Municipal Climate Adaptation: A Report for St. Peters, Missouri




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1.1 Introduction

The Midwest and Great Plains are no strangers to extreme weather and climate events. Each year, events such as thunderstorms, tornadoes, and blizzards impact the local economy, infrastructure, and the safety and well-being of the people living in affected communities. Recent events, such as the back-to-back flooding and drought years of 2011 and 2012 or the recent increase in urban flash flooding due to extreme rainfall events, have left communities in a position of responding to the immediate needs of public safety, while rebuilding infrastructure - often with an eye to the future.

In light of these events, city leaders are increasingly considering climate data and information as a guide for their comprehensive plans. Changes to temperature, precipitation, and the frequency of extreme events in this region are already apparent; however, many of the impacts due to the changing climate are yet to be realized as the rate of future changes generally exceeds that of historical trends. Pinpointing and understanding how municipal-specific climate thresholds have changed historically and how these may change in the future is an important part of the process of preparing and planning for urban life under a changing climate.

"The nation's economy, security, and culture all depend on the resilience of urban infrastructure systems." - Urban Systems, Infrastructure, and Vulnerability NCA Report, 2014

1.2 Project Goals

This preliminary report is part of a larger effort to increase the capacity for municipal climate adaptation planning in the lower Missouri River Basin states (Iowa, Kansas, Missouri, and Nebraska). The goal of this project is to develop a process for incorporating climate information into long-term municipal planning strategies. By utilizing a combination of physical and social science approaches, the project aims to accomplish three objectives: 1) document thresholds associated with climate extremes in the municipal water resources sector; 2) develop municipal-specific climate information for use in planning; and 3) develop a methodology by which this information may be shared and replicated across multiple sectors. This effort builds on previous work with the Heartland Sustainability Directors Network, which is a regional subgroup of the Urban Sustainability Directors Network (http://usdn.org/uploads/cms/documents/climate_in_the_heartland_report.pdf).

Project partners include the High Plains Regional Climate Center, the Nebraska State Climate Office, the University of Nebraska Public Policy Center, the University of Nebraska-Lincoln Community and Regional Planning Program, and the City of Lincoln.

Funding is provided by the National Oceanic and Atmospheric Administration's Sectoral Applications Research Program (NA16OAR4310123).

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Climate Change and Cities

2.1 Data Sources

All historical climate data used in this report originated from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information (NCEI). Although this report is intended to be used on the local level, statewide and regional data analyses were included to help to put the local trends into context.

For each individual location, the last 50 years (1967-2016) worth of data were used in the analyses to allow for quick comparisons between cities. The only exceptions were Kansas City, MO and Lincoln, NE, which used 44 years (1973-2016). These data are a part of NCEI's Global Historical Climatology Network - Daily dataset and were obtained from the Applied Climate Information System. Any season with greater than 9 missing days and any year with greater than 36 missing days were not used in the analyses.

For statewide and regional data, the entire period of record (1895-2016) was used. These data were obtained from NCEI's Climate at a Glance tool. Future projections of climate conditions were summarized from the multi-agency sponsored National Climate Assessment. Links to all climate data used in the report, along with other available resources, are located on page 12.

2.2 Climate Thresholds

The following thresholds were used to generate the contents of this report. The table was modeled after Anderson et al. 2015, which was co-developed by sustainability directors and climatologists during a pilot project funded by the Urban Sustainability Directors Network.

Municipal Concern	Climate Thresholds	Climate Condition
General climate conditions	Average, maximum, and minimum temperatures	Annual and Seasonal Temperature
General climate conditions	Average rainfall	Annual and Seasonal Precipitation
General climate conditions	Average snowfall	Annual and Seasonal Snowfall
Parks and recreation; employees working outdoors; insect vectors	Dates when minimum temperature is less than 32°F	Last Spring and First Fall Frosts
Energy demand; public health	Average heating degree days and cooling degree days	Annual and Seasonal Heating Degree Days and Cooling Degree Days
Energy demand; public health	Temperatures over the hottest and coldest 3-day times period each year	Heat Waves and Cold Waves
Stormwater management; floodplain planning; emergency response; infrastructure design	Days with rainfall ≥ 1.25 inches Days with rainfall ≥ 4.00 inches Amount of rainfall in wettest day Amount of rainfall in wettest 5-day period Amount of rainfall in wettest 15-day period	Heavy Rainfall
Snow and ice management; public safety; electricity and phone service outages	Days with snowfall ≥ 3.0 inches Days with snowfall ≥ 6.0 inches Days with snowfall ≥ 12.0 inches Amount of snowfall in heaviest 3-day period	Snowstorms

Historical Climate Trends - Statewide

3.1 Missouri Temperature Trends

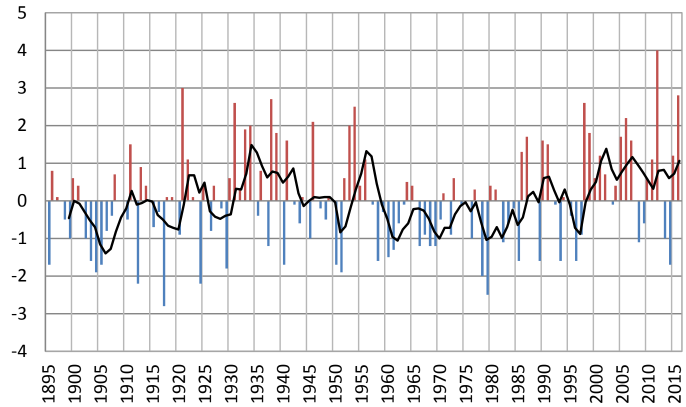
Statewide temperature records for Missouri date back to 1895, resulting in well over 100 years worth of observations. A wide annual temperature range is a feature of Missouri's climate, with hot summers and cold winters. There is generally a north to south temperature gradient across the state, with the warmest weather occurring in the bootheel and the coolest along the Iowa border.

The trend in average annual temperature for Missouri shows a small increase of 0.8°F over the 122-year period. There is high year-to-year variability in the record, with significant warmth during the 1930's Dustbowl Era, and generally warm conditions over the past couple of decades. Like other states in the region, 2012 was the warmest year on record for Missouri. Two other years in the state's recent history join 2012 in the top ten warmest years on record, including 2006 and 2016.

When broken down, the warming trend for Missouri is greater for minimum temperatures (1.4°F) than for maximum temperatures (0.1°F). This is similar to regional and national trends showing minimum temperatures increasing at a much higher rate than maximum temperatures. An increase in atmospheric moisture is one explanation for this difference, as this can impact nighttime low temperatures much more than daytime high temperatures.

On a seasonal basis, winter (1.6°F) and spring (1.3°F) trends indicate the strongest warming, while summer and autumn trends show no change.

Missouri's Average Annual Temperature Departure (°F)



Average annual temperature departure (°F) from the 122-year long-term average for the state of Missouri, along with the 5-year running average. Data courtesy NCEI.

Regional Temperature Trends

The average temperature trend for the four-state region encompassing Iowa, Kansas, Missouri, and Nebraska shows a 1.3°F increase over the 122-year period. This trend is not uniform across the region, however, as warming has been strongest in Nebraska (1.8°F) and weakest in Missouri (0.8°F). Just like each state in the region, minimum temperatures have increased at a higher rate (2.0°F) than maximum temperatures (0.7°F) region wide.

When broken down by season, the warming trend for the region is strongest in the winter (2.4°F) and weakest in the summer and autumn seasons (0.5°F and 0.6°F). Variability in seasonal trends at the regional level is also observed at the global scale.

Statewide Average Temperature Change by Season (1895-2016)
Temperature in degrees F

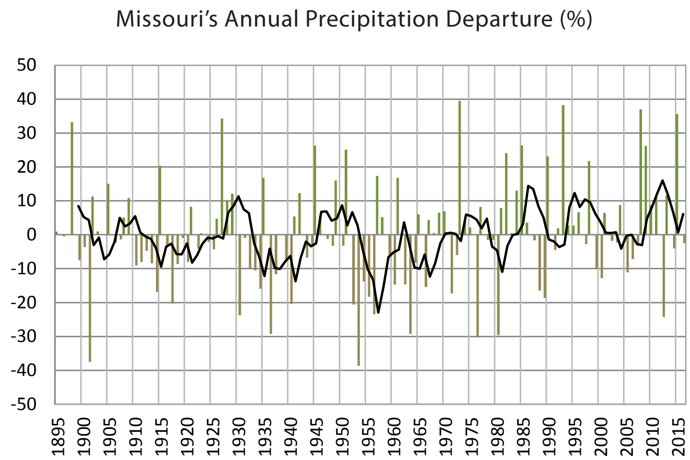
State	Spring	Summer	Autumn	Winter
Iowa	1.5	0.1	0.8	2.1
Kansas	1.8	0.9	0.7	2.6
Missouri	**1.3**	**0.0**	**0.0**	**1.6**
Nebraska	2.1	1.0	1.0	3.2
Four-state Average	1.7	0.5	0.6	2.4

3.2 Missouri Precipitation Trends

Statewide precipitation records for Missouri also date back to 1895, resulting in over 100 years worth of observations. Although not as extreme as areas to the west, Missouri's precipitation does vary seasonally, with a minimum in the winter and a maximum in the spring and summer. Generally, precipitation decreases across the state, from southeast to northwest, with areas of the bootheel receiving nearly 50 inches of precipitation each year on average and northwestern areas receiving less than 40 inches.

Over the 122-year time period, Missouri's average annual precipitation has increased by about 7%. Like other areas of the region, there is variability over this time, with drought periods of the 1930s and 1950s/1960s standing out in the record. The past couple of decades have been fairly wet in comparison and, most recently, three of the top ten wettest years on record have occurred, including 2008, 2009, and 2015.

While there has been an overall increase in annual precipitation for the state, there are differences across the seasons. Trends show substantial increases in the spring (11%) and autumn (15%), but only small changes in the winter (3%). On the other hand, summer precipitation trends are negligible, with only a 1% decrease. These seasonal precipitation trends, especially the large increase in springtime precipitation, are consistent with other locations in the Midwest region, and these trends are expected to continue into the future (Pryor et al. 2014).



Annual precipitation departure (%) from the 122-year average for the state of Missouri, along with the 5-year running average. Data courtesy NCEI.

Regional Precipitation Trends

A distinguishing feature of the region is the east-west precipitation gradient in which annual average precipitation totals range from 50 inches in southeastern Missouri to less than 20 inches in the panhandle of Nebraska.

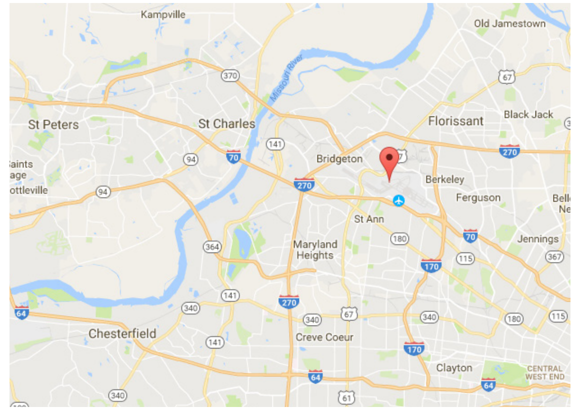
There tends to be high year-to-year variability in precipitation for much of the region; however, over the 122-year period, there has been a 10% increase in average annual precipitation. This increase varies across the region, with a low of 6% in Nebraska to a high of 15% in Iowa. On a seasonal basis, there is variability from state to state, with both increases and decreases in precipitation. On the whole, the strongest trends were in spring (16% increase), while the weakest trends were in winter (4% increase).

Statewide Annual Climate Trends (1895-2016)
Temperature in degrees F, Precipitation in percent

State	Average Temperature	Maximum Temperature	Minimum Temperature	Precipitation
Iowa	1.2	0.2	2.1	15%
Kansas	1.5	1.2	1.8	10%
Missouri	**0.8**	**0.1**	**1.4**	**7%**
Nebraska	1.8	1.2	2.5	6%
Four-state Average	1.3	0.7	2.0	10%

Historical Climate Trends - Local

4.1 General Climate of St. Peters

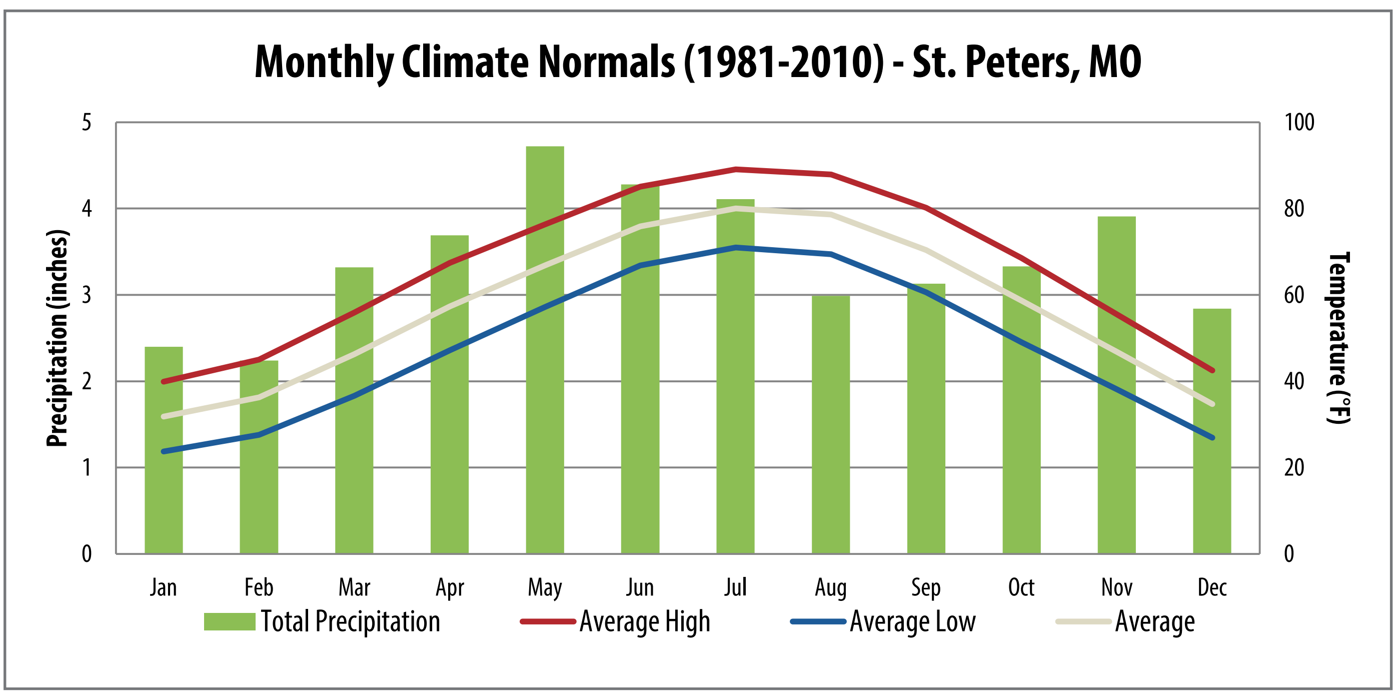


St. Louis Lambert Intl Airport: 38.7525, -90.3736
GHCN ID: USW00013994, Map Data: Google

The weather station at the St. Louis Lambert International Airport, located approximately 15 miles east of St. Peters, was selected for this report due to its nearly continuous 87-year record. Daily measurements of temperature, precipitation, and snowfall have been taken at this location since January 1, 1930.

St. Peters' climate is considered to be humid continental with hot summers, which is characterized by large differences in temperatures throughout the year. St. Peters experiences all four seasons and there can be high variability in both temperature and precipitation. The hottest time of the year is July, when average high temperatures peak at 89°F, while the coldest time of the year occurs in January with average low temperatures dipping to 24°F. The wettest season is spring (March, April, May), with average precipitation totaling 11.73 inches; however, summer (June, July, August) and autumn (September, October, November) precipitation totals are similar. The driest time of the year is winter (December, January, February) with 7.48 inches (liquid equivalent*), but winter in St. Peters is much wetter than many of its northern and western counterparts. Some precipitation in the winter falls as snow, with an average of 14.3 inches. Winds are predominantly from the west/northwest in winter and the south/southeast in summer. Winds from the north bring cold, dry air, while winds from the south bring warm, moist air. St. Peters' location between these contrasting air masses puts it at risk for severe thunderstorms, which can produce tornadoes, high winds, hail, and flooding. The graph below shows the average climate conditions for St. Peters.

*Winter precipitation in St. Peters is a combination of rain and the liquid equivalent precipitation of snow, i.e. the amount of liquid that would have fallen had the precipitation been rain instead of snow.



4.2 St. Peters Temperature Trends

Temperature Trends Vary by Season

St. Peters has experienced an increase in average temperature of 3.9°F over the past 50 years. Each season shows a warming trend, with winter exhibiting the largest increase (4.8°F). Both maximum and minimum temperatures have increased, with minimums far outpacing maximums. Unlike many other cities in the region, maximum and minimum temperatures have increased significantly in the summer, with minimums increasing by 5°F. This is important because fewer cooler nights in the summer can have serious public health implications, as heat is the leading cause of weather-related deaths in the U.S. (Peterson et al. 2013).

Heat Waves and Cold Waves

A look at multi-day heat and cold wave events shows that there has been an increase in the severity of heat waves and a decrease in the severity of cold waves. The hottest 3-day period of each year has increased by about 4°F, while the average temperature of each year's coldest 3-day period has increased by about 8°F.

Future projections already correspond to recent observed changes in temperature and these trends are expected to continue and accelerate.

St. Peters' Changing Seasons

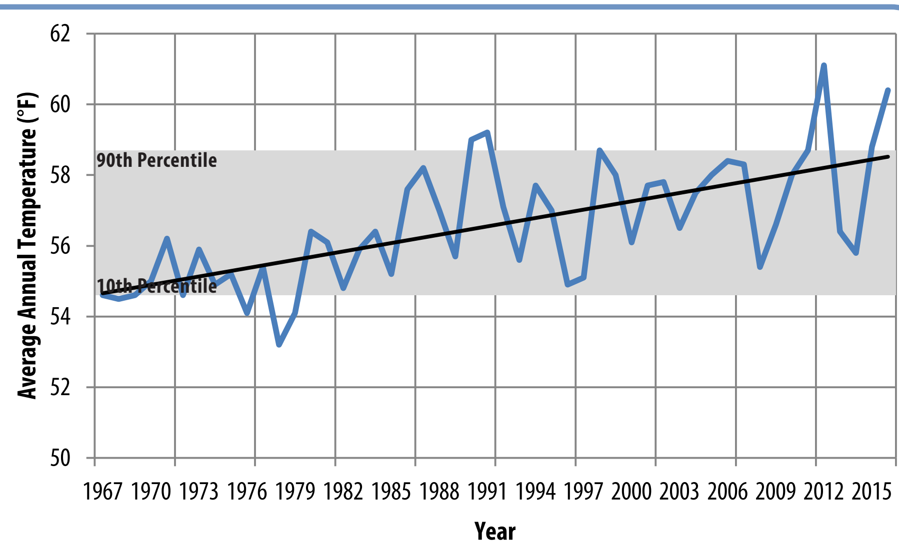
Spring	Summer
4.0°F ↑	3.5°F ↑
Autumn	**Winter**
3.6°F ↑	4.8°F ↑

Changes to Energy Needs

Heating and cooling degrees can be an indication of energy demand. Rising temperatures in St. Peters are leading to changes in energy needs. Trends in cooling degree days show a 31% increase overall, with the largest increase, by percentage, in the spring (61%).

Trends in heating degree days, however, show a 20% decrease, annually. This is due to not only warmer average temperatures in the winter, but also to significantly warmer cold waves, leading to lower peak energy demand.

Over the past 50 years, St. Peters' average annual temperature has increased by 3.9°F. Four of the past six years have met or exceeded the 90th percentile.



4.3 St. Peters Precipitation Trends

Precipitation Trends Vary by Season
Overall, there has been a 17% increase in annual precipitation in St. Peters over the past 50 years. Each season shows increases in precipitation, with spring and summer exhibiting the largest increases of 23% and 28%, respectively.

Heavy Precipitation Events Increasing
In addition to increases in seasonal precipitation, St. Peters has also experienced an increase in the frequency and intensity of heavy rainfall events over the past 50 years (see below). These increases for single-day events could signal an increase in flash flooding potential. The intensity of 5- and 15-day rainfall events has also increased, which could signal the potential for longer-term flooding events because once soils are saturated from initial rains, subsequent rainfall will run off into ditches, streams, and rivers. Agricultural land management practices upstream of St. Peters can also have an impact on the quantity and quality of the water flowing through the watershed (Hatfield et al. 2014).

Future projections already correspond to recent observed changes in increased heavy rainfall events and these trends are expected to continue and accelerate.

St. Peters' Changing Seasons

Spring
23% ↑

Summer
28% ↑

Autumn
7% ↑

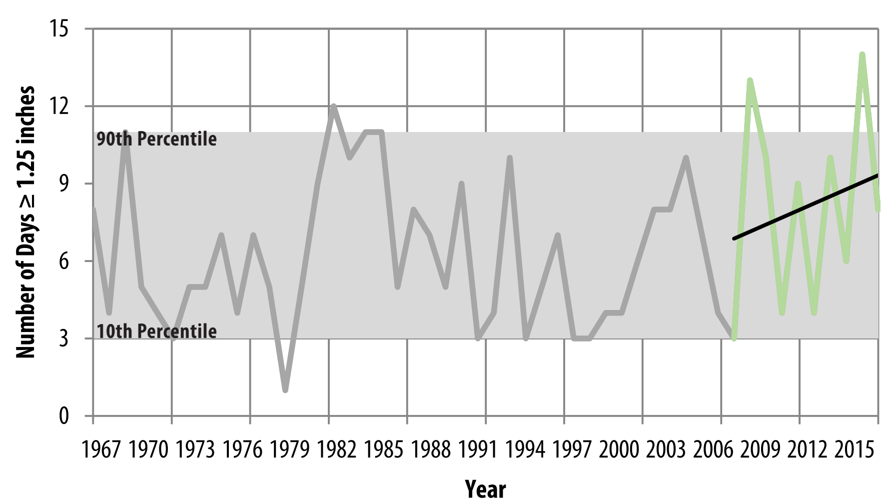
Winter
11% ↑

Changes Within Snow Season

A snow season is defined as the period between July 1 and June 30. Overall, there has been a 24% decrease in seasonal snowfall totals, with steep declines in the transition seasons (autumn and spring). Trends also show that snowfall events of at least 3.0 inches have decreased by one day per year.

Increases in overall wintertime precipitation coupled with a decrease in snowfall indicate that more of St. Peters' precipitation is falling as rain in the winter months.

Trends show that the number of days St. Peters has received at least 1.25 inches of rain has increased by 2 days. This trend has accelerated in the past 10 years.



4.4 St. Peters Climate Extremes

Highest Temperature:

115°F, Jul 14, 1954

Lowest Temperature:

-22°F, Jan 5, 1884

Highest Precipitation:

6.85in, Aug 20, 1915

Highest Snowfall:

12.8in, Feb 26, 1906

Average temperature and total precipitation are helpful for understanding general conditions; however, these do not demonstrate the wide range of conditions that can be experienced at a location. This range of conditions is especially important for a place like St. Peters because 1) extremes are common in the continental type of climate experienced there and 2) extremes are most impactful to people and infrastructure. Extremes in both temperature and precipitation are becoming more common in St. Peters, and those occurring in succession make responding to and preparing for these events quite difficult. Extremes data presented here include stations from around the St. Peters area, beginning in 1874.

Temperature Extremes

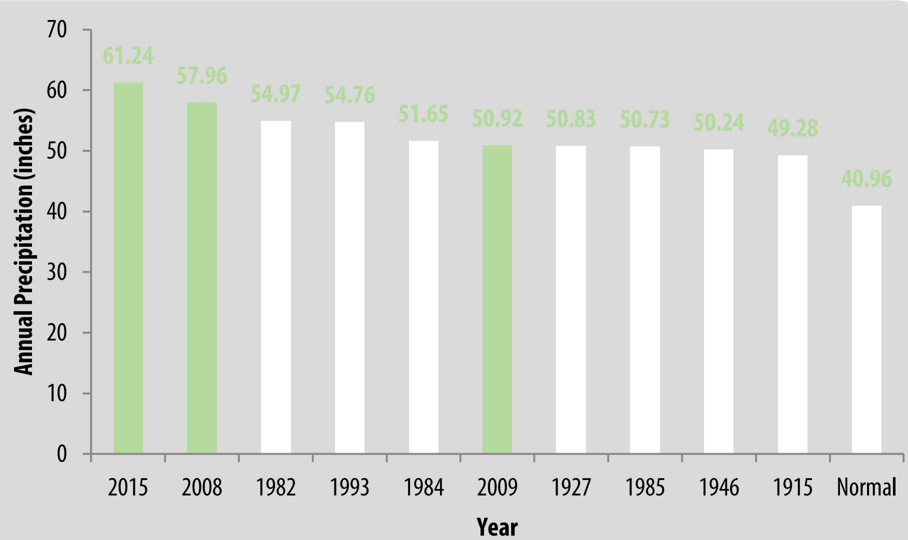
In St. Peters, nearly half of the top twenty warmest years on record have all occurred in this century, with 2012 and 2016 ranking as the warmest and second warmest years, respectively. No year in this century, however, ranks in the top twenty coolest years. Extremes on the seasonal, monthly, and daily basis have also occurred. Interestingly, five of the top ten warmest nighttime temperatures in St. Peters have all occurred in recent years, with 86°F on July 25, 2012 ranking as the warmest on record.

Precipitation Extremes

Overall, there has been a wide range in precipitation totals in St. Peters' history. The wettest year on record, 2015, received 61.24 inches, while the driest year on record, 1953, received only 20.59 inches. Extremes on either end of the spectrum have resulted in losses due to flooding and drought. For example, the 3-day heavy rain event that occurred in December 2015 was the second wettest 3 days on record for St. Peters, with 9.18 inches. This storm was responsible road closures, property damage, and even deaths.

Recent Extremes - Top 10 Wettest Years on Record

Seven out of the past ten years have been wetter than average, with three years ranking in the top ten wettest on record. No recent year has ranked in the top ten driest.



4.5 Summary Tables

For quick reference, the following tables show a summary of recent changes in seasonal climate conditions and damaging events in St. Peters. All trends cover the last 50-year time period of 1967-2016.

Seasons are defined as follows: Spring (March, April, May), Summer (June, July August), Autumn (September, October, November), and Winter (December, January, February).

Season	Recent Changes in Seasonal Weather
Spring	Warmer, Wetter springs Earlier last frosts
Summer	Warmer, Wetter summers Warmer nights; More Cooling Degree Days
Autumn	Warmer, Wetter autumns Later first frosts
Winter	Warmer, Wetter, but Less snowy winters Fewer Heating Degree Days

Damaging Event	Recent Changes in Damaging Events
Heat Waves	Increased intensity of heat waves 3-day: Higher average, maximum, and minimum temperatures
Cold Waves	Decreased intensity of cold waves 3-day: Higher average, maximum, and minimum temperatures
Heavy Rainfall	Increased intensity of heavy rainfall events Daily: 17% increase in wettest 1-day period per year 5-day: 25% increase in wettest 5-day period per year 15-day: 28% increase in wettest 15-day period per year
Snow Storms	Decreased frequency of 3.0 inch snowfall events by 1 day 20% decrease in snowiest 3-day period per year Less snowy autumn, winter, and spring seasons
Late/Early Freeze	Growing season lengthened by nearly one month Earlier last frosts in spring; Later first frosts in autumn
Tornado, Wind, Hail	Inconsistencies in reporting exceed trend

Future Climate Projections

Over the past century, Missouri's climate has become increasingly warmer and wetter. Seasonal differences highlight times of the year that have been impacted the most and future projections indicate that many of these trends could continue into the future. Projections in this section originated from the third National Climate Assessment (NCA) and associated sustained activities (Melillo et al. 2014; Frankson et al. 2017a; Kunkel et al. 2017). The fourth NCA is currently under development and is expected to be released in 2018.

Temperature

Temperatures have increased slightly across Missouri, but projections indicate that temperatures will increase substantially into the future. The amount of future warming, however, is largely dependent upon increases or decreases in greenhouse gas emissions, and so a range of conditions is possible. Depending on the scenario, a 4-9°F increase in average annual temperature could occur for St. Peters (Walsh et al. 2014). Like current trends, cold waves are expected to become less intense; however, heat waves are expected to become more intense as even modest increases in summertime temperature would lead to more extremes. These trends could have serious implications for communities like St. Peters, as increases in cooling demands could put a strain on utilities and vulnerable populations, like the young, elderly, and the poor.

"Extreme rainfall events and flooding have increased during the last century, and these trends are expected to continue, causing erosion, declining water quality, and negative impacts on transportation, agriculture, human health, and infrastructure." - Midwest NCA Report, 2014

Precipitation

Missouri is particularly susceptible to flooding as many communities are located along major rivers, such as the Mississippi, Missouri, and White Rivers, and their tributaries. Due to its position in the lower portions of these river basins, precipitation increases anywhere in the upper reaches must be taken into account. Increases in streamflows of upstream tributaries pose a risk of flooding to downstream areas of Missouri, regardless of changes to the state's precipitation.

Summer rainbow
Photo credit: Ken Dewey

Projections indicate seasonal differences in future precipitation across Missouri, with increases projected in the winter and spring. For St. Peters, this could mean a 10-15% increase in precipitation for each of these seasons (Walsh et al. 2014). Because extreme precipitation events are also expected to increase, this could potentially lead to an increase in the frequency and intensity of floods, both in terms of flash flooding and longer-term events. Unfortunately, this would not be a new hazard as Missouri ranked fourth in terms of losses due to flooding from 1955-1997 (Frankson et al. 2016).

Although not yet apparent in the regional and local trends, summer precipitation is expected to decrease across all of Missouri by 2050. For St. Peters, this could be a decrease of up to 5-10% (Walsh et al. 2014). While this decrease may not seem dramatic, in combination with significant increases in summertime temperatures it may cause an increase in the intensity of droughts, which are a recurring feature of Missouri's climate.

Implications

Hazards originating from extremes in weather and climate conditions impact municipalities in multiple ways, from infrastructure to utilities to human health. While many locations in the Midwest already experience a wide range of weather and climate conditions, this range has increased over time in St. Peters, making the city more prone to weather and climate hazards. Recent and future changes in St. Peters that could have implications for municipal operations include:

Changes to energy needs

Recent

- An increase in winter temperatures coupled with a decrease in the severity of cold waves has led to a decrease in heating demands.
- An increase in temperatures in the spring, summer, and autumn has led to an increase in cooling demands.

Future

- A continued increase in temperatures could further decrease energy needs in the winter.
- A continuation of more intense heat waves in the summer could impact utilities during peak delivery times.

Strains to water resource management

Recent

- An increase in the frequency and intensity of single-day heavy rainfall events has increased the potential for flash flooding.
- An increase in the intensity of multi-day (5-day and 15-day) heavy rainfall events has increased the potential for longer-term flooding events.

Future

- Continued increases in single- and multi-day heavy rainfall events could increase the potential for more intense and frequent flooding episodes, which could lead to soil erosion as well as decreased water quality.
- Projected decreases in summer precipitation could increase the intensity of droughts, potentially putting strains on the quality and quantity of available water.

Human health impacted by extremes in temperature and precipitation

Recent

- Warmer winters could decrease cold weather-related impacts, while warmer nights in the summer could impact vulnerable populations, potentially increasing the need for cooling shelters.
- A longer frost-free season could signal a longer vector-borne disease season.
- More intense and frequent flooding events can lead to short-term concerns, such as injury and death, and long-term concerns, such as a potential increase in water-borne disease and indoor air quality issues due to mold and mildew (Luber et al. 2014).

Future

- More intense heat waves in the summer could negatively impact vulnerable populations.
- Continued increases in winter temperatures could lead to the overwintering of pests.

Other

Recent

- Declines in snowfall could impact the timing and frequency of snow removal operations.

Resources

Historical Climate Data and Information

Historical Temperature and Precipitation Data

- Applied Climate Information System: http://scacis.rcc-acis.org/

Historical Drought Information

- Drought Risk Atlas: http://droughtatlas.unl.edu/

Temperature and Precipitation Trends at National, State, and Climate Division scales

- NCEI's Climate at a Glance: https://www.ncdc.noaa.gov/cag/

Local Trends in Midwest and Great Plains

- Corn Belt Climate Trends (1980-2013): http://www.hprcc.unl.edu/climatetrends.php

Recent and Current Climate Monitoring

Midwest and Great Plains Monthly Climate and Drought Webinar

- To sign up for future webinars: https://www.drought.gov/drought/calendar/webinars
- For archive: http://www.hprcc.unl.edu/webinars.php

Midwest Quarterly and Monthly Climate Summaries

- Quarterly Climate Impacts and Outlook: https://www.drought.gov/drought/resources/reports
- Monthly Climate Overviews: http://mrcc.isws.illinois.edu/cliwatch/watch_highlights.html

Temperature and Precipitation Maps

- HPRCC ACIS Climate Maps: http://www.hprcc.unl.edu/maps.php?map=ACISClimateMaps

Drought Monitoring

- U.S. Drought Monitor: http://droughtmonitor.unl.edu/

Streamflow Conditions

- USGS WaterWatch: http://waterwatch.usgs.gov/index.php

Future Climate Data and Information

National Climate Assessment

- Reports by region and sector: http://nca2014.globalchange.gov/

Climate Change Impacts by State

- EPA: https://www.epa.gov/climate-impacts/climate-change-impacts-state

State Climate Summaries

- NCEI: https://statesummaries.ncics.org/

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