg/year
TDS	2.29E+08	3.85E+07	2.73E+08	1.51E+08	3.57E+06	1.68E+08	3.52E+07	3.24E+08	2.79E+08	4.47E+08	3.57E+08	4.52E+08	kg/year
TIC	1.29E+07	1.40E+06	7.29E+06	7.43E+06	1.29E+05	1.21E+07	5.69E+05	1.06E+07	1.15E+07	1.38E+07	1.47E+07	1.62E+07	kg/year
TKN	1.64E+06	3.00E+05	4.26E+06	1.08E+06	7.81E+04	6.12E+06	1.06E+05	7.50E+06	2.36E+06	2.93E+06	2.52E+06	2.32E+06	kg/year
TOC	1.31E+07	3.13E+06	2.50E+07	1.13E+07	5.73E+05	2.93E+07	6.10E+05	2.98E+07	2.11E+07	2.66E+07	2.06E+07	2.20E+07	kg/year
TSS	1.50E+07	6.99E+06	6.07E+08	8.22E+06	1.86E+06	6.94E+08	2.12E+06	7.29E+08	2.17E+07	2.07E+08	9.62E+07	1.07E+08	kg/year
TVSS	0.00E+00	1.23E+05	6.96E+04	0.00E+00	2.07E+05	8.65E+07	3.08E+05	6.72E+07	0.00E+00	2.13E+07	8.19E+06	1.00E+07	kg/year
Zinc	2.26E+04	3.22E+03	7.73E+04	3.04E+05	1.24E+04	1.33E+05	1.52E+00	1.13E+05	3.08E+04	5.26E+04	4.19E+04	3.64E+04	kg/year

*Mass calculated by multiplying mean concentration (mg/L) by mean flow (100 cfs) calculated from six discrete measurements.

3.6. Storm/Stochastic Events

Six storm/stochastic events were sampled during the study period. The March 2006 sample was conducted during an experimental flood pulse released from Thurmond Dam. A significant storm event occurred during the USACE's experimental flood pulse (Table 3-6).

Table 3-6. Storm/Stochastic Event Sample Collection Summary

Date Range	Sites Sampled	Precipitation*
March 20 - 22, 2006	River Miles 215, 202, 198, 190, 185, 179, 148; Stevens Creek, Horse Creek, and Butler Creek	2.91 inches (March 20 - 21); Also includes Thurmond Dam artificial pulse
June 14 - 15, 2006	River Miles 190 and 185; Butler Creek	3.73 inches (June 12 - 14)
July 25 - 26, 2006	River Miles 215, 202, 190, 185, 148, and 119; Stevens Creek, Horse Creek, and Butler Creek	0.91 inches (July 22 - 24)
November 16 - 17, 2006	River Miles 202, 190, 185, 179, 148, and 119; Stevens Creek, Horse Creek, and Butler Creek	1.59 inches (November 15 - 16)
March 2 - 3, 2007	River Miles 202, 190, 185, 148, and 119; Stevens Creek, Horse Creek, and Butler Creek	1.91 inches (March 1 - 2)
October 24 - 29, 2007	River Miles 190, 185, 179, 148, 119, and 61; Stevens Creek, Horse Creek, and Butler Creek	0.69 inches (October 23 - 24)

*As measured at Bush Field Airport, Augusta, GA

Generally, the concentrations for most constituents in storm event samples were similar to regular samples, with similar upstream-to-downstream trends. Since the artificial flood pulse in 2006 and natural pulse in 2007 both occurred during the same month and were of the same magnitude in terms of discharge, they provided a unique opportunity for comparison. It should be noted that the 2006 pulse consisted almost entirely of releases from Thurmond Dam, while the 2007 pulse consisted almost entirely of watershed drainage downstream of Thurmond Dam. In fact, the USACE ceased generation at Thurmond for an entire day (March 2, 2007) to avoid potential flood impacts downstream.

As can be seen in Figure 3-33, the 2006 and 2007 pulses were very different. Except for sodium, chloride, and alkalinity, the 2007 pulse generally resulted in much larger fluxes of material, especially iron and manganese. Also, the 2007 pulse yield some of the only mainstem BOD_5 detections for the entire study. Differences in metal carbon mass fluxes indicate the magnitude of watershed versus in-stream contributions of material, since both the 2006 and 2007 pulses exposed the river channel to flows of the same magnitude.

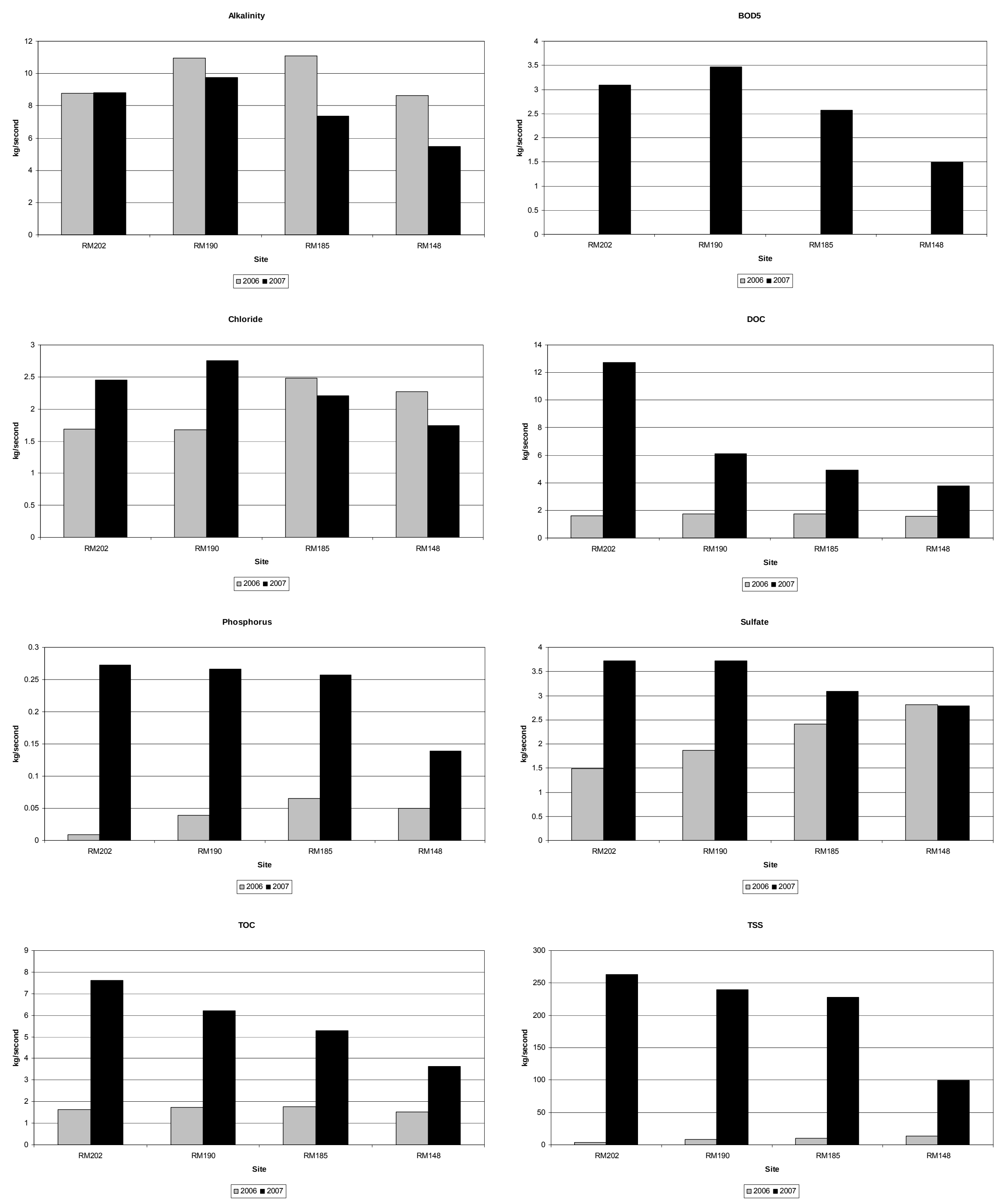

Figure 3-33. Mass flux comparison of March 2006 and 2007 flood events

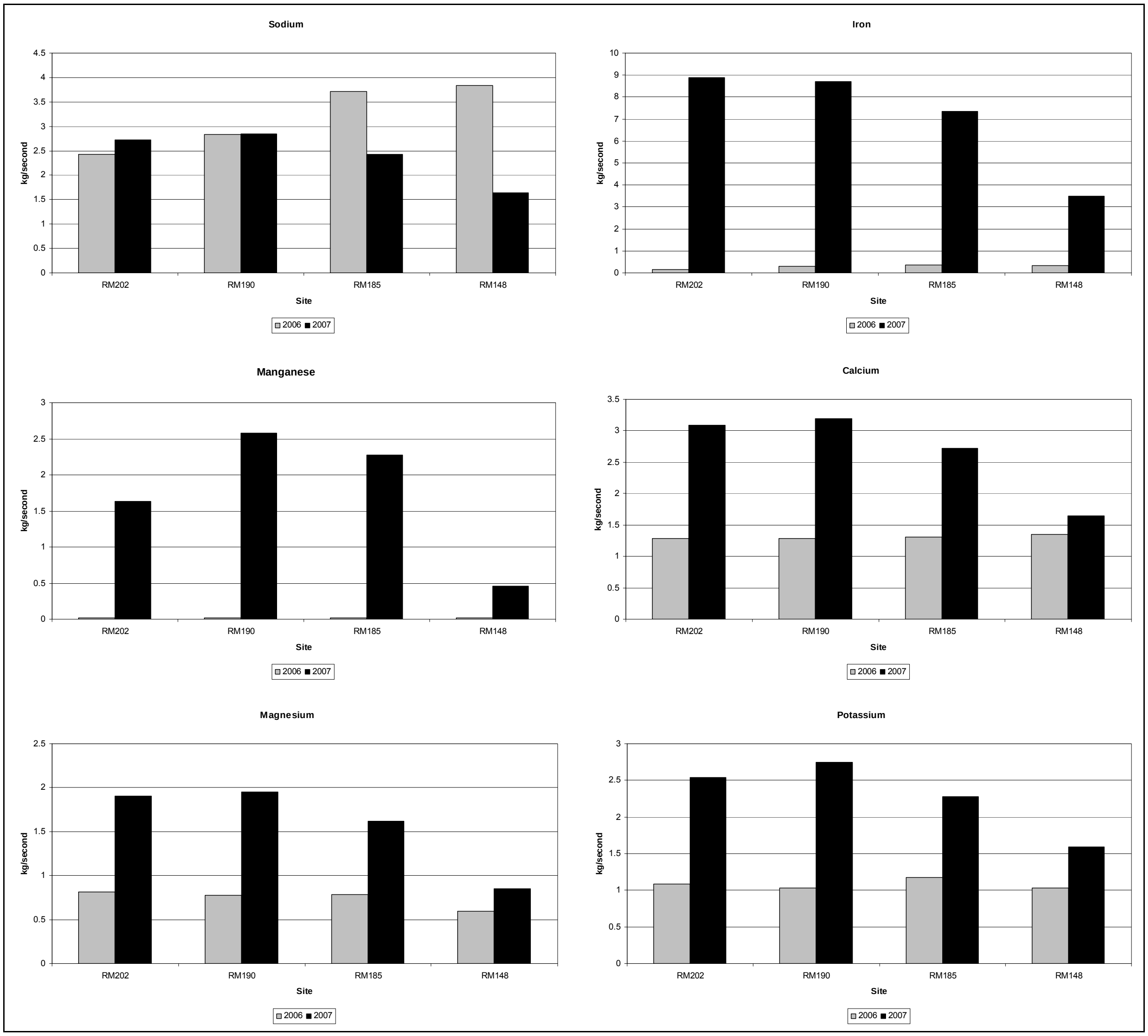

Figure 3-33 (continued). Mass flux comparison of March 2006 and 2007 flood events

In an attempt to determine the impact of the floodplain on river water chemistry during events such as the artificial pulse in March 2006 and natural pulse in March 2007, it was necessary to determine the gauge height at which floodplain inundation occurred. For this exercise, we assumed that the banks of the river channel were roughly vertical and that the slope of the floodplain was significantly less than vertical. We also assumed that the flows during the floodplain inundation events were dampened at the lower reach of the study compared to the upper reach and that the flows were consistent until the event reached peak flow. Figure 3-34 shows the theoretical scenario where the stream channel fills at a constant rate (1), inundates the floodplain (2), and either continues to inundate portions of the floodplain which are topographically higher than the initial floodplain elevation (3), or the floodplain starts to drain due to decreased river discharge (4).

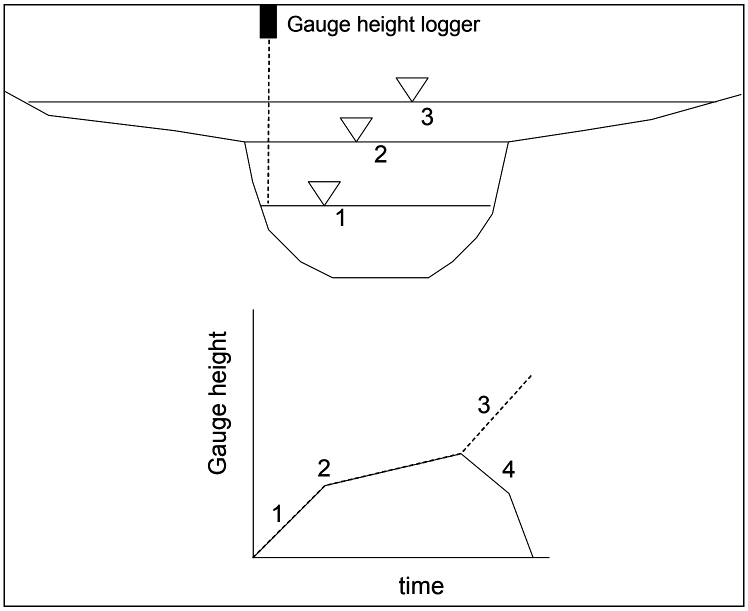

Figure 3-34. Stream cross section (top) and gauge height data (bottom) showing theoretical floodplain inundation scenario.

Figure 3-35 shows the gauge height data for USGS gauge 021973269 near Plant Vogtle. Results showed that floodplain inundation near Plant Vogtle most likely occurred at ~16.5 ft, which correlated to ~17,200 cfs. Of the 761 days of USGS data collected between January 2006 and January 2008, 7.9 days (1%) were at or above the 16.5 ft height near the Plant Vogtle station.

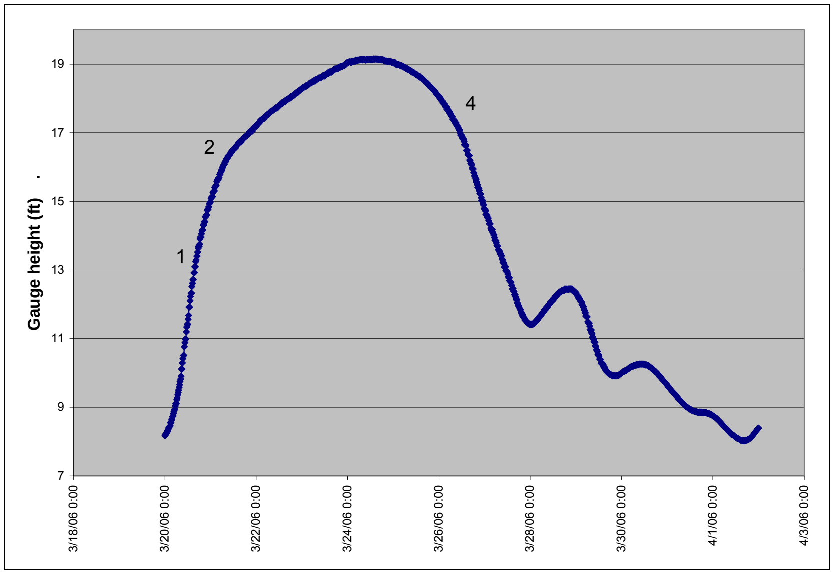

Figure 3-35. Gauge height for USGS gauge 021973269 at Plant Vogtle during the 2006 spring pulse.

Figure 3-36 shows the gauge height data for USGS gauge 02197500 near RM 119. Results showed that floodplain inundation near that gauge most likely occurred at ~11.50 ft which correlated to ~14,000 cfs. Of the 761 days of USGS data collected between January 2006 and January 2008, 21 days (2.8%) were at or above the 11.5 ft height at RM 119 station.

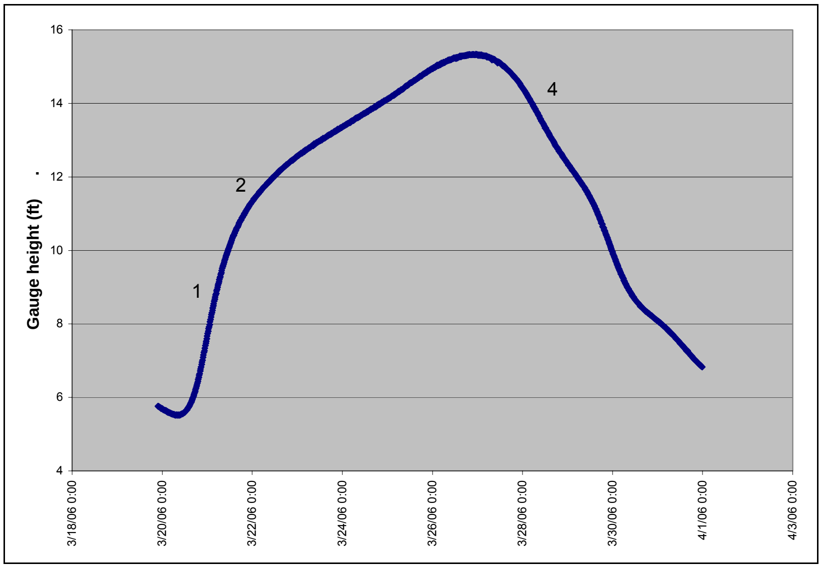

Figure 3-36. Gauge height for USGS gauge 7500 near RM 119 during the artificial pulse in 2006.

Figure 3-37 shows the gauge height data for USGS gauge 02198500 near RM 61. Results showed that floodplain inundation near that gauge most likely occurred at ~9.00 ft which correlated to ~11,700 cfs. Of the 761 days of USGS data collected between January 2006 and January 2008, 27.9 days (3.7 %) were at or above the 9.00 ft height at the RM 61 station.

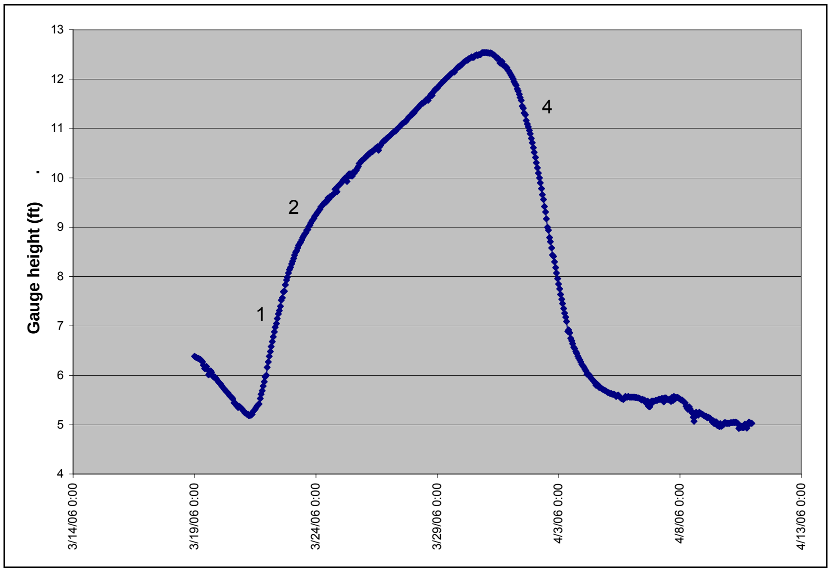

Figure 3-37. Gauge height for USGS gauge 8500 near Clyo during the artificial pulse in 2006.

Figure 3-39 shows the dynamics between dissolved oxygen and floodplain inundation. Firstly, the Vogtle gauge was approximately 2 river miles upstream of the sonde location. This distance may have resulted in a slight lag (<1hr) between the real time data sets. As the river rose to the overbank height, the DO was at a maximum of 10.25 mg O_2/L. After a slight lag (~1-2 days), DO decreased by nearly 1.5 mg O_2/L over the next ~7 days. During this time, the floodplain was inundated, the maximum flows had peaked, and the river stage began to fall. From the point of peak flow to the first flow trough, water most likely drained off the floodplain back into the river and it was during that time that the depressed DO was observed. DO concentrations decreased by only ~1.5 mg/L early on but flows near 17,000 cfs would equate to a DO loss rate of 7.22E5 mg O_2/s. Concentrations dipped even lower in the latter part of the analysis.

Specific conductance dynamics for the same time period showed that the flood pulse diluted the water but as the floodplain drained back to the river, the conductance rose toward the initial value (Figure 3-39). Interestingly, it was during the troughs of the descending limb of the flood pulse that spikes in conductance were observed. This may have indicated entrainment of floodplain or bank material into the river. Similar results were experienced during the March 2007 flood pulse (Figure 3-40, Figure 3-41).

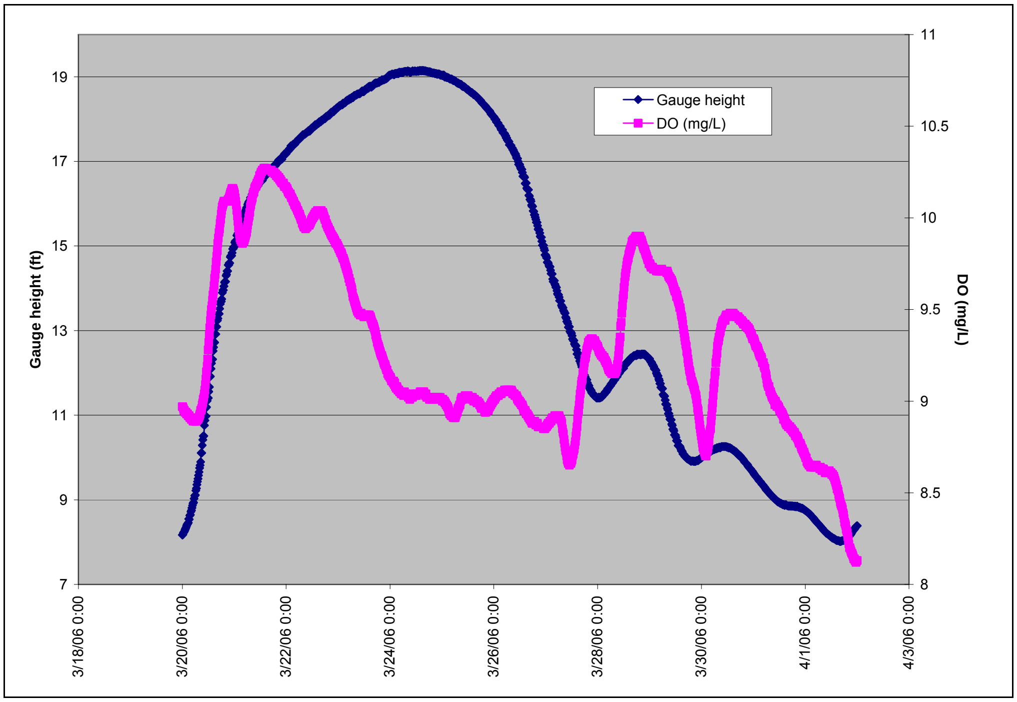

Figure 3-38. Discharge and dissolved oxygen at RM 148 during the 2006 spring pulse.

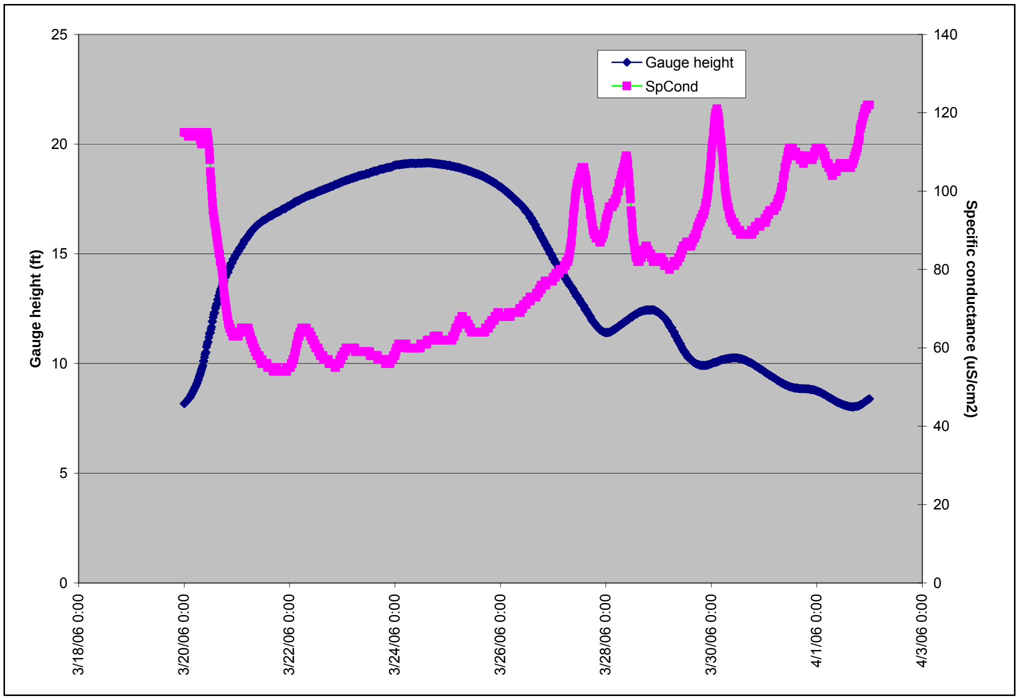

Figure 3-39. Effect of floodplain inundation on specific conductance at RM 148 during the 2006 flood pulse.

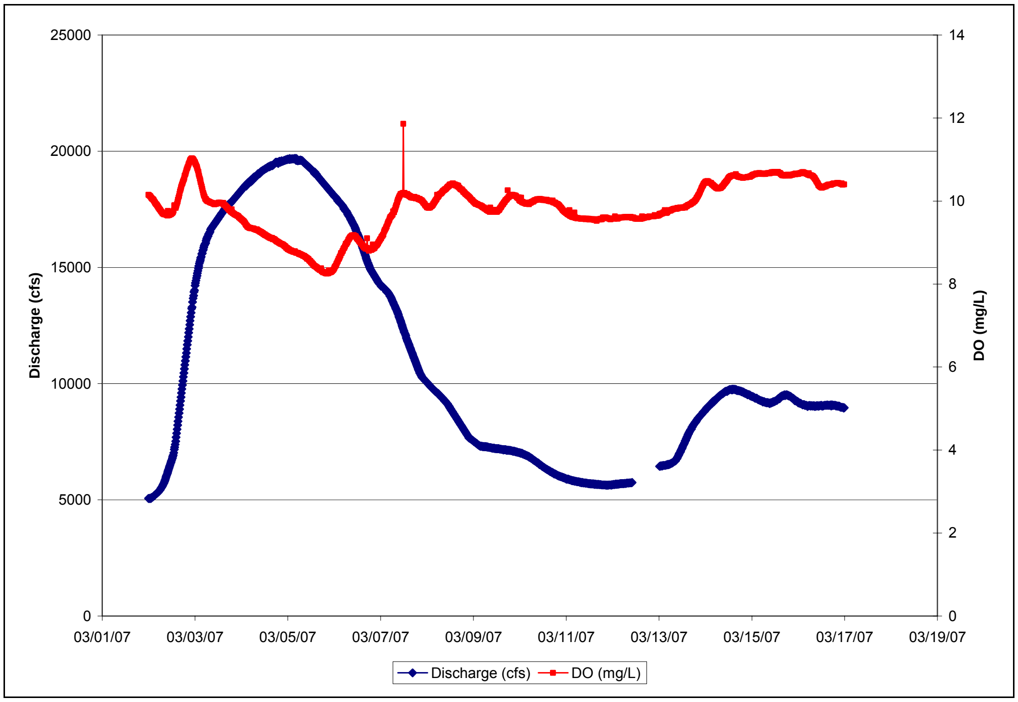

Figure 3-40. Effect of floodplain inundation on dissolved oxygen at RM 148 during the March 2007 flood pulse.

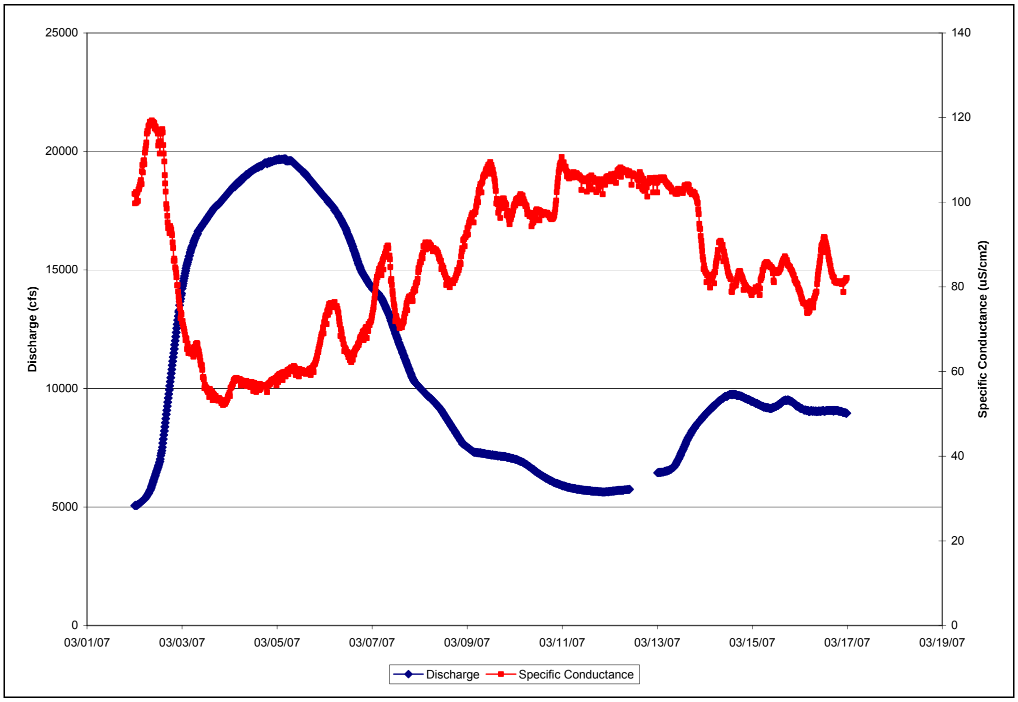

Figure 3-41. Effect of floodplain inundation on specific conductance at RM 148 during the March 2007 flood pulse.

3.7. Sediment Samples

Results from sediment samples are presented in Table 3-7. Samples from Butler Creek yielded the highest concentrations for most analytes, including the only detections of mercury. Additionally, several herbicides, the pesticide DDT (4,4'-DDT), and the PCB Aroclor 1260 were detected in Butler Creek sediment samples.

Figure 3-42 shows percent solids within all sediment samples from each sampling event. Highest percent solids was found at RM61 in September 2007 while lowest percent solids was found within Butler Creek in June 2006. Most samples at all locations ranged from 70% to 80% solids with a slightly increasing trend in percent solids with decreasing river mile.

The lowest percent solids of all sites in April 2006 was RM 202. That site also had the second lowest percent solids in June 2007. Other than the April 2006 sampling date, the lowest percent solids were found within Butler Creek sediments on all other sampling dates. The sampling location within Butler Creek is immediately upstream of a levy and the sampling location at RM202 is immediately below the shoals, where the shoals meet the CSRA pool section of the river. Both of these sites would have been areas of extensive sediment deposition.

Sediment trace metals and TOC concentrations for all samples are shown in Figure 3-43 and Figure 3-44. Of all trace metal results, the highest peak concentration was iron within Butler Creek and RM 202 sediments.

Of all elements that were analyzed for in the 2007 sediment samples (Fe, Mn, Cu, Mg, Na, K, Ca, Cd, Cr, Pb, Ni, Se, Zn, As), iron accounted for >60% of the total mass in all samples (Figure 3-45). Of all elements that were analyzed for in the 2007 sediment samples (Fe, Mn, Cu, Mg, Na, K, Ca, Cd, Cr, Pb, Ni, Se, Zn, As) including TOC, TOC accounted for less than 30% of total mass at all sites except for RM 179 in April 2007 and in Butler Creek in September 2007.

Table 3-7. Average concentrations from sediment samples

	RM 215	SC	RM 202	RM 198	HC	RM 190	BC	RM 185	RM 179	RM 148	RM 119	RM 61	units
% Solids	74.7	69.3	62.5	76.1	75.3	76.8	37.1	77.1	75.0	77.6	77.2	80.3	%
2,4,5-T	ND	28	35	ND	ND	ND	568	ND	ND	ND	ND	ND	ug/kg
2,4,5-TP (Silvex)	ND	17	120	ND	25	ND	ND	ND	22	ND	ND	ND	ug/kg
2,4-D	ND	ND	ND	ND	ND	ND	850	ND	ND	ND	ND	ND	ug/kg
2,4-DB	22	ND	440	89	ND	ND	ND	33	43	ND	ND	ND	ug/kg
4,4'-DDD	ND	ND	ND	ND	ND	ND	18	ND	ND	ND	ND	ND	ug/kg
4,4'-DDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.5	ND	ND	ug/kg
4,4'-DDT	ND	ND	ND	ND	ND	ND	25.0	ND	ND	ND	ND	ND	ug/kg
Aldrin	1.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
alpha-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
alpha-Chlordane	ND	ND	1.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Aroclor 1016	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Aroclor 1221	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Aroclor 1232	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Aroclor 1242	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Aroclor 1248	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Aroclor 1254	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Aroclor 1260	ND	ND	ND	ND	ND	ND	270	ND	ND	ND	ND	ND	ug/kg
Arsenic	1.2	1.0	1.2	0.8	0.8	0.7	3.9	0.5	0.9	0.9	0.8	0.6	mg/kg
beta-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Cadmium	0.0	0.1	0.0	0.0	ND	0.0	1.1	0.0	ND	0.1	0.1	0.0	mg/kg
Calcium	422.5	390.0	1117.5	262.5	102.0	265.0	2225.0	210.0	302.5	198.0	255.0	220.0	mg/kg
Chromium	9.9	10.5	13.7	7.5	24.3	4.4	32.5	5.4	3.8	3.2	4.4	2.6	mg/kg
Copper	2.3	4.9	8.0	2.3	2.2	1.5	33.2	1.7	1.3	0.9	1.5	0.8	mg/kg
Dalapon	ND	ND	ND	ND	ND	ND	ND	450.0	ND	550.0	ND	ND	ug/kg
delta-BHC	ND	ND	7.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Dicamba	ND	ND	57.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Dichloroprop	ND	ND	132	170	ND	20	13000	ND	38	24	20	ND	ug/kg
Dieldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Dinoseb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Endosulfan I	ND	ND	2.2	ND	ND	ND	1.9	ND	ND	ND	ND	ND	ug/kg
Endosulfan II	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Endosulfan sulfate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Endrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Endrin aldehyde	ND	ND	ND	ND	ND	1.0	ND	ND	1.2	ND	ND	ND	ug/kg
Endrin ketone	ND	ND	ND	ND	ND	2.6	ND	ND	ND	ND	ND	ND	ug/kg
gamma-BHC (Lindane)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
gamma-Chlordane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Heptachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Heptachlor epoxide	1.6	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Iron	5400	7550	12500	4750	3025	3350	21375	3125	3225	2475	3650	2400	mg/kg
Lead	2.0	3.4	5.4	3.2	3.0	1.6	54.3	1.6	1.5	1.3	1.7	1.4	mg/kg
Magnesium	230.0	477.5	1377.5	425.0	130.0	108.7	1707.5	140.0	115.3	94.0	190.0	94.0	mg/kg
Manganese	1325.0	390.0	1555.0	735.0	73.8	465.0	1065.0	1375.0	1242.5	900.0	925.0	345.0	mg/kg
MCPA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
MCPP	ND	ND	ND	4700.0	ND	ND	160000.0	ND	ND	ND	ND	ND	ug/kg
Mercury	ND	ND	ND	ND	ND	ND	0.5	ND	ND	ND	ND	ND	mg/kg
Methoxychlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Nickel	4.1	3.4	9.7	4.4	3.8	3.8	16.3	1.9	3.0	2.4	2.5	1.2	mg/kg
Potassium	170.0	327.5	1075.0	200.0	88.7	81.0	1177.5	105.3	88.5	73.0	123.5	50.0	mg/kg
Selenium	0.2	ND	0.4	0.3	ND	0.4	0.9	0.9	0.5	ND	ND	0.4	mg/kg
Sodium	50.0	93.0	133.0	89.5	95.0	84.0	623.3	82.7	76.7	88.0	30.5	61.0	mg/kg
TOC	145.0	1130.0	1400.0	1050.0	915.0	535.0	36145.0	450.0	8750.0	490.0	615.0	260.0	mg/kg
Toxaphene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ug/kg
Zinc	13.2	27.5	55.3	26.7	19.0	24.6	272.8	22.7	18.5	26.7	31.5	25.5	mg/kg

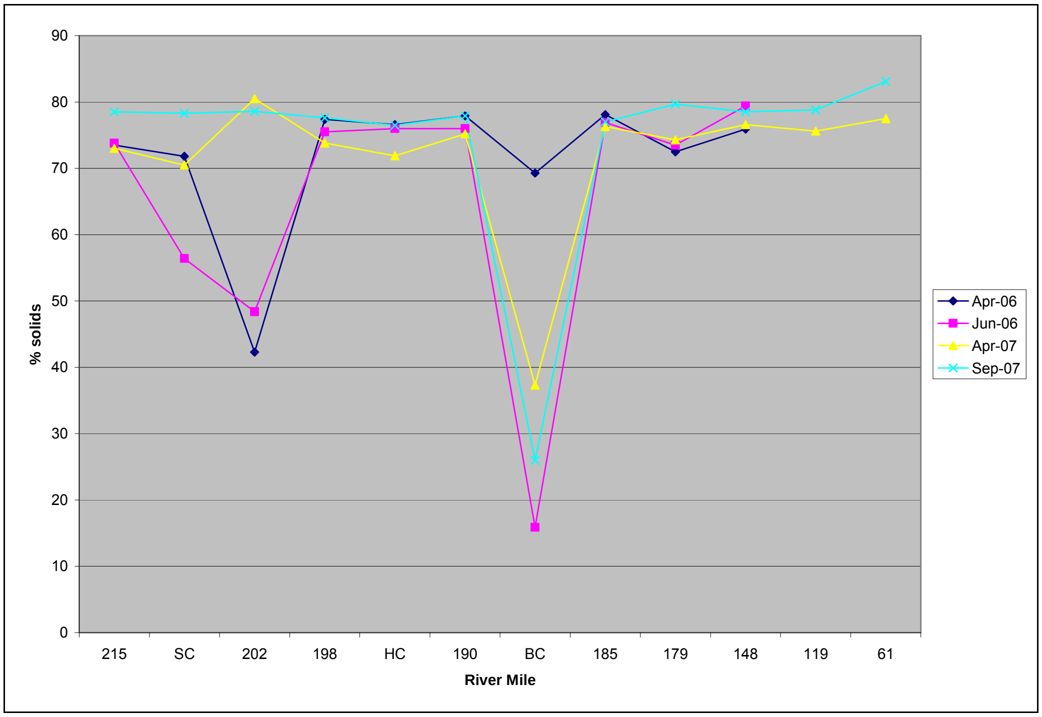

Figure 3-42. Sediment percent solids results for all samples from April 2006 through September 2007.

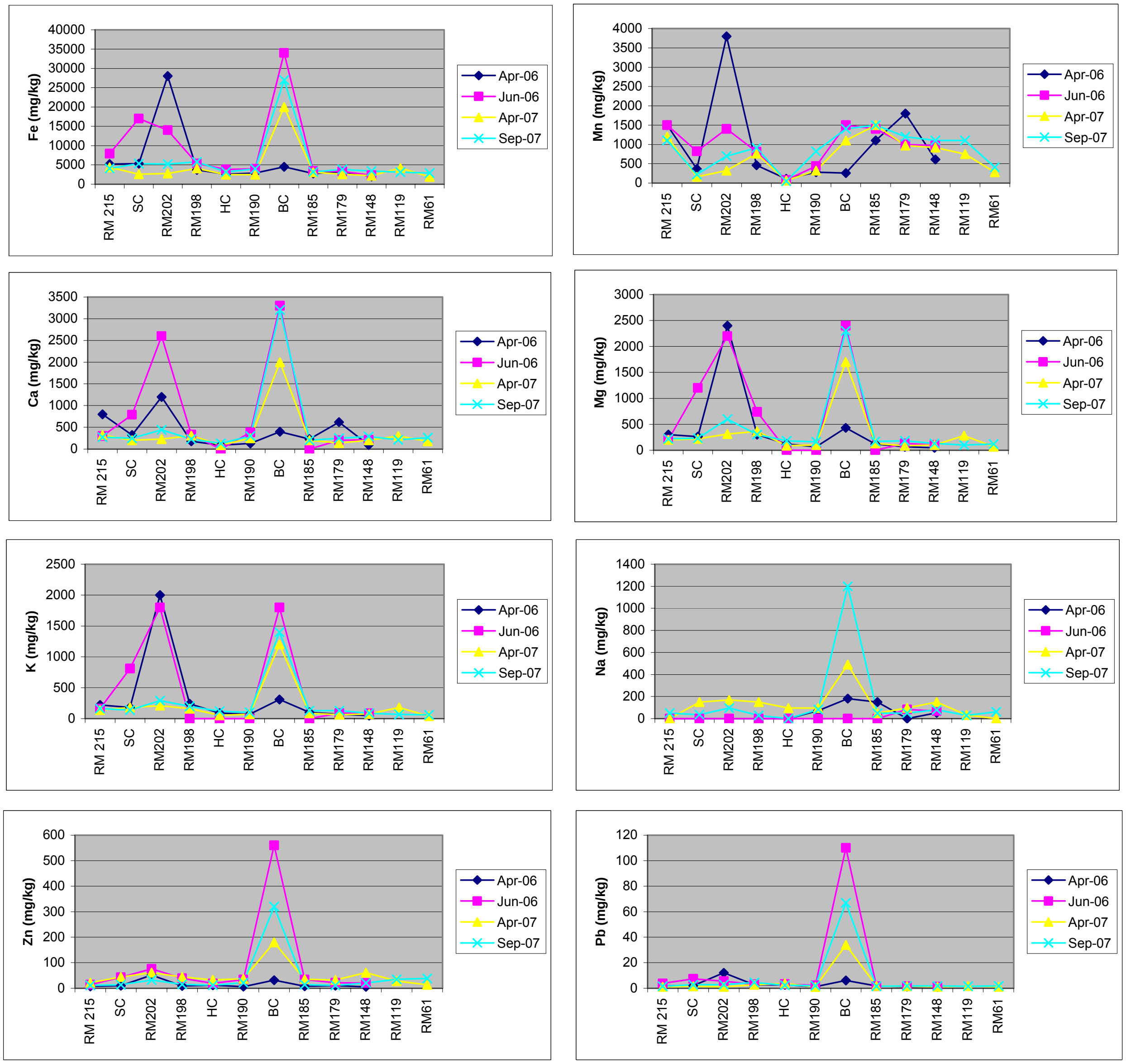

Figure 3-43. Sediment chemistry results for all sites from April 2006 through September 2007 (clockwise from top left: Fe, Mn, Mg. Na, Pb, Zn, K, Ca). All concentrations are shown as mg/kg dry weight.

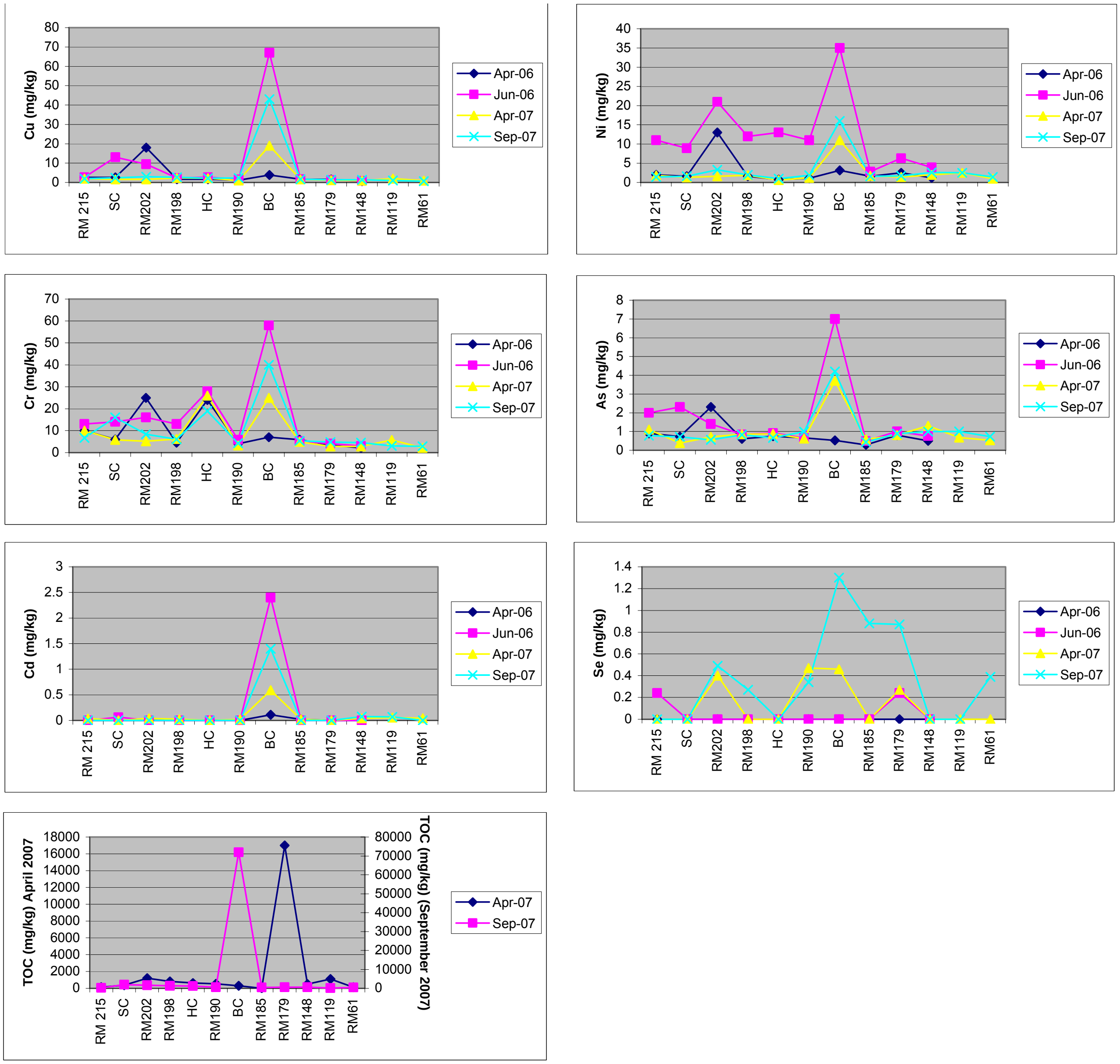

Figure 3-44. Sediment chemistry results for all sites from April 2006 through September 2007 (clockwise from top left: Cu, Ni, As, Se, TOC, Cd, Cr). All concentrations are shown as mg/kg dry weight.

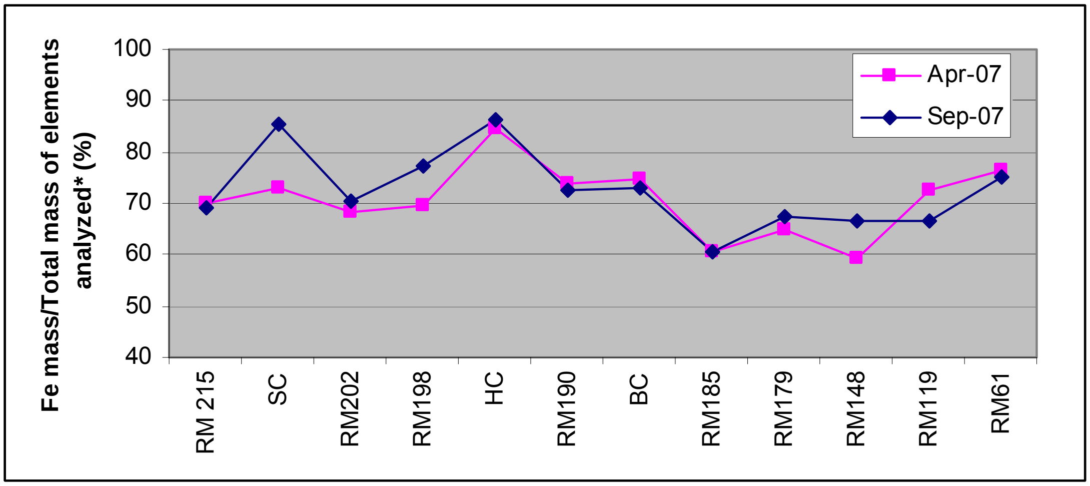

Figure 3-45. Percent iron mass relative to total mass of all elements analyzed within sediment samples (*Fe, Mn, Cu, Mg, Na, K, Ca, Cd, Cr, Pb, Ni, Se, Zn, As).

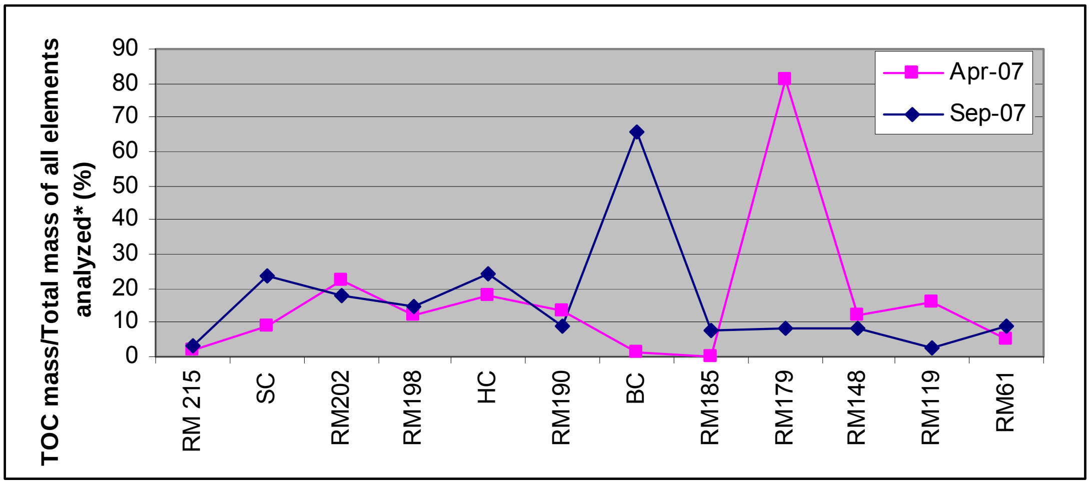

Figure 3-46. Percent TOC mass relative to total mass of all elements analyzed within sediment samples (*TOC, Fe, Mn, Cu, Mg, Na, K, Ca, Cd, Cr, Pb, Ni, Se, Zn, As).

3.8. Macroinvertebrates

EPT taxa increased from RM 215 to RM 190 (Table 3-8, Figure 3-47). River miles 215, 198, and Stevens Creek had the lowest mean EPT taxa. The highest mean EPT taxa was at RM 148. EPT density was low in the pool section (RM 215 to RM 190) relative to the run of the river section (RM 185 to RM 61), but did increase from RM 215 to RM 190. EPT density was lowest at RM 198 and highest at RM 148. A pronounced increase in EPT density in the RM 185 to RM 148 reach was observed from late spring to early winter.

Table 3-8. Results of EPT Analysis of Macroinvertebrate Samples

	Mean Number of Taxa				Mean Density (#/m^2)			
Site	Ephemeroptera	Trichoptera	Plecoptera	EPT	Ephemeroptera	Trichoptera	Plecoptera	EPT
RM215	0.125	0.875	0.125	1.125	0.5208	9.246	1.044	10.81
SC	1	0.5714	0	1.571	5.677	45.61	0	51.28
RM202	0.875	1.375	0	2.25	4.713	11.48	0	16.19
RM198	0.25	0.75	0	1	0.5208	3.006	0.2583	3.785
HC	1.25	2.75	0.75	4.75	62.89	35.03	9.381	107.3
RM190	1.125	2.75	0.125	3.875	7.463	57.08	0.5188	65.06
BC	0.625	1.375	0	2.125	3.275	100.8	0	95.4
RM185	1.5	3.75	0.125	5.75	63.44	650	3.982	717.4
RM179	1.125	2.875	0.25	4.25	76.43	229	0.85	306.3
RM148	3.75	5.375	1.625	10.62	121	788.9	31.12	941
RM119	3.429	2.429	2	7.714	136.9	52.67	18	207.6
RM61	4.25	3.5	2.125	9.75	171.9	122.2	49.65	343.8

Mean Ephemeroptera diversity was lowest at RM 215 and highest at RM 61 (Figure 3-48). Ephemeroptera density was low in the pool section and steadily increased from RM 185 to RM 61 where the highest densities were reached.

Mean Trichoptera diversity was lowest in Stevens Creek and highest at RM 148 (Figure 3-49). For individual sampling periods, Trichoptera diversity was always highest at either RM 185 or RM 179. Mean Trichoptera density was low in the pooled section relative to the run of the river section, with the lowest and highest densities at RM 198 and RM 148, respectively. Trichoptera density at RM 61 was similar to the pool section. The highest mean Trichoptera numbers were seen at RM 185 and RM 148 for every sampling event.

Mean Plecoptera diversity was lowest at Stevens Creek, Butler Creek, RM 202, and RM 198, and highest at RM 61 (Figure 3-50). For every sampling period, maximum Plecoptera diversity was reached by RM 148 or beyond. Mean Plecoptera density was highest at RM 61.

Additionally, Pteronarcyid Plecopterans were observed at RM 61 in December of 2007 and at

RM 119 in January of 2008. Pteronarcyids have been suggested to be indicators of good water quality as they are long lived (>2yrs.) Plecoptera (Fore et al. 1996).

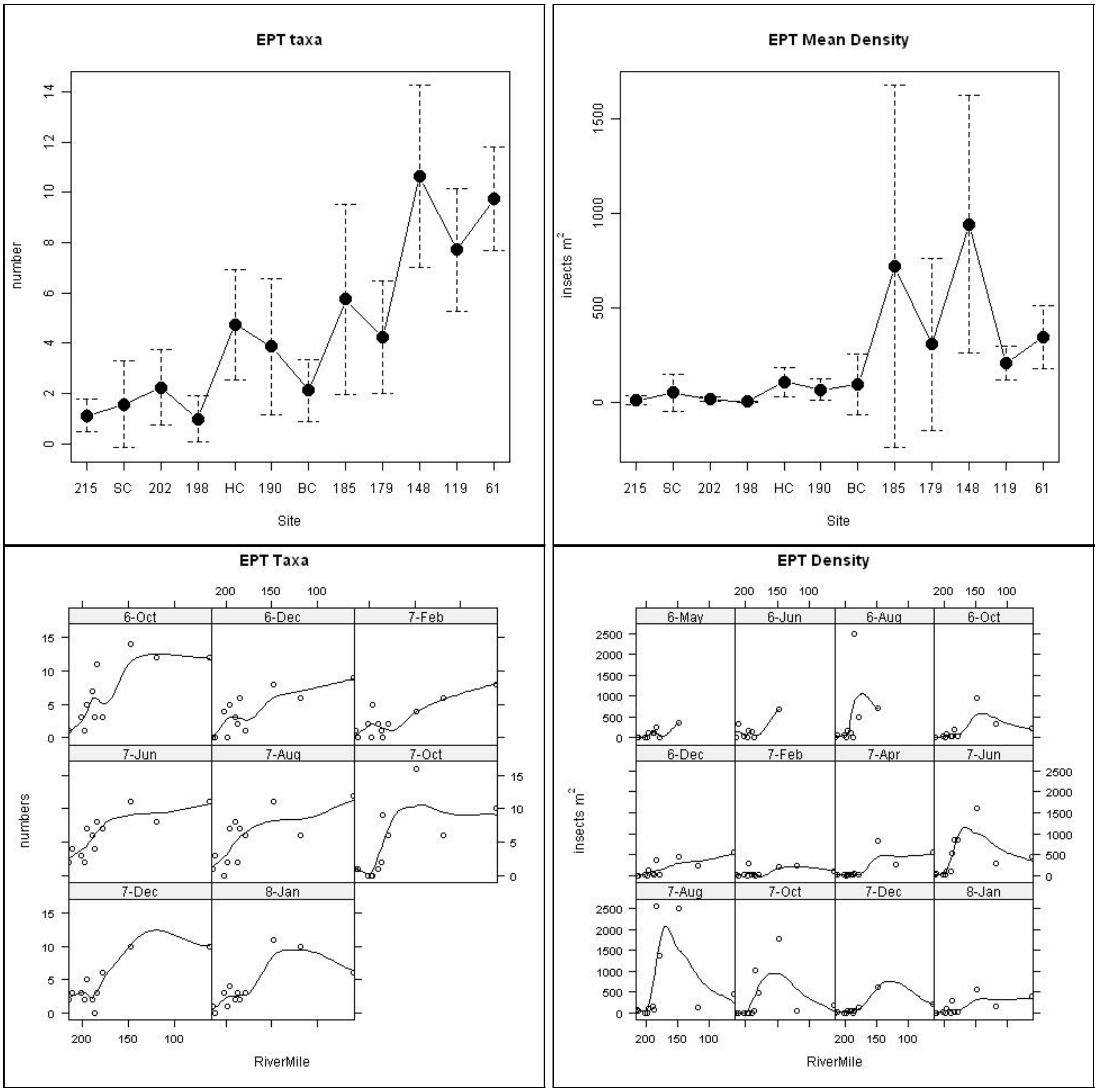

Figure 3-47. EPT taxa diversity and density.

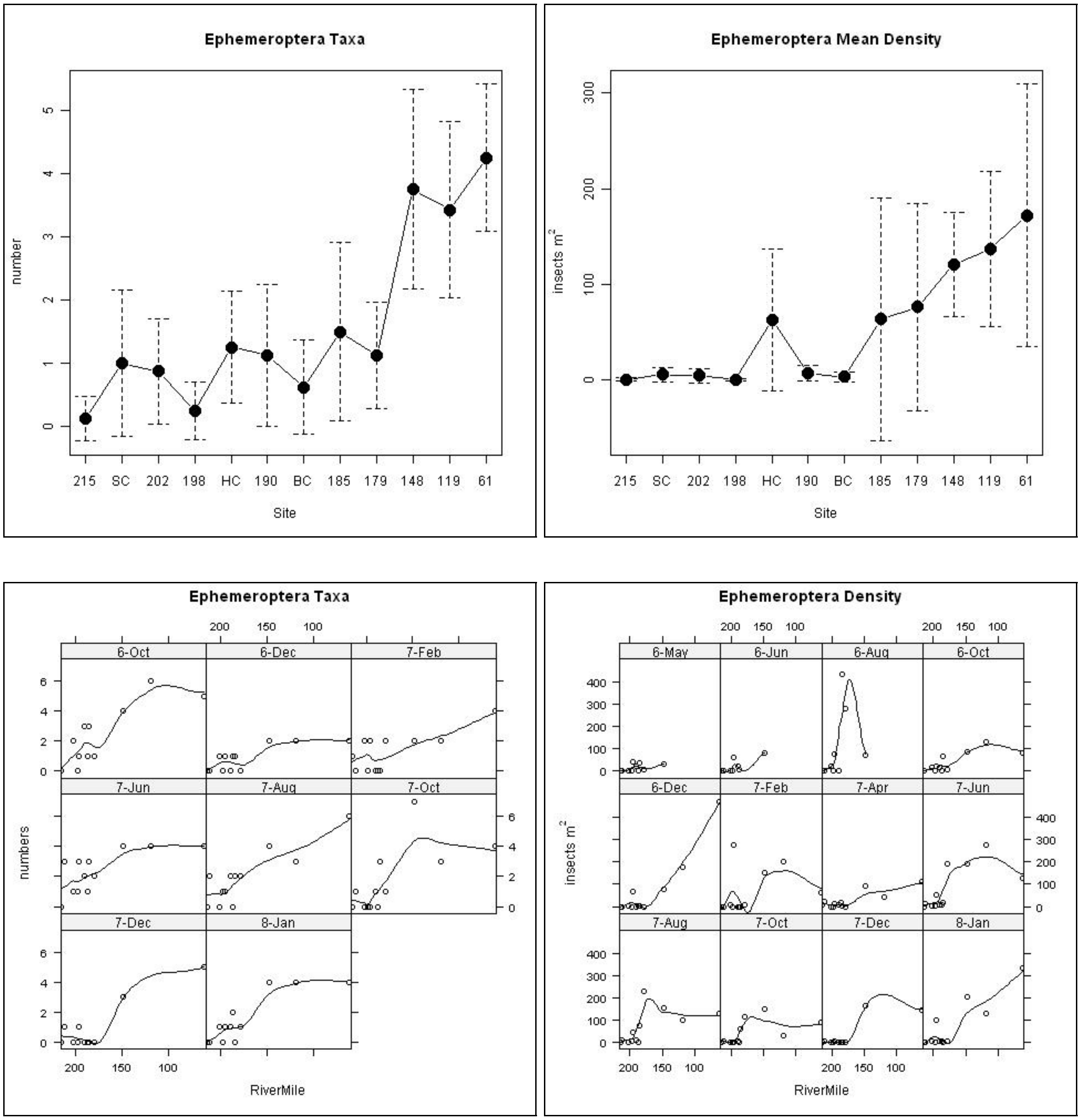

Figure 3-48. Ephemeroptera taxa diversity and density.

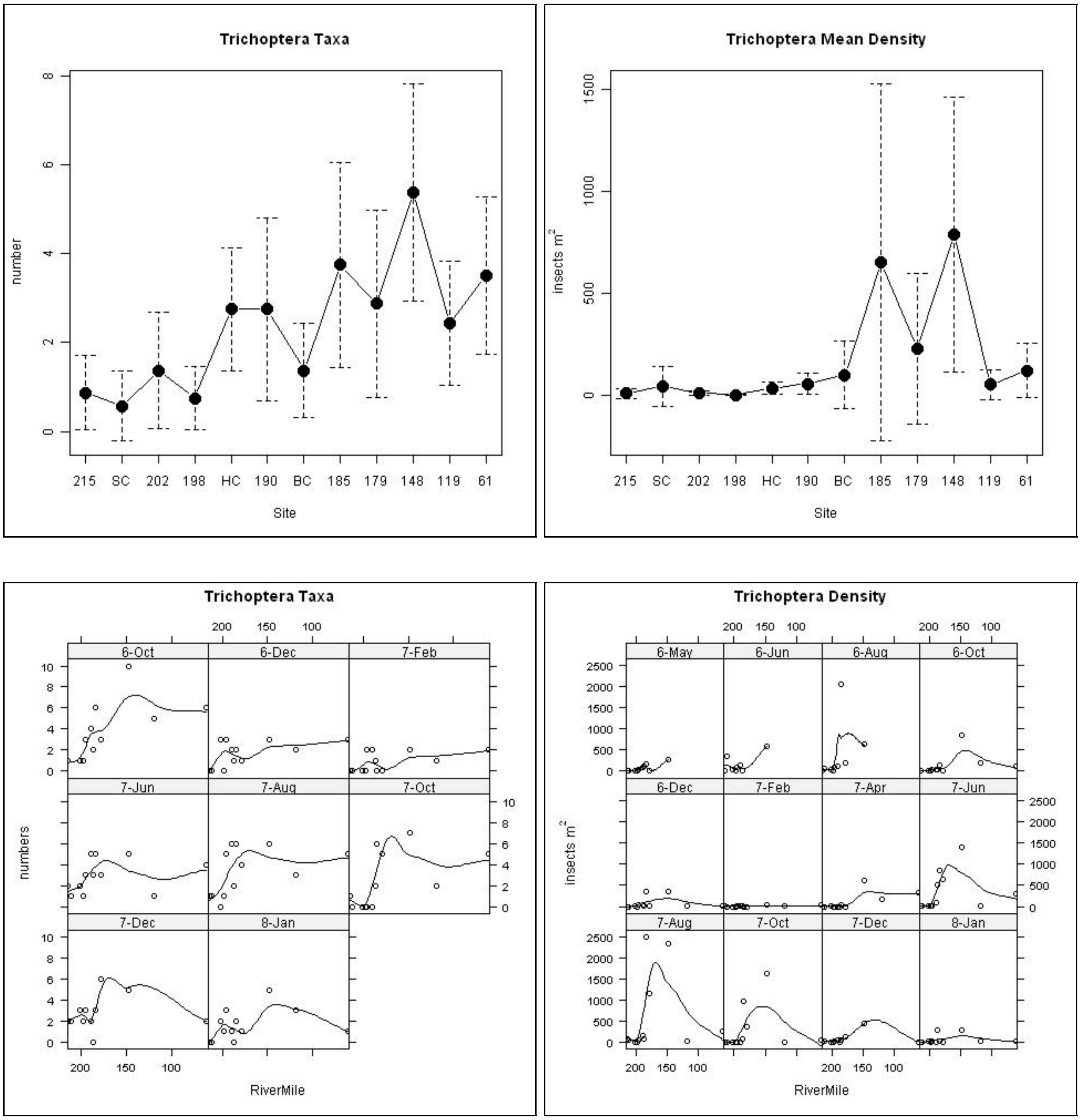

Figure 3-49. Trichoptera taxa diversity and density.

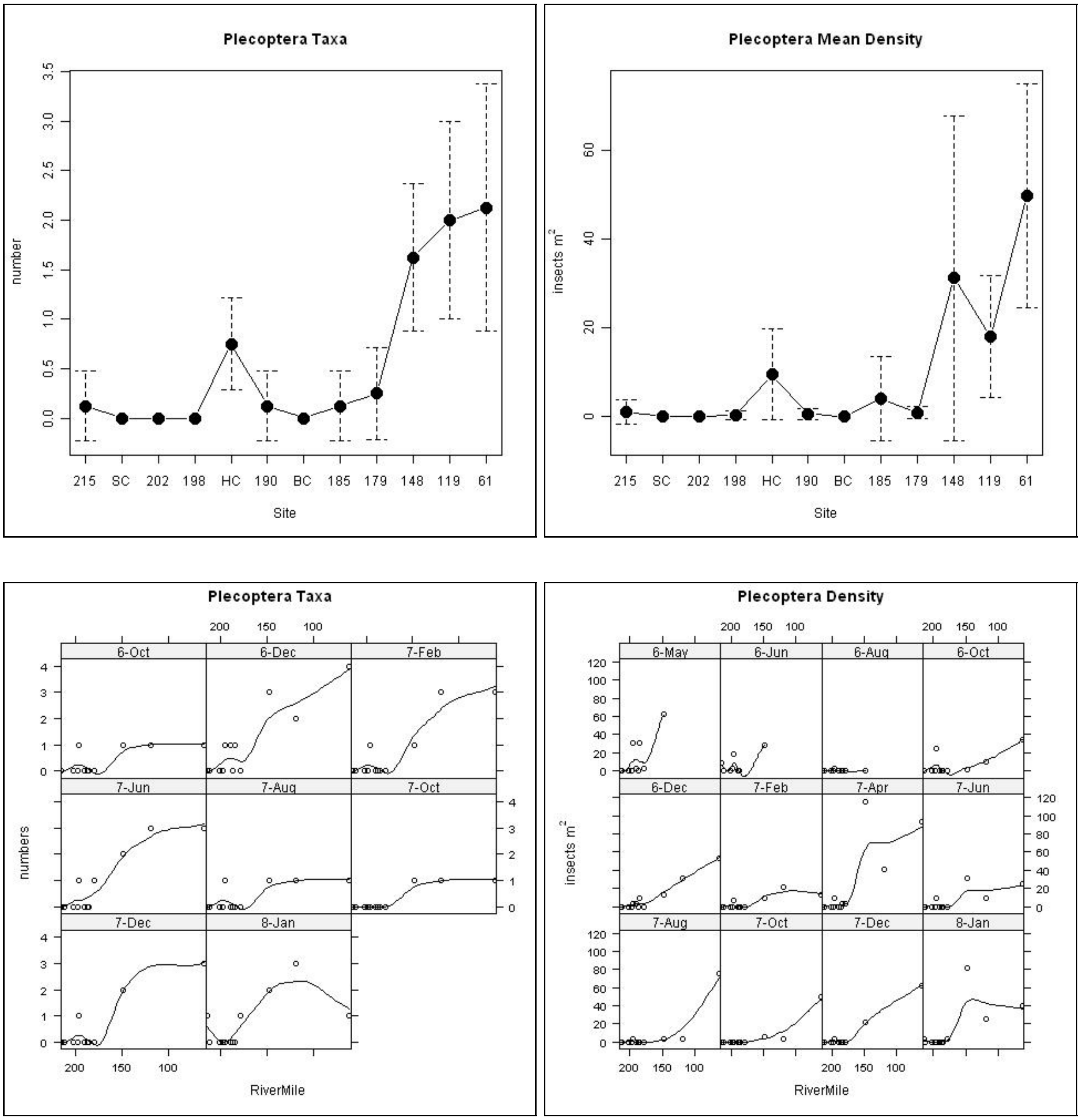

Figure 3-50. Plecoptera taxa diversity and density.

3.9. Fecal Coliform Samples

Fecal coliform results of each sampling location for monthly sampling events are summarized in Table 3-9. Fecal coliform results of all storm water sampling events are summarized in Table 3-10. Samples that were out of hold time (6 hours) were a result of the Lagrangian sampling scheme employed. Samples were taken during day and night hours, however the lab performing fecal coliform analyses only accepted samples between 08:00 and 16:30.

Table 3-9. Monthly fecal coliform (MPN)

	RM215	SC	RM202	RM198	HC	RM190	BC	BCwetland	BCPhinizy	RM185	RM179	RM148	RM119	RM61	Trip Blank
Feb-06	<20	1700	700	230	20	230	300				40	230 (230)			
Mar-06	<20	40	20	230	3000	500	5000			130	130 (130)	230			20
Apr-06	40	130	40*	340	130	110	2300			20 (20)	2070	70			20
May-06	20	<20	<20*	20	40	80	2200			130 (80)	20	20			
Jun-06	30 (110)	13	23	110	220	70	900	500	110	8 (8)	110	50			2
Jul-06	11	22	4 (13)	70*	>1600*	23	900	900	500	23	23	17 (14)	4		2
Aug-06	220	17	50	50*	500*	140	≥1600	1600	≥1600	1600 (1600)	220	>1600	500		
Sep-06	17	26	30(30)*	300*	30*	70*	500*	500	60	23	110	14(23)	23*	30	2
Oct-06	21*	50*	50*	50*	170*	26*	300	900	50	70	170	17(30)	50*	2(11)*	2
Nov-06	9	11	17	8	90	90	>1600	>1600	>1600	500	>1600	900	80(130)	13(30)	2
Dec-06	8	30	23(130)	30	70	23	>1600	110	13	23	17	30	30	13(13)	2
Jan-07	23*	900*	80*	500	900	500*	900*(1600)		300	240*	900	50	70	110 (80)	2
Feb-07	<2*	50*	8(2)	4*	22*	8	220	1600	220	17*	8*	13(30)	23	13	2
Mar-07	4*	80*	50	50	50	50	240	5000	80	50*	8*	30(8)	4	23(22)*	2
Apr-07	2	80	11*	8*	22*	11*	500*	500	500	80	23	11(30)	23	50	2
May-07	8	300	90	23*	130*	8(23)	110	17	130	8	23	11*(30*)	26	9	2
Jun-07	2*	4*	300*	300*	240*	17*	500	80	500	30	13	50(80)	2*	8*(8*)	2
Jul-07	7*	11*	23*	110*	23*	50*	70*			80*	280*	80	30*	17*(2*)	2
Aug-07	23*	13*	14*	17*	50*	13*(8*)	300	80	110	17	17	22	30*	14*	2
Sep-07	70*	11*	17(30)	11*	50*	2*	240			2	23	11	50*	23	2
Oct-07	4*	14*	30(50)	23*	170*	11*	5000		140	170	300	30	50*	23*	23
Nov-07	2	70	22*	7*	17*	2*	130(900)*		80	2	8	50	11	8	2
Dec-07	13	30	17*	30*	23*	8*	900*		70	27	23	23 (50)	13*	4*	2
Jan-08	8	130	27	14*	240*	17*	900			140	50	30 (50)	60	50	<2

* Out of hold time (Duplicate sample)

Table 3-10. Stormwater fecal coliform (MPN).

	Stormwater 1		**Stormwater 2**	**Stormwater 3**	**Stormwater 4**	**Stormwater 5**
	Jun. 14, 2006	**Jun. 15, 2006**	**Jul. 25-26, 2006**	**Nov. 16-21, 2006**	**Mar. 2-5, 2007**	**Oct. 07, 2007**
RM215			22	80	1600	
SC			50	130	2400	50*
RM202			8			
RM198				900	1600	
HC			300			240*
RM190	170	500 (170)	30	300	2400	
BC	>1600	>1600	300	>1600(>1600)	5000	
RM185	1600	130	30 (50)			
RM179					500	
RM148			80	500	2400	
RM119			300		<2	50*
RM61						23*
Trip Blank		<2	<2	140	2400	23
BC Phinizy		500	300		140	

* Out of hold time (Duplicate sample)

4. DISCUSSION

4.1. Thurmond Dam Effects

Savannah River flows below RM 222 originated from water used to generate power through the Thurmond Dam. Water was withdrawn from a 36 – 90 ft zone below the surface of Thurmond Lake (~230-290 msl). As a result, water quality trends for the river (below RM 222) were a consequence of the withdrawn water and were determined by seasonal and stochastic lake dynamics. Examples of seasonal dynamics included lake stratification, lake homogenization (turnover), and phytoplankton blooms; examples of stochastic dynamics included rain events, concomitant runoff, and severe wind events with resulting lake seiche episodes. Since that water was used for power generation, it was released as a daily pulse or series of two pulses, depending on energy needs. Discharge from the metalimnion of Thurmond Lake impacted the following: transport of trace metals, river DO and pH above shoals, and river macroinvertebrate dynamics (Section 4.5).

Lake stratification was one of the important influences on Savannah River water quality trends in regards to trace metals mobilization. As the lake became stratified due to increased thermal heating and wind circulation, the lower lake strata were isolated from the constant flux of wind mixed atmospheric oxygenation. As a result, organic matter was utilized by benthic bacteria at the expense of DO, which caused the redox and pH within the sediment and lower lake strata to decrease. This decrease caused the rate of trace metals flux from the sediment to the overlying water column to increase. As respiration rates within the hypolimnion continued over time, the flux of material into the water column from the sediments increased, causing the sharp interface between high and low redox tension, or "redoxcline", to ascend higher into the water column. Typically in early to mid summer, dissolved material transported from the lake sediments was ultimately captured within the power generating turbine's cone of withdrawal and exported to the middle and lower river basin. A depth time diagram of Thurmond Lake specific conductance, developed from data supplied by USACE, is shown in Figure 4-1. The figure indicates the zone within the lake from which water was withdrawn for supply to the river. Since specific conductance is typically a measure of dissolved constituents in water, the figure shows the sediment flux dynamics as described.

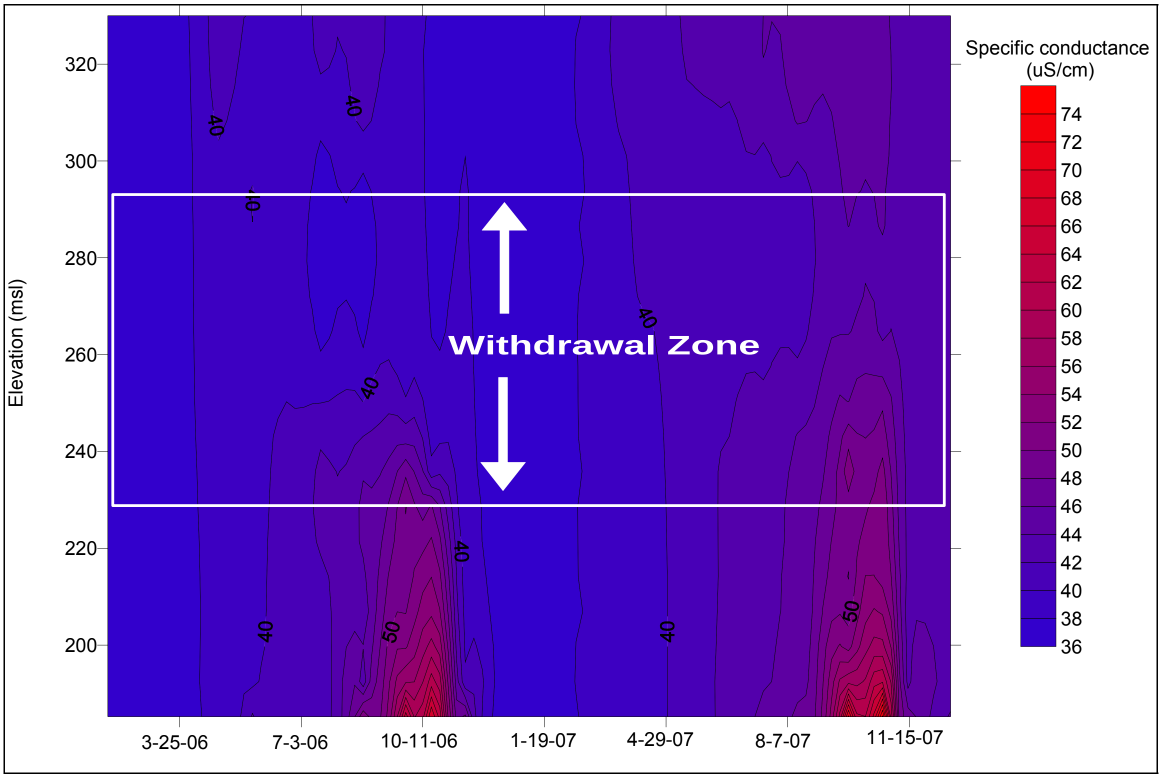

Figure 4-1. Depth-time diagram of Thurmond Lake forebay specific conductance profiles from 2006 and 2007 (data provided by USACE).

Trends in pH indicated that water withdrawn from Thurmond Lake most likely contained reduced chemical constituents that became oxidized as a result of reaeration from RM 222 to RM 215. Oxidation of a portion of those reduced species, as the water traveled through aerating turbines and the river reach between RM 222 to RM 215, produced slightly acidic water at RM 215. April 2006 chemistry results of both iron and manganese from RM 215 showed that ~50% of the iron and manganese was oxidized and in the June 2006 sampling event, ~45% of the iron and manganese was oxidized (0.45um filtration cutoff). In addition, nearly the highest masses of iron and manganese were found in RM 215 sediment samples (5.2g/kg in April and 7.9g/kg in June). These trends showed that considerable precipitation of iron and manganese occurred at RM 215. Such oxidation most likely poised the pH at that location since iron oxidation produces acidity.

Cycles of seasonal stratification and homogenization of the lake's lower depths should have significantly impacted the chemical constituency of the river over seasonal time periods. Figure 4-2 shows trends in dissolved oxygen concentrations in Thurmond Lake at the depths of water withdrawal and dissolved oxygen concentrations at RM 215 from January 2006 through

December 2007. Thurmond Dam was recently retrofitted with autoventing turbines capable of aerating the hypoxic lake water. Those turbines were capable of adding as much as 3-4 mg/L of dissolved oxygen to water discharged into the river. This was evident in Figure 3.18, where lake DO levels approached zero from May to October, while DO levels at RM 215 were maintained above 4 mg/L. There was a strong linear relationship between the lake withdrawal zone and RM215 DO trends (R^2=0.8854) (Figure 4-3).

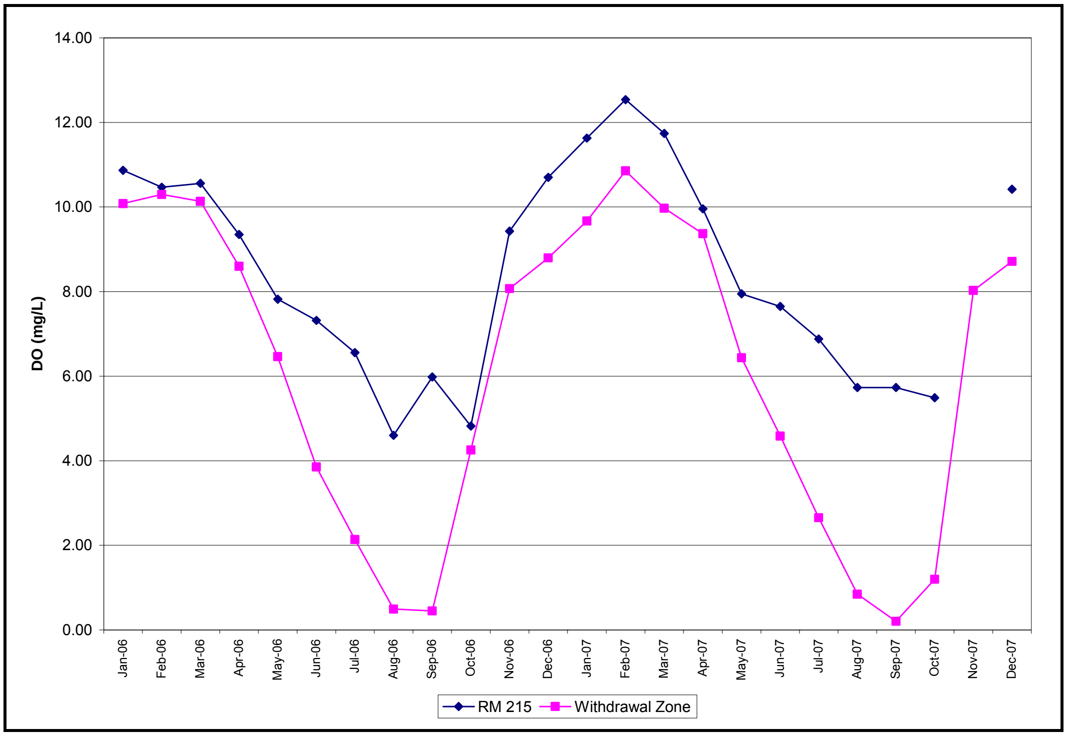

Figure 4-2. Dissolved oxygen trends within the Thurmond withdrawal zone and RM 215.

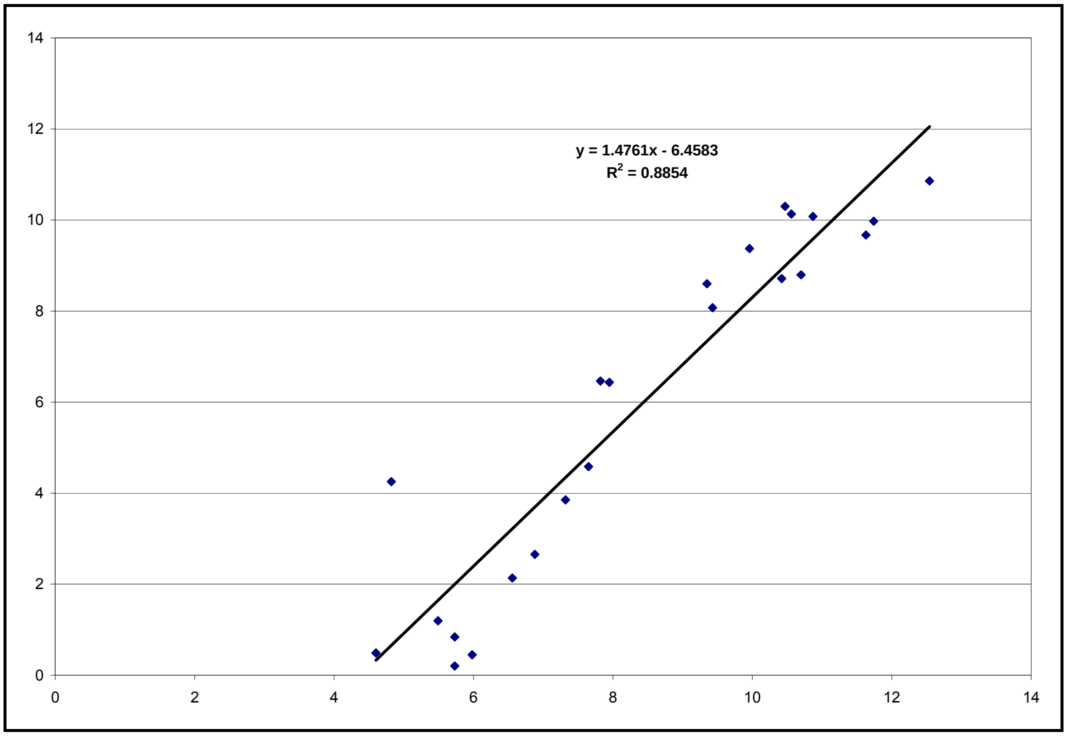

Figure 4-3. Regression of dissolved oxygen concentrations within the Thurmond withdrawal zone and RM 215.

4.2. Oxygen Dynamics

Oxygen dynamics within the middle and lower Savannah River basin were dominated by biotic and abiotic mechanisms. Biotic mechanisms included photosynthesis and respiration and abiotic controls included aeration, reaeration, oxidation/reduction reactions, and the effect of temperature on DO saturation.

As shown above, Thurmond Lake effects on river DO concentrations above the CSRA shoals resulted from bacterial respiration within the lake hypolimnion. A significant portion of water released from Thurmond Dam was retained by the Stevens Creek Dam which resulted in a daily “tidal flow signature” where water backed up into Stevens Creek as a result of the rising river stage at the Stevens Creek Dam. As a result, DO concentrations within Stevens Creek were significantly influenced by hypolimnetic discharges from Thurmond as well. In addition to low DO from Thurmond, the “tidal” nature of Stevens Creek could have exacerbated the deposition of particulate organic matter and reduced metals loads (potentially oxygen consuming substances) load to Stevens Creek. These constituents, along with the low velocities and daily stagnant conditions when flow in the creek reversed direction, were highly conducive to bacterial respiration and concomitant DO loss within Stevens Creek.

Downstream of Stevens Creek Dam, aeration and photosynthesis within the shoals increased DO concentrations to saturation, and most often, supersaturation. Aeration through the shoals and over the dam structures helped to reaerate the water but photosynthesis within the shoals played a dominat role as well. Some evidence that photosynthesis played a significant role came from the tandem diurnal fluctuations in DO and pH (Figure 4-4). Such a trend stems from the fact that photosynthesis and respiration can exert a dominant control on dissolved CO_2 concentrations within natural waters. Since geochemical equilibrium of the carbonate buffer system is also determined, in part, by dissolved CO_2 concentrations within natural waters, respiration and photosynthesis can be significant biogeochemical controls on pH as well. The following set of equations shows the relationship:

$$\begin{tikzcd}[column sep=tiny] CO_2 & + H_2O \Leftrightarrow CH_2O + O_2 \\ CO_2 \arrow[u] & + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow HCO_3^{-} + H^{+} \Leftrightarrow CO_3^{2-} + H^{+} \end{tikzcd}$$

As the demand for CO_2 (during photosynthesis) increased above the rate at which CO_2 could be replenished by the atmosphere, H^+ was consumed and pH increased. So, as a result of photosynthesis DO concentrations increased and pH and DO rose concomitantly within the shoals.

Below the shoals and within the CSRA pool section (above NSBL&D), a slight decrease in dissolved oxygen was observed from RM 202 to RM 198. Since pH decreased as well, this loss may have been due to bacterial respiration but some of the loss was attributed to aeration of the supersaturated water exiting the shoals. The continued loss of DO from RM 198 to NSBL&D most likely resulted from some bacterial respiration since pH decreased as well. That section of the river (from RM 202 to NSBL&D) was the only portion of the study area that had emergent and submerged aquatic vegetation which offered a steady supply of organic material to that river reach. Low flow velocities within the pooled section could have also exacerbated the respiration dominance as well. Some DO loss could have come from an inorganic chemical oxygen demand as well since annual mass flux calculations indicated that section of the river received significant loads of material (Table 3-5). Reaeration within this pooled section of the river was thought to play an insignificant role of reoxygenation due to the low flows and relatively large average depths.

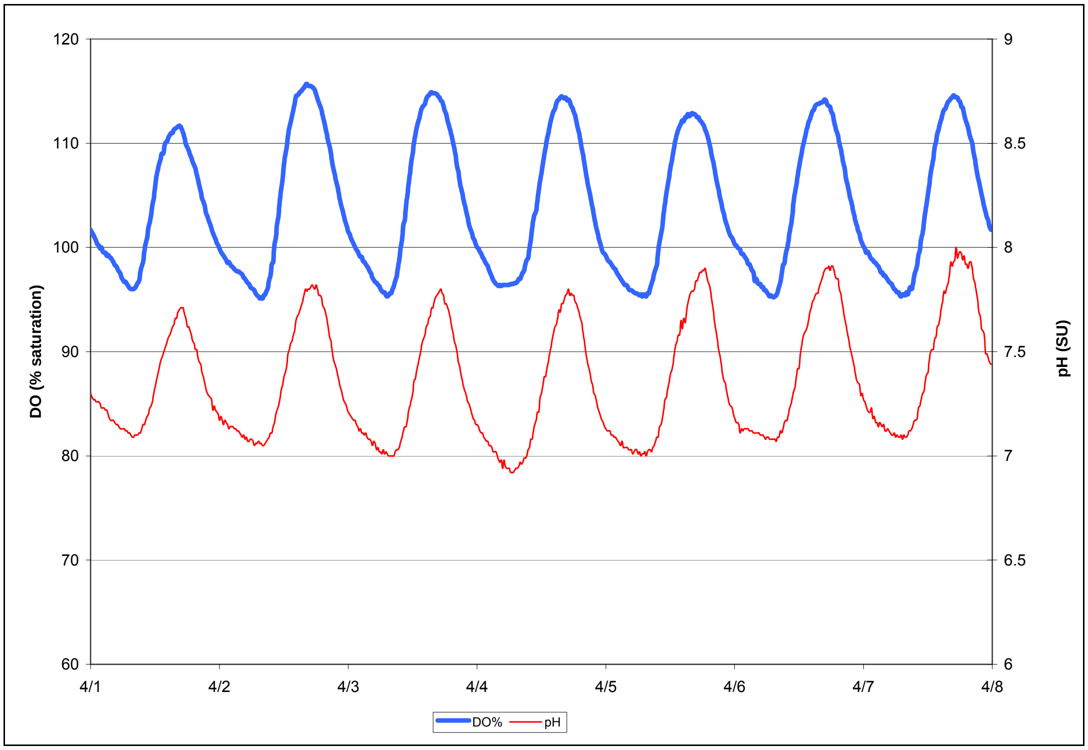

Figure 4-4. Diurnal fluctuations in dissolved oxygen and pH at RM202 in April 2007.

Water passing over NSBL&D (RM 187) helped to increase DO concentrations above saturation, as well. Since the dam helped to reaerate the water to ~107%, at least 7% of the DO should have been lost to aeration in the river below the dam. In the "run-of-the-river" reach (below NSBL&D), both DO and pH decreased from RM185 to RM 148. This most likely indicated that respiration was the dominant control on river DO. At RM 119, DO continued to decrease but pH increased which may have indicated that high respiration rates were offset by higher reaeration rates. Both pH and DO increased from RM119 to RM 61 which most likely indicated that photosynthesis played a significant role in adding oxygen to the river.

4.3. Carbon Dynamics

TOC concentrations in natural systems typically range from 0.5 mg/L in groundwater and seawater to 30 mg/L in "blackwater" swamps with average river concentrations of ~7.0 mg/L; 5 mg/L as DOC and 2 mg/L as Particulate Organic Carbon (POC) (Thurman, 1985). On average, the Savannah had less Total Organic Carbon (TOC) when compared to literature values of other rivers, with Dissolved Organic Carbon (DOC) comprising all of the TOC in 92% of the samples. Average DOC concentrations in Savannah River's mainstem ranged from 2.3 to 4.1 mg/L at RM 215 and RM 179, respectively while concentrations ranged from ~3.1 to 6.5 mg/L in Horse Creek and Butler Creek, respectively (Figure 4-5).

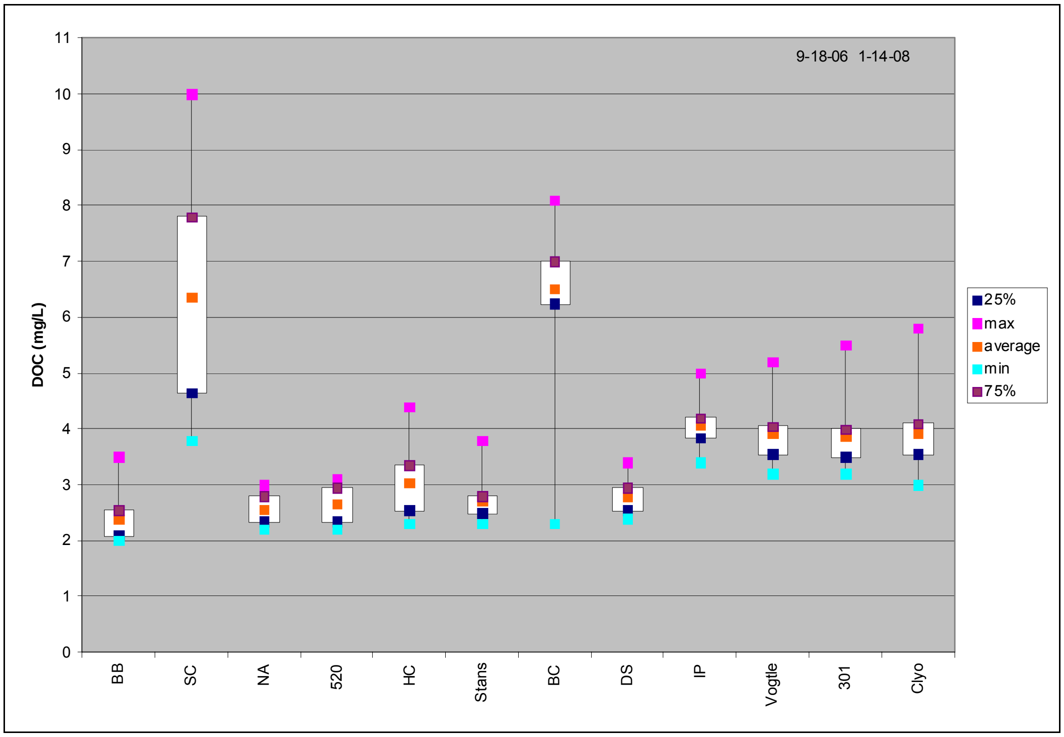

Figure 4-5. Monthly DOC concentrations from each permanent station from September 2006-January 2008. (X-axis nomenclature: BB= RM215, SC = Stevens Creek, NA= RM202, 520= RM198, HC = Horse Creek, Stans= RM190, BC = Butler Creek, DS= RM185, IP= RM179, Vogtle= RM148, 301= RM119, Clyo= RM61)

Compared to other rivers in Georgia, TOC concentrations within the Savannah are either similar (rivers originating in the Piedmont) or significantly below (rivers originating in the Coastal Plain) those of other rivers in the state. Cai et al. (1998) showed DOC concentrations of ~9 mg/L in the Altamaha (Piedmont river) and ~26 mg/L in the Satilla (a Coastal Plain river); at the time of sampling (1995), concentrations within the Savannah were ~4.5 mg/L at the river/estuary interface. Moran, et al. (1999) sampled the Savannah, Ogeechee, Altamaha, Satilla, and St. Marys rivers in March 1996 at the river/estuary interface and reported concentrations of 4.3, 3.8, 3.2, 4.0, 4.2 mg/L, respectively. They sampled the Savannah, Altamaha, and Satilla again in May 1996 and reported concentrations of 3.2, 3.0, and 3.6 mg/L, respectively. Finally, they reported concentrations of 25.4 and 29.9 mg/L in their samplings of the Satilla in March 1997 and August 1997, respectively.

TOC concentrations at Clyo (RM 61) compared to the USGS station at Port Wentworth over the same time period showed that the concentrations were similar from April 2006 through April 2007 (Fig. 4). Although the concentrations were similar between these two sites, the significant difference may be the organic carbon mass between the sites when accounting for discharge. USGS does not supply discharge data for this site but the specific conductance data from this site indicated that it was well within the tidal portion of the harbor (spec. cond. >>1 mS). If the concentrations were the same but the discharges varied by 10x at some points during high tide, then the carbon mass at the Port Wentworth site was 10x higher as well. This logic may indicate that the riverine carbon load contributed only ~10% of the total carbon load to the harbor at that time.

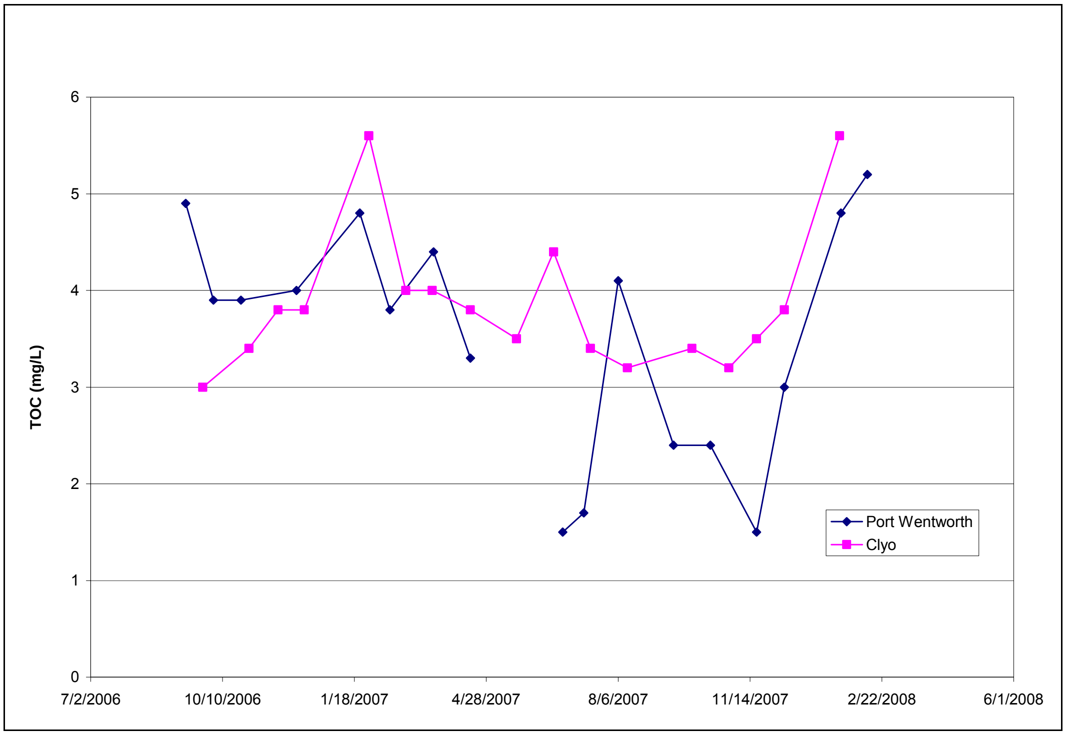

Figure 4-6. TOC concentrations at RM 61 (Clyo) and RM 21 (Port Wentworth).

Overall DOC mass flux trends indicated a seasonal trend where the cooler months exported significantly more carbon than the warmer months (>1E^6 mg C/s versus >8E^5 mg C/s) (Figure 3-32). During the cooler months, presumably due to decreased respiration rates, carbon mass increased steadily with decreasing river mile, even through the floodplain section of the study reach. However in the warmer months, DOC mass often decreased through the section of river with adjacent floodplains. This trend most likely indicated that significant respiration was ongoing especially in July 2007 when a loss of ~ 2E^5 mg DOC/s was observed from RM 179 to RM 61; this loss decreased carbon mass to levels observed within the CSRA pool for that time period and may indicate that a significant amount of CSRA effluent material may be respired within river, prior to the harbor.

TOC/DOC Dynamics

Throughout the first 2 years of the Savannah River study, concentrations of TOC and DOC have been virtually equal. However, measurement error may account for some of this similarity. Both TOC and DOC were determined, by Shealy Environmental Services (Cayce, SC), on an I/O TOC analyzer. This is an often cited instrument for this analysis and is an EPA approved method with a standard error of 1-3% for DOC and 5-10% for TOC. That potential error results from the possible limitation of the instrument to sample larger particulate matter upon analysis (Ron Benner, personal communication; APHA, 1985). If the sampled river system is typically depleted of large particulate matter, then the measurement error for TOC would be minimal. With that in mind, 92% of the TOC data was within 10% of the DOC data (n=309) (Fig. 6). Of the remaining 8%, only half of the data showed TOC>DOC whereas the other half showed DOC>TOC.

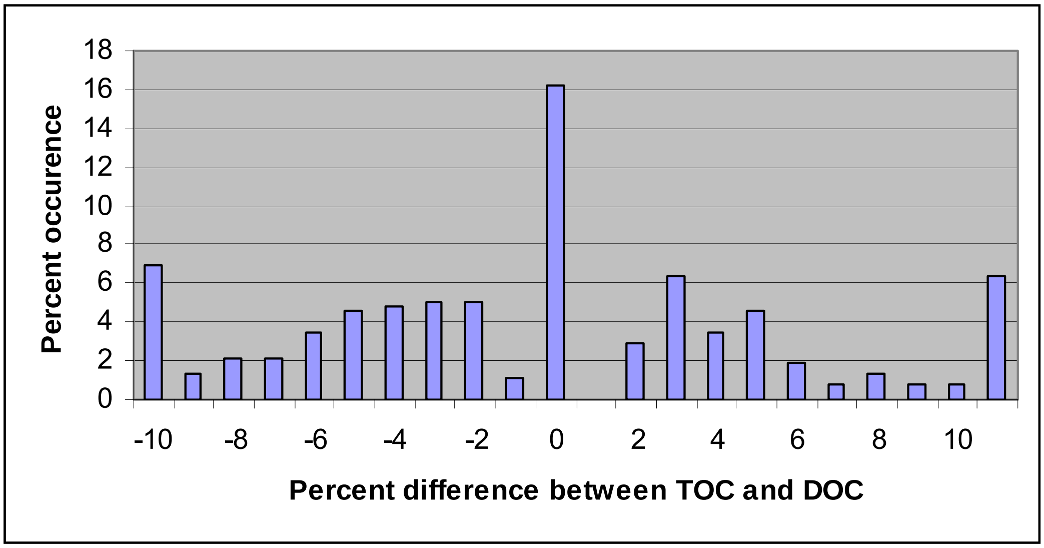

Figure 4-7. Histogram of percent difference between TOC and DOC (n=309).

Of all instances where TOC > DOC (all data included, n=309), 26% occurred within the sampled creeks (Stevens Creek, Horse Creek, and Butler Creek), 16% occurred above New Savannah Bluff Lock & Dam (NSBL&D), and 58% occurred below NSBL&D. Of the instances where TOC exceed DOC by more than 10% (n=24), 54% occurred in the sampled creeks, 25% occurred upstream of NSBL&D, and 21% occurred downstream of NSBL&D.

The apparent discrepancy for the Savannah River TOC/DOC dynamics stems from the fact that it is a highly regulated river. Natural (unregulated) rivers typically contain organic matter from many sources which can be grouped into two main categories, autochthonous and allochthonous. Autochthonous sources originate in-stream and mostly result from bacterial, algal, and aquatic vegetative growth. Allochthonous sources originate from watershed sources outside the river and can come from headwaters, tributaries, floodplain and riparian wetlands, groundwater, and anthropogenic point sources. Since the Savannah is completely disconnected from its headwaters by three reservoirs (Hartwell, Russell, and Thurmond), the typical carbon additions from that source is reduced compared to the amount that could possibly be transported from the headwaters. In addition, the TOC/DOC ratio is significantly altered as a result of the reservoirs. Steep upland catchments typically release more Particulate Organic Carbon (POC; POC=TOC-DOC) material than lowlands. POC released from the reservoirs is negligible because there is extensive bacterial processing and settling of the upland POC within the reservoirs. Water feeding the middle and lower Savannah originates from the mid-depths of Thurmond Lake, so most of the TOC is in the dissolved form. These reservoir effects typically kept the DOC concentrations fairly low and constant at 2.33 mg/L (SD = 0.396 mg/L; n=15) throughout the

2006-2007 study. The three additional impoundments within the middle Savannah (Stevens Creek Dam, Augusta Diversion Dam, and NSBL&D), in addition to the pooling effect of NSBL&D, had a similar effect on TOC/DOC ratio as well.

Downstream of NSBL&D, river meandering and bank erosion was possible from ~RM 185 on. However, POC transport was still minimal because the middle and lower reaches of the Savannah are within the relatively moderate to flat catchments of the Coastal Plain. This resulted in a predominance of DOC export from the watersheds within the middle and lower reaches. Newman (1986) conducted biweekly sampling of organic material for 18 months within the Four Mile Branch watershed (on Savannah River Site property; ~RM148) and found average TOC concentrations of 7.1 mg/L with DOC accounting for 75% of TOC. Mulholland and Keunzler (1979) found that watersheds in North Carolina that had considerable swamp drainage exported 7x more organic carbon than upland watersheds, with >80% being exported as DOC.

Streams and rivers drain varying loads of carbon from watersheds to the ocean. The load typically depends upon the climate where biomes in cooler climates generate more carbon flux to rivers than those in warmer climates and biomes in drier climates generate less carbon flux than wetter biomes with swamp forests generating one of the highest fluxes (9.913 g C m^{-2} yr^{-1}) (Wetzel, 2001). For the Savannah, Dosskey and Bertsch (1994) found that 93% of all carbon entering Four Mile Branch (an SRS tributary; ~RM148) resulted from only 6% of the watershed area which was floodplain wetland forest and that the study watershed (12.6 km^2) exported 26.9 tons C/yr to the Savannah River.

BOD_5 Results

The total number of BOD_5 samples that were analyzed from 2006-2007 was 305. Of the total, 35 samples (11.5%) had results higher than the Practical Quantitation Limit (PQL) of 2 mg/L. Of the 35 samples >2.0 mg/L, 13 (37.1%) were considered storm water samples. Of the samples with results >PQL, 63% were from the sampled creeks (Stevens Creek, Horse Creek, Butler Creek), with sites above and below NSBL&D comprising 17% and 20%, respectively. Of samples >PQL, Butler Creek comprised nearly half of the total with 49% with Stevens Creek and RM 202 comprising ~ 10% each (Figure 4-8) (Box plots of the all results are shown in Figure 3-25). These results are similar to data collected by SCDHEC from 1999 through 2006 for the Savannah River. Their data showed 232/829 (28%) samples with results >PQL. In addition, their results showed that 595/829 (71%) samples had results <PQL but >0. Average concentrations from all SCDHEC data was 1.65 mg/L.

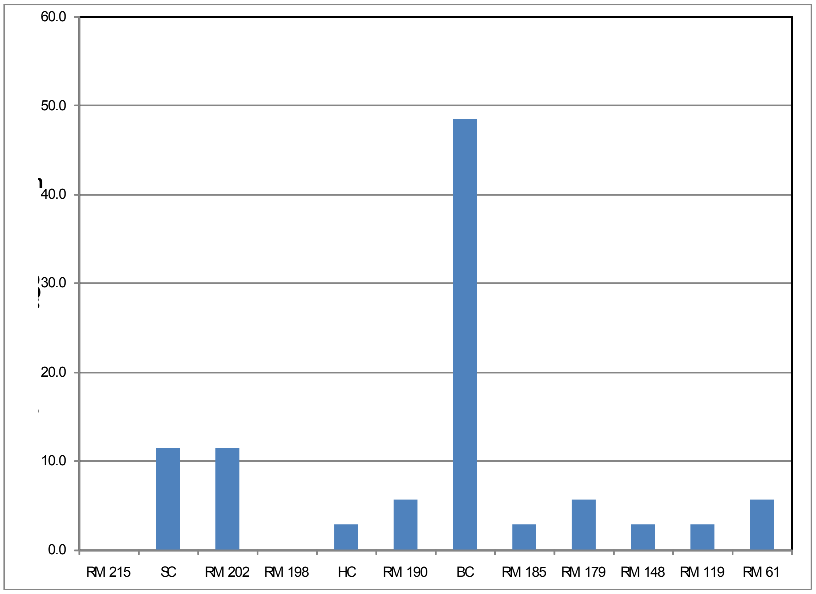

Figure 4-8. Percentage of BOD_5 results >2.0 mg/L by site from 2006-2007 (n=305).

4.4. Sediment Chemistry

Percent solids results showed that RM 202 and Butler Creek were most likely sediment deposition zones. However, the results showed that sediment deposition within those areas was most likely affected by stochastic flood events. The March 2006 pulse, which resulted from a USACE flood release, originated from the metalimnion of Thurmond Lake. Increased inundation of the Stevens Creek watershed during this time most likely mobilized sediment and also mobilized sediment that accumulated behind Stevens Creek and Augusta Diversion Dams. For the RM 202 site, a portion of that sediment load was most likely deposited at the base of the shoals where the pooled CSRA section of the river begins. Such deposition would have resulted from the decrease in water velocity from the shoals to the pool. The percent solids increased slightly from April to June which may have resulted from oxidation reactions and concomitant precipitation of particulate material, especially iron and manganese. The 2007 pulse resulted from a significant rain event within the Stevens Creek watershed. This event most likely deposited less material than the first because most of the debris dams were cleared during the 2006 event.

Percent solids was highest for the Butler Creek site in 3 out of the 4 sampling events. This was due to the sediment accretion behind the Augusta levy. The 2006 pulse most likely backed up into Butler Creek causing a release of sediment from behind the levy which is why the sample in April 2006 (several weeks after the flood event) had the lowest percent solids of all samples taken at that site. The June 2006 sampling event gives some indication as to the sediment accumulation rate behind the levy. The April 2007 event was nearly 6 weeks after the 2007 flood event so enough time had passed after that event so that a significant amount of sediment could buildup behind the levy again.

Although percent solids is not a direct assessment of particle size, smaller particle sizes (i.e. clays) typically have larger water holding capacities. A significant majority of trace metals in river systems can be transported by surface complex adsorption to clay particles (Horowitz, 1991). This most likely explains the association between low percent solids and high metals concentrations at the Butler Creek and RM 202 sampling locations. Furthermore, coincidence of high iron/manganese masses with higher heavy metals concentrations at those locations were indicative of the affinity for heavy metal coprecipitation with iron and manganese oxides.

4.5. Aquatic Macroinvertebrates

Members of the Ephemeroptera, Plecoptera, and Trichoptera families are generally considered pollution sensitive (Resh 1993). EPT taxa richness was used as an assessment of water quality and has been suggested as a metric for water quality determination by the EPA (Barbour et al, 1999, Barbour et al, 1995, and Weber 1973) and others (Wallace et al. 1996 and Lenat 1983). Blocksom and Flotemersch (2005) found that Hester-Dendy sampling devices (Hester and Dendy 1962) preformed consistently well across impoundment groups and were correlated with the most abiotic variables, compared to other methods. Battegazzore (1994) found that Hester-Dendy samplers preformed best in their study.

Low EPT diversity at RM 215 and Stevens Creek was likely the result of impacts due to hydropower generation. River mile 215 had hydrologic instability due to its proximity to J. Strom Thurmond Dam. The Steven's Creek site was impacted by low dissolved oxygen due to stagnation of the water column when water released from Thurmond Dam was backed up by Steven's Creek Dam.

The observed increase in EPT taxanomic diveristy through the pool section was likely due to addition of nutrients and a subsequent increase in algal production, which provided a food source for macroinvertebrates. Nitrogen and Phosphorus contributions from Thurmond Dam releases were low, but increased downstream of RM 198. Increases in EPT diveristy in the free flowing river section were likely due to additional inputs of nutrients observed downstream of Butler Creek, which may have increased algal production. Also, interaction with the floodplain and surface water inputs draining watersheds likely supplied allochthonous material resulting in further diversification of the taxanomic assemblage.

Based on EPT taxanomic diversity, water quality increased as River Mile decreased. The sharp increase in Plecoptera and Ephemeroptera taxanomic diversity and density below RM179 was likely due to an increase in quantity and quality of food resources and indicated increasing water quality. Trichoptera taxanomic diversity showed an increase with decreasing river mile likely due to the same factors attributing to Ephemeroptera and Plecoptera diveristy. Trichoptera density increased with decreasing river mile generally with density spikes at RM185 and RM148. These spikes were likely due to watershed inputs.

5. CONCLUSIONS

The significant findings of this study are:

- Discharge increased with decreasing RM,
- Light attenuation steadily increased with decreasing RM,
- Conductivity increased with decreasing RM, with much of the increase attributable to the Augusta Urban Corridor,
- Temperature increased with decreasing RM,
- Dissolved oxygen dynamics were complex within the urban corridor but overall, DO was higher at RM 61 than RM 215,
- pH steadily decreased with increasing RM, after RM 202, and
- EPT taxa increased with decreasing RM.

These findings point to the importance of characterizing the natural contribution of material to the Savannah River, specifically below RM 185. Those contributions, as this study has shown, can have significant consequences on water chemistry including loss of dissolved oxygen. A clear delineation of the free flowing portion of the river is confounded somewhat by bank erosion control measures (rip-rap lined banks) for miles below RM 187. However once clearly beyond the lined channel boundaries and into the free flowing, floodplain section of the river, a notable difference is observed within the river water itself. This observation is backed by the data within this report and summarized above.

Theoretically, impounded rivers do not behave like first order streams, so a Vannote et al. (1980) synthesis of river dynamics (River Continuum Concept) does not apply to these systems. Furthermore, source water for these systems, the Savannah in particular, is water withdrawn from a lake hypolimnion. Hypolimnia are characterized by highly processed, recalcitrant nutrient constituents. This results from the fact that lake dynamics are gravity driven and can be considered to have a surface to bottom cycle. Primary productivity, the driver for the entire ecosystem, is produced within the upper waters. Energy within is carried through the water column and is processed as it descends toward the bottom of the lake. Therefore, a gradient of nutrient quality exists from the lake surface to the bottom. Much of the high quality nutrients are sequestered and cycled within the upper water so what remains within the hypolimnion is often of poor quality. Although this simplified discussion of lake hypolimnia is heavily geared toward organic material processing, the carbon cycle is considered to be the base of the energy food web.

The significance of the fact that the source water feeding the Savannah is the hypolimnion of Thurmond Lake is that the carbon quality of the river is initially poor and recalcitrant. This is evidenced by the macroinvertebrate data. The fact that macroinvertebrate densities increase near and within tributaries, the fact that densities of macroinvertebrate species which are considered to be indicators of good water quality increase with decreasing RM, and the fact that the first appearance of a top macroinvertebrate predator is observed within the floodplain-influenced reaches of the Savannah are all highly significant findings. This would seem to indicated that Savannah River water quality increases with decreasing RM and is best within the free flowing, floodplain-influenced portion of the river. This trend most likely reflects the gradient of increasing organic carbon quality from downstream of Thurmond Dam to RM 61.

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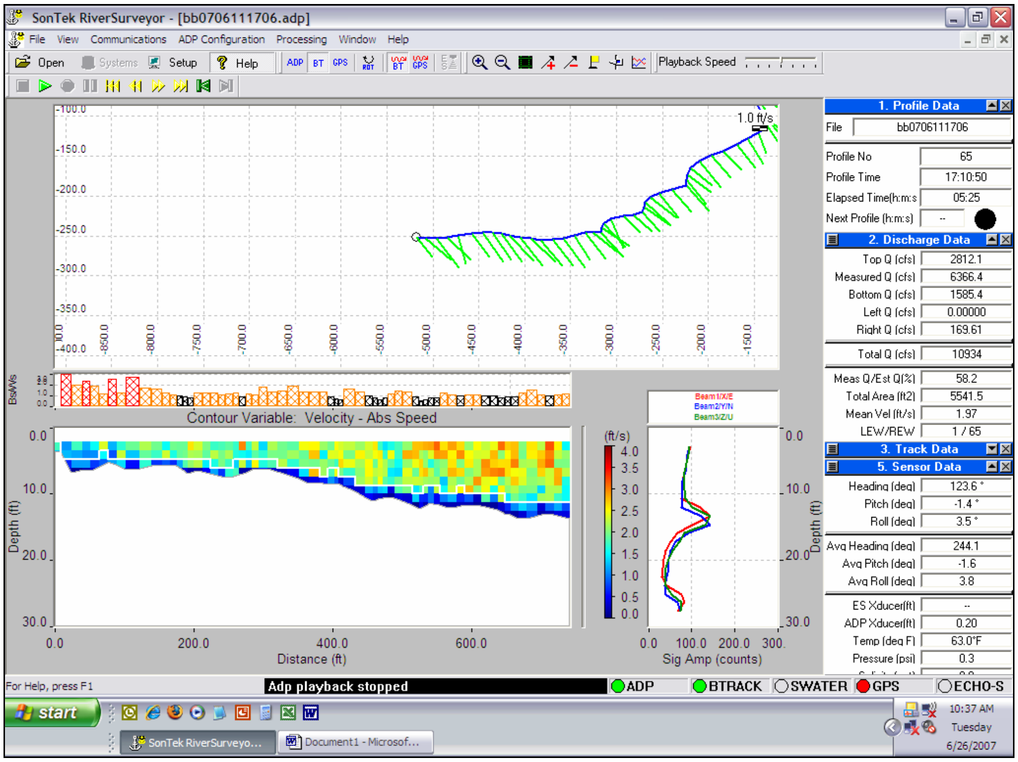
Appendix A - Acoustic Doppler Profiles



1. Profile Data

File bb0706111706

Profile No 65

Profile Time 17:10:50

Elapsed Time(h:m:s 05:25

Next Profile (h:m:s) --

2. Discharge Data

Top Q (cfs) 2812.1

Measured Q (cfs) 6366.4

Bottom Q (cfs) 1585.4

Left Q (cfs) 0.00000

Right Q (cfs) 169.61

Total Q (cfs) 10934

Meas Q/Est Q(%) 58.2

Total Area (ft2) 5541.5

Mean Vel (ft/s) 1.97

LEW/REW 1 / 65

3. Track Data

5. Sensor Data

Heading (deg) 123.6 °

Pitch (deg) -1.4 °

Roll (deg) 3.5 °

Avg Heading (deg) 244.1

Avg Pitch (deg) -1.6

Avg Roll (deg) 3.8

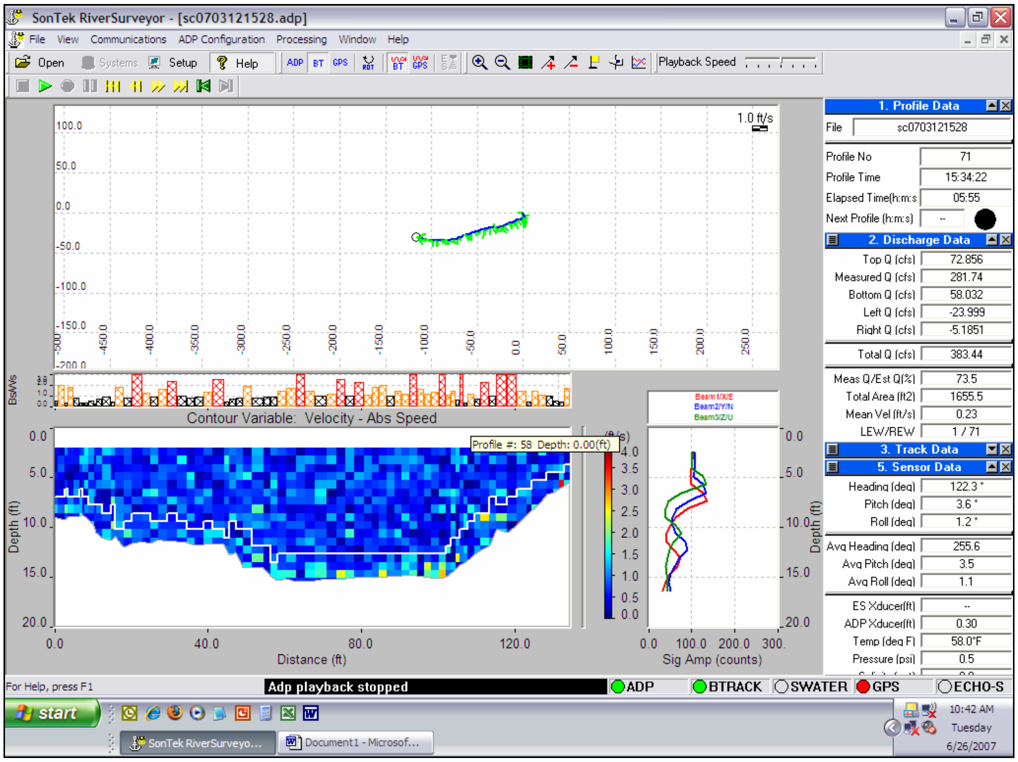
ES Xducer(ft) --

ADP Xducer(ft) 0.20

Temp (deg F) 63.0°F

Pressure (psi) 0.3

Figure A1-1. RM 215



1. Profile Data

File sc0703121528

Profile No 71

Profile Time 15:34:22

Elapsed Time(h:m:s 05:55

Next Profile (h:m:s) --

2. Discharge Data

Top Q (cfs) 72.856

Measured Q (cfs) 281.74

Bottom Q (cfs) 58.032

Left Q (cfs) -23.999

Right Q (cfs) -5.1851

Total Q (cfs) 383.44

Meas Q/Est Q(%) 73.5

Total Area (ft2) 1655.5

Mean Vel (ft/s) 0.23

LEW/REW 1 / 71

3. Track Data

5. Sensor Data

Heading (deg) 122.3 °

Pitch (deg) 3.6 °

Roll (deg) 1.2 °

Avg Heading (deg) 255.6

Avg Pitch (deg) 3.5

Avg Roll (deg) 1.1

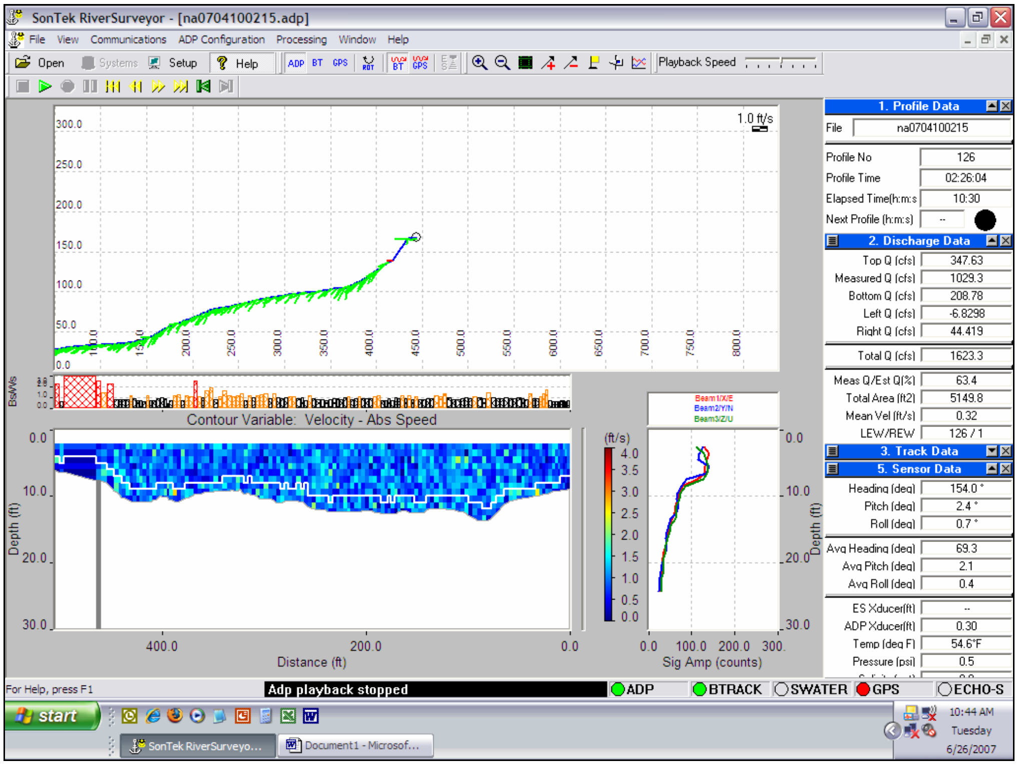
ES Xducer(ft) --

ADP Xducer(ft) 0.30

Temp (deg F) 58.0°F

Pressure (psi) 0.5

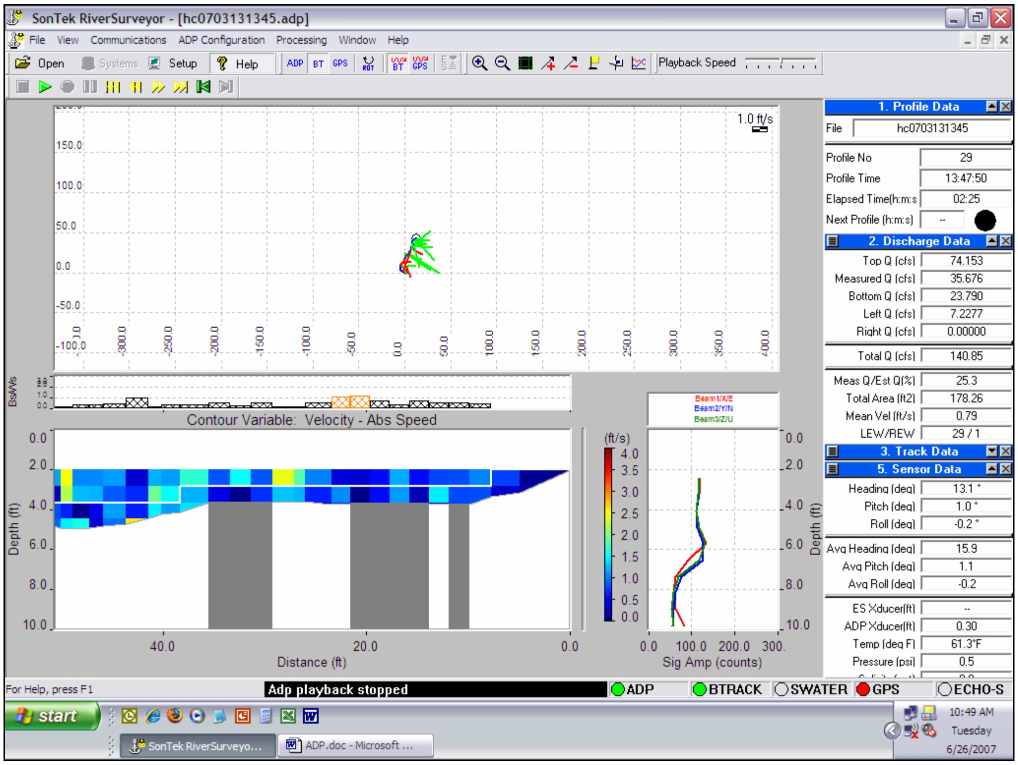
Figure A1-2. Stevens Creek



File na0704100215
Profile No 126
Profile Time 02:26:04
Elapsed Time(h:m:s) 10:30
Next Profile (h:m:s) --
Top Q (cfs) 347.63
Measured Q (cfs) 1029.3
Bottom Q (cfs) 208.78
Left Q (cfs) -6.8298
Right Q (cfs) 44.419
Total Q (cfs) 1623.3
Meas Q/Est Q(%) 63.4
Total Area (ft2) 5149.8
Mean Vel (ft/s) 0.32
LEW/REW 126 / 1
Heading (deg) 154.0 °
Pitch (deg) 2.4 °
Roll (deg) 0.7 °
Avg Heading (deg) 69.3
Avg Pitch (deg) 2.1
Avg Roll (deg) 0.4
ES Xducer(ft) --
ADP Xducer(ft) 0.30
Temp (deg F) 54.6°F
Pressure (psi) 0.5

For Help, press F1
Adp playback stopped

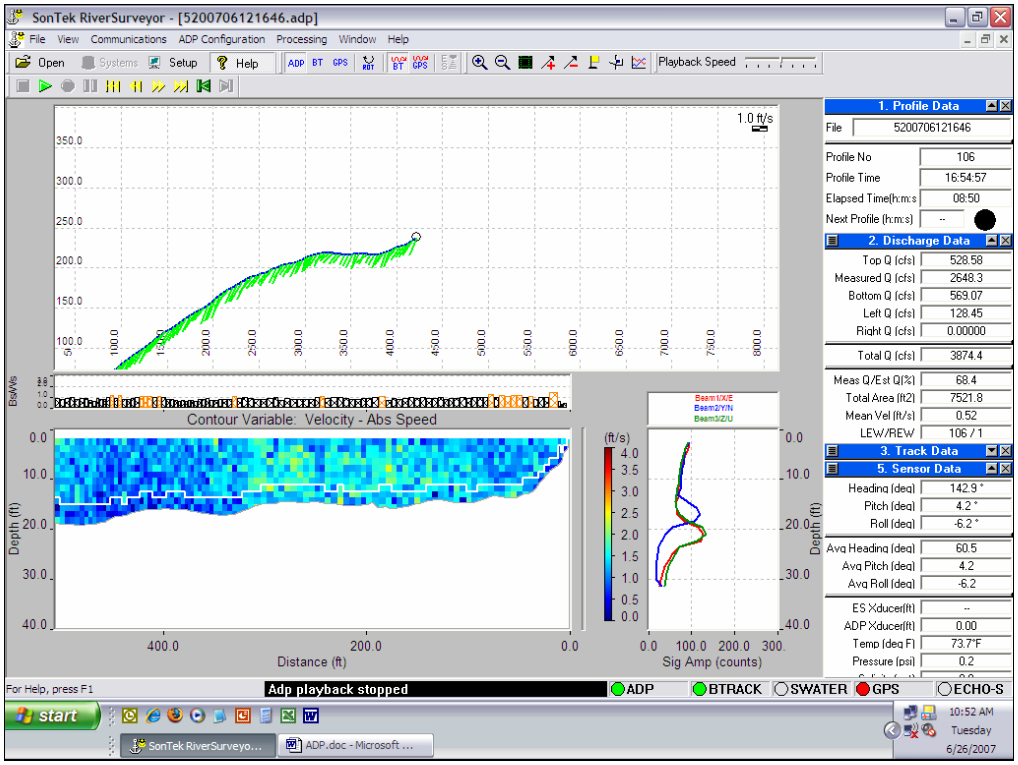
Figure A1-3. RM 202



File hc0703131345
Profile No 29
Profile Time 13:47:50
Elapsed Time(h:m:s) 02:25
Next Profile (h:m:s) --
Top Q (cfs) 74.153
Measured Q (cfs) 35.676
Bottom Q (cfs) 23.790
Left Q (cfs) 7.2277
Right Q (cfs) 0.00000
Total Q (cfs) 140.85
Meas Q/Est Q(%) 25.3
Total Area (ft2) 178.26
Mean Vel (ft/s) 0.79
LEW/REW 29 / 1
Heading (deg) 13.1 °
Pitch (deg) 1.0 °
Roll (deg) -0.2 °
Avg Heading (deg) 15.9
Avg Pitch (deg) 1.1
Avg Roll (deg) -0.2
ES Xducer(ft) --
ADP Xducer(ft) 0.30
Temp (deg F) 61.3°F
Pressure (psi) 0.5

For Help, press F1
Adp playback stopped

A1-4. Horse Creek



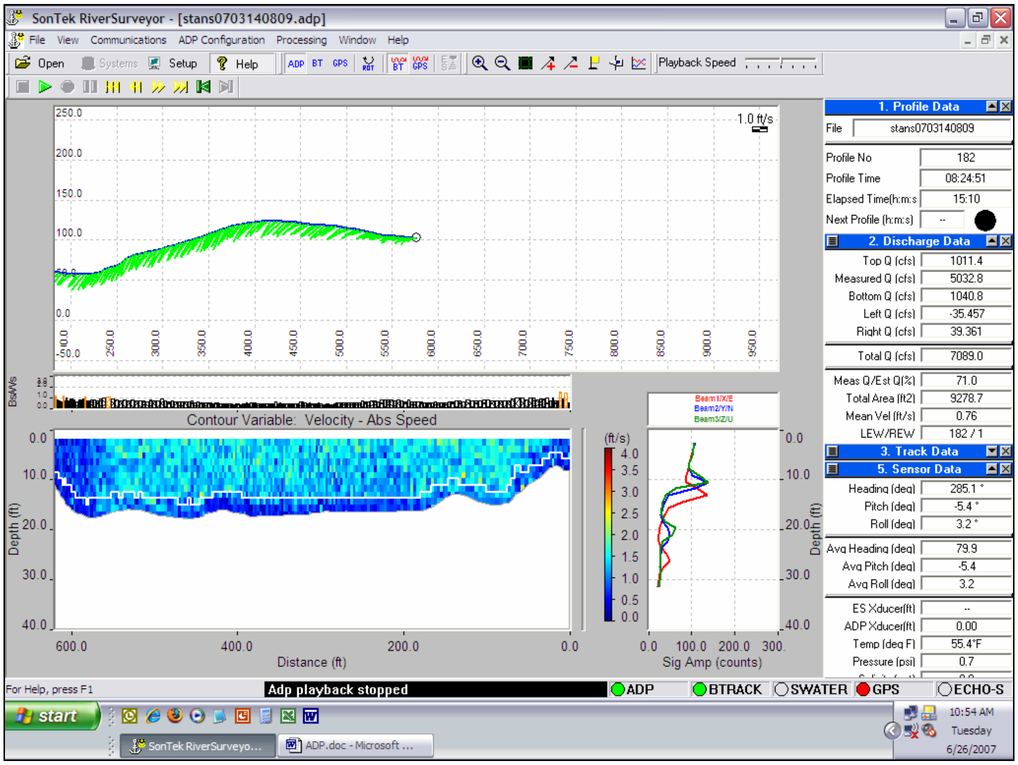
1. Profile Data
File 5200706121646
Profile No 106
Profile Time 16:54:57
Elapsed Time(h:m:s) 08:50
Next Profile (h:m:s) --

2. Discharge Data
Top Q (cfs) 528.58
Measured Q (cfs) 2648.3
Bottom Q (cfs) 569.07
Left Q (cfs) 128.45
Right Q (cfs) 0.00000
Total Q (cfs) 3874.4
Meas Q/Est Q(%) 68.4
Total Area (ft2) 7521.8
Mean Vel (ft/s) 0.52
LEW/REW 106 / 1

3. Track Data

5. Sensor Data
Heading (deg) 142.9 °
Pitch (deg) 4.2 °
Roll (deg) -6.2 °
Avg Heading (deg) 60.5
Avg Pitch (deg) 4.2
Avg Roll (deg) -6.2
ES Xducer(ft) --
ADP Xducer(ft) 0.00
Temp (deg F) 73.7°F
Pressure (psi) 0.2

A1-5. RM 198



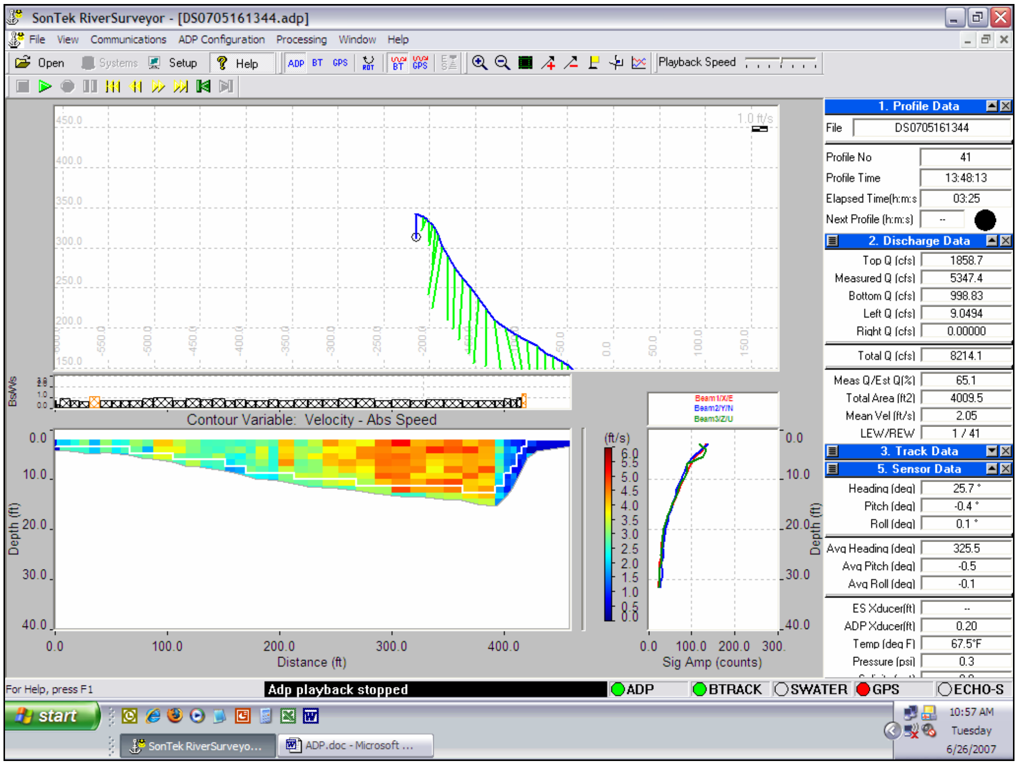
1. Profile Data
File stans0703140809
Profile No 182
Profile Time 08:24:51
Elapsed Time(h:m:s) 15:10
Next Profile (h:m:s) --

2. Discharge Data
Top Q (cfs) 1011.4
Measured Q (cfs) 5032.8
Bottom Q (cfs) 1040.8
Left Q (cfs) -35.457
Right Q (cfs) 39.361
Total Q (cfs) 7089.0
Meas Q/Est Q(%) 71.0
Total Area (ft2) 9278.7
Mean Vel (ft/s) 0.76
LEW/REW 182 / 1

3. Track Data

5. Sensor Data
Heading (deg) 285.1 °
Pitch (deg) -5.4 °
Roll (deg) 3.2 °
Avg Heading (deg) 79.9
Avg Pitch (deg) -5.4
Avg Roll (deg) 3.2
ES Xducer(ft) --
ADP Xducer(ft) 0.00
Temp (deg F) 55.4°F
Pressure (psi) 0.7

A1-6. RM 190



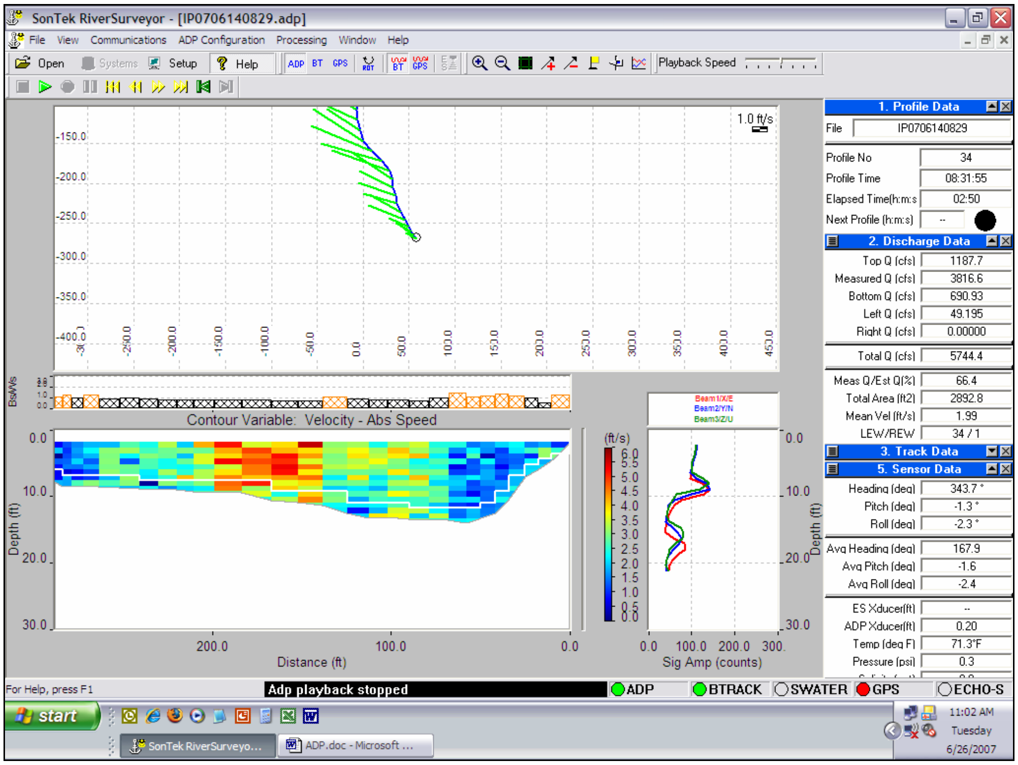
1. Profile Data
File DS0705161344
Profile No 41
Profile Time 13:48:13
Elapsed Time(h:m:s) 03:25
Next Profile (h:m:s) --

2. Discharge Data
Top Q (cfs) 1858.7
Measured Q (cfs) 5347.4
Bottom Q (cfs) 998.83
Left Q (cfs) 9.0494
Right Q (cfs) 0.00000
Total Q (cfs) 8214.1
Meas Q/Est Q(%) 65.1
Total Area (ft2) 4009.5
Mean Vel (ft/s) 2.05
LEW/REW 1 / 41

3. Track Data

5. Sensor Data
Heading (deg) 25.7 °
Pitch (deg) -0.4 °
Roll (deg) 0.1 °
Avg Heading (deg) 325.5
Avg Pitch (deg) -0.5
Avg Roll (deg) -0.1
ES Xducer(ft) --
ADP Xducer(ft) 0.20
Temp (deg F) 67.5°F
Pressure (psi) 0.3

A1-7. RM 185



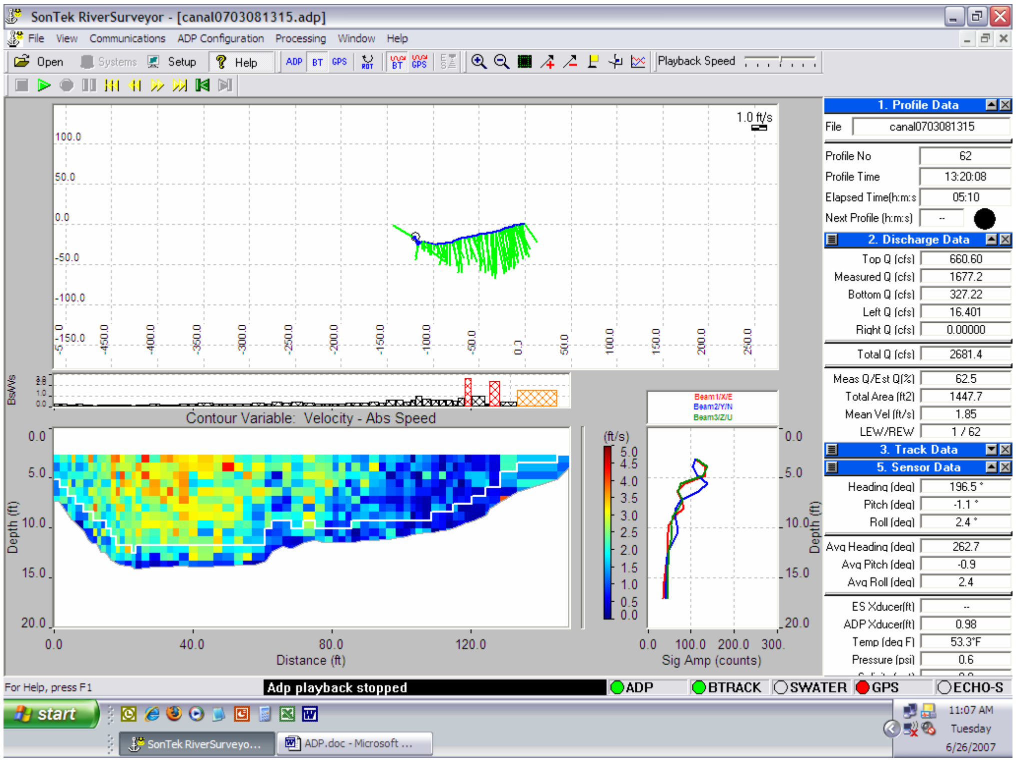
1. Profile Data
File IP0706140829
Profile No 34
Profile Time 08:31:55
Elapsed Time(h:m:s) 02:50
Next Profile (h:m:s) --

2. Discharge Data
Top Q (cfs) 1187.7
Measured Q (cfs) 3816.6
Bottom Q (cfs) 690.93
Left Q (cfs) 49.195
Right Q (cfs) 0.00000
Total Q (cfs) 5744.4
Meas Q/Est Q(%) 66.4
Total Area (ft2) 2892.8
Mean Vel (ft/s) 1.99
LEW/REW 34 / 1

3. Track Data

5. Sensor Data
Heading (deg) 343.7 °
Pitch (deg) -1.3 °
Roll (deg) -2.3 °
Avg Heading (deg) 167.9
Avg Pitch (deg) -1.6
Avg Roll (deg) -2.4
ES Xducer(ft) --
ADP Xducer(ft) 0.20
Temp (deg F) 71.3°F
Pressure (psi) 0.3

A1-8. RM 179



1. Profile Data

File canal0703081315

Profile No 62

Profile Time 13:20:08

Elapsed Time(h:m:s 05:10

Next Profile (h:m:s) --

2. Discharge Data

Top Q (cfs) 660.60

Measured Q (cfs) 1677.2

Bottom Q (cfs) 327.22

Left Q (cfs) 16.401

Right Q (cfs) 0.00000

Total Q (cfs) 2681.4

Meas Q/Est Q(%) 62.5

Total Area (ft2) 1447.7

Mean Vel (ft/s) 1.85

LEW/REW 1 / 62

3. Track Data

5. Sensor Data

Heading (deg) 196.5 °

Pitch (deg) -1.1 °

Roll (deg) 2.4 °

Avg Heading (deg) 262.7

Avg Pitch (deg) -0.9

Avg Roll (deg) 2.4

ES Xducer(ft) --

ADP Xducer(ft) 0.98

Temp (deg F) 53.3°F

Pressure (psi) 0.6

A1-9. Augusta Canal

Appendix B - Chemistry data tables

Table B-1. Annual Statistics of Monthly Chemistry Sample Analyte Concentrations by Site (all values reported in mg/L)

RM215	mean	median	sd	CV	min	max	skewness	N
Alkalinity	14.39	14	1.616	11.23	12	19	1.058	23
BOD 5 day	0	0	0	NA	0	0	NA	23
Cadmium	0.0001383	0	0.0006458	467	0	0.0031	4.472	23
Calcium	2.196	2.1	0.5637	25.67	1.5	4.3	2.238	23
Carbonaceous BOD 5 day	0.01304	0	0.06255	479.6	0	0.3	4.477	23
Chloride	2.687	2.7	0.1842	6.854	2.3	3	0.01671	23
Chromium	0.0006052	0	0.001497	247.3	0	0.0072	3.942	23
COD	2.639	0	4.334	164.2	0	13	1.24	23
Copper	0.001502	0.00092	0.002065	137.5	0	0.0099	3.295	23
Dissolved Ammonia N phenate	0.05957	0.072	0.05496	92.27	0	0.17	0.2383	23
Dissolved Nitrate-Nitrite N	0.1864	0.16	0.2707	145.2	0.022	1.4	4.146	23
Dissolved Nitrite N	0.003017	0	0.004995	165.6	0	0.016	1.517	23
DOC	2.352	2.2	0.3728	15.85	1.9	3.5	1.414	23
Iron	0.08387	0.075	0.0588	70.11	0.02	0.24	1.111	23
Lead	8.15E-05	7.20E-05	8.74E-05	107.2	0	0.00034	1.108	23
Magnesium	1.33E+00	1.30E+00	1.14E-01	8.573	1.1	1.6	0.4219	23
Manganese	0.1186	0.033	0.1725	145.5	0.0067	0.54	1.54	23
Mercury	3.96E-06	0	1.90E-05	479.6	0	9.10E-05	4.477	23
Nickel	4.02E-04	0.00029	7.36E-04	182.9	0.00E+00	0.0034	3.161	23
Ortho-phosphorus	0.02596	0.023	0.02484	95.69	0	0.089	0.8831	23
Potassium	2.348	2.4	0.444	18.91	1.4	3.2	-0.3546	23
Selenium	0.0001322	0	0.0002167	163.9	0	0.00064	1.186	23
Sodium	3.057	2.8	0.5639	18.45	1.9	4.3	0.5049	23
Sulfate	2.663	2.6	0.6929	26.02	0.26	4.1	-1.387	23
TDS	33.61	34	14.65	43.59	0	64	-0.4944	23
TIC	2.191	2.2	1.033	47.15	0.73	4.6	0.5782	23
TOC	2.204	2.2	0.2585	11.72	1.8	2.8	0.7102	23
TSS	1.394	1	1.859	133.3	0	8	2.574	23
TVSS	0.1435	0	0.6881	479.6	0	3.3	4.477	23
Zinc	0.004752	0.0041	0.003283	69.08	0	0.014	1.052	23
place	0	0	0	NA	0	0	NA	23
Arsenic	3.48E-05	0	0.0001167	335.4	0	0.00046	3.058	23
TKN	2.60E-01	0.2	0.204	78.32	0	0.86	0.9758	23

SC	mean	median	sd	CV	min	max	skewness	N
Alkalinity	33.61	31	11.06	32.9	12	53	0.2344	23
BOD 5 day	2.235	0	10	447.5	0	48	4.442	23
Cadmium	1.87E-05	0	3.82E-05	204.7	0	0.00012	1.726	23
Calcium	5.74E+00	5.3	1.83E+00	31.96	2.6	9.1	0.1422	23
Carbonaceous BOD 5 day	0.03217	0	0.1543	479.6	0	0.74	4.477	23
Chloride	5.887	5.8	1.933	32.83	3.5	13	2.115	23
Chromium	0.001084	0.00082	0.001593	146.9	0	0.0078	3.43	23
COD	17.13	16	10.43	60.85	0	51	1.294	23
Copper	0.001765	0.0016	0.001349	76.41	0	0.0068	2.178	23
Dissolved Ammonia N phenate	0.1286	0.11	0.1095	85.1	0	0.4	0.7858	23
Dissolved Nitrate-Nitrite N	0.1642	0.12	0.1758	107.1	0.0069	0.85	2.762	23
Dissolved Nitrite N	0.009326	0.0071	0.01328	142.4	0	0.062	2.886	23
DOC	6.391	5.7	2.249	35.19	3.8	13	1.368	23
Iron	1.031	1.2	0.4442	43.09	0.16	1.7	-0.602	23
Lead	0.0004041	0.0004	0.0002489	61.59	0	0.00082	-0.0926	23
Magnesium	3.126	3	0.8438	26.99	1.7	4.9	0.3957	23
Manganese	0.2429	0.2	0.1729	71.18	0.047	0.65	0.828	23
Mercury	0	0	0	NA	0	0	NA	23
Nickel	0.0007409	0.00066	0.0006937	93.64	0	0.0032	2.041	23
Ortho-phosphorus	0.05583	0.044	0.0789	141.3	0	0.39	3.494	23
Potassium	4.157	4.1	1.676	40.32	1.4	8.6	0.4586	23
Selenium	0.0001726	0	0.0002581	149.6	0	0.00068	0.9685	23
Sodium	5.878	5.6	1.715	29.18	3.1	9.8	0.7764	23
Sulfate	4.43	3.8	1.846	41.67	2.4	9.4	1.11	23
TDS	67.83	73	26.32	38.81	0	120	-0.5303	23
TIC	4.165	3.7	2.247	53.94	1.1	11	1.221	23
TOC	6.27	5.6	2.169	34.6	3.7	12	1.122	23
TSS	9.1	5.9	9.262	101.8	1.3	42	2.28	23
TVSS	0.613	0	1.232	200.9	0	3.4	1.59	23
Zinc	0.005926	0.0047	0.00443	74.76	0	0.018	1.256	23
place	0	0	0	NA	0	0	NA	23
Arsenic	0.0002252	0	0.0003074	136.5	0	0.00086	0.8286	23
TKN	0.55	0.51	0.257	46.73	0	1	0.03302	23

RM202	mean	median	sd	CV	min	max	skewness	N
Alkalinity	15.43	15	2.041	13.22	13	21	1.752	23
BOD 5 day	0.2478	0	0.8322	335.8	0	3.3	3.071	23
Cadmium	0.000168	0	0.0007495	446.2	0	0.0036	4.452	23
Calcium	2.226	2.2	0.2472	11.1	1.7	2.6	-0.1957	23
Carbonaceous BOD 5 day	0	0	0	NA	0	0	NA	23
Chloride	2.865	2.9	0.2347	8.192	2.4	3.4	0.04117	23
Chromium	0.00073	0.00068	0.0007471	102.3	0	0.0032	1.713	23
COD	4.67	0	5.983	128.1	0	20	0.8747	23
Copper	0.0009674	0.00087	0.0008543	88.31	0	0.0046	3.418	23
Dissolved Ammonia N phenate	0.04791	0	0.05923	123.6	0	0.22	1.104	23
Dissolved Nitrate-Nitrite N	0.115	0.13	0.04596	39.97	0.035	0.22	-0.04079	23
Dissolved Nitrite N	0.002348	0	0.004604	196.1	0	0.017	1.956	23
DOC	2.674	2.5	0.5512	20.61	2.2	4.6	2.262	23
Iron	0.1501	0.12	0.08297	55.26	0.064	0.35	0.9142	23
Lead	0.0001023	7.80E-05	8.99E-05	87.91	0	0.00031	0.6758	23
Magnesium	1.37	1.40E+00	1.02E-01	7.444	1.1	1.5	-0.6784	23
Manganese	0.08961	0.079	0.0519	57.92	0.028	0.24	1.475	23
Mercury	9.57E-06	0	3.23E-05	337.3	0	0.00013	3.113	23
Nickel	4.84E-04	0.00039	4.36E-04	90.14	0	0.0018	1.157	23
Ortho-phosphorus	0.02061	0.017	0.02205	107	0	0.085	1.336	23
Potassium	2.409	2.4	0.4709	19.55	1.5	3.3	-0.5525	23
Selenium	0.0001843	0	0.0003413	185.1	0	0.0015	2.64	23
Sodium	3.161	3.1	0.4924	15.58	2.1	4	0.03995	23
Sulfate	2.835	2.9	0.4365	15.4	2.2	3.6	0.00424	23
TDS	36.48	35	16.37	44.88	0	69	-0.2731	23
TIC	2.003	2	0.7995	39.91	0.77	3.9	0.9041	23
TOC	2.622	2.5	0.5359	20.44	2.1	4.3	1.895	23
TSS	2.726	1.6	2.703	99.16	0	9.2	1.282	23
TVSS	0.1043	0	0.5004	479.6	0	2.4	4.477	23
Zinc	0.003809	0.0035	0.002626	68.96	0	0.01	0.3232	23
place	0	0	0	NA	0	0	NA	23
Arsenic	0.0001174	0	0.0001905	162.3	0	0.00059	1.176	23
TKN	0.2539	0.24	0.2099	82.67	0	0.76	0.7708	23

RM198	mean	median	sd	CV	min	max	skewness	N
Alkalinity	15.48	15	2.502	16.17	12	24	1.949	23
BOD 5 day	0	0	0	NA	0	0	NA	23
Cadmium	1.73E-05	0	6.80E-05	392.7	0	0.00032	4.124	23
Calcium	2.278	2.3	0.261	11.46	1.7	2.8	-0.243	23
Carbonaceous BOD 5 day	1.83E-02	0	8.76E-02	479.6	0	0.42	4.477	23
Chloride	2.857	2.8	0.2212	7.744	2.4	3.4	0.3105	23
Chromium	0.0005674	0.00035	0.001037	182.7	0	0.0045	2.745	23
COD	3.013	0	5.328	176.8	0	19	1.699	23
Copper	0.0009687	0.00091	0.0003935	40.62	0	0.0017	-0.09257	23
Dissolved Ammonia N phenate	0.06813	0.069	0.05853	85.91	0	0.18	0.1472	23
Dissolved Nitrate-Nitrite N	0.1454	0.13	0.1461	100.5	0.045	0.79	3.938	23
Dissolved Nitrite N	0.005326	0	0.01328	249.3	0	0.06	3.325	23
DOC	2.683	2.5	0.676	25.2	2	5.4	2.909	23
Iron	0.1253	0.1	0.06941	55.37	0.049	0.32	1.444	23
Lead	0.0001659	0.0001	0.0002876	173.3	0	0.0013	3.141	23
Magnesium	1.378	1.4	0.0998	7.241	1.1	1.6	-0.3961	23
Manganese	0.07752	0.065	0.03748	48.35	0.032	0.17	1.142	23
Mercury	0	0	0	NA	0	0	NA	23
Nickel	0.0006352	0.0003	0.001763	277.5	0	0.0086	4.266	23
Ortho-phosphorus	0.01878	0.015	0.01807	96.18	0	0.084	2.052	23
Potassium	2.461	2.5	0.4812	19.56	1.6	3.5	-0.4544	23
Selenium	0.0002035	0	0.000344	169.1	0	0.0014	2.177	23
Sodium	3.226	3	0.5634	17.47	2	4.4	0.2663	23
Sulfate	2.943	3	0.3883	13.19	2.2	3.7	-0.237	23
TDS	33.35	33	15.8	47.37	0	62	-0.2496	23
TIC	1.925	1.8	0.8389	43.58	0.6	3.8	1	23
TOC	2.6	2.5	0.6053	23.28	2	5	2.848	23
TSS	2.022	1	3.92	193.9	0	19	3.783	23
TVSS	0	0	0	NA	0	0	NA	23
Zinc	0.04631	0.0035	0.2014	434.9	0	0.97	4.475	23
Arsenic	1.70E-05	0	8.13E-05	479.6	0	0.00039	4.477	23
TKN	0.2474	0.21	0.2108	85.18	0	0.91	1.189	23

HC	mean	median	sd	CV	min	max	skewness	N
Alkalinity	4.117	4.4	2.201	53.45	0	8.7	-0.6404	23
BOD 5 day	0.1	0	0.4796	479.6	0	2.3	4.477	23
Cadmium	7.50E-05	0	0.0003329	443.9	0	0.0016	4.456	23
Calcium	1.11	1.1	0.1767	15.92	0.88	1.6	1.231	23
Carbonaceous BOD 5 day	0.01913	0	0.09175	479.6	0	0.44	4.477	23
Chloride	2.917	2.8	0.2269	7.779	2.6	3.6	1.474	23
Chromium	0.002722	0.0026	0.001313	48.22	0	0.0071	1.554	23
COD	7.635	9	5.824	76.28	0	19	-0.1266	23
Copper	0.002065	0.0018	0.001526	73.89	0	0.0084	3.182	23
Dissolved Ammonia N phenate	0.08491	0	0.1093	128.7	0	0.33	0.9651	23
Dissolved Nitrate-Nitrite N	0.1675	0.17	0.08096	48.33	0.072	0.34	0.6698	23
Dissolved Nitrite N	0.006209	0	0.01448	233.3	0	0.057	2.613	23
DOC	3.148	3	0.6748	21.44	2.3	4.6	0.9565	23
Iron	0.9422	0.91	0.2876	30.53	0.36	1.6	0.2542	23
Lead	0.0007148	0.00064	0.0003431	48	0	0.0016	0.6179	23
Magnesium	0.5539	0.55	0.05383	9.718	0.46	0.67	0.6178	23
Manganese	0.04165	0.042	0.01096	26.31	0.023	0.059	0.1014	23
Mercury	4.35E-06	0	2.09E-05	479.6	0	0.0001	4.477	23
Nickel	0.000703	0.00054	0.0007706	109.6	0	0.0038	3.018	23
Ortho-phosphorus	0.02248	0.017	0.01719	76.49	0	0.072	1.253	23
Potassium	1.239	1.3	0.4115	33.22	0.44	1.8	-0.834	23
Selenium	0.0001004	0	0.0002102	209.3	0	0.00066	1.807	23
Sodium	1.96	1.9	0.4988	25.45	0.98	3	0.4786	23
Sulfate	0.9948	0.92	0.4428	44.51	0	2	0.3459	23
TDS	20.26	22	12.2	60.23	0	46	-0.2282	23
TIC	0.9039	0.98	0.3874	42.86	0	1.6	-0.829	23
TOC	3.187	3	0.6247	19.6	2.5	4.6	1.009	23
TSS	7.674	7.4	2.913	37.96	4.1	15	0.9689	23
TVSS	0.5348	0	1.056	197.4	0	3	1.495	23
Zinc	0.009265	0.009	0.003228	34.84	0.0051	0.016	0.5286	23
Arsenic	0.0001543	0	0.0002672	173.1	0	0.001	1.684	23
TKN	0.3835	0.36	0.1962	51.16	0	0.8	0.03393	23

RM190	mean	median	sd	CV	min	max	skewness	N
Alkalinity	15.38	15	2.334	15.17	12	21	1.242	21
BOD 5 day	0	0	0	NA	0	0	NA	21
Cadmium	1.33E-05	0	6.11E-05	458.3	0	0.00028	4.249	21
Calcium	2.4	2.4	0.3162	13.18	2	3.1	0.7388	21
Carbonaceous BOD 5 day	0.02381	0	0.1091	458.3	0	0.5	4.249	21
Chloride	3.281	3.2	0.4191	12.77	2.6	4.4	0.7051	21
Chromium	0.0003176	0	0.0004761	149.9	0	0.0018	1.688	21
COD	3.6	0	6.143	170.6	0	23	1.785	21
Copper	0.001313	0.0011	0.0009024	68.71	0	0.0045	2.198	21
Dissolved Ammonia N phenate	0.09505	0.11	0.07357	77.4	0	0.26	0.1573	21
Dissolved Nitrate-Nitrite N	0.1995	0.2	0.03485	17.47	0.12	0.27	0.004489	21
Dissolved Nitrite N	0.003767	0	0.006213	164.9	0	0.023	1.747	21
DOC	2.719	2.6	0.4094	15.06	2.3	3.8	1.132	21
Iron	0.1404	0.11	0.0801	57.04	0.06	0.42	2.115	21
Lead	0.0001048	7.40E-05	9.48E-05	90.52	0	0.00033	0.9544	21
Magnesium	1.376	1.4	0.1338	9.723	1	1.6	-0.7087	21
Manganese	0.07	0.062	0.02954	42.2	0.022	0.13	0.6187	21
Mercury	3.10E-06	0	1.42E-05	458.3	0	6.50E-05	4.249	21
Nickel	0.0002967	0	0.0007788	262.5	0	0.0036	3.875	21
Ortho-phosphorus	0.04881	0.042	0.02454	50.27	0.012	0.12	1.133	21
Potassium	2.776	2.8	0.7395	26.64	1.2	4.1	-0.6267	21
Selenium	8.95E-05	0	0.0002495	278.7	0	0.0011	3.413	21
Sodium	3.952	3.8	0.9147	23.14	2.1	5.7	0.2049	21
Sulfate	4.033	3.9	0.6011	14.9	3	5.3	0.5599	21
TDS	33.71	37	18.88	56	0	69	-0.3715	21
TIC	1.959	1.7	0.7443	37.99	0.84	3.9	1.453	21
TOC	2.705	2.6	0.3294	12.18	2.3	3.4	0.9121	21
TSS	1.976	1	2.588	131	0	11	2.258	21
TVSS	0	0	0	NA	0	0	NA	21
Zinc	0.005438	0.0048	0.004526	83.23	0	0.023	2.866	21
Arsenic	0.0001048	0	0.0002031	193.9	0	0.0006	1.575	21
TKN	0.3195	0.28	0.3216	100.7	0	1.4	1.853	21

BC	mean	median	sd	CV	min	max	skewness	N
Alkalinity	69.09	70.5	23.68	34.27	28	120	0.1196	22
BOD 5 day	1.732	2.15	1.687	97.43	0	5.7	0.4889	22
Cadmium	1.76E-05	0	3.39E-05	192.4	0	9.70E-05	1.436	22
Calcium	7.568	7.55	0.8725	11.53	5.4	9.7	0.07805	22
Carbonaceous BOD 5 day	0.4818	0	0.9791	203.2	0	3	1.671	22
Chloride	119.4	125	45.12	37.78	33	190	-0.3191	22
Chromium	0.002489	0.00225	0.001644	66.06	0	0.0069	1.041	22
COD	22.09	22	8.574	38.81	0	44	-0.04911	22
Copper	0.00307	0.00275	0.002778	90.49	0	0.014	2.821	22
Dissolved Ammonia N phenate	0.2699	0.275	0.1046	38.78	0.077	0.43	-0.08992	22
Dissolved Nitrate-Nitrite N	1.5	1.13	1.173	78.2	0.28	4.7	1.166	22
Dissolved Nitrite N	0.037	0.0265	0.02736	73.94	0	0.11	1.672	22
DOC	6.75	6.75	1.239	18.35	2.3	8.4	-1.984	22
Iron	1.379	1.4	0.6893	50	0.35	2.8	0.5523	22
Lead	0.001841	0.0013	0.001371	74.49	0.00036	0.0056	1.03	22
Magnesium	1.959	2	0.1593	8.133	1.6	2.2	-0.4585	22
Manganese	0.2158	0.175	0.1438	66.63	0.071	0.58	0.9683	22
Mercury	0	0	0	NA	0	0	NA	22
Nickel	0.003232	0.0034	0.001365	42.25	0	0.0055	-0.2446	22
Ortho-phosphorus	3.703	3.5	2.028	54.77	0.58	7.8	0.3493	22
Potassium	51.88	56.5	32.45	62.54	3.1	140	0.564	22
Selenium	0.0002459	0.00027	0.0002788	113.4	0	0.001	0.9737	22
Sodium	99.05	89	55.95	56.49	28	230	0.9058	22
Sulfate	90.91	63.5	61.55	67.7	28	240	1.063	22
TDS	429.1	435	173.7	40.48	130	800	0.2773	22
TIC	7.168	6.7	3.129	43.65	1.8	17	1.326	22
TOC	7.014	6.85	0.8317	11.86	5.5	8.9	0.5325	22
TSS	22.27	19	16.48	73.99	5.4	75	1.673	22
TVSS	3.495	2.9	4.053	116	0	14	1.283	22
Zinc	0.01636	0.015	0.006244	38.17	0.0078	0.029	0.7404	22
Arsenic	0.0005855	0.00069	0.0003463	59.15	0	0.0013	-0.4212	22
TKN	1.207	1.15	0.3132	25.94	0.7	1.9	0.4912	22

RM185	mean	median	sd	CV	min	max	skewness	N
Alkalinity	16.38	15	3.186	19.45	12	25	1.222	21
BOD 5 day	0	0	0	NA	0	0	NA	21
Cadmium	3.15E-05	0	0.0001289	409.5	0	0.00059	4.155	21
Calcium	2.438	2.5	0.2418	9.918	2	3	0.08398	21
Carbonaceous BOD 5 day	0	0	0	NA	0	0	NA	21
Chloride	5.452	5.4	1.076	19.73	3.4	8.3	0.483	21
Chromium	0.0004433	0.0004	0.0003556	80.2	0	0.0012	0.2484	21
COD	5.41	5.9	6.597	121.9	0	23	1.208	21
Copper	0.002145	0.0012	0.004594	214.2	0	0.022	4.112	21
Dissolved Ammonia N phenate	0.08076	0.09	0.06158	76.24	0	0.21	0.01365	21
Dissolved Nitrate-Nitrite N	0.2376	0.22	0.05338	22.46	0.15	0.36	0.7076	21
Dissolved Nitrite N	0.005633	0	0.0147	260.9	0	0.068	3.885	21
DOC	2.781	2.7	0.3487	12.54	2.2	3.4	0.3299	21
Iron	0.167	0.14	0.07385	44.23	0.074	0.39	1.337	21
Lead	0.000104	8.70E-05	8.81E-05	84.71	0	0.00027	0.3402	21
Magnesium	1.329	1.3	0.09562	7.197	1.1	1.5	-0.5956	21
Manganese	0.06543	0.067	0.025	38.21	0.012	0.12	0.02014	21
Mercury	1.19E-05	0	3.79E-05	318.3	0	0.00014	2.837	21
Nickel	0.0002533	0.0003	0.0003004	118.6	0	0.00094	0.9882	21
Ortho-phosphorus	0.1438	0.14	0.04386	30.5	0.082	0.24	0.7711	21
Potassium	3.743	3.9	1.161	31.02	1.7	5.8	-0.5159	21
Selenium	0.0001595	0	0.0002776	174	0	0.0011	2.033	21
Sodium	5.586	5	1.6	28.64	2.8	9.6	0.6948	21
Sulfate	5.462	5	1.352	24.75	3.4	8	0.4743	21
TDS	38.48	41	21.29	55.33	0	70	-0.5113	21
TIC	1.769	1.7	0.8789	49.68	0.31	4.1	1.45	21
TOC	2.857	2.8	0.4154	14.54	2.2	3.9	0.8565	21
TSS	3.395	1.5	6.529	192.3	0	30	3.509	21
TVSS	0	0	0	NA	0	0	NA	21
Zinc	0.004638	0.0041	0.002679	57.75	0	0.012	1.458	21
Arsenic	0.0001105	0	0.0001902	172.2	0	0.00062	1.376	21
TKN	0.5067	0.36	0.5691	112.3	0	2.6	2.567	21

RM179	mean	median	sd	CV	min	max	skewness	N
Alkalinity	23.43	24	3.613	15.42	16	33	0.2298	21
BOD 5 day	0.1667	0	0.5544	332.6	0	2.3	3.225	21
Cadmium	5.86E-06	0	1.85E-05	316.4	0	6.50E-05	2.776	21
Calcium	3.91	3.9	0.6098	15.6	2.9	5.1	0.05274	21
Carbonaceous BOD 5 day	0.02905	0	0.1331	458.3	0	0.61	4.249	21
Chloride	8.776	8.1	2.772	31.59	5.2	17	1.329	21
Chromium	0.0005752	0.00048	0.0004407	76.61	0	0.0016	0.7501	21
COD	9	8.8	7.05	78.33	0	26	0.478	21
Copper	0.001145	0.0012	0.0006832	59.65	0	0.0032	0.9061	21
Dissolved Ammonia N phenate	0.1168	0.12	0.07436	63.66	0	0.24	-0.1507	21
Dissolved Nitrate-Nitrite N	0.2505	0.25	0.05064	20.22	0.14	0.34	-0.06401	21
Dissolved Nitrite N	0.007581	0.0034	0.01811	238.8	0	0.083	3.688	21
DOC	3.971	3.9	0.4291	10.81	3.2	5	0.3684	21
Iron	0.2824	0.22	0.1532	54.24	0.11	0.77	1.71	21
Lead	0.0001746	0.00014	0.0001444	82.71	0	0.00055	1.047	21
Magnesium	1.476	1.5	0.1841	12.47	1.2	2	0.7527	21
Manganese	0.08324	0.079	0.02023	24.3	0.057	0.13	0.764	21
Mercury	1.76E-05	0	4.53E-05	256.9	0	0.00015	2.221	21
Nickel	0.0005529	0.00043	0.0004252	76.9	0	0.0022	2.873	21
Ortho-phosphorus	0.1337	0.14	0.04801	35.9	0.023	0.23	-0.00141	21
Potassium	6.181	6	2.531	40.95	1.9	12	0.3141	21
Selenium	0.0001124	0	0.0001652	147	0	0.00042	0.7952	21
Sodium	9.305	7.6	3.488	37.49	3.5	16	0.5755	21
Sulfate	11.82	12	3.005	25.42	6.8	19	0.6737	21
TDS	67	65	23.59	35.2	0	110	-0.79	21
TIC	2.569	2.5	1.181	45.96	0.58	5.4	0.9643	21
TOC	4.086	4.1	0.6703	16.41	3.1	6	0.9061	21
TSS	4.948	4.2	2.949	59.6	2.6	16	2.678	21
TVSS	0.07143	0	0.3273	458.3	0	1.5	4.249	21
Zinc	0.005981	0.0052	0.003519	58.84	0.0021	0.019	2.56	21
Arsenic	0.0002471	0	0.0002839	114.9	0	0.00072	0.4494	21
TKN	0.5109	0.42	0.549	107.5	0	2.7	3.138	21

RM148	mean	median	sd	CV	min	max	skewness	N
Alkalinity	21.77	21.5	4.035	18.53	14	29	0.08485	22
BOD 5 day	0	0	0	NA	0	0	NA	22
Cadmium	9.09E-06	0	1.99E-05	218.9	0	6.00E-05	1.717	22
Calcium	4.01E+00	4.05	6.16E-01	15.38	2.8	5.20E+00	0.01633	22
Carbonaceous BOD 5 day	0.09091	0	0.4264	469	0	2	4.364	22
Chloride	8.45	8.45	2.242	26.54	4.7	14	0.6638	22
Chromium	0.0005968	0.00055	0.0005447	91.27	0	0.0019	0.904	22
COD	9.923	8.85	10.81	108.9	0	40	1.128	22
Copper	0.001459	0.0014	0.0009627	65.98	0	0.0049	1.872	22
Dissolved Ammonia N phenate	0.09314	0.094	0.07333	78.73	0	0.21	0.09842	22
Dissolved Nitrate-Nitrite N	0.2818	0.275	0.06551	23.25	0.19	0.49	1.404	22
Dissolved Nitrite N	0.01002	0	0.02978	297.1	0	0.14	4.034	22
DOC	3.85	3.8	0.5271	13.69	3	5.2	0.7398	22
Iron	0.4223	0.39	0.1839	43.56	0.16	0.86	0.946	22
Lead	0.0002358	0.000215	0.0001193	50.59	0	0.00047	0.01761	22
Magnesium	1.441	1.4	0.1623	11.26	1.2	1.8	0.6111	22
Manganese	0.07123	0.0655	0.01862	26.14	0.042	0.12	0.9668	22
Mercury	1.50E-05	0	3.41E-05	227	0	0.00011	1.966	22
Nickel	8.68E-04	0.000505	9.58E-04	110.4	0	0.0046	2.947	22
Ortho-phosphorus	0.1577	0.13	0.1554	98.57	0.015	0.83	3.884	22
Potassium	5.814	5.65	2.059	35.42	1.8	10	-0.2498	22
Selenium	8.36E-05	0	0.0001643	196.4	0	0.00054	1.606	22
Sodium	8.62E+00	7.5	3.108	36.04	3.5	14	0.6821	22
Sulfate	11.58	11.5	2.656	22.93	6.2	17	0.08175	22
TDS	71.41	67.5	23.93	33.51	39	150	1.608	22
TIC	2.483	2.2	1.278	51.49	0.84	5.4	1.177	22
TOC	3.814	3.75	0.4454	11.68	2.9	4.9	0.1426	22
TSS	9.564	8.7	5.963	62.35	2.8	31	2.184	22
TVSS	0.5227	0	1.5	286.9	0	6.3	3.009	22
Zinc	0.006359	0.00575	0.003563	56.03	0.003	0.021	3.297	22
Arsenic	0.0001882	0	0.0002257	119.9	0	0.00072	0.6427	22
TKN	0.3498	0.37	0.1751	50.07	0	0.65	-0.09652	22

RM119	mean	median	sd	CV	min	max	skewness	N
Alkalinity	21.72	21	3.511	16.17	16	28	0.06999	18
BOD 5 day	0	0	0	NA	0	0	NA	18
Cadmium	1.01E-05	0	2.34E-05	231.3	0	6.70E-05	1.831	18
Calcium	4.5	4.5	0.7754	17.23	3.2	6.5	0.7674	18
Carbonaceous BOD 5 day	0.3	0	1.273	424.3	0	5.4	3.881	18
Chloride	9.567	9.3	1.69	17.67	7.4	13	0.4855	18
Chromium	0.0008411	0.000735	0.0005441	64.69	0	0.0023	1.322	18
COD	11.62	8.85	11.7	100.6	0	45	1.502	18
Copper	0.001619	0.00175	0.0006181	38.18	0.00015	0.0027	-0.6608	18
Dissolved Ammonia N phenate	0.1149	0.13	0.07651	66.59	0	0.23	-0.2981	18
Dissolved Nitrate-Nitrite N	0.3044	0.3	0.04422	14.53	0.22	0.39	0.1646	18
Dissolved Nitrite N	0.002472	0	0.00524	212	0	0.02	2.397	18
DOC	3.811	3.8	0.5707	14.98	2.8	5.5	1.191	18
Iron	0.5967	0.57	0.2031	34.04	0.32	1	0.6129	18
Lead	0.0003456	0.000385	0.000179	51.8	0	0.0006	-0.5536	18
Magnesium	1.456	1.4	0.1338	9.194	1.2	1.7	0.2569	18
Manganese	0.08222	0.08	0.01831	22.27	0.058	0.13	0.904	18
Mercury	2.14E-05	0	4.23E-05	197.3	0	0.00012	1.505	18
Nickel	0.0006844	0.00066	0.0002263	33.06	0.00032	0.0012	0.5628	18
Ortho-phosphorus	0.1311	0.14	0.03001	22.9	0.078	0.19	-0.008737	18
Potassium	5.961	5.85	2.183	36.62	1.9	9.3	-0.4566	18
Selenium	7.78E-05	0	0.0002105	270.7	0	0.00084	2.934	18
Sodium	9.25	8.55	2.707	29.26	6.4	16	1.175	18
Sulfate	11.82	12	2.247	19.01	8.2	16	0.2223	18
TDS	66.28	69.5	38.41	57.95	0	180	0.9334	18
TIC	2.772	2.45	1.242	44.81	1	5.7	0.8459	18
TOC	3.767	3.75	0.5499	14.6	2.7	5.2	0.6592	18
TSS	13.56	12.5	5.883	43.38	5.5	27	0.7757	18
TVSS	0.85	0	1.264	148.7	0	3.4	0.852	18
Zinc	0.006811	0.00655	0.001796	26.37	0.0034	0.01	0.1912	18
Arsenic	0.000265	0.00032	0.0002694	101.7	0	0.0008	0.3675	18
TKN	0.4706	0.37	0.3491	74.19	0	1.6	1.967	18

RM61	mean	median	sd	CV	min	max	skewness	N
Alkalinity	23.75	24	2.817	11.86	19	28	-0.2542	16
BOD 5 day	0.175	0	0.7	400	0	2.8	3.615	16
Cadmium	2.31E-05	0	5.40E-05	234.2	0	0.00019	2.232	16
Calcium	5.35	5.4	0.5329	9.961	4.5	6.2	-0.02593	16
Carbonaceous BOD 5 day	0	0	0	NA	0	0	NA	16
Chloride	10.09	10	1.714	16.98	6.9	13	-0.3973	16
Chromium	0.0009838	0.00085	0.0007565	76.9	0	0.0028	0.6186	16
COD	11.38	9.9	7.492	65.87	0	32	1.387	16
Copper	0.001863	0.0018	0.0007455	40.03	0.0005	0.0041	1.403	16
Dissolved Ammonia N phenate	0.08438	0.0825	0.07325	86.82	0	0.23	0.3495	16
Dissolved Nitrate-Nitrite N	0.3456	0.345	0.0686	19.85	0.26	0.53	1.109	16
Dissolved Nitrite N	0.004706	0.0036	0.008306	176.5	0	0.034	2.939	16
DOC	3.944	3.7	0.7615	19.31	3	5.8	1.303	16
Iron	0.8181	0.85	0.2382	29.12	0.47	1.2	-0.1458	16
Lead	0.0004544	0.0005	0.000183	40.27	0	0.0007	-0.7923	16
Magnesium	1.512	1.5	0.1455	9.619	1.3	1.8	0.7169	16
Manganese	0.08581	0.086	0.0112	13.05	0.066	0.1	-0.3371	16
Mercury	3.75E-06	0	1.50E-05	400	0	6.00E-05	3.615	16
Nickel	0.0008437	0.0007	0.0005034	59.66	0.00041	0.0024	2.021	16
Ortho-phosphorus	0.1217	0.115	0.03139	25.8	0.066	0.17	-0.00786	16
Potassium	6.138	6.2	1.945	31.69	2	8.8	-0.6721	16
Selenium	0.0001312	0	0.000207	157.7	0	0.00058	1.012	16
Sodium	9.706	9.05	2.918	30.06	5.9	16	1.002	16
Sulfate	13.26	13	2.271	17.12	9	17	-0.3885	16
TDS	84.25	85	39.59	46.99	0	190	0.6816	16
TIC	3.038	2.75	1.156	38.05	1.4	6	1.332	16
TOC	3.887	3.8	0.7509	19.32	3	5.6	1.413	16
TSS	19.02	18.5	7.741	40.7	6.5	32	0.1202	16
TVSS	1.738	2.3	1.45	83.48	0	3.8	-0.2554	16
Zinc	0.00645	0.00625	0.001224	18.98	0.0046	0.0091	0.6483	16
Arsenic	0.0002619	0.00031	0.0002661	101.6	0	0.00079	0.3836	16
TKN	0.4025	0.345	0.2403	59.71	0	0.84	0.3291	16

Appendix C - Sonde Data Tables and Graphs

Table C-1. Monthly Average Temperature (C)

Month	RM215	RM202	RM198	RM190	RM185	RM179	RM148	RM119	RM61	SC	HC	BC
Jan-06	11.02	11.09	11.18	11.40	11.44		11.50			9.41	11.61	10.78
Feb-06	10.50	10.56	10.67	10.94	10.95		11.14			8.82	11.06	12.05
Mar-06	11.89	13.14	12.95	13.29	13.67		13.67			14.40	14.85	14.85
Apr-06	13.41	17.30	16.73	17.56	17.91		18.84			20.73	20.46	20.94
May-06	14.70	18.60	18.64	18.68	18.69		21.14			23.14	23.00	23.01
Jun-06	16.20	21.35	20.79	22.01	22.50	24.10	23.81			26.90	26.09	25.95
Jul-06	17.53	22.28	21.96	23.25	23.66	23.98	25.21			28.03	27.77	27.71
Aug-06	19.96	23.41	23.13	24.15	24.50	24.76	25.62	26.37		28.92	28.00	27.98
Sep-06	21.66	23.83	23.57	24.22	24.38	24.48	24.71	25.11	25.58	26.32	24.82	24.16
Oct-06	21.09	20.37	20.50	21.01	20.75	20.99	20.76	20.59	20.76	20.01	18.24	17.99
Nov-06	17.01	16.05	16.25	16.37	16.28	16.08	15.83	15.64	15.19	12.69	13.92	13.23
Dec-06	13.62	13.00	13.02	13.23	13.24	13.19	13.06	13.11	12.76		11.69	11.27
Jan-07	12.17	11.53	11.76	12.15	12.09	12.11	12.14	13.39	8.91	8.63	11.50	11.22
Feb-07	9.78	9.75	9.89	10.30	10.33	10.35	10.41	10.31	10.19	7.79	10.02	10.19
Mar-07	11.09	13.45	12.49	12.28	12.83	13.87	14.40		13.43	15.02	15.92	16.94
Apr-07	13.08	16.05	16.67	19.73	16.68	16.80	17.35	17.87	19.54	18.33	18.59	18.68
May-07	14.34	18.77	18.09	19.10	19.46	19.78	20.86	21.49	22.41	23.00	22.95	23.31
Jun-07	16.04	21.08	20.57	21.77	22.21	22.57	23.58	24.62	26.19	26.38	26.05	25.07
Jul-07	17.46	22.22	21.90	23.20	23.48	23.84	24.82	25.70	27.12	26.92	26.87	26.55
Aug-07	19.09	23.87		25.28	25.69	25.99	27.04	27.84	29.04	28.56	28.58	28.86
Sep-07	20.20	23.27	22.96	23.78	24.04	24.18	24.75	25.21	26.10	27.20	25.29	25.26
Oct-07	20.91	21.91	21.83	22.23	22.22	21.98	22.40	22.57	23.07	22.36	21.25	
Nov-07	17.96	16.52	17.70	17.12	17.01	16.93	16.47	16.20	16.08	14.52	14.14	13.17
Dec-07	14.23	13.90	13.61	15.25	13.92	14.90	13.65	13.57	13.60	11.33	12.19	11.49
Jan-08	10.80	9.23	9.10	10.59	10.54		10.34	10.53	10.27	7.04	9.47	9.23

*highlight indicates less than 75% one full month of data

Table C-2. Monthly Average Dissolved Oxygen (mg/L)

Month	RM215	RM202	RM198	RM190	RM185	RM179	RM148	RM119	RM61	SC	HC	BC
Jan-06	11.32	11.90		12.04	11.86		9.70			10.25	10.40	7.50
Feb-06	10.37	12.48		12.23	11.66		10.25			10.71	10.49	9.10
Mar-06	10.56	11.24	10.55	8.30	10.10		9.40			8.30	9.36	8.28
Apr-06	10.01	10.27	9.15	10.31	9.92		7.68			5.55	7.99	6.79
May-06	8.28	9.97	8.98	9.93	9.91		7.24			4.49	6.08	6.16
Jun-06	7.23	9.07	9.32	8.77	9.03	8.42	7.25				6.62	4.81
Jul-06	6.56	9.15	9.15	8.89	9.25	8.97	7.29				7.03	5.36
Aug-06	4.95	8.69	8.06	7.71	8.76	8.69	7.04	6.47				2.91
Sep-06	5.30	8.89	7.33	7.81	8.49	7.76	7.11	6.43	6.61			4.36
Oct-06	6.39	9.19		8.27	9.23			7.75	7.67		8.62	7.16
Nov-06	9.19	10.16		9.78	10.43	9.36		7.89	8.74		9.50	7.33
Dec-06	10.29	10.88	10.35	10.56	10.98	9.56	9.43	8.02	9.19		10.26	7.76
Jan-07	10.95	11.45	10.99	10.63	11.41	10.94	10.25	9.03	10.57	10.20	10.38	8.27
Feb-07	12.15	12.61	12.12	12.06	12.44	11.97	11.46	10.64	10.40	10.88	11.21	9.92
Mar-07	11.45	11.29	10.42	11.61	11.11	10.91	10.05		7.88	8.44	9.42	7.88
Apr-07	10.06	10.20	10.19	9.07	10.24	9.74	8.68	8.14	7.43	6.41	8.58	7.27
May-07	8.54	9.91	9.69	9.18	9.72	9.39	8.13	7.69	7.08	4.13	7.91	6.56
Jun-07	7.65	9.50	9.95	8.84	10.40	8.97	7.60	7.30	6.89	4.10	7.34	4.89
Jul-07	6.98	8.94	9.36	8.34	9.08	8.03	7.11	7.23	7.61	3.70	7.19	5.75
Aug-07	5.70	8.62		8.39	8.56	7.82	6.62	6.43	7.37	3.27	6.65	5.64
Sep-07	5.15	8.78			9.24	8.05	6.93	6.63	7.67	3.18	7.71	5.18
Oct-07	5.96	8.72	7.96	7.80	9.22	8.28	6.70	7.46	7.14	5.69	8.20	
Nov-07		10.02	8.45	9.31	10.20	9.34	9.33	8.95	9.03	7.45	10.09	8.41
Dec-07	10.16	10.65	9.55	10.26	10.73	10.08	9.57	9.32	9.71	6.37	10.61	8.09
Jan-08	11.25	11.90	10.72	11.58	11.80		10.85		10.47	10.45		9.36

Table C-3. Monthly Average Dissolved Oxygen Saturation (%)

Month	RM215	RM202	RM198	RM190	RM185	RM179	RM148	RM119	RM61	SC	HC	BC
Jan-06	102.75	108.1		110.1	108.7		88.9			89.5	95.6	67.3
Feb-06	92.53	112.0		102.7	105.6		93.2			92.1	95.1	84.7
Mar-06	97.79	106.9	100.7	78.5	93.2		90.5			80.8	92.4	82.0
Apr-06	95.82	106.9	94.1	107.9	106.4		82.3			61.5	88.5	76.1
May-06	81.52	106.6	96.1	106.2	106.2		81.5			50.9	70.9	71.7
Jun-06	73.54	102.5	104.1	100.3	105.9	100.2	85.8				81.7	59.5
Jul-06	68.53	105.3	104.6	104.1	109.2	106.5	88.6				89.4	68.3
Aug-06	54.40	102.2	94.2	91.8	105.0	104.4	86.2	80.2				37.3
Sep-06	60.23	105.3	86.5	93.1	101.5	93.0	85.7	78.0	80.6			52.4
Oct-06	71.67	101.8		92.6	102.9			83.6	86.1		90.2	75.5
Nov-06	94.96	103.0		99.7	106.1	94.6		79.2	87.1		91.9	69.9
Dec-06	98.94	103.2	97.4	100.6	104.7	91.0	89.5	76.1	85.7		94.3	70.3
Jan-07	101.92	104.9	101.3	98.9	106.0	101.6	95.2	86.4	90.4	87.2	94.9	74.8
Feb-07	107.03	111.0	107.0	107.6	111.0	106.8	102.5	94.9	91.5	91.2	99.2	88.2
Mar-07	103.93	108.2	97.7	108.4	105.0	105.6	98.4		74.8	83.2	95.0	81.4
Apr-07	95.58	103.4	104.6	99.3	105.1	100.1	90.2	85.6	81.2	67.8	91.5	77.6
May-07	83.42	106.3	102.5	99.1	105.7	102.8	90.9	87.0	82.0	48.1	92.1	77.2
Jun-07	77.59	106.9	110.6	100.7	119.4	103.7	89.5	87.7	85.4	50.9	90.6	59.3
Jul-07	72.84	102.8	106.6	97.5	106.8	95.1	85.7	88.1	95.7	46.3	90.1	71.8
Aug-07	61.62	102.3		100.6	104.9	96.3	83.1	81.8	95.9	42.0	85.8	71.9
Sep-07	56.96	102.9			109.8	95.9	83.4	80.5	94.7	40.0	93.7	63.0
Oct-07	66.85	99.5	84.9	88.8	105.9	94.6	77.1	86.2	83.4	65.4	92.3	
Nov-07		102.5	87.3	96.4	105.5	96.4	95.3	90.9	91.6	73.2	98.0	80.3
Dec-07	98.73	103.2	91.2	102.3	103.9	99.8	92.1	89.7	93.4	59.4	99.9	74.1
Jan-08	101.55	103.5	92.5	103.9	105.7		96.6		93.1	84.2		81.0

Table C-4. Monthly Average Specific Conductance (uS/cm)

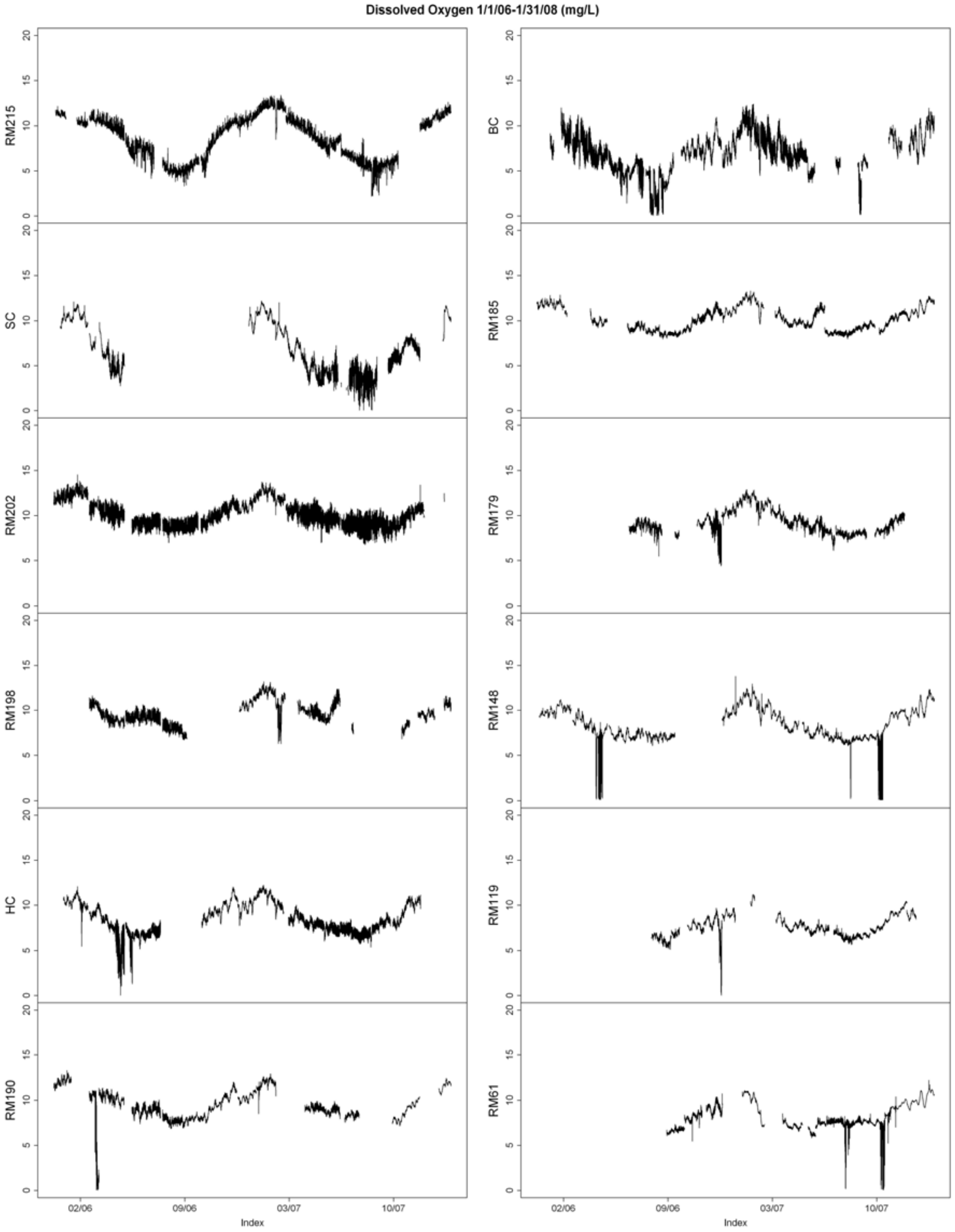
Month	RM215	RM202	RM198	RM190	RM185	RM179	RM148	RM119	RM61	HC	BC	SC
Jan-06	41.9	48.7	46.6	51.5	66.8		85.5			26.9	680.7	88.5
Feb-06	41.9	48.8	47.1	51.2	65.3		88.7			29.7	628.4	80.9
Mar-06	43.8	49.3	48.4	65.8	67.1		86.5			29.4	653.9	93.6
Apr-06	45.3	51.2	51.1	58.9	76.4		107.1			30.3	869.8	119.1
May-06	45.2	51.4	50.2	62.1	81.8		110.5			35.7	1123.2	128.8
Jun-06	43.9	47.2	48.5	56.3	77.4	117.5	101.9			27.2	943.1	110.3
Jul-06	43.8	46.2	48.3	54.6	70.9	103.3	96.3			27.1	1075.0	84.0
Aug-06	44.1	46.9	47.1	52.1	66.9	96.2	94.5	101.9		27.7	966.4	91.2
Sep-06	44.9	47.3	48.1	54.4	70.8	110.1	97.3	115.4	115.4	27.3	705.8	104.3
Oct-06	44.3	43.8	44.7	50.4	65.5	100.9	90.3	111.0	105.5	24.5	1070.4	99.6
Nov-06	42.4	46.0	47.3	51.3	66.4	112.5	91.2	109.0	97.4	26.4	827.4	128.0
Dec-06	42.3	46.8	47.3	52.3	70.4	112.8	98.2	147.8	104.0	26.5	779.7	
Jan-07	42.1	49.8	47.5	53.2	68.8	99.0	96.7	105.9	97.4	27.6	487.1	70.6
Feb-07	42.5	51.0	47.1	51.7	66.1	89.5	86.6	90.7	82.9	27.5	537.9	76.5
Mar-07	43.8	48.6	49.3	55.4	62.0	92.6	86.9		77.6	26.7	598.6	78.6
Apr-07	46.2	51.1	50.5	58.4	75.7	116.4	110.3	116.5	110.0	27.2	759.7	116.5
May-07	47.2	51.0	49.2	55.6	73.9	108.4	106.1	114.7	112.2	28.5	1210.8	109.5
Jun-07	47.6	50.1	47.6	57.0	79.0	106.4	97.9	109.6	113.0	27.5	908.0	108.1
Jul-07	47.8	49.7	47.6	57.5	78.3	112.4	108.6	116.1	115.9	26.9	1326.4	79.9
Aug-07	48.1	49.6		57.9	78.1	115.2	111.3	121.9	110.7	32.4	1067.9	76.4
Sep-07	48.5	49.8	46.5	58.7	80.6	118.7	114.2	124.3	103.3	33.1	1248.2	88.8
Oct-07	49.6	49.8	46.7	58.6	74.5	116.4	102.5	123.0	100.2	30.5		69.2
Nov-07	48.4	49.8	45.9	57.9	73.7	125.0	120.9	125.8	106.7	30.4	1261.3	66.8
Dec-07	49.0	50.0	46.5	56.8	77.9	115.8	113.2	122.6	122.3	30.2	789.7	94.5
Jan-08	48.4	57.5	50.7	61.1	80.8		110.8		107.0	31.2	639.9	105.3

Table C-5. Monthly Average pH (Standard Units)

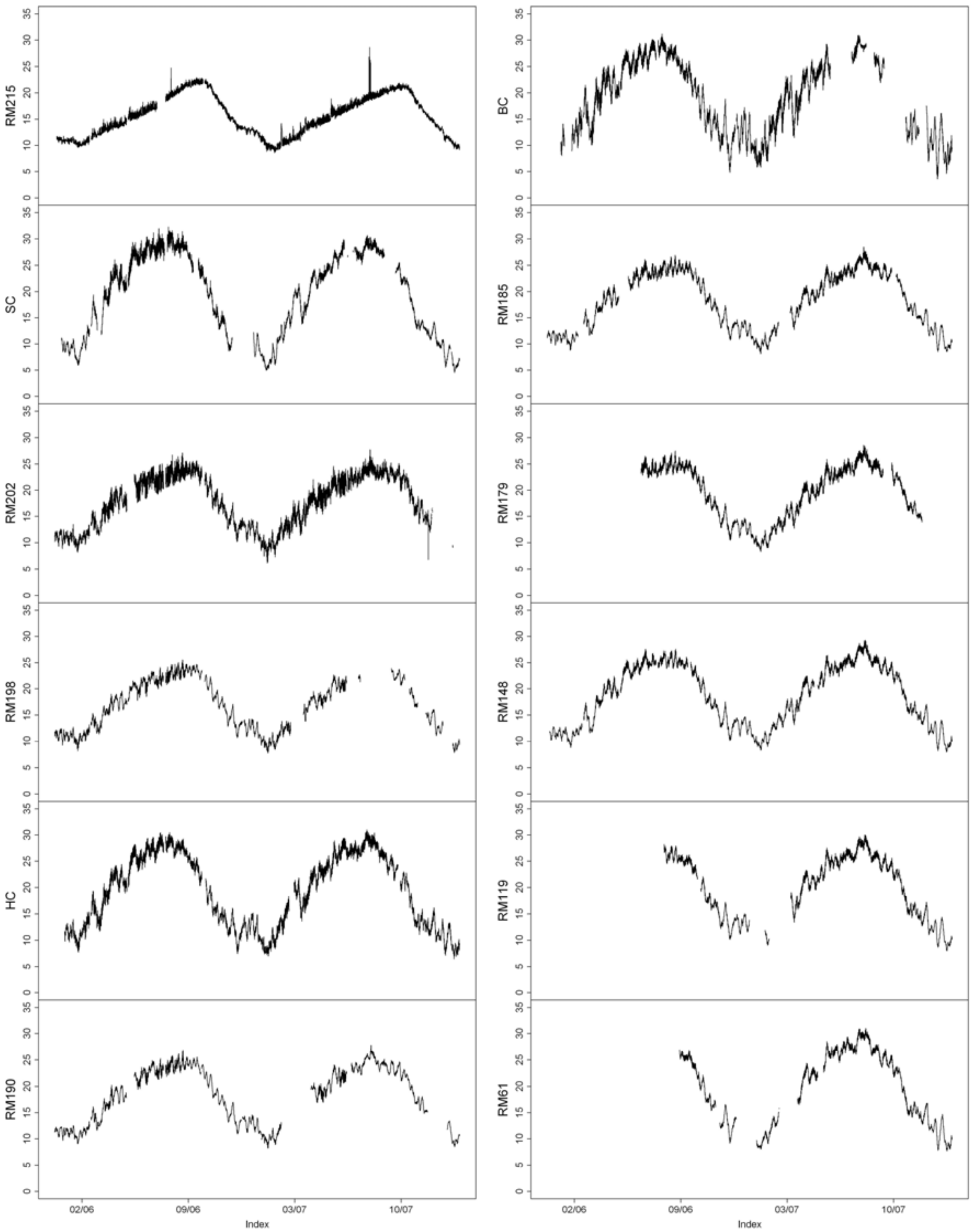
Month	RM215	RM202	RM198	RM190	RM185	RM179	RM148	RM119	RM61	SC	HC	BC
Jan-06	7.21	7.40	7.33	7.19	7.15		6.94			7.45	6.27	6.95
Feb-06	7.18	7.41	7.34	7.25	7.23		6.95			7.39	6.23	7.02
Mar-06	7.05	7.44	7.26	7.10	7.10		6.85			7.21	6.10	7.10
Apr-06	6.89	7.68	7.23	7.16	7.11		6.86			7.12	6.10	7.16
May-06	6.68	7.49	7.12	7.10	7.08		6.87			7.08	6.14	7.23
Jun-06	6.49	7.28	6.93	6.94	7.01	7.10	6.79				6.10	6.99
Jul-06	6.38	7.19	6.84	6.84	6.83	7.00	6.63				6.12	7.10
Aug-06	6.29	7.06	6.77	6.71	6.66	6.82	6.66	6.85			6.00	7.10
Sep-06	6.31	7.16	6.67	6.65	6.67	6.84	6.62	6.81	6.96	6.95	5.92	6.86
Oct-06	6.51	7.12	6.68	6.81	6.71	7.03	6.77	6.96	7.03	7.04	6.34	7.16
Nov-06	6.83	7.26		7.01	6.88	7.21	6.84	6.88	6.98	7.35	6.35	6.99
Dec-06	7.26	7.16	7.00	7.01	7.13	7.28	6.82	6.83	7.00		6.16	6.94
Jan-07	7.77	7.11	7.06	6.72	7.51	7.76	6.84	6.70	7.01	7.60	5.86	6.88
Feb-07	7.96	7.22	7.16	5.81	7.63	7.87	6.91	6.79	6.94	7.72	5.87	7.04
Mar-07	7.59	7.05	6.81	5.26	7.22	7.50	6.63		6.58	7.25	5.73	6.78
Apr-07	7.16	7.20	7.22	6.02		7.38	6.65		6.97			7.00
May-07	6.91	7.21	8.89	5.85		7.15	7.01		7.01			7.06
Jun-07	6.61	7.00	13.99	5.74		6.81	6.87		6.88			6.68
Jul-07	6.37	6.72	9.82	7.13		6.94	6.93	7.08	6.79		5.97	7.44
Aug-07	6.20	6.40		6.84		6.46	6.78	6.97	6.84		5.74	7.46
Sep-07	6.15	6.39	6.61	6.58			6.66	6.84	6.98		5.69	
Oct-07	6.30		6.67	6.98		6.84	6.67	7.64	6.78	6.57	6.45	
Nov-07	6.71		6.91	7.69		7.08		8.19	7.15	6.93	6.97	7.57
Dec-07	7.25	7.63	7.03	7.91		7.11	7.67	7.54	7.21	6.84	6.85	8.01
Jan-08	7.38	8.31	7.02				7.75	7.48		6.96	6.94	8.01

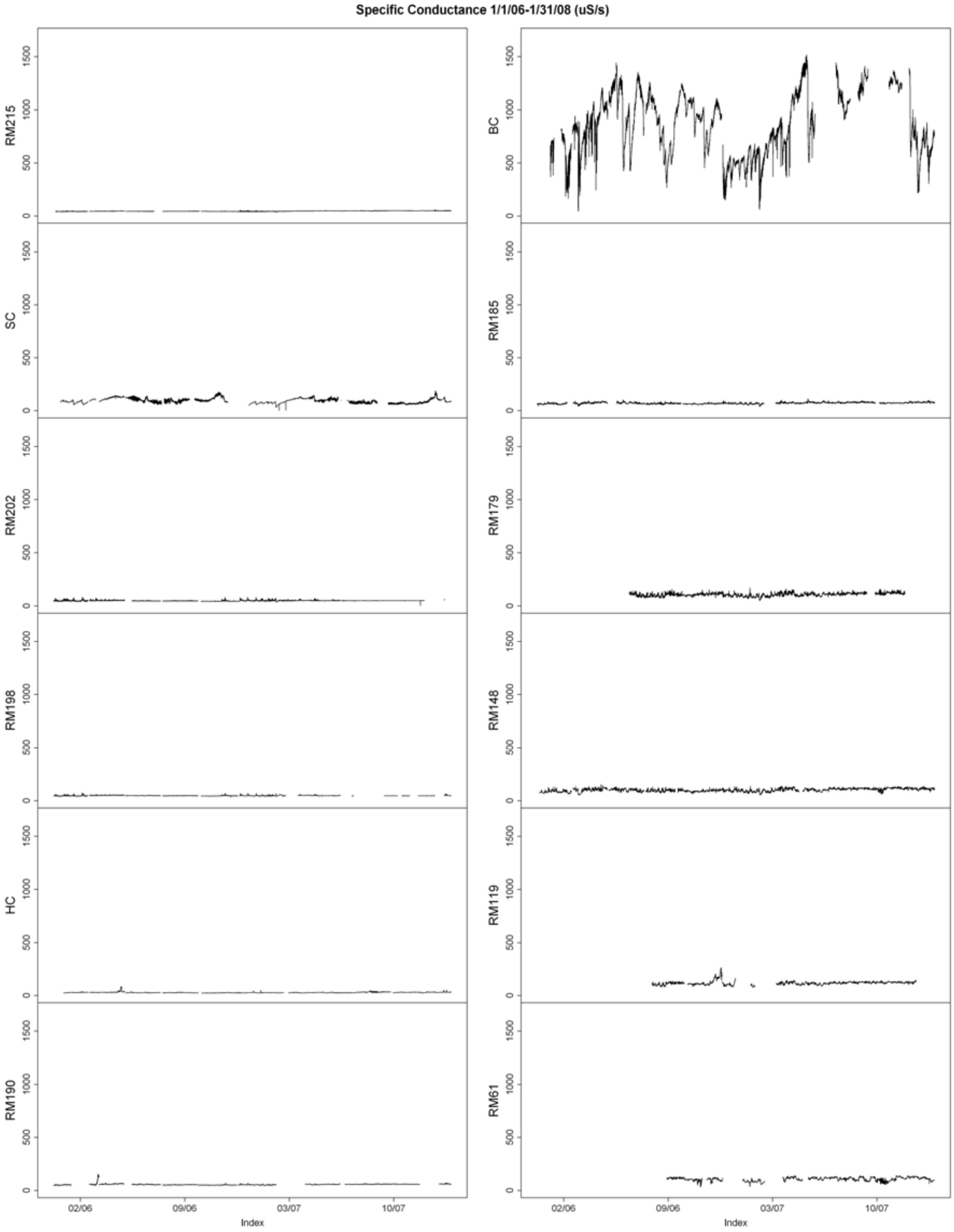
Table C-6. Monthly Average Turbidity (NTU)

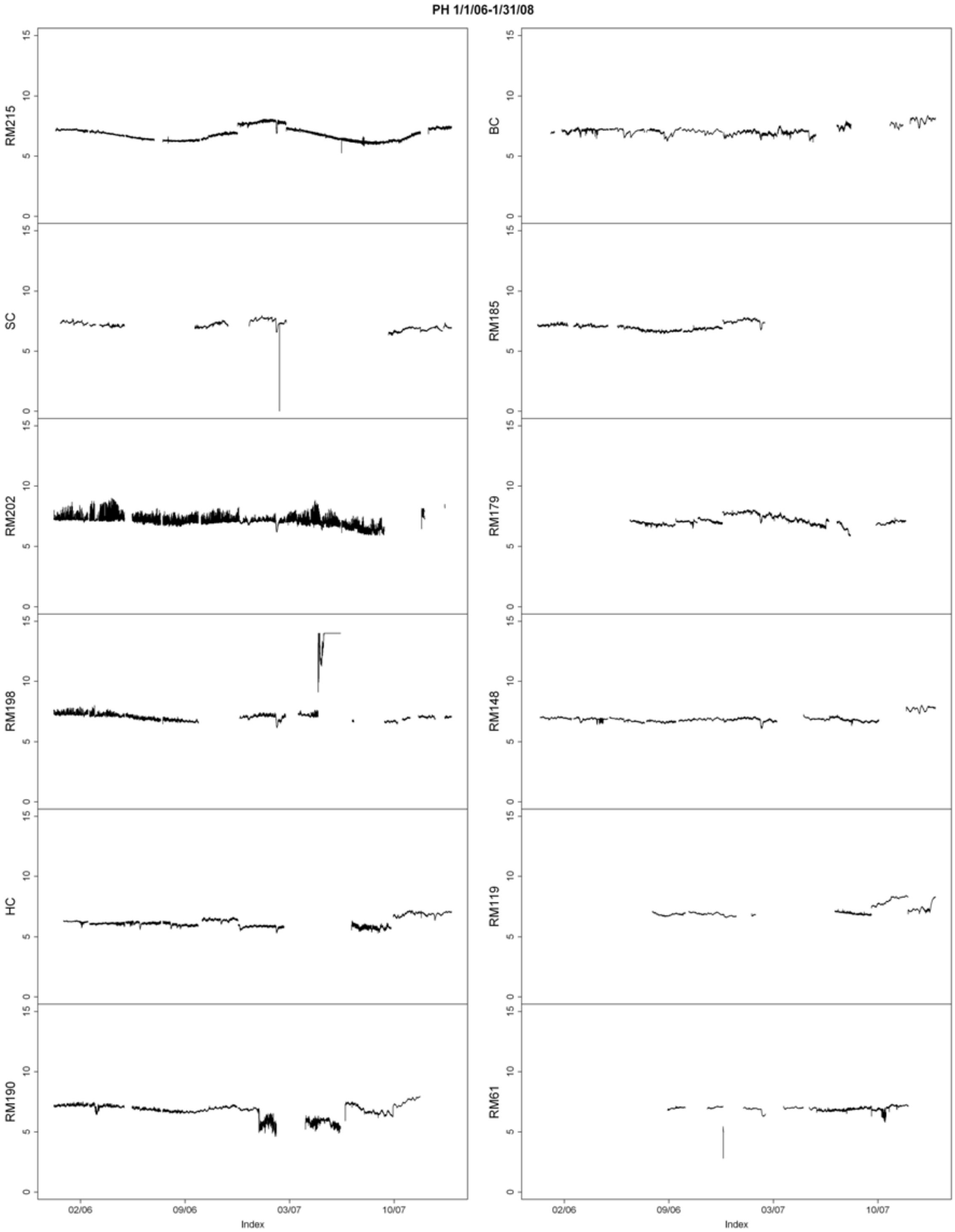
Month	RM215	RM202	RM198	RM190	RM185	RM179	RM148	RM119	RM61	SC	HC	BC
Jan-06	5.5	9.7	8.7	55.1	7.4		9.8			30.1	26.6	11.9
Feb-06	5.0	12.0	10.4	8.9	7.4		9.3			205.2	112.2	12.0
Mar-06	6.8	17.4	6.1	6.0	92.2		14.9			29.6	11.5	10.5
Apr-06	3.4	0.0	320.7		3.3						84.4	
May-06	0.8	0.0	229.7	1.0	16.0		5.4			4.8	573.2	15.5
Jun-06	22.8	0.0	0.0	3.2			8.4				115.5	540.2
Jul-06	117.6	0.0	0.0	3.2	12.7		13.8				20.9	559.3
Aug-06	15.1	6.4	32.5	11.4	-2.1	3.8	9.0	422.6			20.8	418.2
Sep-06	172.0	0.0	7.2	1.0	6.9	164.8	208.4	872.4	55.4		77.2	304.1
Oct-06	74.9	0.5	1.4	2.1	4.6	229.1	9.0	249.2	319.4		99.3	517.1
Nov-06	2.1	1.6	2.4	1.9	7.3	271.4	7.2	229.3	37.8		476.8	
Dec-06	3.5	28.8	6.6	1.1	15.3	498.0	8.3	607.1	56.4		350.6	13.9
Jan-07	2.0	28.8	10.1			643.5		300.2	17.4	29.0	138.1	7.8
Feb-07	2.5	7.6	6.0			382.7		11.4	69.1	41.0	203.3	16.6
Mar-07	27.7	38.1	44.7			108.6			100.1	81.8	49.7	255.1
Apr-07		5.7		4.1	4.8	459.7	17.0	213.9		124.2		54.3
May-07		4.1		2.3	4.1	495.3	1.9	381.6		223.3		180.9
Jun-07		1.9		15.9	39.9	418.7		291.7	18.3	260.7		179.7
Jul-07	8.5	0.2		83.5	88.2	327.4		518.8	25.9	12.7		159.6
Aug-07	9.2	0.2				4.3		9.5	208.9	94.3		247.3
Sep-07	86.8	1.0	0.0			68.7		6.1	22.8	232.5		426.2
Oct-07	2.2	0.0	2.3	0.0				10.2	472.6			
Nov-07	0.0	4.9	6.4	0.0				26.0	127.0			
Dec-07	0.0	0.7		0.0	32.0		5.3	161.5	17.8	2.8		54.7
Jan-08	0.0	1.2	24.5		7.4		27.0	0.0	25.3	97.8		62.4

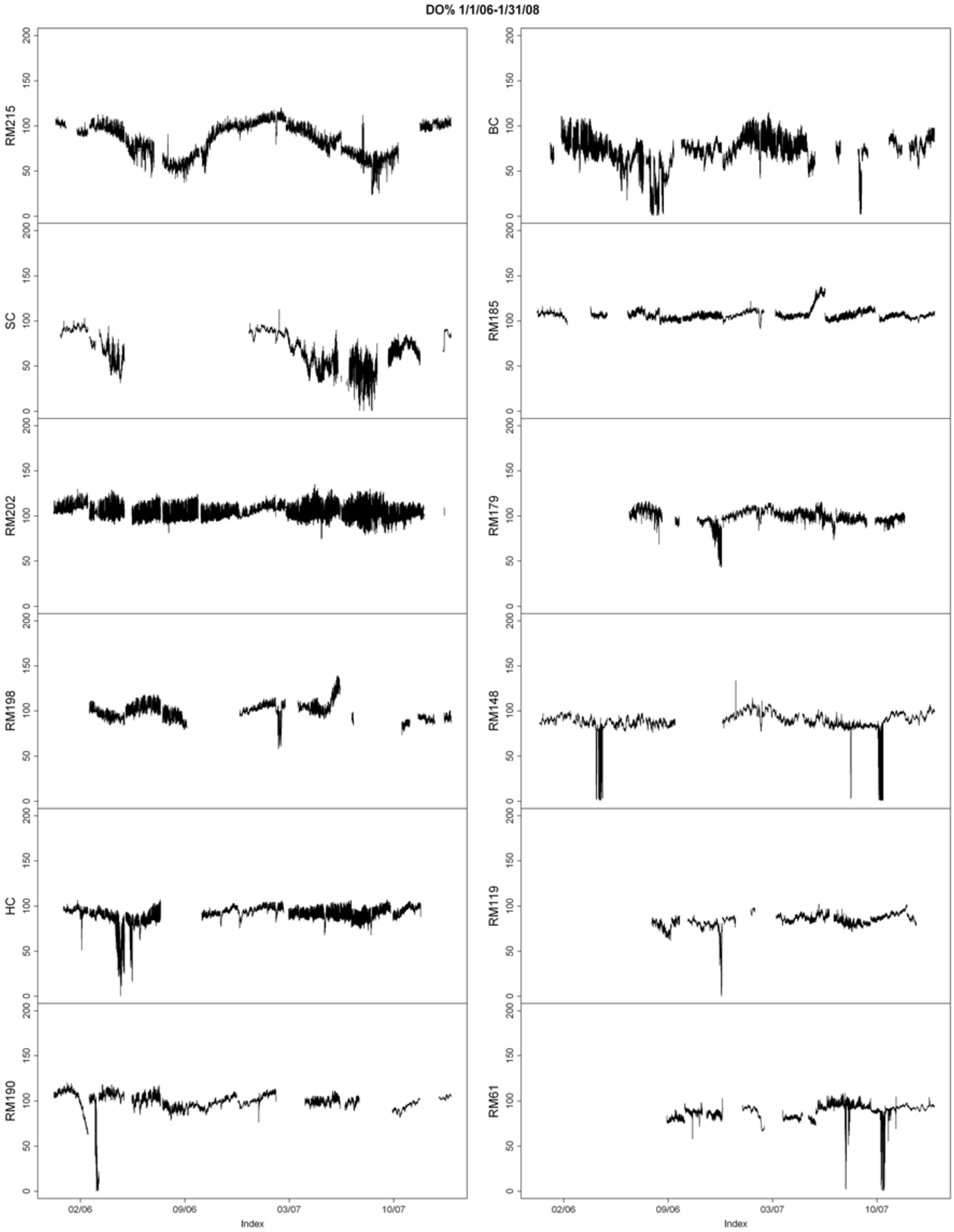

Dissolved Oxygen 1/1/06-1/31/08 (mg/L)
RM215
SC
RM202
RM198
HC
RM190
BC
RM185
RM179
RM148
RM119
RM61
0
5
10
15
20
02/06
09/06
03/07
10/07
Index

Temperature 1/1/06-1/31/08 (°C)




Specific Conductance 1/1/06-1/31/08 (uS/s)
RM215
BC
SC
RM185
RM202
RM179
RM198
RM148
HC
RM119
RM190
RM61
0
500
1000
1500
02/06
09/06
03/07
10/07
Index


PH 1/1/06-1/31/08


DO% 1/1/06-1/31/08
RM215
BC
SC
RM185
RM202
RM179
RM198
RM148
HC
RM119
RM190
RM61
0
50
100
150
200
02/06
09/06
03/07
10/07
Index