Long-term and Two-period Analysis of Hydrologic Conditions of the South Edisto River

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Abstract. The U.S. Geological Survey (USGS) long-term daily streamflow record at station 02173000 in Bamberg County, South Carolina on the South Fork Edisto River (Latitude 33°23'35", Longitude 81°08'00" NAD27) spans from 1932 to 2015 and was used for this study. The Nature Conservancy's Indicators of Hydrologic Alteration (IHA) software was used to analyze the entire record of hydrologic data as ecologically relevant parameters and to categorize the flows. A two-period analysis was conducted to evaluate whether a significant difference could be observed in historic flow data from 1932–1985 (period one) compared to 1986–2015 (period two). An extreme low flow was defined as an initial low flow below 10% of daily flows for the period. Over the entire 76-year period of record, 51 years had at least one occurrence of extreme low flows. A median of 4 days per year had occurrences of extreme flows in period one in contrast to a median of 60 days per year during period two. Annual precipitation totals were not correlated with the number of days per year with extreme low flows. The two-period analysis showed significant differences between period one and period two for monthly mean flow for February, April, May, and August, as well as for 1-day and 30-day minima and maxima values. The analysis calculated the 7Q10 (the lowest stream flow for seven consecutive days that would be expected to occur once in ten years) at 4.4 cubic meters per second (cms), which was -10.9% different from the most recently published estimate. Results presented in this study have shown that spring and summer flows in the South Fork Edisto are statistically significantly lower in period two compared to period one.

INTRODUCTION

The South Fork Edisto River and the Edisto River provide valuable recreational opportunities for the public and economic opportunities for industry; however, this valued resource may be in decline. To effectively manage water resources and understand whether current policies are preserving the resource for public, industrial, and ecological uses, decision and policy makers must have information on historic streamflow conditions to compare to existing conditions, especially during periods of low flow. Therefore, the USGS long-term daily streamflow record at station 02173000 (South Fork Edisto River at the Highway 321 bridge near Denmark, South Carolina) was used to conduct a two-period analysis to evaluate whether a significant difference in historic flow data could be observed in period one as compared to period two. Accounting for historic conditions and departures from normal flows is critical to decision making with regards to water withdrawal policy.

PROJECT DESCRIPTION

BACKGROUND

The Edisto River is the longest (approximately 400 kilometers [Marcy and O'Brien-White, 1995]) free-flowing blackwater river system in the United States. The basin is located in the Coastal Plain Physiographic Province of South Carolina (SC). The South Fork Edisto River begins in the upper Coastal Plain Physiographic Province east of Edgefield, SC, and converges with the North Fork Edisto River near the town of Branchville, SC, to form the Edisto River. The river continues south and east through the lower Coastal Plain Physiographic Province and joins the Atlantic Ocean at Edisto Island, south of Charleston, SC (Feaster and Guimaraes, 2012).

This river, combined with the Ashepoo and Combahee, is referred to as the "ACE" basin and was considered one of the most pristine coastal plain watersheds in the southeastern United States in the late 1990s (NMFS, 1998). Extensive adjacent wetlands and large tracts of forestland within the river

basin have kept water quality relatively high, supporting an abundance of aquatic life. According to respondents in a 1995 State survey, the Edisto River was ranked as the number one river fished with an economic worth of over 1 million dollars annually (Marcy and O'Brien-White, 1995). The economic worth in today's dollars would be 1.6 million (Bureau of Labor Statistics, 2016). The Edisto fishery is diverse, with a high percentage of indigenous species (SCDNR, 1996). SC's State Wildlife Action Plan (2015 revision) identified 16 freshwater fish and 13 mussels of highest conservation priority. Of the state's highest conservation priority species, eight fish species inhabit the Edisto basin (SCDNR, 2015; Marcy and O'Brien-White, 1995) and three mussel species inhabit the ACE basin (SCDNR, 2015). The federally listed aquatic species occurring in the Edisto basin include the endangered Atlantic sturgeon and shortnose sturgeon (USFWS, 2016).

In 2014, American Rivers included the South Fork Edisto River on its annual Most Endangered Rivers list (American Rivers, 2016). In 2015, this listing was extended to the entire Edisto River. American Rivers identified excessive water withdrawals as the main threat to fish and wildlife habitat, recreation, and water quality (American Rivers, 2015). Anecdotal accounts from recreational users of the South Fork Edisto have suggested that over their lifetimes, the once completely fishable, swimmable, and navigable river is now characterized by greatly diminished recreational opportunities for boating, fishing, and swimming.

RELATED WORK

Differing approaches are used to evaluate changes in hydrologic conditions. Many of these approaches are evaluated and discussed by Gao et al. (2009). Shiau and Wu (2004) compared flow conditions before and after weir construction using the parameters generated by the Indicators of Hydrologic Alteration (IHA), with an approach developed by The Nature Conservancy (Richter et al., 1996; Richter, Baumgartner, Wigington, and Braun, 1997; Richter, Baumgartner, Braun, and Powell, 1998). Poff, et al. (2009) developed an alternate method called the ecological limits of hydrologic alteration (ELOHA) as a framework for developing regional environmental flow standards and detecting hydrologic alteration. Finally, others, such as Sun and Feng (2012), have used a combination of statistical methods and multistage hydrologic analysis to identify temporal variability in the flow regimes of the Yellow River in China.

In the southeast, one study on the Satilla River, in Georgia (Elkins, 2001) and a study on the Trinity River basin in Texas (Kiesling, 2003) utilized the IHA to investigate the potential of human-altered flow regimes. Two studies have investigated the hydrology of the South Fork Edisto at USGS station 02173000. Marshall (1993) completed an analysis of the single-mass curves of precipitation and streamflow for USGS station 02173000 during the period

1939 to 1990, indicating that changes in streamflow were the result of changes in precipitation. Feaster and Guimaraes (2012) compiled previously published values for low-flow frequency and flow duration for continuous-record stream gaging stations including USGS station 02173000 and other stations in the Saluda, Congaree, and Edisto River basins. The annual minimum 7-day average streamflow with a 10-year recurrence interval (7Q10) for station 02173000 was found to decrease during the 1970–2012 period from 6.0 cms (Bloxham, 1979) to 5.7 cms (Zalants, 1991) and finally to 5.0 cms (Feaster and Guimaraes, 2012).

EXPERIMENTAL DESIGN

The USGS long-term daily streamflow record at station 02173000 (South Fork Edisto River at the Highway 321 bridge near Denmark, South Carolina) was used to conduct a two-period analysis to evaluate whether a significant difference in historic flow data could be observed from period one compared to period two. For this analysis, values ≤ 0.05 indicate that the difference between periods is highly significant; the significance count can be interpreted similarly to a p-value in parametric statistics (TNC, 2009). Therefore, the difference in the 12 monthly means/medians and 1-day and 30-day minima and maxima between periods were significant if the significance counts were ≤ 0.05 .

METHODS

The USGS long-term daily streamflow record of the South Fork Edisto River (Latitude 33°23'35", Longitude 81°08'00" NAD27) at station 02173000 in Bamberg County, South Carolina, spans from 1932 through 2015 (with a data gap from 1972–1980 due to equipment failure). This streamflow record was used to evaluate the flow alterations associated with human perturbations, such as water withdrawals or global climate change. Station 02173000 is in hydrologic unit code 03050204, the gage datum is 47.45 meters above NGVD29, and the drainage area is 1,865 km² (Feaster and Guimaraes, 2012). The IHA software was used to analyze the entire record of hydrologic data as ecologically relevant parameters and to categorize flows as large floods, small floods, high flow pulses, low flows, or extreme low flows (TNC, 2009). According to the IHA recommendation (based on Richter et al., 1997), at least 20 years of daily records should be used to analyze hydrologic alterations for each period of interest. Also, the USGS characterizes stream gages as long term when the period of record is 30 years or greater (USGS, 2016a). The highest land use/land cover in watershed 03050204-03 is agricultural land (40.2%) (SCDHEC, 2012). In the past 30 years, the population and number of hectares under irrigation in the southeast has grown considerably (Mullen, 2009).

Figure 1. Environmental flow components analysis.

LONG-TERM HYDROLOGIC RECORD ANALYSIS

Basic statistics (count, mean, median, minimum, and maximum) for the long-term hydrologic record were calculated for the 12 monthly means/medians and 1-day and 30-day minima and maxima. The monthly means/medians capture one aspect of flow variability (seasonal flow distribution) and reflect the timing of flow events and magnitude. To capture the variability of flows at top and low ends of the flow range, 1-day and 30-day minima and maxima are presented. Low and high flows represent the smallest/largest values of mean discharge computed over any 1 or 30 consecutive days during the period.

Five different types of environment flow components (EFCs) are calculated by the IHA: low flows, extreme low flows, high flow pulses, small floods, and large floods. These EFCs are ecologically relevant hydrologic patterns that must be present in a system to sustain ecological integrity. For example, extreme low flows may be critical for species such as bald cypress that need dried out floodplains to regenerate, while large floods are necessary to promote the diversity of the physical structure of a river and its floodplain (TNC, 2009). All flows that exceeded 75% of daily flows for the period were classified as high flows. All flows below this level were classified as low flows. A small flood event was defined as an initial high flow with a peak flow greater than the 2-year return interval event (i.e., 50 percent chance of occurrence in any given year, per USGS, 2016b). A large flood event was defined as an initial high flow with a peak flow greater than the 10-year return interval event (i.e., 10 percent chance of occurrence in any given year, per USGS, 2016b). All initial high flows not classified as small flood or large floods were

classified as high-flow pulses. Finally, an extreme low flow was defined as an initial low flow below 10% of daily flows for the period (TNC, 2009).

TWO-PERIOD ANALYSIS

In the two-period analysis, the median (i.e., the 50th percentile), coefficients of variation, deviation factors, and significance counts for the deviation values were calculated. The significance count can be interpreted as being similarly to a p-value in parametric statistics (TNC, 2009). These statistics were calculated for the 12 monthly means/medians and 1-day and 30-day minima and maxima.

PRECIPITATION DATA ANALYSIS

Annual precipitation totals summarized by year (January 1–December 31) were obtained from the U.S. Historical Climatology Network (Menne, Williams, and Vose, 2015) for station number 380764 in Blackville, South Carolina (Latitude 33.3631, Longitude -81.3292). The station is approximately 19 kilometers southeast of USGS station 02173000. Basic statistics (mean, median, minimum, and maximum) were calculated for period one (1932–1985) and period two (1986–2014). Annual precipitation totals (1932–2014) were plotted with annual days with extreme low flows (1932–2014, minus data from 1972–1980 due to equipment failure). Pearson correlations were calculated for annual precipitation and annual days with extreme low flows for period one and two.

RESULTS

LONG-TERM HYDROLOGIC RECORD ANALYSIS

The mean annual flow was 20.4 cms for the 75-year period of record. The monthly median flows increased from October (12.5 cms) to a peak in March (26.5 cms), and then flow sharply declined in April (20.7 cms) and May before steadily decreasing into the growing season months of June (13.5 cms) through September (12.0 cms). The median 1-day minimum and 30-day minimum flows were 7.0 cms and 9.1 cms, respectively, while the median 1-day maximum and 30-day maximum flows were 62.0 cms and 35.6 cms, respectively (Table 1). These low and high flows represent the smallest/largest values of median discharge computed over any 1 or 30 consecutive days during the period. The 7Q10 (the annual 7-day minimum flow with a 10-year recurrence interval or non-exceedance probability of 10 percent) was 4.4 cms. The highest recorded flow in the period of record (4/11/1936, 359.6 cms or 10.91 stage) was verified by the USGS (2016c).

Table 1. Basic statistics for long-term hydrologic record.

Month	Count	Mean	Median	Minimum	Maximum
October	2356	15.8	12.5	4.6	105.1
November	2280	17.6	15.0	4.8	102.2
December	2355	22.0	18.4	6.9	93.7
January	2325	25.9	22.2	8.5	103.4
February	2118	28.5	25.0	8.5	115.2
March	2325	30.6	26.5	10.0	134.8
April	2250	26.7	20.7	5.8	359.6
May	2325	17.7	15.6	4.7	115.0
June	2250	15.3	13.5	3.6	85.2
July	2325	14.4	12.3	3.3	93.2
August	2353	15.5	12.4	3.1	198.2
September	2252	14.7	12.0	3.6	203.3
1-day minimum		7.4	7.0		
30-day minimum		9.8	9.1		
1-day maximum		72.3	62.0		
30-day maximum		39.4	35.6		

The EFCs were calculated, and the flows were categorized as large floods, small floods, high flow pulses, low flows, or extreme low flows. Evaluating the visual representation of this data (Figure 1) from the 1930s to roughly 1970, very few extreme low flows occurred. In contrast, from 2000 to the present, many have taken place. Also, from 1980 to the present, a lower frequency of small and large floods can be observed. Over the entire 76-year period of record, 51 years had at least one occurrence of extreme low flows. A median of 4 days per year had occurrences of extreme low flows in period one in contrast to a median of 60 days per year during period two (Figure 2).

TWO-PERIOD ANALYSIS

The mean annual flow for period one was 22.1 cms compared to 17.7 cms for period two (median). The median

monthly flows also differed greatly between time periods (Figure 3). For example, the median monthly flow for February was 28.9 cms in period one compared to 21.2 cms in period two, while the values for August were 13.5 cms in period one compared to 10.1 cms in period two. The significance count for differences in the median monthly flow for February was 0.04, and August was 0.05 (Table 2). Values ≤ 0.05 indicate that the difference between periods is significant. The significance count for differences between annual minima and annual maxima 1-day and 30-day means for period one and period two were highly significant (between 0.00 and 0.001).

In conclusion, the two-period analysis showed significant differences between 1932–1985 (period one) and 1986–2015 (period two) for monthly mean flow for February, April, May, and August, as well as for 1-day and 30-day minima and maxima values.

Table 2. Basic statistics for two-period analysis.

	Medians		Significance Count	
	Period 1	Period 2	Medians	C.D.
October	12.6	11.3	0.33	0.11
November	15.0	13.4	0.25	0.04
December	19.2	18.2	0.42	0.80
January	24.7	20.8	0.07	0.57
February	28.9	21.2	0.04	0.94
March	28.1	23.1	0.08	0.65
April	25.1	18.0	0.03	0.43
May	16.8	13.2	0.04	0.64
June	14.0	11.5	0.07	0.00
July	13.1	11.1	0.19	0.02
August	13.5	10.1	0.05	0.00
September	12.2	9.9	0.08	0.01
1-day min	7.9	5.3	0.00	0.03
30-day min	9.8	7.1	0.00	0.01
1-day max	76.7	44.5	0.00	0.39
30-day max	41.8	30.0	0.00	0.86

PRECIPITATION DATA ANALYSIS

Basic statistics for the long-term precipitation record are included in Table 3. Annual precipitation totals for the period of record were sorted in order from lowest total precipitation to highest. These values were plotted for annual days with extreme low flows (Figure 4). A Pearson correlation was calculated as -0.48 for annual precipitation and annual days with extreme low flows for the entire period of record (1932–2014).

Table 3. Basic statistics for long-term precipitation (mm) record.

	Period 1	Period 2
Count	46	29
Mean	1149	1127
Median	1103	1040
Minimum	777	800
Maximum	1888	1731
Pearson	-0.39	-0.65

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Figure 2. Number of days with extreme low flow conditions.

Figure 3. Two-period analysis of monthly median flows (cms).

Figure 4. Annual precipitation (mm) and annual days with extreme low flows (1936–2014).

DISCUSSION

The annual minimum 7-day average streamflow with a 10-year recurrence interval (7Q10) for station 02173000 was found to decline from 6.0 cms (Bloxham, 1979) to 5.7 cms (Zalants, 1991) and finally to 5.0 cms (Feaster and Guimaraes, 2012). The analysis presented above calculated the 7Q10 at 4.4 cms, which was -10.9% different from the most recent estimate. This declining trend is concerning, considering that extremely low stream flows also can correspond with low dissolved oxygen values and organic channel bottoms (Ice and Sugden, 2003). Dissolved oxygen is one of the four primary factors controlling river fauna (Hynes, 1966): 1) dissolved salts, 2) current, 3) temperature, and 4) dissolved oxygen. Also, Allan (1995) indicated that the biota of flowing waters is highly dependent on the availability of oxygen. Hydrologic disturbances, such as flood and drought, can affect biota because the frequency, duration, and intensity of such disturbances influence the response and recovery time of communities (Gomi et al., 2002).

The results presented in this study have shown that spring and summer flows in the South Fork Edisto are statistically significantly different. Atlantic sturgeon is federally listed by the NMFS as an endangered species (NMFS, 2012). Spawning has been documented in both the fall and spring in the Edisto (SCDNR, 2016a), and the population size is thought to be similar to the better known populations in the Altamaha and the Savannah Rivers (personal communication, Bill Post). Spawning behavior has

been documented in the South Edisto approximately 30 miles downstream of station 02173000. Most presumed spawning movements for Atlantic sturgeon begin near the end of July through the beginning of August. The diadromous fish were detected on the spawning grounds through October in each year of the study period (Post et al., 2014). It is unclear whether the current hydrologic conditions in the South Fork Edisto are impacting Atlantic sturgeon populations; however, this is a topic for further research. Floodplain inundation is important for the state's other diadromous species of concern that spawn in the spring, such as blueback herring, hickory shad, and American shad, which are known to occur in the South Fork Edisto (SCDNR, 2015, 2016b, 2016c, 2016d). If spring flows are inadequate for spawning, other species of concern in the state could be impacted.

The finding of significant differences between 1932–1985 (period one) and 1986–2015 (period two) for monthly mean flow for February, April, May, and August, as well as for 1-day and 30-day minima and maxima values, indicates that changes occurred in the hydrologic system between time periods. Annual rainfall over the two periods is similar; the mean precipitation was 1,149 mm for period one and 1,127 mm for period two. However, an examination of the relationship between annual precipitation and annual days with extreme low flows (Figure 4) shows that similar precipitation in period one versus period two results in a different number of annual days with extreme low flows. For example, annual precipitation was 793 mm in 1954, with 124 extreme low flow days, while annual precipitation

was 800 mm with 184 extreme low flow days in 2002. The relationship between precipitation and runoff is influenced by the amount of precipitation that fell in the previous year (Searcy and Hardison, 1960, as cited in Marshall, 1993), and future research should explore methods to account for this variability. The Pearson correlation was -0.39 for period one and -0.65 for period two, which indicates a stronger negative relationship between annual precipitation and annual days with extreme low flows for period two. Future research should further evaluate climate data, water withdrawal information, and flow data for a similar river system to explore the potential causes for the departure from historic flows in the South Edisto River.

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