ABSTRACT

Since rainfall is an integral component in the hydrologic cycle, engineers must be able to quantify rainfall in order to design structures dealing with the collection, conveyance, and storage of rainfall runoff. This report deals with the study of rainfall characteristics and patterns in South Carolina. Rainfall analysis involved the assessment of rainfall patterns in the state with special attention to rainfall along the coastal area, the development of new rainfall IDF curves, and the development of new rainfall distribution patterns. The study also involved installing 19 rainfall gauging stations in key areas in the state, collecting the rainfall data at these sites, and developing a website to monitor rainfall at these sites.

The depth-duration-frequency curves and isopluvial maps for South Carolina were developed using the available rainfall data. A total of 17 durations ranging from 15 minutes to 120 hours for return periods of 2, 10, 25, 50, and 100 years were analyzed. Several methods were used to identify homogenous regions, but to no avail. At-site statistics were calculated to develop frequency relationships and the chi-squared goodness-of-fit test was used to determine the best fit probability distribution. The new intensity-duration-frequency curves were found to be slightly lower than the existing curves developed in 1986. The difference between the two set of curves can be attributed to the removal of the outliers in the present study and the existence of the post 1986 drought conditions. The spatial interpolation of the rainfall intensity from the depth-duration-frequency curves yielded accurate intensity-duration-frequency curves and could be used to develop these curves at ungauged sites in the study area.

Dimensionless design rainfall patterns for South Carolina were developed based on actual rainfall events as an alternative to the presently used SCS curves that are based on rainfall bursts. The rainfall data was analyzed, and previously used methods of separating a rainfall event out of the continuous dataset were evaluated and modified for the present application. Two distinct non-dimensional rainfall patterns, one for short durations of rainfall and the other for long durations, were identified. Though the general patterns for South Carolina were similar to rainfall patterns generated for other states in recent studies, they were markedly different when compared to the SCS Type II and Type III curves currently used in South Carolina.

Rainfall patterns along the coast of South Carolina were also studied to determine if there is a historical trend of increasing or decreasing rainfall. Several decades of existing data did not provide a conclusive result. At some locations, the total annual rainfall amounts increased then decreased while at other sites no discernable change could be ascertained.

The study also involved the installation of 19 rainfall gauging stations at key locations in the state. These gauging stations were installed with satellite links to transmit data that are downloaded regularly to a data storage facility. This data is displayable graphically as well as in text format via a dedicated website.

ACKNOWLEDGMENTS

The contributions of the following individuals toward the completion of this project are appreciated: Mr. Danny Metz, for his technical support in installing and maintaining the rainfall gauge sites as well as the construction of several components for each location; Dr. John Raiford and Dr. David Powell for their contributions as Masters of Science graduate students in Civil Engineering (the two supplemental reports are modifications of their MS theses); and Dr. Sebastien Goasgan and his students, Brandon Kagey, Matthew Rardon, and Emily Bauer for their work on developing the website. The contributions of several undergraduate civil engineering students who assisted at various stages of the study are also appreciated.

The authors also acknowledge the support they received from the various branches of the South Carolina Department of Transportation. In particular, the Material and Research Lab staff and the local staff at the various district offices and Section Sheds where the rainfall gauges were installed. Many of these individuals went out of their way to facilitate the progress of this project.

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CHAPTER 1: INTRODUCTION

When designing a hydraulic structure to manage rainfall and runoff, a time-distribution pattern (hyetograph) for the rainfall event is used to create a hydrograph. Hyetographs define how much rain falls at a particular time within a rainfall event. Another type of rainfall representation that is used in design of hydraulics structures is the Intensity-Duration-Frequency (IDF) relationship for a given location. During a period of high intensity rainfall, a large volume of runoff is produced in a short period of time. If the rain is lighter or more uniform in intensity, then the runoff volume accumulates gradually. When considering stormwater management for a new site, a detention structure may be installed to detain runoff and release it at controlled rates. The time over which a given volume of rain falls influences this design. If a large volume of runoff accumulates quickly, most of it has to be stored, leading to large structures.

In the last fifty years, new rainfall frequency analysis techniques have been developed. Furthermore, many government agencies are beginning to make use of these new techniques to update their IDF relationships. It has been suggested that IDF estimates be updated every 20 years. IDF relationships for South Carolina were last updated in 1988 (Purvis et al., 1988). Updating these relationships every 20 years not only increases the record length of the data set, allowing for more accurate prediction of larger return periods, but also allows new rainfall gauging stations to be included in the analysis.

Currently, Soil Conservation Service (SCS) Type II and III curves are used for rainfall distributions in South Carolina. These curves were developed by the SCS (1986) and were specified to be for storms that lasted 24-hours. Since these curves are dimensionless, it is a common practice to scale these curves to represent storm events with durations other than 24 hours. This scaling assumes that events of any duration have the same time-distribution pattern. However, the validity of this assumption is questionable, and it is widely believed that short and long duration events behave differently. Standard events generated from the SCS hyetographs are characterized by a very intense period of rainfall halfway through the event with 10 percent of the duration containing approximately 60 percent of the total rainfall volume. These patterns are at best conservative and may result in an over-design of the capacity of hydraulic structures.

Perhaps the most important component of the hyetograph generation process is the separation of storms. The SCS Type I, IA, II, and III design curves were derived from generalized depth-duration relationships that were obtained from Weather Bureau technical papers (Soil Conservation Service, 1973) and were based on bursts within a storm event, and hence did not represent actual rainfall events. To use actual rainfall events for developing rainfall distribution patters, storm events must be first separated and identified. The problem with separating events in a continuous record of rainfall data is defining the length of the "no-rain" or "dry" period that makes two events independent of each other. Several storm separation techniques are available and were used in this study to develop patterns that are unique to South Carolina.

There have been some observations of change in the rainfall pattern along coastal South Carolina. A significant increase may render some of the hydraulic structures inappropriate. A review of the historical annual precipitation at gauges located near the coast was conducted to identify changes in the total amounts. The data used were from available sources. Although monthly values were also reviewed, this report only presents the results of the evaluation of annual rainfall events along the coast. The monthly data revealed similar results as the annual data.

This report also includes a discussion of the installation of new rainfall gauges at key locations in the State and the web site that was developed to download and display the data collected at these sites.

The data used in this study include data from the 15-minute, 60-minute and 24-hour gauging stations in South Carolina and are shown in Figures 1, 2 and 3, respectively.

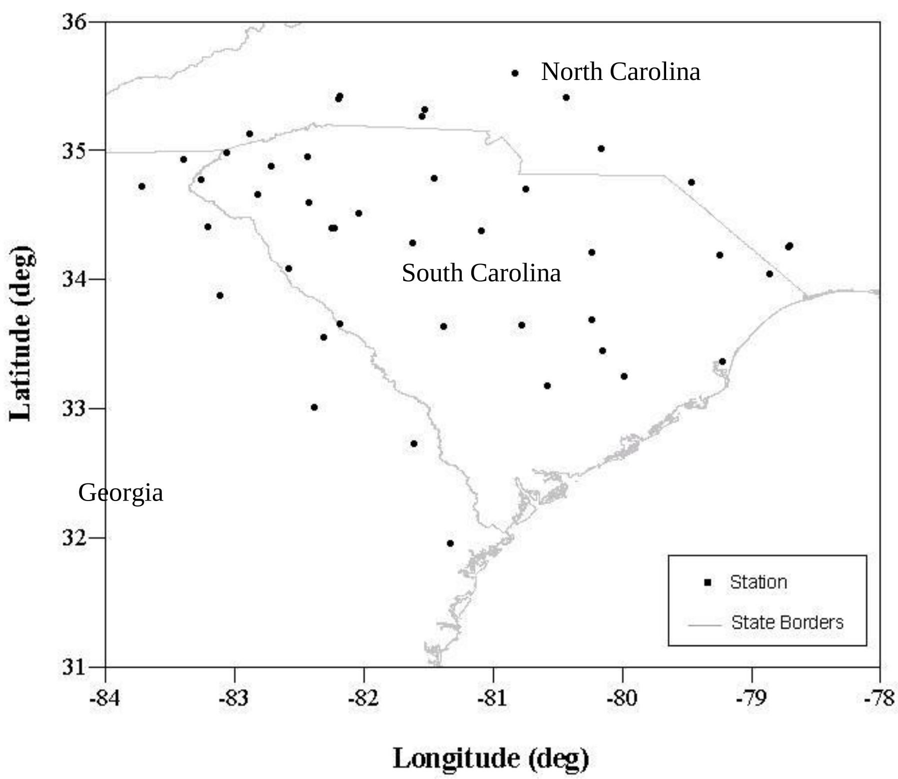

Figure 1. 15-Minute Rainfall Gauging Stations in and around South Carolina

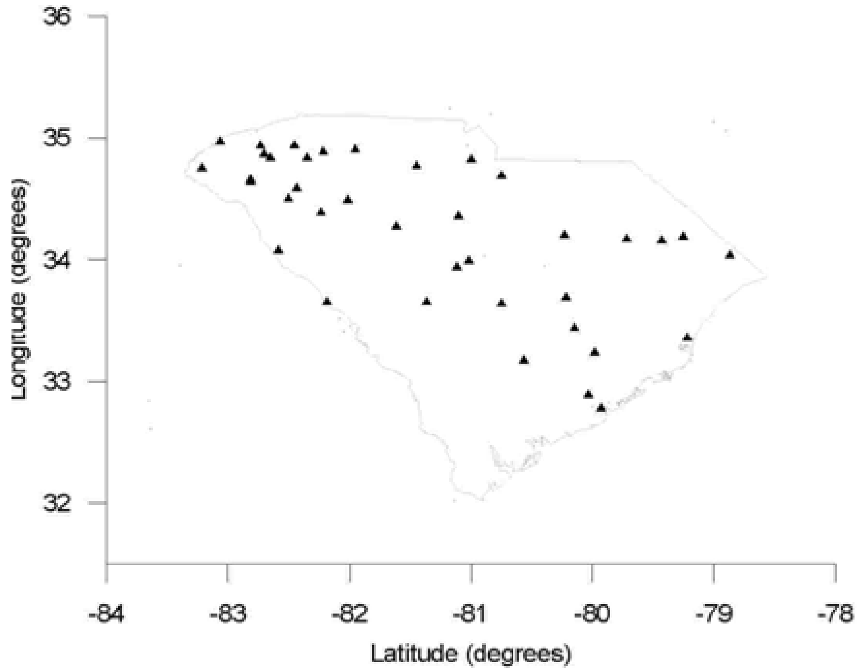

Figure 2. 60-Minute Rainfall Gauging Stations in South Carolina

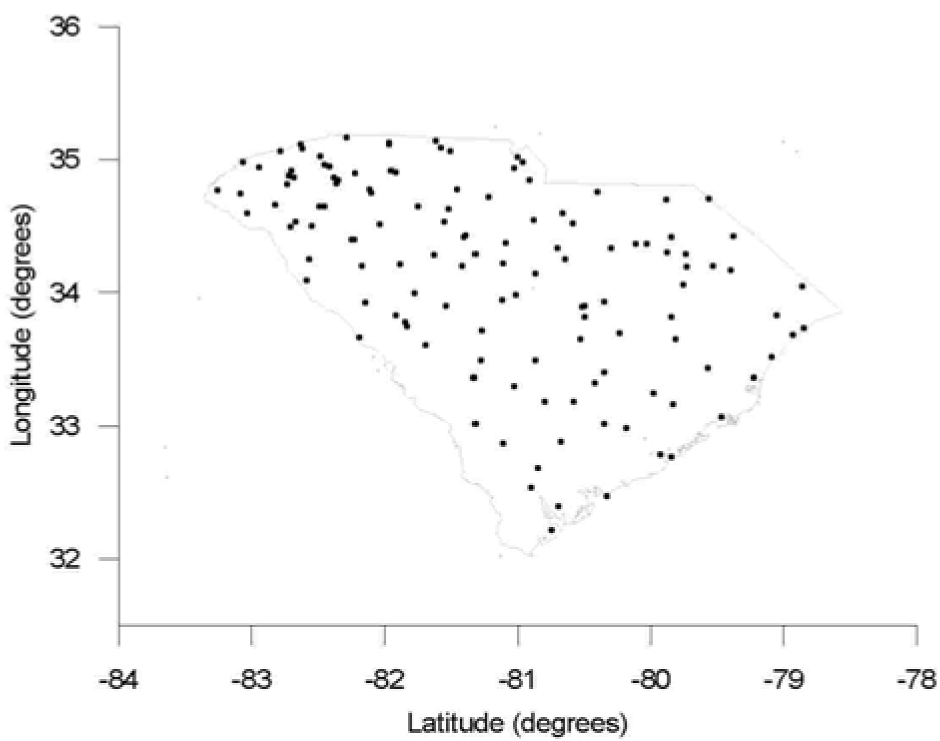

Figure 3. 24-Hour rainfall Gauging Stations in South Carolina

In addition to this main report, two supplemental reports are included that contain the detailed analysis of the two major components of this project:

1. Final Report Supplement 1 - contains the details of the research conducted to develop new rainfall frequency relationships (Raiford, 2004).
2. Final Report Supplement 2 - contains the research and results of the study to develop rainfall temporal patterns (Powell, 2005)

These two supplemental reports also include comparisons with existing information. Further, the second supplemental report includes a study of the impact of the new rainfall distribution patterns on the design of hydraulic structures, namely detention ponds.

It is important to note that this project has resulted in two students receiving the Master of Science degrees in Civil Engineering (John Raiford and David Powell), and in the publication of three refereed journal papers and two conference papers. They are:

1. Powell, D.N., Khan, A.A., and Aziz, N.M., "Impact of New Rainfall Patterns on Detention Pond Design", ASCE Journal of Irrigation and Drainage Engineering, Vol. 134, No. 2. (2008)
2. Raiford, J.P., Aziz, N.M., Khan, A.A., and Powell, D.N., "Rainfall Depth-Duration-Frequency Relationships for South Carolina, North Carolina, and Georgia, American Journal of Environmental Sciences Vol. 3, No. 2, pp. 78-84, (2007)
3. Powell, D.N., Khan, A.A., Aziz, N.M, and Raiford, J.P., "Dimensionless Rainfall Patterns for South Carolina", ASCE Journal of Hydrologic Engineering, Vol. 12, No. 1, pp. 130-133, (2007)
4. Powell, D.N., Aziz, N.M., and Khan, A.A., "Impact of New Rainfall Patterns on the Design of Hydraulic Structures," World Water and Environmental Resources Congress, ASCE, Omaha, Nebraska, May 21-25, 2006.
5. Raiford, J.P., Aziz, N.M., and Khan, A.A., "Development of Depth-Duration-Frequency Relationships Using Homogeneous Region Concept," World Water and Environmental Resources Congress, ASCE, Omaha, Nebraska, May 21-25, 2006.

CHAPTER 2: RAINFALL DEPTH DURATION FREQUENCY

The main objective of this part of the project was to update the rainfall IDF relationships for South Carolina. This was accomplished by first collecting and screening the data for quality, followed by an analysis to determine homogeneous regions, and finally at-site frequency relationships were determined. In order to produce isopluvial maps and IDF curves, these relationships were spatially analyzed, and regression analysis was used to obtain IDF curves at several locations in South Carolina.

Data Quality

The availability of rainfall data is dependent on the type of data sought. Daily data sets are available at many locations with record lengths in excess of 70 years at some stations. However, 15-minute data is available at fewer locations with much shorter record lengths of just over 30 years at best. This research used more than 500 daily stations but only slightly over 100 15-minute stations in South Carolina, North Carolina and Georgia. This dichotomy in data availability gives less accurate IDF relationships for short rainfall durations at large return periods. Figures 1, 2 and 3 show the location of the 15-minute, 60-minute and 24-hour gauging stations in South Carolina.

The quality of the data impacts the accuracy of the frequency relationships. This impact is felt when years of record must be removed from the maximum annual precipitation series due to errors in the data. Many of these errors can be corrected if the aerial density of gauging stations is high enough by combining neighboring stations or using methods such as the normal ratio method. These correction methods inherently assume that variations in rainfall intensity are small over a small area (10 miles). This being true, increasing record length at gauging stations would have a greater impact on the accuracy of short duration frequency relationships than increasing the number of stations in an area.

Homogeneous Regions

Homogeneous regions are a group of sites whose frequency relationships can be described by a similarly shaped probability distribution. In addition to simplifying the process of frequency analysis by describing many sites with an index-distribution, homogeneous regions also alleviate some of the problems associated with shorter record lengths. At-site analysis fits a distribution to each individual site using a sample size of that site's record. Since homogeneous regions encompass many sites, a much larger sample (years of record) is used to fit a distribution. This provides a way to more accurately predict large return period rainfall events of short duration using smaller record lengths than with at-site analysis.

The X-10 test was used in this research to identify homogeneous regions. The X-10 test uses the GEV distribution to determine a regional estimator. While homogeneous regions were identified in this study, they were not geographically contiguous. From the results of the at-site analysis, very few stations fit the GEV distribution. Using a test not based as heavily on the GEV distribution might have provided better regional results.

IDF Curves and Isopluvial Maps

The IDF curves and isopluvial maps were developed based on at-site analysis. Comparisons of existing IDF relationships to those produced in this study showed higher intensities for existing data for all durations and return periods. However, the agreement between the new and existing data improved as duration increased. This difference can be attributed to three sources:

1. The removal of outliers prior to generating intensities at different frequencies. This research used a single tailed 98% confidence interval to identify outliers. Including the outliers in the analysis provided much better agreement with existing values.
2. The length of record at gauging stations used. Data that is not available in electronic form was not used in this research. Also data subsequent to the publication of existing IDF curves encompass a period of severe drought with lower maximum rainfall values. The results show that including data post 1986 contributed to lower intensities. A large disagreement between the current and new curves was seen in Charleston, S.C. However, this may also be attributed to Charleston's location near the study boundary (i.e. near the coast).
3. The size of the study area. This research spatially analyzed sites from a three states. An IDF curve developed from local data may not match one developed from a larger region. In most cases, the spatial analysis increased the magnitude of longer duration values by a small amount. For the most part, however, the spatially analyzed curves showed good agreement with their individual station counterparts.

Isopluvial maps were also generated in this study. Existing maps have coarser resolution due to the much larger area considered. The maps produced by this research have a finer resolution and provide depth-frequency relationships for more durations.

The IDF curves and isopluvial maps were developed for Return periods of 2, 10, 25, 50 and 100 years and rainfall durations of 0.25-, 0.5-, 1-, 2-, 3-, 4-, 6-, 8-, 10-, 12-, 18-, 24-, 48-, 72-, 96-, and 120-hours. The method which best describes the data within the study area was used to produce updated IDF curves and isopluvial maps. Details of the research including background information, analysis details, results, and comparisons are presented in SUPPLEMENT 1. Below is a presentation of the summary of the results for IDF curves.

IDF Curves for County Centers

Using the depth-duration-frequency values at a rain gauge site, the IDF curves were generated using

$$i = \frac{aT^{m}}{(b + D)^{n}} \quad (1)$$

where,

i = the rainfall intensity in in/hr,

D = the rainfall duration in minutes,

T = the return period in years, and

a, b, m, n = curve parameters obtain from curve fitting.

Specifically, the IDF curve parameters for the center of each county are listed in Table 1.

Table 1. IDF Equation Parameters for Center of South Carolina Counties

County	Longitude	Latitude	Coefficients of IDF Equation			
			a	b	m	n
Abbeville	-82.4525	34.2376	99.0090	39.7579	0.2016	0.9076
Aiken	-81.69984	33.5517	87.8856	32.3803	0.2095	0.8851
Allendale	-81.3245	32.994	76.1651	26.1855	0.2120	0.8619
Anderson	-82.618	34.5318	98.2601	40.7357	0.1994	0.9081
Bamberg	-81.077	33.234	74.0442	25.7983	0.2142	0.8580
Barnwell	-81.3523	33.30379	79.4383	28.2968	0.2121	0.8690
Beaufort	-80.728	32.358	60.1787	18.3678	0.2165	0.8250
Berkeley	-79.9806	33.1271	56.5885	18.9223	0.2234	0.8150
Calhoun	-80.7928	33.6694	71.7047	25.9452	0.2160	0.8539
Charleston	-79.9914	32.8096	55.5596	18.1651	0.2248	0.8112
Cherokee	-81.634	35.0803	82.3746	35.5635	0.2048	0.8876
Chester	-81.1193	34.699	77.3396	31.2947	0.2113	0.8745
Chesterfield	-80.156	34.654	57.4814	20.9742	0.2158	0.8299
Clarendon	-80.217	33.677	61.3012	21.3818	0.2192	0.8296
Colleton	-80.6726	32.889	64.4631	21.2152	0.2172	0.8355
Darlington	-79.978	34.329	56.1926	19.8787	0.2179	0.8228
Dillon	-79.355	34.3945	49.3442	16.4729	0.2203	0.8031
Dorchester	-80.328	33.044	60.3295	20.0362	0.2202	0.8252
Edgefield	-81.904	33.77	92.7124	35.0464	0.2076	0.8944
Fairfield	-81.0927	34.384	77.7083	30.4907	0.2125	0.8721
Florence	-79.74	34.065	54.3128	18.8009	0.2202	0.8146
Georgetown	-79.313	33.4239	50.8418	16.8671	0.2257	0.7987
Greenville	-82.353	34.86	96.1411	40.9197	0.2004	0.9078
Greenwood	-82.143	34.188	98.2410	38.8635	0.2050	0.9058
Hampton	-81.132	32.796	71.3628	23.5383	0.2134	0.8516
Horry	-78.943	33.846	47.5735	15.3776	0.2249	0.7912
Jasper	-81.019	32.446	65.4564	20.4439	0.2137	0.8382
Kershaw	-80.605	34.292	66.8119	24.9620	0.2149	0.8487
Lancaster	-80.712	34.695	68.2520	26.8786	0.2132	0.8557
Laurens	-82.01	34.487	96.0770	39.2185	0.2056	0.9040
Lee	-80.266	34.185	60.7189	21.7702	0.2170	0.8332
Lexington	-81.232	33.949	80.5623	30.5161	0.2128	0.8741
Marion	-79.336	34.155	49.8362	16.6602	0.2216	0.8020
Marlboro	-79.668	34.644	51.6962	17.9097	0.2178	0.8134
McCormick	-82.293	33.887	98.7621	37.9413	0.2039	0.9051
Newberry	-81.588	34.265	87.3674	34.7131	0.2093	0.8884
Oconee	-83.02	34.715	94.3897	40.3430	0.1940	0.9039
Orangeburg	-80.812	33.464	70.8607	25.1137	0.2159	0.8514
Pickens	-82.701	34.829	94.6225	40.5638	0.1968	0.9053
Richland	-80.974	34.035	74.9183	28.1400	0.2139	0.8639
Saluda	-81.696	33.9877	89.2306	34.5877	0.2091	0.8896
Spartanburg	-82.004	34.962	91.1477	39.0604	0.2028	0.9009
Sumter	-80.3855	33.9317	63.4769	22.7172	0.2173	0.8375
Union	-81.61	34.719	86.3430	35.7909	0.2074	0.8905
Williamsburg	-79.74	33.633	55.4367	18.8009	0.2219	0.8133
York	-81.089	34.982	73.7284	30.6033	0.2099	0.8712

CHAPTER 3: TEMPORAL DISTRIBUTION OF RAINFALL PATTERNS

In this part of the study, new dimensionless rainfall patterns for various rainfall durations for South Carolina were developed. The impact of the storm separation criteria on the resulting hyetograph was investigated and the selection was tailored toward obtaining a representative distribution pattern. As the new patterns would be based on the rainfall data from the state, these patterns would represent the rainfall temporal distribution better than the currently used SCS curves. The final patterns from this study were compared to the patterns developed for other states. In addition, the impact of these patterns on the design of a pond is demonstrated.

Data Acquisition

Discrete rainfall data from South Carolina and from adjacent sites in North Carolina and Georgia were used to develop the rainfall distribution patterns. Data were obtained from the National Climate Data Center (NCDC) in Asheville, NC, the Southeast Regional Climate Center (SERCC) in Columbia, SC, and a private company called EarthInfo, Inc. The 15-minute dataset from EarthInfo had the most complete dataset with station recordings dating to 1971.

Event Separation

One of the most important aspects of this component of the study was to determine how to separate storm events from a continuous record of rainfall data.

However, before testing various storm separation methods, it was necessary to determine the minimum number of data points needed to define an event. Though only two points are necessary to draw a straight line, there will not be any shape to the pattern. If more points are used, the smallest possible event duration increases as well. Thus, the optimum number of points required to properly define S-shape curve of the cumulative rainfall must be determined. In this study, a minimum of six points (1.5 hours) were deemed necessary to adequately describe the shape of the rainfall pattern and duration percentage criteria was used to separate storms.

Pattern Development

After separating the rainfall events using a duration percentage criteria, rainfall patterns were developed. The process included non-dimensionalizing the storm events using the storm duration and total amount of rain in the storm. The cumulative non-dimensional storm distribution was interpolated to have 81 ordinates. The resulting storms were combined into one hour durations from 2 to 20 hours. That is, all the storms of duration less than 2 hours (1.5 hours to 2 hours) were part of the 2-hour group. The storms with duration higher than 2 hours and less than or equal to 3 hours belonged to the 3-hour group, and so on. The last two groups comprised of durations 21-24 and 25-51 hours. The minimum number of events in a grouping was set as 150 events. This ensured that when the top 50 events were used in the pattern generation procedure, they were a representation of the more extreme events of that group.

The top fifty storms in each group were divided into 9 equal intervals and the amount of rainfall in each interval was determined. The pattern generation method of

Pilgrim and Cordery (1975) was then applied to each group of events. The patterns generated for each group were plotted together to see if these pattern could be combined into a general pattern(s). Because South Carolina uses two regions of the SCS typical patterns, an attempt was made to separate the new dataset into the same regions. However, there were too few events in the coastal region of the SCS Type III pattern for effective analysis.

Storms with durations of 7 hours and less form a close cluster, and durations 10 hours and up form a separate group. The two "transition" durations of 8 and 9 hours show a totally different behavior. All of the shorter duration events were in an early, high intensity band, and all of the long events were in a more gradual band. The final patterns generated from this procedure are called SC Short and SC Long. Figure 4 shows these patterns together with the currently used SCS Type II dimensionless rainfall event. The peak intensity of short type occurs earlier than the SCS peak, while the peak intensity of long type occurs later. Both short and long types have a slow rise to peak as compared to SCS type curve.

The currently used patterns for Illinois and Florida are compared with the SC Short and SC Long curves in Figure 5 and Figure 6, respectively. The Illinois' patterns were generated by Huff in a 1990 report, while those of Florida (HydroCAD, 2003) were generated in a study by the Florida Department of Transportation (FDOT). The comparison shows that the new South Carolina rainfall distribution patterns are similar to those found for other states, even though the rainfall regime in these states may differ from South Carolina. However, they all differ from the SCS type curves.

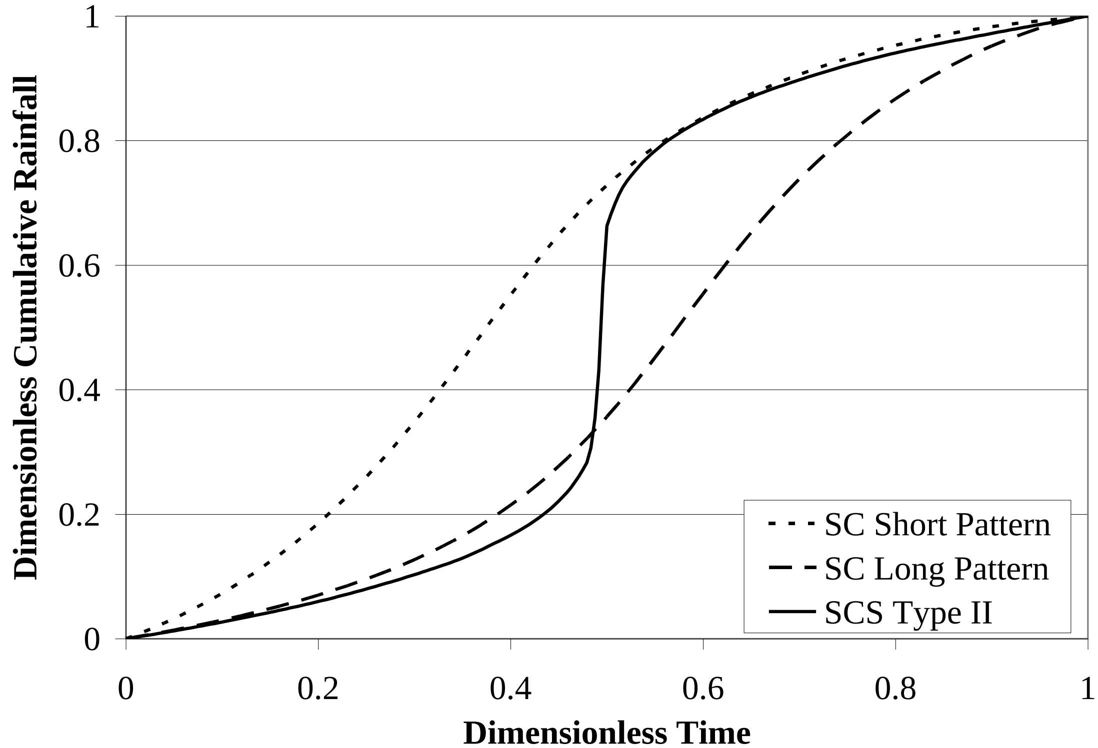

Figure 4. New Rainfall Distribution Patterns for South Carolina

For design purposes, the SC Short type distribution should be used for storms with duration less than or equal to 7 hours. For storms with durations greater than or equal to 10 hours, the SC Long type distribution should be used. For durations between 7 and 10 hours, the distribution that provides the most conservative design should be used. The equations that describe the SC Short Type and the SC Long Type distributions are given in equations (2) and (3), respectively.

$$y = \frac{a + cx + ex^2 + gx^3 + ix^4}{1 + bx + dx^2 + fx^3 + hx^4} \qquad (2)$$

$$y = \frac{a + cx + ex^2 + gx^3}{1 + bx + dx^2 + fx^3 + hx^4} \qquad (3)$$

The coefficients in these two equations are listed in Table 2.

Table 2. Curve Fit Coefficients for SC Short and SC Long Types

SC Short Type	
Coefficients	Value
a	0.000219
b	-4.76581
c	0.560064
d	9.85584
e	-1.13566
f	-10.2291
g	-0.46087
h	6.566747
i	3.460688

SC Long Type	
Coefficient	Value
a	0.00029
b	-4.27906
c	0.255251
d	7.206444
e	-0.73489
f	-5.53176
g	0.685433
h	1.810463

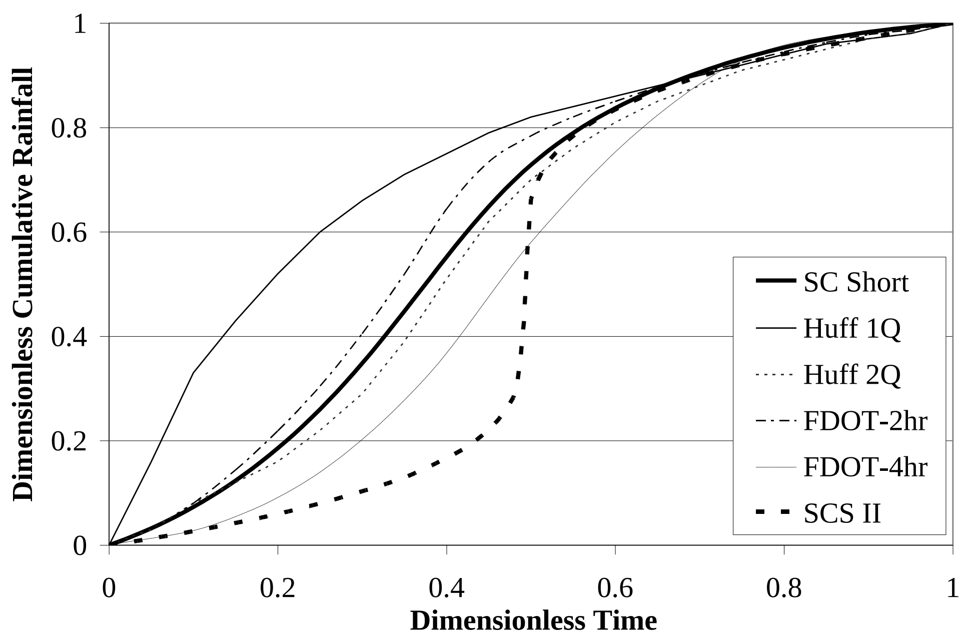

Figure 5. Comparison of the New SC Short Pattern with Other Patterns

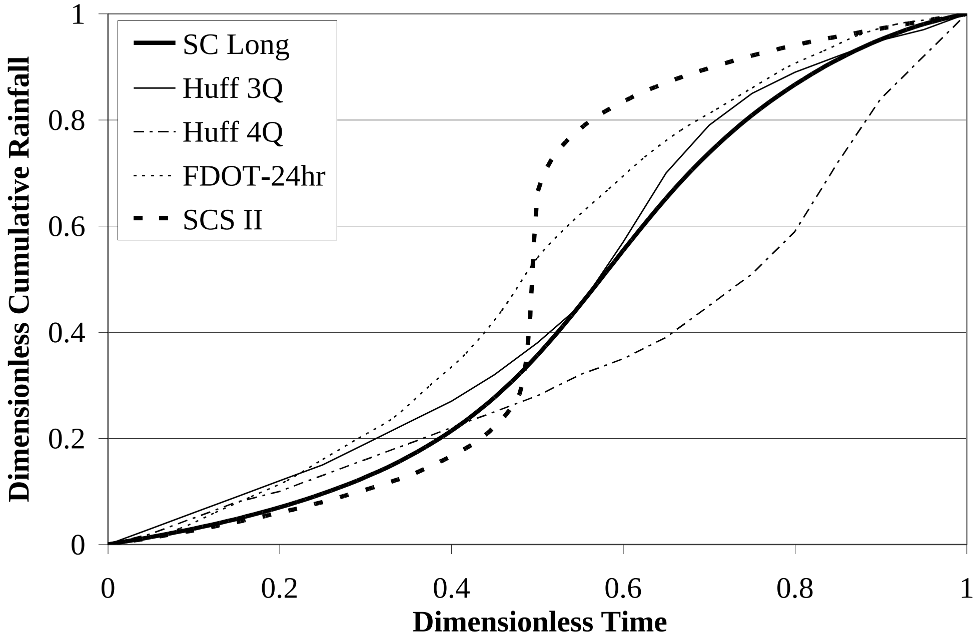

Figure 6. Comparison of the New SC Long pattern with Other Patterns

CHAPTER 4: ANNUAL PRECIPITATION NEAR THE COAST

The annual rainfall record near the coast of South Carolina is examined to identify possible historical trends. Records for six counties are available and include Charleston, Georgetown, Horry, Berkeley, Marion and Dorchester counties. Two rain gauge stations are available for the counties of Charleston and Berkeley. The annual rainfall data for a total of eight stations are shown in Figures 7-14. The data show large fluctuations in the annual rainfall. In each case, a quadratic equation is fit to the rainfall data to assess the trend. Except for the station at Loris (Horry County), all other stations show an increasing trend of annual rainfall up to about 1975, and a decreasing trend thereafter. The station at Loris shows a slight increase in the annual rainfall amount; however the rainfall data is available only up to 1992, so the most recent rainfall trends cannot be ascertained.

The stations at Moncks Corner, Mullins, and Saint George in Berkeley, Marion, and Dorchester counties, respectively, show a severe reduction in the annual rainfall amount in recent years. In general, the counties along the coast show a reducing trend in the annual rainfall amounts.

Monthly trends at these stations were also analyzed. The monthly trends in most part were similar to annual trends. However, there were few months (April, August, September, and October) that showed an increasing rainfall trend in recent years. In general, no discernable pattern could be established from these trends.

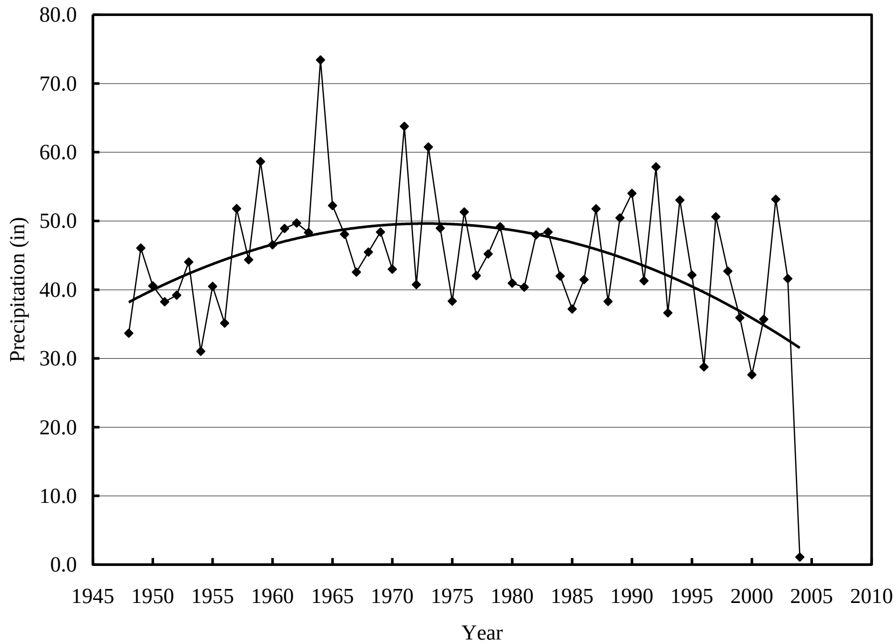

Figure 7. Annual Precipitation for Charleston City (Charleston County)

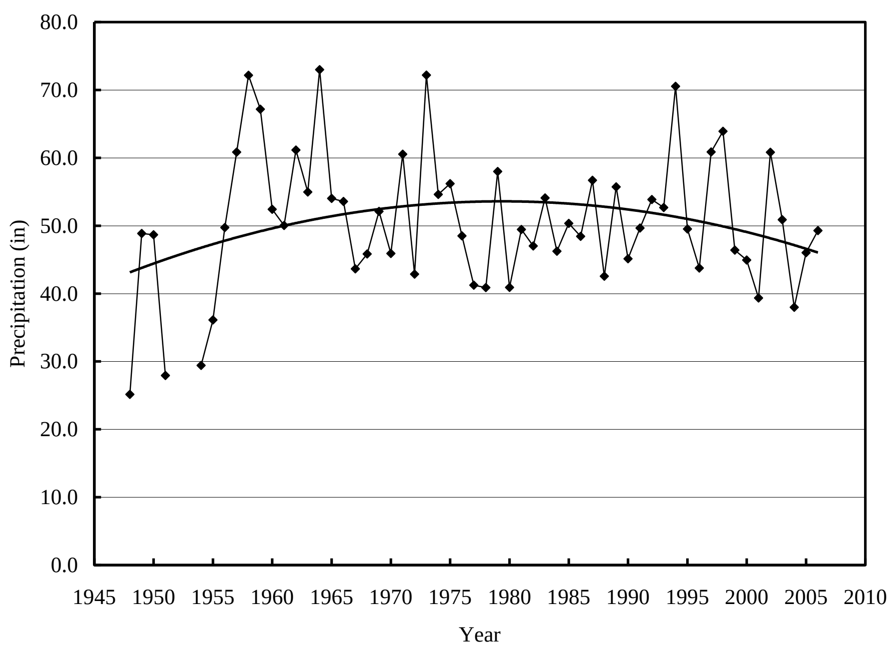

Figure 8. Annual Precipitation for Charleston International Airport (Charleston County)

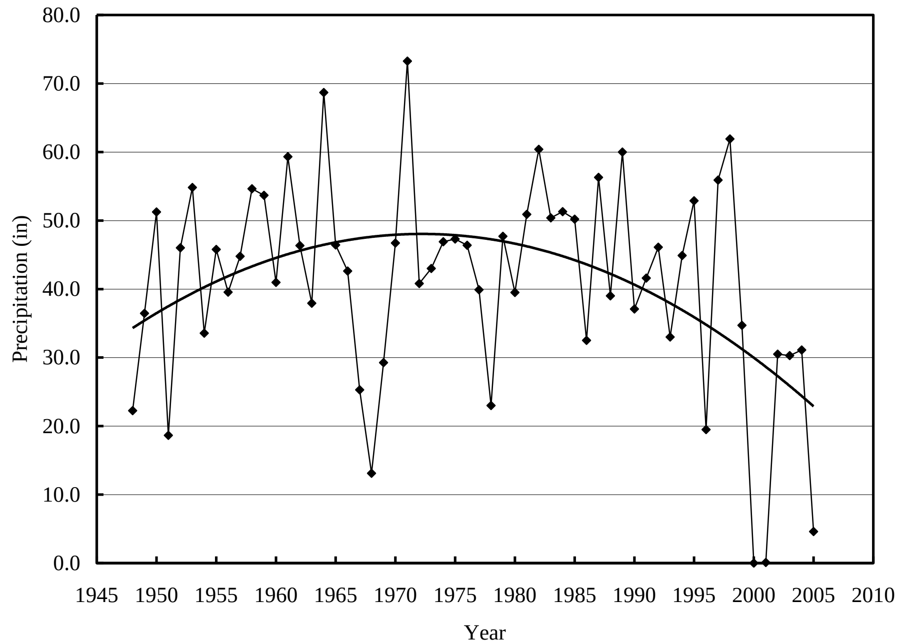

Figure 9. Annual Precipitation for Georgetown (Georgetown County)

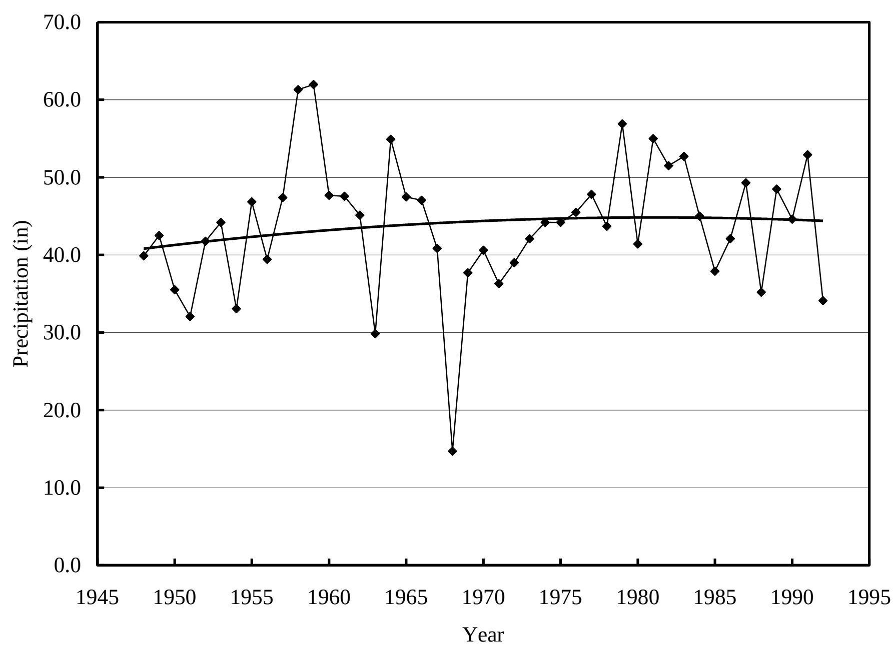

Figure 10. Annual Precipitation for Loris (Horry County)

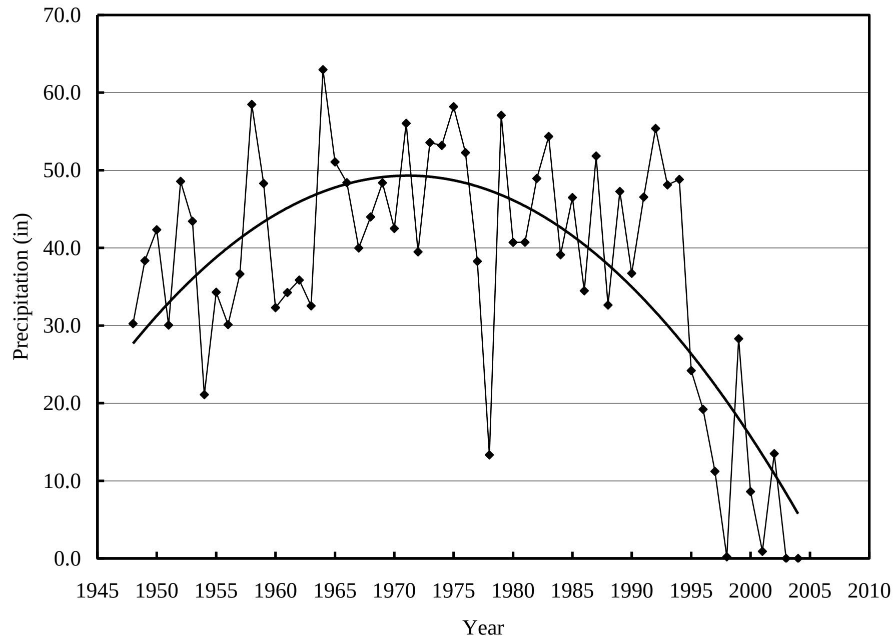

Figure 11. Annual Precipitation for Moncks Corner (Berkeley County)

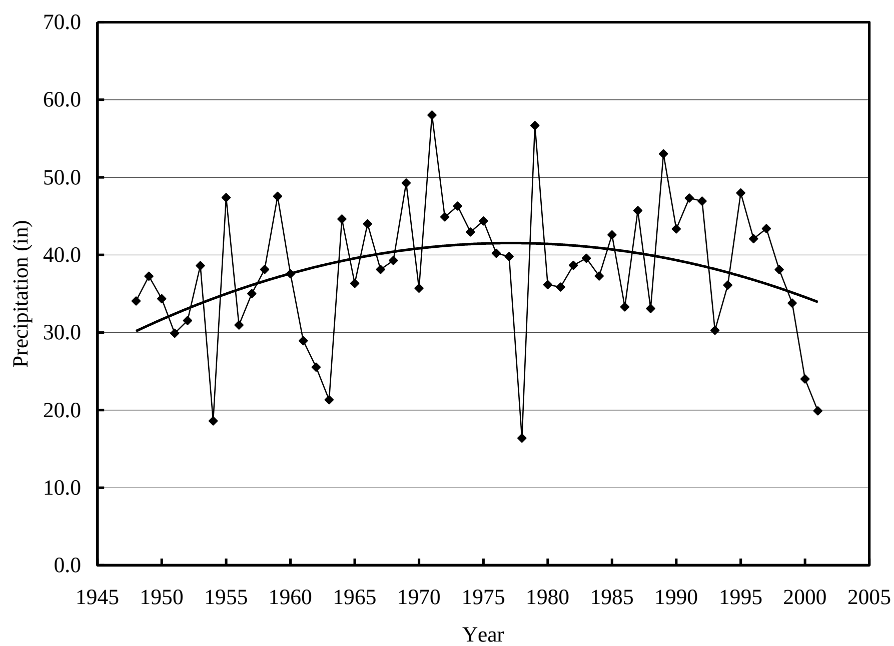

Figure 12. Annual Precipitation for Santee Cooper Spillway (Berkeley County)

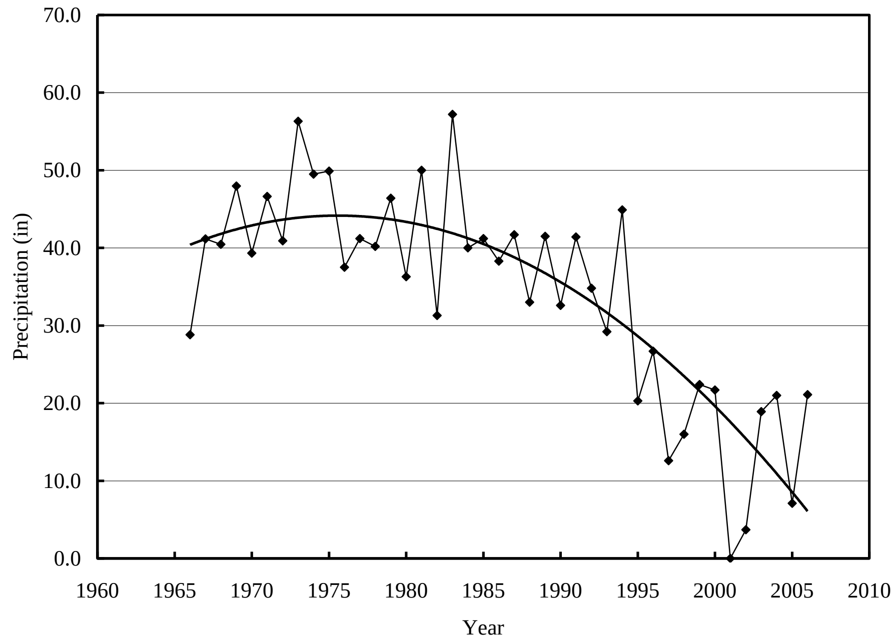

Figure 13. Annual Precipitation for Mullins (Marion County)

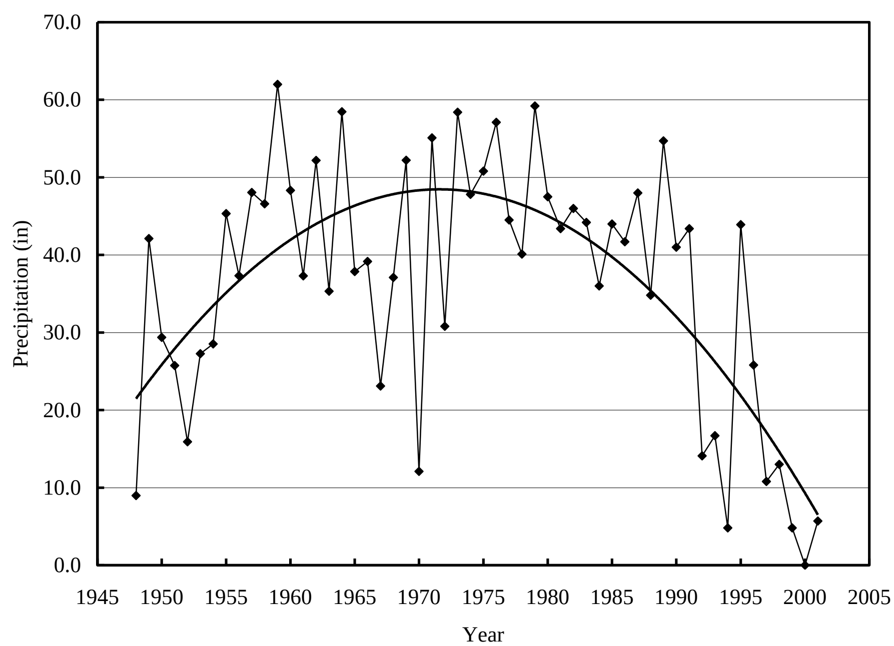

Figure 14. Annual Precipitation for Saint George (Dorchester County)

CHAPTER 5: NEW RAIN GAUGES

A component of this project was to install and maintain 19 rainfall gauges at various sites in South Carolina, especially within 20 to 30 miles from the coastline. These gauges were installed at locations approved by the SC DOT at SC DOT sites for security. The gauging stations are located at the following SC DOT sites listed in Table 3.

Table 3. Location of New Rainfall Gauging Stations

City	Gauge Location	City	Gauge Location
Andrews	SC DOT Section Shed	Jamestown	SC DOT Storage Yard
Aynor	SC DOT Section Shed	Lake City	SC DOT Section Shed
Bamberg	SC DOT Section Shed	Loris	Will be relocated
Bennettsville	SC DOT Section Shed	Moncks Corner	SC DOT Section Shed
Chesterfield	SC DOT Section Shed	Parkers Ferry	SC DOT Section Shed
Conway	SC DOT Section Shed	Ridgeland	SC DOT Storage Yard
Darlington	SC DOT Section Shed	Saluda	SC DOT Section Shed
Hampton	SC DOT Section Shed	Summerville	SC DOT Section Shed
Hemingway	SC DOT Section Shed	Walterboro	SC DOT Section Shed
Huger	SC DOT Section Shed		

Each site is composed of a fenced-in area containing a tipping bucket rain gauge mounted on a stand that was manufactured by the Clemson University Civil Engineering Department technical staff. Attached to the stand is a data collection system that records rainfall data from the tipping bucket and transmits the data through the NOAA GOES Satellite. The setup includes a water-tight equipment box, a solar panel to power the battery for data collection, and an antenna for the transmission of data. Figure 15 is a picture of the rain gauge site at the SC DOT Section Shed in Summerville.

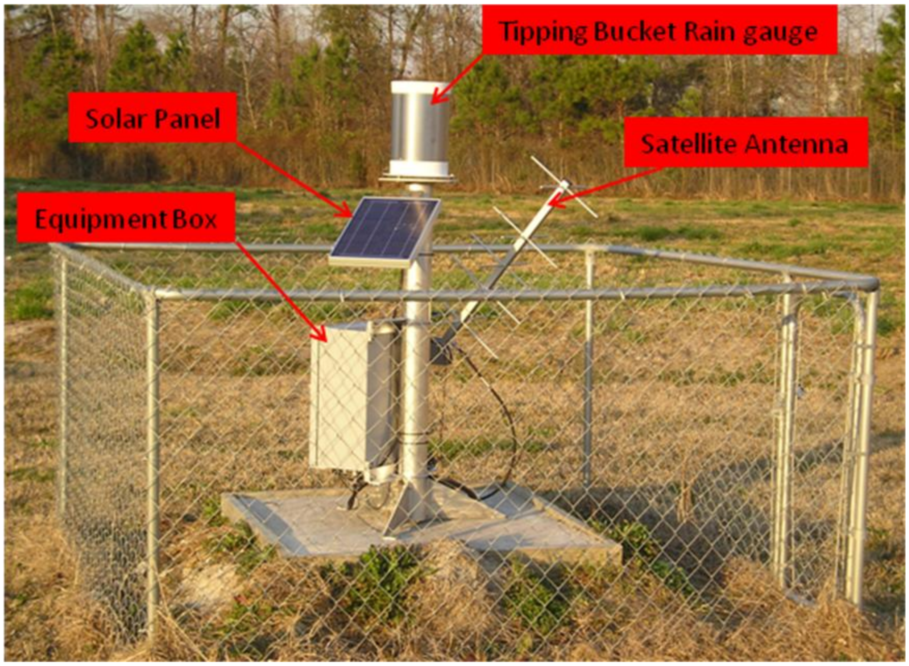

Figure 15. Typical Rainfall Gauging site at Summerville

Figure 16 shows the contents of the equipment box (data logger and a battery). The data is transmitted via the satellite once every hour and is also stored in the data logger. Frequently, the data logger contents must be purged to make room for new data. This is done by connecting a computer to the data logger and downloading the data to the computer, then purging them from the data logger to make room for more data to be collected as shown in Figure 16.

The rainfall data is recorded every five minutes regardless of the rainfall amount. Therefore, every hour, a total of 12 values of rainfall are transmitted via the satellite and are downloaded dynamically to a computer storage device at Clemson University. This data is viewable via a website developed specifically for this project. In addition, the battery voltage is also transmitted via satellite and is used to identify whether the battery is being charged appropriately.

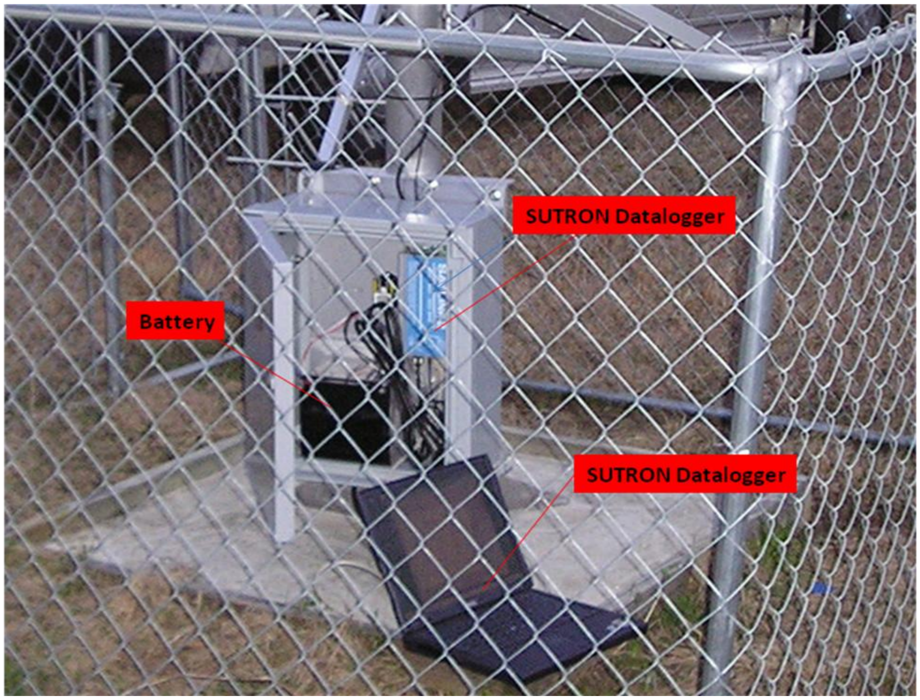

Figure 16. Sample rainfall gauging site showing equipment box contents at Hemingway

Website User Manual

The website is located at http://ciisfun.cs.clemson.edu/dot/2.0/design.html. The main screen is a map that displays the 19 locations (marked with a pin as shown in Figure 17) where rainfall gauges were installed. Clicking on a "pin" will pop up a bubble displaying local weather and recorded rainfall date range. Clicking a "pin" will also display the graph and rainfall history in varying increments.

The main screen also displays a list of cities available as shown in Figure 18. Clicking on a city will pan and zoom the map to the desired city, pop up the information bubble for that city, and show the graph and rainfall history.

Figure 17. Google Map Showing Cities

Figure 18. List of Cities

The graph only displays the results after a city has been selected, either from the map or from the list of cities. By default, the graph lists the past 2 months of data for a given location. The graph is interactive and requires Adobe Flash.

Also displayed, after the selection of a city, is the live feed. The live feed displays various date ranges of information as shown in Figure 19. The default display includes the previous 2½ hours of data displayed in 15 minute intervals. Other options include displaying the previous 24 hours in 1 hour intervals, or displaying the previous 3 weeks in daily intervals.

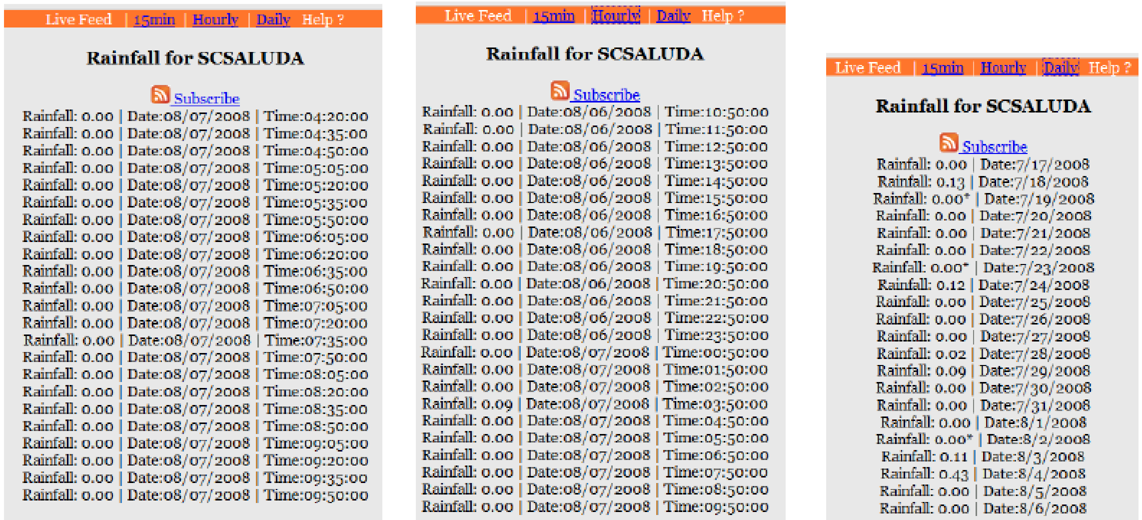

Figure 19. Live Feed Data types (15 min, hourly, and daily)

After selecting the desired city, the page will load the associated graph and the last 2½ hours in the "Live Feed" section. After loading the default graph, the option exists below the graph to customize the date range. The Rainfall Graph section will look similar to Figure 20 after clicking "Customize Graph Display". On this page select the location (if different), interval (hourly or daily), start date, end date, and click "View Graph". CAUTION: Selecting a large date range will increase page load time dramatically and with a large date range with hourly interval (i.e., over 6 months) will cause the application to time out and may fail to display a graph.

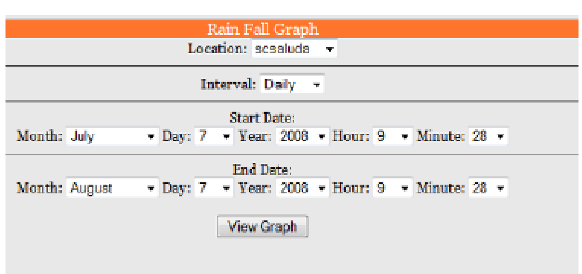

Figure 20. Data Range Selection Menu

Website Technical Development

A dedicated website, using Web 2.0 techniques, was developed to display a visual representation of rainfall collected at the 19 gauging stations in South Carolina. The techniques used are not limited to display rainfall at these stations and can be adapted to any measurable atmospheric data. However, at this time it is only used for rainfall.

Using Asynchronous JavaScript and XML (AJAX), allows the client to browse the application more like a desktop application rather than a web application. This client-side scripting method is convenient to use not only because it is minimally invasive but also allows for a seamless transition in pages. Further, Hypertext Processor (PHP) was used for the server-side scripting and provided an open-source freely available and developed base for operations. Perl is used as the back-end collector and generation of the RSS news feeds. The rainfall data that are transmitted hourly via satellite are downloaded using Telnet, parsed and then placed into the database.

This application uses Google Maps API and the Google Visualization API. It allows for download in a universal format for a selected range of dates and times. This format is a comma separated value (CSV) which may be opened by Excel to OpenOffice.

This application is based on Beta software by Google. As such problems may arise due to changes in Google's code and a possible incompatibility with the Rainfall application's code. Also at anytime Google's API may be unavailable for various reasons, causing problems with the Rainfall application.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the results of this study, IDF curves and isopluvial maps were developed for South Carolina. In addition, using interpolation techniques, the IDF equation parameters at the center of each county are also determined. The IDF curves were not significantly different from the existing curves. In addition, new rainfall distribution patterns were developed. Two rainfall patterns were developed for South Carolina: one for short duration storms and the other for long duration storms. These rainfall patterns are different from the currently used SCS Type II and III patterns used in the state.

Rainfall collected along coastal South Carolina indicates that the annual rainfall shows a decreasing trend since about 1975. The analysis of monthly rainfall data produced no clear patterns of the rainfall trends.

Recommendations

The supplemental reports include specific recommendation. However, below are two broad recommendations for consideration in future studies.

1. This study assumes the stationarity of rainfall patterns. However, with climate change, it is necessary to evaluate the possible impacts of climate change and non-stationarity of rainfall on the IDF relationships and the rainfall patterns.

2. This study developed new rainfall patterns that are significantly different from those currently used. Therefore, it is important to validate these patterns using existing hydraulic structures.
3. The 19 rainfall gauging stations should continue to be operational with more involvement of the local SC DOT authorities in the maintenance of these gauging stations.

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Frequency and Time Distribution of Rainfall in South Carolina

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