HYDROMET CHART PACK – Measured Climatic Metrics

CSKT Water Resources Program August, 2019

The enclosed chart pack contains time series graphs for climate-related environmental parameters at various measurement locations on or near the Flathead Indian Reservation. Environmental parameters include air temperature, surface precipitation and snowpack.

Surface Air Temperature

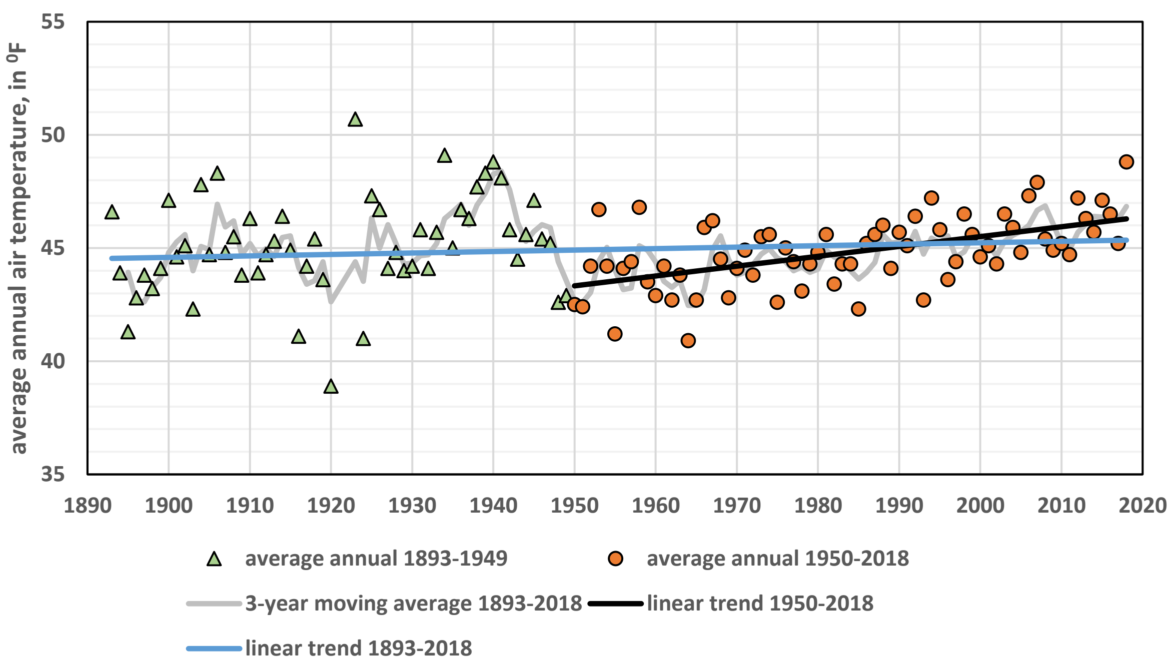
Surface air temperature (air temperature) is a measure of air temperature in the near surface. Air temperature data provides one of the longest time series of measured information available in western Montana. Below we report for four weather stations – Missoula, Saint Ignatius, Hot Springs, and Kalispell. Each has a variable period of record, with the Missoula area station having the longest record, spanning the 1893 to present period. The Hot Springs record is a composite of Hot Springs and Lonepine, stations separated by considerable distance, and the trend in data should be viewed with caution.

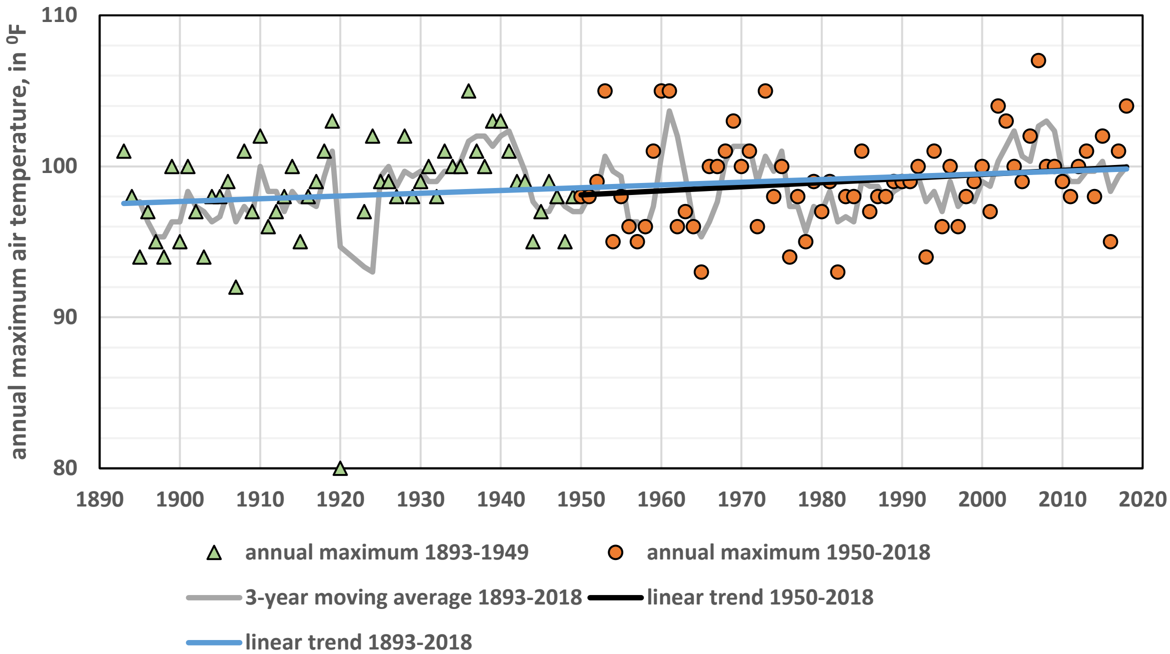
We report average annual, annual maximum, and annual minimum air temperature for the full period of record and the 1950-2018 period. Data are reported by individual year with linear trends lines, and as a three year moving average over the full period; this smooths some of the year-to-year variability and enhances multi-year cycles. We also report a composite station developed by averaging values for the Missoula, Saint Ignatius, and Kalispell stations; this integrates stations, providing a more representative regional perspective.

Surface air temperature increased over the reporting period at each weather station. This is consistent with the Montana Climate Assessment (b), which reported a state-wide increase in air temperature of 1.95^{0}F over the 1950-2015 period, and an increase of 2.5^{0}F over the same period for the northwest climate zone of Montana (b). At a basic level, higher air temperatures indicate a radiative imbalance, with more energy from the sun entering the atmosphere than exiting the atmosphere. Stocker et al. (2013)(a) assign a high confidence to the increase in energy imbalance since at least 1970, with global mean surface temperature reported to have increased 1.5^{0}F over the 1880-2012 period (a).

For air temperature we report information in ^{0}F. The conversion to Celsius: (^{0}F -32)*0.56 = ^{0}C.

Figure 1 - Missoula area air temperature data are available for the 125-year period 1893 to 2018. Average annual, annual maximum, and annual minimum temperature are reported for the full period and the 1950 – 2018 period. All three temperature metrics have increased, with an acceleration in the rate of increase over the 1950-2018 period. Average annual temperatures have been at or greater than the long-term average (44.9^{0}F) since 2003. Annual maximum temperature has increased over 2^{0}F over the period and the trend has remained consistent over the two reporting periods. Annual minimum temperatures show the widest variability, but the more recent period shows an increase in annual minimums. With the exception of two outliers, minimum temperatures have been above the long-term average (-14.4^{0}F) since 2000.




110
100
90
80
annual maximum air temperature, in ⁰F
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual maximum 1893-1949
annual maximum 1950-2018
3-year moving average 1893-2018
linear trend 1950-2018
linear trend 1893-2018

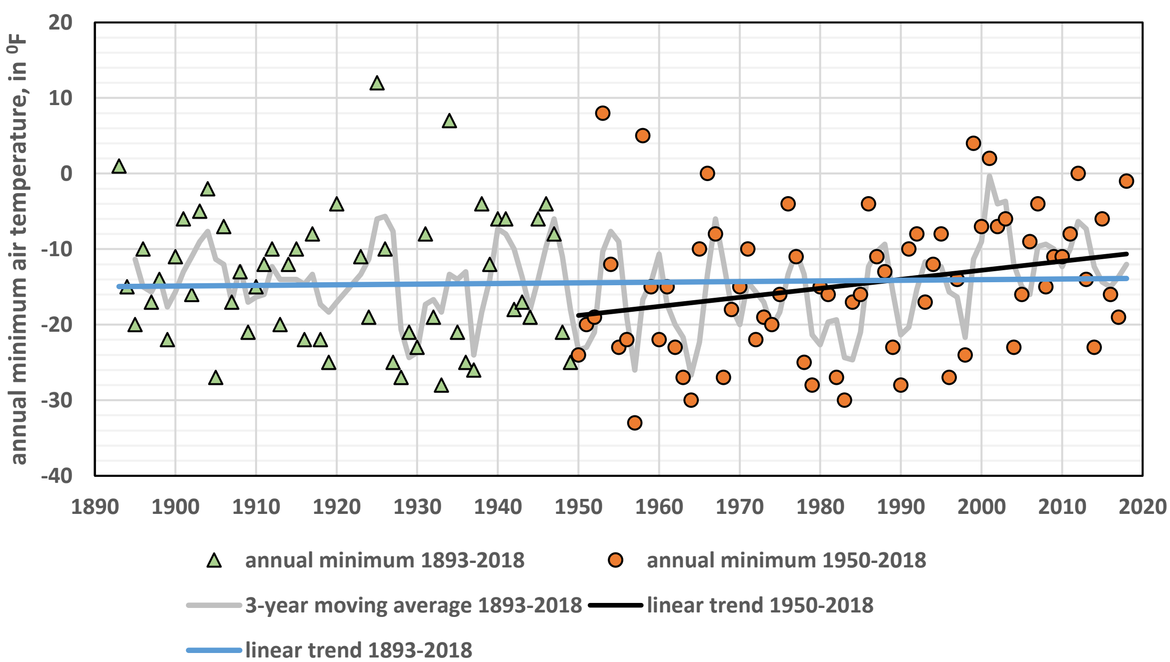
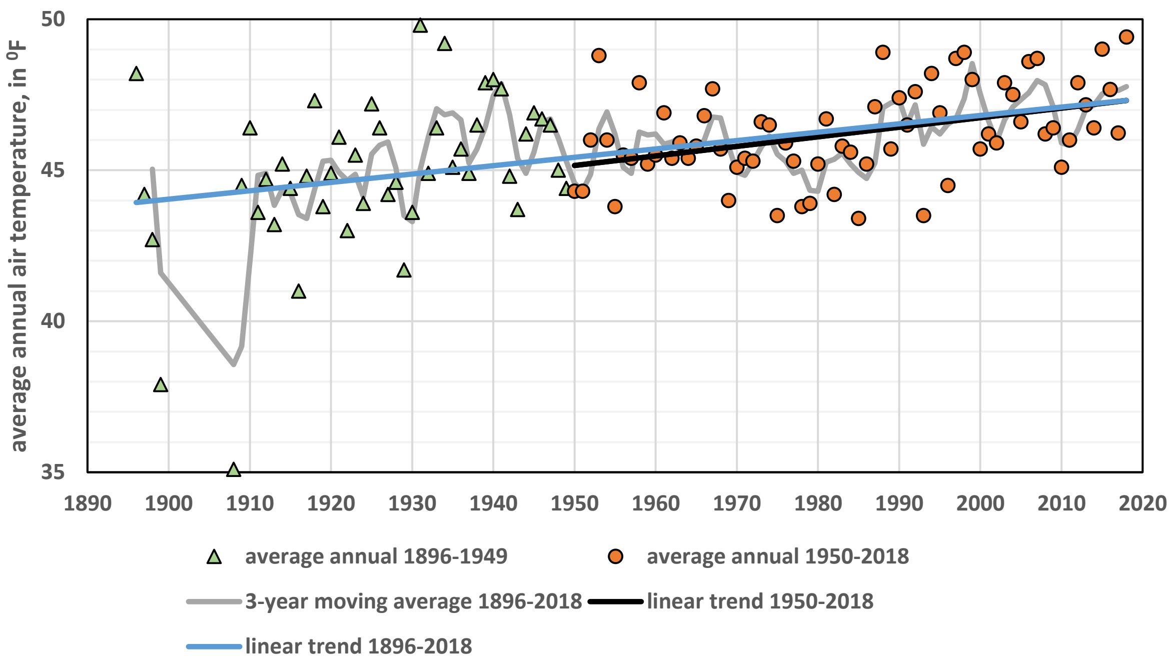
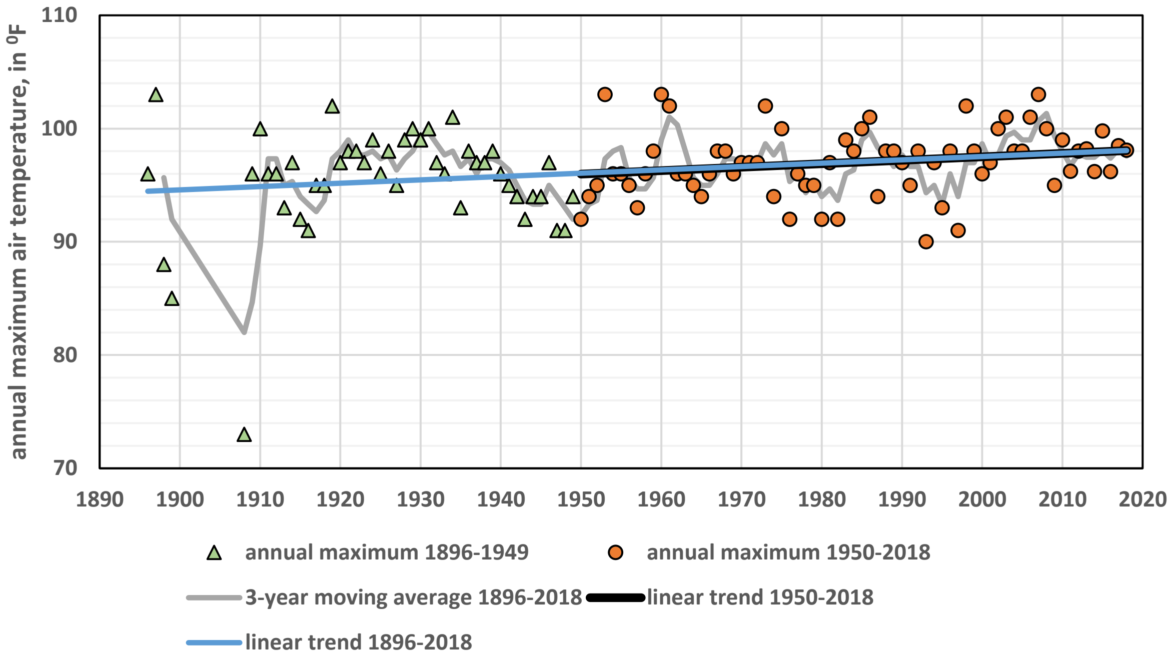

20
10
0
-10
-20
-30
-40
annual minimum air temperature, in ⁰F
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual minimum 1893-2018
annual minimum 1950-2018
3-year moving average 1893-2018
linear trend 1950-2018
linear trend 1893-2018

Figure 2 - St. Ignatius air temperature data are available for the 122-period 1896 to 2018, although data are missing for the 1900 through 1907 period. Average annual, annual maximum, and annual minimum temperatures are reported for the full period and the 1950 – 2018 period. Average annual temperature has increased notably over the period, and generally exceeds rates of increase reported for most Montana stations. With the exception of 2010, average annual temperature has been above the long-term average (45.7^{0}F) since 2000. Annual maximum temperatures have increased approximately 4^{0}F over the period, also increasing at a greater rate than is generally observed in the State. Annual minimums have increased notably over the period, and the year-to-year variability has decreased in the recent record.




annual maximum air temperature, in 0F
110
100
90
80
70
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual maximum 1896-1949
annual maximum 1950-2018
3-year moving average 1896-2018
linear trend 1950-2018
linear trend 1896-2018

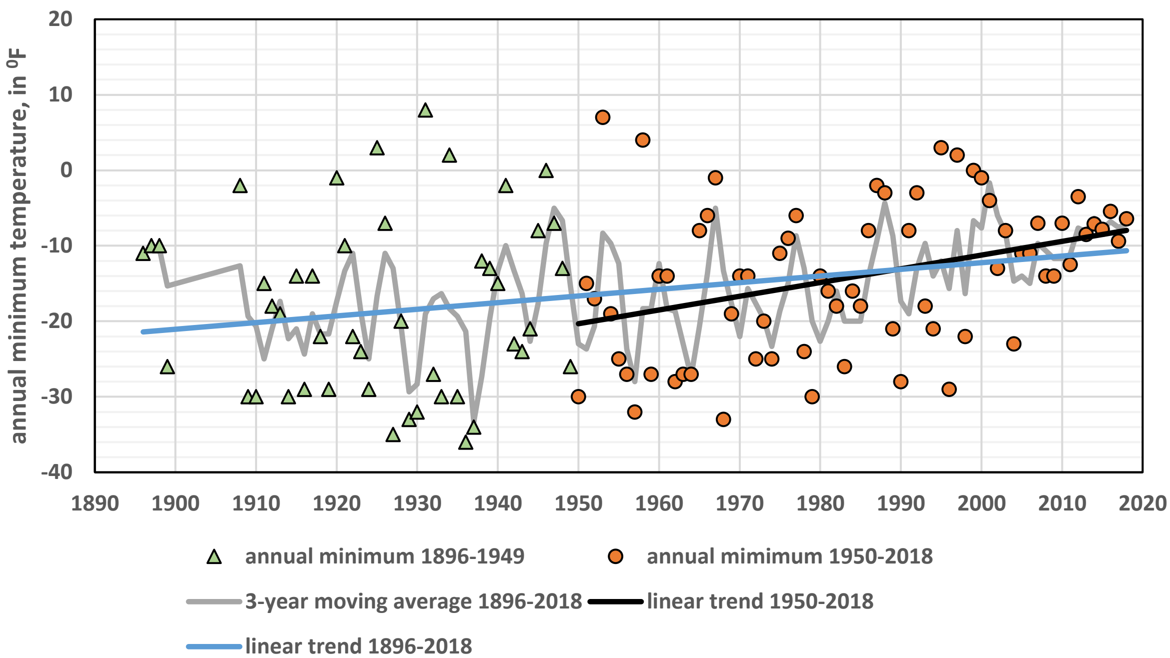
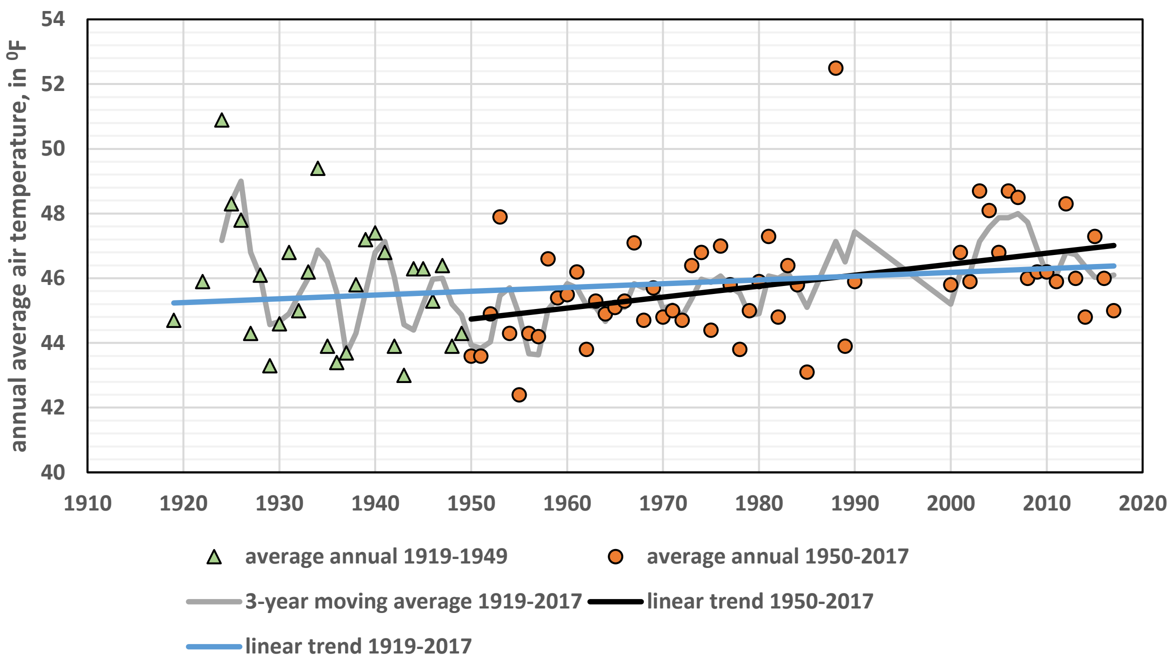
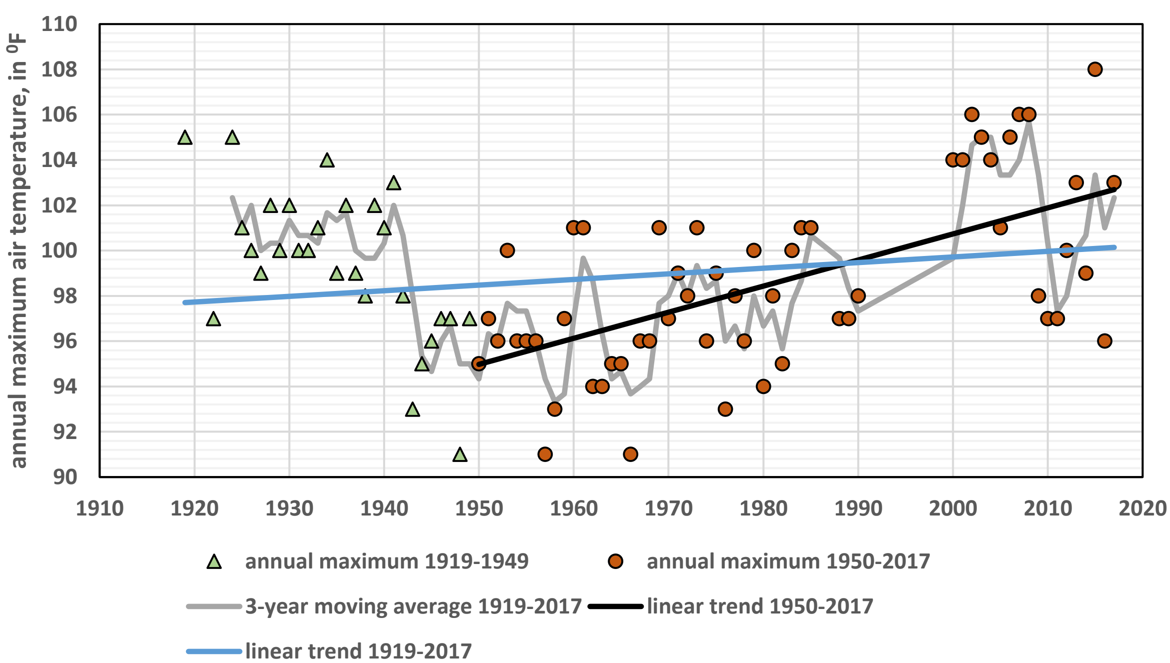

annual minimum temperature, in 0F
20
10
0
-10
-20
-30
-40
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual minimum 1896-1949
annual mimimum 1950-2018
3-year moving average 1896-2018
linear trend 1950-2018
linear trend 1896-2018

Figure 3 - Hot Springs area air temperature data are available for the 1919 – 2017 period, with missing record for 1920-1921, 1923, 1985-1986, 1991 -1999. The record is a composite of the Lonepine (1919-1969) and Hot Springs stations. Trends should be viewed with caution, since the stations are several miles apart.





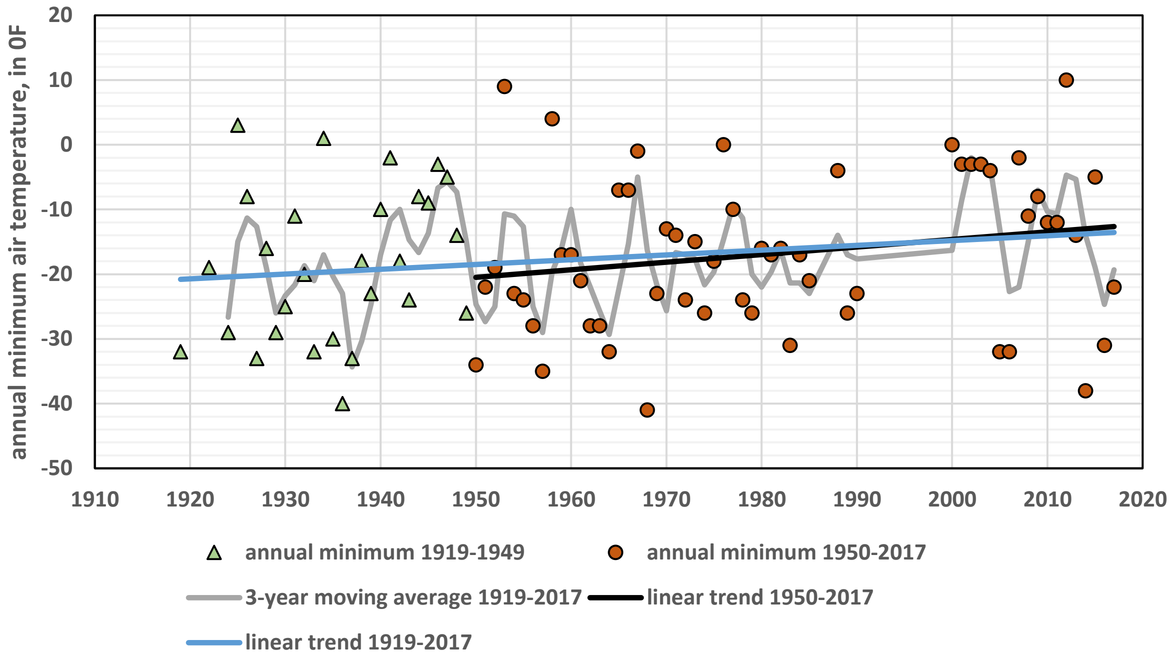
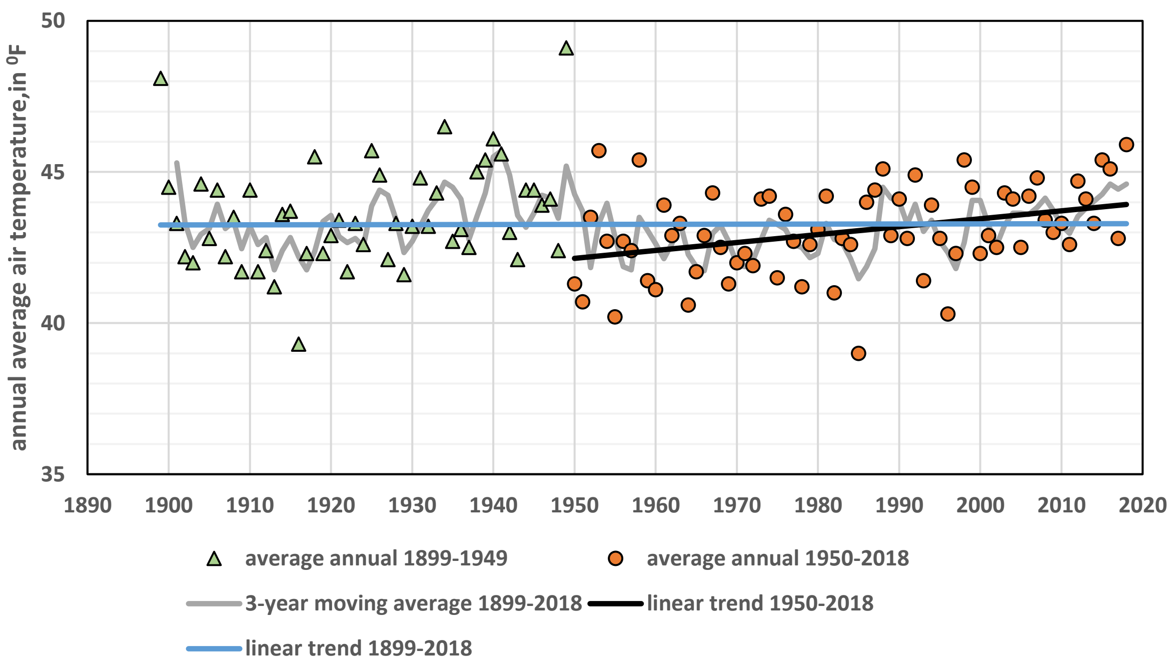
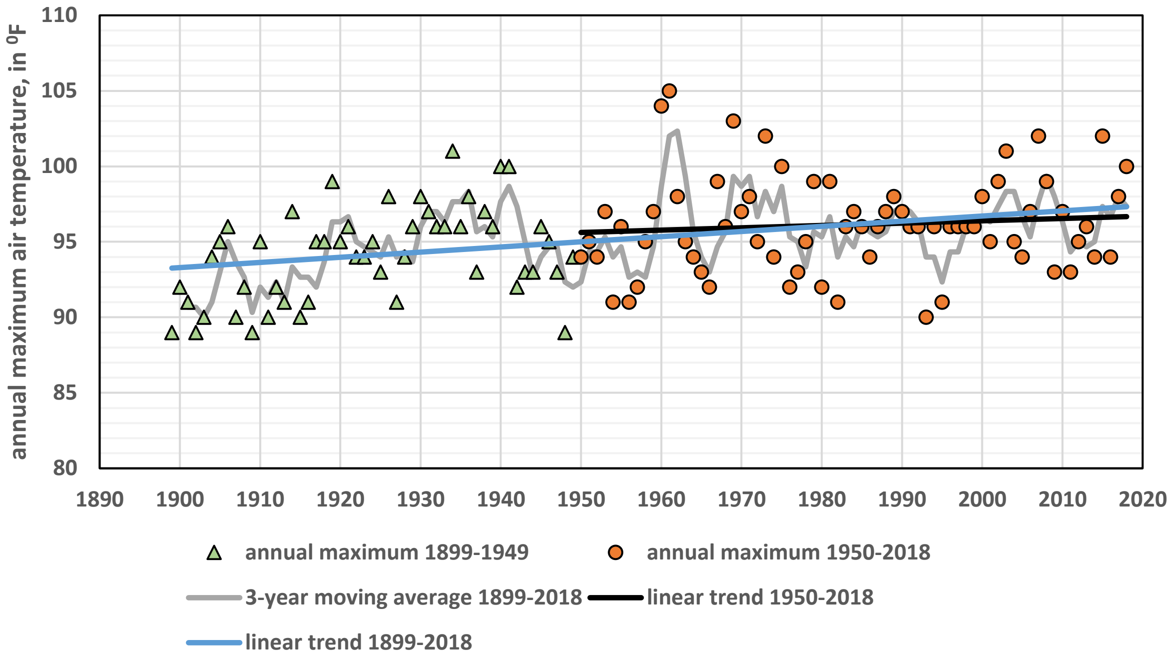
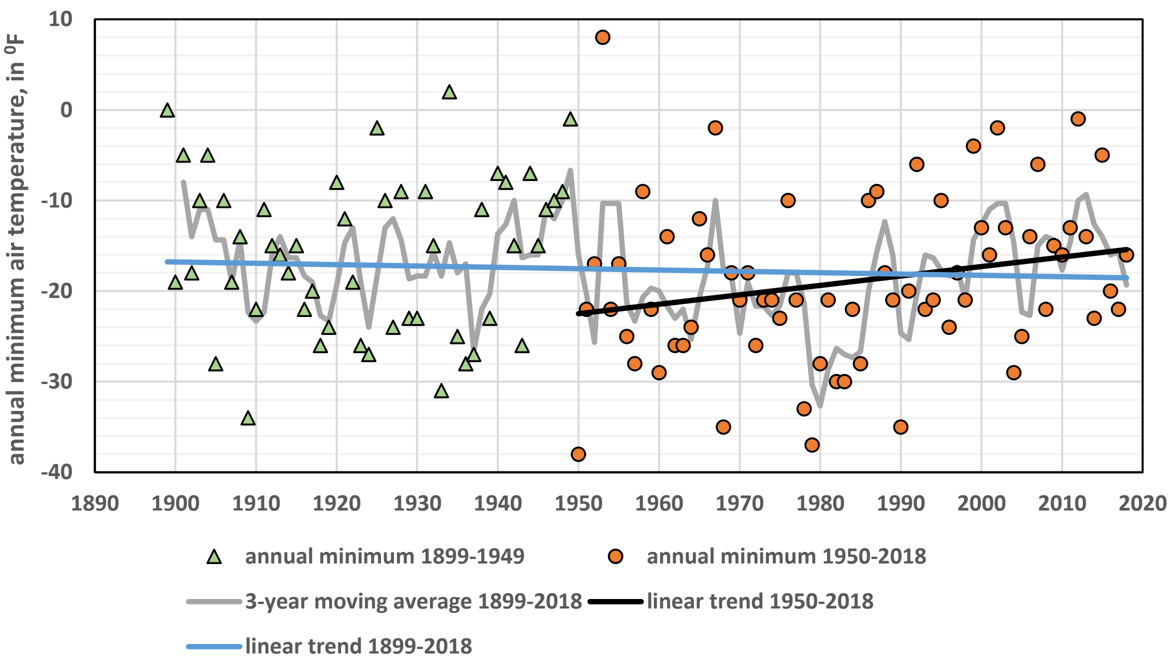

annual minimum air temperature, in 0F
20
10
0
-10
-20
-30
-40
-50
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual minimum 1919-1949
annual minimum 1950-2017
3-year moving average 1919-2017
linear trend 1950-2017
linear trend 1919-2017

Figure 4 - Kalispell area air temperature data are available from 1899 to 2018, a 119 year period. Average annual, annual maximum, and annual minimum temperatures are reported. There is greater variability between the long-term and 1950-2018 trend lines than at other stations, but for each metric, trends have increased over the more recent period. Average annual temperatures have increased at a greater rate in the recent period, and since 2000, values have approached or exceeded the long-term average (43.2^{0}F) value. Annual maximum values have increased over 4^{0}F over the period, and values since 2000 have clustered at or above the long-term average (95.2^{0}F). Annual minimums show wide dispersion, but have decreased in the 2010 to present period.



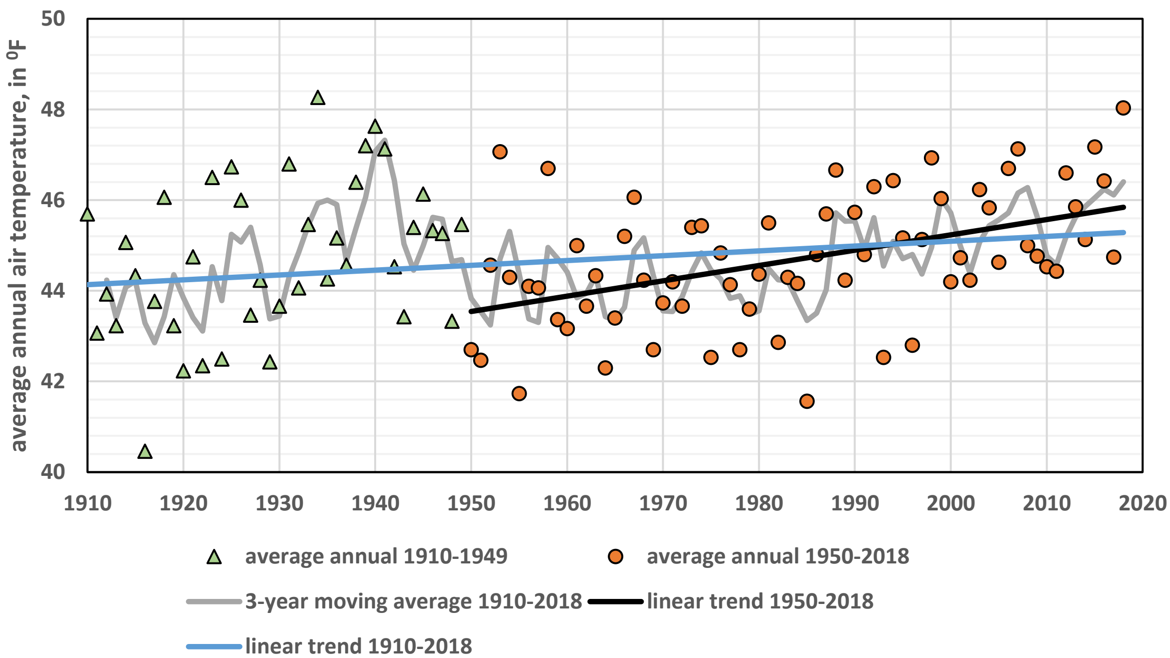


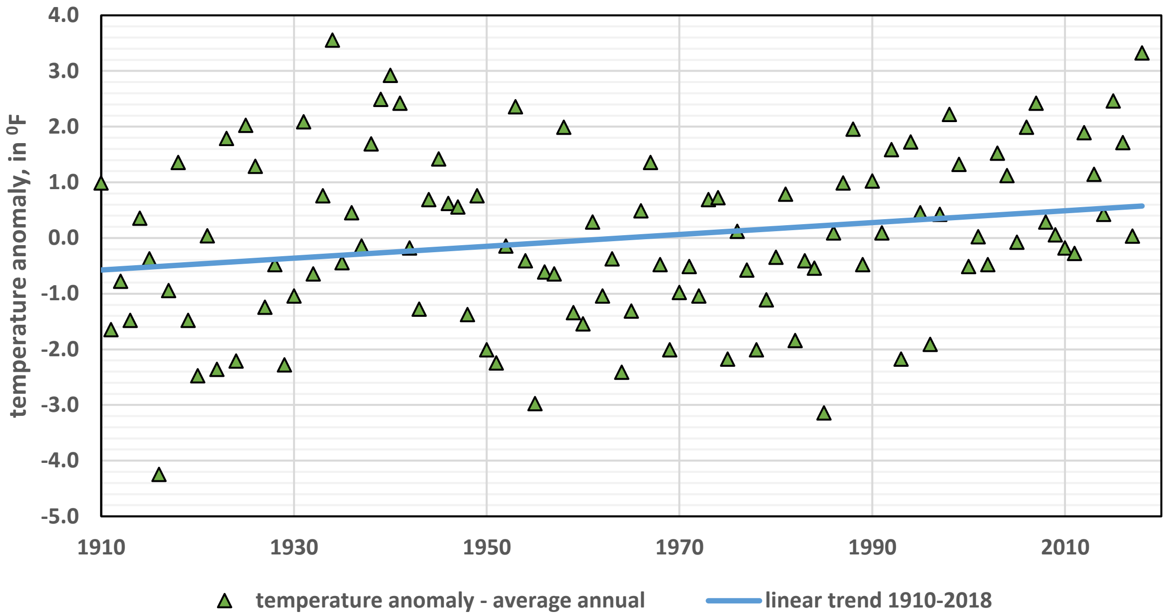
annual maximum air temperature, in °F
110
105
100
95
90
85
80
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual maximum 1899-1949
annual maximum 1950-2018
3-year moving average 1899-2018
linear trend 1950-2018
linear trend 1899-2018

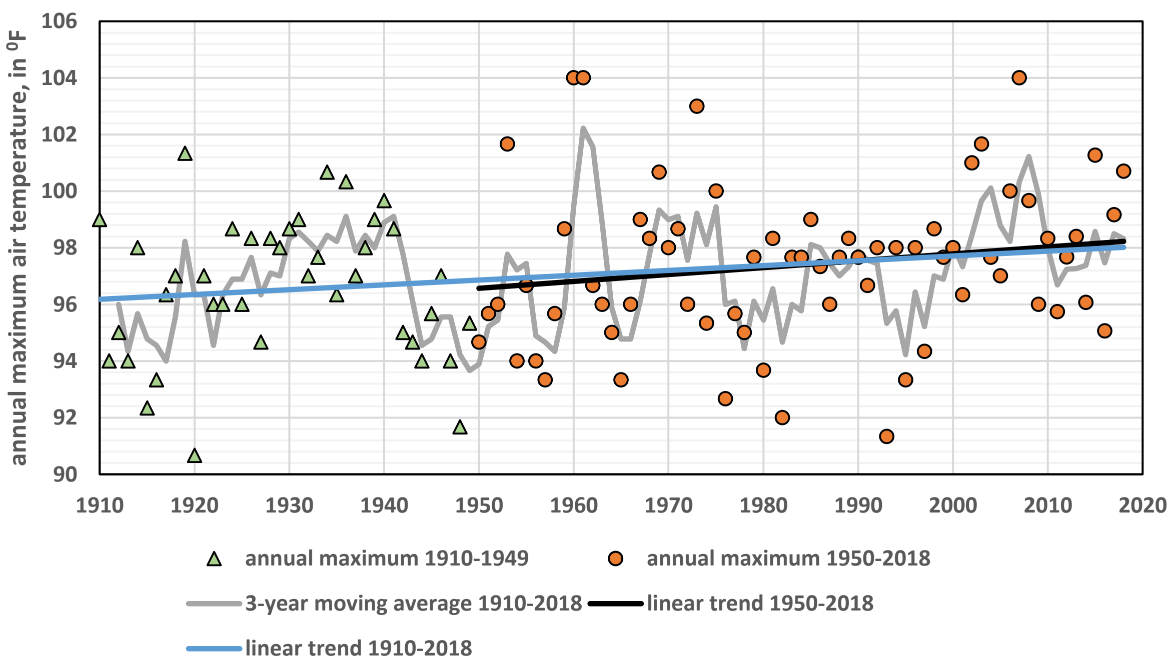


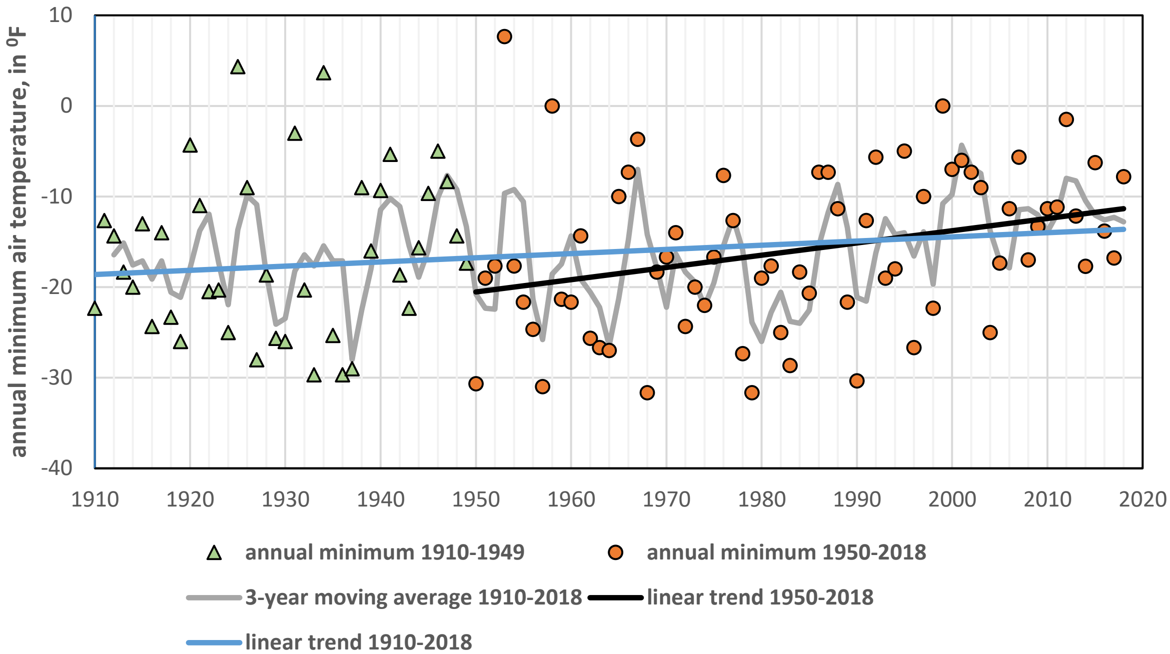
annual minimum air temperature, in °F
10
0
-10
-20
-30
-40
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual minimum 1899-1949
annual minimum 1950-2018
3-year moving average 1899-2018
linear trend 1950-2018
linear trend 1899-2018

Figure 5 – Composite air temperature data are prepared by averaging the Missoula, St. Ignatius, and Kalispell air temperature data for the overlapping 1910 through 2018 period, a 108 year period. The composite figure provides a more regionalized perspective on air temperature trends, reducing the variability that may be associated with an individual location. Average annual temperature has increased over the longer and 1950-2018 period, with the increase at 2.2^{0}F for the 1950-2018 period. Data points since 2000 have clustered around the long-term average (44.7^{0}F). This is more evident in the temperature anomaly figure, which plots the annual temperature deviation from the long-term average. Annual maximum temperature has increased over both time periods, with the temperature increase for the 1950-2018 period equal to 1.9^{0}F. This is less than the state-wide average, reported at 3.3^{0}F (a). There is wider scatter in the minimum temperatures, but an increasing trend over both time periods. The increase over the 1950-2018 period is 8^{0}F, greater than the 3.3^{0}F value reported as the state-wide average (b).




temperature anomaly, in 0F
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
1910
1930
1950
1970
1990
2010
temperature anomaly - average annual
linear trend 1910-2018

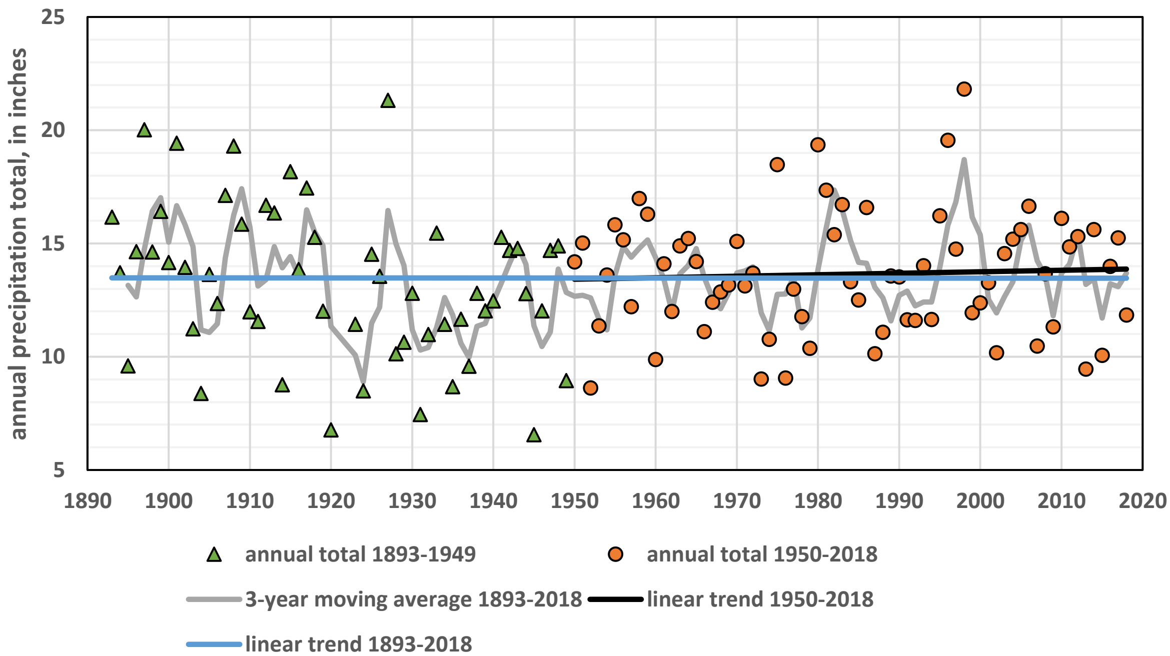

annual maximum air temperature, in 0F
106
104
102
100
98
96
94
92
90
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual maximum 1910-1949
annual maximum 1950-2018
3-year moving average 1910-2018
linear trend 1950-2018
linear trend 1910-2018

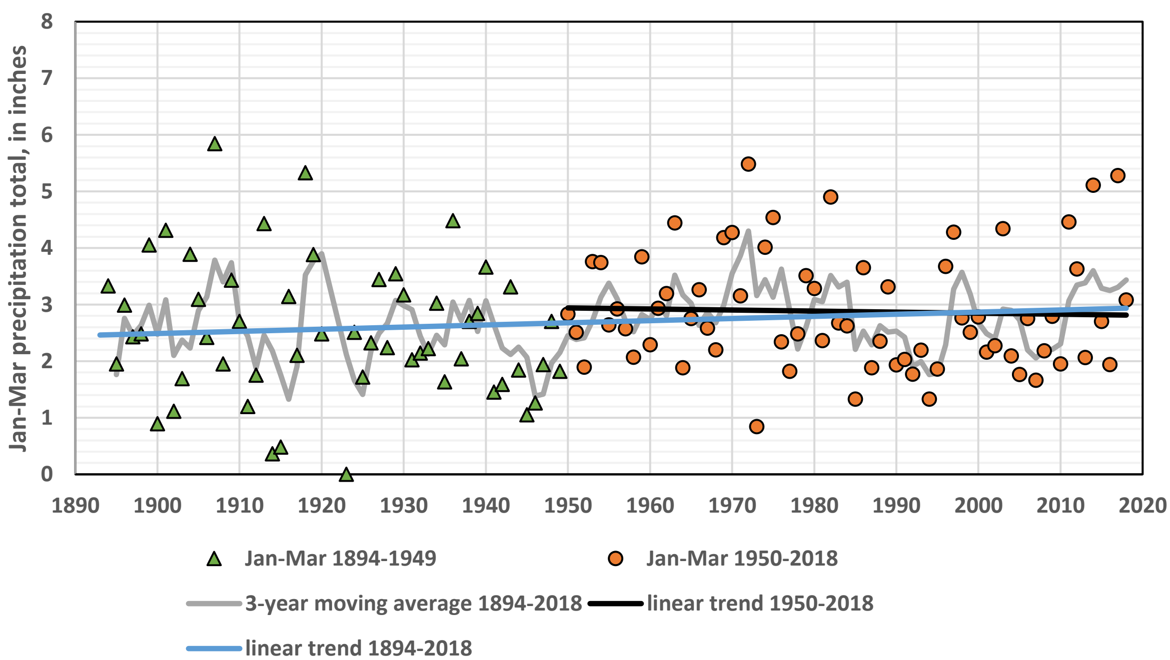

annual minimum air temperature, in 0F
10
0
-10
-20
-30
-40
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
annual minimum 1910-1949
annual minimum 1950-2018
3-year moving average 1910-2018
linear trend 1950-2018
linear trend 1910-2018

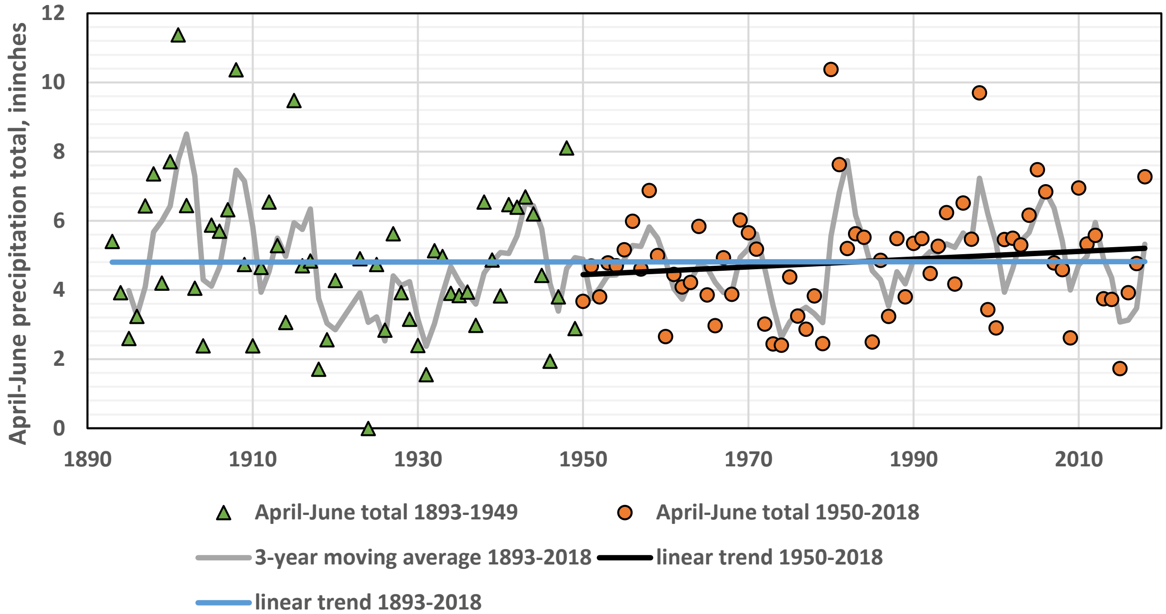
Precipitation

Accumulated valley precipitation is reported for the Missoula, Saint Ignatius, and Kalispell stations for annual totals and three month time periods. A composite station record is developed by averaging the values for the three individual reporting stations. The Hot Springs record is incomplete and is not reported. Average annual precipitation has remained relatively stable over the full period and the 1950-2018 period at each station; this is consistent with both global and state-wide observations (a, b). The most prominent trend, when looking at the seasonal data, has been a decrease in July-September precipitation totals, over 0.5 inches at the composite station for the 1950-2018 period.

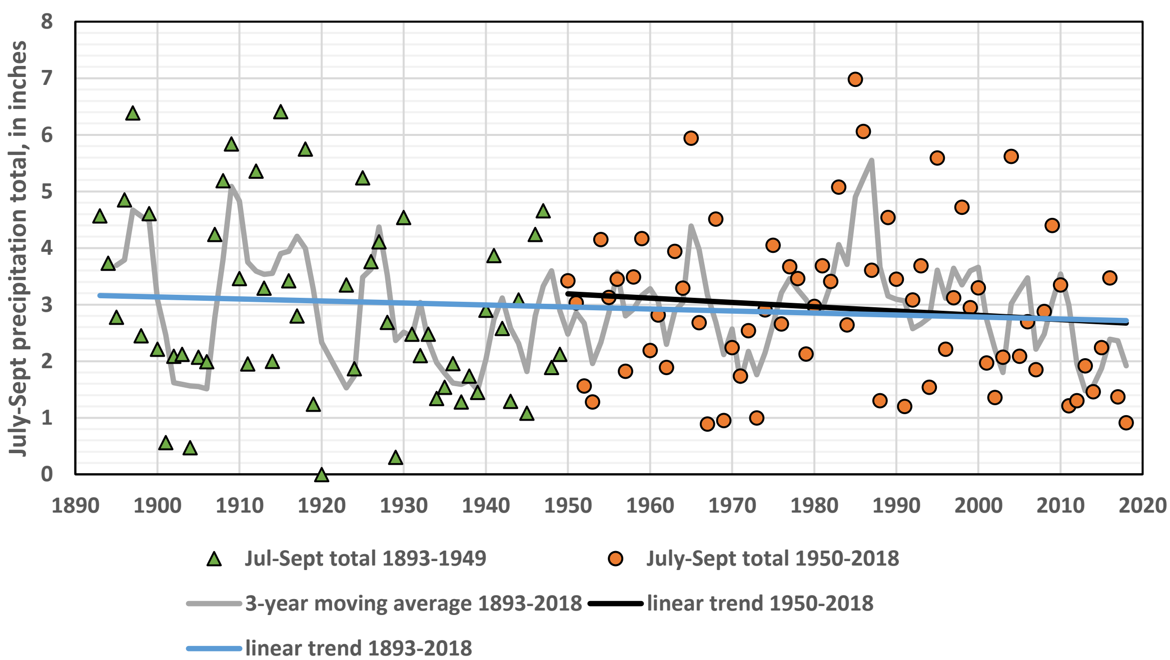
Figure 6 - Missoula area precipitation data are available for the 125-year period 1893 to 2018. Annual total, January through March total, July through September total, and October through December total precipitation are reported. Average annual precipitation has stayed constant near the long-term average value (13.5 inches). The most distinct trend has been a decrease in July through September precipitation, with the rate of decline increasing over the recent record. July through September precipitation has been notably low for the 2010 to present period.







April-June precipitation total, ininches
0
2
4
6
8
10
12
1890
1910
1930
1950
1970
1990
2010
April-June total 1893-1949
April-June total 1950-2018
3-year moving average 1893-2018
linear trend 1950-2018
linear trend 1893-2018



July-Sept precipitation total, in inches
0
1
2
3
4
5
6
7
8
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Jul-Sept total 1893-1949
July-Sept total 1950-2018
3-year moving average 1893-2018
linear trend 1950-2018
linear trend 1893-2018

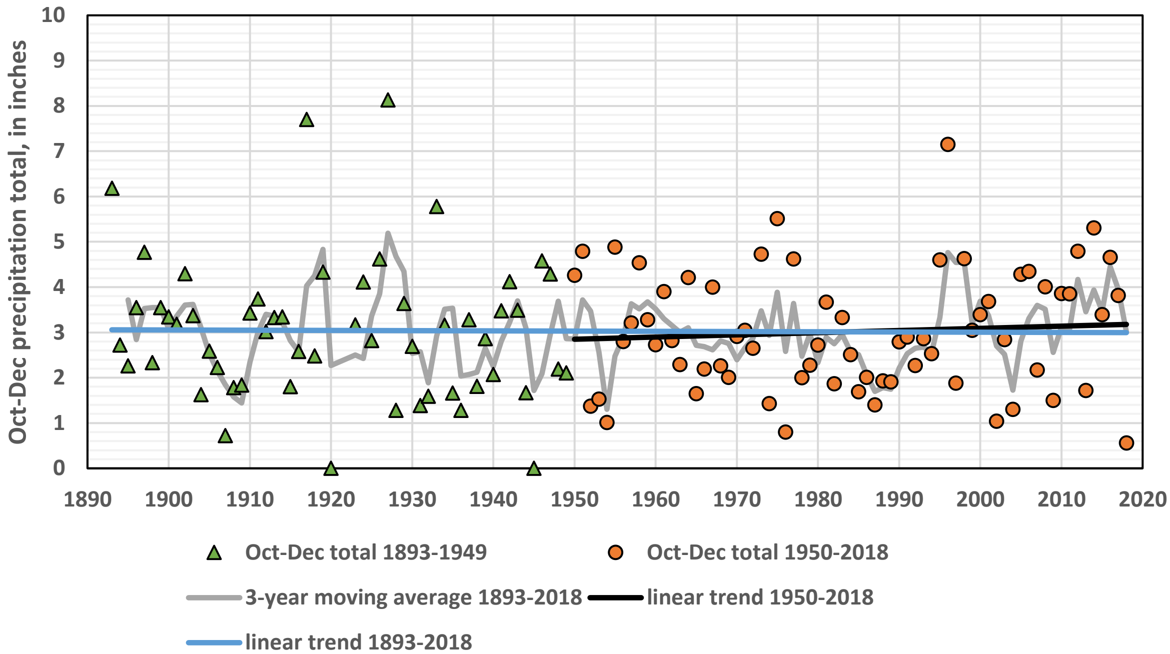
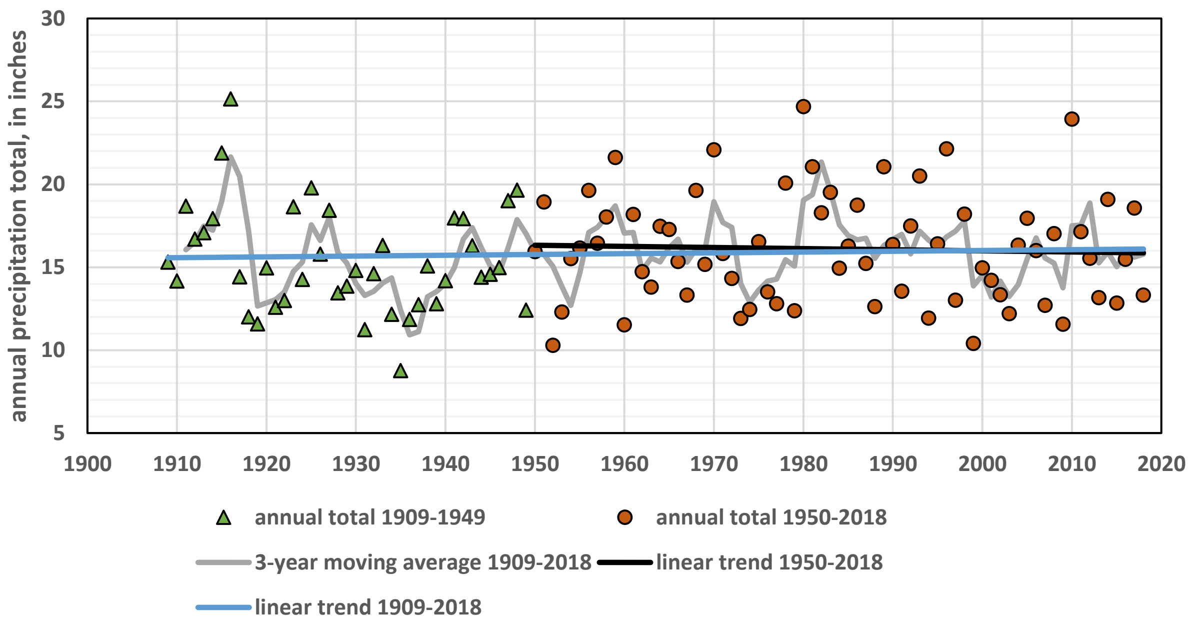
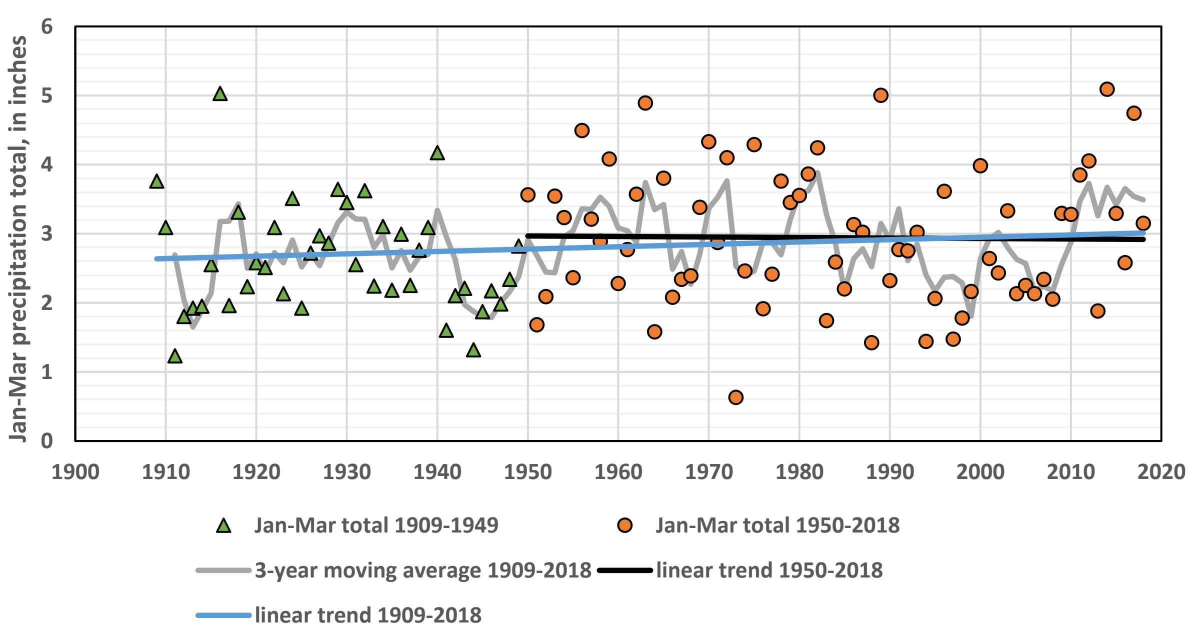
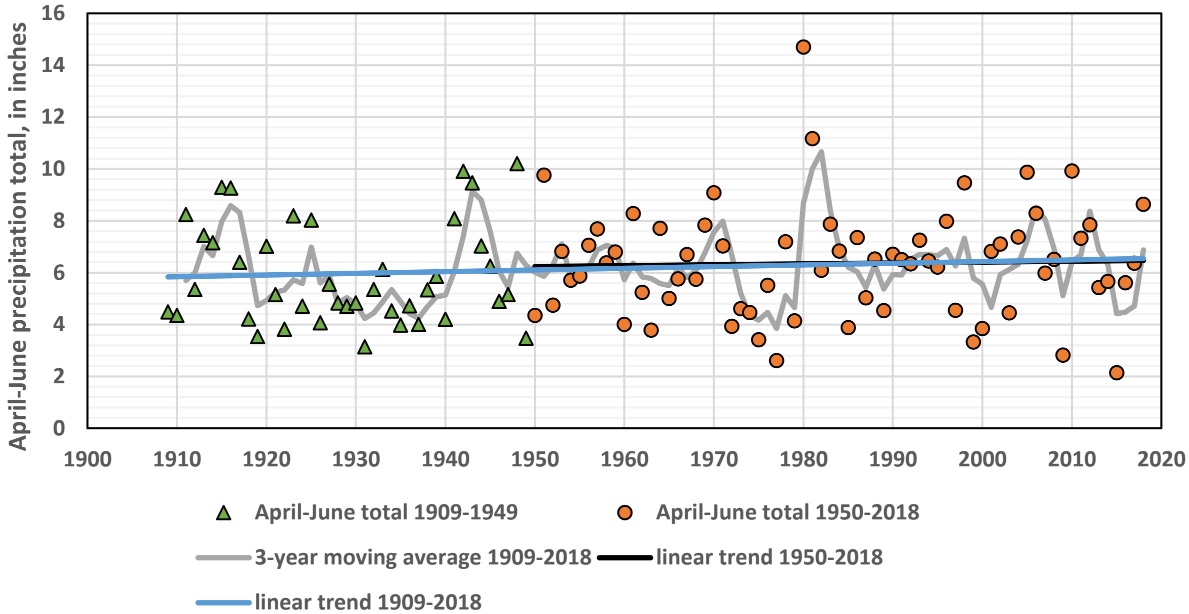

Oct-Dec precipitation total, in inches
0
1
2
3
4
5
6
7
8
9
10
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Oct-Dec total 1893-1949
Oct-Dec total 1950-2018
3-year moving average 1893-2018
linear trend 1950-2018
linear trend 1893-2018

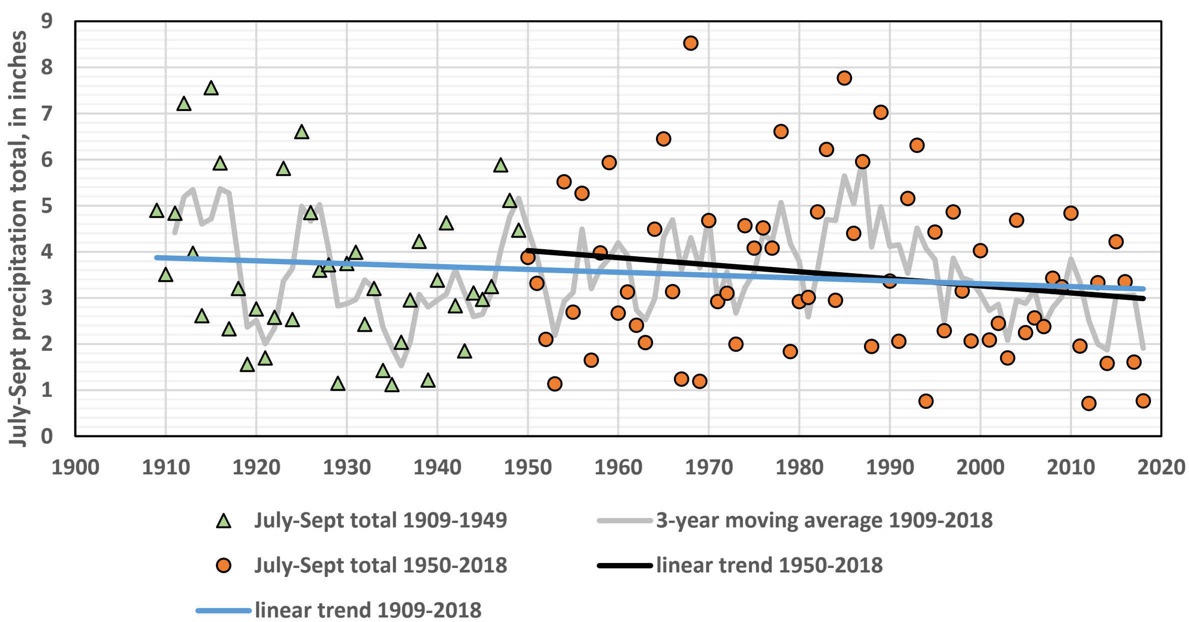
Figure 7 - St. Ignatius precipitation data are available for the 109-period 1909 through 2018. Annual total, January through March total, July through September total, and October through December total precipitation are reported. Trend in annual totals have remained relatively constant, near the long-term average (15.8 inches). The most distinct trend has been an approximately one inch decrease in July through September precipitation, with the rate of decline increasing over the recent trend period.







April-June precipitation total, in inches
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
April-June total 1909-1949
April-June total 1950-2018
3-year moving average 1909-2018
linear trend 1950-2018
linear trend 1909-2018



July-Sept precipitation total, in inches
9
8
7
6
5
4
3
2
1
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
July-Sept total 1909-1949
3-year moving average 1909-2018
July-Sept total 1950-2018
linear trend 1950-2018
linear trend 1909-2018

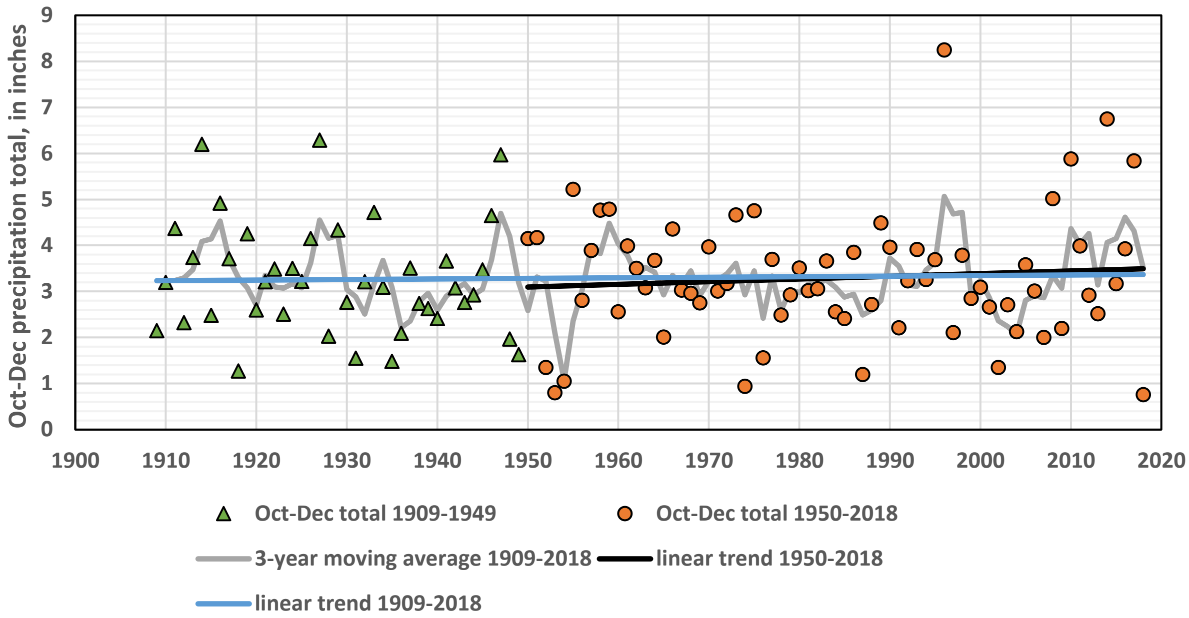
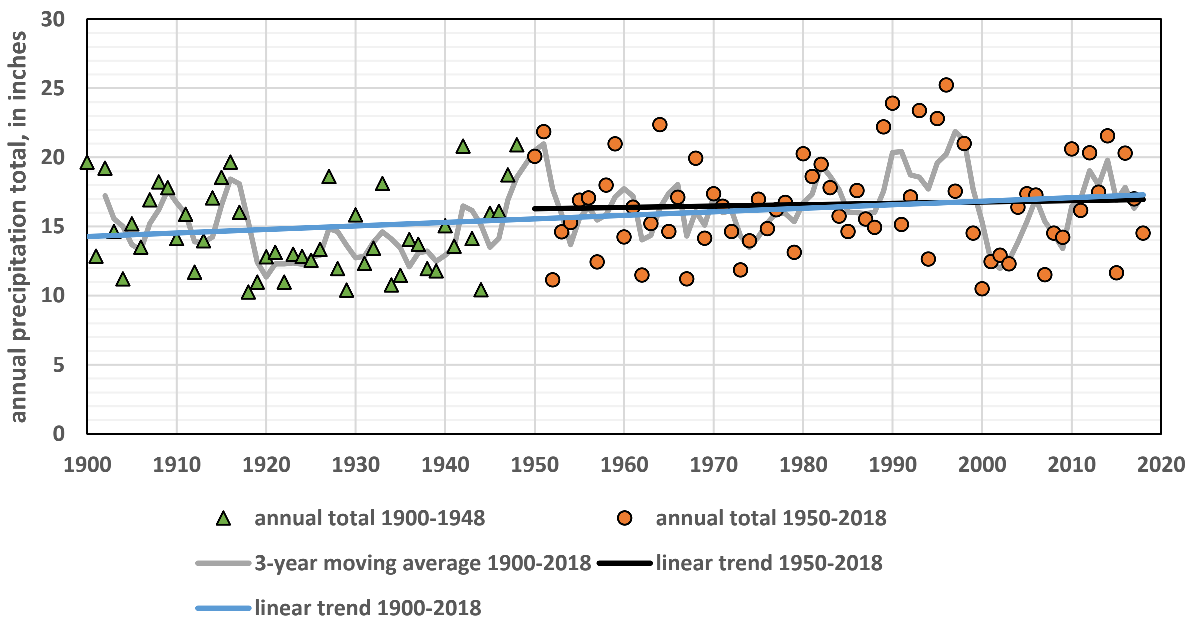
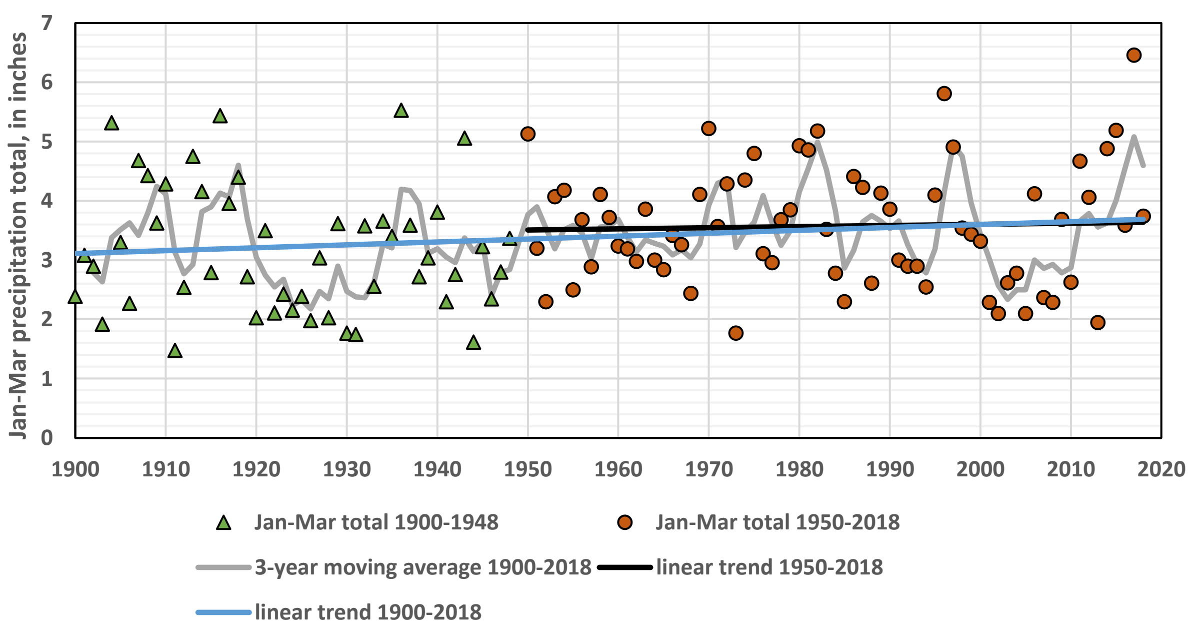
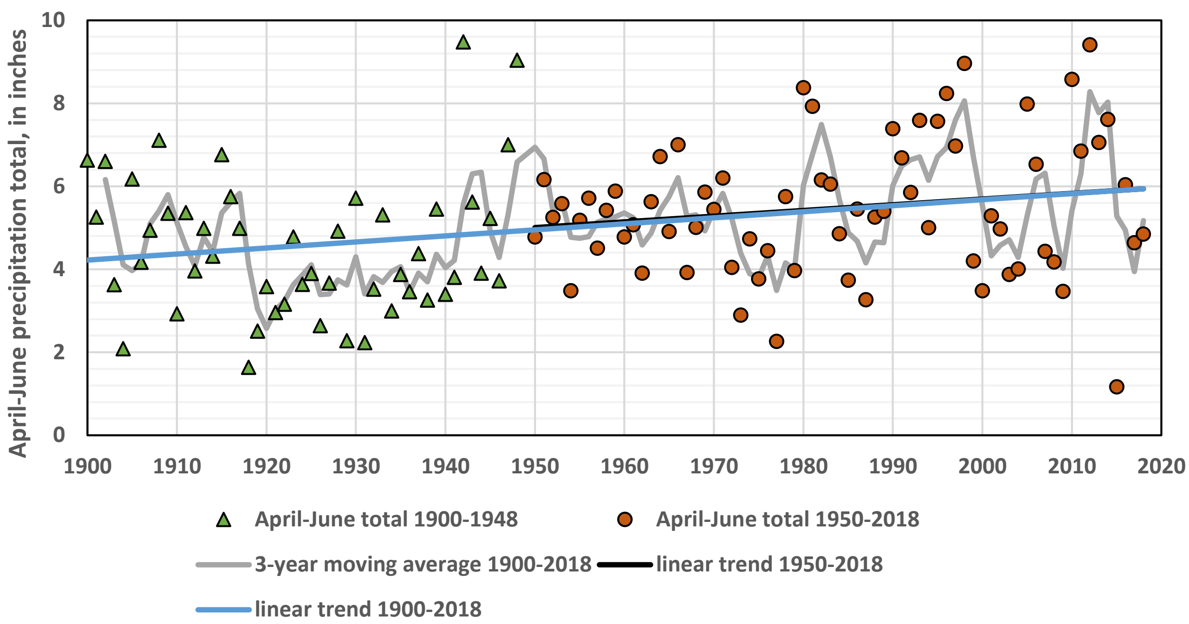
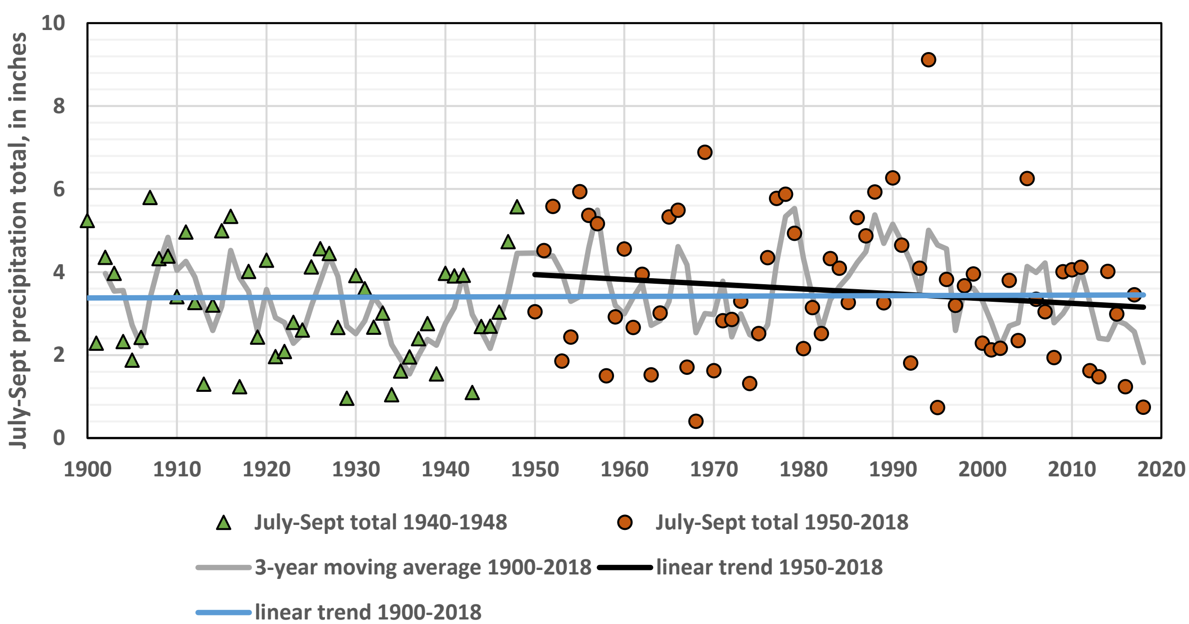

Oct-Dec precipitation total, in inches
0
1
2
3
4
5
6
7
8
9
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Oct-Dec total 1909-1949
Oct-Dec total 1950-2018
3-year moving average 1909-2018
linear trend 1950-2018
linear trend 1909-2018

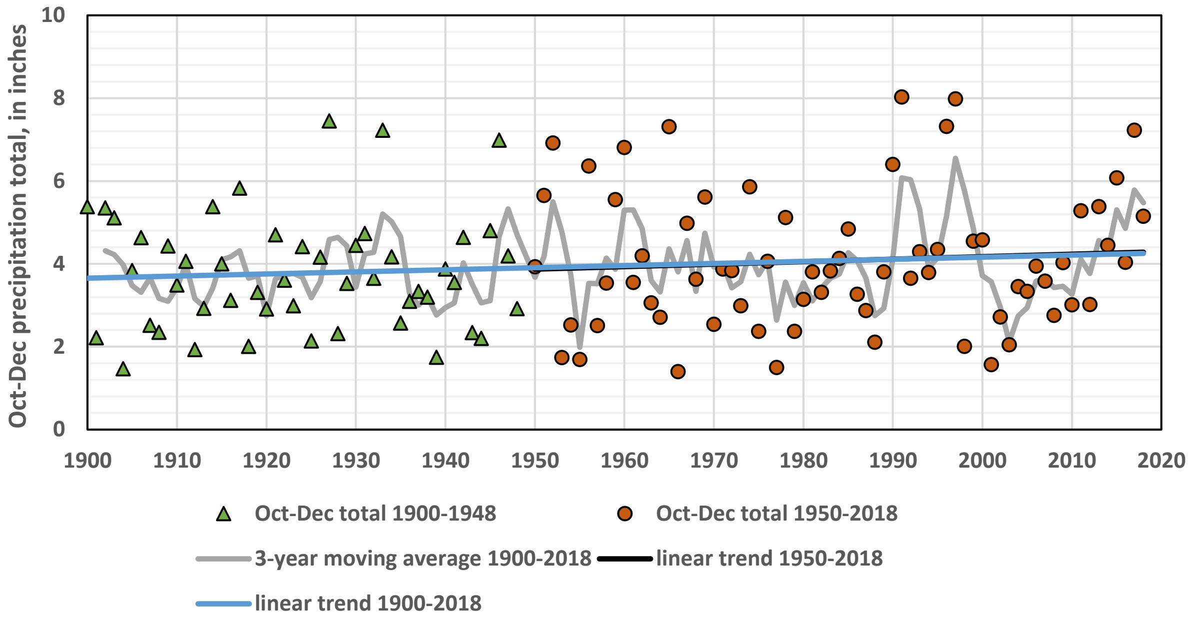
Figure 8 - Kalispell area precipitation data are available from 1900 to 2018, a 118 year period. Annual total, January through March total, July through September total, and October through December total precipitation are reported. Unlike prior stations, precipitation totals have increased for annual totals and for each period, with the exception of July through September totals. The recent trend in annual totals exceeds the long-term average (15.8 inches). July-September totals have decreased, and the rate of decrease has accelerated in the recent record.





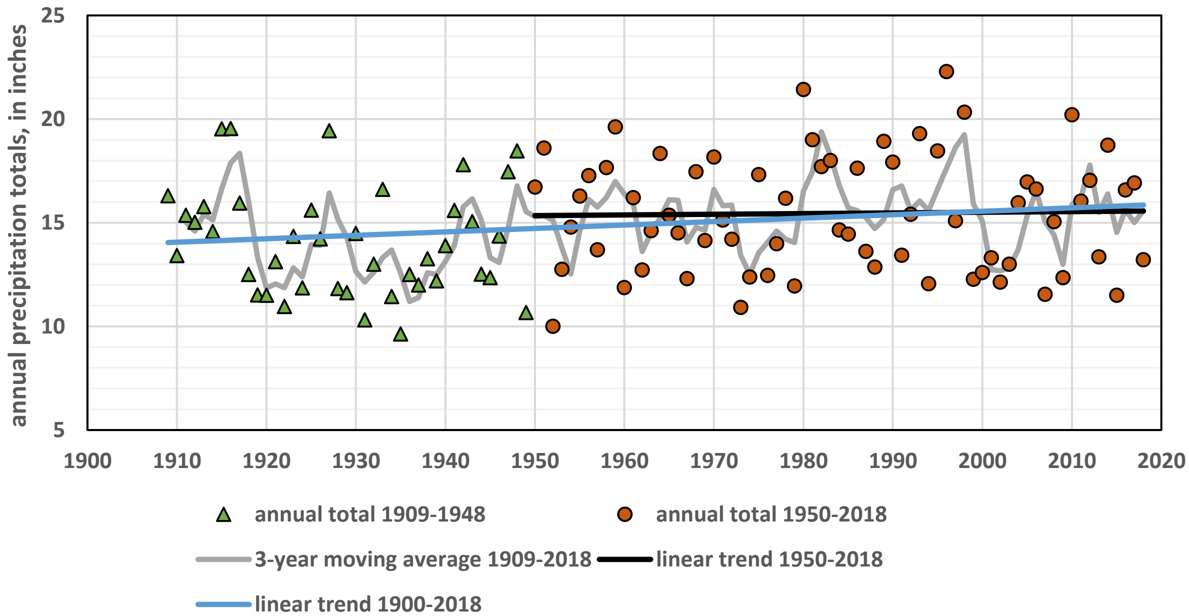

April-June precipitation total, in inches
0
2
4
6
8
10
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
April-June total 1900-1948
April-June total 1950-2018
3-year moving average 1900-2018
linear trend 1950-2018
linear trend 1900-2018

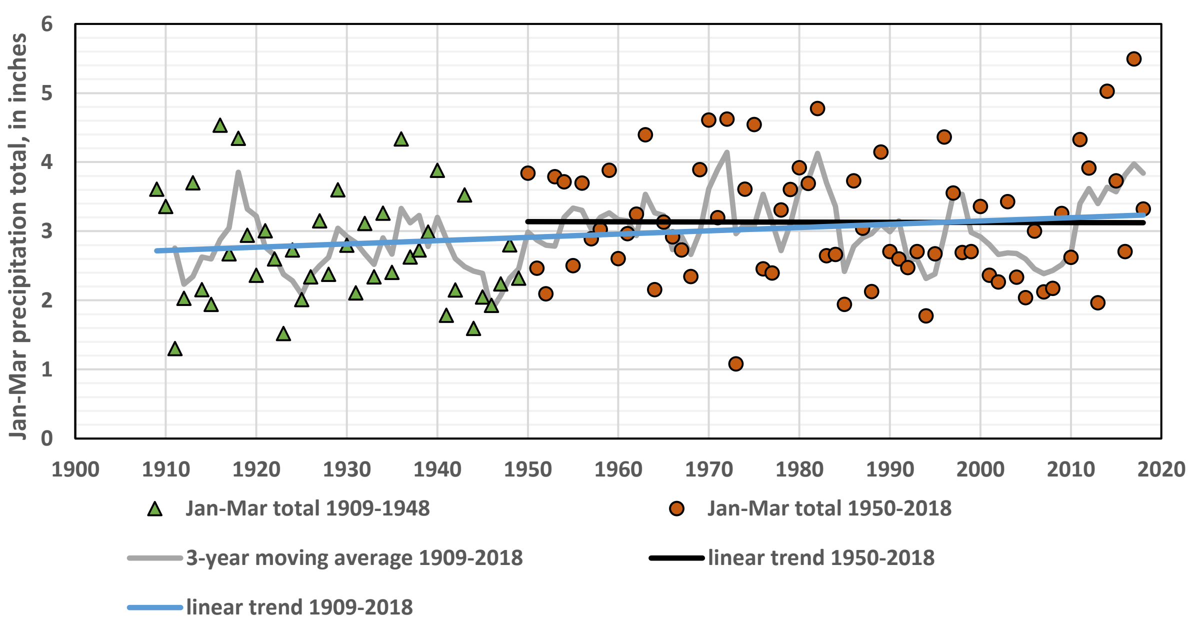

July-Sept precipitation total, in inches
0
2
4
6
8
10
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
July-Sept total 1940-1948
July-Sept total 1950-2018
3-year moving average 1900-2018
linear trend 1950-2018
linear trend 1900-2018

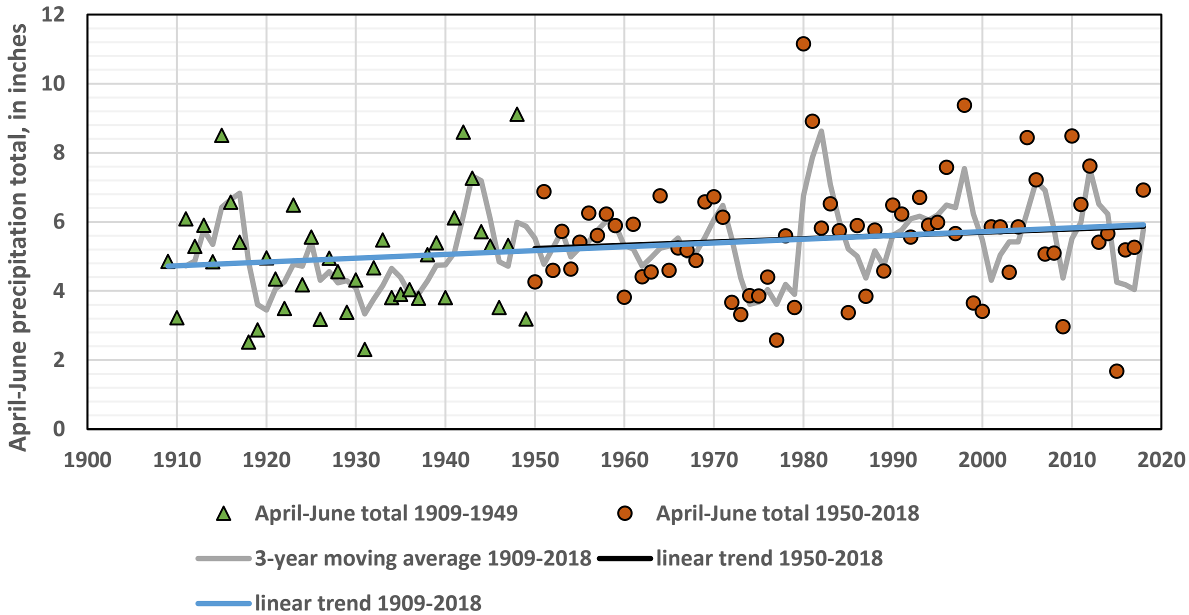


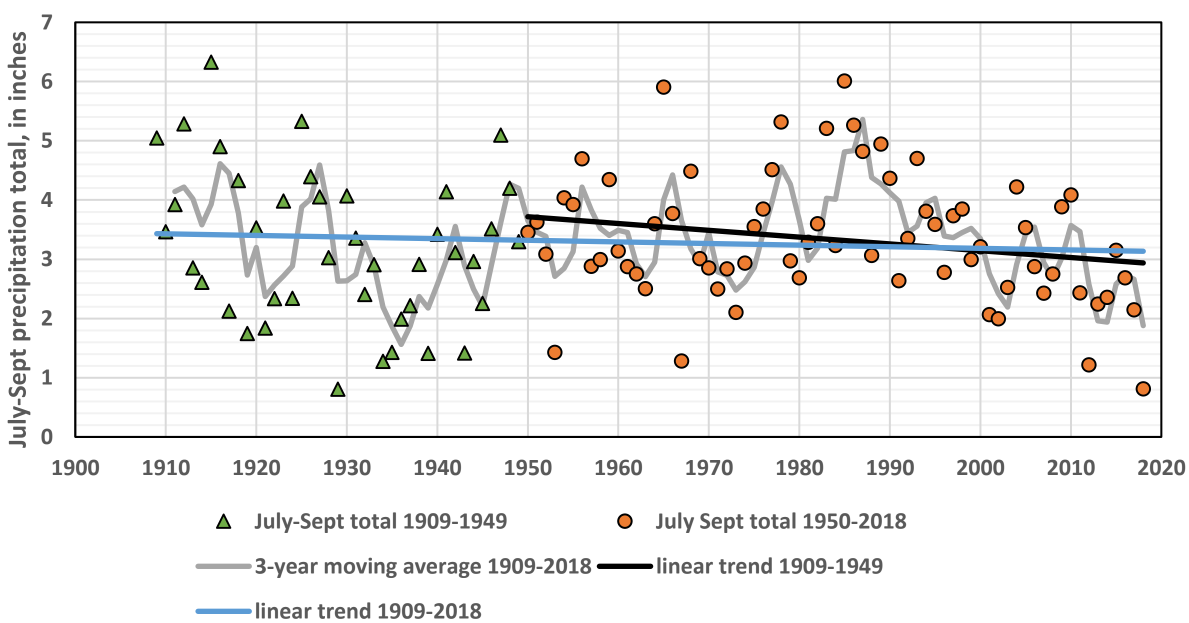
Oct-Dec precipitation total, in inches
0
2
4
6
8
10
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Oct-Dec total 1900-1948
Oct-Dec total 1950-2018
3-year moving average 1900-2018
linear trend 1950-2018
linear trend 1900-2018

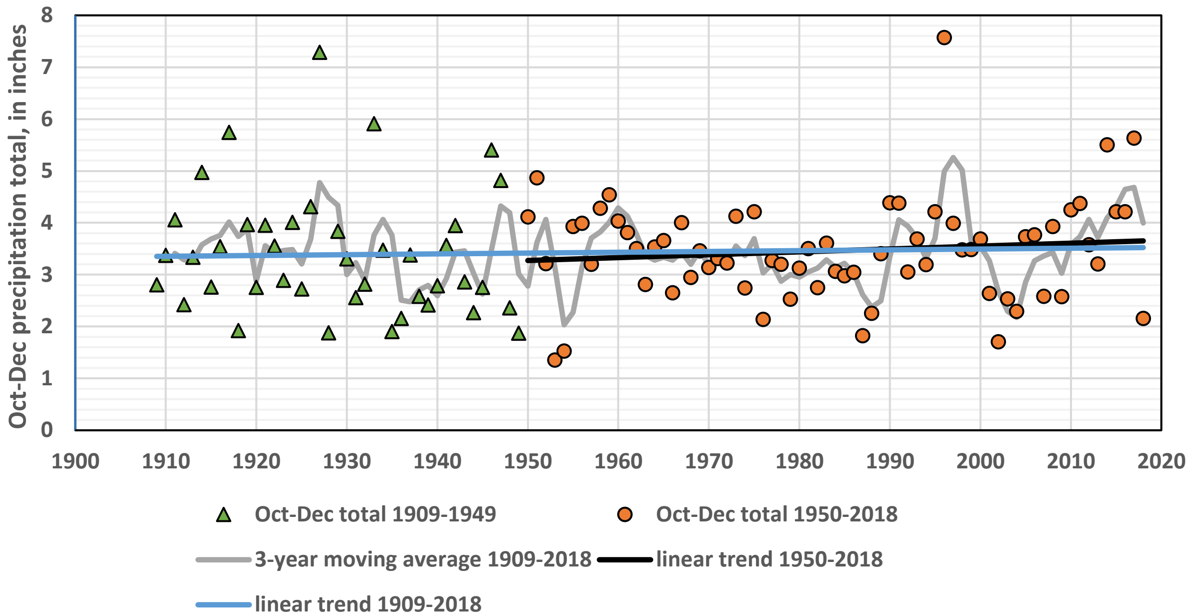
Figure 9 - Composite precipitation data prepared by averaging the Missoula, St. Ignatius, and Kalispell precipitation data for the overlapping 1909 through 2018, 109 year period. The composite figure provides a more regionalized perspective on precipitation trends, reducing the variability that may be associated with an individual location. Annual total, January through March total, July through September total, and October through December total precipitation are reported. Precipitation totals have remained stable or modestly increased for each period, with the exception of July through September totals. These have decreased, and the rate of has accelerated in the recent record. The reported increase in precipitation appears to be weighted by the Kalispell data, which increased at a greater rate than either the Missoula or St. Ignatius data.






April-June precipitation total, in inches
0
2
4
6
8
10
12
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
April-June total 1909-1949
April-June total 1950-2018
3-year moving average 1909-2018
linear trend 1950-2018
linear trend 1909-2018


July-Sept precipitation total, in inches
0
1
2
3
4
5
6
7
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
July-Sept total 1909-1949
July Sept total 1950-2018
3-year moving average 1909-2018
linear trend 1909-1949
linear trend 1909-2018


Oct-Dec precipitation total, in inches
0
1
2
3
4
5
6
7
8
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Oct-Dec total 1909-1949
Oct-Dec total 1950-2018
3-year moving average 1909-2018
linear trend 1950-2018
linear trend 1909-2018

Snowpack Information

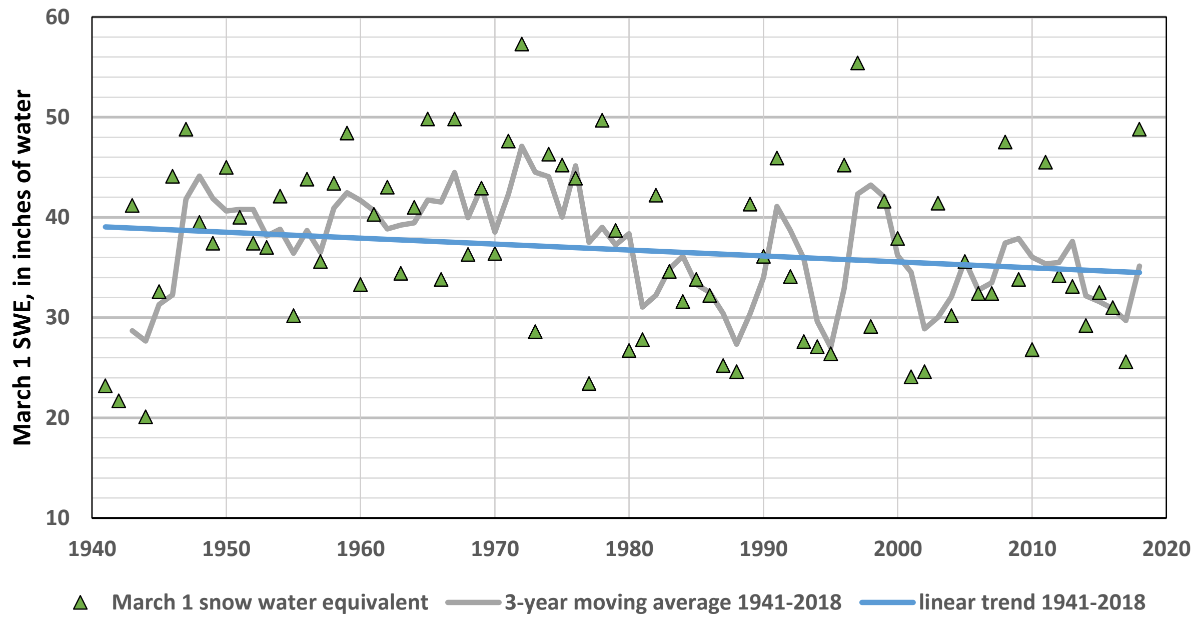
Snowpack information is reported as snow water equivalent (SWE) data for snowpack measurement stations distributed on and near the Reservation. First of month information is reported for March, April, May, and June where available; this reporting format is selected so early snow course data can be combined with more recent SNOTEL data to extend records. Stations are selected with the longest available record and are distributed across a range of elevations, since snowpack accumulation and melt-out is elevation dependent. Data are reported as first of month values with a linear trend line, and as three-year moving average values.

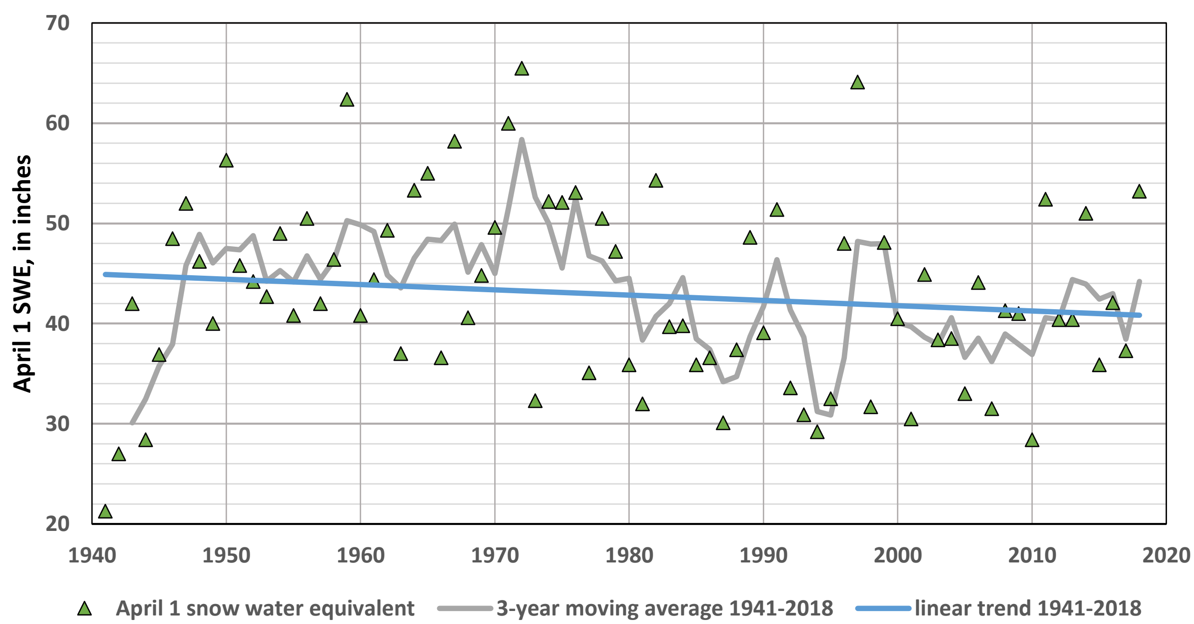
Stations selected for plotting include Kraft Creek in the Swan Valley (4,750 feet); North Fork Jocko (6,330 feet); Moss Peak (6,780 feet) located in the north Mission Range; and Stuart Peak (7,400 feet) located in the Rattlesnake Wilderness. Bisson Creek (4,920 feet) is located on the Mission Front, but has a shorter period of record than Kraft Creek. The North Fork Jocko site includes the NRCS-corrected early record for the snow course station. Moss Peak includes the early record for the Big Creek snow course station (located 30 feet in elevation below SNOTEL site). The record was corrected to combine and extend the station period.

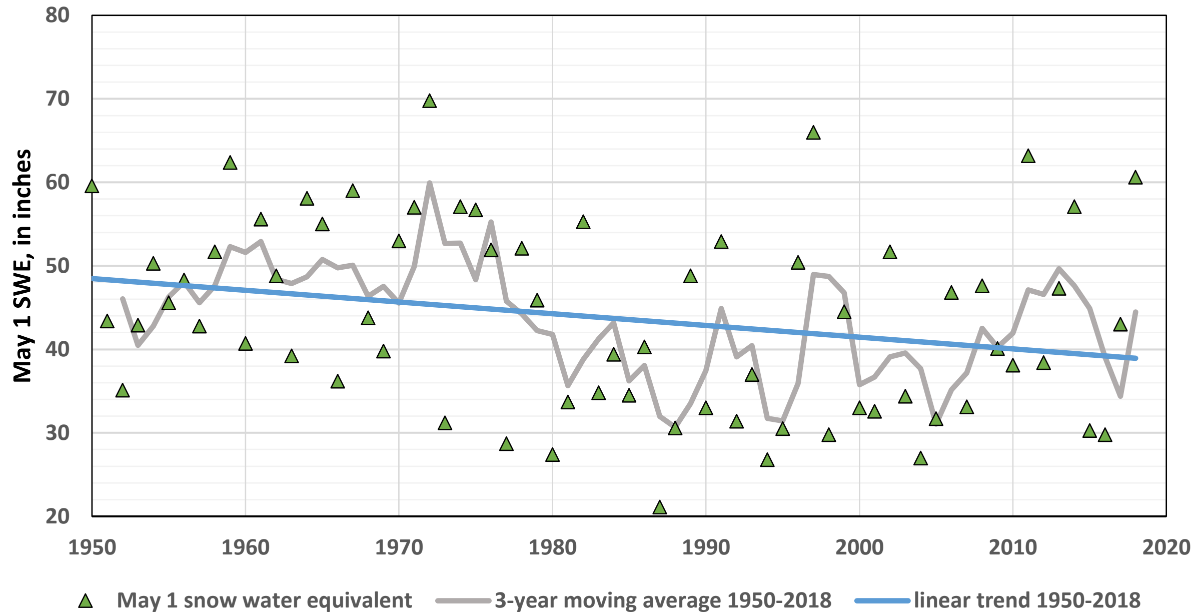
Snow water equivalent is a measure of the combination of snow depth and snowpack density reported in inches of water. As the density of a snowpack changes, for example ripening as spring proceeds, the snow density and SWE will change and generally increase till melt-out.

Snow water equivalent has decreased across the State (b), and the rate of decrease is greater in both the later spring and at lower elevations. This is consistent with observations reported below.

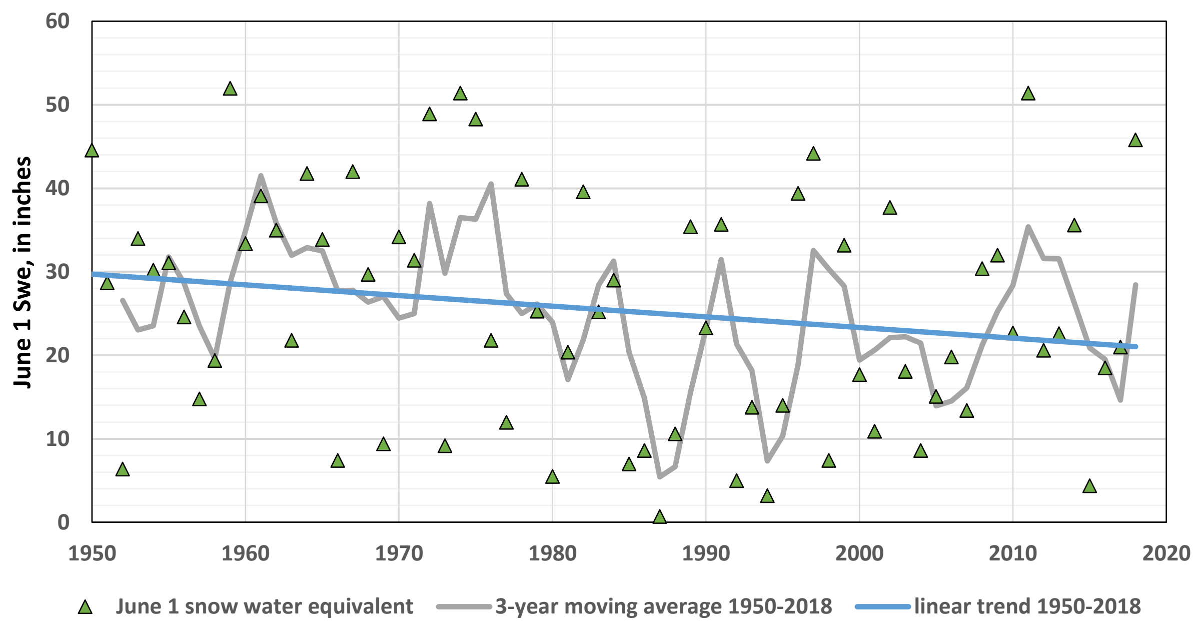
Figure 10 – North Fork Jocko first of month snow water equivalent data are reported for the period 1941 through 2018 for March 1 through June 1. The snow course station was changed to a SNOTEL station in 1989, and early snow course data corrected to the SNOTEL data and provided by the NRCS are applied below. In all months, the SWE has decreased over the measurement period, with higher magnitudes of decrease in May and June. The trend is significant because of the magnitude of change (up to 10 inches of water in May and June) over the period.







May 1 SWE, in inches
80
70
60
50
40
30
20
1950
1960
1970
1980
1990
2000
2010
2020
May 1 snow water equivalent
3-year moving average 1950-2018
linear trend 1950-2018

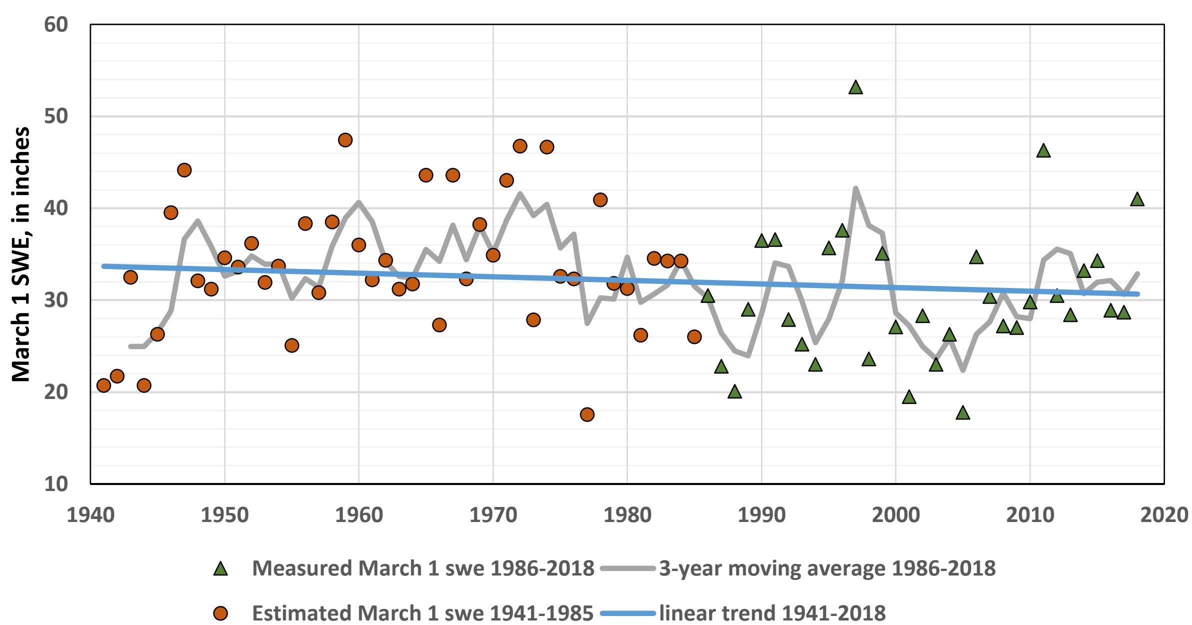


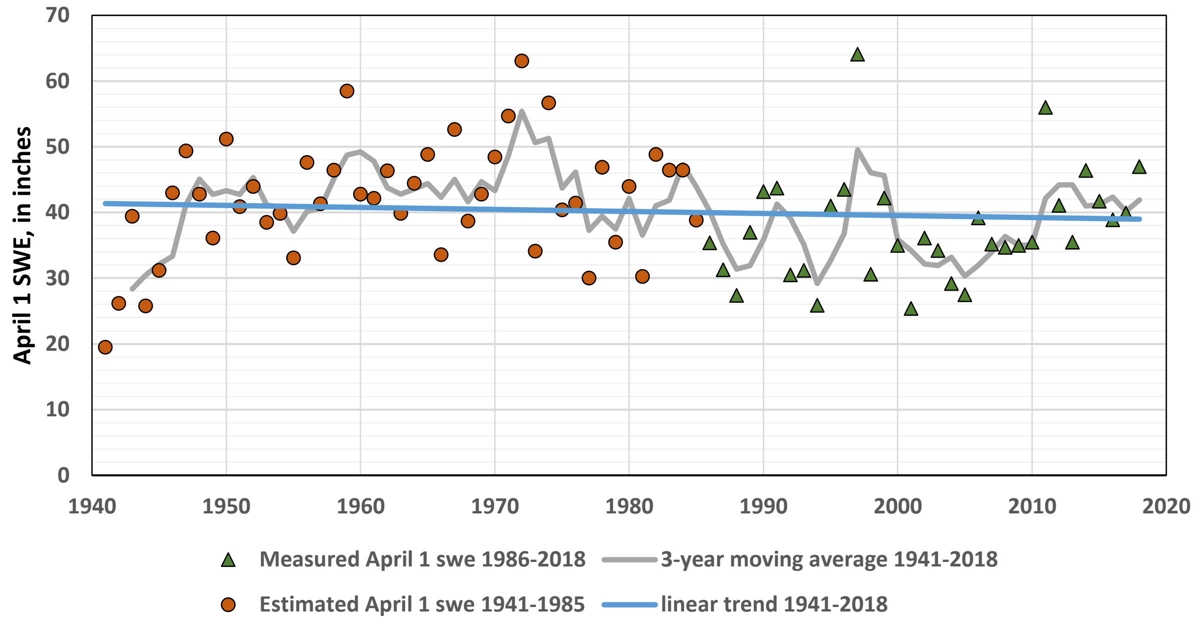
June 1 Swe, in inches
60
50
40
30
20
10
0
1950
1960
1970
1980
1990
2000
2010
2020
June 1 snow water equivalent
3-year moving average 1950-2018
linear trend 1950-2018

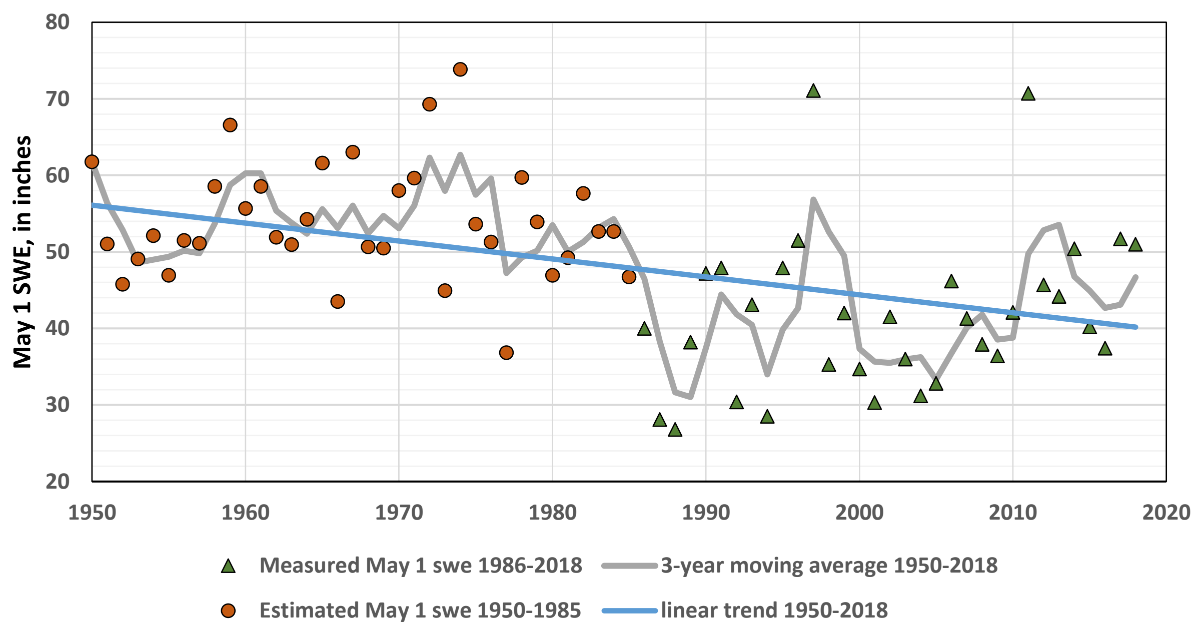
Figure 11 – Moss Peak SNOTEL first of month snow water equivalent data are reported for the 1941-2018 period. The Moss Peak SNOTEL site spans the period 1986 through present. The nearby Big Creek snow course site spans the period 1941 through 2005. SNOTEL data from Moss Peak was extended back to 1941 to provide a longer period of record for trend analysis. June 1 data were not available for the Big creek snow course. Basic statistical indicators for the record extension are below.

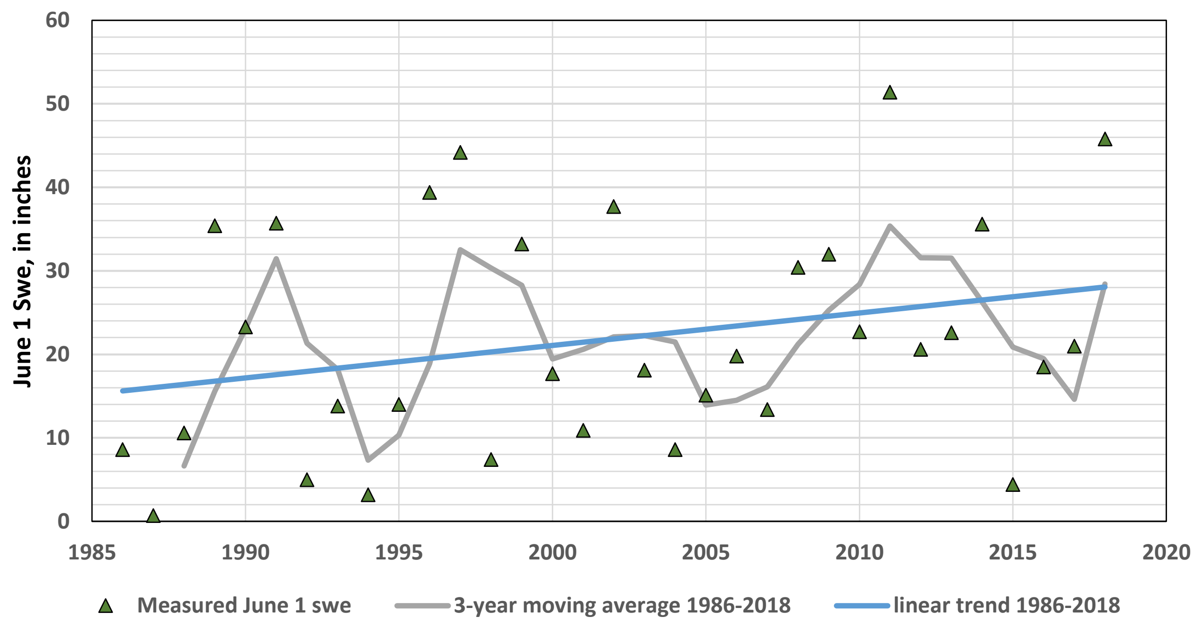
The trend lines generally decrease for months where the full period of record is available. Data suggest the SWE has increased over the 2010 – 2018 period; this may account for the shorter duration June 1 upward trend.

Month	R^2	Standard Error	Distribution of residuals
March 1	0.926	2.417	Equally weighted around zero line
April 1	0.908	2.88	Equally weighted around zero line
May 1	0.900	3.70	Equally weighted around zero line



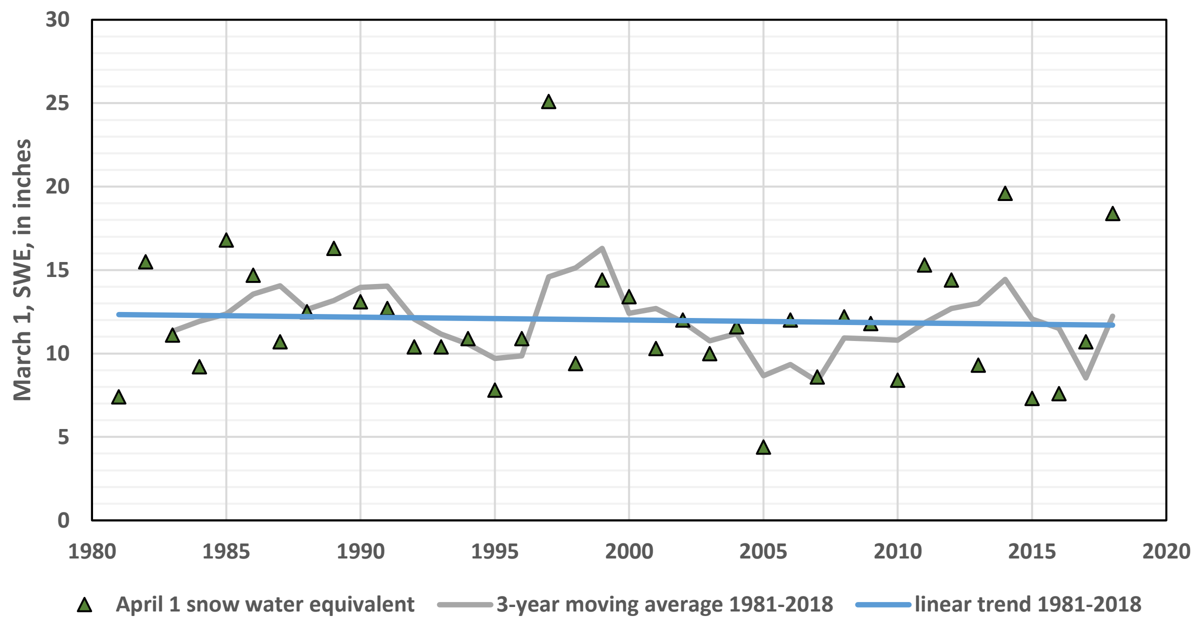

April 1 SWE, in inches
70
60
50
40
30
20
10
0
1940
1950
1960
1970
1980
1990
2000
2010
2020
Measured April 1 swe 1986-2018
3-year moving average 1941-2018
Estimated April 1 swe 1941-1985
linear trend 1941-2018

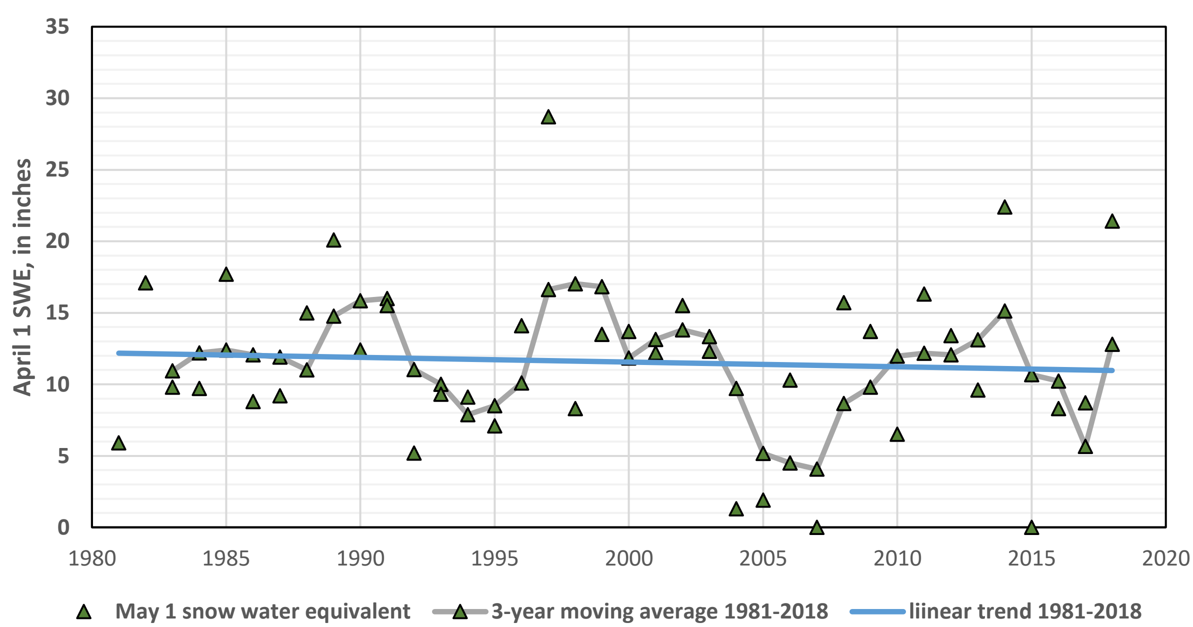

May 1 SWE, in inches
80
70
60
50
40
30
20
1950
1960
1970
1980
1990
2000
2010
2020
Measured May 1 swe 1986-2018
3-year moving average 1950-2018
Estimated May 1 swe 1950-1985
linear trend 1950-2018



June 1 Swe, in inches
60
50
40
30
20
10
0
1985
1990
1995
2000
2005
2010
2015
2020
Measured June 1 swe
3-year moving average 1986-2018
linear trend 1986-2018

Figure 12 – Kraft Creek data are available from 1981 – present. This location represents mid to low elevation snowpack. Data are not reported for June 1, since the values are consistently zero SWE. Data show either a modest declining or increasing trend slope, and do not parallel the widely observed decrease in low elevation snow in the western U.S. (b).





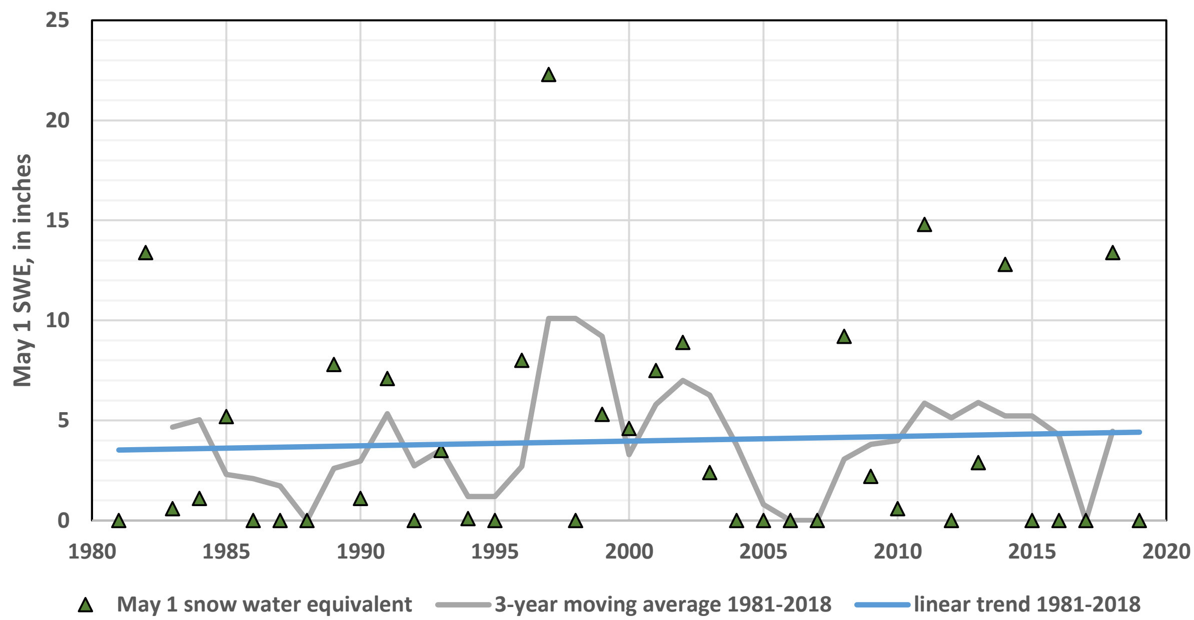
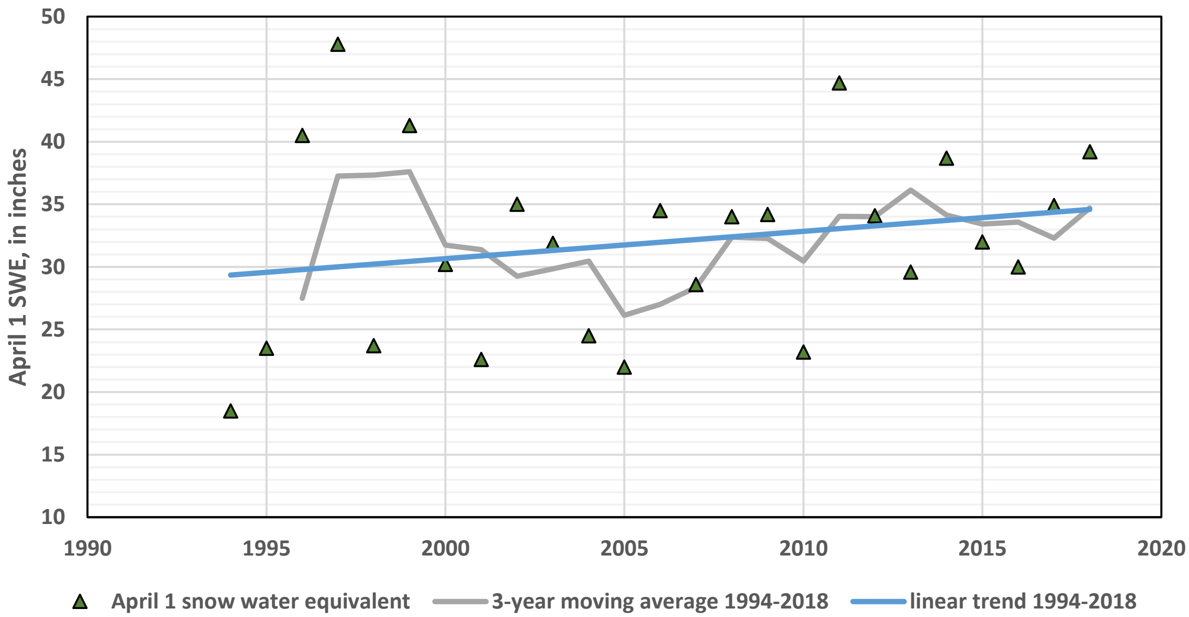
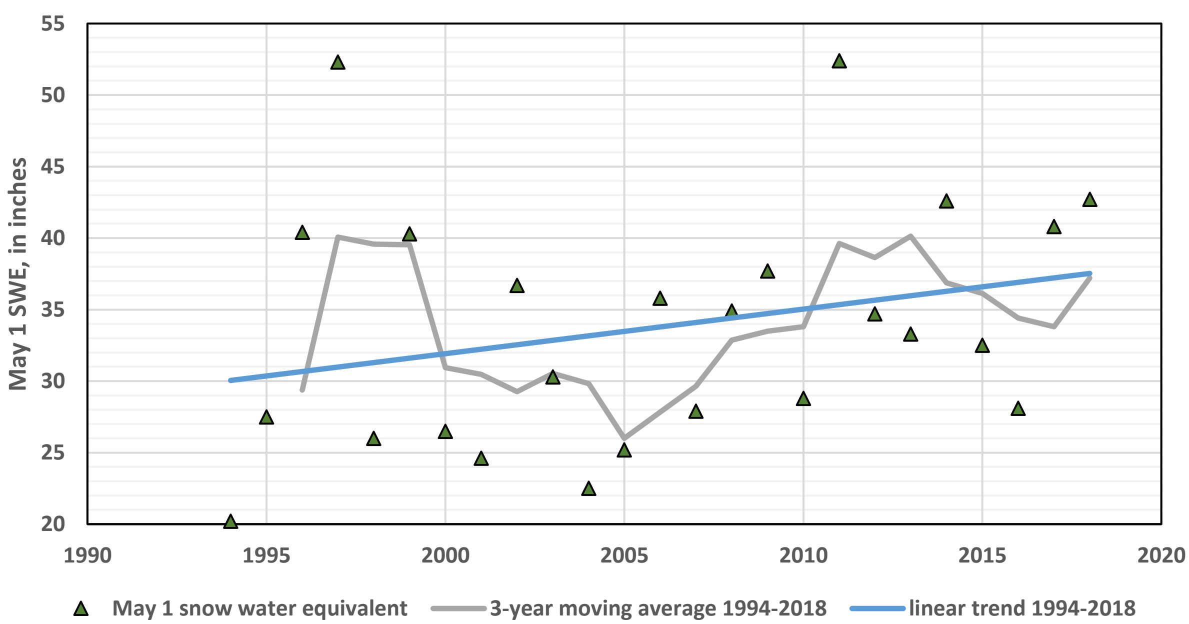
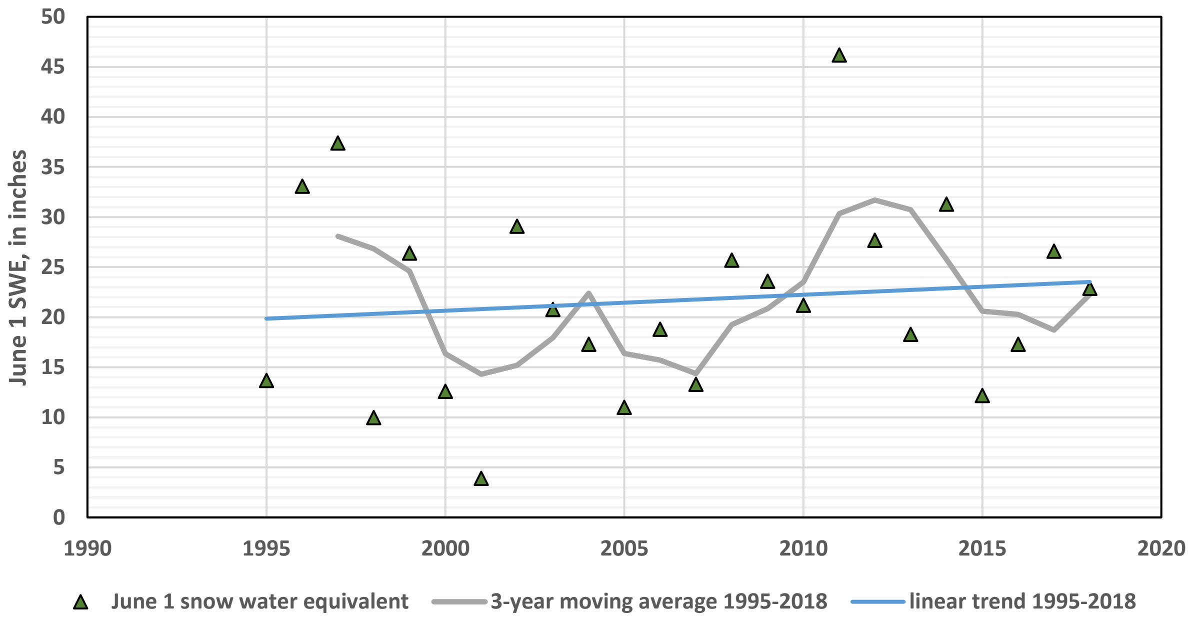

May 1 SWE, in inches
25
20
15
10
5
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
May 1 snow water equivalent
3-year moving average 1981-2018
linear trend 1981-2018

Figure 13 – Stuart Peak SNOTEL data represents a higher elevation SNOTEL site (7,400 feet), recognizing that SNOTEL data representing the upper elevation bands in the Mission Range is not available. The period of record is relatively short (1994-present), and trend information should be viewed with caution. For each plotting period, SWE has increased, contrary to more regional trends. This may reflect the starting point for the trend plot, and the relatively short record.







References

(a) ***Stocker, T.F. and others. 2013. Technical Summary. In. climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.***

(b) ***Whitlock C, Cross W, Maxwell B, Silverman N, Wade AA. 2017. 2017 Montana Climate Assessment. Bozeman and Missoula MT: Montana State University and University of Montana, Montana Institute on Ecosystems. 318 p.***