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Colorado's Large Snow Events' Impact on Tree Ring Growth and Dillon Reservoir

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Colorado's Large Snow Events' Impact on Tree Ring Growth and Dillon Reservoir

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Master of Arts

By
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ABSTRACT

Meteorological observations from 1894 through 2010 suggest that 17 historically large snow events occurred in the mountains of Colorado within Denver's water supply region. Of these 16 events, 14 can be identified in precipitation sensitive tree ring records as positive climatic pointer years. If these storms were to occur today, they would have the potential to fill reservoirs in Denver Water's supply system, even after years of sustained drought. These "drought busters" have the potential to refill Dillon Reservoir by increasing average yearly inflow up to 146% of the previous year's inflow. Such drought busters can help Denver recover from droughts that will most likely increase in frequency and severity in the near future. However, drought busters cannot be precisely predicted because past positive climatic pointer years used for calibration may be falsely identified due to certain climatic patterns and the biological responses of trees.

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CHAPTER 1: INTRODUCTION

Purpose and Importance of Study

Denver, Colorado is the largest city in the Intermountain West of the United States. Its temperate, semi-arid climate produces minimal precipitation each year and mountain snowmelt currently accounts for most of the city's domestic water supply. With a metro area population that is expected to double reaching more than five million people in the late 21st century, Denver must be certain it can provide water to its future residents. Denver's water storage system was recently challenged in 2002 when precipitation and snowpack above Denver was reduced by a severe drought. In fact, 2002 was the single driest year in Colorado since the late-1600s and at least the third year of a sustained regional drought (Pielke et al. 2005). By August 2002, Denver's largest water storage facility (Dillon Reservoir) had declined by approximately 54%, causing widespread water restrictions throughout the city (Denver Water Dataset 2010). The 1999-2002 drought was hydrologically comparable to the 1950s drought, an 11 year dry era from 1946-1956 that was the second worst drought to impact the western United States during instrumental record (Fye, Stahle, and Cook 2003). However, water demand in the 1950s was much lower (Pielke et al. 2005) than in 2002, causing the greatest deficit in Denver's water supply in 2002. Yet, in March 2003 a historically large blizzard descended on Colorado’s Front Range resulting in 221 centimeters of snow measured at the Dillon weather station (NASA 2010). When the snow from this storm and the winter season melted, Dillon Reservoir’s inflow rebounded to over 100% of the 30-year average (Denver Water Dataset 2010) due to stream runoff. This example suggests that some large snow storms may be able to mitigate several years of severe drought, at least from the perspective of Denver water managers who monitor reservoir capacity.

Determining how historically large snow events can mitigate drought by quickly refilling reservoirs is critically important because severe drought is among the greatest reoccurring natural disasters in North America (Cook et al. 2007). Managing finite water resources in metro Denver is of concern because as the population continues to grow, temperatures are predicted to rise 1-2°C by 2025 (Solomon et al. 2007) and droughts are expected to increase in severity (Woodhouse, Russell, and Cook 2009). In addition, multi-decadal droughts (megadroughts) are known to be common features of Earth’s climate system over the past 1,000 years and expected to occur in the near future.

Large snow storms, like the March 2003 event, could be considered “drought busters” if they can refill a reservoir even after years of climatic drought. This study utilizes meteorological observations and streamflow records to identify historically large snow storm events that could be considered drought busters. This study also employs moisture sensitive tree ring records in an attempt to reconstruct the frequency of past drought busters well before humans chronicled their existence.

Using tree ring width records to identify past drought busting events may be feasible because many western United States trees can be used to reconstruct hydroclimatic variables including precipitation, drought, and streamflow (Woodhouse 2003). In this study abnormally thick or thin rings, known as climatic pointer years (CPYs), are compared to modern extreme weather events or years (Knapp, Grissino-Mayer, and Soul´e 2002; Bridge, Gasson, and Cutler 1996). Positive CPYs may identify past snow storms events or wet years that would have been able to refill dry reservoirs by increasing reservoir inflow. Understanding CPYs' influence on inflow is crucial because inflow is the amount of water entering a reservoir and thus the most important predictor of water supply.

By comprehending the past natural variability of positive CPYs, we can better anticipate future drought busting events including the probability of one occurring immediately after a severe drought that could refill a reservoir. Such research has not been thoroughly attempted in Colorado and is vitally important because water managers can better prepare for a growing population's future needs by understanding the past variability of drought busters over several centuries. This study will also increase our understanding of extreme precipitation events' impact on ring width in Colorado's Front Range and Western Slope.

Research Questions

Main Research Objective:

I examined how historically large snow events in Colorado impact tree ring growth and stream inflow near the Dillon Reservoir.

The overriding objective was accomplished by addressing the following five research questions:

Research Question 1:

Can the largest historic snowfall events be recognized in tree ring records?

Years with large snow events identified by data from the Colorado Climate Center were compared to tree ring chronologies from sites located in Colorado's Front Range and Western Slope complied by J. Lukas, C. Woodhouse, and their colleagues. If the rings were significantly wider than average during a year with one (or more) large snow event(s), they indicated higher moisture most likely due to the snow event(s) as suggested by the work of Bridge, Gasson, and Cutler (1996), Knapp, Grissino-Mayer, and Soul´e (2002) as well as Koprowski and Zielski (2008). Thus the 1890-2010 meteorological record was used as a calibration dataset to correlate historically large snowfall events to wide tree rings. According to Speer (2010), calibration is a common dendroclimatology procedure where known records, such as meteorological data, are compared to tree ring chronologies to determine growth response to a variable (weather events in this study) that can also be used to determine patterns for prediction. Examining the chronologies also helped determine the storms' spatial footprint.

Research question 2:

Are high snowfall events positive Climatic Pointer Years According to the Skeleton Plot method?

The second research question was answered by identifying all CPYs in each site's chronology and ascertaining if the positive CPYs were the same years as the large snow events for verification and calibration. (Negative CPYs were also calculated for use in other research questions.) The Skeleton Plot method was used to determine CPYs, but was modified slightly due to environmental differences, type of data available, and to reduce error.

Research Question 3:

Can positive CPYs (if correlated to individual storms) be reconstructed to identify storm frequency and magnitude?

If so, what does the reconstruction predict for future drought busting storms?

Large snow storms and very wet years were correlated to positive CPYs during the meteorological record (as shown by previous research questions answered in later sections of this study). CPY frequency and magnitude (strong or median as identified through the modified Skeleton Plot method) was identified from the 500-800 year-old tree ring chronologies. This period of calibration allowed drought busters to be predicted for Colorado's Front Range. Calibration also enabled the probability of positive CPYs immediately following negative CPYs to be identified, which assisted in predicting the impact of drought busting storms on Dillon reservoir.

Research Question 4:

How are positive CPYs correlated to inflow at Dillon Reservoir?

This question is related to research question 1. The calibration datasets of meteorological records and streamflow data were used to examine tree ring's relation to Dillon Reservoir's inflow. Specifically, positive CPYs were examined in relationship to Dillon Reservoir's inflow to identify if they were related to inflow. Negative CPYs were also examined to determine if they impacted the reservoir, which helped determine the importance of positive CPYs for reservoir refilling.

Research Question 5:

What does the record of natural variability tell us about future water management in terms of large snow events' potential to fill reservoirs?

Snow storm events capable of producing positive CPYs and refilling Dillon Reservoir after a drought were examined based on the calibration datasets of meteorological records and streamflow (inflow from the Blue River into Dillon Reservoir). Because positive CPYs can be predicted on a century time scale, their effect on water management was also evaluated.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

Using Tree Rings to Reconstruct Past Climate

Tree ring chronologies can provide information regarding paleoclimatic events such as drought and wetter-than-average intervals (Fritts, Lofgren, and Gordon 1979). In Colorado tree ring chronologies have been used extensively to reconstruct past hydrocliamtic variability including annual precipitation and stream flow (Woodhouse and Lukas 2006). In addition Woodhouse (2003) and Woodhouse and Lukas (2006) found that snow amounts correlate to ring width. Thus tree ring records may be useful for understanding the natural frequency of historically large snow events (or overall extreme wet years) and their reservoir filling capability through greatly increasing average inflow, which has not be previously studied. Due to the cyclical nature of droughts and wet events, tree rings can be used to estimate future probability of these events (Fye, Stahle, and Cook 2003).

In arid regions, unusually narrow or wide tree rings in relation to neighboring rings often reflect variation in annual precipitation. These rings and can be identified as climatic pointer years (CPYs) if such rings are present in a majority of trees within a chronology (Bridge, Gasson, and Cutler 1996). CPYs at a local scale can reflect logging or insect outbreaks, but regional CPYs are usually caused by widespread climatic conditions (Salzer and Kipfmueller 2004). In previous investigations, widespread CPYs have been correlated to singe-year wet events (Bride, Gasson, and Cutler 1996). Bride, Gasson and Culter (1996) found pointer years highlight the similarity in growth characteristics throughout a range of taxa where narrow rings correlated with known periods of agriculture drought and wide rings correlated to warm, wet summers.

Methods Used to Identify Climatic Pointer Years

Andrew Ellicott Douglass (1904) first described methods for identifying marker years (either negative or positive), that could be used to crossdate multiple trees, based on illustrations of ring width patterns (Douglass 1939). Huber (1943) coined the term "pointer year" in reference to a single crossdated event year within a group of trees (Meyer 1998-1999). Serre (1964) used the same principle, but also took into consideration ring width. These researchers created Skeleton Plots where the summation of several plots into a master plot revealed significant years for a group of trees in a site or region (Schweingruber 1990). Huber and Giertz-Siebenlist documented the modern use of "pointer years" in 1969. They described a pointer year occurring when at least 80% of trees in a series depicted the same trend (Schweingruber 1990). In 1988 Windmann and Avemark as well as Gerecke began to define pointer years based on statistical criteria (Schweingruber 1990). Since then multiple methods to calculate pointer years have been developed as discussed by Meyer (1998:1999).

The Skeleton Plot method as utilized by Neuwirth et al. (2004) and others[1] was originally proposed in its rudimentary form by Cropper (1979). It is a successful method that can be easily modified for individual site conditions to correct for environmental, climatic, and physiological variations due to location and tree species cored. These characteristic make this method very useful for a variety of studies. The Skeleton Plot method as employed by Neuwirth et al. (2004) statistically identifies pointer years when rings are significantly narrower or wider than neighboring rings, which is usually due to extreme climatic variations. This method is based on a five-year running average in which individual years are compared (Neuwirth et al. 2004).

Computer based programs such as COFECHA (Holmes 1982) can also be used to evaluate CPYs because of the programs' ability to identify "outliers" within the chronology. COFECHA identifies data that should be reexamined for possible inaccuracies (Holmes 1983). Pointer years are recognized when the program detects outlier ring measurements that reside in the outer portions ("tails") of the ring width distribution for a given year (Grissino-Mayer 2001). However, COFECHA and other computer programs are not adjusted for the environmental parameters at each site, so the Skeleton Plot method is generally preferred.

WEISER is computer program specifically used to identify pointer years in dendrochronological series (Bijak 2010). WEISER allows for the identification of event and pointer years that employs both pointer intervals and values allowing up to 5 intensity levels or classes (Gonzalez 2001). Both positive and negative years can be

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[1] Other scientists that have modified the Skeleton Plot method are Bridge, Gasson, and Cutler (1996); Esper, Schweingruber, and Winiger (2001); Elferts (2007).

selected to identify a particular intensity level. Years are selected with a two sided filter to calculate mean and standard deviation where the index value is expressed in terms of deviations from the local mean (Gonzalez 2001). WEISER accomplishes this through applying algorithms on numerous tree ring series similar to utilizing a spreadsheet (Gonzalez 2001).

Review of Key Studies Utilizing Climatic Pointer Years

Below is a review of the key studies pertaining to climatic pointer years and the varied methods used to obtain them:

Schweingruber (1990) wrote that "pointer years are annual rings that differ visibly and markedly from the preceding and subsequent rings". Ring properties used for identifying pointer years are ring width, portion of latewood, density, tangential rows of resin ducts, and traumatic tissue. These rings are ecological indicators of local or regional factors and events that influence tree growth. Pointer years form the basis for crossdating and skeleton plot dating. However, Schweingruber found it was seldom possible to attribute the majority of pointer years to climatic events. Most research regarding pointer years as of 1990 were undertaken in northern Switzerland.

Schweingruber et al. (1990) reviewed the identification, presentation, and interpretation of event and pointer years. They stated that growth rings vary in width, structure, as well as density. These variations contain information on the relationship between the tree and its environment. Pointer years are defined as a group of trees that display a common event year. An event year is a single tree ring sequence that varies by a critical level (0.5 standard deviation, for example) from the mean of immediate neighbors. Schweingruber et al. explained how to visually and graphically identify pointer years as well as their ecological purposes: The frequency and/or magnitude of negative or positive events in a ring sequence allowing the strength of meteorological factors to be evaluated. Also, by comparing pointer years in different tree species it is possible to relate the pointer years to environmental factors.

In 1996 Bridge, Gasson, and Cutler (1996) examined the growth response of trees to varying meteorological conditions at Kew Gardens and Wakehurst Place, England. The relation between weather records and event years (for individual trees) as well as overall pointer years was evaluated. Pointer years were determined through percentage variation from a 5-year running mean that was calculated for each series. Pointer years were identified as the five most significant variations that coincided with each series. Pointer years were compared against the soil moisture deficit to note any relation. Bridge, Gasson, and Cutler found the strongest positive pointer year (1958) coincided with a warm wet summer, whereas negative pointer years correlated with known periods of agricultural drought. This study demonstrates that various degrees of refinement can be used to investigate the climate-growth relationships of tree species.

Meyer (1998:1999) reviewed the history of pointer years and compared seven transformation methods, applying each method to a master chronology derived from 90 spruce trees in the northern Swiss Alps. The methods compared were the following:

The Weighted High Pass Filter—a two-sided binomial high pass filter with a wavelength of around 8 years (Fritts 1976).

Normalization in a Moving Window—a five-year moving window (average) for event year detection where threshold values for negative and positive events can be determined by the user (Cropper 1979).

Relative Event Year—sets every threshold in relation to the four previous years' growth (Schweingruber 1996).

Pointer Year Statistics—takes into account the variation within a sample of trees where the mean is multiplied by log and then divided by the standard deviation for the indexed value during the year of focus (Reimer 1994).

Growth Value—developed for dating purposes where the indexed value during the year in focus is expressed in percentage growth compared to the previous year (Hollstein 1966).

Interval Trend—reflects the percentage of rising intervals in a number of tree ring series during a year of focus (Schweingruber et al. 1990).

Annual Sensitivity—is the annual sensitivity describing the relative difference in ring width from a certain ring to the preceding one (Neumann 1993).

Meyer found considerable differences between these methods. Therefore, the application of exactly the same pointer year method to all tree ring series was deemed necessary for pointer year preciseness and comparison. Based on time-depend transformation distortion, the Weighted High Pass Filter and Pointer Year Statistics were both highly recommended. Normalization in a Moving Window and Relative Event Year methods were also recommended, but examination of values is advisable (as with creating threshold values). The other methods were not recommended and found to be problematic.

Esper, Schweingruber, and Winiger (2001) examined more than 200,000 ring width measurements from 384 trees at 20 sites located in the Northwest Karakorum, Pakistan and the Southern Tien Shan of Kirghizia. Statistical skeleton plotting was used to identify pointer years. The aim of the work was to determine the frequency of climatically forced extreme years and the magnitude of decadal to centennial timescale variations in the mountains of Western Central Asia since 618 AD. Pointer years were derived by employing a five-year moving average calculated to eliminate the low-frequency signal. The results utilized the standard deviation of the local mean, which is comparable to the Skeleton Plot method discussed by Schweingruber et al. (1990). Esper, Schweingruber, and Winiger (2001) then multiplied the scaled values by 100 to significantly distinguish them from other chronology types. The extreme values were averaged to build a mean chronology from each site. A 101 year kernel filter was also fitted on each series to emphasize decadal-scale variations. Most of the pointer years identified were found in all sites and represented both precipitation and temperature variation extremes. Within the chronology 8 positive and 17 negative pointer years were identified. The chronologies reflect both the Mediaeval Warm Period and the Little Ice Age in Western Central Asia. There were also pointer years and decadal fluctuations that appeared superregionally that may be helpful in future regional crossdating.

Neuwirth et al. (2004) investigated variations in ring width and ring coloration of 89 spruce trees from 6 sites in Switzerland. Site pointer years represented extreme years common within individual sites whereas valley pointer years represented extreme years common between *all* sites. Pointer years were identified using the Skeleton Plot method originally created by Douglass (1941) and refined by Neuwirth et al. Pointer years were classified from weak to extreme according to the intensity of a single ring's growth deviation in relation to the neighboring five years. If the ring was at least 85% narrower or 400% wider than the mean of neighboring rings, it was classified as a pointer year. The resulting event years were then classified into site pointer years using the intensity equation where maximum intensity of a site pointer year (I=100%) was achieved if all sampled trees showed an extreme positive or negative event in a given year. Valley pointer years were calculated using the same method for the entire region instead of individual sites. Neuwirth et al. (2004) found 14 positive and 15 negative valley (overall) pointer years during the chronology of 1900-1995. These findings illustrated the importance of both precipitation and temperature in the formation of negative and positive pointer years, especially during the month of May for regions of Switzerland.

Levanic and Eggertsson (2006) found that northern Iceland birch produce positive pointer years with above-average summer temperature and above-average snowpack. Likewise, negative pointer years were produced with below-average summer temperature and dry winters. The main objective of their research was to examine the dendrochronological potential of birch in northern Iceland for building an extended chronology. Individual tree ring width measurements were standardized to remove long-term growth trends using ARSTAN and COFECHA was employed to ensure quality control. Pointer years were defined where 80% of at least 10 trees had a significant growth increase or decrease. This differs from other methods that examine the running average in relation to an individual year's ring width. Levanic and Eggertsson's (2006) chronology spanned between 1893 and 2002 where 11 positive and 16 negative pointer years were common within all sites. The limited chronology duration is due to birch being a short-lived pioneer species.

Elferts (2007) sampled 6 sites of Scots pine in northwestern Latvia to obtain tree ring width data and determine site pointer year values. Elferts (2007) identified pointer years as markedly wider or narrower ring widths compared to neighboring rings. Pointer years were identified by the Skeleton Plot method developed by Neuwirth et al. (2004) where tree ring widths for each tree was compared to the five-year mean width and the difference was expressed as intensity classes. Elferts (2007) also performed a correlation analysis between site pointer year intensity values and climatic factors (mean temperature and perception sum). Only three pointer years were found in common with all sites (1940 and 1969 negative pointer years as well as the 1957 positive pointer year). The main climatic impacts on pointer years in Latvia were February mean temperature and June precipitation sum. Higher temperatures in June may have lead to increased evapotranspiration and a decline in soil moisture if enough precipitation did not occur. Overall February temperature was the main climatic factor associated with Scots pine growth in Latvia. Since only three pointer years were found in common among all sites, pointer year development in Latvia was mainly determined by local factors, except years when abrupt changes in climatic conditions were observed.

Koprowski and Zielski (2008) analyzed Norway spruce in Poland where the main aim was to identify climate-growth relationships of Norway spruce and climate's role in pointer year formation. Pointer years were determined by averaging the values inside the time window using the computer program WEISER. Spruce growth was positively correlated with May to July rainfall. The most typical negative pointer years were 1941, 1963/1964, 1979, 1992, and 1999. The typical positive pointer years were 1961 and 1981. Pluvial (extreme wet) conditions between May and July had the largest impact on tree ring width. The higher the precipitation total in those months, the wider the secondary wood layer in a given year.

Bijak (2010) analyzed pointer years of Silver firs in northern Poland where the tree ring width series of 1914-2006 was built and correlated with mean monthly temperature and precipitation. Bijak (2010) found that tree ring studies with year to year resolution were very effective in analyzing tree-environment interactions. The aim for the study was to establish a tree ring chronology for the Kaszubskie Lakeland and to analyze climate conditions on tree ring widths. Bijak (2010) considered pointer years as exceptionally wider or narrower rings in response to unusually favorable or unfavorable conditions. A pointer year was identified when more than 80% of at least 10 trees showed a conspicuously smaller or larger width. This method was the same as Levanic and Eggertsson's (2006) for identifying pointer years. Bijak (2010) found 9 negative pointer years and 2 positive pointer years within the chronology spanning from 1914-2006 where 1940 showed a profound decrease in growth. Negative pointer years in Poland were found in relation to severe winter coldness, not a deficit in precipitation.

History of Drought and Wet Events in Colorado

The need to understand the impact of large snow events on tree rings and reservoirs stems from increased water demand and decreased reservoir inflow. One of the main causes of increased demand *and* decreased reservoir inflow is amplified drought severity and frequency: As the amount of water available in the hydrologic system decreases from drought, human demand often increases as the need for cooling and landscape water rises. However, drought *is* a common occurrence in the western United States (Table 1) as seen through instrument records, drought indexes, and proxy evidence such as tree ring reconstructions (Cook et al. 2007). Tree ring reconstructions have identified western droughts as far back as 900-1300 AD, known as the Medieval Warm period (Cook et al. 2004), as well as more current droughts. Yet, natural drought variability is likely being intensified by global climate change (Woodhouse, Russell, and Cook 2009). In North America temperatures have increased by 2°F in the last 30 years and *most likely* humans have caused much of the warming (Ray et al. 2008; CCSP SAP 3.3 2008, p. 3) that is impacting natural drought cycles. Global warming seems to be increasing drought duration (length of drought), frequency, and magnitude (overall moisture deficit). However, Cook et al. (2007) found that reconstructions from the past 1,000 years illustrate the occurrence of unprecedented megadroughts. These megadroughts exceed any found in the instrumental records since 1850 and dwarf the famous droughts of the 20th century: the Dust Bowl drought, the 1950s drought, and the more recent drought occurring from 1999 until 2005 (Cook et al. 2007). This evidence suggests that even more severe droughts could be in Colorado's future especially when considering the impacts of global warming on natural megadrought cycles.

Table 1: Major Droughts Occurring in the Western United States as Recorded in Tree Ring Reconstructions and/or Instrument Data

Date	**Brief Drought Summary and Reference**
900-1300	The Medieval Warm period (Cook et al. 2004).
1034	Multi-decadal drought (Cook et al. 2004).
1150	Multi-decadal drought (Cook et al. 2004).
1253	Multi-decadal drought (Cook et al. 2004).
1527-1534	An eight year drought analogue to the Dust Bowl (Fye, Stahle, and Cook 2003).
1542-1548	Short, intense drought (Fye, Stahle, and Cook 2003).
1549-1558	Western drought that did not penetrate southern Arizona and southwestern New Mexico (Fye, Stahle, and Cook 2003).
1570-1587	The sixteenth century multi-decadal drought. Equaled or exceeded the Dust Bowl drought in intensity and duration. It was most severe over the southwestern United States (Fye, Stahle, and Cook 2003).
1620s	Equaled or exceeded the 1950s drought (Fye, Stahle, and Cook 2003).
1660s	Equaled or exceeded the 1950s drought (Fye, Stahle, and Cook 2003).
1752-1760	A nine year drought analogous to the Dust Bowl (Fye, Stahle, and Cook 2003).
1818-1824	Analogous to the 1950s drought (Fye, Stahle, and Cook 2003).
1841-1848	Analogous to the 1950s drought (Fye, Stahle, and Cook 2003).
1844-1847	Colorado dry period with the most severe departures from annual averages (Woodhouse 2003).
1856-1865 (Civil War Drought)	The most severe drought in the west since European settlement (Seager 2007).
1870s	A drought with warm Atlantic anomalies and strong Pacific forcing. There was also coincidence with a period of sustained La Niña (Seager 2007).
1897-1904	Analogous to the 1950s drought (Fye, Stahle, and Cook 2003).
1929-1940 (1930s Dust Bowl)	The most severe sustained drought to impact the central and western United States during the period of instrumental observation (Fye, Stahle, and Cook 2003).
1946-1956 (1950s Drought)	The second worst sustained drought to impact the United States during the instrumental period with a focus across the southwestern portion of the United States (Fye, Stahle, and Cook 2003).
1998-2004	This dry period occurred after the 1997-1998 El Niño (Ray et al. 2008). It was the most severe between 1999-2002 (Seager 2007).
2002	Single driest year in Colorado since the late-1600s (Pielke et al. 2002).
2005-2007	Drought returns to the Southern Plains and Southwest at the end of 2005 (Seager 2007).

A good deal of research has been conducted on the natural climatic causes of western drought. Generally, trends in precipitation and temperature are strongly influenced by climatic variability associated with the El Niño–Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) (Hamlet et al. 2005). Climatic variability was linked by the waxing and waning of the PDO especially over the past few centuries, which could impact climatic boundaries and drought frequency (Knapp, Grissino-Mayer, and Soul'e 2002). Specifically, reduced precipitation occurs across the West during La Niña–like states (part of the ENSO cycle) when the tropical Pacific Ocean is anomalously cold (Seager 2007; Cook et al. 2007). Cayan, Redmond, and Riddle (1999) also state that during dry La Niña (positive Southern Oscillation) there is a decrease in the frequency of days with high precipitation and streamflow in the west/southwest. General Circulation Models (GCMs) have simulated short droughts as a response to imposed sea surface temperature (SST) anomalies (Seager 2007). In fact, Schubert et al. (2004) demonstrated that SST anomalies forced the Dust Bowl drought conditions. Overall, tropical Pacific SST anomalies are important for drought generation in the midlatitudes, but there is some disagreement on the roles of specific Pacific, Indian, and Atlantic SST anomalies (Seager 2007).

Wet events are also part of the natural cycle of climatic variability in the Western United States (Fye, Stahle, and Cook 2003). The frequency and duration of wet/dry periods is shown in table 2. According to Diaz (1983), much of the western United States' climate includes prolonged periods of "abnormal" moisture conditions, which have been recorded in tree rings. While wet events may include both liquid and frozen precipitation, thunderstorms most likely do not correlate to wide ring widths due to their restricted spatial range, short duration, and high intensity that limit moisture incorporation into the ecosystem. Thus wide ring widths are more likely due to extreme snow events or overall wet years.

Table 2: The Western United States' Climate Variability—Colorado Drought and Wet Periods Since the Late 1800s to the Early 1980s as Found in Tree Ring Reconstructions (source: Diaz 1983)

Dry Period	Duration (months)	Wet Period	Duration (months)
8/1900-4/1904	45	6/1895-4/1896	11
9/1932-2/1938	66	6/1897-1/1898	8
7/1939-8/1940	14	9/1906-9/1907	13
5/1950-9/1951	17	10/1908-2/1910	17
1/1953-7/1953	7	10/1911-10/1917	73
9/1953-3/1957	43	11/1919-8/1922	34
8/1960-7/1961	12	5/1923-5/1924	13
11/1962-10/1964	24	3/1926-9/1926	7
8/1974-1/1975	6	6/1927-11/1930	42
1/1977-10/1978	22	6/1941-4/1942	11
9/1980-4/1981	8	5/1947-3/1948	11
		5/1957-4/1958	12
		7/1965-2/1966	8
		10/1969-7/1970	10
		4/1973-9/1973	6
Total	**264**		**276**

Other Important Wet Periods:

1825-1840: An extended wet period over Colorado and the western United States (Fye et al 2003).

1905-1917: One of the most intense, long-lasting, and widespread wet episodes over the Great Plains and western United States in the past 500 years (Fye et al 2003).

1960s-1990s: A recent Colorado wet "epoch" (Ray et al. 2008).

Research has also been conducted on the natural climatic causes of wet events in the western United States. According to Mo, Paegle, and Higgins (1997), during dry events high pressure extends through a vertical column in a pattern covering North America. However, during wet events high pressure is confined to eastern North America with low pressure dominating in the west (Mo, Paegle, and Higgins 1997). Mo, Paegle, and Higgins (1997) also state that northward "meridional" winds are found to increase between this cyclonic/anti-cyclonic dipole. Additionally, a significant precursor to wet events includes increased westerlies over the eastern Pacific and western North America (Mo, Paegle, and Higgins 1997).

Cayan, Redmond, and Riddle (1999) found an established link between western precipitation and the tropical Pacific during warm El Niño phases as well as an analogous link to cool La Niña phases. Therefore the west/southwest tends to be wet and the northwest dry during El Niño (negative Southern Oscillation index) and the opposite for La Niña (positive Southern Oscillation index). This pattern was also found by Mo and Higgins (1998) which indicates a portion of western precipitation variability is related to the El Niño Southern Oscillation (ENSO) during the winter. Cayan, Redmond, and Riddle (1999) add that during El Niño (warm tropical Pacific) there is an increase in the frequency of days with high precipitation and streamflow in the west/southwest. However, extreme precipitation events (those above the 90th percentile) may occur at all phases of the ENSO cycle, but most of the extreme precipitation events occur during neutral winters just prior to the onset of El Niño (Higgins et al. 2000).

Reservoir Response to Climatic Changes and Population Increase

There is renewed concern over reservoirs due to growing populations, limited resources, and sustained drought that are increasing pressure on already over-allocated water supplies in the western United States (Rice, Woodhouse, and Lukas 2009). An example of water managers’ renewed concern over water resources is Denver Water, the public agency responsible for the collection, storage, quality control, and distribution of drinking water for Metro Denver (Woodhouse and Lukas 2006). Denver Water makes management decisions based on a model that simulates streamflow, reservoir operations, and water supplies. This model assesses the frequency of periods with high demand and low supply (Woodhouse and Lukas 2006). Variability in demand is most influenced by late spring and summer precipitation as well as temperature, while streamflow is driven by winter-spring precipitation in high-elevation watersheds (Woodhouse and Lukas 2006). However Colorado's 2002 drought proved this model to be insufficient and demonstrated the vulnerability of water supplies previously considered adequate in Colorado as documented by the decline of Dillon Reservoir. To increase the model's accuracy, tree ring reconstructions focusing on drought frequency and magnitude were incorporated in 2006 due to their correlation to streamflow that reservoirs rely on.

The reconstructions used to improve the accuracy of Denver Water's model were provided by Woodhouse and Lukas (2006). Woodhouse and Lukas (2006) utilized chronologies to reconstruct past streamflow focusing on the frequency of events similar in magnitude to the 2002 drought. Robust reconstructions of past streamflow from tree rings were possible because of the strong statistical relationship between tree growth and streamflow resulting from the indirect physical tie to local and regional climatic factors (Meko, Stockton, and Boggess 1995). The reconstructions helped assess the reliability of water supply under a broader range of conditions than provided by stream gauge records alone (Woodhouse and Lukas 2006; Rice, Woodhouse, and Lukas 2009).

However, while Woodhouse and Lukas (2006) specifically took drought into account when assessing the reconstructions for Denver Water, extreme wet events were not evaluated. Since the update of Denver Water's system models, an annual supply shortfall of 18,000 acre-feet is anticipated by 2030 due to demand superseding conservation and recycling efforts (Denver Water 2010). This deficit is currently being addressed by the Moffat Supply Project that will enlarge Gross Reservoir by 72,000 acre feet (Denver Water 2010). Nevertheless, the water supply deficit will likely increase by 2050 stemming from several causes related to global warming.

Global warming will have severe consequences for the hydrologic cycle especially in regions (like the west) where water supply is dominated by melting snow and ice (Barnett, Adam, and Lettenmaier 2005). These consequences will inevitably impact reservoirs and thus water availability. When the climate warms, less winter precipitation falls as snow (Ray et al. 2008). The increase in temperature will likely lead to a shift in peak runoff to winter and early spring from summer and autumn when demand is greatest (Barnett, Adam, and Lettenmaier 2005). This shift in maximum spring streamflow is predicted to occur one month earlier by 2050. According to Ray et al. (2008), these changes are forecasted to occur regardless of variations in precipitation. Additionally, snowpack is declining in arid regions and is predicted to drop 10-20% by the mid-21st century (Ray et al. 2008). This is especially concerning because snowpack is ultimately responsible for reservoir inflow in Colorado. Furthermore, western snowpack is showing a reduction in snow water equivalent (SWE) (Hamlet et al. 2005), which is the amount of water contained within the snowpack. A reduction is SWE translates to a decrease in runoff and thus streamflow. According to Hamlet et al. (2005), downward trends in 1 April SWE over the western United States from 1916 to 2003 and 1947 to

2003 are primarily due to widespread warming. High-elevation areas (like Colorado's Front Range) experience downward trends in SWE not due to temperature trends, but decreases in precipitation (Hamlet et al. 2005).

Recent hydrologic studies of the Upper Colorado River Basin project an average runoff decrease from 6% to 20% by 2050 compared to the 20th century average (Ray et al. 2008). One model estimates a 45% decline in runoff by 2050 (Ray et al. 2008). This is because a relatively small change in rainfall (10-20%) leads to a large change in perennial streamflow (75%) from runoff (Muller 2007). Reservoir yields (inflow) will reduce at the same rate as streamflow: A 30% reduction in average streamflow will result in a 30% reduction in reservoir yield, which will significantly impact water availability (Muller 2007). A reduction in reservoir yield may also increase water cost by more than 40% (Muller 2007). Barnett, Adam, and Lettenmaier (2005) concluded that current water demand in arid places will not be met under plausible future climate conditions, leading to one-third of 5.7 billon humans experiencing water scarcity by 2025 (Vorosmarty et al. 2000). Water scarcity often stems from management systems (such as reservoirs), which are dependent on runoff timing that is more related to temperature than precipitation changes (Barnett, Adam, and Lettenmaier 2005).

However, it is not just global warming at the root of reservoir concern. According to the US Census Bureau, in 2009 Denver County was home to 610,345 people. Yet the population of Metro Denver is predicted to double by 2050 (Solomon et al. 2007). Population growth will increase water demand because warmer, drier conditions also increase water use for cooling, landscape, and agricultural (Boland 1997). Thus, water scarcity will likely increase as population growth coupled with intensified drought causes demand to exceed reservoir inflow (Christensen et al. 2004).

Yet it is important to anticipate the full spectrum of future climate variability, not just drought that will impact water storage in the Denver Water system. Thus it is essential to understand past climate variability in the region where Denver collects mountain snowmelt. Previous research has documented the late Holocene record of climate variability in Colorado (Fye, Stahle, and Cook 2003), but the history of extreme high precipitation events is less apparent even though these events may reduce the impacts of severe drought. Therefore it is imperative for wet events and their impacts on Dillon Reservoir to be studied.

CHAPTER 3: METHODS

Site Selection and Description

For this study the balance of water stored in Denver's largest water storage facility, Dillon Reservoir, was considered. Specifically historically large snow events' impact on Denver's water supply was examined. This was accomplished by reconstructing the frequency of large snow events at Dillon Reservoir and investigating how large snow storms could fill the reservoir. This work was necessary in order to determine if large future snow storms could be relied upon to keep Dillon Reservoir full even after times of extended drought.

Dillon Reservoir is located near Dillon, Colorado along I-70. The region is mountains with Ponderosa pines and Douglas firs. The reservoir's elevation is 2,748 meters (Denver Water 2010) and average temperature ranges from -0.6 degrees Celsius in January to 23 degrees Celsius in July (The Weather Channel 2011). The dam on the Blue River that created Dillon Reservoir was completed in 1963 and the reservoir contains an average of 228,994 acre-feet of water (Denver Water Dataset 2010). Stream inflow from the Blue River above Dillon Reservoir was used to evaluate the reservoir's response to extreme weather because inflow is the best indicator of natural processes that fill the reservoir (i.e. snowpack runoff) and is less dictated by human control. Reservoir storage and outflow below the reservoir are controlled by water managers and thus are more regulated, especially concerning downstream water rights (Denver Water 2010). Dillon Reservoir's inflow is measured daily by Denver Water at the Blue River's entrance into the reservoir (Denver Water 2010). Outflow is measured daily at the Robert's Tunnel outlet below the reservoir and storage is measured daily representing the reservoir's water level (Denver Water 2010).

Data were obtained from the Denver Water Department (Denver Water) to aid in this investigation. The data include measurements from all reservoirs in Denver Water's management system from 1963 until 2009 including collection dates, precipitation at the reservoirs, inflow, outflow, storage, and elevation. Denver Water is the manager of Dillon Reservoir as well as the oldest and largest urban water provider in Colorado serving over one million residents in the Denver Metro area (Woodhouse and Lukas 2006).

In this study new and existing tree ring chronologies that are sensitive to annual precipitation were selected in Colorado's Front Range and Western Slope. Sites representing the Front Range were mostly within the South Platte watershed, but some were also located in the Arkansas watershed. These sites were chosen in order to capture snow events or overall wet years that may have impacted Denver's water supply system and perhaps the watershed of Dillon Reservoir, but were not apparent in the sites near Dillon. The Western Slope sites were all located within the Colorado watershed and were chosen to capture snow events or overall wet year near Dillon Reservoir that would have impacted its inflow. All sites were selected by Lukas, Woodhouse, and their colleagues in order to reconstruct streamflow on the Colorado River and South Platte River (Meko et al. 2007) and all sites chosen were positively correlated to precipitation.

The Front Range sites included Bennett Creek (BEN), Bald Mountain (BLD), Big Thompson (BTU), Crags Hotel (CRA), Deer Mountain Update (DMU), Eagle Rock (EAG), Eleven Mile (ELE), Eldorado Canyon (ELU), Happy Meadows (HAP), Mt. Hermon (HER), Jamestown (JAM), JeffCo Update (JFU), Johnny Park (JOP), Meyer Ranch (MEY), Owl Canyon Update (OWU), Peak to Peak (PTP), Rustic (RUS), Turkey Creek Update (TCU), and Van Bibber Update (VBU). Another Front Range site (VVR), whose name is unknown, did not have metadata so it was not included in maps or tables, but its chronology was used for determining CPYs. Sites from the Western Slope were included to represent the area at and around Dillon Reservoir. The Western Slope sites include Dillon (DIL), Green Mountain Reservoir (GMR), Hot Sulphur Springs (HOT), Pump House (PUM), and Vasquez Mountain (VAS). The Front Range and Western Slope sites are mapped in Figure 1.

Table 3 depicts site location (latitude and longitude) and IntCorrel (correlation between ring width and precipitation) where high values indicate a more climate-sensitive and therefore useful chronology (Lukas 2010, personal communication). Tree ring chronologies of these sites range from 1300s to 2003. They were obtained from living and dead *Pinus ponderosa* (Ponderosa pine), *Pseudotsuga menziesii* (Douglas fir) and *Pinus edilus* (Pinyon pine) trees (Lukas 2010). All data have been crossdated and standardized using standard dendrochronological techniques (Fritts 1976). As part of this research the Dillon chronology was updated through 2010 to ensure the chronology captures the entire 2002 drought as well as the recovery from it.

Table 3: Information on Tree Coring Sites (source: J. Lukas 2010)
Longitude and latitude are in degrees and minutes
IntCorrel=correlation between ring width and precipitation

Site	Long (X)	Lat (Y)	Elevation (m)	Elevation (ft)	IntCorrel
BEN	-105 31	40 40	2301	7550	0.809
BLD	-105 21	40 03	2180	7160	0.729
BTU	-105 17	40 25	2012	6600	0.867
CRA	-105 18	39 56	2002	6570	0.759
DMU	-105 35	40 22	2652	8700	0.811
EAG	-105 10	39 23	2103	6900	0.785
ELE	-105 26	38 52	2743	9000	0.804
ELU	-105 18	39 56	2002	6570	0.749
HAP	-105 22	39 01	2438	8000	0.819
HER	-104 56	39 04	2408	7900	0.802
JAM	-105 25	40 08	2469	8100	0.785
JFU	-105 12	39 41	1965	6447	0.754
JOP	-105 26	40 15	2377	7799	0.740
MEY	-105 16	39 33	2530	8300	0.732
OWU	-105 11	40 47	1874	6150	0.807
PTP	-105 31	40 01	2746	9010	0.760
RUS	-105 35	40 43	2499	8200	0.807
TCU	-104 51	38 36	1951	6400	0.847
VBU	-105 15	39 48	1920	6300	0.766
DIL	-105 54	39 36	2880	9450	0.824
GMR	-106 14	39 51	2514	8250	0.867
HOT	-106 08	40 04	2499	8200	0.805
PUM	-106 31	39 58	2194	7200	0.817
VAS	-106 04	40 02	2865	9400	0.782

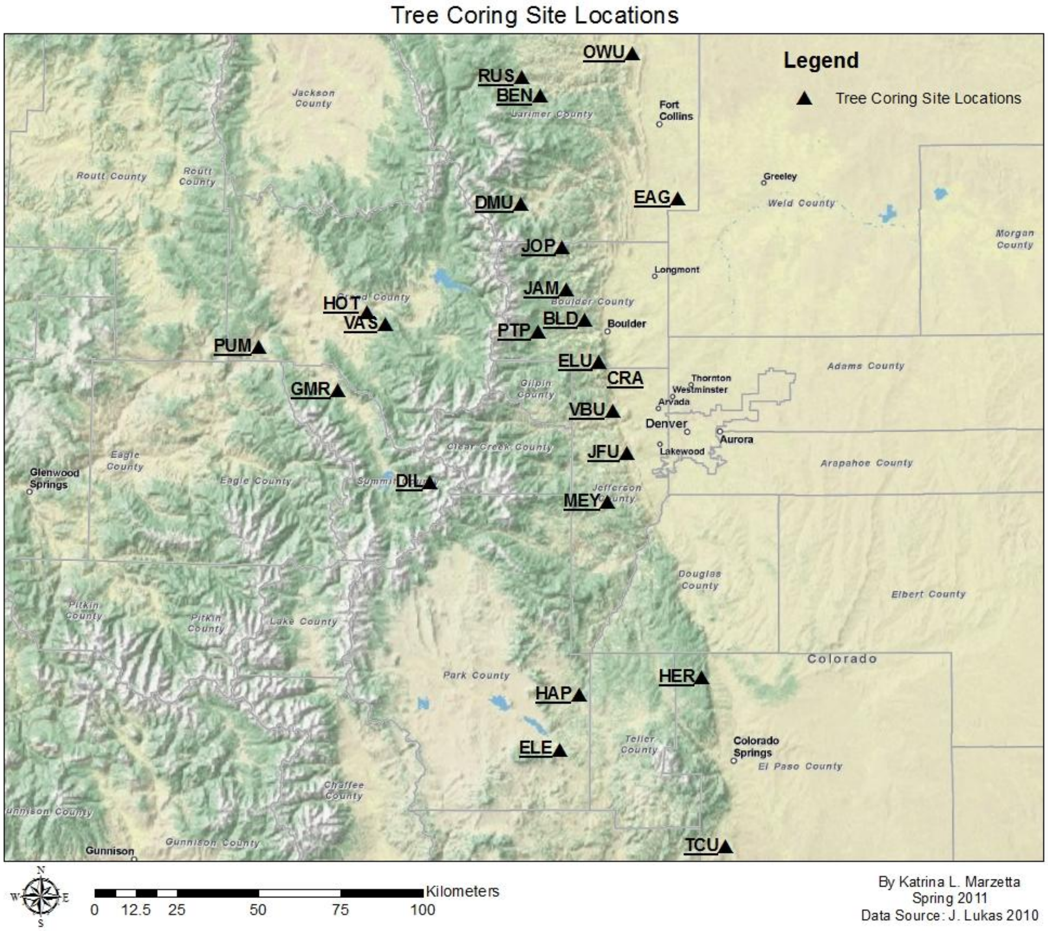


Figure 1: Map of Tree Coring Site Locations (sites provided by J. Lukas 2010)

Core Collection Techniques

To update the Dillon coring site, cores were collected from a combination of 15 *Pinus ponderosa* (Ponderosa pine) and *Pseudotsuga menziesii* (Douglas fir) trees. Standard dendrochronology methods documented by Fritts (1976), LaMarche (1969), as well as LaMarche and Hirschboeck (1984) were used for this research. 2-3 cores were collected 1-meter above the ground from each tree. The cores were dried, mounted, and sanded with progressively finer sandpaper to 400 grit. To make certain ring-counting error due to narrow or missing rings did not occur, cores that included outermost radii were visually crossdated against one another. Crossdating entails matching patterns of wide and narrow rings in tree cores to determine the location of true ring boundaries, which provides a “check” of the actual core date (Speer 2010).

The rings were counted and their width measured with the Velmex system micrometer (Bloomfield, Indiana, USA) with a precision of 1 μm using an Olympus stereoscope linked with a video camera and Measure J2x software. All the measurements were standardized using Arstan, a statistical computer program (Holmes 1994) that detrends the raw ring widths to produce standardized ring indexes (Standard and Residual). The standardized ring width indexes remove undesired trends from the raw ring width series such as age-related growth trends and gap dynamics (Speer 2010). Growth trends refer to the tendency for rings to become narrower towards the bark due to tree growth geometry (Mast, Veblen, and Linhart 1998) as well as the tendency for very young trees to grow more rapidly. Gap dynamics refer to the growth release due to mortality of neighboring trees, which generates “noise” for dendroclimatologists (Speer

2010). The standardized ring width indexes corrects such trends to isolate the ring's climatic response by taking the raw ring width series divided by the fitted model (Grudd et al. 2002). This procedure produces dimensionless indexes with a mean of 1.0 where larger index numbers represent wider rings and smaller index numbers represent narrower rings (Speer 2010).

After the standardized ring width indexes were created for every tree core by Arstan, they were averaged for each year. This produced an updated Standard chronology and Residual chronology. Both were compared to the original Dillon chronology from 1995-2002, where 2002 was the last year in the original chronology. The index that best matched the original chronology was used for the updated standardized ring width values that were employed in all other calculations.

Identifying Large Snow Events and Comparison to Chronologies

Large snow events identified by the Colorado Climate Center for use in this study were based on storms producing 10.2 or more centimeters of water (SWE) at a weather station near the center of the tree coring sites, southwest of Boulder at approximately 2,438 meters. The station was chosen because it was the most the complete and nearest the tree coring sites that also captured large snow events. Weather events were recorded at the station from 1894 to the present, but only large snow storms through 2003 were used because ring widths were only recorded past 2003 at one location (the Dillon site update). The years identified through this data were compared to each sites' chronology. Specifically, if a storm occurred in the winter or spring of a certain year the tree's ring growth would respond to the increased moisture that same calendar year. However, if a storm occurred in the fall or early winter, the tree's ring growth would respond the following calendar year because growth occurs in the spring. If a ring was significantly wider during a year identified as having a large snow storm (if the storm was in the late winter or spring) or the following year (if the storm was in the fall or early winter), the wide ring width was possibly caused by the large snow event.

In this study a significantly wide ring width for a specific site was identified as 1 or more standard deviation greater than the average ring width of that site's chronology (Table 4).

Table 4: Calculating a Significantly Wide Ring Width during a Large Snow Event Year (1994) (source: Jeff Lukas et al. 2010)

Dillon Site Chronology

Chronology's Overall Average Ring Width (AVG)	Chronology's Overall Standard Deviation Of Ring Widths (SD)	1 Standard Deviation greater than the Average Ring Width (AVG + 1 SD)	1984's Ring Width (1894 is a year with a historically large snow event)
0.983	0.326	1.309 (Any ring width equal to or greater than 1.309 is considered a significantly wide ring)	1.977 (This ring width is considered significantly wide for 1984)

The significance (1 or more standard deviation greater than average) employed to designate a wide ring was chosen because of the biological/climatic restrictions on Colorado trees. It is possible to achieve a ring width 2 or more standard deviations greater than average, but it is more difficult because such a wide ring relies on excess soil moisture usually (but not always) accumulated for several years. Each site was evaluated individually and as a group (Western Slope and Front Range sites) to compare the years with large snow storms to ring widths.

Coring sites were geographically grouped as Western Slope sites and Front Range sites. Within each of these larger groupings, sites were organized by location:

> Western Slope sites:
> PUM, HOT, VAS, GMR, DIL (from farthest West to farthest East)
>
> Front Range sites:
> OWU, RUS, BEN, (most northern)
> DMU, BTU, JAM, PTP, JOP, BLD, ELU, CRA, VBU, JFU, MEY, EAG
> (mid from North to South)
> HER, VVR, HAP, ELE, TCU (most southern from East to West)

The percentage of Western Slope sites and Front Range sites found with significantly wider rings for each year with a historically large snow event was also evaluated. If the snow event took place before January, it will be evaluated in the next year's tree ring because tree growth occurs in the spring. For example, if a historically large snow event took place in fall 1959, it would not impact tree rings until the spring of 1960. If 1-25% of either the Western Slope or Front Range sites were found with a significantly wider ring during a year with a historically large snow storm, that storm would be considered a minor extent (in spatial coverage) storm for the Western Slope and/or Front Range sites. If the percentage was 75-100% the storm was considered a major extent storm and if the percentage fell between 25-75% it was considered a moderate extent storm.

Maps were generated to examine the spatial extent of storms by looking at the standardized ring width values at every coring site. This was accomplished by using graduated symbols to represent standardized ring widths from each site's chronology for each year identified as having a historically large snow event. This indicated the spatial coverage of each storm (storm extent) by illustrating what sites received the most snow as identified by their standardized ring widths for a specified year. The assumption that snow amounts correlates to ring width is affirmed by the research of Woodhouse (2003) as well as Woodhouse and Lukas (2006). Maps were generated using ArcMap 10 (ESRI 2010) where graduated symbols were created using equal intervals to divide the data evenly into five width categories for each year analyzed. This was done for each map individually because in order to standardize all maps, more categories would need to be created to accommodate the wide range in ring width values. If more categories were added, the size difference of the symbols would be difficult to discern. Because the tree ring width data was only available through 1997 at *all* coring sites, the ring widths for the large snow events of 1894, 1900, 1921, 1947, 1957, 1959, 1982, 1983, 1984, 1986, 1988, 1990, 1995, and 1997 were mapped. Because the snow events of 1959, 1984, and 1997 occurred in the fall and the snow event of 1982 occurred in December, the impact on ring width would have been evident the following year. Ring width for these years were still included for comparison between late winter/spring vs. fall/early winter snow storms.

Colorado snowpack maps from the National Resources Conservation Service (NRCS) were employed to confirm the historically large snow storms. Snowpack is an important indicator of wet years because it directly influences soil moisture and runoff, which impacts both tree ring width and reservoir inflow. NRCS snowpack maps illustrate the percentage of average snowpack by watershed area (spatial extent), and month. Maps from 1995, 1997, 1999, and 2003 were included for comparison to years with historically large snow events. Other years were not included due to lack of NRCS data available for constructing the maps. The 2002 snowpack map was also included as a comparison between very wet and dry years.

Identifying CPYs Employing the Modified Skeleton Plot Method with Chronologies

After investigating numerous research methods for identifying CPYs, the five-year running average based on the Skeleton Plot method (Neuwirth et al. 2004) was utilized in this study. This method was employed because it was both recommended by Meyer (1998-1999) and could be modified for site conditions through threshold values for negative and positive pointer years. It was also very user friendly and did not rely on computer programs like WEISER, which is not readily available. However extreme values were not averaged to build a mean chronology as in the research of Esper, Schweingruber, and Winiger (2001) because the overall chronology from each site was used to identify CPYs. A kernel filter was also not utilized (Esper, Schweingruber, and Winiger 2001) because climatic variations were adequately visible and was not necessary for the method used in this study. Levanic and Eggertsson (2006) as well as Bijak (2010) indentified pointer years differently than other researchers (>80% of every 10 trees showing conspicuously smaller or larger ring widths). This method was not employed in this study because more precise CPY identification could be made based on the running average.

Each site chronology (including the Dillon update collected, analyzed, and standardized for this study) was evaluated to identify CPYs. Every chronology was based from tree cores that have been collected from each coring site, counted, measured, and statistically corrected (detrended) using standardized methods (Fritts 1976). The modified Skeleton Plot method was employed to calculate CPYs by using a five-year running average which individual years within each chronology were compared against

(Neuwirth et al. 2004). For example, the ring width of 2000 would be compared against the average of 1998-2002. If the individual year's standard index value (SIV) is at least 75% narrower or at least 175% wider than the mean of neighboring rings (running average), it is considered a "strong" pointer year intensity class for Colorado's trees. These percentages differ from those used by Neuwirth et al. (2004) who employed at least 85% narrower and at least 400% wider than the running average to identify pointer years. Lower percentages were used in this study to compare ring widths against the running average because higher percentages detected very few to no pointer years. Higher percentages yielded few to no pointer years due to the climatic and species differences between Colorado's Front Range and Lotschental, Switzerland (where Neuwirth's study took place) that were corrected by adjusting the percentages.

Neuwirth et al. (2004) looked at individual trees, instead of site chronologies to decipher site specific pointer years. Pointer years were identified by classifying the weighted event years obtained by the moving average into site pointer years using the below equation where the maximum intensity of a site pointer year (I=100%) occurs if all trees show an extreme positive or negative ring width (event) in a given year (Neuwirth et al. 2004).

$$I = \frac{100}{k * n} \sum_{j=1}^{k} h_j * i_j$$

Where:
k = number of event year intensity classes
n = total number of trees
h = number of trees with event
I = intensity class of event year

However, in this study chronologies were used to identify pointer years for each site because they compile many tree cores whose ring widths have been crossdated and standardized to remove error thereby improving reliability. Thus, the moving average procedure produced pointer years for the entire site and the equation was not needed. Therefore, this method was modified by using the weighted event years of each chronology: Strong negative CPYs were years with a standard index value (SIV) 75% (or less) of the running average and strong positive CPYs are years with a SIV 175% (or more) of the running average. Median negative CPYs were years with a SIV 50% of the running average and median positive CPYs are years with a SIV 150% of the running average (Table 5).

In order to test the validity of the modified Skeleton Plot method where the equation was not used, Neuwirth et al.'s (2004) equation utilizing with the raw ring widths from the Dillon site were compared to the CPYs identified using the site's chronology. Ten tree's raw width data were selected at random to be used in this analysis. In the equation the number of event year intensity classes (k) were 2 (strong and median), the total number of trees (n) were 10, the number of trees where the event was counted (h), and the intensity class of the specific event year was given (i). If the intensity (I) of a site pointer year (expressed in percentages) equaled 100%, all 10 trees indicated a "strong" pointer year (intensity class). If the CPY's I was 75% or higher it was considered an overall "strong" pointer year. If the CPY's I was 50-74% it was considered an overall "median" pointer year. If the CPY's I was 49% or below it was considered an overall "weak" pointer year.

At each site negative and positive CPYs were identified. Positive CPYs that immediately follow negative CPYS (within 2 years) were also noted. The percentage of negative CPYs that are followed by a positive CPY was calculated at every site. This demonstrated if positive CPYs (possible reservoir filling events) could be relied upon to occur immediately after an extremely dry year, suggesting a drought buster.

Identifying Overall Wet Years

Because positive CPYs may relate to overall wet years and not just historically large snow events, overall wet years were identified in order to compare them to positive CPYs. To identify overall wet years the Colorado Climate Centers' instrument weather observation stations nearest the coring sites that contained the most complete data were examined. To represent the Western Slope sites the Dillon station (39.38 degrees latitude, -106.02 degrees longitude, 2761 meters) was used, which has one of the most complete climate records for Colorado's high elevations. The Dillon station has operated continuously since 1909, but its traditional glass thermometers were replaced in 2002 by an electronic temperature measurement system (Colorado Climate Center 2011). To represent Front Range sites, the closest stations were the Georgetown station (39.71 degrees latitude, -105.7 degrees longitude, 2,597 meters), Cabin Creek station (39.66 degrees latitude, -105.71 degrees longitude, 3,054 meters), Kassler station (39.30 degrees latitude, -105.06 degrees longitude, 1,676 meters), Colorado Springs Airport station (38.49 degrees latitude, -104.43 degrees longitude, 1,856 meters), and Fort Collins station (40.35 degrees latitude, -105.05 degrees longitude, 1,524 meters). The Georgetown station is located in Georgetown and has collected information on and off since 1893, but has continuous data since 1909-1920 and again from 1950-2010 (Colorado Climate Center 2011). The Cabin Creek station is slightly south of Georgetown and has collected data consistently since the late 1960s (Colorado Climate Center 2011). The Kassler station is located on the Kassler filter plant near Chatfield State Park and has experienced few equipment relocations since being established in 1903 (Colorado Climate Center 2011). The Colorado Springs Airport station has continuously collected data since 1948 (Colorado Climate Center 2011). The Fort Collins weather station is located on the CSU campus and has been collecting data since the 1870s (Colorado Climate Center 2011).

Yearly precipitation records were examined at each station and years with statistically high precipitation were selected as overall wet years. Statistically high precipitation was identified by calendar year precipitation amounts 1 or more standard deviation greater than the overall average at a particular station. A number of overall wet years will also contain historically large snow events at some or all of the stations. Even though the stations were not in close proximity to each other, there was a great amount of overlap with overall wet years suggesting precipitation trends were statewide. This fact increased confidence in using these stations to identify overall wet years.

Comparison of Large Snow Events and Overall Wet Years to CPYs

The positive CPYs obtained through the modified Skeleton Plot method were compared to the historically large snow event years to determine if they were the same years (if the storm occurred in the winter or spring) or the following year (if the storm occurred in the fall). Each sites' CPYs was compared separately as the spatial coverage of large storms are variable. Thus, it was not expected that all sites' positive CPYs would overlap with every large snow event because the storm might not have reached a particular site. The amount of overlap between positive CPYs and large snow event years was evaluated through descriptive statistics, such as percentage overlap. Overall wet years and CPYs were also compared through comparative statistics and magnitudes. The comparative statistics included standard deviation and percentage overlap. The descriptive statistics used calibrated the recent CPY record to instrumental weather observations. If CPYs corresponded to certain weather events in relation to magnitude and/or spatial coverage, that information was used to detect patterns in the extended CPY record derived from each sites' chronology. The patterns helped predict the frequency and magnitude of future Front Range drought busters on a site by site basis.

Correlating CPYs to Dillon Reservoir

CPYs identified at the Dillon site were examined in relation to Dillon Reservoir's daily inflow. This was accomplished by assessing inflow's seasonal cycles (low and high flow) on a calendar year basis and employing the yearly average to note if years identified as CPYs significantly differed (more than 1 standard deviation) from yearly average inflow. The seasonal cycles were examined on a yearly basis because ring growth is naturally recorded with annual resolution and the average was used to incorporate seasons of high and low inflow. Descriptive statistics were used to note the percentage overlap between positive CPYs and increased inflow as well as negative CPYs and decreased inflow during the years indentified as CPYs.

Statistical correlation was also examined between CPYs and reservoir inflow to describe the degree of relationship between CPY magnitude and inflow amount in acre-feet (af). CPY magnitudes were derived from the calculation used to assign CPY status (Table 5). CPY magnitude values were compared against Dillon Reservoir's inflow values (af) during the same years as the CPYs. Correlation of CPY magnitude and Dillon Reservoir's yearly average inflow was run in Excel using arrays. These variables were also graphed for a visual display of any trend and to produce a trendline as well as R^2 value for further analysis of their relationship strength. These procedures illustrated if CPYs impact Dillon Reservoir's inflow.

Table 5: Example of how CPY Magnitudes were Derived (source: J. Lukas 2010)

CPY Calculations for the Dillon Site Chronology

1994 Median Negative CPY
When SIV is 50% (or less) narrower than the RA
Identified by a – number or a 0
(For Strong -CPY Calculations, 75% was used)

1996 Median Positive CPY
When SIV is 150% (or more) wider than the RA
Identified by a + number or a 0
(For Strong +CPY Calculations, 175% was used)

Standard Index Value (SIV)	5 Year Running Average of SIVs	50% of the Running Average	50% **less** than the Running Average (50% of average)	SIV – 50% of Running Average (0.388-0.598)	Standard Index Value (SIV)	5 Year Running Average of SIVs	50% of the Running Average	50% **more** than the Running Average (150% of average)	SIV – 150% of Running Average (1.654-1.602)
0.388	1.196	0.598	0.598	-0.210 1994 CPY Magnitude	1.654	1.068	0.827	1.602	0.052 1996 CPY Magnitude

Predicting CPYs' Potential to Fill Reservoirs

After CPYs were calibrated by weather instrumental observations, CPYs were applied to reservoir inflow. Thus approximate timing of drought busters and their impact on Dillon reservoir were predicted. The predictability of large snow storms occurring immediately after a drought (negative CPY) was also examined by looking at the percentage occurrence of this climatic pattern in the past. This information enabled drought busters' probability to be predicted.

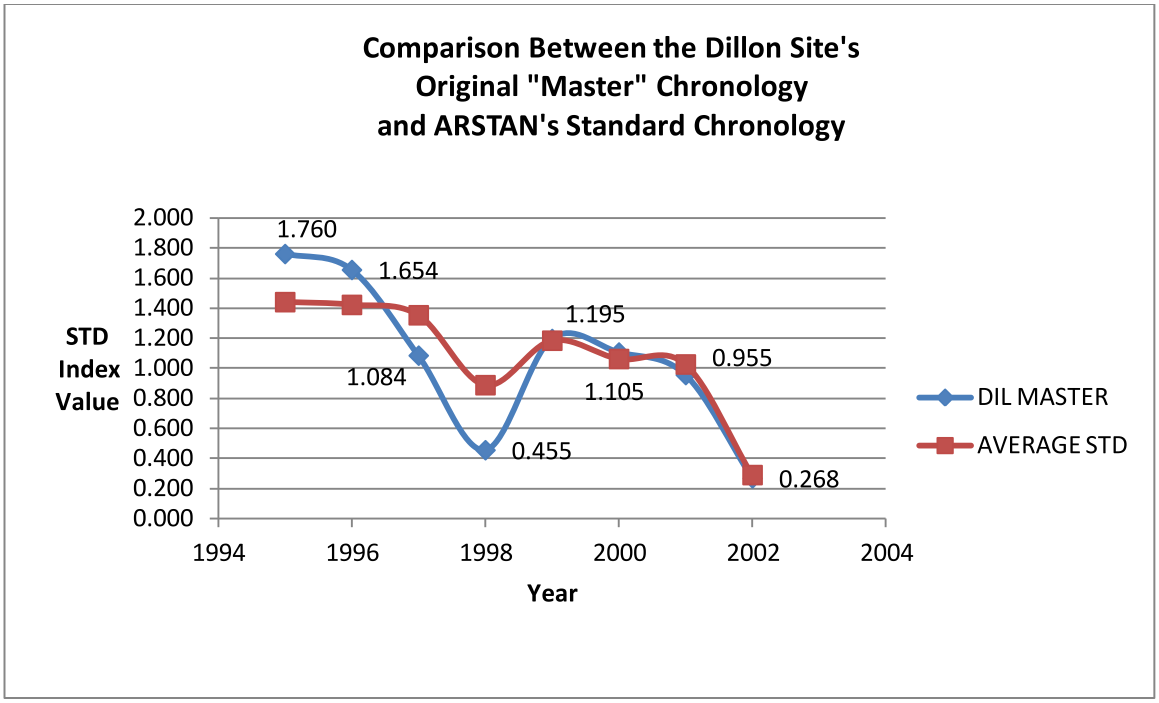
CHAPTER 4: RESULTS

Background Results

Dillon Site Chronology Update

ARSTAN's residual values (averaged from 15 trees) best matched the original Dillon chronology and was therefore used for the updated standardized ring width index values in all calculations involving the Dillon Site chronology (Figure 2). The residual ring width values were closest to the original chronology in 1996, 1997, 1998, 2001, and 2002. In both graphs the 1995 ring width was fairly wide, but rings began to narrow with the narrowest (besides 2002) occurring in 1998. In 1999 the ring width increased, but began decreasing again in 2000 with the most narrow ring occurring in 2002. Both the residual and standardized ring width index values are very close to the original Dillon chronology ring width index values in 1999-2002.

The updated Dillon site chronology employing ARSTAN's residual ring width index values is depicted in Figure 3. There is a large difference (0.888) in ring width value between 2002 (0.268) and 2003 (1.156). The ring width narrows again in 2004 but increased in 2005. The variability between ring width values decreased beginning in 2007.



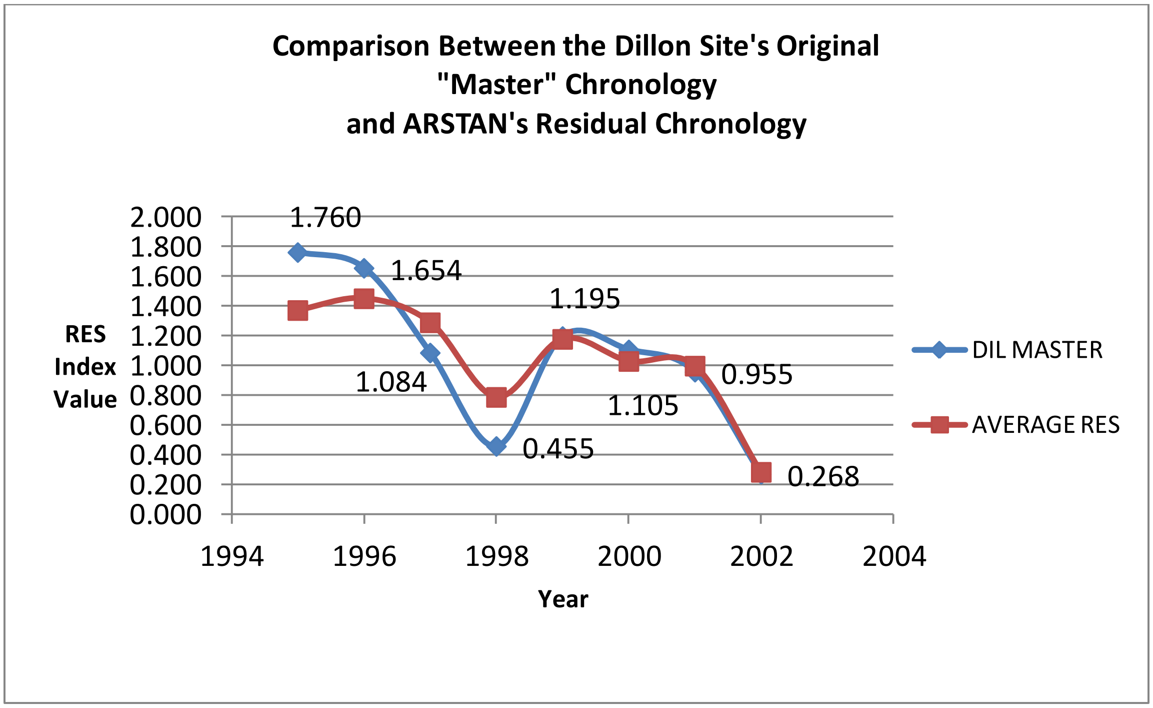


Figure 2: Comparison of the Dillon site's ARSTAN's Standard and Residual Ring Widths Index Values from the Average of 15 Trees to the Original Chronology (source: K. Marzetta 2011 and J. Lukas 2010)

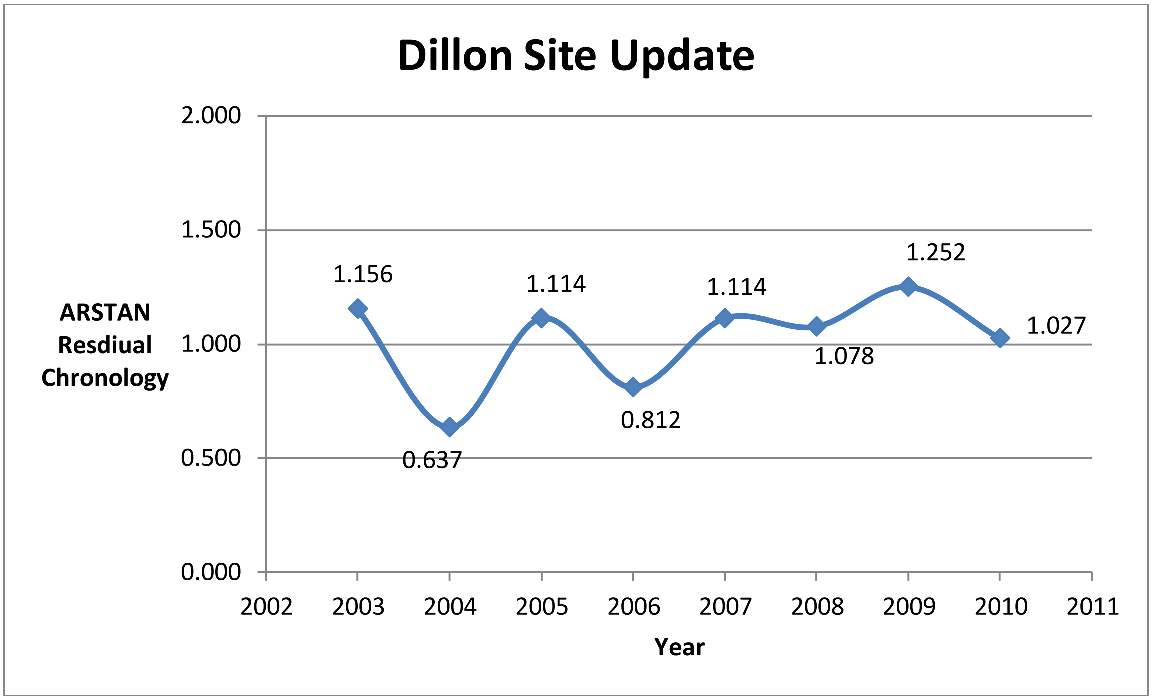


Figure 3: ARSTAN’s Residual Ring Widths Index Values for the Dillon Site Update (source: K. Marzetta 2011)

Comparison of Modified Skeleton Plot to Original Utilizing Dillon Site Raw Data

The data in Table 6 validate the modifications of the Skeleton Plot method utilized in this study. The CPYs calculated using the raw Dillon site data were derived by employing the Neuwirth et al. (2004) equation. The CPYs calculated using the Dillon site chronology were derived by employing only the running average. 82% of the strong negative CPYs found with the Dillon chronology were identical to the CPYs derived from using the Dillon site’s raw width data and 84% of the median negative CPYs were the same (Table 6). 100% of the strong positive CPYs found with the Dillon chronology were identical to CPYs found utilizing the Dillon site’s raw width data and 74% of the median positive CPYs were the same. However, 7 median positive CPYs using the

Dillon chronologies were within 3 years of the positive CPYs derived from the Dillon site's raw width data. If these were included, 91% of the median positive CPYs found within the Dillon chronology would be the same as using the Dillon site's raw width data.

Table 6: Comparison of Skeleton Plot Methods with Dillon Site Data: Raw Width Method vs. Utilizing the Entire Chronology (source: J. Lukas 2010)
Red= strong negative CPYs Green= strong positive CPYs Orange=median negative CPYs Blue= median positive CPYs

Negative CPYs Raw Data	Negative CPYs Chronology	Positive CPYs Raw Data	Positive CPYs Chronology
1445	1584	1435	1372
1474	1609	1443	1610
1475	1685	1473	1621
1479	1845	1477	1633
1496	1851	1486	1843
1503	1883	1498	1853
1506	1887	1507	1921
1515	1898	1514	1965
1519	1902	1521	1443
1531	1954	1529	1490
1538	2002	1530	1498
1542	1506	1536	1507
1546	1528	1540	1529
1545	1531	1546	1530
1559	1542	1549	1540
1575	1545	1583	1543
1580	1558	1586	1546
1584	1559	1599	1560
1593	1575	1610	1565
1600	1580	1621	1568
1609	1598	1633	1582
1612	1600	1640	1583
1625	1620	1651	1586
1627	1654	1655	1599
1637	1671	1657	1667
1654	1700	1661	1673
1656	1704	1667	1698
1659	1714	1673	1705
1668	1722	1683	1720
1671	1729	1690	1731
1675	1730	1699	1746
1677	1748	1705	1757
1685	1756	1713	1790
1700	1763	1720	1796
1704	1770	1726	1823
1707	1777	1728	1826
1711	1786	1734	1831
1714	1789	1739	1849
1715	1795	1744	1895
1717	1798	1746	1900
1723	1824	1747	1903
1729	1830	1749	1907
1730	1833	1753	1912
1740	1842	1757	1917
1748	1847	1761	1930
1750	1868	1768	1933
1756	1871	1780	1947

1770	1908	1785	1956
1777	1919	1787	1962
1786	1922	1790	1969
1789	1932	1831	1996
1795	1959	1832	2000
1798	1964	1843	
1820	1981	1844	
1830	1994	1849	
1833	1998	1850	
1834		1853	
1842		1862	
1845		1863	
1846		1866	
1847		1870	
1851		1876	
1852		1881	
1863		1886	
1868		1887	
1871		1889	
1879		1890	
1880		1895	
1881		1897	
1887		1899	
1888		1900	
1889		1902	
1896		1903	
1898		1906	
1902		1907	
1904		1909	
1905		1912	
1908		1917	
1910		1921	
1915		1930	
1919		1933	
1920		1936	
1922		1947	
1932		1952	
1935		1956	
1940		1957	
1946		1962	
1950		1965	
1954		1969	
1955		1979	
1959		1996	
1961			
1964			
1968			
1981			
1989			
1990			
1994			
1998			

Research Question 1:

Can the largest historic snowfall events be recognized in tree ring records?

Comparing Chronologies' Qualitatively Significant Ring Widths to Large Snow Events

The years designated as historically large snowfall events (storms that produced 10.2 or more centimeters) were 1894, 1900, 1921, 1947, 1957, 1959, 1982, 1983, 1984, 1986, 1988, 1990, 1992, 1995, 1997, 1999, and 2003 (Table 7). The data was supplied by the Colorado Climate Center and derived from the station near the corner of Boulder, Gilpin, and Jefferson Counties that is Southwest of Boulder above 2,438 meters (Colorado Climate Center 2010). The total snow depth of each storm was measured daily and tallied every 3 days. Some years contained multiple historical large snowstorms. For years with multiple storms, the total depth of each storm was added in order to compare years. The total precipitation or snow water equivalence (SWE), for each storm may have accumulated over one day or several depending on the duration of the storm. The SWE was obtained daily at each station by melting the snow captured and measuring the amount of water contained in the snow. For years that contained more than one historically large snowstorm, the SWE for each storm was added in order to compare years.

As seen with each snow storm, the more inches accumulated (snow depth), the greater the SWE. The wettest snow storm occurred in 2003 when 22.6 centimeters of precipitation (SWE) was received. This was the greatest precipitation amount of any storm, but the snow depth was only 182.6 centimeters which was not the deepest snow depth. Also the SWE from the 2003 storm occurred at once, whereas years with other high SWE amounts occurred during several storms as in 1982, 1983, 1984, and 1997. 1990 was the second largest historically large snow storm producing 11.9 centimeters of SWE from 117.1 centimeters of snow. The historically large snow storms contribute 11% to 70% of the year's total precipitation. 1983 contained 3 historically large snow storms that together made up 70% of the year's total precipitation. The snow storm that made up the largest percentage of a year's total precipitation occurred in 2003 where the March storm contributed 37% of the year's total precipitation. On average one historically large snowstorm produces 18% of that calendar year's precipitation. Although this number is impacted by the overall precipitation received during a year. 10 of the 16 historically large snow storm contributed over 20% of the calendar years total precipitation.

Table 7: Summary Table of Historically Large Snow Storms in Colorado (sources: Colorado Climate Center 2011 and NOAA 2010)

Year	Total Snow Depth (cm)	Total Precipitation (SWE) (cm)	Percentage of Annual Precipitation (cm)	Date (Season)	Additional Information (NOAA 2010)
1894	N/A	N/A	N/A	N/A	Noted in climate reconstructions and historical publications
1900	20.7	N/A	N/A	Spring	
1921	35.6	N/A	N/A	April 14-15	Silver Lake received 241.3 centimeters in 32.5 hours
1947	167.4	N/A	N/A	Winter	
1957	10.2	N/A	N/A	April	
1959	35.8	N/A	N/A	Sept. 29	DU campus received 25.4 centimeters of snow
1982	231.9	15.4	(15.4/52.7)*100= 29%	Dec. 23-25 May 12-14	Christmas Eve Blizzard; Denver received 63.5 centimeters of snow
1983	263.7	20.3	(20.3/29.12)*100= 70%	March 4-6 March 14-17, May 16-17	Berthoud Pass received 544.8 centimeters of snow by end of Spring
1984	148.6	14.3	(14.3/54.4)*100= 26%	Oct. 14-17 April19-21	"Bronco Blizzard"; Denver received 30-90 centimeters of snow
1986	110	12.8	(12.8/60.5)*100= 21%	April 2-3	Denver received 80 centimeters of snow
1988	32.8	10.2	(10.2/46.5)*100= 22%	May 18-21	
1990	117.1	11.9	(11.9/60.7)*100= 20%	March 5-7	
1992	64.8	6.6	(6.6/52.4)*100= 13%	March 8-10	
1995	42.4	7.6	(7.6/66.5)*100= 11%	May 16-18	
1997	242.6	18.1	(18.1/72.1)*100= 25%	Oct. 23-25, April 26	
1999	69.9	7.0	(7/66.3)*100= 11%	April 21-25	
2003	182.6	22.6	(22.6/60.4)*100= 37%	March 16-19	Areas near Dillon received 221 centimeters of snow

Table 8: Largest Historic Snow Events and Standardized Ring Widths for Tree Coring Site Chronologies (sources: J. Lukas et al. 2010 and The Colorado Climate Center 2011)

Green highlight=qualitatively significant wide rings

Year	PUM	HOT	VAS	GMR	DIL	OWU	RUS	BEN	DMU	BTU	JAM	PTP	JOP
1894	1.075	1.172	1.084	1.070	0.956	0.976	1.274	1.028	1.400	0.611	1.378	1.207	1.365
1900	1.047	1.151	1.007	1.121	1.007	1.116	1.118	1.039	1.156	1.056	1.185	1.005	0.869
1921	1.428	1.329	1.200	1.387	1.552	0.950	1.638	1.823	1.412	1.547	1.624	1.230	1.482
1947	1.208	0.860	1.302	1.075	1.446	1.207	1.481	1.255	1.329	1.946	1.161	1.308	1.284
1957	1.359	1.375	1.488	1.184	1.197	1.207	1.261	0.975	1.234	1.146	1.205	1.089	1.009
1959	0.934	0.754	0.742	0.770	0.499	0.993	0.895	0.882	0.917	1.08	1.153	1.046	0.956
1960	0.99	1.01	0.93	1.34	0.9	0.83	0.97	1	1.002	0.771	0.9	0.81	0.917
1982	1.115	1.024	0.922	1.288	1.162	1.116	1.036	0.889	1.152	0.806	0.950	1.029	0.866
1983	1.489	1.214	1.349	1.361	1.536	1.518	1.205	1.141	1.468	1.622	1.297	1.146	0.961
1984	1.389	1.435	1.389	1.583	1.977	1.158	1.119	1.169	1.121	0.957	0.738	0.683	0.923
1985	1.448	1.099	1.086	1.477	1.290	0.720	0.607	0.567	0.940	0.835	1.195	0.874	0.874
1986	1.010	1.276	1.179	1.568	1.132	1.218	1.413	1.485	1.408	0.811	1.039	0.761	0.872
1988	0.687	0.965	0.938	0.895	0.777	0.955	0.797	0.821	0.767	0.31	0.905	0.840	0.939
1990	0.609	0.987	0.928	0.547	0.735	1.425	1.255	1.004	1.282	1.369	1.019	0.876	1.102
1992	0.634	0.934	1.050	0.817	0.815	1.127	1.222	1.420	0.910	0.807	1.101	0.968	1.209
1995	1.189	1.228	1.163	1.144	1.760	1.373	1.459	1.460	1.785	1.103	1.589	1.120	1.436
1997	1.198	1.059	0.859	1.157	1.084	0.930	1.268	1.255	0.766	1.852	1.330	0.960	1.275
1998	0.992	0.666	1.029	0.385	0.455	1.366	1.255	1.348	1.620	1.327	0.964	0.899	0.993
1999	1.018	1.023	0.946	1.015	1.195	1.385	1.070	1.052	1.400	1.231	1.319	1.523	1.469
2003					1.560					1.248			

Year	BLD	ELU	CRA	VBU	JFU	MEY	EAG	HER	VVR	HAP	ELE	TCU
1894	1.886	1.155	1.688	1.709	1.203	1.380	1.065	0.911	0.534	1.540	1.087	1.246
1900	1.163	0.964	1.032	0.869	1.118	0.980	0.918	0.409	1.196	1.028	0.986	1.186
1921	1.156	1.218	1.316	1.156	1.275	1.426	1.139	1.41	0.949	1.802	1.517	1.734
1947	1.288	1.297	1.030	1.405	1.704	1.172	1.073	1.449	2.177	1.278	1.416	1.688
1957	0.952	0.956	1.142	1.027	1.273	0.924	1.160	1.146	1.519	1.337	1.458	1.172
1959	0.986	1.095	0.850	0.774	0.953	0.886	0.797	0.883	1.192	0.971	0.935	1.272
1960	1.1	1.025	1.130	1.283	1.284	1.147	1.070	0.881	0.999	1.503	1.080	1.352
1982	0.703	0.738	0.920	0.762	0.683	0.920	0.928	1.039	1.417	1.044	1.264	1.571
1983	1.044	1.245	1.159	1.501	1.418	1.351	1.221	1.308	1.607	1.312	1.306	1.498
1984	0.847	1.090	0.749	0.63	0.763	0.759	0.858	0.717	0.666	0.753	1.143	0.537
1985	1.167	1.025	1.327	1.159	1.308	1.201	1.166	0.971	1.291	1.228	1.157	1.902
1986	0.722	1.036	1.344	1.133	1.168	1.338	1.109	1.024	0.569	0.829	0.779	0.472
1988	0.992	1.370	1.106	0.667	1.270	1.198	1.265	1.155	1.159	1.552	1.181	0.567
1990	1.435	0.726	0.842	1.357	1.063	0.962	0.773	0.958	1.349	1.061	0.944	1.258
1992	1.008	0.846	1.161	1.175	1.187	0.981	0.933	1.012	0.836	1.110	1.060	1.673
1995	1.435	0.846	1.325	1.583	1.221	1.371	1.176	1.247	1.529	1.772	1.244	2.003
1997	1.065	1.260	0.837	0.955	1.037	1.382	0.931	1.345	1.656	0.636	0.825	1.773
1998	0.992	1.370	1.106	0.667	1.270	1.198	1.265	1.155	1.159	1.552	1.181	0.567
1999	1.571	1.299	1.129	1.469	0.996	1.046		1.449		1.586		1.999
2003		0.959	1.492	1.538	1.401			1.235		0.793		0.872

Table 9: Statistical Significance Wide Ring Calculations for Each Site
(sources: J. Lukas et al. 2010 and The Colorado Climate Center 2011)
OA=Overall Chronology Average; OSD=Overall Chronology Standard Deviation;
1OSD>OA=1 OSD more than the OA (OSD+OA)
Designates statistical significance if the ring width is the same to the tenth or higher when rounded

	PUM	HOT	VAS	GMR	DIL	OWU	RUS	BEN	DMU	BTU	JAM	PTP	JOP
OA	0.993	0.983	0.994	0.988	0.983	0.993	0.993	0.991	0.990	0.986	0.987	0.992	0.995
OSD	0.282	0.305	0.254	0.318	0.326	0.260	0.320	0.350	0.311	0.436	0.289	0.235	0.261
1OSD>OA	1.275	1.288	1.248	1.306	1.309	1.253	1.341	1.341	1.301	1.422	1.276	1.227	1.256

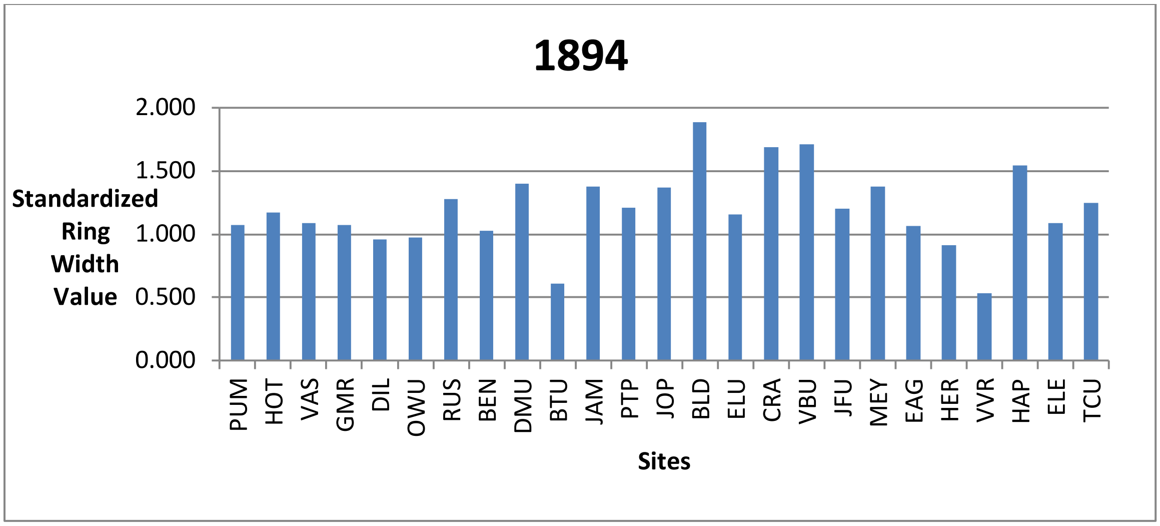
	BLD	ELU	CRA	VBU	JFU	MEY	EAG	HER	VVR	HAP	ELE	TCU
OA	0.991	0.990	0.992	0.971	0.993	0.994	0.995	0.994	0.984	0.993	0.996	0.992
OSD	0.265	0.243	0.292	0.415	0.291	0.248	0.278	0.314	0.425	0.347	0.283	0.432
1OSD>OA	1.256	1.233	1.284	1.386	1.284	1.242	1.273	1.308	1.409	1.340	1.279	1.424

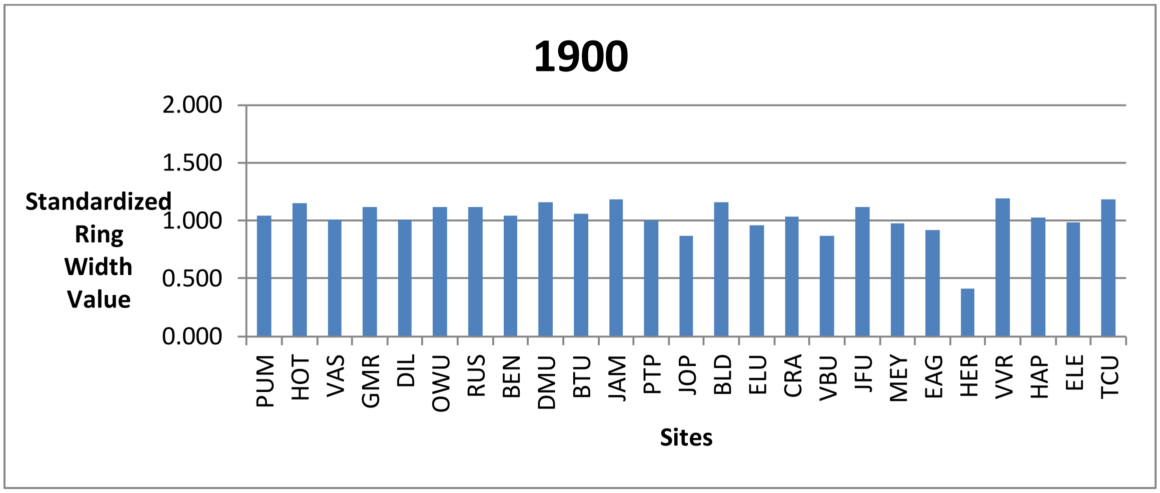
The standardized ring widths for all sites during the calibration record (1894-2003) with an overlay of the historically large snowfall events as well as graphs of this information are included in the appendix. These data show natural climate variation (times of drought as well as wet events) as well as an increase of historically large snow events since the 1980s. The standardized ring widths at each site during the years of historically large snow storm or the following year for storms occurring in the fall or early winter are listed in Table 8. For the fall storms of 1959, 1984, and 1997 as well as the early winter storm of 1982, the ring widths for both those exact years and the following years are included for comparison because these storms would have impacted the growth of the next year’s ring. Table 8 reflects the extent (spatial coverage) of the historically large snowfall events. If the standardized ring width was considered significantly wide (to the tenth) it was highlighted. Table 9 lists the calculations for statically wide ring widths for each site chronology (1 standard deviation more than the average). Table 10 summarizes the content of Table 8 by listing the spatial extent (presence) of the historically large snow storms in the Western Slope and Front Range sites.

Figure 4 graphs each site's standard ring width value during each historically large snow storms. In 1894 there are narrower ring widths in the Western Slope sites with wider ring widths concentrated in the mid sites of the Front Range. In 1900 none of the ring widths were very wide. In 1921 most of the rings were fairly wide (close to or wider than 1.5). In 1947 wider rings were present in the Western Slope sites, but the Front Range sites contained more wide rings. In 1957 wider rings were found in both the Western Slope and Front Range sites, but none were wider than 1.5. In 1959 rings were narrower with none above 1.272, meaning none were significantly wide. The 1959 snow storm occurred in the fall so the ring widths of 1960 were also included, which indicated a minor extent storm in the Western Slope and Front Range. In 1982 there was an early winter storm and a few wider ring widths were found in the Western Slope sites as well as in the southern Front Range sites (four sites total). In 1983 there were two historically large spring snow events and it was the calendar year that would have shown the impacts of the 1982 storm on ring width. In 1983 wider rings were found at 20 sites in both the Western Slope and Front Range with some well above 1.5. In 1984 rings were very wide (near 2) in a Western Slope site, but wide rings were not present in the Front Range sites. The 1984 snow storm occurred in the fall so the ring widths of 1985 were also included, which indicated a moderate extent storm in the Western Slope and Front Range sites. In 1986 some wide rings were found in the Western Slope and mid Front Range sites, but the southern sites of the Front Range were very narrow. In 1988 there were narrower rings in the Western Slope sites but rings were wider in the mid Front Range sites, yet only 1 was slightly higher than 1.5. In 1990 rings were narrow in the Western Slope sites and somewhat wider in the Front Range sites, but none reached 1.5. In 1992 narrow rings were present in the Western Slope sites, but wider rings were found in the Front Range sites with one site in the southern region greater than 1.5. In 1995 rings widths were greater than 1 in the Western Slope sites with Dillon more than 1.5 and there were many wide rings in the Front Range sites with 6 greater than 1.5. In 1997 the Western Slope sites were slightly above 1, but 3 Front Range sites had ring widths over 1.5. The 1997 snow storm occurred in the fall so the ring widths of 1998 were also included, which also indicated a moderate extent storm in the Front Range sites. In 1999 there was some missing data, but overall narrower rings were found in the Western Slope sites and wider rings were concentrated in the mid region of the Front Range with 1 southern site's ring width near 2. In 2003 many of the sites had not been updated, but DIL was above 1.5 and 3 Front Range sites were near or slightly above 1.5.

Table 10: Summary of Historically Large Snow Storms' Presence at Western Slope and Front Range Sites Based on Sites' Qualitatively Significant Wide Ring Widths
(sources: Lukas et al. 2010 and The Colorado Climate Center 2011)

Year	Presence in Western Slope	Presence in Front Range	Summary
1894	0%	*60% Northern Sites: RUS Mid Sites: missing in BTU, EAG Sothern Sites: HAP	Front Range moderate extent storm, mostly in the mid sites
1900	0%	10% Northern Sites: none Mid Sites: JAM, BLD Southern Sites: none	Front Range minor extent storm, only in the mid sites
1921	**100%	**75% Northern Sites: missing in OWU Mid Sites: missing in BLD, VBU, EAG Southern Sites: missing in VVR	Western Slope and Front Range major extent storm
1947	*60% Missing in HOT, GMR	**85% Northern Sites: all Mid Sites: missing in JAM, CRA, EAG Southern Sites: all	Western Slope moderate extent storm and Front Range major extent storm
1957	*60% Missing in GMR, DIL	*40% Northern Sites: missing in BEN Mid Sites: DMU, JAM, JFU Southern Sites: missing in HER, TCU	Western Slope and Front Range moderate extent storm
1960	20% GMR	20% Northern Sites: none Mid Sites: VBU, JFU Southern Sites: HAP, TCU	Western Slope and Front Range minor extent storm
1982	20% GMR	15% Northern Sites: none Mid Sites: none Southern Sites: VVR, ELE, TCU	Western Slope and Front Range minor extent storm
1983	**100%	**75% Northern Sites: OWU Mid Sites: missing in JOP, BLD, CRA Southern Sites: all	Western Slope and Front Range major extent storm
1985	*60% Missing in HOT, VAS	*40% Northern Sites: none Mid Sites : JAM, BLD, CRA, JFU, MEY, EAG Southern Sites: ELE, TCU	Western Slope and Front Range moderate extent storm
1986	*60% Missing in PUM, DIL	*30% Northern Sites: all Mid Sites: DMU, CRA, MEY Southern Sites: none	Western slope and Front Range moderate extent storm
1988	0%	25% Northern Sites: none Mid Sites: ELU, JFU, MEY, EAG Southern Sites: HAP	Front Range minor extent storm
1990	0%	*35% Northern Sites: OWU, RUS Mid Sites: DMU, BTU, BLD, VBU Southern Sites: VVR	Front Range moderate extent storm
1992	0%	25% Northern Sites: RUS, BEN Mid Sites: JOP, JFU Southern Sites: TCU	Front Range minor extent storm
1995	**80% Missing in GMR	**85% Northern Sites: OWU, RUS Mid Sites: missing in BTU, PTP, ELU Southern Sites: all	Western Slope and Front Range major extent storm
1998	0%	*33% Northern Sites: OWU, RUS, BEN Mid Sites: DMU, VBU, JFU Southern Sites: none	Front Range moderate extent storm (in '98 chronology not extended at EAG, ELE)
1999	0%	*65% Northern Sites: OWU Mid Sites: missing in BTU, CRA, JFU, MEY Southern Sites :HER HAP, TCU	Front Range moderate extent storm (in '99 chronology not extended at EAG, VVR, ELE)
2003	DIL (data only available for 1 site)	*50% of available sites CRA, VBU, JFU (mid) and HER (southern)	Data only from 9 sites


1894
Standardized Ring Width Value
2.000
1.500
1.000
0.500
0.000
PUM
HOT
VAS
GMR
DIL
OWU
RUS
BEN
DMU
BTU
JAM
PTP
JOP
BLD
ELU
CRA
VBU
JFU
MEY
EAG
HER
VVR
HAP
ELE
TCU
Sites


1900
Standardized Ring Width Value
2.000
1.500
1.000
0.500
0.000
PUM
HOT
VAS
GMR
DIL
OWU
RUS
BEN
DMU
BTU
JAM
PTP
JOP
BLD
ELU
CRA
VBU
JFU
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EAG
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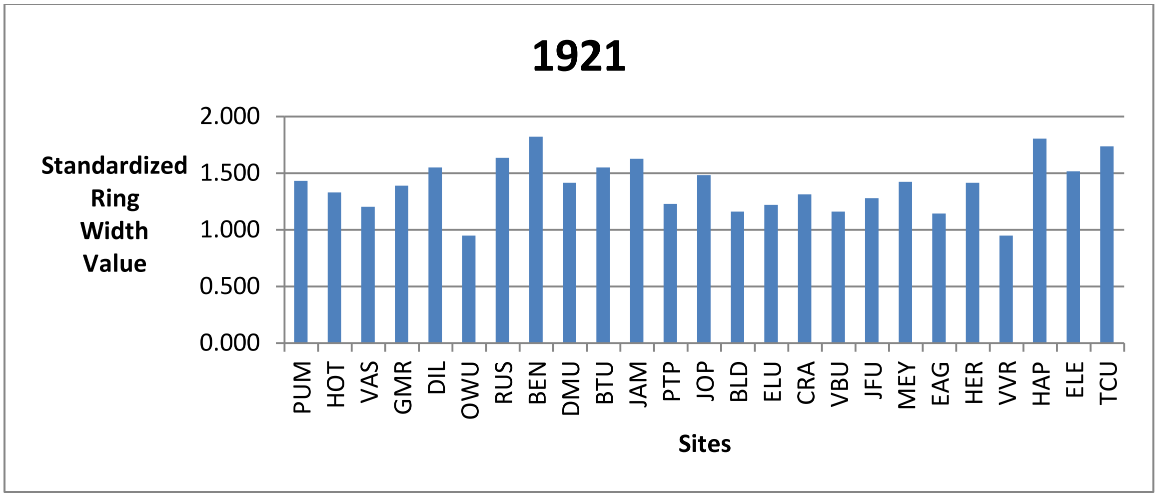
TCU
Sites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Standardized Ring Width Value
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0.500
0.000
PUM
HOT
VAS
GMR
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BEN
DMU
BTU
JAM
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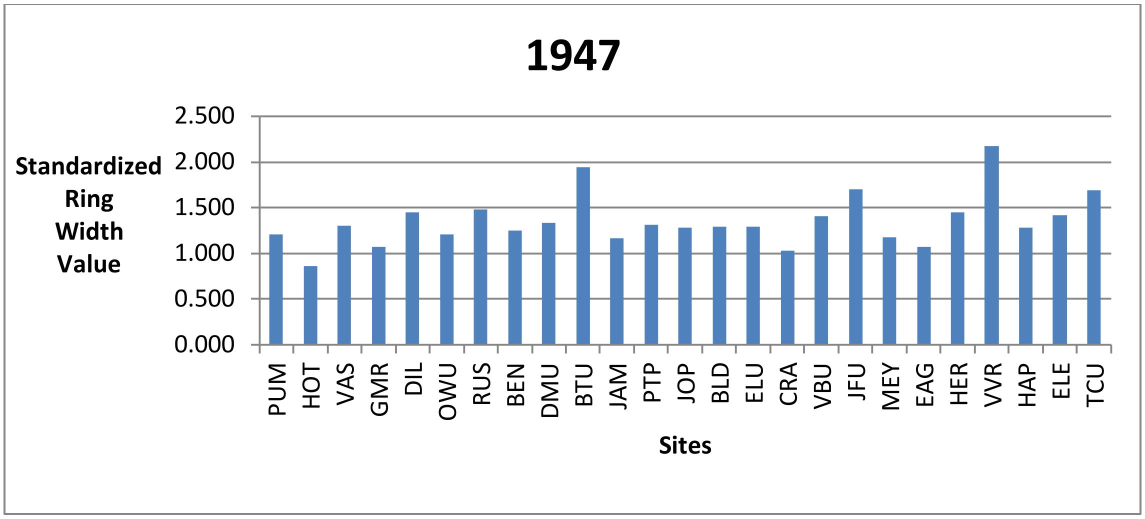
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1.000
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0.000
PUM
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OWU
RUS
BEN
DMU
BTU
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TCU
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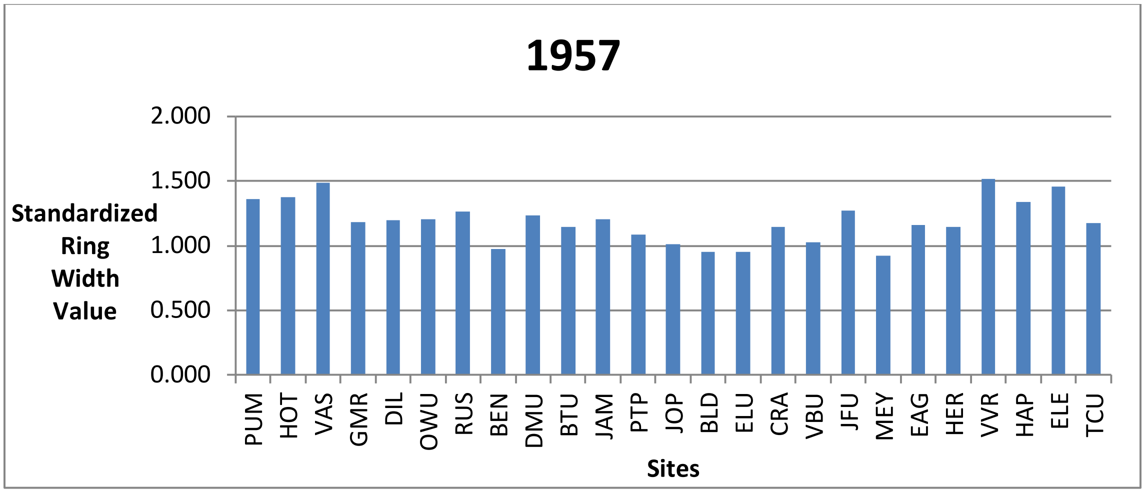
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DMU
BTU
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ELE
TCU
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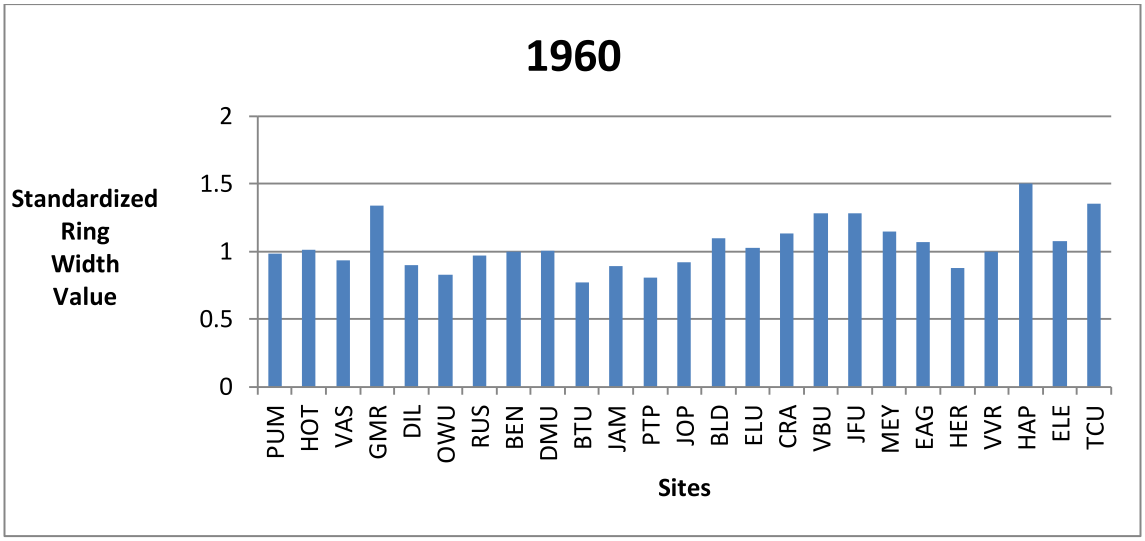
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0
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VAS
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DMU
BTU
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PTP
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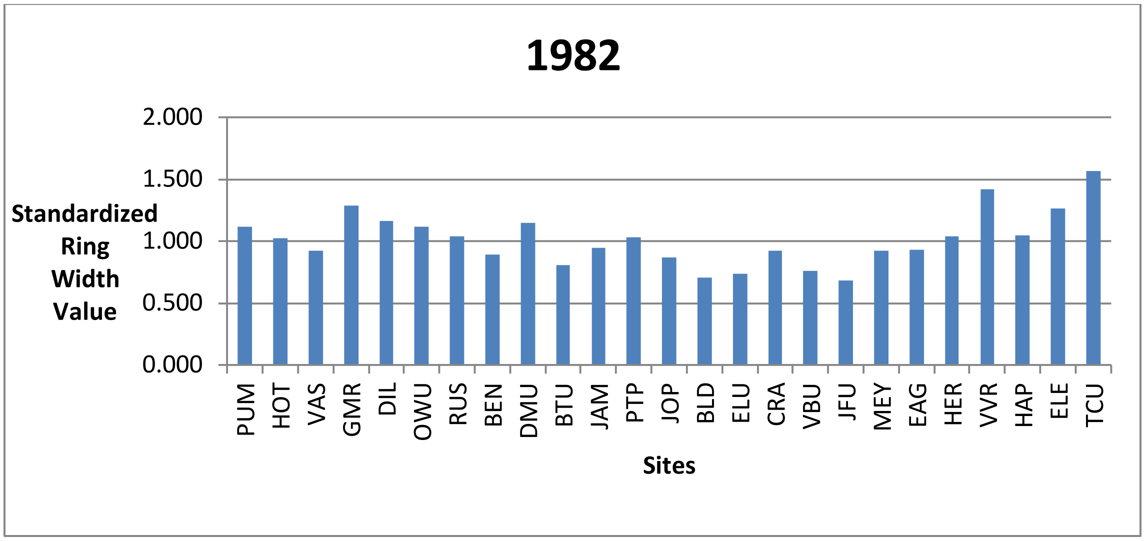
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1.000
0.500
0.000
Standardized Ring Width Value
PUM
HOT
VAS
GMR
DIL
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BEN
DMU
BTU
JAM
PTP
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BLD
ELU
CRA
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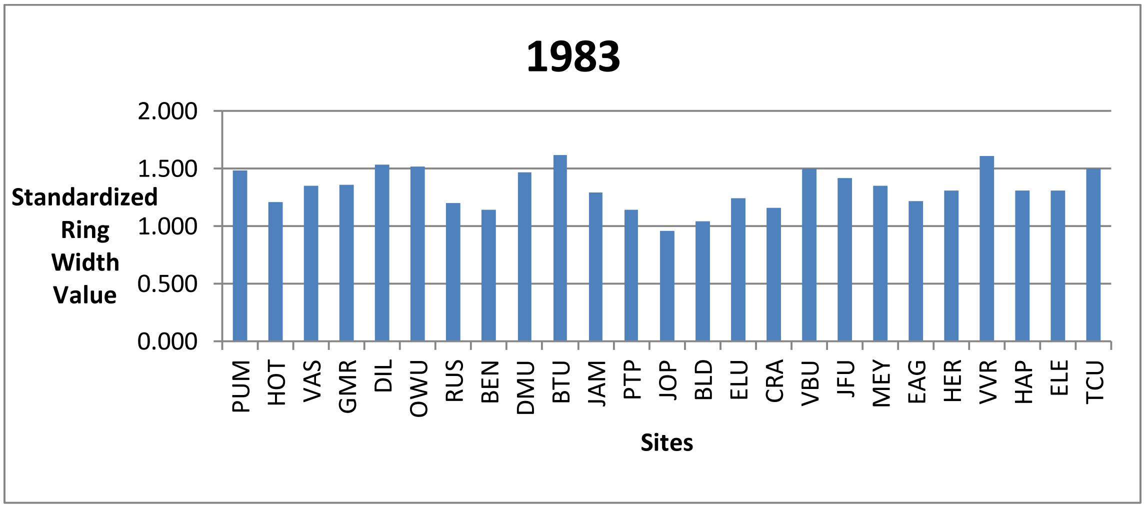
ELE
TCU
Sites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Standardized Ring Width Value
PUM
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GMR
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DMU
BTU
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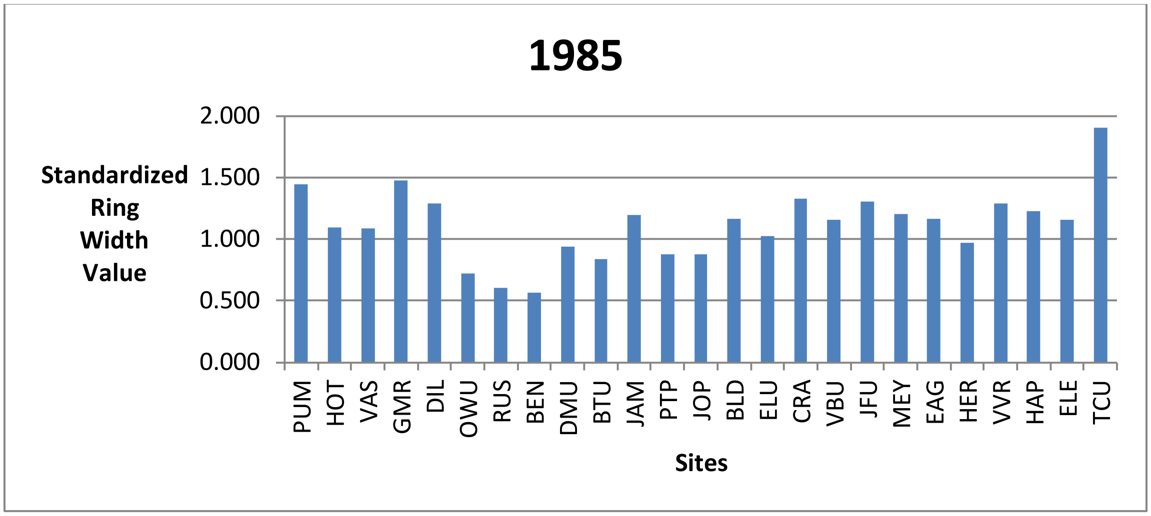
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Standardized Ring Width Value
PUM
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DMU
BTU
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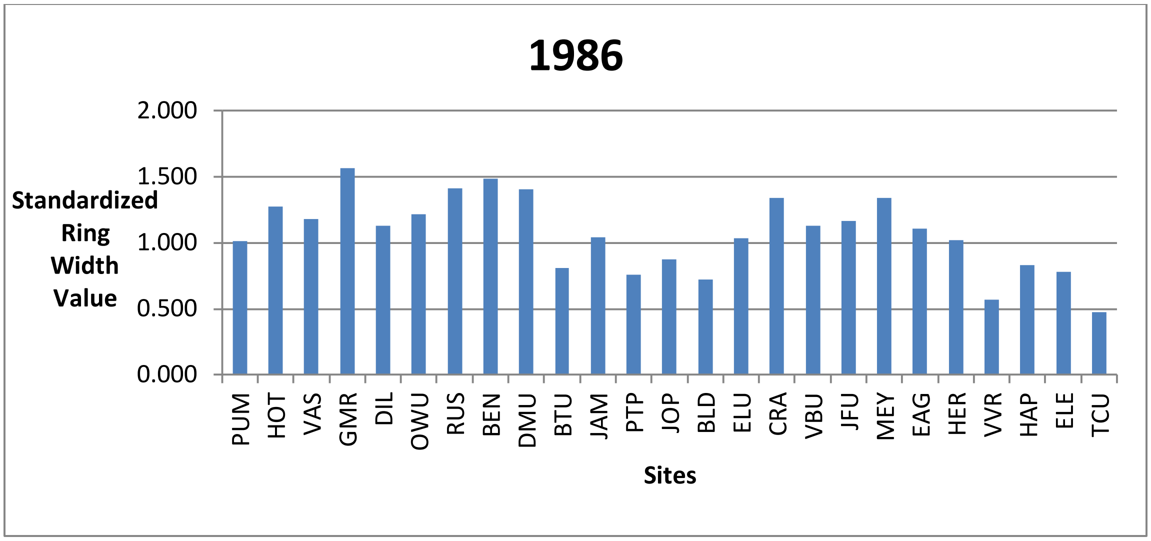
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Standardized Ring Width Value
PUM
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GMR
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DMU
BTU
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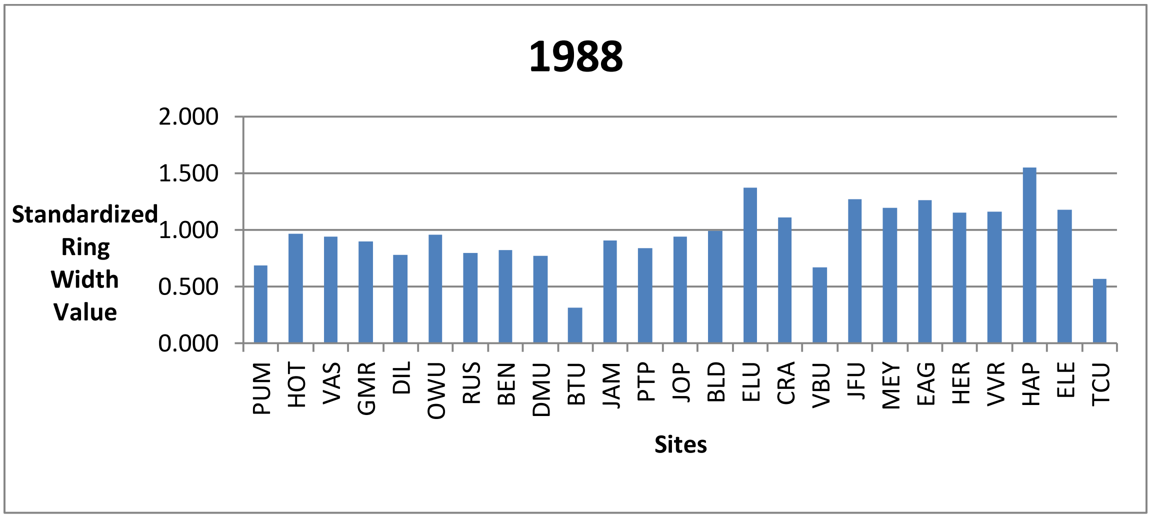
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DMU
BTU
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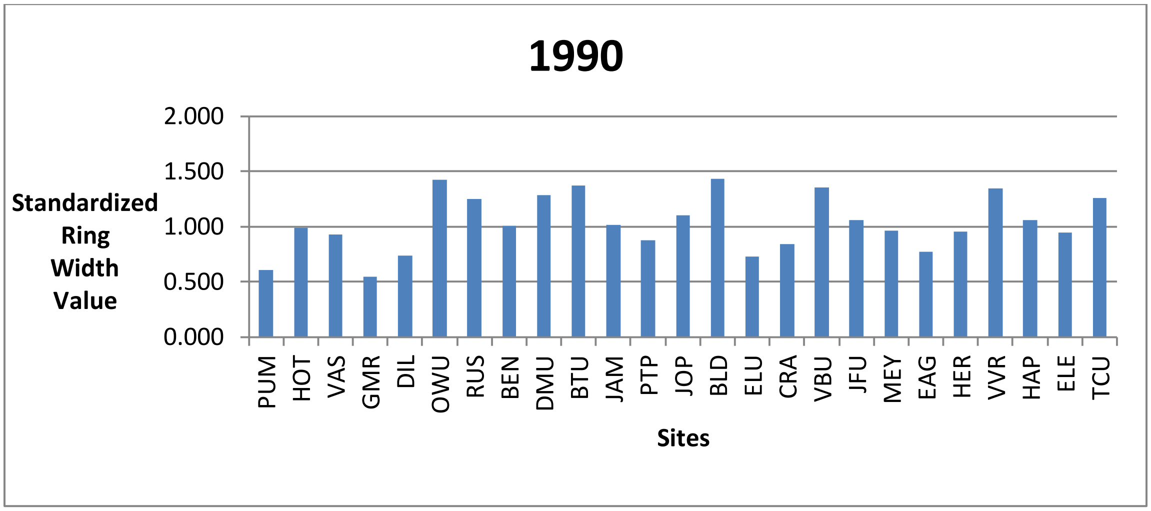
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1.000
0.500
0.000
Standardized Ring Width Value
PUM
HOT
VAS
GMR
DIL
OWU
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BEN
DMU
BTU
JAM
PTP
JOP
BLD
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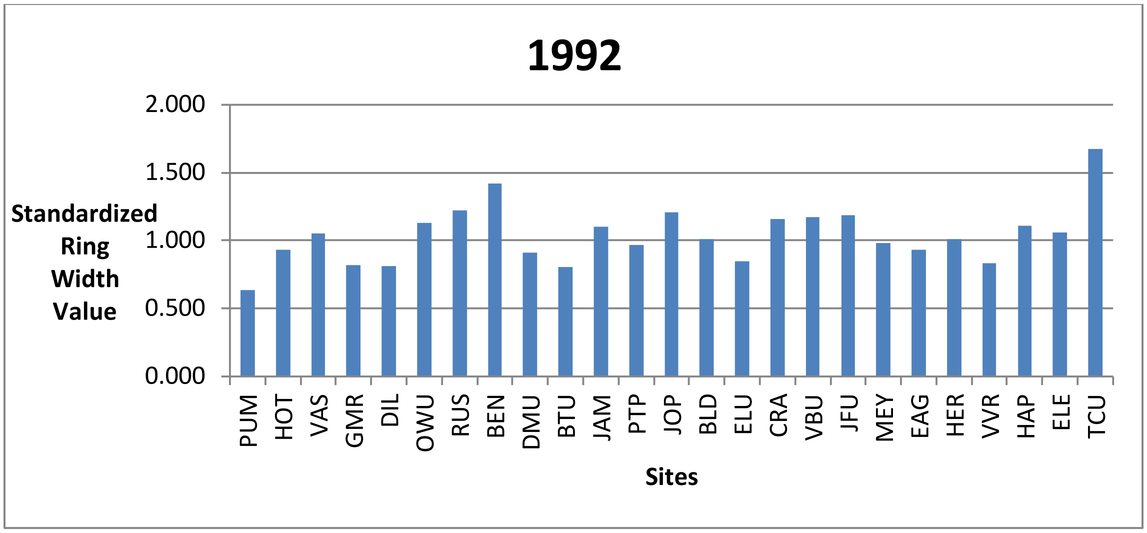
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DMU
BTU
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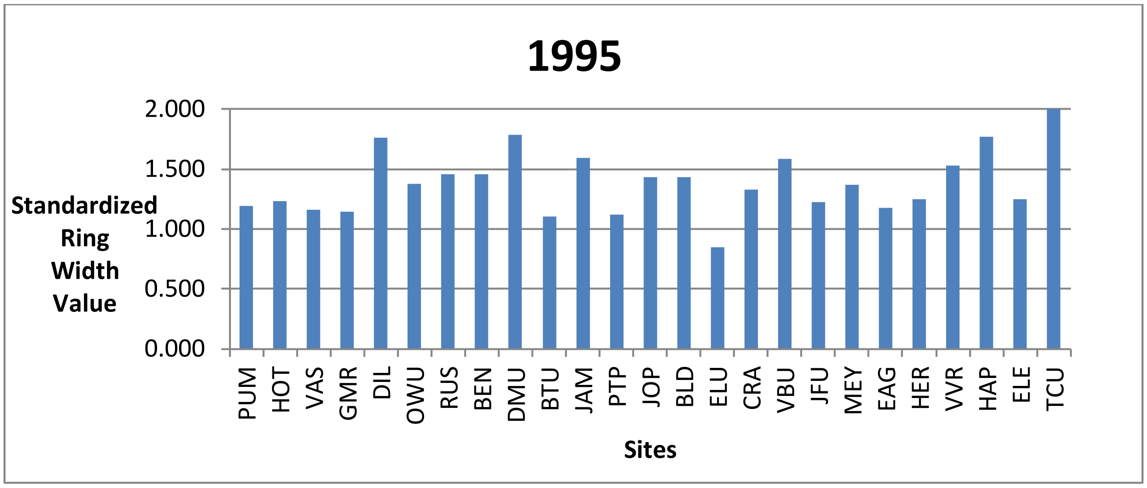
1995
Standardized Ring Width Value
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0.000
PUM
HOT
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GMR
DIL
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DMU
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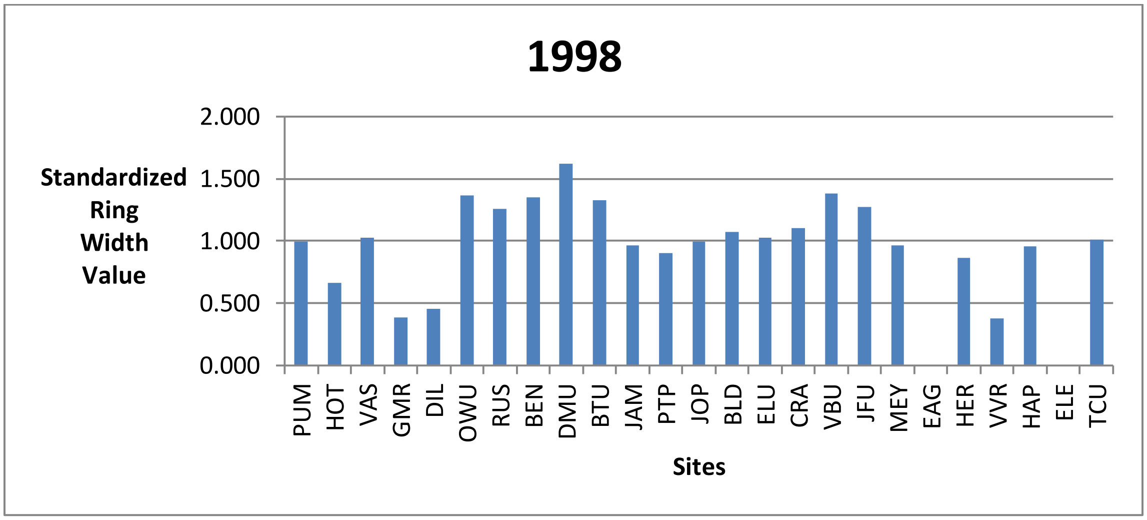
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Standardized Ring Width Value
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0.500
0.000
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HOT
VAS
GMR
DIL
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DMU
BTU
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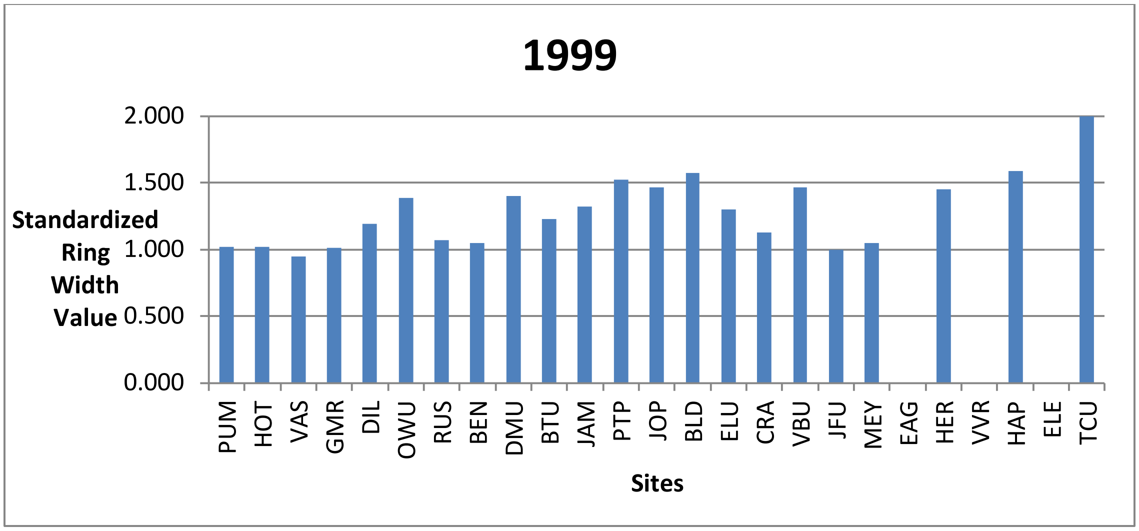


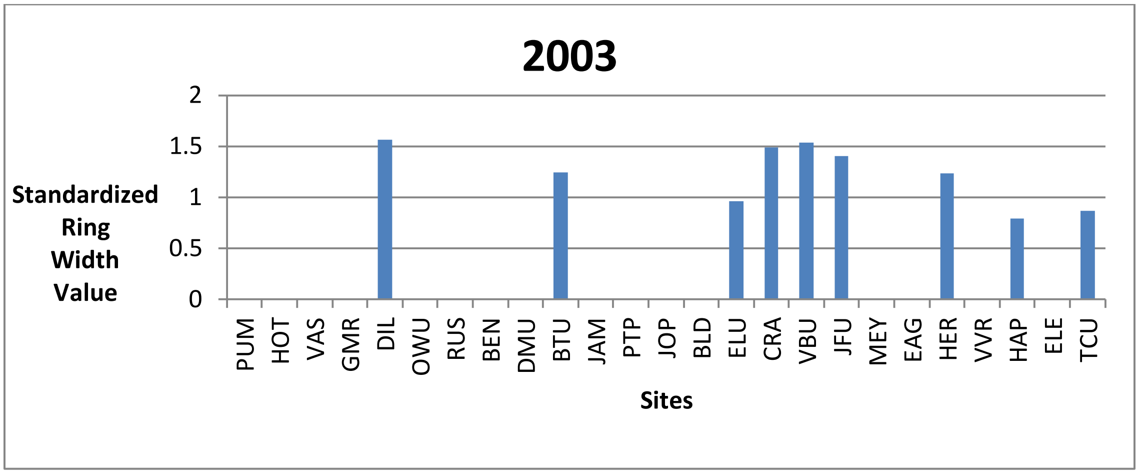


Figure 4: Standard Ring Width Value for Each Site During Historically Large Snow Storms Graphed by Year
(sources: J. Lukas et al. 2010 and The Colorado Climate Center 2011)
The first 5 sites are Western Slope sites, the next 3 are northern Front Range sites, the next 12 are mid Front Range sites, and the last 5 are southern Front Range sites.

Mapping Ring Widths at Each Site during Historically Large Snow Events

The standardized ring widths for tree coring sites were mapped during historically large snow storms, as represented by graduated symbols (Figure 5). Figure 5 maps the standardized ring widths instead of CPYs to better illustrate research question 1. The results of Figure 5 illustrate that of Table 8 as they are the same data: In 1894 the map depicted ring widths much wider in the Front Range sites with the largest ring widths in the mid sites. This illustrated the data in Table 8, where a moderate extent storm producing statistically wide rings was concentrated in the Front Range. At first glance the map of 1900 depicted wide ring widths in both the Western Slope and Front Range sites, but when the legend was consulted even the widest ring was only 1.186 (a considerably thin ring). This was also seen in Table 8. The map legend of 1921 indicated the next to smallest symbol represented 1.329 ring widths. This illustrated that most sites had a considerably wide ring except the Front Range's most northern site and three mid sites. In the map of 1947 very wide ring widths were located in the Front Range, while the Western Slope had moderately wide rings at a few locations. In 1947 Table 8 indicated a moderate extent storm in the Western Slope sites and a major extent storm in the Front Range sites, which was illustrated with the map. In the map of 1957 wide rings were found in both Western Slope sites and almost half of the Front Range sites, which illustrated with the wide ring widths of 1957 in Table 8. In 1959 the map illustrated most of the wider ring widths were found in the mid Front Range sites. However, the legend depicted that even the widest rings were only 1.272, which is not considerably wide. This information depicted Table 8 where no large ring widths were produced in 1959 in which the snow storm occurred in the fall. The map of 1982 depicted a few wider ring widths in the Western Slope and southern Front Range sites because the snow storm occurred in the early winter. In 1983 (a year with two spring snow storms and the calendar year after an early winter snow storm) indicated a major extent storm for both the Western Slope and Front Range. The map of 1983 also depicted similar trends with many large symbols in the Front Range and Western Slope sites. In the map of 1984 (during this year the storm occurred in the fall) wider ring widths were only present in the Western Slope sites. This was also illustrated in Table 8 that only identified wide rings in Western Slope sites, indicating a major extent storm in that area. The map of 1986 illustrated wider ring widths in both the Western Slope and Front Range sites. The map of 1988 and 1990 both depicted wider rings in the Front Range sites, but not in the Western Slope sites. The 1995 map first looked to illustrate only wider ring widths in the Front Range sites. However, the legend identified the smallest symbol as representing 1.326 ring widths (substantially wide rings), which indicated wide rings present in both the Western Slope and Front Range sites. The 1997 map, which was also a year with a fall snow storm, indentified some wider ring widths in the Western Slope and several very wide ring widths in the Front Range.

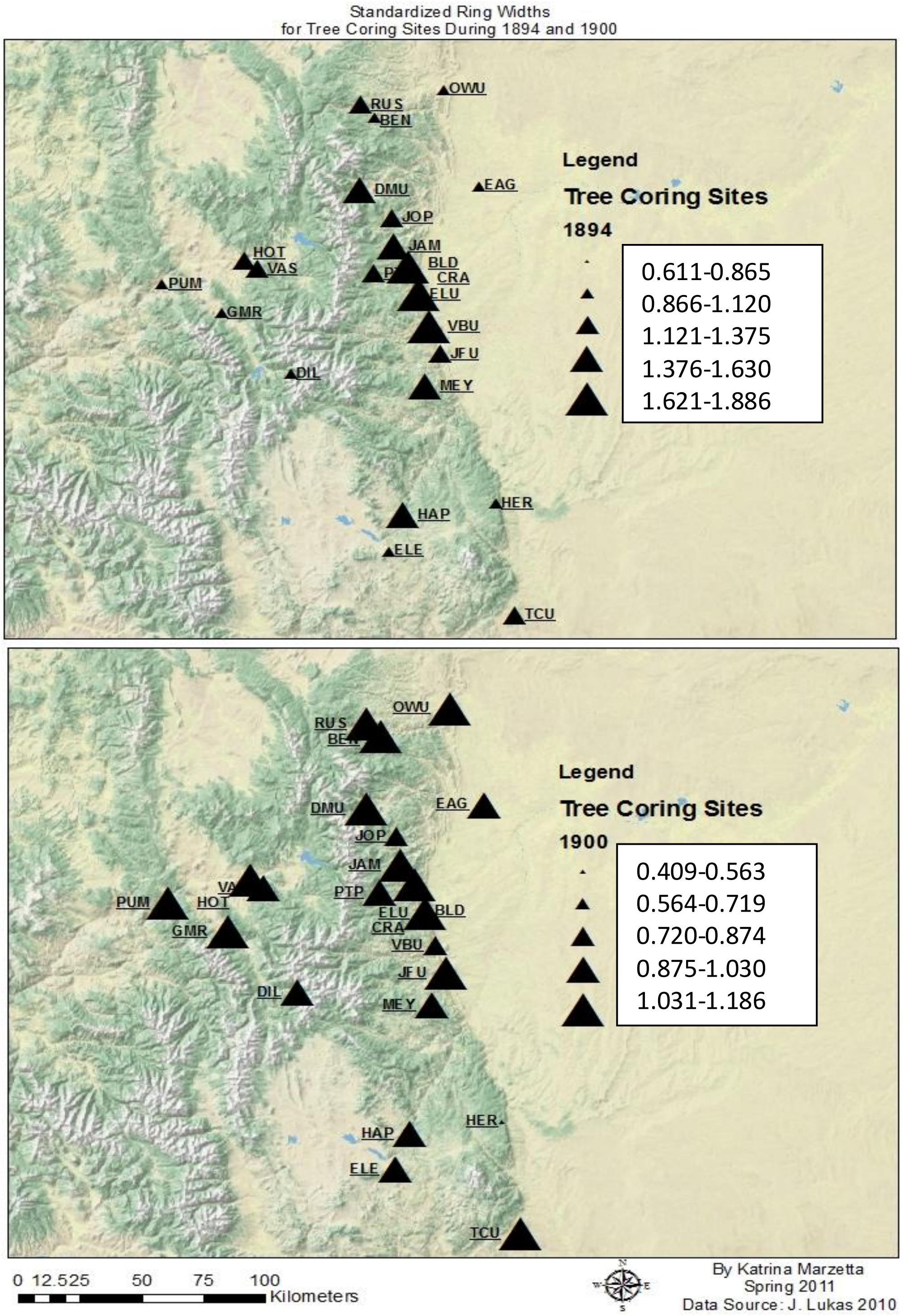


Figure 5a: Standardized Ring Widths at Tree Coring Sites for the Historically Large Snow Storms of 1894 and 1900.

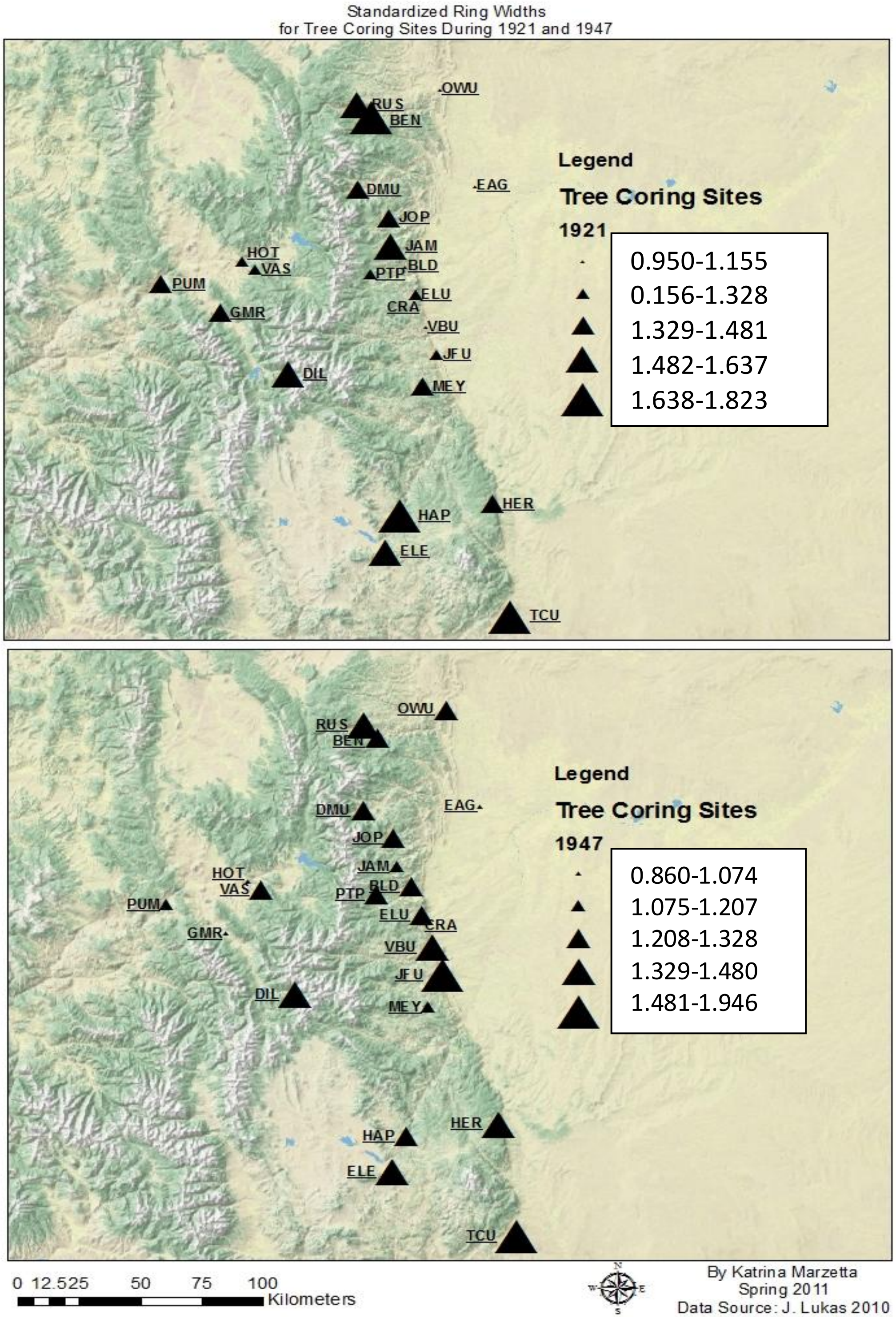
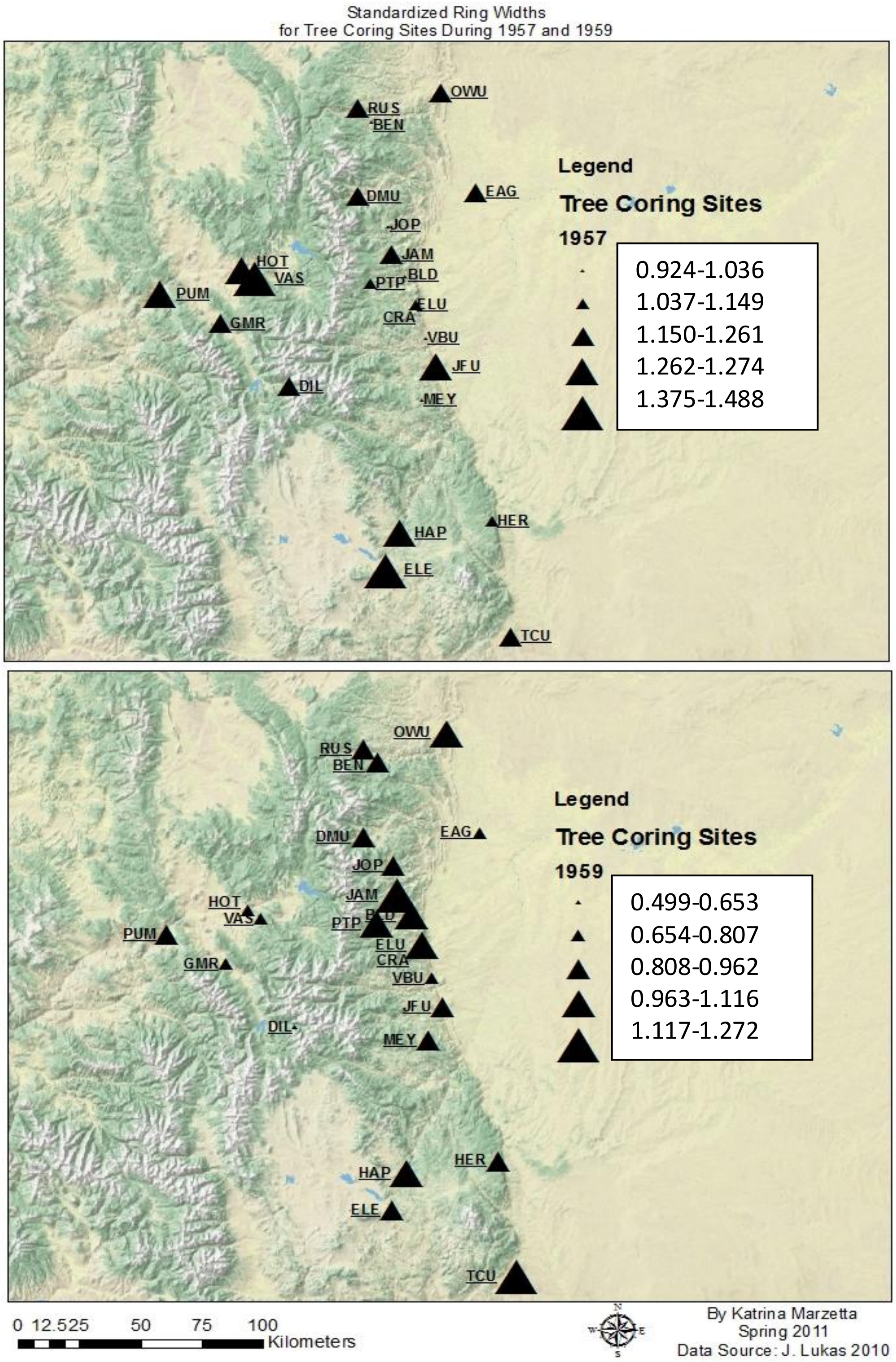


Figure 5b: Standardized Ring Widths at Tree Coring Sites for the Historically Large Snow Storms of 1921 and 1947.


Standardized Ring Widths
for Tree Coring Sites During 1957 and 1959

By Katrina Marzetta
Spring 2011
Data Source: J. Lukas 2010

Figure 5c: Standardized Ring Widths at Tree Coring Sites for the Historically Large Snow Storms of 1957 and 1959.

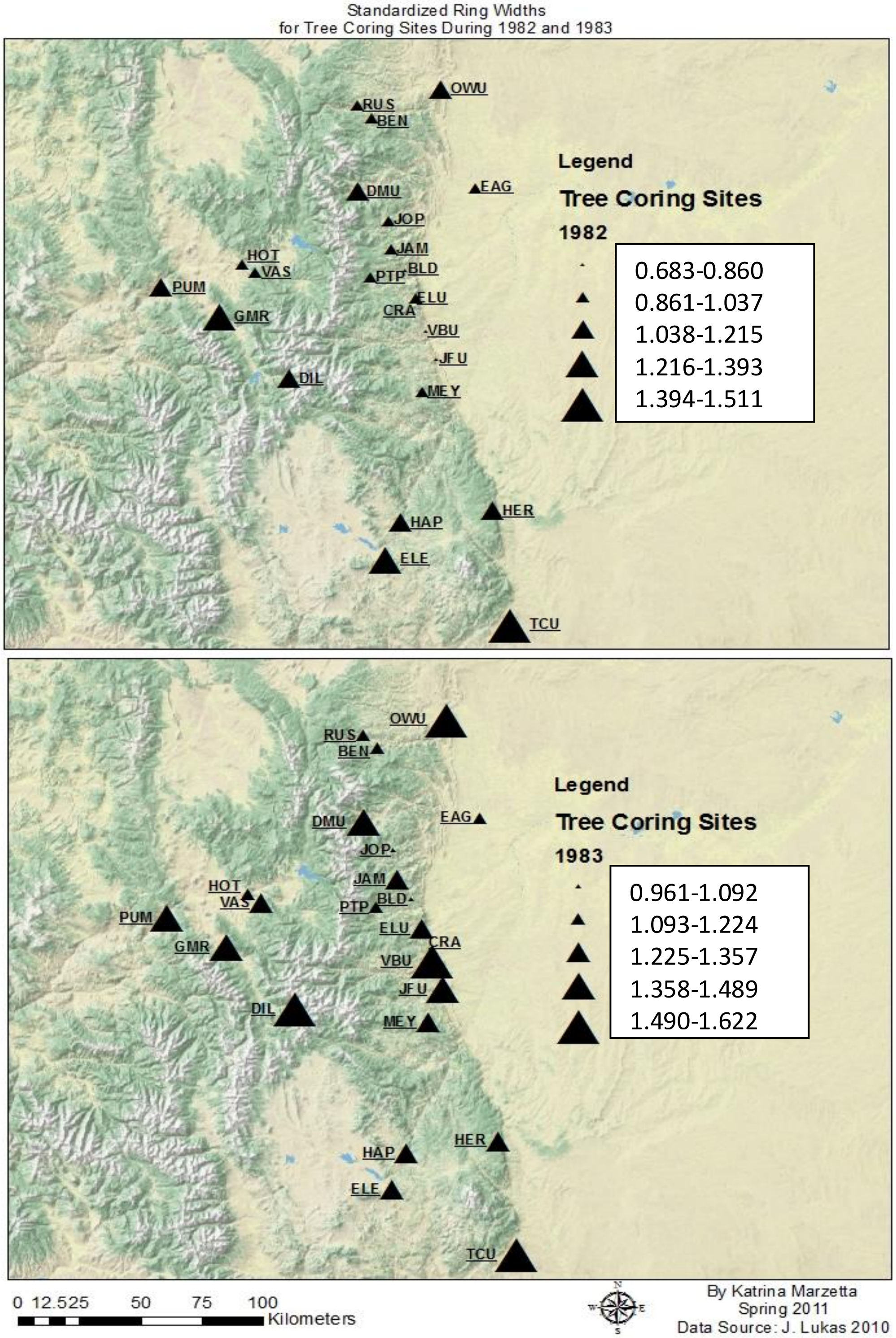


Figure 5d: Standardized Ring Widths at Tree Coring Sites for the Historically Large Snow Storms of 1982 and 1983.

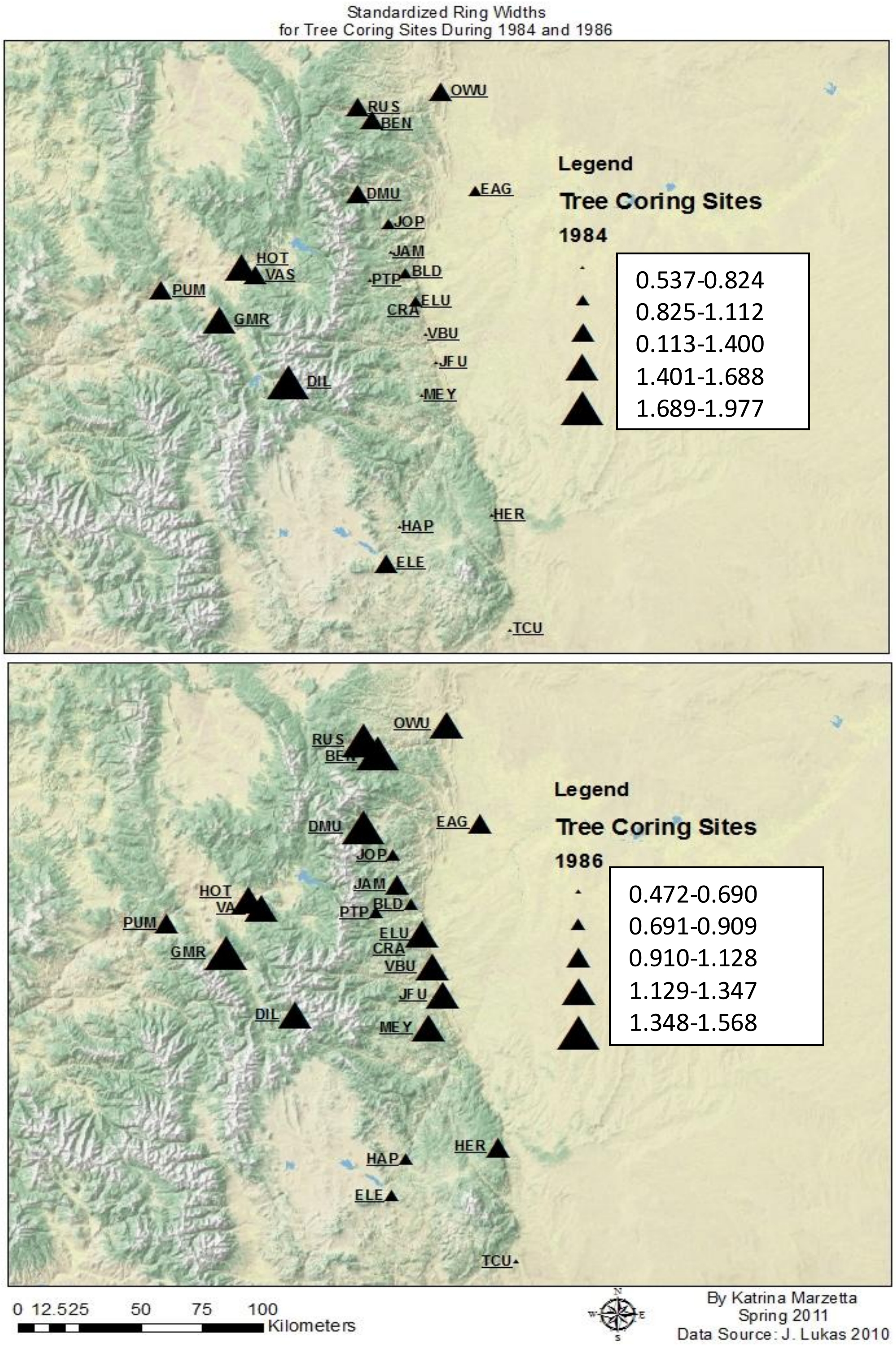
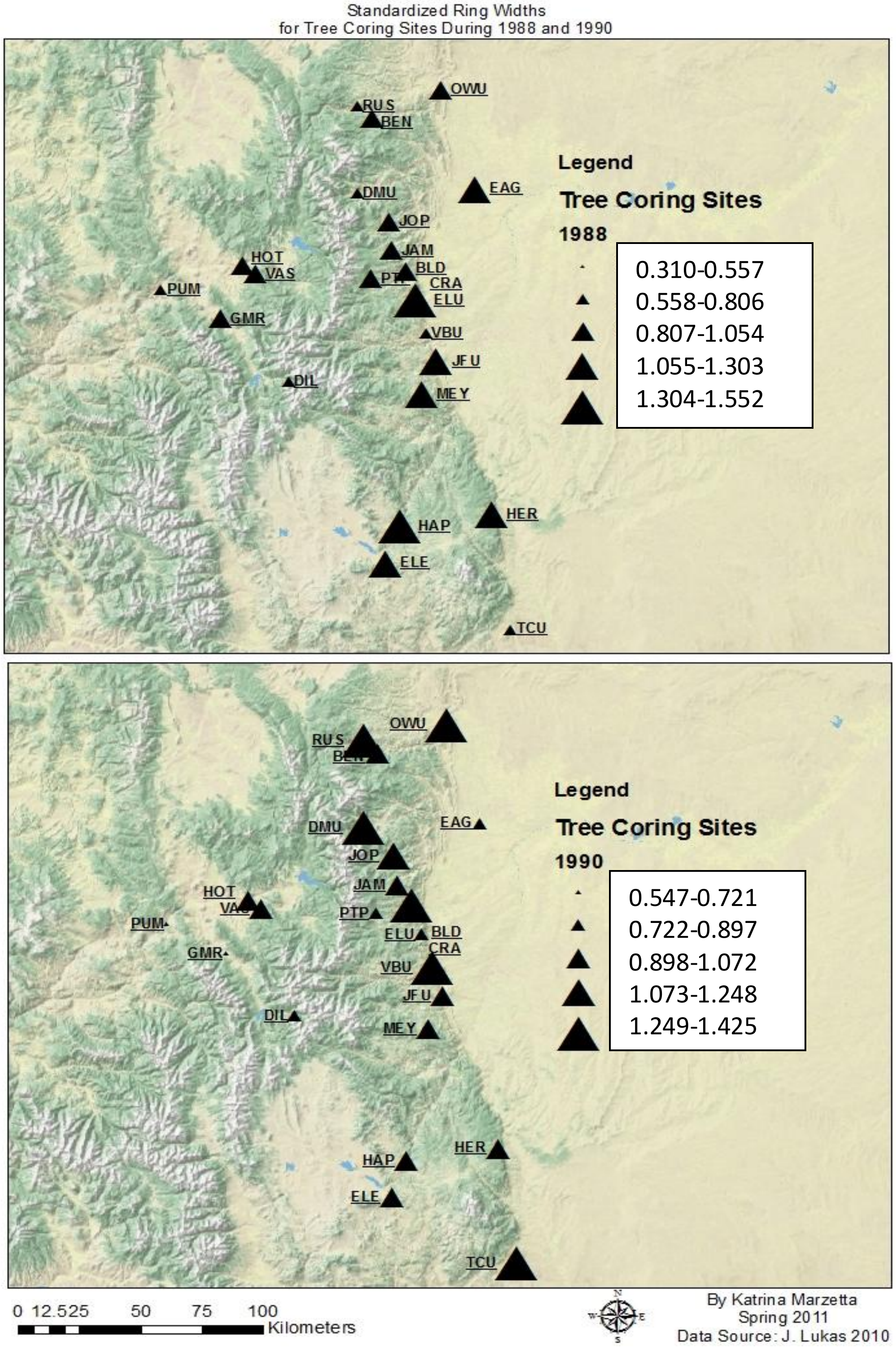


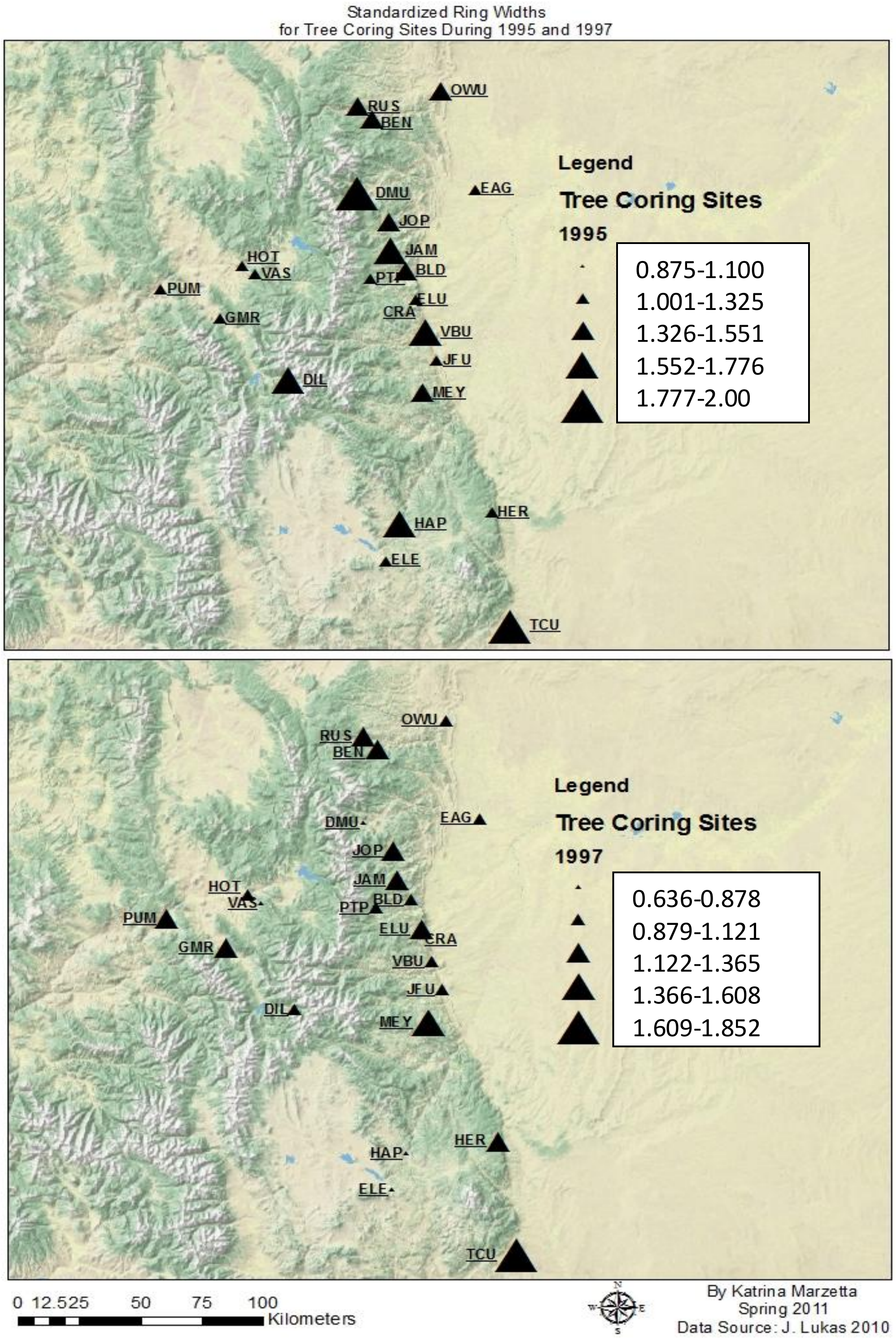
Figure 5e: Standardized Ring Widths at Tree Coring Sites for the Historically Large Snow Storms of 1984 and 1986.



Standardized Ring Widths for Tree Coring Sites During 1988 and 1990

By Katrina Marzetta
Spring 2011
Data Source: J. Lukas 2010

Figure 5f: Standardized Ring Widths at Tree Coring Sites for the Historically Large Snow Storms of 1988 and 1990.



By Katrina Marzetta
Spring 2011
Data Source: J. Lukas 2010

Figure 5g: Standardized Ring Widths at Tree Coring Sites for the Historically Large Snow Storms of 1995 and 1997.

Snowpack Maps of Years with Historically Large Snow Storms

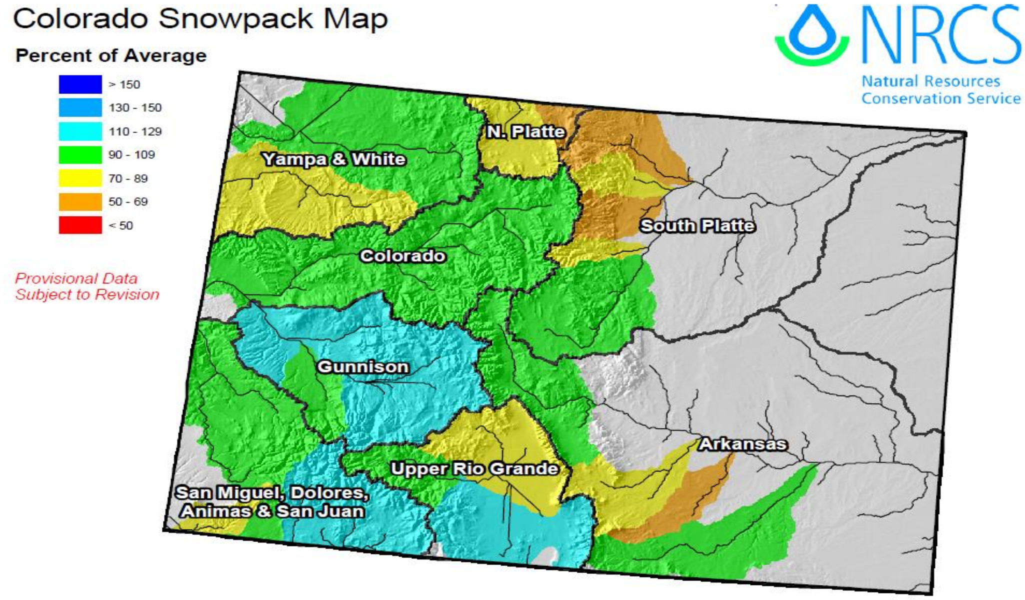
Figure 6 depicts March, April, and May snowpack during years with historically large snow storms. Only data from 1995, 1997, 1999, and 2003 were available through the Natural Resources Conservation Service. The drought year snowpack of 2002 was also included for comparison. Because the total snow water equivalency may not be equivalent from map to map, these maps are only an illustration of the differences between wet and dry years.

In 1995 the snowpack was greater than 150% of average in all or a portion of the Colorado, Gunnison, South Platte, Upper Rio Grande, and Arkansas watersheds. The snowpack was 110-150% of average in all or a portion of the Yampa & White, North Platte, South Platte, Colorado, Upper Rio Grande, and San Miguel, Dolores, Animas, & San Juan watersheds. This snow pack had accumulated by May 1st.

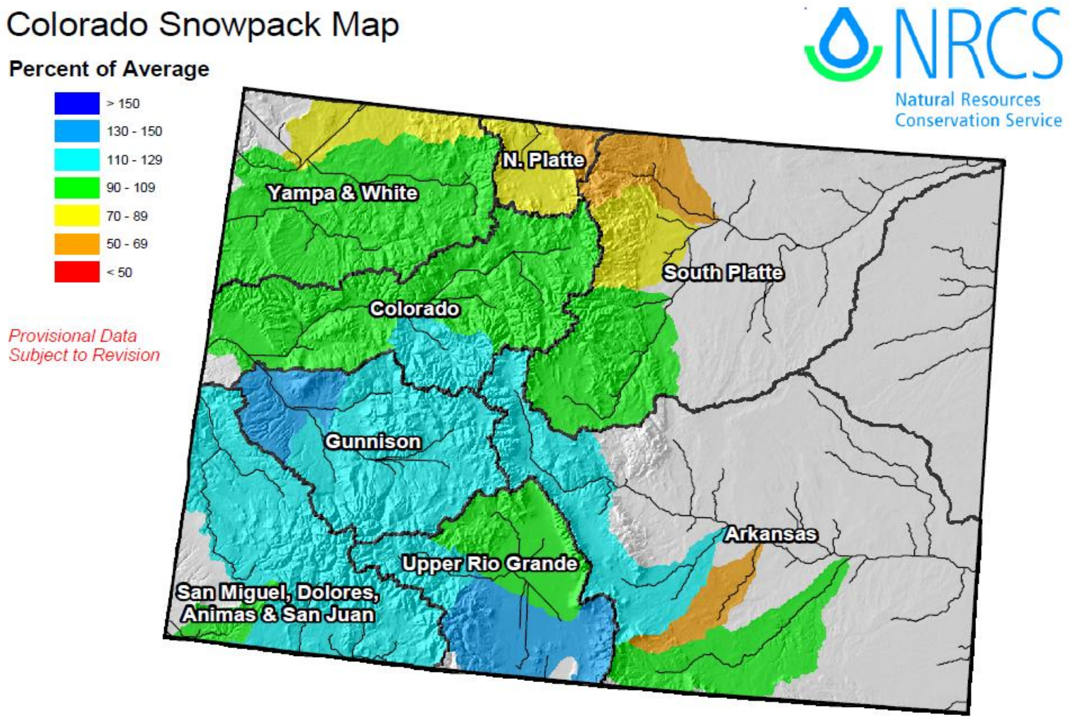
In 1997 the snowpack was greater than 150% of average in all or part of the Gunnison, Upper Rio Grande, and San Miguel, Dolores, Animas, & San Juan watersheds. The snowpack was 110-150% of average in all or part of the Yampa & White, North Platte, South Platte, Colorado, Arkansas, Upper Rio Grande, and San Miguel, Dolores, Animas, & San Juan watersheds. Only a section of the Upper Rio Grande was between 90-110% of average. This snowpack had accumulated by March 1st but not as much as the average. However, additional snowpack was accumulated by May 1st where portions of or all the Yampa & White, South Platte, Gunnison, Upper Rio Grande, and Arkansas watersheds had more than 150% of average snowpack. All or portions of the North Platte, South Platte, Colorado, Gunnison, Upper Rio Grande, Arkansas, and San Miguel, Dolores, Animals & San Juan watersheds had between 110-150% of average snowpack.

In 1999 above 150% of average snowpack was found in all or portions of the South Platte and Arkansas watersheds. This snowpack occurred by May 1st. Prior months were very dry (as of April 1st) where no region was above 89% of average snowpack. In 2003 by April 1st all or portions of the Yampa & White, North Platte, South Platte, Colorado, Upper Rio Grande, and Arkansas watersheds were 90-129% of average snowpack. As of March 1st no region was above 109% of average. For comparison, in 2002 snowpack did not reach above 89% of average in any region. By April 1st the majority of regions were less than 50% of average or between 60-69% of average snowpack. By May 1st all watersheds except a portion of the Yampa and White had less than 50% of average snowpack.

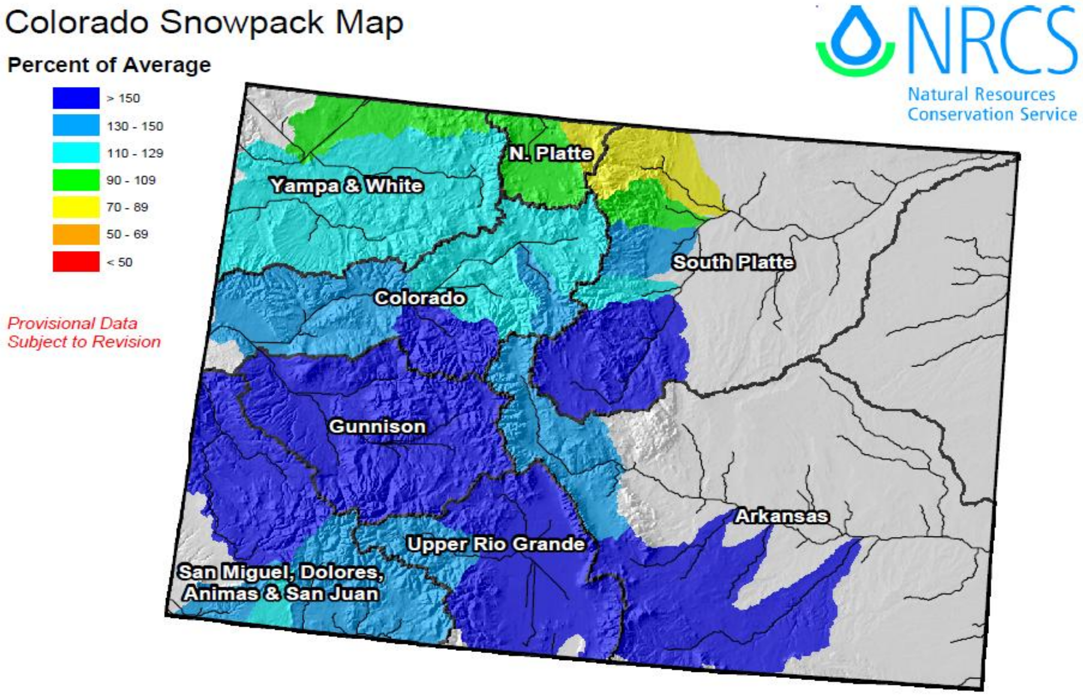
March 1st 1995



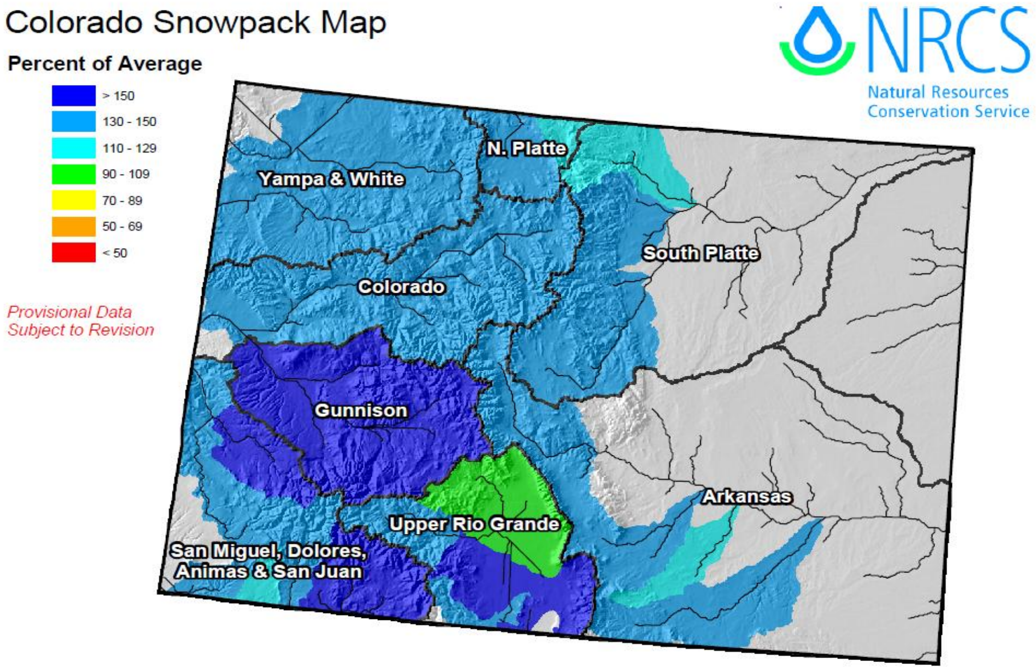
April 1st 1995



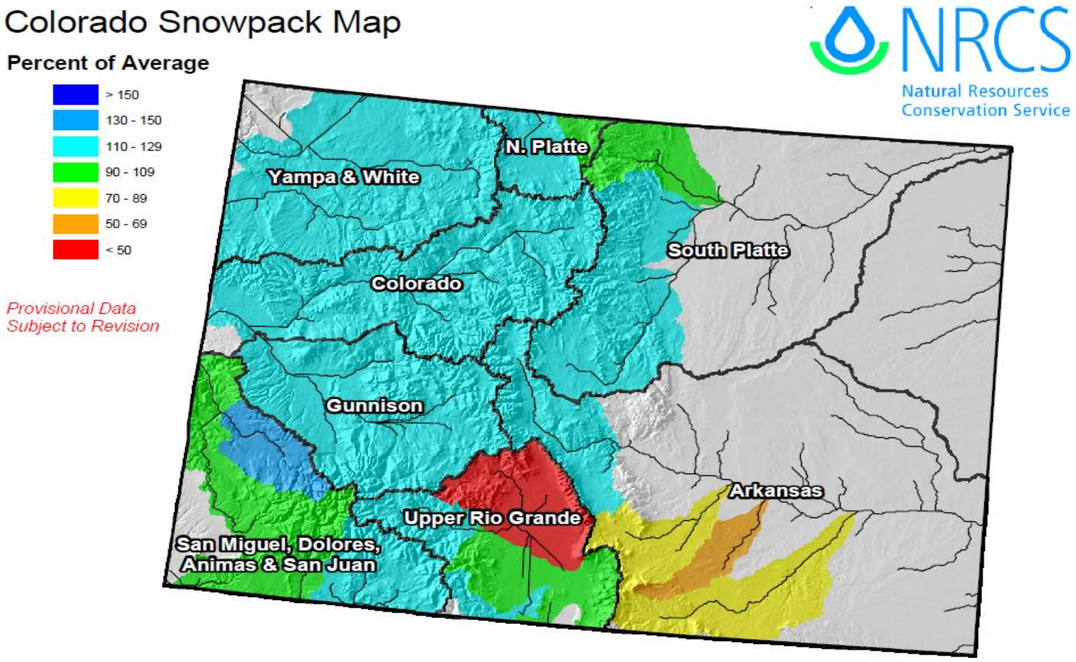
May 1st 1995



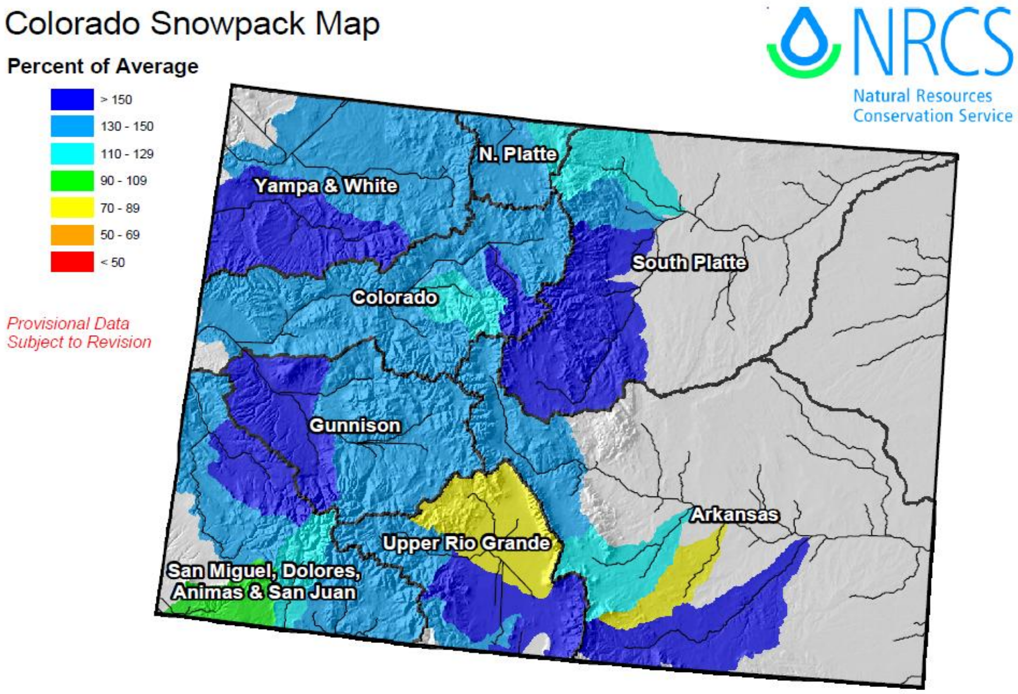
March 1st 1997



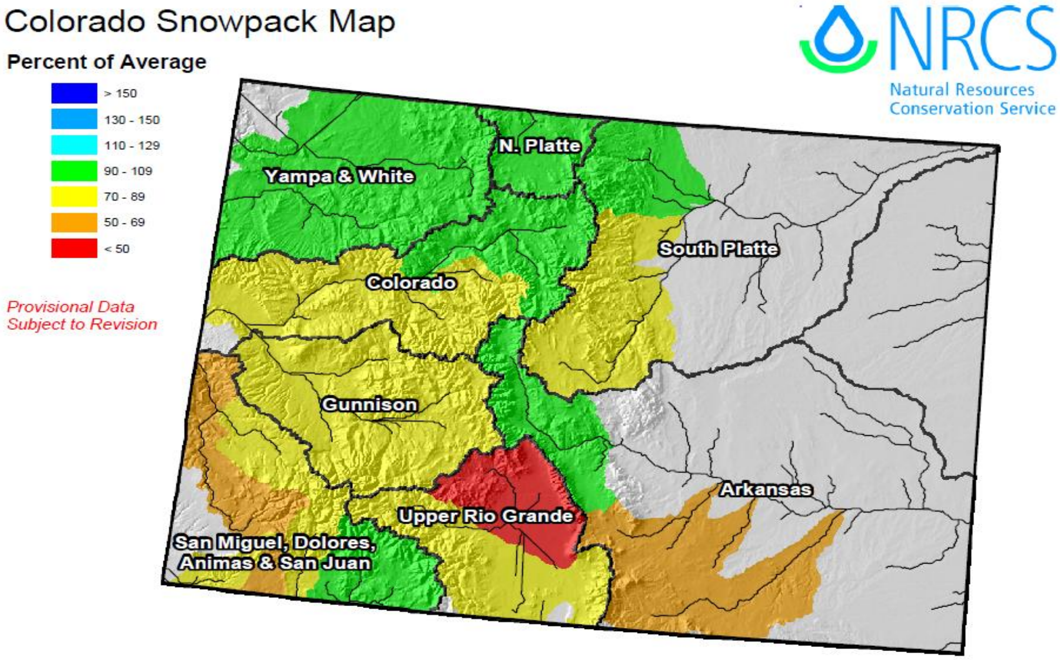
April 1st 1997



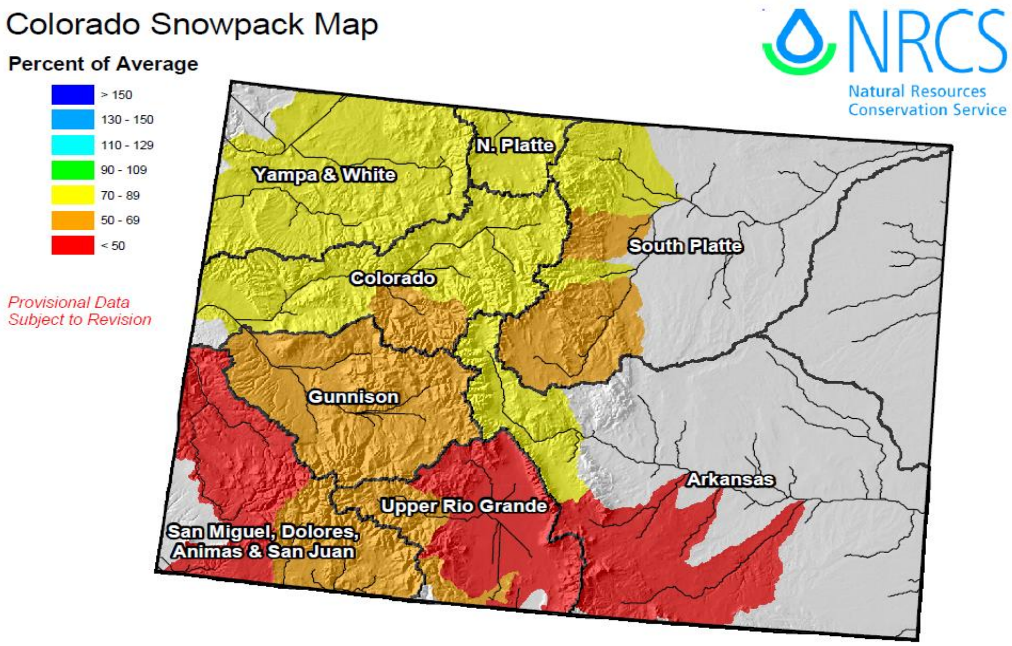
May 1st 1997



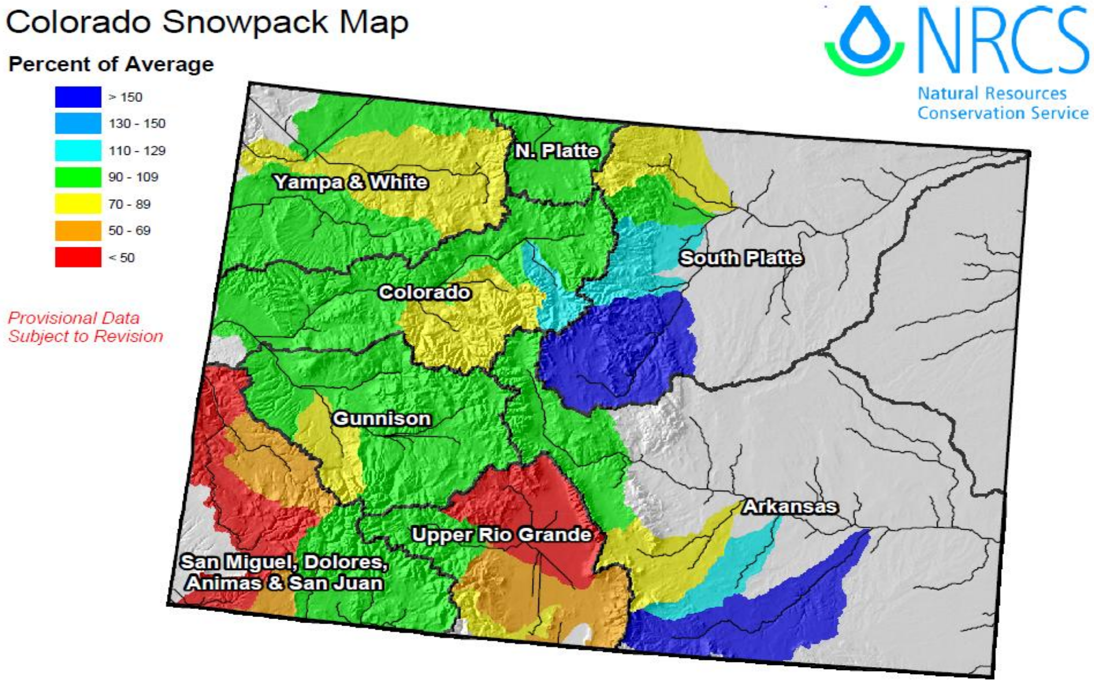
March 1st 1999



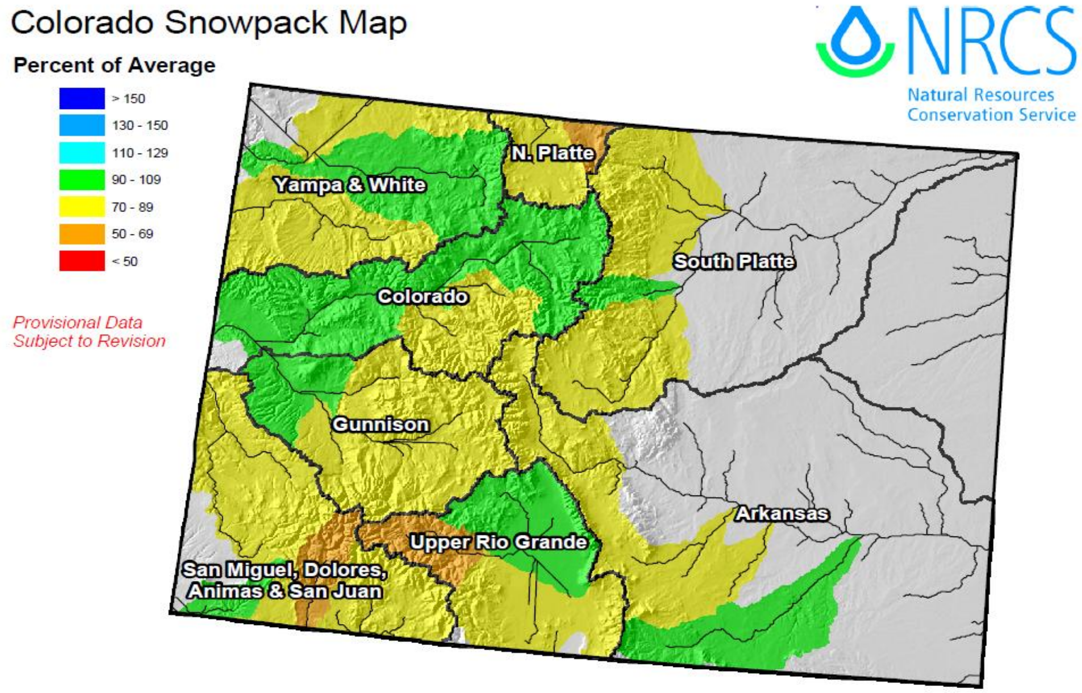
April 1st 1999



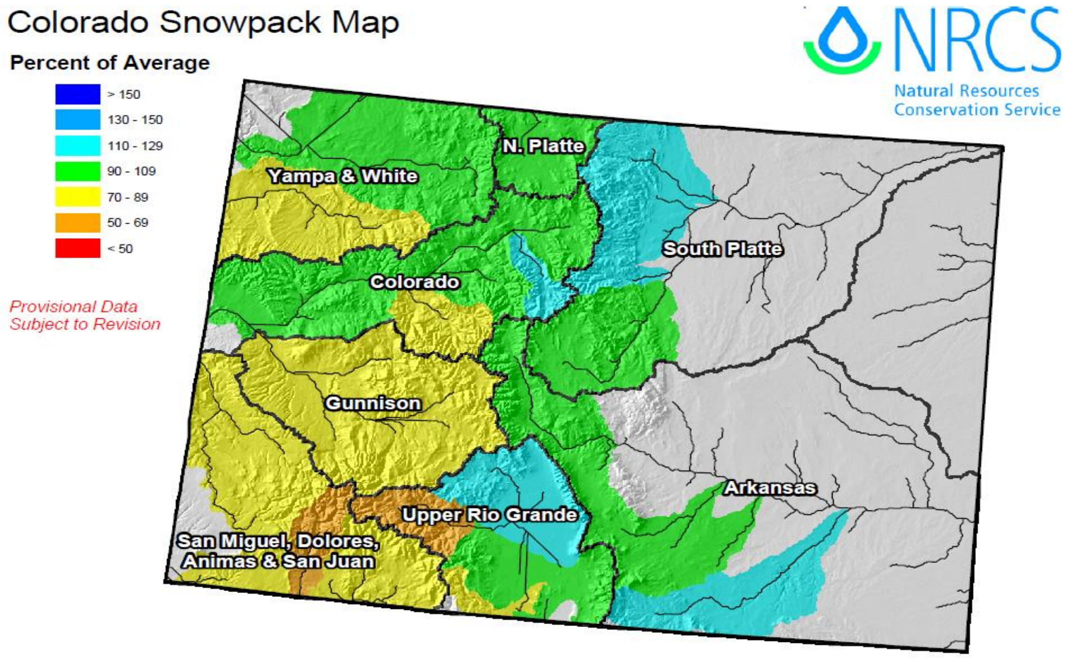
May 1st 1999



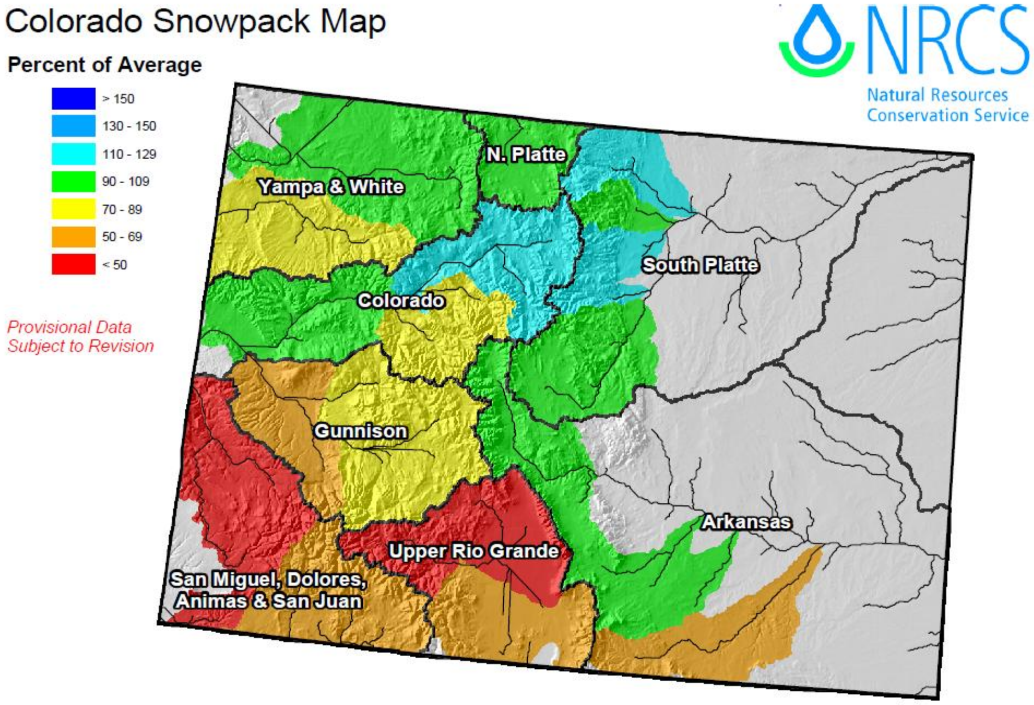
March 1st 2003



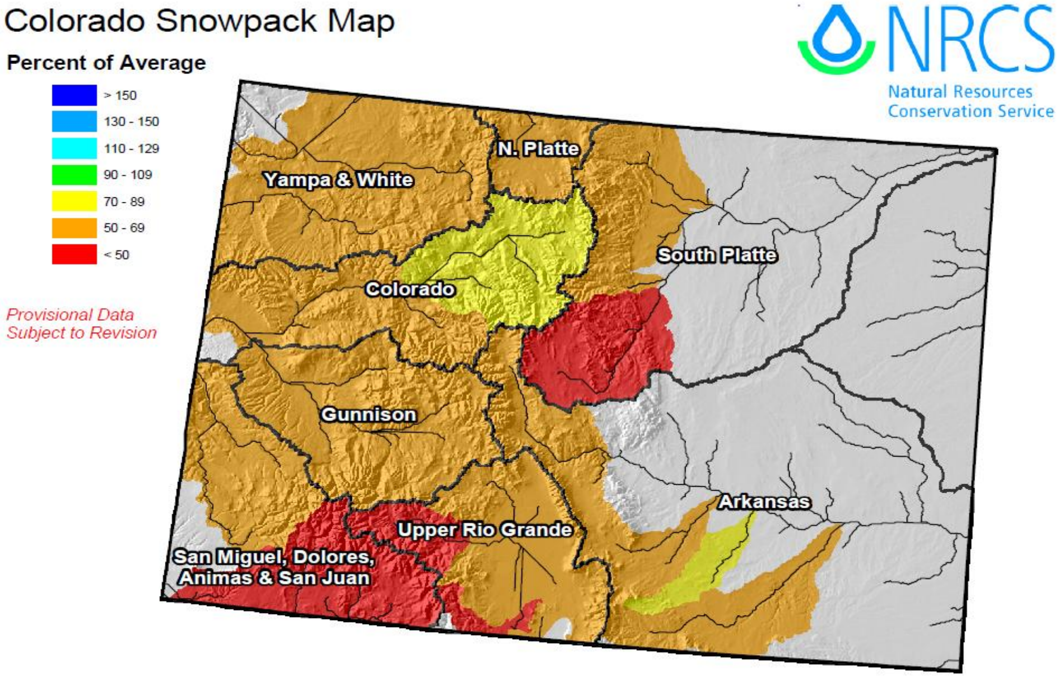
April 1st 2003



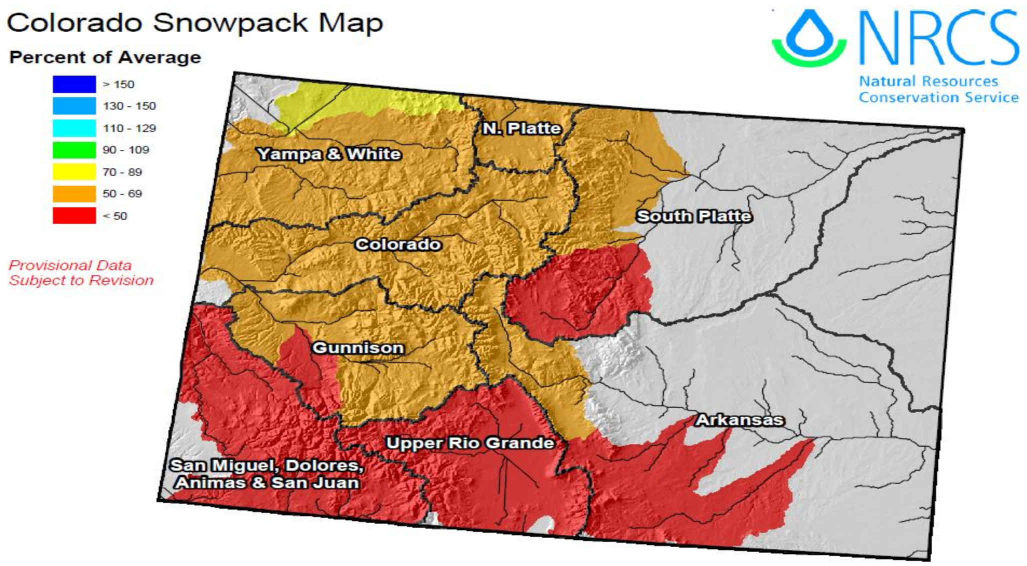
May 1st 2003



March 1st 2002



April 1st 2002



May 1st 2002

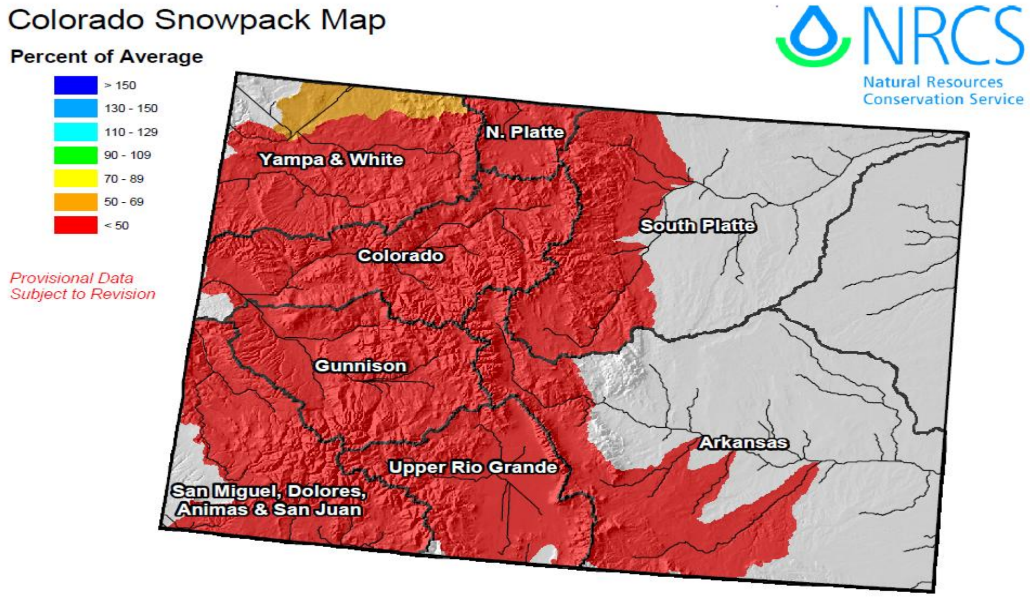


Figure 6: NRCS Colorado Snowpack Maps during 1995, 1997, 1999, 2002, and 2003 (source: NRCS 2011)

Research Question 2:

Are high snowfall events positive Climatic Pointer Years According to the Skeleton Plot model?

Comparison of Sites with Positive CPYs and Historically Large Snow Events

Of the 16 historically large snow event years recorded in the instrument weather observation data from the late 1800s to the early 2000s, 14 were also identified as a CPY in *at least* 1 coring site (Table 11). This indicates 88% of the historically large snow events were represented as CPYs. The 16 years recorded in Table 11 were years with late winter/spring historically large snow events or the calendar year following a fall/early winter historically large snow event. The only year not represented as a CPY, but also containing a historically large snow event was 1992 and 1998. The CPYs not only identified a significantly wet event, but seem to represent a pattern possible indicating the spatial footprint of each storm. The most wide spread historically large snow storm was during 1921 represented at 9 sites and 2003 represented at 7 sites.

Table 11: Sites with Positive CPYs Occurring During a Historically Large Snow Event (source: J. Lukas 2010)

Strength=CPY magnitude (Strong or Median) Location=Based on CPY site location;
FR=Front Range WS=Western Slope

Year	Tree Coring Site w/CPY	# of Sites w/ CPY	CPY Strength	Location
1894	CRA, VBU, BLD, DMU	4	M, S, M, M	FR (mid)
1900	DIL, GMR	2	M, M	WS
1921	BEN, RUS, DMU, HAP, TCU, DIL, GMR, VAS, HOT	9	M, M, M, M, M, S, M, M, M	FR (entire) and WS
1947	BTU, VVR, DIL	3	S, S, M	FR (mid & southern) and WS
1957	ELE, VAS	2	M, M	WS and FR (southern)
1960	HAP	1	M	FR (southern)
1983	BTU, JFU, VVR	3	S, M, M	FR (mid & southern)
1985	TCU	1	M	FR (southern)
1986	BEN, RUS	2	M, M	FR (northern)
1988	HAP	1	M	FR (southern)
1990	DMU	1	M	FR(mid)
1992		0		
1995	DMU, HAP, TCU	3	M, M, M	FR (mid & southern)
1998		0		
1999	BLD, HAP, TCU	3	M, M, S	FR (mid & southern)
2003	BTU, CRA, JFU, VBU, HAP, HER, TCU, DIL	8	M, M, M, S, M, M, M, M	FR (mid & southern) and WS

Research Question 3:

Can positive CPYs be reconstructed to identify storm frequency and magnitude? If so, what does the reconstruction predict for future drought busting storms?

Summary of Qualitatively Significant Overall Wet Years

Overall wet years were derived by qualitatively high precipitation (yearly precipitation 1 or more standard deviation greater than the overall average of a particular site) at Dillon, Georgetown, Cabin Creek, Fort Collins, Kassler, and/or Colorado Springs weather stations (Table 12a). There is also a great amount of overlap between stations with only 15 out of 43 wet years that are not present in multiple stations or within one year of another station(s) wet year (Table 12a). Eleven wet years were found within 1 years of another stations(s) wet year and 17 wet years were found at multiple stations. Table 12b was created by examining if CPYs occurred during each year identified as an overall wet year. Table 12b illustrates that all years identified as qualitatively significant overall wet years (except 1945, 1959, and 1982) occur within 2 years of identified CPYs (92%). 1945, 1959, and 1982 overall wet years occurred within 3 years of identified CPYs. It is interesting to note that 1959, 1984, and 1997 also contained a fall historically large snow event and 1982 contained an early winter historically large snow event.

Table 12a: Descriptions of Qualitatively Significant Overall Wet Years
(sources: Colorado Climate Center 2011
Standard Deviation for Each Station for All Years Available

Weather Station	Standard Deviation (cm)
Cabin Creek	59.1
Colorado Springs	51.7
Dillon Station	49.7
Fort Collins	48.6
Georgetown	51
Kassler	55.1

Years with Total Precipitation Greater than Overall Standard Deviation for Each Station
Blue=Wet year within 1 year of another station(s) wet year
Green=Wet year that multiple stations have in common

Wet Years at **Cabin Creek** Weather Station	Total Precipitation per Year (cm)	Wet Years at **CO Springs** Weather Station	Total Precipitation per Year (cm)	Wet Years at **Dillon** Weather Station	Total Precipitation per Year (cm)
1969	70.7	1957	63	1926	59.8
1983	62.2	1965	64.4	1927	58
1984	62.4	1969	53.2	1934	52.5
1999	73.2	1972	50.9	1935	54.9
2006	67.4	1976	51.6	1936	66.7
2008	61.3	1982	55.7	1938	52.7
		1984	53.3	1945	66.6
		1994	53.7	1947	60.9
		1995	56.5	1951	55.3
		1997	57.8	1957	53.7
		2004	53.7	1959	51.1
				1983	53.1

Wet Years at **Fort Collins** Weather Station	Total Precipitation per Year (cm)	Wet Years at **Georgetown** Weather Station	Total Precipitation per Year (cm)	Wet Years at **Kassler** Weather Station	Total Precipitation per Year (cm)
1900	48.8	1913	59.8	1933	57
1901	54.2	1957	57	1938	62.4
1905	50.4	1961	55	1941	62.3
1906	50.5	1965	53.7	1942	65.9
1912	49.8	1969	64.6	1947	62
1915	56.8	1995	62.3	1961	54.8
1918	55.2	1997	54.8	1965	57.4
1923	70	2006	52	1967	60.5
1938	50.1			1969	71.4
1945	54			1973	63.8
1951	57.4			1979	55.9
1957	49.6			1983	60.4
1961	126			1987	58.5
1967	126			1995	56.5
1979	56.2			1997	57.8
1982	55.1				
1983	49.4				
1995	51.2				
1997	64.1				
1999	52.5				
2009	55.5				

Table 12b: Qualitatively Significant Overall Wet Years Compared to Positive CPYs (sources: Colorado Climate Center 2011 and K. Marzetta 2011)

*= CPY found within 2 years of overall wet years **=CPY and overall wet year occurring the same

Grey highlight indicates years with no chronology data available

Overall Wet Years	**Also CPYs**
1900	*
1901	**
1905	**
1906	*
1912	**
1913	*
1915	*
1918	**
1923	**
1926	**
1927	*
1933	**
1934	*
1935	**
1936	*
1938	**
1941	**
1942	**
1945	
1947	*
1951	*
1957	*
1959	
1961	**
1965	**
1967	**
1969	**
1972	**
1973	**
1976	*
1979	**
1982	
1983	**
1984	*
1987	*
1994	**
1995	*
1997	**
1999	*
2004	
2006	
2008	
2009	

Positive CPYs Identified Using the Modified Skeleton Plot Method

Table 13 lists each CPY for all sites identified using the modified Skeleton Plot method and describes each CPYs proximity to qualitatively significant overall wet years (historically large snow event years were excluded for this examination or the year following if the snow events took place in the fall). Proximity of a CPY to an overall wet year was described as occurring the same year, within 2 years, or within 3 years. As illustrated in Table 13, the most wide spread CPYs were 1843 represented at 11 sties (44% of all sites), 1878 was represented with 11 sites, and 1926 represented at 8 sites (32% of all sites). 1952 and 1965 were both represented by 7 sites (28% of all sites) as well as 1909, 1923, and 1975 represented at 6 sites (24% of all sites). The magnitude (strong or median) of each CPY varies among the different sites due to spatial variations. Of the 79 years identified as CPYs (that were not representative of historically large storms), 47 occurred during the timeframe of consistent instrument observations. Those 47 years will be the calibration period for the CPYs in relation to overall wet years (years lacking a historically large snow event). Of the 47 CPYs occurring during the period of instrument weather observations, 18 (38%) were identical to years identified as qualitatively significant overall wet years, and 26 (56%) were within a two year lag time. The 3 (6%) remaining years identified as a CPY were within 3 years of a qualitatively significant overall wet year. In summary, 94% of the CPYs identified that did not occur during a historically large snow storm year, were identical to or within 2 years of a statically significant overall wet year.

Table 13: All Sites’ Positive CPYs

Grey highlight years= instrument weather observation data not available
No highlight=the **same year** as a qualitatively significant overall wet year
Blue highlight years=qualitatively significant overall wet year **within 2 years**
Red highlight years=**no** statically significant overall wet year within 2 years

Years	**Sites**	**# of Sites**	**% of Sites w/CPY**	**CPY Strength**
1840	HAP	1	4	M
1843	BEN, JAM, CRA, JFU, VBU, RUS, DMU, HER, DIL, PUM, VAS	11	44	S, S, M, M, S, M, M, M, S, M, S
1844	BTU, EAG, JFU, VVR, RUS, HAP, TCU	7	28	S, M, M, S, M, M, M
1849	BTU, CRA, VVR, DIL	4	16	M, M, M, M
1850	EAG, JFU, RUS, TCU	5	20	M, M, M, S
1852	HER, PUM	2	8	M, M
1853	BEN, EAG, RUS, TCU, DIL, PUM, VAS, HOT	8	32	S, M, M, M, S, M, M, S
1854	VVR, HAP, TCU	3	12	S, M, M
1857	TCU	1	4	M
1858	JAM, JOP, VVR, HER,	4	16	S, M, M, M
1860	VBU	1	4	S
1862	OWU, PUM	2	8	M, M
1864	BID, VVR,	2	8	M, M
1866	VVR	1	4	M
1869	BTU, VVR, HER, TCU	4	16	S, M, M, S
1872	BTU, VVR, HER, TCU, HOT	5	20	S, S, M, M, M
1873	ELU, GMR	2	8	M, M
1875	VBU	1	4	S
1876	DMU	1	4	M
1878	BEN, BTU, JAM, CRA, VBU, JOP, BID, VVR, ELU, OWU, HAP	11	44	M, M, M, M, S, M, S, M, M, M, M
1880	PUM	1	4	M
1881	BTU, OWU, HER	3	12	S, M, M
1882	EAG, CRA, BID, VVR, TCU	5	20	M, M, S, M, S
1883	JAM, CRA, VBU,	3	12	M, M, S
1885	HER	1	4	M
1886	VVR	1	4	M
1888	GMR	1	4	M
1889	DMU	1	4	M
1891	VVR	1	4	M
1892	VVR	1	4	M
1895	BTU, DIL	2	8	M, M
1897	JFU, VAS, HOT	3	12	M, M, M
1898	PTP, VVR, HER	3	12	M, M, M
1901	TCU	2	8	M
1903	BEN, RUS, DMU, PUM, DIL	5	20	M, M, M, M, M
1904	HER	1	4	M
1905	TCU	1	4	M
1907	DMU, DIL	2	8	M, M
1909	BTU, EAG, JFU, VBU, TCU, PUM	6	24	M, M, M, S, M, M
1912	DIL, VAS, HOT	3	12	M, M, M
1917	DIL	1	4	M
1918	JOP	1	4	M
1919	VVR, TCU	2	8	S, M
1920	BTU, RUS, OWU	3	12	S, M, M
1923	BEN, VBU, JOP, BID, OWU, DMU	6	24	M, S, M, M, M, M
1924	TCU	1	4	S
1926	BEN, BTU, ELE, CRA, JFU, PTP, MEY, RUS	8	32	M, M, M, M, M, M, M, M
1928	VVR, DMU, TCU	1	4	S, M, M
1930	BTU, HAP, HER, DIL	4	16	M, M, M, M
1931	DMU	1	4	M
1933	JFU, VBU, HAP, TCU, DIL	5	20	M, S, M, M, M

1935	HAP	1	4	M
1937	BEN, PTP	2	8	M, M,
1938	HAP	1	4	M
1941	RUS	1	4	M
1942	VVR	1	4	M
1948	TCU	1	4	S
1949	HAP	1	4	M
1952	BTU, VVR, JAM, OWU, HAP, TCU, PUM	7	28	M, M, M, M, M, S, M
1955	MEY	1	4	M
1956	DIL, GMR	2	8	M, M
1961	BTU, JOP	2	8	M, M
1962	HER, PUM, HOT, DIL	4	16	M, S, M, M
1964	JFU, HAP	2	8	M, M
1965	BEN, JFU, VBU, OWU, TCU, DIL, PUM	7	28	M, M, S, M, M, S, M
1967	BTU, JOP	2	8	M, M,
1969	VVR, DIL	2	8	M, M
1970	TCU, GMR	2	8	S, M
1972	JOP	1	4	M
1973	TCU	1	4	S
1975	BEN, BTU, JAM, JOP, MEY, DMU	6	24	M, S, S, S, M, M
1978	GMR	1	4	M
1979	BTU, VVR, TCU	3	12	M, M, S
1991	MEY	1	4	M
1994	JOP	1	4	M
1996	DIL, GMR	2	8	M, M
1997	BTU, VVR, TCU	3	12	M, M, M
2000	DIL	1	4	M
2001	BEN, MEY, RUS, OWU	4	25	S, M, S, M,

Percentage of Positive CPYs Immediately Following Negative CPYs

The percentage of negative CPYs followed immediately (within 2 years) by positive CPYs is site specific due to spatial differences (Table 14). Western Slope sites range from 28-52%. The Front Range northern sites range from 25-47%, the mid sites range from 6-44% (with the lowest percentage occurring near each other in the middle of the mid Front Range), and the southern sites range from 23-51%. The overall average percentage of positive CPYs following negative CPYs is 30% (VAS was left out because it only contained 1 negative CPY).

Table 14: Percentage of Positive CPYs Immediately (within 2 years) Following Negative CPYs by Site

Western Slope (from West to East)

PUM	HOT	VAS	GMR	DIL
28%	28%	N/A	35%	52%

Front Range

Northern

OWU	RUS	BEN
33%	25%	47%

Mid (from North to South)

DMU	BTU	JAM	PTP	JOP	BLD	ELU	CRA	VBU	JFU	MEY	EAG
32%	44%	42%	36%	6%	8%	11%	32%	20%	28%	18%	26%

Southern (from East to West)

HER	VVR	HAP	ELE	TCU
36%	32%	33%	23%	51%

CPYs per Century at Each Site

Table 15 depicts the average number of negative and positive CPYs per century at each site. Grey highlight indicates centuries that are not complete due to the available chronology data. The number of negative and positive CPYs varies by site depending on spatial characteristics of the site as well as local climatic factors impacting where drought and precipitation events occurred. The most negative CPYs per century were at VVR (16.33) and the most positive CPYs per century were also at VVR (13.67). The fewest negative CPYs per century were at VAS (0.25) and the fewest positive CPYs per century were at PTP (2.25). At most sites the number of negative and positive CPYs per century were very similar to each other (within 3 events). This was not true for only 3 sites (VBU, EAG, and ELE).

Table 15: Average Number of CPYs per Century at Each Site (source: K. Marzetta 2011)
Grey=data not available for the entire century, so century not included in the average

Western Slope

PUM			**HOT**			**VAS**		
Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs
1300	0	2	1500	0	1	1400	0	3
1400	2	2	1600	3	4	1500	0	2
1500	5	8	1700	5	4	1600	0	3
1600	7	5	1800	8	3	1700	0	3
1700	5	5	1900	2	3	1800	1	4
1800	8	6				1900	0	3
1900	6	5						
2000	0	0						
Average	5.5	5.17	Average	4.5	3.5	Average	0.25	3

GMR			**DIL**		
Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs
1300	1	1	1300	0	1
1400	10	10	1400	0	3
1500	6	9	1500	11	13
1600	6	7	1600	6	6
1700	11	5	1700	15	7
1800	7	3	1800	12	7
1900	8	6	1900	11	14
2000	0	0	2000	2	2
Average	8	6.67	Average	9.17	8.33

Front Range

OWU			**RUS**			**BEN**			**PTP**		
Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs
1500	5	4	1400	2	1	1400	2	3	1100	0	0
1600	3	2	1500	8	4	1500	11	9	1200	3	2
1700	2	2	1600	11	7	1600	12	12	1300	7	3
1800	7	3	1700	8	6	1700	8	8	1400	1	4
1900	8	4	1800	13	7	1800	10	7	1500	3	2
2000	2	1	1900	9	6	1900	9	8	1600	3	2
Average	5	2.75	2000	1	1	2000	1	1	1700	2	2
			Average	9.8	6	Average	10	8.8	1700	2	2
									1800	3	1
									1900	3	2
									2000	0	0
									Average	3.125	2.25

JOP			**BLD**			**ELU**			**CRA**		
Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs
1600	4	2	1600	1	0	1500	1	1	1500	4	2
1700	4	2	1700	4	4	1600	10	6	1600	12	9
1800	3	3	1800	3	4	1700	2	0	1700	8	6
1900	5	7	1900	4	2	1800	3	2	1800	6	6
2000	0	0	2000	0	0	1900	2	0	1900	3	1
Average	4	4	Average	3.67	3.33	2000	1	0	2000	1	1
						Average	4.25	2	Average	7.25	5.5

VBU			**JFU**			**MEY**			**EAG**		
Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs
1500	4	0	1400	3	2	1500	0	0	1400	2	4
1600	14	3	1500	3	4	1600	5	4	1500	7	2
1700	11	4	1600	6	4	1700	6	2	1600	9	4
1800	12	7	1700	8	7	1800	7	0	1700	10	4
1900	7	4	1800	9	5	1900	3	4	1800	7	5
2000	1	1	1900	6	6	2000	1	1	1900	4	1
Average	11	4.5	2000	1	1	Average	5.25	2.5	Average	8.25	3.75
			Average	6.4	5.2						

HER			**VVR**			**HAP**		
Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs
1500	2	5	1500	14	10	1600	9	5
1600	10	6	1600	16	13	1700	10	10
1700	2	5	1700	13	10	1800	10	6
1800	4	10	1800	20	18	1900	13	12
1900	6	3	1900	16	9	2000	1	1
2000	1	1	Average	16.33	13.67	Average	11	9.33
Average	5.5	6						

ELE			**TCU**		
Year	# of – CPYs	# of + CPYs	Year	# of – CPYs	# of + CPYs
1500	8	5	1600	11	11
1600	12	6	1700	8	8
1700	6	3	1800	14	10
1800	4	1	1900	15	19
1900	5	2	2000	2	1
Average	7.33	3.33	Average	12.33	12.33

Research Question 4:

How are positive CPYs correlated to inflow at Dillon Reservoir?

Dillon Reservoir Yearly Average Inflow

To help analyze the overall yearly average inflow at Dillon Reservoir, a graph was created (Figure 7). The graph illustrates the trends of both high and low yearly average inflow (af) as well as seasonal and climatic variations. The highest yearly average inflow occurred in 1984 with over 500 af and 1995 was the next highest with just under 500 af. The lowest yearly average inflow (not counting when the reservoir was initially filling) occurred in 2002 with just over 110 af. Other very low yearly average inflow years were 1966, 1977, 1981, and 2004 with inflow between 120-140 af.

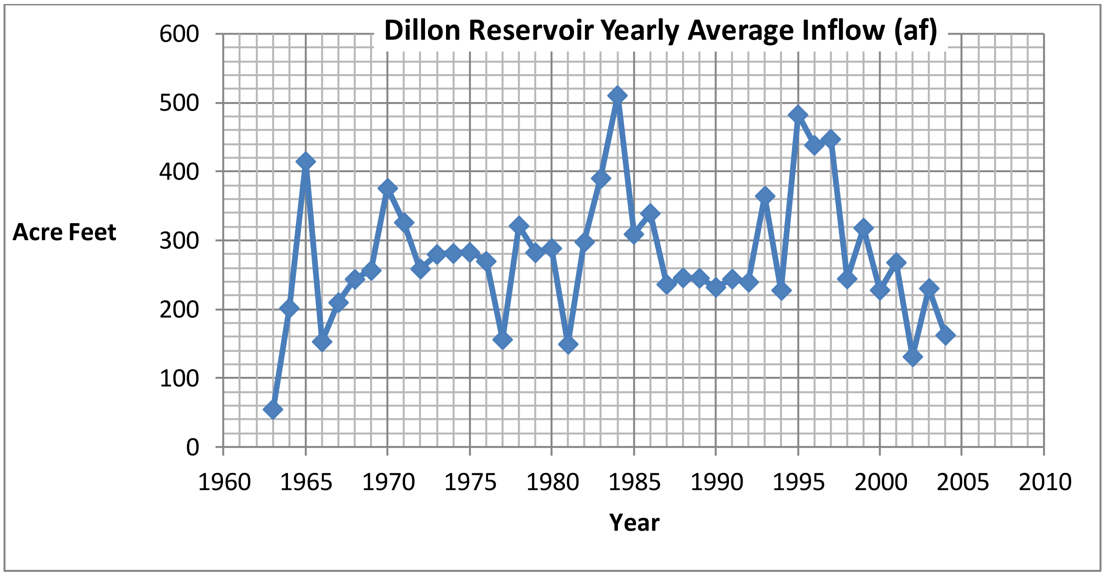


Figure 7: Dillon Reservoir Yearly Average Inflow (af) (source: Denver Water 2010)

Qualitatively Significant Low and High Yearly Average Inflow at Dillon Reservoir

As seen in Table 16, Dillon Reservoir experienced a qualitatively significant yearly average low inflow 6 different years since its completion. Three years were also negative CPYs found at the Dillon coring site. 1977 was not a CPY at the Dillon site, but was classified as a moderate CPY in both PUM and GMR, which are also Western Slope sites very near to the Dillon site. 1966 was not a CPY at the Dillon site, but was identified as a moderate CPY site at BEN, BTU, CRA, and JFU. 2004 was not present in the Dillon chronology. There was 7 qualitatively significant high yearly average inflow years identified at Dillon Reservoir. Five years were also positive CPYs found at the Dillon coring site. 1983 and 1984 were not identified as CPYs at the Dillon site, but are considered qualitatively significant overall wet years and identified as a strong positive CPY during 1983 at BTU and moderate positive CPYs at BTU, JFU, and VVR. Also the ring widths of 1983 contained the impact of the 1982 historically large snow storm. Overall, 100% of Dillon Reservoir's qualitatively significant low and high average inflow years are the same (or within 1 year) of identified CPYs.

Table 16: Qualitatively significant Low and High Yearly Average Inflow Years at Dillon Reservoir Compared to CPYs
S=strong CPY M=moderate CPY

Low Inflow (Dry Year)			High Inflow (Wet Year)		
Year	Inflow (af)	Also negative CPY	Year	Inflow (af)	Also positive CPY
1963	55.1	Dillon 1964 (M)	1965	414.8	Dillon (S)
1966	153.3		1970	376	Dillon 1969 (M)
1977	156.3		1983	390.4	
1981	149.7	Dillon (M)	1984	510.6	
2002	131.5	Dillon (S)	1995	482.5	Dillon 1996 (M)
2004	162.8	N/A for all sites	1996	438.5	Dillon (M)
			1997	447.1	Dillon 1996 (M)

Correlation Between CPYs and Dillon Reservoir

The correlation between Dillon Reservoir's inflow and Dillon site's CPYs' magnitude was calculated using excel. The correlation was 0.58 (Table 17 and Figure 8) and the R^2 value was 0.34 with the trendline equation of $y = 835.19x + 266.9$. This was an average correlation and a fairly low R^2 value.

Table 17: Correlation Data between Dillon CPY Magnitude (for the same year or 1 year lag) and Yearly Average Dillon Reservoir Inflow (af) (source: Denver Water Data 2010)

	Year	**Dillon Site CPY Magnitude**	**Yearly Average Reservoir Inflow (af)**
-CPYs	1963	-0.076	55.1
	1981	0.073	149.7
	2002	-0.096	131.5
+CPYs	1965	0.297	414.8
	1970	0.077	376
	1995	0.052	482.5
	1996	0.052	438.5
	1997	0.052	447.1

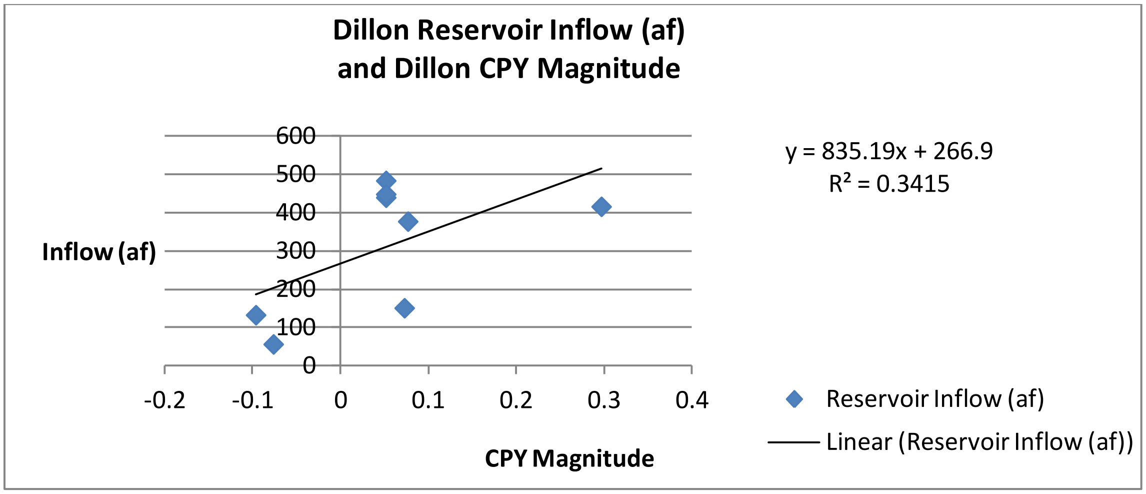


Figure 8: Correlation Between Dillon CPY Magnitude (for the same year or 1 year lag) and Dillon Reservoir Inflow (af) (source: Denver Water Data 2010)

Research Question 5:

What does the record of natural variability tell us about future water management in terms of large snow events' potential to fill reservoirs?

Dillon Reservoir High and Low Yearly Average Inflow Percent Change

After examining Dillon Reservoir's inflow, an extremely dry year as in 2002 (also indicated in tree ring width) can decreases reservoir average yearly inflow by 49% from the year before (Table 18). An extremely wet year as in 1965 (also indicated in tree ring width) can increase reservoir average yearly inflow by over 205% from the year before (Table 17). Overall a significantly high yearly average inflow can increase Dillon Reservoir's inflow by an average of 146% of the previous year's inflow. A significantly low yearly average inflow can decrease Dillon Reservoir's inflow by an average of 53% of the previous years' inflow. This information combined with Table 15 (average number of CPYs per century at each site) was used to predict future CPYs at the Dillon site and their impact on Dillon Reservoir, which is discussed in the next chapter.

Table 18: Dillon Reservoir's Qualitatively significant High and Low Yearly Average Inflow Percent Change from the Year Before (source: Denver Water Data 2010)

Low Inflow		High Inflow	
Year	Inflow % Change from Year Before	Year	Inflow % Change from Year Before
1963	N/A	1965	+ 205
1966	-37	1970	+ 147
1977	-58	1983	+ 131
1981	-52	1984	+ 131
2002	-49	1995	+ 212
2004	-71	1996	+ 91
		1997	+ 102

CHAPTER 5: DISCUSSION

Background Results

The Dillon site update was run through ARSTAN and the Residual index was found to the closest to the original chronology (Figure 2). Both the Residual and Standard indexes followed the same trends as the original chronology from 1995-2002, but were not identical with values most similar during 1999-2002. Variation in exact values between the update and original chronology most likely stem from different individual trees cored and/or choices made within ARSTAN. In all chronologies the downward trend of index values began in 1996 and was the lowest in 2002. This coincided with meteorological data that places the beginning of the drought in 1999 with the most severe year being 2002 (Pielke et al. 2005). All chronologies showed a drastic increase in ring width during 2003 indicating the impacts of the 2003 blizzard. There was a good deal of variation after 2003, but the general trend for all chronologies is an upward (positive) increase in ring width indicating the drought's end. Figure 3 depicts the Dillon update which indicates decreasing variability in more recent years most likely responding to a more consistent current climate. However, more extreme dry and wet years likely will occur in the future as predicted by climate models (Ray et al. 2008).

The use of the modified Skeleton Plot method was validated by comparing the modified version to the original method utilizing the Dillon site's raw width data (Table 6). The modified method was validated because 100 percent of the "strong" negative CPYs identified were identical in both methods and 82% of the positive CPYs identified were identical in both methods. Thus, site chronologies were employed in the Skeleton Plot method for *all* sites. This decision was made based on the availability of chronologies and statistical corrections performed on the chronologies, which reduce a great amount of measurement error.

When the updated Dillon chronology was run through the Skeleton Plot method, 2003 was identified as a positive moderate CPY. This confirms the 2003 blizzard heavily impacted tree ring width, especially after the 2002 drought. Since the 2003 blizzard and positive CPY immediately followed the 2002 drought and negative CPY, it is truly considered a drought buster.

Can the largest historic snowfall events be recognized in tree ring records?

All sites' ring width are strongly correlated to precipitation (Table 3) with correlation values between .729 and .867, but exceptionally wide rings' overlap with historically large snow storms needed to be evaluated. The largest historic snowfall events recorded as producing at least 10.2 centimeters of precipitation in Colorado's Western Slope and Front Range were identified as 1984, 1900, 1921, 1947, 1957, 1959, 1982, 1983, 1984, 1986, 1988, 1990, 1992, 1995, 1997, 1999, and 2003 (Table 7). The large historic snowfall events of 1959, 1984, and 1997 occurred in the fall and the large historic snowfall event of 1982 occurred in the early winter indicating the tree's ring growth would not respond to these snow storms until the following calendar year during the spring growing season. The extreme snow events can be recognized in tree ring records (Table 8) either in the same year (if the storm occurred in the late winter or spring) or the following year (if the storm occurred in the fall or early winter). This was indicated by rings at least one standard deviation greater than average at a specific site during a given year (Table 9).

Table 8 indicates that no significantly wide ring widths were produced in 1959, but 5 sites had significantly wide rings in 1960. This was due to the 1959 snow storm occurring in the fall, which impacted rings widths in the spring of the following year. There were significantly wide rings in the Western Slope sites in 1994 even though the snow event occurred in the fall of that year. The significantly wide rings of 1994 most likely occurred due to residual soil moisture from the 1993 spring historically large snow events and the ring growth in response to the 1982 storm that occurred in the early winter. However in 1995 an additional 8 sites in the Front Range showed significantly wide rings, indicating the impact of the fall snow storm of 1994. The rings of 1997 and 1998 were significantly wide in quite a few sites because of the moist conditions of the 1990s. It was also found the years of 1959, 1984, and 1997 were overall wet years, which contributed to significantly wide rings found at sites in 1984 and 1997 as well as CPYs during those years. Overall, every year identified as having a historically large snow storm(s) in the winter or spring also indicated coring sites having significantly wide ring most likely due to the large snow event(s). Likewise every year identified as having a historically large snow storm in the fall also indicated coring sites having significantly wide rings the following year responding most likely to the large snow event the previous fall that impacted growth in the spring.

By examining the location of sites with a significantly wide ring during historic storms, the storms' spatial footprint could be noted (Figure 4 and Table 10). The 1894 storm was moderate in extent and occurred only in the Front Range, concentrated in the mid Front Range. The 1900 storm was minor in extent and only occurred in mid Front Range sites. The 1921 storm was large in extent impacting both the Western Slope and Front Range sites. The 1947 storm was moderate in extent within the Western Slope, but had major spatial extent in the Front Range. The 1957 storm was a moderate extent storm in the Western Slope and Front Range. The 1959 storm did not impact the Western Slope or Front Range because it was a fall snow storm that impacted ring growth in the spring of the following calendar year. The 1982 storm occurred in the early winter and thus did not impact the Western Slope or Front Range ring widths until spring of the next calendar year. The 1983 storm was a major extent storm in both the Western Slope and Front Range. The rings were also very wide during 1983 because this year contained two historically large snow events and was the year rings showed the effects of the 1982 historically large early winter snow storm. The 1984 storm was not found in the Front Range because the storm occurred in the fall, which impacted ring growth in 1995. The wider rings found in the Western Slope sites during 1994 were most likely due to residual soil moisture of the 1983 snow event. The 1986 storm was a moderate extent storm in both the Western Slope and Front Range. The 1988 storm was not present in the Western

Slope, but minor in extent over the Front Range. The 1990 storm was not present in the Western Slope, but was of minor extent in the Front Range. The 1992 storm was of minor extent in the Front Range and was not present at all in the Western Slope. The 1995 storm was major in extent for the Western Slope and Front Range. The 1997 fall storm produced wider rings in 1998, but there were still many wider rings in the Western Slope and the Front Range in 1997 most likely due to the overall wetness of the 1990s. The 1999 storm was absent in the Western Slope, but moderate in extent for the Front Range. This data indicated the spatial variability of climatic factors that impact tree ring growth as well as water availability.

From the information in Table 8 and Table 10, it is difficult to note the type of storm that produced the historical accumulations of snow. Also, not all sites will have a significantly wide ring during all years identified as having a large snow event. This is due to the spatial variability of snow storms as well as residual soil moisture (or lack thereof) that varies both temporally and spatially between coring sites. Also some trees may experience a year lag time in ring width response to a large snow event depending on the timing of the event, soil moisture, or physiological/environmental factors.

When the standardized ring widths for tree coring sites were mapped during historically large snow storms (Figure 5), the visual information supported the results found in Table 8. The larger ring widths, as depicted by larger symbols on the map, generally represented significantly wide ring widths. Thus if a historically large snow event produced significantly wide rings for a majority of sites, which indicated a major extent (spatial coverage storm), this was also represented in the map with a majority of sites being represented by a large graduated symbol. The same was true for the opposite scenario. Examples of this relationship are depicted in Figure 5 for the historically large snow storms. The standardized ring widths mapped during historically large snow storm supported the results found in Table 8 because larger ring widths relate to qualitatively significant wide ring widths.

The NRCS snowpack maps (Figure 6) confirm the historically large snow event of 1995 (that occurred by May 1st), 1997 (that occurred by March 1st and again by May 1st indicating two separate storms), and 1999 (that occurred by May 1st but was very spatially limited). During those years all or portions of the watershed areas accumulated snowpack greater than 150% of average. 2003 was also confirmed as having a historically large snow event by April 1st, which was documented as occurring March 18th and 19th where Denver alone received 76 centimeters of snow (NASA 2010). However this storm only increased snowpack by no more than 129% of average due to the severe drought of 2002 in which much of Colorado was below 50% of average snowpack. Soil moisture deficit was replenished first by the 2003 blizzard and then snowpack accumulated.

Do high snowfall events correlate to positive (wet) Climatic Pointer Years?

When the modified Skeleton Plot method was utilized, high snowfall events were found in relation to positive (wet) Climatic Pointer Years with 88% representation between historical large snow storms and CPYs (Table 11). It is also important to remember that if a historically large snow storm occurred in the fall or early winter it would be seen in the following year's ring width (1959, 1982, and 1984). Statistical correlation was not performed between historically large snow events and CPYs because CPY magnitude is indicated by the mean of surrounding years, not just a specific year a large snow event occurred. Thus, the percentage overlap of CPYs and years with large snow events was evaluated. Most likely the high snowfall events caused the CPYs as confirmed by the research of Salzer and Kipfmueller (2004) as well as Bridge, Gasson, and Cutler (1996).

CPYs at specific sites do not necessarily represent where the snow storm had the most extensive spatial footprint, as the significantly wide ring widths do. This is because CPYs are not just wider rings, but the comparison of ring widths to surrounding rings. Thus a large snowfall event may occur at a site, but if the year before was also fairly wet a CPY may not be identified. Therefore the site location of a CPY indicates a historically large storm with significantly smaller rings the years before and after. The season of historically large snow events varies (spring, winter and fall), as does the number of storms, inches of precipitation (from 8.13-103.8), and number of historically large storms in a specific year (from 1-2 events). Again, the CPY strength (strong and median) at each site is dependent on the widths of neighboring rings, which also impacts the number of sites with CPYs.

Even though CPYs were found corresponding to 88% of the historical large snow storms and CPYs, they were not wide spread. Only in 1921 and 2003 were the CPYs found throughout the Western Slope and Front Range sites, so it could be argued that those years were the only true CPYs. However, CPYs were present at other sites but were not spatially as wide spread for unknown reasons that may include residual soil moisture, spatial extent of storm, or the trees' biological factors. Also 1983, a very wet year as documented by NOAA and in the memory of many Coloradans, was not well represented by CPYs. This is due to the incredibly wet 1980s where the ground and trees were so saturated with water, the trees did not produce a ring significantly wider than its neighbors because those rings were also very wide.

Can positive CPYs be reconstructed to identify storm frequency and magnitude? If so, what does the reconstruction predict for future drought busting storms?

In order to fully answer this question, overall wet years had to be examined in addition to historically large snow events. This information will allow a fuller picture of storm frequency and magnitude to be reconstructed through positive CPYs. Qualitatively significant overall wet years were identified by the Dillon, Georgetown, Cabin Creek, Fort Collins, Kassler, and Colorado Springs weather stations, which showed a 65% agreement as to what were overall wet years (Table 12b). This might at first not seem like a significant amount, but when considering the distance between stations and the different environments each represents (elevation, spatial location, and mircocliamte) it indicates a good amount of overlap between stations. This overlap illustrates that similar weather patterns can be present across the entire state of Colorado in a given year. As seen in Table 12b, 36 of the 39 years identified within the overlap timeframe of weather station and coring site data (1900-1999) occur within 2 year of identified CPYs (92%). This information indicates the CPYs identified occurred during a historically large snow storm, an overall wet year, or within 2 years of an overall wet year. Table 13 depicts all the CPYs identified that did not occur during historically large snow events, again 94% occur during a qualitatively significant overall wet event or within 2 years of one. The lag time may be due to the timing wetness, the tree's biological factors, residual soil moisture, or the weather before or after the year in question impacting the identification of a CPY. Because CPYs are determined by comparing a year's ring width to the running average, the weather prior or immediately after a certain year greatly impacts its status as a CPY.

The above data analysis reveals CPYs *can* be used to identify general frequency of historically large snow storms or overall wet years during the last 500-800 years. However, it will not be possible to distinguish the cause of a CPY (a historically large snow storm or an overall wet year). Also a CPY may not indicate the exact year of an overall wet year. The overall wet year may have occurred 2 years prior to the CPY. (According to the data, lag time is related to overall wet years only, not historically large snow storms). If a historically large snow storm occurred but wasn't identified as a CPY, it most likely did not occur in the area of the coring site. Additionally, CPYs are not able to determine the magnitude of storms because the magnitude of the CPY depends upon the ring widths of the years before and after the year in question. It is not just the strength of the storm(s) that cause a CPY that determines its magnitude. This is because positive CPYs are indicators of extreme precipitation events (or years) in relation to the average weather during a 5 year period.

The percentage of positive CPYs immediately following negative CPYs *should* be correlated since the definition of a positive CPY is the rings surrounding it are small. However, Table 14 illustrates this is *not* necessarily true because the percent of positive CPYs immediately following negative ones is no greater than 52%. If positive CPYs followed negative CPYs the majority of the time, their percent occurrence would be much greater. Positive CPYs' lower percent occurrence is due to the nature of their surrounding smaller rings: the smaller rings are just narrower, but not narrow enough to be considered negative CPYs. Therefore these rings represent dry years that are not severe enough to greatly impact trees or reservoirs, unlike negative CPYs.

Table 15 illustrated the number of CPYs per century. Most sites' number of positive and negative CPYs are very similar (within 3 events of each other). This phenomena is most likely due to natural climate variability. More climatic variability means more wet *and* dry years (positive and negative CPYs, respectively). Climatic variability is related to each site's specific location and thus varies accordingly. In the future it is likely that climate will become even more variable both in frequency and magnitude of events, which will most likely impact all sites (Ray et al. 2008). This may even cause more positive and negative CPYs.

By examining the data in Table 14 and 15, future drought busting storms *can* be generally predicted at a site by site basis on a century timescale if the climatic systems remain similar to those that occurred over the last few centuries. A drought buster can either be a historically large snow event (like the 2003 blizzard) or a qualitatively significant overall wet year (as in 1965). For example, at the Dillon coring site (the site most significant to Dillon Reservoir) drought busters occur 52% of the time after a negative CPY. Negative CPYs approximately occur 9 per century at the Dillon site. Therefore 4-5 drought busters will occur every century immediately following a negative CPY at the Dillon site (Dillon Reservoir area).

The years containing drought busting storms (a positive CPY following a negative CPY) can be found in the final section of the appendix for each site's chronology and are identified by yellow highlight. However some positive CPYs that occur after negative CPS may not be a drought busting event. Some drought busters may be falsely identified because a CPY could be a return to normal precipitation during an ongoing drought. This occurs when soil moisture conditions are very dry for an extended period of time and almost any large (but perhaps *not* historic) precipitation event (either an individual snow storm *or* wetter year) may cause a positive CPY. Such as positive CPY may not be anything close to a drought buster because it would not significantly increase reservoir inflow and storage. An example occurred in the1950s drought era recorded at the Dillon Weather Station. 1954 was considered a negative CPY and indeed there was little precipitation that year (33.9 centimeters) (Colorado Climate Center 2011). 1956 was identified as a wet CPY because its neighboring rings were significantly narrower and 1956 was truly wetter than 1954 with 39.7 centimeters of precipitation (Colorado Climate Center 2011). 1956 was also identified as a drought buster because it occurred two years after a negative CPY. Yet 1956's total precipitation was lower than any overall wet year identified in this study (the least amount of precipitation occurring during an overall wet year was 48.8 centimeters). Therefore 1956 may not have significantly increased reservoir inflow or storage and thus should not be considered a drought buster.

Likewise, some historically large snow storms or overall wet years may not be as well represented as CPYs and thus drought busters even if they occur after a drought and would greatly increase reservoir inflow and storage. This may occur when several wet years follow one another, but due to the definition of a CPY would not be classified as a one. An example is 1983 where many sites did not record a positive CPY because of the wet years of 1982 and 1984.

So what do these two climatic situations mean? The calibration data set illustrates that *not* all positive CPYs immediately following dry CPYs are drought busters, even though a good amount are. This translates to past patterns of CPYs as well as future predictions. Therefore 4-5 positive CPYs most likely will occur every century immediately following a negative CPY at the Dillon site (Dillon Reservoir area), but they all might not be true drought busters.

How are positive CPYs correlated to inflow at Dillon Reservoir?

Dillon Reservoir's average yearly inflow is very variable and relies on yearly precipitation (Figure 7). Dillon Reservoir experienced qualitatively significant low inflow 6 different years since its completion (Table 16). All but 2 years were also negative CPYs identified at the Dillon coring site or within a year lag time due to tree dynamics and residual soil moisture. The other years were either identified as negative CPYs at other Western Slope sites or at Front Range sites. Thus significantly low inflow at Dillon Reservoir is connected to negative CPYs that represent extreme dry years. Low inflow seems to be the most connected to negative CPYs at the Dillon site (closest in proximity to the reservoir) or other Western Slope sites (also very near the reservoir).

In Table 16, Dillon Reservoir is impacted (illustrated by a significant increase or decrease of inflow) by the same years identified as positive and negative CPYs. Inflow most related to the Dillon site's CPYs, but the reservoir is also impacted during the same years as CPYs in the immediate area (other Western Slope sites) as well as overall wet years that may not be identified as CPYs at the Dillon site due to spatial variation among sites. Qualitatively significant high average yearly inflow at Dillon Reservoir was identified during 7 years since its completion (Table 16). Five of those years are identical to or within a one year lag time of positive CPYs identified at the Dillon coring site. Again the year lag time is most likely due to tree dynamics and residual soil moisture. Thus, Dillon Reservoir's inflow is connected to positive CPYs which represent an extreme snow storm or overall wet year. It appears that Dillon Reservoir's high inflow is most connected to positive CPYs at the Dillon site (the closest in proximity to Dillon Reservoir). Also not all positive CPYs may not be illustrated by extremely high inflows respectively because the drought busters may have been miss identified as discussed earlier.

The correlation between Dillon site's CPY magnitude and the average yearly inflow was examined in Table 17 and Figure 8. There is a weak to moderate correlation between the two variables as indicated by a low R^2 value of 0.34 and a moderate correlation value of 0.58. This is because inflow is related to the actual year of a negative or positive CPY, but not necessarily the CPY's magnitude. This is due to the magnitude incorporating the weather for that particular year *in relation* to surrounding years. For example, an extremely large snow storm may produce a positive CPY, but that CPY may not be classified as a strong CPY because the year after was also somewhat wet. However the CPY were also associated with qualitatively significant high or low average yearly inflow at Dillon Reservoir. Therefore every time a CPY is identified from the Dillon site chronology, there most likely would have been a qualitatively significant high or low inflow at Dillon Reservoir (depending on it being a positive or negative CPY) either that year or the previous year *if* the reservoir was in existence. However the magnitude of the CPY most likely will not reflect the magnitude of significantly high or low inflow for Dillon Reservoir. This information can be used to predict the future of Dillon Reservoir's inflow during extreme dry or wet years (examined in question 5).

What does the record of natural variability tell us about future water management in terms of large snow events' potential to fill reservoirs?

At each site the number of negative and positive CPYs per century varied (Table 15) as well as the percentage of drought busters following a drought (Table 18). This was most likely due to the spatial variations between sites. Therefore every site would need to be examined individually for information concerning future water supply in the surrounding areas, especially if a reservoir is located in the vicinity.

As seen in Table 18, during a positive CPY average yearly inflow can *increase* by an average of 146% of the previous year's inflow at Dillon Reservoir. During a negative CPY average yearly inflow can *decrease* by an average of 53% of the previous year's inflow at Dillon Reservoir. If a positive CPY (caused by either a historically large snow event or an overall wet year) occurs immediately after a negative CPY (a drought buster), it *does* have the potential to refill Dillon Reservoir. At Dillon Reservoirs such drought busters do occur 52% of the time as illustrated by the 2003 blizzard following the 2002 extreme drought. This was most likely due to the natural variability associated with El Niño/La Niña cycle that impacts the western United States.

Table 16 illustrated the number of negative CPYs at Dillon Reservoir per century (approximately 9). This information was obtained from the extended climate record derived from tree ring chronologies that document the natural climatic variability in Colorado's Western Slope and Front Range. This record informs water managers that most likely there will be 4 to 5 drought busters (caused by historically large snow events or an overall wet years) occurring at Dillon Reservoir that will refill it after a drought. The concern is the other 4 to 5 droughts that most likely will occur without a drought buster. However, there were also an average of 8 positive CPYs occurring per century at Dillon Reservoir (including drought busters) that will help increase the reservoir's inflow after a drought even if they do not occur immediately after none. However, not all drought busters may have been correctly identified in the past when precipitation records were absent thereby impacting future predictions. Also global warming is expected to increase the number and severity of droughts and consequently the number of positive

CPYs may also be impacted, which would alter future predictions of drought busters. Positive CPYs may increase due to increased climatic variability or decrease due to an increase in aridity. Therefore there may still be times of water restrictions even with water conservation efforts (as in 2002), but due to drought busters they should not be too prolonged (as seen after the 2003 blizzard). Yet there should be a back up for water resources if a drought is not followed by a drought buster especially with increasing water demand stemming from population growth and global warming.

As seen through the results of this study, CPYs were found to be indicators of extreme weather events that impact Dillon Reservoir because they integrate soil moisture, perception, and snowpack. Due to the CPYs extended long-term record they are also an illustration of past patterns and thus give insight on future drought busters. Therefore the study's supportive research questions and the main research objective were answered: Historically large snow events increase ring width usually enough to produce a positive CPY. Also large snow events can increase Dillon Reservoir's yearly average inflow to the point of significance. Therefore drought busters are truly a feasible means to refill reservoirs, but only occur *at the most* 52% of the time after a drought at Dillon Reservoir.

Conclusions

This study supports the research of Salzer and Kipfumeller (2004) who found that trees were climatically responsive and their rings were products of internal processes directly or indirectly limited by climatic factors. The work of Bridge, Gasson, and Cutler (1996), Knapp, Grissino-Mayer, and Soul´e (2002) as well as Koprowski and Zielski (2008) was also verified because the CPYs found in this study affirm that single-year wet events are recorded in tree rings and are characterized by very wide rings. This study was also useful in modifying the methods presented by Neuwirth et al. (2004) used to identify CPYs. Modifications allowed chronologies to be utilized and took into account Colorado's climatic differences as well as the variation in tree species cored.

Unlike the conclusion of Schweingruber (1990), pointer years were able to be attributed to climatic events (extreme wet and dry years) during the majority of CPYs. This is probably due to the region of research. Schweingruber's data was collected from northern Switzerland whereas this study was conducted in Colorado. Colorado's semiarid and highly variable climate heavily impacts tree growth, especially precipitation because the radial growth of trees cored in this study seem to be more related to precipitation than temperature.

The positive CPYs found in this study fall into wet years or decades described by other researchers. The 1894, 1921, and 1947 positive CPYs relate to the wet decades occurring in Colorado during the late 1800s, 1920s, and 1940s described by Diaz (1983). The wet 1920s was also mentioned by Fye, Stahle, and Cook (2003) as an extremely wet regime that impacted the historical 1922 Colorado River Compact. High streamflow during this unusually wet era gave the "erroneous assumption of abundant flow sufficient to meet all future needs, [which] left a legacy of dispute and litigation over the water resource of the Colorado" (Fye, Stahle, and Cook 2003). Diaz (1983) also documented the wet year of 1957, which was also a positive CPY identified in this study. The 1960s-1990s was known as a wet epoch (Ray et al. 2008), which overlaps with many positive CPYs found in this study. These wet episode are influenced by the El Niño–Southern Oscillation (ENSO) cycle (Fye, Stahle, and Cook 2003), where times of abnormal wetness are associated with El Niño in the western United States.

The negative CPYs identified in this study also fall into the drought decades discussed by Fye, Stahle, and Cook (2003). The 1897-1904 drought was analogous to the 1950s drought (Fye, Stahle, and Cook 2003) and also corresponded to a majority of sites' negative CPYs. The same is true for the 1930s drought known as the Dust Bowl (1929-1940), which was the most sever sustained drought captured in the instrumental record and strongly correlated with the Palmer Drought Severity Index (PSDI) (Fye, Stahle, and Cook 2003). The 1950s drought (1946-1956) was well represented with CPYs identified at most sites. The 1950s drought was the second worst sustained drought during instrumental record and was also strongly correlated to the PDSI (Fye, Stahle, and Cook 2003). The 1998-2004 drought was also well represented with CPYs from many sites. This drought occurred after the 1997-1998 El Niño (Fye, Stahle, and Cook 2003), but was the most severe in 1999-2002 (Seager 2007). Again, La Niña is associated with such times of drought in the western United States.

This study built upon the research of Woodhouse and Lukas (2006) that investigated the frequency and magnitude of past droughts (similar to Colorado's 2002 severe drought) through tree ring reconstructions. Their work provided Denver Water with valuable information to increase the accuracy of models used to ensure future water supply to Metro Denver residents. This study looked at the opposite end of the spectrum by investigating the frequency of extreme wet years that occurred immediately after a drought (drought busters). This information could be incorporated into Denver Water's model to help increase its accuracy. Drought busters occurring at Dillon Reservoir negate the impacts of drought, but only occur 52% of the years immediately following a drought. Drought buster can definitely decrease the overall long-term strain on Denver Water's reservoir system, but additional actions need to be implemented to compensate for droughts that are not followed by drought busters. This study demonstrates the importance of looking at positive spikes in Colorado's variable climate, not just the overall trends. This study also validated the value of tree ring reconstructions for evaluating climate's impact on reservoirs.

Sources of Error and Future Research

Sources of error include measurement of tree ring widths that ARSTAN might not have corrected as well as different selections within ARSTAN that may have caused discrepancies between the original Dillon chronology and the update. Also the thresholds for determining CPYs may not be ideal and using entire chronologies instead of raw width data to identify CPYs may have skewed the results. In addition no filters were placed on the data due to their easily discernable trends, which may have altered to some extent CPY identification.

Extensions of this study would include evaluating other Colorado reservoirs in terms of their response to extreme drought and wet events. If CPYs could be identified in chronologies near these reservoirs, predictions of future drought busters could be made that would further assist water managers. Also the predictions of CPYs (number of positive and negative per century at each site) as well as the chance of a drought buster (% occurrence immediately after a negative CPY) could be more accurately pinpointed if more reservoirs were evaluated. Finally, determining how to incorporate CPYs into Denver Water's model as well as drought busters would be very useful for water managers.

Main Conclusions and Implications from Study

Overall, this study permitted conclusions to be drawn concerning Dillon Reservoir's water supply when faced with drought. This was due to the extended record that tree ring chronologies provided when calibrated with instrument weather observations. These conclusions also added novel information to dendroclimatology's body of knowledge as well as potentially assisting water managers in their decisions regarding Dillon Reservoir:

1. The largest historic snowfall events recorded as producing at least 10.2 centimeters of SWE can be recognized in tree ring records.

2. The modified Skeleton Plot method found high snowfall events in relation to positive CPYs with 94% representation between historical large snow storms and CPYs.

3. Positive CPYs occurred during historically large snow storms, overall wet years, or within 2 years of an overall wet year.

4. CPYs *can* be used to identify frequency of historically large snow storms or overall wet years for the last 500-800 years. However, not all positive CPYs are truly indicative of historically large snow storms or overall wet years due to the biological responses of trees. An example is a return to normal precipitation during extended periods of drought.

5. It is not possible to distinguish the cause of a CPY (a historically large snow storm or an overall wet year) or its magnitude. Only the CPYs' spatial footprint can be deducted from examining the sites' CPYs.

6. Future drought busters *can* be predicted at a site by site basis on a century timescale, but are not completely accurate due to possible misidentification of positive CPYs.

7. Qualitatively significant high and low average yearly inflow at Dillon Reservoir is related to positive and negative CPYs, respectively.

8. During a positive CPY, average yearly inflow can *increase* by an average of 146% of the previous year's inflow at Dillon Reservoir.

9. During a negative CPY average yearly inflow can *decrease* by an average of 53% of the previous year's inflow at Dillon Reservoir.

10. If a truly identified positive CPY occurs immediately after a negative CPY (a drought buster), it *does* have the potential to refill Dillon Reservoir. At Dillon Reservoir such drought busters do occur 52% of the time after a drought.

11. Most likely there will be *up* to 4 to 5 drought busters per century occurring at Dillon Reservoir that will refill it after a drought. The concern is the other 4 to 5 (or possibly more) droughts that most likely will occur without a drought buster.

12. There are an average of 8 positive CPYs (if identified correctly) occurring per century at Dillon Reservoir (including drought busters) that will help increase the reservoir's inflow after a drought even if they do not occur immediately after.

Overall, drought busters are part of a natural cycle that is beneficial for water managers to predict as drought busters can refill a reservoir after a drought. This potentially alleviates some of the concerns over water resources in the western United States. However, precisely predicting drought busters is not possible. This is due to climate change as well as possible misidentification of past positive CPYs that occur when very wide rings do not represent precipitation that would significantly increase reservoir inflow. Thus conservation efforts still need to take place to ensure water availability as population and temperatures increase as well as the potential for megadroughts that may occur without a drought buster immediately following.

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APPENDIX

Updated Dillon Chronology with ARSTAN's Standard (STD) and Residual (RES) Index Width Values

PP=Ponderosa pine DF=Douglas Fir

The master (original) Dillon chronology is included for comparison to the average STD and RES

Purple highlight indicates overlap time period between the Dillon Master chronology and the average STD as well as the average RES derived from the update

Year	PP1a STD	PP1a RES	PP2b STD	PP2b RES	DF1c STD	DF1c RES	DF2c STD	DF2c RES	DF3-2 STD
1995	1.40394		1.32072	1.2353	1.22404	1.31904	1.51072	1.50705	1.29518
1996	1.30482	1.27849	1.36332	1.35083	1.51452	1.45936	1.32769	1.24049	1.33537
1997	0.94152	0.92164	0.95911	0.95039	1.40546	1.27878	1.02586	0.9699	1.35349
1998	0.77695	0.78077	0.78664	0.78848	0.97053	0.8707	0.62395	0.61954	0.88712
1999	1.48787	1.50242	1.40911	1.4158	1.50132	1.50858	0.90569	0.9699	1.29806
2000	0.74512	0.71331	1.10554	1.09058	1.15627	1.03283	0.866	0.88211	1.31313
2001	0.82266	0.83928	0.8832	0.89284	0.94521	0.90674	0.82501	0.84789	1.09938
2002	0.1821	0.19367	0.22381	0.20858	0.35845	0.37195	0.31217	0.34205	0.22379
2003	0.7296	0.78293	0.7296	0.78293	0.85997	1.01795	1.03875	1.1562	1.1341
2004	0.75352	0.77115	0.75352	0.77115	0.71243	0.74692	0.84387	0.83725	0.61469
2005	1.28638	1.30245	1.28638	1.30245	1.12317	1.19398	1.29713	1.32379	1.13107
2006	1.01022	0.99154	0.90965	0.91197	0.64573	0.61541	0.81544	0.76471	0.74316
2007	1.30209	1.30142	1.15226	1.15175	1.14353	1.23077	1.12218	1.15369	0.88061
2008	0.59906	0.57937	0.70068	0.70156	1.11765	1.08231	1.39239	1.37153	1.13554
2009	1.39214	1.41829	1.39214	1.41829	1.13927	1.11031	0.9481	0.8811	1.1103
2010	1.26199	1.23642	1.23471	1.15634	1.02024	0.98595	1.12355	1.13241	1.10364

Year	DF3-2 RES	DF4-2 STD	DF4-2 RES	DF6-1 STD	DF6-1 RES	DF6-2 STD	DF6-2 RES	DF7-1 STD	DF7-1 RES
1995	1.35513	1.07963	1.20321	1.2149	1.30646	1.35017	1.40972	1.20823	1.31598
1996	1.2852	1.34305	1.3299	1.39929	1.40679	1.45554	1.48367	1.43173	1.51441
1997	1.29714	1.55599	1.39808	1.61856	1.51123	1.68113	1.62437	1.5388	1.43161
1998	0.82855	1.15029	1.03756	1.02274	0.92852	0.89518	0.81949	0.87021	0.76553
1999	1.31774	1.12832	1.04199	1.09857	1.06039	1.12832	1.0788	1.11261	1.12678
2000	1.26404	1.17334	1.12883	1.29338	1.26791	1.28162	1.23013	1.1731	1.14916
2001	1.0479	1.37375	1.24791	1.39515	1.30218	1.37375	1.24791	1.16981	1.13459
2002	0.20781	0.28521	0.14082	0.28016	0.18401	0.27511	0.14534	0.26817	0.22844
2003	1.26442	1.03875	1.1562	1.06891	1.16195	1.0815	1.16769	1.04694	1.17864
2004	0.59241	0.56001	0.66866	0.47276	0.50812	0.38552	0.34757	0.52361	0.46643
2005	1.1953	0.96502	1.0668	1.01822	1.10255	1.0515	1.1383	0.96199	1.05438
2006	0.72071	0.81544	0.76471	0.74316	0.72071	0.67087	0.6767	0.68261	0.69093
2007	0.92363	1.00753	0.97757	1.01889	1.02892	1.00753	1.0574	1.01821	1.06373
2008	1.15501	1.36959	1.36695	1.23953	1.23681	1.10947	1.10668	1.22905	1.23427
2009	1.08686	1.27249	1.29262	1.27828	1.2832	1.27249	1.27378	1.25834	1.27365
2010	1.08554	1.08373	1.03866	0.98028	0.94434	1.04165	0.99372	1.02362	0.92298

Year	DF7-2 STD	DF7-2 RES	DF9-1 STD	DF9-1 RES	DF10-1 STD	DF10-1 RES	DF11-1 STD	DF11-1 RES	DF11-2 STD
1995	1.21111	1.33406	1.28739	1.39141			1.49399	1.35155	1.74073
1996	1.5887	1.56069	1.60909	1.59565			1.37556	1.59914	1.71164
1997	1.55321	1.41747	1.51933	1.41879			1.24394	1.10272	1.23697
1998	0.82795	0.7112	0.78873	0.70063	1.28324		0.76049	0.76236	0.98516
1999	1.06144	1.07881	1.12588	1.14466	1.35091	1.23967	1.15702	1.14112	1.07579
2000	1.17032	1.16461	1.20812	1.19945	0.92098	0.78317	0.82324	0.78317	0.87211
2001	1.10629	1.07773	1.04999	1.0295	0.78588	0.81691	0.84474	0.81691	0.89597
2002	0.25985	0.24072	0.27453	0.25268	0.35575	0.43984	0.35575	0.43984	0.33586
2003	1.10874	1.2491	1.13929	1.2286	0.88408	1.1371	1.17051	1.31357	1.2351
2004	0.52881	0.446	0.5167	0.45595	0.93102	0.97654	0.4664	0.60145	0.69871
2005	0.93279	1.0325	0.9742	1.05274	1.18703	1.21412	0.93315	0.82416	1.06009
2006	0.66168	0.64179	0.6276	0.64915	1.09003	1.01658	0.76852	1.01658	0.88299
2007	1.01201	1.05394	1.03722	1.06964	1.22123	1.18587	1.22123	1.18587	1.09088
2008	1.25435	1.25712	1.21187	1.21921	0.88369	0.79681	1.02518	1.01713	0.95444
2009	1.39156	1.2848	1.34295	1.30141	1.08557	1.13124	1.63209	1.25293	1.35883
2010	1.07723	0.93416	1.01942	0.93856	1.02058	0.98697	1.03102	0.98697	1.0258

Year	DF11-2 RES	DF12-1 STD	DF12-1 RES	DIL MASTER	AVERAGE STD	AVERAGE RES
1995	1.61269	1.37961	1.46665	1.760	1.44003	1.36987
1996	1.86297	1.1406	1.32038	1.654	1.42149	1.44914
1997	1.38236	1.30638	1.31845	1.084	1.35284	1.28735
1998	0.7355	0.68708	0.64434	0.455	0.88775	0.78523
1999	0.98821	0.9116	1.02074	1.195	1.18350	1.17571
2000	0.78285	0.82324	0.93291	1.105	1.06170	1.02700
2001	0.89343	0.81103	0.83348	0.955	1.02545	0.99568
2002	0.37853	0.35575	0.43984	0.268	0.28976	0.28094
2003	1.29175	1.29162	1.44641		1.03716	1.15570
2004	0.78135	0.52552	0.58615		0.61914	0.63714
2005	1.01914	0.90358	0.89112		1.07411	1.11425
2006	0.83944	1.09003	1.15592		0.81048	0.81179
2007	1.04011	1.45268	1.28045		1.11254	1.11365
2008	0.90697	1.24337	1.14543		1.09772	1.07848
2009	1.38424	1.63209	1.39311		1.30044	1.25239
2010	1.07357	1.03102	0.98343		1.07190	1.02667

Standardized Ring Width for Each Site During the Calibration Record

Green highlight represents the historically large snowfall events

Western Slope

Year	PUM	HOT	VAS	GMR	DIL
1800	0.780	0.834	0.978	0.971	1.340
1801	0.803	0.712	0.991	0.818	1.491
1802	1.170	1.043	1.521	1.126	1.419
1803	1.130	1.161	1.211	1.156	0.881
1804	0.608	0.810	0.699	0.786	0.874
1805	1.127	0.972	1.032	0.779	0.997
1806	0.845	1.047	1.085	1.010	0.774
1807	0.885	0.423	0.532	0.490	0.646
1808	1.125	1.079	1.187	0.905	0.597
1809	0.875	0.646	0.601	0.740	0.783
1810	1.039	0.798	0.909	0.872	0.966
1811	1.291	1.259	1.257	1.269	1.234
1812	1.224	1.204	1.198	1.318	1.273
1813	0.981	0.994	0.880	0.880	0.824
1814	0.639	0.968	0.922	0.852	0.996
1815	1.103	0.875	0.916	1.105	0.941
1816	1.046	0.948	1.437	1.384	1.233
1817	0.856	1.016	1.067	1.060	1.440
1818	1.153	1.265	0.984	1.271	1.024
1819	0.969	0.805	0.878	1.111	1.122
1820	0.950	0.788	0.866	0.968	0.829
1821	1.163	1.330	1.122	1.582	1.104
1822	0.684	1.039	1.120	0.974	1.213
1823	1.021	1.210	1.232	0.794	1.586
1824	0.454	0.671	0.679	0.609	0.638
1825	0.391	0.761	0.907	0.805	0.672
1826	1.108	1.103	1.040	1.305	1.465
1827	0.996	0.921	0.973	1.029	0.851
1828	1.142	1.061	1.197	1.079	1.168
1829	0.744	0.821	0.937	0.976	1.070
1830	0.846	0.520	0.840	0.478	0.513
1831	1.082	1.490	1.450	1.471	1.732
1832	1.345	1.177	1.324	1.041	1.397
1833	1.086	0.988	0.822	1.149	0.601
1834	0.659	0.722	0.896	0.876	0.942
1835	0.786	1.190	1.203	1.592	0.938
1836	1.091	1.130	1.027	1.275	0.948
1837	1.571	1.366	1.318	1.561	1.162
1838	1.000	1.026	0.904	1.069	1.045
1839	1.398	1.253	0.631	0.919	1.154
1840	1.405	1.294	1.133	1.287	1.025
1841	1.390	1.007	1.162	1.263	1.203
1842	0.742	0.626	0.641	0.411	0.373
1843	1.563	2.005	1.727	1.929	1.928
1844	0.832	0.863	0.947	0.842	1.062
1845	0.214	0.431	0.453	0.419	0.070
1846	0.412	0.900	0.993	0.633	0.780
1847	0.500	0.440	0.399	0.455	0.380
1848	0.979	1.091	1.164	1.076	1.017
1849	1.612	1.350	1.115	1.020	1.232
1850	1.375	1.005	0.950	1.188	1.071
1851	0.064	0.065	0.251	0.168	0.193
1852	1.449	1.346	1.150	1.191	0.800
1853	1.207	1.493	1.594	1.434	1.382
1854	0.852	0.904	0.787	1.124	0.885

1855	0.265	0.503	0.582	0.490	0.694
1856	1.214	1.145	1.049	0.831	0.709
1857	0.776	0.877	0.907	0.923	0.876
1858	1.237	1.159	1.100	1.199	1.078
1859	1.181	0.902	0.927	0.799	1.085
1860	1.047	1.182	1.165	1.054	1.403
1861	0.584	0.855	0.986	0.709	1.023
1862	1.417	1.039	1.140	1.044	1.297
1863	0.878	0.766	1.033	0.620	0.299
1864	1.070	1.350	1.165	1.258	1.600
1865	1.073	0.795	0.722	1.024	1.204
1866	1.503	1.571	1.556	1.280	1.846
1867	1.616	1.345	1.192	1.709	1.457
1868	1.189	1.041	0.703	1.036	0.735
1869	0.877	1.425	1.306	0.931	1.331
1870	1.213	1.177	1.102	1.223	1.146
1871	0.301	0.317	0.438	0.701	0.218
1872	1.280	1.318	0.649	1.062	1.043
1873	1.264	1.093	0.871	1.369	0.968
1874	0.980	0.599	0.571	0.557	0.834
1875	0.721	1.090	0.779	0.908	1.109
1876	1.189	1.177	1.037	1.231	1.298
1877	0.793	0.808	0.776	0.887	0.949
1878	0.949	1.006	0.885	0.867	0.525
1879	0.232	0.603	0.857	0.949	0.565
1880	1.358	0.920	0.670	0.792	0.527
1881	1.101	0.901	0.775	0.833	1.096
1882	0.653	1.077	1.010	1.284	1.047
1883	0.962	1.192	1.053	1.149	0.962
1884	1.207	1.358	1.084	1.006	1.007
1885	1.172	1.221	1.342	0.842	1.034
1886	0.792	0.853	0.907	0.579	0.881
1887	0.712	0.690	0.510	0.423	0.245
1888	0.895	0.676	0.906	1.093	0.728
1889	0.802	0.777	0.949	0.884	0.753
1890	0.980	0.754	0.655	0.798	0.842
1891	1.014	0.813	0.835	0.820	0.753
1892	0.982	1.111	1.110	0.982	1.016
1893	0.927	0.799	0.724	0.865	0.839
1894	1.075	1.172	1.166	1.070	0.956
1895	1.343	1.463	1.316	1.314	1.406
1896	0.420	0.387	0.566	0.438	0.629
1897	1.177	1.500	1.416	1.116	1.090
1898	0.817	0.544	0.882	0.435	0.244
1899	1.238	1.108	0.642	0.983	1.113
1900	1.047	1.151	1.007	1.121	1.007
1901	0.755	0.899	0.965	0.761	0.882
1902	0.252	0.574	0.552	0.393	0.226
1903	1.200	0.822	0.975	0.948	1.028
1904	0.857	0.879	1.070	0.960	0.873
1905	1.097	0.936	1.033	0.873	0.734
1906	1.319	1.196	1.214	0.958	1.033
1907	1.046	1.588	1.667	1.185	1.338
1908	0.599	0.771	1.064	0.916	0.546
1909	1.364	0.983	0.749	0.989	1.030
1910	0.814	0.815	0.826	1.148	0.588
1911	0.882	1.035	1.131	0.884	1.051
1912	0.940	1.560	1.651	1.485	1.508
1913	0.814	0.642	0.932	0.773	0.938
1914	1.109	1.170	0.941	1.234	1.059
1915	0.763	0.978	0.948	0.972	0.824
1916	0.879	1.048	0.946	1.053	1.077
1917	1.332	1.294	1.147	1.433	1.513
1918	1.170	1.087	1.126	1.126	1.221

1919	0.757	0.638	0.837	0.421	0.452
1920	1.351	0.661	0.567	0.808	0.710
1921	1.428	1.329	1.200	1.387	1.552
1922	0.882	0.770	0.878	0.875	0.569
1923	1.439	0.954	0.757	0.946	1.271
1924	1.382	1.100	0.925	1.274	0.782
1925	0.956	0.893	1.087	0.829	0.869
1926	1.027	1.343	1.240	1.527	1.567
1927	1.022	1.058	1.063	0.936	1.067
1928	1.316	1.273	1.286	1.382	1.300
1929	1.055	0.871	0.810	0.767	0.678
1930	1.059	0.939	1.015	1.372	1.368
1931	0.808	0.902	1.106	1.123	0.930
1932	1.071	0.875	0.898	0.795	0.518
1933	0.995	0.872	0.947	0.966	1.365
1934	0.520	0.649	0.804	0.762	1.123
1935	0.984	0.867	0.898	0.842	0.811
1936	0.893	0.696	0.810	0.753	1.094
1937	0.997	0.791	1.154	0.818	1.149
1938	0.940	1.091	1.074	1.156	1.409
1939	0.869	0.720	0.838	0.801	1.127
1940	0.919	0.889	1.047	0.935	0.731
1941	1.125	0.934	1.085	0.945	1.262
1942	1.032	0.923	1.201	1.197	1.414
1943	0.918	1.188	1.277	1.280	0.983
1944	0.701	0.778	0.904	0.536	0.820
1945	0.913	0.993	1.067	0.968	0.887
1946	0.830	1.102	1.196	1.181	0.700
1947	1.208	0.860	1.302	1.075	1.446
1948	0.799	0.800	0.877	1.009	0.936
1949	1.272	1.393	1.192	1.050	1.049
1950	0.713	0.734	0.779	1.103	0.791
1951	1.175	1.295	1.292	1.156	1.375
1952	1.315	1.056	1.032	1.074	0.953
1953	0.833	1.163	1.126	0.921	0.890
1954	0.514	0.261	0.559	0.232	0.190
1955	1.098	1.148	0.854	0.955	0.809
1956	1.059	1.150	0.949	1.557	1.260
1957	1.359	1.375	1.488	1.184	1.197
1958	0.955	1.005	0.999	1.179	1.044
1959	0.934	0.754	0.742	0.770	0.499
1960	0.987	1.012	0.933	1.341	0.902
1961	0.632	0.417	0.686	0.625	0.724
1962	1.728	1.418	1.058	1.259	1.389
1963	0.979	1.073	0.992	0.513	0.834
1964	0.608	0.632	0.646	0.689	0.447
1965	1.279	1.231	1.140	1.285	1.668
1966	0.629	0.652	0.886	0.936	0.895
1967	0.981	1.156	1.003	1.289	0.727
1968	0.881	0.790	1.032	0.640	0.643
1969	1.191	1.246	1.413	0.931	1.454
1970	0.986	1.171	1.009	1.590	1.129
1971	1.004	1.085	0.926	1.006	1.149
1972	1.005	1.038	0.979	0.869	0.774
1973	1.451	1.235	1.092	1.284	1.121
1974	0.968	1.379	1.111	1.556	1.419
1975	1.068	0.868	0.926	1.114	0.875
1976	0.609	0.548	0.766	0.823	1.073
1977	0.394	0.764	0.723	0.369	0.900
1978	1.322	1.118	1.103	1.309	1.015
1979	1.483	1.062	1.169	0.942	1.075
1980	1.117	0.801	0.794	1.057	0.981
1981	0.710	0.819	1.150	0.937	0.609
1982	1.115	1.024	0.922	1.288	1.162

1983	1.489	1.214	1.349	1.361	1.536
1984	1.389	1.435	1.389	1.583	1.977
1985	1.448	1.099	1.086	1.477	1.290
1986	1.010	1.276	1.179	1.568	1.132
1987	0.950	0.895	0.890	0.417	0.856
1988	0.687	0.965	0.938	0.895	0.777
1989	1.195	0.818	0.748	0.799	0.971
1990	0.609	0.987	0.928	0.547	0.735
1991	1.204	0.874	0.834	1.171	1.213
1992	0.634	0.934	1.050	0.817	0.815
1993	1.262	1.133	1.073	1.212	1.362
1994	0.537	0.581	0.696	0.408	0.388
1995	1.189	1.228	1.163	1.144	1.760
1996	1.141	1.067	1.083	1.388	1.654
1997	1.198	1.059	0.859	1.157	1.084
1998	0.992	0.666	1.029	0.385	0.455
1999	1.018	1.023	0.946	1.015	1.195
2000	0.674			1.190	1.105
2001	0.806				0.955
2002	0.518				0.268
2003					1.156
2004					0.637
2005					1.114
2006					0.812
2007					1.114
2008					1.078
2009					1.252
2010					1.027

Front Range

Year	OWU	RUS	BEN	DMU	BTU	JAM	PTP	JOP	BLD	ELU
1800	0.963	1.304	1.257	1.393	1.068	1.518	0.840	1.381	1.136	0.933
1801	0.731	0.598	0.587	0.800	0.63	0.501	0.742	0.771	0.831	0.850
1802	0.648	1.284	1.222	1.151	0.771	1.300	1.167	1.305	1.095	0.832
1803	0.997	1.496	1.713	1.261	1.376	1.535	0.917	1.398	1.149	1.019
1804	0.907	0.490	0.425	0.674	0.921	1.076	1.019	0.995	0.65	1.099
1805	0.458	0.617	0.593	0.266	0.196	0.711	0.783	0.644	0.705	0.756
1806	1.021	0.710	0.966	1.207	1.551	1.150	1.173	1.316	1.234	1.031
1807	0.962	0.849	1.035	0.549	0.907	0.844	0.891	0.729	0.841	1.181
1808	0.870	1.253	1.192	1.135	0.808	1.244	0.699	0.989	1.039	0.986
1809	0.838	0.448	0.232	0.501	0.697	0.784	1.005	0.676	0.8	1.126
1810	1.352	0.900	1.052	0.997	1.046	1.382	1.003	1.264	1.158	1.063
1811	0.796	1.028	1.198	1.026	0.827	0.934	0.971	0.949	0.816	1.074
1812	0.873	0.967	1.035	1.004	1.004	0.757	0.912	0.925	1.014	0.912
1813	0.853	1.001	0.803	1.042	0.894	0.636	0.952	0.828	0.843	1.251
1814	1.106	1.051	1.162	1.166	1.193	0.997	1.031	1.171	0.996	1.140
1815	1.029	1.107	0.888	1.026	1.137	1.053	0.889	0.938	1.063	1.001
1816	1.106	1.100	0.685	1.044	0.957	1.138	1.162	1.337	1.008	1.097
1817	1.071	0.817	0.801	0.859	1.222	0.935	1.054	0.976	1.108	1.030
1818	0.746	0.489	0.562	0.410	0.423	0.814	0.977	0.873	0.973	1.034
1819	1.029	0.949	0.914	1.142	0.755	0.701	0.703	0.708	0.858	0.784
1820	0.294	0.469	0.556	0.350	0.306	0.548	0.849	0.552	1.11	0.941
1821	1.383	1.218	1.143	1.245	0.922	0.834	0.937	0.859	0.809	0.882
1822	1.260	1.206	1.199	1.274	1.25	1.032	1.216	1.287	1.03	1.116
1823	0.994	1.006	0.933	1.192	0.847	0.781	0.974	0.695	0.755	0.872
1824	0.876	0.448	0.373	0.571	0.624	0.611	0.599	0.647	0.826	0.756
1825	1.281	1.498	1.430	1.354	1.339	1.113	1.308	1.317	1.138	1.135
1826	1.107	0.808	0.606	1.196	0.943	1.024	1.228	1.193	1.063	1.154
1827	1.185	1.031	1.045	1.472	1.198	1.082	1.019	1.188	1.158	1.203
1828	1.326	1.359	1.147	1.446	1.612	0.979	1.083	1.344	1.121	1.445
1829	1.076	1.177	0.811	1.230	1.219	0.693	0.751	0.977	1.09	0.896

1830	0.946	1.138	1.137	1.003	0.934	0.891	0.893	1.253	1.256	0.785
1831	0.700	1.026	0.923	0.773	1.022	0.993	1.215	0.756	0.842	1.027
1832	1.365	1.039	0.937	0.437	1.093	0.883	0.878	1.019	1.128	1.014
1833	1.174	1.403	1.313	1.110	1.132	1.031	1.118	1.154	1.175	1.037
1834	1.133	0.765	0.756	0.874	0.943	0.974	0.885	1.212	1.077	1.107
1835	0.993	1.444	1.363	1.136	1.303	1.130	1.310	1.213	1.303	1.079
1836	1.760	1.481	1.356	1.473	1.662	1.296	1.140	1.158	1.009	1.209
1837	1.132	1.464	1.329	1.341	1.7	1.342	1.477	1.082	1.05	1.048
1838	1.252	1.283	1.316	1.562	1.839	1.372	1.111	1.342	1.34	1.396
1839	0.945	1.474	1.607	1.454	2.681	1.132	1.328	1.278	1.367	1.596
1840	0.255	0.917	1.287	1.069	0.489	0.885	0.762	0.835	0.857	0.830
1841	0.756	0.982	0.689	1.369	1.57	1.030	0.913	0.917	1.151	0.929
1842	0.610	0.301	0.264	0.157	0.107	0.063	0.623	0.349	0.312	0.271
1843	1.281	1.303	1.423	1.549	1.563	1.507	1.286	1.515	1.437	1.460
1844	1.161	1.111	1.059	1.143	1.729	1.049	1.244	1.259	1.127	1.425
1845	0.900	0.460	0.592	0.694	0.952	0.653	0.514	1.356	0.909	0.565
1846	0.857	0.704	0.740	0.844	0.452	0.998	0.868	0.748	0.805	1.057
1847	0.810	0.903	0.560	0.674	0.404	0.773	0.659	0.819	0.672	0.900
1848	0.588	0.784	0.720	0.625	0.72	0.777	0.884	0.675	0.814	0.893
1849	1.479	0.969	0.863	1.252	1.255	1.124	1.176	1.353	0.855	0.929
1850	0.763	1.247	1.365	1.216	1.188	0.807	1.020	0.897	0.892	1.104
1851	0.642	0.216	0.510	0.411	0.376	0.406	0.624	0.577	0.592	0.533
1852	0.972	0.992	0.811	1.032	0.977	1.044	1.169	1.375	0.725	0.797
1853	1.182	1.028	1.379	1.154	1.058	1.030	1.078	1.129	1.367	1.122
1854	0.913	0.910	1.048	1.011	0.786	1.037	1.193	1.155	1.01	0.998
1855	0.534	0.598	0.458	0.627	0.553	0.718	1.132	0.773	0.938	0.747
1856	1.006	0.658	0.853	1.050	0.936	0.440	0.603	0.587	0.898	0.769
1857	1.176	0.842	1.219	1.069	0.976	1.006	0.881	1.094	1.245	0.863
1858	1.024	1.273	1.488	1.405	1.021	1.540	1.331	1.385	1.223	1.229
1859	1.076	0.961	1.146	1.045	0.901	0.651	0.855	0.94	0.91	0.996
1860	0.950	0.794	1.390	0.918	0.916	0.918	1.125	0.713	1.102	1.233
1861	0.443	0.431	0.595	0.123	0.304	0.669	0.983	0.515	0.745	0.768
1862	1.317	0.871	1.305	0.735	0.95	0.816	1.006	1.173	0.995	0.812
1863	0.686	0.590	0.717	0.517	0.487	0.400	0.614	0.646	0.798	0.537
1864	1.320	0.858	1.289	0.925	1.075	1.299	1.053	1.323	1.281	1.090
1865	1.087	0.869	1.135	0.810	0.952	0.931	1.032	1.026	0.656	0.934
1866	1.372	1.250	1.489	1.050	1.24	1.376	1.442	1.205	0.817	1.221
1867	1.314	1.067	1.267	1.015	1.013	1.015	1.030	0.741	0.738	1.192
1868	0.825	1.075	1.060	1.201	0.735	0.948	0.623	0.811	0.989	0.702
1869	1.311	1.100	0.994	1.379	1.362	1.200	1.283	1.309	1.216	1.299
1870	0.739	1.061	0.873	1.128	0.536	0.887	1.191	1.135	0.728	0.939
1871	0.784	0.603	0.521	0.695	0.425	0.776	0.765	0.764	0.864	0.775
1872	1.070	1.057	1.320	1.202	1.34	0.921	0.897	1.031	1.16	0.972
1873	0.699	0.827	0.425	0.763	1.089	1.196	1.256	0.642	0.902	1.240
1874	0.991	0.467	0.590	0.615	0.417	0.863	0.850	0.876	0.631	0.661
1875	1.097	1.245	1.058	0.521	0.796	1.148	1.002	0.958	0.917	0.573
1876	1.175	1.374	1.425	1.514	1.269	1.044	1.216	1.012	1.159	0.999
1877	1.005	0.925	0.846	0.883	0.9	0.952	1.030	0.832	0.854	0.900
1878	1.236	1.292	1.561	1.171	1.631	1.398	1.191	1.27	1.647	1.322
1879	0.174	0.946	0.671	0.440	0.549	0.564	0.801	0.679	0.768	1.060
1880	0.291	0.437	0.330	0.547	0.106	0.416	0.817	0.366	0.206	0.432
1881	0.980	0.676	0.671	0.786	1.402	0.970	1.361	0.948	1.055	1.216
1882	1.028	1.268	0.973	0.939	1.13	1.191	1.033	0.884	1.424	1.234
1883	1.022	1.203	1.290	1.145	1.053	1.466	1.003	1.093	1.084	1.173
1884	1.117	1.130	0.922	1.124	1.002	0.944	0.863	0.753	1.007	0.874
1885	1.213	1.129	0.873	1.071	1.248	0.466	0.862	0.585	0.895	0.580
1886	0.941	0.649	0.679	0.656	0.941	0.809	0.729	0.761	0.84	0.708
1887	0.504	0.882	0.734	0.751	0.202	0.339	0.747	0.508	0.503	0.559
1888	0.775	0.825	0.824	0.608	0.971	1.137	0.988	0.93	0.986	1.089
1889	1.113	1.629	1.238	1.513	1.234	1.132	1.257	1.291	1.136	1.195
1890	1.178	1.034	0.942	1.020	1.142	0.831	0.615	0.903	1.398	1.007
1891	1.340	1.420	1.226	1.049	0.963	1.236	1.186	1.264	1.518	0.961
1892	1.207	0.965	0.890	0.842	1.264	1.251	0.983	1.072	0.939	1.168
1893	0.590	0.347	0.425	0.368	0.728	0.638	0.633	0.669	1.026	0.712

1894	0.976	1.274	1.028	1.400	0.611	1.378	1.207	1.365	1.886	1.155
1895	1.421	1.491	1.233	0.874	1.358	1.281	1.277	1.301	1.266	1.249
1896	0.757	1.160	0.820	0.840	0.804	0.828	0.790	1.008	0.571	1.049
1897	1.517	1.286	0.958	0.931	1.189	1.138	1.095	1.377	1.295	1.147
1898	0.970	1.062	1.031	1.295	1.196	1.279	1.419	1.255	1.168	1.342
1899	1.130	0.423	0.644	0.560	0.594	0.872	0.748	0.926	0.717	0.688
1900	1.116	1.118	1.039	1.156	1.056	1.185	1.005	0.869	1.163	0.964
1901	1.311	1.089	0.964	1.015	0.947	1.103	0.765	1.204	0.963	0.813
1902	1.178	0.365	0.485	0.487	0.714	0.792	0.748	0.881	0.696	0.807
1903	1.344	1.722	1.865	1.713	1.167	1.606	1.055	1.267	1.332	1.227
1904	0.888	1.406	1.338	1.508	1.054	1.306	0.950	1.432	1.438	1.142
1905	1.223	1.063	1.069	0.918	1.466	0.973	0.885	0.939	0.812	1.220
1906	0.916	1.390	1.149	1.138	0.889	1.151	0.994	1.249	0.987	0.756
1907	1.032	1.493	1.626	1.557	1.36	1.267	1.062	1.306	1.409	1.184
1908	1.055	1.097	0.942	0.904	0.67	1.273	0.974	0.929	0.638	1.181
1909	1.161	1.215	1.285	0.777	1.596	1.274	1.116	1.081	1.3	1.130
1910	0.564	0.537	0.354	0.593	0.683	0.525	0.929	0.666	0.516	0.743
1911	0.934	0.670	0.918	0.379	0.644	1.031	1.096	1.014	0.914	0.777
1912	1.317	1.289	1.197	1.218	1.487	1.190	1.115	1.146	0.762	1.282
1913	1.236	1.246	1.189	1.184	1.157	1.113	1.000	1.157	0.944	0.939
1914	1.218	1.251	1.228	1.285	1.661	1.524	1.180	1.304	1.059	1.308
1915	0.968	1.559	1.298	1.471	1.223	1.424	1.032	1.295	1.146	1.177
1916	0.755	1.070	0.786	1.307	0.818	0.954	0.974	1.163	0.96	1.145
1917	1.197	0.940	1.060	0.980	1.087	0.759	1.052	0.701	0.754	1.037
1918	1.195	0.863	0.992	1.050	0.902	1.248	1.233	1.419	1.037	1.094
1919	0.566	0.130	0.327	0.299	0.427	1.039	0.940	0.391	0.828	1.272
1920	1.354	1.358	1.378	1.153	1.918	0.904	1.175	1.016	0.846	1.236
1921	0.950	1.638	1.823	1.412	1.547	1.624	1.230	1.482	1.156	1.218
1922	0.721	0.599	0.591	0.576	0.57	0.759	1.142	0.586	0.896	0.622
1923	1.221	1.297	1.541	1.506	1.182	1.433	1.031	1.547	1.464	1.113
1924	1.159	0.914	0.875	1.300	1.237	0.772	1.022	0.749	0.892	1.163
1925	0.282	0.405	0.305	0.134	0.003	0.710	0.516	0.577	0.33	0.120
1926	1.265	1.317	1.254	1.246	1.72	1.221	1.508	1.212	1.385	1.446
1927	1.009	0.812	0.716	0.829	1.174	0.770	0.781	0.923	1.024	1.178
1928	1.128	1.258	1.237	1.367	1.021	1.352	1.029	1.226	1.335	1.277
1929	0.781	1.023	0.986	0.724	0.421	0.630	0.775	0.838	0.896	1.008
1930	1.152	0.860	0.814	0.587	1.171	0.986	1.341	0.951	0.96	0.941
1931	0.819	1.118	0.898	1.227	0.993	1.181	1.514	0.77	1.009	1.297
1932	0.375	0.835	0.862	0.707	0.245	0.726	0.845	0.596	0.349	0.558
1933	0.881	1.073	1.290	0.885	1.091	1.002	1.314	0.863	0.997	0.990
1934	0.811	0.794	0.938	0.935	0.926	0.825	0.741	0.921	0.997	0.943
1935	0.818	1.038	0.700	1.119	0.863	0.852	0.610	0.881	0.744	0.821
1936	0.686	0.752	0.671	0.904	1.032	1.202	1.107	0.952	0.933	1.206
1937	0.950	1.290	1.275	1.148	0.519	1.223	1.458	1.128	0.878	0.987
1938	0.784	1.203	1.084	1.379	0.995	1.210	0.787	1.174	0.982	1.053
1939	0.849	0.513	0.537	0.933	0.88	0.328	0.548	0.427	0.907	0.973
1940	0.500	0.641	0.646	0.641	0.367	1.172	1.053	1.061	0.737	0.625
1941	1.365	1.372	1.043	1.658	1.36	0.907	0.864	1.271	1.456	1.096
1942	1.134	1.200	1.125	1.397	1.516	1.188	1.249	1.082	1.128	1.360
1943	1.039	1.046	1.484	1.258	1.41	1.145	0.993	1.039	0.915	1.308
1944	0.879	1.066	1.197	1.042	0.695	0.728	0.779	0.772	1.016	0.586
1945	0.937	1.374	1.251	1.514	1.073	1.235	0.858	1.186	1.159	0.875
1946	0.737	0.731	0.566	0.322	0.34	0.975	1.102	0.681	0.546	0.889
1947	1.318	1.481	1.255	1.329	1.946	1.161	1.308	1.284	1.288	1.297
1948	0.687	0.620	0.593	0.679	1.308	1.003	1.075	0.848	1.29	1.224
1949	1.249	1.428	1.034	1.235	0.931	1.176	0.975	1.133	1.266	1.012
1950	0.841	0.671	0.641	0.782	1.076	0.768	0.908	0.823	0.85	0.870
1951	1.177	0.898	0.878	1.070	1.238	0.792	1.037	1.011	0.998	1.041
1952	1.233	0.917	0.938	1.038	1.293	1.086	0.913	1.04	1.303	0.834
1953	0.822	0.995	1.047	0.851	0.781	1.046	0.933	0.918	1.072	0.809
1954	0.203	0.343	0.060	0.244	-0.017	0.176	0.515	0.105	0.303	0.429
1955	0.870	0.835	1.004	1.029	0.671	1.037	1.213	1.053	0.943	0.812
1956	1.054	0.937	0.734	0.546	1.035	0.900	0.897	0.782	0.838	0.789
1957	1.207	1.261	0.975	1.234	1.146	1.205	1.089	1.009	0.952	0.956

1958	1.315	1.058	1.036	1.109	1.398	1.082	1.193	1.072	1.084	1.217
1959	0.993	0.895	0.882	0.917	1.08	1.153	1.046	0.956	0.986	1.095
1960	0.827	0.969	1.000	1.002	0.771	0.895	0.808	0.917	1.1	1.025
1961	1.208	1.390	1.092	1.217	1.195	1.190	1.122	1.327	1.293	0.931
1962	1.142	1.016	0.737	0.964	0.665	0.803	1.055	0.949	0.966	1.063
1963	0.792	0.314	0.315	0.333	0.426	0.369	0.672	0.501	0.693	0.611
1964	0.763	0.521	0.828	0.597	0.73	0.728	1.087	0.556	0.922	0.787
1965	1.136	1.369	1.111	1.526	0.881	1.134	1.162	1.041	1.09	1.008
1966	0.395	0.604	0.408	0.508	0.335	0.535	0.969	0.642	0.527	0.681
1967	0.933	1.209	1.368	1.025	1.233	1.518	1.570	1.678	1.356	1.270
1968	1.096	0.890	0.824	0.478	1.053	1.114	0.917	1.044	1.051	1.191
1969	0.811	1.383	1.467	1.358	0.788	1.217	1.229	1.299	1.212	0.986
1970	1.132	1.005	1.247	0.991	1.194	1.143	0.959	1.047	1.127	1.209
1971	0.960	1.106	1.126	1.018	1.018	0.646	0.658	0.923	1.251	0.756
1972	0.519	0.925	1.117	0.907	0.817	1.000	0.945	1.489	1.373	0.709
1973	1.128	1.034	1.219	1.198	1.238	0.737	0.887	0.707	1.113	0.975
1974	0.741	1.013	1.174	0.628	0.382	0.631	0.987	0.828	0.759	0.752
1975	1.368	1.486	1.496	1.446	1.336	1.322	1.335	1.384	1.189	1.005
1976	0.764	0.641	0.427	0.716	0.474	0.759	0.883	0.838	0.785	0.872
1977	0.955	0.877	0.923	0.590	0.46	0.592	1.094	0.338	0.542	0.971
1978	1.127	0.856	0.661	1.217	1.426	0.755	0.923	1.001	0.674	1.076
1979	1.492	0.739	0.701	1.219	1.627	0.844	0.902	1.097	0.747	1.065
1980	1.070	0.617	0.879	0.685	1.15	0.455	0.637	0.798	0.808	0.904
1981	0.981	1.252	1.213	0.705	0.456	1.154	1.015	0.829	0.855	0.776
1982	1.116	1.036	0.889	1.152	0.806	0.950	1.029	0.866	0.703	0.738
1983	1.518	1.205	1.141	1.468	1.622	1.297	1.146	0.961	1.044	1.245
1984	1.158	1.119	1.169	1.121	0.957	0.738	0.683	0.923	0.847	1.090
1985	0.720	0.607	0.567	0.940	0.835	1.195	0.874	0.874	1.167	1.025
1986	1.218	1.413	1.485	1.408	0.811	1.039	0.761	0.872	0.722	1.036
1987	1.011	0.782	0.920	1.137	1.348	1.474	0.907	1.329	0.991	1.265
1988	0.955	0.797	0.821	0.767	0.31	0.905	0.840	0.939	0.992	1.370
1989	0.614	0.784	0.606	0.466	1.382	1.117	1.037	1.26	1.04	1.335
1990	1.425	1.255	1.004	1.282	1.369	1.019	0.876	1.102	1.253	0.726
1991	1.260	0.939	1.236	0.923	1.12	1.198	1.172	1.059	0.964	1.566
1992	1.127	1.222	1.420	0.910	0.807	1.101	0.968	1.209	1.008	0.846
1993	0.858	0.740	1.013	0.826	1.114	1.082	1.003	0.938	1.112	1.058
1994	0.842	0.661	0.764	1.124	1.097	1.127	1.156	0.986	1.01	0.836
1995	1.373	1.459	1.460	1.785	1.103	1.589	1.120	1.436	1.435	0.875
1996	1.381	1.170	1.334	1.243	0.792	1.240	1.224	1.613	1.477	1.365
1997	0.930	1.268	1.255	0.766	1.852	1.330	0.960	1.275	1.065	1.260
1998	1.366	1.255	1.348	1.620	1.327	0.964	0.899	0.993	1.071	1.022
1999	1.385	1.070	1.052	1.400	1.231	1.319	1.523	1.469	1.571	1.299
2000	0.539	0.435	0.315	1.037	0.365	0.701	1.310	0.604	0.587	0.530
2001	1.401	1.667	1.766		0.744			0.648	1.037	0.884
2002	0.200	0.596	0.551		0.516				0.503	0.588
2003					1.248					0.959

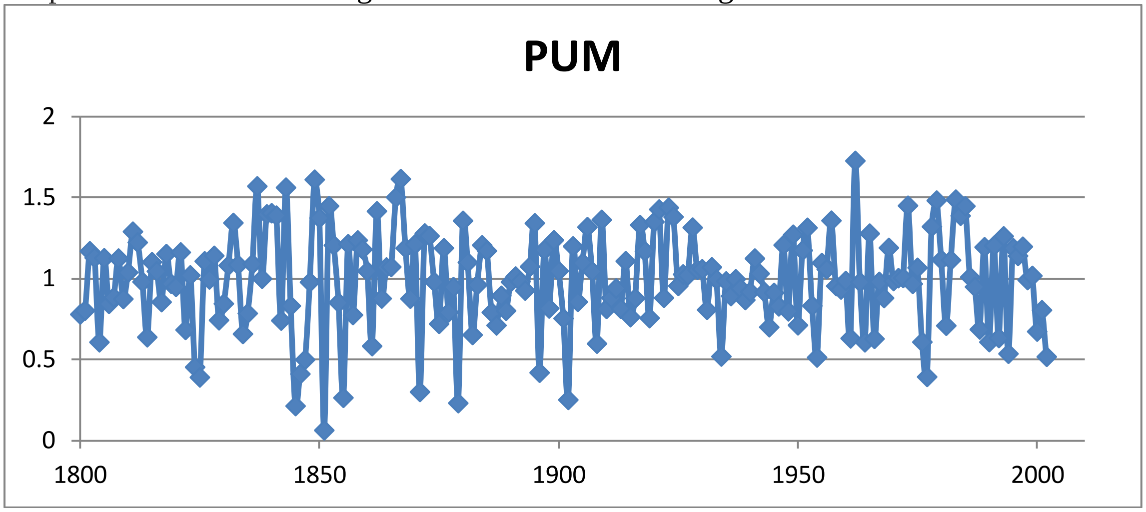
Year	**CRA**	**VBU**	**JFU**	**MEY**	**EAG**	**HER**	**VVR**	**HAP**	**ELE**	**TCU**
1800	1.210	1.055	1.072	1.092	1.068	0.896	1.412	1.167	0.933	1.579
1801	0.785	1.067	0.537	0.498	0.534	0.695	0.442	0.513	0.850	0.457
1802	1.076	0.805	1.104	1.145	1.120	0.946	1.127	1.054	0.832	1.378
1803	1.309	1.183	1.298	1.310	1.469	1.271	1.563	1.610	1.019	1.409
1804	0.914	0.406	0.940	0.944	0.783	1.233	1.436	0.881	1.099	0.993
1805	0.767	0.651	0.768	0.917	1.041	0.946	0.390	1.026	0.756	0.190
1806	1.417	1.102	1.091	1.023	1.101	0.806	1.177	1.119	1.031	0.498
1807	0.722	0.845	0.893	0.775	0.942	1.236	1.544	0.664	1.181	0.974
1808	0.989	2.226	1.378	0.716	1.015	0.908	1.141	1.219	0.986	0.787
1809	0.965	0.575	0.678	0.697	0.328	0.58	0.229	0.284	1.126	0.903
1810	1.157	0.873	1.054	1.011	1.068	1.301	1.154	1.243	1.063	1.009
1811	0.863	0.501	0.777	0.937	0.944	0.855	0.887	0.809	1.074	0.275
1812	0.890	1.128	1.051	0.964	1.024	0.834	0.782	0.951	0.912	1.083
1813	1.058	0.795	0.932	1.053	1.004	0.97	0.747	1.074	1.251	1.112
1814	1.058	1.076	1.042	0.961	0.957	0.957	0.825	0.796	1.140	1.202
1815	1.197	1.123	1.156	1.102	1.097	1.039	1.044	0.822	1.001	1.459
1816	1.366	1.094	1.049	1.112	0.853	1.151	1.318	0.943	1.097	1.252
1817	1.041	0.847	0.932	1.078	0.872	1.389	1.274	1.125	1.030	1.076
1818	1.106	0.622	0.789	1.062	0.933	1.14	0.304	0.745	1.034	0.347
1819	0.783	0.7	0.797	0.816	1.047	0.933	0.656	0.996	0.784	0.724
1820	1.094	1.157	0.928	0.960	1.033	1.115	0.742	0.791	0.941	0.249
1821	0.446	0.867	0.954	0.847	0.769	0.893	0.889	0.533	0.882	0.487
1822	0.951	0.74	1.132	1.079	1.071	1.461	1.440	0.974	1.116	0.802
1823	0.607	0.599	0.898	0.743	1.034	0.969	1.008	0.933	0.872	1.217
1824	0.673	0.643	0.746	0.510	0.674	0.635	0.708	0.592	0.756	0.527
1825	0.987	1.38	1.296	1.038	1.138	1.222	1.297	1.186	1.135	1.672
1826	1.081	0.965	1.013	1.043	1.062	0.792	0.669	0.981	1.154	1.104
1827	1.126	0.847	1.315	1.268	1.159	1.004	1.419	1.090	1.203	1.236
1828	1.493	1.611	1.310	1.195	1.316	1.277	1.646	1.749	1.445	1.963
1829	0.757	1.106	0.962	0.986	0.979	0.994	1.089	1.153	0.896	1.505
1830	1.104	1.162	1.099	0.758	0.894	0.752	0.413	0.824	0.785	1.299
1831	0.760	0.674	0.904	0.925	0.983	1.181	1.176	1.087	1.027	1.295
1832	0.943	1.497	1.188	0.913	0.913	0.536	0.995	0.864	1.014	0.943
1833	1.077	1.193	1.199	1.014	0.996	0.688	1.118	1.196	1.037	1.134
1834	1.154	0.484	1.088	0.965	0.919	0.989	1.159	0.406	1.107	0.662
1835	1.231	1.37	1.479	1.278	1.146	1.151	1.223	1.204	1.079	2.032
1836	1.203	1.48	1.389	1.296	1.033	1.244	1.850	1.196	1.209	1.681
1837	1.257	1.491	1.183	1.254	0.708	0.991	1.473	1.081	1.048	0.843
1838	1.518	1.808	1.645	1.316	1.187	1.247	1.353	1.385	1.396	1.639
1839	1.263	1.539	1.571	1.343	1.217	1.342	1.751	1.460	1.596	1.817
1840	0.605	0.507	1.001	1.007	1.179	1.114	0.391	1.399	0.830	0.903
1841	0.831	0.575	1.024	1.032	0.953	0.889	1.084	0.260	0.929	0.955
1842	0.067	0.211	0.056	0.470	0.385	0.474	0.326	0.274	0.271	0.079
1843	1.442	1.393	1.424	1.026	1.402	1.681	0.499	1.114	1.460	1.185
1844	1.266	0.861	1.248	1.071	1.254	1.219	1.579	1.458	1.425	1.522
1845	0.804	0.72	0.807	0.485	0.670	0.771	0.393	0.956	0.565	0.968
1846	1.075	0.546	0.884	0.977	1.031	0.872	0.979	0.680	1.057	0.905
1847	0.721	0.784	0.710	0.626	0.447	0.799	0.319	0.517	0.900	0.076
1848	0.702	0.518	0.860	0.860	0.889	0.85	0.500	0.889	0.893	0.567
1849	1.001	0.764	0.743	0.999	0.517	0.671	0.874	0.766	0.929	0.730
1850	0.797	0.839	1.191	0.998	1.189	0.943	0.866	0.946	1.104	1.111
1851	0.367	0.462	0.402	0.447	0.609	0.345	0.358	0.310	0.533	0.294
1852	0.736	0.614	0.882	1.083	0.552	1.291	0.837	0.615	0.797	0.404
1853	0.961	0.896	1.065	1.368	1.174	0.869	0.920	0.968	1.122	0.979
1854	0.922	0.642	1.013	1.232	1.019	0.858	1.344	1.332	0.998	1.143
1855	0.871	0.641	0.705	0.885	0.663	0.763	0.311	0.704	0.747	0.561
1856	0.671	0.643	0.913	0.356	0.680	0.571	0.335	0.714	0.769	0.971
1857	0.797	0.782	1.355	1.162	1.223	0.962	0.778	1.002	0.863	1.753
1858	1.083	0.928	1.178	1.629	1.392	1.28	1.202	1.403	1.229	1.526
1859	0.803	0.672	0.754	0.924	0.914	0.66	0.874	0.831	0.996	0.880
1860	1.020	1.947	0.998	0.965	1.277	1.006	1.032	0.997	1.233	1.094
1861	0.923	0.581	0.874	0.762	0.636	0.546	0.331	0.611	0.768	0.152
1862	0.839	0.645	0.813	1.046	1.176	0.925	1.036	1.131	0.812	0.783

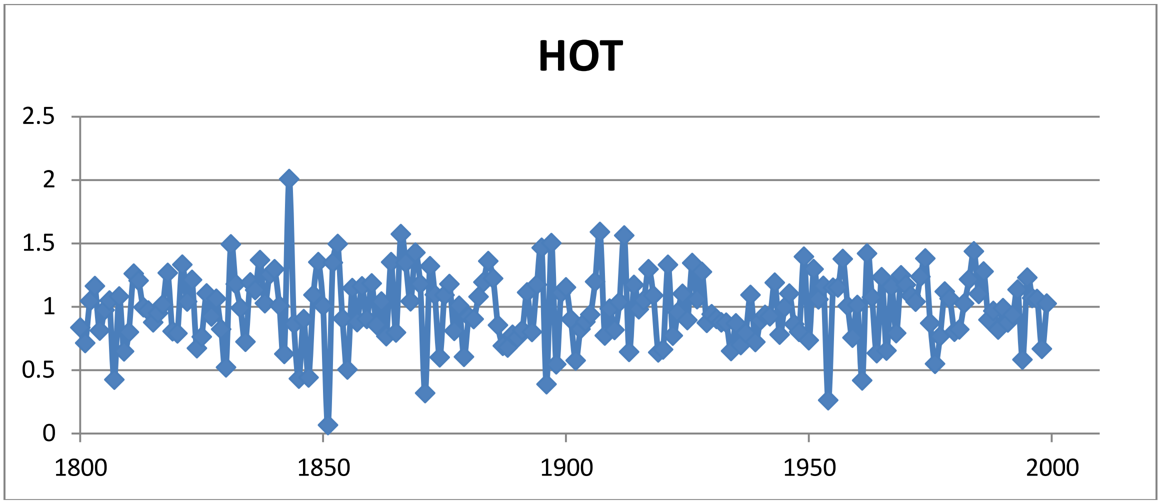
1863	0.718	0.591	0.459	0.414	0.389	0.297	0.504	0.550	0.537	0.354
1864	0.976	1.27	1.116	1.111	1.092	1.128	1.471	1.225	1.090	1.192
1865	0.853	1.17	0.963	0.910	0.668	0.737	0.472	0.692	0.934	1.076
1866	1.266	1.45	1.147	1.124	1.175	1.241	1.401	1.370	1.221	1.483
1867	1.004	1.099	1.126	0.898	1.132	1.204	0.939	1.073	1.192	0.904
1868	0.727	2.227	1.259	0.937	1.202	0.641	0.694	1.174	0.702	0.661
1869	1.250	1.558	1.317	1.364	1.476	1.27	1.466	1.419	1.299	1.564
1870	0.929	0.322	0.548	0.958	1.042	0.633	0.507	1.245	0.939	0.525
1871	1.162	0.816	1.030	0.999	0.992	0.677	0.419	0.493	0.775	0.623
1872	1.021	1.46	1.150	1.132	1.181	1.288	1.433	1.211	0.972	1.431
1873	1.301	1.595	0.763	1.059	0.927	0.644	0.892	0.933	1.240	0.839
1874	0.708	0.555	0.731	0.856	0.612	0.678	0.896	1.068	0.661	1.094
1875	0.760	1.873	0.323	0.775	0.567	0.784	0.950	0.607	0.573	1.272
1876	0.943	0.419	0.851	1.153	1.105	1.121	0.891	1.400	0.999	0.867
1877	0.913	0.425	0.776	0.886	0.924	0.928	0.899	0.947	0.900	0.797
1878	1.623	1.635	1.259	1.483	1.343	1.148	1.298	1.372	1.322	0.953
1879	1.286	0.797	0.898	0.947	1.066	0.941	1.059	0.923	1.060	0.915
1880	0.007	0.226	0.316	0.307	0.334	0.062	0.056	0.229	0.432	0.108
1881	1.071	0.714	1.223	0.877	0.779	1.27	0.975	1.143	1.216	1.040
1882	1.351	0.841	1.234	1.084	1.230	1.205	1.406	1.245	1.234	1.515
1883	1.442	1.373	1.277	1.114	0.834	0.667	1.187	1.258	1.173	0.771
1884	0.866	0.595	1.220	0.860	1.131	0.86	1.090	1.481	0.874	1.305
1885	0.390	0.499	0.762	0.918	0.758	1.313	0.677	1.274	0.580	1.033
1886	0.821	0.607	0.647	0.849	0.940	0.653	1.403	1.246	0.708	0.924
1887	0.511	0.554	0.503	0.913	0.897	0.707	0.739	0.837	0.559	0.744
1888	1.143	0.705	1.049	1.096	1.016	0.815	0.948	1.208	1.089	0.616
1889	1.160	0.994	1.125	1.216	1.090	1.008	0.883	0.886	1.195	1.097
1890	1.243	0.735	1.126	0.734	0.784	0.727	0.454	0.447	1.007	1.182
1891	1.560	1.375	1.086	1.311	1.295	1.106	1.280	1.478	0.961	1.329
1892	0.932	0.762	1.017	1.111	1.279	1.034	1.031	1.142	1.168	0.765
1893	0.667	0.566	0.809	0.681	0.733	0.762	0.333	1.004	0.712	0.765
1894	1.688	1.709	1.203	1.380	1.065	0.911	0.534	1.540	1.155	1.246
1895	1.102	1.191	0.871	0.987	1.260	1.309	1.014	1.496	1.249	1.512
1896	0.872	0.615	0.853	0.784	0.634	1.018	1.071	0.927	1.049	0.732
1897	1.271	1.157	1.431	1.174	1.318	1.473	1.246	1.287	1.147	1.123
1898	0.952	0.576	0.960	1.193	1.243	1.294	1.641	1.298	1.342	1.080
1899	0.637	1.175	0.545	0.663	0.519	0.236	0.229	0.248	0.688	0.341
1900	1.032	0.869	1.118	0.980	0.918	0.409	1.196	1.028	0.964	1.186
1901	1.038	0.497	0.833	0.913	0.931	0.767	1.156	0.949	0.813	1.283
1902	0.954	0.872	0.784	0.833	0.486	0.707	1.442	0.336	0.807	0.614
1903	1.230	0.822	1.172	1.046	1.125	0.913	0.949	1.096	1.227	0.938
1904	1.444	1.563	1.340	1.285	1.361	1.321	1.464	1.290	1.142	0.963
1905	0.977	1.534	0.995	1.008	0.996	0.509	1.768	1.192	1.220	1.441
1906	0.744	1.197	1.069	1.051	1.298	0.865	1.066	1.367	0.756	0.602
1907	1.328	1.691	1.315	1.102	0.994	0.904	1.173	1.224	1.184	0.921
1908	1.046	0.593	0.444	0.989	0.614	0.973	0.273	0.332	1.181	0.168
1909	1.359	1.922	1.544	1.257	1.305	1.41	1.110	1.208	1.130	1.119
1910	0.886	0.455	0.674	0.868	0.901	0.901	0.894	1.119	0.743	0.996
1911	1.036	0.789	1.126	1.068	0.604	0.883	1.084	0.789	0.777	0.681
1912	0.858	1.233	1.146	0.896	1.334	1.181	1.125	1.279	1.282	1.342
1913	0.951	0.787	0.912	0.808	0.811	0.981	0.984	0.898	0.939	0.946
1914	1.353	1.277	1.087	1.156	1.376	1.654	2.086	1.304	1.308	1.581
1915	1.197	0.99	1.333	1.131	1.429	1.354	0.766	1.249	1.177	1.767
1916	1.041	0.743	0.979	0.826	1.278	0.823	0.683	1.365	1.145	1.077
1917	0.736	0.851	0.923	0.731	1.222	0.961	0.839	1.113	1.037	0.920
1918	1.217	1.482	1.078	1.144	1.295	1.179	0.999	1.762	1.094	0.841
1919	0.878	1.186	0.789	1.083	0.924	1.347	1.681	0.825	1.272	1.788
1920	0.941	0.591	0.826	1.033	0.843	0.691	0.247	1.200	1.236	0.966
1921	1.316	1.156	1.275	1.426	1.139	1.41	0.949	1.802	1.218	1.734
1922	0.791	0.791	0.737	1.107	1.227	1.136	1.180	1.151	0.622	0.568
1923	1.217	1.96	1.397	1.258	1.235	0.903	0.996	1.207	1.113	0.348
1924	0.941	1.24	1.004	1.006	1.145	1.042	1.597	1.212	1.163	1.378
1925	0.376	0.393	0.467	0.244	0.479	0.613	0.989	0.013	0.120	0.441
1926	1.323	1.843	1.575	1.273	1.245	1.4	1.116	1.384	1.446	1.161

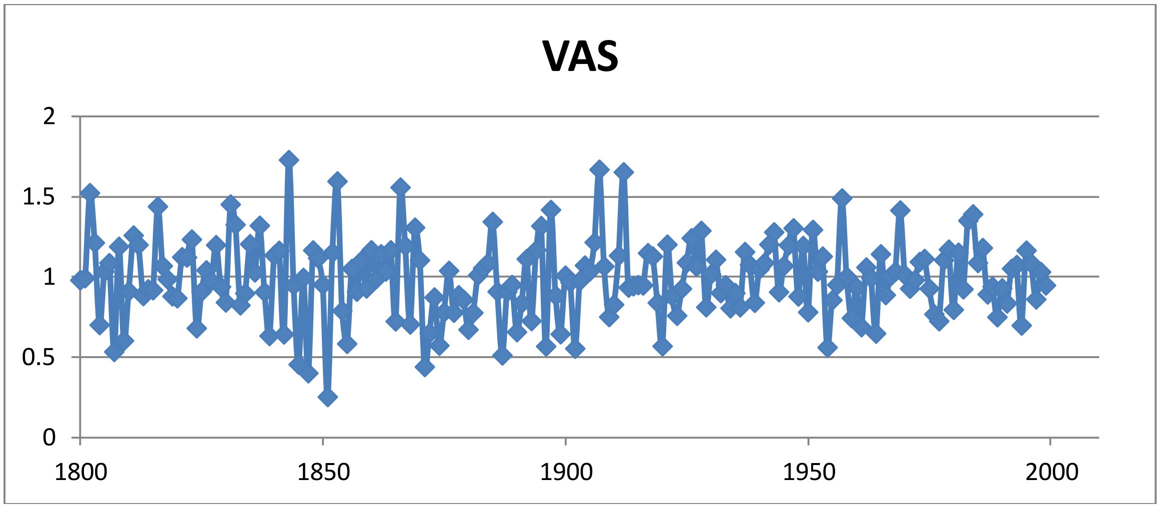
1927	0.700	1.105	0.752	0.894	0.898	1.471	0.490	0.509	1.178	0.558
1928	1.290	1.603	1.413	1.103	1.114	1.446	2.007	1.143	1.277	1.486
1929	1.051	1.609	0.904	0.915	0.869	0.629	0.343	0.262	1.008	0.490
1930	0.982	0.63	1.173	0.960	1.085	1.88	0.635	1.157	0.941	1.230
1931	1.188	0.773	0.840	0.945	0.863	1.175	1.264	1.120	1.297	1.254
1932	0.761	0.427	0.375	0.852	0.776	0.768	0.467	0.430	0.558	0.464
1933	0.921	1.6	1.106	1.055	1.186	0.79	1.101	1.338	0.990	1.376
1934	1.183	0.655	0.875	0.821	0.817	0.411	0.306	0.372	0.943	0.660
1935	0.703	0.669	0.746	0.844	0.972	0.857	1.202	1.441	0.821	0.723
1936	0.762	0.787	0.836	1.045	0.999	1.139	1.092	0.631	1.206	0.614
1937	1.107	0.898	1.230	1.139	1.139	0.924	0.839	1.084	0.987	0.668
1938	1.002	1.132	1.123	1.215	1.129	0.997	0.884	1.473	1.053	1.049
1939	0.715	0.645	0.885	0.628	0.674	0.748	0.878	0.836	0.973	0.982
1940	0.715	0.634	0.742	0.931	0.846	1.025	0.668	0.904	0.625	0.714
1941	1.156	1.12	1.033	1.093	1.198	1.475	1.511	0.871	1.096	1.166
1942	1.128	1.345	1.266	1.101	0.972	1.595	1.738	0.901	1.360	1.645
1943	0.933	0.763	1.165	0.901	0.741	1.128	1.460	0.877	1.308	1.462
1944	0.841	1.141	1.137	0.768	1.042	0.748	0.672	0.767	0.586	1.183
1945	1.100	1.183	1.103	1.006	0.648	0.663	0.690	0.560	0.875	1.005
1946	0.944	0.774	0.926	0.739	0.870	1.077	1.062	0.748	0.889	0.247
1947	1.030	1.405	1.704	1.172	1.073	1.449	2.177	1.278	1.297	1.688
1948	1.208	1.174	1.248	1.057	1.425	0.996	0.935	1.105	1.224	1.865
1949	1.104	1.441	0.908	1.007	1.152	1.086	0.929	1.529	1.012	1.415
1950	0.971	0.624	1.022	0.949	0.914	0.673	0.578	0.895	0.870	0.204
1951	0.992	0.92	0.984	0.951	0.769	0.957	0.847	0.393	1.041	0.441
1952	1.076	1.008	1.000	0.962	0.964	0.66	0.886	1.065	0.834	1.135
1953	0.883	1.04	0.810	1.020	0.810	0.924	0.657	0.950	0.809	0.664
1954	0.375	0.539	0.240	0.172	0.381	0.697	0.300	0.509	0.429	0.149
1955	1.180	0.694	1.016	1.041	1.170	0.63	0.801	0.727	0.812	0.548
1956	0.727	0.674	0.710	0.488	0.672	0.874	0.619	1.069	0.789	0.809
1957	1.142	1.027	1.273	0.924	1.160	1.146	1.519	1.337	0.956	1.172
1958	1.240	1.341	1.192	1.107	1.149	1.272	1.705	1.360	1.217	1.631
1959	0.850	0.774	0.953	0.886	0.797	0.883	1.192	0.971	1.095	1.272
1960	1.130	1.283	1.284	1.147	1.070	0.881	0.999	1.503	1.025	1.352
1961	1.261	0.843	1.145	1.027	1.033	1.431	1.178	0.525	0.931	1.320
1962	0.907	0.883	0.827	0.821	1.062	1.132	0.523	0.586	1.063	0.894
1963	0.514	0.28	0.283	0.279	0.376	0.407	0.456	0.022	0.611	0.067
1964	1.160	0.814	1.217	0.908	0.963	0.817	1.085	0.988	0.787	1.070
1965	1.189	1.435	1.246	0.986	1.259	1.243	1.080	0.887	1.008	1.276
1966	0.462	0.406	0.384	0.623	0.852	0.693	0.539	0.824	0.681	0.447
1967	1.201	1.047	0.988	1.454	1.250	1.257	1.544	1.053	1.270	1.043
1968	1.014	0.754	0.862	1.036	0.695	0.831	0.334	0.631	1.191	0.616
1969	1.181	1.293	1.154	1.353	1.360	1.365	1.329	1.333	0.986	1.113
1970	1.307	1.193	1.169	1.218	0.981	0.951	0.741	1.247	1.209	1.850
1971	1.072	1.117	1.102	0.951	1.092	1.092	0.555	0.573	0.756	1.116
1972	1.100	0.875	1.010	0.809	0.944	0.875	0.563	0.750	0.709	0.694
1973	0.683	1.082	0.928	0.876	0.914	1.16	0.872	1.164	0.975	1.443
1974	0.946	0.602	1.086	0.819	0.756	0.97	0.685	0.661	0.752	0.195
1975	1.072	1.088	1.312	1.474	1.108	1.032	0.936	1.003	1.005	0.948
1976	0.809	0.778	0.882	0.885	0.820	0.693	0.430	1.098	0.872	0.526
1977	0.519	0.683	0.832	0.800	1.066	0.966	0.920	1.270	0.971	0.761
1978	0.706	0.768	0.866	0.831	0.875	0.863	0.964	0.248	1.076	0.508
1979	1.048	1.102	1.274	0.777	0.968	1.035	1.581	1.015	1.065	1.644
1980	0.841	1.019	0.981	0.766	1.092	0.808	1.402	0.995	0.904	1.064
1981	1.083	0.705	0.725	0.930	1.064	0.873	0.528	1.132	0.776	0.099
1982	0.920	0.762	0.683	0.920	0.928	1.039	1.417	1.044	0.738	1.571
1983	1.159	1.501	1.418	1.351	1.221	1.308	1.607	1.312	1.245	1.498
1984	0.749	0.63	0.763	0.759	0.858	0.717	0.666	0.753	1.090	0.537
1985	1.327	1.159	1.308	1.201	1.166	0.971	1.291	1.228	1.025	1.902
1986	1.344	1.133	1.168	1.338	1.109	1.024	0.569	0.829	1.036	0.472
1987	1.317	1.266	1.066	1.330	1.078	1.185	1.081	1.541	1.265	1.385
1988	1.106	0.667	1.270	1.198	1.265	1.155	1.159	1.552	1.370	0.567
1989	1.043	0.627	0.839	0.796	0.828	0.448	0.497	0.431	1.335	0.936
1990	0.842	1.357	1.063	0.962	0.773	0.958	1.349	1.061	0.726	1.258

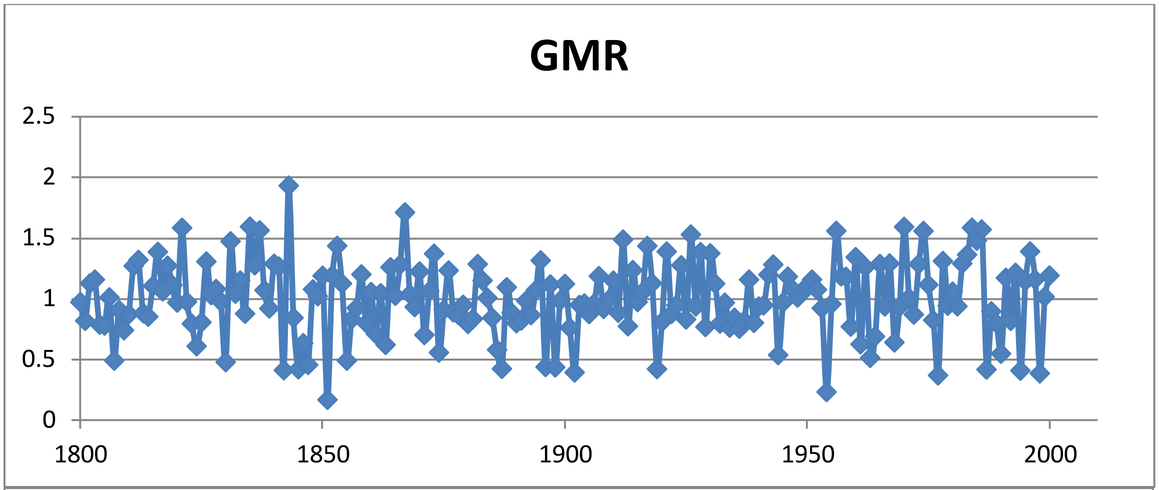
1991	0.925	0.977	0.957	1.524	1.191	1.208	1.192	1.442	1.566	0.936
1992	1.161	1.175	1.187	0.981	0.933	1.012	0.836	1.110	0.846	1.673
1993	1.156	0.956	0.813	0.956	0.820	0.922	1.502	1.097	1.058	0.870
1994	0.753	1.015	0.667	0.987	0.890	1.132	1.523	1.288	0.836	1.344
1995	1.325	1.583	1.221	1.371	1.176	1.247	1.529	1.772	0.875	2.003
1996	1.252	1.327	1.119	1.138	0.862	1.069	1.017	1.200	1.365	0.767
1997	0.837	0.955	1.037	1.382	0.931	1.345	1.656	0.636	1.260	1.773
1998	1.101	1.381	1.217	0.963		0.886	0.377	0.957	1.022	1.013
1999	1.129	1.469	0.996	1.046		1.449		1.586	1.299	1.999
2000	0.627	0.921	0.719	0.851		1.042		1.101	0.530	0.386
2001	0.781	0.873	1.052	1.316		1.301		0.926	0.884	0.669
2002	0.473	0.319	0.180	0.189		0.054		0.004	0.588	0.019
2003	1.492	1.538	1.401			1.235		0.793	0.959	0.872

Graphs of Standardized Ring Width for Each Site During the Calibration Record





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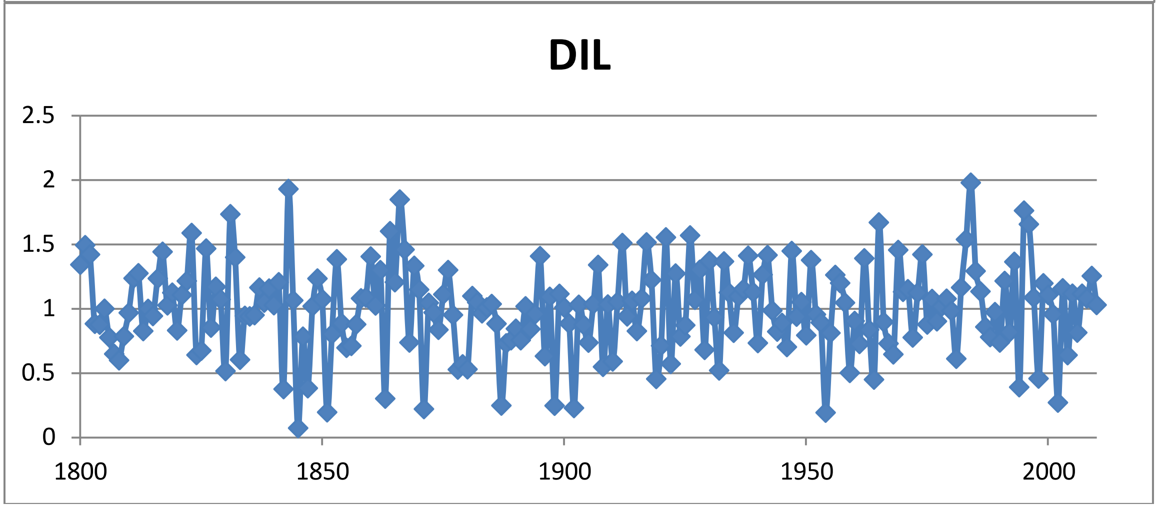
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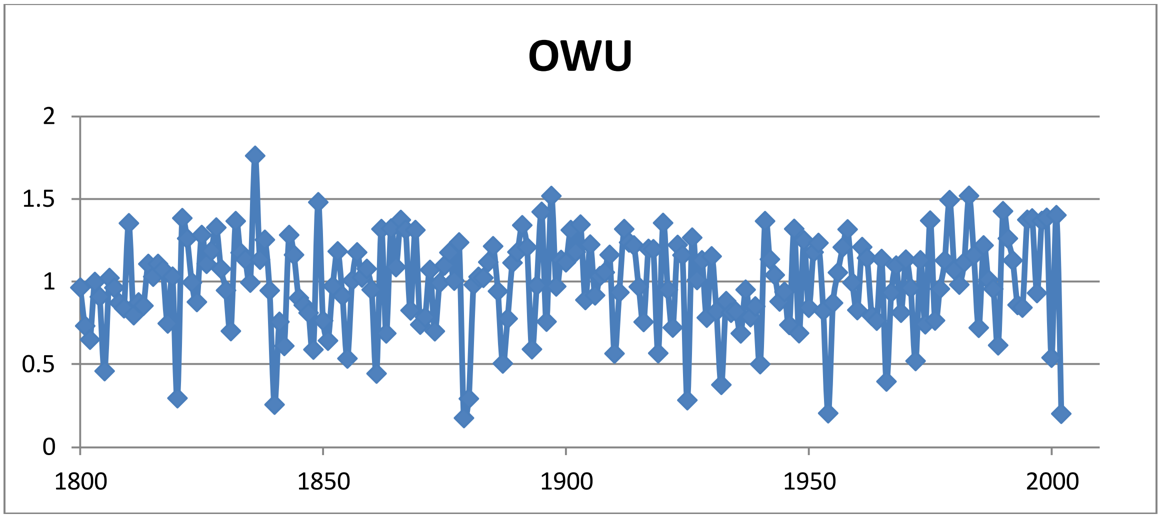
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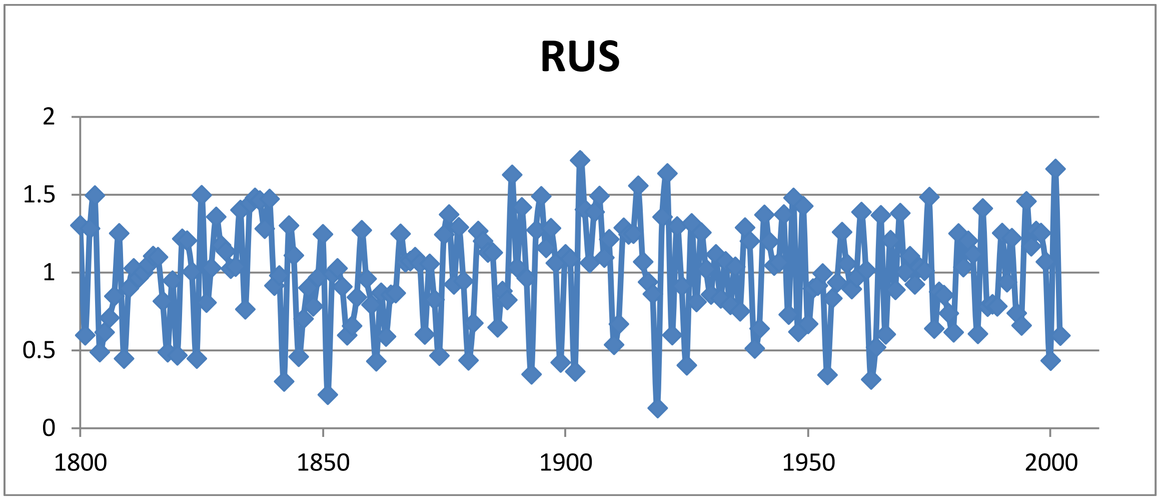
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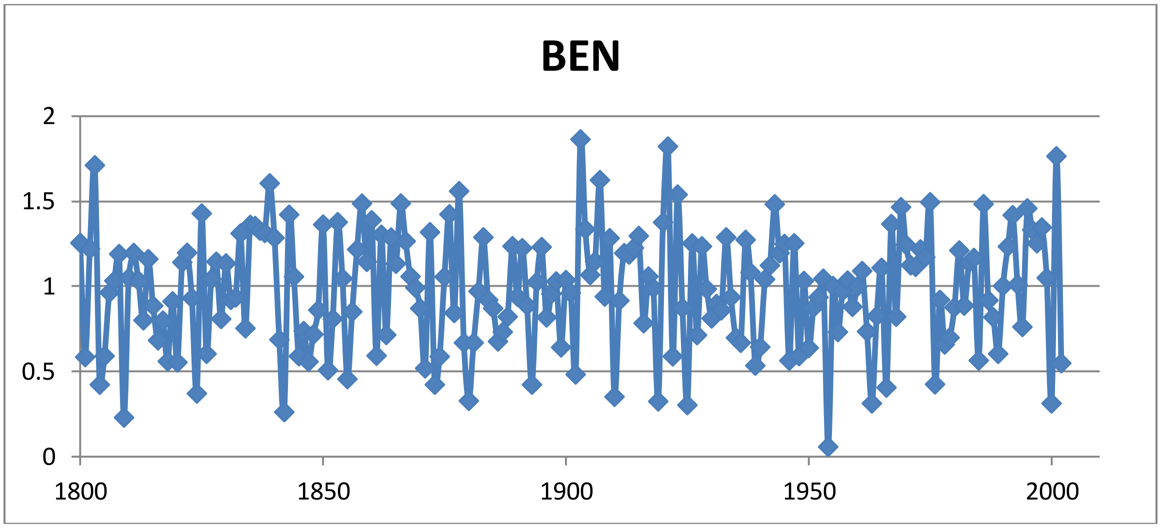
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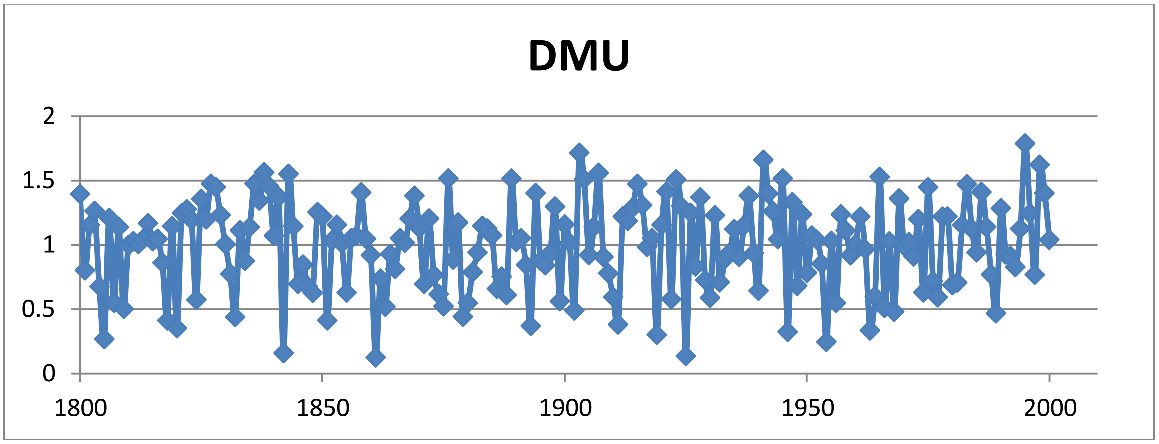
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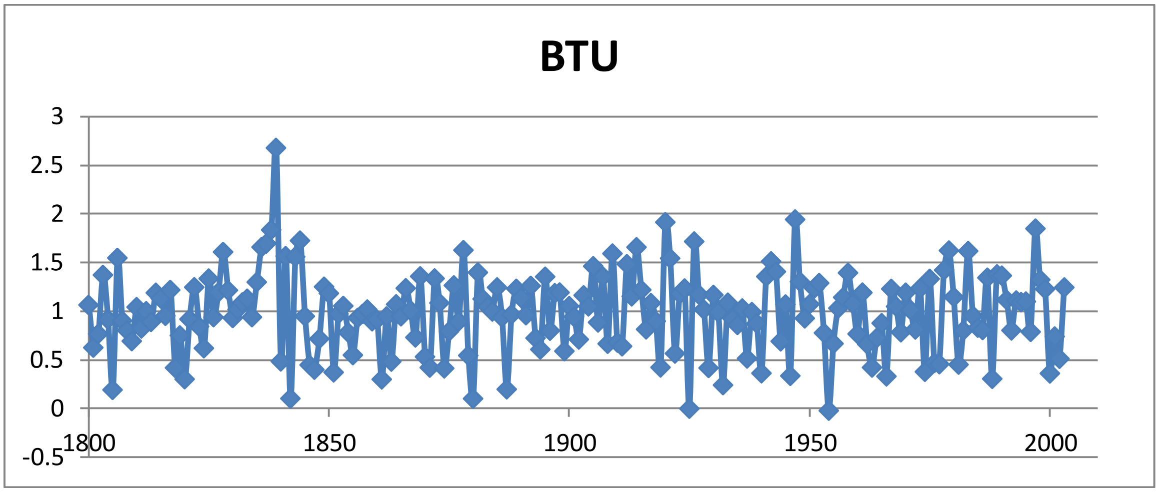
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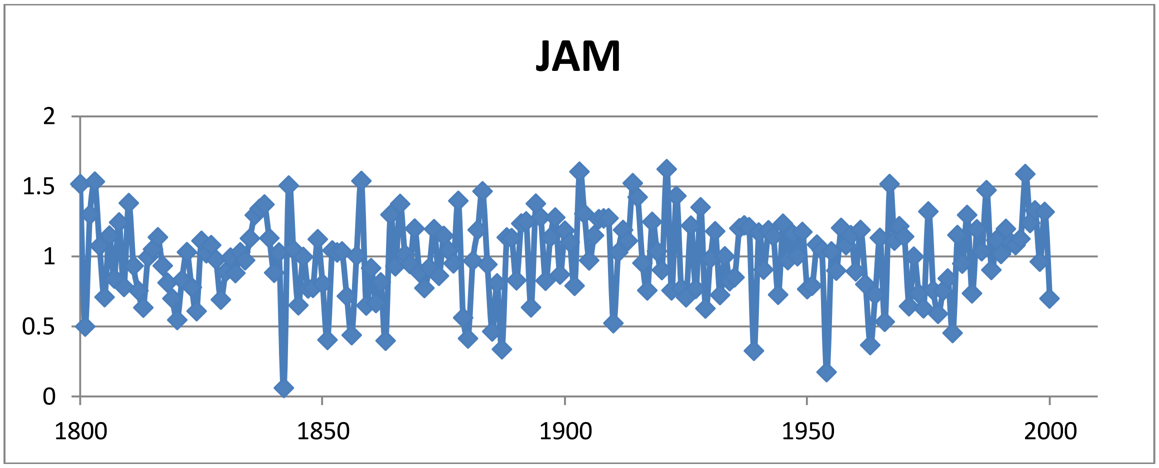
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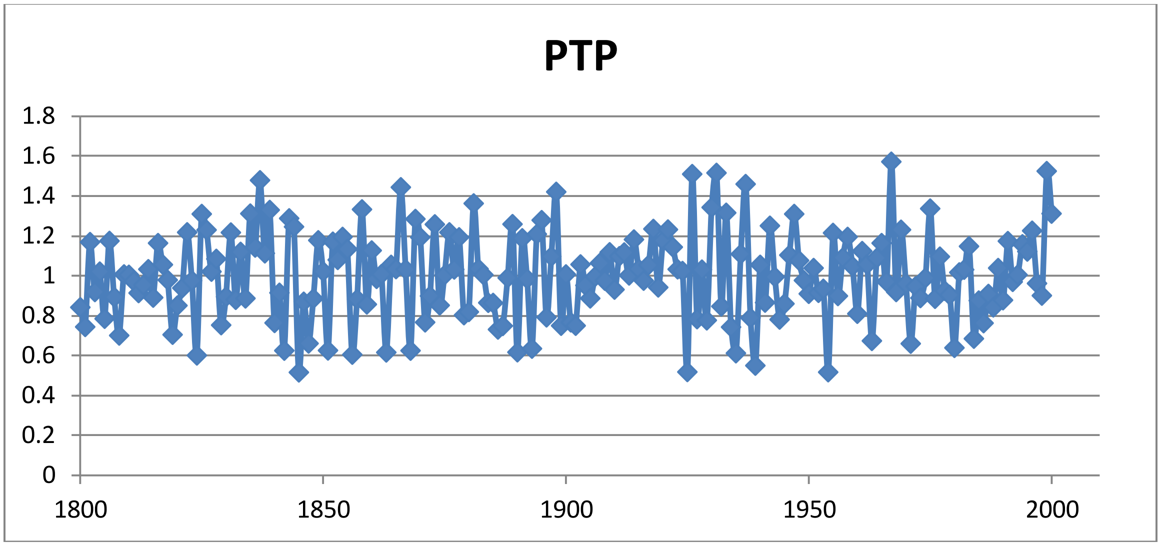
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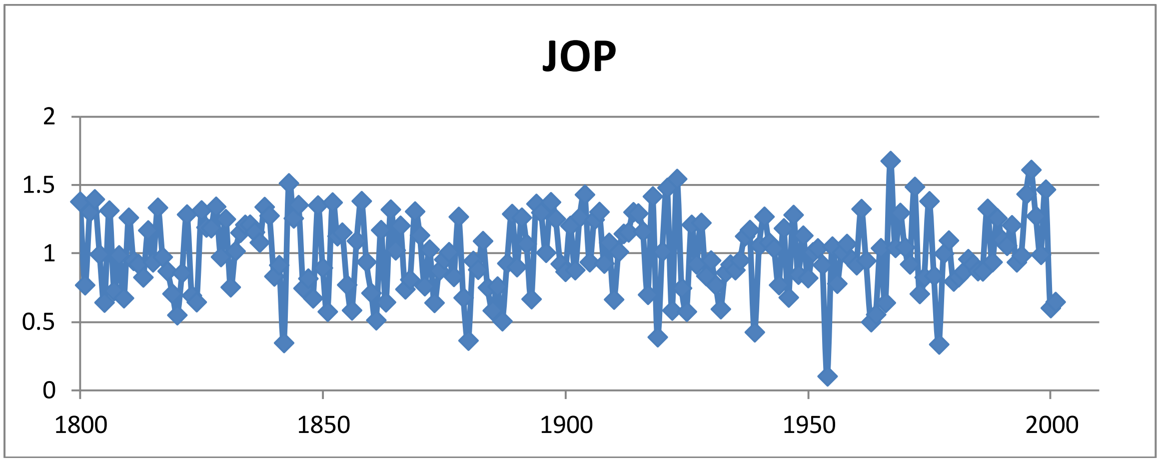
1950
2000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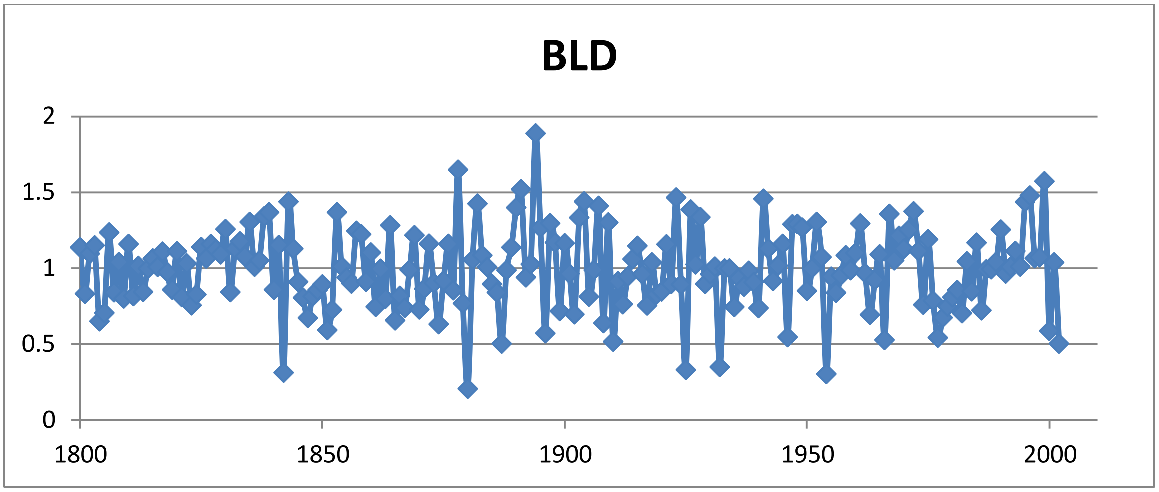
1800
1850
1900
1950
2000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2
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1800
1850
1900
1950
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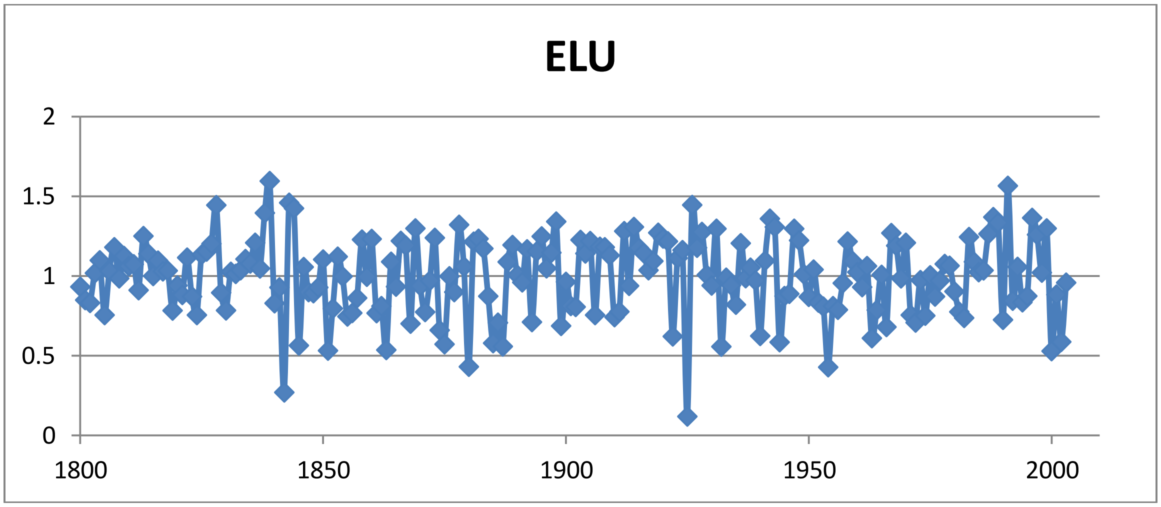
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1800
1850
1900
1950
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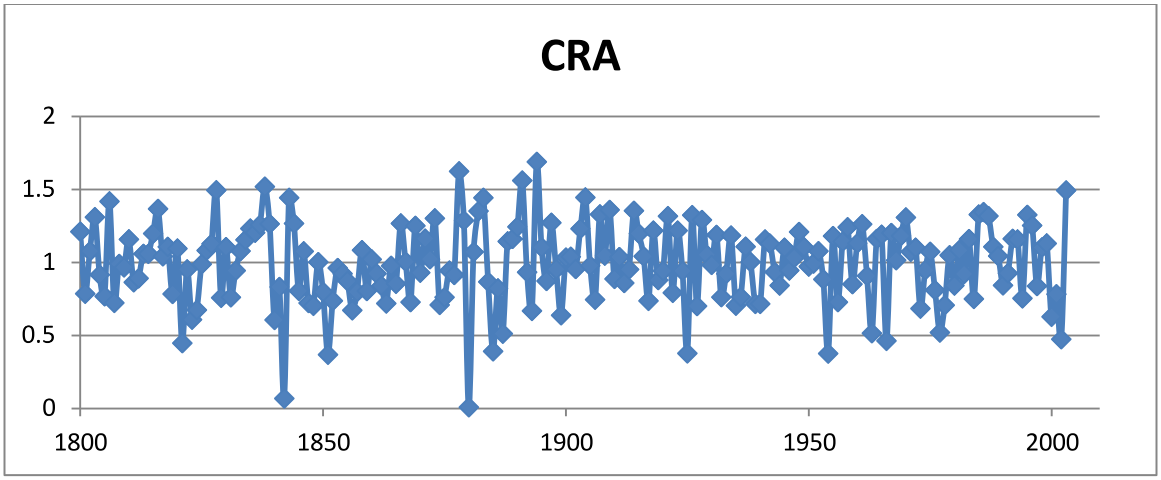
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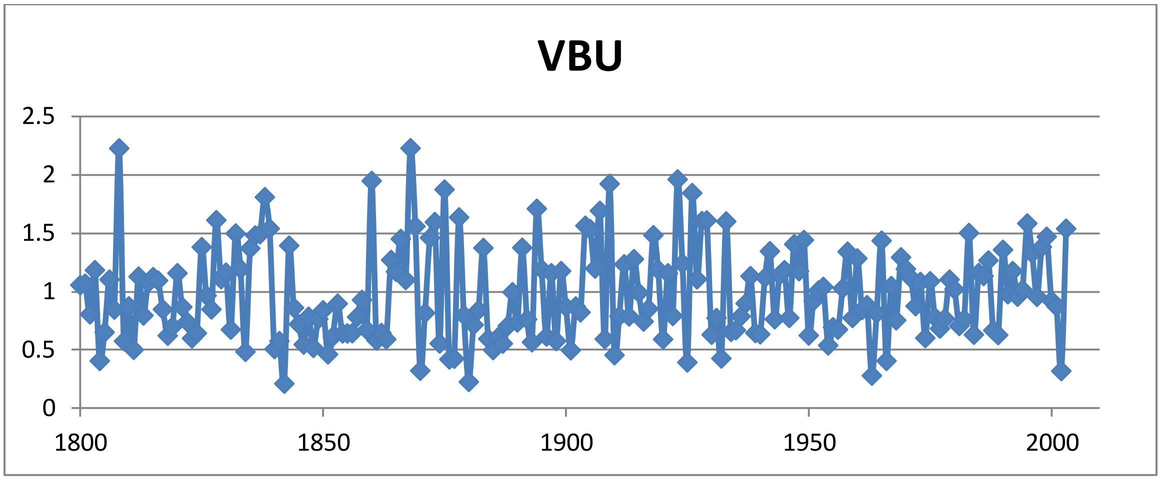
1850
1900
1950
2000


VBU
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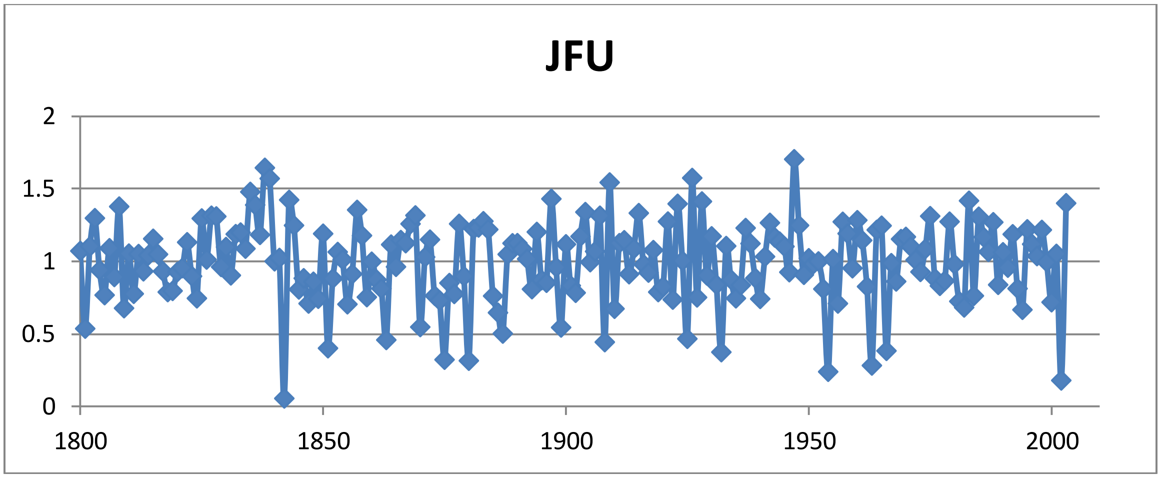
1800
1850
1900
1950
2000


JFU
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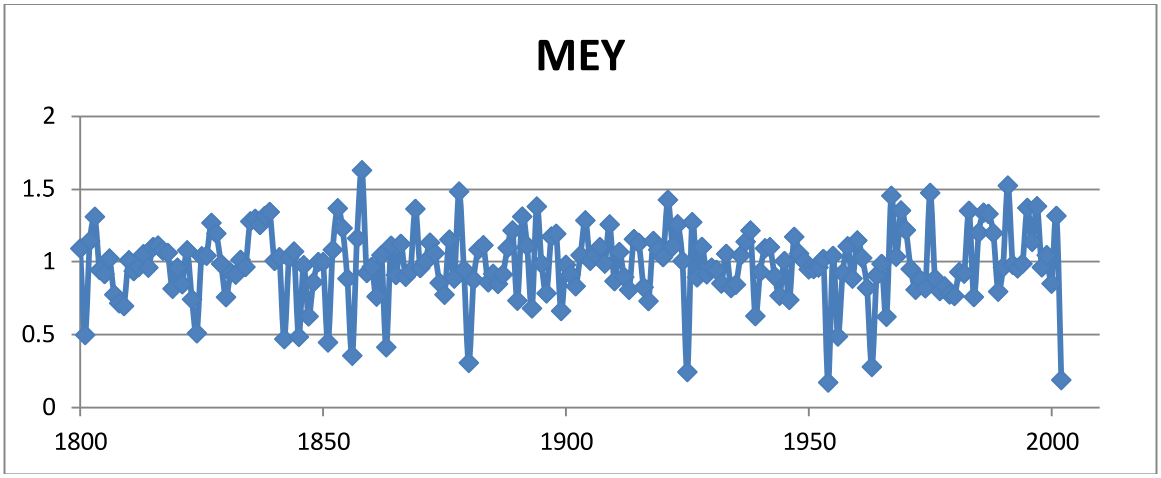
1850
1900
1950
2000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1
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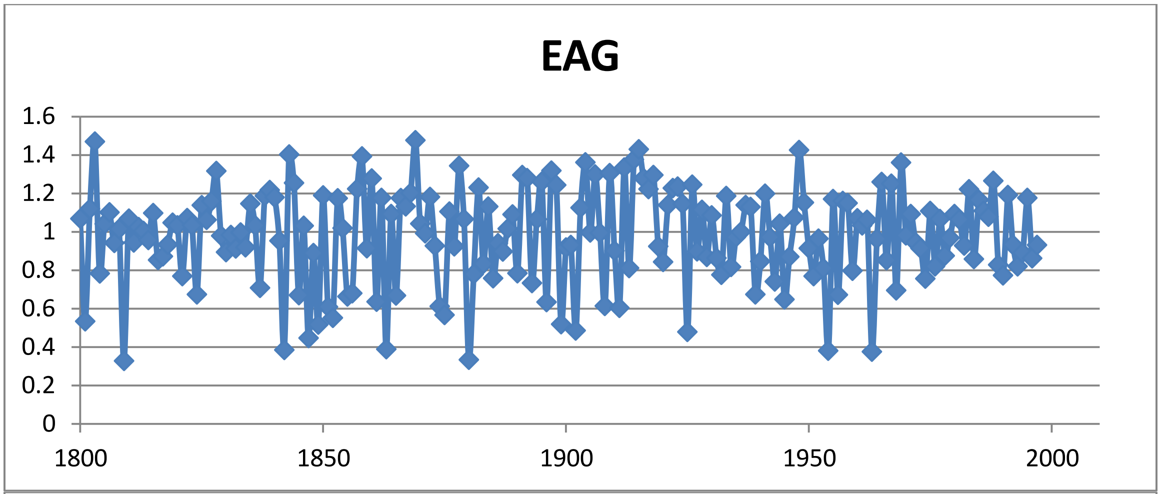
1800
1850
1900
1950
2000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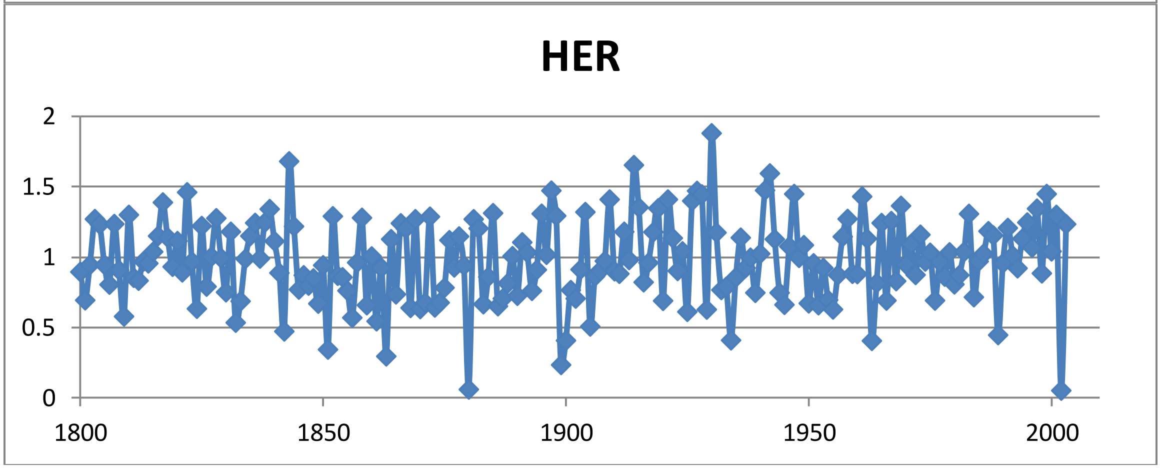
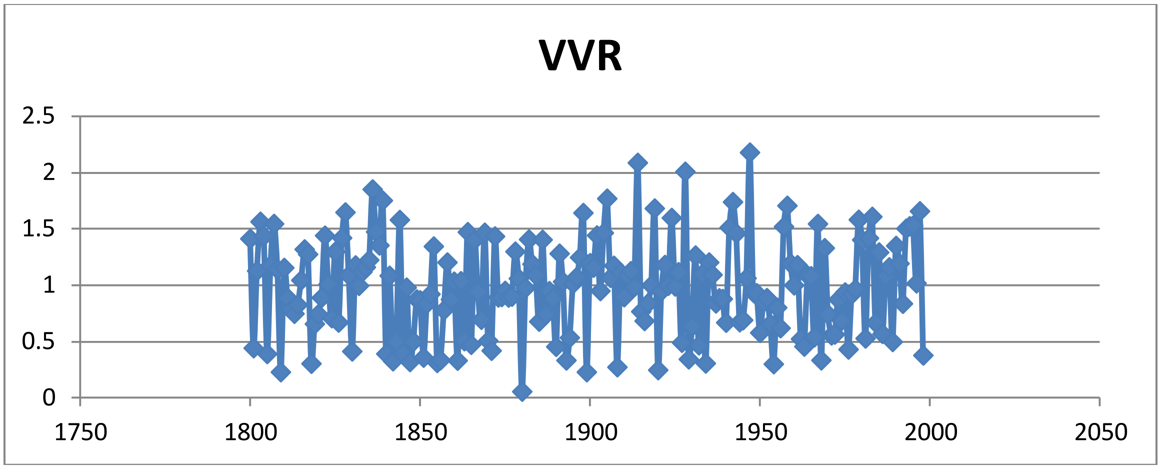
0.4
0.2
0
1800
1850
1900
1950
2000


HER
2
1.5
1
0.5
0
1800
1850
1900
1950
2000


VVR
2.5
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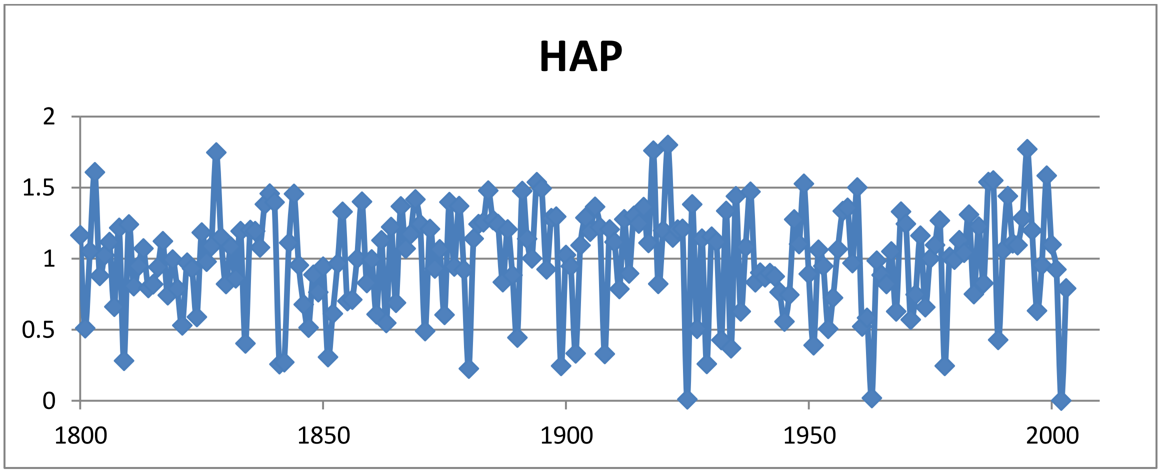
1.5
1
0.5
0
1750
1800
1850
1900
1950
2000
2050


HAP
2
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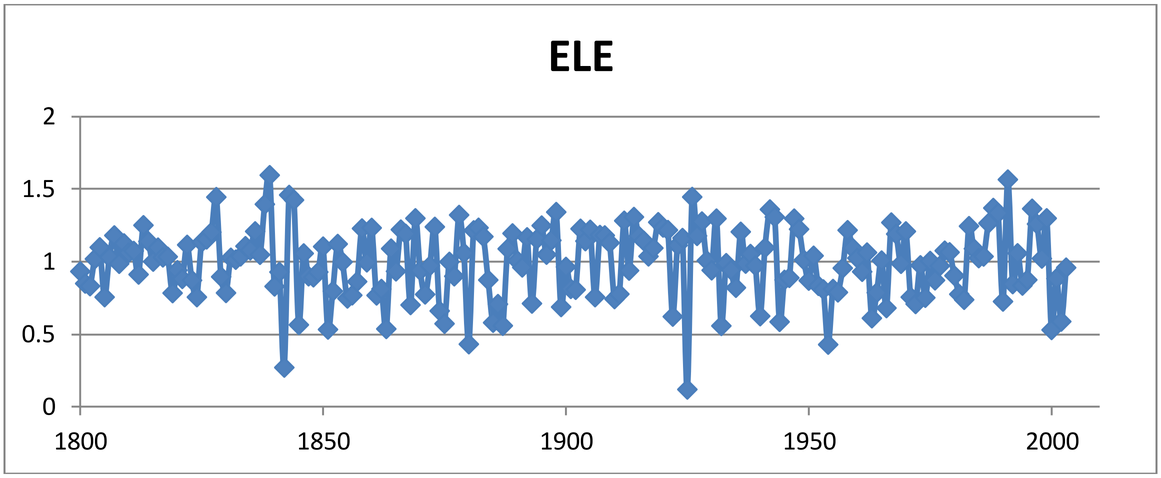
1800
1850
1900
1950
2000


ELE
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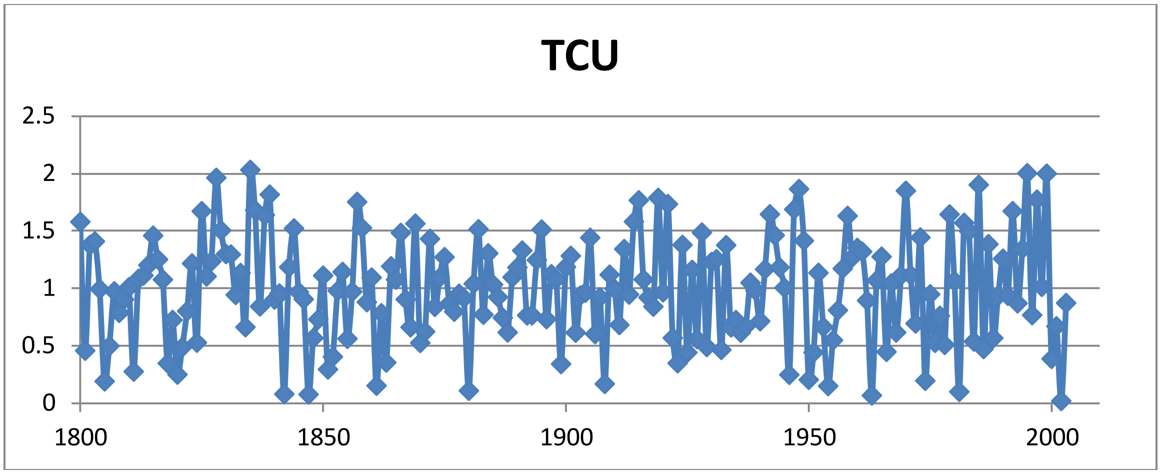
1
0.5
0
1800
1850
1900
1950
2000


TCU
2.5
2
1.5
1
0.5
0
1800
1850
1900
1950
2000

List of Climatic Pointer Years (both negative and positive) by sites

Highlighted years represent negative CPYs followed immediately by positive CPYs
*Years represent years with historically large snowstorms

Western Slope sites

PUM

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1798	1442	1498	1350
1845	1475	1543	1357
1851	1506	1582	1494
	1542	1655	1501
	1584	1669	1521
	1591	1962	1586
	1598		1589
	1607		1596
	1634		1599
	1654		1633
	1667		1655
	1685		1684
	1686		1702
	1692		1705
	1714		1734
	1736		1749
	1748		1797
	1759		1823
	1825		1843
	1855		1852
	1861		1853
	1871		1862
	1879		1880
	1896		1903
	1902		1909
	1934		1952
	1954		1965
	1964		
	1977		
	1994		

HOT

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1798	1622	1621	1599
1851	1634	1633	1683
1871	1675	1853	1694
	1714		1701
	1736		1720
	1756		1797
	1789		1799
	1807		1872
	1845		1897
	1855		1912
	1874		1921*
	1896		1962
	1898		
	1954		
	1961		

VAS

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1851		1491	1484
		1498	1502
		1549	1621
		1843	1673
			1683
			1712
			1734
			1746
			1802
			1853
			1897
			1912
			1921*
			1957*

GMR

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1531	1399	1498	1391
1664	1411	1521	1401
1798	1413	1768	1414
1851	1423		1420
1954	1430		1426
	1436		1429
	1469		1443
	1472		1446
	1488		1470
	1493		1494
	1496		1529
	1522		1530
	1544		1533
	1551		1549
	1558		1560
	1584		1575
	1600		1578
	1646		1582
	1654		1621
	1671		1632
	1685		1651
	1727		1655
	1748		1665
	1750		1678
	1750		1683
	1759		1712
	1765		1726
	1767		1790
	1770		1799
	1777		1831
	1789		1873
	1807		1888
	1830		1900*
	1842		1921*
	1845		1956
	1874		1970
	1887		1978
	1902		1996

	1919		
	1963		
	1977		
	1987		
	1994		
	1998		

DIL

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1584	1506	1372	1443
1609	1528	1610	1490
1685	1531	1621	1498
1845	1542	1633	1507
1851	1545	1843	1529
1883	1558	1853	1530
1887	1559	1921	1540
1898	1575	1965	1543
1902	1580		1546
1954	1598		1560
2002	1600		1565
	1620		1568
	1654		1582
	1671		1583
	1700		1586
	1704		1599
	1714		1667
	1722		1673
	1729		1698
	1730		1705
	1748		1720
	1756		1731
	1763		1746
	1770		1757
	1777		1790
	1786		1796
	1789		1823
	1795		1826
	1798		1831
	1824		1849
	1830		1895
	1833		1900
	1842		1903
	1847		1907
	1868		1912
	1871		1917
	1908		1930
	1919		1933
	1922		1947
	1932		1956
	1959		1962
	1964		1969
	1981		1996
	1994		2000
	1998		2003

Front Range sites

OWU

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1820	1522		1523
1879	1550		1549
1954	1579		1589
2002	1591		1599
	1597		1621
	1622		1647
	1645		1771
	1682		1787
	1708		1862
	1789		1878
	1805		1881
	1840		1920
	1861		1923
	1880		1952
	1893		1965
	1910		2001
	1919		
	1925		
	1932		
	1940		
	1966		
	1972		
	2000		

RUS

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1522	1438	1799	1443
1620	1483	1803	1529
1627	1538	2001	1539
1653	1551		1549
1685	1567		1589
1781	1576		1621
1851	1579		1628
1919	1584		1644
	1597		1651
	1601		1655
	1611		1683
	1622		1684
	1648		1702
	1654		1726
	1682		1734
	1696		1743
	1708		1761
	1735		1808
	1748		1825
	1763		1843
	1775		1844
	1789		1850
	1798		1853
	1801		1903
	1804		1920
	1809		1921*
	1820		1926
	1824		1941

	1842		1986*
	1845		
	1861		
	1874		
	1880		
	1893		
	1899		
	1902		
	1910		
	1922		
	1925		
	1939		
	1954		
	1963		
	1985		
	2000		

BEN

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1522	1448	1529	1472
1552	1481	1539	1491
1567	1500	1575	1494
1648	1508	1578	1501
1654	1528	1585	1507
1685	1573	1603	1523
1809	1576	1655	1588
1824	1579	1743	1629
1872	1587	1761	1647
1925	1591	1799	1651
1954	1601	1803	1652
2000	1604	1843	1673
	1620	1853	1680
	1627	2001	1683
	1645		1687
	1653		1688
	1682		1692
	1686		1705
	1696		1746
	1717		1753
	1724		1779
	1729		1790
	1735		1811
	1748		1822
	1759		1825
	1789		1878
	1798		1903
	1801		1921*
	1824		1923
	1851		1926
	1853		1937
	1861		1965
	1880		1975
	1893		1986 *
	1902		
	1910		
	1919		
	1922		

	1939		
	1946		
	1963		
	1966		
	1976		

DMU

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1576	1566	1549	1565
1620	1584	1621	1578
1654	1601	1710	1599
1709	1622		1610
1805	1627		1618
1842	1712		1652
1861	1729		1702
1919	1748		1726
1925	1761		1743
1946	1789		1803
1954	1820		1806
	1851		1819
	1875		1843
	1893		1876
	1902		1889
	1911		1894*
	1922		1903
	1963		1907
	1966		1921*
	1968		1923
	1977		1928
	1989		1931
			1975
			1990*
			1995*

BTU

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1522	1542	1521	1520
1543	1544	1570	1541
1552	1558	1613	1553
1568	1563	1621	1565
1579	1576	1644	1578
1591	1580	1647	1583
1620	1598	1680	1589
1622	1601	1683	1596
1645	1611	1731	1600
1679	1612	1787	1602
1685	1625	1803	1610
1709	1636	1806	1619
1723	1648	1844	1624
1736	1667	1869	1655
1780	1680	1872	1687
1789	1684	1878	1690
1805	1689	1881	1695
1842	1697	1920	1696
1880	1703	1947*	1702
1887	1711	1975	1705
1925	1717	1983 *	1710

1932	1718		*1719*
1946	1729		1738
1954	1730		1741
	1734		1778
	1739		1822
	1750		1839
	1758		1849
	1798		1895
	1820		1909
	1840		1926
	1846		1930
	1847		1952
	1851		1961
	1861		1967
	1870		1979
	1871		1997 *
	1874		2003 *
	1879		
	1899		
	1919		
	1922		
	1929		
	1937		
	1940		
	1963		
	1966		
	1974		
	1977		
	1981		
	2000		

JAM

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1360	1359	1361	1364
1374	1380	1372	1414
1522		1549	1437
1602		1843	1472
1620		1858	1497
1654		1975	1498
1700			1546
1709			1571
1842			1575
1954			1583
			1603
			1653
			1655
			1702
			1734
			1747
			1761
			1773
			1776
			1800
			1803
			1878
			1883

			1952

PTP

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1307	1233	1316	1253
	1251	1325	1259
	1258		1362
	1314		1412
	1318		1414
	1340		1485
	1354		1497
	1360		1507
	1399		1510
	1487		1610
	1509		1655
	1538		1707
	1551		1710
	1601		1898
	1631		1926
	1654		1937
	1708		
	1709		
	1824		
	1845		
	1868		
	1925		
	1939		
	1954		

JOP

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1620	1616	1975	1618
1954	1654		1684
	1685		1734
	1703		1761
	1709		1822
	1786		1858
	1797		1878
	1842		1918
	1851		1923
	1880		1961
	1919		1967
	1925		1972
	1939		1994
	1977		

BLD

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1702	1698	1878	1705
1841	1721	1882	1738
1880	1735		1761
	1750		1764
	1896		1864
	1925		1894*
	1932		1923
	1946		1999*
	1954		

ELU

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1620	1550		1578
1679	1601		1621
1685	1611		1625
1842	1616		1655
1925	1623		1680
	1631		1683
	1645		1698
	1667		1873
	1709		1878
	1789		
	1845		
	1880		
	1932		
	2000		

CRA

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1620	1576	1610	1578
1679	1579	1652	1589
1685	1590	1683	1603
1739	1591	1710	1621
1758	1601	1738	1629
1842	1611		1633
1880	1612		1644
	1645		1647
	1650		1734
	1654		1744
	1667		1761
	1668		1787
	1698		1843
	1703		1849
	1709		1878
	1711		1882
	1735		1883
	1767		1894*
	1789		1926
	1821		2003*
	1851		
	1885		
	1893		
	1925		
	1954		
	1966		
	2002		

VBU

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1576	1570	1618	
1604	1583	1677	
1612	1593	1683	
1620	1639	1705	
1634	1645	1720	
1679	1653	1754	
1721	1654	1787	
1757	1661	1808	

1842	1668	1843	
1870	1684	1860	
1880	1689	1875	
1925	1698	1878	
1963	1704	1883	
2002	1706	1894*	
	1762	1909	
	1765	1923	
	1770	1933	
	1772	1965	
	1785	2003*	
	1789		
	1795		
	1804		
	1809		
	1834		
	1840		
	1874		
	1876		
	1877		
	1893		
	1896		
	1901		
	1910		
	1920		
	1932		
	1966		

JFU

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1488	1495	1720	1487
1496	1542		1494
1576	1544		1536
1616	1645		1549
1667	1654		1575
1711	1679		1578
1789	1685		1621
1842	1722		1629
1880	1733		1644
1954	1739		1652
1963	1748		1710
2002	1767		1737
	1770		1746
	1801		1761
	1851		1768
	1863		1787
	1870		1803
	1875		1843
	1887		1844
	1899		1850
	1908		1897
	1925		1909
	1932		1926
	1966		1933
			1964
			1965
			1983*

			2003*

MEY

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1654	1601		1603
1856	1616		1652
1880	1620		1655
1925	1631		1683
1954	1703		1740
1963	1742		1761
2002	1748		1926
	1756		1955
	1767		1975
	1775		1991
	1801		2001
	1824		
	1842		
	1851		
	1863		

EAG

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
	1471	1652	1465
	1496	1683	1496
	1509	1710	1473
	1522		1498
	1524		1523
	1538		1543
	1552		1647
	1558		1688
	1584		1707
	1609		1739
	1645		1773
	1648		1803
	1650		1844
	1654		1850
	1666		1853
	1675		1882
	1679		1909
	1690		
	1703		
	1709		
	1711		
	1715		
	1725		
	1748		
	1754		
	1767		
	1789		
	1798		
	1801		
	1809		
	1842		
	1852		
	1863		
	1880		
	1896		

	1902		
	1925		
	1954		
	1963		

HER

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1616	1563	1613	1565
1654	1598	1655	1580
1679	1612	1683	1585
1880	1631		1588
2002	1645		1596
	1663		1632
	1675		1661
	1682		1678
	1685		1700
	1730		1706
	1789		1710
	1842		1741
	1851		1746
	1899		1822
	1900		1831
	1905		1843
	1929		1852
	1934		1858
	1963		1869
	1989		1872
			1881
			1885
			1898
			1904
			1930
			1962
			2003*

VVR

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1552	1534	1539	1551
1559	1540	1557	1560
1597	1543	1620	1562
1631	1553	1667	1565
1645	1563	1680	1570
1679	1572	1683	1580
1685	1579	1686	1592
1715	1584	1703	1596
1722	1587	1706	1624
1744	1591	1713	1629
1754	1598	1735	1637
1780	1607	1807	1652
1809	1616	1844	1655
1818	1621	1854	1677
1880	1622	1872	1692
1899	1638	1919	1695
1908	1639	1928	1719
1920	1650	1947*	1743
	1654		1746

	1666		1753
	1669		1785
	1682		1799
	1694		1800
	1701		1803
	1705		1839
	1711		1849
	1730		1858
	1736		1864
	1775		1866
	1786		1869
	1789		1878
	1801		1882
	1805		1886
	1826		1891
	1830		1892
	1840		1898
	1842		1942
	1845		1952
	1847		1969
	1851		1979
	1855		1983*
	1856		1997*
	1861		
	1865		
	1871		
	1890		
	1893		
	1927		
	1929		
	1932		
	1934		
	1945		
	1954		
	1962		
	1963		
	1968		
	1976		
	1981		
	1986		
	1989		
	1998		

HAP

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1675	1632	1683	1624
1880	1645	1743	1644
1899	1650		1647
1908	1654		1692
1925	1670		1728
1929	1682		1734
1963	1690		1746
1978	1691		1747
2002	1703		1753
	1729		1761
	1737		1773
	1745		1780

	1748		1799
	1754		1803
	1763		1828
	1767		1840
	1775		1844
	1789		1854
	1801		1878
	1809		1921*
	1834		1930
	1841		1933
	1842		1935
	1851		1938
	1871		1949
	1890		1952
	1902		1960
	1932		1964
	1934		1988*
	1951		1995*
	1954		1999*
	1971		2003*
	1989		
	1997		

ELE

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1675	1509	1652	1523
	1522		1565
	1524		1572
	1558		1575
	1573		1583
	1584		1655
	1591		1678
	1598		1680
	1601		1683
	1609		1689
	1616		1701
	1625		1710
	1631		1746
	1645		1803
	1650		1926
	1654		1957*
	1659		
	1666		
	1682		
	1705		
	1709		
	1729		
	1745		
	1748		
	1789		
	1801		
	1851		
	1880		
	1889		
	1902		
	1908		
	1951		

	1963		
	1978		

TCU

Strong Negative CPY	Moderate Negative CPY	Strong Positive CPY	Moderate Positive CPY
1645	1638	1635	1640
1654	1650	1680	1647
1659	1676	1683	1652
1682	1679	1698	1655
1707	1684	1754	1660
1756	1685	1761	1677
1805	1699	1850	1695
1842	1709	1869	1702
1847	1729	1882	1706
1861	1741	1924	1710
1880	1748	1948	1728
1899	1752	1952	1739
1908	1789	1970	1774
1946	1801	1973	1835
1950	1811	1979	1839
1954	1818	1982*	1844
1965	1824	1999*	1853
1974	1851		1854
1981	1852		1857
2002	1855		1872
	1863		1901
	1922		1905
	1923		1909
	1929		1919
	1932		1921*
	1951		1928
	1978		1933
	1984		1985
	1986		1995*
	2000		1997*
			2003*

Statistically Significant Years at Each Instrument Weather Observation Station and the Overall Amount of Precipitation for Each Year
(source: Colorado Climate Center 2011)

Green highlight=years identical to other stations Blue highlight=years identified within 1 year of other stations

Dillon	Precip in Inches	Georgetown	Precip in Inches	Cabin Creek	Precip in Inches
1926	23.55	🟦 1913	23.56	🟩 1969	27.85
1927	22.83	🟩 1957	22.46	🟩 1983	24.49
🟦 1934	20.65	🟩 1961	21.67	🟩 1984	24.57
🟦 1935	21.6	🟩 1965	21.16	🟩 1999	28.8
1936	26.25	🟩 1969	25.45	🟩 2006	26.53
🟩 1938	20.73	🟩 1995	24.54	🟦 2008	24.12
🟩 1945	26.23	🟩 1997	21.56		
🟩 1947	23.96	🟩 2006	20.47		
🟩 1951	21.79				
🟩 1957	21.13				
🟦 1959	20.11				
🟩 1983	20.91				

Fort Collins	Precip in Inches	Kassler	Precip in Inches	CO Springs	Precip in Inches
1900	19.22	🟦 1933	22.44	🟩 1957	24.81
1901	21.32	🟩 1938	24.56	🟩 1965	25.34
1905	19.84	1941	24.54	🟩 1969	20.96
1906	19.88	1942	25.95	🟦 1972	20.02
🟦 1912	19.6	🟩 1947	24.39	1976	20.33
1915	22.36	🟩 1961	21.56	🟩 1982	21.92
1918	21.75	🟩 1965	22.61	🟩 1984	20.99
1923	27.57	🟩 1967	23.81	🟦 1994	21.16
🟩 1938	19.74	🟩 1969	28.11	🟩 1995	22.25
🟩 1945	21.27	🟦 1973	25.11	🟩 1997	22.76
🟩 1951	22.58	🟩 1979	21.99	2004	21.13
🟩 1957	19.54	🟩 1983	23.79		
🟩 1961	28.28	1987	23.03		
🟩 1967	21.29	🟩 1995	22.25		
🟩 1979	22.13	🟩 1997	22.77		
🟩 1982	21.69				
🟩 1983	19.46				
🟩 1995	20.15				
🟩 1997	25.23				
🟩 1999	20.68				
🟦 2009	21.87				