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Stream Flow Analysis of the Big Sioux River Just South of Brookings, South Dakota

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STREAM FLOW ANALYSIS OF THE BIG SIOUX RIVER JUST SOUTH OF BROOKINGS, SOUTH DAKOTA

BY

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STREAM FLOW ANALYSIS OF THE BIG SIOUX RIVER JUST SOUTH OF BROOKINGS, SOUTH DAKOTA

This thesis is approved as a credible and independent investigation by a candidate for the Master of Science in Civil and Environmental Engineering degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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TABLE OF CONTENTS

ABBREVIATIONS

BMP	Best Management Practice
CPC	Climate Prediction center
ft.	Feet
in.	Inches
NWS	National Weather Service
QA/QC	Quality Assurance/Quality Control
SD	South Dakota
SDSU	South Dakota State University
STEDV	Standard Deviation
USGS	United States Geological Survey

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

STREAM FLOW ANALYSIS OF THE BIG SIOUX RIVER JUST SOUTH OF BROOKINGS, SOUTH DAKOTA

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Floods are the most common type of natural disaster in the world and one of the most damaging. Changes in climate conditions such as precipitation and temperature are causing changes in stream flow. This means that in order to better understand flooding and possibly develop a system for making flood predictions, stream flow needs to be analyzed more closely.

The primary objective of this thesis is to analyze the Big Sioux River just south of Brookings, South Dakota, both annually and seasonally. The United States Geological Survey (USGS) has stream gauges placed in rivers and streams all over the United States. One of those gauges was installed in 1953 and is located in the Big Sioux River just south of Brookings, South Dakota and is the gauge that will be used for this study.

The daily stream flow from October, 1953, to September, 2018, was selected as the time period of study. The stream flow data was grouped into yearly stream flow then classified as very wet, wet, average, dry and very dry for each year. Then the steam flow data was broken into four seasons for each year; fall, winter, spring and summer.

The climate classification fit a log normal distribution with twenty-four years classified as average, sixteen classified as wet, seventeen classified as dry and the very

wet and very dry classifications each having four years. The seasonal analysis showed that the spring months had the highest stream flow and the fall had the lowest stream flow.

The streamflow analysis results were then compared to multiple other research projects, but the main comparison was to a study performed by Sadichya Amatya. That project focused on the development of climate scenarios based on precipitation analysis for five different locations in eastern South Dakota, including Brookings South Dakota. In comparing results, it was found that similar climate classifications were made between the two studies. However, in Amatya's study she classified eight-year periods of precipitation rather than each individual year. This proved to be less useful than analyzing each individual year for flood prediction purposes but did allow an analysis of how a wet or very wet 8-year cycle is related to high streamflows.

In order to continue the process of making flood predictions, more research is suggested in the area of an analysis of precipitation data for the area, snow melt and runoff analysis, ground water analysis, stream height analysis and other stream studies.

Chapter 1 Introduction

1.1 Background

Flooding is the most common natural disaster worldwide, with 40% of all natural disasters being floods (Baldassarre & Uhlenbrook, 2011). Floods have claimed the lives of millions of people and caused complete destruction of property and natural habitats. The ability to predict flooding would be an extremely valuable benefit worldwide and could save thousands of lives and prevent billions of dollars in damages.

One method to determine flood risk is to perform stream flow analysis. Stream flow analyses have been conducted all around the world. A study on the impact of climate variability on stream flow in the Yellow River in China indicated that precipitation and temperature affected stream flow (Fu & Charles, 2007). Their study of annual precipitation in La Nina and El Nino years showed that for small precipitation increases, the stream flow percentage change is less than the precipitation change for the Yellow River. These findings act as a resource to allow for watershed water resources planning and management to maintain the proper function of the river.

Another study was conducted in an arid region of northwest China. It was found that climate variability accounted for an estimated 64% of the reduction in average annual stream flow, with most of the reduction due to decreased precipitation (Ma & Kang, 2008). Their findings also concluded that the stream flow in the Shiyang river basin is more sensitive to precipitation changes than potential evaporation.

Changes in climactic conditions such as precipitation, temperature, wind and evaporation can cause large and rapid changes in stream flow (Robson & Stewart, 1990). Hence, the need for stream flooding predictions and analysis based on historic data. In order to conduct a stream flow analysis, sufficient stream flow data needs to be collected. Entities such as the United States Geological Survey (USGS, 2019a) have installed and maintained stream gauges to retrieve data and the information is stored in the USGS data base. Stream flow data is one type of data collected from the gauges.

1.2 Scope and Objectives

The objective of this study was to perform a stream flow analysis of the Big Sioux River just south of Brooking, South Dakota. Historical stream flow data was used to classify each year into five different climate classifications. The data is then analyzed on a seasonal scale. The basic sub objectives of this study are:

I. To develop five climate classifications for very wet, wet, average, dry and very dry years using stream flow data for the Big Sioux River.

II. To separate the stream flow data into four different seasons, fall, winter, spring, and summer.

III. To analyze the difference in seasonal stream flow based on the climate classification.

IV. To compare the results to precipitation analyses performed in the same geographic region.

V. To recommend future work.

1.3 Overview of the Thesis

This thesis is arranged by chapters starting with the introduction in Chapter 1. Chapter 2 covers the materials and methodologies, which describe how the data was obtained and analyzed. The results from the analysis are presented in Chapter 3. Chapter 4 presents the discussion of results from the data analysis. The summary and conclusion are presented in Chapter 5. Finally, Chapter 6 presents recommendations for future research.

Chapter 2 Materials and Methodologies

This chapter will cover the geographical background of the study region, where the data for this research was obtained, the Quality Assurance/Quality Control (QA.QC) procedures, how the data was analyzed and definitions.

2.1 Geographical Background

In the 2010 federal census, Brookings, South Dakota had a population of 22,056 and a population density of 1,704 inhabitants per square mile (U.S. Census Bureau, 2018). The elevation of Brookings is 1,621 feet. Sixmile Creek runs through Brookings and then feeds into the Big Sioux River south west of town. Figure 2.1 shows a satellite photo of Brookings, South Dakota. The location of study (Figure 2.2) for this thesis is located just south of Brookings, South Dakota on the Big Sioux River.

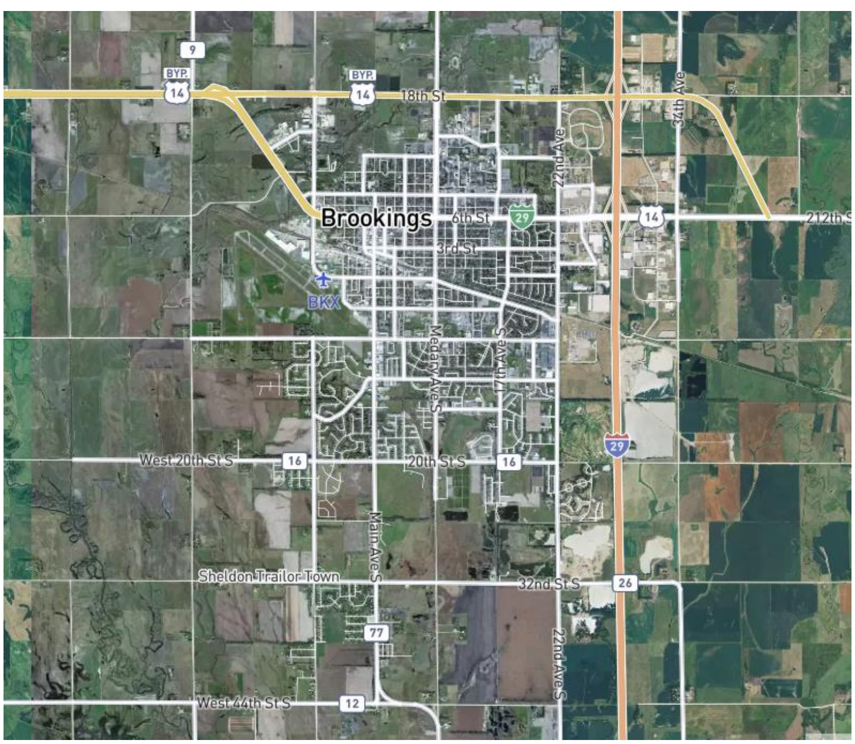

Figure 2.1: Brookings South Dakota Aerial Photo (Anyplace America, 2019)

Figure 2.2: Location of Study Area (Anyplace America, 2019)

The Big Sioux River rises in Roberts County, South Dakota, and feeds into the Missouri River in Sioux City, Iowa. The Big Sioux River flows 419 miles through Watertown, Castlewood, Bruce, Flandreau, Egan, Trent, Dell Rapids and Sioux Falls, South Dakota. Figure 2.3 shows the map of the Big Sioux River.

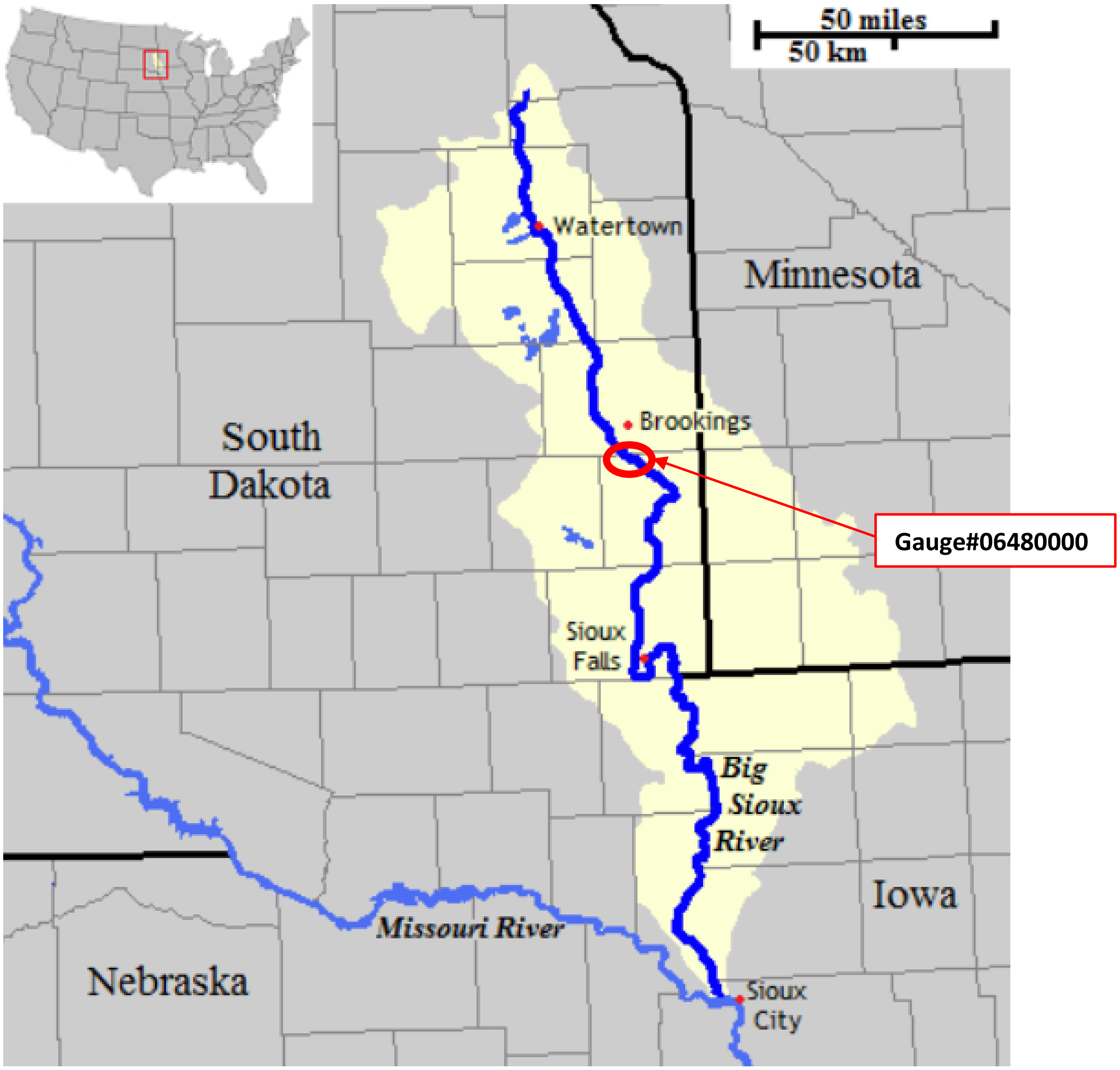

Figure 2.3: Map of the Big Sioux River (Cronin, 2014)

2.2 Data Source

All stream flow data used in this thesis came from USGS gauge #0648000, which is located just south of Brookings, South Dakota. Figure 2.4 and Figure 2.5 show the location of the gauge station used for data analysis.

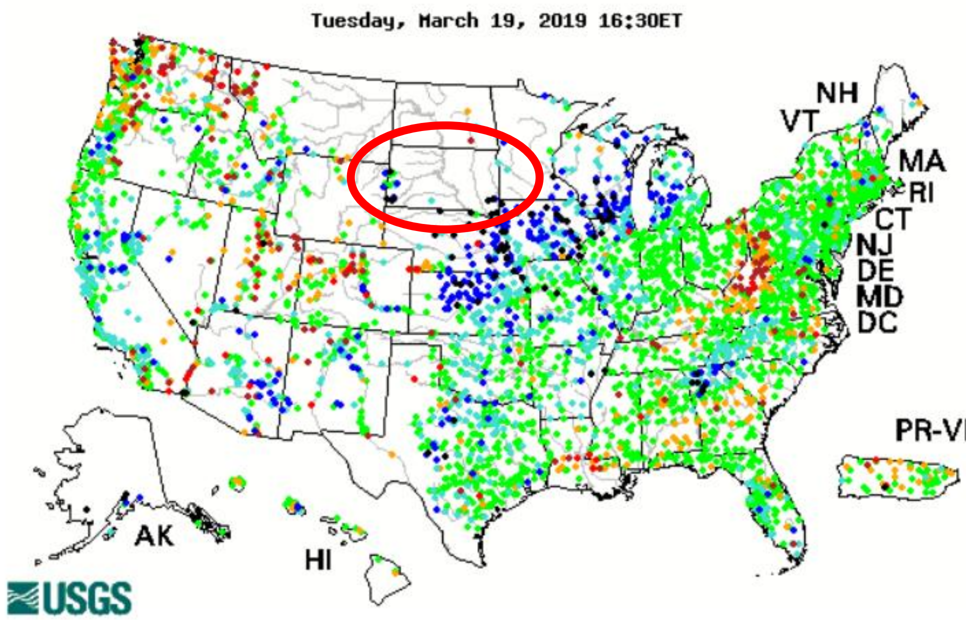

Figure 2.4: USGS Stream Flow Gauge Sites in the United States (USGS, 2019b)

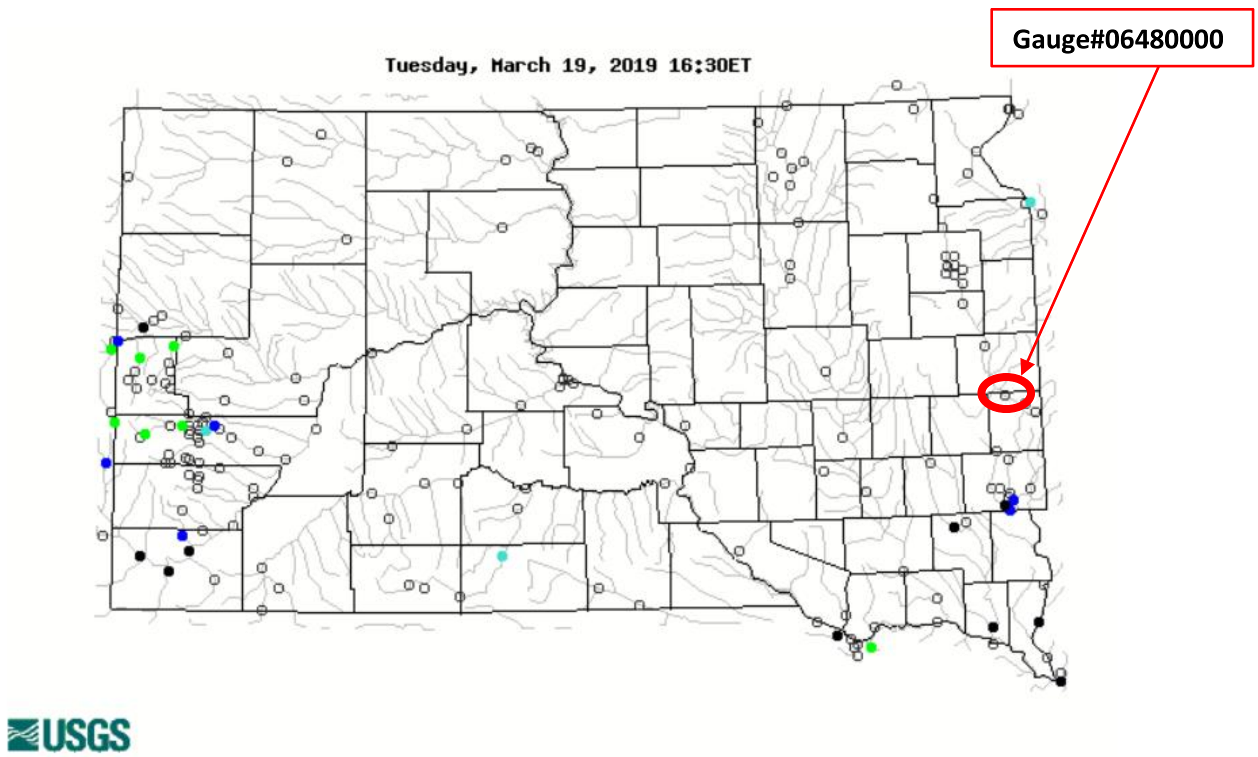

Figure 2.5: USGS Stream Flow Gauge Sites in South Dakota (USGS, 2019c)

The Big Sioux River gauge station #06480000 is located in Moody County just south of Brookings, South Dakota. The gauge has a contributing drainage area of 2,469 square miles. The flood stage is nine feet and the datum of the gauge is 1,551.91 above NGVD29. The daily discharge, in cubic feet per day, was recorded from 08-01-1953 to present. There is a continuous record of stream flow data without any missing data points (USGS, 2019a).

2.3 Quality Assurance/Quality Control

The stream flow data used in this thesis was obtained from USGS. The data was thoroughly reviewed and has received final approval, with the exception of the stream flow data for 2018. The 2018 stream flow data is still listed as provisional and needs to be reviewed by USGS as part of their normal review process.

2.4 Data Processes

This section will discuss the methods used to analyze the data. First it will discuss how the data was converted into cubic feet from cubic feet per day. Then it will discuss how the data was graphed and what statistical analyses were performed.

The data provided by USGS was for stream flow and had units of cubic feet per day. It was converted to a volume with units of cubic feet. The volume values from each day were then summed over a water year (defined in section 2.5.1) to obtain a cumulative annual stream flow volume

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2.4.1 Statistical Analyses

Mean

The mean of a list of numbers is the sum of the list divided by the number of items in the list (Yamen, 1967). The mean is the most commonly used type of average and is often referred to as simply the average. The mean (μ) is defined as:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} X_i$$

The mean calculation is used to calculate the average seasonal stream flow. In Microsoft® Excel, the function '=AVERAGE(N1:N2)' is used to calculate the mean for a list of data.

Standard Deviation

The standard deviation (σ) of a data set is the square root of its variance. The variance of a data set is the mean of the deviation squared of that variable from its expected value or mean. The variance is simply the measure or the amount of variation within the values of a set (Yamane, 1967). In other words, the standard deviation is the calculation of how much a data set deviates from its average.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{1}(x_i - \mu)^2}$$

The standard deviation was used to define the climate classification for the annual analysis. In Microsoft® Excel the function '=STDEV(N1:N2)' is used to calculate the standard deviation for a list of data.

Variability

Variability is the amount in which data points in a statistical distribution or data set diverge from the average value, as well as the extent to which these data points differ from each other (Kenton, 2018).

$$Variability = \frac{\sigma}{\mu}$$

The variability was used to determine which season was the most different when compared to the other seasons.

Skewness

In probability and statistics, skewness is a measure of the degree of asymmetry of a distribution (Yamane, 1976). A distribution is considered to be skewed if the tail on one side of the distribution is longer than the tail on the other side. If the data is skewed in the direction of higher values, it is positive skewed. If the opposite is true, it has a negative skewness. In a perfect distribution there will be no skewness and the skew value will be zero.

The skewness was used to determine whether the data fit a normal or log normal distribution. In Microsoft® Excel the function '=SKEW(N1:N2)' is used to calculate the skewness for a list of data.

2.5 Definitions

This section will discuss how a water year was defined then it will cover how the cumulative annual stream flow was sorted into climate classifications. Finally, the manner in which the data was divided into seasons will be explained.

2.5.1 Water Year Convention

The daily stream flow data obtained from USGS needed to be divided into years. USGS defines a water year to be from October 1 to September 30. For example, the 2018 water year is from 10-1-17 to 9-30-18. Once the data was separated by water year, the daily data within each year was summed to obtain a cumulative stream flow for that water year.

2.5.2 Climate Classification

The average and standard deviation of the annual cumulative stream flow of the entire data set was manipulated to determine boundaries for climate classification. Table 2.1 shows the classification boundaries.

Table 2.1: Boundaries for Climate Classification Based on Stream Flow

	Parameter	Classification
Above	Average + 1.5xStandard Deviation	Very Wet
Between	Average + 1.5xStandard Deviation & Average + 0.5xStandard Deviation	Wet
Between	Average + 0.5xStandard Deviation & Average - 0.5xStandard Deviation	Average
Between	Average - 0.5xStandard Deviation & Average - 1.5xStandard Deviation	Dry
Below	Average - 1.5xStandard Deviation	Very Dry

2.5.3 Season Classification

After each year was classified as either very wet, wet, average, dry or very dry, a seasonal analysis was performed. The weather year defined by USGS starts in the Fall and ends in the Summer. Knowing this, the months were divided into seasons as seen in Table 2.2.

Table 2.2: List of Moths Separated into Seasons

Season	Months
Fall	October, November, December
Winter	January, February, March
Spring	April, May, June
Summer	July, August, September

After the data was split into seasons, it was analyzed. Each season was compared against each other in their respective climate classifications. Finally, all the results were compiled into one chart in order to visually compare seasonal stream flow in different climate classifications.

Chapter 3 Results

The results from the stream flow analysis of the Big Sioux River are presented in this section. This chapter is divided into two sections. The first section shows the results from the annual stream flow analysis and the second shows results from the seasonal analysis.

3.1 Annual Analysis

The plot in Figure 3.1 presents the cumulative annual stream flow of the Big Sioux River from 1954 to 2018. Note that the total flow in the figure is displayed using log scale.

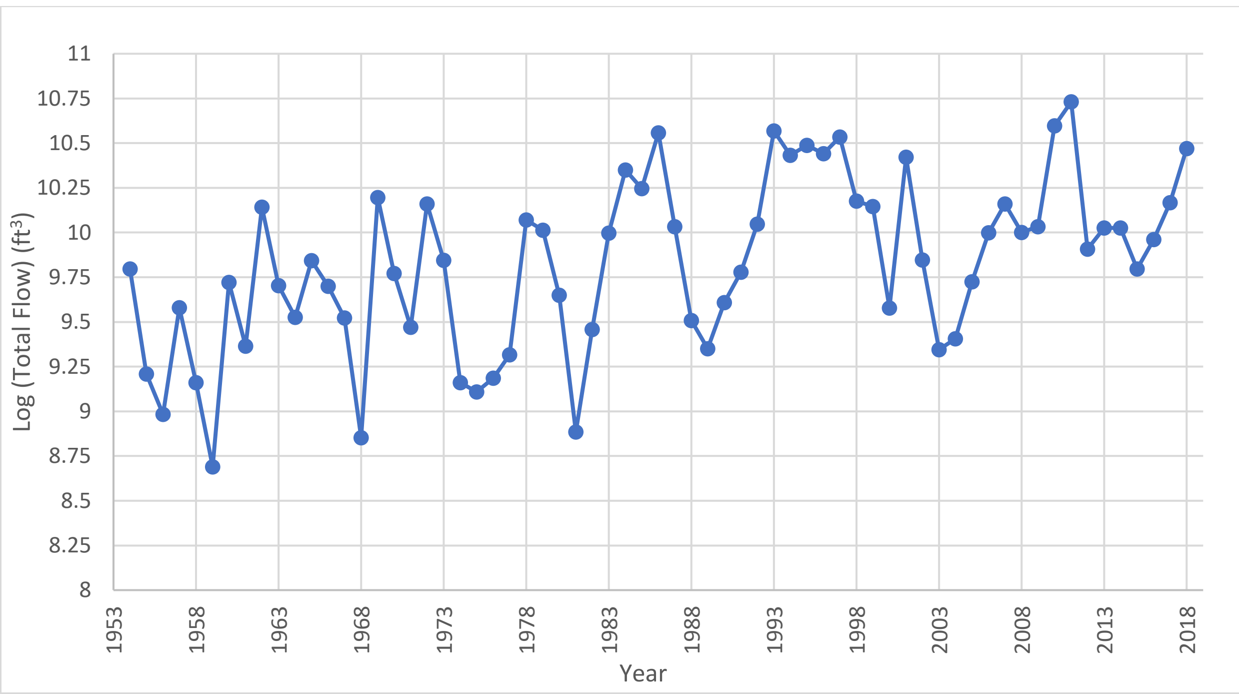

Figure 3.1: Cumulative Annual Stream Flow of the Big Sioux River South of Brookings

The results indicate that the year with the highest cumulative stream flow was 2011, with a cumulative stream flow volume of 53,791,603,200 cubic feet. Whereas, 1959 had the lowest cumulative stream flow volume of 488,963,520 cubic ft.

Figure 3.2 shows the threshold for a very wet, wet, average, dry or very dry year according to the cumulative stream flow of each year from 1954 to 2018, as defined in Table 2.1. The figure is in log scale.

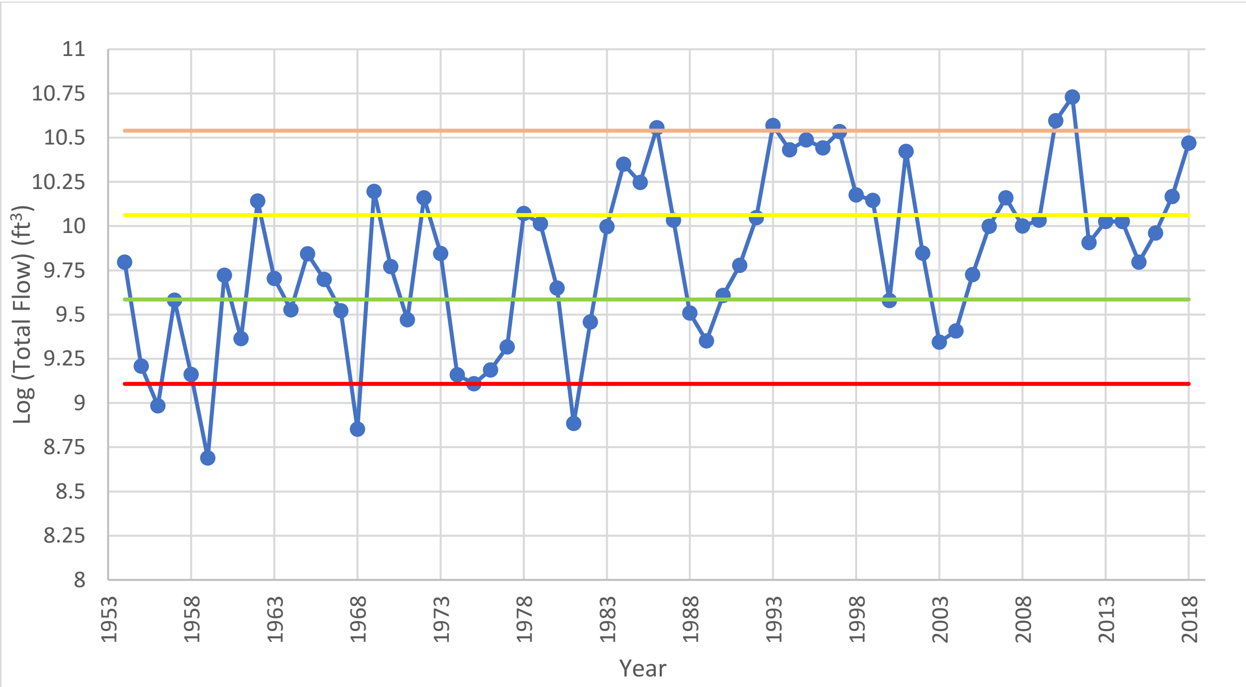

Figure 3.2: Cumulative Annual Stream Flow of the Big Sioux River South of Brookings With Threshold Indicators. The threshold indicators are lines on the graph that denote the cutoff values for very wet (above orange line), wet (between orange and yellow lines), average (between yellow and green lines), dry (between green and red lines) and very dry (below red line).

The average volume was 6,667,070,609 cubic feet. Any year with a cumulative stream flow volume higher that the average plus one and a half times the standard deviation (represented by the orange line) is considered to be a very wet year. Any year with a cumulative stream flow volume between the average plus one and a half times the standard deviation (orange line) and the average plus half the standard deviation (represented by the yellow line) are considered to be wet years. Years with cumulative stream flow volume that falls between the average plus half the standard deviation (yellow line) and the average minus half the standard deviation represented by the green line) are considered average years. Years with cumulative stream flow volume that fall between the average minus half the standard deviation (green line) and the average minus one and a half times the standard deviation (represented by the red line) are considered to be dry years. Years with cumulative stream flow volumes that are below the average minus one and a half times the standard deviation (red line) are considered very dry years. Table 3.1 shows the years sorted into the climate classifications and Table 3.2 shows the cut-off values used in the analysis.

Table 3.1: Very Wet, Wet, Average, Dry and Very Dry Climate Classifications

Climate Classification				
Very Wet Years (4)	**Wet Years (16)**	**Average Years (24)**	**Dry Years (17)**	**Very Dry Years (17)**
1986	1962	1954	1955	1956
1993	1969	1960	1957	1959
2010	1972	1963	1958	1968
2011	1978	1965	1961	1981
-	1984	1966	1964	-
-	1985	1970	1967	-
-	1994	1973	1971	-
-	1995	1979	1974	-
-	1996	1980	1975	-
-	1997	1983	1976	-
-	1998	1987	1977	-
-	1999	1990	1982	-
-	2001	1991	1988	-
-	2007	1992	1989	-
-	2017	2002	2000	-
-	2018	2005	2003	-
-	-	2006	2004	-
-	-	2008	-	-
-	-	2009	-	-
-	-	2012	-	-
-	-	2013	-	-
-	-	2014	-	-
-	-	2015	-	-
-	-	2016	-	-

Table 3.2: Cutoff Values for the Climate Classifications of Cumulative Annual Stream Flow Volume From 1954 to 2018

Analysis of Cumulative Annual Stream Flow of the Big Sioux River From 1954 to 2018		
Parameter	Log Transformed	Non-Log Transformed
Average - 1.5 STDEV	9.108	1,283,130,811
Average - 1/2 STDEV	9.585	3,849,287,484
Average	9.824	6,667,070,609
Average + 1/2 STDEV	10.062	11,547,547,616
Average + 1.5 STDEV	10.540	34,641,698,369

3.2 Seasonal Analysis

From the information gained in the annual analysis of stream flow volume, the seasonal analysis could be then be conducted. The main information needed from the annual analysis was the climate classification of very wet, wet, average, dry or very dry for each year (Table 3.1).

Each year was broken into four seasons: Fall, Winter, Spring and Summer. Fall is October through December, Winter is January through March, Spring is April through June and Summer is July through September. The years were separated into five different tables depending on their climate classification (very wet, wet, average, dry, very dry) and then the average and total stream flow volume for each season was found, along with the standard deviation for each group (Table 3.3 to Table 3.7). From these tables, graphs were made using the average cumulative seasonal flow volume of each classification to visually compare the seasonal differences within each classification (Figure 3.3 to Figure 3.7).

Table 3.3: Total, Average and Standard Deviation for Each Year Classified as Very Wet

(Red = Lowest Seasonal Flow Value, Green = Highest Seasonal Flow Value)

Very Wet Years				
Year	**Cumulative Seasonal Flow Volume (ft^3)**			
	Fall	**Winter**	**Spring**	**Summer**
1986	2,414,966,400	4,081,104,000	21,541,507,200	8,016,364,800
1993	1,275,955,200	2,158,272,000	18,303,753,600	15,294,182,400
2010	2,689,675,200	6,732,720,000	13,099,104,000	16,954,358,400
2011	6,565,190,400	10,651,824,000	28,443,744,000	8,130,844,800
Total	12,945,787,200	23,623,920,000	81,388,108,800	48,395,750,400
Average	3,236,446,800	5,905,980,000	20,347,027,200	12,098,937,600
STDEV	1,993,605,434	3,185,201,013	5,560,821,952	4,068,103,416

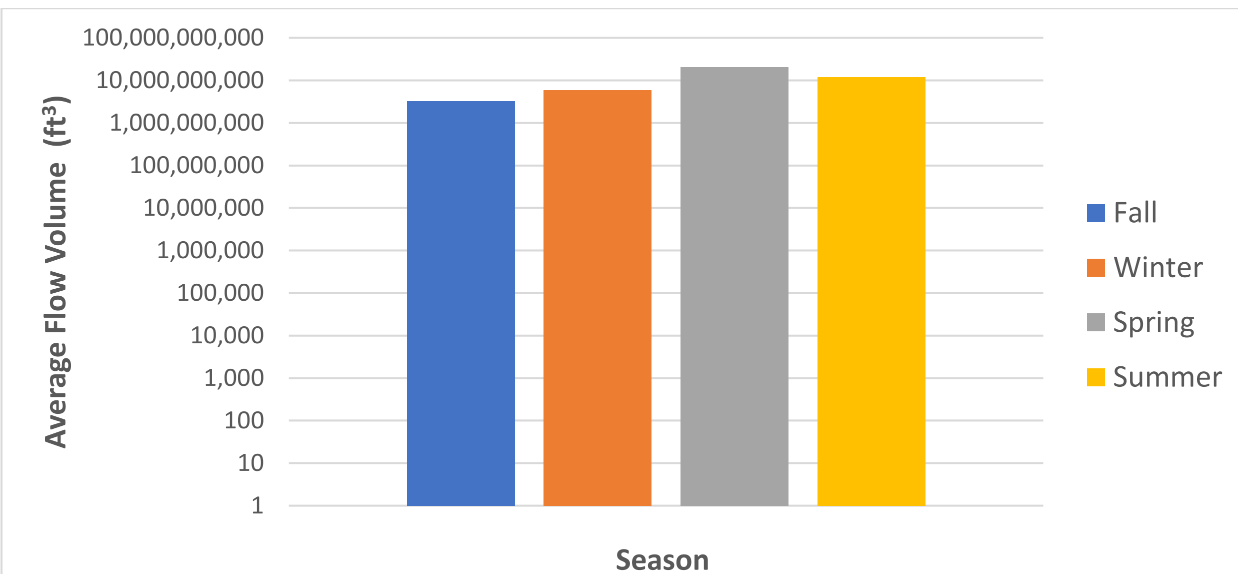

Figure 3.3: Comparison of Average Seasonal Stream Flow for Very Wet Years

The Spring had the highest average stream flow volume for very wet years with an average stream flow value of 20,347,027,200 cubic feet. The highest seasonal flow volume value for the Spring was 28,443,744,000 cubic feet and it was in 2011. The lowest Spring seasonal flow volume occurred in 2010 and was 13,099,104,000 cubic feet.

The season with the lowest average stream flow volume for very wet years was the Fall with an average stream flow value of 3,236,446,800 cubic feet. Again, 2011 had the highest Fall cumulative flow volume with a value of 6,565,190,400 cubic feet. The lowest Fall flow volume value was in 1993 with a Fall cumulative flow volume value of 1,275,955,200 cubic feet.

Table 3.4: Total, Average and Standard Deviation for Each Year Classified as Wet (Red = Lowest Seasonal Flow Value, Green = Highest Seasonal Flow Value)

Wet Years				
Year	Cumulative Seasonal Flow Volume (ft^3)			
	Fall	Winter	Spring	Summer
1962	120,960,000	2,561,414,400	6,070,550,400	5,138,467,200
1969	378,259,200	66,960,000	14,340,412,800	938,476,800
1972	384,376,320	1,675,373,760	9,054,720,000	3,362,256,000
1978	590,630,400	3,492,979,200	7,021,296,000	669,945,600
1984	552,407,040	2,777,673,600	16,220,304,000	2,820,795,840
1985	3,391,796,160	6,015,168,000	5,733,849,600	2,497,236,480
1994	3,288,643,200	5,629,824,000	11,784,182,400	6,325,344,000
1995	2,254,780,800	3,207,513,600	17,637,696,000	7,650,374,400
1996	7,932,211,200	3,834,432,000	12,953,692,800	2,957,904,000
1997	1,684,886,400	2,627,164,800	23,854,435,200	6,083,164,800
1998	2,363,558,400	3,952,540,800	6,965,827,200	1,729,641,600
1999	2,414,016,000	2,469,571,200	6,848,928,000	2,239,833,600
2001	216,561,600	85,864,320	21,607,776,000	4,510,080,000
2007	649,598,400	4,495,132,800	8,355,657,600	935,236,800
2017	2,140,992,000	3,552,076,800	5,381,856,000	3,650,745,600
2018	5,620,924,800	3,733,776,000	13,924,396,800	6,224,860,800
Total	33,984,601,920	50,177,465,280	187,755,580,800	57,734,363,520
Average	2,124,037,620	3,136,091,580	11,734,723,800	3,608,397,720
STDEV	2,091,629,011	1,584,907,511	5,636,295,635	2,099,045,090

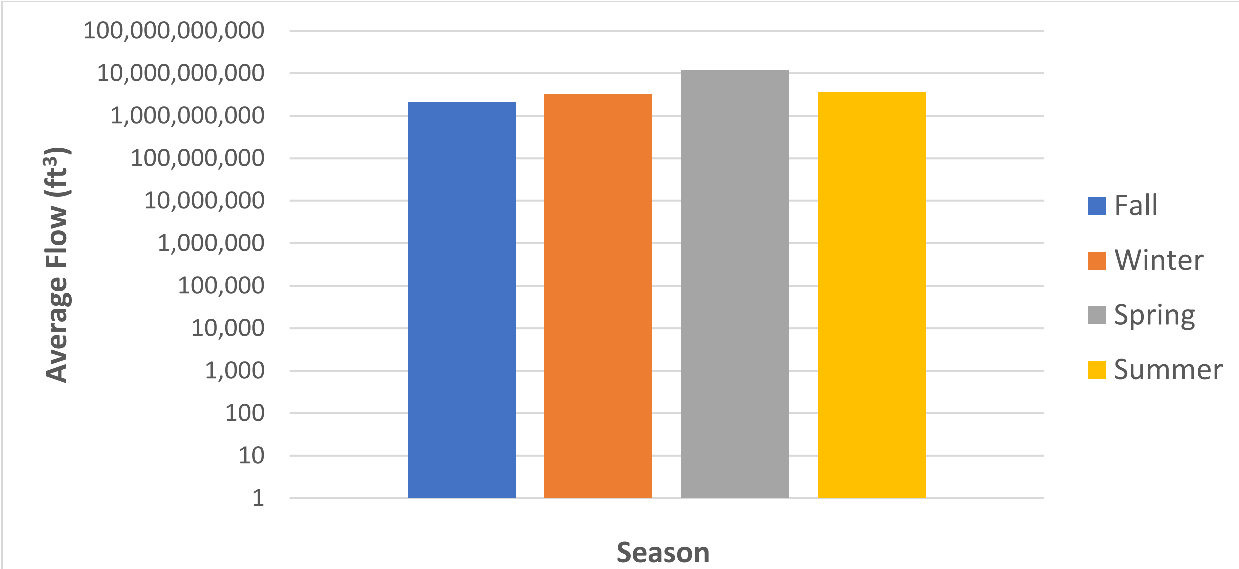

Figure 3.4: Comparison of Average Seasonal Stream Flow Volume for Wet Years

Similar to the very wet years, Spring for the wet years had the highest average stream flow volume with an average stream flow volume value of 11,734,723,800 cubic feet. The highest seasonal flow volume value for the Spring was 21,607,776,000 cubic feet and it was in 2001. The lowest Spring seasonal flow volume occurred in 2017 and was 5,381,856,000 cubic feet.

The season with the lowest average stream flow volume for wet years was the Fall with an average stream flow volume value of 2,124,037,620 cubic feet. The year 2018 had the highest Fall cumulative flow volume with a value of 5,620,924,800 cubic feet. The lowest Fall flow volume value was in 2001 with a Fall cumulative flow volume value of 216,561,600 cubic feet.

Table 3.5: Total, Average and Standard Deviation for Each Year Classified as Average

(Red = Lowest Seasonal Flow Value, Green = Highest Seasonal Flow Value)

Average Years				
Year	**Cumulative Seasonal Flow Volume(ft^3)**			
	Fall	**Winter**	**Spring**	**Summer**
1954	338,601,600	1,725,494,400	3,344,112,000	856,656,000
1960	26,498,880	1,136,721,600	3,785,356,800	317,520,000
1963	374,803,200	477,014,400	1,586,822,400	2,621,548,800
1965	86,313,600	27,820,800	6,243,868,800	622,771,200
1966	394,588,800	2,589,079,680	1,586,822,400	436,492,800
1970	426,124,800	1,539,388,800	3,434,659,200	512,265,600
1973	1,033,344,000	3,581,539,200	2,174,169,600	212,976,000
1979	219,343,680	497,016,000	8,293,622,400	1,319,846,400
1980	756,000,000	559,699,200	2,290,723,200	858,643,200
1983	1,366,416,000	3,725,568,000	4,202,064,000	631,152,000
1987	3,583,180,800	3,115,411,200	3,231,990,720	870,929,280
1990	142,853,760	142,896,960	2,090,102,400	1,683,331,200
1991	361,238,400	216,259,200	3,230,755,200	2,186,956,800
1992	461,376,000	2,229,206,400	4,450,982,400	4,011,292,800
2002	1,361,491,200	949,968,000	4,285,396,800	439,413,120
2005	1,132,427,520	382,639,680	2,708,035,200	1,087,568,640
2006	1,984,694,400	2,047,766,400	5,210,611,200	748,967,040
2008	1,225,152,000	633,657,600	7,091,452,800	1,080,535,680
2009	1,025,291,520	3,424,291,200	4,910,889,600	1,433,021,760
2012	1,701,216,000	1,844,985,600	4,178,131,200	353,808,000
2013	187,591,680	148,348,800	6,947,856,000	3,318,468,480
2014	886,109,760	797,085,792	6,520,867,200	2,423,347,200
2015	660,355,200	829,180,800	2,218,752,000	2,559,116,160
2016	1,105,980,480	2,229,552,000	3,551,558,400	2,262,384,000
Total	20,840,993,280	34,850,591,712	97,569,601,920	32,849,012,160
Average	868,374,720	1,452,107,988	4,065,400,080	1,368,708,840
STDEV	770,857,906	1,155,839,809	1,816,501,912	1,016,756,007

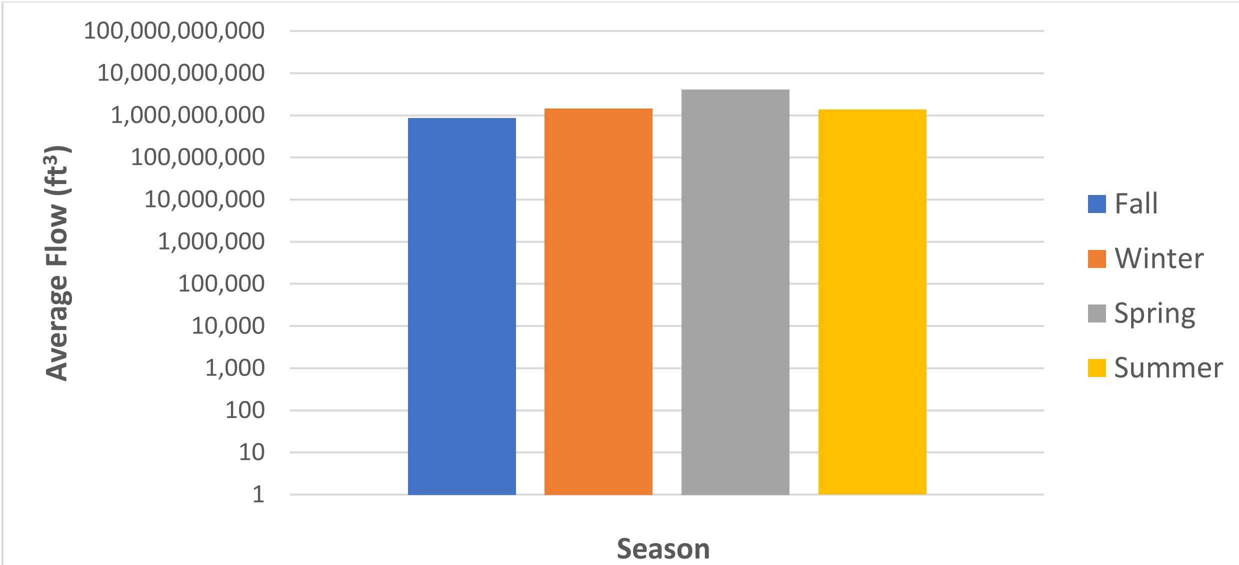

Figure 3.5: Comparison of Average Seasonal Stream Flow Volume for Average Years

Again, the Spring had the highest average stream flow volume for the average years with an average stream flow volume value of 4,065,400,080 cubic feet. The highest seasonal flow volume value for the Spring was 7,091,452,800 cubic feet and it was in 2008. The lowest Spring seasonal flow volume occurred in 1963 and 1966. Both years having a cumulative Spring flow volume of 1,586,822,400 cubic feet.

The season with the lowest average stream flow volume for average years was the Fall with an average stream flow volume value of 868,374,720 cubic feet. 1987 had the highest Fall cumulative flow volume with a value of 3,583,180,800 cubic feet. The lowest cumulative flow volume value was in 1960 with a Fall cumulative flow volume value of 26,498,880 cubic feet.

Table 3.6: Total, Average and Standard Deviation for Each Year Classified as Dry (Red = Lowest Seasonal Flow Value, Green = Highest Seasonal Flow Value)

Dry Years				
Year	Cumulative Seasonal Flow Volume (ft^3)			
	Fall	Winter	Spring	Summer
1955	229,219,200	703,641,600	612,835,200	72,066,240
1957	104,716,800	505,267,200	2,641,766,400	556,329,600
1958	238,636,800	231,984,000	884,649,600	94,305,600
1961	138,153,600	996,969,600	936,748,800	243,388,800
1964	504,921,600	189,648,000	2,448,316,800	214,531,200
1967	157,783,680	639,290,880	2,060,294,400	466,473,600
1971	333,331,200	1,253,664,000	1,033,084,800	332,285,760
1974	163,382,400	601,663,680	622,684,800	58,661,280
1975	54,836,352	12,146,976	1,123,200,000	93,484,800
1976	64,912,320	955,065,600	514,010,880	2,598,912
1977	585,792	1,033,737,120	841,492,800	198,097,920
1982	124,588,800	1,020,548,160	1,164,067,200	561,772,800
1988	484,099,200	1,374,105,600	1,309,564,800	60,056,640
1989	90,331,200	1,091,352,960	795,571,200	266,457,600
2000	774,144,000	728,265,600	1,704,326,400	585,273,600
2003	388,895,040	589,078,656	1,018,474,560	214,926,048
2004	137,514,240	462,896,640	1,192,250,880	760,086,720
Total	3,990,052,224	12,389,326,272	20,903,339,520	4,780,797,120
Average	234,708,954	728,783,898	1,229,608,207	281,223,360
STDEV	196,347,317	371,060,941	609,052,948	219,690,493

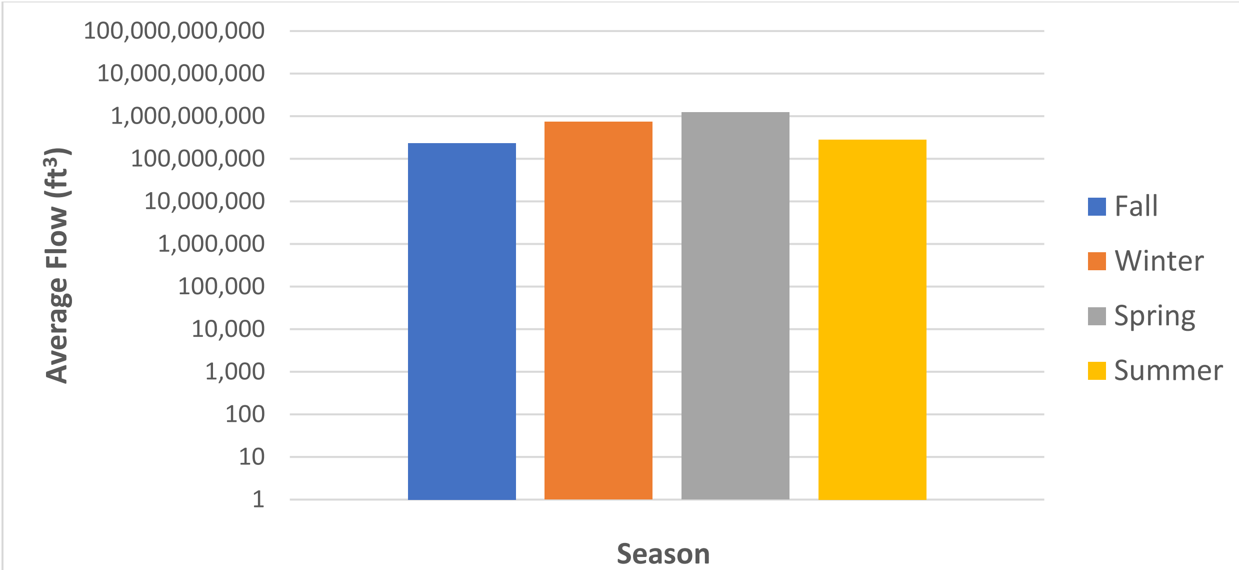

Figure 3.6: Comparison of Average Seasonal Stream Flow Volume for Dry Years

Spring had the highest average stream flow volume in dry years with an average stream flow volume value of 1,229,608,207 cubic feet. The highest seasonal flow volume value for the Spring was 2,641,766,400 cubic feet and it was in 1957. The lowest Spring seasonal flow volume occurred in 1976, having a cumulative Spring flow volume of 514,010,880 cubic feet.

Again, the Fall was the season with the lowest average stream flow volume for dry years with an average stream flow volume value of 234,708,954 cubic feet. 2000 had the highest Fall cumulative flow volume with a value of 774,144,000 cubic feet. The lowest cumulative flow volume value was in 1977 with a Fall cumulative flow volume value of 585,792 cubic feet.

Table 3.7: Total, Average and Standard Deviation for Each Year Classified as Very Dry

(Red = Lowest Seasonal Flow Value, Green = Highest Seasonal Flow Value)

Very Dry Years				
Year	**Cumulative Seasonal Flow Volume (ft^3)**			
	Fall	**Winter**	**Spring**	**Summer**
1956	51,563,520	18,144,000	423,187,200	470,016,000
1959	34,102,080	255,631,680	187,142,400	12,087,360
1968	107,049,600	64,091,520	367,459,200	172,834,560
1981	148,029,120	134,507,520	328,838,400	155,554,560
Total	340,744,320	472,374,720	1,306,627,200	810,492,480
Average	85,186,080	118,093,680	326,656,800	202,623,120
STDEV	45,186,593	89,571,602	87,252,480	166,512,489

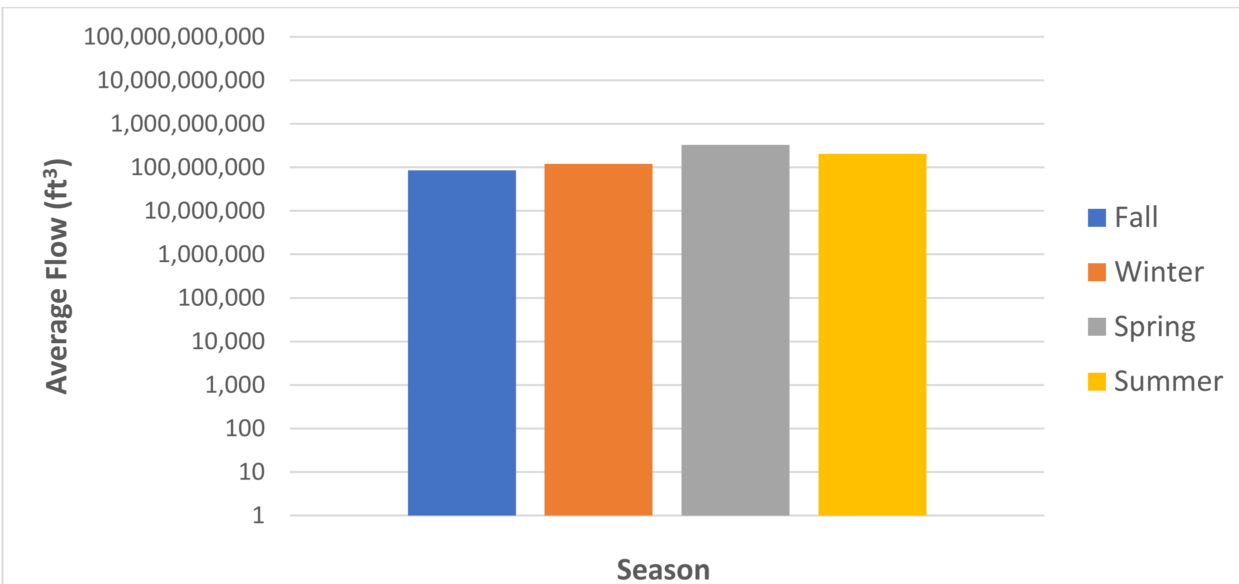

Figure 3.7: Comparison of Average Seasonal Stream Flow Volume for Very Dry Years

Like all other climate classifications, Spring had the highest average stream flow volume in very dry years with an average stream flow volume value of 326,656,800 cubic feet. The highest seasonal flow volume value for the Spring was 423,187,200 cubic feet and it was in 1956. The lowest Spring seasonal flow volume occurred in 1959, having a cumulative Spring flow volume of 187,142,400 cubic feet.

Again, the Fall was the season with the lowest average stream flow volume for very dry years with an average stream flow volume value of 85,186,080 cubic feet. The year 1981 had the highest Fall cumulative flow volume with a value of 148,029,120 cubic feet. The lowest Fall cumulative flow volume value was also in 1959 with a cumulative flow volume value of 34,102,080 cubic feet.

All climate classifications were graphed together to visually compare each classification (Figure 3.8). Spring shows the highest and Fall shows the lowest stream flow volume amounts in all cases. The highest average stream flow volume in the Spring was 20,347,027,200 cubic feet in the very wet years and the lowest average stream flow volume Fall was 86,112,015 cubic feet in the very dry years.

The main difference found in these graphs is in the Summer and Winter seasons. In all cases, the Spring season has the highest average flow volume and the Fall season has the lowest average flow volume. However, the Summer has the second highest average flow volume in very wet, wet, and very dry years but the Winter season has the second highest stream flow volume in the average and dry years.

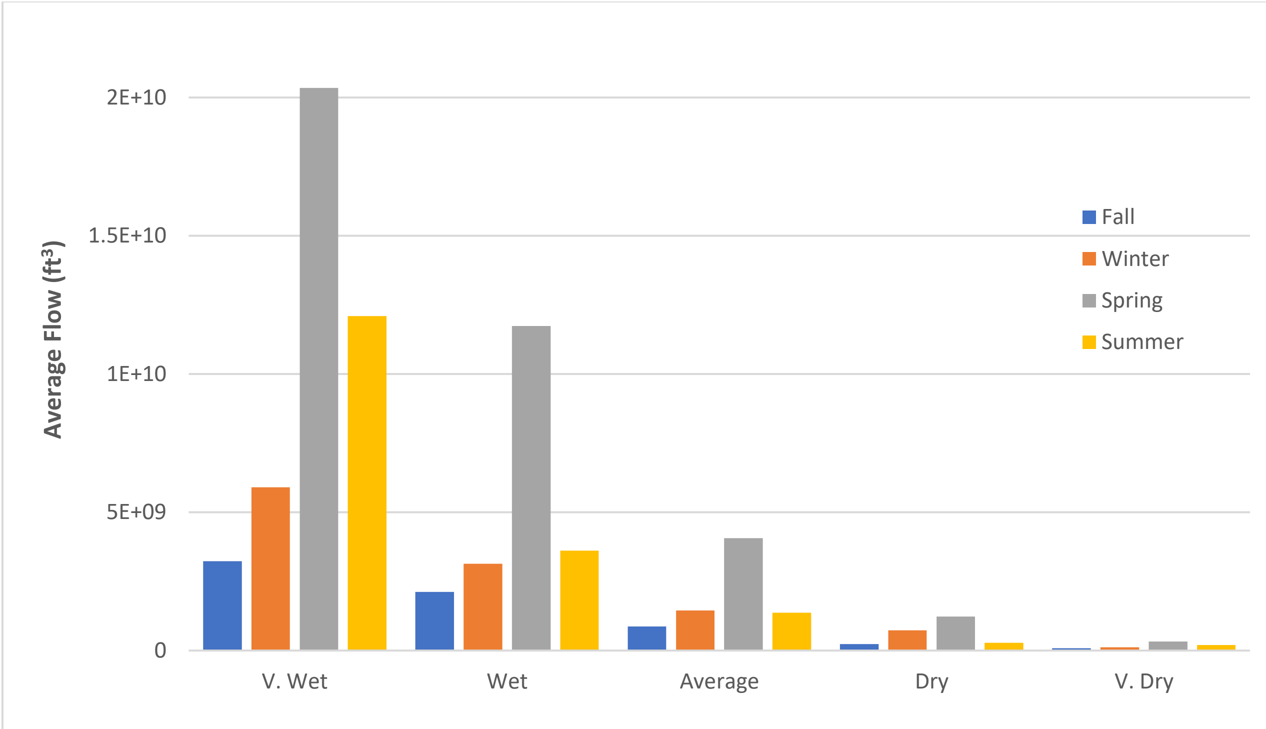

Figure 3.8: Average Stream Flow Amounts for Each Season in the Respective Climate Classification

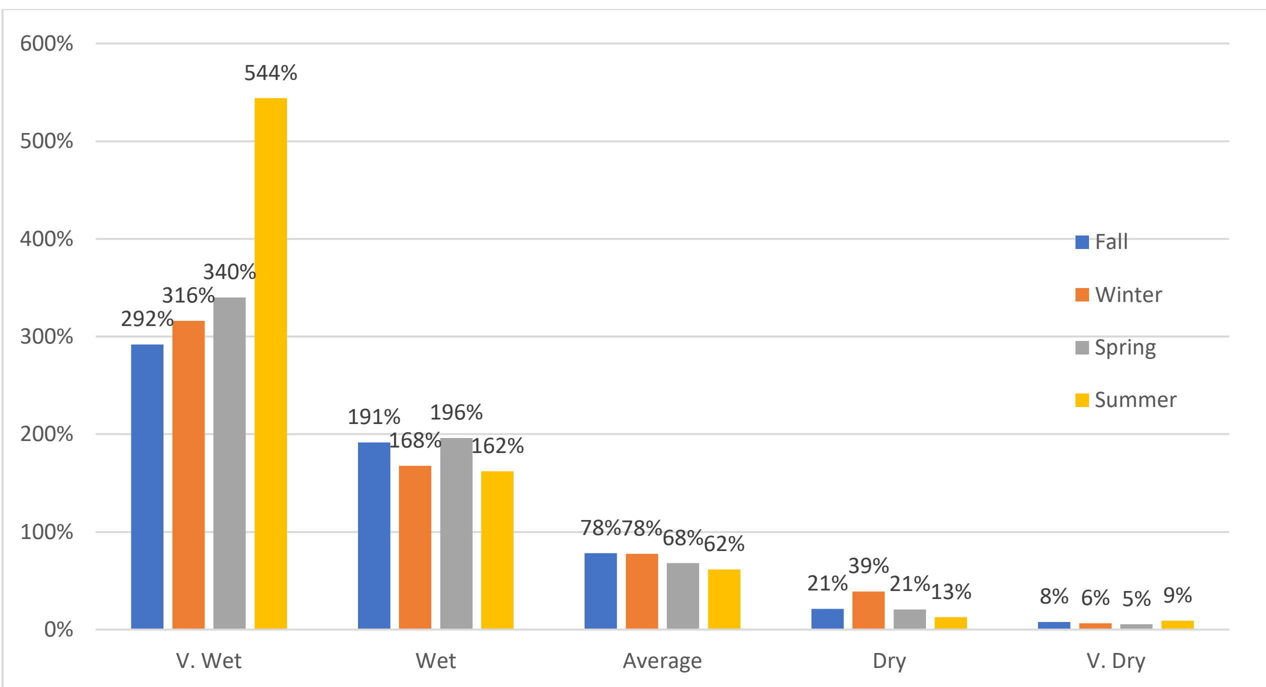

Figure 3.9: Graphed as a Percent of Average in Their Respective Climate Classification

To help show which seasons have the most variability depending on the classification, all the seasons were graphed as a percent of the season average flow (Figure 3.9). This illustrates the point that the Summer and Spring months are the most variable by the type of climate.

The largest positive difference was found in the Summer season of the very wet years, with the average seasonal flow volume being 544% of the overall summer average, or 5.44 times overall average seasonal flow volume. The largest negative difference was found in the Spring of the very dry years, with the average seasonal flow volume being 5% of the overall spring average, or 0.05 times the overall average seasonal flow volume. The closest to the overall average seasonal flow volume was found in the Fall and Winter months of the average years, with the average seasonal flow volume being 78% of the overall average, or 0.78 times the overall average seasonal flow volume. This indicates that the spring and summer months had the largest effect on climate classification of a year.

Chapter 4 Discussion and Analysis of Results

Presented in this section are the analysis and discussion of results for the stream flow study of the Big Sioux River.

4.1 Discussion on Yearly Analysis Results

The goal for the yearly analysis of stream flow for the Big Sioux River was to be able to classify each year as either a very wet, wet, average, dry or very dry year. After analyzing the results, this was able to be achieved.

The cumulative annual stream flow volume was used for the year classification as opposed to the average annual stream flow volume. The reason for this was to more accurately represent the stream flow for each year in the analysis. Some of the years had a stream flow of zero (0) cubic feet per day in the Winter. Even though the stream had no flow, there was more than likely still precipitation in the form of snow during the Winter. By using the cumulative stream flow for each year, the precipitation in the winter would still be taken into account in the form of Spring runoff from snow melt. If the average stream flow for each year was used, the precipitation in the Winter would not be as accurately accounted for. This means that if the stream was frozen during the Winter of a year that had a very high amount of precipitation and the average yearly stream flow was used, that year may be classified as an average year when in reality it was a wet or very wet year.

The cumulative annual stream flow volume data did not fit a normal distribution. When performing the statistical analysis of the cumulative annual stream flow volume assuming a normal distribution, the standard deviation was almost the same as the average for the sample, with a standard deviation of 11,397,689,359 and an average of 11,186,300,475 cubic feet. Also, the normal distribution was skewed toward the left, meaning there would be more years being classified as dry to very dry than there were years being classified as wet. Forty-five out of sixty-four years were below average when using a normal distribution. This is due to such large cumulative stream flow volume values in the very wet years, causing a skewness of 1.68 in the data. Figure 4.1 shows the normal scale of the data with the solid horizontal line representing the average.

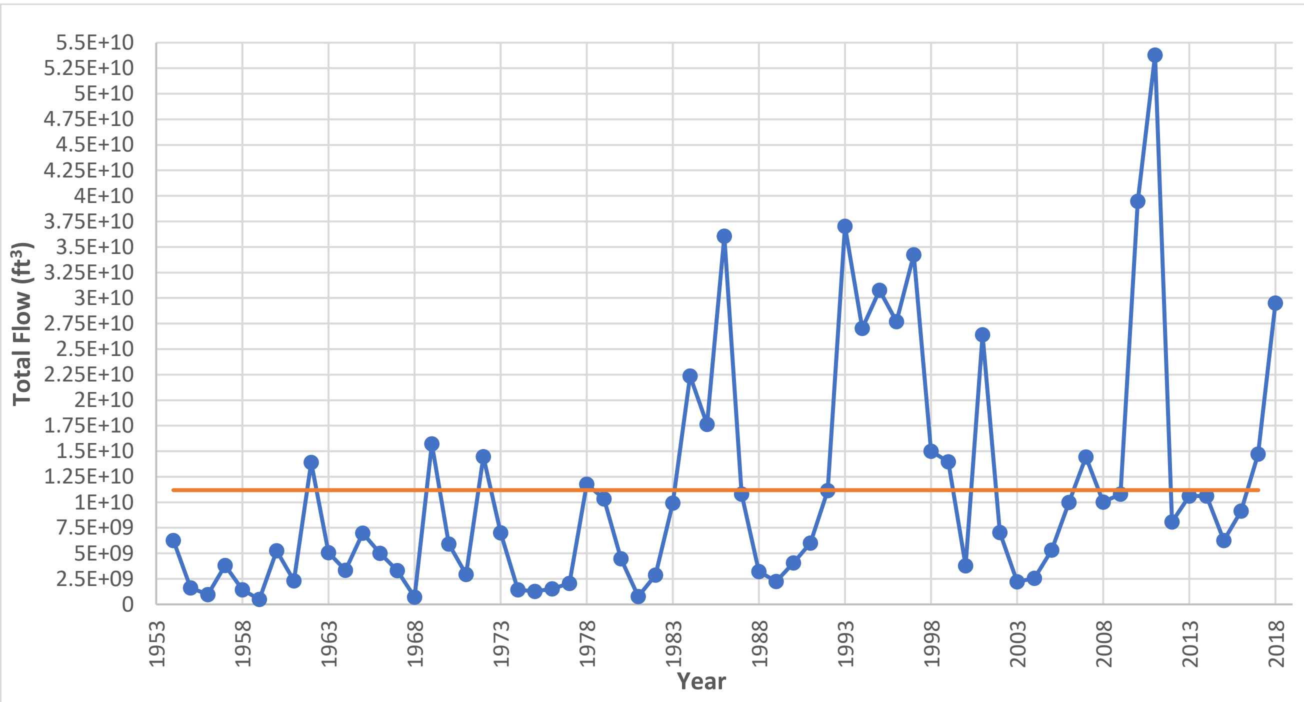

Figure 4.1: Normal scale of the Cumulative Annual Stream Flow of The Big Sioux River

Figure 4.2 shows the log scale of the data with the solid horizontal line representing the average. A log transform of the data was then used, which gave a standard deviation value of 0.4771 and an average of 9.824.

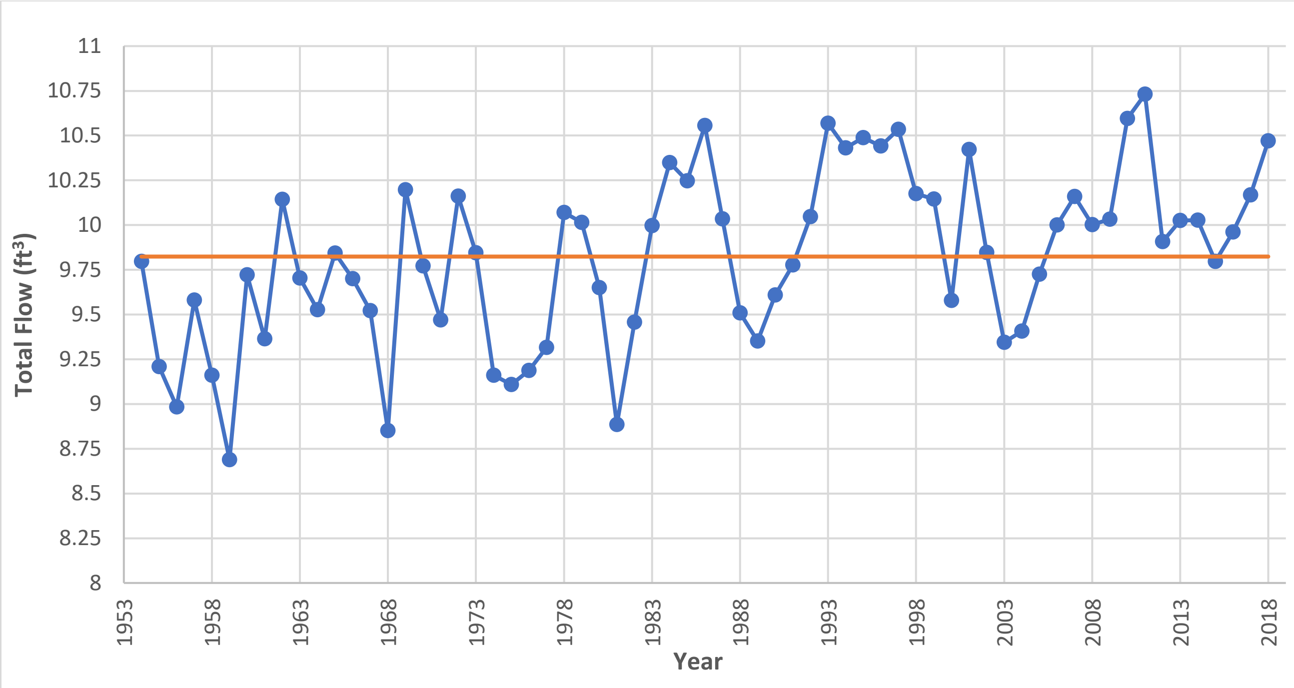

Figure 4.2: Log Scale of the Cumulative Annual Stream Flow of The Big Sioux River

When analyzing the log transformed data, half of the data falls below average. Also, the skewness of the log scale data was -0.27. This means that the data set more closely fits a log normal distribution.

The classification of each year was then made using the average and standard deviation of the sample size. A clear indicator that the classification of years more closely fits a log normal distribution is the number of years that is in each classification. Before performing the analysis, it was expected that the grouping of years in their respective classifications should form a centered bell-shaped curve. This is because one would expect an equal number of very wet to very dry years and wet to dry years with a majority of years that fall in the average classification assuming that the data was taken from a large enough sample size.

The number of years classified as average years were 24, 16 years were classified as wet and 17 were classified as dry. Lastly, four years were classified as very wet and another four were classified as very dry. This means that the resulting classification distribution forms a nearly perfect bell curve, indicating that the sample size is large enough and that this classification of seasons can be used to perform a seasonal analysis of the data.

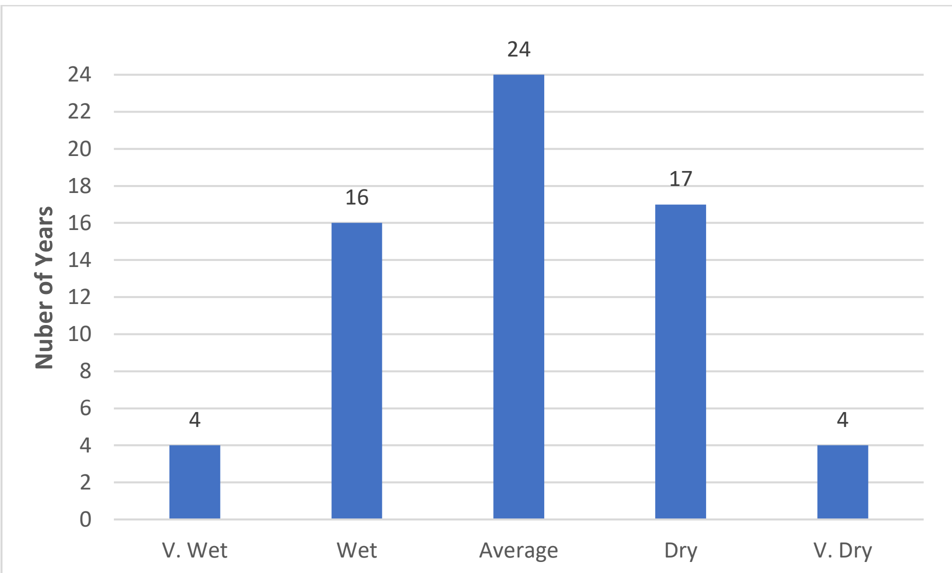

Figure 4.3: Distribution of Years in Each Climate Classification

4.2 Discussion on Seasonal Analysis Results

The goal for the seasonal analysis of stream flow for the Big Sioux River was to find any patterns, or lack thereof, that may occur as it relates to climate classification. The results obtained from the yearly analysis allow for an accurate seasonal analysis to be conducted.

When performing the seasonal analysis, the average cumulative seasonal flow volume was used as opposed to the total cumulative seasonal flow due to the varying number of years in each climate classification (see Figure 4.3). The average is being used in this case because the seasonal flow analysis is not being compared to the yearly flow analysis; the yearly analysis was only used to determine the climate classifications for each year.

A graph was made for each year classification of the average cumulative seasonal flow volume. In all cases, Spring had the highest flow and Fall had the lowest. Spring having the largest average cumulative seasonal flow volume is not a surprise because, aside from normal precipitation, snowmelt runoff and the contribution of ground water will also contribute to the stream flow volume. What is surprising, however, is that the Fall season has the lowest stream flow in all cases.

It was expected that the Winter would have the lowest stream flow volume due to little to no immediate precipitation runoff and frozen ground. However, the parameters for Winter and Fall defined by USGS may not be what is commonly perceived as Fall and Winter months. Winter is from January through March, which means that in some years the snow starts to melt, and the ground starts to thaw in March due to an increased average temperature over that time period, contributing to more runoff and higher stream flow. Fall is October through December, which is when the ground is starting to freeze, and the precipitation is turning to snow instead of rain.

The Summer season varied the most between year classifications. In very wet and wet years, it was the season with the second highest average cumulative stream flow volume, but in average and dry years it was the season with the second lowest average cumulative stream flow volume.

In order to better understand how seasonal stream flow volume varied for each climate classification, a percent of average analysis was performed for each season in each climate classification. From this analysis, it was clear that Summer and Spring seasonal stream flow volume had the most variation, with the Summer seasonal flow volume being 5.43 times higher than the overall Summer average flow volume in the very wet years and the Spring being 0.05 times the spring average flow volume in the very dry years. Figure 3.9 shows the percent of average for all seasons in all climate classifications.

Note that all seasons in the average climate classification were below 100%, where it would be expected that they would be. This is due to the large stream flow volumes in the wet and very wet years skewing the average value toward larger flows.

The importance of this finding is in the ability to create more accurate seasonal stream flow simulations. Simulations could be in the form of estimating missing data from previous years, or making future seasonal predictions. Based on the work of Basnet (2011) and Kshatriya (2018), future precipitation predictions cannot be made simply based on the climate classification of a year alone. Due to the variability of precipitation in each season, future seasonal precipitation predictions would have to be made, rather than yearly precipitation predictions. The findings of this thesis support the findings of Basnet (2011) and Kshatriya (2018) in that the seasonal variability of stream flow shows that predictions based on yearly climate classifications alone will not be accurate, i.e. creating a wet or very wet years by simply multiplying an average stream flow volume by some factor does not accurately reflect reality. Table 4.1 shows the variability of each season as a further illustration of this.

Table 4.1: Seasonal Cumulative Stream Flow Volume Variability

Cumulative Seasonal Stream Flow Analysis				
Parameter	**Fall**	**Winter**	**Spring**	**Summer**
Average (ft^3)	1,109,264,291	1,869,441,200	5,983,434,742	2,224,160,241
Standard Deviation	1,551,144,710	1,955,047,406	6,461,984,094	3,262,532,313
Variability	1.3984	1.0458	1.0800	1.4669

From the seasonal analysis in this study, it was determined that Spring and Summer flow volume has the highest stream flow for every climate classification. This matches the measured flood reports since about 75% of flash flood reports occur between April and September (NWS, 2019), with a majority of high stream flow occurring in the Spring and Summer months. Figure 4.5 was obtained from the NWS and shows the number of flash floods reported per month.

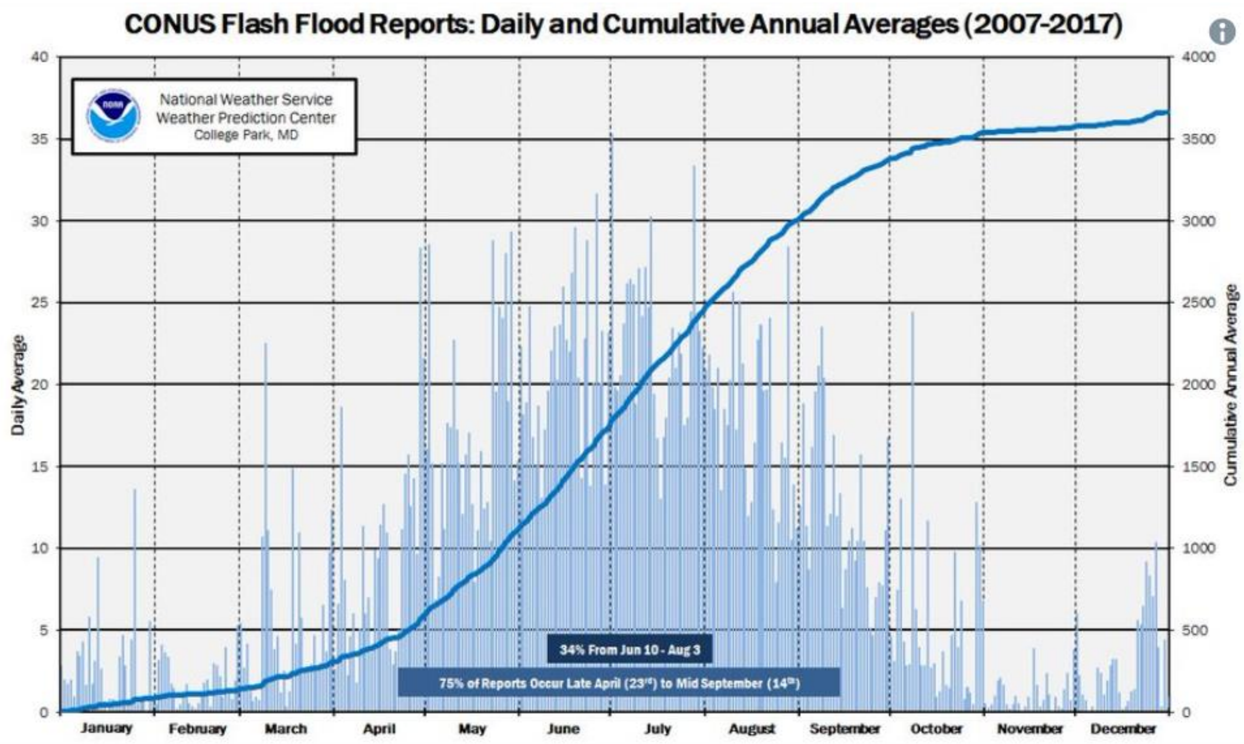

Figure 4.4: Daily Flash Flood Reports (NWS, 2019)

4.3 Comparison to Climate Scenario Development Using Precipitation Data

Nabin Basnet (2011) conducted a climate study but instead of using stream flow data, he used precipitation data. Basnet's thesis is titled *Development of Climatic Scenarios Using Precipitation Data for Aberdeen South Dakota.* The goal of his research was to define five climate scenarios for Aberdeen, South Dakota, using the precipitation data. The methods for climate classification in Basnet's study were very similar to the methods used in this thesis. This means that comparing classifications based on precipitation data and stream flow data could be performed. The information found in Basnet's study does not directly correlate to this study, as it was not conducted for the same geographic area. However, both studies were conducted in the same climate zone, Humid Continental "B" as shown in Figure 4.5.

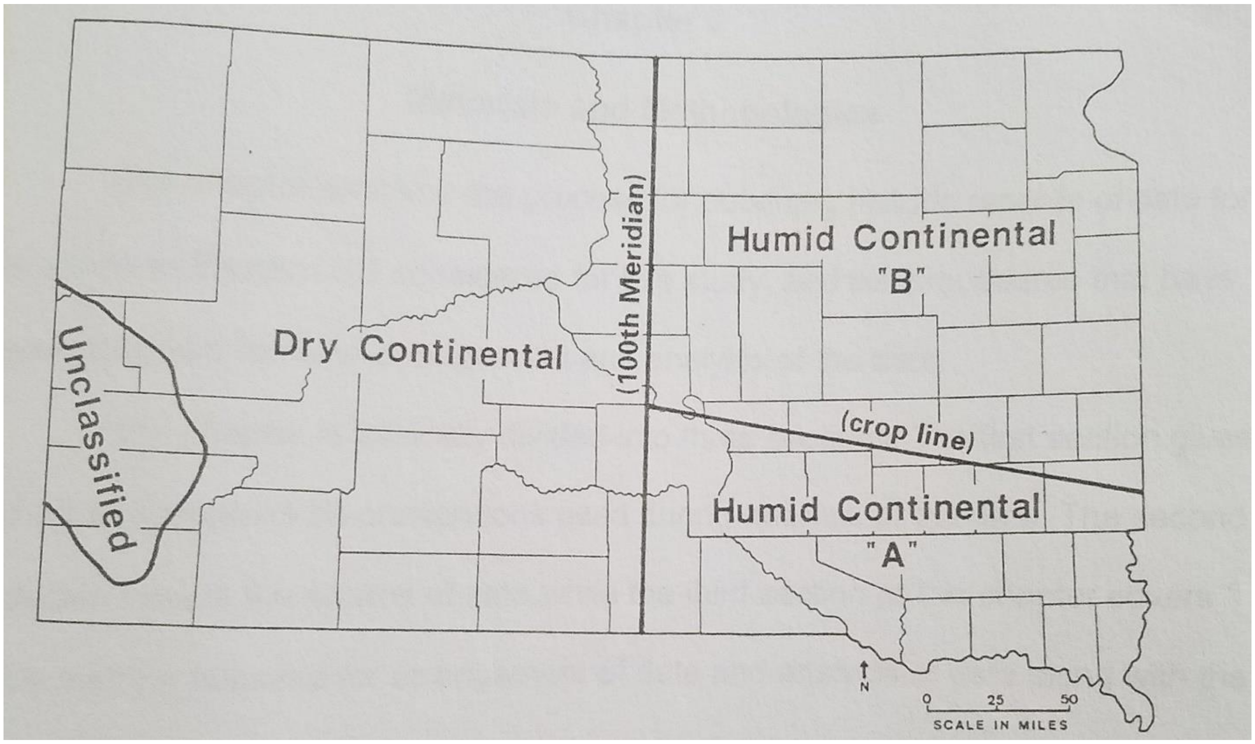

Figure 4.5: Climate Zones of South Dakota (Hogan, 1998)

In Table 4.2, the comparison of results from Basnet's research and this study is presented. Note that there is no stream flow data for (1942-1949, wet years) since the data set the current study is using does not include data prior to 1953 due to the gauge being installed that year. therefore a full comparison cannot be made. Also, the climate classifications are based on the 8-year precipitation classifications made in Basnet's study and not the classifications made in this thesis.

Table 4.2: Comparison of Cumulative Annual Stream Flow Near Brookings and Basnet's Precipitation Near Aberdeen, South Dakota

Cumulative Annual Stream Flow and Precipitation Comparison		
Climate Classification (8-year period)	**Accumulated 8-year Precip. (in)**	**Accumulated 8-year Stream Flow Volume (ft^3)**
Very Wet (1993-2000)	189.72	189,514,339,200
Wet (1942-1949)	172.18	-
Average (1977-1984)	156.44	64,577,945,952
Dry (1959-1966)	140.61	42,367,078,080
Very Dry (1969-1976)	127.63	50,334,315,840

The 8-year period classified as "very wet" can be compared to the stream flow volume data in this thesis. The cumulative annual stream flow volume calculated for the 8-year period from 1993-2000 is much higher than the cumulative annual stream flow volumes for the other identified 8-year periods. The 8-year period from 1977-1984 was classified as 'average' and can also be confirmed by the stream flow analysis. However, the very dry and dry 8-year period classifications in the precipitation analysis are contradicted by the stream flow analyses of those periods. In the stream flow analysis, the 8-year period from 1969-1976 has a higher cumulative annual stream flow volume compared to the 8-year period from 1959-1966. This could be due to the time period before 1959-1966 also being dry years with less potential for runoff. For the stream flow to reflect runoff from precipitation, the infiltration rate of precipitation must be lower which occurs when the soil moisture and/or ground water levels are higher. Table 4.3 illustrates the lagging of precipitation from the stream flow analysis since 1969 to 1971 still showed climate classifications of wet and average even though the 8-year precipitation period was very dry. This means that there was very little runoff from precipitation from 1969-1976 but the soil moisture and groundwater levels were still high from previous wet precipitation years.

Table 4.3: Climate Classification Comparison to Basnet's Research

Basnet's Climate Classification	This Thesis Climate Classification							
1993-2000	1993	1994	1995	1996	1997	1998	1999	2000
Very Wet	Very Wet	Wet	Wet	Wet	Wet	Wet	Wet	Dry
1942-1949	1942	1943	1944	1945	1946	1947	1948	1949
Wet	-	-	-	-	-	-	-	-
1977-1984	1977	1978	1979	1980	1981	1982	1983	1984
Average	Dry	Wet	Average	Average	Very Dry	Dry	Average	Wet
1959-1966	1959	1960	1961	1962	1963	1964	1965	1966
Dry	Very Dry	Average	Dry	Wet	Average	Dry	Average	Average
1969-1976	1969	1970	1971	1972	1973	1974	1975	1976
Very Dry	Wet	Average	Dry	Wet	Average	Dry	Dry	Dry

4.4 Comparison to Historical Precipitation for Northern South Dakota

Uday Singh Kshatriya (2018) conducted a study similar to Basnet's study but for multiple locations in north central South Dakota. This thesis is titled *Comparison of Historical Precipitation for Aberdeen, Ipswich, and Eureka, South Dakota* (Kshatriya, 2018). The goal of that study was to analyze precipitation records for the locations stated. One of the analyses was to classify years as wet, moderately wet, average, moderately dry and dry based on the precipitation patterns.

Kshtriya's study defined the years with precipitation values that occurred between the mean plus one half the standard deviation and the mean plus one and a half times the standard deviation to be wet years and anything above this as very wet (the same definition for dry and very dry but you subtract from the average instead of add to it). In Kshtriya's thesis, moderately wet years are defined as years that fall between the average and the average plus the standard deviation and anything above that is considered wet. By classifying the years by this definition, fewer years would be considered average compared to the number considered wet or dry.

One comparison that should be made is between the results for Aberdeen and this thesis study, as stated in the previous section, Aberdeen and Brookings are both classified as humid continental "B" climate zones. The data analyzed by Kshatriya also includes data that is more recent than the data in Basnet's research.

In Table 4.4, the comparison of results from Kshatriya's research and this thesis study are presented. Because the data set used for Kshatriya's thesis includes more recent precipitation data, we can compare the wet 8-year periods, unlike in Basnet's research where there was a missing set of years. Again, note that the climate classifications are based on the 8-year precipitation classifications made in Kshatriya's study and not the yearly classifications made in this study.

Table 4.4: Comparison of Cumulative Annual Stream Flow Near Brookings and Kshatriya's Precipitation Near Aberdeen, South Dakota

Cumulative Annual Stream Flow and Precipitation Comparison		
Climate Classification (8-year period)	**Precip. (in)**	**Stream Flow (ft^3)**
Very Wet (1993-2000)	189.78	189,514,339,200
Wet (2006-2013)	177.66	157,199,823,360
Average (1985-1992)	159.32	91,172,295,360
Dry (1957-1964)	141.39	35,636,976,000
Very Dry (1969-1976)	127.63	50,334,315,840

Even with the larger and more current data set, most of the results are similar to the findings in Basnet's research. In both studies, the very wet 8-year period was from 1993-2000 and the very dry 8-year period was from 1969-1976 with the total precipitation calculations being the same for the very dry period and only six hundredths of an inch different for the very wet years. The dry 8-year period was shifted back two years in Kshatriya's study. The main differences in the two studies (Kshtriya and Basnet) are the average and wet 8-year periods. With the more current precipitation data being considered for Kshatriya's study, an entirely different 8-year wet period was found. Also, due to the more current information, the average 8-year period was shifted back by 8 years from Basnet's study results.

The 8-year periods classified as very wet, wet and average in Kshatriya's thesis can all be confirmed by the stream flow analysis in this thesis. However, just like in Basnet's study, the 8-year periods classified as dry and very dry in Kshatriya's study are contradicted by the stream flow data analysis for this thesis study. In the stream flow analysis, the 8-year period from 1969-1967 has a higher cumulative annual stream flow than the 8-year period from 1957-1964. This could again be due to the period before 1957-1964 also being dry years, so for the stream flow to reflect precipitation, the soil moisture and ground water must be recharged first. Table 4.5 illustrates the lagging of precipitation from the stream flow analysis since 1969 to 1971 still had climate classifications of wet and average even though the 8-year precipitation period was very dry. This means that there was very little runoff from precipitation during 1969-1976 but the soil moisture and groundwater were still recharged from previous wet years.

Table 4.5: Climate Classification Comparison to Kshatriya's Research

Kshatriya's Climate Classification	**This Thesis Climate Classification**							
1993-2000 Very Wet	1993 Very Wet	1994 Wet	1995 Wet	1996 Wet	1997 Wet	1998 Wet	1999 Wet	2000 Dry
2006-2013 Wet	2006 Average	2007 Wet	2008 Average	2009 Average	2010 Very Wet	2011 Very Wet	2012 Average	2013 Average
1985-1992 Average	1985 Wet	1986 Very Wet	1987 Average	1988 Dry	1989 Dry	1990 Average	1991 Average	1992 Average
1957-1964 Dry	1957 Dry	1958 Dry	1959 Very Dry	1960 Average	1961 Dry	1962 Wet	1963 Average	1964 Dry
1969-1976 Very Dry	1969 Wet	1970 Average	1971 Dry	1972 Wet	1973 Average	1974 Dry	1975 Dry	1976 Dry

In order to more accurately compare the two results, Kshatriya's classification system should be changed to match the classification system of this thesis.

4.5 Comparison to Climate Scenario Development in Eastern South Dakota

Sadichya Amatya conducted a study in 2011 that can be compared more directly to the results of the current study. Amatya's thesis is titled *Development of Climate Scenarios Using Climate Data from Specific Stations in Eastern South Dakota* (Amatya, 2011). The goal of her study was to develop climate scenarios in multiple locations of eastern South Dakota using precipitation data and then analyze the evaporation and precipitation scenarios in each location.

One of the locations in the study was Brookings, South Dakota, which is the same geographic area as the current study. Amatya used a very similar method of climate classification to determine the climate scenarios as the current study making it easier to compare the results. However, Amatya used an 8-year period when finding the climate scenarios, similar to Kshtriya and Basnet. This differs from the current study, which defined each individual year as very wet, wet, average, dry or very dry.

In Amatya's research 1989-1996 was considered wet (very wet), 1982-1989 was considered moderately-wet (wet), 1998-2005 was considered Average, 1970-1977 was considered moderately-dry (dry) and 1952-1959 was considered dry (very dry), with the text in parentheses noting the finding from the current study. The text in the parentheses are noting the findings from the current study.

Looking at Figure 4.7, four out of the eight years fall in either the very wet stream flow classification or near the upper boundary of the wet stream flow classification. However, one of the years (1989) is considered to be dry and three of the others are average with one of the average years (1992) being on the edge of the wet classification.

The current study shows a closer representation of a very wet 8-year period being 1992-1999.

The reason for this shift could be due to precipitation events being discrete and stream flow continuous. If there is a large rain event, there will usually be a spike in the stream flow value on the hydrograph depending on how close the precipitation event is to watershed. This means that data collected from precipitation studies is discrete, i.e. if there is a large rain event, a stream flow analysis may show a gradual increase in a stream flow rather than a large spike depending on how widespread the precipitation event is and the location of the precipitation gauge within the watershed. The volume of precipitation is a major factor in determining the volume of runoff and, hence, stream flow.

Increased precipitation over an extended period would result in an increase in soil moisture and ground water. This means that there will be more direct runoff from a precipitation event that follows a long period of wet conditions and the stream will maintain a stable flow due to high quantities of ground water, which can contribute to stream flow as base flow. This also means that stream flow will not reflect high precipitation when coming directly from a dry period as part of the precipitation would infiltrate the soil and potentially lead to ground water recharge and not direct runoff. If there is abundant ground water storage available, the majority of precipitation events will contribute to the recharging of ground water, rather than direct runoff.

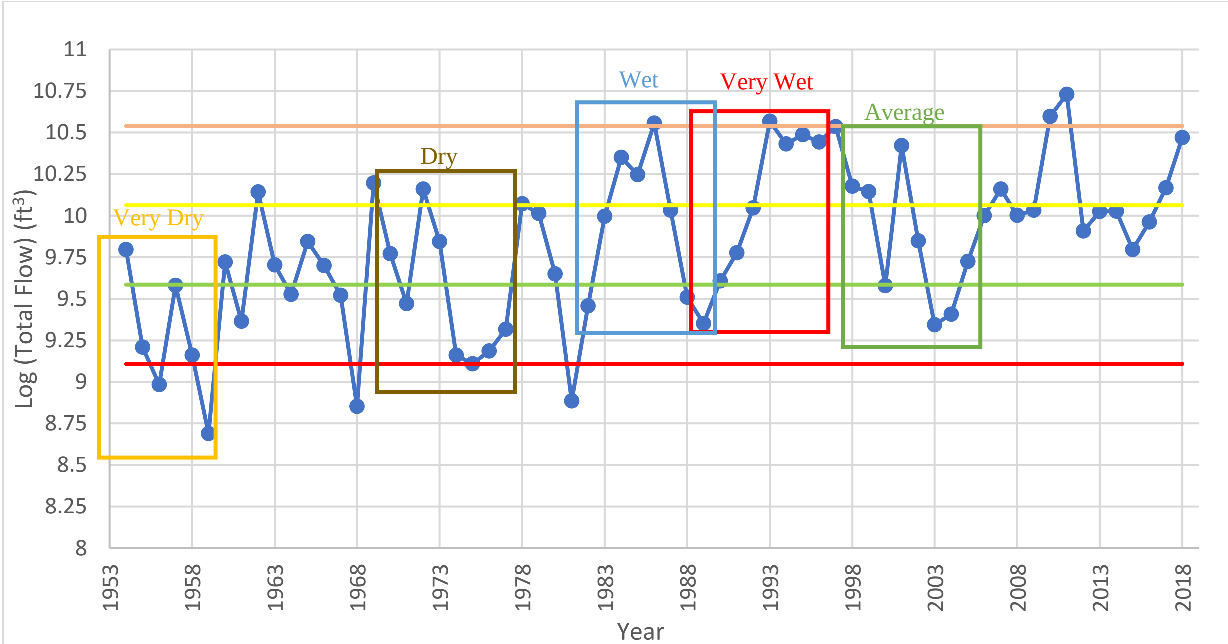

Figure 4.6: Comparison of the current study to the work of Sadichya Amatya. The boxes annotated on the graph represent the climate periods as identified by Amatya (2011)

The comparison of the remaining four climate scenarios show similar patterns to that of the very wet classification. It is important to note that when conducting a precipitation study, most of the precipitation that occurs in the winter is not accounted for in stream flow because it is in the form of snow and precipitation gauges can’t accurately measure the amount of moisture from snow fall. However, when performing a stream flow analysis, most of the precipitation due to snow is accounted for in the form of runoff during periods of snow melt. This can be seen from analyzing the data in Table 4.6.

Table 4.6: Cumulative Seasonal Stream Flow and Precipitation Near Brookings, South Dakota Comparison

Years	Cumulative Seasonal Stream Flow and Precipitation Comparison									
	Fall		Winter		Spring		Summer		Total	
	Precip. (in)	Stream Flow (ft^3)	Precip. (in)	Stream Flow (ft^3)	Precip. (in)	Stream Flow (ft^3)	Precip. (in)	Stream Flow (ft^3)	Precip. (in)	Stream Flow (ft^3)
1989-1996	36.27	15,807,389,760	7.34	18,509,757,120	50.81	71,246,736,000	106.89	40,375,843,200	201.31	145,939,726,080
1982-1989	57.24	12,007,785,600	6.47	23,200,931,520	50.54	54,198,918,720	78.97	15,724,765,440	193.22	105,132,401,280
1998-2005	46.9	8,788,608,000	7.82	9,620,824,896	57.33	46,331,015,040	69.24	11,566,823,328	181.29	76,307,271,264
1970-1977	38.8	2,487,642,023	8.46	10,770,619,949	52.19	19,004,593,751	68.71	4,824,502,645	168.16	37,087,358,368
1952-1959	21.97	1,174,117,398	11.55	5,635,644,783	41.84	12,956,631,349	73.31	2,650,873,617	148.67	22,417,267,148
Total	201.18	40,265,542,781	41.64	67,737,778,268	252.71	203,737,894,861	397.12	75,142,808,230	892.65	386,884,024,140

In Amatya's research, the Winter accounts for 4.7% of the total precipitation and the Spring accounts for 28.3%. In this study, the Winter accounts for 17.5% of the total stream flow and the Spring accounts for 52.6%. This shows that the precipitation that occurs in the Winter is not being fully accounted for in the stream flow analysis at the time it occurs but is being mostly accounted for in the stream flow analysis in the form of runoff after a period of time.

In order to truly compare and obtain results from a precipitation analysis in the Brookings, South Dakota, area, the data in Amatya's research would need to be re-analyzed to study the classification of each individual year and not the 8-year period. Doing this would allow for more accurate comparisons and potentially lead to accurate flood predictions.

4.6 Comparison to Stream Flow and Sediment Load Study

Brittany Leibel conducted a study of stream flow and sediment load in the Bad River watershed in order to analyze the effects of best management practices (BMPs). BMPs are practices that aim to improve water quality parameters with the addition of structural or non-structural improvements (Leibel, 2012). Structural BMPs are constructed basins or facilities where non-structural BMPs are developmental practices or land uses that reduce pollutants (Protect with Pride, 2012). Her thesis was titled *A Study of Stream Flow and Sediment Load From the Bad River Watershed Before and After BMP Implementation* (Leibel, 2012).

The main information found in her research that relates to this study is the correlation of precipitation to stream flow for various precipitation and stream flow gauges. In Leibel's study, precipitation and stream flow in the same water year were compared to one another and the comparison showed that the amount of stream flow had a direct correlation to the amount of precipitation in that year.

This further illustrates the point that the amount of stream flow in the Spring and Summer months is influenced by the amount of precipitation in the Fall and Winter. In order to more accurately predict flooding and stream flow conditions, a closer analysis of precipitation needs to be performed.

The research conducted by Leibel is just one example of the other uses for stream flow analysis. In the current study the main analysis was intended for future flood predictions. However, you could also use this data to perform other studies, like Leibel's sediment load study.

Chapter 5 Summary and Conclusion

Based on the USGS stream flow data at gauge #06480000, located just south of Brookings, South Dakota, years were classified into five categories. This study focused on the yearly classification and study of seasonal stream flow of the Big Sioux River just south of Brookings, South Dakota. The yearly classification and seasonal analysis involved the collection of historical daily stream flow data from the USGS website. This data was converted to a stream flow volume and then summed into cumulative yearly stream flow data consisting of the years 1954 to 2018. The data fit a log normal distribution.

A graph was made to illustrate the yearly stream flow from 1954 to 2018. The average and standard deviation were then calculated and manipulated to determine the ranges for climate classification. Each year was classified as either very wet, wet, average, dry, or very dry. The years within the classifications were then analyzed.

A seasonal analysis was then performed, and the yearly data was broken into four seasons per year: Fall, Winter, Spring and Summer. The cumulative stream flow volume for each season in each year was then calculated. Then the seasonal average stream flow volume for each classification was calculated and analyzed. Patterns were observed and noted and further analysis, such as percent of average and percent of total flow volume, were performed on each season.

It was found that the Spring seasons had the highest stream flow volume and Fall seasons had the lowest stream flow volume in all climate classifications. It was expected that Spring season would have the highest stream flow, however initially it was not expected that Fall season would have the lowest.

It was also found that the Summer season had the most variability and influenced the classification by providing significant amounts of stream flow volume. The summer months had some of the highest or some of the lowest stream flow volume values. This could be because the wetter the year is, the longer the runoff from Winter will last and the more ground water will be stored and contribute to stream flow.

The data was then compared to other research projects such as the development of climate scenarios using precipitation data in many locations, historical precipitation studies and the study of sediment loading for stream flow. From these comparisons, correlations were made and it was determined that it is possible to relate annual stream flow volume classifications to annual precipitation classifications. However, either new data needs to be analyzed or the studies need to be re-evaluated to more accurately portray the annual precipitation data for Brookings South Dakota.

Chapter 6 Future Research

This thesis presented results for stream flow analysis of the Big Sioux River just south of Brookings, South Dakota. Further comparisons of this research to other studies could provide useful data to use in making flood predictions. The following are suggested for future work:

I. Further precipitation analysis for the Brookings, South Dakota, area could be performed and then compared to the stream flow analysis in this study. This could be done by either expanding on the work done by Sadichya Amatya (2011) or conducting an entirely new precipitation study for the area.

II. A study of snow melt and runoff in the area could be performed. This would help determine how much flooding is due to precipitation in the winter season and give a clearer understanding of how stream flow is affected by precipitation during other seasons.

III. A study of ground water storage and its effect on runoff and stream flow could be conducted. This would benefit possible flood prediction in that, the more information obtained on how ground water levels fluctuate with season and climate, more accurate predictions of stream flow can be made.

IV. Finally, a comparison of all studies listed, along with this study, could be performed to develop flood prediction parameters.

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Appendix

Please visit http://openprairie.sdstate.edu/etd/XXXXX for the raw data and seasonal stream flow data from this thesis.