EC717
October 2020

Long-term (1893-2012) Changes in Monthly, Growing Season and Annual Precipitation Trends and Magnitudes in Central Nebraska

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Precipitation has a profound impact on both irrigated and rainfed crop production and hydrological functions of ecosystems in arid, semiarid, humid, and subhumid regions. In arid and semiarid regions, precipitation amount and distribution within the growing season is one of the primary drivers of agricultural productivity. In humid/subhumid regions, even though precipitation is generally adequate for crop production, a few inches of variability (i.e., below or above normal precipitation) can have substantial negative impacts on agro-ecosystem productivity. Small deviations from long-term average precipitation can result in large fluctuations in stream flows and surface runoff, which impact wildlife and natural habitats in wetlands, riparian areas, etc. Effects also may be observed in the amount of water collected in reservoirs, ponds, lakes and other water bodies; and depths to groundwater for irrigation, municipal, recreational, and other uses. Thus, understanding and quantifying the long-term changes in precipitation amount and variability can help managers better evaluate the long-term trends in agricultural productivity. This, in turn, will allow for better assessments in food security, policy decisions, resource assessments, land and water resources enhancement, and management decisions.

In the United States, the long-term average annual precipitation ranges from about 64 inches per year in Hawaii to only about 9.5 inches in Nevada. Hawaii, Louisiana (60 in), Mississippi (59 in), Alabama (58 in), and Florida (54.5 in) are the top five (in order) ranked states in terms of largest annual precipitation amounts. Nevada, Utah (12.2 in), Wyoming (12.9 in), Arizona (13.6 in), and New Mexico (14.6 in) are the top five states in terms of lowest annual precipitation amounts. On a statewide average, the annual average precipitation in Nebraska is about 23 inches. The reported "long-term" annual average precipitation for any given location varies depending on the number of years used to estimate these values. In Nebraska, annual precipitation exhibits significant variability, ranging from 30 inches in the southeastern part of the state to 11.8 inches in the western part of the Panhandle.

In this publication, changes in trends and magnitudes of the long-term (1893 to 2012) monthly, growing season, and annual precipitation are presented and discussed. This is the first of a series of publications that quantifies and evaluates the changes in long-term precipitation for various parts of Nebraska (eastern, central, south central, and western). Another companion publication analyzes the long-term trends in annual and growing season precipitation for each of the 93 counties. For this publication, the Central City, Neb., area is selected to represent central Nebraska. The analyses were conducted on monthly, growing season (May 1 to Sept. 30), and annual (Jan. 1-Dec. 31) periods.

Long-term Monthly Total Precipitation Trends

The long-term trends from Jan. 1, 1893, to Dec. 31, 2012, for each month are presented in *Figure 1*. The data points (bars) in *Figure 1* for each month represent a record of measured precipitation data for a 120-year period. The trend (blue) line represents the regression line and indicates the direction (decreasing or increasing) and magnitude of change in monthly total precipitation. There is a slight increase in **January** precipitation. There were 11 years (1899, 1900, 1903, 1920, 1928, 1961, 1962, 1986, 1987, and 2011) when no precipitation was recorded in January. The highest amount of January precipitation occurred in 1992 (1.85 in); the second highest amount was in 1916 (1.80 in). *The January precipitation increased by 0.10 inches from 1893 to 2012*. In the last decade, from 2001 to 2012, there was a gradual decline in January precipitation.

The trend was opposite in **February** with a slight declining trend from 1893 to 2012. There were only six years (1923, 1946, 1991, 1996, and 2011) without any February precipitation. The highest amount of February precipitation occurred in 1971 (2.80 in). There was a sharp decline in precipitation from 1915 to 1950 and gradual incline from 1950 to 1971; another incline until 2004 and another sharp decline in precipitation until 2012. The duration of these increasing and decreasing trends in February precipitation, as well as in other months, shows no regularity. *The February precipitation decreased by 0.10 inches from 1893 to 2012*.

March displayed a greater increasing trend than January. There were two years with very large precipitations, 1987 (8.45 in) and 1973 (6.86 in). Another large precipitation event occurred in 1988 (4.55 in). There is a strong increasing trend in March precipitation which began in 1973 and continued until 2007. There were only five years (1910, 1967, 1994, and 2011) without any March precipitation. *The monthly total March precipitation increased considerably by 0.83 inches from 1893 to 2012*.

An increasing trend in precipitation was noticed for **April** where precipitation exceeded 5.0 inches during eight years. The largest precipitation occurred in 1978 (8.2 in). There were not any years without April precipitation. *The monthly total precipitation in April increased considerably by 0.60 inches from 1893 to 2012*.

Among all months, the change in **May** precipitation was greatest with a strong increasing trend. There were 17 years when May precipitation exceeded 6.0 inches, and six years when precipitation exceeded 8.0 inches. The largest precipitation occurred in 1903 (9.80 in). *The monthly total precipitation in May increased substantially by 1.30 inches from 1893 to 2012*. There were not any years without May precipitation. The lowest amount of precipitation in May occurred in 1934 (0.6 in) during the Dust Bowl era. Overall trends indicate increasing precipitation in the winter and spring months in central Nebraska near the Central City area. Given the significant spatio-temporal variability in precipitation, these trends and magnitudes of changes may not be applicable in all locations in central Nebraska. However, when the long-term (120-year) average records are considered, these trends and magnitudes may not show significant variability in central Nebraska.

Increased precipitation during the winter (dormant) season is beneficial for recharging the soil profile for the next growing season and providing beneficial soil moisture for some crops (e.g., winter wheat). In contrast, the increase in spring precipitation (e.g., May) may alter farming practices during the planting season by delaying planting, which may cause yield reduction. Late emergence; lodging; cooler than optimum soil temperatures, which delay plant growth and development; and leaching of nutrients also may occur.

Summer precipitation exhibited a greater level of variability in trends and magnitudes when compared to the winter and spring months. **June** exhibited a decreasing trend, *the monthly total precipitation decreased by 0.35 inches from 1893 to 2012*. The lowest June precipitation occurred in 1978 (0.61 in), while the record high occurred in 1967 (14.9 in), which caused one of the major flood events in Nebraska's history. This represents the record high monthly precipitation for Nebraska in the last 120 years of climate records. On June 18, 1967, the worst flood since 1952 occurred in Nebraska City. The 1967 event, with 23-foot crest and 18-foot flood stage, flooded the docks and industrial areas as well as residential areas, causing significant damage. The record June precipitation also caused record flooding from the Wood River, damaging 1,800 buildings, impairing streets and highways, and causing sewer failures in the Grand Island (Hall County) area. The Wood River Diversion Project, completed in 2004, was initiated in response to this flood event.

July precipitation had a considerable increasing trend. Cyclic inclines and declines are noticed in July precipitation data at about 15 to 20 year intervals. Extreme precipitation events were also found within these intervals. The record-high July precipitation occurred in 1958 (9.63 in) and the lowest July precipitation occurred in 1935 (0.21 in). There were not any years without July precipitation. *The monthly total precipitation in July increased substantially by 0.80 inches from 1893 to 2012*. An increase in July precipitation has significant positive implications to crop production, especially for maize and soybean.

During this time, crops are in their critical growth and development stages, and water stress can cause significant yield quantity and quality reductions. However, the potential positive implications of an increase in July precipitation strongly depends on the changes in other climate variables such as air temperature. Extreme temperature (heat) stress also can cause yield quantity and quality reductions, even under optimal soil moisture conditions. Thus, it is important to understand the simultaneous interactions between various climatic variables to infer any information in terms of the impact(s) of changes in climatic variables on agricultural productivity.

August precipitation had a decreasing trend, which was more prominent from 1924 to 1968. Three highest August precipitations occurred in 1987 (6.82 in), 1986 (6.64 in), and 1903 (6.56 in). The lowest was recorded in 1988 (0.33 in). It is interesting to note that the August precipitation was surprisingly suitable for crop production in some years during the Dust Bowl era in early 1930s. For example, in 1933, August precipitation was 5.92 inches, but in 1934 it was only 1.51 inches. *Overall, the monthly total precipitation in August decreased by 0.40 inches from 1893 to 2012*. Because both maize and soybean are typically in their critical growth stages (i.e., grain fill for maize and full-seed/pod development for soybean) in August in central Nebraska, any decrease in precipitation during this month may create challenges in meeting crop water requirements, especially for rainfed settings.

Fall precipitation showed the least amount of variation with a slight decrease in September and December precipitation and slight increases in October and November. The second largest recorded monthly precipitation in the last 120-year period occurred in **September** 1965 (11.0 in). While there was a slight decreasing trend in September precipitation, there has been an increase in larger (extreme) precipitation events since the 1970s. There was only one year (2011) with no record of September precipitation. The least amount of precipitation occurred in 2009 (0.01 in). *The monthly total precipitation in September decreased by 0.17 inches from 1893 to 2012*.

Two of the largest **October** precipitations occurred in the last decade [2007 (5.4 in) and 2008 (6.1 in)]. There is a general decline in October precipitation from 1894 until 1965, and an increasing trend since 1965. *The monthly total precipitation in October increased by 0.19 inches from 1893 to 2012*.

Similar fluctuations in **November** precipitation were observed. There is a general increasing trend in November precipitation from 1893 to 1931, a decreasing trend from 1931 to 1970, another increasing trend from 1970 to 1983, and a decreasing trend from 1983 to 2012. The largest November precipitation occurred in 1909 (5.1 in). The months with the greatest number of years without precipitation events are November and December. There were 10 years (1894, 1914, 1917, 1921, 1927, 1939, 1949, 1954, 2011, and 2012) when precipitation did not occur in November. The least amount of precipitation (0.01 in) occurred in 1936. *The monthly total precipitation in November increased by 0.32 inches from 1893 to 2012*.

While the overall trend for **December** was decreasing, two general trends were noted. There is a decreasing trend from 1893 towards the late 1950s, and an increasing trend thereafter. The largest December precipitation occurred in 2006 (3.0 in). There were 10 years (1903, 1905, 1922, 1929, 1943, 1949, 1995, 2010 and 2011) when there was no recorded December precipitation. *The monthly total precipitation in December decreased slightly by 0.04 in. from 1893 to 2012*.

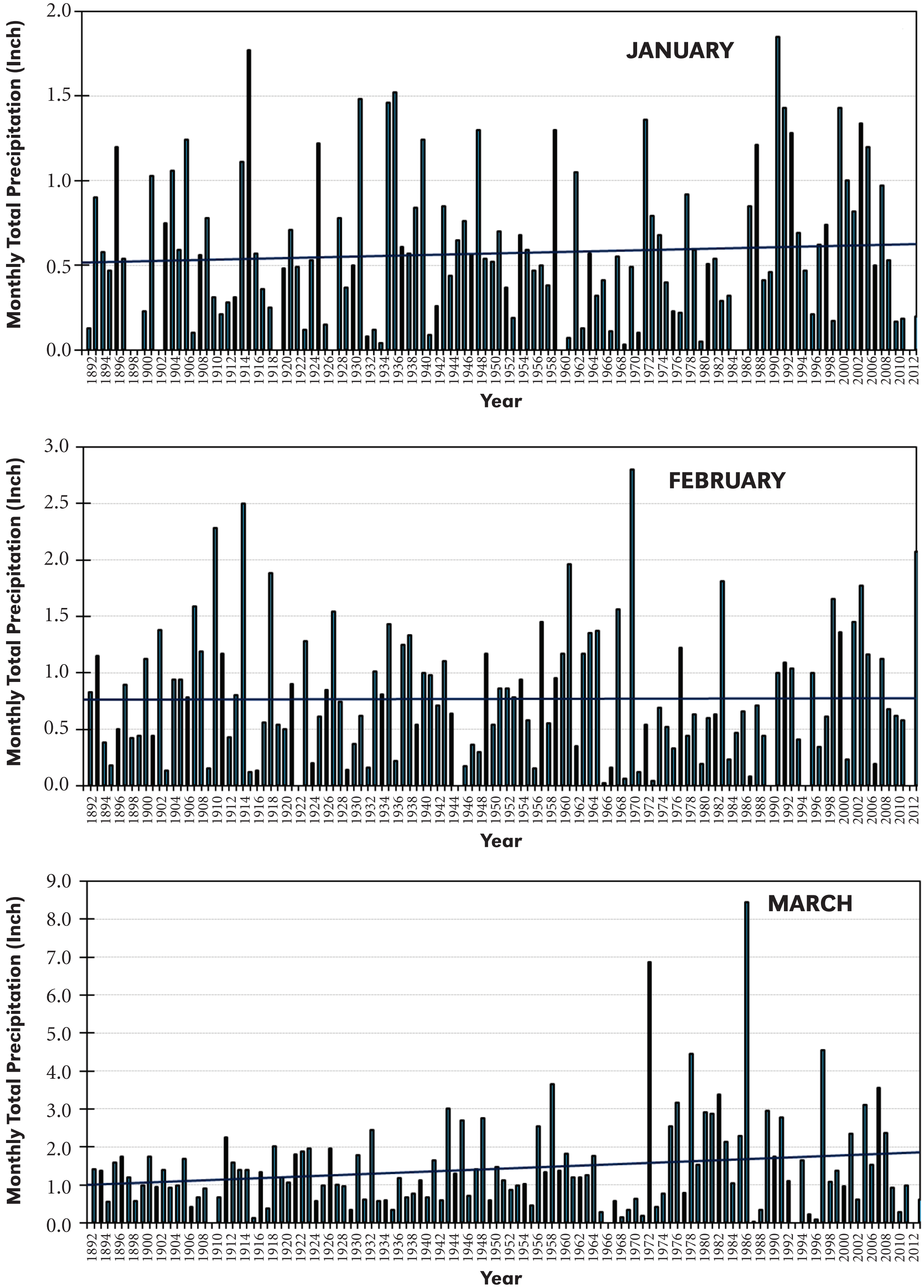
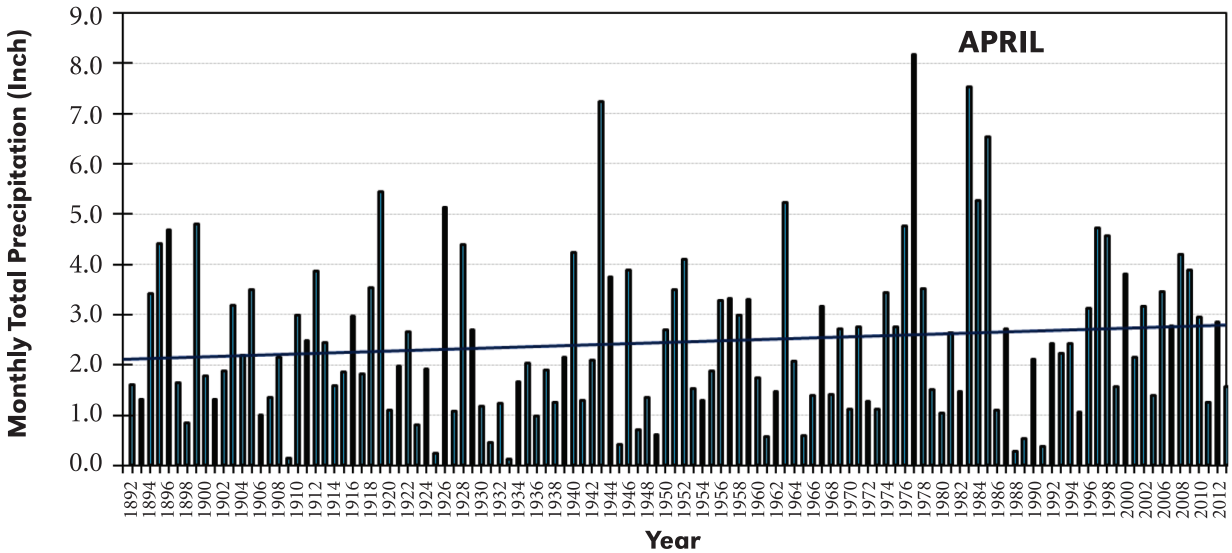
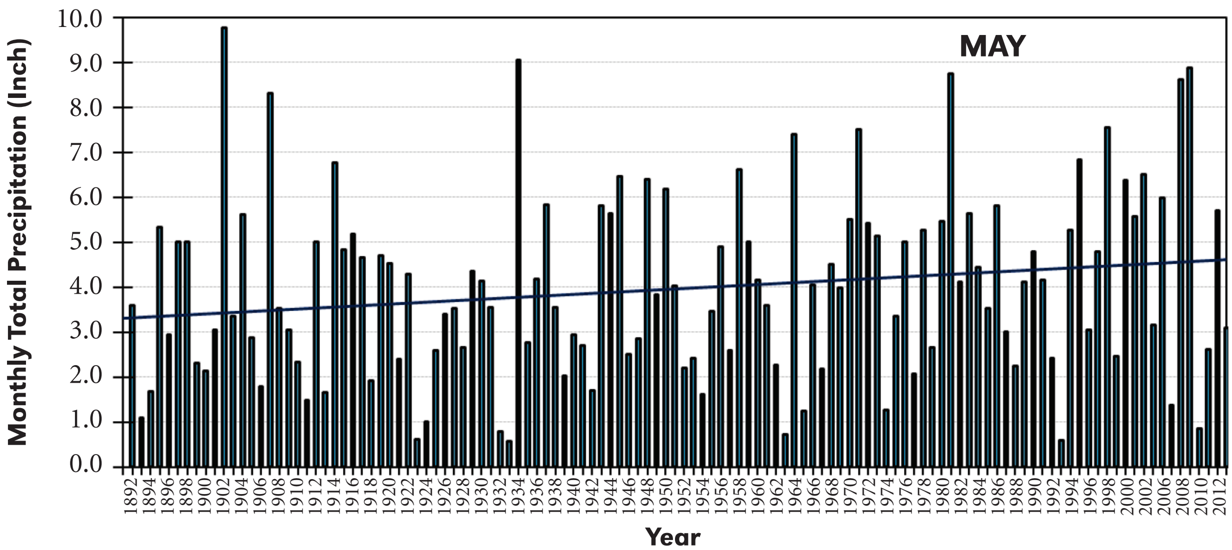


Figure 1. Long-term (1893-2012) monthly total precipitation for each month in central Nebraska.





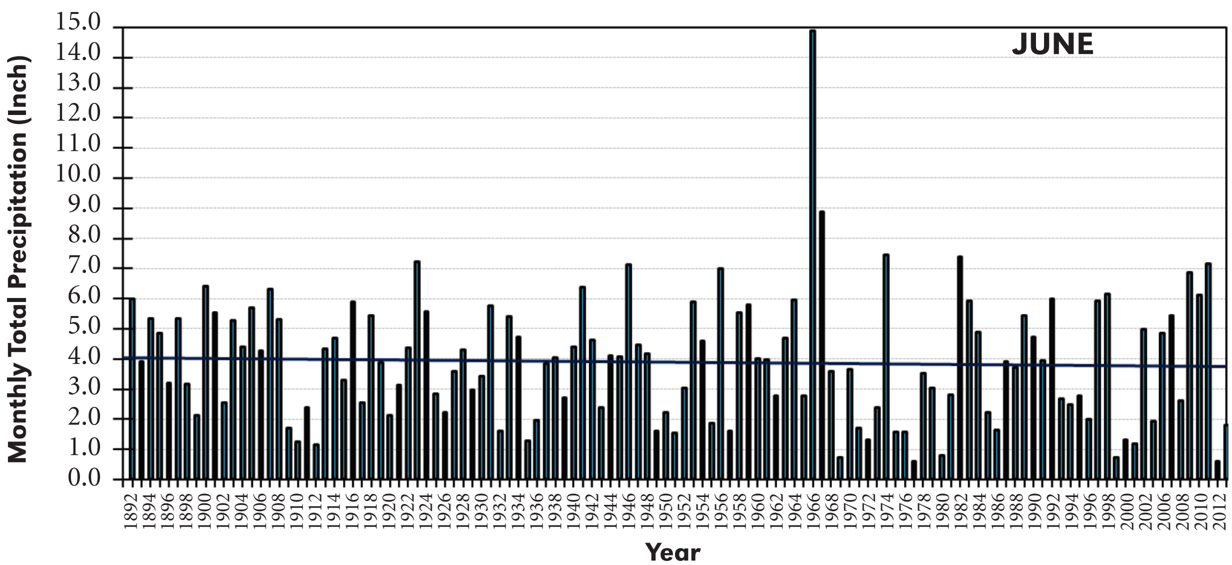


Figure 1. Long-term (1893-2012) monthly total precipitation for each month in central Nebraska (continued).

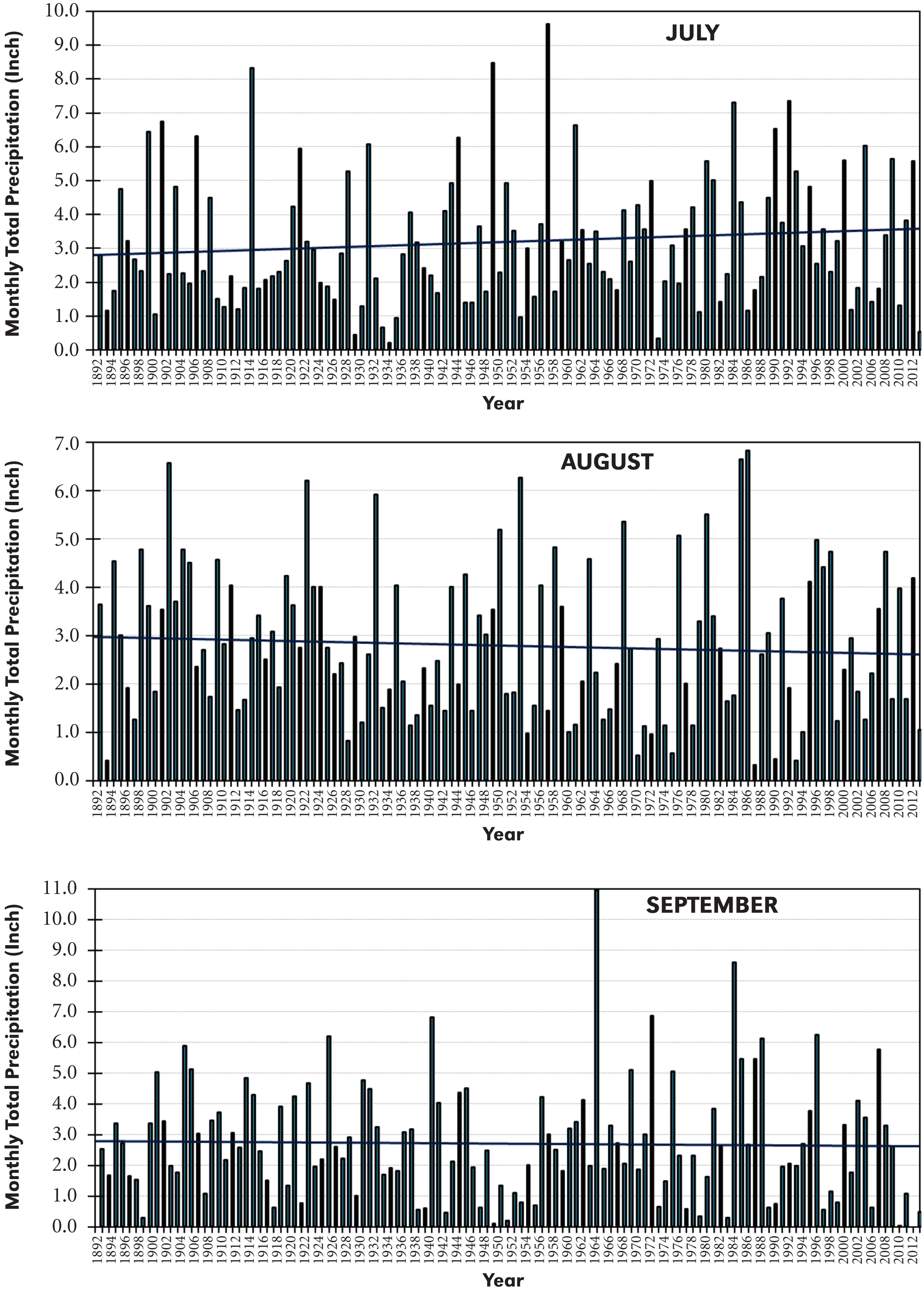


Figure 1. Long-term (1893-2012) monthly total precipitation for each month in central Nebraska (continued).

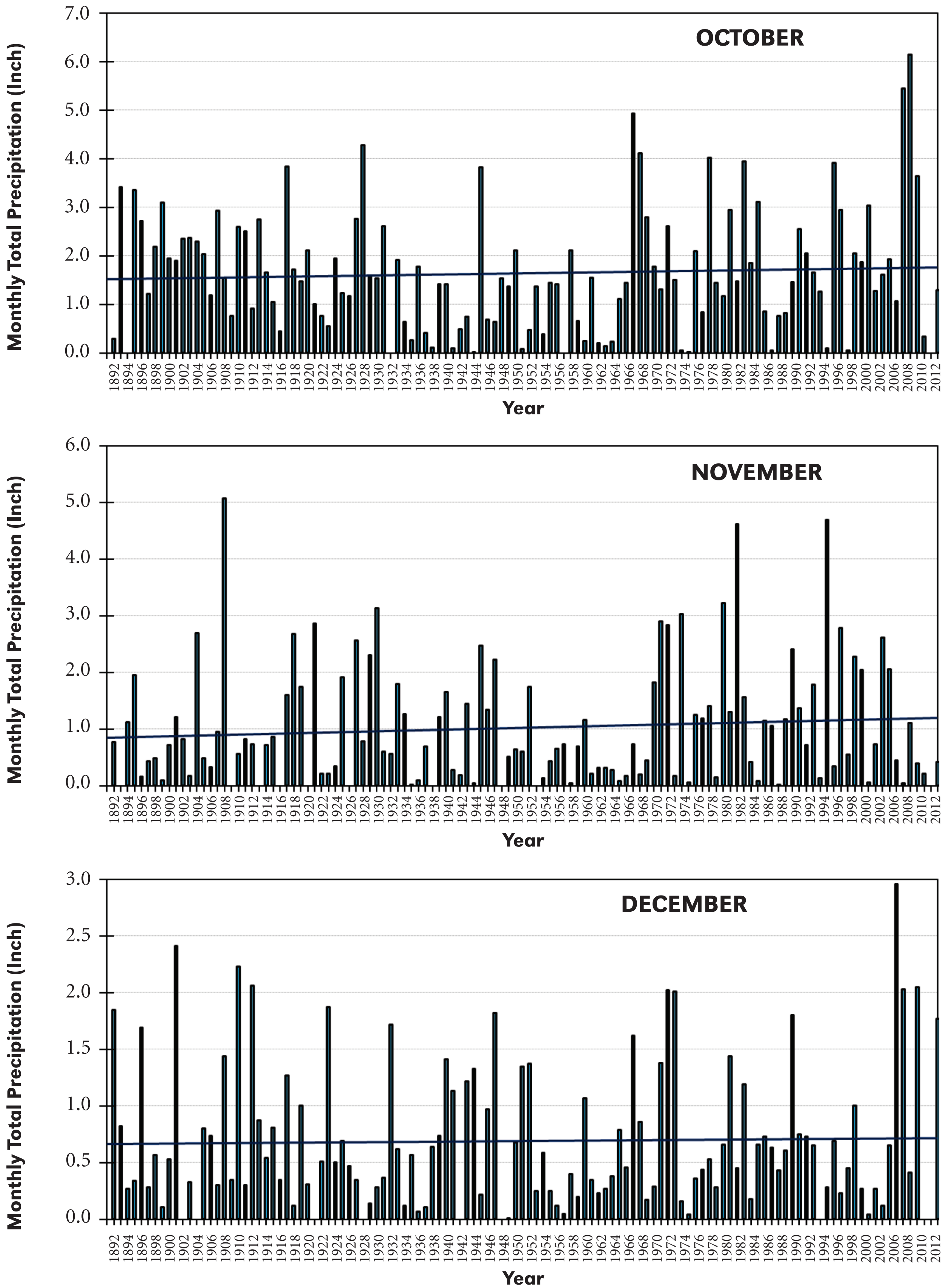


Figure 1. Long-term (1893-2012) monthly total precipitation for each month in central Nebraska (continued).

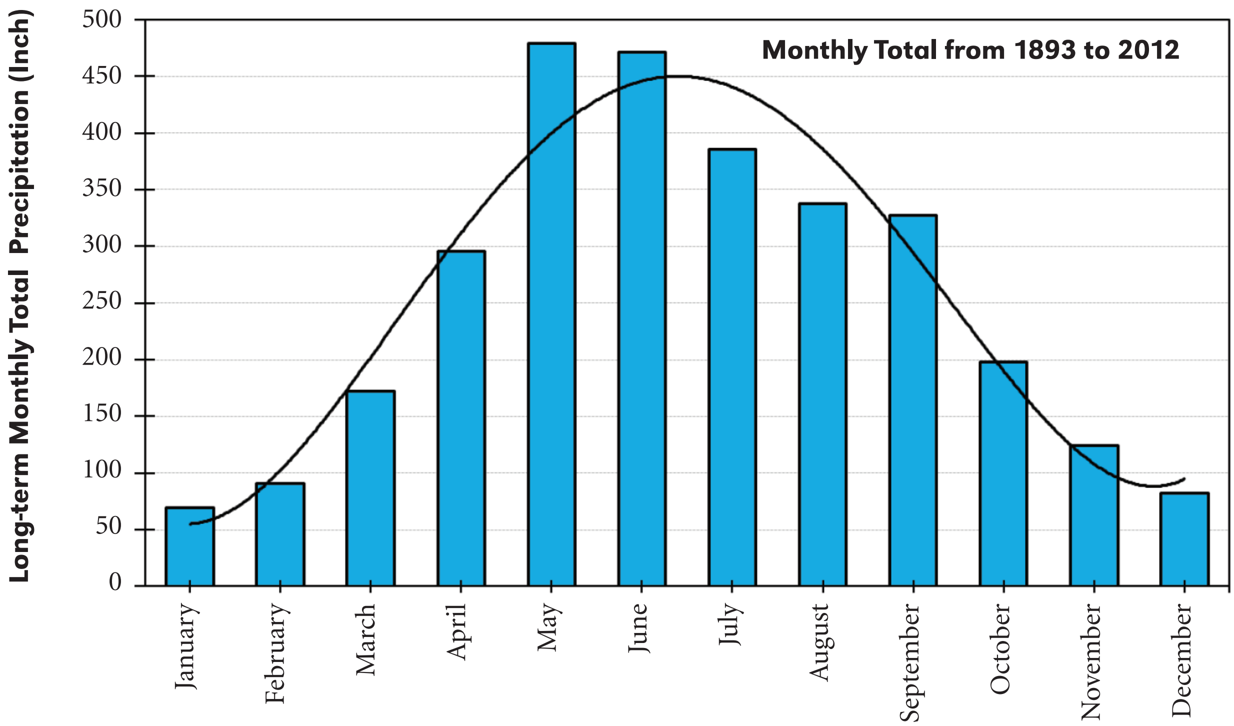


Figure 2. Long-term (1893-2012) monthly total precipitation in central Nebraska.

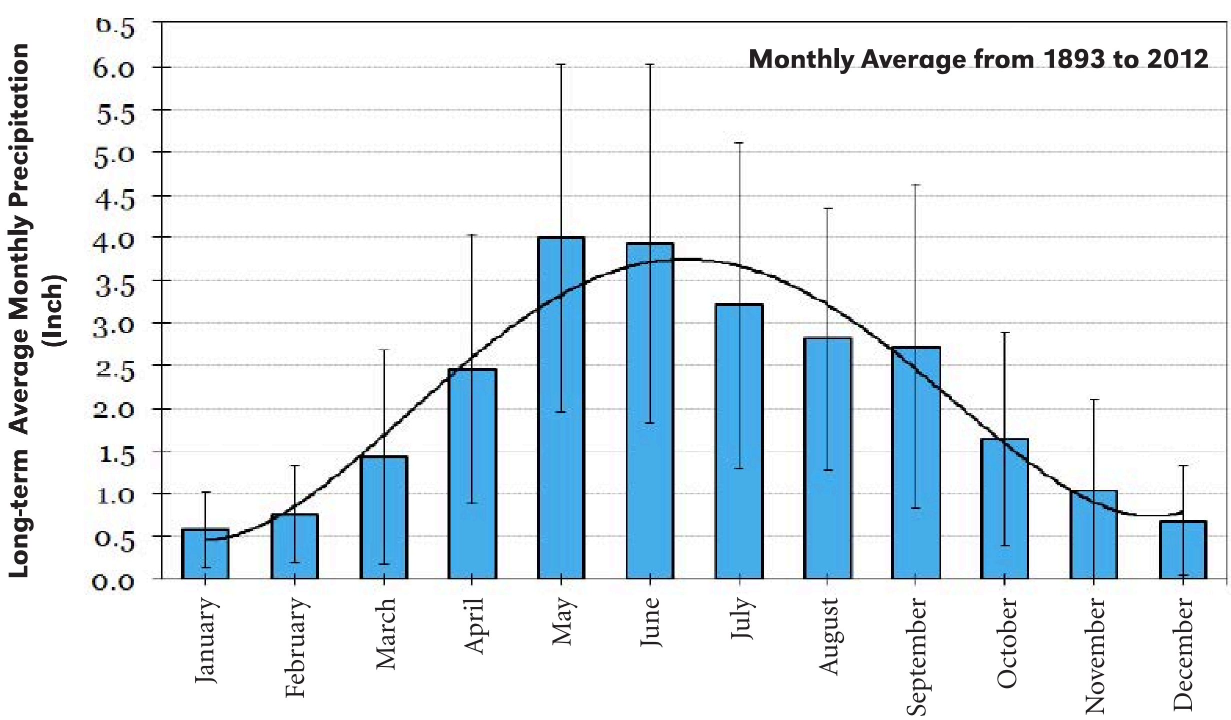


Figure 3. Long-term (1893-2012) monthly average precipitation in central Nebraska. Vertical bars represent long-term (120-yr) standard deviations.

Long-term Total and Long-term Average Precipitation for Each Month

The total precipitation for each month from 1893 to 2012 is presented in *Figure 2*. The 120-year total monthly precipitation had a bell-shaped (normal distribution) curve, increasing from January towards May and June, and decreasing from June towards fall. In the last 120-year period the most amount of precipitation (peak precipitation month) occurred in May (a total of 480 inches for the 120-year period), with June following the peak precipitation month very closely (471 in). The least amount of precipitation was observed in January (69 in) and December (82 in). The long-term average monthly precipitation (*Figure 3*) had similar distribution as long-term total precipitation for each month.

Annual Total and Cumulative Annual Precipitation

Annual total precipitation amounts are presented in *Figure 4*. Annual (Jan. 1 to Dec. 31) precipitation exhibited substantial variability among the years since 1893. On a long-term average basis (1893 to 2012), annual total precipitation increased considerably, but the increase was not significant ($P = 0.3029 > 0.05$). The annual total precipitation has increased due to an increase in extreme daily precipitation events. From 1893 to 2012, the annual total precipitation has increased by 1.94 inches with a rate of 0.0162 inches per year. Also, there was a significant increase in maximum daily precipitation (the value for the day with the largest amount of precipitation) and a noticeable increase in large or extreme events (i.e., daily precipitation greater than 1.57 inch) (*Figure 5*).

The increase in maximum daily precipitation means there is an increase in precipitation events that may not be beneficial to recharging the soil profile due to increased potential for surface runoff. The maximum daily precipitation has increased by about 1.57 inches between 1893 and 2008 with a rate about 0.0131 inches per year. Annual total precipitation in 2012 in the Central City area (14.9 inch) was the third lowest annual precipitation amount recorded since 1893. The lowest precipitation occurred in 1966 as 14.0 inches, and the second lowest value was recorded in 1956 as 14.8 inches. Although the Dust Bowl era had significantly greater air temperatures and vapor pressure deficits and had greater drought conditions than in 2012: years 1956, 1966, and 2012 were drier than the Dust Bowl era in terms of precipitation. Daily maximum precipitation events (*Figure 5*) were low from 1893 to 1931, ranging between approximately 1.2 inches and 1.5 inches per day and exhibited a sharp increase afterwards. The 120-year average annual total precipitation in central Nebraska is 25.3 inches. The maximum daily precipitation occurred on June 14, 1967, as 4.8 inches. Year 2008 had the record high precipitation as 39.4 inches, and year 2007 had the second highest annual precipitation as 39.0 inches. Based on the 10-year (decadal) running (moving) average trend line in *Figure 5*, there is a clear decline in annual total precipitation from 1893 to 1943 and the annual total precipitation had an increasing trend until 2012, although it fluctuated between the decades. For daily maximum precipitation, the 10-year running average had a decline in the trend from early records towards the start of the Dust Bowl era in early 1930s and steadily increased since that period. The cumulative total amount of precipitation received from 1893 to 2012 in central Nebraska is 3,041 inches (*Figure 6*).

Growing Season Precipitation

While the annual precipitation can provide invaluable information about overall water resources, the growing season precipitation primarily dictates crop productivity, especially in the rainfed settings. The long-term growing season precipitation for central Nebraska is shown in *Figure 7*. While the growing length varies from eastern to western Nebraska, the growing season in this publication is assumed to be from May 1 to Sept. 30 for a given year in central Nebraska. Thus, in *Figure 7*, the growing season total precipitation was summed from May 1 to Sept. 30 for each year and plotted with time. The growing season precipitation had a slight increasing trend. The largest amount of growing season precipitation occurred in 1965 as 30.1 inches, and the minimum was observed in 2012 as 6.97 inches. It is interesting to note in *Figure 7* that there seems to be a 10-year cyclic pattern of increasing and decreasing trends in growing season precipitation. For example, the growing season precipitation increased gradually from 1893 to 1903; a decreasing trend from 1903 to 1911; an increasing trend from 1911 to 1923; a decreasing trend from 1923 to 1934; another increasing trend from 1934 to 1945 and a decreasing trend from 1945 to 1956; an increasing trend from 1956 to 1965; a decreasing trend from 1965 to 1978; an increasing trend from 1978 to 1985; a decreasing trend from 1985 to 1994; an increasing trend from 1994 to 2008; and finally a decreasing trend until 2012. While the 10-year cyclic pattern is not uniformly distributed, the dry and normal (or wet) 10-year cycles are clearly visible in the data. *The growing season (May 1 through Sept. 30) total precipitation in central Nebraska increased by 0.35 inches from 1893 to 2012.*

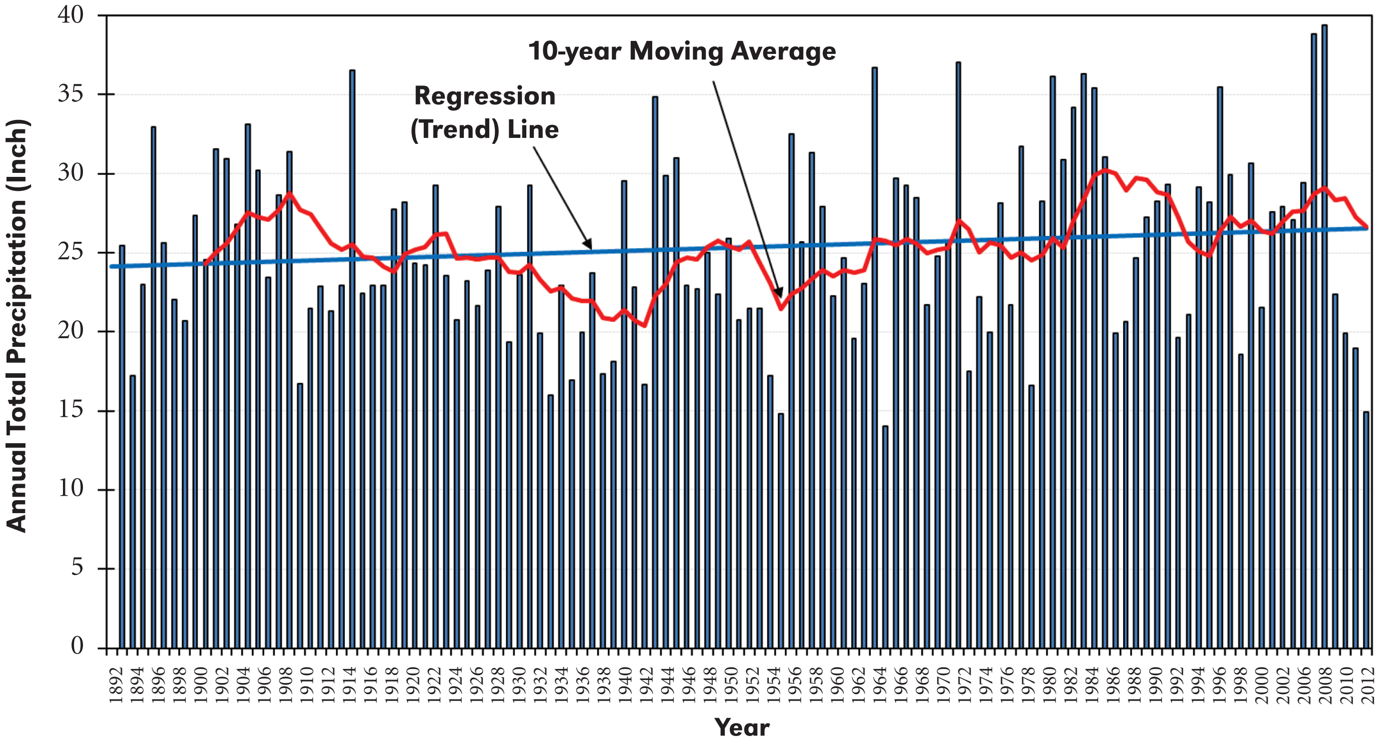


Figure 4. Distribution and trends in annual total precipitation from 1893 to 2012 in central Nebraska (Central City area; adopted from Irmak et al., 2012).

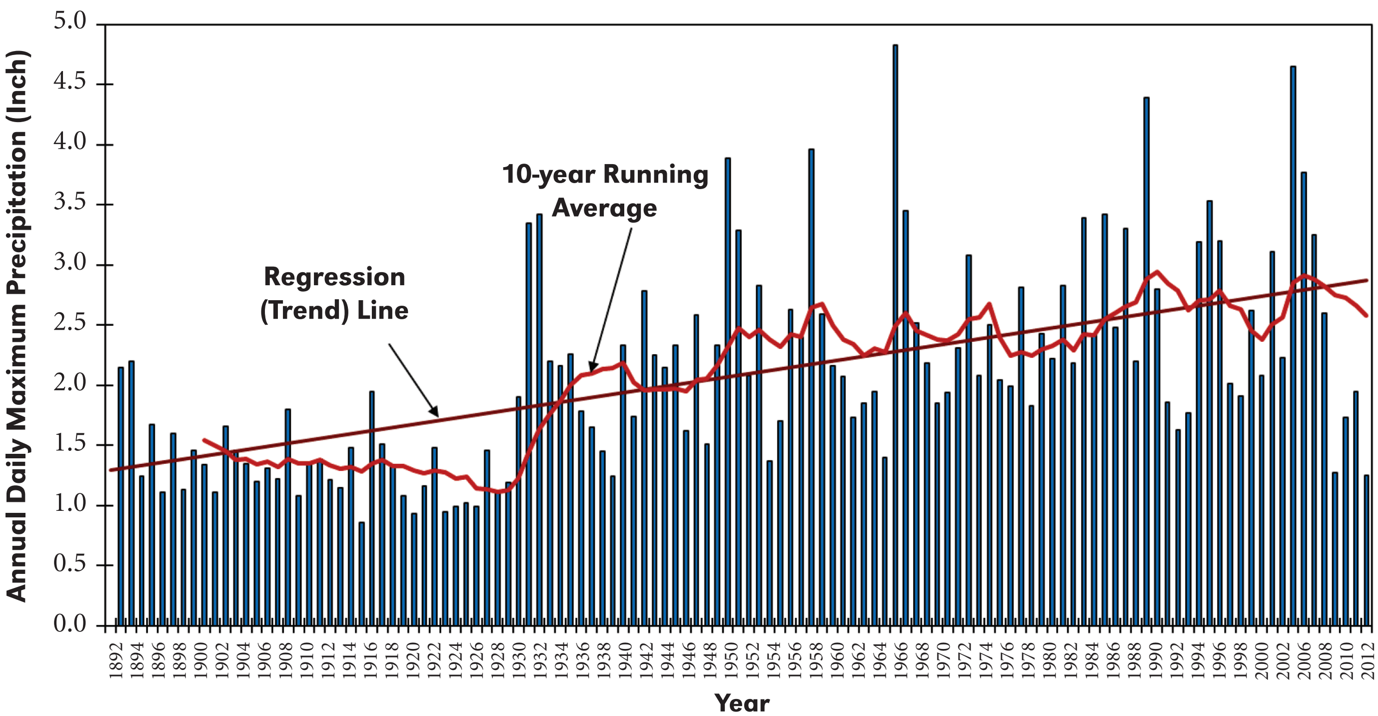


Figure 5. Distribution and trends in daily maximum precipitation in a given year from 1893 to 2012 in central Nebraska (Central City area; adopted from Irmak et al., 2012).

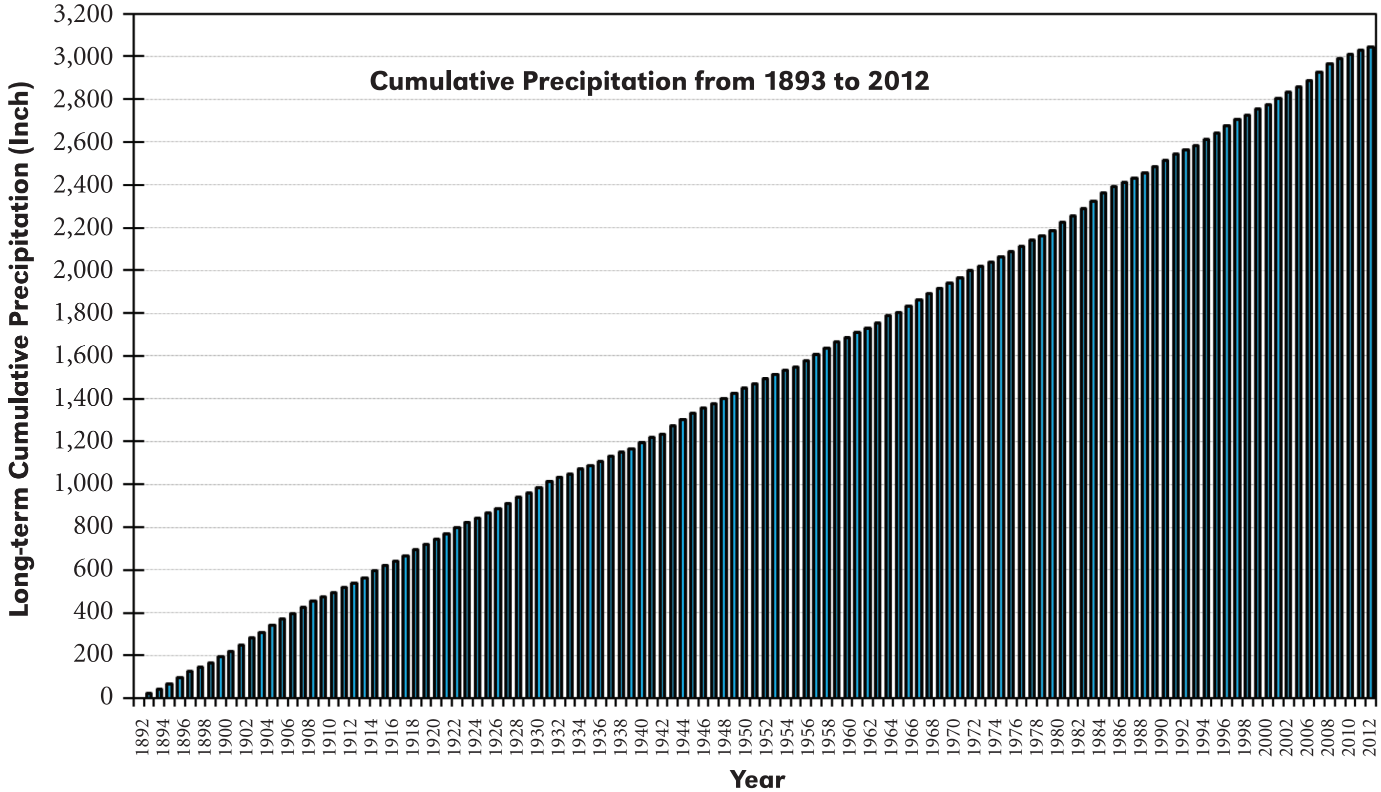


Figure 6. Cumulative total precipitation received from 1893 to 2012 in central Nebraska (Central City area).

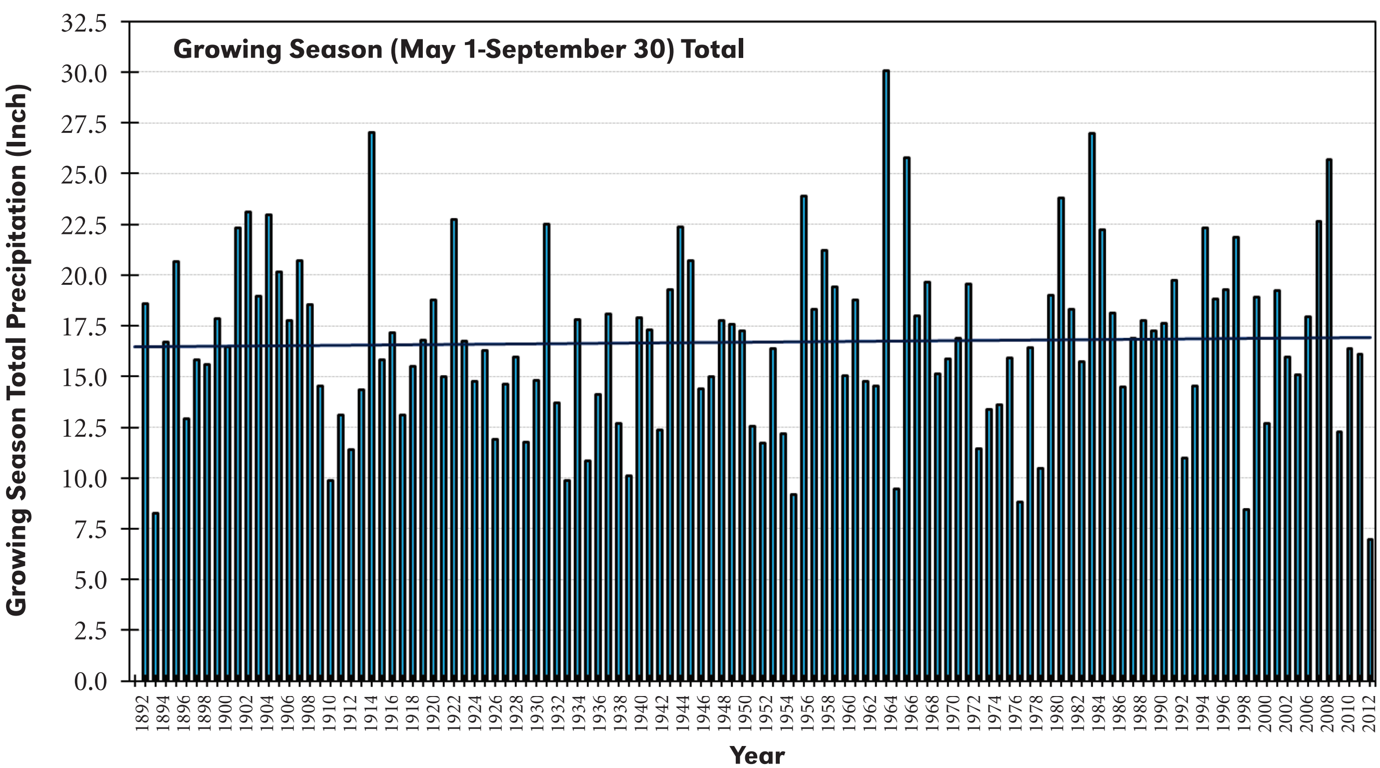


Figure 7. Growing season (May 1-Sept. 30) precipitation from 1893 to 2012 in central Nebraska (Central City area).

Summary

Precipitation has profound influence on agriculture and ecosystem productivity and other functions. Long-term analyses of this critical variable can be beneficial for many different purposes, including design and management of various agro-ecosystem infrastructures, long-term forecasting, precipitation vs. productivity analyses, etc. The findings of analyses of long-term changes in monthly, growing season and annual precipitation for central Nebraska led to the following summary:

- The January precipitation increased by 0.10 inches from 1893 to 2012. In the last decade, from 2001 to 2012, there was a gradual decline in January precipitation.
- The duration of these increasing and decreasing trends in February precipitation, as well as in other months, shows no regularity. The February precipitation decreased by 0.10 inches from 1893 to 2012.
- There were only five years (1910, 1967, 1994, and 2011) without any March precipitation. The monthly total March precipitation increased considerably by 0.83 inches from 1893 to 2012.
- There were not any years without April precipitation. The monthly total precipitation in April increased considerably by 0.60 inches from 1893 to 2012.
- The monthly total precipitation in May increased substantially by 1.30 inches from 1893 to 2012. There were not any years without May precipitation.
- June exhibited a decreasing trend, the monthly total precipitation decreased by 0.35 inches from 1893 to 2012. The lowest June precipitation occurred in 1978 (0.61 in), while the record high occurred in 1967 (14.9 in), which caused one of the major flood events in Nebraska's history.
- The monthly total precipitation in July increased substantially by 0.80 inches from 1893 to 2012. An increase in July precipitation can have positive implications for irrigation requirements and crop production.
- Three highest August precipitations were in 1987 (6.82 in), 1986 (6.64 in), and 1903 (6.56 in). The lowest was in 1988 (0.33 in). The monthly total precipitation in August decreased by 0.40 inches from 1893 to 2012.
- The least amount of precipitation occurred in 2009 (0.01 in). The monthly total precipitation in September decreased by 0.17 inches from 1893 to 2012.
- The monthly total precipitation in October increased by 0.19 inches from 1893 to 2012.
- The monthly total precipitation in November increased by 0.32 inches from 1893 to 2012.
- The largest December precipitation occurred in 2006 (3.0 in). There were 10 years (1903, 1905, 1922, 1929, 1943, 1949, 1995, 2010 and 2011) when there was no recorded December precipitation. The monthly total precipitation in December decreased slightly by 0.04 in. from 1893 to 2012.
- There is a clear decline in annual total precipitation from 1893 to 1943 and the annual total precipitation had an increasing trend until 2012, although it fluctuated between the decades.
- The cumulative total amount of precipitation received from 1893 to 2012 in central Nebraska is 3,041 inches.
- The largest amount of growing season precipitation occurred in 1965 as 30.1 inches, and the minimum was observed in 2012 as 6.97 inches.
- The growing season (May 1 through Sept. 30) total precipitation in central Nebraska increased by 0.35 inches from 1893 to 2012.

References and Further Reading

Irmak, S., I. Kabenge, K. Skaggs, and D. Mutiibwa. 2012. Trend and magnitude of changes in climate variables and reference evapotranspiration over 116-year period in the Platte River Basin, central Nebraska-USA. *Journal of Hydrology* 420-421: 228-244.

Irmak, S. 2013. Long-term (1893-2012) changes in air temperature, relative humidity and vapor pressure deficit (atmospheric evaporative demand) in central Nebraska. University of Nebraska–Lincoln Extension Circular 715.

This publication has been peer reviewed.

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