Municipal Climate Adaptation: A Report for Hays, Kansas




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Climate Change and Cities

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).

Methods

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 Kansas Temperature Trends

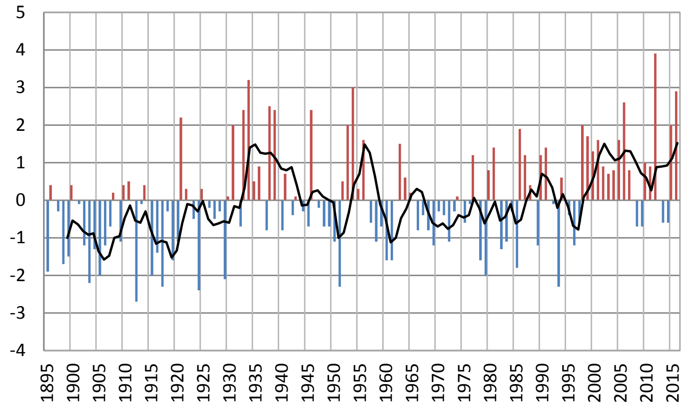
Statewide temperature records for Kansas date back to 1895, resulting in well over 100 years worth of observations. A wide annual temperature range is a feature of Kansas' climate, with hot summers and cold winters. There is generally a north to south temperature gradient across the state, with the warmest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

The trend in average annual temperature for Kansas shows an increase of 1.5°F over the 122-year period. There is high year-to-year variability, with significant warmth during the 1930's Dust Bowl era, and generally warm conditions since the mid-1980s. Like the other states in the region, 2012 was the warmest year on record for Kansas. Three of the top ten warmest years on record have occurred since 2005, including 2006, 2012, and 2016.

The annual warming trend is greater for minimum temperatures (1.8°F) than for maximum temperatures (1.2°F), and this pattern holds true for the region, and much of the world. 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 trends indicate the strongest warming with a 2.6°F increase, while summer and autumn trends show the least, with a 0.9°F and 0.7°F increase, respectively. This is consistent with regional trends, as well.

Kansas' Average Annual Temperature Departure (°F)



Average annual temperature departure (°F) from the 122-year long-term average for the state of Kansas, 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

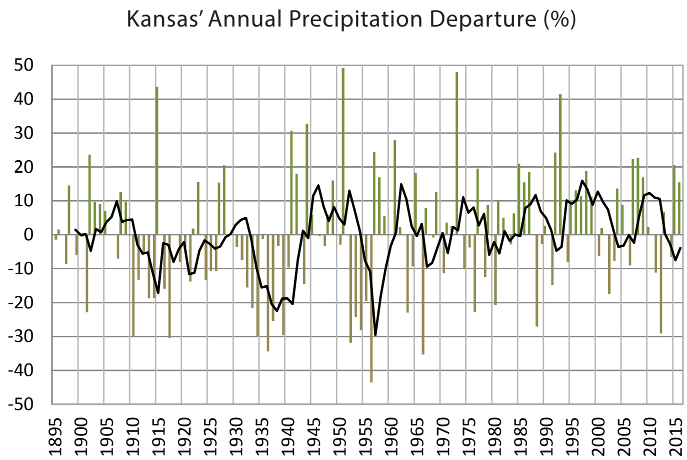
State	Spring	Summer	Autumn	Winter
Iowa	1.5	0.1	0.8	2.1
Kansas	**1.8**	**0.9**	**0.7**	**2.6**
Missouri	1.3	0.0	0.0	1.6
Nebraska	2.1	1.0	1.0	3.2
Four-state Average	1.7	0.5	0.6	2.4

3.2 Kansas Precipitation Trends

Statewide precipitation records for Kansas also date back to 1895, resulting in over 100 years worth of observations. Precipitation varies seasonally, with a maximum in summer and a minimum in winter. Generally, precipitation decreases across the state from east to west. Much like Nebraska, this precipitation gradient is a defining climatic feature of the state, with southeastern areas receiving just over 45 inches of precipitation each year on average and western areas receiving less than 20 inches.

Over the 122-year time period, average annual precipitation has increased by about 10% in Kansas. There is variability in the precipitation record with drought periods of the 1930s and 1950s standing out, as well several extremely wet individual years, such as 1915, 1951, 1973, and 1993. Despite being in an overall fairly wet period over the past couple of decades, drought has been an issue, especially during 2012, which was the 9th driest year on record for Kansas. It is important to note that statewide precipitation totals can mask local conditions, like the multi-year drought experienced across western areas of the state, which had five consecutive dry years from 2010 to 2014.

Seasonal trends in precipitation show an increase during all four seasons in Kansas, with the largest increases in the spring (16%) and winter (14%) and the smallest increases in the summer (7%) and autumn (6%). Although one of the larger increases, Kansas' winter precipitation is generally light, so this increase is, in effect, negligible.



Annual precipitation departure (%) from the 122-year average for the state of Kansas, 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

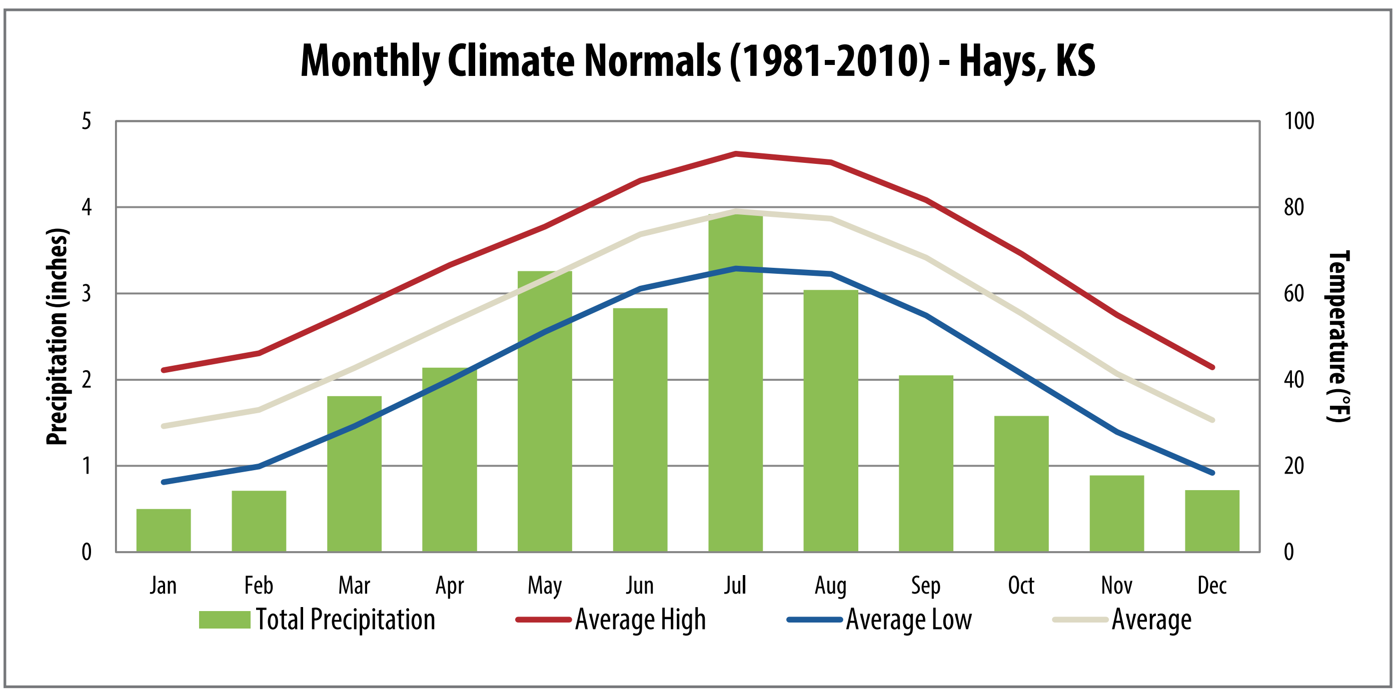
4.1 General Climate of Hays

Hays 1S: 38.8586, -99.3358
GHCN ID: USC00143527, Map Data: Google

The weather station at the K-State Agricultural Research Center (Hays 1S), located approximately 1 mile to the south of town, was selected for this report due to its nearly continuous 125-year record. Daily measurements of temperature, precipitation, and snowfall have been taken at this location since January 1, 1893.

Hays' climate is considered to be humid continental with hot summers, which is characterized by large differences in temperatures throughout the year due to its interior location far from the moderating effects of the oceans. The city experiences all four seasons and there can be high variability in temperature and precipitation. Hays is also near the transition to an arid, steppe climate, experienced by its neighbors just to the west. The hottest time of the year is July, when average high temperatures peak at 92°F, while the coldest time of the year occurs in January with average low temperatures dipping to 16°F. The wettest time of the year is the summer (June, July, August), with precipitation totals averaging 9.79 inches, while the driest time of the year is the winter (December, January, February) with only 1.93 inches (liquid equivalent*). Much of the precipitation in the winter falls as snow, with an average of 11.6 inches. Winds are predominantly from the north/northwest during winter and the south/southeast during summer. Winds from the north bring cold, dry air, while winds from the south bring warm, moist air. Hays' 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 Hays.

*Winter precipitation in Hays 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.



Historical Climate Trends - Local

4.2 Hays Temperature Trends

Temperature Trends Vary Slightly by Season
Hays has experienced an increase in average annual temperature of 2.6°F over the past 50 years. Each season shows a warming trend, with autumn exhibiting the largest increase (3.2°F). Overall, both maximum and minimum temperatures have increased at similar rates, but there is variation across the seasons. For instance in the summer, trends indicate that minimum temperatures have increased slightly more than maximum temperatures. 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 almost 2°F, while the coldest 3-day period has increased by about 3°F.

Future projections correspond to recent observed changes in temperature. These trends are expected to continue, with an increase in the frequency and intensity of heat waves.

Hays' Changing Seasons

Spring	Summer
2.8°F ↑	2.2°F ↑

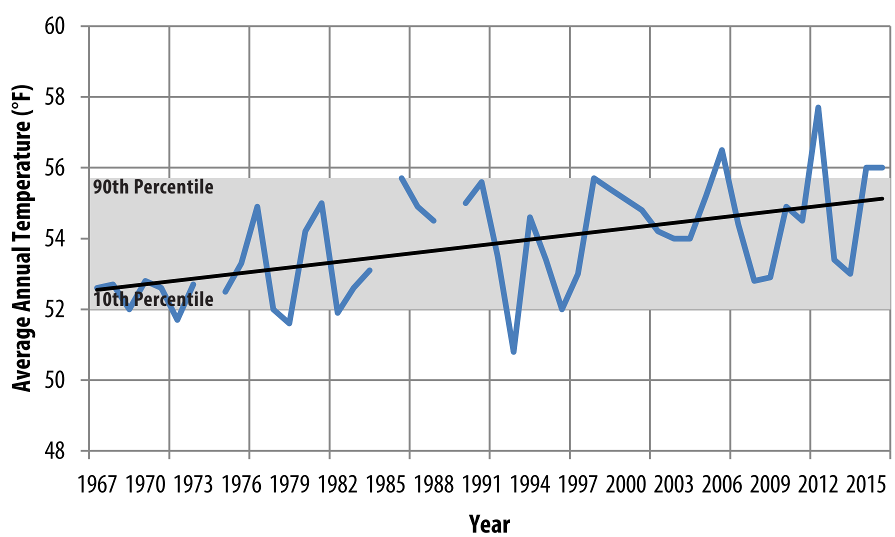
Autumn	Winter
3.2°F ↑	2.7°F ↑

Changes to Energy Needs

Heating and cooling degree days can be an indication of energy demand, and rising temperatures in Hays are leading to changes in energy needs. Trends in cooling degree days show a 22% increase overall, with the largest increase, by percentage, in spring (67%).

Trends in heating degree days, however, show an 11% decrease, annually. This is not only due to warmer average temperatures in the winter, but also to significantly warmer cold waves, leading to lower peak energy demand.

Over the past 50 years, Hays' average annual temperature has increased by 2.6°F. Four of the past fifteen years exceeded the 90th percentile (2006, 2012, 2015, and 2016).



Historical Climate Trends - Local

4.3 Hays Precipitation Trends

Precipitation Trends Vary by Season
Overall, there has been a 5% increase in annual precipitation in Hays, with seasonal differences. Over the past 50 years, summer and autumn precipitation has increased by 4% and 7%, respectively, while spring precipitation has decreased by 4%. Winter shows a large increase, by percentage, which constitutes about a 1 inch increase.

Intensity of Precipitation Events Increasing
Unlike neighbors to the east, there has not been an increase in the number of heavy rainfall events over the past 50 years (days receiving at least 1.25 inches). But, the amount of rain in individual rainfall events has increased. For single-day events this could signal an increase in flash flooding, while increases in 5- and 15-day events could signal longer-term flooding events. Once soils are saturated from initial rains, subsequent rainfall will run off into ditches, streams, and rivers. Agricultural land management practices upstream can also have an impact on the quantity and quality of the water flowing through the watershed (Hatfield et al. 2014).

Future projections indicate that winter precipitation may continue to increase, while summer precipitation may begin to decline.

Hays' Changing Seasons

Spring
4% ↓

Summer
4% ↑

Autumn
7% ↑

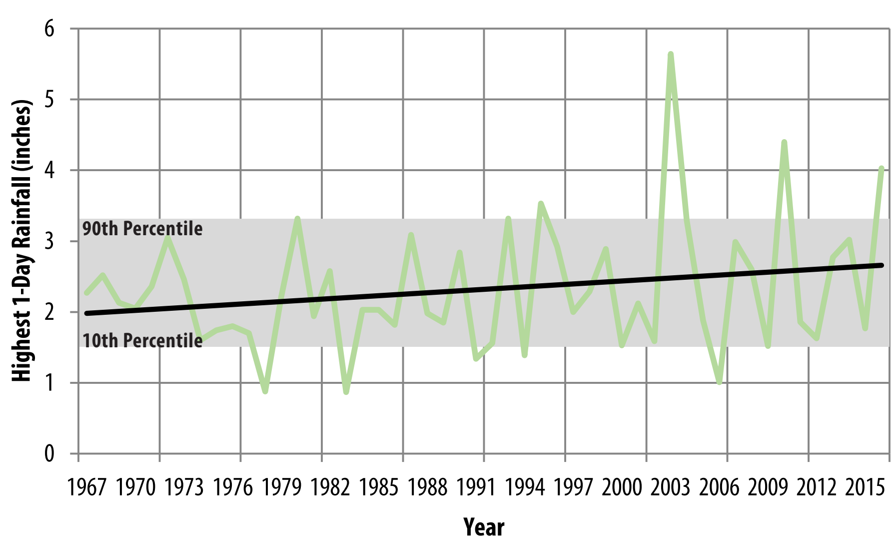
Winter
54% ↑

Changes Within Snow Season

A snow season is defined as the period between July 1 and June 30. Overall, Hays' seasonal snowfall totals have declined by about one third, with drastic changes within the snow season.

Trends show that less snow is falling in the spring and autumn, with steep declines in snowfall totals over the past 50 years. Conversely, there has been a 6% increase in wintertime snowfall totals, with two of the past ten years exceeding the 90th percentile.

Over the past 50 years, the amount of rain in each year's heaviest rainfall event has increased by 30%. Three of the past fifteen years have exceeded the 90th percentile.



4.4 Hays Climate Extremes

Highest Temperature:

117°F, Jul 13, 1934

Lowest Temperature:

-26°F, Feb 13, 1905

Highest Precipitation:

5.64in, Sep 11, 2003

Highest Snowfall:

12.0in, Dec 15, 2007

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 Hays because 1) extremes are common in the continental type of climate experienced there and 2) extremes are impactful to people and infrastructure. Certain extremes in temperature and precipitation are becoming more common in Hays, and those occurring in succession can make responding to and preparing for these events quite difficult. Extremes data presented here span the entire period of record for Hays, starting in 1893.

Temperature Extremes

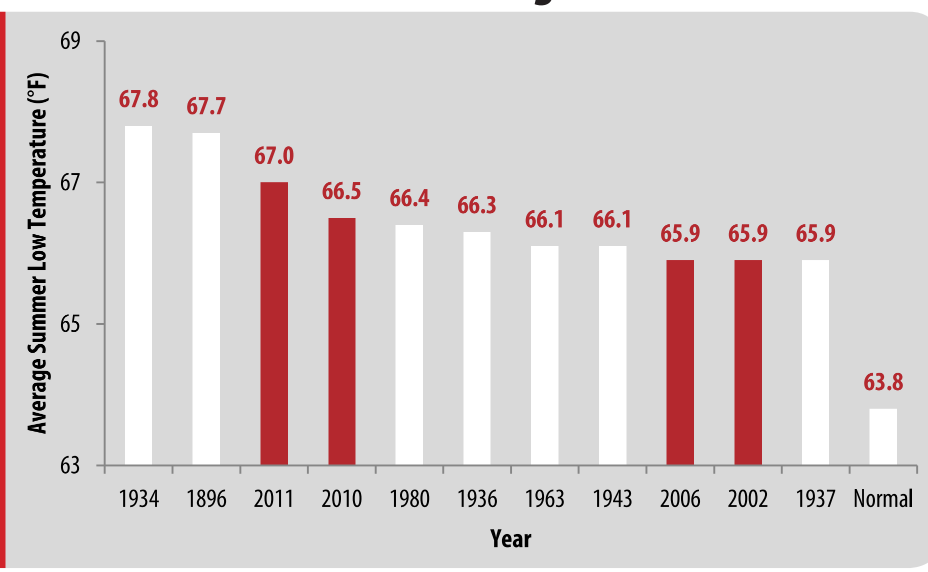
Two of the top ten warmest years on record occurred in the past 15 years, including 2012 (2nd) and 2006 (7th). 2015 and 2016 were not far behind, tied in the 11th spot. A look at the daily temperature data shows that extreme high temperatures are increasing in frequency and occurring earlier in the year. Over the past 50 years, the number of 100°F+ days has increased by nearly 7 days. Additionally, the average date of the first 100°F day has moved from mid- to early-June.

Precipitation Extremes

There has been a wide range in precipitation totals in Hays' history. The wettest year on record, 1951, received 43.34 inches, while the driest year on record, 1956, received only 9.21 inches. Recent standout years include 2012, which was the 7th driest year on record, and 2007, which was the 6th wettest. Extremes in single-day heavy rain and snow events have also occurred in recent years. Three of the top ten wettest days and three of the top ten snowiest days on record have occurred this century, with recent years holding the top spots (see above).

Recent Extremes - Warm Summer Nights

Over the past 50 years, low temperatures in the summer have increased by 2.4°F in Hays. Four of the last fifteen years have ranked as some of the warmest on record.



4.5 Summary Tables

For quick reference, the following tables show a summary of recent changes in seasonal climate conditions and damaging events in Hays. 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, Drier springs Little change in last frost date
Summer	Warmer, Wetter summers Warmer nights; More Cooling Degree Days
Autumn	Warmer, Wetter autumns Later first frosts
Winter	Warmer, Snowier 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: 30% increase in wettest 1-day period per year 5-day: 26% increase in wettest 5-day period per year 15-day: 13% increase in wettest 15-day period per year
Snow Storms	Decreased frequency of 3.0 inch snowfall events by 1 day 3% increase in snowiest 3-day period per year Snowier winters; Less snowy transition seasons (spring/autumn)
Late/Early Freeze	Growing season lengthened by 5 days Little change in spring; Later frosts in autumn
Tornado, Wind, Hail	Inconsistencies in reporting exceed trend

Future Climate Projections

Over the past century, Kansas' climate has become increasingly warmer and wetter. Seasonal differences in these overall trends 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. 2017; Kunkel et al. 2017). The fourth NCA is currently under development and is expected to be released in 2018.

Temperature

Temperatures have increased across Kansas, predominantly in the winter and spring. Projections indicate that temperatures will continue to rise; however, the amount of future warming is largely dependent upon increases or decreases in greenhouse gas emissions. This means a range of conditions is possible and, depending on the scenario, a 4-9°F increase in average annual temperature could occur for Hays (Walsh et al. 2014). Like current trends, cold waves are expected to become less intense and heat waves are expected to become more intense. Even a modest increase in summertime temperature could lead to more extremes. These trends could have serious implications for communities like Hays, as increases in cooling demands could put a strain on utilities and more intense heat waves could impact vulnerable populations, like the young, the elderly, and the poor.

"Communities that are already the most vulnerable to weather and climate extremes will be stressed even further by more frequent extreme events occurring within an already highly variable climate system." - Great Plains NCA Report, 2014

Precipitation

Precipitation projections for the Central Plains are less certain than areas of the Midwest, but, in general, increases in precipitation are expected in the winter and spring seasons, while decreases are expected for the summer (Shafer et al. 2014). For Hays, these projections could mean a 10-15% increase in winter precipitation and a 5-10% increase in spring precipitation (Walsh et al. 2014). Extreme precipitation events are also expected to increase across Kansas and, depending on the scenario, this could mean up to a 3-fold increase in the number of heavy precipitation events in Hays by the end of the century (Walsh et al. 2014). This increase in heavy precipitation could potentially lead to an increase in the frequency and intensity of flash flooding events. Even with these increases in wetness, interestingly, the number of consecutive dry days is also expected to increase by up to 4 days per year (Walsh et al. 2014).

Summer sunflowers
Photo courtesy: Ken Dewey

Although not yet apparent in regional and local trends, summer precipitation is expected to decrease across all of Kansas by 2050. For Hays, this could be a decrease of 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 Kansas' climate. Drought years can already put a strain on Hays' water supply, including wells along the Smoky Hill River. For a city like Hays, which already takes measures to conserve water, any sustained decrease in precipitation in this water-limited area could prove to be quite challenging.

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 Great Plains already experience a wide range of weather and climate conditions, this range has increased over time in Hays, making the city more prone to weather and climate hazards. Recent and future changes in Hays 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.
- More intense heat waves in the summer could impact utilities during peak delivery times.

Strains to water resource management

Recent

- An increase in the intensity of single-day heavy rainfall events has increased the potential for flash flooding.
- An increase in the intensity 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 spring/autumn snowfall coupled with increases in winter 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

High Plains Quarterly and Monthly Climate Summaries

- Quarterly Climate Impacts and Outlook: https://www.drought.gov/drought/resources/reports
- Monthly Climate Overviews: http://www.hprcc.unl.edu/climatesummaries.php

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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