Municipal Climate Adaptation: A Report for Dubuque, Iowa

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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).

HPRCC NEBRASKA STATE CLIMATE OFFICE UNIVERSITY OF Nebraska PUBLIC POLICY CENTER CITY OF LINCOLN NEBRASKA

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

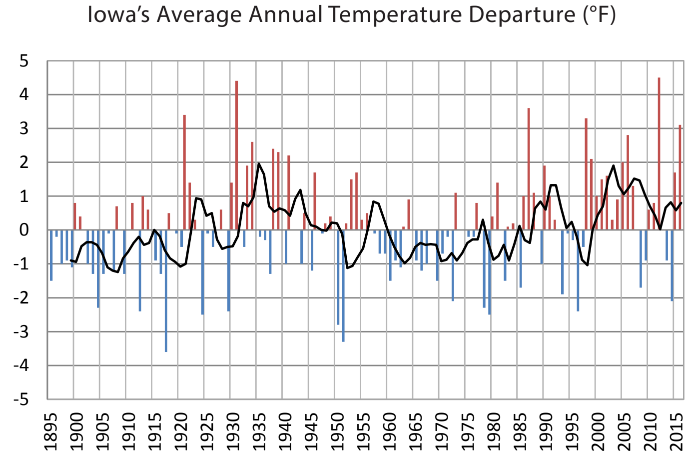
3.1 Iowa Temperature Trends

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

The trend in average annual temperature for Iowa shows an increase of 1.2°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. 2012 was the warmest year on record, followed closely by 1931. Three of the top ten warmest years on record have occurred since 2005, including 2006, 2012, and 2016.

The annual warming trend is much greater for minimum temperatures (2.1°F) than for maximum temperatures (0.2°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 disproportionately impacts nighttime low temperatures much more than daytime high temperatures.

On a seasonal basis, winter trends indicate the strongest warming with a 2.1°F increase, while summer trends show little warming, with only a 0.1°F increase. This is consistent with regional trends, as well.



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

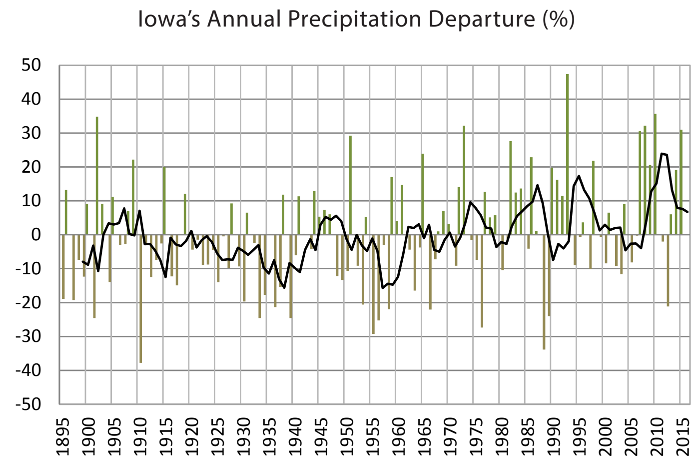
State	Spring	Summer	Autumn	Winter
Iowa	**1.5**	**0.1**	**0.8**	**2.1**
Kansas	1.8	0.9	0.7	2.6
Missouri	1.3	0.0	0.0	1.6
Nebraska	2.1	1.0	1.0	3.2
Four-state Average	1.7	0.5	0.6	2.4

3.2 Iowa Precipitation Trends

Statewide precipitation records for Iowa 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 southeast to northwest with areas of extreme southeast Iowa receiving about 40 inches of precipitation each year on average, while areas of the northwest receive less than 30 inches.

Over the 122-year time period, average annual precipitation has increased by about 15% in Iowa, which is the largest increase in the four-state region. There is variability in the precipitation record, with drought periods of the 1930s and 1950s evident in the record, as well as the extremely dry years of 1910 and 1988. The past few decades have been part of a wetter period for the state, with two of Iowa's worst flooding years in modern history occurring in 1993 and 2008 (Zogg 2014). Although 1993 stands out as the wettest year on record for Iowa, it is worth noting that four of the top ten wettest years have occurred in the past ten years, including 2007, 2008, 2010, and 2015.

Seasonal trends show that there has been an increase in precipitation during all four seasons in Iowa, with the largest increase in the spring (23%) and the smallest increase in autumn (1%). These precipitation trends, especially the large increase in spring-time 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 Iowa, 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).

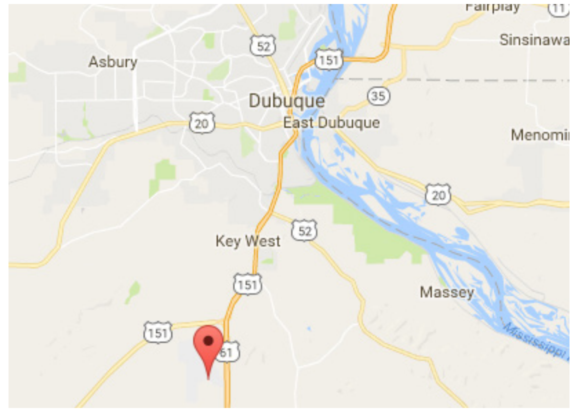
Statewide Annual Climate Trends (1895-2016)

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 Dubuque

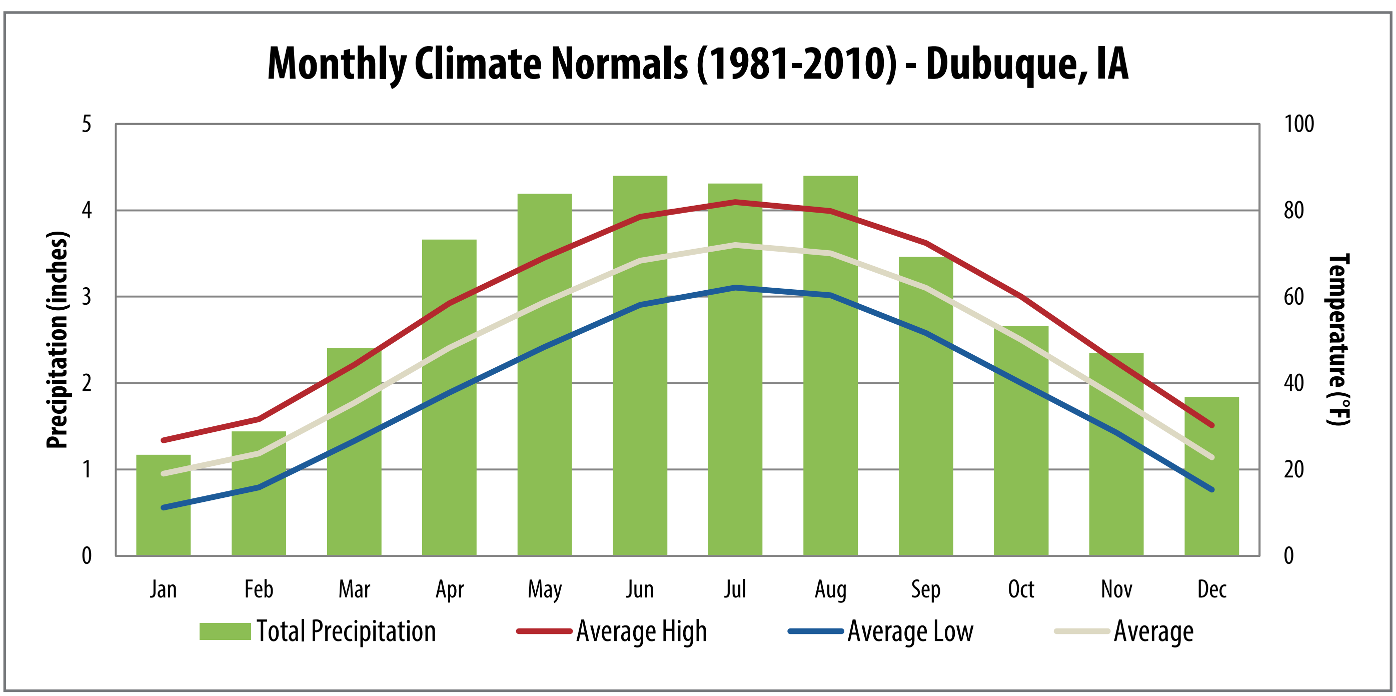


Dubuque Regional Airport: 42.3978, -90.7036
GHCN ID: USW00094908; Map Data: Google

The weather station at the Dubuque Regional Airport, located about 7 miles to the south-southwest of the city, was selected for this report due to its nearly continuous 66-year record. Daily measurements of temperature, precipitation, and snowfall have been taken at this location since February 1, 1951.

Dubuque's 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. Dubuque experiences all four seasons and there can be variability in temperature and precipitation; however, this variability is not as extreme as locations to the west across the Plains. The hottest time of the year is July, when average high temperatures peak at 82°F, while the coldest time of the year occurs in January with average low temperatures dipping to 11°F. The wettest time of the year is the summer (June, July, August), with precipitation totals averaging 13.11 inches, while the driest time of the year is the winter (December, January, February) with only 4.45 inches*. Much of the precipitation in the winter falls as snow, with an average of 30.8 inches. Winds are predominantly from the northwest and the south. Winds from the northwest bring cold, dry air, while winds from the south bring warm, moist air. Dubuque's 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 Dubuque.

*Winter precipitation in Dubuque 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 Dubuque Temperature Trends

Temperature Trends Vary by Season
Dubuque has experienced an increase in average temperature of 1.7°F over the past 50 years. Each season shows a warming trend, with winter exhibiting the largest increase (3.0°F). Overall, both maximum and minimum temperatures have increased at similar rates, but there is variation across the seasons. For instance in the summer, there has been little change to maximum temperatures; however, there has been an increase in minimum 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 a decrease in the severity of both heat waves and cold waves. The hottest 3-day period of each year has decreased slightly by about 1°F, while the coldest 3-day period of each year has increased by about 5°F.

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

Dubuque's Changing Seasons

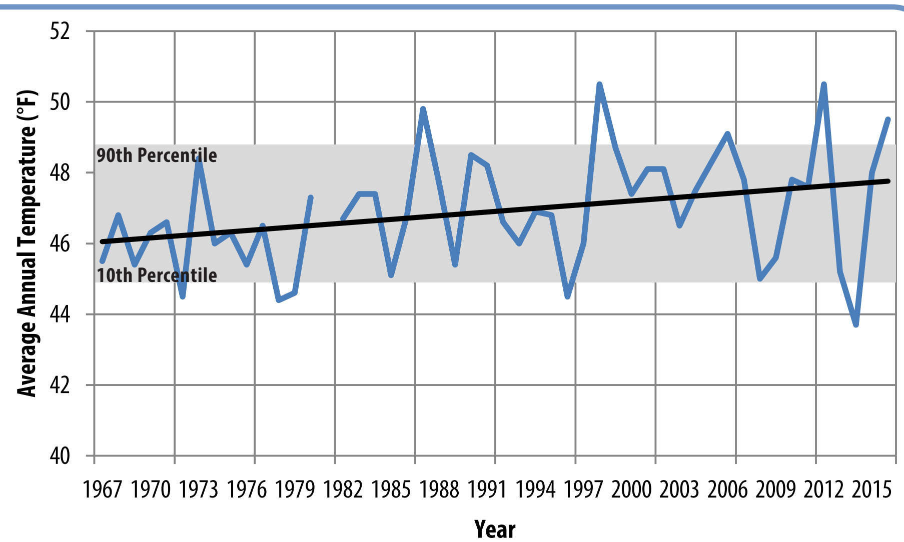
Spring	Summer
1.5°F ↑	0.6°F ↑
Autumn	**Winter**
1.7°F ↑	3.0°F ↑

Changes to Energy Needs

Heating and cooling degree days can be an indication of energy demand. Rising temperatures in Dubuque are leading to changes in energy needs. Trends in cooling degree days show a 5% increase overall, with the largest increase, by percentage, in autumn (17%).

Trends in heating degree days, however, show a 9% 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, Dubuque's average annual temperature has increased by 1.7°F. High year-to-year variability has occurred recently, especially in the past 15 years.



Historical Climate Trends - Local

4.3 Dubuque Precipitation Trends

Precipitation Trends Vary by Season
Trends in Dubuque's annual precipitation are negligible (2% increase); however, noteworthy changes have been observed from season to season. Over the past 50 years, summer precipitation has increased by 23%, while autumn precipitation has decreased by 39%. Increases were also observed in the spring and winter seasons.

Heavy Precipitation Events Increasing
Over the past 50 years, Dubuque has had an increase in the frequency and intensity of single-day heavy rainfall events (days with at least 1.25 inches of rain). These increases could lead to an increased potential for flash flooding. The intensity of multi-day (5- and 15-day) events has also increased, which could signal the potential for longer-term flooding because 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 already correspond to recent observed changes in increased heavy rainfall events and these trends are expected to continue and accelerate.

Dubuque's Changing Seasons

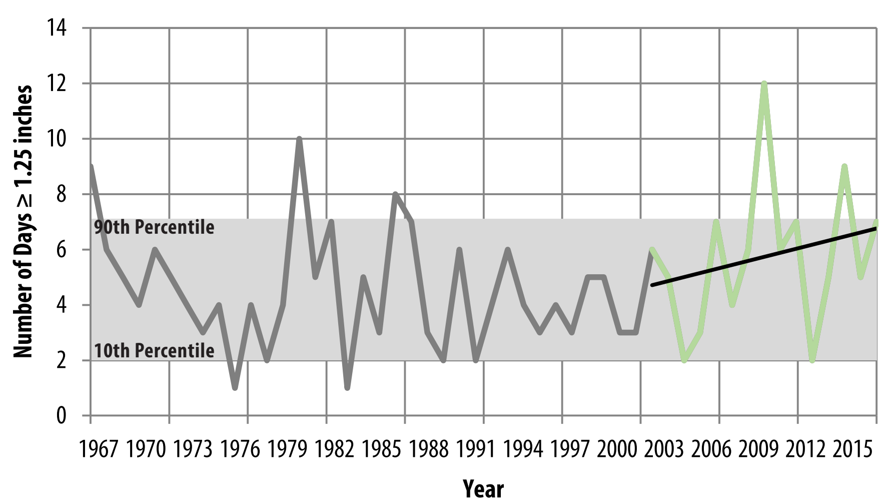
Spring	Summer
8% ↑	23% ↑
Autumn	**Winter**
39% ↓	3% ↑

Changes Within Snow Season

A snow season is defined as the period between July 1 and June 30. Overall, there has been a 4% increase in snowfall totals in Dubuque; however, there have been significant 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 34% increase in wintertime snowfall totals, with three of the past ten years exceeding the 90th percentile.

Over the past 50 years, the number of days that Dubuque has received at least 1.25 inches of rain has increased by 5 days. This trend has accelerated in the past 15 years.



4.4 Dubuque Climate Extremes

Highest Temperature:
110°F, Jul 14, 1936

Lowest Temperature:
-32°F, Jan 1, 1887

Highest Precipitation:
8.85in, Sep 14, 1967

Highest Snowfall:
15.0in, Mar 5,1959

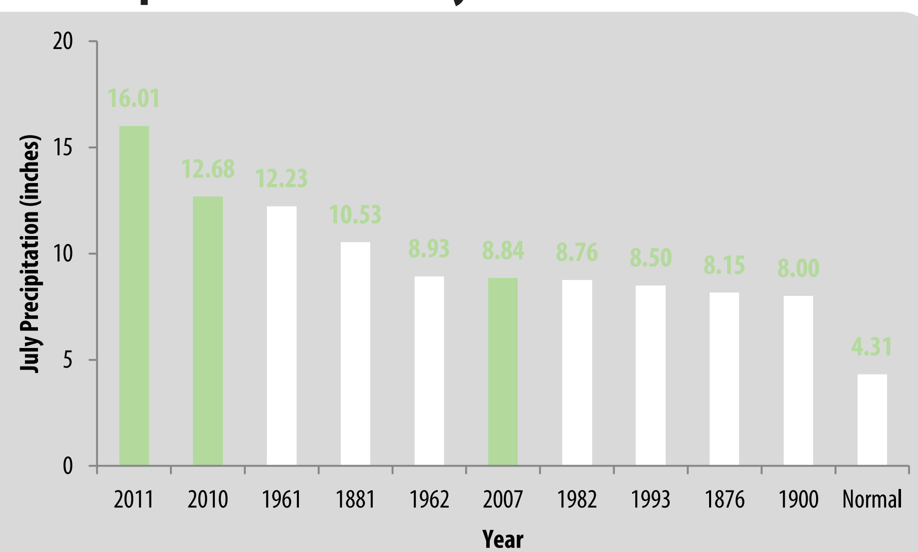
Average temperature and total precipitation are helpful for understanding the general conditions; however, these do not demonstrate the wide range of conditions that can be experienced. This range of conditions is especially important for a place like Dubuque because 1) extremes are common in the continental type of climate experienced there and 2) extremes are impactful to people and infrastructure. Extremes in both temperature and precipitation are becoming more common in Dubuque, and those occurring in succession make responding to and preparing for these events quite difficult. Extremes data presented here include stations from around the Dubuque area, beginning in 1873.

Temperature Extremes
It has been somewhat of a roller coaster ride over the past several years in Dubuque. Although average temperatures have increased over the past 50 years, two of the top ten coldest years have occurred recently. 2008 ranked as the 9th coldest year, while 2014 tied with 1875 as the coldest year on record. 2013 was not far behind in the 11th spot. 2012 was the only recent year to rank in the top 10 warmest years on record (10th warmest).

Precipitation Extremes
Extremes in annual precipitation have also occurred recently, with four consecutive years (2008-2011) ranking in the top 15 wettest years on record. This extremely wet period was followed by the 10th driest year on record, 2012. Extremes on either end of the spectrum have resulted in losses due to flooding and drought. For example, the 2-day heavy rainfall event that occurred July 27-28, 2011 was the wettest 2 days on record for Dubuque, with 10.74 inches. This storm produced damaging flash flooding in and around the Dubuque area.

Recent Extremes - Top 10 Wettest Julys on Record

Increases in summer precipitation have been driven by the months of June and July. Three recent Julys have ranked in the top ten wettest 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 Dubuque. 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 Little change in last frost date
Summer	Wetter summers Warmer nights; More Cooling Degree Days
Autumn	Warmer, Drier autumns Later first frosts
Winter	Warmer, Snowier winters Fewer Heating Degree Days

Damaging Event	Recent Changes in Damaging Events
Heat Waves	Decreased intensity of heat waves 3-day: Lower average and maximum temperatures Little change to 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: 14% increase in wettest 1-day period per year 5-day: 28% increase in wettest 5-day period per year 15-day: 23% increase in wettest 15-day period per year
Snow Storms	Decreased frequency of 3.0 inch snowfall events by 1 day 5% decrease in snowiest 3-day period per year Snowier winters; Less snowy transition seasons (spring/autumn)
Late/Early Freeze	Growing season extended by 6 days due to later frosts in autumn
Tornado, Wind, Hail	Inconsistencies in reporting exceed trend

Future Climate Projections

Over the past century, Iowa's climate has become increasingly warmer and wetter. Seasonal differences in these overall trends highlight specific 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 substantially across Iowa, and projections indicate that this trend will continue. The amount of future warming 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 Dubuque (Walsh et al. 2014). Like current trends, cold waves are expected to become less intense; however, unlike recent trends, heat waves are expected to become more intense in the future. Even a modest increase in summertime temperature could lead to more extremes. These trends could have serious implications for communities like Dubuque, 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.

"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

Iowa is particularly susceptible to flooding due to the thousands of miles of rivers and streams that flow through the state. Large rivers, such as the Mississippi River, the Big Sioux River, and the Missouri River, flow along Iowa's eastern and western borders, and many communities, like Dubuque, are located along these waterways. Complicating matters is that precipitation changes across Iowa cannot be the sole focus for planning, as the water flowing through these rivers also comes from upstream sources.

Mississippi River, Summer 2012
Photo courtesy: Ken Dewey

All across Iowa, precipitation is projected to increase, especially in the winter and spring seasons. For Dubuque, this could mean a greater than 15% increase in precipitation in the spring and a 10-15% increase in precipitation during the winter (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.

Although not yet apparent in the regional and local trends, summer precipitation is expected to decrease across much of Iowa by 2050. For Dubuque, this could be a decrease of up to 5% (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 Iowa'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 Dubuque, making the city more prone to weather and climate hazards. Recent and future changes in Dubuque 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 summer and autumn has led to an increase in cooling demands. Warmer minimum temperatures have driven the increased demand in the summer.

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 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.
- Although modest, 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 the Midwest and Great Plains Regions
- Corn Belt Climate Trends (1980-2013): http://www.hprcc.unl.edu/climatetrends.php

Monitoring of Current and Recent Climate Conditions

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

National, Regional, and Statewide 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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