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Tree Ring Reconstructions of Streamflow for the Lower Rio Grande Valley of Texas

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TREE RING RECONSTRUCTIONS OF STREAMFLOW FOR THE LOWER RIO GRANDE VALLEY OF TEXAS

A Thesis
by
ADEDOLAPO MUTIYAT ADEYANJU

Submitted in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

Major Subject: Civil Engineering

The University of Texas Rio Grande Valley

August 2022

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August 2022

ABSTRACT

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The Rio Grande River is a major water source for people living within the USA-Mexico border. The Rio Grande River has its headwaters in the San Juan Mountains in Colorado and the Sierra Madre Occidental in Mexico before flowing into Texas through El-Paso. The water supply issues facing the Lower Rio Grande Basin (LRGB) are extremely complex from international restrictions to severe climate change. The river shares its flow between the U.S.A and Mexico based on the provisions of the 1944 treaty between the U.S.A and Mexico. The LRGB flow is regulated by releases from Falcon and Amistad Reservoirs managed by the International Boundary and Water Commission (IBWC).

The rapid increase in population and agricultural activities coupled with the recent droughts conditions has greatly impacted the water supply in the region leading to water demands being unmet. This research uses tree ring chronologies obtained from the International Tree Ring Data Bank (ITRDB) combined with naturalized streamflow data from United States Geological Survey (USGS) streamflow for 8 gages within the Lower Rio Grande Basin to develop historical streamflow reconstructions in the Lower Rio Grande Basin starting from the year 1613. Various prescreening methods used to include date screen, correlation coefficient, and cross-validation methods were used to develop reliable reconstructions. Stepwise regression method was used to reconstruct streamflow. Three of the eight streamflow stations identified were considered statistically skillful ($R2 \geq 0.40$) and selected for reconstruction. The streamflow reconstructions at Devils River at Pafford, Texas, Pecos River Nr Pecos, Texas, and Rio Ruidoso River at Hollywood, New Mexico explained 44% -67% of the variance with the January-February-March streamflow. The result revealed several periods of extreme wet and dry periods in the past centuries, and these were compared with extreme (wet and dry) patterns in the 20th century. This research aims to provide water managers with an excellent starting point to analyze future patterns of extreme streamflow.

DEDICATION

This master's thesis is dedicated to my father, Mr. Bayo Adeyanju, my mother, Mrs. Nurat Adeyanju, and my siblings, Bamidele, Barakat, Faridat and Dapo, and to my partner, Azeem Farinmade.

ACKNOWLEDGMENT

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Special appreciation goes to my boss Mr. Fernando Gonzalez for accepting me into the Office of Technology Commercialization and providing support and funding during my program. My appreciation goes to my friends Daphne, Wilma, Vincent, Somto and Abdul-Kabir for their support and contributions during this time.

Finally, I would like to express my gratitude to my parents Mr. and Mrs. Adeyanju for their endless moral and financial support throughout my life. To my siblings, Bamidele, Adebukola, Faridat and Adedapo for their immense support and encouragement throughout my life's journey. Special appreciation goes to my partner, Azeem Farinmade for always supporting my dreams and providing guidance as my best friend and mentor.

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CHAPTER I

INTRODUCTION

The Lower Rio Grande Basin also known as Rio Bravo (or formally, the Rio Bravo del Norte) in Mexico has been a major source of irrigation for several people living along the USA-Mexican border. The river supply has several challenges ranging from severe climate change caused by increased temperature to the high demand of water supply for population increase and irrigation systems. The river has been so impacted by human activities such that it gets dry during climatically dry season. This issue has raised concerns amongst water planners on the ability of the Lower basin to meet its obligations to supply clean water for drinking, irrigation, and recreational uses. The two main sources for the Lower Rio Grande river are from the headwaters of Colorado in San Juan Mountains and the Sierra Madre Occidental in Mexico(Woodhouse et al., 2012). Winter snowmelt occurring from April to June is the major source of surface flow in Colorado, while summer monsoon storms contribute a significant amount of surface flows for the Rio Conchos River (July-September). Reconstructions of streamflow for gauges in the upper Rio Grande (1508-2002) and in Rio Conchos watershed (1649-1993) has indicated a lack of correlation between the two basins, hence the two sources are largely independent of each other (Woodhouse et al., 2012).While significant reconstructions have been carried out to understand past climate in the upper Rio Grande Basin, there has no adequate research on the reconstruction of the Lower Rio Grande Basin region due to the high influence of summer monsoon in the region (Woodhouse et al., 2012). The North American monsoon affects most areas across the Southwest U.S which typically last from June to September (NOAA, 2022). Over 50% of the annual precipitation is delivered during this period (Woodhouse et al., 2012). However, research conducted on Yaqui

River which is on Northwestern part Mexico found out that cool season precipitation (November-May) flows which contributes about 10% of the annual flow is highly correlated with winter streamflow (Nicholas & Battisti 2008). By examining the streamflow variations through dendrohydrological studies, a relative understanding of the past, present, and future drought severity and duration can be obtained. This provides a complete understanding of historical streamflow variability and provides water planners with valuable information to make better management practices for future water supply.

1.1 Statement of the Problem

The LRGB (Figure 1.1) has faced several magnitude and severity of water supply shortages. The supply issues are extremely complex, ranging from international to local scale. First, the basin is controlled by international treaties and multiple administrative agencies between the United States and Mexico. The treaty of 1944 utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande distributed water in the Lower Rio Grande basin between Fort Quitman, Texas, and the Gulf of Mexico. The Treaty allocates to Mexico all waters from San Juan and Alamo rivers, two-thirds of the flows from rivers Conchos, Salado, San Diego, San Rodrigo, Escondido, and Las Vacas, and 50% of the follows from other tributaries.

Figure 1.1. Map of the Rio Grande Basin (Brandes, 2004)

The United States allotment includes one- third of the flows from River Conchos and other five tributaries from Mexico and all water flows from Pecos and Devils rivers, good enough spring, and Alamito, Terlingua, San Felipe and Pinto Creeks, and 50% of unmeasured tributaries. It was estimated that the US allotment is no less than an annual amount of 350,000 acre-feet over a period of 5 years from the Mexican tributaries(Woodhouse et al., 2013). Fourteen gaging stations are operated and maintained by the U.S. for flood control and water supply regulation in the Amistad and Falcon reservoirs through the International Boundary and Water Commission (IBWC), while the Mexican section operates and maintain four gaging stations of the Rio Grande. The U.S. maintains twelve other gaging stations on the six tributaries, while Mexico maintains eight gaging stations from measured tributaries. These data are used to form the basis for joint accountability of water belonging to each country.

Secondly, the climate condition of the LRGB ranges widely throughout the year, from arid subtropical in the western region to humid subtropical in the southeastern portion of the region. The prevailing winds in the region are southeasterly all through the year, and warm tropical air from the Gulf of Mexico produces hot, humid summers and mild dry winters. The maximum temperature in the region ranges from about 96^0F to 98^0F in July, while the lowest temperature ranges from about 40^0F to 49^0F in January (US Department of the Interior, 2013).

The amount of precipitation in the Lower Rio Grande Region ranges between 18 inches in the northwestern region to 28 inches at the coastal region. Precipitation occurs mostly during the spring from April- June and early fall from August-October. The spring precipitation occurs through thunderstorms from the Pacific Ocean and warm tropical air from the Gulf of Mexico, while fall precipitation occurs because of hurricane season. The effect of this storms leads to extensive flooding of the region due to its relatively flat terrain.

1.2 Research Objectives

This thesis reports the findings on tree ring reconstructions of stream flows in the Lower Rio Grande Basin. This research included several investigations on tree ring chronologies of stream flows for the Rio Grande Basin. A comprehensive review of the published literatures was conducted, and the main objectives of the research are to accomplish the following:

(1) Identify unimpaired streamflow data of rivers contributing to the lower Rio Grande Basin

(2) Investigate tree ring chronologies surrounding the Lower Rio Grande region

(3) Develop a regression model for simulating the unimpaired streamflow data with the information from tree ring chronologies

(4) Develop a historical reconstruction of streamflow to understand the long-term variability of the water resources in the region

1.3 Study Area and Background

The Rio Grande River is a major river that form international boundaries between the United States and Mexico. The river is the fifth longest river in North America at 1,896 miles (3,034km) long and drainage area of 182,215 square miles (471,934 square km), and among the 20 longest rivers in the world. The river which has its headwaters in San Juan Mountains of Colorado runs through New Mexico and flows into Texas from El-Paso. The Rio Grande River is a major source of water for both countries supplying water to about 12-13 million people across the US-Mexico border. It is considered is one of the most impacted rivers in the world and has multiple issues that are related to water quality and quantity (Dahm et al., 2005). There has been a significant reduction (roughly 75%) in annual discharge of the Rio Grande to the Gulf of Mexico due to the construction of Falcon Dam [International Boundary and Water Commission, 2001].

The upper Rio Grande Basin is mainly fed by snowmelt from winter storms that occurs form April to June in its headwater's region. Its streamflow decreases progressively from its headwaters in Colorado to El Paso, Texas and almost diminishes near Fort Quitman about 78 miles (125km) south of El Paso. From here, the Rio Grande flow consists mostly of wastewater and irrigation return flows until its confluence with the Rio Conchos. The major tributaries to the Rio Grande River in Texas are the Pecos and Devils rivers. Rio conchos, San Diego, San Rodrigo, Escondido, Salado, Alamo, and San Juan rivers are the primary tributaries in Mexico (Figure 1.2). The basin consists of 26 major reservoirs, eight in Texas and eighteen in Mexico, including off-channel reservoirs.

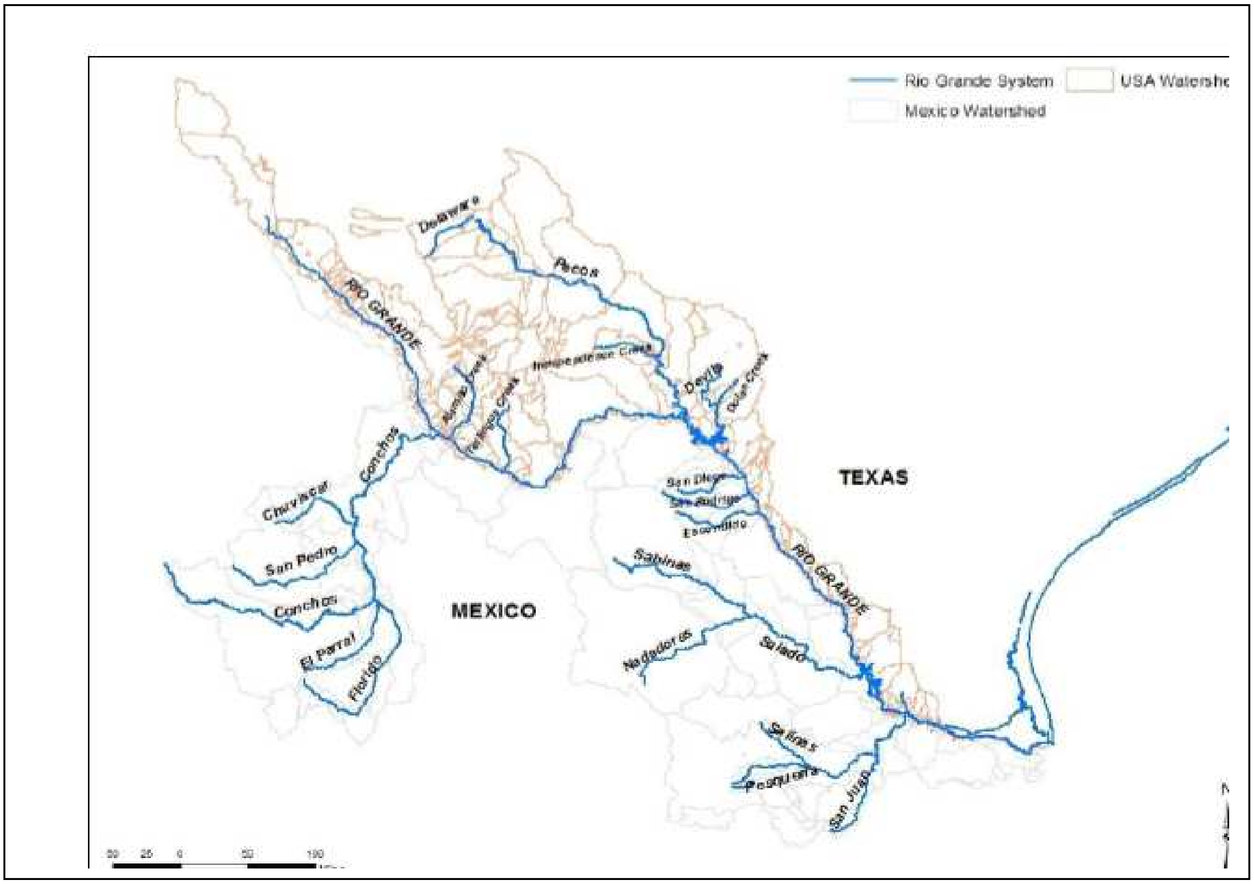

Figure 1.2. Primary tributaries of the Rio Grande. Source (Karimov, 2016).

There are a variety of moisture sources for the lower Rio Grande (e.g., monsoon rainfall, snowmelt, spring flow, and agricultural drains, etc.), but most of the streamflow consists of runoff from convective activities (thunderstorms) of the summer Mexican monsoon.

1.4 The Basics of Dendrochronology

The properties of tree rings (e.g., width and density) provides valuable information to scientists to retrieve valuable information on how old the tree is and what the weather conditions were during each year of the tree's life. The characteristics of tress-rings makes it easy to measure the ring width for a continuous sequence of years. The annual growth rings of the trees can be placed precisely with a well-defined climatic information to provide both chronological control and a continuous time series of proxy environmental variables (Luckman, 2013). These can also be used to reconstruct variations in climate that occurred prior to the interval covered by direct climatic measurements. These reconstructions can extend backwards in time help to better understand past climate variability. This could provide information to water planners to better understand the past climate and better anticipate possible future climatic changes as well (Fritts, 1976).

1.4.1 Structure of a Tree

A cross section of most moisture sensitive trees (Figure 1.3) shows a continuous series of alternating lighter and darker bands. The tree ring is made up of a sequence of large, thin-walled cells known as Earlywood/ Springwood and a less porous, more densely packed, thick-walled cells known as Latewood/Summerwood.

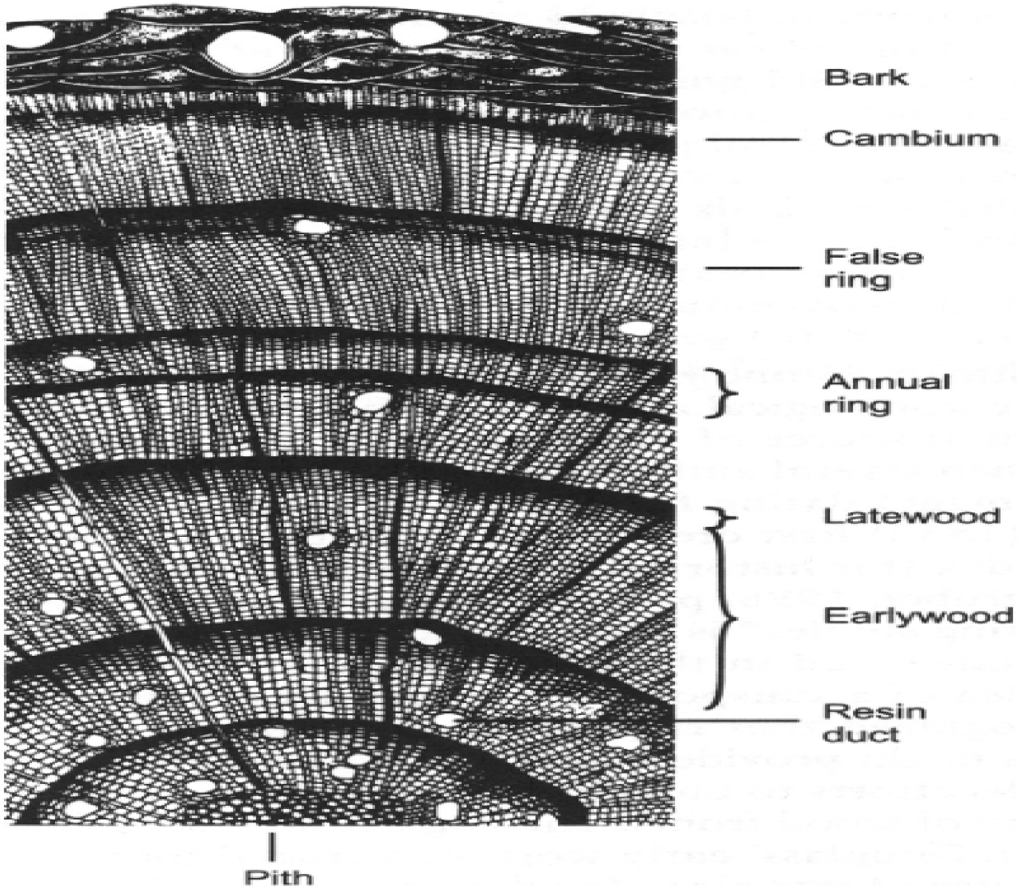

Figure 1.3. Cross section of a young stem of a conifer. The early-wood is made up of a large and relatively thin- walled cells (Tracheid); latewood is made up of small, thick-walled tracheid. Variations in tracheid thickness may produce false rings in either early- wood or latewood (Fritts, 1976).

Collectively, both earlywood and latewood comprise an annual growth increment, called a tree ring (Figure 1.4). Climatic factors such as sunshine, precipitation, temperature, wind speed and humidity, soil moisture and nutrients can impact tree growth (Vaganov et al., 2011). Therefore, for a climatic signal to be considered chronically useful, it is important to distinguish the signal and background noise. The method of matching patterns of tree ring width (cross-dating) is used to remove locally absent or false rings (Figure 1.5). The yearly ring width must be cross dated among all radii within a stem and Among different trees in each stand, as well as among ring-width of neighboring stands (Fritts, 1976).

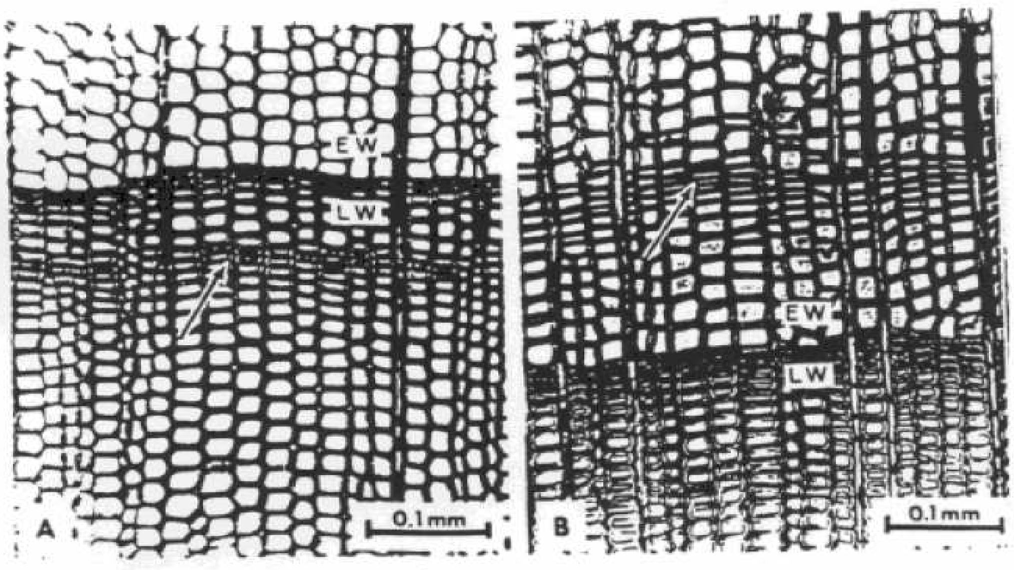

Figure 1.4. Annual growth rings showing early wood (EW), latewood (LW) and False rings (arrows) (Fritts, 1976)

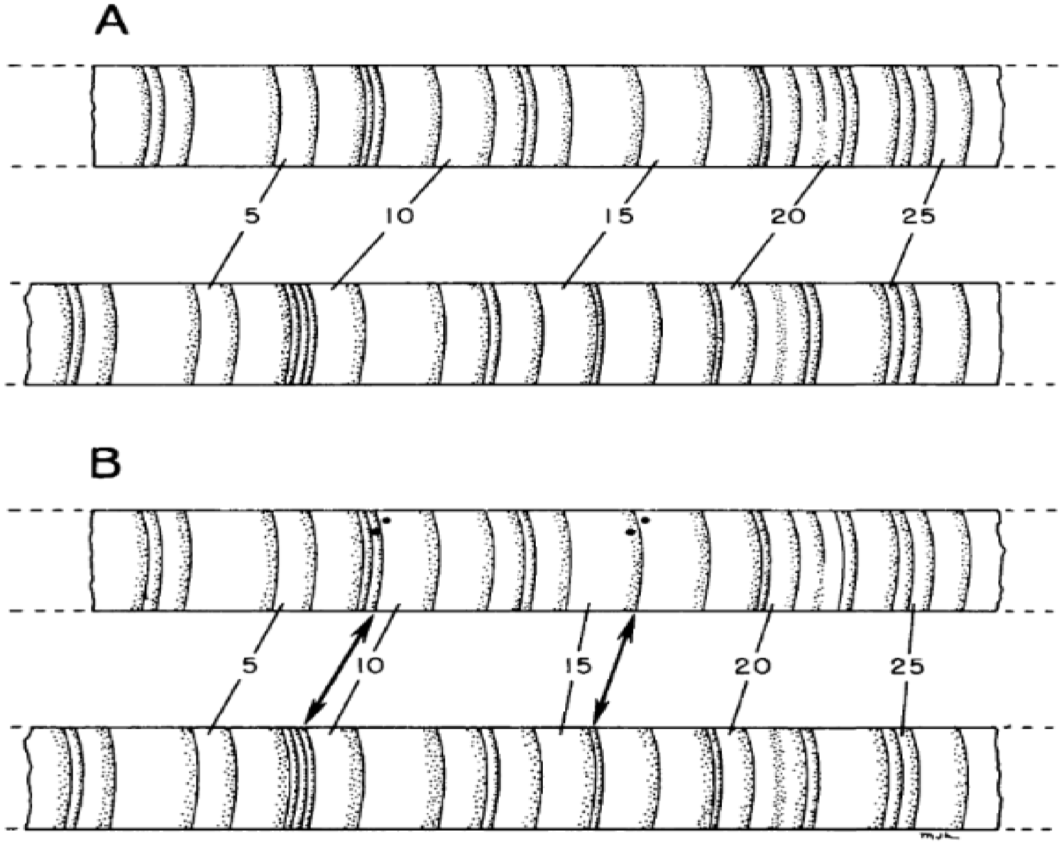

Figure 1.5. Cross dating makes it possible to identify locally absent rings or where an intra-annual growth band appears like a true annual ring

1.4.2 Sample selection

In dendroclimatological studies, tree rings are sampled in sites where they are under stress. Usually, trees that are growing on the extreme of their ecological amplitude. In such situations, climatic variations will greatly influence annual growth increments and the tree is said to be sensitive (Figure 1.6). However, in a beneficial situation where the tree has access to groundwater, tree growth may not be noticeably influenced by climate, and this will be reflected in the low interannual variability of ring width (Bradley,2015).

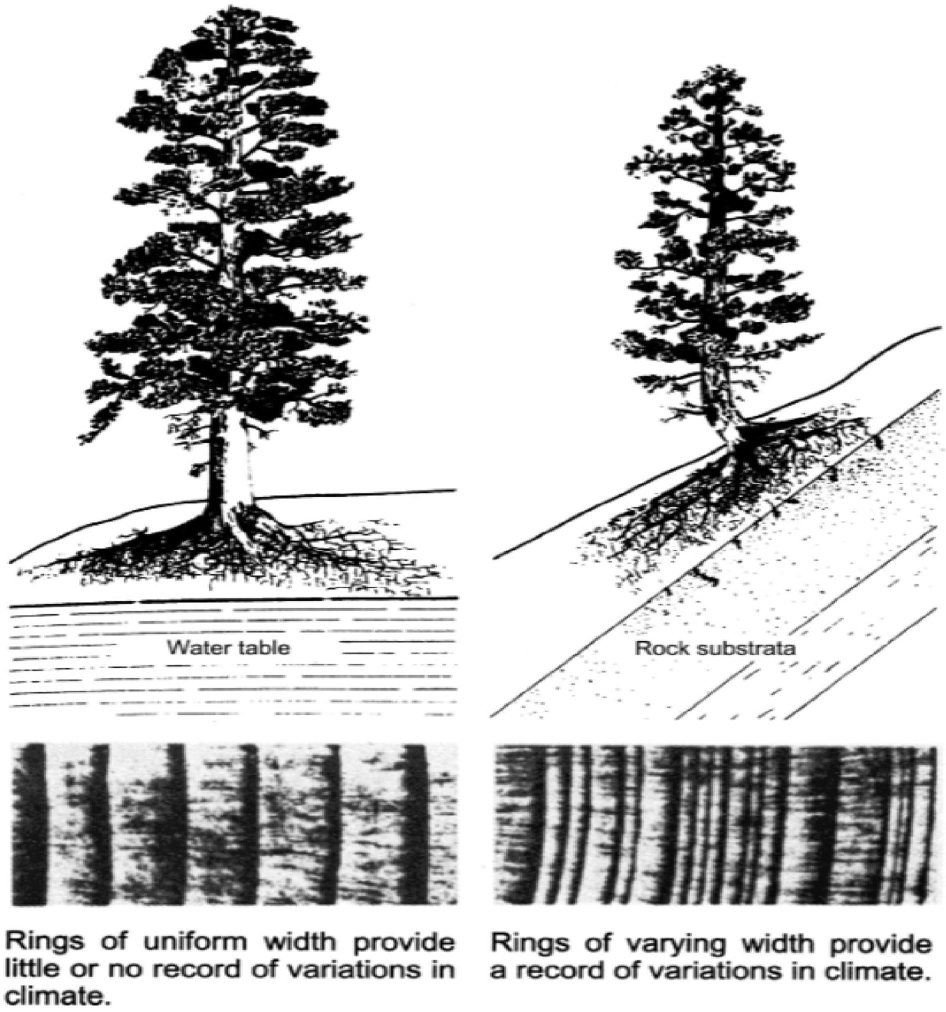

Figure 1.6. Left: Trees growing on site where climate limits growth processes produce rings that are uniformly wide. The ring widths provide little or no record of variations in climate and are termed complacent. Right: Trees growing on sites where climatic factors are frequency limiting produce rings that vary in width from year to year. These are termed sensitive. (Fritts, 1976)

1.5 Previous Studies

Previous studies within the past 30 years have researched the use of dendrochronology and tree rings to reconstruct streamflow variability in North America. Watson et al., (2009) reconstructed spring-summer streamflow for the headwaters of wind river, Wyoming. They investigated using three different statistical methods, Principal Component Regression (PCR) Partial Least Squared Regression (PLSR) and Stepwise regression. Results from three analysis found out Stepwise regression to be the best due to the poor performance of PCR models (roughly 0.1-0.2 lower) and signs of over-fitting from PLSR model (high Mallows' Cp). They achieved 40%-64% of variance explained in their reconstruction. The longest runs of severe dry years (25th percentile) spanned from 1887 to 1890 and 1952 to 1955, while they found the wettest years (upper 75th percentile) from 1601- 1605.

Similar research has been conducted to reconstruct the Upper Rio Grande Basin. Research conducted by Woodhouse (2001) used existing tree ring chronologies in the Colorado Front Range to extend records for the Middle Boulder Creek located within the South Platte River Basin. Stepwise regression equation was used to account for 70% of the variance. However, their reconstructions suggested that the instrumental record of streamflow is not representative of flows in the past centuries and period of low flow events in the 19th century were found to be more severe than those recorded in the 20th century.

Another notable research carried out by Woodhouse et al., (2012) to understand the water supply variability between the Upper Rio Grande and Rio Conchos River. The two major tributaries of the Rio Grande. The research attempted the correlate the October-July precipitation from Rio Conchos with October to September water year streamflow from the Rio Grande Basin. Results found out that there was no significant correlation between the two flows. They also found out that there was no correlation (R=0.08, p=0.496) between the water year precipitation in Rio Conchos and the water year streamflow in the Upper Rio Grande. However, they found some common drought years between both flows to have occurred in the 18th century (1748,1763,1773, and 1798).

CHAPTER II

DATA AND METHODS

2.1 Streamflow Data

To create a reliable streamflow for reconstruction, it was important to identify stream gaging stations free from the effects of diversions and storage. Streamflow data for 8 gages that contributes flow into the Lower Rio Grande Valley were obtained from the United States Geological survey (USGS) stream gage information through the National Water Information System (NWIS) (https://waterdata.usgs.gov/nwis/sw) and United States International boundaries and water commission (IBWC) (https://www.ibwc.gov/Water_Data/histflo1.htm). However, to create statistically significant data, it was necessary to use accurate streamflow information available for a given gage station. Therefore, unimpaired, or naturalized streamflow data must be obtained. An unimpaired stream gage station is defined as a station that is relatively free of anthropogenic influences including storage, diversion and consumptive use (Barnett et al., 2010). The difference between unimpaired and naturalized streamflow is that naturalized flow is the back calculation from an impaired gage record to represent a historical streamflow conditions without any anthropogenic activity at the station (Barnett et al., 2010). Basically, naturalized streamflow excludes the effects of historical diversions, return flows, and reservoir storage and evaporation (Brandes et., al 2004).

Unimpaired stations were identified from sites included in the Hydro-Climatic data network (HCDN) (Slack, J.R., Lumb Alan M., 1993) https://pubs.usgs.gov/wri/wri934076/region13.html. Of the 8 gages identified, 6 gages stations were selected for reconstruction, and two additional naturalized gages station was added at El-Paso (Table 2.1). These stations provided continuous record of unimpaired datasets available within the Lower Rio Grande Basin. Dataset used for 4 gages stations (Black River above Malaga, Delaware river nr Red Bluff, Rio Ruidoso, and Pecos River) were collected from the National Water Information System (NWIS). Datasets for streamflow gages in Texas (Devils River and Alamito Creeks) were obtained from United States IBWC databank. For the naturalized flows at El-paso, (Brandes et al.,2004) generated two stream flows distributed between Mexico and the U.S. that covered a 61-year period from 1940-2000. These were back calculated from impaired gages for the Rio Grande Water Availability Modeling (WAM).

Table 0-1: Gaging Stations and Record Information

Gage	State	Station ID	Drainage Area (sq. mi)	Gage Record	Record Provided By
Alamito Creek Nr Presido	TX	08374000	1504	1932-1971	IBWC
Black River Above Malaga	NM	08405500	371	1947-1988	NWIS
Devils' River at Pafford [a]	Tx	08449400	3961	1960-2007	IBWC
Delaware River Nr Red Bluff	NM	08408500	689	1938- 1988	NWIS
El Paso gage above Fort Quitman	Mex.			1940-2000	Brandes
El Paso gage above Fort Quitman [b]	TX			1940-2000[c]	Brandes
Rio Ruidoso at Hollywood	NM	08387000	120	1954- 1988	NWIS
Pecos Rover Nr Pecos	NM	08378500	189	1930-1988	NWIS

[a] Full gage names- Devils' River at Pafford at Crossing Nr Comstock

[b] March-September instrumental record only

Monthly streamflow data for all gage stations were converted from daily streamflow to water year streamflow, except for the streamflow at El-Paso. In this case, available data were converted from acre-feet/month to cubic feet/second to allow for a uniform measurement of the streamflow.

2.2 Tree Ring Chronologies

Tree ring datasets within and around the Rio Grande River basin were obtained from the International Tree Ring Data Bank (ITRDB) https://www.ncei.noaa.gov/. A total of 23 tree ring chronologies were considered for the reconstruction. Tree species used in these chronologies are considered moisture sensitive. Of the 23 chronologies, 13 are from Douglas-fir (*Pseudotsuga menziesii*, PSME), 4 are from ponderosa pine (*Pinus ponderosa Douglas*, PIPO), 3 from Pinyon (*Pinus edulis Engelm, PIED*), 1 from Mexican Mountain Pine (*Pinus hartwegii lindl*, PIHR), 1 from Arizona Pine (*Pinus arizonica engelm,* PIAZ), and 1 from Limber pine (*Pinus flexilis*, PIFL) (Barnett et al., 2010). All these chronologies cover the period from 1613-1994, and they represent sites within Texas, New Mexico, and Mexico. All tree width series were uniformly processed and standardized using the Autoregressive standardization (ARSTAN) program (Cook et al., 1990). Conservating detrending methods removes growth trends in individual tree ring series using negative exponential/straight line or a cubic spline two thirds the length of the series. The program creates chronologies using bi-weight robust mean approach and outputs different chronologies-standardized and residual chronologies. The residual chronology has low order autocorrelation that may be attributed to biological tree-growth factors removed (Fritts, 1976). The residual chronology has been found to be more appropriate for reconstruction (Anderson et al., 2019b;Woodhouse, 2001). The streamflow had higher correlation with the residual tree rings (R= 0.66 to 0.82) than the standard chronologies (R= 0.43 to 0.69). Therefore, it is evident that streamflow will be accurately represented by the residual chronology and of the selected twenty-three tree rings, only four have the residual chronologies required for reconstruction (Table 2-2). Figure 2.1 shows the map of the Rio Grande Basin, the selected streamflow gage stations and the tree ring chronologies considered for reconstruction.

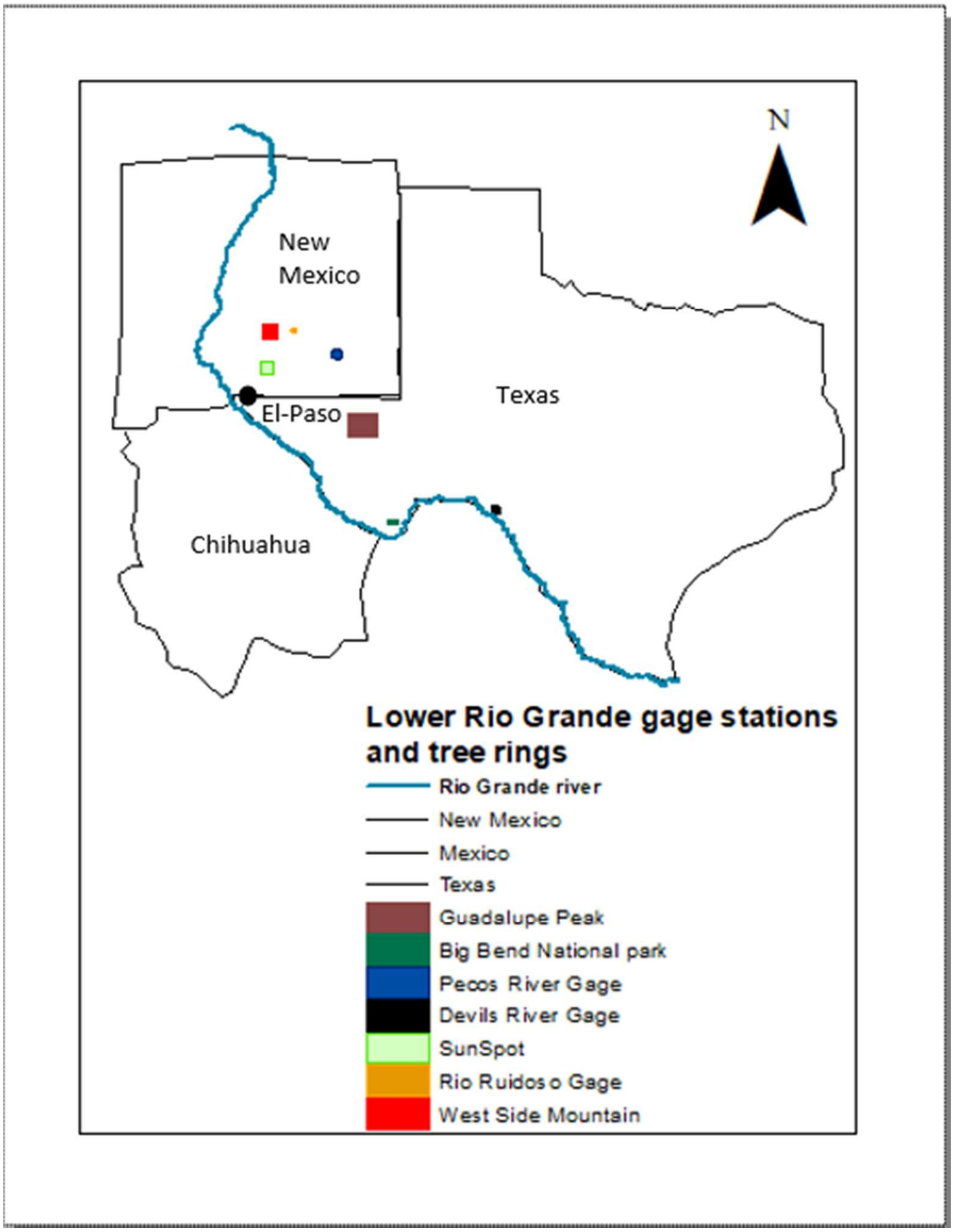

Figure 2.1. Map of the Rio Grande River showing the selected tree rings and streamflow gage stations

Table 0-2: Tree Ring Records obtained from International Tree Ring Data Bank

Site Name	**Species**	**Period**	**Lat. N**	**Long. W**	**Elevation (m)**
Big Bend National Park incl. camp spring	PSME	1473- 1992	29 25	103 03	2057
Guadalupe peak	PSME	1537-1992	31 09	104 85	2438
Sunspot	PSME	1627-1992	32 08	105 08	2865
West Side Rd Sacramento Mountains	PIPO	1610-1994	32 08	105 09	2250

PSME = Pseudotsuga menziesii, PIPO = Pinus ponderosa.

2.3 Reconstruction Procedure

Figure 2.2 shows the flow chart used for the streamflow reconstructions. Regression models were calibrated to create reconstructions for the selected stream gage stations by utilizing residual tree ring chronologies. Three standard regression techniques were assessed for the reconstruction. Techniques includes stepwise regression (Woodhouse et al., 2006), principal component analysis (Hidalgo et al., 2000) and partial least square regression (Tootle et al., 2007). However, stepwise multiple linear regression was selected based on its wide acceptance in water resources.

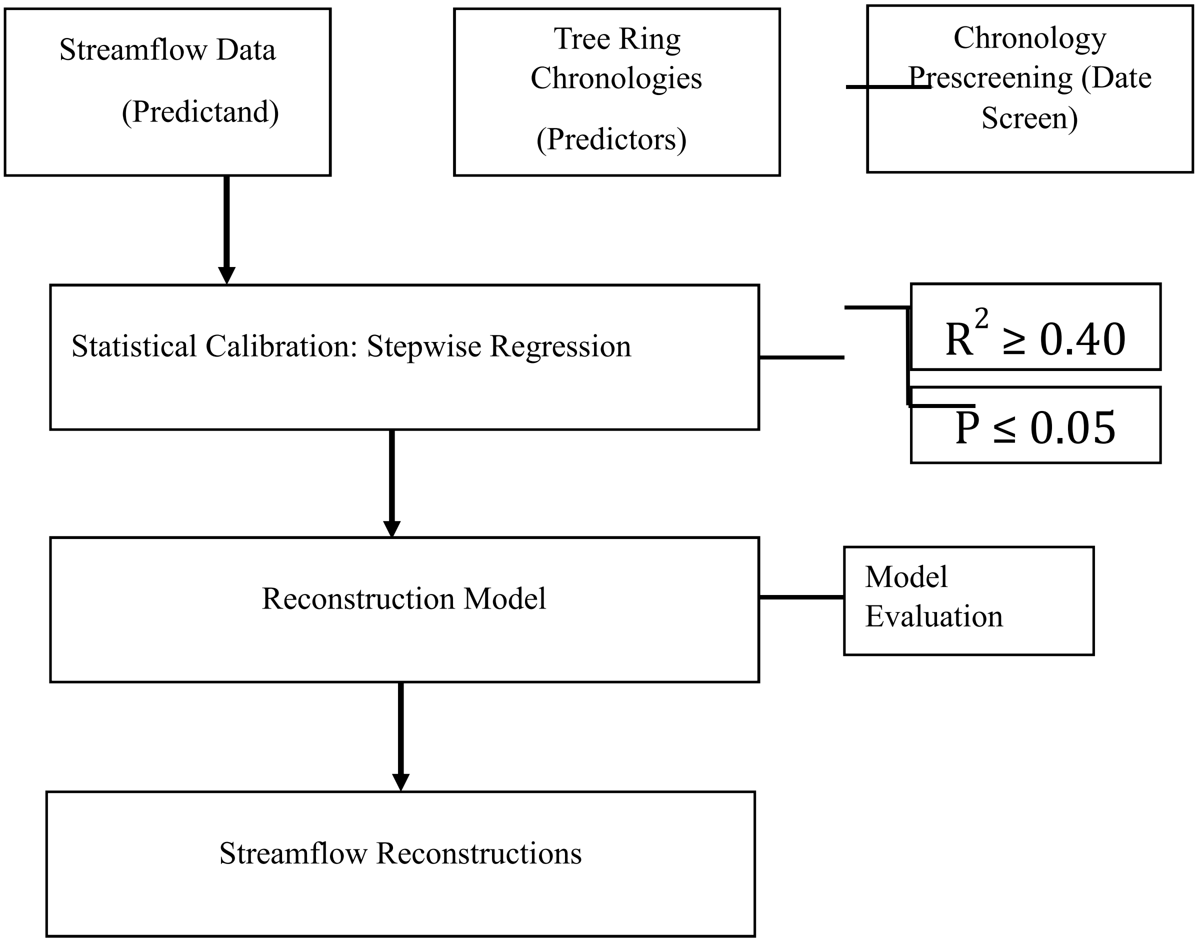

Figure 2.2. Reconstruction Modeling Flow Chart

2.3.1 Predictor Prescreening Method

First, a date screen prescreening method was used to identify the most suitable tree -ring chronologies for the reconstruction models (Anderson et al., 2019a). The tree ring chronologies were set to have a common date from 1627-1988. The year 1627 was used as the cutoff date for initial predictor pool tree ring chronologies, and removed any chronologies cored before 1627 from the analysis.

Next, the residual chronologies were considered in the regression model for each of the eight gage stations. The correlation coefficients between various streamflow seasons and residual tree ring chronologies were inspected to identify the most influential season that contributes to tree growth, similar to the procedure adopted by (Anderson et al., 2019). Based on various studies examined, the relationship between tree growth and eleven different streamflow seasons were analyzed. Two-month seasonal streamflow periods included May-June, June-July, July-August. Three-month seasonal streamflow periods included January-March, April-June, May-July, July-September, and October- December. Six-month seasonal streamflow included January-June, April-September, and July-December. March-June, and annual streamflow were considered.

2.3.2 Monthly correlation

The correlation graphs (Figure 2.3) show the sensitivity of Douglas Fir (P*seudotsuga menziesii*) and Ponderosa Pine (Pi*nus ponderosa Douglas*) chronologies to various streamflow seasons. Monthly streamflow data were correlated against each chronology. Delaware streamflow shows the highest correlation with both West Side Road Sacramento Mountains chronology (R=0.54) and Guadalupe Park (R=0.54).

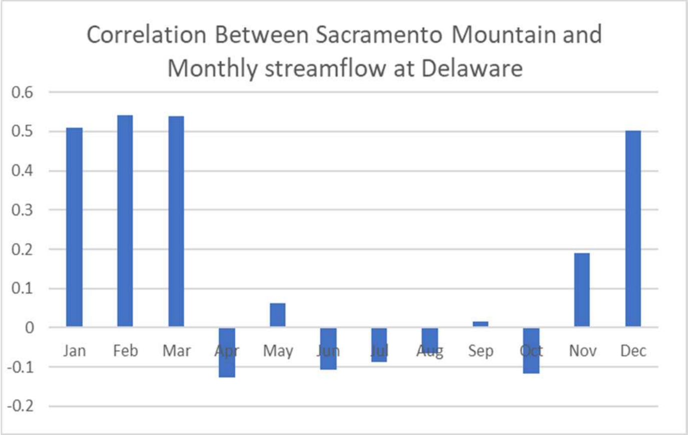

Figure 2.3. Monthly Correlation Between Sacramento Mountain and Delaware Streamflow

2.3.3 Three-Month Correlations

The correlation graphs (Figure 2.4) show the sensitivity of Douglas Fir (P*seudotsuga menziesii*) and Ponderosa Pine (Pi*nus ponderosa Douglas*) chronologies using three month streamflow intervals streamflow seasons. Figure 2.4 shows the correlations between flows at Delaware River and Guadalupe Park chronology (R= 0.54).

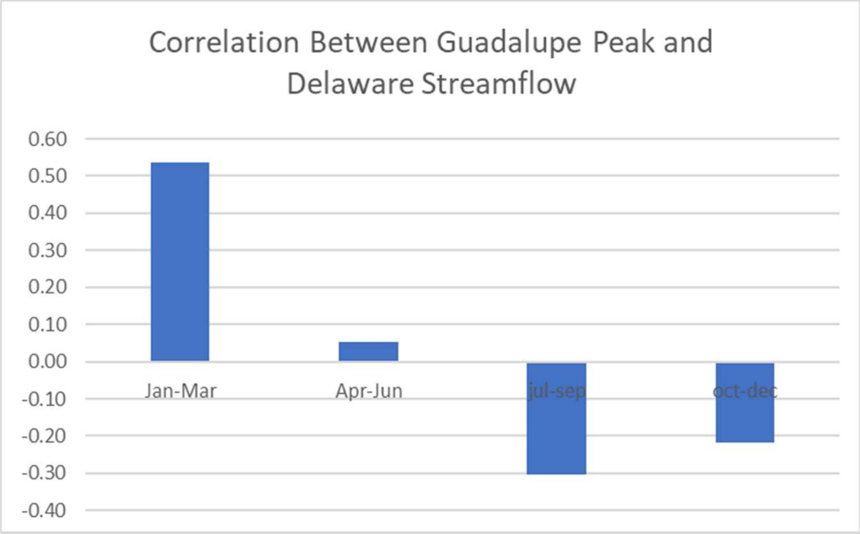

Figure 2.4. Correlation Between Guadalupe Park chronology and Delaware Streamflow

2.4 Stepwise Multiple Linear Regression

A stepwise regression adds and removes predictor that are less than or equal to the specified alpha-to-remove value (Anderson et al., 2019a). F-level was set to have a *p*- value maximum value of 0.05 for entry and 0.1 for removal. F- statistics and *p*-value are used in making statistical deciding to either support or reject the null hypothesis. Analysis was carried out using statistical tool of SPSS and Microsoft Excel to generate regression models. The statistical strength of each predictor was tested on different streamflow seasons. However, January-February-March streamflow shows the highest correlations and was considered. R^2, R^2 (predicted), R^2 (adjusted), F statistic, cross validation standard error (CVSE), Variance Inflation Factor (VIF), predicted error sum of squares (PRESS) and the Durbin-Watson statistic were measured.

Multiple linear regression (Eqn.2.1) attempts to model the relationship between multiple independent variables and one dependent variable. The dependent variable is modeled as a function of the independent variables with their corresponding coefficients, along with the constant (Eqn 2.2 to Eqn 2.4).

Model for multiple linear regression equation is given as:

$$\hat{Y} = b_o + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p \text{ --------------------------------(Eqn.2.1)}$$

Where:

$\hat{Y}$ = predicted value of the dependent variable

βo = y-intercept (value of y when all parameters are set to 0)

β1 X1 = regression coefficient of first independent variable (X1)

β2X2 = regression coefficient of second independent variable (X2)

βpXp = regression coefficient of the last independent variable (Xp)

Streamflow Reconstruction Regression Equation

Pecos River
= 42.374 + (0.028 * Guadalupe peak) + (0.023 *West Side Sacramento Mountain) … (Eqn 2.2)

Rio Ruidoso River
= -0.544+(0.033* West Side Sacramento Mountain) …………………………………... (Eqn 2.3)

Devils River
= 7525.78+(8.783* West Side Sacramento Mountain) ………………………………… (Eqn 2.4)

R^2 indicate the proportion of variance in the streamflow that can be explained by the tree ring predictors. R^2 predicted was calculated by using the predicted residual sum of squares (PRESS) statistics. Variance Inflation Factor measures whether multicollinearity exist in a regression analysis. Durbin-Watson tests for autocorrelation in the residuals from a regression analysis. A Two sample-test is a hypothesis testing technique used to test for consistent differences between different groups following the procedure used by Thomas Watson (2009). In statistics, two-sample t-test is used to determine whether the means of two populations are statistically different given the two samples are independent of each other (Eqn 2.5).

$$t = \frac{(x_1-x_2)}{\sqrt{\frac{s_1^2}{n_1}}+\sqrt{\frac{s_2^2}{n_2}}} \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eqn 2.5)}$$

Where:

X_1 = mean of first sample

X_2 = mean of second sample

N_1 and N_2 = sample size

S_1 and S_2= standard deviation of the two samples

The regression models were evaluated using two validation techniques. A regression model was calibrated on the first half of the data and validated on the second half of the data. The procedure was reversed by calibrating the second half of the data and validated on the first half. The second approach involved using Leave-One-Out Cross (LOOCV) validation technique. This model is repeated for n times for each observation. The technique measures the mean squared error (MSE) by using each observation from the original sample as the validation set, and the remaining as the training set. The result from the cross validation verifies that total variance explained (R^2)

by the regression model is not excessive by the regression model since the R^2 from the LOOCV is not significantly less than the R^2 explained by the first calibration model.

CHAPTER III

CALIBRATION AND VERIFICATION OF MODEL

Streamflow was reconstructed for all the streamflow gages. A three-month period of January-March, and July-September season showed a significant correlation with the tree ring chronologies. However, the January-March streamflow was selected for reconstruction as it has higher correlations with residual chronologies than July-September streamflow season. To assess each of the reconstruction, a split-sample calibration and validation approach was used for reconstruction model. The common period between the streamflow data and tree ring chronologies were used to calibrate and verify the models. The most feasible calibration models were selected for reconstruction (Table 3-1). $R^2 \geq 0.40$ are considered statistically skillful and only models with these values were considered (Anderson et al., 2019a). Monthly streamflow for the three rivers is shown in Figure 3.1.

Table 0-1 Calibration Model Summary

Gauge Station	**Calibration Period**	**R^2**	**R^2(Adj)**	**Std error of estimate**	**D-W**	**F change**
Alamito Creek Nr Presido	1945-1957	0.29	0.26	79.59	1.62	8.96
Black River Above Malaga	1947-1975	0.21	0.18	18.85	1.49	7.11
Devils' River at Pafford	1960-1976	0.44	0.40	6065.79	1.45	11.61
Delaware River Nr Red Bluff	1938-1976	0.01	0.08	4.097	0.62	4.13
El Paso gage above Fort Quitman, Texas	1940-1965	0.3	0.27	329.07	1.82	10.38
Rio Ruidoso at Hollywood	1954-1975	0.67	0.65	13.25	1.73	39.88
Pecos River Nr Pecos	1930-1958	0.44	0.40	18.75	2.05	4.78

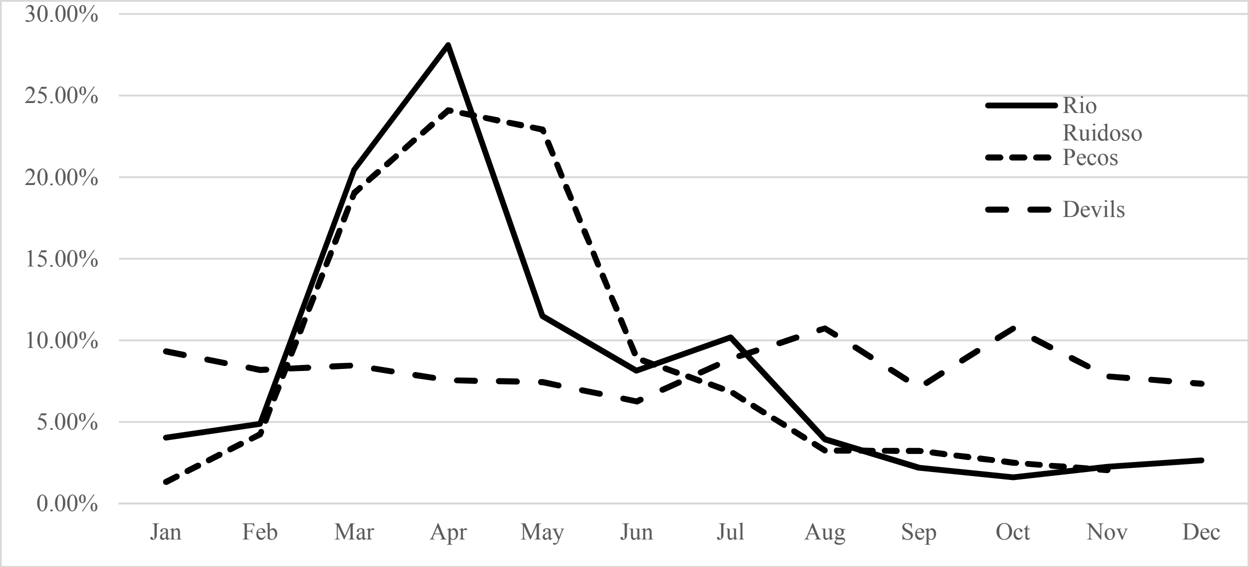

Figure 3.1. Monthly streamflow for three gages stations (Rio Ruidoso, Pecos, and Devils River

3.1 Streamflow Reconstruction

Reconstruction of each seasonal models were generated for all the eight streamflow gages and their respective predictors (Table 3.1). The regression models produced R^2, D-W and standard error of estimate values at a significant value of 95%. The D-W values of Pecos gaging stations revealed a little autocorrelation within the predictor. Results for three gaging stations were considered statistically skillful and were retained for reconstruction (Devils river, Rio Ruidoso and Pecos river) explained 44% -67% of the variance for the January-February-March seasonal streamflow (Figure 3.2).

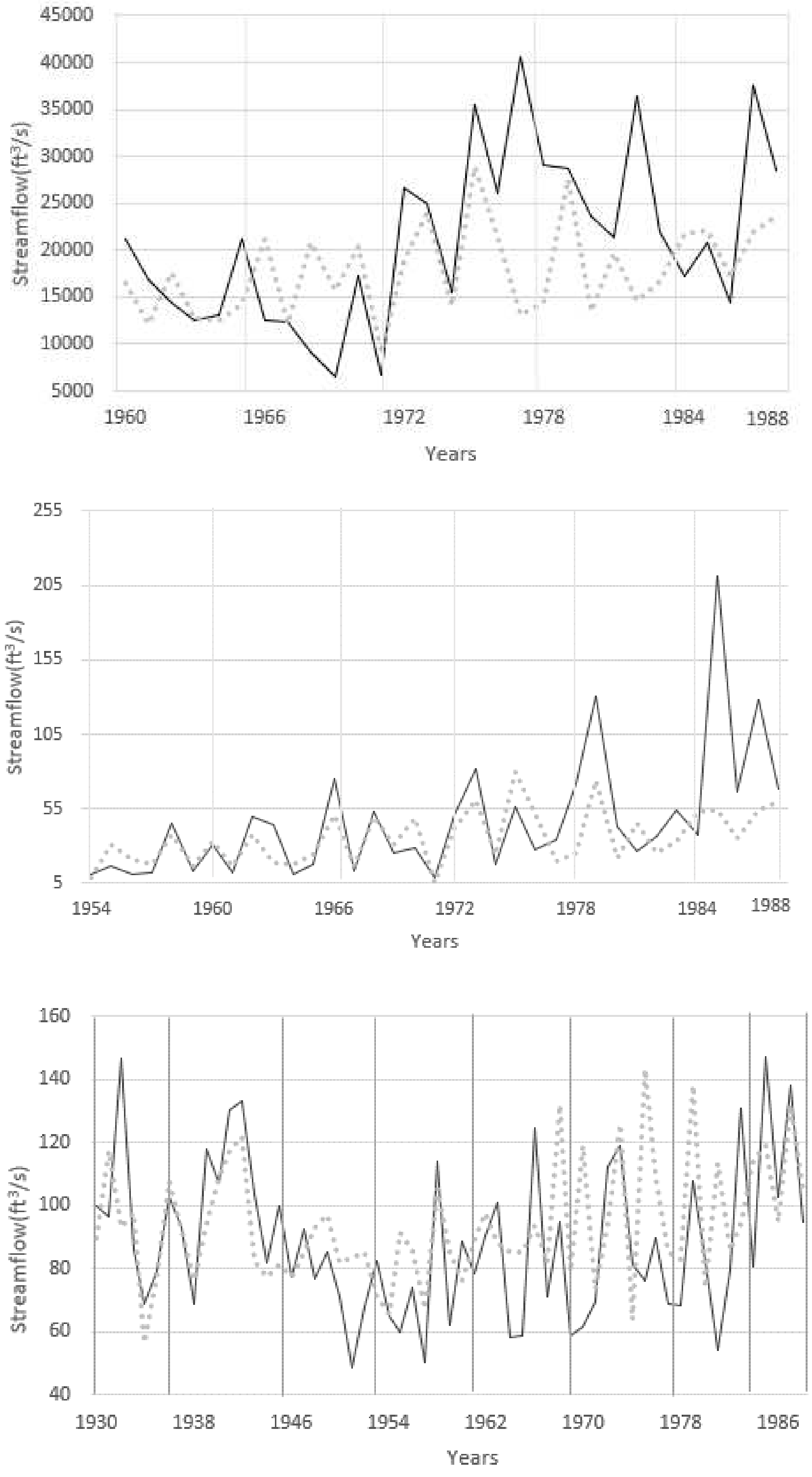

Figure 3.2. January-February-March streamflow calibration model. Observed flow *(*dark, solid line), reconstructed (gray, dashed line). (a) Devils River (1960-1976), (b) Rio Ruidoso River (1954-1988), (c) Pecos River (1930-1988)

3.2 Result Analysis

Reconstruction for the three streamflow gages were tested for normality using Kolomogorov Smirnov test, and two-sample t-tests were performed on each reconstruction (Watson et al., 2009) with observed gage data to ensure equivalence of 95% significane ($p<0.05$).

3.2.1 Devils Streamflow

The streamflow at Devils gaging station was reconstructed back to 1613 (Figure 3.3 &3.4). This resulted in a 382-year long streamflow reconstruction for the January-February-March streamflow season. Only one tree ring chronology from within the basin was utilized since no other chronologies passed the requirement when using stepwise regression. The two-sample t-test applied to the difference in mean of the extended reconstruction (1613-1960) shows a similar statistical significance at 95% confidence level ($p<0.05$) to the original gage data (1960-1994) for the overlapping period of record. Figure 3.3 displays the 10-year moving average and mean reconstructed flow for Devils River.

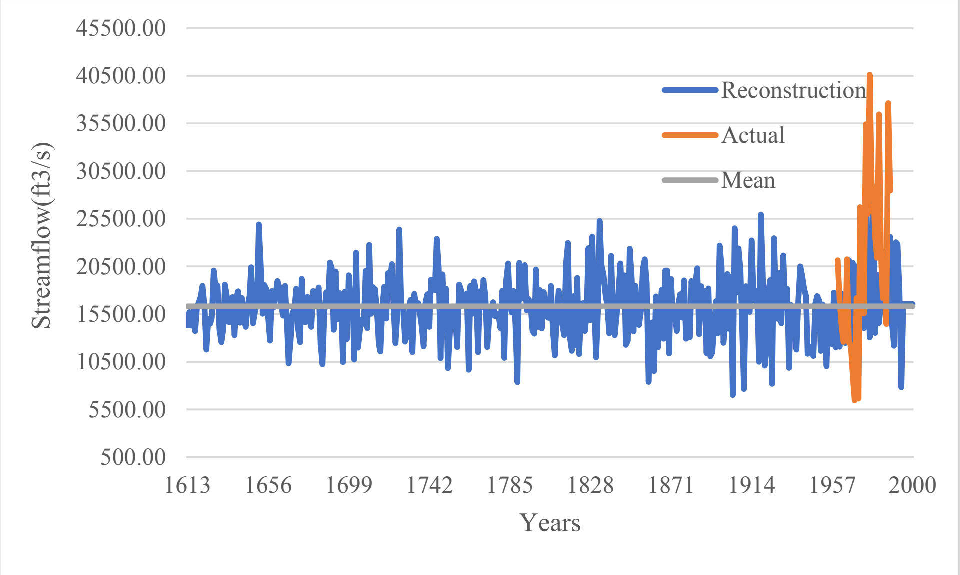

Figure 3.3. Comparison of January-March reconstructed flow and actual flow.

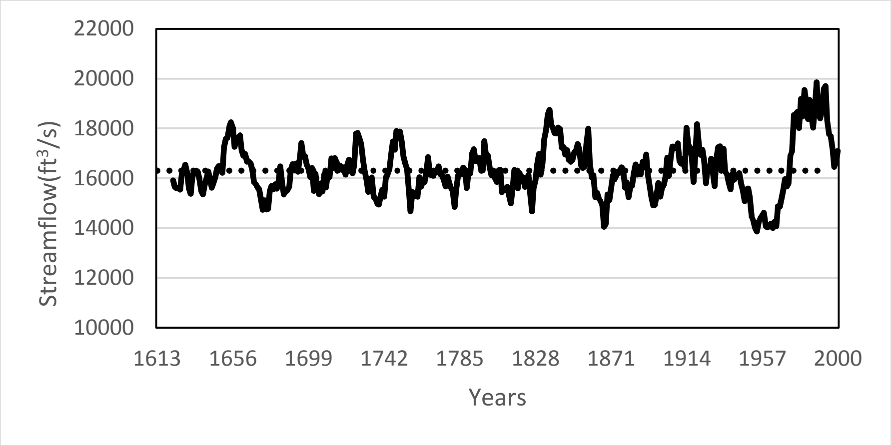

Figure 3.4. 10-year moving average (black, continuous line) and mean reconstructed flow (black, dashed line)

3.2.2 Rio Ruidoso Streamflow

The streamflow at Rio Ruidoso gaging station with a period record of 382-years yearlong streamflow reconstruction for the streamflow season (Figure 3.5 & 3.6). Some negative values were observed in the reconstructed data. This could likely be an error of This is to ensure that reliable streamflow reconstructions were generated. The common period between the observed gage and the reconstructed data generated a significant two sample t-test results ($p<0.05$) confidence level.

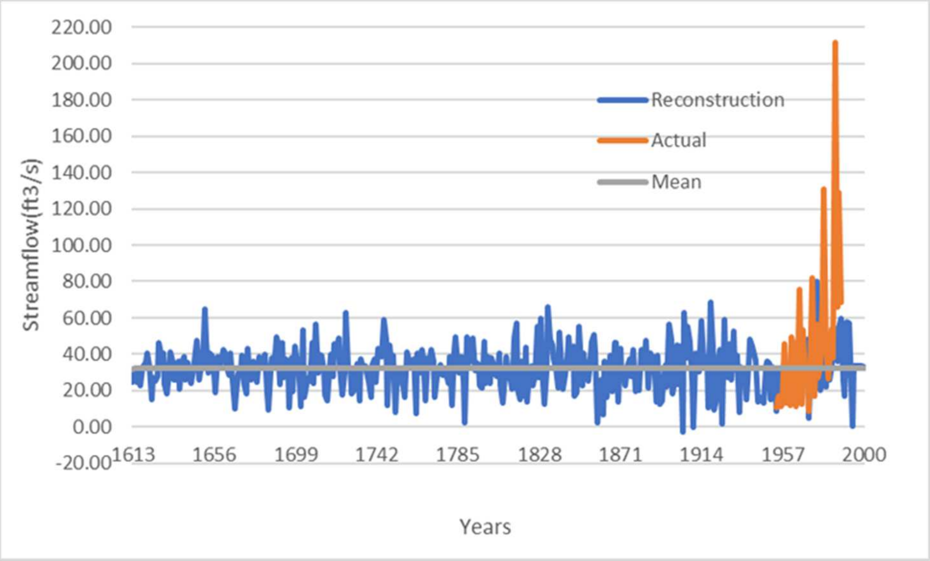

Figure 1.5. Comparison of January-March reconstructed streamflow (blue) and actual streamflow (orange).

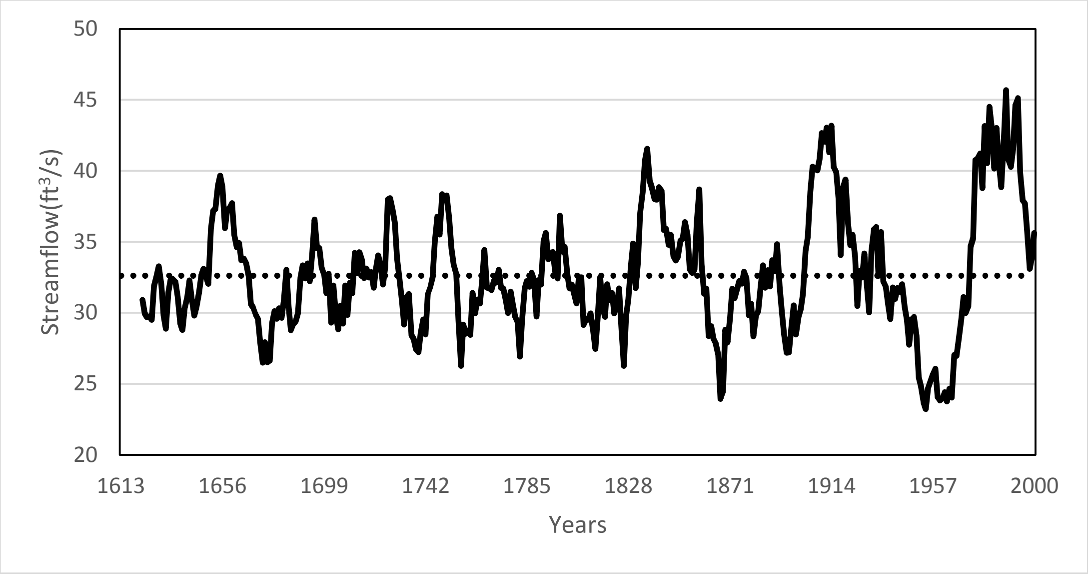

Figure 3.6 10-year moving average (black, continuous line) and mean reconstructed flow (black, dashed line)

3.2.3 Pecos Streamflow

The streamflow at Pecos gaging station with a period record of 380-years yearlong streamflow reconstruction for the streamflow season (Figure 3.7 &3.8). The two-sample t-test applied to the difference in mean of the extended reconstruction (1613-1930) shows a similar statistical significance at 95% confidence level (p less than 0.05) to the original gage data (1930-1992) for the overlapping period of record.

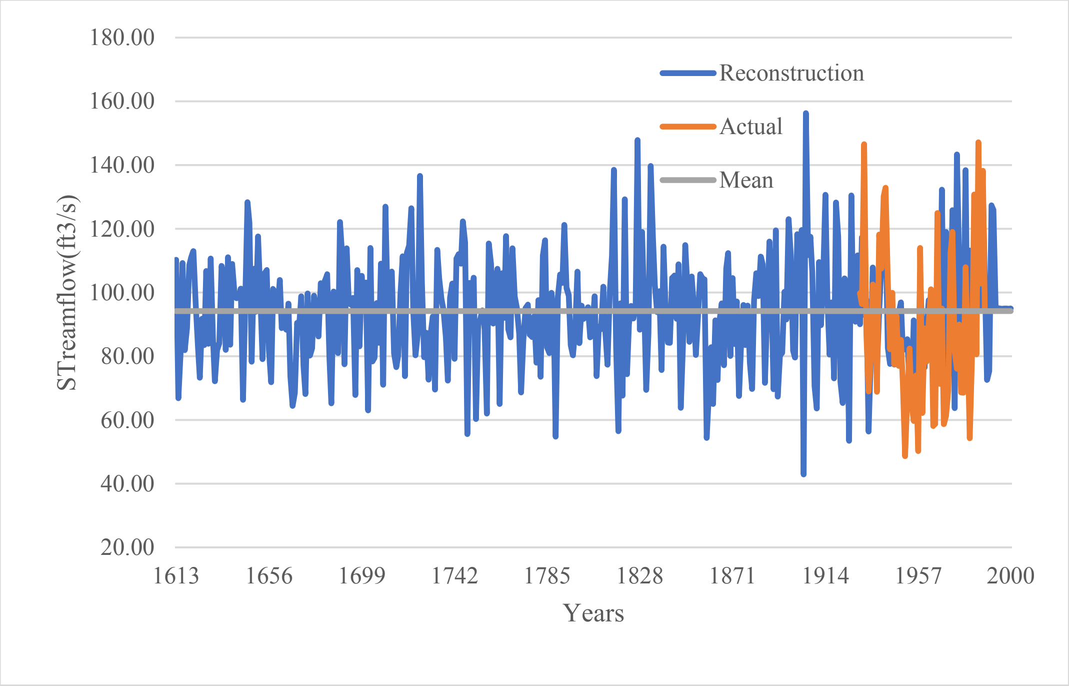

Figure 3.7. Comparison of January -March reconstructed streamflow (blue) and actual streamflow (orange)

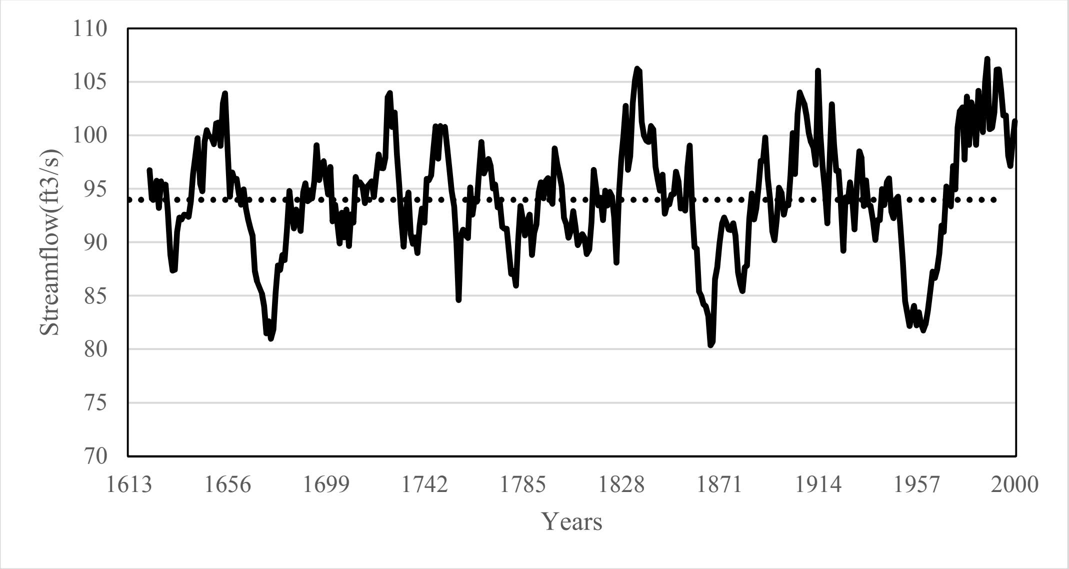

Figure 3.8. 10-year moving average (black, continuous line) and mean reconstructed flow (black, dashed line)

3.3 Extreme droughts

The analysis showed varying periods of dry years observed in the instrumental streamflow record. Significant dry event failing to meet the lower 5th percentile are also evident in the reconstruction (Figure 3.9). Common drought year was observed between the instrumental and reconstructed years which occurred in 1971 at Devils and Rio Ruidoso gauges (less than 5th percentile). A ranking of extreme years shows that most of the dry years occurred in the 20th century as compared to the 19th century (Table 3-2). However, notable drought years were also noticed in 18th century. It was observed that most drought events that occurred in the 18th century was common (1702,1748,1752,1763 and 1789) to all the three streamflow gauges. These results are similar to the findings of conducted by Woodhouse and co-workers on climate variability between the Upper Rio Grande and Rio Conchos River. They found the common drought years in the 18th century to be 1748,1763, 1773 and 1798 (Woodhouse et al., 2012). While their research identified 1934 as the single driest year common to Rio Grande and Rio Conchos, this finding found 1904 to be the driest single year amongst the three streamflow.

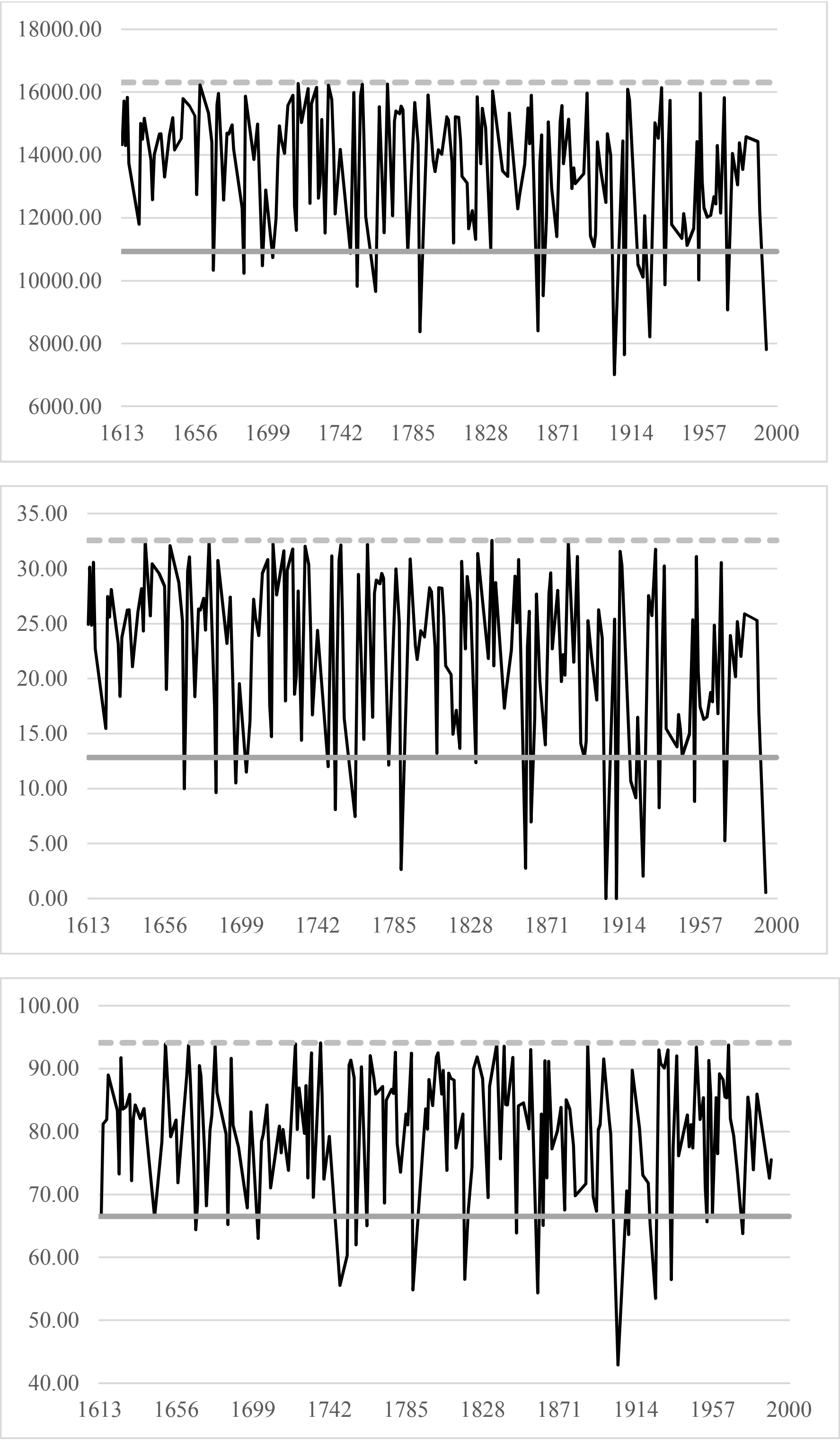

Figure 3.9. Reconstructed period of dry years for Devils, Rio Ruidoso, and Pecos streamflow respectively (Black). Mean flow (dashed, grey line), 5th percentile (continuous grey line).

3.4 Wet period

Analysis was carried out to show the wet events for the reconstructed gages exceeding the upper 95th percentile. Wet years were significantly higher in the 20th century as compared to previous century. It is interesting to observe that most dry event that occurred during the 20th century were succeeded by runs of wet periods, most notably. When analysis was compared the 18th century, it was observed that 18th century experienced more dry events than wet events (Table 3-2). The driest and wettest years are ranked based on the lowest 5th percentile for dry years and upper 95th percentile for wet years. Devils and Rio Ruidoso streamflow gages both shared the same chronology (West side Rd Sacramento Mountains), and as a result both showed similarities in their wet events.

Table 0-2**:** Significant wet and dry years

	Driest Years			**Wettest Years**		
Rank	Devils	Rio Ruidoso	Pecos	Devils	Rio Ruidoso	Pecos
1	1904	1994	1904	1975	1975	1905
2	1910	1925	1925	1979	1979	1827
3	1994	1789	1859	1919	1919	1975
4	1925	1859	1789	1833	1833	1833
5	1789	1971	1748	1651	1651	1816
6	1859	1862	1934	1905	1905	1979
7	1971	1763	1818	1726	1726	1726
8	1862	1752	1752	1973	1973	1968
9	1763	1934	1757	1829	1829	1987
10	1752	1954	1702	1988	1988	1914
11	1934	1921	1910	1926	1926	1926
12	1954	1685	1974	1746	1746	1821
13	1921	1667	1847	1914	1914	1646
14	1685	1696	1667	1991	1991	1919
15	1667	1918	1763	1816	1816	1991
16	1696	1702	1862	1992	1992	1710
17	1918	1748	1685	1710	1710	1722
18	1702	1782	1922	1897	1897	1992
19	1748	1831	1954	1827	1827	1973
20	1782	1892	1644	1907	1907	1897

CHAPTER IV

SUMMARY AND CONCLUSIONS

The magnitude and frequency of water supply shortages due to severe drought conditions and complex river system of the Lower Rio Grande Basin makes it essential to understand the history of past hydroclimate variability within the area. All three streamflow reconstructions developed in this research shows that the 20^{th} century has noticeably wetter periods than past centuries. An analysis of the instrumental record in the three streamflow gages indicates that extreme dry event occurred between 1950s (1951, 1954, 1957), 169 and 1981 (less than 5th percentile). This result correlates with the drought period (mid 1950s) reported by the Rio Grande Regional Water Authority in 2013. Similarly, individual dry event observed in the reconstructed flow occurred in 1910s, 1920s and 1954.

While these events of extreme individual dry events observed in the 20^{th} century significantly impacted water supply in the LRGB, it is likely that these low events have been equaled or exceeded by dry events prior to instrumental stream gage record. However, it is important for water managers to develop a water supply strategy in response to a repeat of drought patterns.

The reconstructions in this research were limited due to non-availability of significant tree ring chronologies within the focus area and limited period of record in the observed data. Only few tree ring-based reconstructions exist in the LRGB, as most are based on streamflow from the Colorado

River Basin. Most streamflow gages in the LRGB are affected by diversions and reservoir storage making it challenging to get long records of naturalized streamflow data. Reconstruction of streamflow within the LRGB has yet to be conducted. Thus, the aim of this research was to utilize statistical tools to reconstruct streamflow within the area which will enhance the understanding of extreme hydroclimate events. This could provide water managers with excellent starting point for future research on extreme streamflow patterns within the Lower Rio Grande Basin.

Future works can be directed towards using the models to predict future drought and wet seasons. Research can also be focused towards finding additional moisture sensitive tree rings to extend residual chronologies within the area with a view to improve the streamflow reconstructions.

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APPENDIX

APPENDIX

Appendix A1: Table Comparison

Table A-1: Flow comparisons (in ft3/s) between instrumental and reconstructed streamflow

Gage Name	**USGS Gage**	**Instrumental Period**				**Reconstructed Period**			
	Number	Mean	StDev	Min	Max	Mean	StDev	Min	Max
Pecos River	8378500	94.01	19.26	46.44	143.29	94.13	17.55	42.89	156.27
Rio Ruidoso	8387000	35.47	18.33	5.25	79.84	32.58	12.79	0.54	79.84
Devils River	8449400	17875	4927	9072	28965	16312	3462	7016	28965

Table A-2**:** Correlation Matrix for Tree Ring Chronology

	Sunspot	**West side**	**Guadalupe**
Sunspot			
West side	0.67		
Guadalupe	0.54	0.60	
Big Bend	0.63	0.63	0.624

Table A-3**:**Streamflow Correlations

	Sunspot	**West side**	**Guadalupe**	**Big Bend**
Pecos River, Tx	0.34	0.45	0.36	0.42
Rio Ruidoso R., NM	0.47	0.62	0.39	0.62
Devils River, Tx	0.49	0.36	0.18	0.60

Appendix A2: Streamflow Data

2.1 Rio Ruidoso River

Year	Jan	Feb	Mar	Apr	May	Jun
1954	3.31	3.86	3.65	5.14	3.43	1.6
1955	4.18	3.62	9.03	17.8	9.97	2.82
1956	2.65	3.96	4.74	2.61	2.01	2.77
1957	3.24	3.02	6.09	17.7	12.5	5.34
1958	6.77	9.41	29.4	90.2	63.5	13.2
1959	4.72	4.1	4.16	6.41	6.25	1.16
1960	4.29	5.19	21.7	29.8	12.2	8.63
1961	3.01	3.67	5.24	10.7	4.32	2.37
1962	7.44	25.4	16.5	67	33.5	6.31
1963	8.51	18.8	17.4	19.8	8.71	1.88
1964	3.35	3.32	4.84	7.14	2.34	1.65
1965	4.75	4.82	8.34	20.4	17.2	12.5
1966	16.4	10.1	49	46.8	32.6	8.62
1967	3.95	3.89	5.03	4.01	1.79	1.98
1968	5.69	13.6	34.2	69.6	61.3	20.7
1969	7.21	6.94	11.3	39.6	22.5	8.24
1970	9.94	6.34	12.4	23.5	11.5	4.43
1971	2.78	2.86	3.05	2.23	2.16	1.69
1972	16.4	13.5	21.1	12	6.6	8.09
1973	20.6	20.5	41	77.3	101.7	34.7
1974	5.11	4.65	7.45	10.5	6.31	3.13
1975	12.8	19.5	24.1	36.7	39.8	13.4
1976	7.21	12.7	7.48	13.4	39	14.7
1977	8.36	11.8	14.3	40.8	28.8	10.9
1978	7.84	8.9	54.9	73.3	45.9	17.9
1979	37.5	35.8	57.5	92.9	61.2	47.6
1980	10.9	15.1	17.4	26.1	40	14.1
1981	6.92	7.88	12	23.8	13.4	7.21
1982	7.74	11.6	17.1	20.2	17.7	5.96
1983	9.44	14	30.5	70.5	79.3	28.8
1984	11.5	9.87	16.6	19.9	26.8	15.7
1985	61.5	58.6	91.2	75.1	57.5	24.4
1986	12.1	22.6	31.3	39.9	17.1	52.3
1987	33.2	36.7	58.8	95.4	76.3	35.8
1988	12.2	23.3	33.1	27.8	21.9	14.5

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Year	Jul	Aug	Sep	Oct	Nov	Dec
1954	2.48	9.21	10.8	11.8	4.67	3.2
1955	19.9	34.8	13.6	13.4	3.73	3.6
1956	3.52	19.4	2.56	2.55	2.58	2.79
1957	5.13	14.9	17.8	14.3	13.5	9.62
1958	5.05	4.67	19.3	21.7	11.1	9.52
1959	3.36	17.6	7.04	3.66	2.93	2.8
1960	10.8	4.19	2.34	1.72	2.41	2.81
1961	2.53	5.71	15	4.76	3.83	6.97
1962	22.8	24.1	13	16.6	10.5	9.69
1963	3.73	9.85	25	6.51	5.05	3.51
1964	2.31	5.06	4.95	2.65	2.55	2.67
1965	6.25	33.4	44.4	8.98	5.91	11.6
1966	10.1	22.3	24.5	7.79	6.97	5.02
1967	11.2	49.7	13.3	6.98	4.81	4.27
1968	20.7	19.1	11.8	5.65	5.85	5.75
1969	7.09	17.6	40	10.3	9.36	9.33
1970	3.82	5.86	3.48	3.88	3.52	2.95
1971	7	22.1	8.04	21.8	16.9	13.3
1972	17.3	14.5	42.6	33.5	27.5	16.3
1973	18.1	13.8	6.49	4.35	4.26	4.65
1974	5.27	10	28.7	42.8	29.8	10.5
1975	12.6	14.6	40.5	8.39	7.76	7.2
1976	9.07	12.9	19.9	10.6	7.81	8.06
1977	12.6	29.5	15.9	8.11	7.36	6.42
1978	9.43	12	23.8	17.8	65.9	77.3
1979	13.1	23	16.8	9.43	9.07	8.32
1980	7.58	12.9	35.3	14.7	8.61	8.22
1981	8.99	26.4	14.2	9.4	7.43	6.59
1982	7.94	21.4	31.3	12.7	8.02	9.31
1983	8.92	8.25	12.5	20.8	11.8	11.5
1984	10.8	162.2	22	20.6	26.7	129.5
1985	11.2	18.9	13.3	61.5	21.8	16.4
1986	49.8	38.2	50.1	80.8	68.9	44.9
1987	13.5	31.7	19.4	12	14.1	11.6
1988	29.6	60.8	63.4	19	14.3	16.9

2.3 Pecos River

Year	Jan	Feb	Mar	Apr	May	Jun
1930	30.4	32.9	36.5	159.8	147	133.8
1931	26.3	28	42.1	162.9	368.3	201
1932	35.5	40.7	70.3	286.4	511.6	231.2
1933	24.9	27	34.8	51.4	136.8	153.4
1934	18.7	21.1	29.2	68.3	78.8	33.6
1935	20.3	21.8	37.2	124.4	315.7	450.7
1936	26.7	25.3	50.5	178.2	326.6	133.2
1937	23.6	30.1	39.2	259.3	445.1	325.4
1938	20.6	20.6	27.7	103.5	169.9	110.5
1939	26.3	25.1	66.8	201.2	303.3	100
1940	21.6	25.1	60.8	169.1	332.3	154.8
1941	35.5	34	60.6	172.2	1158	839.7
1942	49.7	40	43.2	366.5	708.4	417
1943	27.6	29.5	46.5	212.3	258.6	97.7
1944	26.9	25	30.3	71.6	424.2	349.7
1945	27.3	34.3	38.3	124.5	516.5	251.7
1946	21.7	28	27.8	110.1	95.3	39.6
1947	25.8	28.2	38.7	96	308.3	80.8
1948	16.1	23.7	37.2	208.9	450.2	335.1
1949	20.7	27.6	36.8	140.8	506.9	360.2
1950	22.2	23.4	25.9	53.9	43.7	30.2
1951	15.8	14.8	18.1	40.1	87.3	50.1
1952	21.2	20.7	25.7	157.3	403.5	400.6
1953	23.3	22.2	36.9	84.9	221.4	258.7
1954	19.6	21.7	24	87.7	134.6	62.2
1955	16.6	19.7	23.4	50.8	224.9	163.1
1956	18.9	18.9	36.2	47.7	64.4	28.6
1957	11.2	16.4	22.7	87.6	169.1	323.4
1958	38.5	31.4	44.1	252.4	873.9	494
1959	21.1	18.8	22.3	64.5	193.6	119.2

Year	Jan	Feb	Mar	Apr	May	Jun
1960	18.3	16.9	53.6	239.7	303.5	288.5
1961	23.2	20.3	34.8	158.5	400.5	202.8
1962	25.5	31.5	33.5	244	340.2	106.1
1963	22.2	28.9	49.9	138.9	149.7	55.7
1964	17.9	19.7	20.5	63.1	179.4	92.7
1965	19.3	19.6	19.8	120.4	338.9	362.4
1966	29.6	29.4	65.9	152.3	246.3	118
1967	20.6	21.7	29.1	51.8	57	43.5
1968	34.4	25.4	35.2	91.8	284.3	266.8
1969	16.6	18.1	24	118.5	316.2	222.9
1970	20.6	20.4	20.4	55.4	210.1	124.1
1971	23.1	19.8	26.5	45.8	63.4	45.8
1972	25.8	25.1	61.6	68.8	80.6	69.4
1973	37.8	34	47.2	151.9	782.3	699.3
1974	26.8	23.5	31.2	55.7	120.6	51.2
1975	21.3	24.5	30.3	72.2	332.4	323.7
1976	29.5	30.2	30.3	64.5	194.4	170.7
1977	19.8	22.3	26.6	68	170.1	89.5
1978	21.5	19.8	27.3	97.4	260.6	200
1979	23.9	29	55	254.5	703.2	950.3
1980	22.8	28.6	31	91.1	331.4	452.6
1981	18	17.8	18.5	56.4	77.9	49.2
1982	22.5	23.6	33.4	81.9	277.1	236.9
1983	42	33.6	55.2	157.4	537.9	642.9
1984	26.8	20.2	33.6	114.1	524.2	234.3
1985	30.7	35.5	80.9	272.2	677	521
1986	29.7	29.9	43.2	109.7	293.3	346.5
1987	39.8	39.7	58.7	161.8	496.2	400.4
1988	38.9	24	31.7	79.9	221.2	160.9

Year	Jul	Aug	Sep	Oct	Nov	Dec
1930	120.6	226.2	76.9	65.6	40.5	24.9
1931	95.8	67	284.2	137.8	62.8	55.3
1932	98.1	85.1	63.1	50	31	25.8
1933	113.5	70.8	36.7	27.9	23.5	18.2
1934	35	48.8	58.1	40.1	25.5	22.5
1935	109.3	203.4	149.2	62.9	40.7	33.9
1936	62.3	80.9	55	63.4	43.6	29.5
1937	161.7	64.2	77	44.4	29.7	24.6
1938	63.9	64.2	124.6	82.9	43.2	28.4
1939	50.3	80.5	69.8	47.7	28.1	19.5
1940	58.3	91.1	91.6	80.2	44.4	38.3
1941	299.5	258.7	167.7	216.9	138.4	61.9
1942	98.2	75.5	151.3	57.7	37.6	29
1943	45.3	61.5	38.8	35.7	28.6	26.7
1944	176.4	71.8	37.8	42.6	37.7	34
1945	79.9	64.3	46.6	34.2	25.5	19.8
1946	30.6	103.6	58.6	55.5	46	41.7
1947	40.4	60.6	38.6	32.6	21.2	17.9
1948	81	51.7	28.5	28.7	25.6	21
1949	148.9	104	47.4	34.4	27.3	22.4
1950	35.6	26.1	23.4	19.2	13.9	15.9
1951	26.8	159.2	54.3	27.3	21.5	19.4
1952	98.8	89.3	74	36.5	28.5	20.2
1953	68.8	43.3	22.8	21.5	25.1	22.4
1954	45.9	49.2	27.3	26.9	18.6	18
1955	75.9	240.8	105.7	43.3	34.8	34
1956	20.5	20	10.8	11.9	11.6	9.52
1957	137.2	401.9	168.3	99.3	92.6	61.8
1958	92.7	59.3	61.8	43.1	34	25.8
1959	47.1	103.4	47.9	33.4	26.1	20.9

Year	Jul	Aug	Sep	Oct	Nov	Dec
1960	112.1	86.5	41	40.9	31.8	26
1961	86.3	157.5	96	51.9	38.9	23.5
1962	65.1	40.7	29.6	26.3	27.6	22.5
1963	32.7	56.2	72.9	43.2	26.4	23.6
1964	44.5	52.6	39	26.1	24.3	19.5
1965	154	223.3	118.2	64.8	43.3	39.4
1966	88.1	127.6	56.7	33.2	25.2	27.4
1967	54.2	224.8	117.5	54.6	33.8	32.5
1968	102.6	219.2	61.7	32.5	23	20.7
1969	113.6	139.5	97.3	62.6	50.3	29.5
1970	89.4	108.1	58.5	39.4	31.3	27.3
1971	46.2	94.7	57.9	65.7	53.6	41.5
1972	52.5	85	78.8	78.7	69.9	49.8
1973	250.5	86.2	49.9	34.2	29.7	27.3
1974	37.5	47.9	28.7	43.7	36.9	24.7
1975	131.2	60.4	126.7	46.9	32.7	30.6
1976	73.4	79.2	53.1	34.4	24.2	21.5
1977	59.1	58.1	39.2	26.6	25.3	21.9
1978	65.5	40.9	27.8	26.7	43.1	27.6
1979	205.8	105.8	54.2	33.1	30.8	30.9
1980	95.6	53.4	46.4	30.7	29.6	25.4
1981	43.2	104.9	88	45.9	26.2	24.7
1982	78.4	194.5	187	84.6	53.5	45.7
1983	214.3	163.8	72.3	45	33.1	23.3
1984	82.5	95.7	52.3	50.5	41.3	32.7
1985	125.6	71.8	57.3	81	55.5	42.4
1986	208.9	88.9	69.9	70.3	75.9	48.7
1987	90.4	90.6	57.2	31.4	30.3	30.9
1988	177.4	193.2	216.2	83.5	44.4	29.6

2.3 Devils River

Year	Jan	Feb	Mar	April	May	June
1960	215.13	189.01	195.13	174.74	171.77	144.52
1961	175.27	159.54	144.99	125.5	119.04	636.32
1962	154.28	127.04	124.8	105.71	98.8	175.3
1963	136.4	111.06	109.33	95.85	157.08	143.93
1964	167.28	120.05	85.61	94.13	69.77	65.39
1965	229.54	192.23	180.15	155.08	169.83	776.16
1966	132.97	109.97	111.7	552.97	467.23	151.96
1967	135.9	105.24	106.85	85.42	76.52	68.23
1968	88.29	81.39	84.99	76.26	141.07	88.67
1969	66.32	57.1	59.71	64.5	70.19	60.81
1970	194.05	150.2	142.47	109.85	101.48	88.85
1971	69.32	59.31	60.2	77.34	64.48	560.92
1972	296.05	227.95	225.3	186.28	224.67	190.95
1973	259.62	223.29	224.12	196.01	202.08	172.95
1974	156.9	134.64	149.23	126.05	140.99	117.17
1975	344.2	336.3	322.2	299.39	320.67	294.69
1976	264.89	223.67	240.65	245.06	326.3	235.52
1977	412.3	361.2	377	549.6	398.6	353.7
1978	295.99	256.21	273.97	303.65	302.53	402.33
1979	292.59	252.89	270.13	246.06	353.52	354.17
1980	233.75	205.73	221.71	200.99	211.32	194.9
1981	222.17	186.28	198.26	263.87	504.45	494.34
1982	376.1	325.7	330.6	285.03	367.73	369.93
1983	221.56	197.65	203.91	186.79	185.38	153.44
1984	180.49	149.96	150.97	135.6	136.11	123.6
1985	260.68	163.25	163.41	146.82	146.7	163.41
1986	149.8	129.49	130.41	119.33	224.01	226.68
1987	365	379.3	321.67	271.01	267.76	545.3
1988	289.72	253.94	253.73	230.74	230.78	212.13

Year	July	Aug	Sep	Oct	Nov	Dec
1960	204.8	247.76	164.19	247.68	180.04	169.66
1961	342.4	236.46	205.03	211.36	188.32	167.3
1962	139.96	111.95	134.54	270.11	173.31	153.07
1963	118.89	110.28	99.58	102.08	87.83	88.22
1964	58.87	56.46	3900.21	453.3	292.42	257.8
1965	195.54	181.87	172.03	164.04	146.44	143.16
1966	123.94	192.85	151.24	166.05	141.91	142.86
1967	73.85	89	136.13	129.59	98.51	91.5
1968	109.15	74.72	76.81	65	64.7	64.87
1969	57.64	63	71.41	725.81	278.44	263.11
1970	77.51	71.75	74.97	79.83	69.95	70.97
1971	364.22	5834.2	449.6	406.4	357.1	331.64
1972	175.82	4057.22	372.9	356.22	298.76	277.93
1973	165.25	156.28	151.64	211.59	170.1	162.51
1974	111.99	586.21	7181.29	583.9	424.2	375.5
1975	411.81	356.9	312.65	298.79	281.15	273.07
1976	2667.27	559.1	726.4	504.4	471.3	443.6
1977	349.8	339.2	316.9	328.1	310.3	309.89
1978	274.44	267.3	295.56	288.45	312.18	302.75
1979	286.39	269.48	244.96	244.57	238.16	241.57
1980	187.58	216.56	1001.48	289.24	242.45	228.93
1981	327.61	307.2	301.24	2317.55	414.3	392.2
1982	322.91	287.69	256.7	243.97	237.42	234.09
1983	148.24	145.04	134.9	580.67	173.09	179.05
1984	113.33	108.36	114.37	160.56	132.1	167.75
1985	153.87	131.58	167.53	232.85	156.69	152.68
1986	180.66	263.52	231.34	3151.3	391.7	384.2
1987	379.7	353.5	354.3	336.2	313.2	308.98
1988	802.52	331	572.15	362.6	303.88	304.04

Appendix 3: Residual Chronologies

A3.1 Big Bend National Park

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1477	822	1508	1230	1539	1107	1570	1052
1478	1013	1509	1435	1540	1349	1571	981
1479	1346	1510	889	1541	910	1572	1000
1480	1022	1511	1574	1542	302	1573	618
1481	1293	1512	1082	1543	1247	1574	846
1482	1203	1513	1473	1544	636	1575	916
1483	822	1514	790	1545	886	1576	944
1484	1007	1515	727	1546	1146	1577	612
1485	847	1516	713	1547	459	1578	1113
1486	1590	1517	596	1548	937	1579	541
1487	621	1518	1020	1549	1074	1580	1155
1488	856	1519	1577	1550	1156	1581	1159
1489	1163	1520	853	1551	721	1582	799
1490	1272	1521	968	1552	1015	1583	580
1491	1393	1522	773	1553	1396	1584	1085
1492	1256	1523	993	1554	1902	1585	201
1493	794	1524	531	1555	1813	1586	1334
1494	999	1525	712	1556	1526	1587	1036
1495	393	1526	1539	1557	858	1588	1209
1496	1012	1527	612	1558	894	1589	446
1497	1202	1528	503	1559	710	1590	1158
1498	1224	1529	931	1560	890	1591	698
1499	1515	1530	1419	1561	1027	1592	662
1500	812	1531	937	1562	856	1593	1122
1501	857	1532	796	1563	1375	1594	1305
1502	857	1533	1132	1564	1026	1595	905
1503	753	1534	1061	1565	1376	1596	924
1504	967	1535	922	1566	1186	1597	1035
1505	1400	1536	1955	1567	752	1598	947
1506	1094	1537	1244	1568	1256	1599	1207
1507	1513	1538	110	1569	899	1600	703

Year	Trsgi
1601	561
1602	1321
1603	1274
1604	704
1605	556
1606	811
1607	1100
1608	1360
1609	1233
1610	1171
1611	957
1612	1290
1613	768
1614	841
1615	853
1616	1165
1617	912
1618	1169
1619	972
1620	1194
1621	1214
1622	996
1623	613
1624	760
1625	1103
1626	755
1627	1550
1628	1185
1629	1791
1630	1151
1631	896
1632	344
1633	801
1634	1377
1635	1037
1636	918
1637	936
1638	1066
1639	1338
1640	1387
1641	1122
1642	1075
1643	1073
1644	728
1645	774
1646	1198
1647	1012
1648	518
1649	1091
1650	1050
1651	1561
1652	1193
1653	644
1654	740
1655	1224
1656	981
1657	1050
1658	1205
1659	841
1660	1212
1661	1348
1662	937
1663	1144
1664	744
1665	1307
1666	759
1667	610
1668	494
1669	1057
1670	434
1671	1375
1672	923
1673	712
1674	1265
1675	1067
1676	552
1677	1404
1678	908
1679	1208
1680	1297
1681	855
1682	1203
1683	1193
1684	851
1685	500
1686	1410
1687	842
1688	889
1689	1360
1690	1216
1691	844
1692	1414
1693	955
1694	826
1695	934
1696	473
1697	1088
1698	906
1699	1355
1700	951
1701	1546
1702	944
1703	877
1704	581
1705	737
1706	940
1707	920
1708	679
1709	715
1710	1423
1711	792
1712	1202
1713	776
1714	984
1715	676
1716	654
1717	1214
1718	1280
1719	798
1720	1171
1721	1454
1722	1206
1723	1071
1724	1083

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1725	806	1756	906	1787	1031	1818	663
1726	1956	1757	618	1788	1148	1819	333
1727	849	1758	1188	1789	603	1820	993
1728	742	1759	1134	1790	645	1821	1336
1729	904	1760	878	1791	1138	1822	803
1730	675	1761	1322	1792	1151	1823	727
1731	720	1762	1308	1793	1401	1824	1324
1732	865	1763	562	1794	872	1825	1109
1733	517	1764	1133	1795	1432	1826	1634
1734	1355	1765	967	1796	797	1827	1395
1735	1013	1766	1546	1797	875	1828	1116
1736	1113	1767	1125	1798	854	1829	1368
1737	1257	1768	1071	1799	1299	1830	962
1738	892	1769	1016	1800	1165	1831	755
1739	375	1770	1132	1801	688	1832	814
1740	1092	1771	1172	1802	1078	1833	1308
1741	1202	1772	811	1803	905	1834	1036
1742	670	1773	731	1804	913	1835	1248
1743	990	1774	937	1805	414	1836	871
1744	1051	1775	1157	1806	890	1837	1376
1745	1208	1776	819	1807	971	1838	1057
1746	1746	1777	865	1808	594	1839	1110
1747	1399	1778	783	1809	1222	1840	681
1748	329	1779	952	1810	1191	1841	438
1749	952	1780	835	1811	979	1842	683
1750	873	1781	847	1812	719	1843	1149
1751	1134	1782	713	1813	646	1844	1287
1752	498	1783	1360	1814	1089	1845	1458
1753	847	1784	1394	1815	1405	1846	1552
1754	1019	1785	469	1816	1752	1847	382
1755	736	1786	870	1817	832	1848	1243

Year	Trsgi
1849	944
1850	1316
1851	584
1852	953
1853	1283
1854	503
1855	1173
1856	1534
1857	912
1858	1684
1859	620
1860	744
1861	809
1862	758
1863	356
1864	915
1865	1164
1866	1034
1867	860
1868	1182
1869	1391
1870	839
1871	511
1872	578
1873	1099
1874	1029
1875	787
1876	1293
1877	1149
1878	1100
1879	663
1880	900
1881	1323
1882	1403
1883	1053
1884	589
1885	1259
1886	546
1887	781
1888	1462
1889	1052
1890	538
1891	1223
1892	503
1893	857
1894	649
1895	834
1896	1203
1897	744
1898	1046
1899	746
1900	900
1901	1415
1902	417
1903	1584
1904	395
1905	1459
1906	1096
1907	1169
1908	1942
1909	539
1910	113
1911	1278
1912	1312
1913	926
1914	1089
1915	1386
1916	740
1917	1134
1918	738
1919	1511
1920	1390
1921	821
1922	691
1923	1265
1924	1310
1925	48
1926	1720
1927	1198
1928	939
1929	806
1930	1119
1931	1462
1932	937
1933	1096
1934	363
1935	1436
1936	1054
1937	1030
1938	972
1939	821
1940	1365
1941	1580
1942	991
1943	925
1944	1205
1945	978
1946	931
1947	1027
1948	813
1949	1354
1950	565
1951	828
1952	1128
1953	627
1954	359
1955	787
1956	457
1957	984
1958	1117
1959	918
1960	1183
1961	648
1962	964
1963	794
1964	602
1965	984
1966	981
1967	931
1968	1301
1969	674
1970	964
1971	422
1972	1139

Year	Trsgi
1973	1346
1974	60
1975	1482
1976	927
1977	1164
1978	963
1979	1578
1980	603
1981	1331
1982	1400
1983	1125
1984	952
1985	1416
1986	916
1987	1601
1988	1065
1989	476
1990	682
1991	1526
1992	1436

A3.2: Guadalupe peak

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1539	107	1570	705	1601	650	1632	796
1540	1486	1571	494	1602	1037	1633	441
1541	1374	1572	409	1603	1193	1634	1409
1542	1478	1573	871	1604	1226	1635	1549
1543	226	1574	494	1605	1079	1636	731
1544	2515	1575	598	1606	1517	1637	1512
1545	500	1576	727	1607	947	1638	916
1546	1082	1577	852	1608	306	1639	1444
1547	722	1578	1097	1609	1802	1640	1071
1548	979	1579	610	1610	1696	1641	1306
1549	1781	1580	536	1611	1274	1642	1075
1550	904	1581	828	1612	1607	1643	1359
1551	1484	1582	1062	1613	1758	1644	225
1552	900	1583	945	1614	99	1645	1124
1553	588	1584	343	1615	737	1646	2112
1554	955	1585	463	1616	1582	1647	1597
1555	1803	1586	1351	1617	815	1648	613
1556	946	1587	1266	1618	814	1649	1523
1557	1601	1588	966	1619	1478	1650	979
1558	2082	1589	1050	1620	1510	1651	1027
1559	0	1590	884	1621	1469	1652	788
1560	1042	1591	718	1622	1083	1653	547
1561	1963	1592	1317	1623	1047	1654	1214
1562	147	1593	561	1624	391	1655	1287
1563	254	1594	1561	1625	1090	1656	670
1564	668	1595	1403	1626	739	1657	552
1565	1361	1596	1280	1627	1100	1658	1099
1566	1555	1597	781	1628	462	1659	1225
1567	804	1598	1086	1629	1382	1660	943
1568	50	1599	348	1630	945	1661	1100
1569	366	1600	1323	1631	580	1662	636

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1663	982	1694	945	1725	813	1756	967
1664	891	1695	1143	1726	1749	1757	270
1665	885	1696	623	1727	1313	1758	1541
1666	463	1697	1315	1728	511	1759	1376
1667	515	1698	937	1729	1108	1760	838
1668	445	1699	1093	1730	549	1761	1199
1669	942	1700	1082	1731	856	1762	1348
1670	849	1701	1206	1732	882	1763	599
1671	997	1702	427	1733	586	1764	1223
1672	626	1703	1176	1734	1560	1765	1005
1673	440	1704	856	1735	1378	1766	1592
1674	930	1705	721	1736	1112	1767	671
1675	665	1706	1223	1737	1055	1768	1163
1676	752	1707	824	1738	908	1769	1554
1677	1080	1708	1180	1739	630	1770	1179
1678	1109	1709	401	1740	1117	1771	779
1679	924	1710	1559	1741	1190	1772	662
1680	1163	1711	1124	1742	678	1773	502
1681	1005	1712	1221	1743	1327	1774	795
1682	1264	1713	1271	1744	1390	1775	1128
1683	1230	1714	575	1745	1370	1776	1036
1684	865	1715	755	1746	1334	1777	838
1685	553	1716	958	1747	1378	1778	790
1686	1263	1717	1198	1748	152	1779	1033
1687	778	1718	1419	1749	1005	1780	651
1688	527	1719	407	1750	1087	1781	971
1689	1560	1720	1316	1751	1203	1782	784
1690	1246	1721	1454	1752	417	1783	1366
1691	648	1722	1727	1753	1140	1784	1366
1692	1360	1723	1017	1754	946	1785	553
1693	1277	1724	878	1755	1019	1786	603

Year	Trsgi
1787	1055
1788	1128
1789	359
1790	743
1791	1333
1792	1062
1793	1554
1794	1301
1795	1103
1796	587
1797	753
1798	1064
1799	1079
1800	852
1801	907
1802	1135
1803	806
1804	1018
1805	820
1806	959
1807	970
1808	526
1809	1312
1810	909
1811	1122
1812	899
1813	584
1814	1484
1815	1196
1816	1950
1817	904
1818	113
1819	992
1820	451
1821	1961
1822	775
1823	900
1824	1028
1825	1166
1826	1153
1827	2330
1828	938
1829	1195
1830	1021
1831	635
1832	784
1833	1775
1834	1422
1835	981
1836	872
1837	1219
1838	617
1839	1222
1840	980
1841	939
1842	746
1843	1224
1844	979
1845	894
1846	1221
1847	313
1848	986
1849	1169
1850	1028
1851	911
1852	1190
1853	1122
1854	704
1855	1005
1856	1051
1857	904
1858	1125
1859	341
1860	345
1861	761
1862	613
1863	807
1864	647
1865	1017
1866	928
1867	723
1868	1124
1869	1297
1870	969
1871	1102
1872	759
1873	1181
1874	307
1875	659
1876	955
1877	739
1878	812
1879	744
1880	400
1881	1429
1882	1178
1883	1172
1884	1390
1885	1145
1886	485
1887	800
1888	1807
1889	1141
1890	599
1891	1721
1892	548
1893	967
1894	722
1895	1167
1896	1176
1897	1428
1898	1221
1899	929
1900	646
1901	1538
1902	1272
1903	1610
1904	66
1905	2432
1906	1490
1907	1263
1908	1072
1909	348
1910	738

Year	Trsgi
1911	1350
1912	871
1913	1423
1914	1648
1915	1050
1916	472
1917	945
1918	802
1919	1308
1920	1530
1921	797
1922	385
1923	1232
1924	992
1925	328
1926	1615
1927	922
1928	1009
1929	1293
1930	1028
1931	1323
1932	980
1933	958
1934	277
1935	400
1936	1683
1937	984
1938	793
1939	945
1940	1129
1941	1522
1942	1818
1943	496
1944	885
1945	935
1946	838
1947	1179
1948	953
1949	1000
1950	514
1951	1062
1952	675
1953	372
1954	587
1955	937
1956	1008
1957	423
1958	1283
1959	1097
1960	374
1961	1226
1962	1000
1963	1136
1964	1062
1965	883
1966	540
1967	968
1968	1923
1969	528
1970	1488
1971	959
1972	781
1973	1407
1974	145
1975	1556
1976	1052
1977	1004
1978	801
1979	1519
1980	550
1981	1368
1982	879
1983	989
1984	1213
1985	1344
1986	942
1987	1817
1988	706
1989	421
1990	732
1991	1548
1992	1517

A3.3: Sunspot

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1630	825	1661	1342	1692	1068	1723	871
1631	863	1662	1084	1693	993	1724	587
1632	631	1663	902	1694	882	1725	960
1633	786	1664	791	1695	966	1726	1308
1634	1156	1665	1178	1696	521	1727	1113
1635	990	1666	1072	1697	1313	1728	958
1636	1081	1667	479	1698	811	1729	715
1637	1200	1668	641	1699	1380	1730	655
1638	1035	1669	1178	1700	1237	1731	821
1639	1007	1670	862	1701	1196	1732	948
1640	1293	1671	1268	1702	543	1733	580
1641	1024	1672	728	1703	873	1734	955
1642	1272	1673	897	1704	823	1735	970
1643	1062	1674	1251	1705	575	1736	1137
1644	1013	1675	1095	1706	923	1737	994
1645	1261	1676	1060	1707	856	1738	803
1646	1157	1677	1337	1708	1316	1739	506
1647	838	1678	976	1709	819	1740	892
1648	751	1679	973	1710	1339	1741	1182
1649	877	1680	1215	1711	912	1742	711
1650	1021	1681	1027	1712	1091	1743	1510
1651	1426	1682	1061	1713	1042	1744	1541
1652	1014	1683	1182	1714	973	1745	1433
1653	908	1684	651	1715	688	1746	1516
1654	979	1685	470	1716	619	1747	1465
1655	1206	1686	1325	1717	1182	1748	45
1656	802	1687	1191	1718	1180	1749	1306
1657	1051	1688	1014	1719	720	1750	920
1658	1062	1689	1366	1720	1257	1751	1437
1659	1119	1690	1261	1721	1382	1752	335
1660	1054	1691	806	1722	1623	1753	1133

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1754	938	1785	671	1816	1610	1847	505
1755	918	1786	764	1817	797	1848	946
1756	1235	1787	1131	1818	455	1849	1230
1757	1212	1788	795	1819	1075	1850	1142
1758	1167	1789	384	1820	765	1851	706
1759	1061	1790	1183	1821	1058	1852	1089
1760	851	1791	1275	1822	749	1853	1066
1761	930	1792	1304	1823	846	1854	1291
1762	1367	1793	1726	1824	992	1855	958
1763	465	1794	791	1825	925	1856	1402
1764	1122	1795	693	1826	1253	1857	1187
1765	1184	1796	1079	1827	1413	1858	1306
1766	1289	1797	892	1828	1147	1859	599
1767	988	1798	690	1829	1023	1860	1030
1768	687	1799	1303	1830	783	1861	1397
1769	1193	1800	866	1831	775	1862	906
1770	852	1801	764	1832	1058	1863	737
1771	1119	1802	899	1833	937	1864	986
1772	987	1803	966	1834	984	1865	857
1773	434	1804	1135	1835	937	1866	896
1774	733	1805	904	1836	958	1867	1121
1775	1126	1806	1170	1837	789	1868	1014
1776	899	1807	1369	1838	847	1869	1540
1777	795	1808	1196	1839	1014	1870	549
1778	885	1809	921	1840	1254	1871	1184
1779	954	1810	943	1841	699	1872	968
1780	767	1811	1024	1842	571	1873	859
1781	1048	1812	924	1843	1034	1874	642
1782	551	1813	794	1844	1052	1875	763
1783	1357	1814	1019	1845	1250	1876	1201
1784	1345	1815	1285	1846	1299	1877	1104

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1878	763	1909	894	1940	1285	1971	487
1879	813	1910	632	1941	1395	1972	962
1880	1124	1911	1318	1942	869	1973	1295
1881	1006	1912	1121	1943	1450	1974	341
1882	1272	1913	1047	1944	1216	1975	1249
1883	1718	1914	1100	1945	391	1976	1225
1884	1056	1915	822	1946	659	1977	900
1885	991	1916	994	1947	922	1978	1089
1886	1102	1917	1220	1948	988	1979	1043
1887	955	1918	857	1949	921	1980	892
1888	1206	1919	1300	1950	1034	1981	988
1889	954	1920	1539	1951	864	1982	1169
1890	879	1921	687	1952	1063	1983	951
1891	1233	1922	842	1953	956	1984	1353
1892	701	1923	884	1954	227	1985	1111
1893	664	1924	980	1955	948	1986	1034
1894	817	1925	515	1956	601	1987	1199
1895	1327	1926	1550	1957	895	1988	1185
1896	1029	1927	1128	1958	992	1989	709
1897	1028	1928	851	1959	698	1990	1105
1898	1419	1929	916	1960	975	1991	1231
1899	906	1930	1055	1961	796	1992	1438
1900	933	1931	1059	1962	759		
1901	1346	1932	1413	1963	918		
1902	848	1933	1380	1964	767		
1903	1264	1934	252	1965	1237		
1904	367	1935	988	1966	1155		
1905	1453	1936	1199	1967	707		
1906	970	1937	1095	1968	996		
1907	1234	1938	1068	1969	888		
1908	1300	1939	518	1970	990		

A.3.4 West Side Mountains

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1613	774	1644	755	1675	816	1706	843
1614	932	1645	1005	1676	813	1707	794
1615	771	1646	1124	1677	1117	1708	1426
1616	945	1647	1469	1678	846	1709	743
1617	707	1648	797	1679	758	1710	1734
1618	1012	1649	941	1680	1185	1711	915
1619	1039	1650	1024	1681	1004	1712	1230
1620	1110	1651	1981	1682	1099	1713	1209
1621	1245	1652	1490	1683	1226	1714	953
1622	1014	1653	914	1684	546	1715	552
1623	486	1654	1258	1685	309	1716	464
1624	851	1655	1211	1686	950	1717	996
1625	794	1656	879	1687	1169	1718	1236
1626	870	1657	594	1688	1018	1719	855
1627	1428	1658	1185	1689	1526	1720	1399
1628	1224	1659	991	1690	1447	1721	1330
1629	1251	1660	1114	1691	721	1722	1507
1630	720	1661	1303	1692	1417	1723	977
1631	575	1662	1223	1693	849	1724	562
1632	738	1663	1010	1694	1160	1725	923
1633	1262	1664	889	1695	1011	1726	1918
1634	1119	1665	1246	1696	336	1727	1025
1635	813	1666	783	1697	1177	1728	982
1636	814	1667	320	1698	610	1729	581
1637	1111	1668	582	1699	1370	1730	632
1638	657	1669	920	1700	1043	1731	866
1639	1100	1670	960	1701	1143	1732	1079
1640	1182	1671	1212	1702	366	1733	454
1641	808	1672	723	1703	1644	1734	1152
1642	1101	1673	574	1704	507	1735	989
1643	872	1674	1329	1705	722	1736	1040

Year	Trsgi
1737	938
1738	763
1739	524
1740	1050
1741	1146
1742	757
1743	1318
1744	1300
1745	1195
1746	1809
1747	1472
1748	381
1749	1382
1750	963
1751	1210
1752	262
1753	679
1754	952
1755	993
1756	805
1757	515
1758	1260
1759	1187
1760	1039
1761	1114
1762	1155
1763	243
1764	1245
1765	912
1766	1299
1767	1165
1768	456
1769	1179
1770	994
1771	1313
1772	1118
1773	517
1774	860
1775	896
1776	1050
1777	886
1778	914
1779	900
1780	740
1781	1189
1782	385
1783	1314
1784	1515
1785	1062
1786	927
1787	1186
1788	779
1789	97
1790	1521
1791	1093
1792	1311
1793	1494
1794	954
1795	1090
1796	1056
1797	715
1798	677
1799	1441
1800	756
1801	1196
1802	739
1803	1172
1804	1040
1805	875
1806	865
1807	1245
1808	711
1809	418
1810	875
1811	1189
1812	873
1813	793
1814	659
1815	1518
1816	1756
1817	635
1818	470
1819	1122
1820	536
1821	1343
1822	431
1823	948
1824	1041
1825	706
1826	906
1827	1696
1828	835
1829	1835
1830	1018
1831	392
1832	969
1833	2020
1834	1486
1835	1380
1836	1153
1837	1007
1838	679
1839	1606
1840	1005
1841	659
1842	889
1843	1184
1844	1512
1845	1034
1846	1370
1847	542
1848	591
1849	1690
1850	1348
1851	703
1852	1244
1853	907
1854	778
1855	953
1856	1443
1857	1564
1858	1282
1859	100
1860	711

Year	Trsgi	Year	Trsgi	Year	Trsgi	Year	Trsgi
1861	810	1892	405	1923	1164	1954	285
1862	228	1893	451	1924	1313	1955	961
1863	1118	1894	784	1925	78	1956	643
1864	511	1895	1063	1926	1816	1957	546
1865	857	1896	681	1927	1052	1958	1164
1866	1201	1897	1726	1928	853	1959	511
1867	617	1898	1477	1929	1401	1960	1009
1868	1430	1899	565	1930	798	1961	518
1869	1428	1900	814	1931	1609	1962	1155
1870	441	1901	1388	1932	981	1963	586
1871	1330	1902	735	1933	1211	1964	560
1872	858	1903	1358	1934	267	1965	771
1873	916	1904	-58	1935	1016	1966	1550
1874	706	1905	1932	1936	762	1967	527
1875	1030	1906	1165	1937	935	1968	1521
1876	1145	1907	1691	1938	485	1969	944
1877	867	1908	1437	1939	1076	1970	1480
1878	1312	1909	788	1940	1480	1971	176
1879	616	1910	14	1941	1362	1972	1290
1880	690	1911	1242	1942	1213	1973	1871
1881	633	1912	975	1943	1125	1974	743
1882	1302	1913	936	1944	435	1975	2441
1883	1001	1914	1787	1945	525	1976	1585
1884	1267	1915	1134	1946	484	1977	629
1885	1456	1916	1065	1947	410	1978	781
1886	669	1917	1190	1948	1033	1979	2276
1887	1241	1918	341	1949	1123	1980	685
1888	961	1919	2097	1950	1074	1981	1378
1889	1184	1920	1358	1951	471	1982	803
1890	445	1921	295	1952	1025	1983	1039
1891	1216	1922	517	1953	786	1984	1613

Year	Trsgi
1985	1654
1986	1106
1987	1650
1988	1831
1989	785
1990	533
1991	1765
1992	1744
1993	1185
1994	33

BIOGRAPHICAL SKETCH

Adedolapo Adeyanju was born in Osogbo, Nigeria in November 1993. She completed her high school education at Ataoja School of Science in July 2009. She received her bachelor's degree in quantity surveying from Obafemi Awolowo University, Ile-Ife in September 2015, and proceeded to obtain a master's degree in construction management from the University of Lagos, Akoka in December,2020. In the Spring of 2021, Adedolapo commenced her graduate studies in civil engineering at the University of Texas, Rio Grande Valley under the supervision of Dr. Abdoul Oubeidillah, and completed her degree in August 2022. His research is focused on water resources, particularly surface hydrology, hydro-informatics, hydro-climatology, and hydrological modelling. During her time at UTRGV, Adedolapo was an active member of the Society of Women Engineer and the National Society of Black Engineers (NSBE).

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