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Precipitation variability of streamflow fraction in West Central Florida

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Precipitation Variability of Streamflow Fraction in West Central Florida

by

Michael H. Scott

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering Department of Civil and Environmental Engineering College of Engineering University of South Florida

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PRECIPITATION VARIABILITY OF STREAMFLOW FRACTION IN WEST CENTRAL FLORIDA

Michael H. Scott

ABSTRACT

There is a strong interest to develop a method to estimate mean annual ungaged streamflow with varying precipitation. A method was developed utilizing GIS and other statistical analysis to estimate ungaged mean annual streamflow. This method utilizes a normalized streamflow fraction (NSF) method previously developed which relies on drainage basin area, coupled with mean annual local precipitation, to estimate the ungaged streamflow variability. This method has been applied to west central Florida. The test of the method yielded an R squared value of 0.9894, proceeded by a verification that yielded an R squared value of 0.998. This method is believed to be generally applicable to other areas and the particular results should be useful in and around west central Florida and perhaps, other coastal plain environments.
CHAPTER ONE

INTRODUCTION

There is a continued need for mean annual flow estimates using simple techniques for environmental studies and other water resource assessments. Streamflow must be considered when planning for various water resource projects such as estuary management, storm water impacts, and impact of development. Expensive and time consuming mathematical modeling is not always an option. Nor, in the absence of calibration data, is it necessarily more reliable.

One common method for determining the streamflow for an ungaged area is to use flow measurements or records from the nearest streamflow gaging station and estimate the streamflow for the desired area scaled by the ratio of the drainage areas (USGS, 2006). Depending on the distance and hydraulic similarity between the watershed contributing to the flow station and the area to be estimated, it has been shown that considerable errors can arise (Clayback, 2006). This method usually leads to lower than actual values when a gage is installed to verify the estimates.

A procedure was developed that yields flow estimates for ungaged areas using several key hydrologic variables. This procedure was tested and verified on west central Florida streamflow measurements reported by USGS.
Purpose

This study presents the precipitation variability of mean annual streamflow in west central Florida. The purpose of this study is to relate the behavior of streamflow to precipitation and to discover the time variability of this relationship and how it differs regionally within the study domain.

Previous Studies

There have been several studies done prior to this project regarding ungaged streamflow; however, none have been done specifically for the precipitation variability of streamflow in west central Florida. Additionally, of the reports that exist on this topic, all of them speak of some type of mathematical analysis on the streamflow, disregarding any physical correlations that may exist.

One method developed, estimates August median streamflow for ungaged, unregulated streams in eastern coastal Maine (Lombard, 2004). This method took into account the drainage basin area and the percent underlain by a sand and gravel aquifer. Lombard (2004) also related base-flow measurements at partial-record and short-term continuous-record streamflow gaging stations to concurrent daily streamflows at nearby long-term continuous-record streamflow gaging stations.

A generalized least-squares regression analysis was used to develop equations that were applied to estimate August median streamflow on ungaged streams. The equations that were developed resulted in an error of prediction ranging from -30 to 43 percent (Lombard, 2004). With this relatively large amount of error, it was concluded that
improved estimates of basin characteristics could be important to the improvement of low-flow estimates.

The United States Geological Survey (USGS) generated a program called StreamStats that can be used to estimate streamflow statistics for ungaged sites (United States Geological Survey, 2004). This program is a web application that uses existing USGS data and ESRI ArcGIS (Ormsby, et al., 2004) to analyze surrounding basins and their respective regression equations to predict the flows for the ungaged site. However, StreamStats assumes that the error for the ungaged sites is the same as the known sites, which could be hazardous to the accuracy of the calculated data. Figure 1 shows the states in which StreamStats has been implemented.

![Figure 1: StreamStats Availability (Red = Implemented, Blue = Implementation in Process) (USGS, 2004)]

In a study done by Teemu Kokkonen (2003), rainfall runoff predictions were discussed. One aspect of this study was to look at those catchments that lacked
streamflow records within the Coweeta Hydrologic Laboratory in North Carolina and to predict the runoff for these catchments using data from other catchments within the same region that had streamflow records. However, Kokkonen concluded that it would be more ideal to incorporate the observed physical catchment properties into the model structure and parameters (Kokkonen, 2003).

Horn (1988) examined annual streamflow records for 124 stream gages in and near Idaho to determine the annual flow characteristics. Two sets of equations for north-central and southern Idaho provided the best predictive results, with the equations for north-central Idaho yielding multiple correlation coefficients in excess of 0.97 (Horn, 1988). The equations coupled with the maps that were developed in this study can be used to estimate the annual flow at and ungaged location throughout Idaho.

Another attempt to use spatially weighted averages to estimate ungaged streamflow was done by Altunkaynak, Ozger, and Sen (2005). A standard regional dependence function was proposed to describe the weighted average using available data points. However, it was concluded that the discharge at any particular station was better described as a function of discharge at 3.5 closest stations. Validation of this method yielded streamflow predictions with less than 10% relative error.

Kroll, Luz, Allen, and Vogel (2004) realized that regional hydrologic models of low-flow processes often produce estimators with unacceptably large errors. Using the watershed boundaries from the USGS, many watershed characteristics were developed from digital grids. The inclusion of hydrogeologic indices, in particular a new smoothed baseflow recession constant estimator, led to dramatic improvements in low-flow prediction. However, no quantitative results were reported.
CHAPTER TWO

DESCRIPTION OF STUDY AREA

The study domain in west central Florida is approximately 10,400 square miles encompassing 16 counties with a population of 3.1 million people (Figure 2). The average precipitation across the domain for the eleven year period used in the study was 52 inches per year, but precipitation shows substantial spatial and temporal variability. On average, the driest months of record are November and April, with the wettest being July and August (NOAA, 2006). The mean annual temperature is 73°F. The mean annual open-water evaporation rate for the region is 52 inches per year (Ruskauff et al., 2003).

The study area is over the surficial, Floridan, and Intermediate aquifers. The surficial aquifer system is predominately sand, the Intermediate aquifer system is interbedded siliciclastics and carbonates and the Floridan aquifer system consists of massive carbonates (Tihansky and Knochemas, 2001). The central part of the study domain shows carbonate units dipping and becoming overlain by the thickening Hawthorne Formation (a distinct carbonate unit) that forms the Intermediate aquifer system south of Tampa Bay. Below the Intermediate Aquifer System is a confining unit for the Floridan Aquifer and the presence of the confining unit is the primary cause of the
change in geologic environments between the north and south portions of west central Florida.

The three largest rivers in the study domain are the Withlacoochee, Hillsborough and Peace Rivers. The combined drainage area of the three watersheds is 5100 square miles, more than half of the study area. In the north, the Weeki Wachee, Chassahowitzka, Homosassa and Crystal Rivers all originate from coastal springs. In the south, the Alafia, Little Manatee and Manatee Rivers all terminate into Tampa Bay along with the Hillsborough River. The Myakka and Peace Rivers terminate into Charlotte Harbor.

The land-surface elevations for the study domain range from just over 200 feet above sea level to sea level. Ridge systems are found in the interior and along the eastern boundary of the study domain, with the largest being the Lake Wales Ridge to the West, and the Brooksville Ridge in the northeastern corner of the domain.
Figure 2: West-Central Florida Study Domain
Methodology

To create the study area in GIS, several shape files were used from the Southwest Florida Water Management District (SWFWMD). The files were imported into GIS and then overlaid with a basin delineation coverage obtained from a previous study (Geurink, 2000).

The streamflow gaging stations used for this study were all USGS gages with an eleven year period of record from 1993 to 2003. All of the gages are read and maintained on a regular basis by the USGS.

Each gaging station was selected on the basis of elevation, location, period of record and previous studies. The overall study area was divided into sub basins using previous USGS delineations, further interpreted to close at USGS gaging stations. Basins were closed to incorporate only areas that contributed to the gaging station; resultant basins are shown in Figure 3.
Figure 3: Sub-basin Delineation and USGS Streamflow Gages
Initially, twenty-five years (1981-2005) of precipitation records at thirty-one unique gaging stations were downloaded from NOAA; however, most of the gages had extensive missing (or incomplete) data during part of the selected study period (1981 and 1982 rainfall records). Therefore, all 1981 thru 1982 records were discarded. Also, for this particular study, the available streamflow records only went to 2003, so all 2004 thru 2005 precipitation data were deleted. After these edits, a twenty-one year period of record remained for rainfall with matching streamflow data.

Some of the thirty-one stations had some missing records for the 1983 thru 2003 record. In order to obtain some numerical value of reliability, all of the stations were analyzed to determine how much data were missing or incomplete. Eleven of the original thirty-one gages had greater than 20% missing records, and were therefore discarded.

Nevertheless, the twenty-one years of record was considered a reasonable period of record for several reasons. Analysis showed that this period exhibited the desired mean and extreme rainfall characteristic observed for the region. Also, from 1960 to 2000, the population in Florida had increased by 400%; however, from 1980 to 2000, the population increased by only 50% (Figure 4) (Census, 2006). Therefore, it was inferred that anthropogenic stresses might be different for the two periods.
As the population increased, the state became more urbanized, therefore changing the rainfall/runoff characteristics of the area. The mean annual precipitation fluctuations for the twenty-one year period of record are shown graphically (Figure 5) with the statistical information tabulated (Table 1).
Figure 5: Annual Precipitation for 1983-2003

Table 1: Annual Precipitation Statistics for West-Central Florida

<table>
<thead>
<tr>
<th>NOAA ID</th>
<th>Avg. (in.)</th>
<th>Min. (in.)</th>
<th>Max. (in.)</th>
<th>Std. Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>236</td>
<td>52.50</td>
<td>27.31</td>
<td>72.61</td>
<td>8.97</td>
</tr>
<tr>
<td>369</td>
<td>51.93</td>
<td>26.10</td>
<td>66.20</td>
<td>10.77</td>
</tr>
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<td>945</td>
<td>55.75</td>
<td>43.96</td>
<td>78.33</td>
<td>9.47</td>
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<tr>
<td>1046</td>
<td>53.14</td>
<td>40.62</td>
<td>70.98</td>
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<td>85.10</td>
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<td>32.87</td>
<td>69.16</td>
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<td>3153</td>
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<td>34.00</td>
<td>78.08</td>
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<td>67.83</td>
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</tr>
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<td>35.66</td>
<td>63.25</td>
<td>8.21</td>
</tr>
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<td>39.90</td>
<td>67.27</td>
<td>8.66</td>
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<tr>
<td>5076</td>
<td>50.35</td>
<td>29.26</td>
<td>66.88</td>
<td>8.85</td>
</tr>
<tr>
<td>5973</td>
<td>48.97</td>
<td>29.53</td>
<td>64.16</td>
<td>8.76</td>
</tr>
<tr>
<td>6065</td>
<td>60.20</td>
<td>44.03</td>
<td>82.31</td>
<td>13.26</td>
</tr>
<tr>
<td>6414</td>
<td>48.63</td>
<td>28.58</td>
<td>62.92</td>
<td>8.21</td>
</tr>
<tr>
<td>6880</td>
<td>53.47</td>
<td>30.05</td>
<td>71.70</td>
<td>11.65</td>
</tr>
<tr>
<td>7205</td>
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<td>39.74</td>
<td>71.97</td>
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<td>29.85</td>
<td>67.71</td>
<td>10.46</td>
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<tr>
<td>9176</td>
<td>50.96</td>
<td>29.07</td>
<td>75.08</td>
<td>10.77</td>
</tr>
<tr>
<td>Overall Avg</td>
<td>52.15</td>
<td>33.77</td>
<td>71.92</td>
<td>10.02</td>
</tr>
</tbody>
</table>

12
For this study only eleven years of rainfall record, 1993 thru 2003, were used due to the limited availability of reliable streamflow data prior to 1993. It was determined that the rainfall record from 1983 thru 1992 and 1993 thru 2003 were statistically similar. The 1983 thru 1992 record had an average of 50.38 inches of precipitation with a standard deviation of 6.21 inches, while the 1993 thru 2003 record had an average precipitation of 53.48 inches with a standard deviation of 7.62 inches. Below is a graph showing the similar characteristics between the two periods (Figure 6).

![Figure 6: Comparison of Annual Precipitation for 1983-1992 and 1993-2002](image)

Note that in the graph above (Figure 6), the calendar year only goes to 2002 for the second period of record. This was done solely for graphical purposes so that two ten year periods would be plotted against each other.

After defining the period of record that was to be used, the precipitation data were spatially analyzed. Due mainly to hydrogeologic differences previously discussed, the west central Florida area is hydrologically divided by Interstate 4 going East-West from
Tampa to Orlando (Ross, 2005). North of I-4 is henceforth referred to as the northern region, or north zone, and to the south of I-4 is the southern region, or south zone. ArcGIS utilities (Ormsby, et al., 2004) were used to spatially determine which precipitation gages were in the north and which were in the south (Figure 7).
Figure 7: North and South Precipitation Zones and Corresponding Gages
The north and south zones were then statistically analyzed using Microsoft Excel. To verify that the gages should be separated in the above manner, the entire twenty-one year period of record was analyzed. The north zone gages had an average mean annual rainfall of 50.57 inches while the south zone gages had an average mean annual rainfall of 52.82 inches. Also, depicted in Figure 8 below, the south zone had a greater mean annual precipitation than the north on average.

![Figure 8: Comparison of Annual Precipitation for North and South Zones (1983-2003)](image)

This characteristic of the south having a greater precipitation is likely due to slight climatological differences with greater convective storm activity towards the south. Also, previously mentioned geological differences result in the south having a shallower depth-to-water-table in certain areas (Figure 9), which would allow for a greater rate of evapotranspiration and therefore, a more productive environment for convective rainfall than in the north.
Figure 9: Depth-to-water-table for West-Central Florida
When the 1993 thru 2003 period was analyzed, it was discovered that an even greater difference existed between the north and south zones. For this eleven year period, the north had an average mean annual precipitation of 50.25 inches, while the south had an average mean annual precipitation of 53.89 inches. This greater difference could have been due to the heavy hurricane activity in the south zone during this period of record. During that time, twelve named storms (either hurricanes or tropical storms) came over Florida (NOAA, 2005). All twelve of these storms impacted the south zone, while only four of them significantly affected the north zone (Table 2).

Table 2: Storm Activity in West-Central Florida from 1993-2003

<table>
<thead>
<tr>
<th>Storm Name</th>
<th>Hurricane</th>
<th>Tropical Storm</th>
<th>North Zone</th>
<th>South Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michelle</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Gabrielle</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gordon</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Irene</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Harvey</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Floyd</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Mitch</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Earl</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Josephine</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Opal</td>
<td>x</td>
<td></td>
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<td>x</td>
</tr>
<tr>
<td>Jerry</td>
<td></td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Erin</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

The streamflow gages were also divided into north and south zones by I-4. Mean annual, spatially averaged streamflow was then plotted against precipitation for the entire domain and analyzed.

Preliminary results suggested that there might be a significant difference between the north and south zone streamflow precipitation relationship as a result of the
hydrologic and climologic differences. However, it was determined that the difference in precipitation between the two zones was not great enough to be statistically meaningful. Therefore, for the remaining procedures, the study domain was analyzed without the separation into zones.

A normalized streamflow fraction (NSF) was calculated for each streamflow gaging station used in this study according to the method of Clayback (2006). The resultant NSF values are shown in Figure 10. The mean annual regional precipitation values were plotted against the NSF for each gage to determine the correlation that existed between them.

The slope was then taken from each of these graphs for each gage and the NSF value for a precipitation of 52 inches, \( NSF_0 \). This represented the NSF for the particular gage for an average precipitation (52 inch) rainfall year. These slope and \( NSF_0 \) values were then plotted against one another.

In order to use the most accurate precipitation data, a localized mean annual precipitation was calculated for each of the streamflow gages. This was done using Theisan polygons. Polygons were created for the precipitation gages that had at least 3 years of record. Then a table was made for each of the years of record from 1993-2003 in which the local precipitation value was recorded for each streamflow station used in this study.

NSF and the precipitation values were plotted for all gages using the localized mean annual precipitation. The slope was then taken from this graph for each gage and \( NSF_0 \). These NSF values were then plotted versus the slope values.
Analysis will be done using the multi-year preceding average if the precipitation was increasing, but if the precipitation was decreasing, the current year precipitation was used (referred to as the modified two-year preceding average method). This method took into account the apparent storage delays in streamflow response to wetter cycles that were found from the regression analysis. The same procedure was followed to obtain the NSF versus slope graph (Figure 23).

It is the objective of this research that, with only NSF and precipitation data, one can determine the ungaged streamflow of a desired site. It is first proposed to formulate a non-dimensional annual discharge as, 
\[ Q'_i = \frac{Q_i}{A_b P_0} \] 
where \( Q_i \) is the annual streamflow rate, \( A_b \) is the basin area, and \( P_0 \) is the long term mean annual precipitation (e.g., 52 inches in west-central Florida). Also, a non-dimensional annual precipitation volume, \( P'_i \), can be defined as 
\[ P'_i = \frac{P_i}{P_0} \] 
where \( P_0 \) is the long term mean annual precipitation for a basin \( i \).

Using a linear equation of the form, \( y = mx + b \), unknown streamflow at a station can be related to mean annual precipitation, \( P'_i \), as,
\[ Q'_i = m_i (P'_i) + b_i \]  
(1)

Where \( m_i \) and \( b_i \) are the stream specific precipitation sensitivity slope and intercept, respectively. Noting that the long term mean annual streamflow, \( Q_0 \), should follow the same relationship, the equation can be written as:
\[ Q'_0 = m_i (P'_0) + b_i \]  
(2)

20
It should be noted that $Q'_{in}$ is exactly the NSF value proposed by Clayback (2006) and previously discussed. Subtracting equation 2 from equation 1 to remove the intercept yields:

$$Q'_i - Q'_0 = m_i (P'_i - P'_{in})$$  \hspace{1cm} (3)

This form of the equation yields precipitation variability of the streamflow desired. Noting that precipitation was non-dimensionalized by dividing by mean annual precipitation ($P_0$), $P'_{in} = 1$, then the following simplified equation was found.

$$Q'_i = m_i (P' - 1) + Q'_0$$ \hspace{1cm} (4)

Adapting equation 4 to dimensional discharge in cubic feet per second (cfs), a value for streamflow in an ungaged region can be expressed as,

$$Q = [m_i (P' - 1) + Q'_0] \left[ (A_b) (P_0) (c) \right]$$ \hspace{1cm} (5)

where $c$ is a coefficient of unit conversions (e.g., for $Q$ in cfs and $P_0$ in inches and $A_b$ in miles squared, $c = .074$).

Using Figure 10 for a spatial reference $Q'_{in}$ can be taken obtained for a particular sub basin from the method of Clayback (2006).
Figure 10: Normalized Streamflow Fraction for West-Central Florida
The above derivation demonstrated that \( Q'_0 = f(m) \) and that \( Q'_i = f(m) \).

The next step was to determine a relationship for the precipitation sensitivity variable \( m_i \). The precipitation and NSF for each gage were plotted. The slope of each line (m) and the intercept at P = 52 inches were then plotted on one graph. The resultant equation of the best fit line is below.

\[
y = 13.908x + .1246
\]

In equation 6, \( y = Q'_0 \), and \( x = m_i \). By making these substitutions and rearranging, the variable \( m_i \) can be obtained from equation (7).

\[
m_i = \frac{Q'_i - .1246}{13.908}
\]

To test the above equation for determining \( Q'_0 \), all \( m_i \) values for the gages used in this study were calculated. These values along with the drainage basin area and local mean annual precipitation values were used to calculate the \( Q'_i \) for all the gages. These predicted values were then compared to the actual annual Q mean values that were collected for this study. To verify the method, streamflow was predicted for seven streamflow gaging stations that were not used in the development of the method.

Some of the data used in the study was not normally distributed. Many parametric approaches rely on the data being normally distributed. Nonparametric methods can be employed on non-normal data sets. Nonparametric methods should be used only when the underlying distribution is unknown or cannot be transformed to make it normal (Berthouex and Brown, 1994). Some of the results obtained in this study were suspected to be nonparametric (non-normal).
Kendall’s tau, $T_k$, is a measure of correlation between the strength of the relationship between two variables, regardless of whether the relationship is increasing or decreasing. Tau measures the strength of the monotonic relationship between an ordered paired observation, $X$ and $Y$. A monotonic relationship shows one variable increasing while the other variable always increases or always decreases. Tau is a rank-based procedure and is therefore resistant to the effect of a small number of unusual (nonparametric) values. Tau is dependent on the ranks of the data, not the values themselves and can be used where the data is limited (Helsel and Hirsch, 2002). The $T_k$ values will generally be lower than values of the traditional correlation coefficient $r$. A strong value of $r$ is 0.9 or higher. The tau value corresponding to the same data set is about 0.7 (Helsel and Hirsch, 2002).

With this in mind, Kendall’s tau was calculated in addition to $R$ squared for any of the data sets that had a sample size of 20 or less. Table 3 lists the Kendall values necessary for a sample size, $n$, to achieve a 99% confidence level (Rohlf, 1969).

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CHAPTER THREE

RESULTS

In testing the approach, regional average precipitation was first used. Comparing mean annual streamflow to regional annual precipitation only show a modest relationship (Figure 11). The linear regression only showed a correlation of 58%; however, a regression for the two year preceding average precipitation versus annual streamflow showed a slightly improved correlation of 68% (Figure 12).

Figure 11: Regression of Annual Precipitation Versus Streamflow (1993-2003)
A possible reason for the improved correlation (68%), for the two year preceding average mean annual precipitation versus streamflow, may be from the apparent phase lag in streamflow reaction to rainfall shown in Figure 13. From the figure, it is observed that there is a one year lag in streamflow peak, but no lag in streamflow decline.

An investigation of longer-term preceding average precipitation/streamflow relationships revealed no improved correlations. In fact, correlations to longer-term averaging significantly degraded ($R^2 = 37\%$) (see for example the three-year average relationship shown in Figure 15).
The phase lag was most pronounced when there was a peak in the precipitation, upon which the streamflow peak laged by one year. However, when there was a decline in the precipitation, there was a direct decline in the streamflow (no lag). With this observation, a modified two-year preceding average mean annual precipitation versus streamflow was explored (Figure 14), which had a correlation further improved to 77%. The modified two-year preceding average approach used the first derivative (slope) of mean annual precipitation. If the slope was positive (increasing rainfall) between two subsequent years, the two-year preceding average rainfall was used. If the slope was negative (decreasing rainfall), only rainfall for that year was used in the regression. The modified approach yielded an improved correlation (77%) over the simple one-year or two-year rainfall relationships. Therefore, this approach was used in all further analysis.

Figure 13: Mean Annual Precipitation and Streamflow (1993-2003)
To verify that the modified two-year preceding average precipitation was the best correlation, a three-year preceding average precipitation versus streamflow was plotted (Figure 15).
The spatial variability between the precipitation and the streamflow was very prominent. As mentioned in the methodology, the precipitation difference between the north and south zones was not statistically meaningful. However, the variation in the characteristics of the precipitation is interesting to note.

In the north zone, the phase lag was similar to that of the overall domain (Figure 16). Interestingly, there was less correlation in the north zone when a linear plot was generated of annual precipitation versus mean annual streamflow, which yielded a correlation of only 44% (Figure 17).

![Figure 16: Annual Precipitation and Streamflow for North Zone (1993-2003)](image-url)
However, when the two year preceding average mean annual precipitation versus streamflow was plotted for the north zone, an improved (but not profound) correlation (69%) was calculated (Figure 18).

Figure 17: Annual Precipitation Versus Streamflow for North Zone (1993-2003)

Figure 18: Two-Year Preceding Average Precipitation Versus Streamflow for North Zone (1993-2003)
Perhaps owing to the differences in hydrogeology (better confinement between surficial and confined aquifers), the south zone yielded a more in-phase graph when annual precipitation and annual streamflow were plotted for the period being investigated (Figure 19).

Figure 19: Annual Precipitation and Streamflow for South Zone (1993-2003)

When annual precipitation was plotted against mean annual streamflow for the south zone, a correlation of 71% was calculated (Figure 20).
Figure 20: Regression of Annual Precipitation Versus Streamflow for South Zone (1993-2003)

The two year preceding average mean annual precipitation versus streamflow (Figure 21) yielded a lower correlation (61%) in comparison to the 71% of the previous graph (Figure 20).

Figure 21: Two-Year Preceding Average Precipitation Versus Streamflow for South Zone (1993-2003)
The regional approach resulted in a 47% correlation. A higher correlation was desired so that the overall accuracy of the final equation would be as high as possible. A graph of this correlation is shown in Figure 22.

![Figure 22: NSF Versus Rainfall Sensitivity Slope, m, for West-Central Florida](image)

For the localized mean annual precipitation a correlation of 51% was achieved. This was only a slightly better result than using an overall average precipitation value.

Lastly, incorporating the previous rainfall/streamflow findings, a modified two-year preceding average analysis yielded a correlation of 48% for NSF versus $m_i$. This correlation is shown graphically in Figure 23.
Figure 23: NSF Versus Rainfall Sensitivity Slope, \( m \), for West-Central Florida Using Modified Two-Year Preceding Average Precipitation Method

This was the graph from which the equation was taken from for determining \( m \), previously discussed in the methodology chapter.

The results for determining ungauged streamflow using the procedure described in the previous chapter are presented in the following figures. In Figure 24 the predicted mean annual streamflow is plotted versus the observed mean annual streamflow for the eleven year study period.
Figure 24: Predicted Versus Observed Annual Streamflow (1993-2003)

The comparison of the predicted mean annual streamflow versus the observation yielded an average relative error of 1.85% with a standard deviation of 8.11%. The maximum relative error was 16.34%. The absolute relative error was 6.68% with a standard deviation of 4.89%.

Seven streamflow stations that were not used in the above approach were used to verify the calibration data. A Q value was predicted for each of the stations and then compared to the observed value. The results yielded an average relative error of 6.32% with a standard deviation of 3.28%. The maximum relative error was 8.94%. The absolute relative error was 6.32% with a standard deviation of 3.28%. This verification is shown graphically in Figure 25.
Figure 25: Predicted Versus Observed Mean Annual Streamflow for Verification Data Set (1993-2003)
CHAPTER FOUR

DISCUSSIONS AND CONCLUSIONS

The results show that streamflow sensitivity to rainfall varies in west central Florida. One interesting finding, is the apparent phase lag occurring in the streamflow with precipitation. Depending on the area, streamflow may vary directly with precipitation or they may be a two-year lag for wetting conditions. Where the two-year lag occurs, it is theorized that aquifer and/or storages may need to be filled for longer than a year before the full response of streamflow is seen.

For the north and south zone analysis, the results were significantly different for each zone. The north zone had a correlation of only 44% when precipitation was plotted against streamflow, while the south had a correlation of 71%. However, for the two year preceding average precipitation, the north had a correlation of 69%, while the south had a correlation of 61%, which was less than the 71% correlation mentioned previously. This suggests that the north has a stronger phase lag than the south. Also, it could be concluded that since the north two year preceding average precipitation had a steeper slope than the south, that the north is more sensitive to a rainfall deficit.

Hydrogeologically, the south has a shallow depth-to-water-table in certain areas. Therefore, it has less storage capacity in the vadose zone than the north. On the other hand, the north has a deeper depth-to-water-table and concurrently more water storage.
capacity. The north is also more karst, with lower confinement (leaky) and thus may also be responding to potentiometric head changes occurring over two years. Both areas have about the same coverage of wetlands (25%), so this does not seem to be responsible for the difference.

The eleven year period of record used for this investigation did seem sufficient, but this is uncertain. The precipitation data were characteristically similar to that of the prior 10 year period. There does seem to be some spatial variability in the rainfall for the north and south zones. However, statistically, there is not a significant enough difference to be able to draw any definitive conclusions regarding this anomaly.

In regards to the normalized streamflow fraction (NSF), the average precipitations used for the north and south zones had a difference of approximately 3.5 inches. As mentioned above, this difference does not seem to be statistically meaningful.

The equation that was developed in this study for the ungaged steamflow, does seem to be relatively predictive, even though it was developed with parameters derived with relatively modest correlations. The result was a very good (0.99) correlation to observed streamflow. This equation would allow one in the field to determine the ungaged streamflow for any given area in the study domain. This equation also demonstrates the time variability of the streamflow fraction and the differences between hydrogeologic settings.

To further explore the validity of the model, a validation data set (same region) was analyzed and demonstrated the same degree of high correlation (0.99) in results. This further supports the preliminary findings that the method may be viable for other areas and other times that were not included in the study area.
It is unclear whether the method will work in other regions or other times with the same success. The methodology may be applicable outside of the west-central Florida area; however, further testing remains.
REFERENCES


APPENDICES
## Appendix A: Streamflow Estimates for West Central Florida

### Table 4: Streamflow Estimates for West Central Florida

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**Average:** 80.98 0.3224 86.5 83.56 2.93 1.85% 5.20 6.68%

**Max:** 326.47 3.9279 295.6 306.69 32.75 16.34% 32.75 16.34%

**Min:** 2.00 0.0092 2.4 2.76 -11.05 -11.24% 0.03 0.15%

**Std Dev:** 74.99 0.4937 82.7 80.30 9.00 8.11% 7.90 4.89%

**Median:** 54.74 0.2486 56.9 51.29 -0.21 -1.13% 2.52 4.90%
Appendix A: (Continued)

Table 5: Verification of Streamflow Estimates for West Central Florida

<table>
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<tr>
<th>Station</th>
<th>Area (sq mile)</th>
<th>NSF</th>
<th>Predicted Q (cfs)</th>
<th>Observed Q (cfs)</th>
<th>Error</th>
<th>Relative Error</th>
<th>ABS Error</th>
<th>ABS Relative Error</th>
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