

**An Analysis of the Geographic Distribution of Flash Flood  
Events across the Southeastern United States**

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## **Abstract**

Flooding contributes to more than 100 deaths each year across the United States with most deaths due to flash flooding. Though most flash floods are caused by intense rainfall, the magnitude of a flash flood is dramatically affected by pre-existing physical factors such as ground cover, topography and soil moisture. This study looks at two of these pre-existing physical factors by examining the relationship between the number of flash flood events within a county to both the county population density and mean county slope.

Results showed that with increasing county population density there is an increase in the average annual number of flash flood events. With increasing mean county slope there is also an increase in the average annual number of flash flood events. A composite factor was developed to account for both population density and mean slope together. This factor when compared to the average annual number of flash flood events indicates that densely populated areas within hilly to high terrain are the most susceptible to flash flooding. It is the hope that these results will highlight hydrologically vulnerable areas that are prone to flash flooding in the southeastern United States. With this improved understanding, National Weather Service (NWS) forecaster situational awareness will increase, leading to more accurate and timely flash flood warnings.

## **1. Introduction**

The National Weather Service (NWS) defines a flash flood event as a flood which occurs within six hours or less of the causative event. (NWS, 2005) This fast occurring type of flood is often a threat to life and property. In fact, flash flooding is the convective storm-related event across the United States that is associated with the most fatalities (Doswell et al., 1996). For this reason, the NWS has greatly improved flash flood prediction through better forecasting tools and techniques during the past decade. These advances have come mainly in the improvement of heavy precipitation forecasting, a key component of flash flood prediction. However, the challenge of flash flood forecasting is made more difficult by the interaction of the meteorology with hydrology. A given precipitation event's chance of producing a flash flood are dramatically affected by such factors as soil moisture, the size of the drainage basin, the topography of the basin, the amount of urban use within the basin, etc. Thus, a flash flood event is many times a result of the combined effects of a meteorological event with a particular hydrological situation (Doswell et al, 1996).

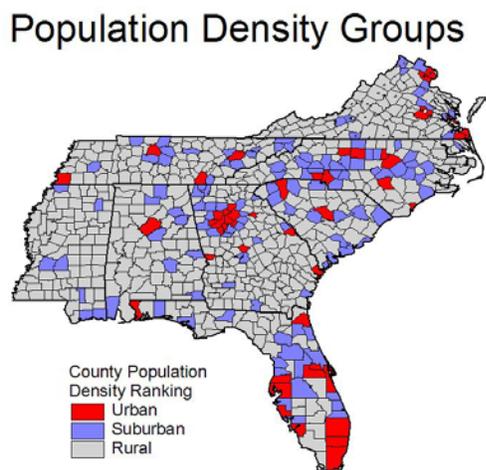
The primary objective for the study is to examine the number of flash flood events in counties across the southeastern United States relative to county population density (PD) and/or a mean county slope. It is theorized that counties with high population density and/or high mean county slope should have a greater potential for flash flood events than counties that are rural and/or flat. The intent of the author is to show a relationship between the number of flash flood events to urbanization and topography. It is the hope that this paper will enhance forecaster awareness to an inherent flash flood potential caused by these two factors.

## **2. Methodology**

Flash flood event data was taken from the National Weather Service Verification Database for the period 1994 through 2004 inclusive. A total of 6566 flash flood events across 713 counties were utilized

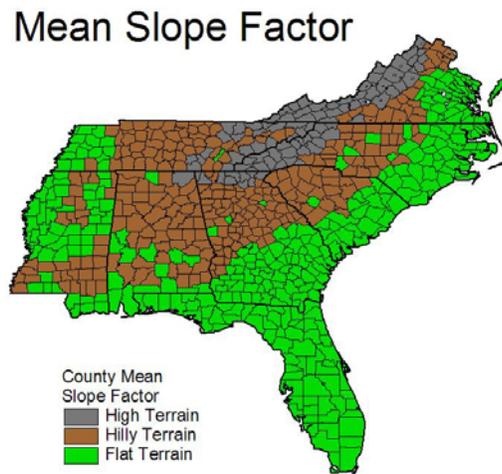
in the study covering an eight state area (Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia) within the southeastern United States. This total area encompassed 374,905 square miles. The number of flash flood events per county was normalized by the county area per 1000 square miles. County population density data was calculated from Environmental Systems Research Institute (ESRI) Geographic Information Systems (ESRI, 2000) data. To account for variations in county area that may influence the number of events, counties less than 100 square miles were excluded from the analysis which consisted of 36 municipality counties in Virginia. Slope data was calculated using ESRI Arc/Info Geographic Information Systems utilizing USGS 1-degree Digital Elevation Map (DEM) data.

Counties were grouped into three groups for analysis (Fig. 1). Average population density for the dataset was 138 people per square mile with a standard deviation of 255. Thus the author established that the “Urban” county group included all counties whose population density exceeded 393 people per square mile. The “Suburban” county group included all counties whose population density was equal to or between 138 to 393 people per square mile, while the “Rural” county group included all counties with population density less than 138 people per square mile.



**Fig. 1.** Population Density Groups utilizing 1999 Census data provided through ESRI Arcview.

Mean county slope was calculated using the USGS 1-degree DEM data in ArcGIS with Spatial Analysis Extension. Average county slope was calculated at 0.754 with a standard deviation of 0.990. The data was classified into three different groups (Fig. 2). The “High Terrain” group included counties whose mean slope was greater than 1.744. Based on the statistics and knowledge of the topography, the author established that counties with a mean slope equal to or between 0.400 and 1.744 were classified as “Hilly Terrain”, while counties with mean slope less than 0.400 were considered “Flat Terrain”.

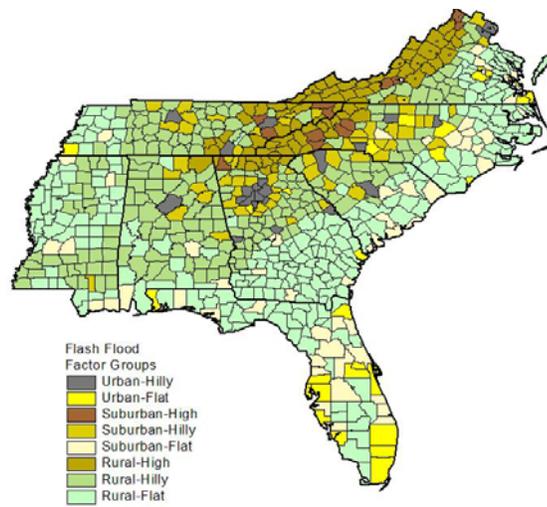


**Fig. 2.** Mean County Slope Factor derived from USGS elevation data using ArcGIS.

Utilizing both the mean county slope along with the county population density, a merged field was created called the “Composite Group” (Fig. 3). By cross-referencing the population density groups and the mean county slope groups, a total of 9 groups would be defined (three population density groups by three mean slope groups). Only 8 of these groups were possible in this study as no counties meet the criteria for both “Urban Group” and “High Terrain”, and thus no “Urban-High” group was created (Table 1).

Category	PD (100 sq miles)	Slope
<i>Urban-Hilly</i>	> 394	0.400 -1.744
<i>Urban-Flat</i>	> 394	< 0.400
<i>Suburban-High</i>	138-393	> 1.744
<i>Suburban-Hilly</i>	138-393	0.400 -1.744
<i>Suburban-Flat</i>	138-393	< 0.400
<i>Rural-High</i>	< 138	> 1.744
<i>Rural-Hilly</i>	< 138	0.400 -1.744
<i>Rural-Flat</i>	< 138	< 0.400

**Table 1.** Composite Groups and criteria



**Fig. 3.** Composite Groups

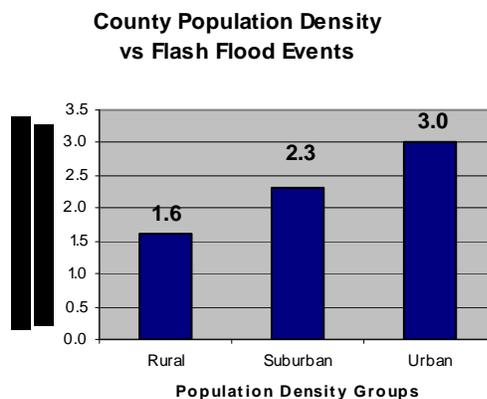
The average number of county flash flood events per 1000 square miles was calculated for each of the population density groups, mean county slope groups, and the composite groups. Correlation coefficients

comparing the relationship between the average annual number of flash flood events per 1000 square miles and the three groups were also calculated. The intervals depicted within the correlation analysis were computed by using every tenth percentile within each of the three groups to provide for an even breakdown in the groups for comparison to flash flood events. To further support the analysis of the relationship between flash flood events to both slope and population density, the number of county flash flood events per 1000 square miles will be shown geographically providing a comparison to known urban and high slope areas in the southeastern United States.

### 3. Results

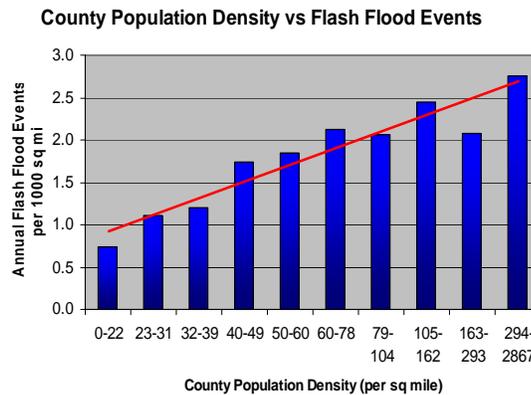
#### *a. Population Density Groups*

When comparing flash flood events against county population density groups, data showed that the urban county group had the highest density of flash flood events with an average of 3.0 flash flood events per 1000 square miles per year through the 11-year period. The suburban county group observed 2.3 events per 1000 square miles per year with the rural county group at 1.6 events per 1000 square miles per year (Fig. 4).



**Fig. 4.** The annual number of flash flood events per 1000 sq miles by population density group.

Correlation coefficients between county population density intervals and the annual number of county flash flood events per 1000 sq miles for those intervals were computed to be 0.94 (Fig. 5).



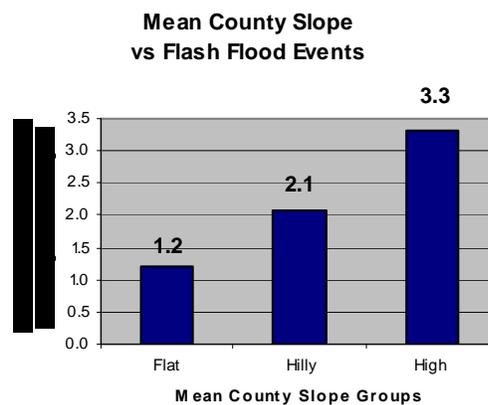
**Fig. 5.** The average annual number of flash flood events per 1000 sq miles compared to population density intervals with linear trendline.

Results show that there is a strong positive relationship between the average annual number of flash flood events and county population density. The urban county group represents nearly twice as many flash flood events as the rural county group. This connection between increasing population density and the number of flash floods may be attributed to several reasons. We must keep in mind that an event must be observed and reported, and thus counties with denser populations may have an increased chance of both observing and reporting flash floods. Another reason may be linked to the fact that with increasing population density, an increase in impervious surface is often the result. The effects of added impervious surface and urbanization on the flood hydrograph include increased total runoff volumes and peak flow rates. The changes in hydraulic efficiency associated with artificial channels, curbing, gutters, and storm drainage collection systems typical of an urban setting increase the velocity of flow and magnitude of flood peaks. (Chow, 1988) These hydrologic characteristics of an urban environment affect the hydrologic response and can lead to flash flooding. A third basis for the connection between population

density and the increase in flash flood events may be credited to an enhancement in rainfall intensity within urban areas. Shepherd and Burian (2003), as well as Huff and Changnon early on (1973), found elevated rainfall rates over and downwind of urban areas in their studies.

*b. Mean Slope Factor Groups*

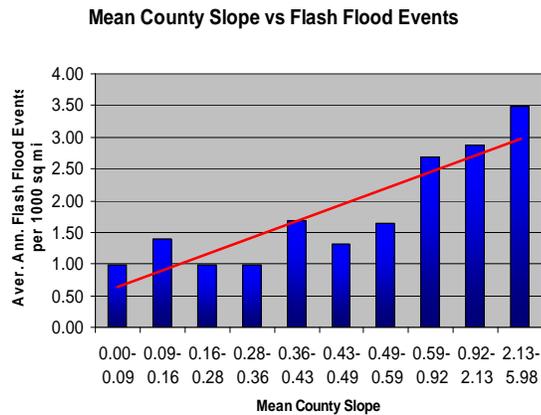
The comparison of the county mean slope and the annual number of county flash flood events per 1000 square miles indicated that counties with mountainous and hilly terrain tend to have more flash flood events than those counties with flat terrain. The high terrain group though the 11-year period (1994-2004) had on average 3.3 events per 1000 square miles per year. The hilly terrain group observed 2.1 events per 1000 square miles per year, while the flat terrain group reported only an annual average of 1.2 events per 1000 square miles (Fig. 6).



**Fig. 6.** The average number of flash flood events per year by mean county slope group.

Correlation coefficients between the mean county slope intervals and the average annual number of flash flood events per 1000 square miles for those intervals were computed to be 0.88 (Fig. 7). The likely reason for the link between mean county slope and the number of flash flood events is due to the fact that

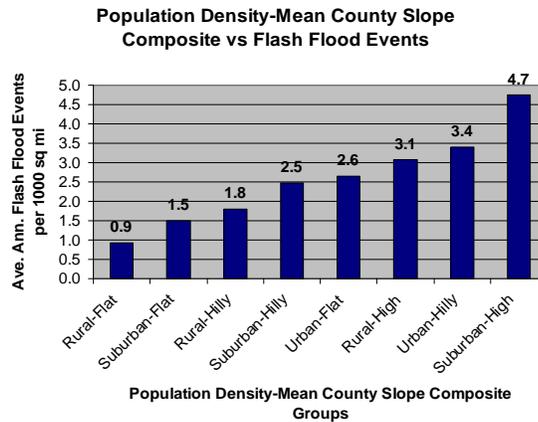
higher sloped areas have a greater potential for faster flow velocities due to gravity. These faster flow velocities can contribute to a faster responding channel or stream which can lead to a flash flood event. In addition, soils in steeper terrain tend to be of shallow depth due to erosion and other physical mechanisms. The shallow, rocky soils can promote more efficient runoff as the soil will be less capable for both infiltration and vegetation growth. Moreover, although most flash floods are caused by deep convection induced by synoptic forcing or convective heating, a strong updraft can also be caused or enhanced by orographic forcing. Chen et al found landscape variability at both large and small scales significantly affects the location and intensity of moist convection (2001). In the Big Thompson Canyon flash flood in 1975 and the Rapid City Flash Flood in 1972, both studied by Maddox et al (1978), orographic lifting in the eastern slopes of the Rockies played a notable role in producing rainfall sufficient for flash flooding.



**Fig. 7.** The average annual number of flash flood events compared to mean county slope intervals with linear trendline.

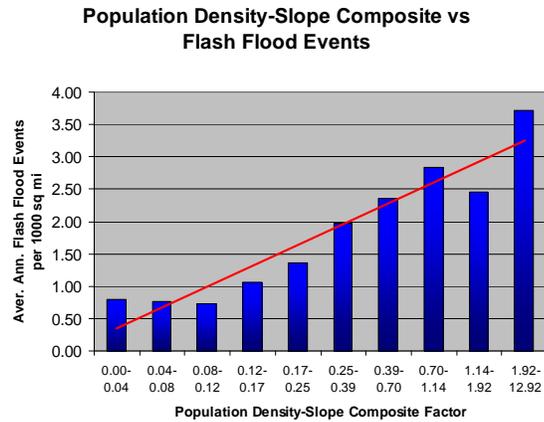
*c. Composite Groups*

Comparison of the “Composite Groups” to flash flood events showed that the “Suburban-High” group observed the most flash flood events with an average annual 4.7 flash flood events per 1000 square miles. The “Rural-Flat” group observed the least number of events with an average of 0.9 flash flood events per 1000 square miles annually (Fig. 8).



**Fig. 8.** The average number of flash flood events per year by the population density-mean county slope composite groups.

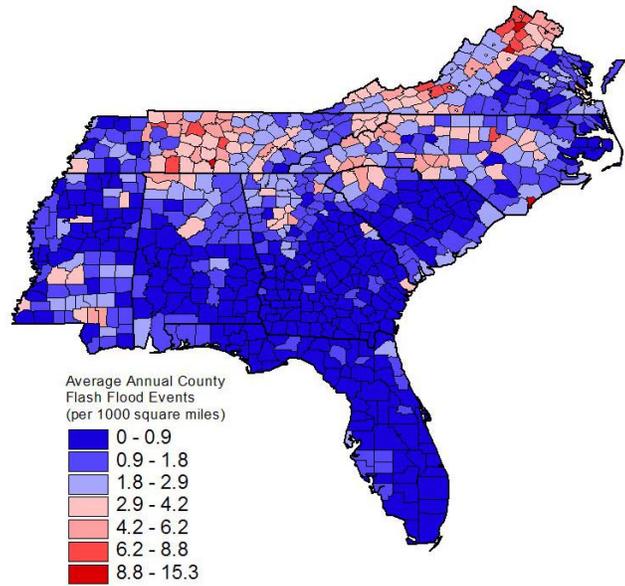
In examining the correlations between the “Composite Groups” and flash flood events, population density and mean county slope were normalized to the corresponding average value. These two normalized values were then multiplied together to calculate a “Composite Group” factor. The “Composite Group” factor was then used to determine correlations between the composite group and the number of flash flood events. In comparing the every tenth percentile intervals of the “Composite Group” factor and the average annual number of flash flood events per 1000 square miles, correlations coefficients were 0.95, indicating a strong positive relationship (Fig. 9). More importantly, the correlation between the merged factors and the number of flash flood events is slightly greater than the correlation when comparing county population density or mean county slope alone.



**Fig. 9.** The average annual number of flash flood events compared to the population density-mean county slope composite factor intervals with linear trendline

*d. Geographic Distribution of Flash Flood Events*

To further support the results of the study, an assessment of the geographic distribution on the number of county flash flood events per 1000 square miles was completed. The resulting map depicts elevated numbers of flash flood events in many of the major urban areas of the southeast with emphasis on urban areas in the depicted high terrain urban areas. Urban areas including Raleigh-Durham, Greenville-Spartanburg, Atlanta, Nashville, Birmingham, Mobile, Jackson, Memphis, Jacksonville, and Tampa show elevated numbers of flash flood events relative to surrounding areas (Fig. 10).



**Fig. 10.** Spatial distribution of the average annual number of flash flood events per 1000 square miles by county across the southeastern United States from 1994-2004. Red color shades indicate areas of elevated numbers of flash flood events.

#### 4. Conclusion

It is apparent that the number of flash flood events by county in the southeast United States can be influenced by both population density and mean county slope. This association between flash flooding to both mean county slope and population density provides an important awareness to inherent flash flood hydrologic vulnerabilities. For forecasters at the National Weather Service Forecast Offices who are responsible for issuing flash flood warnings, having an understanding of the areas which are hydrologically vulnerable can greatly enhance situational awareness to a potential flash flood event. This enhanced awareness can often lead to increased warning time and thus mitigation and protection of lives and property. In addition, at the NWS River Forecast Centers, daily flash flood rainfall guidance, used by NWS warning forecasters as criteria to issue flash flood warnings, should also be representative of the relative hydrologically vulnerable areas. Further studies into identifying higher resolution hydrologic

vulnerable areas would provide even greater awareness, and could be incorporated into NWS warning programs such as the Flash Flood Monitoring Program, or FFMP.

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