Anacortes Climate History

Introduction

This report summarizes the history of temperatures and rainfall in Anacortes for the past 120 years, from January 1, 1900 through December 31, 2019. Its purpose is to provide a climate baseline for the Fidalgo Forest Stewards (FFS). This volunteer "citizen science" group has a long term forest monitoring program underway in the Anacortes Community Forest Lands (ACFL) aimed at understanding the effects of climate change on the forest, with the expectation that monitoring will continue many decades into the future. To assess the relationship between climate change and changes that are observed in the forest over such a long period of time, it will be helpful to understand as precisely as possible how the climate in Anacortes changes in future decades. The FFS plans to continue to record local weather data for this purpose and to periodically update the history for future interpretation. The history presented in this report will provide a basis for comparison of future changes and variations with those that occurred from the early 1900's to the present, a period during which both global and local temperatures have been increasing.

Climate change may already be making an impact on the ACFL. In the Puget Sound region as a whole, historical temperatures have risen significantly, and in recent years, summers have been considerably drier than normal. During this same time, local observers have seen a decline in the health of the western red cedars in the ACFL, with large numbers of trees having died in the last few years. According to the University of Washington Climate Impacts Group[1], most climate change models predict that the summers in the Puget Sound area will be drier than in the past. If the drier summer weather pattern does continue, a significant reduction of the cedar population may prove to be one of the lasting changes the forest will experience as a result of climate change.

Data Sources

Most of the data used in this study was downloaded from NOAA's ncdc.noaa.gov website. This site provides convenient downloadable access to a very large database of weather data for thousands of locations across the U.S. For Anacortes, the primary source of data in the NOAA database, covering the period September 1892 through May 2016, is the National Weather Service (NWS) weather station that was located at the Mt Erie fire station. The Mt Erie station was one of many Cooperative Observer Program (COOP) stations set up by the NWS and operated by volunteer organizations or individuals. The COOP program started when the NWS was established in 1890 and is still continuing. The COOP sites report daily maximum and minimum temperatures, and total daily precipitation. Records from the Anacortes station during the 1890's are highly irregular, so a complete daily history is not available for those years. The 1900 starting year for this compilation was chosen in part because of the irregular reporting in the earlier years as well as for convenience in organizing the data by decades.

Unfortunately, the NWS closed the Mt Erie station, as well as a number of others, in 2016. Data for the remainder of the period comes from other sources. Precipitation data from the Community Cooperative Rain Hail and Snow Network (CoCoRaHS) is also stored on the ncdc.noaa.gov website. CoCoRaHS is a separate volunteer organization sponsored by NOAA and the National Science Foundation (NSF). Volunteers report precipitation measurements from manual rain gauges on a daily basis. There are several CoCoRaHS stations in Anacortes, but because they are mostly operated by individuals or families, it is very difficult for them to report every day of every year. One of the Anacortes stations, located at the Vince Streano residence in Dewey Beach on the south side of Fidalgo Island, has a far more complete record than any of the other stations, but it does not cover 100% of the days. To construct a complete daily record of rainfall from June 2016 through the end of 2019, an average of Mr Streano's data and the data from three other CoCoRaHS stations in Anacortes was used.

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[1] State of Knowledge: Climate Change in Puget Sound. Mauger et al, Climate Impacts Group, University of Washington, 2015

Temperature data from Mr Streano's electronic weather station was used to complete the daily minimum and maximum temperature time series after the closure of the COOP station.

While the data from the above sources covers the vast majority of days over the 120 year period, there are some significant gaps in the COOP station data. The largest gaps are in the period from May 1993 to June 1994 and, for temperature data only, from 1900 to 1904. Although longer term averages that could be taken in the absence of that data might still provide a reasonable representation of the climate during a long period of time, a proxy was used to fill in the missing data. It was assumed that the proxy approach would capture any significant variations from normal that may have occurred during the gap periods, as well as providing a more complete graphical picture of the history.

The proxy is another weather station in the area, near Olga on Orcas Island, which, like Anacortes, sits on the edge of the Olympic Rain Shadow. The climate at that station has historically been very similar to Anacortes, with annual rainfall slightly higher and average temperatures slightly lower than the Anacortes averages. The proxy data was used for monthly rainfall totals and monthly average high and low temperatures. Monthly averages were calculated by adjusting the Olga data by the average difference between the Fidalgo monthly averages and the corresponding Olga values published by the Western Regional Climate Center (WRCC).[2] Additional smaller gaps in the data were filled in the same manner.

Although this compilation of Anacortes weather history has some inconsistencies and imperfections as highlighted above, as well as other possible errors, it should provide a reasonable picture for the purpose of describing climate change in Anacortes over the 120 year period. A comparison with the WRCC averages suggests that these imperfections do not introduce any significant differences.

Historical Temperature and Rainfall Averages

	WRCC Rainfall Averages*, Inches		**WRCC Temperature Averages*, Deg F**				**Anacortes Averages, This Compilation**		
			Anacortes		**Orcas**			**Temperatures**	
	Anacortes	**Orcas**	**High**	**Low**	**High**	**Low**	**Rainfall**	**High**	Low
January	3.56	3.91	45.1	34.8	44.2	34.5	3.47	45.3	34.8
February	2.48	2.79	48.6	36.0	47.3	35.8	2.46	48.5	36.0
March	2.31	2.41	52.4	38.2	51.1	37.6	2.33	52.4	38.2
April	1.83	1.89	57.8	41.6	56.6	40.6	1.82	57.8	41.6
May	1.57	1.60	63.6	46.0	62.1	44.5	1.57	63.6	46.0
June	1.37	1.33	68.2	49.8	66.4	48.0	1.32	68.3	49.8
July	.80	.81	72.2	52.0	70.0	50.0	.78	72.5	52.0
August	1.00	1.02	72.2	52.2	69.7	50.3	.94	72.3	52.2
September	1.53	1.68	67.5	49.6	65.4	48.1	1.49	67.6	49.6
October	2.64	2.93	59.2	44.7	57.5	44.0	2.68	59.3	44.7
November	3.84	4.24	51.0	39.6	49.8	39.1	3.76	51.2	39.6
December	3.79	4.35	46.3	36.0	45.6	36.0	3.74	46.4	36.0
Totals/Averages	26.72	28.96	58.7	43.2	57.1	42.4	26.36	58.8	43.4

* *WRCC Averages are for the entire history of COOP station data*

The daily temperature and precipitation records and associated calculations are currently in Excel spreadsheet format, to be stored in the FFS database for future reference.

[2] *Western Regional Climate Center website wrcc.dri.edu. Averages from NOAA COOP stations.*

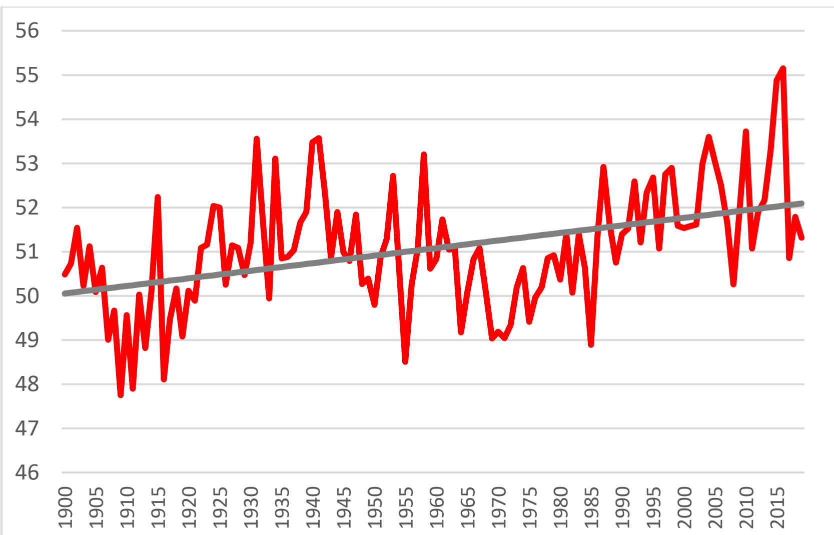
Analysis

Temperature

Not surprisingly, temperatures in Anacortes have followed the overall upward trend observed globally and within the Puget Sound region. The annual temperatures in the graph below represent the average of daily high and low temperatures for each year, an approximation of the actual mean temperature. While year to year averages have swung by as much as 4 degrees up or down, and downward trends due to natural cycles and other factors appear periodically, the long-term trend is clearly upwards. The linear regression fit of the individual yearly average temperatures has a slope of .017 degrees per year, about 2 degrees over the 120 year period.

Temperatures in recent decades have been moderately higher than at any other time in the last 120 years. There were several exceptionally warm years in the 1930's through the 1960's, but the 1990's, 2000's and 2010s are the three warmest decades in the history, all with temperatures averaging over 52°, and the last decade, the 2010's, was the warmest of the three. The highest average annual temperatures were in 2015 and 2016, 54.9° and 55.2° respectively. Both average highs and average lows for the decade were higher than in any previous decade. There have been 21 years with average temperatures below 50°, the last of which was in 1986.

Average Annual Mean Temperatures, Degrees F



There are three broad segments in the temperature data, which also follow global trends. The first segment is in the earlier years, roughly between the early 1900's and the early 1940's. This time period corresponds to the time frame of the extensively studied "Early Twentieth Century Warming" (ETCW)[3] a relatively long period during which global temperatures increased more rapidly than would be expected solely as a result of greenhouse gas emissions. Following the ETCW period, there is a shorter period, between the mid 1940's and the mid 1970's, of slightly falling temperatures. This too follows a global pattern, the "Mid-Century Cooling," which has also been extensively studied.[4] During the third period, from the mid-1970's onward, the trend has been steadily upward.

A ten-year moving average helps to show the sub-trends as well as the overall trend more clearly, by smoothing out the year to year variations. The moving average represents the recent "climate" in each year as the average

[3] The Early Twentieth Century Warming, Anomalies, Causes and Consequences. Hegerl et al, Wiley Online Library 25 April 2018

[4] https://www.climatecentral.org/blogs/was-mid-century-cooling-caused-by-the-oceans-dont-ask

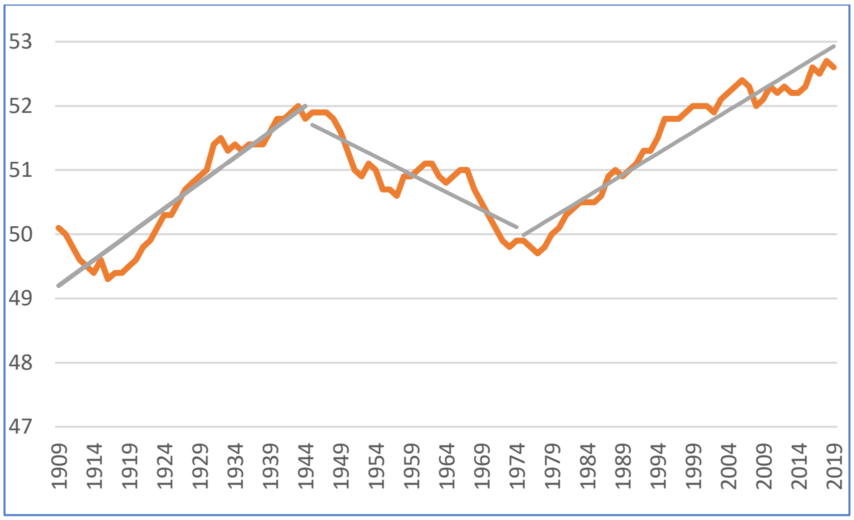
of that year and the nine previous years. The sub-trends are illustrated in the graph below by regression lines based on three separation regressions of the 10 year moving averages:

Temperature Sub-Trends

Years	Period	Slope*
1900-1944	ETCW	.08
1945-1974	Mid-Century Cooling	-.06
1975-2019	Past 45 Years	.07

* *Slope of regression line based on the moving averages*

Average Mean Temperature: Ten Year Moving Average, Degrees F



Rainfall

According to the University of Washington's Climate Impact Group report cited above, "there has been no discernible long-term trend in precipitation for the Puget Sound region" although "spring precipitation is increasing." The Anacortes history may differ in this respect from the overall Puget Sound history, as there has been a moderate increase in rainfall over the past 120 years which is clearly evident in the data.

One simple way to see the change in rainfall over the 120 years is to look at the averages for two climate intervals of 60 years. The averages for the second sixty-year period are higher for all four seasons as well as for total annual rainfall.

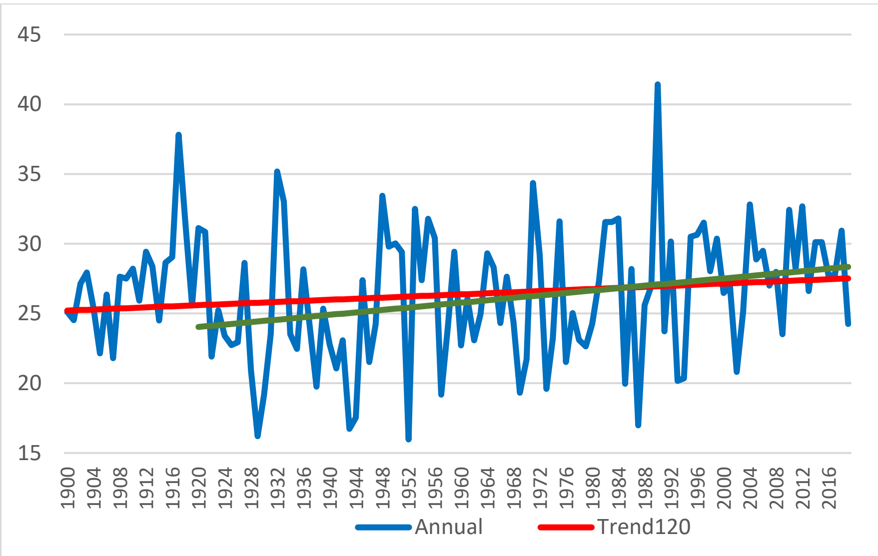
Sixty Year Climate Averages

	1900 - 1959	**1960 - 2019**	**% Increase**
Annual Rainfall, Inches	25.84	26.88	4.05%
Spring (Mar-May) Rainfall	5.45	6.00	10.11%
Summer (Jun-Aug) Rainfall	2.94	3.15	7.37%
Fall Rainfall (Sep-Nov)	7.83	8.03	2.56%
Winter Rainfall (Dec-Feb)	9.63	9.71	0.81%

For the purpose of this report, seasons have been defined as three calendar months as above

Although the past 60 years have clearly had moderately more rainfall than the previous 60, any further interpretation of these results should recognize the high variability of rainfall, as a few extreme years can skew averages. The standard deviation of yearly rainfall is 4.6 inches or 17.5% of average. The largest consecutive year to year differential in rainfall was 17.7 inches, or 67% of average, and the difference between the wettest year and the driest was 25.5 inches, or 97% of average. The high degree of variability in the rainfall data can be seen clearly in the graph of annual rainfall, while the trend is less clear.

Annual Rainfall, Inches



But there is a statistical trend. The regression line for total annual rainfall has an upward slope of .19 inches every 10 years, or 2.3 inches over the 120 year period. With the influence of the unusually wet 1910's excluded, from 1920 forward, annual rainfall has increased a little more than twice as fast, at an average rate of .43 inches per decade. Seasonal trends are all upwards as well, and all of the seasonal slopes are even higher when the regression line is calculated over the past 100 years rather than from 1900.

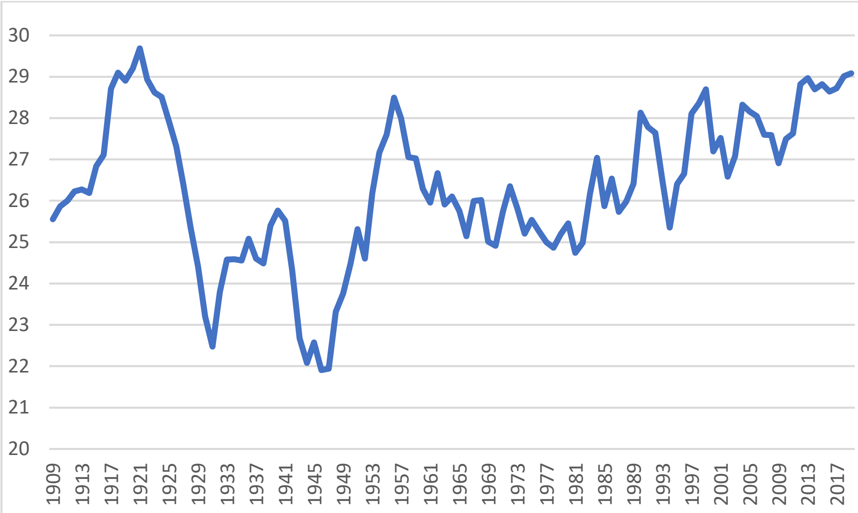
Historical Rainfall Trends

Season	Slope, Inches per Decade	
	1900-2019	1920 -2019
Spring	.089	.194
Summer	.016	.023
Fall	.067	.161
Winter	.016	.064
Full Year	.194	.435

Given the high variability of rainfall, these trends may be only marginally significant, but they do confirm that at least numerically there has been a modest increase in rainfall along with the increase in temperature over the past 120 years.

Again, the 10-year moving average illustrates longer term variations and trends a little more clearly than the annual data itself. Rainfall history does not have the same clearly defined three segments as the temperatures, but there is a period of decline in rainfall that corresponds roughly to the Mid-Century cooling, as well as a period of increasing rainfall afterward.

Annual Rainfall: Ten Year Moving Average, Inches

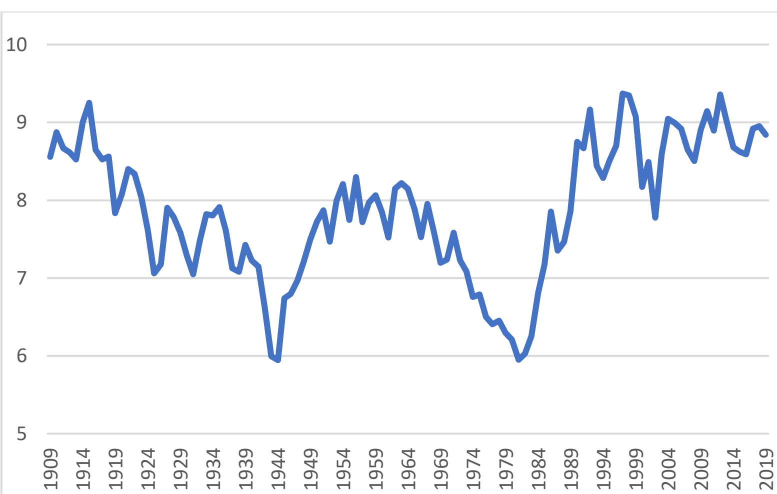


The moving average also helps to show how very large swings in precipitation can occur, even over multiple decades. Three such swings occurred during the first half of the twentieth century. The exceptional spike in the moving average in the late 1910's through mid-1920's, is the result of a very wet 13 year period when rainfall averaged over 29 inches per year. Following that period, average rainfall during the 26 years from 1922 through 1947 was only 23.5 inches. Another shorter wet period followed, with a peak in the late 1950's. Since the early 1960's, there have been no further comparably large swings in the 10 year averages. Rainfall was fairly steady through the 1960's and 70's. During the last 25 years, while the trend has been upward, there have been no exceptionally wet years.

Moving averages for individual seasons have their own unique signatures, with major swings over long periods.

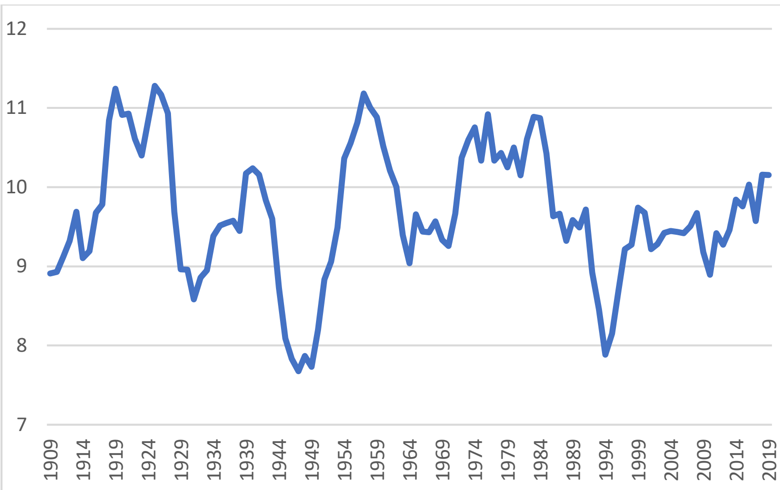
Fall history can be seen in three segments, the first, with consistently declining rainfall until the mid 1940's, followed by a "bump", where rainfall rose then fell between the late 1940's and the early 1980's, then a sharp jump upwards to higher levels that have stayed more constant over the last 30 years. Perhaps coincidentally, the three segments occur in approximately the same periods as the three temperature segments.

Fall Rainfall: Ten Year Moving Average, Inches



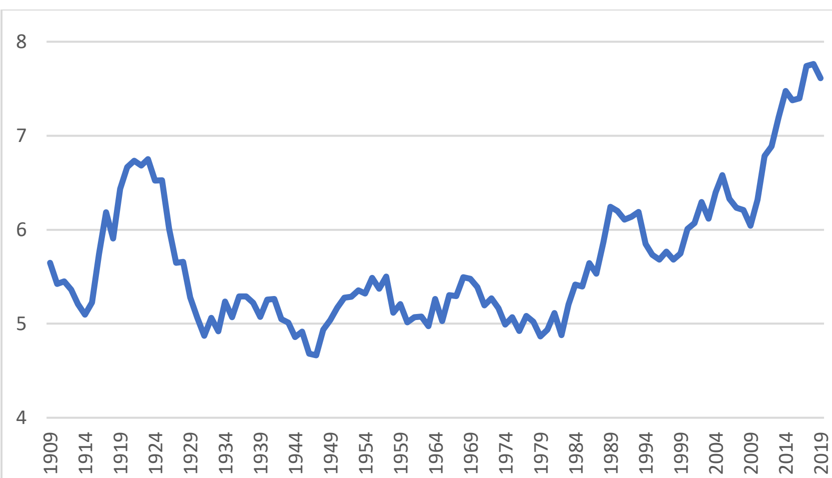
The pattern of **winter averages** appears to be more random. There have been several large swings up and down, occurring over shorter periods of time, due mainly to a few years with exceptionally wet or exceptionally dry winters during those periods. For example, the spike in the late 1910's and early 1920's is heavily influenced by the extraordinarily wet winter of 1917-1918, which saw over 21 inches of rain, and another very wet winter in 1924-1925. While there is a very slight upward trend in the 120 year regression line, it amounts to only about 0.2 inches over the 120 year period.

Winter Rainfall: Ten Year Moving Average, Inches



Consistent with the Puget Sound regional history, **spring rainfall** has increased at a faster rate than any other season since 1920, about .2 inches every 10 years. Essentially all of the increase has occurred over the last 40 years. In this case, after the early spike of the late 1910's/early 1920's the moving averages stay relatively flat for about 50 years before increasing rather dramatically from the early 1980's onward.

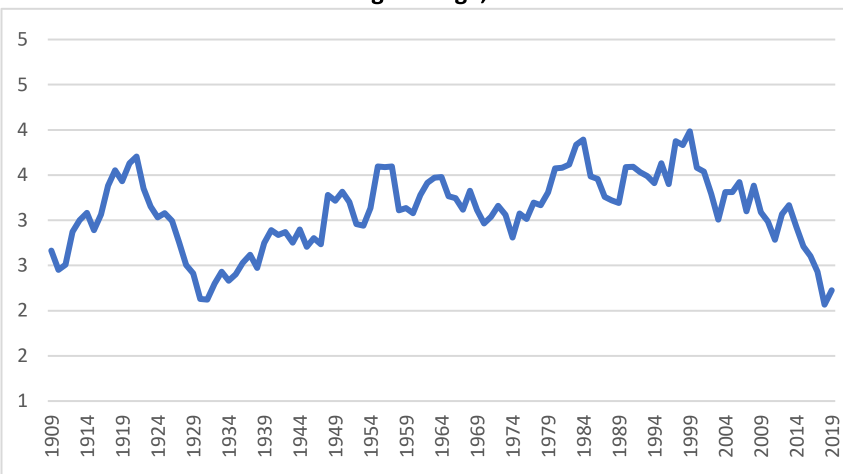
Spring Rainfall: Ten Year Moving Average, Inches



In terms of impact on future changes in the forest, the dry **summer season,** June through August, may be more significant than any other season. Although the longer-term historical trend for summer rainfall has been upward, there is a significant anomaly in recent summers that differs from the other seasonal patterns. Since the turn of the century, while annual, spring, and fall rainfall have been well above average and winter has been average, summers have become drier. Summers in the 1990's were the wettest in the history, averaging 3.98 inches over the three months, the 2000's were about average, and the 2010's were the driest, at an average of only 2.22 inches over the three months. Only one year in the 2010's, 2012, saw a wetter than average summer. Although there was a long period of drier than normal summers in the 1920's, and there have been drier individual years in the 1930's and 1940's, the four years from 2015 through 2018 are the driest four consecutive years in the history, the only four year period in the history with less than 2 inches of total summer rainfall in each year.

The 2010's were historically unique in one other respect: while summers were the driest in the history, average annual rainfall for the decade as a whole, at 29.08 inches, was the highest. The other three decades with average summer rainfall of less than three inches were all drier than average in terms of total annual rainfall.

Summer Rainfall: Ten Year Moving Average, Inches



Even with a history of 120 years, it is difficult to clearly differentiate trends related to global warming from natural variations caused by large-scale natural drivers of weather variability, some of which can be decades in length. The history speaks for itself, but it does not necessarily speak for the future.

Long term climate models do predict an increase in total annual rainfall for the Puget Sound region as a whole, as well as a decrease in summer rainfall. It is possible that the recent period of dry summers represents the beginning of the new long-term trend that is predicted by the models. It is also possible that it is just another extreme multi-year swing resulting from natural large-scale cycles. Or, it might be both. A few more decades of rainfall data may well be necessary to see more clearly how these changes play out.

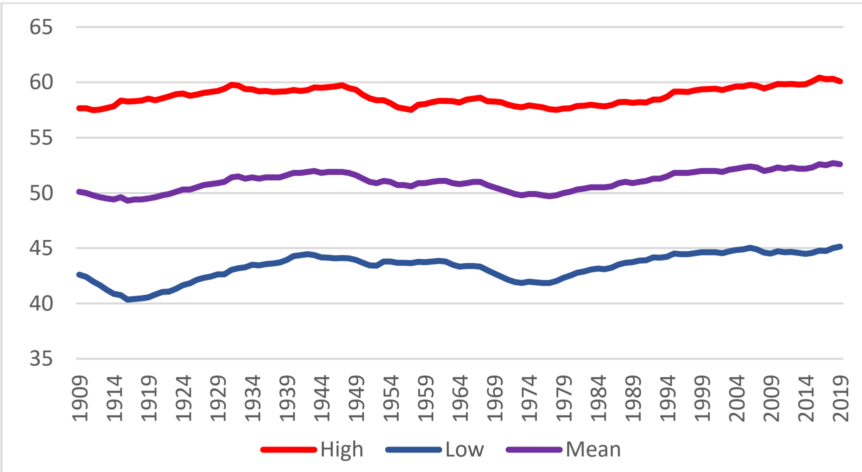
It is hoped that the Fidalgo Forest Stewards Project can make a small contribution to the understanding of Puget Sound regional climate change by continuing to maintain this record of temperatures and rainfall in the coming decades.

Jon Ranney

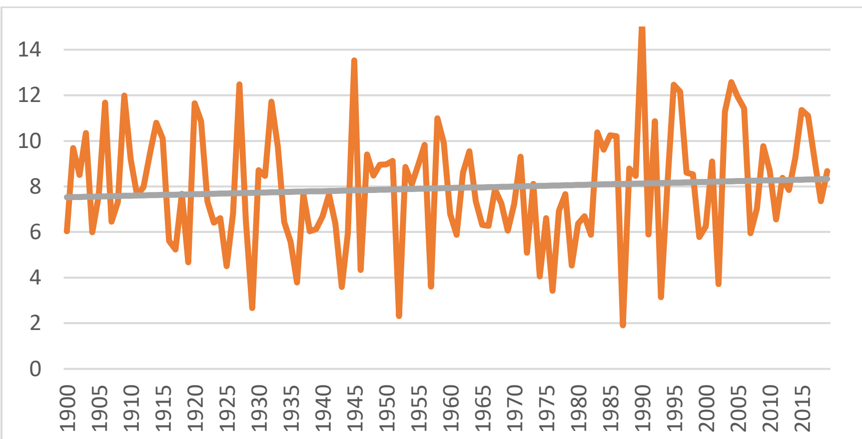
April 15, 2020

Appendix

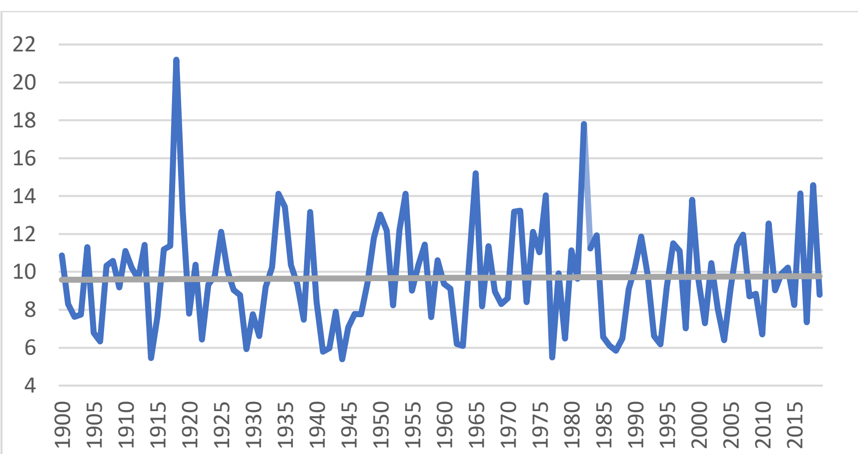
Temperatures, Ten Year Moving Average, Degrees F



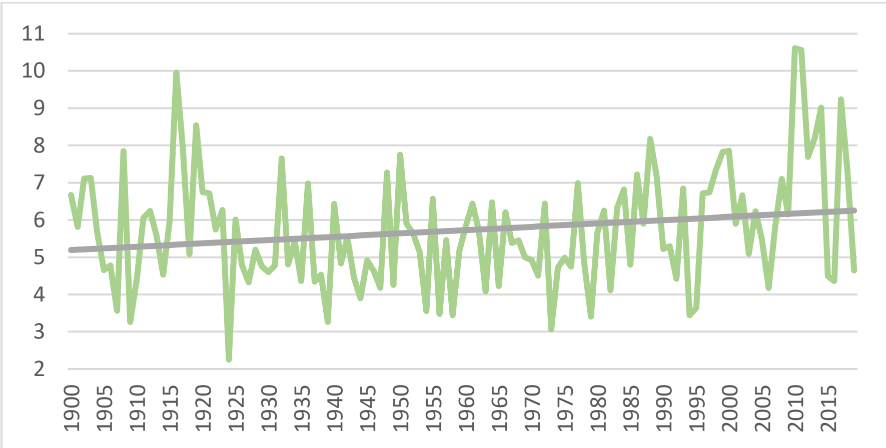
Fall (Sep – Nov) Rainfall, Inches



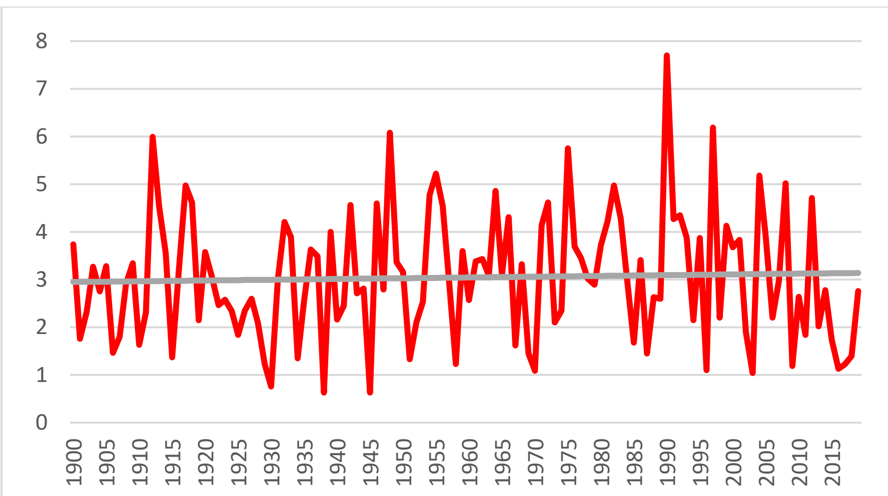
Winter (Dec-Feb) Rainfall, Inches



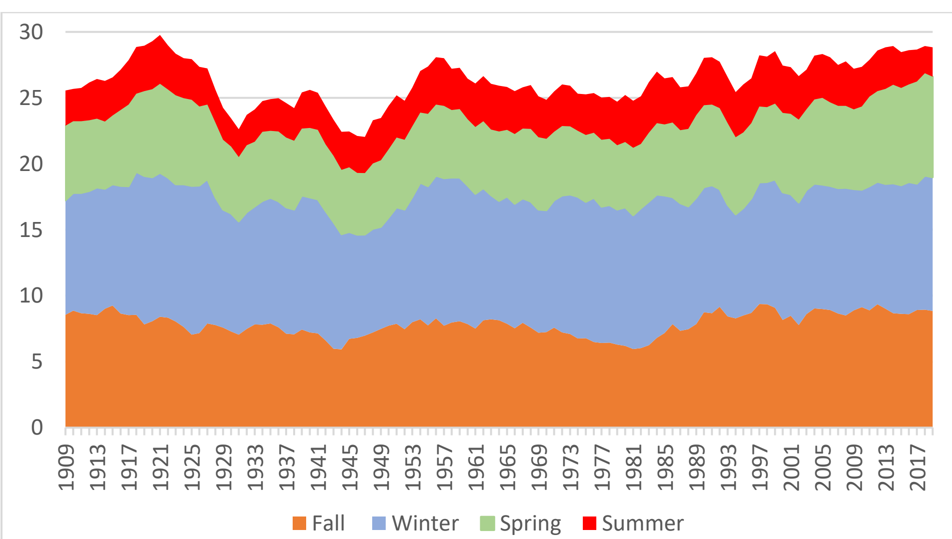
Spring (March – May) Rainfall, Inches



Summer (June – August) Rainfall, Inches



Rainfall Seasonal 10 Year Moving Averages, Inches



High Temperature Averages by Decade, Deg F

	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Avg
Jan	44.2	43.0	46.0	45.2	45.7	43.0	44.6	44.0	46.1	46.9	47.2	47.4	45.3
Feb	47.4	46.0	49.1	48.7	49.0	46.8	49.8	48.4	48.0	49.8	50.0	48.4	48.5
Mar	50.5	51.9	53.3	53.4	53.6	49.8	51.7	51.0	52.8	53.7	52.8	53.9	52.4
Apr	56.3	57.9	57.2	59.4	59.2	57.7	56.4	55.8	57.5	58.5	58.1	58.8	57.7
May	61.8	64.4	63.2	63.9	65.5	64.4	62.3	62.3	62.5	64.4	63.8	65.2	63.6
Jun	66.5	69.1	69.4	69.2	69.5	67.5	67.9	66.8	67.7	67.9	69.0	69.0	68.3
Jul	71.5	73.8	73.0	71.9	72.8	72.3	71.3	71.3	70.9	72.7	74.2	73.9	72.5
Aug	70.8	73.2	71.9	72.5	71.8	71.5	71.1	71.1	72.2	73.2	73.7	74.8	72.3
Sep	66.2	67.3	67.9	67.2	67.9	67.3	66.9	66.7	66.6	68.3	68.9	69.2	67.5
Oct	58.8	58.5	60.6	59.5	59.8	58.7	59.3	58.1	58.7	59.4	59.8	60.3	59.3
Nov	51.5	51.2	52.6	51.4	50.8	50.4	51.5	49.8	49.8	51.5	51.8	52.7	51.3
Dec	46.3	46.3	46.7	48.0	46.3	47.1	46.4	46.1	45.0	45.9	46.2	47.0	46.5
	57.7	**58.5**	**59.2**	**59.2**	**59.3**	**58.0**	**58.3**	**57.6**	**58.2**	**59.4**	**59.6**	**60.1**	**58.8**

Low Temperature Averages by Decade, Deg F

	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Avg
Jan	34.1	32.5	34.2	35.0	35.0	33.9	34.1	32.7	35.3	36.6	36.6	37.2	34.8
Feb	35.8	33.4	35.4	35.2	36.9	36.8	36.5	36.1	35.9	36.9	36.0	36.8	36.0
Mar	37.4	35.4	37.9	39.3	38.9	37.5	37.1	37.1	39.2	39.2	39.5	39.9	38.2
Apr	40.5	39.4	40.0	42.5	42.9	41.5	40.7	40.2	42.3	43.2	42.6	43.6	41.6
May	45.1	42.8	44.8	46.4	46.5	46.1	44.6	44.8	46.9	48.1	47.3	48.1	46.0
Jun	48.2	46.0	48.6	50.2	50.0	50.4	49.5	49.0	50.7	51.3	51.9	51.8	49.8
Jul	50.9	47.8	51.1	51.7	52.3	52.3	51.1	51.4	52.8	54.1	54.3	54.1	52.0
Aug	51.2	47.6	51.2	52.2	52.4	52.3	51.4	51.7	53.1	54.1	53.9	54.7	52.2
Sep	48.8	46.9	48.2	50.0	49.9	50.6	48.4	49.0	49.9	50.8	51.2	51.8	49.6
Oct	43.5	42.7	44.9	45.8	45.9	45.7	44.0	42.8	44.3	45.1	45.6	46.3	44.7
Nov	39.7	38.3	39.5	40.6	39.9	39.6	39.7	37.4	39.6	40.5	39.6	41.2	39.6
Dec	36.0	34.0	35.1	38.6	36.9	38.3	35.6	35.5	34.8	35.8	35.7	36.3	36.0
	42.6	**40.6**	**42.6**	**44.0**	**43.9**	**43.7**	**42.7**	**42.3**	**43.7**	**44.6**	**44.5**	**45.1**	**43.4**

Rainfall Averages by Decade, Inches

Total Annual Rainfall

	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Avg
Jan	2.92	3.99	3.44	3.67	2.19	3.77	3.41	3.90	3.27	3.61	3.87	3.57	3.47
Feb	2.72	2.66	1.65	2.46	2.54	2.77	2.29	2.46	2.49	2.57	1.94	3.00	2.46
Mar	2.33	2.42	2.15	2.69	2.00	2.55	2.01	1.93	2.46	2.03	2.47	2.96	2.33
Apr	1.63	2.17	1.85	1.30	1.58	1.53	1.94	1.69	1.82	2.07	1.76	2.52	1.82
May	1.69	1.85	1.28	1.09	1.46	1.13	1.53	1.24	1.97	1.65	1.82	2.13	1.57
Jun	1.30	1.65	0.82	1.36	1.58	1.44	0.98	1.08	1.57	1.72	1.24	1.13	1.32
Jul	0.59	0.80	0.30	0.87	0.66	0.82	0.98	1.14	0.99	0.98	0.63	0.59	0.78
Aug	0.78	0.99	1.29	0.52	0.98	0.88	1.16	1.08	0.63	1.28	1.22	0.50	0.94
Sep	1.79	1.36	1.53	1.58	1.51	1.34	1.56	1.30	1.67	1.05	1.45	1.76	1.49
Oct	2.36	2.75	3.04	2.49	2.72	3.18	2.58	1.92	2.12	2.72	3.21	3.08	2.68
Nov	4.41	3.73	3.01	3.36	3.27	3.55	3.05	3.07	4.07	5.30	4.25	3.99	3.76
Dec	3.05	4.55	4.04	4.02	3.29	4.08	3.52	4.38	3.37	3.71	3.07	3.84	3.74
	25.55	**28.90**	**24.40**	**25.40**	**23.76**	**27.02**	**25.01**	**25.20**	**26.42**	**28.69**	**26.91**	**29.08**	**26.36**

Seasonal Rainfall

	1900s	1910s	1920s	1930s	1940s	1950s	1960s	1970s	1980s	1990s	2000s	2010s	Avg
Winter	8.68	11.20	9.12	10.15	8.01	10.61	9.22	10.73	9.12	9.89	8.87	10.41	9.67
Spring	5.65	6.44	5.28	5.07	5.04	5.21	5.48	4.86	6.25	5.75	6.04	7.61	5.72
Summer	2.66	3.43	2.41	2.75	3.22	3.14	3.11	3.31	3.19	3.98	3.09	2.22	3.04
Fall	8.56	7.83	7.58	7.43	7.50	8.06	7.20	6.30	7.86	9.08	8.90	8.84	7.93
	25.55	**28.90**	**24.40**	**25.40**	**23.76**	**27.02**	**25.01**	**25.20**	**26.42**	**28.69**	**26.91**	**29.08**	**26.36**

Note: For convenience, winter averages above use calendar year values. Annual values shown elsewhere in his report use consecutive months data for winter, i.e. December values are from the previous calendar year.