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THE RELATIONSHIP BETWEEN DRAINAGE BASIN AREA AND ANNUAL PEAK-FLOOD SEASONALITY IN THE SOUTHEASTERN UNITED STATES[1]

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This study examines relationships between drainage basin area and flood seasonality in the southeastern United States. To assess this relationship, a flood seasonality analysis of annual peak flood series for 84 individual drainage basins is completed, identifying five distinct annual peak-flood seasonality regions: the Tennessee, the Gulf Coast, Peninsular Florida, the Carolinas, and the Georgia Coastal Plain. These results confirm previous research except for the Carolina region, which possesses no dominant season in annual peak-flood frequency. Further statistical analysis indicates that the Georgia Coastal Plain is the only region of the five with a statistically significant relationship between drainage basin area and annual peak-flood seasonality. The statistical relationships for this region are interpreted as spring annual peak floods occurring more frequently on larger drainage basins because of high soil moisture and frequent extratropical-cyclone passage. Weak, significant statistical relationships exist between drainage basin area and annual peak-flood seasonality when all streams are placed in a single data set representing the entire southeastern United States. These results suggest the need for a wide range in drainage-basin area to identify a relationship between drainage-basin area and annual peak-flood seasonality.

Flooding represents the greatest weather-related hazard in the United States. In the Eastern Region of the National Weather Service (ME, NH, VT, MA, RI, CT, NY, PA, OH, WV, VA, MD, DE, NJ, NC, SC), flooding killed 1024 people and caused $20.3 billion dollars in damage from 1955 to 1989 (LaPenta et al., 1995). One of the difficulties facing planners and engineers is that the probability of flood hazard does not remain consistent throughout the year. With the progression of the seasons, atmospheric circulations shift which changes moisture inflows and precipitation patterns for any given region. Thus, a knowledge of flood seasonality (the frequency of flood occurrence within a given season) is required by officials to determine seasonal runoff forecasts for hydroelectric power, irrigation, crop calendars, recreational activities, and emergency preparedness schedules.

An understanding of flood seasonality requires information about both climatic conditions (i.e., dominant storm types and tracks) and a watershed's physiographic characteristics (i.e., slope, elevation, drainage density). The most important of these physiographic variables is drainage-basin area (Pitlick, 1994). Drainage basin area can control the size of storms that cause flooding on a given

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watershed. Hirschboeck (1988) offered a conceptual model linking drainage basin area and flood seasonality. Accordingly, some of the greatest floods recorded on small drainage basin areas are associated with intense, localized precipitation created by isolated convection cells or mesoscale convective complexes (MCCs). However, moderate flood magnitudes on small drainage basins also can be created by a large variety of storm types and scales of storm activity. A small isolated thunderstorm, a mesoscale convective complex, or a synoptic-scale extratropical cyclone all can create sufficient precipitation for flooding in a small drainage basin. In contrast to these small drainage basins, large, persistent atmospheric circulations, such as a tropical storm or midlatitude cyclone, are required to produce intense precipitation over a sufficiently wide enough area to cause flooding over a large drainage basin. The size and scale of storms shifts with seasonal changes in atmospheric circulation, creating a seasonal pattern in flooding. Storms that produce floods within a drainage basin of specific size may be dominant during the "flood" season, or absent during the "dry" season.

PURPOSE. The purpose of this study is to identify relationships between drainage basin area and flood seasonality in the southeastern United States. To date, little research has addressed the flood frequency of all four seasons within the region or link seasonal frequency to drainage basin area. Existing information of flood seasonality for the southeastern U.S. consists of a series of generalizations taken from global- or continental-scale research for the purpose of identifying regions dominated by different flood-climate types (Hayden, 1988) or different kinds of flood-producing storms (Hirschboeck, 1991). Assuming that these macroscale patterns can be applied at a regional scale, three distinct flood climate regions can be identified for the southeastern U.S., with the annual peak flood most likely to occur in winter/spring for the interior southeastern U.S. and fall for the Florida peninsula (Fig. 1). The first flood climate region (TsoCp) covers Florida, the Gulf Coast, the Atlantic coastal plain, and the Appalachian piedmont. In this region, floods occur year round, with winter and spring floods produced by frontal zones with imbedded mesoscale convective clusters, and summer and fall floods produced by tropical depressions. The second region (TsoCpSe*) possesses all the properties of the first, except that snow can accumulate in mountains and result in winter flooding. The Appalachian mountains in Virginia and North Carolina represent this second flood climate region. The third flood climate region (TsuCpSe*) covers the interior and western slope of the Appalachians in Tennessee, where tropical storms are rare or absent and floods are produced by frontal storms or snow melts in the winter or spring.

Research in this paper is intended to complement and expand upon these regional generalizations. Beyond confirmation of the season with greatest annual flood frequency, annual peak-flood frequency for all four seasons will be determined, allowing for seasonal prioritization in planning efforts. In addition, since

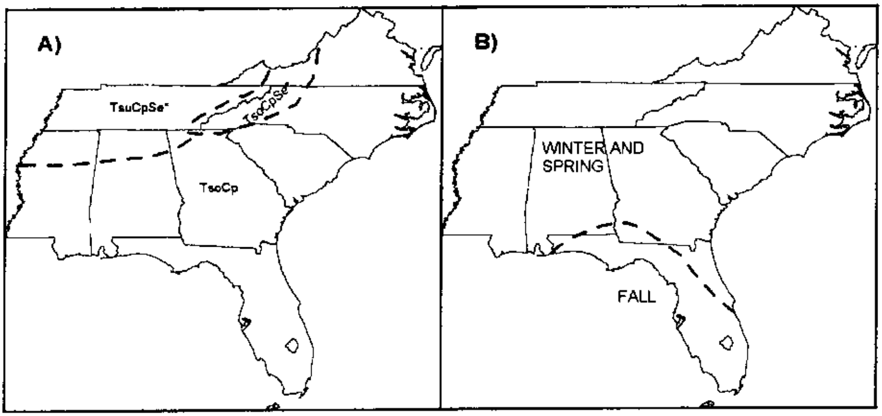

Fig. 1. Previous southeastern United States flood seasonality research indicating (A) climatic mechanisms associated with floods and (B) the season in which the annual peak flood is most likely to occur. *Source*: (A) Modified from Hayden, 1988 (T = barotropy; C = baroclinicity; p = perennial; s = seasonal; o = organized convection; u - unorganized convection; S = snow cover; e = ephemeral snow cover; * = snow cover 10 to 50 days); (B) Modified from Hirschboeck, 1991.

the analysis is based upon data for individual stream gauge stations rather than an approximation of continental-scale processes, areas within the region that deviate from regional generalizations can be identified. Furthermore, through the analysis of individual stream gauge stations, drainage basin area can be included so that the relationship between flood seasonality and drainage basin area can be tested. Such information may prove helpful to planners and other officials who are required to assess flood hazards for individual watersheds, rather than to make regional flooding policies.

DATA AND METHODOLOGY. The analysis is completed in four steps: (1) calculation of annual flood frequency for each of the four seasons (seasonal frequency is expressed as a percentage and is derived from the number of annual peak-floods occurring within each of the four seasons, winter [December, January, February], spring [March, April, May], summer [June, July, August], and fall [September, October, November]); (2) identification of annual peak-flood seasonality regions from maps of annual peak-flood seasonal frequency; (3) testing of the hypothesis that annual peak-flood seasonal frequency and drainage basin area are independent using a Chi-square test for independence; and (4) determination of the degree of association between drainage basin area and annual peak-flood seasonality through the calculation of the Spearman rank correlation coefficient. The first two steps expand the concept of annual flood seasonality to four seasons. This identification of annual peak-flood seasonality regions assists in linking specific climatic

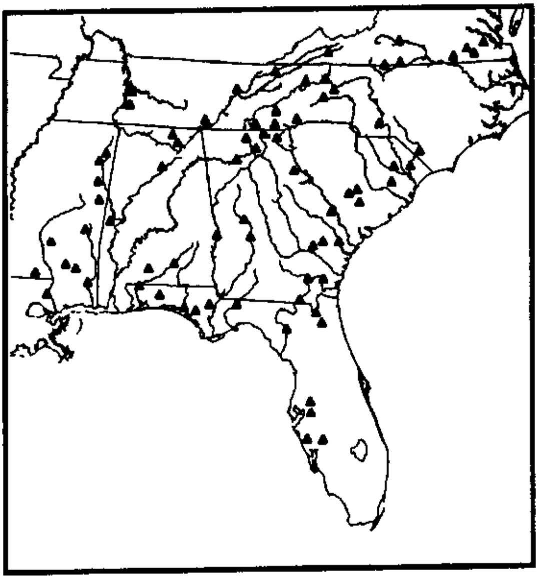

Fig. 2. Location of stream gauge stations and major rivers in the study area.

mechanisms to statistical results generated in the last two steps of analysis. Specific dominant climate mechanisms can be associated with seasonality characteristics of each region, escaping the dependence upon a general description of continental-scale processes to interpret statistical results.

The study area includes the Tennessee and South Atlantic–Gulf Atlantic Hydrologic Regions, as defined by the United States Geological Survey (USGS) (Seaber et al., 1987) (Fig. 2). The area includes Alabama, Florida, Georgia, North Carolina, South Carolina, and parts of Louisiana, Mississippi, Tennessee, and Virginia. A total of 84 stream gauge stations were selected from the USGS Hydro-climatic Data Network (HCDN) CD-ROM for the study area (Slack and Landwehr, 1992).[2] Requirements for stream gauge station selection were a minimum of 41 continuous water years of observations (October 1, 1950-September 31, 1990) and location on an undiverted and unregulated stream. The time period 1950-1990 was selected because of the highest total available stream gauge stations for a 40-year period within the study area. The HCDN includes only undiverted and unregulated streams, as was confirmed through an examination of USGS Hydrologic Unit maps for each state. Unfortunately, many of the largest drainage basins in the southeastern U.S. (e.g., Tennessee River and Savannah River) have been dammed or diverted in some fashion, limiting the range of drainage basin area in the study. The use of dammed or diverted streams would be inappropriate because human activities—dam releases and generation of hydroelectric power—possess their own seasonality, which in turn interferes with the climatically produced seasonality of annual peak floods.

The HCDN also provides physiographic variables for each stream gauge station. The drainage-basin area, in square miles, is used in this study. The annual peak-flood series for each stream gauge station is taken from the Earth Info Inc. Peak Flow 1993 CD-ROM and used for calculation of annual peak-flood seasonal frequency. The annual peak-flood series is used rather than the partial-duration (or peaks above base) flood series to allow for comparison with previous research, and stream gauge stations with partial-duration flood series were not available for South Carolina. Such a spatial gap compromises the identification of flood seasonality regions within the southeastern U.S. In this study, results pertain only to annual peak-floods, or the highest flood on record for a given year. Results should not be applied to lower-magnitude floods, such as those in a partial-duration flood series.

RESULTS AND DISCUSSION. Flood Seasonality Regions. The kriging algorithm from the computer software Surfer for Windows$_{TM}$ is used to construct one contour map of annual peak-flood frequency for each season (Figs. 3 and 4). These maps display spatial patterns in seasonal frequency that are used to identify annual peak-flood seasonality regions within the southeastern U.S. Upon identification of each of the regions, annual peak-flood seasonal frequencies for each stream gauge station are examined to confirm map pattern results. The four maps of annual peak-flood seasonal frequency display a high frequency of annual peak-floods inland during winter, a high frequency of annual peak-floods near the Gulf Coast in spring, and a high frequency of annual peak floods in southern Florida in fall (Figs. 3 and 4). Specifically, five distinct flood seasonality regions can be identified based upon these spatial patterns in seasonal flood frequency (Figs. 5 and 6). Three of these regions—Tennessee (Ten), Gulf Coast (Gul), and Peninsular Florida (Fla)—are defined by a clearly dominant season in flood frequency. For this study, a dominant season is a one in which nearly 50% of the annual peak floods are observed.

The winter dominant region is the Tennessee region (48.3% winter flood frequency), which is approximated as the area north of the 40% contour line in the winter panel of Figure 3. A comparison of this winter annual peak-flood frequency map with the spatial patterns of precipitation-event frequency, magnitude, and duration displayed by Robinson and Henderson (1992) offers potential attributes of storms associated with annual peak floods. The winter annual peak-flood frequency spatial patterns are similar to patterns of winter-precipitation-event frequency, and winter precipitation events with duration equal to or exceeding 5 and 15 hours. The similarity suggests that winter precipitation events associated with annual peak-floods do not require a high rate of rainfall, and since the floods occur in regions of high precipitation-event frequency, the floods may not be associated with anomalous atmospheric circulation patterns. Heavy winter

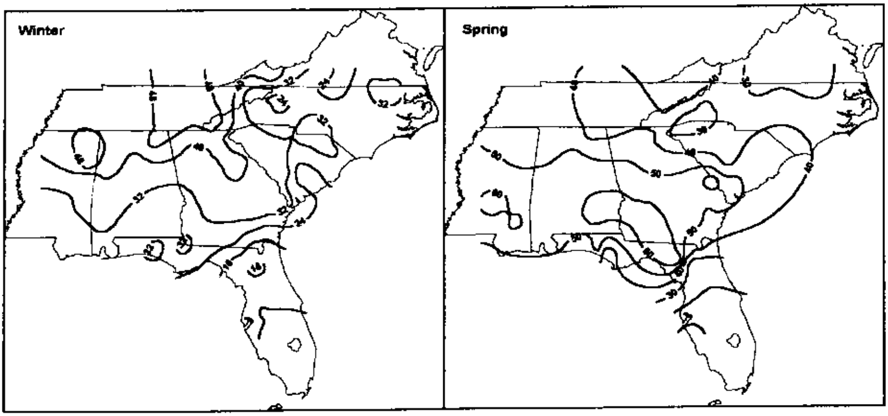

Fig. 3. Spatial patterns in annual peak-flood winter and spring frequency for the southeastern United States.

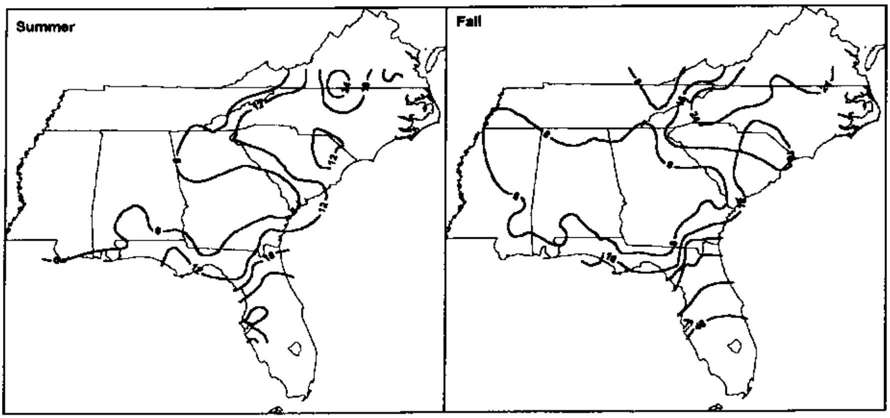

Fig. 4. Spatial patterns in annual peak-flood summer and fall frequency for the southeastern United States.

precipitation in this region usually is produced by frontal-type storms, particularly extratropical cyclones that originate in the Gulf of Mexico or Colorado region and track over the area (Henderson and Vega, 1996; Keim, 1996; Whittaker and Horn, 1981,1984).

The spring-dominated region is the Gulf Coast, with 52.2% flood frequency (an area approximated by the 50% contour line in the spring panel of Fig. 3). The spatial patterns in this panel are similar to spatial patterns in spring precipitation events with total precipitation greater than 1.5 inches and events producing

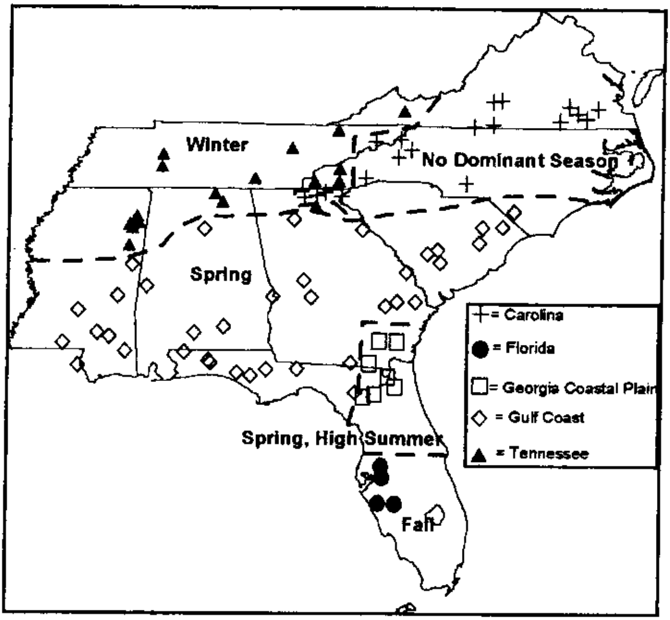

Fig. 5. Location of stream gauge stations within the five annual peak-flood seasonality regions for the southeastern United States.

more than 1.0 inch of precipitation in 24 hours or less, as displayed by Robinson and Henderson (1992). Such a similarity suggests that in this region, as in the Tennessee region, a high precipitation rate is not required for the occurrence of spring annual floods since storms can last up to 24 hours. The storms producing spring precipitation events in the Gulf Coast region have been linked to frontal-type storms associated with migrating extratropical cyclones in the early spring (Henderson and Vega, 1996; Keim, 1996).

The similarities between the Tennessee and Gulf Coast region in regard to long-duration, low intensity storms indicates that soil moisture is an important factor in the generation of both spring and winter annual floods. Muller and Faiers (1984) demonstrated that nearly saturated soil moisture exacerbated a series of Louisiana floods in 1982 and 1983. Because of low potential evapotranspiration in the winter and spring, soils rarely dry out, and high rates of rainfall are not required to saturate soils and produce a soil moisture surplus. Calculation of the average monthly annual Thornthwaite and Mather (1957) water balance for the Alabama Coastal Plain Climate Division illustrates this concept (Fig. 7). Potential evapotranspiration is greater than precipitation in the summer, creating a soil-moisture deficit. In the winter and spring, precipitation is greater than potential evapotranspiration, creating a soil moisture surplus. Therefore, long-duration

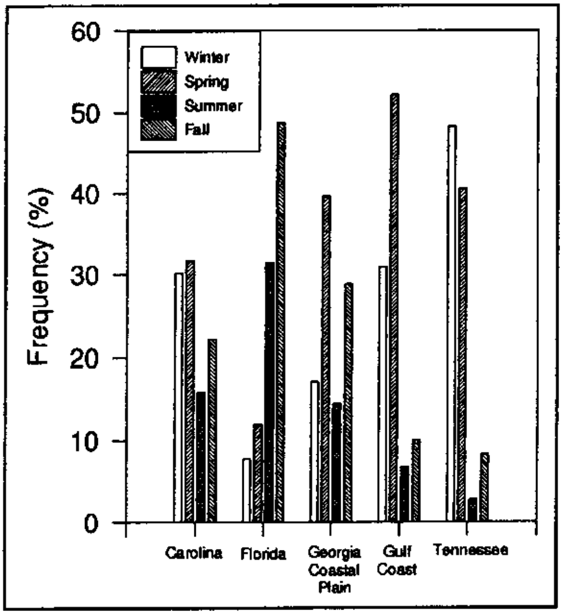

Fig. 6. Bar graph of annual peak-flood seasonal frequency for each of the flood seasonality regions.

rainfall events with less intense rainfall rates can create floods in winter and spring, as compared to short-duration, intense storms with high precipitation rates that are required to saturate the soil in the summer or fall.

Peninsular Florida represents the fall-dominated flood seasonality region (48.8% flood frequency), and is the area south of the 40% contour in the fall panel of Figure 4. Of the four seasons, fall annual peak-flood frequency exhibits the least similarity with spatial patterns in precipitation events, as mapped by Robinson and Henderson (1992). The only spatial patterns that are similar to the map of fall annual peak-flood frequency is precipitation events greater than 0.5 inches in one hour or less. The atmospheric mechanisms that may create such storms are convective storms created by tropical disturbances moving across the region or land-sea breezes over the peninsula (Waylen, 1991; Keim, 1996).

The fourth region, the Carolina region, possesses no clear dominant season of flooding. Flooding frequency is balanced across the three seasons of winter, spring, and fall (30.2%, 31.8%, and 22.2% flood frequency, respectively), and the lowest frequency occurs in the summer (15.8%). Perhaps this balance can be attributed to diverse atmospheric circulation patterns that Keeter et al. (1995) and Konrad (1994, 1995a, 1995b) document for heavy precipitation throughout all four seasons in the region. In addition, since the drainage basins in this flood

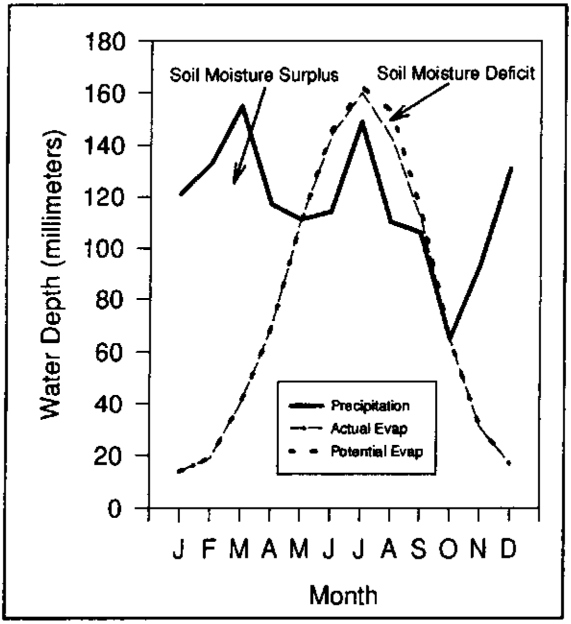

Fig. 7. Alabama Coastal Plain climate division monthly annual Thornthwaite and Mather water balance for the period 1950-1990. Source: NCDC, 1997.

seasonality region are predominantly small (Figs. 1 and 8), a large variety of storm sizes can be associated with floods. Thunderstorms, extratropical cyclones, and tropical systems all can create sufficient precipitation to create flooding, with no one season dominating annual peak-flood occurrence.

Finally, the Georgia Coastal Plain region is characterized by a peak flooding season in spring (39.7%), much like the adjacent Gulf Coast region, but also possesses a relatively high fall frequency of floods (28.8%) like the Peninsular Florida region. The region is identified on the fall panel of Figure 4 as south of the 16% contour and north of the 40% contour. The reason for this "bimodal" frequency of floods is a geographic location that is affected by tracks of extratropical cyclones in late winter and early spring and by tracks of tropical cyclones in fall (Whittaker and Horn, 1984; Hirschboeck, 1991). It is unclear why the Atlantic Coastal Plain in South Carolina and the Gulf Coast do not have this high fall flooding frequency, given their proximity to tropical-storm activity. Perhaps a comparison of flood producing hurricane/tropical storm tracks within each region may offer a physical mechanism that creates this difference.

As mentioned in the introduction, climatological mechanisms alone cannot explain annual peak-flood seasonality. The physiography within each region contributes to the spatial patterns and dominant season of annual peak-flood

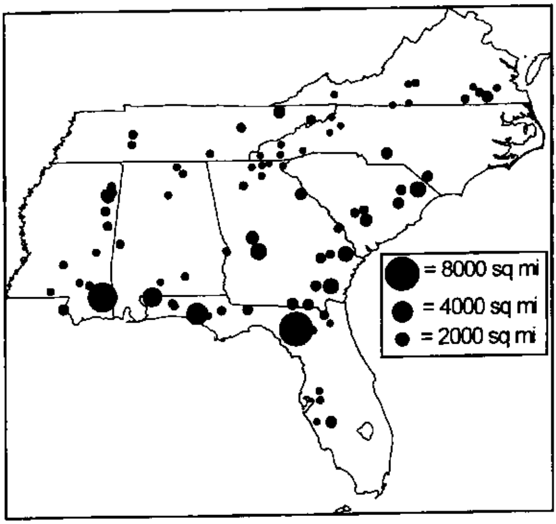

Fig. 8. Location of stream gauge station and relative drainage basin area upstream of stream gauge station.

occurrence. The border between the Tennessee and Carolina regions coincides with the peaks of the southern Appalachian mountains. Konrad (1994) indicated that these mountains are important in influencing the moisture sources and flows associated with extreme heavy-precipitation events in the mountain range. Moisture trajectories associated with the majority of extreme heavy-precipitation events in the cool season are south/southwesterly from the Gulf of Mexico and the Mississippi Valley and occur in the Tennessee region. Heavy precipitation occurs less frequently on the eastern side of the Appalachians (in the Carolina region) during the cool season and is associated with south/southeasterly moisture advection from the Atlantic–Eastern Gulf of Mexico. Such a climate mechanism indicates that storms that create floods on the western slope of the Appalachians in the winter may not possess enough moisture to create heavy precipitation and flooding on the eastern slope of the Appalachians, establishing a boundary between the Tennessee and Carolina regions.

In the Gulf Coast region, the majority of the stream gauge stations are located in the Coastal Plain physiographic region. One characteristic of the Coastal Plain is the relatively coarse soil texture as compared to the soils of the Piedmont and Appalachia regions (Walker and Coleman, 1987). The coarse, or sandy, soil structure is important in regard to soil moisture levels, usually requiring large amounts of precipitation and extended periods of low potential evaporation in order to produce a soil moisture surplus or runoff. In addition, the relatively large drainage basins in the Gulf Coast region (Fig. 8), require storms that can create precipitation over a large geographic area. Local and mesoscale storms are less likely to create precipitation over a sufficiently large spatial area to create flooding on the larger drainage basins. Therefore, spring in the Gulf Coast region represents a season with relatively cool temperatures and low potential evapotranspiration, a high frequency of synoptic-scale frontal storms, and a high frequency of annual peak floods.

Chi-square Test for Independence. The Chi-square test for independence is used to test the null hypothesis that annual peak flood seasonal frequency is independent of stream drainage basin area. The test is performed separately for each of the five flood seasonality regions and for one data set containing all 84 stream gauge stations from the study area. The drainage basin areas for each stream are used as the expected variable in each test and are divided into three classes— small, medium and large. The classes were selected based upon the ranking of all drainage basin areas within the region and placing an equal number of drainage basins in each class. Since the number of streams for each region was not divisible by three, some classes within a given region may possess one or two more streams than the other classes. For the regions with unequal classes, the medium class contains the greatest number of streams, in an effort to avoid a bias toward either small or large drainage basins. However, for two of the regions, Florida and Georgia Coastal Plain, the difference in drainage basin area is small between the small and medium and the medium and large classes, respectively. Because of this small difference in drainage basin area, the greatest number of streams is found in the small class for the Florida region and the large class for the Georgia Coastal Plain region.

The Chi-square values for four of the regions—Carolina, Florida, Gulf Coast, and Tennessee—indicate the acceptance of the null hypothesis, concluding that annual peak-flood seasonality is independent of drainage basin area (Table 1). For the Georgia Coastal Plain region, the Chi-square value of 16.1 with six degrees of freedom is significant at the 0.05 level, indicating that within this region annual peak-flood seasonality is not independent of drainage-basin area. The test performed with the data set containing all 84 streams in the study area produced a Chi-square value of 119.9 with six degrees of freedom, significant at the 0.05 level, indicating a rejection of the null hypothesis, i.e., a finding that annual peak flood seasonality is not independent of drainage basin area.

These results suggest that the range of drainage basin area is important in determining links between annual peak-flood seasonality and drainage basin area. The range of drainage basin area for all 84 streams is 28 to 7,880 mi^2, offering a range over several orders of magnitude. However, the range in drainage basin area for each of the flood-seasonality regions is much lower than this aggregate range (Table 2). Given a small range in drainage basin area, the impact of large scale, long-duration storms that create flooding on large drainage basins may not be recorded. Thus, even though the division of the study area into flood-seasonality regions increases interpretability of atmospheric conditions associated with

TABLE 1
CHI-SQUARE (χ^2) STATISTICS AND PROBABILITIES (p) FOR DRAINAGE BASIN AREA CLASSES (OBSERVED) AND ANNUAL PEAK-FLOOD SEASONAL FREQUENCY (EXPECTED) WITHIN EACH REGION

Region	$\chi 2$	Probability value
Carolina	3.146	0.790
Florida	3.425	0.754
Georgia coastal plain	15.940	0.014
Gulf Coast	1.883	0.930
Tennessee	7.027	0.318
Southeastern United States	119.960	0.001

TABLE 2
TOTAL NUMBER OF STREAM GAUGE STATIONS AND DRAINAGE BASIN AREA RANGE FOR EACH ANNUAL PEAK-FLOOD SEASONALITY REGION

	Number of stream gauge stations	Drainage-basin are range (mi^2)
Carolina	19	28-1421
Florida	4	220-1367
Georgia coastal plains	7	177-2790
Gulf Coast	37	122-7880
Tennessee	17	104-1928

floods, it may inhibit attempts to identify the link between drainage basin area and flood seasonality.

It should be noted that the test for the Gulf Coast region, which has the largest range in drainage basin area of the five regions, indicates that flood seasonality and drainage basin area are independent. This result is unexpected, given the indication that a large range in a sample's drainage basin area is required to assess the relationship between flood seasonality and drainage basin area. One reason for difficulty in identifying a link between annual peak-flood seasonality and drainage basin area within this region is the Gulf Coast's high frequency of intense rainfall (Herschfield, 1961). Often, the precipitation is so intense that drainage basin area is not a factor, and flooding will occur across a wide range of drainage basins.

Spearman Rank Correlation Coefficient. The nonparametric Spearman rank correlation coefficient is used in this study because of the nonnormal distribution of drainage basin area within each region. Since the Chi-square test indicates that in the Georgia Coastal Plain region, and for all 84 streams in the southeastern United States, drainage basin area and annual peak-flood seasonal frequency are

TABLE 3
SPEARMAN RANK CORRELATION COEFFICIENT BETWEEN DRAINAGE BASIN AREA AND ANNUAL PEAK-FLOOD SEASONAL FREQUENCY FOR THE GEORGIA COASTAL PLAIN AND SOUTHEASTERN UNITED STATES REGIONS

	Southeastern United States	Georgia Coastal Plain
Winter	-0.014	0.222
Spring	0.488*	0.821*
Summer	-0.266*	-0.661
Fall	-0.282*	-0.556

*Represents significance at the 0.05 level.

dependent, the correlation coefficients are calculated utilizing these two data sets. Results of the correlation represent a measurement of the association between annual peak-flood frequency (number of floods) and drainage basin area (mi^2) for each season. For all 84 streams in the southeastern United States, statistically significant correlation coefficients exist between drainage-basin area and spring annual peak-flood frequency (0.488), summer annual peak-flood frequency (-0.266), and fall annual peak-flood frequency (-0.282) (Table 3). The signs of the correlation coefficients indicate that larger the drainage basin the higher the spring annual peak-flood frequency, and the smaller the drainage basin the higher the summer and fall annual peak-flood frequency. The results support the previous conceptual model described by Hirschboeck (1991), that large persistent frontal storms, which occur frequently in spring, create floods more frequently in large drainage basins, and the small localized thunderstorms that are more frequent in the summer and fall create flooding more frequently on small drainage basins. However, since these correlation coefficients are not high, the influence of other physical factors contributing to flood occurrence must be taken into account. Spatial heterogeneity in atmospheric mechanisms creating floods, soil moisture, and other physiographic variables all are important contributors to flood seasonality across the southeastern United States.

For the Georgia Coastal Plain region, the only statistically significant (0.05 level) correlation coefficient exists between drainage-basin area and spring annual peak-flood frequency (0.821) (Table 3), suggesting that the frequency of spring annual peak floods increases with drainage-basin area. Assuming that heavy spring precipitation is dominated by frontal systems, as reported by Henderson and Vega (1996) and Keim (1996), it can be inferred that frontal systems have a profound effect upon flooding in large drainage basins in this region. Such frontal storms may not produce precipitation that is sufficiently intense to allow runoff to accumulate quickly and produce floods in small drainage basins, as compared to the rapid hydrologic response of these basins to short-lived, spatially limited convective cells (Knox, 1988).

SUMMARY AND CONCLUSIONS. This study examines relationships between flood seasonality and drainage basin area for the southeastern United States. To assess this relationship, a flood seasonality analysis based upon individual drainage basins is first developed. The flood-seasonality analysis identifies five distinct flood regions for the southeastern United States—the Tennessee, the Gulf Coast, Peninsular Florida, the Carolinas, and the Georgia Coastal Plain. In completion of this flood seasonality analysis, the season in which annual peak floods are most likely to occur in the southeastern United States, as described in previous research, was confirmed. In the northern portion of the study area, annual peak floods occur most frequently in winter. Southward, closer to the coastal regions, annual peak floods occur most frequently in the spring, and in peninsular Florida annual peak floods are most frequent in fall. This study expands previous flood-seasonality research by also determining the frequency of annual peak floods for each of the three remaining seasons. The results that deviate the most from previous research involve the identification of the Carolina region which possesses no dominant season in annual peak-flood frequency.

Statistical analysis indicates that the Georgia Coastal Plain is the only region with a significant relationship between drainage basin area and annual peak-flood seasonality. The statistical relationships for this region are interpreted as annual peak floods occurring more frequently on large drainage basins in the spring because of high soil moisture and frequent extratropical cyclone passage. Analysis of a single data set containing all 84 streams indicates that a weak, statistically significant relationship exists between drainage basin area and annual peak-flood seasonality for the entire study area. These results suggest the need for a wide range of drainage basin areas to identify a relationship with annual peak flood seasonality. However, by placing all 84 streams within a single data set, the interpretability of climatic mechanisms associated with flood seasonality becomes more difficult.

NOTES

[1]The author thanks Vernon Meentemeyer, K. K. Hirschboeck, Suzanne Davies-Withers, and two anonymous reviewers for providing constructive comments and guidance toward completion of this manuscript.

[2]A list of the stream gauge stations used in analysis are available from the author.

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