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RESULTS OF AN INTENSIVE WATER QUALITY STUDY OF THE MIDDLE AND LOWER SAVANNAH RIVER BASIN

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Abstract. Southeastern Natural Sciences Academy conducted a two-year intensive water quality study within the middle and lower Savannah River Basin between 2006 and 2008. We monitored nine mainstem river stations and three major tributaries to determine effects of the Central Savannah River Area (CSRA) on water quality. Multi-parameter sondes were used to collect continuous temperature, dissolved oxygen, conductivity, pH, and turbidity data at 15-minute intervals. Monthly discrete aqueous chemistry samples and several storm/stochastic event samples were collected and analyzed for major inorganic and organic constituents. Several sediment samples were also collected and analyzed for metals, mercury, pesticides, herbicides, and polychlorinated biphenyls (PCBs). We also monitored aquatic macroinvertebrate populations bimonthly.

Continuous monitoring indicated that river water quality was well above state standards for dissolved oxygen, with exceptions at stations downstream of J. Strom Thurmond Dam, Stevens Creek (SC), and Butler Creek (GA). Especially notable was supersaturated dissolved oxygen levels immediately downstream of the shoals reach of the river. Discrete aqueous chemistry sample results fell within expected ranges. Some samples did exceed chronic and/or acute toxicity limits for copper, cadmium, lead, and zinc. One or more samples from seven mainstem river stations exceeded chronic toxicity limits for mercury. However, mercury was detected in only a single sediment sample. Additionally, several herbicides, DDT, and a PCB were detected in some sediment samples. Macroinvertebrate data indicated EPT taxa increased with distance downstream of J. Strom Thurmond Dam.

INTRODUCTION

The Savannah River flows for approximately 312 miles from its headwaters in the Blue Ridge Mountains to the Atlantic Ocean near Savannah, Georgia. The Savannah River Basin (SRB) drainage area consists of 10,715 mi^2 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 U. S. Army Corps of Engineers (USACE) impoundments drain a combined 6,144 mi^2 and stretch 120 river miles (USACE, 1996), and are primarily managed for flood control and hydroelectric power generation.

Beginning approximately 13 river miles (RM) below Thurmond Dam, three additional features regulate river flow: Stevens Creek Reservoir and Dam (RM208); Augusta Diversion Dam (RM207) and Augusta Canal; and New Savannah Bluff Lock & Dam (NSBLD, RM187.5). The Savannah River becomes a free flowing river below NSBLD. Flow remains rather consistent seasonally, but varies widely throughout the day due to hydroelectric production schedules. 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).

In 2006, Georgia listed 252 miles of rivers and streams within the middle and lower SRB as not supporting designated uses due to a variety of criteria, including dissolved oxygen, fecal coliform, and toxins such as lead and copper (GAEPD, 2006). Fish consumption advisories exist for much of the Savannah River downstream of Thurmond Dam due to mercury levels in fish tissue. Additionally, low dissolved oxygen levels in the Savannah Harbor have been partially attributed to anthropogenic inputs of oxygen-demanding substances within the CSRA urban corridor (USEPA, 2010).

This study extended the length of the CSRA urban corridor and was designed to investigate the effects of the corridor on river chemistry and biota. Several municipal and industrial river water withdrawals and NPDES wastewater discharges exist within the corridor.

METHODS

Study Area

Nine study sites were selected on the mainstem Savannah River and three major tributaries, including Stevens Creek (SC) (Edgefield County) and Horse Creek (HC) (Aiken County) in South Carolina, and Butler Creek (Richmond County) in Georgia. 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.

Hydrology and Climate

Discharge data from several USGS stations located at or near study sites were obtained for the study period. Also, hourly and daily average discharge and water level data from USACE's Thurmond Dam were obtained for comparison to the study site 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). Meteorological 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.

Continuous Monitoring

SNSA deployed continuous multiparameter water quality monitors (sondes) at all 12 study sites (YSI Model 6600 EDS and Hach Hydrolab Series 4a). All sondes were equipped with probes that measured temperature, dissolved oxygen, pH, and specific conductance. Each sonde was programmed to record data at 15-minute intervals and was deployed at or near in the thalweg. All sondes were calibrated according to the manufacturer's specifications.

Discrete Chemistry Sampling

Water samples were collected at all sites monthly using either a US-D96-A1 collapsible bag sampler (water velocities >2 ft/sec) or electric water pump and polyethylene tubing. Additional samples were collected during storm or high-flow events. Sites were sampled in a lagrangian scheme using water travel times calculated from continuous monitoring and discharge data. Approximately 20L of sample was collected in an HDPE carboy and placed on ice for transport to the lab.

Sediment samples were collected from each site biannually using a stainless steel Wildco Petite Ponar. All discrete aqueous and sediment samples were analyzed by Shealy Environmental Services, Inc. (NELAC No. E87653) in West Columbia, SC.

Macroinvertebrate Sampling

Hester-Dendy samplers (14-plate) 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. Samplers were deployed near the left and right river banks and suspended 1 foot below the water surface using floats. After a deployment period of approximately 30 days, the samplers were retrieved and processed. Macroinvertebrates were counted and identified to the lowest practical taxonomic level.

RESULTS

Hydrology and Climate

Daily discharge was 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 1). Total precipitation for 2006 and 2007 was 41 in. and 33.9 in., respectively, compared to the long-term average (1971-2008) of 44 in. (NCDC, 2008). 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 (UGA, 2008).

Continuous Monitoring

A combined total of over 2.8 million individual measurements were recorded by the sondes over the entire continuous monitoring study period. These data revealed that water quality standards were met or exceeded at all stations, with few exceptions. Box plots summarizing continuous data are presented in Figure 2.

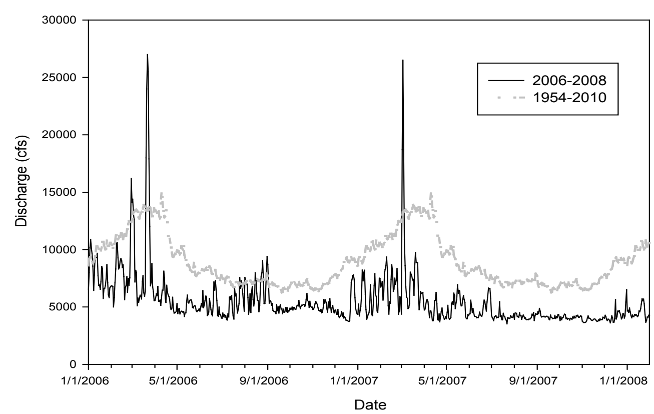

Figure 1. Daily average discharge at NSBLD (USGS, 2008)

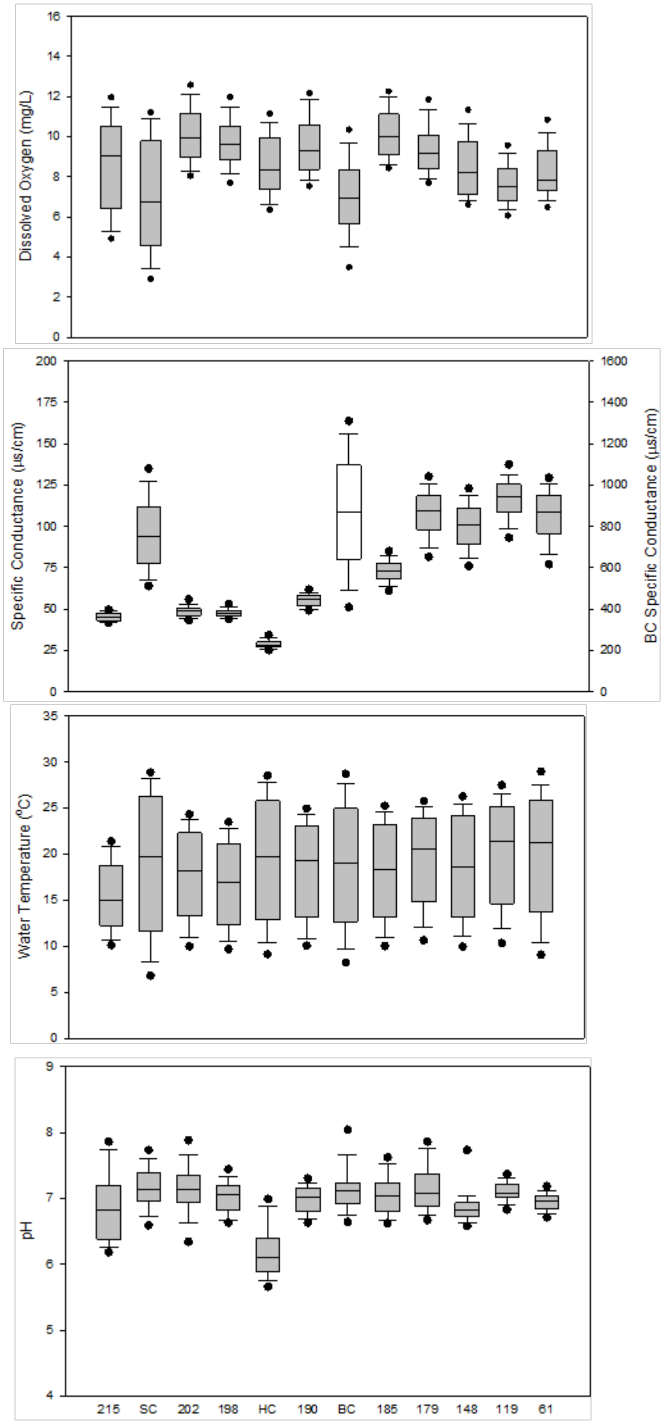

Figure 2. Box plot of continuous monitoring data (Box = 25th and 75th percentiles, line = median, whiskers = 10th and 90th percentile, and closed circles = 5th and 95th percentile outliers; SC = Stevens Creek, HC = Horse Creek, BC = Butler Creek).

Dissolved Oxygen (DO) concentrations at RM215, Stevens Creek, and Butler Creek fell below a daily average of 5 mg/L for 31, 122, and 89 days, respectively. Additionally, instantaneous DO concentrations at these same sites were below 4.0 mg/L for a total of 315, 6,701, and 3,639 measurements, respectively. Daily average DO percent saturation averaged greater than 100% at RM202 and RM185 for much of the study period.

Mean water temperature was lowest and had the smallest standard deviation at RM 215 (15.4° C, ±3.7). Horse Creek exhibited the lowest mean specific conductance (28.8 µs/cm) and pH (6.19) of all sites monitored. Diurnal fluctuations of pH and DO at RM 202 were sizeable.

Discrete Chemistry - Aqueous

A total of 307 discrete surface water samples were collected and analyzed. Five-day Biochemical Oxygen Demand (BOD_5) was below the detection limit (2 mg/L) for 89% of all samples, and 95% of all river samples. Mean dissolved organic carbon (DOC) concentrations increased from 2.2 mg/L at RM 215 to a maximum of 4.0 mg/L at the lower reach of the urban corridor (RM 179), and remained relatively constant downstream to RM 61 (3.9 mg/L) (Figure 3). Concentrations of total organic carbon (TOC) were nearly identical to DOC, especially at mainstem river stations. All but two stations had samples that exceeded either acute and/or chronic toxic criteria limits (GA/SC/EPA) for cadmium, copper, lead, mercury, and zinc.

Sediment Chemistry

A total of 44 sediment samples were collected and analyzed. Samples from Butler Creek yielded the highest concentrations for most analytes, including the only detection of mercury. Additionally, several herbicides, the pesticide DDT, and a PCB cogner (Aroclor 1260) were detected in Butler Creek. Mean sediment TOC concentrations were highest in Butler Creek (36.1 g/kg) and RM 179 (8.75 g/kg), and lowest at RM215 (0.15 g/kg).

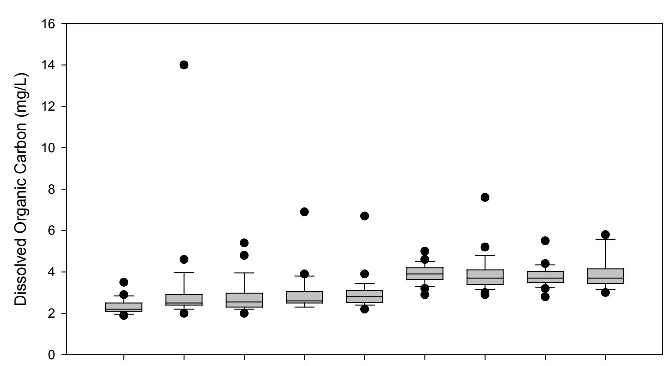

Figure 3. Box plot of dissolved organic carbon concentrations by river mile.

Macroinvertebrates

Mean macroinvertebrate densities generally increased in the downstream direction, with the lowest densities at RM 215 and RM 202, and highest densities at RM 148 (Figure 4). Similarly, the mean number of EPT taxa increased in the downstream direction, with the highest numbers at RM 148. Ephemeroptera (mayfly) taxa increased in the downstream direction, with a maximum at RM 61. Mean Trichoptera (caddisfly) diversity was lowest in Stevens Creek and highest at RM 148.

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 (below NSBLD), with the lowest and highest densities at RM 198 and RM 148, respectively. The highest mean Trichoptera numbers were seen at RM 185 and RM 148 for every sampling event.

Mean Plecoptera (stonefly) diversity was lowest at Stevens Creek, Butler Creek, RM 202, and RM 198, and highest at RM 61. Mean Plecoptera density was highest at RM 61. Additionally, Pteronarcyid Plecopterans were collected at RM 61 in December of 2007 and at RM 119 in January of 2008.

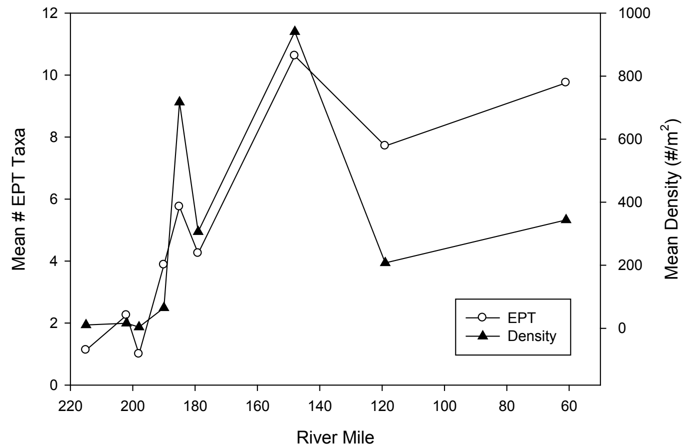

Figure 4. Mean number of EPT taxa and density by river mile.

DISCUSSION

This study was conducted during a significant drought, during which the USACE curtailed releases from Thurmond Dam and river discharge was well below the long-term averages for much of the study period, especially in late summer and early fall. As such, this period represents a potential "worst-case" scenario during which the assimilative capacity of the river receiving inputs from the CSRA would theoretically be lowest.

Continuous monitoring data revealed that dissolved oxygen levels were well above state standards at all mainstem river stations except RM215, seven miles downstream of Thurmond Dam. The USACE has upgraded its turbines at Thurmond Dam such that they can aerate the hypoxic hypolimnetic releases enough to meet dissolved oxygen standards in the tailrace, which represents a marked improvement over historical conditions. However, once generation ceases, dissolved oxygen levels in this reach fall below the standards.

Low dissolved oxygen levels at the Stevens Creek station were likely due to Thurmond Dam releases and the operation of Stevens Creek Dam, which result in daily flow reversals that extend up to eight miles upstream of the Creek's confluence with the Savannah River. We documented that, upstream of this reach, dissolved oxygen levels were above state standards. Low dissolved oxygen levels at the Butler Creek station were due to a variety of factors, including treated wastewater inputs, organic matter inputs from Phinizy Samp, backwater effects of the levee gates, and a dense tree canopy that limits in-stream production.

Diurnal patterns of simultaneous dissolved oxygen supersaturation and elevated pH levels at RM202 indicate high levels of photosynthetic activity within the shoals. Supersaturated conditions at RM185 were likely due to physical aeration as water flowed over NSBLD and, to a lesser extent, photosynthetic activity.

Downstream of RM185, dissolved oxygen concentrations decreased steadily before leveling off at RM61. This was likely due to a variety of factors, including decreased water clarity and associated lower P-R ratios, increased water temperature, and inputs from tributaries and adjacent floodplain wetlands. However, sites downstream of RM185 were consistently at or above 80% dissolved oxygen saturation (~7 mg/L).

Biochemical Oxygen Demand (BOD_5) tests yielded few results above the quantitation limit (2 mg/L) for mainstem river samples. Concentrations of oxygen-demanding constituents (according to the BOD data) did not increase significantly within or downstream of the Augusta area. Increases in organic carbon between RM185 and RM179 are likely attributable to the pulp and paper mill discharge located at RM183. Since organic carbon levels did not change between RM179 and RM61, watershed inputs within that reach are insufficient to result in measureable changes to river concentrations.

Since macroinvertebrates are considered indicators of water quality impairment (Lenat, 1993), our data seem to indicate that water quality improves steadily downstream of Thurmond Dam. However, the increases in both density and diversity of EPT taxa may suggest improvements in *carbon* quality and food availability. Preliminary data suggest that these increases are fairly linearly related to increases in particulate organic matter in the river.

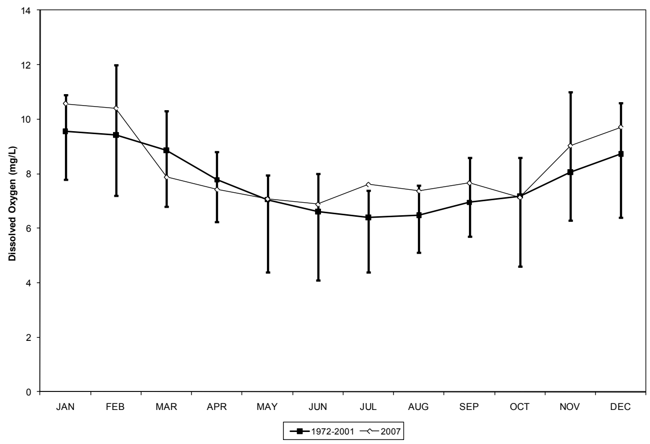

Figure 5. Comparison of long-term and 2007 dissolved oxygen levels at RM61. Vertical bars represent long-term maxima and minima. (Long-term data source: USGS, 2010)

CONCLUSIONS

The CSRA urban corridor has several effects on the chemistry and biology of the Savannah River. Conductivity and organic carbon both increase downstream of Augusta. However, river regulation by dams has resulted in stable water levels within the shoals which allow autotrophic communities to persist there. As a result, dissolved oxygen levels below the shoals are consistently supersaturated. Additionally, the chain of ACOE lakes upstream of the CSRA appear to remove virtually all particulate organic carbon, and effectively provide the urban corridor with a relatively clean but barren supply of water. Future research should focus on the ecological effects of this “resetting” of the stream continuum and its effects on the ecology of the river. Additionally, the nature of natural and anthropogenic inputs should be investigated to determine their relative contributions level of lability/recalcitrance.

Compared to historical data, the period of drought experienced in 2006 and 2007 did not appear to result in any significant dissolved oxygen issues. In fact, dissolved oxygen levels at RM61 were at or above long-term monthly averages for most months (Figure 5). Conversely, the low flow periods may have exacerbated the transport of certain metals to levels that exceeded toxicity limits.

Perhaps one of the most important conclusions that can be drawn from this effort is the importance and value of continuous monitoring. Most regulatory monitoring occurs on an infrequent basis, typically monthly or bimonthly. While this frequency may enable the detection of serious problems, especially with respect to dissolved oxygen, it does not allow for an adequate assessment of whether standards are being met. Our continuous monitoring revealed that, although modifications at Thurmond Dam have resulted in improvements to dissolved oxygen levels downstream, significant periods of low dissolved oxygen are still being experienced.

ACKNOWLEDGMENTS

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