2018

Comparison of Historical Precipitation for Aberdeen, Ipswich, and Eureka, South Dakota

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COMPARISON OF HISTORICAL PRECIPITATION FOR ABERDEEN, IPSWICH AND EUREKA, SOUTH DAKOTA

BY

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A thesis submitted in partial fulfillment of the requirements for the degree

Master of Science

Major in Civil Engineering

South Dakota State University

2018

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This thesis is approved as a credible and independent investigation by a candidate for the Master of Science in Civil Engineering degree and is acceptable for meeting all 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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ACKNOWLEDGMENTS

This is a good opportunity for me to express my sincere respect to my advisor, Dr. Suzette R. Burckhard for her ‘patience’, inspiring guidance, outstanding cooperation, constant encouragement, and for providing me the foundation for independent thinking that inspired me in the most important moments of making right decisions throughout the study. I still remember my low grades in the first semester at South Dakota State University. But I’m proud to say that her constant support, critical appreciation and parental concern gave a glitter of confidence to my studies and the foreground for this research. Her expertise, understanding, work ethics, and passion for water and environmental engineering, and her students will never be forgotten.

I thank my friends for their unconditional love, care, utmost cooperation and help to complete this arduous task and for having stood by me every time. Words fail to express my deepest gratitude and genuine love to the pillars of my strength my dad Rekha Singh Kshatriya and mom Lalitha Bai Kshatriya for their belief in me and standing by my side during my good and bad times. Their inevitable love, care and positively friendly suggestions made me a better human being.

I honorably express my deepest gratefulness towards my parents for their godly influence upon my life and their countless blessings. In spite of my modest attempt to enlist every name whom I would like to pay my gratitude, if any person who have helped me in one or the other way and have not been included in this list were greatly acknowledged by me for their help.

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LIST OF ABBREVIATIONS

P_x	Estimate for ungauged station
P_i	Rainfall values of rain gauges used for estimation
N_x	Normal annual precipitation of X station
N_i	Normal annual precipitation of surrounding stations
m	Number of surrounding stations
$\sum_{i=1}^{N}(A_j - A_i)$	Thiessen Polygon area for the station with missing values
A_j	Thiessen Polygon area when a station with missing values is excluded
A_i	Thiessen Polygon area when a station with missing values is included
P_i	Annual precipitation of surrounding stations
P_x	Estimation of monthly missing rainfall data
° F	Degree Fahrenheit
^{o}C	Degree Celsius
µ	Mean
σ	Standard Deviation
ft	Feet
APR	Areal Precipitation Ration
COOP	Cooperative Observer Program

HPRCC	High Plains Regional Climate Center
IDWM	Inverse Distance Weighting Method
km	Kilometer
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
R^2	Coefficient of Determination
SD	South Dakota
SDSU	South Dakota State University
Std Dev	Standard Deviation
USGS	United States Geological Survey
USDA-ARS	United State Department of Agriculture-Agricultural Research Service

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ABSTRACT

COMPARISON OF HISTORICAL PRECIPITATION FOR ABERDEEN, IPSWICH AND EUREKA, SOUTH DAKOTA

UDAY SINGH KSHATRIYA

2018

The availability of water resources varies from time to time with the climate conditions. Keeping track of climate conditions would eventually benefit for the future predictions. The objective of this research was to compare and contrast the climate especially for Aberdeen, Ipswich and Eureka, South Dakota utilizing the historical monthly precipitation records and to develop the techniques that are reliable to estimate the missing data. For these necessary statistical analyses were performed using the monthly precipitation data from High Plains Regional Climate Center (HPRCC) for the annual and 8-Year periods for Aberdeen, Ipswich and Eureka, South Dakota. 63 water years of precipitation data were used for the study to develop the climate periods for 'Dry', 'Moderately Dry', 'Mean', 'Moderately Wet' and 'Wet'. The results were compared with the previous studies and concluded that the maximum precipitation in a year occurs for the month of June in the summer season and the minimum precipitation occurs for the month of January in winter. The highest variability in precipitation was for the months of June, July and August. This study also confirms the results from similar previous studies of different geographic areas in South Dakota, USA.

CHAPTER 1: INTRODUCTION

1.1 Background

Climate change is an alarming factor in recent years due to rapid urbanization and increase in global warming. Atmospheric concentrations of carbon dioxide and carbon monoxide are increasing at an alarming rate leads to increase in surface temperature. Imbalance in the hydrologic cycle is due to increase in surface temperature in the atmosphere. Changes in climatic conditions, for example, precipitation, temperature, wind, and dissipation can cause extensive and fast changes in stream flow and more slow changes in groundwater flow (Robson and Stewart, 1990).

Creating climatic situations incorporate concentrate climatic variability in the hydrologic cycle. For example, evaporation, precipitation, temperature, relative humidity, wind speed (Amatya, 2011).

1.2 Hydrologic cycle

The hydrologic cycle starts with the evaporation of water from the surface of the sea. As humid air is lifted, it cools, and water vapor consolidates to form clouds. Dampness is transported the world over until the point when it comes back to the surface as precipitation. The evaporation of water is usually estimated using evaporation pans, has been diminishing in the recent decades over extensive territories with various atmospheres. The basic interpretation is that the pattern is identified with expanding cloudiness, furthermore, that it gives a sign of diminishing potential evaporation and a diminishing terrestrial evaporation part in the hydrologic cycle. Figure 1.1 represents hydrologic cycle consists of evaporation, transpiration, condensation and precipitation (Brutsaert, & Parlange, 1998).

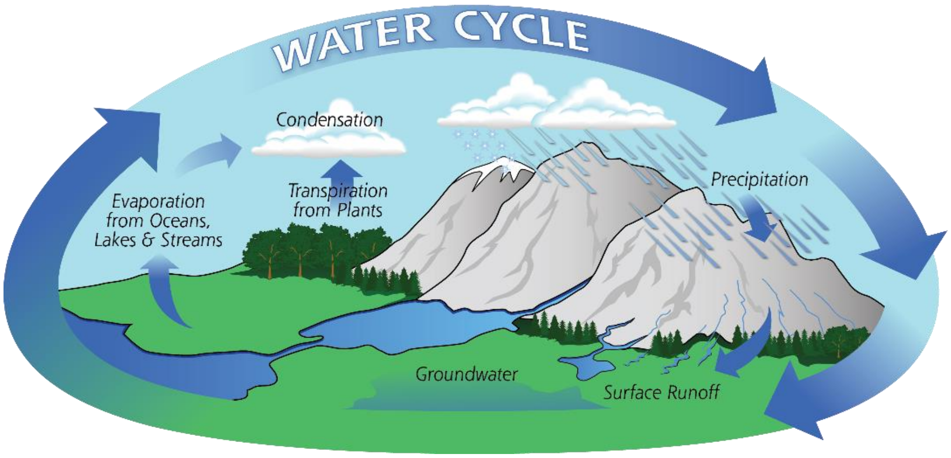

Figure 1-1 A Representation of the Water Cycle (NASA, 2018)

1.3 Objectives

- The objective of this research was to compare and contrast the climate specifically for Aberdeen, Ipswich and Eureka, South Dakota utilizing the historical monthly precipitation records and to develop the techniques that are reliable to estimate the missing data.

1.4 Tasks

- To perform statistical analyses on the annual accumulated precipitation of 8-Year periods for Aberdeen, Ipswich and Eureka, South Dakota, using 64 years of monthly precipitation data for the years 1954 to 2017.
- To develop different climate periods for Wet, Moderately Wet, Mean, Moderately Dry, and Dry for the annual 8-Year period of the study stations.
- Also, to compare the climatic periods with previously defined climatic periods (Amatya, 2011) and (Basnet, 2011) by this study.

CHAPTER 2: LITERATURE REVIEW

2.1 Background

Water is one of the primary sources of living for any species on the Earth. The water on the Earth is available by means of surface water and groundwater. Precipitation is water discharged from mists as rain, slush, snow, or hail. It is the essential association in the water cycle that accommodates the conveyance of atmospheric water to the Earth. Technically in precipitation, only rain and snow are important (McCuen, 2005).

The availability of water depends on the climatic condition of the region. South Dakota is a continental climate. Continental climate is portrayed by hot summers, chilly winters, and little precipitation. Generally, continental climate occurs in the central portion of the continent. South Dakota is considered to be continental due to its geographical location in central North America equally distant from the Atlantic and Pacific oceans (Hogan. et al., 2001).

Cyclones and droughts in the Great Plains are natural calamities that occur during extreme precipitation and temperature conditions. Occasional variations in precipitation on a watershed result in variations in stream flow that can affect the availability of water. An investigation was carried out to assess the effect of occasional speculative variations in precipitation on streamflow (Van Liew et al., 2003). The goal was to build a prototype for streamflow response along with a range of hypothetical precipitation forecasts. The prototype was developed for the 33 km^2 subwatershed, 442, located in the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) Little Washita River Experimental Watershed in Southwestern Oklahoma. The Soil and Water Assessment Tool was used to determine streamflow responses to hypothetical precipitation forecasts that represent changes of ±20% and ±40% for the fall quarter. Results of this study indicated that when precipitation events that are drier than normal were used, the streamflow responses approached baseflow conditions on the watershed, while using wetter than normal precipitation lead to higher streamflow values which were characterized by considerable variability which was attributed to variations in storm size, duration, and intensity during the fall months (Van Liew et al., 2003). Twentieth-century patterns of precipitation have been studied by an assortment of strategies to determine how precipitation has changed or differed over the years. One study noted that since 1910, precipitation has increased by approximately 10% over the continental United States (Karl & Knight, 1998).

Different climatic scenarios were developed using the accumulated annual precipitation data for 8-Year periods for Aberdeen, South Dakota. Outcomes of this research concluded that the developed climatic scenarios using one-year climatic data may not produce the accurate results for the 8-Year climatic scenario (Basnet, 2011). Another similar kind of approach was performed for five stations in Eastern South Dakota to develop the climatic scenarios using evaporation and precipitation data. Also, the results were compared with the climatic scenarios developed by USGS study (Amatya, 2011).

2.2 Estimation Techniques for Missing Precipitation Data

Distance-weighted and data-driven strategies are widely utilized for estimation of missing precipitation data. Inverse distance weighting method (IDWM) is a standout amongst most of the time utilized techniques for evaluating missing precipitation values at a gauge in view of values recorded at all other accessible account gauges. Conceptual improvements were introduced in the IDWM method that led to several modified distance-based methods. These strategies were tested for estimation of missing precipitation data. Historical precipitation data from 20 rain-checking stations in the state of Kentucky, USA. (Teegavarapu & Chandramouli, 2005).

The Normal ratio method is used when annual precipitation exceeds 10% of the considered gauge. This method weights the effect of each surrounding station based on normal precipitation for that station and the missing station (Singh, 1994). The following equation estimates the missing data.

$$P_x = \frac{1}{m}\sum_{i=1}^{m}[\frac{N_x}{N_i}]\ P_i$$

Where P_x = Estimate for ungauged station

P_i = Rainfall values of rain gauges used for estimation

N_x = Normal annual precipitation of X station

N_i = normal annual precipitation of surrounding stations

m = Number of surrounding stations

Areal Precipitation Ratio (APR) method was developed based on spatial distribution of daily rainfall without accounting for historical recurrence. The technique related point precipitation records to Thiessen Polygon areas. The APR method assumes the contribution of rainfall from surrounding stations is proportionate to the areal contribution of each sub-catchment (Thiessen polygon area claimed by each station without considering the missing gauge) when the station of missing values is excluded (De Silva et al., 2007). The formula for the APR method is as follows

$$P_x = \frac{\sum_{i=1}^{N}[\left(A_j - A_i\right)P_i]}{\sum_{i=1}^{N}(A_j - A_i)}$$

Where $\sum_{i=1}^{N}\left(A_j - A_i\right)$ = Thiessen Polygon area for the station with missing values

A_j = Thiessen Polygon area when a station with missing values is excluded

A_i = Thiessen Polygon area when a station with missing values is included

P_i = Annual precipitation of surrounding stations

P_x = Estimation of monthly missing rainfall data

CHAPTER 3: METHODOLOGY

3.1 Description of Study Area

South Dakota, USA is approximately 1300 miles equally distant from the Atlantic and Pacific oceans. It is in central North America i.e., a Midwestern portion of the United States of America. South Dakota is the seventeenth largest by area which is surrounded by six states, North Dakota in the north, Minnesota and Iowa in the east, Nebraska in the south, and Wyoming and Montana in the west. Figure 3.1 shows the location of South Dakota in the map of the United States of America (USA). (National Geographic Partners, 2018)

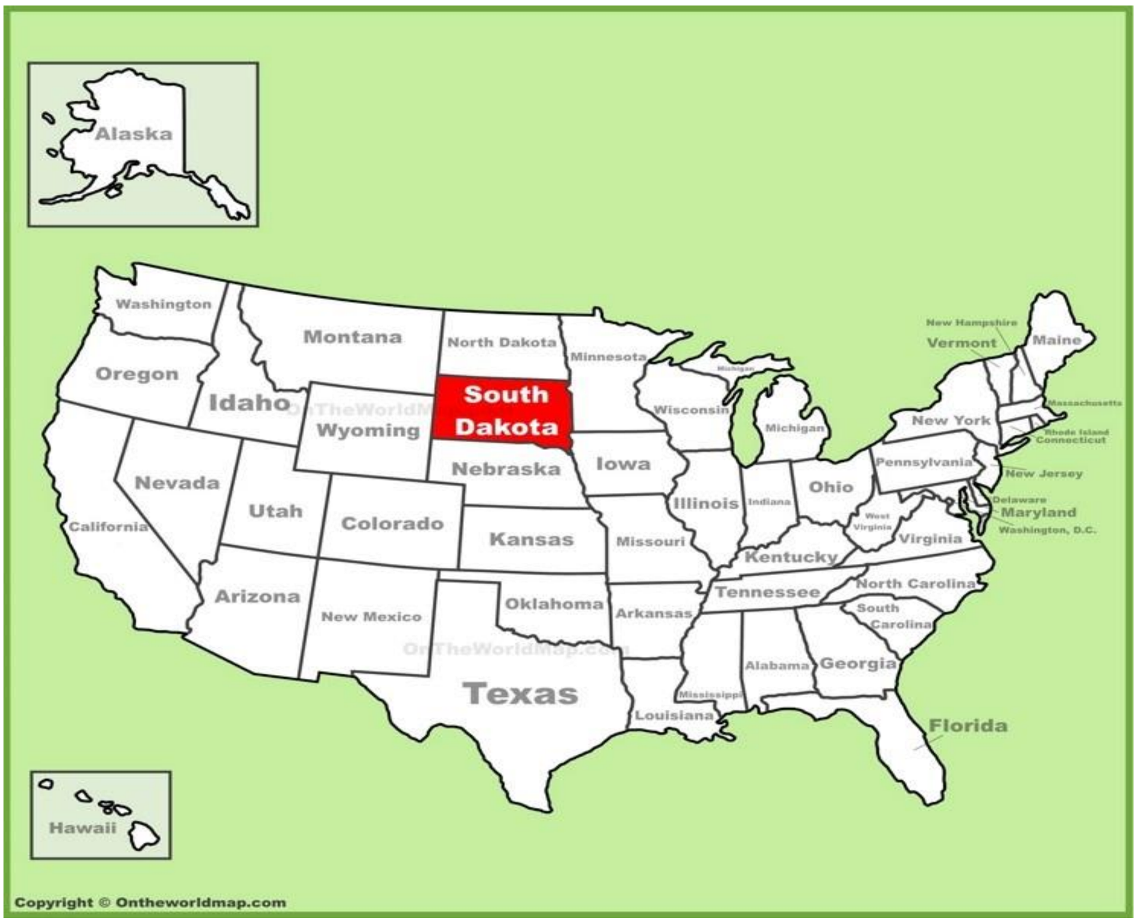

Figure 3-1Map of United States of America (On the World Map, 2018)

Figure 3.2 shows the 66 counties of South Dakota. The study stations for the research Aberdeen, Ipswich and Eureka, SD are highlighted in Figure 3.2, as well as, Pierre, the state capital, which is located in the center of South Dakota map.

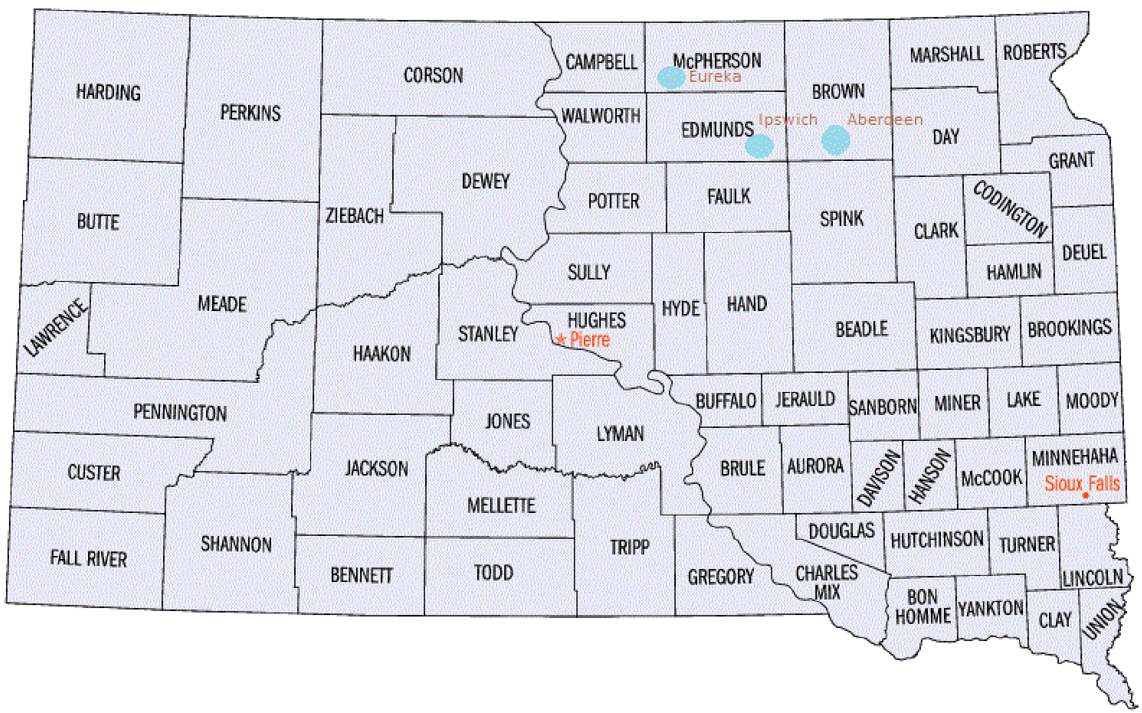

Figure 3-2Counties of South Dakota, USA (Wikimedia, 2018)

3.1.1 Geography of Aberdeen

Aberdeen is in Brown County, which is located in a northeastern portion of South Dakota. According to the United States of Census Bureau (2010), the city has a total area of 15.60 square miles (40.40 km^2), of which 15.50 square miles (40.14 km^2) arrive and 0.10 square miles (0.26 km^2) is water. It has a huge variation in climate during cold winters and hot summers. The National Oceanographic and Atmospheric Administration (NOAA) maintains a National Weather Service (NWS) office in Aberdeen which tracks precipitation at that site.

3.1.2 Geography of Ipswich

Ipswich is 1.34 square mile area city in Edmunds County, SD. In Ipswich summers are warm and winters are freezing and dry. The warmest season lasts for approximately 4 months with temperature varies from 85^0F to 61^0F. The winter season lasts for 3 and half months with 6^0F to 24^0F A wet day is considered only if it has at least 0.04 inches of liquid or any other form of precipitation. The pattern of precipitation or wet days in Ipswich does not follow a specific discernible trend or pattern throughout the year other than having more wet days during some months. The wetter period lasts for five months, from April through September (Weather spark, 2018).

3.1.3 Geography of Eureka

Eureka has almost the similar geographical type of Ipswich and Aberdeen. Eureka is a city in McPherson County, South Dakota. According to the United States Census Bureau (2010), The city has a total area of 1.00 square mile (2.59 km^2), of which, 0.93 square miles (2.41 km^2) is land and 0.07 square miles (0.18 km^2) is water. The average yearly temperature in Eureka is cool at 5.8 °C (42.4 °F). There is a variety of normal month to month temperatures of 34.5 °C (62.1°F) which is above the moderate rate range. There is a range/variety of normal diurnal temperatures of 13.7 °C (24.7 °F). The hottest month (July) is extremely warm having a mean temperature of 22.1 °C (71.78 °F). The coldest month (January) is exceptionally cool having a normal temperature of - 12.4 °C (9.68 °F) (Climatemps.com, 2018).

3.2 Source of Data

The primary source of climate data for the research is obtained from High Plains Regional Climate Center (HPRCC, 2018). The Cooperative Observer Program (COOP) is a volunteer network of observers which collects and reports on the Nation's weather and climate. The purpose of the COOP is to provide the observational climatic data like 24-hour precipitation totals, maximum and minimum temperatures and rains. The data were obtained at: https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/cooperative-observer-network-coop

The precipitation data required for the study was obtained from High Plains Regional Climatic Center (HPRCC). The data range available for each station was not consistent, i.e., a different set of data periods were available. So, the common data periods were adjusted to 1954 to 2017 which turned out to be 64 years of monthly precipitation data for Aberdeen, Ipswich and Eureka, SD, according to the US Geological Survey (2018). The raw data were further adjusted to water year which starts from October 1 to September 30 of every year.

Table 3-1Eastern South Dakota Water Stations used in the study

Stations	**County**	**COOP ID Number**	**Climate Data**	**No. of Years**
Aberdeen	Brown	390020	Precipitation	1954-2017
Ipswich	Edmunds	394206	Precipitation	1954-2017
Eureka	McPherson	392797	Precipitation	1954-2017

Table 3.1 shows the stations considered for the study, location, Cooperative Observer station (COOP) and the number of years of record used for the analysis.

3.2 Conventions Used

3.2.1 Water Year

In general, a year is considered to be twelve months which is from January 1 through December 31. A water year is also known as a hydrological year or a discharge year which deals with the surface water supply. According to the USGS (2018), the hydrological year or discharge year is defined as “the 12-month period October 1, for any given year through September 30, of the following year. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1999 is called the "1999" water year.”

3.2.2 Statistical Analysis

Data were assumed to be Normally distributed based on prior research by Basnet (2011). The terms that have been used in the statistical analysis in the process of the thesis are explained in detail below:

Mean (Average)

The mean is simply often referred to as the average of a given set of numbers. It is the sum of the given set of numbers divided by a total number of items in the set. The mean is denoted by ‘μ’ is defined as:

$$\mu = \frac{1}{n}\sum_{i=1}^{n} X_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where μ = Mean

n = Number of items in the set

X_i = Value of each individual item

Standard Deviation

The square root of its variance measures the standard deviation of the set of data. The variance is the average of the squared contrasts from the mean. The standard deviation of a data set indicates how close each data value in the data set is to the mean value. A low standard deviation value specifies the data points to be close to the mean and a high standard deviation specifies the data points spread out a wide range from its mean value. The standard deviation formula is given below, and it is denoted as ‘σ’.

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

Skewness

A measure of the asymmetry of a statistical distribution is known as skewness. The value of skewness may not necessarily be a positive or a negative value in every case. It could also be a zero. Skewness describes the distribution side which has a longer tail than another side. The skewness said to be positive if the long tail is on the right side and it is said to be negative when the long tail is on the left side. If the data is equally distributed on each side, then the skewness is said to be zero.

3.3 Estimating Missing Precipitation Data

The raw precipitation data gathered from High Plains Regional Climate Center (HPRCC, 2018) had some missing monthly data which may lead to inaccurate results in the analysis. To overcome this situation alternate stations were selected to estimate the missing data (Amatya, 2011). Van Liew et al. (2003) conducted studies on how the seasonal changes in precipitation affect the streamflow of the watersheds which showed how important the role of estimating accurate results. Caution must be taken to choose stations for comparison so that the estimated values are not biased to the trend at the comparison station.

The alternate stations were identified using Sando (1998) who developed the hydrologic subregions for the regional peak-flow magnitude for South Dakota (Figure 3.3). The subregions specified in Figure 3.3 is explained in Table 3.2. As the streamflow and the precipitation are related to each other, Table 3.3 shows the alternative stations which are selected within the specific hydrologic subregions to estimate missing precipitation records (see Appendix A for dataset).

Figure 3-3 Hydrologic Subregions for South Dakota (Sando,1998).

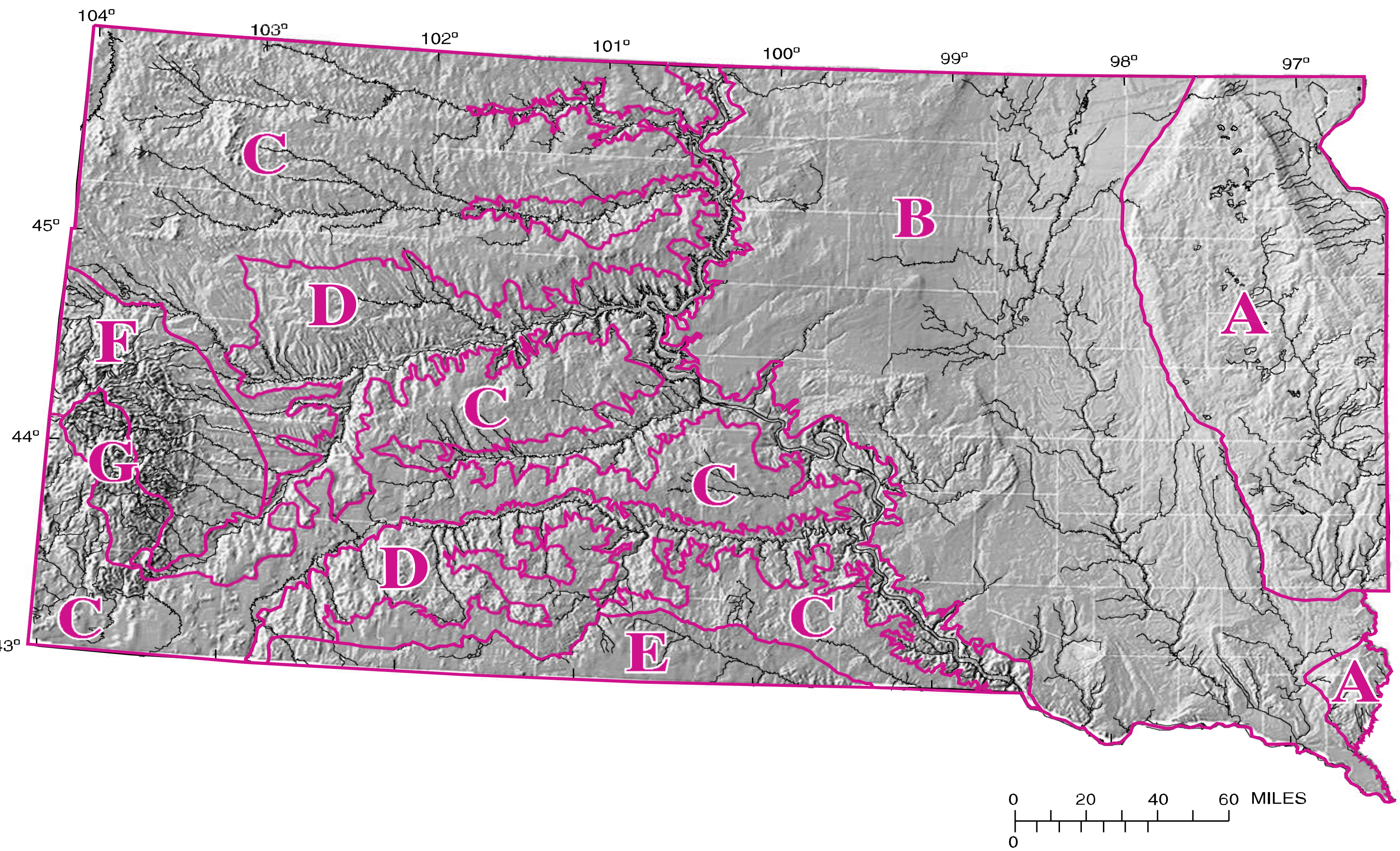

Table 3-2 Description of hydrologic subregions determined for the regional peak-flow magnitude and frequency analysis for South Dakota (Sando,1998)

Subregions	Description
A	Minnesota-Red River Lowland, Coteau des Prairies, and eastern part of the Southern Plateaus physical divisions of Flint (1955).
B	Lake Dakota Plain, James River Lowland and Highlands, and Coteau du Missouri physical divisions of Flint (1955): part of Coteau du Missouri in central South Dakota that has topography typical of Great Plains “breaks” sites were excluded from this subregion.
C	Great Plains physiographic division of Fenneman (1946), excluding the Sand Hills, influenced areas in south-central South Dakota, and areas with topography typical of “breaks” sites, primarily in the Cheyenne, Bad, and White River basins.
D	Includes areas in the Great Plains physiographic division of Fenneman (1946) with topography typical of “breaks” sites.
E	Generally, corresponds to the Sand Hills physical division of Flint (1955).
F	Generally, corresponds to the northeast exterior part of the Black Hills physical division of Flint (1955).
G	Generally, corresponds to the southwest interior part of the Black Hills physical division of Flint (1955).

Note: Fenneman, (1946) and Flint, (1955).

Table 3-3Counties and Subregions for Aberdeen, Ipswich and Eureka, SD

Stations	**County**	**Subregions**
Aberdeen	Brown	B
Ipswich	Edmunds	B
Eureka	McPherson	B

3.4: Identification of Annual 8-Year periods

Monthly precipitation data collected from HPRCC was used to calculate the Annual precipitation for Aberdeen, Ipswich and Eureka, SD. Using the total annual precipitation data for the selected years (1954-2017), the group of 8 years was made as a set of 8-year period by adding the annual precipitations. Similarly, each having continuous 8-years were found for the remaining years (see Appendix B for dataset). According to USGS (2018), the climate has a tendency of reoccurrence of a similar type of climate for every 7 to 10 years of time (Niehus et al., 1999). So, for this research, the climate periods were developed using the strategy of consecutive 8-year periods for the entire 63 water years from 1955 through 2017.

3.5 Climate Periods

For the study of climate situations, the climate periods were divided into five major periods. They are: Dry, Wet, Average/Mean, Moderately Dry and Moderately Wet (Amatya, 2011). These periods were defined for the study as follows.

Dry Period

The water year with the least annual precipitation is defined as the Dry period.

Wet Period

The water year with the highest amount of precipitation is defined as the Wet period.

Average Period

The period with an average amount of precipitation is said to be the Average period.

Moderately Wet Period

The Moderately Wet period is obtained by calculating the mean of the period plus its standard deviation. The periods that lies between the average plus standard deviation is called Moderately Wet period.

Moderately Dry Period

The Moderately Dry period is obtained by subtracting the standard deviation from the average.

CHAPTER-4: RESULTS

4.1 Climate for Aberdeen

4.1.1: Monthly Precipitation of Aberdeen

Monthly missing data was calculated based on the correlation method. The Coefficient of determination (R^2) values was obtained from the trend line for the full data set. Missing data of monthly precipitation of Aberdeen is estimated from the linear equation shown in Figure. 4.1. A set of 8-Years was grouped to represent a period. The different colors shown on the plot represents each 8-Year period. Similarly, 8-Years grouped periods are used for Ipswich and Eureka stations.

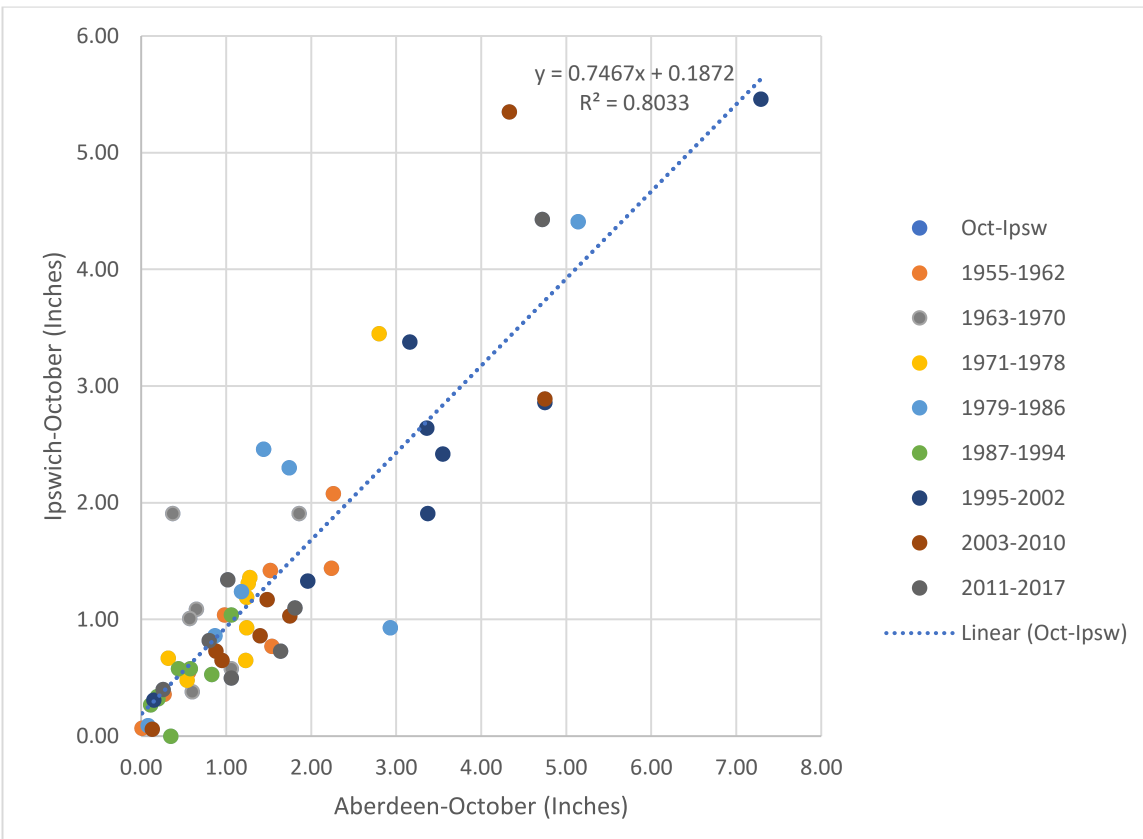

Figure 4-1Plot of Aberdeen vs Ipswich, SD for October Months

Table 4-1Statistical Results of Monthly Precipitation of Aberdeen, SD

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.55	0.66	0.50	0.47	0.56	1.03	1.93	2.86	3.31	2.84	2.20	1.82
Standard Deviation	1.49	0.61	0.38	0.33	0.36	0.77	1.3675	1.94	1.82	1.66	1.34	1.34
Skewness	1.69	1.34	1.38	0.92	0.81	1.06	1.4813	2.05	0.53	1.02	0.83	0.82
Driest Year Precipitation	0.01	0.01	0.03	0.01	0.03	0.04	0.12	0.3	0.37	0.3	0.24	0.01
Dry Period Year	1956	1977	1967	1961	2002	1971	1981	1994	1974	1975	1996	2012
Wettest Year Precipitation	7.29	2.87	1.78	1.34	1.54	3.45	7.88	12.23	7.72	7.71	6.19	5.32
Wet Period Year	1999	2001	2017	1997	1969	1977	1986	2007	1990	1972	2014	1996

Table 4.1 shows the statistical results of monthly precipitation of Aberdeen, SD it is observed that the maximum mean was in June which is found to be 3.31 Inches (in) and the minimum is 0.47 Inches (in) in January. The maximum and minimum standard deviation are 1.94 in May and 0.33 in January respectively. Similarly, the maximum and minimum skewness is 2.05 (May) and 0.53 (June) respectively.

The results during the dry period precipitations were interesting that the minimum precipitation was recorded in October, November, January and September and found to be 0.01 inches (in) during the years 1956, 1977, 1961 and 2012 respectively. The maximum precipitation during dry periods was 0.37 inches in June 1974. The maximum and minimum precipitation during wet periods were 12.23 inches and 1.34 inches in May 2007 and January 1997 respectively.

4.1.2: Annual Precipitation of Aberdeen

The 63 water years of monthly precipitation data collected from Aberdeen station for the period of 1955 to 2017 was used to calculate the annual precipitation data. For this, the monthly missing data was estimated by using alternate stations to fill the gaps so that to estimate the closest accurate annual precipitation data.

The recorded annual precipitation data shows an extensive range in the maximum and minimum precipitation data. The precipitation data varies from a maximum of 30.85 inches in 1999 to a minimum of 9.07 inches in 1976. The higher standard deviation of 4.51 inches explains the drastic variability in the wet and dry water years. Figure. 4.2 shows how the series does not follow any discernible pattern of precipitation periods. Also, it has the average annual precipitation of 19.73 inches.

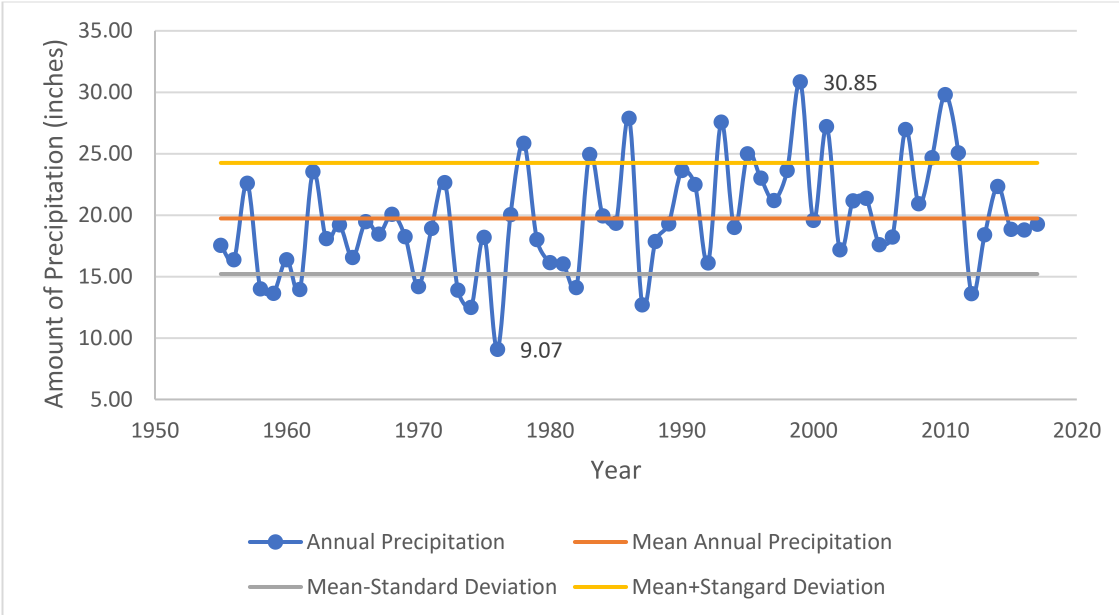

Figure 4-2Plot of Annual Precipitation for Aberdeen, SD

4.1.3: Cumulative 8-Year Precipitation Periods for Aberdeen

USGS noted that the pattern of reoccurrence of the analogous climate conditions would be in every 7 to 10 years in a cycle for northeastern South Dakota (Niehus et al., 1999). So, in this research, a sequential 8-year annual period is used similarly to the procedure followed by (Putez, 2013).

As mentioned the 8-year annual precipitation period is a good cumulative period to estimate the climate forecasts. The plot of cumulative 8-year annual precipitation period is shown in Figure 4.3. The plot shows a wide variation between the Wet and Dry periods. Another interesting notable object with the plot is that there is a gradual increment from the dry periods to the wet periods which shows the uncertainty in the climate cycle.

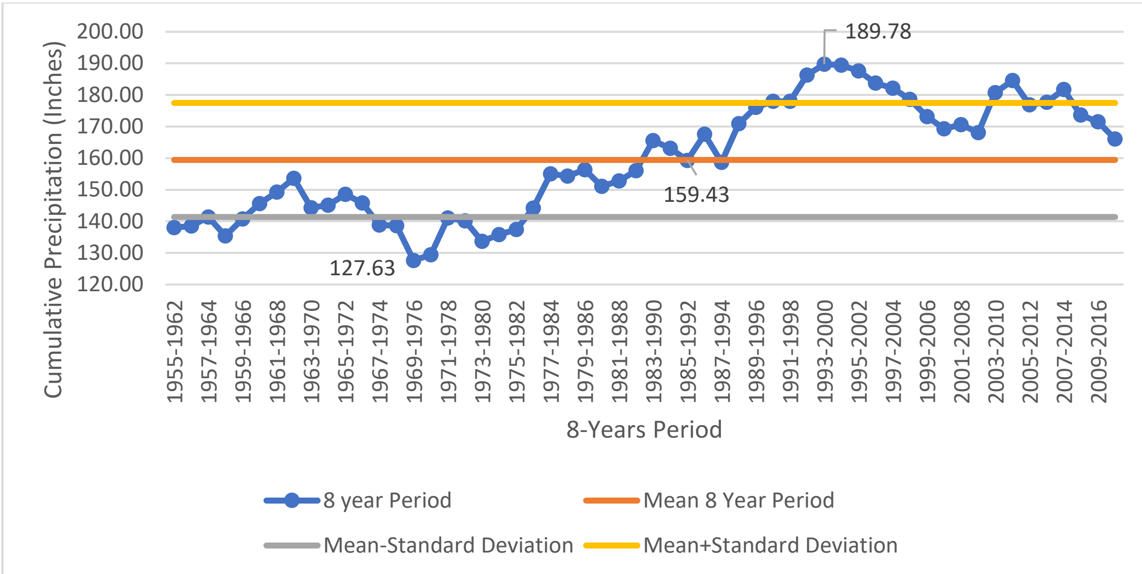

Figure 4-3 Plot of cumulative 8-Year Precipitation Period for Aberdeen

Different sets of precipitation circumstances were recognized based on the cumulative annual 8-year periods. The orange color line in the plot shows the mean/average amount of precipitation for the total annual 8-year period. Whereas, the data above the orange line are the wet periods and the data below the orange line are the dry periods.

The estimated precipitation is sorted into customary sets based on the accumulated annual 8-year periods. The period 1993 to 2000 has the maximum precipitation of 189.78 inches making that a ‘Wet period’. Likewise, the minimum precipitation of 127.63 inches for the period 1969 to 1976 makes that a ‘Dry period’.

The average/mean of total annual 8-year periods was calculated to be 159.43 inches. The period of 1985 to 1992 was measured to be the mean period which has the 8-year period precipitation of 159.32 inches. The standard deviation for the cumulative 8-year precipitation was 18.05 inches. Also, ‘Moderately Wet’ and ‘Moderately Dry’ periods of the annual 8-year precipitation were found by adding and subtracting the standard deviation to the mean. The annual 8-year precipitation for the ‘Moderately Wet’ and ‘Moderately Dry’ were 177.48 inches and 141.37 inches. The low skewness indicates the data are fairly normally distributed.

Table 4-2 Identified Climate Situations Based on 8-Year Precipitation Amount for Aberdeen, SD

	Total Precipitation (Inches)	**8-year Period**
Wet Period	189.78	1993-2000
Moderately Wet	177.66	2006-2013
Mean	159.32	1985-1992
Moderately Dry	141.39	1957-1964
Dry	127.63	1969-1976
Standard Deviation	18.05	
Skewness	0.04	

4.2 Climate for Ipswich

4.2.1: Monthly Precipitation of Ipswich

Missing data of monthly precipitation of Ipswich was estimated from the linear equation shown in Figure 4.1 and 4.4.

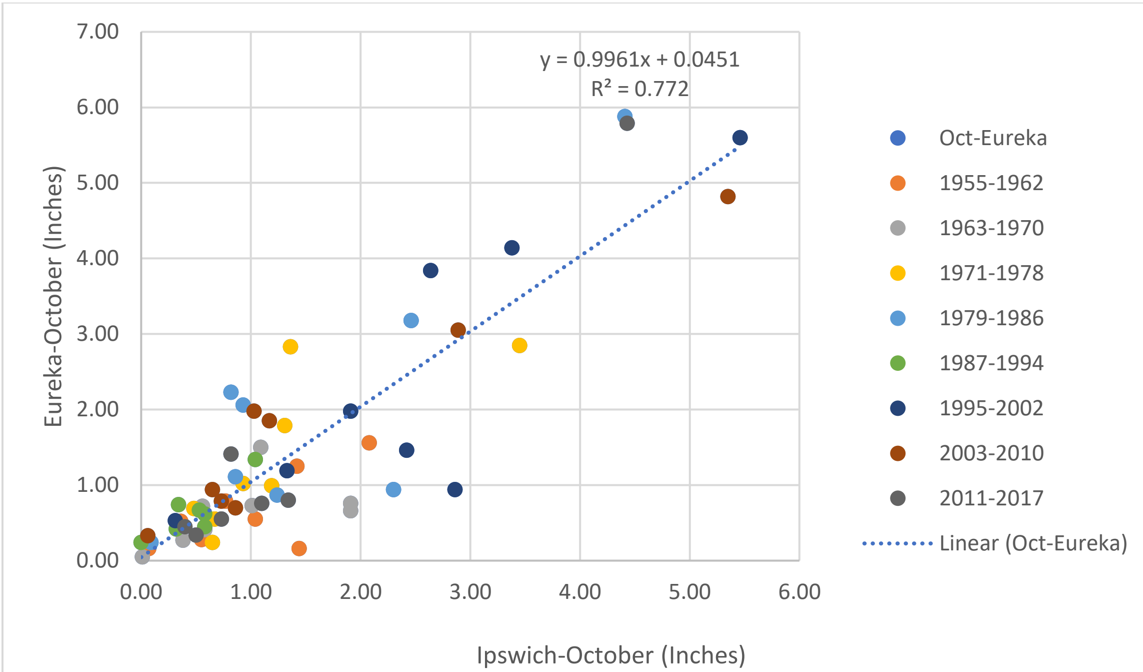

Figure 4-4 Plot of Ipswich vs Eureka, SD with 8-Year Data Sets

Table 4-3 Correlation between Ipswich and alternate stations

Ipswich	**Aberdeen**	**Eureka**
Correlation	0.8962	0.8786
R^2	0.8033	0.7720

Figure 4.1 and 4.4 shows the scatter plots of Aberdeen vs Ipswich and Ipswich vs Eureka. The highest R^2 value for the alternative stations between Ipswich and (Aberdeen and Eureka) is 0.8033. So, the station Aberdeen is used to calculate the missing data for Ipswich station. Similarly, necessary calculations are performed to determine the coefficient of determination for the remaining stations to estimate the monthly missing precipitation data.

Table 4.4 shows the statistical results of monthly precipitation of Ipswich, SD. The maximum and minimum means were 3.54 inches in June and 0.37 inches in January respectively. The maximum and minimum standard deviations were 1.91 and 0.26 respectively. The former was in July and the latter in January. Similarly, the maximum and minimum Skewness values were found to be 2.23 and 0.26 inches in July and June respectively.

The highest precipitation during dry period was 0.52 inches in May 2009 and lowest dry period precipitation of 0.00 inches was found in three months October, November and September in 1994, 1981 and 2012 respectively. The highest and lowest precipitations during the wet period were 12.03 inches and 1.05 inches in July 1993 and January 2010 respectively.

Table 4-4Statistical Results of Monthly Precipitation of Ipswich, SD

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.34	0.59	0.41	0.37	0.50	0.96	1.99	2.86	3.54	2.84	2.26	1.64
Standard Deviation	1.24	0.57	0.31	0.26	0.39	0.74	1.30	1.65	1.71	1.91	1.32	1.30
Skewness	1.71	1.36	0.83	0.90	1.48	1.20	1.07	0.92	0.26	2.23	0.88	1.39
Driest period Precipitation	0.00	0.00	0.02	0.03	0.03	0.04	0.19	0.52	0.51	0.15	0.18	0.00
Dry period Year	1994	1981 2008 2000	1975 1987	1974	1985	1967	1988	2009	1974	2014	1972	2012
Wettest Period Precipitation	5.46	2.32	1.44	1.05	1.91	3.67	6.10	8.19	7.05	12.03	6.28	6.43
Wet period Year	1999	1978	2017	2010	1969	1977	1986	2015	1984	1993	2014	1996

4.2.2: Annual Precipitation of Ipswich

Similarly, for the station Ipswich, the monthly precipitation data was used to calculate the annual precipitation data for the study water years (1955-2017). The monthly missing data was estimated by comparing with the alternate stations to fill the unknown monthly precipitation values so that to estimate the closest accurate annual precipitation data for Ipswich.

The recorded annual precipitation data shows an extensive range in the maximum and minimum precipitation data like Aberdeen which is a good sign of following the same pattern. The precipitation data varies from a maximum of 31.80 inches in 1988 to a minimum of 9.90 inches in 1998. The higher standard deviation of 4.20 inches explains the drastic variability in the wet and dry water years. Figure 4.5 shows that the series does not follow any pattern during high and low annual precipitation periods. Also, it has the average annual precipitation of 19.29 inches.

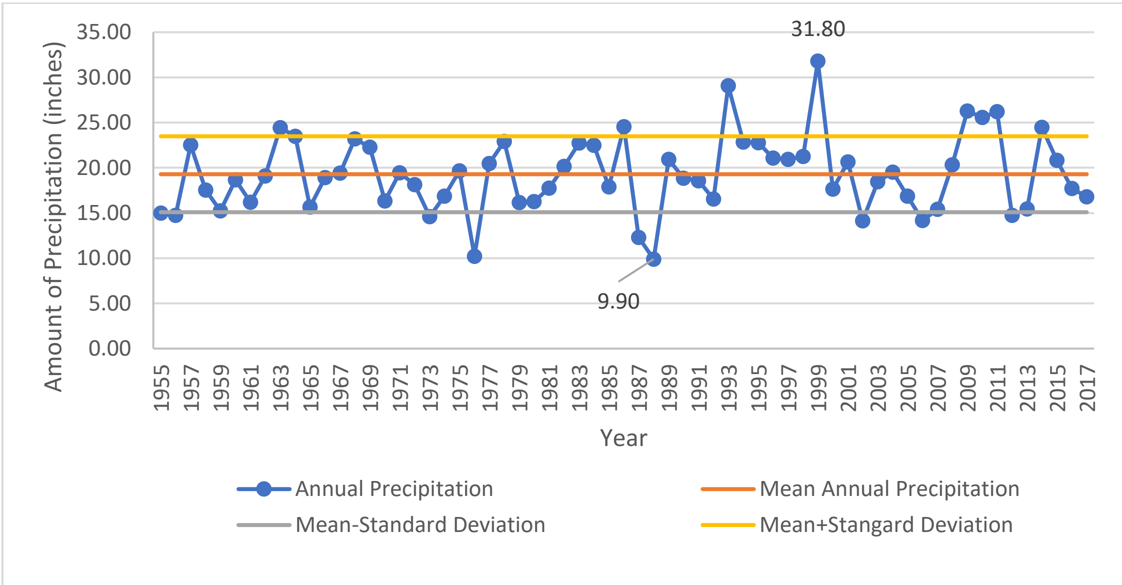

Figure 4-5 Plot of Annual Precipitation for Ipswich, SD

4.2.3: Cumulative 8-Year Precipitation Periods for Ipswich

The plot of cumulative 8-year annual precipitation period is shown in Figure 4.6. The plot represents the similar variability as Aberdeen which shows a wide variation between the Wet and Dry periods and the uncertainty in the climate cycle. The estimated precipitation was sorted into customary sets based on the accumulated annual 8-year periods were: The maximum precipitation for Aberdeen and Ipswich has the same set of periods 1993 to 2000 with the maximum precipitation of 187.43 inches making that a 'Wet period' Similarly, the minimum precipitation of 135.74 inches for the period 1970 to 1977 which makes that a 'Dry period' was also very close to the cumulative 8-year period of Aberdeen which makes more sense that they follow the same pattern.

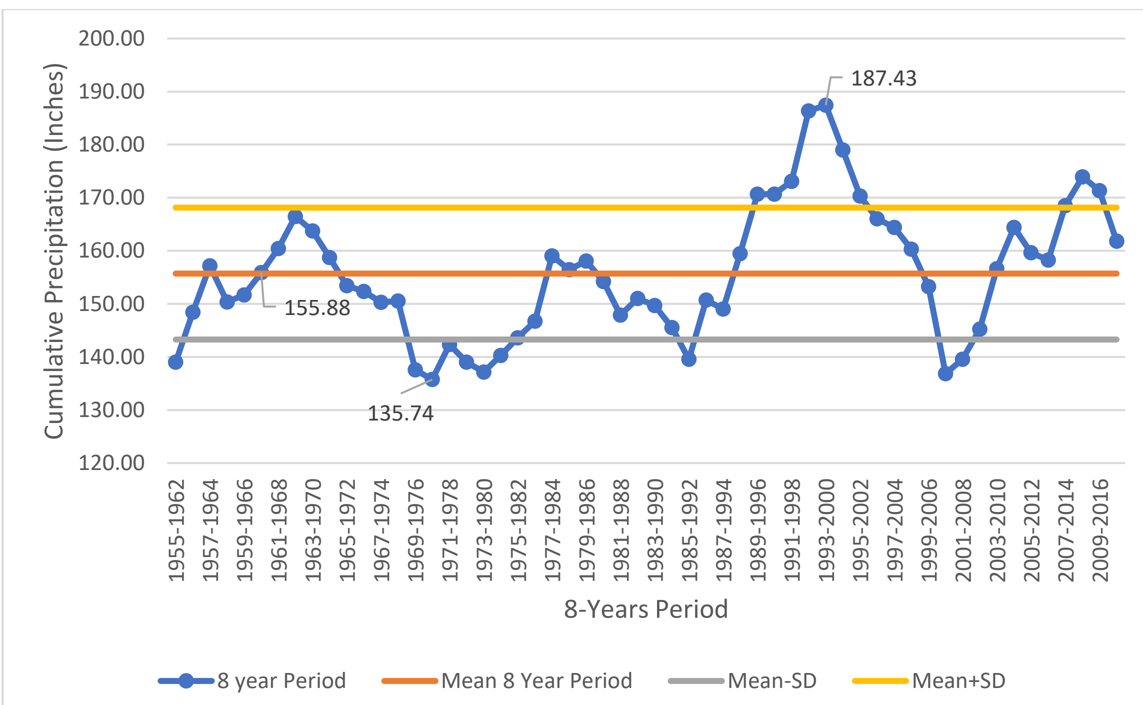

Figure 4-6 Plot of cumulative 8-Year Precipitation Period for Ipswich, SD

The average/mean of total annual 8-year periods was calculated to be 155.71 inches for the period of 1960 to 1967. The standard deviation for the cumulative 8-year precipitation was 12.43 inches. Also, the annual 8-year precipitation for the ‘Moderately Wet’ and ‘Moderately Dry’ are 168.14 inches and 143.28 inches.

Table 4-5 Identified Climate Situations Based on 8-Year Precipitation Amount for Ipswich, SD

	Total Precipitation (Inches)	**8-year Period**
Wet Period	187.43	1993-2000
Moderately Wet	168.54	2007-2014
Mean	155.88	1960-1967
Moderately Dry	143.63	1975-1982
Dry	135.74	1970-1977
Standard Deviation	12.43	
Skewness	0.46	

4.3 Climate for Eureka

4.3.1: Monthly Precipitation of Eureka

Missing data of monthly precipitation of Eureka were estimated from the linear equation shown in Figure. 4.4. From Table 4.6 the maximum and minimum mean values are 3.42 inches and 0.31 inches in June and January respectively. The maximum and minimum standard deviation is 1.93 and 0.23. The former was in June and January respectively. The maximum skewness is 2.49 in February and minimum skewness is 0.46 in August.

Table 4-6 Statistical Results of Monthly Precipitation of Eureka, SD

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.38	0.56	0.37	0.31	0.42	0.80	1.75	2.84	3.42	2.70	2.30	1.56
Standard Deviation	1.41	0.60	0.32	0.23	0.38	0.68	1.19	1.54	1.93	1.72	1.36	1.19
Skewness	1.87	1.75	1.66	1.50	2.49	1.05	1.09	0.64	1.01	1.69	0.46	1.03
Driest Period Precipitation	0.05	0.00	0.00	0.02	0.01	0.03	0.07	0.46	0.47	0.24	0.19	0.01
Dry Period Year	1965	2012	2008 1987	2007	1985	2012	1987	1976	1974	2014	2010	2012
Wettest Period Precipitation	5.88	2.78	1.57	1.21	2.17	2.68	5.30	6.70	9.59	10.34	5.82	4.64
Wet period Year	1983	2001	2011	1997	2000	1968	1989	2015	1964	1993	1993	1973

The maximum driest precipitation of 0.47 inches occurred in June and the minimum was found in November and December to be 0.00 inches. Similarly, the maximum and minimum wettest year precipitation is 10.34 inches and 1.21 inches in July 1993 and January 1997 respectively

4.3.2: Annual Precipitation of Eureka

Similarly, for the station Eureka, the monthly precipitation data was used to calculate the annual precipitation data for the study water years (1955-2017) to estimate the closest accurate annual precipitation data for Eureka.

The precipitation data varies from a maximum of 30.96 inches in 1993 to a minimum of 7.94 inches in 1988 are shown in Figure. 4.7. The higher standard deviation of 4.30 inches clarifies the fluctuation in the wet and dry water years. Figure 4.7 demonstrates the arrangement does not follow any pattern during high and low annual precipitation periods. Also, it has the mean annual precipitation of 18.41 inches.

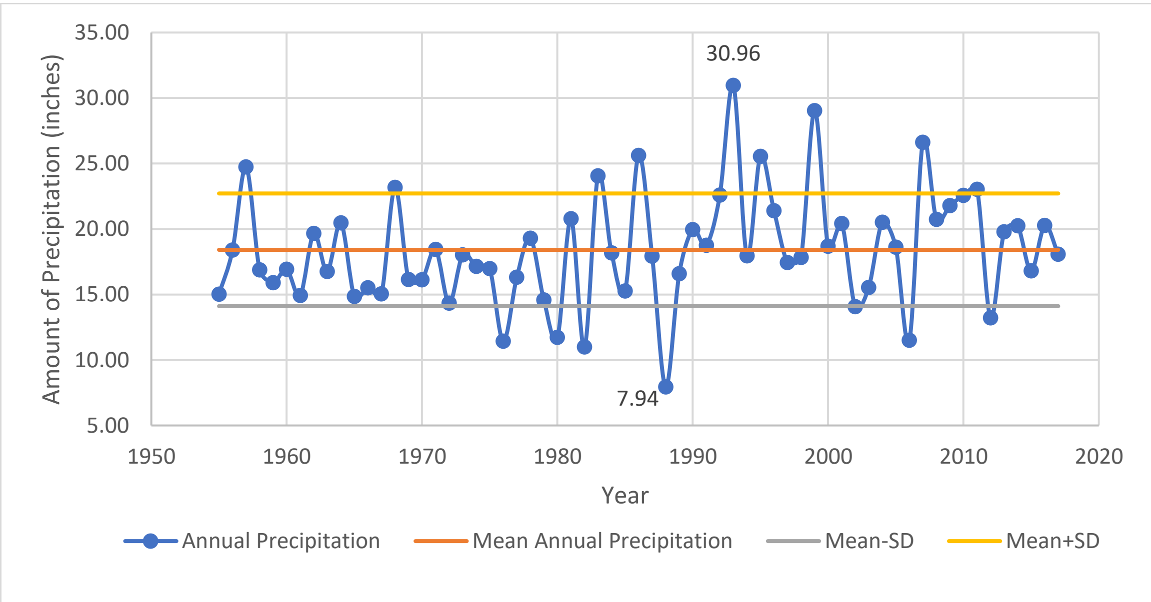

Figure 4-7 Plot of Annual Precipitation for Eureka, SD

4.3.3: Cumulative 8-Year Precipitation Periods for Eureka

The plot of 8-year annual precipitation periods is shown in Figure 4.8. The plot represents the similar variability as Aberdeen and Ipswich during the Wet and Dry periods and the uncertainty in the climate cycle.

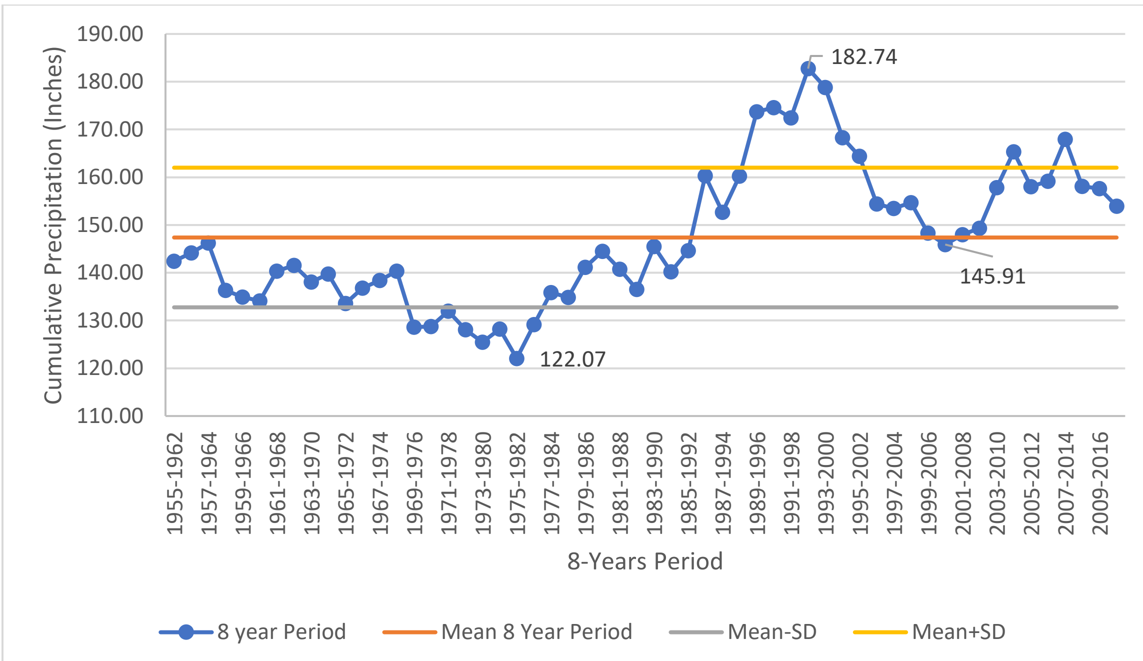

Figure 4-8 Plot of 8-Year Precipitation Period for Eureka, SD

The period 1992 to 1999 has the maximum precipitation of 182.74 inches making that a ‘Wet period’. Similarly, the minimum precipitation of 122.07 inches for the period 1975 to 1982 makes that a ‘Dry period’.

The average/mean of total annual 8-year periods was calculated to be 147.38 inches. The period of 2001 to 2008 was measured to be the mean period which has the 8-year period precipitation of 147.96 inches. The standard deviation for the cumulative 8-

year precipitation was 14.61 inches. The annual 8-year precipitation for the 'Moderately Wet' and 'Moderately Dry' periods were 162.0 inches and 132.76 inches.

Table 4-7 Identified Climate Periods Based on 8-Year Precipitation Amount for Ipswich, SD

	Total Precipitation (Inches)	**8-year Period**
Wet Period	182.74	1992-1999
Moderately Wet	164.41	1995-2002
Mean	147.96	2001-2008
Moderately Dry	133.56	1965-1972
Dry	122.07	1975-1982
Standard Deviation	14.61	
Skewness	0.53	

CHAPTER-5: DISCUSSION

5.1: Introduction

Climate results for Aberdeen, Ipswich and Eureka were compared for several factors. The following section details those comparison.

5.2: Comparative Annual Precipitation

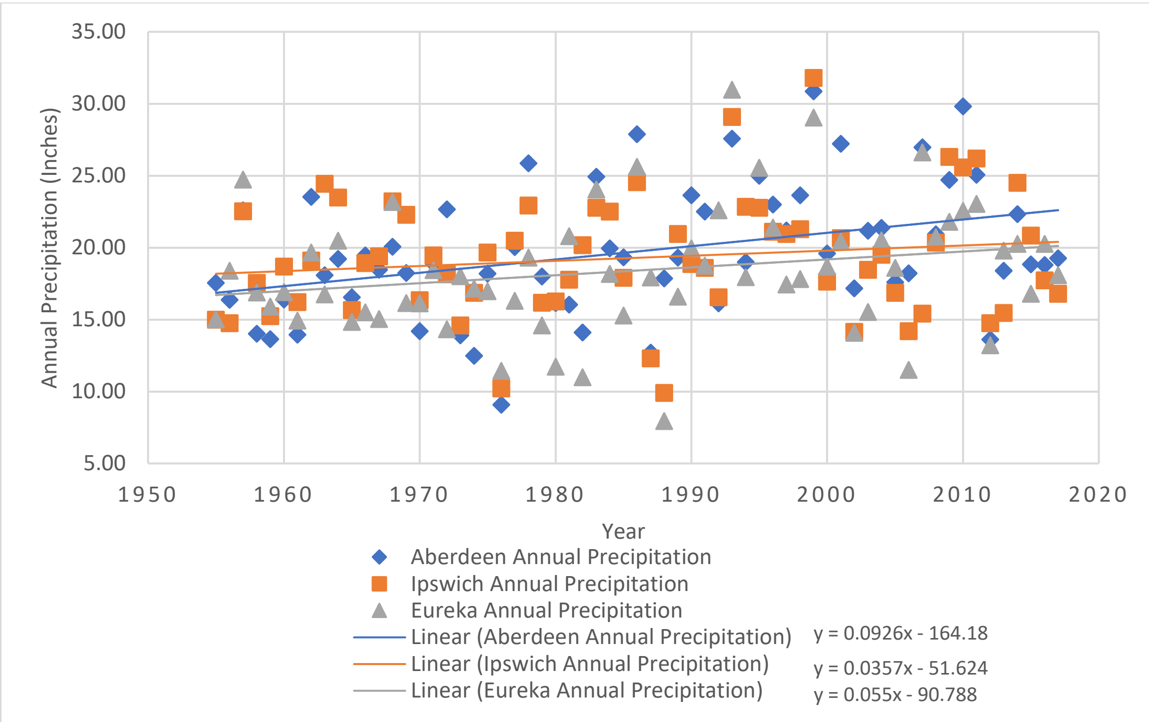

Figure 5-1 Combined Plot of Annual Precipitation with Linear Trends for Aberdeen, Ipswich and Eureka, SD.

From the Figure 5.1, the trend lines of annual precipitation for the last 63 water years (1955-2017) has an increment. Aberdeen shows the highest increment in the trend with a slope value of 0.0926 inches per year which shows that in the past few decades the amount of precipitation was greater than occurred in the past. Similarly, though the precipitation trends of Ipswich and Eureka were lower compared to Aberdeen. Ipswich and

Eureka have a slight increment in the trend which follows the similar pattern in which Ipswich has the least slope of 0.0357 inches per year.

And, the precipitation growth rates were calculated for each station and found to be 20.33% for Aberdeen, 16.38% for Ipswich and 8.10% for Eureka. According to Karl and Knight (1998), precipitation has increased by approximately 10% over the continental zones in the USA which supports the precipitation growth rates for the study areas.

From the Figure 5.1 for Aberdeen, Ipswich and Eureka there might be a possibility that the amount of precipitation in coming decades could increase following the precipitation patterns found during this study. Along with the precipitation patterns, the flooding patterns in the future could also increase. This research would indicate the necessity of updated plans and regulations for the study area if they were not updated in recent years.

5.3: Combined Annual 8-Year Periods

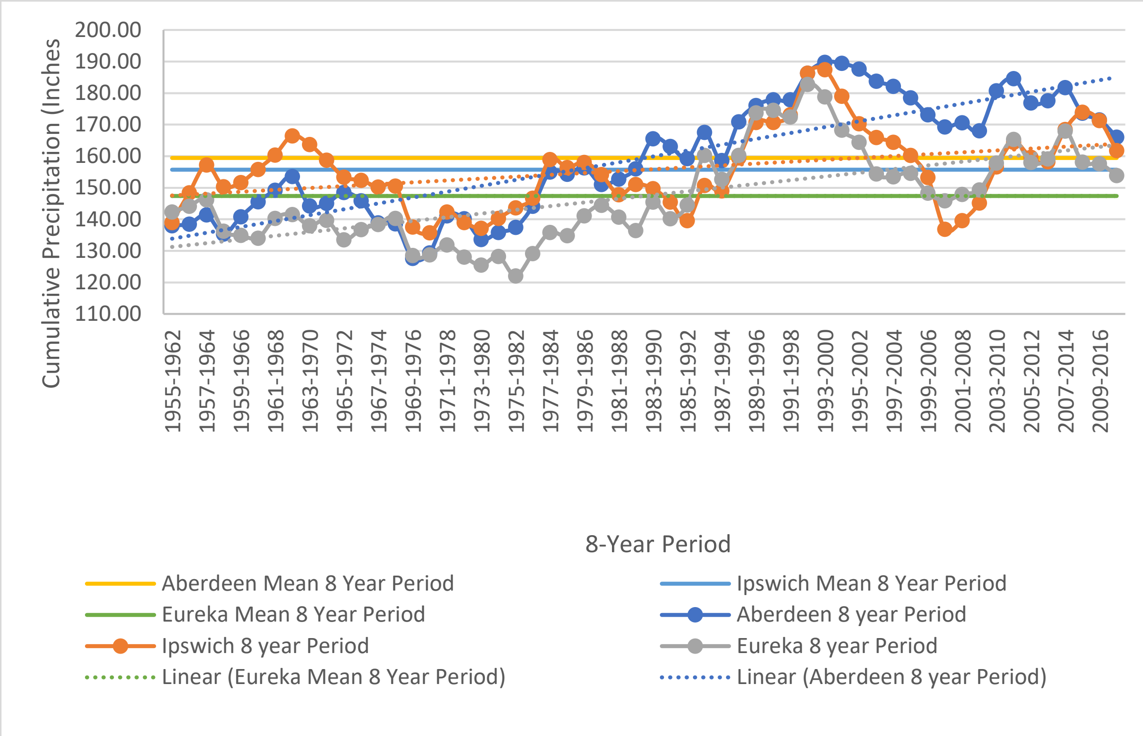

Figure 5-2 Combined Plot of 8-Year Periods Precipitation with Linear Trends for Aberdeen, Ipswich and Eureka, SD

Figure 5.2 shows the plot of combined annual 8-Year periods for the selected 63 water years for Aberdeen, Ipswich and Eureka. Also, Table 5.1 shows the climate situations of 8-Year periods for different stations. The climate situations were divided into five categories ‘Wet’, ‘Moderately Wet’, ‘Mean’, ‘Moderately Dry’ and ‘Dry’. According to the statistics performed for the study. The occurrence of wet periods for Aberdeen, Ipswich and Eureka were close to each other with different maximum ranges in precipitation. The 8-Year period for the wettest climate for Aberdeen and Ipswich was 1993-2000 and with a slight variation, Eureka had the wettest 8-Year period on 1992-1999. So, it could be concluded that the wet period for the three stations was the same. Similarly, the dry periods were statistically analyzed for the three stations. The dry 8-Year periods were varied from the 70s and early 80s. By looking at the plot the overlapping of the data indicates that the 1990's were the wettest periods from the last 63 water years.

Table 5-1 8-Year Periods for Each Climate Situation

	Aberdeen	Ipswich	Eureka
Wet	1993-2000	1993-2000	1992-1999
Moderately Wet	2006-2013	2007-2014	1995-2002
Mean	1985-1992	1960-1967	2001-2008
Moderately Dry	1957-1964	1975-1982	1965-1972
Dry	1969-1976	1970-1977	1975-1982

Whereas, the mean annual 8-Year periods for Aberdeen, Ipswich and Eureka were also included in Figure 5.1. The yellow color line in the plot indicates the mean annual 8-Year period of Aberdeen. The plot available above the yellow was considered to moderately wet and wet periods and the scatter points below the yellow line was moderately dry and dry periods for Aberdeen, SD.

Similarly, for Ipswich, SD the blue line represents the mean annual 8-Year period and the green line indicates the mean annual 8-Year for Eureka, SD.

Table 5-2 Mean Annual 8-Year Period Precipitation for Aberdeen, Ipswich and Eureka.

Stations	Mean Annual 8-Year Period	Total 8-Year Period Precipitation (in)
Aberdeen	1985-1992	159.32
Ipswich	1960-1967	155.88
Eureka	2001-2008	147.96

Table 5.2 shows the precipitation data for Mean Annual 8-Year period precipitation data for the selected three stations Aberdeen, Ipswich and Eureka, SD, and shows the different time periods of precipitation. The mean annual precipitation for 8-Year period for Aberdeen had the highest precipitation records followed by Ipswich and Eureka. Whereas, the mean 8-year period had different periods, unlike the Maximum precipitation records. As explained in section 3.2 the study areas for this research were shown as located in Humid Continental 'B' in the hydrologic subregions. From the Table 5.2 it could be clearly seen that the precipitation increased from western station to the eastern stations, i.e., Eureka followed by Ipswich and Aberdeen.

5.4: Mean Monthly Precipitation for Aberdeen, Ipswich and Eureka, SD

Mean monthly precipitation was calculated by taking the average of each individual month in a year from October through September as discussed in section 3.2.1. Figure 5.3 and Table 5.1 clearly explains that the monthly mean precipitation for Aberdeen, Ipswich and Eureka, SD was very much similar to the annual 8-Year period precipitation. Making Aberdeen with the highest average precipitation followed by Ipswich and Eureka.

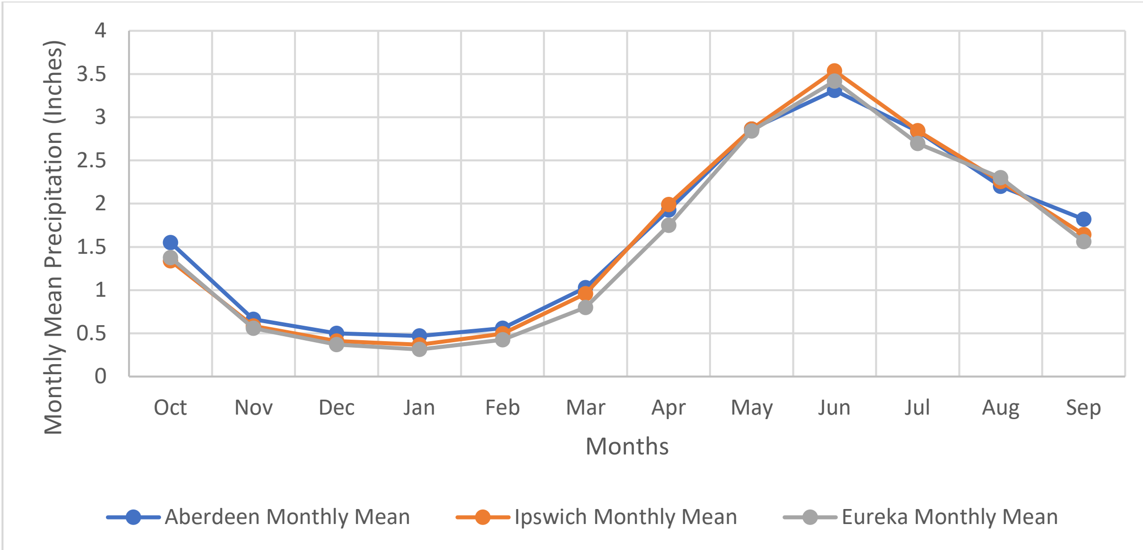

Figure 5-3 Plot for Monthly Precipitation for Aberdeen, Ipswich and Eureka, SD

Figure 5.3 shows that the maximum precipitation in water year occurred in June and minimum precipitation occurred in January. Also, if the results are discussed in terms of seasons. In general, the total amount of precipitation decides the year as the Wet or Dry year. For further analysis, the annual precipitation was divided into four climate seasons.

From the previous studies on the seasonal variation of precipitation four seasons were classified from the annual precipitation. They are; fall season (September, October and November), winter season (December, January and February), spring season (March, April and May) and summer season (June, July and August). Statistical analyses were performed to calculate mathematical functions. (Basnet, 2011).

Table 5-3 Statistical Results for Monthly Mean Precipitation for Aberdeen, Ipswich and Eureka, SD

Season	Months	Aberdeen Monthly Mean (in)	Ipswich Monthly Mean (in)	Eureka Monthly Mean (In)
Fall	Sep	1.82	1.64	1.56
	Oct	1.55	1.34	1.38
	Nov	0.66	0.59	0.56
Winter	Dec	0.50	0.41	0.37
	Jan	0.47	0.37	0.31
	Feb	0.56	0.50	0.42
Spring	Mar	1.03	0.96	0.80
	Apr	1.93	1.99	1.75
	May	2.86	2.86	2.84
Summer	Jun	3.31	3.54	3.42
	Jul	2.84	2.84	2.70
	Aug	2.20	2.26	2.30
	Total Precipitation	19.73	19.29	18.41

Table 5.3 shows the statistical results for monthly precipitation for a period of 63 water years (1955 to 2017) for the stations Aberdeen, Ipswich and Eureka. The annual precipitation was further classified into four seasons as stated previously. From Table 5.3 the highest mean precipitation for all the three stations had a common month of June.

Ipswich had the highest monthly mean precipitation. Also, looking at the statistics, January had the least mean monthly precipitation with Eureka having the lowest mean monthly precipitation among the three stations. In terms of seasons, summer shows the maximum precipitation among the four seasons. The colors yellow and green represents the maximum precipitation season i.e., summer whereas, the green row specifically highlights the individual month of June which has the highest precipitation. Similarly, the observed season with least mean monthly precipitation was winter. The highlighted rows with the colors blue and red represent the driest season whereas, red row highlights the individual month with the lowest mean precipitation.

So, from Table 5.1 and Figure 5.3 the seasons with the highest to lowest monthly mean precipitations were summer followed by spring, fall and winter. According to Amatya (2011) and Basnet (2011), the seasons followed the same sequence as this study does. Also, this research is further extended to investigate the exact months for the wettest and driest period of precipitation, specifically to identify the months with the most variability.

Figure 5.4 and Table 5.4 shows that the standard deviations for the monthly precipitation follow the same pattern as the mean monthly precipitation. The more the standard deviation value is, the more it fluctuates from its average precipitation. So, Table 5.4 shows January with the lowest standard deviation value for the three stations. June is the wettest month with the highest standard deviation. These observations also support the previous studies of Amatya (2011) and Banset (2011) which showed that 'wet' periods had more precipitation in the months with the highest standard deviation.

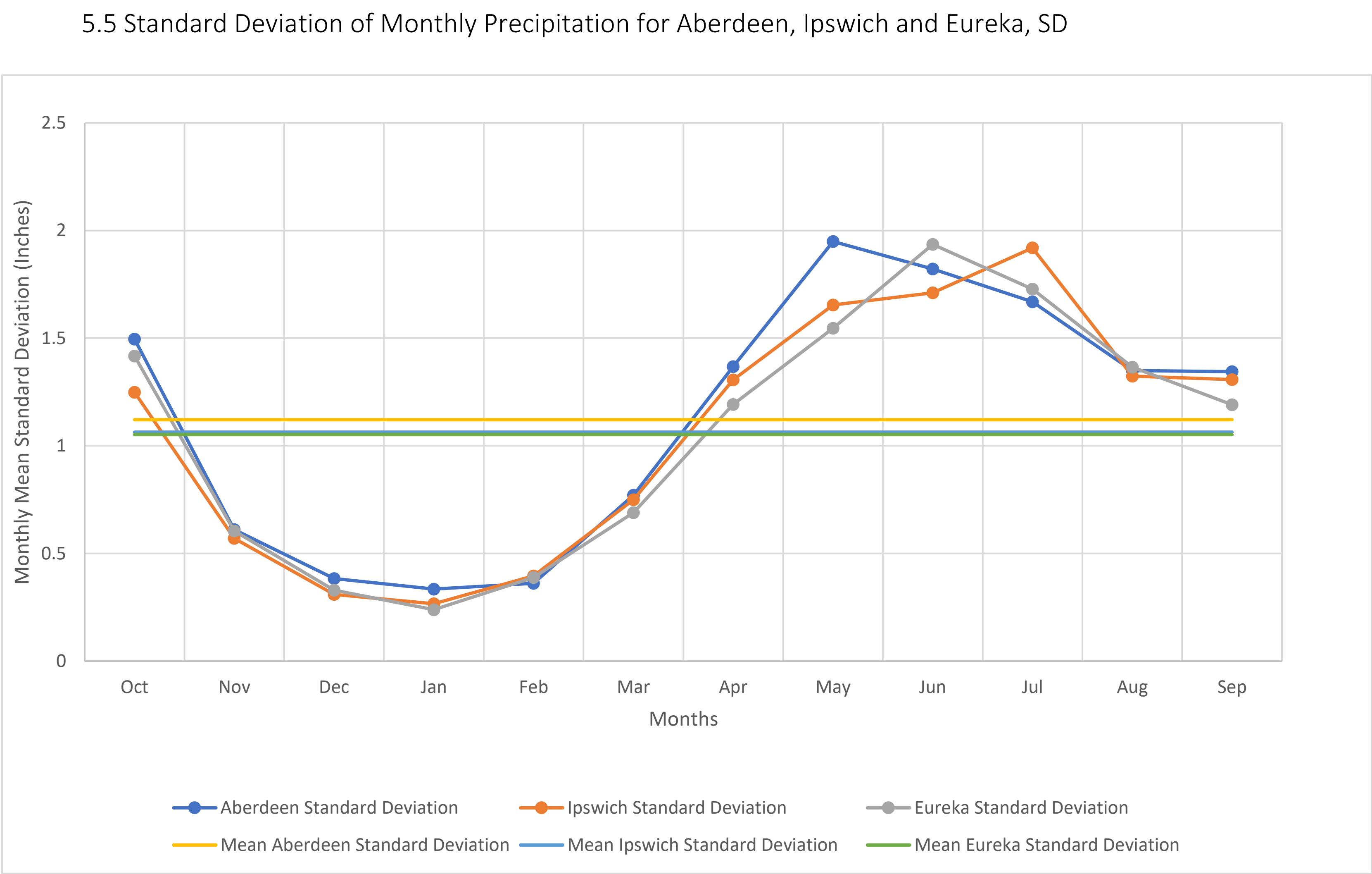

Figure 5-4 Standard Deviation of Monthly Precipitation for Aberdeen, Ipswich and Eureka, SD

Table 5-4 Standard Deviations for Monthly precipitations for Aberdeen, Ipswich and Eureka

Season	Months	Aberdeen Standard Deviation	Ipswich Standard Deviation	Eureka Standard Deviation
Fall	Sep	1.34	1.30	1.19
	Oct	1.49	1.24	1.41
	Nov	0.61	0.57	0.60
Winter	Dec	0.38	0.31	0.32
	Jan	0.33	0.26	0.23
	Feb	0.36	0.39	0.38
Spring	Mar	0.77	0.74	0.68
	Apr	1.36	1.30	1.19
	May	1.94	1.65	1.54
Summer	Jun	1.82	1.71	1.93
	Jul	1.66	1.91	1.72
	Aug	1.34	1.32	1.36
	Mean of Standard Deviation	1.12	1.06	1.05

CHAPTER – 6: CONCLUSION

Precipitation plays an important role in the hydrologic cycle which impacts in environmental changes. A period with high precipitation can cause floods and property loss and similarly, a period with low precipitation can cause severe droughts. So, the study of precipitation is critical in the field of water resources management. Based on the previous studies, climatic periods were developed for Aberdeen, Ipswich and Eureka, South Dakota.

The monthly historical precipitation for the last 63 water years (1955 to 2017) was collected from High Plain Regional climate center (HPRCC) for Aberdeen, Ipswich and Eureka, South Dakota and analyzed using a statistical approach. Based on annual accumulated 8-Year periods different climate periods were developed.

For the station Aberdeen, the period 1993 to 2000 has the maximum precipitation of 189.78 inches making that a Wet period and the minimum precipitation of 127.63 inches for the period 1969 to 1976 makes that a Dry period. Similarly, for Ipswich, the maximum precipitation for the annual 8-Year period was recorded to be on the period 1993 to 2000 with 187.43 inches of precipitation and the minimum precipitation was 135.74 inches for the period 1970 to 1977. For the station Eureka the maximum precipitation was recorded for the period 1992 to 1999 with 182.74 inches and the minimum precipitation with 122.07 inches for the period 1975 to 1982.

The comparison made with the previous studies had ended up with positive results. The previous studies conclude that the wettest season for the north-eastern South Dakota was summer season followed by spring, fall and winter. This research is further extended to investigate the exact months for the wettest and driest period of precipitation. The observations made from the mean monthly precipitation concludes the wettest month to be

June and the driest month to be January. In general, people assume spring to be the wettest season, but this study clarifies that the maximum precipitation in a year occurs in the summer season. This study helps in identifying and tracking the precipitation for every particular month for the stations Aberdeen, Ipswich and Eureka and can be used by water resource departments and the planners for forecasting the possible future precipitations.

CHAPTER – 7: SUGGESTIONS FOR FUTURE RESEARCH

The climatic periods were developed by using the monthly historical precipitation data of Aberdeen, Ipswich and Eureka, South Dakota from HPRCC.

- A similar kind of method can be used to estimate the climate periods for other study areas.
- Climate periods can be developed by using the other different climatic factors like evaporation, humidity, temperature, wind speed and stream flow.
- By taking the average periods of the different cities based on the different climatic factors, an average period can be developed for the specific region.

CHAPTER – 8 REFERENCES

Amatya, S., 2011. Development of Climate Scenarios Using Climate Data from Specific Stations in Eastern South Dakota. Master's Thesis, South Dakota State University.

Basnet, N., 2011. Development of Climatic Scenarios Using Precipitation Data for Aberdeen, South Dakota. Master's Thesis, South Dakota State University.

Brutsaert, W., & Parlange, M. B., 1998. Hydrologic cycle explains the evaporation paradox. Nature, 396(6706), 30.

Climatemps.com, 2018. Average Temperatures in Eureka, South Dakota; Available online at http://www.eureka-sd.climatemps.com/temperatures.php. Accessed on July 12, 2018.

De Silva, R.P., Dayawansa, N.D.K., & Ratnasiri, M.D., 2007. A Comparison of Methods used in Estimating Missing Rainfall Data. The Journal of Agricultural Sciences, Vol.3, No.2, 101-108 p.

High Plains Regional Climate Center., 2018. Precipitation Data; Available online at http://climod.unl.edu/. Accessed on April 21, 2018.

Hogan, E. P., Fouberg, E.H., & Gab, O.E., 2001. The geography of South Dakota. Center for Western Studies.

Karl, T. R., & Knight, R. W., 1998. Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States. Bulletin of the American Meteorological Society, Vol.27, No.2, 231-242 p.

McCuen, H.R., 2005. Hydrologic Analysis and Design, Third Edition, Pearson Prentice Hall, New Jersey.

National Geographic Partners, 2018. Geography of South Dakota; Available online at https://kids.nationalgeographic.com/explore/states/south-dakota/#south-dakota-mount-rushmore.jpg, Accessed on July 11, 2018.

Niehus, C. A., Vecchia, A. V. & Thompson, R. F. 1999: Lake-Level Frequency Analysis for the Waubay Lakes Chain, Northeastern South Dakota. U.S. Geological Survey Water-Resources Investigations Report 99-4122, 166 p.

Puetz, J. A., 2013. Analysis of Historical Cooperative Observation Program (COOP) Climate Data Through Trend and Correlation Determination for Selected South Dakota Sites and Comparisons of COOP Sensors with the Automated Weather Data Network (AWDN) Remote Sensors. Electronic Theses and Dissertations. 1375. https://openprairie.sdstate.edu/etd/1375

Robson, S.G., & Stewart, M., 1990, GeoHydrologic Evaluation of the Upper Part of the Upper part of the Mesaverde Group Northwestern Colorado. U.S. Geological Survey, Water-Resources Investigations Report 90-4020, 25.

Sando, S.K., 1998. Techniques for Estimating Peak-Flow Magnitude and Frequency Relations for South Dakota Streams. Water-Resources Investigation Report, 98-4055.

Singh, V. P., 1994. Elementary Hydrology. Prentice Hall of India: New Delhi.

Tabios, G. Q., & Salas, J. D., 1985. A comparative analysis of techniques for spatial interpolation of precipitation. Water Resource Bull. 21(3), 365-380.

Teegavarapu, R. S., & Chandramouli, V., 2005. Improved weighting methods, deterministic and stochastic data-driven models for estimation of missing precipitation records. Journal of Hydrology, 312(1-4), 191-206 p.

United States Geological Survey, 2018. Water Resources of The United States; Available online at https://water.usgs.gov/nwc/explain_data.html. Accessed on July 9, 2018.

Van Liew, M. W., Schneider, J. M., & Garbrecht, J. D., 2003. Streamflow response of an agricultural watershed to seasonal changes in precipitation. In Proceedings of the 1st interagency conference on research in the watersheds (ICRW), 27-30 p.

Weather spark, 2018. Average weather in Ipswich, South Dakota; Available online at https://weatherspark.com/y/6301/Average-Weather-in-Ipswich-South-Dakota-United-States-Year-Round. Accessed on July 12, 2018.

Appendix: A: SEASONAL STATISTICS

Table A1: Total Monthly Annual Precipitation (inches) Data of Aberdeen, SD

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1955	0.98	0.40	0.33	0.30	1.39	0.16	1.19	2.81	2.98	3.69	2.32	1.00	**17.55**
1956	0.01	0.30	0.87	1.22	0.58	0.94	0.74	2.01	3.06	2.95	2.87	0.82	**16.37**
1957	1.52	1.30	0.40	0.23	0.52	0.32	3.91	4.95	4.05	2.50	1.29	1.60	**22.59**
1958	2.26	0.52	0.53	0.23	1.29	0.52	2.04	1.46	2.54	1.61	0.93	0.08	**14.01**
1959	0.27	1.17	0.29	0.22	0.85	0.15	0.42	3.40	0.50	1.74	1.48	3.15	**13.64**
1960	1.54	0.88	0.73	1.01	0.52	0.79	1.27	2.18	1.59	0.97	4.21	0.69	**16.38**
1961	0.56	0.49	0.68	0.01	0.39	0.15	1.12	3.61	1.62	2.08	1.15	2.09	**13.95**
1962	2.24	0.02	0.59	0.50	1.41	0.87	1.08	4.74	5.74	3.14	0.75	2.44	**23.52**
1963	1.06	0.46	0.18	0.46	0.30	0.33	1.15	3.92	2.10	3.93	2.55	1.64	**18.08**
1964	0.50	0.30	0.23	0.36	0.31	0.89	3.19	2.68	2.69	3.47	4.04	0.56	**19.22**
1965	0.19	0.24	0.39	0.15	0.09	0.71	2.93	3.01	2.11	2.22	1.26	3.25	**16.55**
1966	0.37	0.65	0.38	0.16	0.52	2.34	0.92	0.91	4.53	4.66	2.77	1.25	**19.46**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1967	1.86	0.59	0.03	0.50	0.42	0.09	3.38	0.58	5.13	1.06	1.40	3.41	**18.45**
1968	0.65	0.15	0.47	0.15	0.10	2.74	4.81	1.66	3.24	2.20	1.07	2.82	**20.06**
1969	0.60	0.83	0.94	1.11	1.54	0.36	0.92	3.38	3.37	4.07	0.74	0.38	**18.24**
1970	0.57	0.14	0.71	0.21	0.17	1.33	3.42	1.49	2.11	2.04	0.33	1.67	**14.19**
1971	1.24	1.39	0.19	0.35	0.41	0.04	1.86	1.70	4.29	3.75	1.39	2.30	**18.91**
1972	2.80	1.39	0.47	0.39	0.39	1.02	1.05	4.86	1.80	7.71	0.52	0.25	**22.65**
1973	1.26	0.26	0.88	0.21	0.15	1.29	1.02	1.00	1.37	1.77	1.17	3.51	**13.89**
1974	1.28	0.66	0.44	0.05	0.26	0.74	2.10	3.77	0.37	1.72	0.94	0.15	**12.48**
1975	0.54	0.12	0.05	0.82	0.29	2.71	2.60	2.26	5.28	0.30	1.50	1.73	**18.20**
1976	1.23	0.29	0.30	0.81	0.52	0.70	1.27	0.52	1.41	0.50	0.66	0.86	**9.07**
1977	0.32	0.01	0.30	0.34	0.91	3.45	0.90	2.82	1.99	2.16	2.48	4.36	**20.04**
1978	1.24	2.36	0.83	0.15	0.23	0.46	2.25	4.23	7.30	2.17	4.04	0.60	**25.86**
1979	0.08	0.77	0.11	1.01	0.73	1.60	2.93	1.93	4.99	2.56	1.24	0.05	**18.00**
1980	1.18	0.02	0.14	0.51	0.44	0.88	1.15	1.64	2.53	0.80	5.93	0.92	**16.14**
1981	1.44	0.06	0.14	0.12	0.20	2.00	0.12	1.60	2.10	3.97	2.91	1.38	**16.04**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1982	1.74	0.82	0.26	0.53	0.18	2.04	0.54	2.80	2.14	1.66	0.44	0.95	**14.10**
1983	5.14	0.59	0.09	0.16	0.26	2.65	0.69	1.66	3.47	6.46	2.21	1.55	**24.93**
1984	0.81	0.60	0.55	0.47	0.70	1.94	2.39	1.13	5.65	2.64	2.23	0.84	**19.95**
1985	2.93	0.06	0.61	0.23	0.08	1.82	0.63	3.41	1.76	2.38	2.71	2.71	**19.33**
1986	0.87	1.60	0.57	0.43	0.71	0.58	7.88	3.32	2.48	3.78	2.85	2.82	**27.89**
1987	0.19	0.77	0.11	0.09	1.12	1.91	0.41	2.01	0.77	2.13	1.87	1.33	**12.71**
1988	0.20	0.79	0.09	0.35	0.31	0.37	0.13	3.43	0.93	3.14	2.80	5.31	**17.85**
1989	0.11	0.73	1.37	0.52	0.37	1.46	3.42	1.20	2.05	2.00	3.83	2.23	**19.29**
1990	0.58	0.74	0.15	0.13	0.39	0.81	1.87	1.41	7.72	1.98	4.85	3.01	**23.64**
1991	0.44	0.11	0.37	0.11	0.70	0.77	3.70	7.36	4.76	1.32	2.28	0.57	**22.49**
1992	1.06	0.32	0.13	0.66	0.47	0.54	0.40	0.78	5.61	2.97	1.55	1.63	**16.12**
1993	0.83	1.19	0.20	0.61	0.49	0.42	1.51	3.11	6.20	7.37	4.42	1.21	**27.56**
1994	0.35	1.88	0.56	0.80	0.42	0.43	2.28	0.30	1.10	5.37	3.87	1.63	**18.99**
1995	3.36	0.77	0.38	0.62	0.50	2.34	2.26	5.98	1.34	3.57	2.36	1.50	**24.98**
1996	3.16	0.20	0.47	1.32	0.78	0.87	0.15	4.46	4.12	1.91	0.24	5.32	**23.00**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1997	3.55	1.40	0.87	1.34	0.88	0.79	2.01	1.72	2.65	1.41	3.75	0.82	**21.19**
1998	3.37	0.46	0.18	0.63	0.75	1.54	1.81	4.29	6.47	1.12	2.95	0.06	**23.63**
1999	7.29	1.41	0.18	0.62	0.21	0.92	1.76	2.97	5.23	2.80	3.19	4.27	**30.85**
2000	0.15	0.06	0.15	0.27	0.69	1.21	2.47	2.93	4.94	4.51	1.69	0.51	**19.58**
2001	4.75	2.87	0.38	0.28	1.01	0.30	3.43	2.67	3.31	4.81	0.79	2.61	**27.21**
2002	1.96	1.39	0.06	0.27	0.03	0.56	1.15	1.82	1.22	3.96	3.82	0.93	**17.17**
2003	1.40	0.09	0.30	0.24	0.45	0.57	2.01	4.33	6.94	1.98	1.59	1.26	**21.16**
2004	0.88	0.70	0.33	0.56	0.72	1.27	0.62	5.10	3.68	3.02	0.96	3.53	**21.37**
2005	1.75	0.23	0.33	0.41	0.63	0.16	0.35	2.64	6.21	0.80	2.90	1.19	**17.60**
2006	0.95	1.35	1.11	0.33	0.20	0.65	2.41	2.16	3.21	0.71	2.47	2.67	**18.22**
2007	0.13	0.12	0.88	0.09	1.16	1.88	3.42	12.23	2.43	0.79	2.19	1.64	**26.96**
2008	1.48	0.02	0.90	0.07	0.24	1.76	0.81	1.32	3.21	6.26	1.24	3.61	**20.92**
2009	4.75	0.30	0.88	0.68	0.87	1.41	1.76	0.47	3.87	2.47	2.82	4.41	**24.69**
2010	4.33	0.22	0.96	0.91	0.81	1.24	3.15	4.46	5.40	3.24	1.01	4.08	**29.81**
2011	1.02	0.12	1.77	1.17	1.05	1.19	2.98	2.93	4.69	6.63	0.87	0.64	**25.06**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
2012	0.80	0.03	0.33	0.70	0.87	0.38	3.65	1.11	1.27	2.70	1.76	0.01	**13.61**
2013	1.06	0.38	0.75	0.78	1.06	0.24	2.12	4.32	2.20	2.70	0.34	2.44	**18.39**
2014	4.72	0.10	0.88	0.28	0.16	0.77	2.04	2.18	3.31	0.70	6.19	1.00	**22.33**
2015	0.26	0.64	0.25	0.68	0.37	0.23	0.55	6.39	2.10	4.06	2.94	0.37	**18.84**
2016	1.64	1.21	0.64	0.14	0.55	0.46	3.66	2.13	1.41	3.69	2.02	1.23	**18.78**
2017	1.81	1.71	1.78	0.51	0.17	0.67	1.38	0.65	3.94	2.05	2.69	1.89	**19.25**

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.55	0.66	0.50	0.47	0.56	1.03	1.93	2.86	3.31	2.84	2.20	1.82
Minimum Precipitation	0.01	0.01	0.03	0.01	0.03	0.04	0.12	0.3	0.37	0.3	0.24	0.01
Year	1956	1977	1967	1961	2002	1971	1981	1994	1974	1975	1996	2012
Maximum Precipitation	7.29	2.87	1.78	1.34	1.54	3.45	7.88	12.2	7.72	7.71	6.19	5.32
Year	1999	2001	2017	1997	1969	1977	1986	2007	1990	1972	2014	1996
Standard Deviation	1.5	0.61	0.38	0.335	0.361	0.77	1.37	1.95	1.82	1.67	1.35	1.34
Skewness	1.7	1.34	1.39	0.929	0.818	1.06	1.48	2.06	0.54	1.02	0.84	0.82

Table A2: Total Monthly Annual Precipitation (inches) Data of Ipswich, SD

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1955	1.04	0.31	0.34	0.17	1.03	0.16	0.85	1.76	2.58	2.62	3.02	1.12	**15.00**
1956	0.07	0.21	0.44	0.57	0.33	0.54	0.99	2.57	3.93	2.04	2.21	0.84	**14.74**
1957	1.42	1.90	0.23	0.14	0.29	0.19	2.79	5.54	3.43	3.00	2.24	1.35	**22.52**
1958	2.08	0.73	0.37	0.34	1.66	0.41	2.13	2.51	3.20	2.39	1.61	0.12	**17.55**
1959	0.36	0.80	0.22	0.26	0.43	0.11	0.48	3.40	3.55	2.14	1.12	2.36	**15.23**
1960	0.77	0.54	0.41	0.69	0.18	0.86	1.03	3.57	5.49	1.09	3.22	0.82	**18.67**
1961	0.55	0.57	0.65	0.09	0.34	0.69	1.06	4.86	2.49	2.29	0.46	2.16	**16.21**
1962	1.44	0.06	0.38	0.40	0.75	0.93	0.89	3.92	4.10	3.22	1.21	1.81	**19.11**
1963	0.58	0.29	0.16	0.24	0.29	0.54	2.71	4.30	4.65	4.90	4.23	1.54	**24.43**
1964	0.56	0.21	0.35	0.18	0.11	0.55	4.16	3.81	5.33	4.68	3.13	0.41	**23.48**
1965	0.01	0.36	0.29	0.16	0.16	0.74	2.78	4.20	1.82	1.96	0.50	2.68	**15.66**
1966	1.91	0.35	0.84	0.15	0.37	2.34	1.71	0.91	2.21	2.95	4.14	1.04	**18.92**
1967	1.91	0.56	0.28	0.34	0.62	0.04	5.88	0.79	5.67	1.02	1.22	1.07	**19.40**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1968	1.09	0.15	0.76	0.34	0.04	1.25	4.88	2.40	4.49	3.37	1.34	3.10	**23.21**
1969	0.38	1.04	0.94	1.02	1.91	0.37	2.15	2.51	4.20	4.79	2.61	0.36	**22.28**
1970	1.01	0.12	0.85	0.38	0.14	0.59	2.64	2.41	3.79	1.75	0.73	1.94	**16.35**
1971	0.93	1.48	0.21	0.67	0.47	0.11	2.77	2.41	4.49	2.36	1.14	2.41	**19.45**
1972	3.45	1.25	0.60	0.33	0.54	1.02	1.29	5.27	2.04	2.13	0.18	0.04	**18.14**
1973	1.31	0.28	0.83	0.44	0.08	2.19	2.02	1.16	1.23	1.07	0.56	3.43	**14.60**
1974	1.36	0.56	0.61	0.03	0.29	0.43	3.21	5.80	0.51	2.86	0.93	0.26	**16.85**
1975	0.48	0.20	0.02	0.96	0.16	2.42	4.20	2.85	5.29	0.34	1.53	1.21	**19.66**
1976	0.65	0.22	0.37	0.74	0.54	0.65	1.35	0.68	2.04	0.80	1.53	0.65	**10.22**
1977	0.67	0.22	0.19	0.39	0.66	3.67	0.97	3.26	1.83	3.36	3.08	2.17	**20.47**
1978	1.19	2.32	0.86	0.12	0.30	0.45	2.53	3.20	6.73	1.99	2.65	0.59	**22.93**
1979	0.09	0.51	0.09	0.87	0.50	1.17	2.25	1.32	3.42	5.03	0.85	0.06	**16.16**
1980	1.24	0.04	0.04	0.49	0.51	0.92	1.37	1.45	1.99	1.24	6.04	0.93	**16.26**
1981	2.46	0.00	0.07	0.07	0.09	2.46	0.24	2.28	3.18	3.92	1.59	1.40	**17.76**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1982	2.30	2.11	0.34	0.76	0.20	1.49	1.12	3.37	3.32	2.88	1.40	0.88	**20.17**
1983	4.41	0.71	0.03	0.13	0.16	1.86	1.24	1.48	3.64	4.63	3.03	1.44	**22.76**
1984	0.82	0.66	0.34	0.67	0.7	2.5	2.94	1.78	7.05	1.81	2.34	0.96	**22.51**
1985	0.93	0.03	0.38	0.08	0.03	1.36	1.14	3.71	2.07	1.47	3.57	3.14	**17.91**
1986	0.86	1.22	0.27	0.33	0.70	0.39	6.10	3.10	3.85	3.14	2.53	2.06	**24.55**
1987	0.34	0.45	0.02	0.14	1.06	1.61	0.3	1.41	0.96	3.70	1.85	0.49	**12.30**
1988	0.32	0.18	0.05	0.06	0.36	0.07	0.19	1.67	1.19	1.63	1.68	2.50	**9.90**
1989	0.27	1.05	0.44	0.29	0.27	1.79	2.70	0.57	5.61	1.88	3.33	2.74	**20.94**
1990	0.58	0.62	0.10	0.11	0.18	0.82	1.98	1.92	6.71	1.27	2.02	2.54	**18.85**
1991	0.58	0.05	0.30	0.04	0.51	0.70	2.85	7.22	4.30	0.40	1.14	0.49	**18.58**
1992	1.04	0.29	0.04	0.70	0.56	0.49	0.31	1.52	5.31	3.59	1.74	0.95	**16.54**
1993	0.53	1.35	0.13	0.57	0.22	0.25	1.14	2.08	4.71	###	4.65	1.41	**29.07**
1994	0.00	1.42	0.91	0.50	0.60	0.54	2.57	0.58	1.11	8.67	3.93	2.01	**22.84**
1995	2.64	0.44	0.58	0.36	0.44	2.01	3.01	5.45	1.55	2.84	2.36	1.09	**22.77**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1996	3.38	0.18	0.21	0.43	0.39	1.11	0.35	3.50	2.62	2.30	0.19	6.43	**21.09**
1997	2.42	1.56	0.69	1.01	0.88	0.70	2.27	2.11	4.24	2.55	2.03	0.49	**20.95**
1998	1.91	0.43	0.06	0.33	0.94	1.10	1.12	2.91	4.34	4.21	3.82	0.10	**21.27**
1999	5.46	1.13	0.05	0.48	0.18	1.34	2.39	4.57	5.13	3.66	2.01	5.40	**31.80**
2000	0.31	0.00	0.12	0.19	0.74	1.75	1.62	2.47	3.02	4.25	2.74	0.43	**17.64**
2001	2.86	2.07	0.37	0.45	0.96	0.09	2.71	1.97	2.69	3.53	1.33	1.62	**20.65**
2002	1.33	0.47	0.04	0.04	0.08	0.80	1.02	1.08	0.76	3.14	4.67	0.72	**14.15**
2003	0.86	0.04	0.34	0.19	0.53	0.68	2.23	5.41	4.02	2.06	1.20	0.90	**18.46**
2004	0.73	0.32	0.18	0.51	0.21	1.84	0.67	3.62	2.89	3.61	1.54	3.39	**19.51**
2005	1.03	0.18	0.11	0.30	0.29	0.15	0.26	2.28	5.96	1.50	3.33	1.47	**16.86**
2006	0.65	0.86	0.85	0.15	0.05	0.83	1.58	0.55	2.02	1.21	2.26	3.18	**14.19**
2007	0.06	0.15	0.68	0.08	1.44	1.28	1.92	2.92	1.84	0.63	2.99	1.43	**15.42**
2008	1.17	0.00	0.66	0.05	0.22	1.31	1.73	1.56	4.59	4.81	1.31	2.94	**20.35**
2009	2.89	0.31	0.68	0.37	1.28	1.17	1.46	0.52	6.11	3.98	3.67	3.86	**26.30**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
2010	5.35	0.13	0.49	1.05	0.65	1.04	1.26	5.51	2.81	1.02	1.61	4.65	**25.57**
2011	1.34	0.13	0.98	0.38	0.62	1.48	2.85	2.92	6.30	6.19	1.73	1.28	**26.20**
2012	0.82	0.02	0.20	0.18	0.99	0.12	4.47	3.17	1.25	1.61	1.92	0.00	**14.75**
2013	0.50	0.31	0.63	0.48	0.97	0.26	1.97	3.80	1.94	2.09	0.58	1.93	**15.46**
2014	4.43	0.17	0.47	0.28	0.27	0.52	2.07	2.36	7.03	0.15	6.28	0.46	**24.49**
2015	0.40	0.89	0.44	0.33	0.29	0.19	0.28	8.19	3.20	2.91	2.79	0.92	**20.83**
2016	0.73	0.78	0.87	0.06	0.39	0.47	3.09	2.71	3.47	2.09	1.95	1.12	**17.73**
2017	1.10	0.88	1.44	0.54	0.2	0.50	1.23	1.22	1.47	2.39	3.52	2.30	**16.78**

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.34	0.59	0.41	0.37	0.50	0.96	1.99	2.86	3.54	2.84	2.26	1.64
Minimum Precipitation	0.00	0.00	0.02	0.03	0.03	0.04	0.19	0.52	0.51	0.15	0.18	0.00
Year	1994	1981 2008 2000	1975 1987	1974	1985	1967	1988	2009	1974	2014	1972	2012
Maximum Precipitation	5.46	2.32	1.44	1.05	1.91	3.67	6.10	8.19	7.05	12.03	6.28	6.43
Year	1999	1978	2017	2010	1969	1977	1986	2015	1984	1993	2014	1996
Standard Deviation	1.249	0.5706	0.31	0.27	0.4	0.75	1.31	1.65	1.71	1.92	1.32	1.31
Skewness	1.714	1.3652	0.83	0.9	1.48	1.21	1.08	0.93	0.27	2.23	0.88	1.4

Table A-3: Total Monthly Annual Precipitation (inches) Data of Eureka, SD

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1955	0.55	0.10	0.17	0.21	1.12	0.12	1.31	2.24	2.72	2.08	3.25	1.15	**15.02**
1956	0.16	0.32	0.31	0.81	0.12	1.21	0.50	3.26	2.96	3.93	4.30	0.51	**18.39**
1957	1.25	2.21	0.17	0.19	0.32	0.10	2.65	3.91	3.51	3.61	4.06	2.75	**24.73**
1958	1.56	0.55	0.29	0.69	0.82	0.22	1.36	2.46	3.90	3.15	1.31	0.57	**16.88**
1959	0.52	0.95	0.34	0.27	0.45	0.07	0.53	4.33	2.13	1.80	2.51	1.99	**15.89**
1960	0.79	0.42	0.10	0.19	0.32	0.28	0.86	3.71	1.94	1.71	5.13	1.46	**16.91**
1961	0.28	0.20	0.41	0.1	0.20	0.45	0.93	2.39	2.61	1.67	1.33	4.36	**14.93**
1962	0.16	0.08	0.27	0.47	0.73	0.21	0.38	3.61	3.66	6.18	1.14	2.76	**19.65**
1963	0.41	0.39	0.09	0.26	0.35	0.84	0.99	2.69	2.98	2.55	3.54	1.66	**16.75**
1964	0.72	0.14	0.17	0.04	0.15	0.43	2.37	2.95	9.59	2.37	0.80	0.74	**20.47**
1965	0.05	0.15	0.19	0.11	0.13	0.32	2.38	4.74	1.25	1.19	2.10	2.23	**14.84**
1966	0.66	0.17	0.66	0.08	0.20	2.21	1.54	0.83	2.11	2.98	3.37	0.69	**15.50**
1967	0.76	0.19	0.15	0.36	0.74	0.12	3.93	0.91	4.67	1.82	0.86	0.53	**15.04**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1968	1.50	0.24	0.50	0.12	0.09	2.68	3.62	3.11	5.88	1.49	1.79	2.15	**23.17**
1969	0.27	0.48	0.43	0.70	0.65	0.36	1.49	1.59	3.81	4.70	1.34	0.33	**16.15**
1970	0.73	0.05	0.57	0.34	0.13	0.32	2.03	2.89	3.95	2.51	0.68	1.92	**16.12**
1971	1.02	1.77	0.20	0.27	0.09	0.05	2.19	2.75	5.18	2.33	1.07	1.51	**18.43**
1972	2.85	0.47	0.52	0.32	0.31	0.79	1.11	4.25	1.94	1.18	0.48	0.11	**14.33**
1973	1.79	0.05	0.82	0.26	0.13	1.99	1.84	1.88	0.77	2.48	1.37	4.64	**18.02**
1974	2.83	0.67	0.48	0.12	0.50	0.91	2.67	3.03	0.47	1.93	3.46	0.08	**17.15**
1975	0.69	0.26	0.03	0.31	0.32	1.90	4.58	2.02	3.60	0.68	1.63	0.95	**16.97**
1976	0.24	0.35	0.54	0.74	0.58	0.63	1.77	0.46	3.14	0.64	1.99	0.35	**11.43**
1977	0.55	0.21	0.38	0.35	0.46	2.40	1.04	1.94	1.88	1.73	2.80	2.57	**16.31**
1978	0.99	2.35	0.48	0.08	0.24	0.27	1.85	3.09	5.04	1.68	2.80	0.43	**19.30**
1979	0.24	0.86	0.09	0.60	0.58	0.70	1.93	1.92	2.94	3.10	0.50	1.12	**14.58**
1980	0.87	0.05	0.10	0.17	0.22	0.43	0.35	0.64	1.85	2.71	3.62	0.71	**11.72**
1981	3.18	0.02	0.09	0.08	0.17	1.48	0.38	1.75	3.27	6.13	2.73	1.50	**20.78**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1982	0.94	0.90	0.29	0.38	0.15	0.87	0.84	3.44	1.31	0.86	0.24	0.76	**10.98**
1983	5.88	1.04	0.07	0.08	0.20	1.73	1.04	2.12	2.64	4.40	3.58	1.26	**24.04**
1984	2.23	0.42	0.38	0.30	0.28	1.33	3.02	1.43	6.12	1.43	0.55	0.67	**18.16**
1985	2.06	0.08	0.52	0.23	0.01	0.63	0.64	2.73	2.23	1.30	2.92	1.92	**15.27**
1986	1.11	1.04	0.50	0.30	0.38	0.95	5.30	5.43	1.42	3.04	3.06	3.09	**25.62**
1987	0.74	1.30	0.00	0.12	1.67	1.09	0.07	2.87	1.40	3.95	3.77	0.95	**17.93**
1988	0.42	0.32	0.22	0.22	0.31	0.15	0.18	1.49	1.14	0.63	1.64	1.22	**7.94**
1989	0.08	0.86	0.53	0.32	0.28	1.91	5.30	1.65	1.90	1.16	1.80	0.79	**16.58**
1990	0.45	0.94	0.06	0.26	0.14	0.67	1.90	0.80	5.08	2.94	4.65	2.06	**19.95**
1991	0.62	0.02	0.33	0.12	0.59	0.32	2.44	6.61	5.35	1.26	0.81	0.28	**18.75**
1992	1.34	0.35	0.01	0.59	0.29	0.45	0.61	2.20	4.76	5.33	4.86	1.80	**22.59**
1993	0.67	1.35	0.17	0.32	0.24	0.20	0.82	3.54	6.50	10.34	5.82	0.99	**30.96**
1994	0.24	1.35	1.02	0.30	0.37	0.42	1.86	1.14	1.92	6.06	2.21	1.05	**17.94**
1995	3.84	0.77	0.42	0.40	0.58	1.32	2.10	3.73	5.79	4.23	1.22	1.15	**25.55**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
1996	4.14	0.18	0.36	0.98	0.62	0.51	0.54	4.57	2.79	1.36	1.11	4.24	**21.40**
1997	1.46	1.56	0.85	1.21	0.55	0.59	2.80	1.87	4.21	1.33	0.53	0.48	**17.44**
1998	1.98	0.22	0.06	0.35	0.68	1.07	1.09	1.22	2.55	3.22	4.70	0.68	**17.82**
1999	5.60	0.67	0.20	0.58	0.26	0.48	2.08	5.20	3.45	3.17	2.86	4.49	**29.04**
2000	0.53	0.07	0.11	0.15	2.17	1.58	1.24	3.04	4.30	2.92	1.68	0.89	**18.68**
2001	0.94	2.78	0.18	0.29	0.38	0.04	3.41	1.52	4.27	3.43	1.09	2.08	**20.41**
2002	1.19	0.59	0.13	0.44	0.06	0.53	1.01	1.03	1.13	4.29	2.88	0.79	**14.07**
2003	0.70	0.02	0.14	0.07	0.29	0.22	2.00	4.59	4.23	1.72	0.34	1.21	**15.53**
2004	0.79	0.31	0.23	0.18	0.39	1.47	0.75	3.81	3.51	3.23	2.06	3.78	**20.51**
2005	1.98	0.15	0.05	0.15	0.17	0.17	0.80	3.31	7.21	1.34	2.58	0.69	**18.60**
2006	0.94	0.96	0.70	0.05	0.13	0.17	0.93	1.04	0.71	0.72	3.20	1.94	**11.49**
2007	0.33	0.02	0.93	0.02	0.35	2.47	1.94	5.77	9.16	1.11	3.14	1.38	**26.62**
2008	1.85	0.04	0.00	0.03	0.16	0.71	0.73	1.33	5.73	3.68	2.73	3.74	**20.73**
2009	3.05	0.28	0.12	0.70	1.53	1.82	1.60	1.13	4.31	3.86	1.82	1.57	**21.79**

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	**Annual Precipitation**
2010	4.82	0.05	0.78	0.55	0.38	1.59	2.07	5.65	1.51	1.45	0.19	3.51	**22.55**
2011	0.80	0.16	1.57	0.39	0.49	1.29	3.61	2.69	5.83	3.68	2.41	0.11	**23.03**
2012	1.41	0.00	0.15	0.19	1.02	0.03	2.83	2.79	1.81	1.35	1.62	0.01	**13.21**
2013	0.34	0.36	0.45	0.40	0.38	0.37	1.82	5.74	1.58	4.64	0.88	2.82	**19.78**
2014	5.79	0.16	0.52	0.15	0.05	0.55	2.26	2.00	4.61	0.24	3.47	0.45	**20.25**
2015	0.45	0.62	0.47	0.29	0.3	0.24	0.44	6.7	2.37	2.16	1.88	0.87	**16.79**
2016	0.55	0.50	0.83	0.10	0.52	0.61	2.83	4.49	2.32	3.27	2.30	1.94	**20.26**
2017	0.76	1.13	1.52	0.28	0.23	0.43	0.69	0.91	2.38	2.50	4.38	2.86	**18.07**

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	1.38	0.56	0.37	0.31	0.42	0.80	1.75	2.84	3.42	2.70	2.30	1.56
Minimum Precipitation	0.05	0.00	0.00	0.02	0.01	0.03	0.07	0.46	0.47	0.24	0.19	0.01
Year	1965	2012	2008 1987	2007	1985	2012	1987	1976	1974	2014	2010	2012
Maximum Precipitation	5.88	2.78	1.57	1.21	2.17	2.68	5.30	6.70	9.59	10.34	5.82	4.64
Year	1983	2001	2011	1997	2000	1968	1989	2015	1964	1993	1993	1973
Standard Deviation	1.42	0.61	0.33	0.24	0.39	0.69	1.19	1.55	1.94	1.73	1.37	1.19
Skewness	1.87	1.75	1.67	1.5	2.49	1.06	1.1	0.65	1.01	1.69	0.47	1.03

APPENDIX B: 8-YEAR PERIODS STATISTICS

Table B-1: 8-year Periods Precipitation (inches) Data Summary of Aberdeen, SD.

Water Year Period	**8-year Period**	**Remarks**
1955-1962	138.01	
1956-1963	138.54	
1957-1964	141.39	**Moderately Dry**
1958-1965	135.35	
1959-1966	140.80	
1960-1967	145.61	
1961-1968	149.29	
1962-1969	153.58	
1963-1970	144.25	
1964-1971	145.08	
1965-1972	148.51	
1966-1973	145.85	
1967-1974	138.87	
1968-1975	138.62	
1969-1976	127.63	**Dry**
1970-1977	129.43	
1971-1978	141.10	
1972-1979	140.19	
1973-1980	133.68	

Water Year Period	**8-year Period**	**Remarks**
1974-1981	135.83	
1975-1982	137.45	
1976-1983	144.18	
1977-1984	155.06	
1978-1985	154.35	
1979-1986	156.38	
1980-1987	151.09	
1981-1988	152.80	
1982-1989	156.05	
1983-1990	165.59	
1984-1991	163.15	
1985-1992	159.32	**Mean**
1986-1993	167.55	
1987-1994	158.65	
1988-1995	170.92	
1989-1996	176.07	
1990-1997	177.97	
1991-1998	177.96	
1992-1999	186.32	
1993-2000	189.78	**Wet**
1994-2001	189.43	
1995-2002	187.61	

Water Year Period	**8-year Period**	**Remarks**
1996-2003	183.79	
1997-2004	182.16	
1998-2005	178.57	
1999-2006	173.16	
2000-2007	169.27	
2001-2008	170.61	
2002-2009	168.09	
2003-2010	180.73	
2004-2011	184.63	
2005-2012	176.87	
2006-2013	177.66	**Moderately Wet**
2007-2014	181.77	
2008-2015	173.65	
2009-2016	171.51	
2010-2017	166.07	

Mean 8-year periods precipitation	159.43	Closest Mean	1985-1992	159.32
Minimum 8-year periods precipitation's	127.63		1969-1976	127.63
Maximum 8-year periods precipitation's	189.78		1993-2000	189.78
8-year periods precipitation Standard Deviation (Std Dev)	18.05775682			
8-year periods precipitation Skewness	0.043364546			
8-year periods precipitation Mean- Standard Deviation (Std Dev)	141.37	Mean-Std Dev	1957-1964	141.39
8-year periods precipitation Mean+ Standard Deviation (Std Dev)	177.48	Mean+Std Dev	2006-2013	177.66

Table B.2: 8-year Periods Precipitation (inches) Data Summary of Ipswich, SD.

Water Year Period	**8-year Period**	**Remarks**
1955-1962	139.03	
1956-1963	148.46	
1957-1964	157.20	
1958-1965	150.34	
1959-1966	151.71	
1960-1967	155.88	**Mean**
1961-1968	160.42	
1962-1969	166.49	
1963-1970	163.73	
1964-1971	158.75	
1965-1972	153.41	
1966-1973	152.35	
1967-1974	150.28	
1968-1975	150.54	
1969-1976	137.55	
1970-1977	135.74	**Dry**
1971-1978	142.32	
1972-1979	139.03	
1973-1980	137.15	

Water Year Period	**8-year Period**	**Remarks**
1974-1981	140.31	
1975-1982	143.63	**Moderately Dry**
1976-1983	146.73	
1977-1984	159.02	
1978-1985	156.46	
1979-1986	158.08	
1980-1987	154.22	
1981-1988	147.86	
1982-1989	151.04	
1983-1990	149.72	
1984-1991	145.54	
1985-1992	139.57	
1986-1993	150.73	
1987-1994	149.02	
1988-1995	159.49	
1989-1996	170.68	
1990-1997	170.69	
1991-1998	173.11	
1992-1999	186.33	
1993-2000	187.43	**Wet**
1994-2001	179.01	

Water Year Period	**8-year Period**	**Remarks**
1995-2002	170.32	
1996-2003	166.01	
1997-2004	164.43	
1998-2005	160.34	
1999-2006	153.26	
2000-2007	136.88	
2001-2008	139.59	
2002-2009	145.24	
2003-2010	156.66	
2004-2011	164.40	
2005-2012	159.64	
2006-2013	158.24	
2007-2014	168.54	**Moderately Wet**
2008-2015	173.95	
2009-2016	171.33	
2010-2017	161.81	

Mean 8-year periods precipitation	155.71	Closest mean	1960-1967	155.88
8-year periods precipitation Median	155.05			
Minimum 8-year periods precipitation's	135.74		1970-1977	135.74
Maximum 8-year periods precipitation's	187.43		1993-2000	187.43
8-year periods precipitation Standard Deviation (Std Dev)	12.43534845			
8-year periods precipitation Skewness	0.466700362			
8-year periods precipitation Mean-Standard Deviation (Std Dev)	143.28	Mean-Std Dev	1975-1982	143.63
8-year periods precipitation Mean+ Standard Deviation (Std Dev)	168.14	Mean+Std Dev	2007-2014	168.54

Table B-3: 8-year Periods Precipitation (inches) Data Summary of Eureka, SD.

Water Year Period	8-year Period	Remarks
1955-1962	142.40	
1956-1963	144.13	
1957-1964	146.21	
1958-1965	136.32	
1959-1966	134.94	
1960-1967	134.09	
1961-1968	140.35	
1962-1969	141.57	
1963-1970	138.04	
1964-1971	139.72	
1965-1972	133.58	**Moderately Dry**
1966-1973	136.76	
1967-1974	138.41	
1968-1975	140.34	
1969-1976	128.60	
1970-1977	128.76	
1971-1978	131.94	
1972-1979	128.09	
1973-1980	125.48	
1974-1981	128.24	

Water Year Period	8-year Period	Remarks
1975-1982	122.07	**Dry**
1976-1983	129.14	
1977-1984	135.87	
1978-1985	134.83	
1979-1986	141.15	
1980-1987	144.50	
1981-1988	140.72	
1982-1989	136.52	
1983-1990	145.49	
1984-1991	140.20	
1985-1992	144.63	
1986-1993	160.32	
1987-1994	152.64	
1988-1995	160.26	
1989-1996	173.72	
1990-1997	174.58	
1991-1998	172.45	
1992-1999	182.74	**Wet**
1993-2000	178.83	
1994-2001	168.28	
1995-2002	164.41	**Moderately Wet**
1996-2003	154.39	

Water Year Period	**8-year Period**	**Remarks**
1997-2004	153.50	
1998-2005	154.66	
1999-2006	148.33	
2000-2007	145.91	
2001-2008	147.96	**Mean**
2002-2009	149.34	
2003-2010	157.82	
2004-2011	165.32	
2005-2012	158.02	
2006-2013	159.20	
2007-2014	167.96	
2008-2015	158.13	
2009-2016	157.66	
2010-2017	153.94	

Mean 8-year periods precipitation	146.6890192	Closest Mean	2001-2008	147.96
8-year periods precipitation Median	144.57			
Minimum 8-year periods precipitation's	122.07		1975-1982	122.07
Maximum 8-year periods precipitation's	182.74		1992-1999	182.74
8-year periods precipitation Standard Deviation (Std Dev)	14.61741615		1957-1964	146.21
8-year periods precipitation Skewness	0.53108943			
8-year periods precipitation Mean-Standard Deviation (Std Dev)	132.76	Mean-Std Dev	1965-1972	133.58
8-year periods precipitation Mean+ Standard Deviation (Std Dev)	162	Mean+Std Dev	1995-2002	164.41