An Analysis of Past River Flooding at Select National Weather Service River Forecast Locations in South Carolina

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Abstract. Flooding, including river flooding, has affected many areas of South Carolina over the past decades. In 2009, the Federal Emergency Management Agency reported that South Carolina had more than seven billion dollars in damage from flooding and hurricane events. As recently as July 2004, flooding on the Reedy River destroyed several homes and businesses in Greenville, South Carolina, with over three million dollars in total damage. Tropical storms, such as Gaston in 2004 and Floyd in 1999, produced major to record flooding along sections of South Carolina rivers. In addition, the South Carolina State Climatologist Office has reported some of the worst flooding in South Carolina history occurred in August 1908, when heavy rains of over ten inches in less than 24 hours produced widespread disastrous river flooding. Overall, South Carolina has a long history of flooding.

The National Weather Service (NWS) issues river forecasts and warnings for over 30 river gage locations across South Carolina. The purpose in issuing these river flood warnings is to call people to action so that lives are saved and property is protected. Two- to five-day forecasts are made daily for several of these gages, while others are event-driven issuances. Flood stages at these locations are set by the National Weather Service in coordination with local emergency management officials and are based on flooding impacts at different stages. A three-tier category system of "minor," "moderate," and "major" is used to define the impact of river flooding at certain heights of the river. The National Weather Service defines "significant flooding" as river levels exceeding the moderate flood category.

In this study, daily peak flows were estimated using United States Geological Survey daily mean flow data at select South Carolina river forecast points from 1975 to 2006. This peak flow was compared to flood flow based on the latest rating curves and latest flood stages as of February 2009. A historical examination of river floods was made to determine seasonality and geographic distribution of river floods in South Carolina.

Results showed that most river floods occur from early January through late April with peak river flood periods occurring during late January and most of March. Analysis of past years indicated that the El Niño in 1998 lead to a long period of rainfall and significant river flooding for the state and that most El Niño time periods have brought a period of significant river flooding.

INTRODUCTION

Flooding has and always will be part of the history of natural hazards for the State of South Carolina. With river watersheds that encompass from the Upstate which includes parts of the eastern slopes of the southern Appalachians to the Piedmont and Coastal Plain, South Carolina rivers run through a wide range of geographic areas. As in many cases, population centers have grown around these rivers beginning centuries ago and thus flooding is of concern. Today, the National Weather Service is responsible for issuing flood warnings to alert people to take action so that lives are saved and property is protected. This study of past river flooding in South Carolina was undertaken to gain a better perspective on the annual temporal distribution of river flooding, frequency of events at particular locations and a more detailed examination of events that lead to some of South Carolina's larger river flood episodes of the past 30 years. The author hopes that having a better understanding of the historical scope of river flooding in South Carolina will lead to a better awareness of the seasonality and potential magnitude of river flooding on different rivers in the state. With this inherent knowledge base available, emergency managers can become more aware and better prepare their communities. For National Weather Service River Forecast Hydrologists, this knowledge will provide for better warnings and increased lead time.

METHODOLOGY

The locations chosen were identified as those South Carolina National Weather Service river forecast points having complete United States Geologic Survey (USGS) mean daily flow for the designated period from 1975 to 2006. Twelve locations meet these criteria for the study (Table 1) (Fig 1). Due to the lack of hourly stage data or complete event peak flow data readily available that spanned the 1975 to 2006 period, a method was used to estimate peak flow data from mean daily flow data. Methods to estimate the peak flow based on mean daily data have been studied by hydrologists for almost a century (Dieter 2003). One method that was utilized in this study is the peak flow coefficient defined as the ratio of the instantaneous peak and the corresponding mean daily flow with physiographic characteristics of the basin (Fuller 1914). Fuller's study used data from 24 river basins with drainage areas varying from 3.06 to 151,592 km^2 and proposed the following relationship:

$$Q\text{max} = Q(1 + 2.66\ A^{-0.3})$$

Where Qmax = predicted peak flow (m^3/s); Q = maximum mean daily flow (m^3/s); and A = drainage area (km^2). Dieter (2003) also notes various literature that highlight the many relationships derived from the ratio of peak flow and mean daily flow as a function of drainage area. Due to its flexibility and efficiency, this method was used in the study to estimate daily peak flows from the readily available mean daily flow data from the USGS. The estimated peak daily flows from this method were then compared against and calibrated to the annual peak daily flows also available from the USGS using the equation:

$$Q\text{max} = Q(1 + 2.66\ A^{-B})$$

Where B = the adjustable exponential coefficient used to calibrate the estimated daily peak flows to the actual annual peak flow provided by the USGS. The reason that the annual peak flows were not simply used was that if there were multiple peak flows over flood stage during the year then the annual peak flow data would only show the highest of these peak flows for the year. The estimated peak flows were then compared against the flood stage flow (minor flood stage) as of April 2008.

The flood stage flow was obtained by cross-referencing the National Weather Service (NWS) flood stage as of April 2008 to the USGS rating table as of April 2008. The NWS utilizes a three tier category system of "minor", "moderate" and "major" to define the impact of river flooding at certain heights of the river. The National Weather Service defines "Significant Flooding" as river levels exceeding the moderate flood category. When the peak daily flows were estimated above the established minor flood flow, then this would result in a "flood day". When one or multiple continuous "flood days" occur, this was counted as a "flood event". Significant river flood events were also examined in this similar fashion. The author acknowledges there are multiple ways that river flood events could be delineated, though decided this approach worked best to examine the number of critical occurrences when the river would go from non-flood conditions to flood conditions/significant flood conditions.

NWS ID	***River Name***
GALS1	Little Pee Dee River at Galivants Ferry
KINS1	Black River at Kingstree
PDES1	Pee Dee River at Pee Dee
EFFS1	Lynches River at Effingham
BSPN7	Broad River near Boiling Springs
COLS1	Congaree River at Columbia
GIVS1	Edisto River near Givhans
GSLS1	Saluda River near Greenville
ORBS1	North Fork Edisto River at Orangeburg
AUGG1	Savannah River at Augusta
CLYG1	Savannah River near Clyo
WHMS1	Enoree River at Whitmire

Table 1. Selected South Carolina forecast points

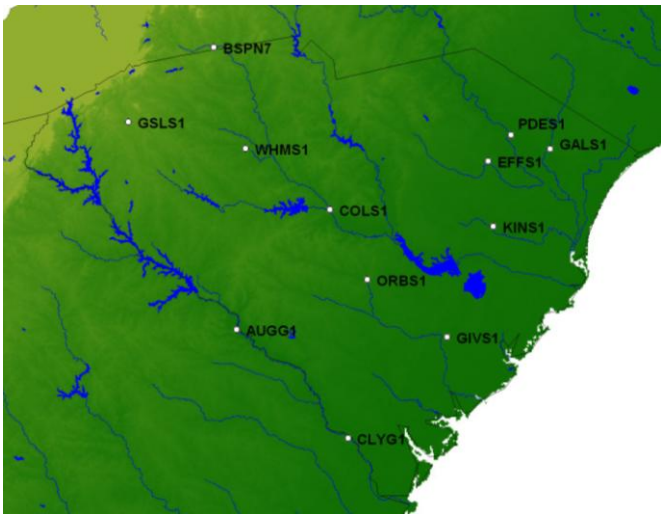

Figure 1. Map of selected South Carolina forecast points

RESULTS

From 1975 through 2006 for the twelve selected locations, the analysis estimated 708 river floods with 216 significant river flood events.

River Flood Events by Week of the Year

The analysis showed that river flood events were most common beginning on the first week of the year through week 19 (roughly the first week in May). Nearly 71 percent of total river floods were approximated to occur during this 19 week winter to spring period. A secondary bump was noted during weeks 35 to 43 (roughly the first week in September through the last week in October). Significant floods followed this same general pattern though were most pronounced from week 2 through week 4 (roughly mid to late January) and week 8 to week 12 (roughly last week in February to late March).

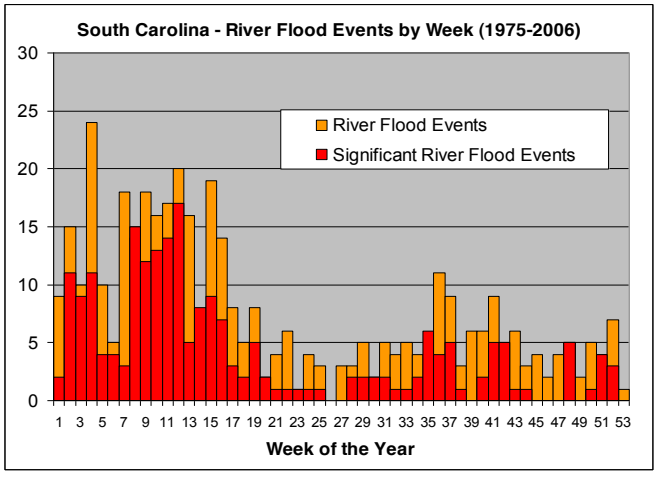

Figure 2. River Floods by Week of the Year

River Flood Events by Location

The number of river flood events and significant river flood events by location showed minimal geographic consistency. The number of river flood events was greatest at sites PDES1, CLYG1, GIVS1 and ORBS1 (Fig. 3) where the number of significant flood events was greatest at PDES1, CLYG1 and GIVS1 (Fig. 4). At PDES1, the considerable number of floods relative to the other sites is due to the fact that the minor flood stage is set for 19 feet and moderate flood stage, or the beginning significant flooding, is set 23 feet. Since flood stages are set by the stage flood waters begin to impact property or threaten lives, the stages at PDES1 are set at these stages mainly due to the logging industry near the Pee Dee River in this region. At 20 feet, flood waters affect logging interests and logging equipment may need to be moved.

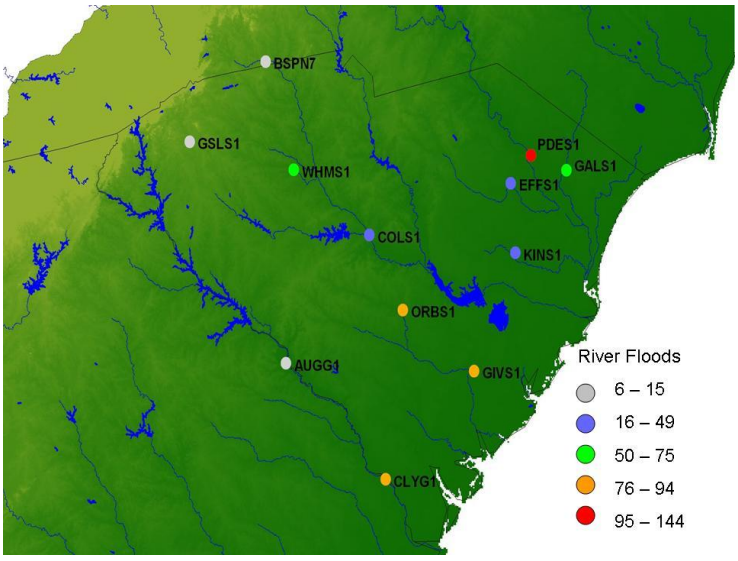

Figure 3. River Flood Events by location

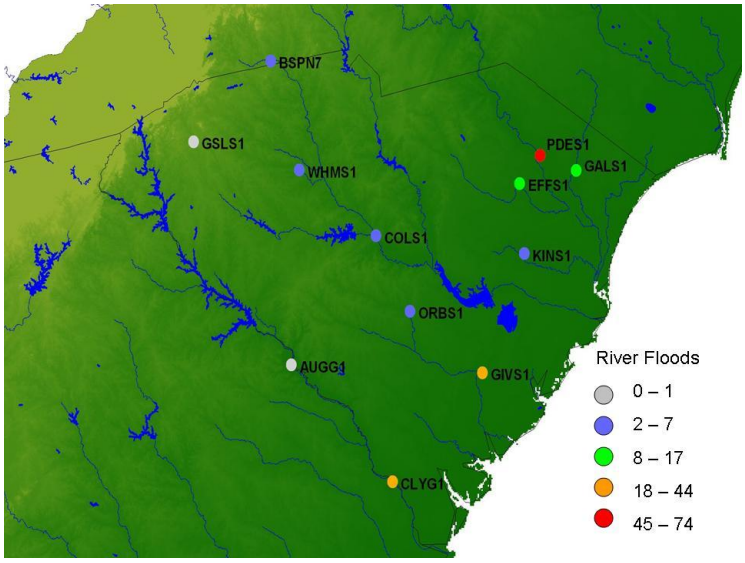

Figure 4. Significant River Flood Events by location

Significant River Flood Events in Past Years

The number of significant river flood events by year from 1975 to 2006 indicated that 1998 had the most significant flood events with the flooding attributed to non-tropical rainfall during that year (Fig. 5). It is noted that most of the flooding occurred during the winter and early spring season at the time of a particular strong El Nino. Further investigation into the Enso affects on river flooding in South Carolina is discussed later in this paper. As far as the most active year for river flooding attributed to tropical storm rainfall, the 1990 tropical season has the greatest number of significant floods. With the combination of Tropical Storm Klaus and Tropical Marco from October 12th through October 14th, rainfall amounts of 5 to 12 inches fell across many locations of the state bringing significant flooding to eight of the 12 locations looked at in this study. Other notable years for tropical storm rainfall and flooding include 1979 with Hurricane David, 1995 with Tropical Storm Jerry and the 2004 season with Frances and Ivan which affected mostly the Upstate. Of the 216 significant river flood events, 186 (86%) were associated with non-tropical rainfall weather systems and 30 (14%) were linked to tropical systems. When examining just the tropical season between June 1st and October 31st, the data shows that of the 44 estimated significant river flood events, 29 (66%) were linked to tropical systems and 15 (34%) events were non-tropical weather systems that produced the rainfall leading to the flooding.

Significant River Flood Events and the El Niño-Southern Oscillation (ENSO)

Data was examined comparing the significant river flood events that were not associated with tropical systems and the time of the events relative to the phase of the El Niño-Southern Oscillation (ENSO). Results depicted that 60 percent of these significant river floods had occurred during an El Niño phase of the ENSO, with 26 percent during the neutral ENSO phase and 14 percent during the La Niña phase. The 60 percent of significant river flood events during El Niño is especially noteworthy considering the El Niño phase represents only about 20 percent of the time period from January 1975 through December 2006.

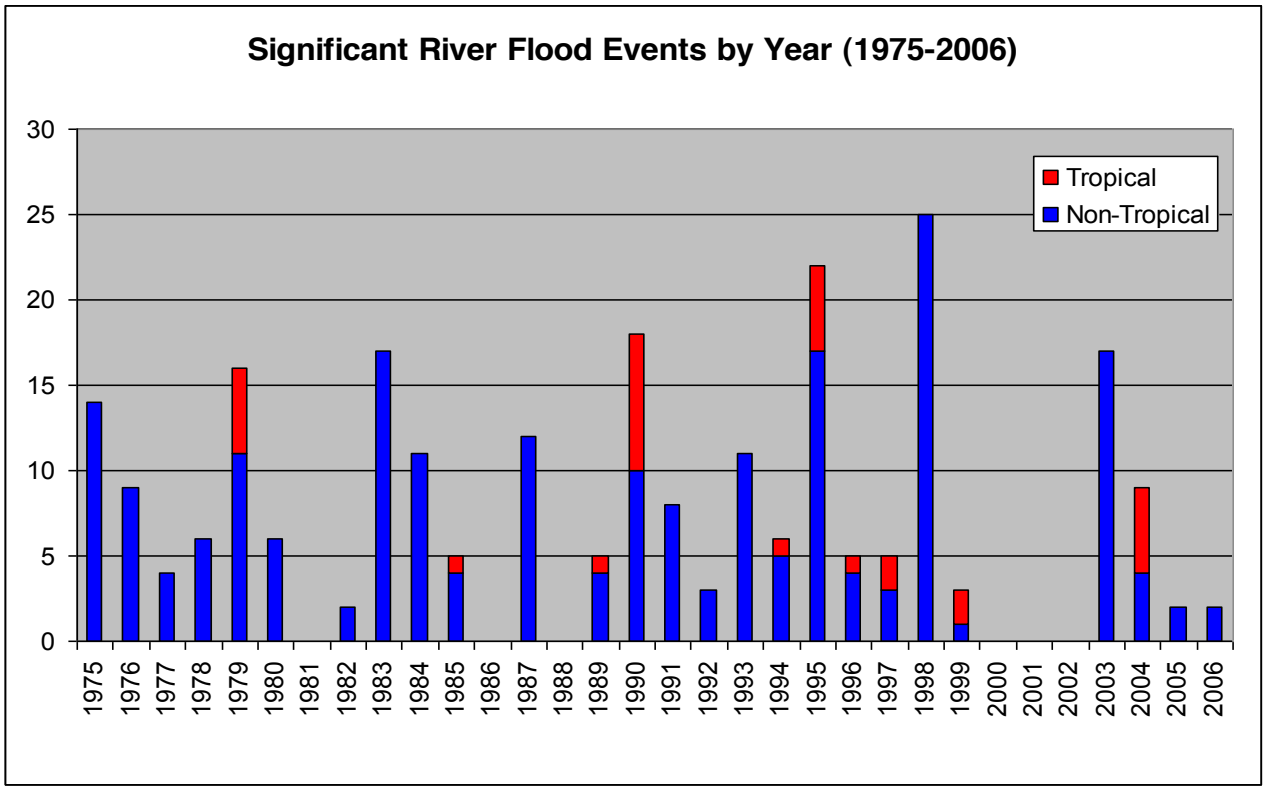

Figure 5. The number of significant river flood events each year in South Carolina (1975-2006)

CONCLUSION

Though river flooding can occur any time of year, the typical river flood season for South Carolina is from early January through most of April with the peak time period in mid to late January and also late February through late March. From the middle of May through most of August river flooding is minimal and infrequent with evapotranspiration playing a larger role in the water budget. Tropical systems have played a bigger role as far as river flooding in September and October as evident in the weekly climatology results. The increase of river flood events in the winter and early spring are connected to the rainfall climatology and lower evapotranspiration rates. The jet stream becomes more active across the middle Tennessee Valley and into the Mid Atlantic this time of year bringing more storm systems and more substantial widespread long duration rains. With dormant vegetation and minimal evapotranspiration rates during winter into early spring, the scenario presents an optimum time period for rainfall to runoff efficiency and thus higher flows in rivers. Higher flows alone do not always indicate an increased flood risk on a particular river. Higher flows relative to the NWS flood category levels together dictate the overall flood risk at a certain location on a particular river. For this reason, the number of floods and flood frequency can vary greatly on the same river.

It is the hope that having a better knowledge of South Carolina's river flood past can help us improve our understanding of the river flooding in the future. Increased awareness to a defined river flood season similar to the current public awareness to hurricane season or severe weather season can help keep Emergency Management Officials and the public itself conscious of a seasonal river flood hazard period and prepared for any mitigating efforts that may be needed.

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