Georgia Journal of Science

Volume 74 *No. 2 Scholarly Contributions from the Membership and Others* | Article 8

2016

Water Quality and Fecal Coliform Levels in Georgia Oxbow Lakes Relative to Connectivity with the Savannah River

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Cover Page Footnote

This research was sponsored by The Citadel Biology Department. Also, this research was permitted through Georgia's Department of Natural Resources – Tuckahoe Wildlife Management Area Division.

WATER QUALITY AND FECAL COLIFORM LEVELS IN GEORGIA OXBOW LAKES RELATIVE TO CONNECTIVITY WITH THE SAVANNAH RIVER

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ABSTRACT

The state of Georgia has many bodies of water that provide important wildlife habitats as well as recreational opportunities. The objective of the current study was to investigate water quality and fecal coliform levels in oxbow lakes relative to their connectivity to the Savannah River. For most water quality parameters, no significant differences were observed between the Savannah River and the oxbow lakes. However, pH and turbidity values were lower in the oxbow lakes (both connected and disconnected) relative to the Savannah River. Fecal coliform values between connected oxbow lakes and the Savannah River were similar to each other and significantly higher than those of the disconnected oxbow lake. The results suggest that fecal coliform levels of oxbow lakes along the Savannah River are influenced by their connectivity to the river. Furthermore, these results indicate a potential health risk for human contact with water located in connected oxbow lakes and the Savannah River.

Keywords: oxbow lakes, water quality, fecal coliform, Savannah River

INTRODUCTION

Rivers, totaling 12,000 miles, have played a vital role in the history and development of the state of Georgia (Discover Scenic 1999). Throughout history, these rivers have been major sources of drinking water, navigation, and recreation (McCallister 2014). One particular river, the Savannah, forms most of the border between the states of Georgia and South Carolina. The main ecosystem that is found in the Savannah River floodplain is that of oxbow lakes. The majority of oxbow lakes are formed by natural transformations such as erosion, flooding, or accumulation, with their curved, u-shape being their most prominent attribute (Obolewski 2011). The constitution of these lakes encompasses a relatively narrow width in relation to their length, with bottoms composed of sediments that correspond closely to their connected river's current state, or state before disconnection (Obolewski 2011). Oxbow lakes have proven to be very interesting research objects due to the diversity between the connected and disconnected ecosystems (Obolewski 2011). For connected oxbow lakes, water quality mainly depends on the quality of the connected river, while disconnected oxbow lakes become closed entities (Lewis et al. 2000; Cullum et al. 2006).

Hydrological connectivity between an oxbow lake and the river is the governing factor that influences the environment of the oxbow lake (Obolewski 2011). The Savannah River impacts the ecosystems and biodiversity of each adjacent oxbow lake. These lakes are classified as either lentic (disconnected) or lotic (connected) in relation

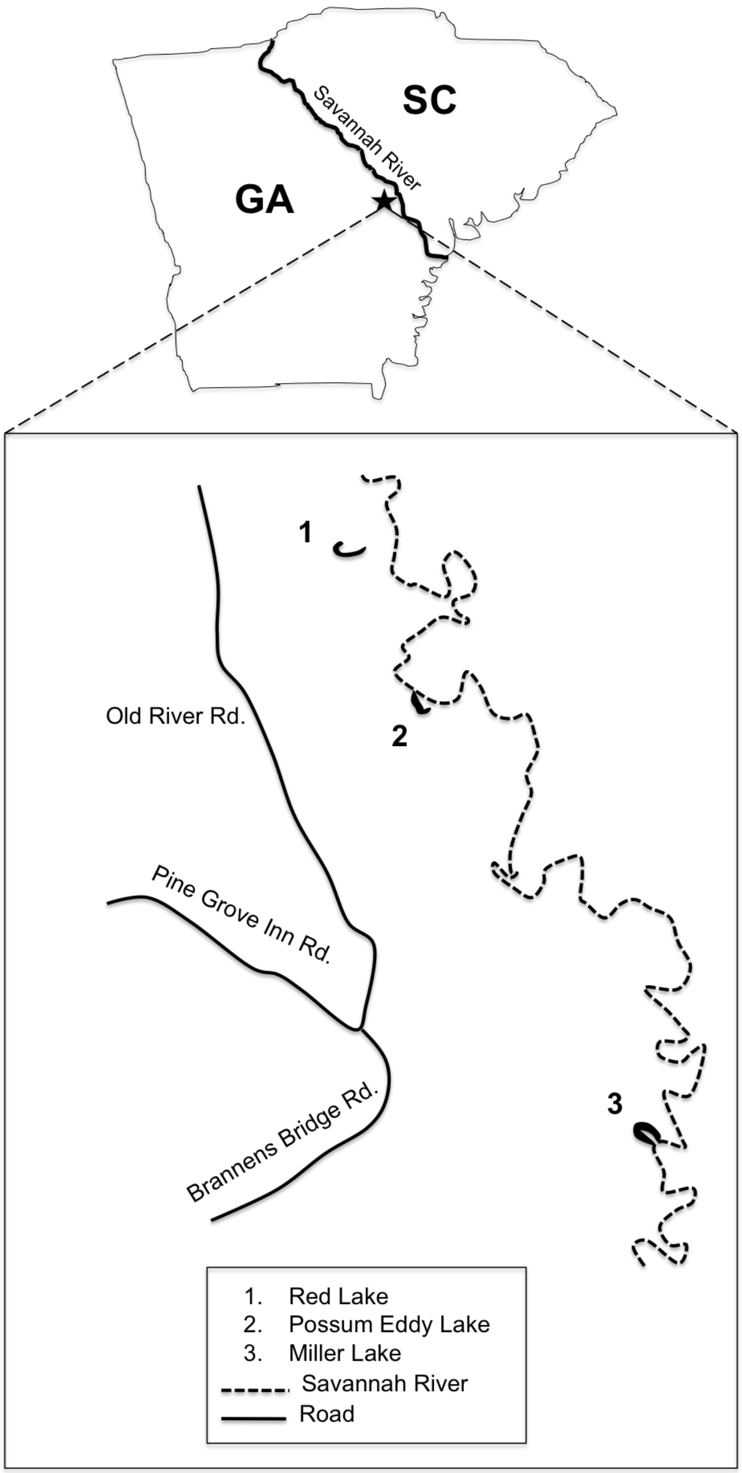

Figure 1. Tuckahoe Wildlife Management Area (WMA); the numbers represent the oxbow lakes that samples were taken from, and show their location in relation to Savannah River; the star within the state of Georgia represents where WMA is in relation to the Savannah River.

to the Savannah River (Obolewski 2011). Van den Brink (1991) showed that hydrological conditions (connected or disconnected) influence the water quality of oxbow lakes. Isolated conditions, as seen in disconnected oxbow lakes, can cause changes in physical and chemical characteristics of the water (Cullum et al. 2006). Water quality is undeniably important to the environment, but also to human health. For instance, low oxygen can result in the production of toxic ammonia that can lead to the death or decline of organisms in that environment. Another important indicator of water quality is the level of fecal coliform bacteria. The presence of fecal coliform indicates that contamination has occurred either via humans or animals. Research has shown that increasing fecal coliform levels negatively impact human health (Gregory 2000).

The objective of this study was to investigate water quality and fecal coliform levels in oxbow lakes relative to their connectivity with the Savannah River. The Tuckahoe Wildlife Management Area (WMA) in Sylvania, Georgia (Figure 1), contains numerous oxbow lakes, both connected and disconnected, allowing it to serve as the ideal place to study water quality and fecal coliform levels in oxbow lakes relative to their connectivity with the Savannah River. The lakes in this study are all classified as *recreational* by the state of Georgia, meaning they can have primary (swimming) and secondary (fishing) human contact. As such, fecal coliform levels during summer months are not to exceed 200 colony-forming units (CFU) 100 mL^{-1} sample and, during winter, are not to exceed 1100 CFU 100 mL^{-1} sample (McCallister 2014).

MATERIALS & METHODS

The locations in which surface water samples were collected were the Savannah River (Burton's Ferry Landing), two connected oxbow lakes (Possum Eddy and Miller Lake), and one disconnected oxbow lake (Red Lake) (Figure 1). Samples for water quality parameters were collected in a 100 mL sterilized container during the months of June and July 2013, and analyzed with an Oakton Model 100 meter for *dissolved oxygen*, a Hach test kit model AL-DT for *alkalinity*, a Hach test kit model HA-DT for *hardness*, a Thermo Orion model 230-A meter for *conductivity*, a LaMotte model 200 meter for *turbidity*, and an Oakton waterproof EcoTestr pH 2 meter for *pH*; for a total of six water quality parameters studied. Dissolved oxygen, conductivity, turbidity, and pH were tested upon immediate retrieval of water sample. Alkalinity and hardness were tested for within 1 hr of retrieval of the water sample. Fecal coliform bacteria measurements were obtained from two samples collected during August 2013, two samples collected during October 2013, and one collected during February 2014 (Table I).

Table I. Sample Collection Dates: Water sample collection dates for water quality parameters and fecal coliform bacteria.

	Month			
Sample Type	July	August	October	February
Water Quality	11-Jul-13	5-Aug-13		
	14-Jul-13	9-Aug-13		
	20-Jul-13	12-Aug-13		
Fecal Coliform (MPN)		2-Aug-13	21-Oct-13	1-Feb-14
		14-Aug-13	27-Oct-13	

The samples for fecal coliform testing were also collected in a 100 mL sterilized container and placed into a cooler on ice for 4-6 hrs before they were used for fecal coliform measurement via the most probable number (MPN) test, which measures CFU 100 mL^{-1} sample. The MPN tests were set up within 6 hrs of the initial sample collection. The multiple-tube fermentation technique with A-1 medium was used for each MPN test following the procedure in *Standard Methods for the Examination of Water and Wastewater* (Standard Methods 2013). The standard procedure called for the five tubes and five dilutions (10 mL, 1 mL, 0.1 mL, 0.01 mL, 10^{-3} mL) per site. All tubes contained 10 mL of A-1 medium with five tubes containing double strength A-1 medium. The correct volume (10 mL, 1 mL, 0.1 mL, 0.01 mL, and 10^{-3} mL) of sample was added to appropriate tubes. The A-1 tubes were incubated in a 35 ^{o}C water bath for 3 hrs. Then, they were incubated in a 44.5 ^{o}C water bath for 21 +/- 2 hrs. The number of positive tubes with gas production was observed for each site where a sample was collected. The combination of positive tubes was then compared to an MPN table to determine MPN value for each sample. Most probable number values during summer months are not to exceed MPN 200 CFU 100 mL^{-1} sample and, during winter, are not to exceed MPN 1100 CFU 100 mL^{-1} sample.

After the MPN value had been determined, a loop full of broth from the positive A-1 tubes was streaked onto separate violet red bile agar (VRBA) plates for colony isolation. Plates were then incubated at 35-37 ^{o}C for 16-24 hrs. Nutrient agar plates with 4-methylumbelliferyl-beta-D-glucuronide (MUG) (NA/MUG) were divided into quarters, and 16 isolated colonies from the VRBA plates were streaked onto NA/MUG. NA/MUG plates were then incubated at 35-37 ^{o}C for 16-24 hrs. The presence or absence of blue fluorescence was determined under a long-wave UV light. Fluorescence indicated the presence of *E. coli*. *Escherichia coli* ATCC 25922 and *Enterococcus faecalis* ATCC 19433 were used as positive and negative controls, respectively, for all tests.

In order to determine if there were any differences in the water quality parameters or fecal coliform levels between the Savannah River and that of the connected and disconnected lakes, statistical analyses were performed and compared to USEPA guidelines (State Standards 2015). A $\log_{10}$ transformation was performed on all of the data in order to meet the assumptions of normality. One-way analysis of variance (one-way ANOVA) tests, followed by the Ryan-Einot-Gabriel-Welsch (REGWQ grouping) multiple comparison tests were used to compare the water quality parameters and fecal coliform values (MPN) of the Savannah River, connected oxbow lakes, and disconnected oxbow lake (Table II).

Table II. REGWQ Test: Ryan-Einot-Gabriel-Welsch multiple comparison test; this was used to compare the water quality parameters and MPN values of the Savannah River and connected and disconnected oxbow lakes. The same letter indicates that the groups do not differ significantly; different letters mean the groups differ significantly (DO = dissolved oxygen, FC = fecal coliform, Cond. = Conductivity, Turb. = Turbidity).

Sample Sites	Cond.	DO	Turb.	Alkalinity	pH	Hardness	FC
Savannah River	A	A	A	A	A	A	A
Connected Oxbow Lakes	A	A	B	A	B	A	A
Disconnected Oxbow Lake	A	A	B	A	B	A	B

RESULTS

For most, but not all, water quality parameters, there was no significant difference observed between the Savannah River, the connected oxbow lakes, and the disconnected oxbow lake (Figure 2). Dissolved oxygen content ranged from 5.35 mg/L in the Savannah River, to 5.2 mg/L in the connected oxbow lakes, to 5.19 mg/L in the disconnected oxbow lake. There was no significant difference ($p = 0.96$) between dissolved oxygen content in the Savannah River and the oxbow lakes. Likewise, alkalinity ranged from 24.5 mg/L in the Savannah River, to 22.25 mg/L in the connected oxbow lakes, to 22.3 mg/L in the disconnected oxbow lake. There was no significant difference ($p = 0.41$) between the alkalinity in the Savannah River and the

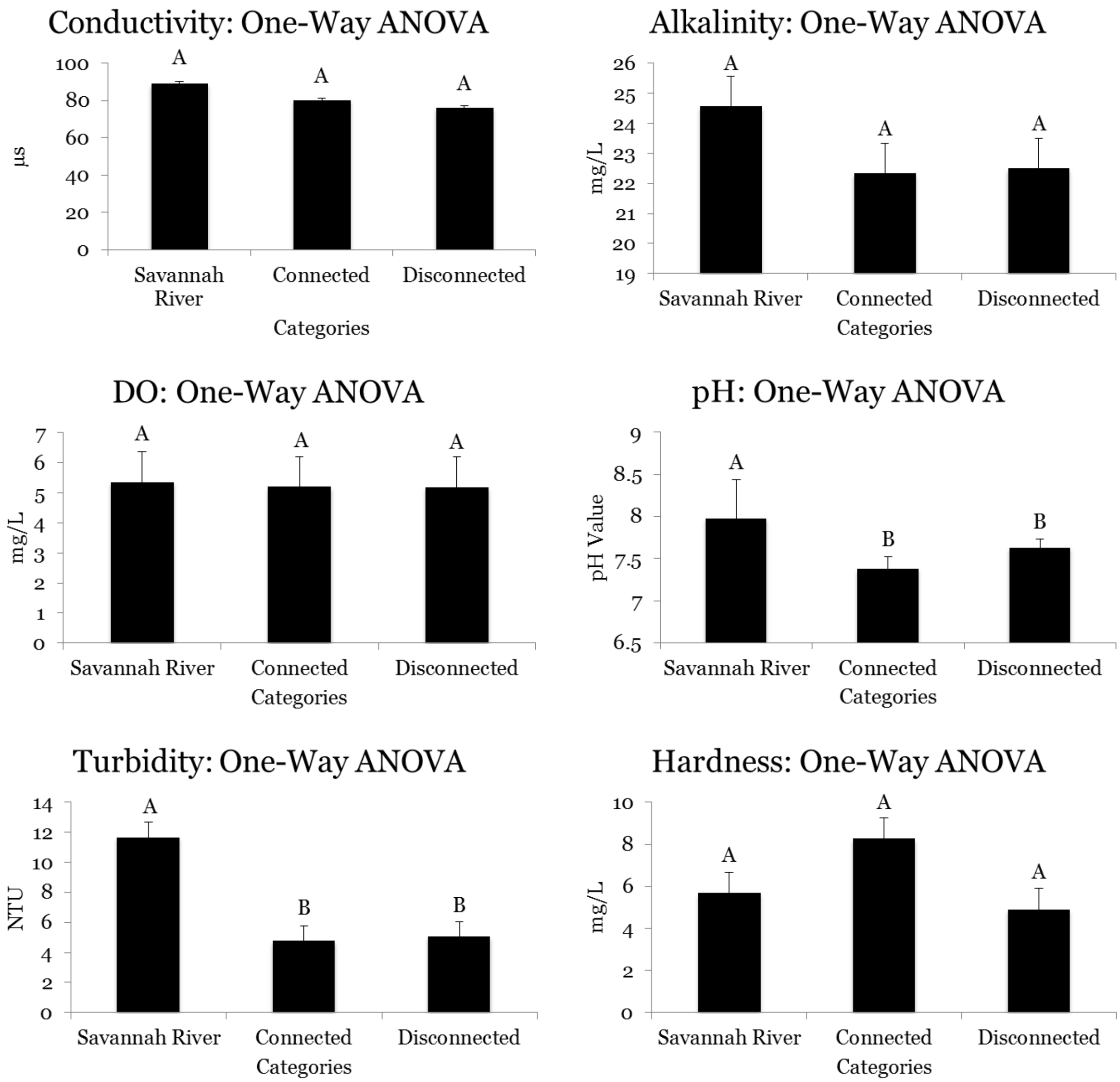

Figure 2. Values represent mean + standard error; groups that have the same letter (e.g. A or B) do not differ significantly, while groups that have different letters do differ significantly. From top left, down the column: conductivity (no significant difference based on connectivity with the Savannah River, $p = 0.56$); dissolved oxygen (no significant difference based on connectivity with the Savannah River, $p = 0.96$); turbidity (a significant difference was observed between oxbow lakes and the Savannah River, $p < 0.0001$). From top right, down the column: alkalinity (no significant difference based on connectivity with Savannah River, $p = 0.41$); pH (a significant difference was observed between oxbow lakes and the Savannah River, $p = 0.01$); hardness (no significant difference based on connectivity with Savannah River, $p = 0.07$). Categories are as follows: Savannah R. = Savannah River, Connect = oxbow lakes connected to the Savannah River, and Disconnect = oxbow lake not connected to the Savannah River.

oxbow lakes. Hardness values ranged from 5.5 mg/L in the Savannah River, to 8 mg/L in the connected oxbow lakes, to 5 mg/L in the disconnected oxbow lake. There was no significant difference ($p = 0.07$) in hardness between the Savannah River and the oxbow lakes. Similarly, conductivity ranged from 85 μS in the Savannah River, to 75 μS in the connected oxbow lakes, to 70 μS in the disconnected oxbow lake. There was no significant difference ($p = 0.56$) in conductivity between the Savannah River and the oxbow lakes.

By contrast, there was a significant difference in turbidity ($p < 0.001$) and pH ($p = 0.0076$) between the Savannah River, the connected oxbow lakes, and the disconnected oxbow lake. Turbidity ranged from 11.5 NTU in the Savannah River, to

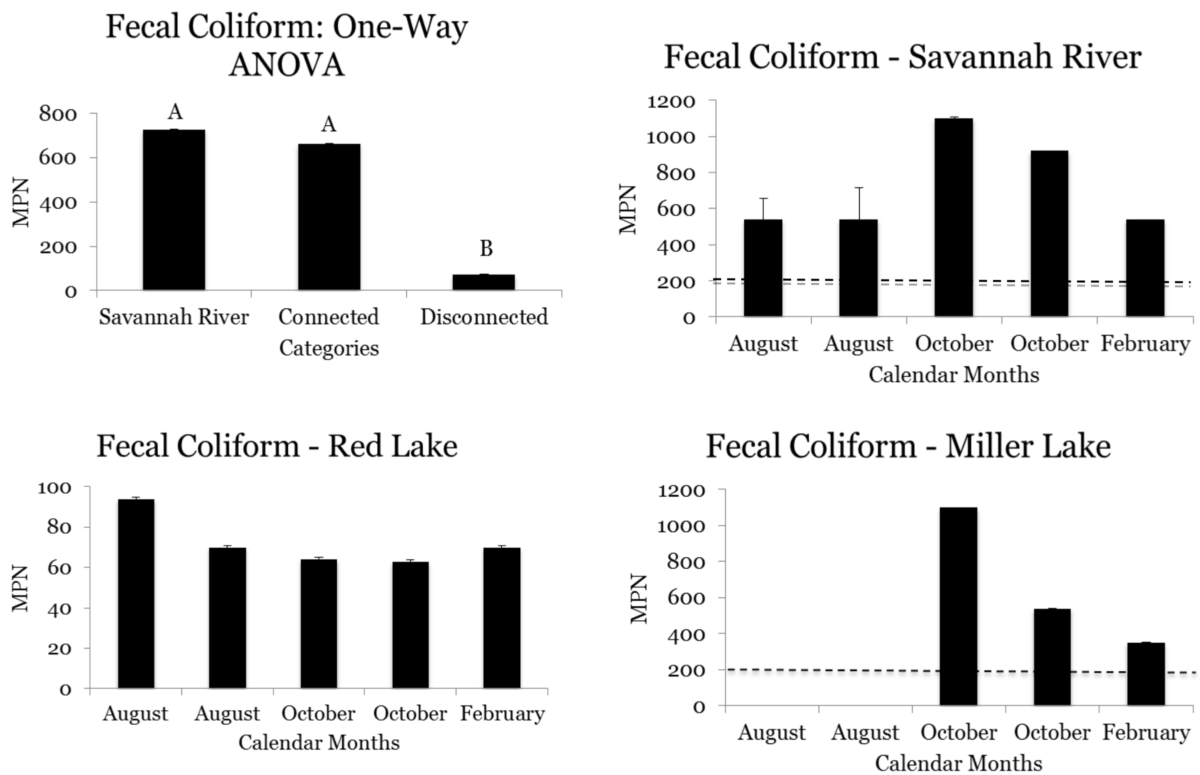

Figure 3. Fecal coliform values represent mean + standard error; groups that have the same letter (e.g. A or B) do not differ significantly, while groups that have different letters do differ significantly. From top left, down the column: total fecal coliform levels for the Savannah River, connected and disconnected oxbow lakes; fecal coliform levels for Red Lake (disconnected oxbow) from August 2013-February 2014 (difference based on connectivity with Savannah River, $p < 0.0001$). From top right, down the column: Savannah River fecal coliform levels from August 2013-February 2014; Miller Lake (connected oxbow) fecal coliform levels from August 2013-February 2014. Categories are as follows: Savannah R. = Savannah River, Connect = oxbow lakes connected to the Savannah River, and Disconnect = oxbow lake not connected to the Savannah River. Months are Aug = August, Oct = October, Feb = February. Dashed horizontal lines represent the Georgia recreational limit (200 CFU 100 mL^{-1}) for fecal coliform values.

NTU in the connected oxbow lakes, to 5 NTU in the disconnected oxbow lake. The pH values ranged from 7.9 in the Savannah River, to 7.4 in the connected oxbow lakes, to 7.55 in the disconnected oxbow lake (Figure 2). The difference in turbidity could have implications on fecal coliform levels in these bodies of water.

When comparing fecal coliform MPN values between the Savannah River, the connected oxbow lakes, and disconnected oxbow lake, a significant difference was observed. MPN values (Figure 3) ranged from 1050 CFU 100 mL^{-1} sample in the Savannah River, to 1000 CFU 100 mL^{-1} sample in connected oxbow lakes, to 90 CFU 100 mL^{-1} sample in the disconnected oxbow lake. These results display a significant difference ($p < 0.001$) in fecal coliform between the Savannah River and the disconnected oxbow lake. In the Savannah River, fecal coliform levels were highest (1100 CFU 100 mL^{-1} sample) in the month of October 2013, and lowest (510 CFU 100 mL^{-1} sample) in the month of February 2014. In connected oxbow lakes, fecal coliform levels were highest (1100 CFU 100 mL^{-1} sample) in the month of October 2013, and lowest (375 CFU 100 mL^{-1} sample) in the month of February 2014. In the disconnected oxbow lake, fecal coliform levels were highest (90 CFU 100 mL^{-1} sample) in the month of August 2013, and lowest (60 CFU 100 mL^{-1} sample) in the month of October 2013.

DISCUSSION

Water quality parameters in both connected and disconnected oxbow lakes shared similar values with the Savannah River, suggesting that connectivity has minimal influence on overall water quality of oxbow lakes. However, turbidity and pH values were similar in both connected and disconnected oxbow lakes, and varied from those of the Savannah River, suggesting that these parameters may be more influenced by local factors (e.g. habitat) or type of water body (e.g. swift moving river vs. stagnant lake).

The pH values recorded for each site were all above neutral (pH = 7), meaning the water at these locations was more basic than acidic. Fish can normally survive only in these types of waters (Hirate et al. 2002). Fluctuation in pH in either direction could be harmful to the aquatic organisms present; a decrease in pH could increase the amount of metals released into the environment, which can have negative effects on fish metabolism, while an increase in pH could result in the conversion of ammonium to toxic ammonia (NH_3), which kills fish. There are a variety of epithelial cell types in fish gills, with functions ranging from gas exchange, ion regulation, and inhibiting metabolic acidosis and alkalosis (Goss et al. 1992; Evans 1998; Claiborne et al. 2002). If a fish is exposed to acidic waters (low pH) it will affect the number and distribution of chloride cells within their gills, which can then lead to loss of sodium chloride, acidification of plasma, and can eventually lead to fish death (Wendelaar et al. 1990).

Research has shown that oxbow lakes tend to have high levels of turbidity, which correlates to decreased clarity of a liquid (Obolewski 2011; Rainfall Scorecard 2013). High levels of turbidity in oxbow lakes can occur due to excessive soil erosion from increased rainfall or high river levels (Obolewski 2011; Cullum et al. 2006). In Georgia during 2013, the average rainfall was 166 cm resulting in the Savannah River at Burton's Ferry entering "flood stage" (Rainfall Scorecard 2013; Flood Warning 2015). This amount of rainfall and rise in Savannah River water level could be the principle factor influencing high turbidity in the oxbow lakes.

When turbidity is high, light penetration and productivity, recreational values, and habitat quality can be negatively affected (Bacterial Water 2003). Bodies of water that have increased turbidity will reflect an increase in water temperature, which has a negative impact on the dissolved oxygen content (Mitchell 1992). Also, dissolved oxygen content can be lowered based on the reducing effect that turbidity has on photosynthesis (Mitchell 1992). Other research has shown that reduced dissolved oxygen content decreases the survival of fecal coliform bacteria in an aquatic environment (Curtis et al. 1992). However, the results from this study do not show this trend. Instead, they suggest that the higher the turbidity, the higher the dissolved oxygen, along with the higher the fecal coliform. This could be due to the fact that the water samples were taken from the surface level, which contains the most oxygen because this is where oxygen-producing processes take place (Volunteer Water 2007). Nevertheless, these results suggest that *high turbidity influences fecal coliform growth*; the Savannah River showed the highest turbidity along with the highest levels of fecal coliform. The disconnected oxbow lake showed significantly lower turbidity compared to that of the Savannah River, along with the lowest levels of fecal coliform.

High turbidity could be used as an indicator, in aquatic environments, for potential human health threats due to the fact that this study demonstrated high turbidity correlating with high fecal coliform populations. The presence of fecal coliform in recreational waters means that human or animal waste is present, which does not necessarily mean a person will experience illness; however, it does present the stage for other disease-causing organisms to be present (Coliform Bacteria 2014). In recreational waters, if fecal coliform exceeds MPN 200 CFU 100 mL^{-1} sample during the summer months, or MPN 1100 CFU 100 mL^{-1} sample during the winter months, the waters are banned from use (McCallister 2014). Fecal coliform levels were above the limit for recreational use in the Savannah River and connected oxbow lakes during the summer months of 2013. In contrast, fecal coliform levels were below the limit in the disconnected oxbow lake throughout the entire sampling period (Table I). The one-way ANOVA and REGWQ grouping results suggest that fecal coliform levels may be influenced by connectivity to the Savannah River (Table II). In other words, the high levels of fecal coliform in the Savannah River could be contaminating the connected oxbow lakes, potentially via increased turbidity, thereby posing a threat to human health.

Glinska-Lewczuk (2009) notes that the lack of permanent connection between oxbow lakes and rivers limits an exchange of organic matter and nutrients only to the periods of raised water levels and floods. According to the *flood pulse* theory, alternating periods of floods and stream flow favor decomposition and the circulation of nutrients, which increase biological diversity and productivity (Zalewski 2006). Even though this study demonstrated that most water quality parameters were within state guidelines, turbidity and fecal coliform levels presented a different story. In the case of the Savannah River, periodic flooding may negatively impact oxbow lakes via increased turbidity and fecal coliform levels. Similar to Glinska-Lewczuk (2009), Obolewski (2011) suggested that permanent oxbow-river connection would be beneficial to the surrounding habitat. However, the results of this study suggest that reestablishing an oxbow lake connection or having a current oxbow lake connection to the Savannah River adversely impacts those lakes by causing an influx of fecal coliform bacteria, and increased turbidity, leading to potential human health risks. Since humans have frequent contact with the water in these oxbow lakes through recreational activities, the fecal coliform and turbidity results from this study indicate a potential health risk for individuals exposed to the water in the connected oxbow lakes and the Savannah River.

When analyzing water quality of recreational waters, human health has to be taken into consideration. The Savannah River, a major recreational site in Georgia, contains high levels of fecal coliform bacteria, and high turbidity levels that could harbor disease producing bacteria or viruses (Coliform Bacteria 2014), and lead to waterborne disease outbreaks (Bacterial Water 2003). Fecal coliform levels in the connected oxbow lakes are a direct reflection of those of the Savannah River, suggesting that connectivity with the Savannah River negatively impacts the connected oxbow lakes, which are also labeled for recreational use. Not only could these high levels of fecal coliform harm humans, but they could also lead to the elimination of organisms linked with these aquatic environments. Routine evaluations of these waters need to be implemented in the future.

Furthermore, future studies should focus on the temperature relative to water surface samples, the level of oxbow-river connection, species diversity (Shannon diversity index), source of fecal coliform, Savannah River water level, and amount of rainfall. Methods for lowering fecal coliform content could be used to improve the water quality in the Savannah River, while simultaneously improving the water quality of all connected oxbow lakes, thus creating environments less harmful to humans and organisms associated with these bodies of water.

ACKNOWLEDGEMENTS

This research was sponsored by The Citadel Department of Biology. Also, this research was permitted through Georgia’s Department of Natural Resources – Tuckahoe Wildlife Management Area Division.

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