IOWA DOT
I-380 Planning Study

INTERSTATE 380

PLANNING STUDY (PEL)

Evaluation of I-380 Resiliency and Vulnerability

Office of Location and Environment | February 2018

EXECUTIVE SUMMARY

This technical memorandum analyzes information from previous studies that have identified historic and projected future climate trends and the impacts of future climate variability on the Interstate 380 (I-380) transportation infrastructure between Interstate 80 (I-80) and U.S. Highway 30 (US 30) in eastern Iowa. This study, which relies on existing literature, available historical climate records, and projected climate information, focuses on the rural, non-urban areas of the corridor. Using this information, this technical memorandum identifies resiliency recommendations to be considered in subsequent environmental and engineering studies of the I-380 corridor. The change in greenhouse gas (GHG) emissions (thought by some to be a contributing factor of climate variability) that may occur as a result of the planned I-380 project is not considered part of this resiliency evaluation.

This resiliency study uses the following methodology:

1. Assess threats – based on historical climate and projected future climate trends documented in existing literature identify the characteristics of future potential climate change and weather events that could occur in the area of the study corridor.
2. Identify and understand vulnerabilities – based on historical closure events and surrogate factors that may suggest a risk of impact to the transportation mobility within the study corridor resulting from an extreme weather event.
3. Identify strategies – note possible strategies for future consideration that may adapt and minimize the risk of traffic interruption along the corridor as a result of an extreme weather event.
4. Provide recommendations – list considerations for future environmental and engineering studies.

Historic climate data show strong trends in increasing temperature, precipitation, streamflow and flooding and decreasing snowfall and wind throughout this section of the I-380 corridor. These trends are expected to continue into the future and will impact the I-380 corridor in various ways. Available information on historical weather-related impacts and closure events along the I-380 corridor is limited. The locations and events summarized in this memorandum were identified through Iowa Department of Transportation (DOT) information sources, existing literature and research, web searches, and anecdotal information provided by Iowa DOT maintenance staff. Based on available historical information and projected changes in future climate, potential future impacts of extreme weather conditions are summarized in Table ES-1 and Figure ES-1.

Table ES-1. AREAS MOST AT RISK OF CLIMATE RELATED IMPACTS

Feature Name	I-380 Mile Post [Range]	Impact Type	Notes
	0 to 16	High Temperature – average change	Temperature change likely to be uniform across study area and average compared to statewide projected increases.
	0 to 16	Snow, Blizzard	Iowa DOT reports historical snow and ice throughout corridor. However, historical and projected trends in this area show decreasing snow totals and storm events.
Clear Creek	0.5	Flooding	Intersects I-380, but not within study area (0.3 mile outside). During a flood event on June 17,1990 water level rose approximately to an elevation of 680 feet, or within about 6 feet of nearby roadway low point. Otherwise, no available flooding history identified at this location.
Unnamed Creek C	6.4	Flooding	Roadway low point. Backwater from Coralville Reservoir (Iowa River) likely floods at this location.
Unnamed Creek B	6.6	Flooding	Roadway low point. Backwater from Coralville Reservoir (Iowa River) likely floods at this location.
Coralville Reservoir (Iowa River)	7.9	Flooding	Flood closure during 1993 (water surface elevation 716.71 feet) and 2008 (717.29 feet) events. During June 2008 flood event, water level rose to within 3 feet of bridge approach sag.

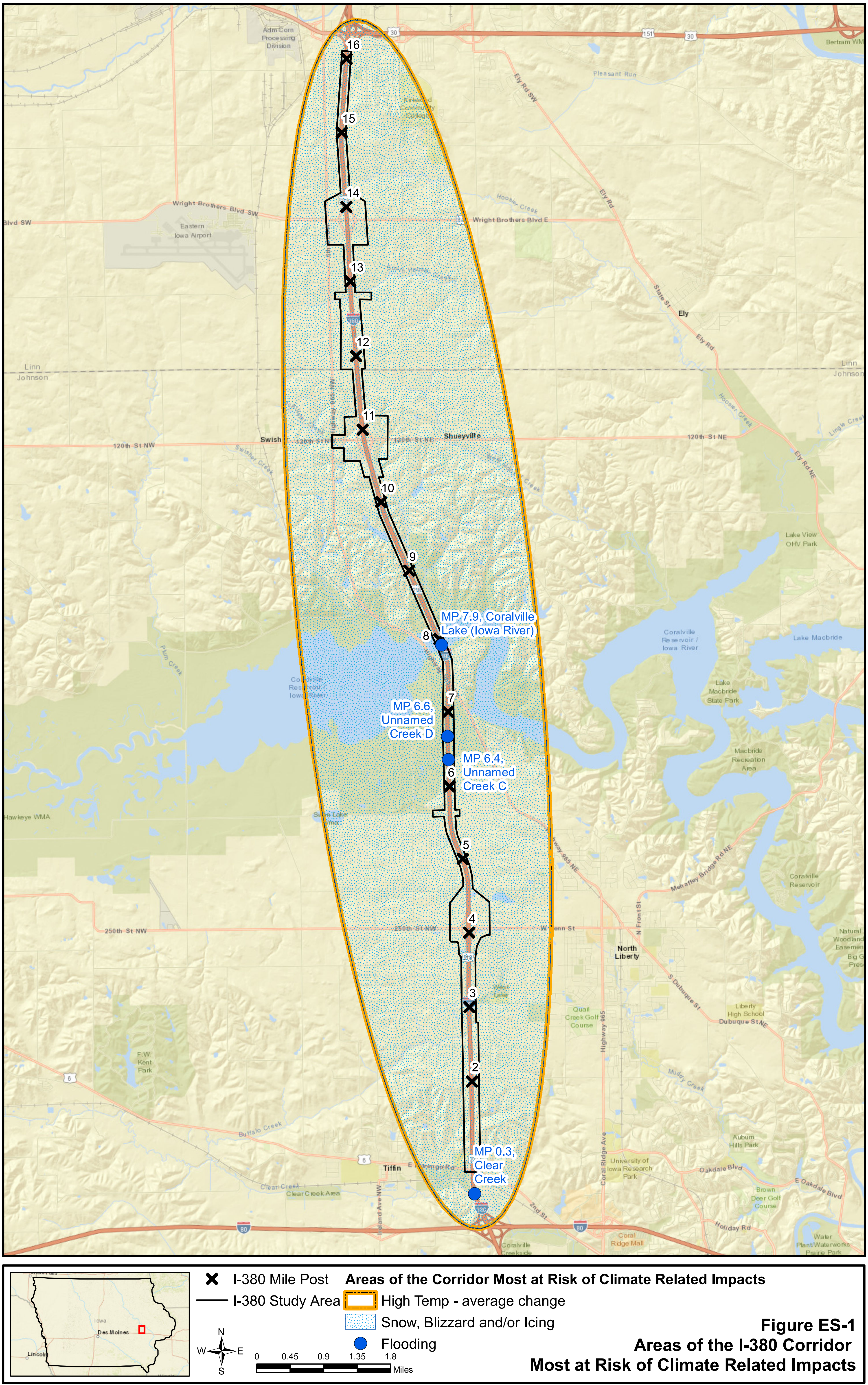

Figure ES-1
Areas of the I-380 Corridor Most at Risk of Climate Related Impacts

Sources: ESRI, 2017b

The U.S. DOT provides guidelines for transportation and infrastructure climate resiliency planning. Their recommendations are discussed in this document as they relate to Iowa's changing climate conditions and projected future impacts and include design, operational, and cost and economic planning strategies. Engineering and design considerations include, but are not limited to, pavement compositions that are more durable at higher temperatures, raising roadway embankments and bridges above projected flood levels, constructing additional stormwater management, overflow, and conveyance features, construction of natural windbreaks, and acquisition of additional rights-of-way in an effort to control snow drifts. Operational strategies include adjusting maintenance schedules to cooler times of the day per year and expanding infrastructure monitoring programs. Economic planning strategies include evaluating road-user costs from climate and weather-related impacts and resiliency planning of adjacent transportation corridors considered key to maintaining regional mobility during periods of extreme weather occurrences.

This technical memorandum makes the following five recommendations for climate resiliency planning along the I-380 corridor:

1. Develop a road closure monitoring and documentation program with a more comprehensive understanding of weather-related events disrupting the flow of I-380 traffic and other nearby potential alternative routes, including I-80. This type of program may provide value for future resiliency evaluations.

2. Monitor maintenance performance and adjust maintenance practices considering recent weather events and projected climate variability.

3. Review and update stormwater design standards to account for (1) recent changes in hydrologic records, (2) assets (such as, road surface, road base, culvert, bridges, and other infrastructures) with a long design life, and (3) projected future changes in precipitation intensity and hydrology. Use the most recent discharge data for hydraulic analysis for stream crossings with long asset design life, and consider projected increases in discharge within the asset design life.

4. For vulnerable locations, perform risk analysis during design development. This risk analysis should incorporate location specific features, possible detours, and possible mitigation strategies to improve the resiliency of the roadway network and maintain the flow of traffic along I-380. Perform an economic evaluation as part of the risk analysis to compare the cost of mitigation to the cost of the impact created by disrupting I-380 traffic.

5. Because of the close proximity of I-80 to the I-380 study corridor, the two corridors are interdependent in cases of closure and the need for traffic diversion. Efforts to improve the resiliency of both corridors can be considered and should be coordinated.

The findings of this memorandum are high-level in that they provide guidance for areas of I-380 where traffic flow could be disrupted by an extreme weather event. However, further, more-detailed project-level studies are encouraged regarding existing infrastructure, the risk of impact at specific locations, possible strategies to remedy identified weaknesses of the I-380 corridor, and a benefit-cost evaluation on a location-by-location basis. The eventual outcome of additional analysis will be identification of cost-effective and feasible means to provide for the safe and dependable mobility of the I-380 corridor.

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ACRONYMS AND ABBREVIATIONS

°F	degree(s) Fahrenheit
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ABC	accelerated bridge construction
ADTT	Average Daily Truck Traffic
AEPD	annual exceedance-probability discharge
Census	U.S. Census Bureau
cfs	cubic feet per second
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	carbon dioxide
DOT	Department of Transportation
DRUC	Direct Road User Cost
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
ft	foot/feet
GCCV	Global Climate Change Viewer
GHG	greenhouse gas
GIS	geographic information system
GPS	global positioning system
HERS-ST	Highway Economic Requirements System - State
HSM	Highway Safety Manual (AASHTO, 2010b)
HU4	Hydrologic Unit 4
HU8	Hydrologic Unit 8
I-35	Interstate 35
I-80	Interstate 80
I-380	Interstate 380
IA	Iowa
ICCAC	Iowa Climate Change Advisory Council
ICF	ICF International for U.S. Department of Transportation
IPCC	Intergovernmental Panel on Climate Change
ITS	Intelligent Transportation Systems
mph	miles per hour
MP	mile post
N/A	not available
NARCCAP	North American Regional Climate Change Assessment Program

NAVD88	North American Vertical Datum of 1988
NEPA	National Environmental Policy Act of 1969
NESDIS	National Environmental Satellite, Data, and Information Service
NGVD29	National Geodetic Vertical Datum of 1929
NHDPlus	National Hydrography Dataset Plus
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council of the National Academies
NWS	National Weather Service
OODT	Out-of-Distance-Travel
PEL	Planning and Environmental Linkages
RCB	reinforced concrete box
RCP	Representative Concentration Pathway
SRES	*IPCC Special Report Emissions Scenarios* (IPCC, 2000)
Study	I-380 Resiliency and Vulnerability Study
US 30	U.S. Highway 30
USGS	U.S. Geological Survey
vpd	vehicles per day
Zone A	Is defined as an area inundated by the 1 percent annual chance flood (100-year recurrence interval) for which no base flood elevations have been determined.
Zone AE	Is designated by FEMA on flood insurance maps. It indicates that these areas are inundated by the 1 percent annual chance of flood and have documented base flood elevations.

1. INTRODUCTION

The purpose of this technical memorandum is to summarize existing information associated with observed and projected future climate along the Iowa Interstate 380 (I-380) corridor and to evaluate the overall resiliency of the I-380 corridor with respect to future projected climate variability. This memorandum will focus on the resiliency of weather-related closure events, identify areas of the corridor most at risk, and recommend solutions for further consideration at the at-risk areas. Some consider greenhouse gas (GHG) emissions to be a contributing factor to climate variability. The change in GHG emissions as a result of the planned I-380 project is not considered part of this resiliency evaluation; rather the study relies solely on existing literature and available climate and weather projection information. The results of this evaluation will support the Iowa Department of Transportation's (DOT's) I-380 Planning and Environmental Linkages (PEL) Study. Additional supporting documentation about this evaluation is included as Appendixes to this document. These items are listed below.

Appendix A – Existing Data Collection Summary
Appendix B – List of All Sources and Data Reviewed
Appendix C – User Costs due to Road Closure Events
Appendix D – Photo Log of Areas Most at Risk of Climate Related Impacts

1.1 POLICY DRIVERS

The National Environmental Policy Act (NEPA) of 1969 process requires federal agencies to evaluate, document, and disclose anticipated environmental impacts created by proposed projects and actions. Changes in expected GHG emissions, carbon footprints, and resultant climate impacts are popular topics of conversation and research. However, the way GHG emissions and climate adaptation are to be addressed or evaluated within the framework of required NEPA studies is not clearly defined.

Regarding resiliency of a major transportation corridor like I-380, understanding and correcting the weaknesses of the existing infrastructure creates a better transportation system that is able to consistently and reliably meet the transportation needs of all road users. Evaluating the resiliency of the corridor provides value and important information to consider as the I-380 planning study transitions from program-level evaluations to more-detailed, project-level studies.

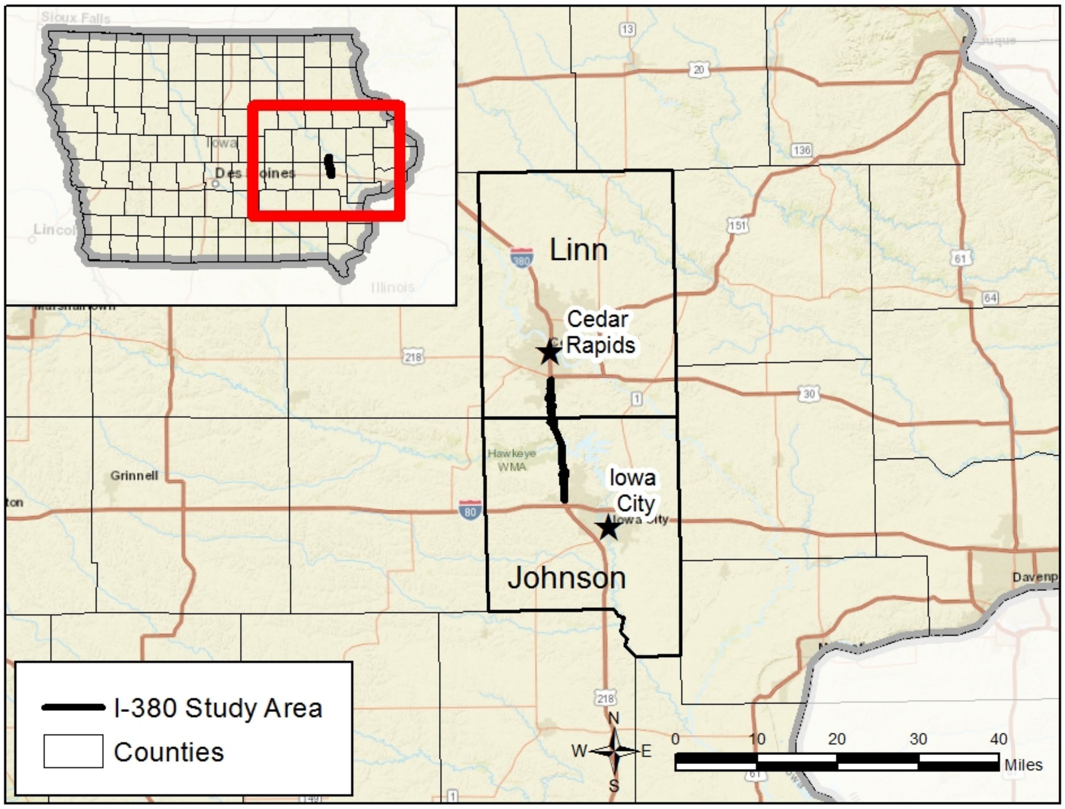
2. GEOGRAPHIC DESCRIPTION OF STUDY AREA

Section 2 defines and briefly describes the geography of the study area.

2.1 STUDY AREA

The study area (Figure 1) is a precisely defined polygon that extends along the existing I-380 corridor in eastern Iowa for approximately 15 miles across parts of Linn and Johnson Counties from south of Cedar Rapids near the U.S. Highway 30 (US 30) crossing, to just northwest of Iowa City near the Interstate 80 (I-80) crossing. This technical memorandum is limited to rural areas, and excludes urban areas, including the Cedar Rapids and Iowa City metropolitan areas. Also, discussions of possible climate risks (such as, floodplains, rivers, traffic incidents, and other factors) are limited to the study area.

Figure 1. MAP OF REGION SURROUNDING THE STUDY AREA (ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE [ESRI], 2017a; ESRI, 2017b)

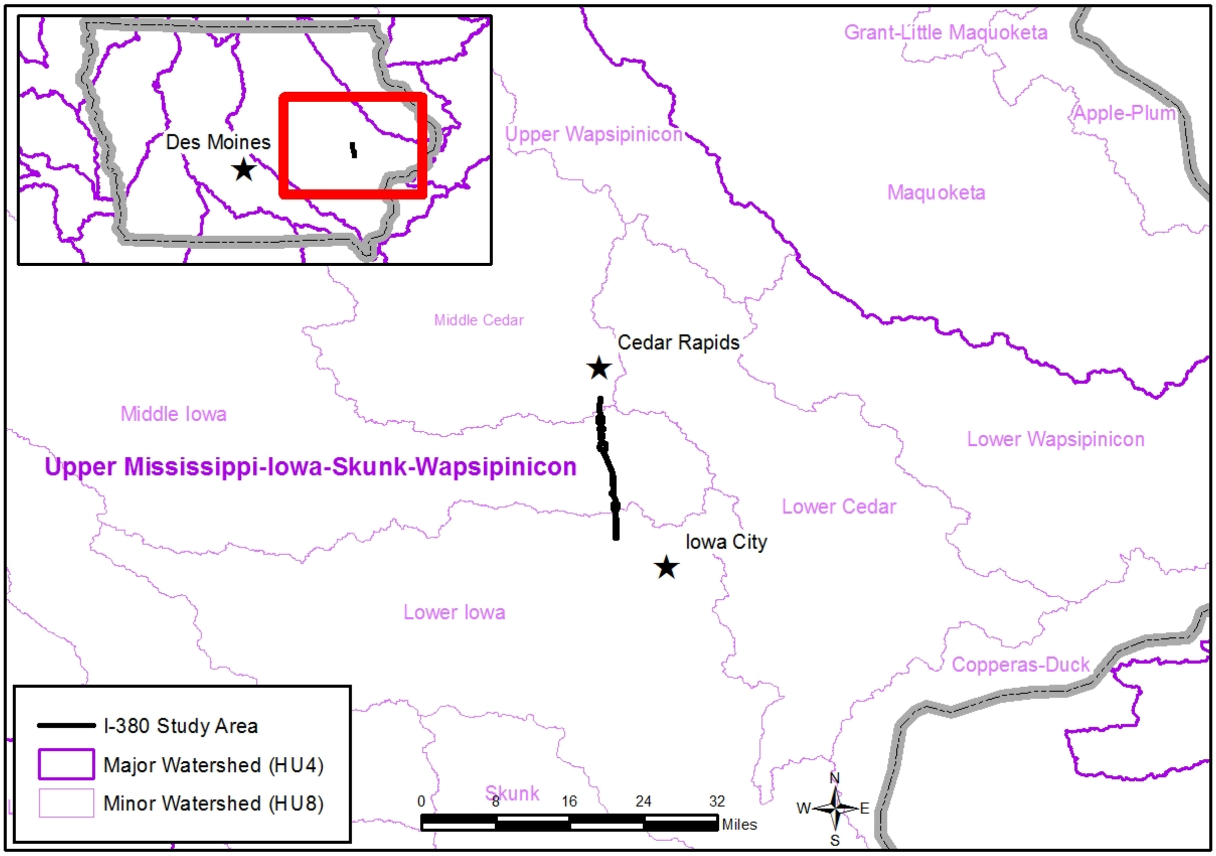


2.2 WATERSHED BASINS

The I-380 study area is contained within one major watershed basin (Hydrologic Unit 4 [HU4]) and three minor (Hydrologic Unit 8 [HU8]) sub-basins (Figure 2). These basins are part of the Upper Mississippi-Iowa-Skunk-Wapsipinicon watershed, and generally drain from northwest to southeast. Within these three sub-basins, the study area crosses one major river – the Iowa River (Figure 3 and Table A-1), with mean annual flow above 2,000 cubic feet per second (cfs) as approximated by the National Hydrography Dataset Plus (NHDPlus) dataset (Horizon

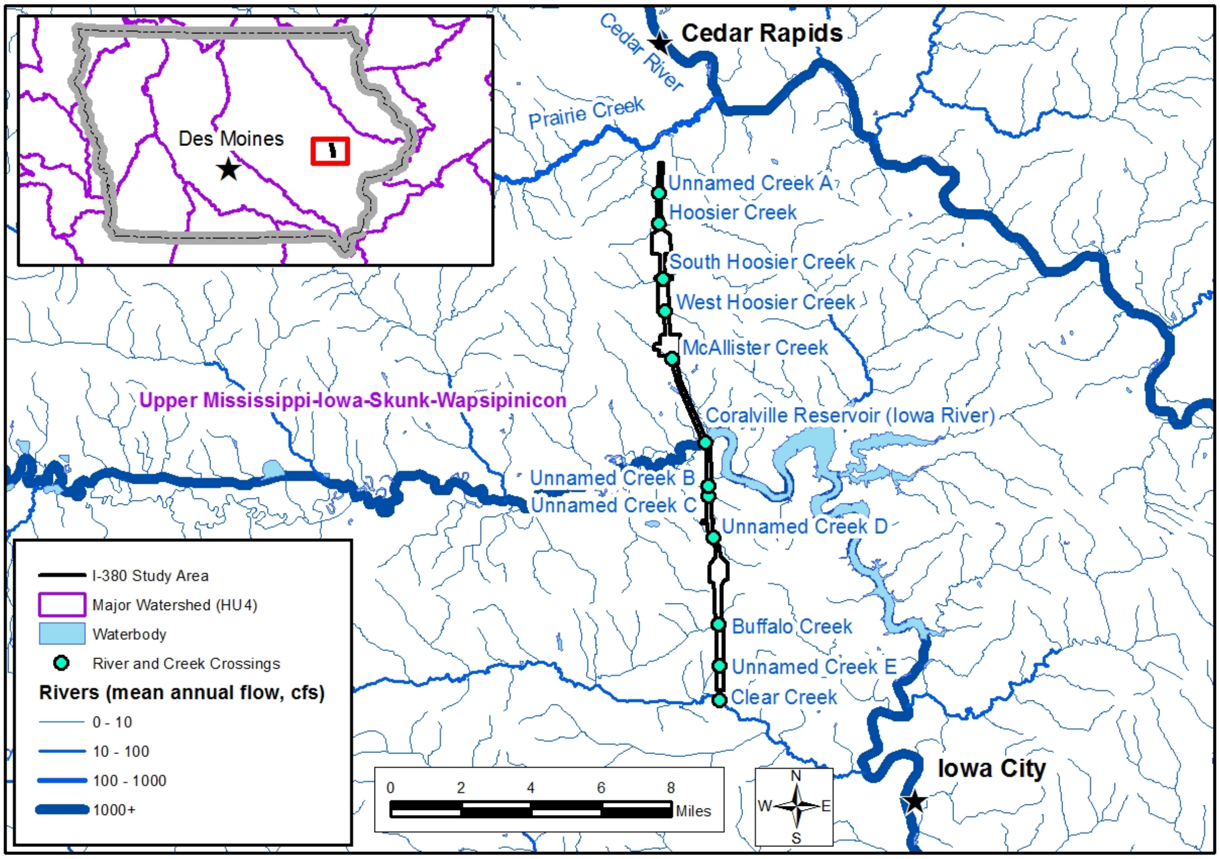
Systems, 2017). The study area also crosses 10 small creeks with mean annual flow below 5 cfs. The Iowa River crossing occurs over the Coralville Reservoir, an inline reservoir along the Iowa River.

Figure 2. MAJOR (HU4) AND MINOR (HU8) WATERSHEDS ALONG THE I-380 CORRIDOR (HORIZON SYSTEMS, 2017; ESRI 2017a)



While Clear Creek is outside the study area's southern boundary, it is near enough to have potential impacts on I-380 within the study area. Thus, it is included in this technical memorandum. Other nearby waterways with a documented history of flooding (such as Prairie Creek and the Cedar River impact portions of I-380) are outside the study area's northern boundary and, thus, are not included in this study. Combined, the 11 small creeks (including Clear Creek) and the Iowa River located within and adjacent to the study area have a collective mean annual flow of approximately 2,300 cfs.

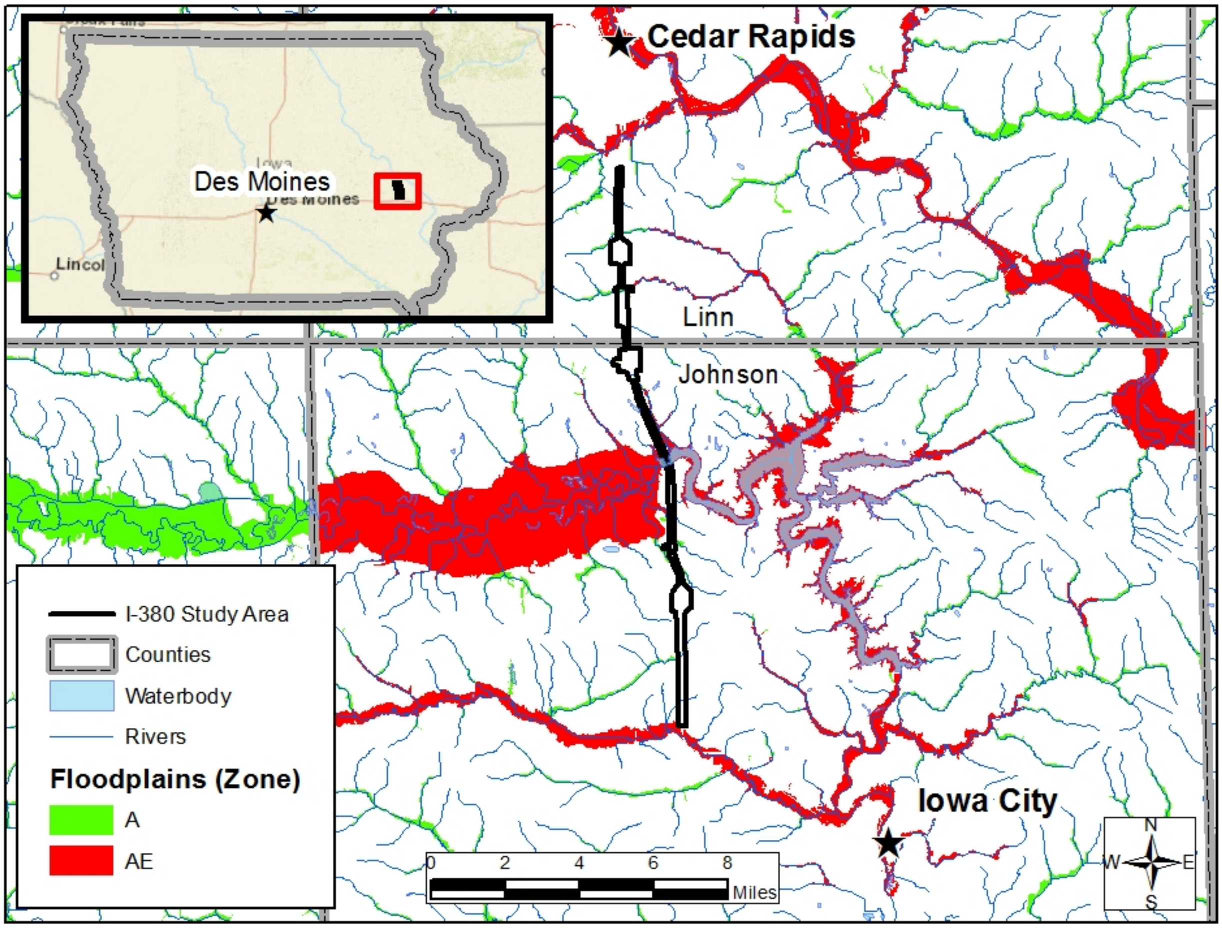
Figure 3. RIVERS AND CREEKS CROSSING THE I-380 CORRIDOR, CATEGORIZED BY MEAN ANNUAL FLOW (HORIZON SYSTEMS, 2017; ESRI 2017a)



2.3 FLOODPLAINS

Of the 11 small creeks (including Clear Creek) and the Iowa River, 8 have Federal Emergency Management Agency (FEMA) floodplains (Figure 4 and Table A-1). The remaining four creek crossings do not have floodplains mapped on the National Flood Hazard Layer (FEMA, 2013). Most FEMA floodplains that intersect I-380 are mapped as flood Zone A, which is defined as an area inundated by the 1 percent annual chance flood (100-year recurrence interval) for which no base flood elevations have been determined. One floodplain that intersects I-380 is mapped as Zone AE, that of the Coralville Reservoir (part of the Iowa River), which means these are areas inundated by the 1 percent annual chance of flood (100-year recurrence interval) and have documented base flood elevations. South Hoosier Creek is mapped as Zone AE, with base flood elevations, approximately 0.2 mile downstream of I-380.

Figure 4. FLOODPLAINS CROSSING THE I-380 CORRIDOR, CATEGORIZED BY ZONE (FEMA, 2013; HORIZON SYSTEMS, 2017; ESRI, 2017a; ESRI, 2017b)



3. EXISTING DATA COLLECTION SUMMARY

Existing data, studies, and reports were used to understand historical and projected future climate, hydrology and weather patterns. This information came from a wide variety of academic, government, and non-governmental sources, with areas ranging from local (such as, a specific river basin), to national, and global. These sources and the data they contain are detailed in Appendix A, but Section 3 provides a brief summary.

3.1 OBSERVED CLIMATE, HYDROLOGY, AND WEATHER

Historic climate data show strong trends in increasing temperature, precipitation, streamflow and flooding. The data also show decreasing snowfall and wind throughout eastern Iowa, including the I-380 study corridor. Statewide, temperature increases are more apparent during certain seasons and certain times of day – winter temperatures are increasing more than annual averages (+0.18 degree Fahrenheit [°F] per decade vs.+ 0.1°F per decade on average), and nighttime temperatures increasing more than daytime temperatures. Similarly, while average annual precipitation increases are relatively modest (0.6 percent increase per decade), seasonal changes are larger (6 percent increase per decade in spring/summer and 3 percent decrease per decade in fall/winter). Historically, extreme precipitation events have also trended upward. These precipitation trends are more noticeable in the eastern portion of the state, including Johnson and Linn Counties where the I-380 study corridor is located. Historical flooding has occurred most frequently in the late spring and summer, the times of year when precipitation has also been increasing.

3.2 FUTURE CLIMATE AND HYDROLOGY PROJECTIONS

Based on analysis of future climate projections, the trends are expected to continue into the future. Annual average temperatures throughout the Midwest region are expected to increase by about 3°F by 2035 and by up to 8.5°F by the end of the century. Projected temperature increases are greatest in the summer and winter in the study area. The number of days with freezing temperatures (daily low temperature below 32°F) is expected to decrease by about 20 days from the late 20th Century to the middle of the 21st Century. The freeze-free period (period between the last spring frost and first autumn frost) is projected to increase by a range of 22 to 24 days during the same period. Days with high rainfall (more than 1 inch in a day) are expected to increase by up to 30 percent, with these heavy downpour increases occurring especially in spring.

Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot (Iowa DOT, 2015) project attempts to translate rainfall climate projections into streamflow projections to assess the highway infrastructure vulnerability to weather extremes in Iowa. The study incorporates future precipitation projections into a river system model to predict impacts to streamflow and flooding in the Skunk and Cedar River basins. The analyses compare streamflow simulations for a historical period (1960 to 2009) and historical/future period (1960 to 2059). Although the study has only been conducted on the Skunk and Cedar River basins, these are directly adjacent to the I-380 study area and likely embody similar hydrological trends as those within the study area. Thus, findings from this study are applicable to the I-380 study area and are summarized in this document for understanding of historic and future hydrological conditions.

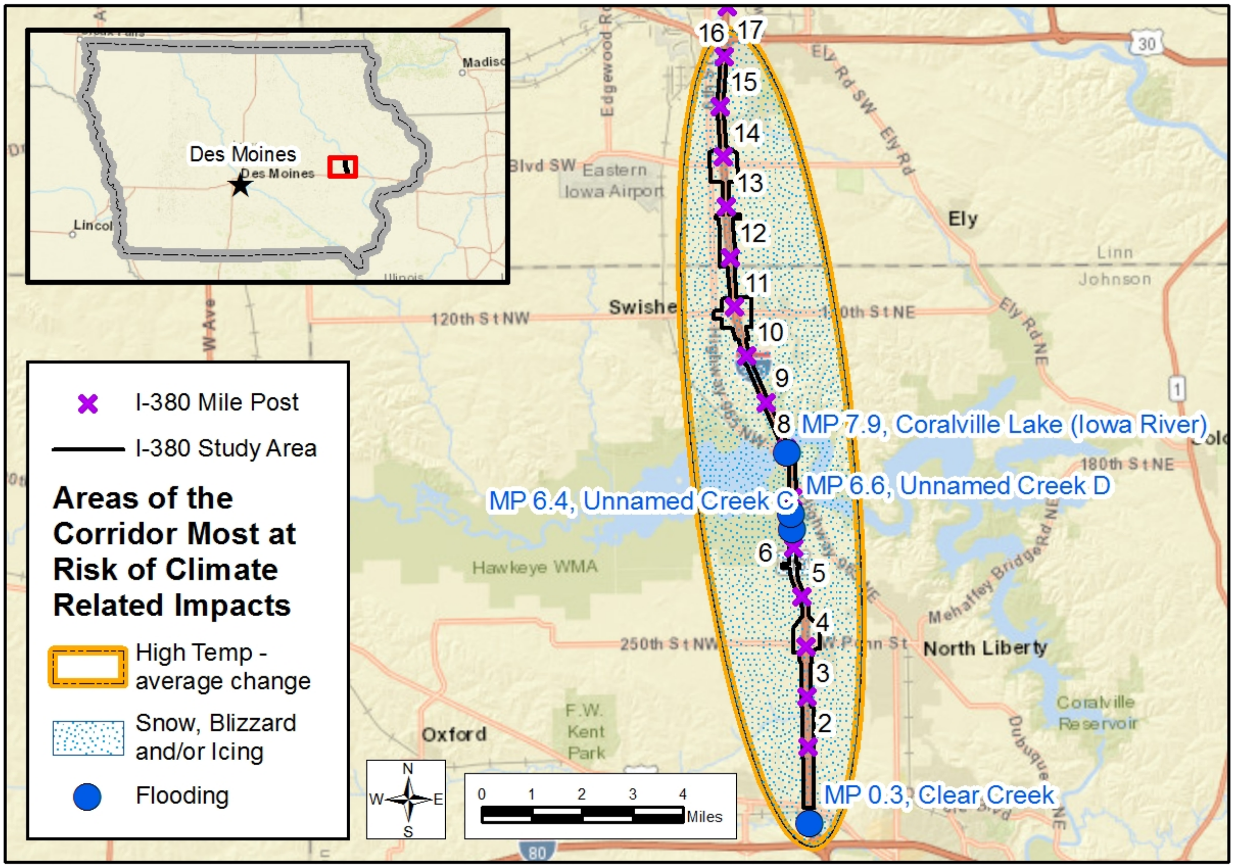
The study validates the consensus that increased precipitation intensity and frequency will likely lead to greater stream flows during major rainfall events, as well as greater frequency and magnitude of flooding. Model results (see Appendix A, Figure A-22 for additional details) signify that the 1 percent annual exceedance-probability discharge (AEPD) increase ranged from 37 to 67 percent for Cedar River Basin and ranged from 9 to 50 percent for South Skunk River Basin. (The 1 percent AEPD metric was chosen because it is a common design standard for bridge engineers.) Jha et al. (2004) found similar results in the Upper Mississippi River Basin.

The simulations of drainage have shown that increases ranging from 24 to 32 percent in precipitation (and accompanying warming) can lead to drainage flow increases ranging from 35 to 80 percent, respectively (Jha et al., 2004). However, the Skunk and Cedar River Basin model analyses show differences between model simulation and observed annual peak flow data to be between 47.7 and 59.8 percent. While there is a fair amount of certainty of increased stream flow projections (that they are expected to increase with increasing precipitation intensities), the magnitude of the increase should be interpreted with caution.

4. WEATHER-RELATED IMPACTS ON ROADWAY TRANSPORTATION AND INFRASTRUCTURE

Available historical weather-related closures and impacts within the study corridor are presented in Section 4.1; it is unknown how comprehensive this list of historical data is. Regardless, with the minimal data points to evaluate, the discussion of possible future impacts in this section focuses on broad areas where climate-related impacts are expected to be greatest. Section 4.2 describes types of impacts that can occur from increased climate variability and extreme weather events, where each of these impacts is most likely to occur along the I-380 corridor. Figure 5 summarizes the geographic extent of these impacts. Table 1 lists these impacted areas. Discussion in this section of impacts specific to transportation infrastructure is informed primarily by *Potential Impacts of Climate Change on U.S. Transportation* (National Research Council of the National Academies [NRC], 2008) and the *Transportation Climate Change Sensitivity Matrix* (ICF International for U.S. Department of Transportation [ICF], 2014). Appendix D shows an I-380 photo log of areas identified as most at risk of possible climate related impacts.

Figure 5. AREAS OF THE I-380 CORRIDOR MOST AT RISK OF CLIMATE RELATED IMPACTS (ESRI, 2017b)



4.1 HISTORICAL I-380 IMPACTS DUE TO WEATHER-RELATED EVENTS

The resilience of I-380 with respect to existing and projected future climate is tied to existing roadway and bridge infrastructure and the general topography of the surrounding areas.
In general, climate-related roadway closures and reduced capacity events are likely to increase as temperature, precipitation, and flooding events become more frequent and/or intense. Understanding historical I-380 event type, frequency, and location is important for projecting future corridor resilience.

Historical I-380 closure event information is limited. A 2015 database of traffic incidents on all Iowa highways was filtered to I-380 and no record of any climate related closure events for this highway segment were noted. Similar database information for years other than 2015 was not available at the time of this study. Other reports indicate closure of I-380 for flood events in 1993 (The Cedar Rapids Gazette, 1993) and 2008 (Iowa DOT, 2008). The 2008 event resulted in closure between mile post (MP) 3 and MP 9 in Johnson County for more than 3 days in July 2008 due to flooding from the Iowa River.

Based on available information, the Iowa River (Coralville Reservoir) is the only river with historical I-380 flooding issues (U.S. Army Corps of Engineers [USACE], No Date; Linhart and Eash, 2010).

Additional non-flood event impacts in the corridor that Iowa DOT maintenance staff provided suggest that snow and ice events during the winter months are problematic due to the volume of traffic that travels the corridor on a daily basis. No specific section of the 15-mile corridor was noted by Iowa DOT as more problematic than others.

4.2 POTENTIAL CHANGE IN CLIMATE RELATED IMPACTS

Climate related impacts most likely to affect the I-380 corridor are anticipated to be the result of projected changes in temperature and precipitation. These impacts are most likely to occur from extreme weather events that the I-380 infrastructure cannot withstand, such as existing bridges unable to accommodate the range of flood flows, or roadway pavements and changes in the range of freeze-thaw cycles and high temperature. Those locations that have shown vulnerability to extreme weather events like flooding in the past are most likely those locations that will be impacted by future events. Locations vulnerable to other climate variability factors such as temperature change are harder to predict and may be systemic in nature.

Table 1. AREAS MOST AT RISK OF CLIMATE RELATED IMPACTS

Feature Name	I-380 Mile Post [Range]	Impact Type	Notes
	0 to 16	High Temperature – average change	Temperature change likely to be uniform across study area and average compared to statewide projected increases.
	0 to 16	Snow, Blizzard	Iowa DOT reports historical snow and ice throughout corridor. However, historical and projected trends in this area show decreasing snow totals and storm events.
Clear Creek	0.5	Flooding	Intersects I-380, but not within study area (0.3 mile outside). During a flood event on June 17,1990 water level rose approximately to an elevation of 680 feet, or within about 6 feet of nearby roadway low point. Otherwise, no available flooding history identified at this location.
Unnamed Creek C	6.4	Flooding	Roadway low point. Backwater from Coralville Reservoir (Iowa River) likely floods at this location.
Unnamed Creek B	6.6	Flooding	Roadway low point. Backwater from Coralville Reservoir (Iowa River) likely floods at this location.
Coralville Reservoir (Iowa River)	7.9	Flooding	Flood closure during 1993 (water surface elevation 716.71 feet) and 2008 (717.29 feet) events. During June 2008 flood event, water level rose to within 3 feet of bridge approach sag.

LOW TEMPERATURE AND FREEZE-THAW IMPACTS

An increase in freeze-thaw cycles may occur in some localized areas and isolated periods of time. Future climate projections suggest that, as winter temperatures warm, periods that were historically below freezing for the full day will be closer to the thawing threshold during the day and below the freezing threshold at night. Similarly, because roadway icing tends to be more frequent at temperatures between 25°F and 32°F than at temperatures below 15°F (Hans et al., 2014), an increase in roadway icing may occur in some locations as very cold winter temperatures (below 15°F) rise into the range more attributed to icing. Road icing can also be affected by local road geometry and shading. Although localized increases in icing and freeze-thaw may occur, the occurrence of these events will generally decrease as overall temperatures warm.

Future climate projections suggest that approximately 20 more frost-free days are expected by 2041 to 2070 than occurred during 1980 to 2000. Similarly, the number of days below 10°F historically have been observed between 10 and 20 days per year and are expected to decrease to 0 to 10 (2041 to 2070). The freeze-free season (period of time between the last spring frost and first autumn frost) may increase by 23 days by 2055. Additional freeze-thaw cycles may deteriorate pavement more quickly and require more frequent pavement maintenance and/or replacement. Climate model projections show that the probability of these changes occurring is approximately equal along the entire I-380 corridor.

HIGH TEMPERATURE IMPACTS

High temperature extremes are expected to impact transportation infrastructure nationwide. High temperature extremes primarily affect pavement longevity and maintenance. Future climate projections and literature suggest the number of days above 95°F is expected to increase from 20 to 30 days per year (1980 to 2000) to 35 to 50 days per year by 2041 to 2070. This can increase thermal expansion on bridge expansion joints and paved surfaces, decrease pavement integrity (soften), and limit periods of construction activity because of health and safety concerns. High temperature extremes are expected throughout the region surrounding the I-380 study corridor. However, temperature extremes will potentially be most impactful in the western portion of the state where the greatest changes are expected to occur, with only slightly less changes projected for the eastern portion of the state where the I-380 corridor lies. Specific locations or portions of I-380 most susceptible to high temperature effects are closely linked to infrastructure age and type of construction. While higher anticipated atmospheric temperatures should be considered with new pavement construction and design (refer to Recommendations in Section 6), some existing pavement may remain as part of the I-380 project. These existing sections of I-380 pavement may be less resilient to temperature increases due to construction materials used and historical design specifications, which tend to vary over time and by project. Identification of these locations is beyond the scope of this report and should be considered at the project level during future planning and engineering studies.

Increasing temperature trends also have an impact on increasing atmospheric moisture. This manifests in increased convective storms, as well as potential for increase in fog intensity and frequency.

FLOOD IMPACTS

The I-380 corridor is expected to see greater risks of flood impacts as winter, spring, and fall precipitation are expected to increase. Climate model projections show a potential increase of high precipitation extremes ranging from 4 to 6 days per year (1980 to 2000) to a range of 6 to 8 days per year (2041 to 2070). Future flooding is projected to include increases in the flood flows and higher flood stages (Appendix A).

While increases in precipitation are projected to occur, precipitation increases don’t always relate directly (or linearly) to increased flooding. Flooding is dependent on local hydrology and requires historical data, hydrologic modeling, and hydraulic modeling analyses to translate into flood extents and impacts. Regionally, precipitation changes are projected to be more severe in the eastern portion of Iowa which is where the I-380 corridor lies. Impacts from these changes result in the potential for increased flood events, erosion, road washout, and embankment deterioration that can damage roadways and disrupt traffic flow along I-380 and possibly other routes.

River and creek crossings that have a history of flooding are summarized in Table 1 and described in greater detail in Table A-1. Given the history of flooding at these locations, future flooding impacts are more likely at these locations.

SNOW AND BLIZZARD IMPACTS

Snow and blizzards can cause closure events, generally as a safety precaution and to protect motorists. Historical data suggest a decrease in annual snowfall along the I-380 corridor and future climate projections expect this downward trend to continue. The documented highest historical snowfall along I-380 occurred in 1954 in Cedar Rapids. Although annual snowfall is generally expected to decrease, extreme blizzard events may still occur, and may still follow historical patterns resulting in travel impacts to sections of I-380, particularly those areas with a history of being prone to drifting and snow related closures.

4.3 POTENTIAL RISK MITIGATION AND CLIMATE ADAPTATION STRATEGIES

Risk mitigation and climate adaptation strategies related to climate-caused I-380 closure events are unique to specific climate impacts and the location of the impacts. Strategies can be categorized as changes in operations, changes in infrastructure design, and changes in transportation planning. Some strategies are best suited as short-term response, while others tend to be long-term actions. Given the uncertainty associated with changes in climate, flexible adaptation strategies, and those that are otherwise low-regret are recommended. Low-regret strategies are those that provide benefit(s) regardless of the actual magnitude of change in climate and related impacts. Discussion in this section is informed primarily by *Potential Impacts of Climate Change on U.S. Transportation* (NRC, 2008) and the *Transportation Climate Change Sensitivity Matrix* (ICF, 2014). The following section describes potential climate adaptation strategies. These should be evaluated during future project development, planning, and engineering design studies, with consideration of overall strategy cost and risk.

OPERATIONAL STRATEGIES

Changes in operations as a way to mitigate risk and adapt to climate tend to be low-cost strategies that can be implemented in the short term. Operational strategies to consider include:

- Expand bridge pier and abutment scour monitoring programs.
- Monitor the performance of pavement and bridge maintenance activities for reduced service life, which may be caused by changes in climate conditions. Plan to increase general maintenance budgets based on monitoring results, and decrease the time between scheduled repaving to account for anticipated increases in pavement deterioration due to high temperatures and possible increase of freeze-thaw cycles in some locations.
- Confirm flood closure detour routes and plans are in place with contingency routes considered in the event the preferred alternative route is also impacted.
- Adjust schedules so maintenance- and construction-related activities occur during cooler parts of the day and/or cooler parts of the year when possible.
- Revise snow and ice removal plans to account for overall decrease in annual snowfall. Snow and ice removal flexibility will be critical, as extreme snow events will likely still occur. Increased snow and ice removal training should be considered, as on-the-job snow and ice removal experience may become less frequent.

DESIGN AND INFRASTRUCTURE STRATEGIES

Design and infrastructure strategies tend to be more expensive, but are required in the long term. Where possible, changes to infrastructure design should be incorporated into normal infrastructure life-cycle replacement schedules. New infrastructure should be designed for anticipated future conditions, rather than recent or historical conditions. Specific design and infrastructure strategies to consider include:

- Revise pavement composition and design to be more durable at higher atmospheric temperature, and to better resist the effects of freeze-thaw cycles that are predicted near the end of the asset's service life.
- Raise roadway embankments and bridges above projected flood levels based on climate projections at the end of asset service life. These may be higher than historical observed flood levels. This is especially applicable to the section of I-380 between MP 3 and MP 9, which has experienced flood-related closures in 1993 and 2008 related to the flooding of the Iowa River near the Coralville Reservoir.
- Revise highway drainage design standards for local scale drainage features such as ditches, storm drains, and inlets to account for increased precipitation intensity and/or more frequent extreme precipitation events based on climate projections at the end of asset service life.
- Increase conveyance capacity for large watershed scale hydraulic structures such as bridges and culverts, and increase scour protection at these structures based on projected future flood hydrology and hydraulics due to climate projections at the end of asset service life.
- Implement infrastructure, such as dynamic message boards, Intelligent Transportation Systems (ITS) applications and other remote sensing technologies measuring pavement temperature, water elevations and flow rates, or wind speeds, and communication protocols to better facilitate flexible transportation operations and data sharing along I-380 during closure events. Develop pre-identified detour routes and provide reliable real-time information to all road users, vehicle navigation systems and aids (global positioning system [GPS] systems, Iowa 511 [Iowa DOT, No Date], and Google Maps), and other vehicle communication systems (autonomous vehicle communications).

PLANNING STRATEGIES

Planning strategies to consider include:

- Plan transportation infrastructure to avoid climate sensitive locations, such as low-lying areas prone to flooding.
- Incorporate projected climate impacts on transportation infrastructure into broader land use master planning. Encourage development in areas that are naturally more resilient to climate.
- Develop and implement comprehensive asset management and maintenance programs to assure I-380 infrastructure elements are well monitored and remain in good condition and that repair and reconstruction needs are well planned for future investment.
- Develop weather incident management plans, such as hypothetical scenarios, communication protocol, alternative routes, and pre-identification of conditions that trigger implementation.
- Evaluate resiliency of potential I-380 detour routes, namely I-80, in an effort to minimize out-of-distance travel during major events that could impact travel along multiple corridors.

5. USER COSTS DUE TO ROAD CLOSURE EVENTS

5.1 INTRODUCTION TO ROAD USER COSTS

Impacts to the mobility of the I-380 transportation corridor can have a significant economic impact locally and to the region. To improve resiliency of the I-380 corridor and maintain acceptable levels of mobility, certain design features may be appropriate to consider as part of the I-380 expansion project to mitigate locations susceptible to mobility impact by extreme weather events. Such design features may include, but are not limited to, increasing the elevation of a roadway, raising or building larger bridges, constructing larger culverts, constructing additional stormwater management, overflow, and conveyance features, placement of man-made or natural wind breaks, or additional right-of-way purchase for attempted snow storage and drift control. To determine the feasibility of such design features, the added infrastructure cost of such features can be compared to the estimated economic impact of disrupting the safe and efficient flow of people and goods along I-380.

Section 5.2 summarizes the evaluation of user costs for the purposes of this I-380 study. Refer to Appendix C for additional background information on how road user costs can be identified and estimated, factors influencing road user costs, and insight into the value of safety performance.

5.2 I-380 ROAD USER COST CALCULATIONS AND ESTIMATES

For the purposes of this study, a high-level evaluation of user costs based on estimated out-of-distance travel resulting from an extreme weather event that requires a closure of I-380 between I-80 and US 30 was performed. User costs were calculated using two methods. The first method was a calculation used by Iowa DOT as part of an evaluation that considers the need or feasibility of accelerated bridge construction alternatives (Accelerated Bridge Construction [ABC] Evaluation Method). The second method used available census and labor statistic data to estimate an average hourly value of a traveler’s time. The intent of these calculations is to gain a high-level sense of possible economic impacts of a closure of I-380 and serve as the foundation for future studies as the I-380 project continues to develop.

The scope of the user cost evaluation focuses on roadway flooding events due to the limited historic information available regarding other types of weather events impacting I-380 travel such as, high wind, dense fog, or snowfall. In addition, there is well documented information from the floods of 2008 in eastern Iowa available in regard to alternate routes for I-380 travel during a closure event. In 2008, Interstate 35 (I-35) in central Iowa, US 20 in northern Iowa, and US 61 in eastern Iowa were used as I-380 detour routes when I-380 was closed between Cedar Rapids and I-80. It should be noted that, during this same flood event, a portion of I-80 east of Iowa City was also closed due to high water overtopping the interstate.

The out-of-distance travel for the detour routes used during the 2008 floods was calculated by comparing the length of the assumed detour route to the length of travel along I-380 between the I-80 and US 30 corridors. This out-of-distance travel was converted to added travel time assuming posted speed limits along I-380 and the respective detour route roadways.

Table 2 summarizes the results of the user cost analysis with the two calculation methods noted above; the calculated values vary between the two methods. These road user cost estimates are based solely on assumed value of time and out-of-distance travel and do not consider costs involved with the transportation of freight across the state; the economic impact of stoppage or delay of delivery of such freight; or any of the other tangible or intangible factors that could be considered (see Appendix C for additional details and other possible considerations). This high-level user cost estimate calculation suggests that the economic impact of a closure of I-380 between Cedar Rapids and I-80 could be in the range of $1.5 million to $2.8 million per day. These estimates are driven by the large volume of traffic that uses the I-380 corridor on a daily basis and the significant out-of-distance travel of an acceptable official detour route. The value of economic impacts will likely only increase if freight characteristics, premiums for unexpected/unreliable events and alternate route(s) performance, and/or other factors discussed in Appendix C are included in the evaluation. Based on these calculations, a strong argument can be made that frequent events or those with a sustained duration will certainly have economic ramifications to the road users and the region.

6. RECOMMENDATIONS

Because of the minimal availability of documented weather-related I-380 events, the evaluation of projected climate impacts along the I-380 corridor is guided by historical closure events, existing literature, and surrogate factors, such as floodplain locations, that may indicate future risk. Based on the available information, the following recommendations are suggested for future I-380 studies and design.

1. Develop a road closure monitoring and documentation program with a more comprehensive understanding of weather-related events disrupting the flow of I-380 traffic and other nearby potential alternative routes, including I-80. This type of program may provide value for future resiliency evaluations.

2. Monitor maintenance performance and adjust maintenance practices considering recent weather events and projected climate variability.

3. Review and update stormwater design standards to account for (1) recent changes in the hydrologic records, (2) assets with a long design life, and (3) projected future changes in precipitation intensity and hydrology. Use the most recent discharge data for hydraulic analysis for stream crossings with long asset design life, and consider projected increases in discharge within the asset design life. One of the largest projected threats to mobility in the I-380 study corridor is increased flooding. While climate models describe projected changes to precipitation and temperature, the translation of this information to changes in flooding is indirect and non-linear. Flooding is affected by local and regional hydrology, hydraulics, and land use. Climate impacts on flooding were analyzed extensively for the South Skunk River and Cedar River as part of the Iowa DOT's *Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot* (Iowa DOT, 2015). While the overall results of this study can be generally translated to other rivers, additional analysis is recommended to further quantify specific flood risks at individual locations. This analysis should include hydrologic and hydraulic modeling, similar to that performed as part of the Pilot project (Iowa DOT, 2015). Local-scale and project-specific hydrologic and hydraulic modeling should build on existing available resources, such as existing FEMA hydraulic models. This information should be used in subsequent environmental and engineering studies to be performed following the PEL Study.

4. For vulnerable locations, perform risk analysis during future planning studies and design development. This should be performed especially for roadway profile low points between MP 3 and MP 9 that Coralville Reservoir/Iowa River and associated backwater flooding may impact. Risk analysis should incorporate location specific features, possible detours, strategies to improve the resiliency of I-380 to minimize the likelihood of disruption of traffic due to a weather event, and the economic benefit cost of implementing a mitigation strategy.

5. Because of the close proximity of I-80 to the I-380 study corridor, the two corridors are interdependent in cases of closure and the need for traffic diversion. Efforts to improve the resiliency of both corridors can be considered and should be coordinated.

Table 2. CALCULATED USER COSTS

ID	Destination	Origination	Assumed Detour Operating Speeds (mph)	Distance Along I-380 (miles)	Assumed Detour Distance (miles)	Out-of-Distance Travel (miles)	Estimated Added Travel Time (hours)	Average Annual Daily Traffic (2014)[a]	Average Daily Truck Traffic (2014)[b]	Estimated Daily Economic Impact of I-380 Closure	
										Iowa DOT ABC Evaluation Method	Hourly Rate with Census and Labor Statistics Method
1	Cedar Rapids	I-80 West of I-380	60-70 mph	65	230	165	2.5	6300	1000	$514,500	$384,500
2	Cedar Rapids	I-80 East of I-380	60-70 mph	50	220	170	2.6	5800	900	$488,000	$376,200
3	Cedar Rapids	US 218 South of I-80	55-65 mph	15	38	23	0.4	11,900	1900	$135,500	$124,300
4	Coralville	US 30 West of I-380	60-70 mph	15	275	260	3.8	5900	950	$759,300	$146,500
5	Coralville	US 30 East of I-380	60-70 mph	15	250	235	3.5	6500	1050	$756,100	$161,400
6	Coralville	I-380/US 218 North of US 30	55-65 mph	15	38	23	0.4	13,700	2200	$156,000	$340,200
									Total (Rounded)	**$2,800,000**	**$1,500,000**

Mileage Rate (Iowa DOT, 2017a)	$0.375
Average Annual Income in Iowa (U.S. Census Bureau, 2017)	$53,183
Average Hourly Rate per Average Annual Income (U.S. Census Bureau, 2017)	$25.57
Average Truck Driver Hourly Rate (U.S. Department of Labor, Bureau of Labor Statistics, 2017)	$20.96

[a] Source: Iowa DOT, 2017b
[b] Source: Iowa DOT, 2014

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Appendix A

EXISTING DATA COLLECTION SUMMARY

APPENDIX A: EXISTING DATA COLLECTION SUMMARY

LIST OF TABLES

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EXISTING DATA COLLECTION SUMMARY

Appendix A summarizes the data collection effort conducted to support the I-380 Resiliency and Vulnerability Study (Study). Data collection efforts were focused on three types of sources that could provide applicable information on historical and forecasted extreme weather events, especially those that may significantly reduce capacity or require closure of a portion(s) of the I-380 corridor between the Cedar Rapids and Iowa City metropolitan areas. These three source types included scientific literature and previous studies, historical meteorological data and statistical analyses, and hydrologic and infrastructure geographic information system (GIS) data in the Iowa and Midwest Region.

This appendix material details the sources used in the Study, findings on historical climate and future climate projections, hydrological and weather trends, and weather-related impacts on transportation systems. Although there are many publications regarding these topics, this report only summarizes those that are most relevant to this Study. A great deal of information was collected on historical and future projections of climate trends and extreme weather events in the Iowa Region. However, only limited information was available regarding their effects on existing transportation systems and specifically their impacts on the I-380 study corridor. A full list of documents and data reviewed are included in Appendix B.

SOURCES

Within the study area, existing climate, climate impacts, variability, resiliency and adaptation has been documented by the Iowa Department of Transportation (DOT), National Oceanic and Atmospheric Administration (NOAA), Iowa State University, U.S. Federal Highway Administration (FHWA), Iowa Climate Change Advisory Council (ICCAC), U.S. Geological Survey (USGS), and others. These sources provide information on observed climate trends, observed flooding and roadway closure events, future projections of climate, and extreme weather-related impacts on infrastructure. Some national sources are included. However, regional sources and sources specific to transportation infrastructure are preferred, as they describe information and trends specific to Iowa and the I-380 corridor. Because the I-380 study area extends across a relatively small portion of Iowa, local studies that pertain to the I-380 study area were generally unavailable. Instead, local studies that pertain to regions outside of the immediate study corridor were used to provide an example of detailed local information that may be available. Additional local resources specific to the I-380 study area may prove beneficial for review when the I-380 corridor is evaluated in future studies at the project level.

The primary sources of information for many of these references come from *Assessment of Potential Impacts of Climate Changes on Iowa Using Current Trends and Future Projections* (Takle, 2011), which provides a comprehensive assessment of historic climate trends, future projections, and future anticipated impacts in the Iowa Region. Much of the meteorological data utilized in the report are sourced from NOAA (2016, 2017a, 2017b, and 2017c) and the Iowa Environmental Mesonet (Iowa State University, 2017). These are the three main sources utilized for meteorological information provided in subsequent sections of this report.

Stream flow and flooding information was collected and analyzed as GIS datasets, intersected with a spatial representation of I-380. Key GIS datasets include the NHDPlus, which includes modeled annual average and monthly average stream flow for most rivers and creeks, and floodplain information (both floodplains and base flood elevations, where available) from the National Flood Hazard Layer (FEMA, 2013).

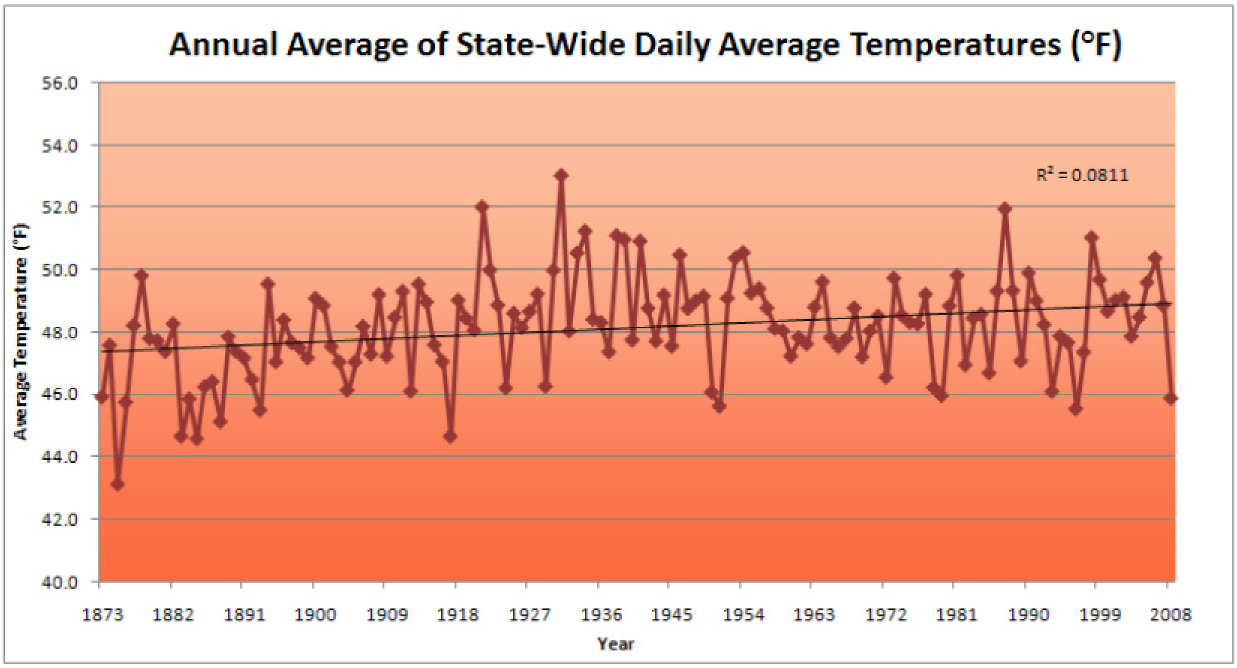
OBSERVED CLIMATE, HYDROLOGY, AND WEATHER TRENDS

Observed climate, hydrology and extreme weather events are summarized in this appendix material; particularly temperature, precipitation, stream flow, snow fall, and wind as they pertain to the I-380 study corridor. These components are generally presented in order of most to least available projected climate information. A few of these components are described in terms of normal climate, which is a method of analyzing climate information on the scale of three decades developed by the World Meteorological Organization and NOAA. This method is commonly used for engineering planning purposes (Takle, 2011).

TEMPERATURE

Temperature measurements going back as far as 1873 show increasing trends throughout the state of Iowa. Figure A-1 shows the annual average trend statewide since 1873. The chart indicates an increasing trend, more quickly in the end of the 19th Century and more slowly in the last 50 years. Increasing trends are more apparent seasonally and at different times of the day, such as higher nighttime temperatures, especially for the most recent decades. Figure A-1 minimizes these seasonal and daily trends as it is only showing annual averages. Further discussion of temporal trends is included in this appendix material as they are important in understanding trends in extreme weather events.

Figure A-1. ANNUAL AVERAGE STATEWIDE DAILY AVERAGE TEMPERATURES (°F) FROM 1873-2008 (TAKLE, 2011; IOWA CLIMATE CHANGE IMPACTS COMMITTEE, 2010)



Source: Graphic is from Takle, 2011, and the data are from Iowa Climate Change Impacts Committee, 2010.

On an annual basis, average temperature trends have shown an increase of about 1 to 2 degrees Fahrenheit (°F) since 1873 (annual average increase about +0.1°F per decade). However, winter seasonal and day-night changes have been found to be larger resulting in more significant impacts. Seasonal temperature increases are on the order of +0.18°F per decade in the winter and +0.03°F per decade in summer. Frost free periods are now longer than in the past, with a statewide average of approximately 5 more frost-free days than in 1950 (Takle, 2011).

A larger increase has been occurring in nighttime temperatures than in daytime temperatures. More recent years especially have been reporting higher nighttime temperature records. Takle (2011) suggests that these seasonal and daily variances (higher temperature increases during winter versus summer, and nighttime versus daytime) can be attributed to changes in precipitation, cloud coverage, and soil moisture. Each of these variables show increasing moisture content, suppressing surface heating and as a result, extreme daily and summer high temperatures (Takle, 2011).

Statewide and along the I-380 corridor, temperature geospatial trends generally follow a north to south increasing gradient throughout Iowa. Figures A-2 to A-8 graphically describe temporal and spatial variation throughout the state. Annual statistics on temperature normals for the period of 1981 to 2010 are provided by NOAA's National Weather Service (NWS) (2017a). Annual high, average, and low temperature normals are shown, as well as winter and summer high and low temperature normal, to provide the range of temperature-extreme months. The I-380 corridor study area has been overlaid on the figures to provide context.

Figures A-2 to A-8 indicate an annual high temperature normal ranging from 58°F to 60°F along the study area. The annual average temperature ranges from 48°F to 50°F, and the annual low temperature ranges from 38°F to 40°F. Winter high and low temperature normals range from 31°F to 33°F and 14°F to 16°F, respectively. Summer high and low temperature normals range from 82°F to 83°F and 61°F to 63°F, respectively.

Figure A-2. IOWA ANNUAL AVERAGE TEMPERATURE NORMAL (1981-2010) PROVIDED BY NWS (NOAA, 2017a)

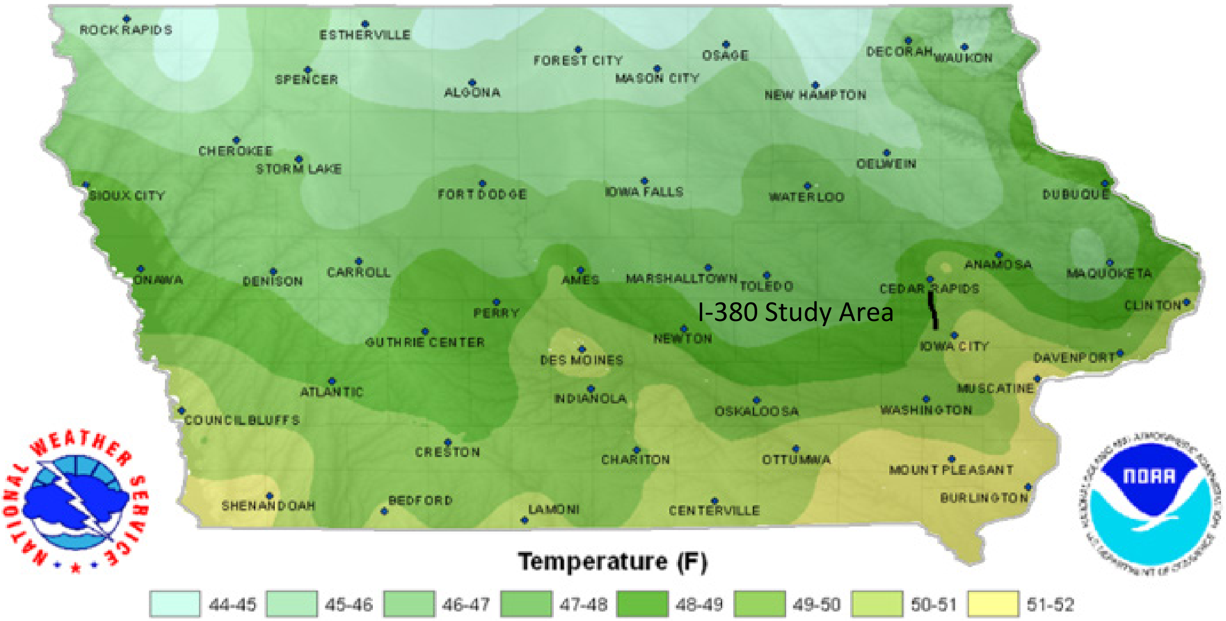


Figure A-3. IOWA ANNUAL HIGH TEMPERATURE NORMAL (1981-2010) PROVIDED BY NWS (NOAA, 2017a)

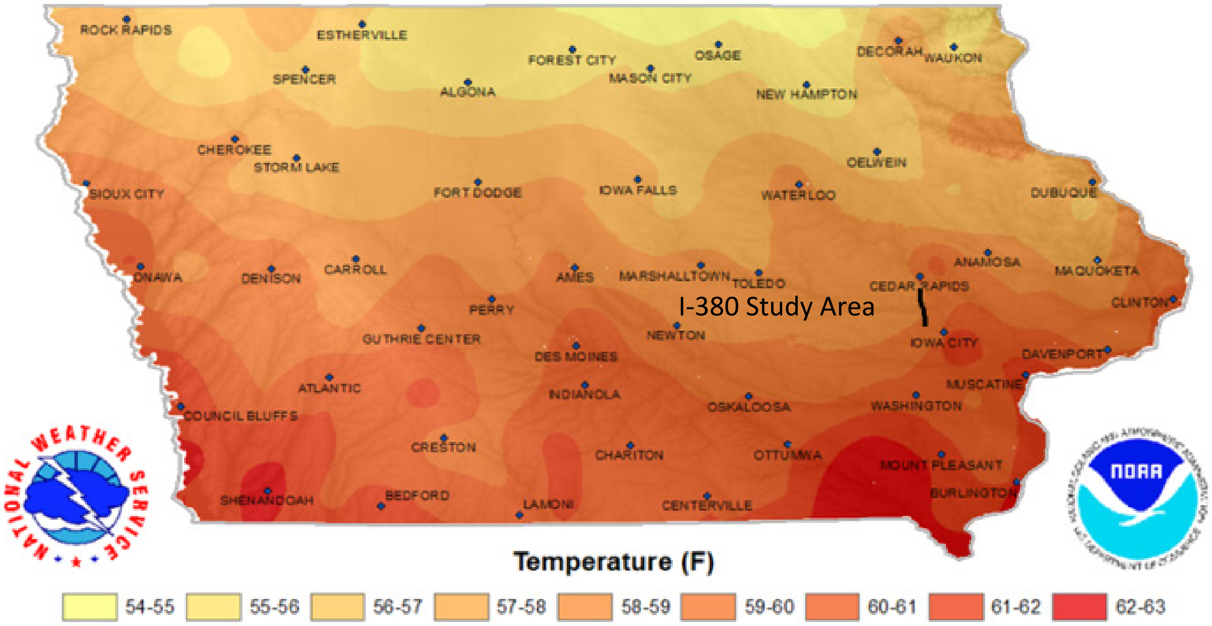


Figure A-4. IOWA ANNUAL LOW TEMPERATURE NORMAL (1981-2010) PROVIDED BY NWS (NOAA, 2017a)

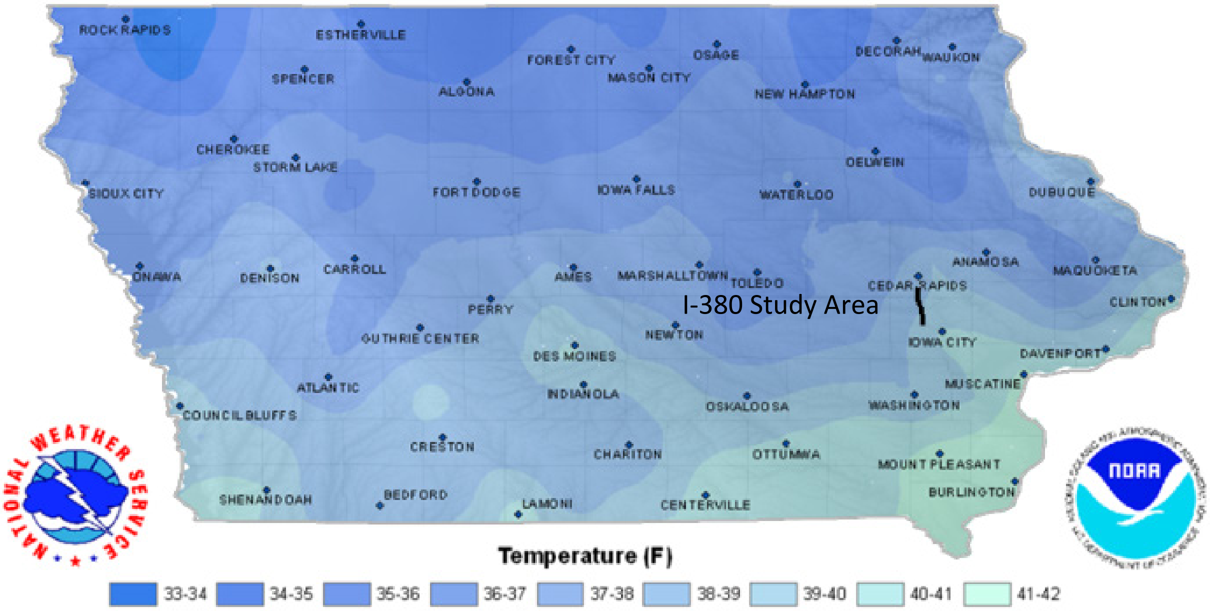


Figure A-5. IOWA WINTER HIGH TEMPERATURE NORMAL (1981-2010) PROVIDED BY NWS (NOAA, 2017a)

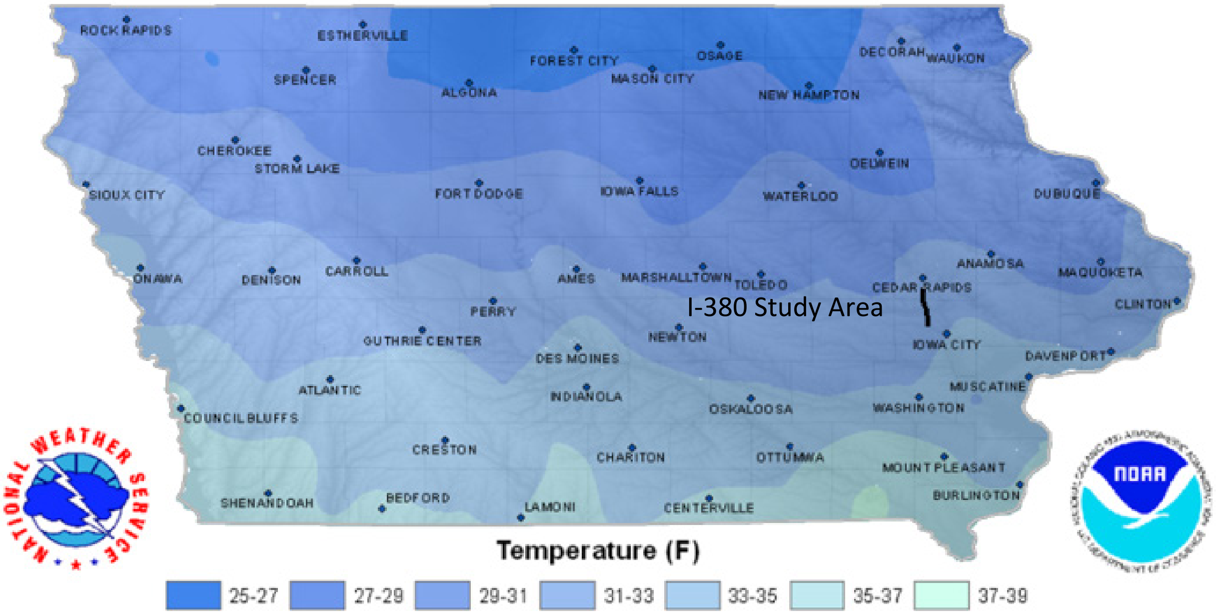


Figure A-6. IOWA WINTER LOW TEMPERATURE NORMAL (1981-2010) PROVIDED BY NWS (NOAA, 2017a)

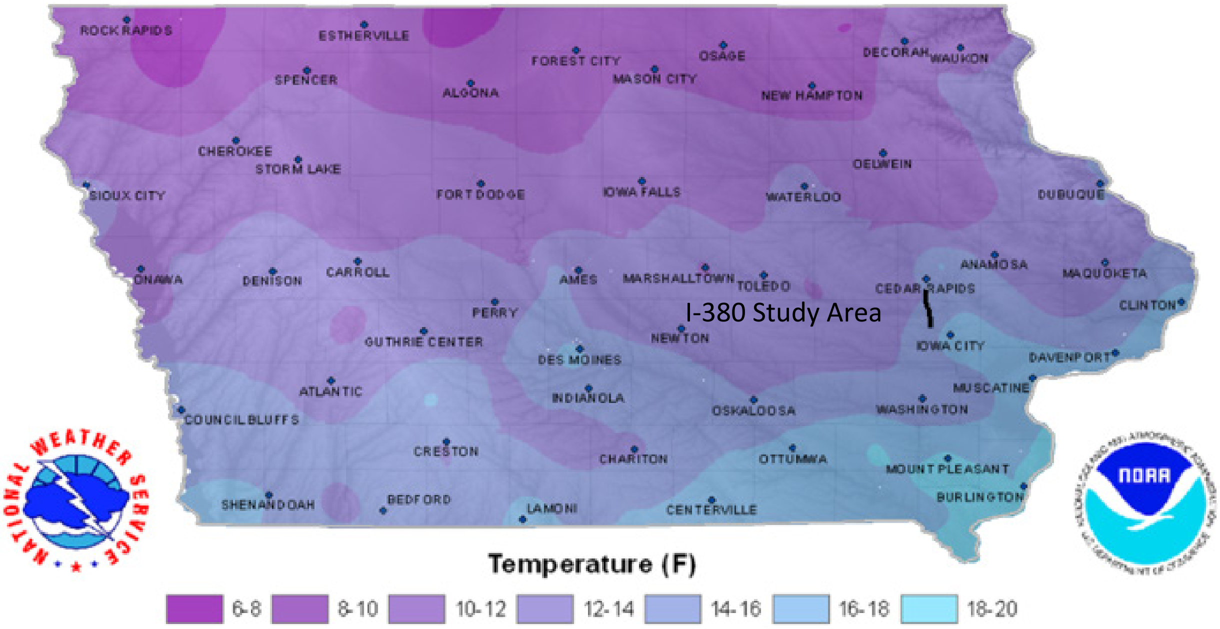


Figure A-7. IOWA SUMMER HIGH TEMPERATURE NORMAL (1981-2010) PROVIDED BY NWS (NOAA, 2017a)

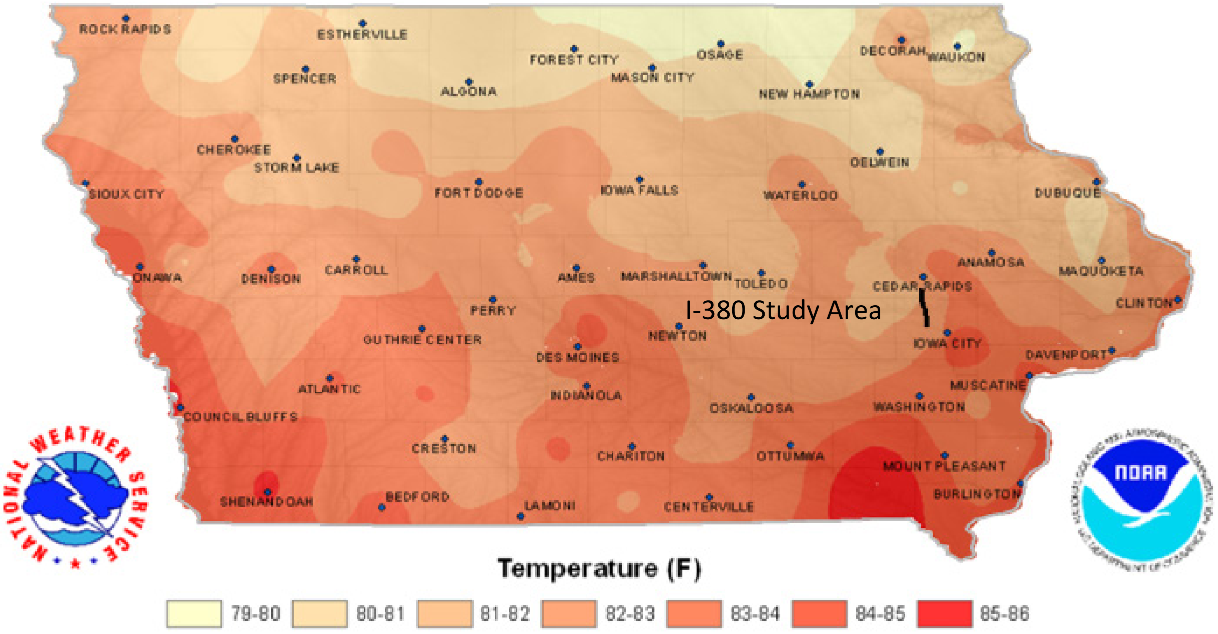
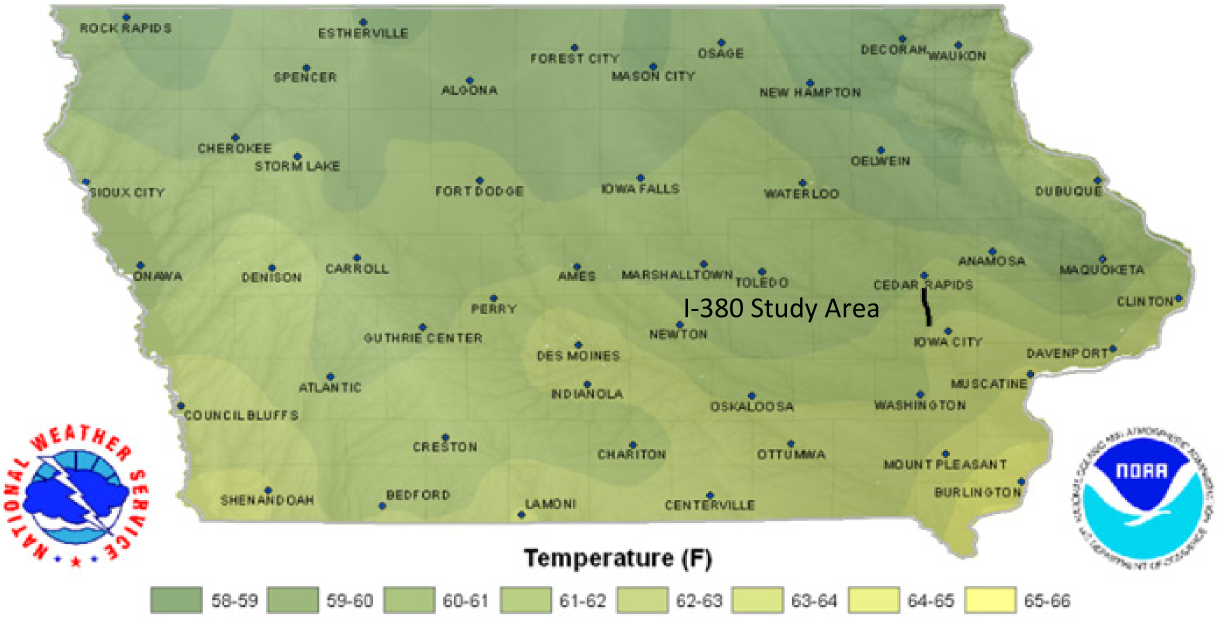


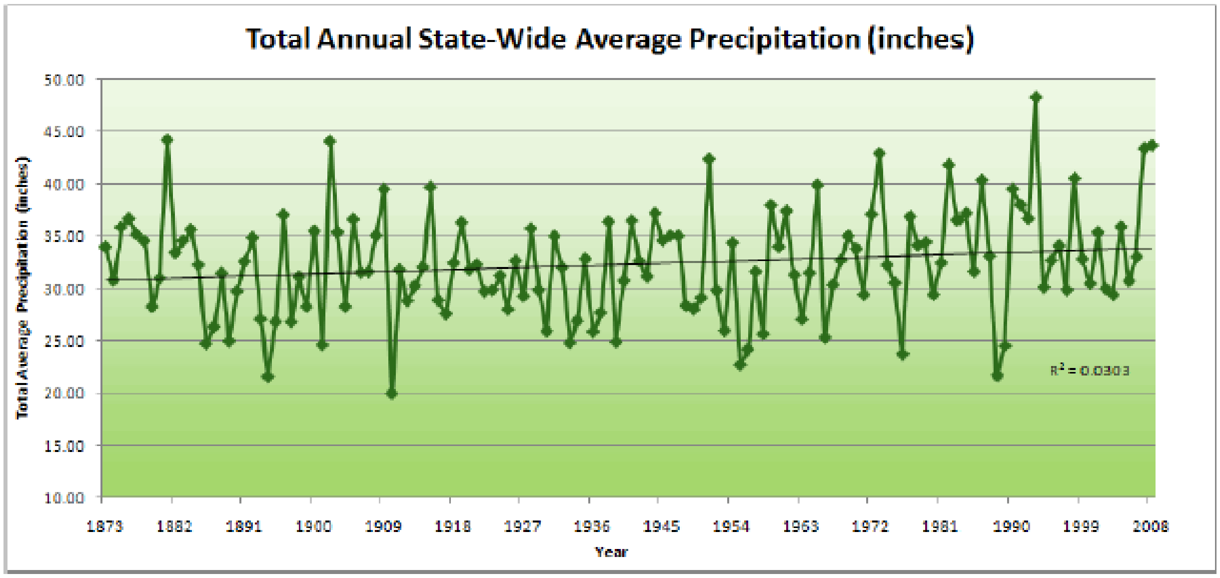
Figure A-8. IOWA SUMMER LOW TEMPERATURE NORMAL (1981-2010) PROVIDED BY NWS (NOAA, 2017a)



PRECIPITATION

Iowa is in a transition zone of competing Pacific Ocean moisture in the west and Gulf of Mexico moisture in the east, which drives the state’s storm events. Precipitation generally increases from the west to east throughout the state, as well as a slight gradient from north to south. Although annual statewide average precipitation has high variability from year to year, Figure A-9 shows an overall increasing trend of roughly 8 percent from 1873 to 2008. Figure A-9 also shows that years with relatively high rainfall (above 40 inches per year) have increased in frequency in the latter half of the century.

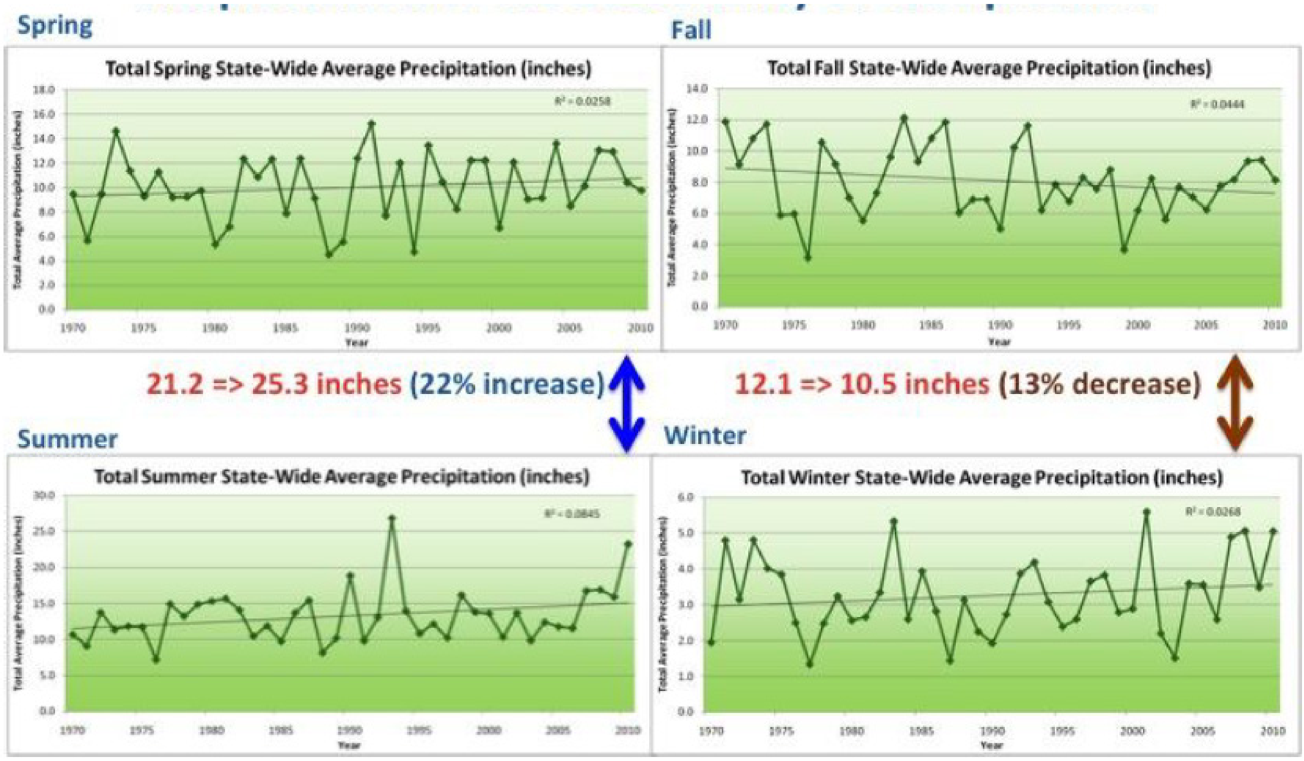
Figure A-9. IOWA ANNUAL STATEWIDE PRECIPITATION IN INCHES FROM 1873-2008 (TAKLE, 2011; IOWA CLIMATE CHANGE IMPACTS COMMITTEE, 2010)



Source: Graphic is from Takle (2011), and the data are from Iowa Climate Change Impacts Committee (2010). The state has had an 8 percent increase in annual average precipitation over this 136-year period.

Increasing trends in historical precipitation are evident through increased intensity and frequency of rainfall events. The number of days with relatively high rainfall intensity (days with more than 1.25 inches) has also been found to increase for many regions throughout the state. This threshold relates precipitation to flood likelihood, since Iowa's soil can absorb about 1.25 inches of rain in a 1-day rain event and any excess results in increased runoff (Iowa Climate Change Impacts Committee, 2010). This historical trend is stronger in eastern Iowa, with overall precipitation increase most prevalent in spring and summer months (Figure A-10). The fall months have been found to show a downward trend in precipitation across Iowa. These trends are expected to continue (Takle, 2011), meaning an increase in annual total precipitation and an increased frequency of larger precipitation events can be expected in the future. These trends are more noticeable in the eastern portion of the state.

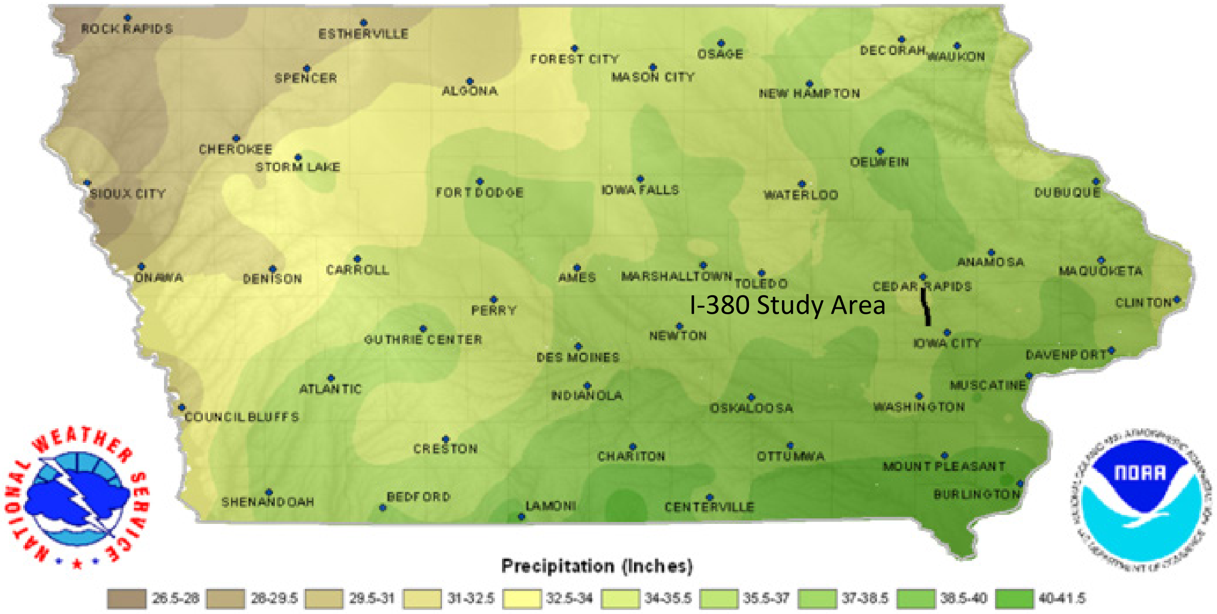
Figure A-10. IOWA STATEWIDE PRECIPITATION SHOWING A SHIFT IN SEASONALITY TOWARD MORE RAIN IN SPRING AND SUMMER (MARCH-AUGUST) AND LESS IN FALL AND WINTER (SEPTEMBER-FEBRUARY) (TAKLE, 2011)



Source: Graphic is from Takle, 2011. Combined Spring and Summer precipitation increased 22 percent, while combined Fall and Winter precipitation decreased 13 percent.

Figure A-11 spatially describes the 1981 to 2010 precipitation normals throughout Iowa. Average annual precipitation along the I-380 corridor ranges from 34 to 37 inches per year. The southern half of the corridor shows a slightly wetter tendency than the northern half.

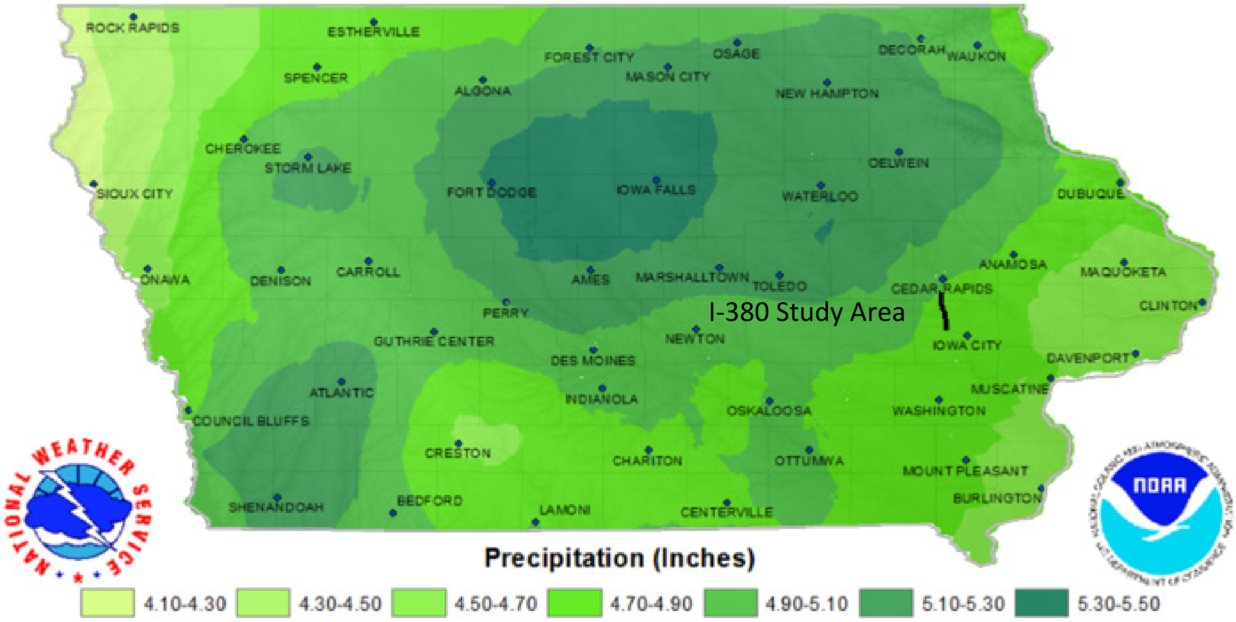
Figure A-11. IOWA ANNUAL AVERAGE PRECIPITATION NORMAL (1981-2010) (NOAA, 2017a)



Source: Graphic is from the NWS (NOAA, 2017a).

Spring and summer months have historically shown greater precipitation than other seasons. Figure A-12 shows the monthly precipitation normals for June, as it is the highest month for 1981 to 2010 precipitation normals throughout the I-380 corridor. June is also the month in which flooding in Iowa has occurred most often. Figure A-12 indicates June precipitation normals ranging from 4.7 to 5.1 inches. While annual averages indicate the southern portion of the I-380 corridor is wetter than the northern portion, this is not necessarily true for June. Figure A-12 indicates the northern portion may have a wetter tendency than the southern.

Figure A-12. IOWA JUNE PRECIPITATION NORMALS (1981-2010) (NOAA, 2017a)



Source: Graphic is from the NWS (NOAA, 2017a).

Historically, spring storms tend to track southwest-northeast and summer storms track west-east orientations, with some northwest-southeast tracks in mid-summer (Takle, 2011). Many of the river basins crossing the I-380 corridor are oriented northwest-southeast, thus, having an axis and stream flow that align more with these occasional summer storm tracks. For a given amount of precipitation, summer season storm events have a higher likelihood of leading to flood events along the I-380 corridor. Further discussion of flood events can be found in the subsequent section.

In addition to increasing precipitation trends, a strong trend in increasing dew-point and humidity has been observed across Iowa and the Midwest. It is estimated that summer atmospheric moisture increased by approximately 13 percent in Des Moines, Iowa, between 1980 and 2011. Higher atmospheric moisture provides more moisture to supply convective thunderstorms, an increase potential for fog, and precipitation and soil moisture (Takle, 2011). Rural areas tend to have higher humidity than nearby cities during daytime hours. This is related to differences in the rate of moisture generation from evapotranspiration in rural areas and automobile exhaust and industrial combustion in cities.

STREAMFLOW AND FLOODING

Observed flooding across Iowa, especially as it relates to transportation and highways, is summarized in *Summary of USGS Reports Documenting Flood Profiles of Streams in Iowa, 1963-2012* (Eash, 2014), which further references multiple flood profile reports unique to individual rivers, river basins, and flood events. Additional observed flood information for creeks and rivers crossing the I-380 study area is available in the Flood Insurances Studies for Johnson and Linn Counties (FEMA, 2007 and 2010). A summary of flooding of Coralville

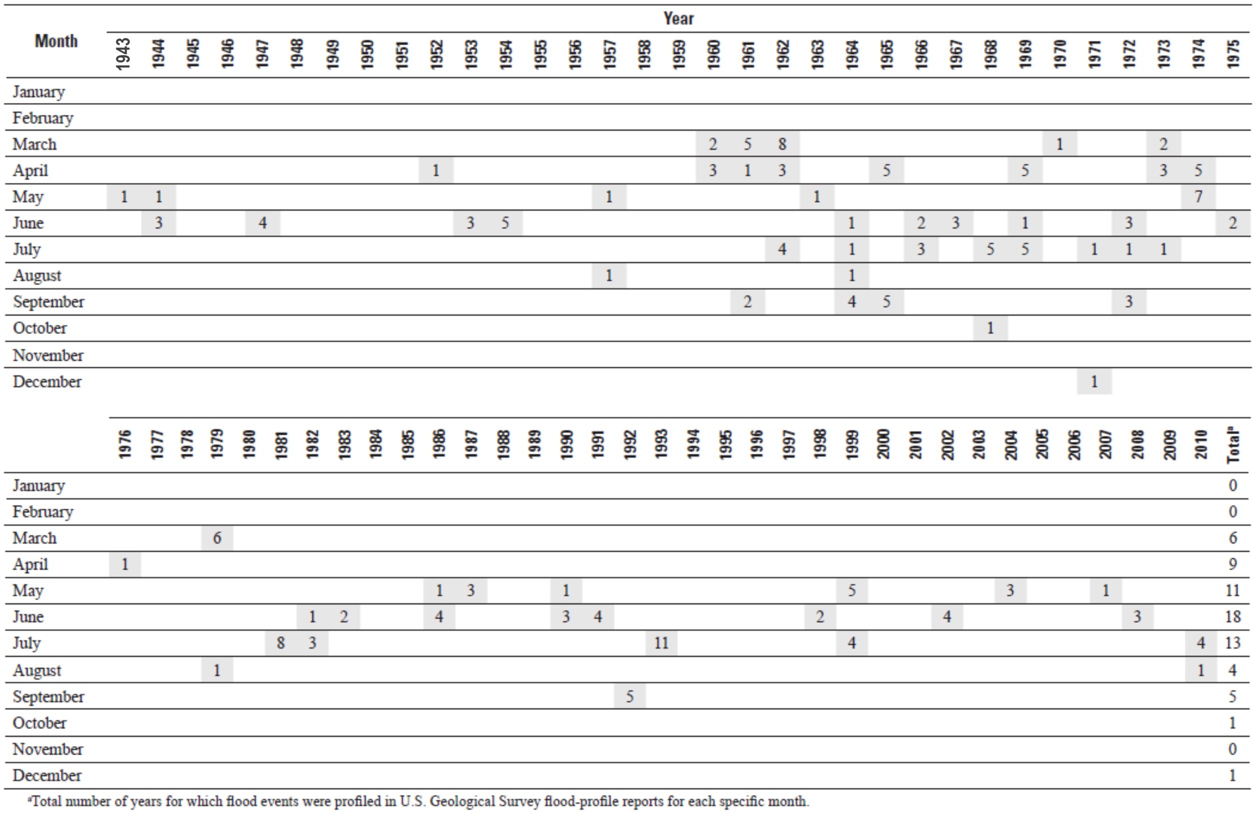
Reservoir (Iowa River) is provided by the *Coralville Lake Project Fact Sheet* (USACE, No Date). A summary of rivers and creeks crossing the I-380 corridor, with additional information about observed flooding, is presented in Table A-1. Rivers in Iowa tend to flood most from May through July, as evidenced by approximately 60 percent of the storm events and river reaches analyzed in the Eash report (2014) occurring in these months (Figure A-13). A part of the tendency toward late spring and early summer flooding is due to occasional storms that track from northwest to southeast, which generally follow the drainage pattern and, thus, cause higher flooding.

Based on the available information, the I-380 study area was only impacted by flood events on the Coralville Reservoir (Iowa River). The highest recorded Coralville Reservoir pool elevations occurred in June 2008 (717.02 feet [USACE, No Date], which resulted in an elevation at the I-380 bridge of 717.29 feet[1] [Linhart and Eash, 2010]) and in July 1993 (716.71 feet [USACE, No Date]). The next highest flood event was in 1984, with a pool elevation about 5 feet lower than the 1993 flood event. For comparison, I-380 roadway low points near the Coralville Reservoir bridge are at elevation 720.22 feet, and the bridge low chord at elevation 721.51 feet. Low points near Unnamed Creek B (MP 6.6) and Unnamed Creek C (MP 6.4) have roadway elevations at approximately elevation 717 feet. I-380 was closed for flooding during the 1993 event (The Cedar Rapids Gazette, 1993) and the 2008 event (Iowa DOT, 2008). Specific flooding locations were not available, but may include the low points near Unnamed Creek B and Unnamed Creek C, due to backwater from the Coralville Reservoir. It is important to note that the Coralville Reservoir water surface elevations are controlled by the Coralville Dam operated by the USACE.

Clear Creek, which crosses the I-380 study corridor just north of I-80, flooded in June 1990 and July 1993 (Barnes and Eash, 1994), with water surface elevations (about 680 feet) near the I-380 road surface elevations during both events. These flood levels are approximately 7 feet below the adjacent roadway sag elevation of 687.18 feet, and approximately 10 feet below the I-380 bridge low chord elevation of 690.58 feet. There is no record of I-380 closures at Clear Creek during either of these events. Table A-1 summarizes key I-380 roadway and structure elevations and flood event information at each of the 10 river and creek crossings.

Other past flood events, flood locations, and related I-380 closures/impacts may have occurred within the study area but were not included in available records and literature reviewed as part of this study.

Figure A-13. YEARS AND MONTHS OF FLOOD EVENTS PROFILED ACROSS IOWA IN USGS REPORTS DURING 1943-2012 AND NUMBER OF STREAM REACHES PROFILED IN EACH MONTH (EASH, 2014)



Month	Year																																
	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
January																																	
February																																	
March																		2	5	8								1			2		
April										1								3	1	3			5				5				3	5	
May	1	1													1						1											7	
June		3			4						3	5										1		2	3		1			3			2
July																				4		1		3		5	5		1	1	1		
August															1							1											
September																			2			4	5							3			
October																										1							
November																																	
December																													1				

Month	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total[a]
January																																				0
February																																				0
March				6																																6
April	1																																			9
May											1	3			1									5					3			1				11
June							1	2			4				3	4							2				4						3			18
July						8	3											11						4											4	13
August				1																															1	4
September																	5																			5
October																																				1
November																																				0
December																																				1

[a] Total number of years for which flood events were profiled in U.S. Geological Survey flood-profile reports for each specific month.

Source: Figure is from Table 5 in Eash, 2014. The events profiled by USGS and summarized by Eash (2014) occur across Iowa, and are not necessarily specific to flooding along I-380. However, this table highlights the seasonal trends of much of the riverine flooding along Iowa rivers, a trend that also applies to rivers and creeks crossing I-380.

SNOWFALL

Snowfall throughout Iowa generally shows a south to north increasing trend. However, the trend is relatively consistent along the I-380 study corridor. Figure A-14 shows average annual snowfall normals ranging from 26 to 30 inches along the I-380 corridor.

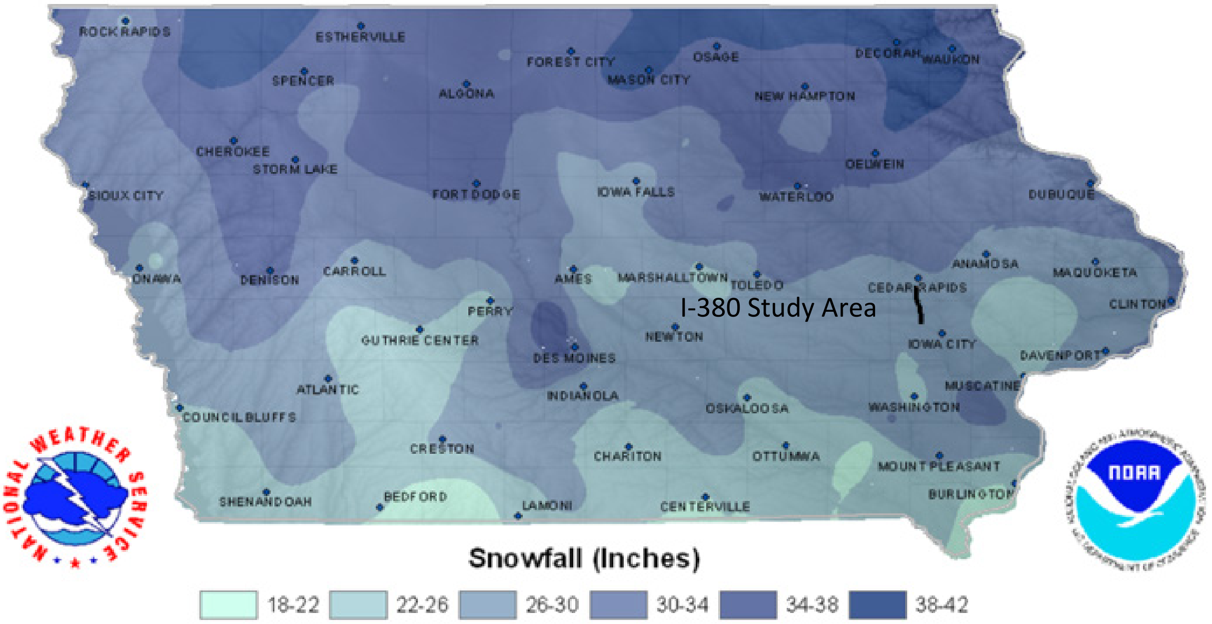
Table A-1. RIVER CROSSINGS, FLOODPLAIN CROSSINGS, AND FLOOD INFORMATION ALONG THE I-380 CORRIDOR STUDY AREA

Reach Name	Crossing Mile Post	Mean Annual Flow (cfs)[a]	Mean June Flow (cfs)[a]	Drainage Area (sq. miles)[a]	Floodplain – Zone[b]	Approximate Floodplain Width (ft)[b]	Upstream Base Flood Elevation (ft)[b]	Structure Type	Low Structure Elevation (ft)	Adjacent Roadway Sag Elevation (ft)	Flooding Notes[c,d,e,f,g,h,i]
Unnamed Creek A	15.2	0.2	0.3	0.5	Not mapped as floodplain[b]			6x6 RCB	773.80	800.45	N/A**.
Hoosier Creek	14.3	0.7	0.9	1.4	A	250	N/A*	8x6 RCB	801.00	819.60	N/A**
South Hoosier Creek	12.8	3.6	4.3	6.8	A	350	791	Twin 8x10 RCB	785.40	800.5	Within 0.25 mile of AE zone.
West Hoosier Creek	11.9	0.5	0.6	1.0	Not mapped as floodplain[b]			Does not intersect with I-380 but comes within 0.03 mile, and is within study area.			N/A**
McAllister Creek	10.5	1.2	1.5	2.2	A	200	727	12x10 RCB	735.30	755.80	McAllister Creek also comes within 0.1 mile of I-380 at MP 8.7. Base flood elevation only available downstream of I-380.
Coralville Reservoir (Iowa River)	7.9	2310	4110	2990	AE	2,000	713	Bridge	721.51	720.22	Flood closure during 1993 (water surface elevation 716.71 feet) and 2008 (717.29 feet) events. During June 2008 flood event, water level rose to within 3 ft of bridge approach sag.
Unnamed Creek B	6.6	0.5	0.6	1.0	Not mapped as floodplain[b]			Does not intersect with I-380 but comes within 0.07 mile, and is within study area.			This is one of the lowest roadway sag elevations in the vicinity of Coralville Reservoir (Iowa River). Backwater from Coralville Reservoir likely floods at this location.
Unnamed Creek C	6.4	0.9	1.1	1.7	A	2,200	N/A*	Twin 8X4 RCB	709.50	717	River runs adjacent to roadway, creating a large floodplain width. This is one of the lowest roadway sag elevations in the vicinity of Coralville Reservoir (Iowa River). Backwater from Coralville Reservoir likely floods at this location.
Unnamed Creek D	5.2	1.8	2.1	3.2	A	1,300	N/A*	8x8 RCB	716.00	732	N/A**
Buffalo Creek	2.7	1.3	1.5	2.3	A	200	N/A*	Twin 8x8 RCB	746.70	763.69	N/A**
Unnamed Creek E	1.7	0.4	0.4	0.6	Not mapped as floodplain[b]			6x6 RCB	717.00	748.52	N/A**
Clear Creek	0.5	61	69	81	AE	2,000	682	Dual 40' Bridge	690.58	687.18	Intersects I-380 but not within study area (0.3 mile outside); during flooding of June 17,1990, water level rose to approximately elevation 680 feet, within 6 feet of nearby roadway sag, within 9 ft of Northbound bridge deck and 12 ft of Southbound bridge deck 1993 flood event water surface elevations were similar to 1990.

Sources and Notes:
[a] Horizon Systems, 2017
[b] FEMA, 2013
[c] USGS, 2016
[d] *Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot* (Iowa DOT, 2015)
[e] Barnes and Eash, 1994
[f] Iowa DOT. 2008
[g] Iowa Department of Natural Resources and Iowa Flood Center. 2017
[h] State of Iowa, State Highway Commission. 1972a, 1972b, 1972c
[i] State of Iowa, State Highway Commission. 1979

MP –mile post
N/A* – Base flood elevations have not been determined in Floodplain Zone A
N/A** – Evidence of historical flooding or other flood information **not available** in any of the sources reviewed. Flooding may or may not be an issue at this location
RCB – reinforced concrete box

Figure A-14. IOWA ANNUAL AVERAGE SNOWFALL NORMAL (1981-2010) (NOAA, 2017a)

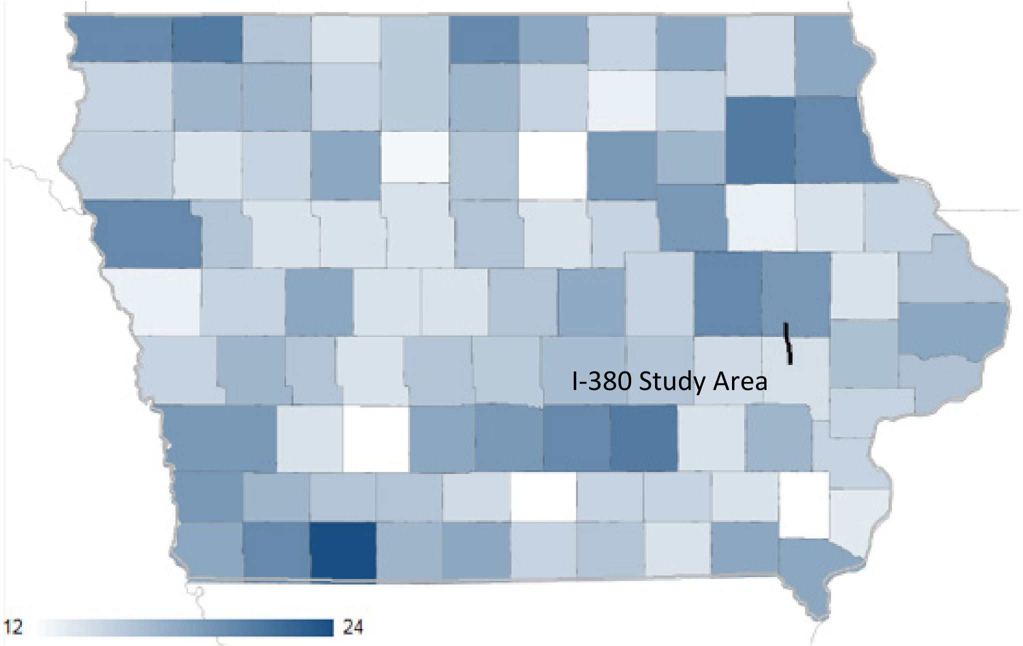


Source: Graphic is from the NWS (NOAA, 2017a).

The NOAA Snowfall Extremes Database (NOAA, 2017b) tabulates 1-day, 2-day, and 3-day extreme snowfall by county, and is shown for Iowa in Figures A-15 through A-17. A review of this information along the I-380 corridor shows typical 1-day extreme snowfall in the range of 14 to 18 inches, 2-day extreme snowfall in the range of 17 to 23 inches, and 3-day extreme snowfall in the range of 17 to 24 inches. A few extreme exceptions include:

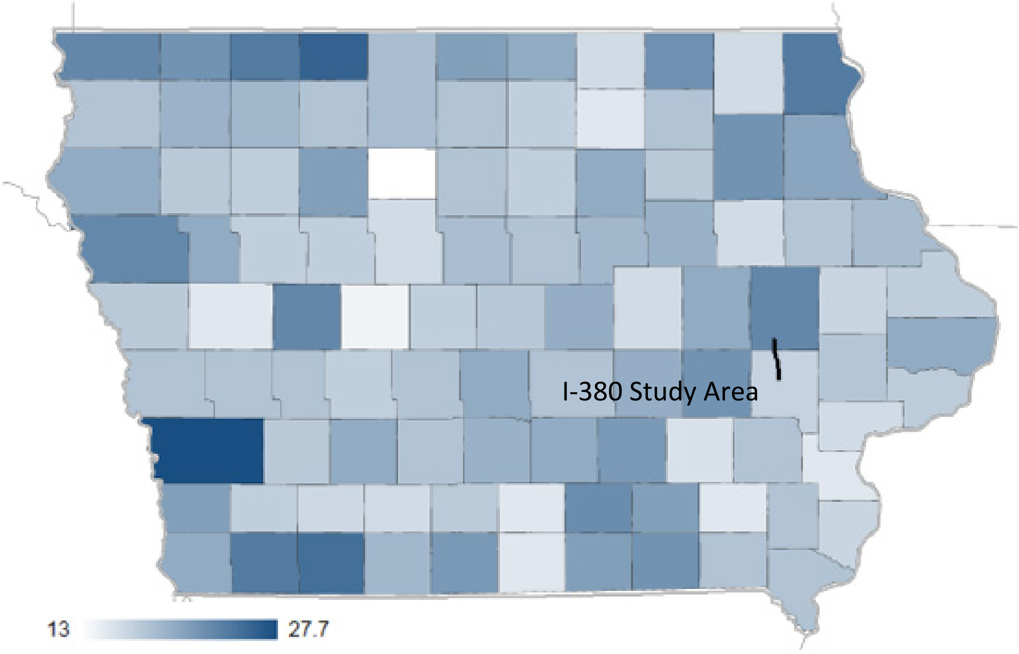
- 1-day extremes: 19 inches on February 26, 1954 at Cedar Rapids in Linn County.
- 2-day extremes: 23 inches on February 26, 1954 at Cedar Rapids in Linn County.
- 3-day extremes: 23.5 inches on February 27, 1954 at Cedar Rapids in Linn County.

Figure A-15. IOWA EXTREME 1-DAY SNOWFALL, BY COUNTY, IN INCHES (NOAA, 2017b)



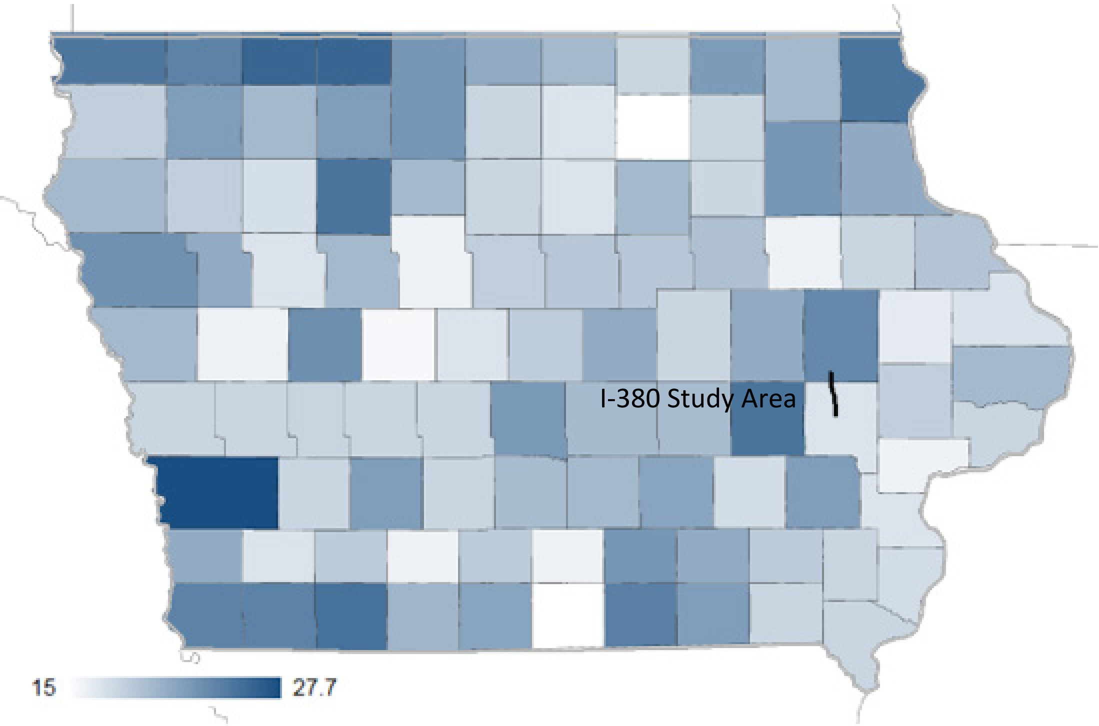
Source: Graphic is from the Snowfall Extremes Database (NOAA, 2017b).

Figure A-16. IOWA EXTREME 2-DAY SNOWFALL, BY COUNTY, IN INCHES (NOAA, 2017b)



Source: Graphic is from the Snowfall Extremes Database (NOAA, 2017b).

Figure A-17. IOWA EXTREME 3-DAY SNOWFALL, BY COUNTY, IN INCHES (NOAA, 2017b)



Source: Graphic is from the Snowfall Extremes Database (NOAA, 2017b).

WIND

Wind trends have been analyzed much less than the other climate components discussed previously and, as such, little information is available regarding wind within the I-380 study corridor. On average, near-surface wind speeds have shown a consistent negative trend throughout the country from 1973 to 2005, with this trend being particularly prominent in the Midwest Region. These negative trends are prominent in all seasons and at all times of day (Pryor et al., 2009).

Records at the Cedar Rapids Municipal Airport show that extreme winds can exceed 80 miles per hour, with the highest wind gust speeds generally in June and July (NOAA, 2017c). Other months generally have experienced extreme winds above 50 miles per hour. Winter months tend to have the highest average daily sustained winds, about 30 miles per hour in November, December, and January.

Anderson (2013) reports that tornado and wind loss events increased about 30 to 40 percent from 2000 to 2004 to 2008 to 2012, respectively. However, these periods are too short for meaningful trend analysis. Over longer periods, Anderson (2013) reports EF2 to EF5 tornados in Iowa have been relatively consistent since the early 1990s at 0 to 10 reports per year, with a slight decrease in reported tornado events since a busy period of about 20 to 30 tornados per year in the mid-1960s.

None of the available information or literature reviewed included any documented wind-related events in the I-380 study area that would impact the transportation mobility of the interstate.

FUTURE CLIMATE AND HYDROLOGY PROJECTIONS

Future climate projections described in this section refer to a report by the National Environmental Satellite, Data, and Information Service (NESDIS) (NOAA, 2013); this information was in turn used to inform the Midwest portion of the National Climate Assessment. Greenhouse gas emission (GHG) scenarios utilized in the climate projection models in this report include the Coupled Model Intercomparison Project Phase 3 (CMIP3) high and low scenarios based on *IPCC Special Report Emission Scenarios* (Intergovernmental Panel on Climate Change [IPCC], 2000).[2] No explicit information is provided on the probabilities of these scenarios, and these scenarios are meant to provide projections of possible future conditions, not actual forecasts. Projections provided in this report utilize several model datasets, including CMIP3, downscaled CMIP3, and the North American Regional Climate Change Assessment Program (NARCCAP). These climate models use projected atmospheric concentrations of GHGs to drive representations of atmospheric physics and simulate future climate, and are standard IPCC-accepted methods.

More recent climate projections have been produced as part of the Coupled Model Intercomparison Project Phase 5 (CMIP5). However, the regional and Iowa state-wide analyses used to inform this technical memorandum do not use the most recent CMIP5 data. In general, climate projections in Iowa generally show similar trends between the CMIP3 models discussed below, and the USGS CMIP5 *Global Climate Change Viewer* (USGS, 2016).

Future climate projections are typically reported for a stated future period ranging from a single year to a 30-year period. The assumed traffic design year for the Iowa I-380 PEL Study is 2040. Because individual assets have varied design lives, and because climate conditions at the end of an asset's design life should be considered during design, a range of projection years is reported in this technical memorandum. Analysis from the NOAA (2013) report is provided for the periods of 2021 to 2050, 2041 to 2070, and 2070 to 2099. Depending on source document, projection periods are sometimes referred to by their midpoints, 2035, 2055, and 2085, respectively. Depending on the source dataset used, changes are recommended in reference to periods 1971 to 1999, 1971 to 2000, or 1980 to 2000.

TEMPERATURE PROJECTIONS

Temperatures are expected to continue to increase throughout the entire I-380 study area. NOAA/NESDIS multi-model analysis found annual average temperatures can potentially rise by about 3°F between 2021 and 2050, between 4°F and 5°F for 2041 to 2070, and between 5°F and 8.5°F for 2070 to 2099. According to the observed data plotted in Figure A-1, the statewide annual average temperatures ranged from 45°F to 52°F for the period of 1971 to 2000. This would result in a potential statewide annual temperature average range of 48°F to 55°F for

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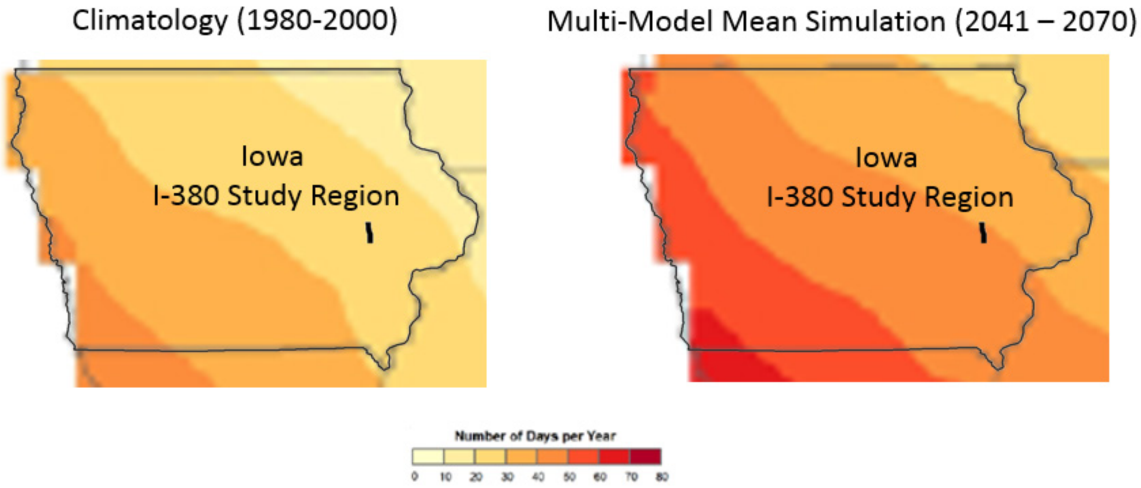
the period of 2021 to 2050, 49°F to 57°F for the period of 2041 to 2070, and 50°F to 60.5°F for the period of 2070 to 2099.

Greatest increases are projected to occur in summer through winter, and smaller increases in spring. Annual average increases are estimated to be around 1.5°F for 2035, range from 3 to 4.5°F for 2055, and 4 to 9.5°F for 2085 for both high and low emission scenarios from CMIP3. NARCCAP projects seasonal average increases for 2055 to range from approximately 4°F to 5°F for winter, 3°F to 4°F for spring, 5°F to 6°F for summer, and 4.5°F to 5°F for fall. Regionally throughout the Midwest, summer temperature increases show a northeast to southwest increasing gradient with a reverse gradient in winter. Fall shows an increasing gradient from east to west. However, increases are expected to be relatively consistent throughout the entire I-380 corridor.

High temperature extremes are often categorized as number of days above 95°F. In general, the number of high temperature extremes is expected to increase throughout the I-380 corridor. Figure A-18 shows NARCCAP multi-model mean annual number of days in which maximum temperature is above 95°F, for the high emissions scenario. The number of days with maximum temperature above 95°F along the I-380 corridor ranged from 20 to 30 days per year in 1980 to 2000 and is projected to increase to range from 35 to 50 days per year for the 2041 to 2070 period.

Low temperature extremes are often categorized as number of days below 10°F. In general, the number of low temperature extremes is expected to decrease throughout the I-380 corridor. Figure A-19 shows NARCCAP multi-model mean annual number of days in which minimum temperature is below 10°F, for the high emissions scenario. The number of days with minimum temperature below 10°F along the I-380 corridor ranged from 10 to 20 days per year in 1980 to 2000 and is projected to decrease to 0 to 10 days per year for the 2041 to 2070 period. Similarly, the number of days less than 32°F is expected to decrease from 70 to 110 days per year (in 1980 to 2000) to 50 to 90 days per year (in 2041 to 2070) along the I-380 corridor (NOAA, 2013).

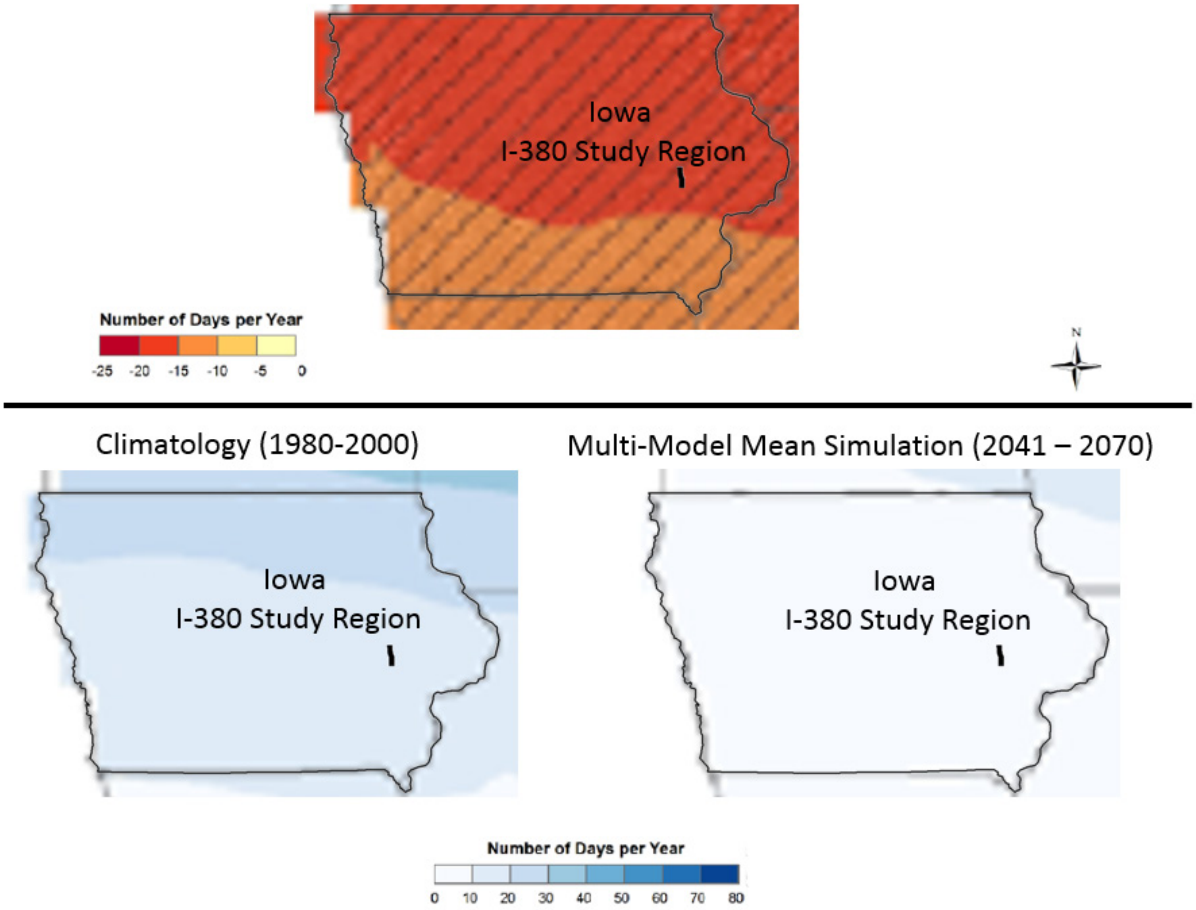
Figure A-18. MIDWEST REGION SIMULATED DIFFERENCE IN THE MEAN ANNUAL NUMBER OF DAYS WITH A MAXIMUM TEMPERATURE GREATER THAN 95°F, FOR THE 2041-2070 TIME PERIOD IN REFERENCE TO 1980-2000 FOR THE NARCCAP MULTI-MODEL MEAN HIGH EMISSIONS SCENARIO.


Climatology (1980-2000)

Multi-Model Mean Simulation (2041 – 2070)

The NOAA/NESDIS analysis also discusses an upward trend in the freeze-free season, which is defined as the period of time between the last spring frost and the first autumn frost (a daily minimum temperature of less than 32°F). An upward trend has been observed since the 1980s and is expected to continue increasing up to 23 additional days by 2041 to 2070, according to the NARCCAP projections. All models and scenarios are in agreement with this projected trend.

Figure A-19. MIDWEST REGION SIMULATED DIFFERENCE IN THE MEAN ANNUAL NUMBER OF DAYS WITH A MINIMUM TEMPERATURE LESS THAN 10°F, FOR THE 2041-2070 TIME PERIOD IN REFERENCE TO 1980-2000 FOR THE NARCCAP MULTI-MODEL MEAN HIGH EMISSIONS SCENARIO.



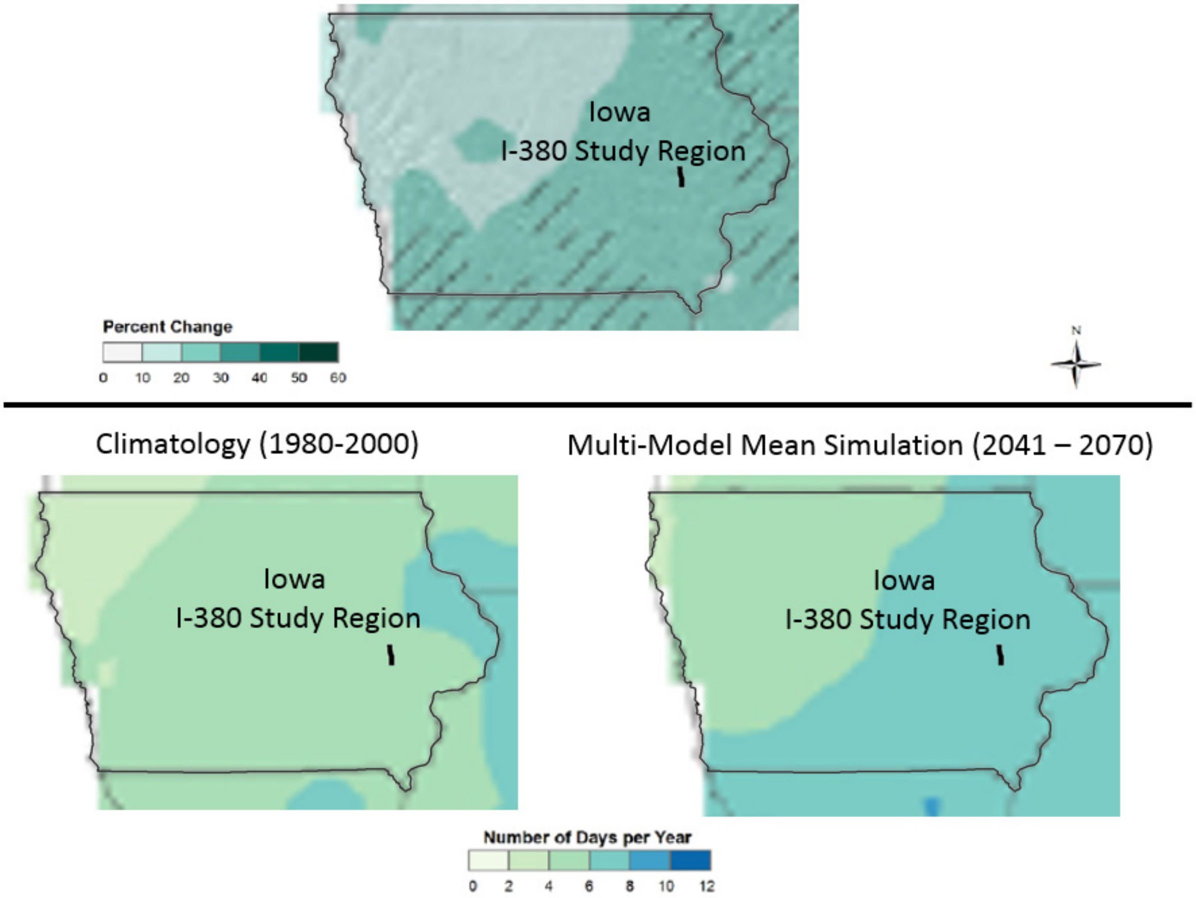
PRECIPITATION PROJECTIONS

Precipitation is expected to continue increasing throughout the entire I-380 corridor, although much greater variation and uncertainty is inherent in the multiple models analyzed in the NOAA/NESDIS report. In general, annual average precipitation is projected to increase, while seasonally the models show greater uncertainty. A majority of the models indicate increasing precipitation for winter, spring and fall, but models show both increasing and decreasing projections for summer. Projections generally show consistent changes throughout the I-380 corridor. The models for both high and low emission scenarios show that in 2035, average precipitation changes are not expected to be greater than the year-to-year variations that already occur (NOAA, 2013).

High precipitation extremes are often categorized as number of days with rainfall exceeding 1.25 inches. This threshold relates precipitation to flood likelihood, since Iowa’s soil can absorb about 1.25 inches of rain in a 1-day rain event and any excess results in increased runoff

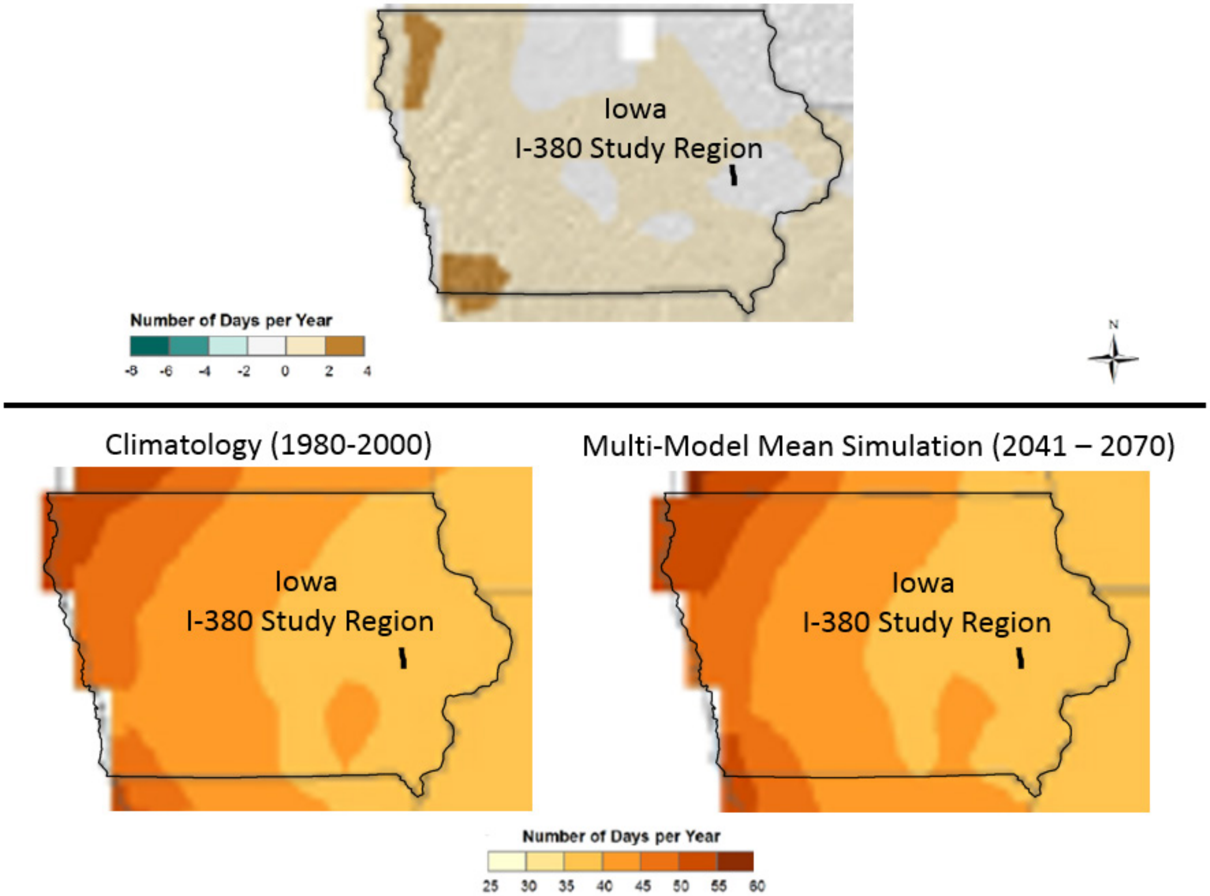
(Iowa Climate Change Impacts Committee, 2010). However, increases in precipitation do not directly translate to increases in flooding, which is also dependent upon local hydrology.
In general, the number of high precipitation extremes is expected to increase throughout the I-380 corridor (NOAA, 2013, and Iowa DOT, 2015). Figure A-20 shows NARCCAP multi-model mean annual number of days in which maximum precipitation is above 1 inch, for the high emissions scenario. The number of days with maximum precipitation above 1 inch along the I-380 corridor ranged from 4 to 6 days per year from 1980 to 2000 and is projected to increase to range from 6 to 8 days per year for the 2041 to 2070 period, with a larger increase in frequency in the eastern half of the corridor. Heavier downpours are expected to increase in springtime (Takle, 2011).

FIGURE A-20. MIDWEST REGION SIMULATED DIFFERENCE IN THE MEAN ANNUAL NUMBER OF DAYS WITH A MAXIMUM PRECIPITATION GREATER THAN 1 INCH, FOR THE 2041-2070 TIME PERIOD IN REFERENCE TO 1980-2000 FOR THE NARCCAP MULTI-MODEL MEAN HIGH EMISSIONS SCENARIO.



Low precipitation extremes are often categorized as number of consecutive days with precipitation less than 0.1 inch. In general, the average annual maximum number of days with precipitation less than 0.1 inch is not expected to change significantly throughout the I-380 corridor. Figure A-21 shows NARCCAP multi-model average annual maximum number of consecutive days with precipitation less than 0.1 inch, for the high emissions scenario. This number along the I-380 corridor ranged from 35 to 40 days per year in 1980 to 2000, and is projected to remain the same along the study area.

Figure A-21. MIDWEST REGION SIMULATED DIFFERENCE IN THE MEAN ANNUAL MAXIMUM NUMBER OF DAYS WITH PRECIPITATION LESS THAN 0.1 INCHES, FOR THE 2041-2070 TIME PERIOD IN REFERENCE TO 1980-2000 FOR THE NARCCAP MULTI-MODEL MEAN HIGH EMISSIONS SCENARIO.



The jet stream is one of the climate mechanisms recognized to have a strong influence on Iowa weather, particularly in the late spring and summer when heavy rain and flooding are historically most prevalent. When jet streams are located near Iowa, and mixed with abundant Gulf moisture, they enhance convective cloud development causing storms that produce strong winds and heavy precipitation linked to flooding.

While research indicates an observable poleward shift (north/south) in the jet stream (Francis and Vavrus, 2012) since the 1970s and climate models project a continued poleward shift (Mann et al., 2017), more precise projections are under development including future changes to the jet stream and quantified impacts on precipitation and wind in specific regions, such as Iowa.

STREAMFLOW AND FLOODING PROJECTIONS

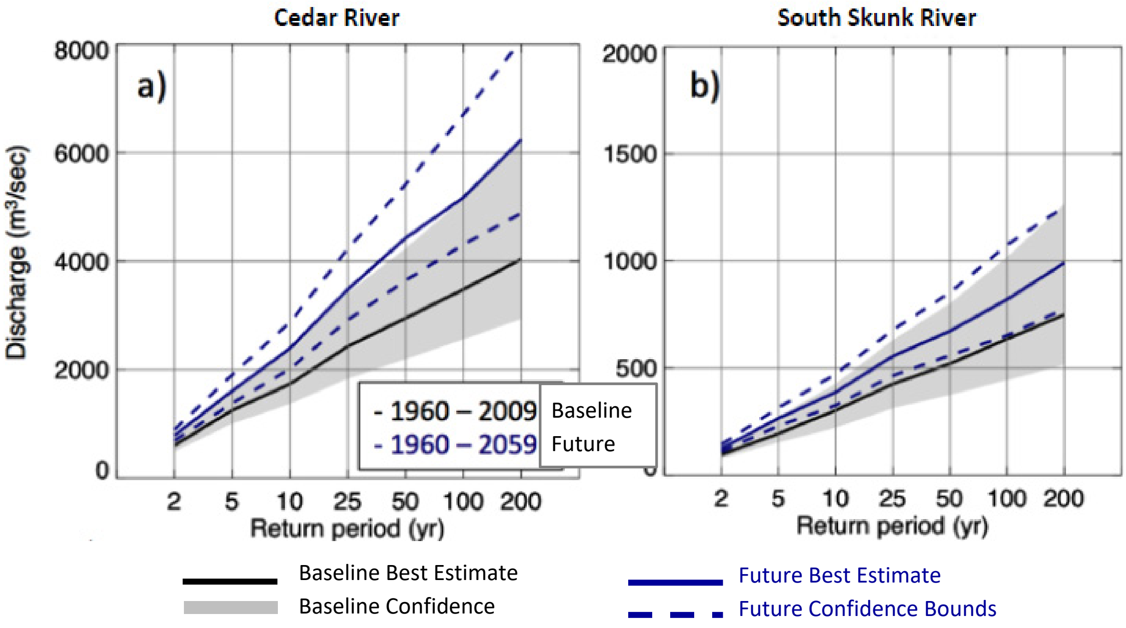
Precipitation intensity increases that are projected to continue will lead to greater instances of flood events, increasing stress on the I-380 study corridor's bridges, culverts, and other infrastructure. Climate variability impacts on streamflow and flood projections inherently include greater level of uncertainties. This is because they are not only correlated to projected changes in precipitation, of which already include a level of uncertainty, but many more evolving hydrological factors that compound upon this uncertainty.

Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot (Iowa DOT, 2015) project attempts to translate rainfall climate projections into streamflow projections to assess the highway infrastructure vulnerability to weather extremes in Iowa. The study incorporates future precipitation projections into a river system model to predict impacts to streamflow and flooding in Skunk and Cedar River basins. The analysis compares streamflow simulations for a historical period (1960 to 2009) and historical/future period (1960 to 2059). Neither the Skunk or Cedar Rivers cross the I-380 study area; however, the Cedar River crosses I-380 in Cedar Rapids approximately 4 miles north of the northern limits of this study corridor. Although the study has only been conducted on these two eastern Iowan basins, general trends and conclusions from this study are most likely to be found for other river basins throughout the state.

The study validates the consensus that increased precipitation intensity and frequency will likely lead to greater stream flows during major rainfall events, as well as greater frequency and magnitude of flooding. Model results from the study, shown in Figure A-22, signify that the 1 percent annual exceedance-probability discharge (AEPD) increase ranged from 37 to 67 percent for Cedar River Basin and ranged from 9 to 50 percent for South Skunk River Basin. (The 1 percent AEPD metric was chosen because it is a common design standard for bridge engineers.) Jha et al. (2004) found similar results in the Upper Mississippi River Basin, as well.

The simulations of drainage have shown that increases ranging from 24 to 32 percent in precipitation (and accompanying warming) can lead to drainage flow increases ranging from 35 to 80 percent, respectively (Jha et al., 2004). However, the Skunk and Cedar River Basin streamflow model error analyses signifies percent differences between model simulation and observed annual peak flow data to range between 47.7 and 59.8 percent. Thus, while there is a fair amount of certainty in the direction of stream flow projections (that they are expected to increase with increasing precipitation intensities), the magnitude of these values should be interpreted with caution.

Figure A-22. PROJECTED CHANGE IN FLOOD DISCHARGE FOR CEDAR RIVER AT CEDAR RAPIDS AND SOUTH SKUNK RIVER AT AMES (IOWA DOT, 2015)



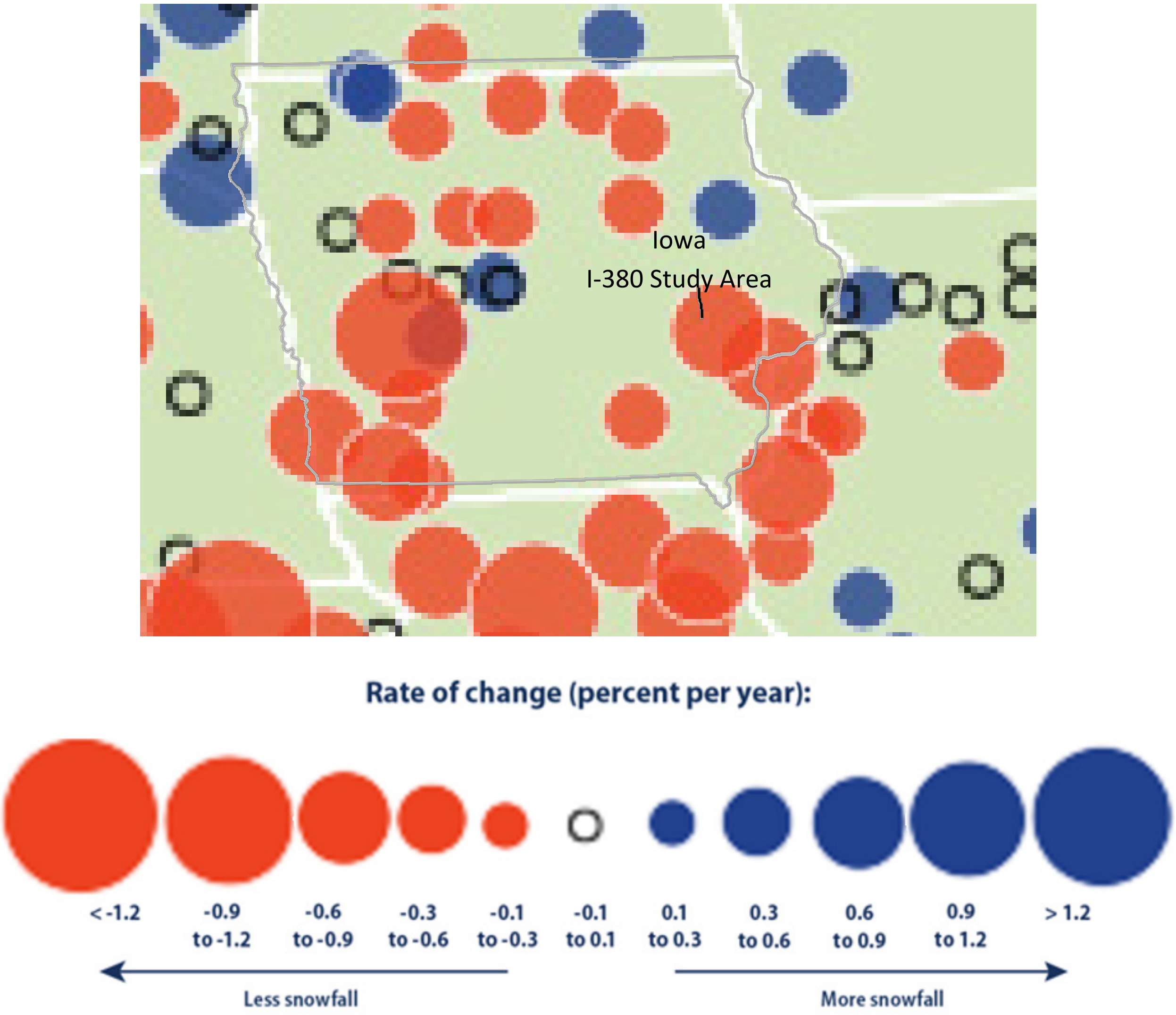
Source: Graphic is from Iowa DOT, 2015.

SNOWFALL PROJECTIONS

A decreasing trend of total annual snowfall has been observed along the I-380 corridor for the last several decades and is expected to continue. As atmospheric temperatures are rising, precipitation is falling more frequently as rain rather than snow. Figures A-23 and A-24 below indicate these trends based on data from 1930 through 2007, and 1949 through 2016 (U.S. Environmental Protection Agency [EPA], 2014). Figure A-23 shows decreasing snowfall of approximately 0.6 to 0.9 percent per year throughout all of the I-380 corridor. Figure A-24 indicates that this manifested in approximately a 20 to 30 percent decrease of snow-to-rain ratio in 2016 compared to 1949.

In some cases, decreases in the snow-to-rain ratio can lead to rain-on-snow events that can lead to significant flooding. This is most likely not the case for much of Iowa since snowfall is decreasing so much, there is not enough snowfall for rain-on-snow events to have much impact on flooding (Takle, 2017, personal communication). To illustrate the decreasing trend in snow further, Ning and Bradley's study (2015) explored snow occurrence changes of 1981 to 2000 compared to future (2081 to 2100) warming scenarios throughout the central and eastern United States. The study found that the snow-rain transition zone is expected to shift northward, assuming a global warming at magnitudes ranging from 4°F to 11°F. This indicates that areas such as Iowa will experience increasingly large loss of snow occurrence in the future. The findings are summarized in Figure A-25.

Figure A-23. CHANGE IN TOTAL SNOWFALL IN THE CONTIGUOUS 48 STATES, 1930-2007. AVERAGE RATE OF CHANGES AT 419 WEATHER STATIONS. BLUE CIRCLES REPRESENT INCREASED SNOWFALL; RED CIRCLES REPRESENT A DECREASE (EPA, 2017)

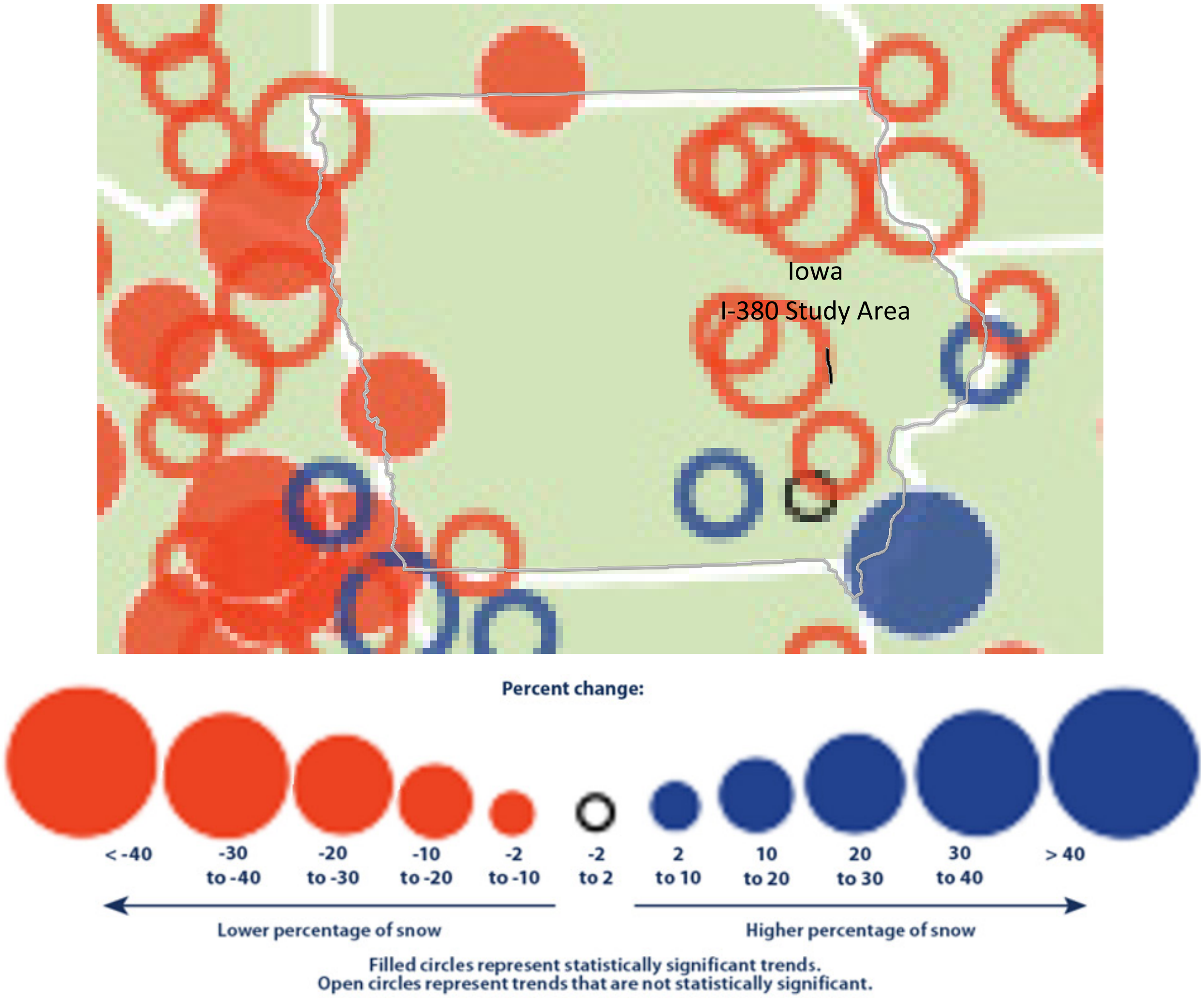


Data source: Kunkel, K.E., M. Palecki, L. Ensor, K.G. Hubbard, D. Robinson, K. Redmond, and D. Easterling. 2009. Trends in twentieth-century U.S. snowfall using a quality-controlled dataset. J. Atmos. Ocean. Tech. 26:33–44.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: Graphic is from the U.S. Environmental Protection Agency (EPA), 2017.

Figure A-24. CHANGE IN SNOW-TO-PRECIPITATION RATIO IN THE CONTIGUOUS 48 STATES, 1949-2016. SOLID-COLOR CIRCLES REPRESENT STATIONS WITH THE TREND WAS STATISTICALLY SIGNIFICANT (EPA, 2017)

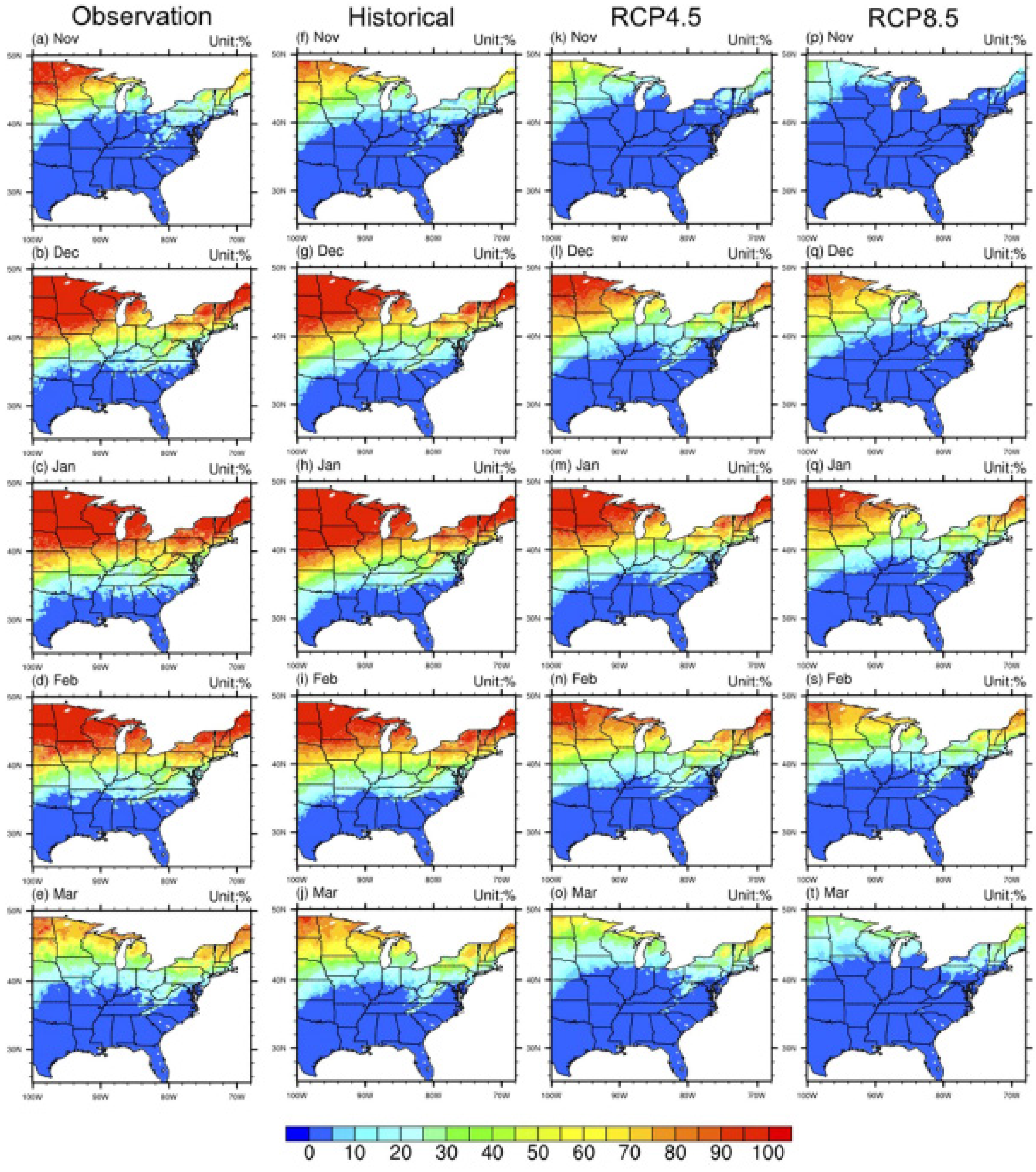


Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. National Centers for Environmental Information. Accessed June 2016. www.ncdc.noaa.gov.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.

Source: Graphic is from the EPA, 2017.

Figure A-25. CHANGE IN SNOW OCCURRENCE BY MONTH, FROM NOVEMBER THROUGH MARCH, FOR THE EASTERN UNITED STATES. COLORS INDICATE PERCENTAGE OF TOTAL PRECIPITATION OCCURRING AS SNOW (NING AND BRADLEY, 2015)



Source: Graphic is from Ning and Bradley, 2015.

WIND PROJECTIONS

Climate projections for wind and especially extreme wind events such as tornados are quite limited and have high uncertainty. Average wind speeds are projected to continue to decrease, however, not at a rate greater than the interannual variability that has been historically observed (Takle, 2011). Reduced wind speeds can lead to increased surface heating, having a negative impact on the I-380 roadway infrastructure.

Appendix B

LIST OF ALL SOURCES AND DATA REVIEWED

APPENDIX B: LIST OF ALL SOURCES AND DATA REVIEWED

List of Tables

Row	Author	Document Name	Date
1	American Association of State Highway and Transportation Officials (AASHTO)	User and Non-User Benefit Analysis for Highways	2010
2	American Association of State Highway and Transportation Officials (AASHTO)	Highway Safety Manual	2010
3	Anderson, C., R. Arritt, B. Gutowski, G. Takle	Climate Science and Public Policy in Iowa	
4	Anderson, C.J.	Extreme Weather and Climate Change in Iowa: Now and Future Trends (presentation)	12/11/2013
5	Barnes, K. K. and D. A. Eash	Flood of August 11-16, 2010, in the South Skunk River Basin, Central and Southeast Iowa	2012
6	Barnes, K. K. and D. A. Eash	Flood of June 17, 1990, in the Clear Creek Basin, East-Central Iowa	1994
7	Bernhard, C.J.	Iowa DOT Email Thread re: Draft Response to EPA's US 30 Letter	12/28/2015
8	The Cedar Rapids Gazette	Chronology (Floods)	10/24/1993
9	CH2M and Iowa Department of Transportation	Flood Map Location Limits (spreadsheet)	8/25/2015
10	Eash, D. A.	Summary of USGS Reports Documenting Flood Profiles of Streams in Iowa, 1963-2012	2014
11	Eash, D. A. and A. J. Heinitz	Floods in the Nishnabotna River Basin, Iowa	1991
12	Eash, D. A. and B. A. Koppensteiner	Flood of July 9-11, 1993, in the Raccoon River Basin, West-Central Iowa	1997
13	Federal Emergency Management Agency (FEMA)	Flood Insurance Study: Johnson County, Iowa and Incorporated Areas	2007
14	Federal Emergency Management Agency (FEMA)	Flood Insurance Study: Linn County, Iowa and Incorporated Areas, Volume 1 of 2	2010
15	Federal Emergency Management Agency (FEMA)	National Flood Hazard Layer	2013
16	Federal Highway Administration (FHWA)	Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries	2005
17	Federal Highway Administration (FHWA)	FHWA Climate Resilience Pilot Program: Iowa Department of Transportation	2015
18	Fisher, E. E.	Flood of June 15-17, 1998, Nishnabotna and East Nishnabotna Rivers, Southwest Iowa	1999
19	Francis, J., and S. Vavrus	Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophysical Research Letters.	2012
20	Hans, Z., N. Hawkins, K. Gkritza, M. Shaheed, and I. Nlenanya	Safety and Mobility Impacts of Winter Weather - Phase 3	2014
21	ICF International for U.S. Department of Transportation (ICF)	Transportation Climate Change Sensitivity Matrix (Excel File)	June 2014
22	Intergovernmental Panel on Climate Change (IPCC)	IPCC Special Report Emissions Scenarios	2000
23	Iowa Climate Change Advisory Council (ICCAC)	Iowa Climate Change Advisory Council's Final Report (part 1)	2008
24	Iowa Climate Change Advisory Council (ICCAC)	Iowa Climate Change Advisory Council's Final Report (part 2 - Appendices)	2008
25	Iowa Climate Change Impacts Committee	Climate Change Impacts on Iowa 2010: Report to the Governor and the Iowa General Assembly	1/1/2010

Row	Author	Document Name	Date
26	Iowa Department of Transportation (DOT)	Iowa In Motion - Planning Ahead 2040	5/8/2012
27	Iowa Department of Transportation (DOT)	Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot	March 2015
28	Iowa Department of Transportation (DOT)	2015 Iowa Traffic Incidents (spreadsheet)	2016
29	Iowa Office of Energy Independence	2010 Energy Independence Plan	2010
30	Iowa State University Center for Earthworks Engineering Research	Western Iowa Missouri River Flooding - Geo-Infrastructure Damage Assessment, Repair, and Mitigation Strategies	September 2013
31	Iowa State University Center for Transportation Research and Education	Iowa's Renewable Energy and Infrastructure Impacts	April 2010
32	Jha, M., Z. Pan, E. S. Takle, R. Gu	Impacts of climate change on streamflow in the Upper Mississippi River Basin: A regional climate model perspective	5/1/2004
33	Kunkel, K.E., M. Palecki, L. Ensor, K.G. Hubbard, D. Robinson, K. Redmond, and D. Easterling	“Trends in twentieth-century U.S. snowfall using a quality-controlled dataset.” Journal of Atmospheric and Oceanic Technology. 26:33-44	2009
34	Liang Ning & Raymond S. Bradley	Snow Occurrence Changes over the Central and Eastern U.S. Under Future Warming Scenarios	2015
35	Linhart, S. M. and D. A. Eash	Floods of May 30 to June 15, 2008, in the Iowa River and Cedar River Basins, Eastern Iowa	2010
36	Mann, M., S. Rahmstorf, K. Kornhuber, B. Steinman, S. Miller, D. Coumou	Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events. Scientific Reports 7. Article No. 45242	2017
37	Maze, T., Michael Crum., and Garrett Burchett.	An Investigation of User Costs and Benefits of Winter Road Closures	2005
38	Meinshausen, Malte, and S. J. Smith, K. Calvin, J. S. Daniel, M. L. T. Kainuma, J-F. Lamarque, K. Matsumoto, S. A. Montzka, S. C. B. Raper, K. Riahi, A. Thomson, G. J. M. Velders and D.P. P. van Vuuren. 2011	“The RCP greenhouse gas concentrations and their extensions from 1765 to 2300”. Climatic Change. 109 (1-2): 213–241.	2011
39	Minnesota Department of Transportation (MnDOT)	Benefit-Cost Analysis for Transportation Projects	2016
40	National Oceanic and Atmospheric Administration (NOAA)	9th Annual Climate Prediction Applications Science Workshop Report	3/1/2011
41	National Oceanic and Atmospheric Administration (NOAA)	NOAA Technical Report NESDIS 142-3: Regional Climate Trends and Scenarios for the U.S. National Climate Assessment - Part 3 Climate of the Midwest U.S.	1/1/2013
42	National Oceanic and Atmospheric Administration (NOAA)	Comparative Climatic Data for the United States Through 2015	2016
43	National Research Council of the National Academies (NRC)	Potential Impacts of Climate Change on U.S. Transportation	2008

Row	Author	Document Name	Date
44	Ning, L., and R.S. Bradley	Snow Occurrence Changes over the Central and Eastern U.S. Under Future W	2015
45	Parsons Brinckerhoff and Sarah J. Siwek & Associates	Climate Change: Impacts, Challenges, and Strategies (Workshop Presentation)	6/22/2010
46	Pryor, S.C., R.J. Barthelmie, D.T. Young, E.S. Takle, R.W. Arritt	Wind speed trends over the contiguous US	2009
47	State of Iowa, State Highway Commission	Plan and Profile of Proposed Improvement on the Interstate Road System Johnson County | Grading Project No. 1-16-6(5)243--04-52; Paving Project No. 1-IG-380-6(19)243--04-52	1972
48	State of Iowa, State Highway Commission	Plan and Profile of Proposed Improvement on the Interstate Road System Johnson County | Paving Project No. 1-IG-380-6(20)247--04-52	7/18/1972
49	State of Iowa, State Highway Commission	Plan and Profile of Proposed Improvement on the Interstate Road System Linn County | Grading and P.C.C.Paving Project No. 1-IG-380-6(9)255--01-57	3/28/1972
50	State of Iowa, State Highway Commission	Plan and Profile of Proposed Improvement on the Interstate and Primary Road System Linn County | Grading and Paving Project No. 1-IG-380	3/7/1979
51	Takle, E. S.	Assessment of Potential Impacts of Climate Changes on Iowa Using Current Trends and Future Projections	10/26/2011
52	Takle, E. S.	Personal communication	4/21/2017
53	Takle, E. S. et al.	Iowa Climate Statement 2013: A Rising Challenge to Iowa Agriculture	2013
54	Transportation Research Board (TRB)	Surface Transportation System Resilience to Climate Change and Extreme Weather Events	2/1/2016
55	U.S. Army Corps of Engineers	Coralville Lake Project Fact Sheet	
56	U.S. Department of Transportation (USDOT)	US Department of Transportation Climate Adaptation Plan 2014 - Ensuring Transportation Infrastructure and System Resilience	2014
57	U.S. Department of Transportation (USDOT)	US DOT Climate Adaptation Plan - Ensuring Transportation Infrastructure and System Resilience	2013
58	U.S. Environmental Protection Agency (EPA)	Greenhouse Gas Emissions from a Typical Passenger Vehicle	May 2014
59	U.S. Environmental Protection Agency (EPA)	Iowa Climate Change Adaptation & Resilience Report	2011
60	Zogg, J	The Top Five Iowa Floods	3/1/2014

Table B-2. LIST OF ALL SOURCES REVIEWED

Row	Author	Website Name	Date	URL
61	American Association of State Highway and Transportation Officials (AASHTO)	Resilient and Sustainable Transportation Systems Program	2017	http://environment.transportation.org/center/rsts/products_programs.aspx
62	California Department of Transportation.	Life-Cycle Benefit-Cost Analysis Economic Parameters 2016	2017	http://dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html
63	Climate Change in Australia	Projections for Australia's NRM Regions	No Date	https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/experiments/
64	Environmental Systems Research Institute (ESRI)	World Street Map Web Map Service	2017	http://goto.arcgisonline.com/maps/World_Street_Map
65	Federal Highway Administration (FHWA)	Tools: Climate Change Adaptation	2017	https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/index.cfm
66	Federal Highway Administration (FHWA)	HERS-ST Highway Economic Requirements System - State Version.	No Date	https://www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.cfm
67	Google	Google Maps	No Date	https://www.google.com/maps/@47.040146,-117.6029845,7z
68	Horizon Systems	NHDPlus	2017	http://www.horizon-systems.com/nhdplus/
69	Iowa Department of Agriculture and Land Stewardship	Climatology Bureau Home Page	2017	http://www.iowaagriculture.gov/climatology.asp
70	Iowa Department of Natural Resources	Climate Change	2017	http://www.iowadnr.gov/Conservation/Climate-Change
71	Iowa Department of Natural Resources	Iowa Flood Maps	2017	http://ifis.iowafloodcenter.org/ifis/newmaps/hazard/
72	Iowa Department of Transportation (DOT)	Iowa 511	No Date	http://www.511ia.org/
73	Iowa Department of Transportation (DOT)	Iowa DOT News Release: Iowa Roadways Remain Closed Due to Flooding	2008	http://www.news.iowadot.gov/newsandinfo/2008/06/iowa-roadway-42.html
74	Iowa Department of Transportation (DOT)	Iowa DOT News Release	2/2/2011	http://www.news.iowadot.gov/newsandinfo/2011/02/high-winds-still-affecting-iowa-road-conditions.html
75	Iowa Department of Transportation (DOT)	Truck Traffic	2014	https://iowadot.gov/maps/msp/pdf/TruckTrafficMap.pdf.
76	Iowa Department of Transportation (DOT)	511 Information: Iowa Winter Travel Condition Definitions	2015	http://www.iowadot.gov/511/road_condition_terms.html

Row	Author	Website Name	Date	URL
77	Iowa Department of Transportation (DOT)	Office of Bridges and Structures LRFD Design Manual.	2017	https://iowadot.gov/bridge/design-policies/bridge-design-manual
78	Iowa Department of Transportation (DOT)	County Traffic Maps	2017	https://iowadot.gov/maps/digital-maps/traffic-maps/county
79	Iowa Flood Center	Iowa Flood Center Home Page	2017	http://iowafloodcenter.org/
80	Iowa Flood Center and Iowa Department of Natural Resources	Iowa Statewide Floodplain Mapping Project	2017	http://www.iihr.uiowa.edu/iowafloodmaps/
81	Iowa State University Climate Science Program	Data Archive Page	2017	http://climate.engineering.iastate.edu/DataArchive.html
82	Iowa State University Climate Science Program	Education and Presentations Page	2017	http://climate.engineering.iastate.edu/CSPPresentations.html
83	Iowa State University Climate Science Program	Publications and Presentations by the CSP Research Team	2017	http://climate.engineering.iastate.edu/CSPPublications.html
84	Iowa State University Climate Science Program	Publications Page - Impacts of Climate Change	2017	http://climate.engineering.iastate.edu/ImpactsResearch.html
85	Iowa State University Climate Science Program	Publications Page - Regional Climate Model Development and Regional Analysis	2017	http://climate.engineering.iastate.edu/RCMResearch.html
86	Iowa State University Climate Science Program	Resources Page	2017	http://climate.engineering.iastate.edu/Resources.html
87	Iowa State University of Science and Technology	Iowa Environmental Mesonet	2017	https://mesonet.agron.iastate.edu/
88	Iowa State University of Science and Technology	Roadway Weather Information System	2017	https://mesonet.agron.iastate.edu/RWIS/
89	National Climate Assessment (NCA)	Climate Change Impacts in the United States	2014	http://nca2014.globalchange.gov/report/regions/midwest#intro-section-2
90	National Geodetic Survey	VERTCON North American Vertical Datum Conversion	2017	https://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html
91	National Oceanic and Atmospheric Administration (NOAA)	National Centers for Environmental Information	2017	http://www.ncdc.noaa.gov
92	National Oceanic and Atmospheric Administration (NOAA)	2017 U.S. spring climate and flood outlook	2017	https://www.climate.gov/news-features/videos/2017-us-spring-climate-and-flood-outlook
93	National Oceanic and Atmospheric Administration (NOAA)	National Centers for Environmental Information - Climate at a Glance	2017	https://www.ncdc.noaa.gov/cag/time-series/us
94	National Oceanic and Atmospheric Administration (NOAA)	National Weather Service (NWS) Homepage	2017	https://www.weather.gov/

Row	Author	Website Name	Date	URL
95	National Oceanic and Atmospheric Administration (NOAA)	Regional Snowfall Index	2017	https://www.ncdc.noaa.gov/snow-and-ice/rsi/societal-impacts
96	National Oceanic and Atmospheric Administration (NOAA)	Snowfall Extremes - Iowa	2017	https://www.ncdc.noaa.gov/snow-and-ice/snowfall-extremes/IA
97	National Oceanic and Atmospheric Administration (NOAA)	National Centers for Environmental Information - Climate Data Online	1953-2017	https://www.ncdc.noaa.gov/cdo-web/datasets/GHCND/stations/GHCND:USW00014990/detail
98	New York Department of Transportation	Value of Time for Work Zone Delay Cost Calculations Using 2012 Income Data	2012	
99	Ohio Department of Transportation (DC	Work Zone User Cost Calculations.	2017	http://www.dot.state.oh.us/Divisions/ConstructionMgt/Admin/Innovative Contracting/RoadUserCostsRevised041515.xls. A
100	Takle, E., D. Hofstrand	Global warming - impacts of global climate change on the Midwest	2017	http://www.extension.iastate.edu/agdm/articles/others/TakJuly08.html
101	Texas Department of Transportation	Road User Costs	2017	http://www.txdot.gov/inside-txdot/division/construction/road-user-costs.html.
102	The Center for Climate Strategies	Documents Library	2017	http://www.climatestrategies.us/library/library/index/39
103	Transportation Research Board (TRB)	Climate Change: Activities of the Transportation Research Board	2017	http://www.trb.org/Main/SpecialtyPageClimateChange.aspx
104	U.S. Environmental Protection Agency (USEPA)	Climate Change Indicators: Snowfall	2017	https://www.epa.gov/climate-indicators/climate-change-indicators-snowfall
105	U.S. Environmental Protection Agency (USEPA)	Climate Change Indicators in the United States	2017	http://www.epa.gov/climate-indicators
106	U.S. Environmental Protection Agency (USEPA)	Climate Impacts in the Midwest	2017	https://19january2017snapshot.epa.gov/climate-impacts/climate-impacts-midwest_.html
107	U.S. Geological Survey (USGS)	The Global Climate Change Viewer (GCCV)	2016	https://www.usgs.gov/software/global-climate-change-viewer-gccv
108	United States Census Bureau	Iowa Quick Facts	2017	https://www.census.gov/quickfacts/table/PST045216/19
109	United States Department of Labor, Bureau of Labor Statistics	National Occupational Employment and Wage Estimates	2017	https://www.bls.gov/oes/current/oes_nat.htm#530000

Row	Data Source	Date	Author
110	I-80 - ESRI ArcMap 10.4 Template data - highways	2016	Environmental Systems Research Institute (ESRI)
111	Environmental Systems Research Institute (ESRI) ArcMap 10.5.1 Template Data - USA Map Layers	2017	Environmental Systems Research Institute (ESRI)
112	National Flood Hazard Layer	7/16/2013	FEMA
113	NHDPlus. http://www.horizon-systems.com/nhdplus/.	2017	Horizon Systems

Appendix C

USER COSTS DUE TO ROAD CLOSURE EVENTS

APPENDIX C: USER COSTS DUE TO ROAD CLOSURE EVENTS

List of Tables

USER COSTS DUE TO ROAD CLOSURE EVENTS

INTRODUCTION TO ROAD USER COST

The section of Interstate 380 (I-380) between Interstate 80 (I-80) and U.S. Highway 30 (US 30) serves the transportation needs of the local communities and of the region. Locally, this corridor is a major commuter route between the Iowa City and Cedar Rapids metropolitan areas. With its close proximity to I-80 and US 30, it also provides access to regional trips from these two east-west corridors to points south and north, respectively. This section of I-380 is also part of the Avenue of the Saints, a transportation corridor connecting St. Louis, Missouri, to St. Paul, Minnesota. Thus, it also serves interstate travel of people and goods. Because of the needs that this corridor serves from a transportation perspective, the inability of this transportation corridor to meet future travel demands and/or the interruption of travel along this corridor due to a closure or some other event can have a significant economic impact.

To improve resiliency of the I-380 corridor and maintain acceptable levels of mobility, certain design features may be appropriate to consider as part of the I-380 expansion project to mitigate locations susceptible to impact by extreme weather events. Such design features may include, but are not limited to, increasing roadway grade, raising or building larger bridges, constructing larger culverts, constructing additional stormwater management, overflow, and conveyance features, placement of man-made or natural wind breaks, and an additional right-of-way purchase for attempted snow storage and drift control. To gauge the feasibility of such design features, the added infrastructure cost can be compared to the estimated economic impact of disrupting the safe and efficient flow of people and goods along the transportation corridor in question.

Economic impacts of travel disruption can be measured in different ways and can consider a number of different aspects such as lifecycle maintenance and rehabilitation needs of the existing infrastructure, fuel consumption, safety, and congestion and delay. In terms of resiliency, the two aspects that may most effectively provide a basis of a high-level comparison of potential economic impacts between alternatives are travel time/delay and safety performance.

To evaluate potential impact due to increased travel time and delay, a road user cost methodology can be used to determine the value of time that is lost due to out-of-distance travel or increased travel time due to diminished level-of-service along a transportation corridor. To evaluate safety performance, a value, intended to consider the comprehensive economic impact and loss, is placed on the effects and consequences of a crash. The following sections further describe how road user costs and safety performance can be applied when measuring the resiliency of a transportation corridor.

The economic impact to road users resulting from an event that disrupts traffic can be very difficult to quantify and can have a number of complex factors and metrics to consider. Existing literature suggests a wide range of user cost values that have been used by agencies or suggested through various research projects. Table C-1 summarizes documented road user costs recently used by other public agencies in the United States.

Table C-1. ESTIMATED ROAD USER COSTS USED BY OTHER AGENCIES

State	Year	Auto ($/hour)	Truck ($/hour)	Source
Texas	2017	$22.40	$32.70	Texas Department of Transportation, 2017 (http://www.txdot.gov/inside-txdot/division/construction/road-user-costs.html)
Minnesota	2016	$16.80	$28.30	Minnesota Department of Transportation, 2016 (http://www.dot.state.mn.us/planning/program/appendix_a.html)
New York (intercity)	2012	$31.06-$36.41	$26.74	New York Department of Transportation, 2012 (https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm/hdm-repository/Recommended%20Value%20of%20Time.pdf)
California	2016	$13.65	$31.40	California Department of Transportation, 2016 (http://dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html)
Ohio	2017	$22.42	$60.52	Ohio Department of Transportation, 2017 (http://www.dot.state.oh.us/Divisions/ConstructionMgt/Admin/Innovative%20Contracting/RoadUserCosts%20-%20Revised041515.xls)

A search of existing literature did not identify processes or values specific to resiliency of a transportation system. Many of the documented existing policies and processes utilize road user costs to evaluate construction work zones, pavement life-cycle costs, and congestion and delay at intersections or along urban arterials. While resiliency and weather-related events are not discussed directly, those policies and processes used for evaluation of work zones may still be relevant since many of the same characteristics, such as lane reductions or road closures/detours, are common between the two types of events.

FACTORS INFLUENCING ROAD USER COSTS

Development of a road user cost can be complex and consider a number of different factors related to a transportation trip and the makeup of the composition of the traveling public at a given location. Previous research and road user cost rates used in practice by other jurisdictions have included various factors such as:

- Type of trip (personal or business)
- Vehicle type (auto, medium truck, and heavy truck)
- Vehicle occupancy
- Travel time delay
- Out-of-distance travel
- Inconvenience on local communities
- Crashes/safety
- Vehicle emissions/fuel consumption
- Maintenance/repair/tire wear
- Vehicle depreciation based on mileage or hours of operation
- Noise impacts

If a project or study corridor contains a significant proportion of heavy vehicles and/or is critical to the movement of freight, research and existing literature suggests that an additional layer of factors may be warranted for consideration when performing road user costs and economic impact analyses. This added layer of factors may include:

- Type of commodity being transported (perishable or non-perishable)
- Value of payload being transported
- Oversized loads (horizontal and vertical clearance needs)
- Follow-on synchronous events (factory shut downs, delay of follow-on shipments, multi-modal transfer coordination, and delivery penalties)

In addition to the factors listed above, two intangible factors (expectancy and reliability) can have the greatest influence on the road user cost and economic impact associated with a roadway closure or reduction in capacity. Some studies suggest that these two intangibles can play a greater role in determining economic impact of an event than many of the other factors listed above. For example, Maze et al. (2005) suggest that the economic impact of an unexpected roadway closure can be up to 30 times greater than that of an expected closure.

Expected roadway closures tend to be more acceptable, manageable, and may minimize economic losses and inconvenience to road users. If the closure is known in advance and can be expected, the traveling public is able to plan appropriately whether that means rescheduling or repurposing a trip, identifying an alternative route early in the trip, and/or proactively coordinating follow-on synchronous events. In contrast, unexpected closures do not allow for the opportunity to plan ahead and can significantly increase the out-of-distance travel and delay to the overall trip as well as negatively impacting those synchronous activities of any given trip. In the case of extreme weather-related impacts, the majority of these will be unexpected events and, thus, it is reasonable to anticipate these events will come with greater economic impact and inconvenience to users of the transportation system compared to a planned closure for roadway or bridge construction, which will likely be publicized and communicated to the traveling public in advance of the closure occurring. Possible weather-related event exceptions would be a sustained weather event, such as major flooding, or large events that can be forecasted with some certainty in advance (such as major winter storms). The sustained nature or early forecasting of the potential impact can provide some level of expectancy or build that expectancy over a period of time.

Reliability of a transportation trip when an impact is known is measured by the confidence in which the traveling public puts in the ability of alternate routes to serve their travel needs. In the context of using an alternate route to avoid a weather-related impact on the primary travel route, reliability may include such things as a user’s confidence in the amount of additional travel time needed to take the alternate route or the confidence that the alternate route won’t be impacted by the same weather event. The more reliable the route, the less additional cost to the road user. In contrast, if the traveling public does not feel travel time along an identified detour route is reliable, additional travel time may be added to create a buffer or an alternative route requiring greater out-of-distance travel but deemed more reliable.

CALCULATING ROAD USER COSTS

The American Association of State Highway and Transportation Officials (AASHTO) Red Book (2010a), software applications like HERS-ST (Highway Economic Requirements System -

State) Version (FHWA, No Date), and agency-specific developed Excel spreadsheets and software tools that can be used to estimate road-user costs based on user inputs are currently used in practice or cited in research studies. Other sources of data (such as the U.S. Census Bureau, Bureau of Labor Statistics, and Consumer Price Indices) can be used to obtain data to estimate average annual income levels and hourly wage rates for the traveling public and inflation values to predict present day or future value costs. User costs developed using such statistics are based on the assumed average value of time of the traveling public directly correlated to an average hourly rate of employment. If movement of freight is considered a critical factor, other sources will need to be identified to obtain information on the shipping characteristics and types of goods being moved to fully understand impacts related to delayed freight delivery. These sources may include state commerce agencies, trucking associations, and interviews with major shippers and carriers within a project corridor.

Review of Iowa DOT policies and practices did not reveal any specific road user values or processes to evaluate the economic impact of a road closure or reduction in capacity. The one exception is a process outlined in Chapter 8 of the *Office of Bridges and Structures LRFD Design Manual* (Iowa DOT, 2017a) that discusses the process and inputs desired when evaluating the feasibility of possible accelerated bridge construction (ABC) techniques. Per the design manual guidance, user cost, calculated using the equation below, is only one of several factors taken into consideration when weighing the feasibility of implementing ABC alternatives.

$$\text{DRUC} = (\text{AADT} + 2\text{xADTT} + \text{OODT}) \text{ x Mileage Rate}$$

where:

DRUC = Direct Road User Cost ($)
AADT = Average Annual Daily Traffic (vehicles per day [vpd])
ADTT = Average Daily Truck Traffic (vpd)
OODT = Out-of-Distance Travel (miles)
Mileage Rate = $0.375 per mile

The methodology to determine the source of the $0.375 per mile mileage rate is not provided in the Design Manual (Iowa DOT, 2017a) guidance.

CALCULATING USER COSTS FOR I-380

For the purposes of this memorandum, road user costs for the I-380 corridor were considered at a high level to gain a sense of possible economic impacts of an interstate closure. The corridor under study is approximately 15 miles in length. Given the relatively short distance between I-80 and US 30, a single official detour route will likely serve a closure at any point along the corridor. When evaluating possible detour routes, the resiliency of the alternate routes must also be considered when estimating out-of-distance travel and associated road user costs.

For this study, road user costs and estimated economic impacts based on out-of-distance travel/ added travel time were calculated two ways. The first utilizes the Iowa DOT equation for direct road user costs when evaluating ABC opportunities. The second uses available Census data, labor statistics, daily traffic volumes, and estimated percentages of heavy trucks to generate an average hourly rate for the traveling public. For both calculation methods, detour routes for a closure on I-380 were assumed to estimate potential out-of-distance travel. The out-of-distance travel was converted to delay, or added travel time, based on posted speed limits of I-380 and the assumed detour routes.

Because of the close proximity of I-80 to the I-380 study corridor and the regional and interstate travel that comprises a significant portion of I-80 traffic as well as a portion of the daily traffic in the I-380 study area, the origin and destination of the trips in the corridor can also have an influence on the alternate route likely used in the event of an I-380 closure. Available I-80, I-380, and US 30 AADT volumes in Johnson and Linn Counties were referenced from the Iowa DOT website (https://www.iowadot.gov/maps/). The daily volumes, along with engineering judgment, were used to estimate approximate daily trips entering the corridor from each direction and from I-80 and US 30. Table C-2 summarizes the estimated volumes.

Table C-2. APPROXIMATE DAILY TRAVEL VOLUMES ALONG I-380 BETWEEN CEDAR RAPIDS AND IOWA CITY

Daily Trip Origin/Destination	Approximate Daily Volume Estimate (vpd)	Assumed Detour Route
Northbound		
From I-80 West of I-380	6300	I-35 at Des Moines to US 20 Near Webster City to I-380/US 218 at Waterloo
From I-80 East of I-380	11900	US 61 at Davenport to US 20 at Dubuque to I-380/US 218 at Waterloo
From US 218 South of I-80	5800	I-80 to IA 1 in Iowa City to US 30 in Cedar Rapids
Within the I-380 Study Corridor	1000	IA 1 or IA 965 between Coralville and Cedar Rapids
Southbound		
From US 30 West of I-380	5900	I-380/US 218 to US 20 at Waterloo to I-35 near Webster City to I-80 at Des Moines
From US 30 East of I-380	6500	I-380/US 218 to US 20 at Waterloo to US 61 in Dubuque to I-80 at Davenport
From I-380/US 218 North of US 30	13700	US 30 to IA 1 in Cedar Rapids to I-80 in Iowa City
Within the I-380 Study Corridor	1000	IA 1 or IA 965 between Coralville and Cedar Rapids

In the event of an interstate closure, it would be desired for the official detour route to follow the National Highway System primary road network, maintain traffic on four-lane divided facilities, and avoid travel through urban areas with at-grade intersections and traffic signals, when possible. For the purposes of this evaluation, the detour routes used for I-380 during the 2008 floods were assumed (I-80 east of Iowa City was also closed in 2008). These detour routes use I-35 in central Iowa, US 20 in northern Iowa, and US 61 in eastern Iowa. These routes would be used by interstate and regional travelers along I-80 and US 30 approaching the corridor from the east and west. For the purposes of estimating out-of-distance travel, trips were assumed to start along I-80 approximately halfway between the north-south detour route and I-380. For US 30 traffic, trips were assumed to start at the I-380/US 30 interchange. Trips ended in either

Cedar Rapids or Iowa City at the I-380/US 30 and I-80/I-380 system interchanges, respectively. It was assumed that traffic approaching the I-380 study corridor from the north and south on I-380/US 218 (that is, I-380 thru trips) would mainly be local commuter trips with drivers familiar with the area. The detour route for these trips assumed Iowa 1 (IA 1) would be used between Iowa City and Coralville because of the out-of-distance travel associated with the official detour route. There are also a number of daily trips that originate or end within the study corridor. Because it was assumed these trips will use the local roadway and state highway networks to travel to Cedar Rapids or Iowa City, they were not considered further in this evaluation.

The road user cost estimates in this memorandum are based solely on assumed value of time and do not consider costs involved with the transportation of freight across the state, the economic impact of stoppage or delay of delivery of such freight, or any of the other tangible or intangible factors that could be considered as noted earlier in this memorandum. To estimate the economic impact of freight delays or other factors such as safety, personal versus business trips, vehicle emissions, expectancy, or alternate route reliability additional study would be required to gain a better understanding of travel characteristics of a given section of I-380 and the available alternate routes.

Table C-3 summarizes the calculated user costs for interstate/regional and local trips using the assumed detour routes. Available truck traffic volume data from the Iowa DOT website (Iowa DOT, 2017c) would suggest that heavy vehicles account for approximately 16 percent of the daily trips within the I-380 study corridor.

Table C-3. CALCULATED USER COSTS

ID	Destination	Origination	Assumed Detour Operating Speeds (mph)	Distance Along I-380 (miles)	Assumed Detour Distance (miles)	Out-of-Distance Travel (miles)	Estimated Added Travel Time (hours)	Average Annual Daily Traffic (2014)[a]	Average Daily Truck Traffic (2014)[b]	Estimated Daily Economic Impact of I-380 Closure	
										Iowa DOT ABC Evaluation Method	Hourly Rate with Census and Labor Statistics Method
1	Cedar Rapids	I-80 West of I-380	60-70 mph	65	230	165	2.5	6300	1000	$514,500	$384,500
2	Cedar Rapids	I-80 East of I-380	60-70 mph	50	220	170	2.6	5800	900	$488,000	$376,200
3	Cedar Rapids	US 218 South of I-80	55-65 mph	15	38	23	0.4	11,900	1900	$135,500	$124,300
4	Coralville	US 30 West of I-380	60-70 mph	15	275	260	3.8	5900	950	$759,300	$146,500
5	Coralville	US 30 East of I-380	60-70 mph	15	250	235	3.5	6500	1050	$756,100	$161,400
6	Coralville	I-380/US 218 North of US 30	55-65 mph	15	38	23	0.4	13,700	2200	$156,000	$340,200
									Total (Rounded)	**$2,800,000**	**$1,500,000**

Mileage Rate (Iowa DOT, 2017a)	$0.375
Average Annual Income in Iowa (U.S. Census Bureau, 2017)	$53,183
Average Hourly Rate per Average Annual Income (U.S. Census Bureau, 2017)	$25.57
Average Truck Driver Hourly Rate (U.S. Department of Labor, Bureau of Labor Statistics, 2017)	$20.96

[a] Source: Iowa DOT, 2017b
[b] Source: Iowa DOT, 2014

As shown in Table C-3, the calculated values vary between the two calculation methods. However, it is clear that economic impacts of between $1.5 million and $2.8 million per day are possible. These impacts will likely only increase in dollar value if freight characteristics, premiums for unexpected/unreliable events and alternate routes, and/or other factors listed in this memorandum are included in the evaluation. These values also consider ideal conditions along IA 1 with free-flow speeds matching the posted speed limit; with the increase in traffic it is likely the free-flow speed of IA 1 will decrease during heavy commuter periods. Based on these high-level calculations, a strong argument can be made that frequent events or those with a sustained duration that close a portion of I-380 between I-80 and US 30 will have economic ramifications to the road users, the local communities, and the overall region.

VALUE OF SAFETY PERFORMANCE

As with the road user costs, the value assigned to the consequences of a crash vary across different jurisdictions and research projects and findings. No Iowa DOT specific values or standard practices were identified. A number of factors can be taken into consideration when evaluating a proper unit cost for a given crash outcome including property damage values, medical costs, insurance and legal costs, quality of life impacts, lost wages and reduced household income, pain and suffering, and traffic congestion to name a few.

AASHTO's *Highway Safety Manual* (HSM) (2010b) suggests monetary comprehensive values for the various consequences of a crash. The values provided in the HSM are based on a 2005 Federal Highway Administration (FHWA) report (*Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries*) with the values being reported in 2001 dollars.

I-380 SAFETY PERFORMANCE COSTS AND RESILIENCY

A possible application of using roadway crashes and safety performance for evaluating resiliency would be through the use of crash data to identify areas that are overly represented in crashes occurring under snow and ice conditions. Applying the comprehensive crash costs reported in Table C-4 to the snow- and ice-related crashes can provide a means for a benefit cost comparison of possible engineering strategies to lessen the frequency and severity of snow- and ice-related crashes at these over-represented areas of I-380. Engineering strategies may include purchase of additional rights-of-way to contain and control snow drifting, construction of wind breaks to lessen the effects of blowing snow and roadway icing, improvements resulting in more forgiving roadsides, placement of additional barriers to avoid lane departures under poor driving conditions, or inclusion of additional traffic control devices or implementation of ITS and technological strategies to communicate hazardous road conditions to drivers and Iowa DOT maintenance staff.

Table C-4. 2001 COMPREHENSIVE CRASH COSTS BY INJURY SEVERITY

Injury Level	Cost
Fatality	$4,008,900
Major/Disabling Injury	$216,000
Minor/Evident Injury	$79,000
Possible Injury	$44,900
Property Damage Only	$7,400

Source: HSM (AASHTO, 2010b)

PROJECT LEVEL NEXT STEPS

Based on the findings of the high-level analyses, it would appear that weather-related closures or capacity reductions within this I-380 study corridor can have significant economic ramifications to road users and the local and regional economy, particularly if the events are frequent and/or sustained events disrupting traffic for days at a time. Considering the volume of traffic along I-380 on a daily basis, which is projected to increase in the future, the large percentage of heavy vehicles using the corridor, and the out-of-distance travel required for a suitable I-380 alternate route, it is anticipated that improvements to increase the resiliency of the I-380 corridor will have some level of viability and should be considered as the corridor project advances.

As the I-380 project continues to develop, further consideration should be given to those areas of the corridor with a history of weather-related impacts or those locations most at risk for future weather-related impacts as determined by information documented in this memorandum. At the project level, the mix of traffic and purpose of vehicular trips can be better defined including the volume and characteristics of the heavy trucks and freight movement within the various individual project corridors. Alternate detour route information can be studied in greater detail to hone in on likely out-of-distance and time delay impacts associated with a closure; and specific crash data and coordination with maintenance staff can help pinpoint specific safety and weather-related crash locations and characteristics. The more detailed project level analyses will help compare design alternatives, consider benefits gained by implementing a given alternative, and help understand the economic tradeoffs between the level of resiliency along I-380 and added infrastructure capital investment.

Appendix D

PHOTO LOG OF AREAS MOST AT RISK OF CLIMATE RELATED IMPACTS

Photo 1. I-380 SB OVER CLEAR CREEK NEAR MILE POST (MP) 0.5 (FLOODING, SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING SOUTH FROM CLEAR CREEK TRAIL

Photo 2. I-380 OVER CLEAR CREEK (MP 0.5) (FLOODING, SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – I-380 SOUTHBOUND LANES LOOKING SOUTH

Photo 3. I-380 NEAR MP 1 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 4. I-380 NEAR MP 2 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 5. I-380 FROM FOREVERGREEN ROAD (NEAR MP 2) (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING SOUTH FROM OVERPASS

Photo 6. I-380 FROM FOREVERGREEN ROAD (NEAR MP 2) (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING NORTH FROM OVERPASS

Photo 7. I-380 NEAR MP 3 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 8. I-380 NEAR MP 5 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 9. I-380 FROM SWAN LAKE ROAD (NEAR MP 5.5) (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING SOUTH FROM OVERPASS

Photo 10. I-380 FROM SWAN LAKE ROAD (NEAR MP 5.5) (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING NORTH FROM OVERPASS

Photo 11. I-380 TOWARDS MP 6 TO MP 7 (FLOODING, SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING NORTH FROM SWAN LAKE ROAD OVERPASS (NEAR MP 5.5)

Photo 12. I-380 NEAR MP 6 (FLOODING, SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 13. I-380 NEAR MP 7 (FLOODING, SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 14. I-380 NEAR MP 7.5 (FLOODING, SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 15. I-380 NORTHBOUND OVER IOWA RIVER/CORALVILLE RESERVOIR (MP 8) (FLOODING, SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING NORTHWEST FROM BOAT LANDING EAST OF I-380.

Photo 16. I-380 NEAR MP 8.5 (FLOODING, SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 17. I-380 NEAR MP 10 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 18. I-380 SB MERGE FROM COUNTY ROAD F-12 NEAR MP 11 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING SOUTH FROM OVERPASS

Photo 19. I-380 FROM COUNTY ROAD F-12 NEAR MP 11 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING SOUTH FROM OVERPASS

Photo 20. I-380 FROM COUNTY ROAD F-12 NEAR MP 11 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING NORTH FROM OVERPASS

Photo 21. I-380 NEAR MP 12 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 22. I-380 NEAR MP 13 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 23. I-380 FROM WRIGHT BROTHERS BLVD. NEAR MP 14 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING SOUTH FROM OVERPASS

Photo 24. I-380 FROM WRIGHT BROTHERS BLVD. NEAR MP 14 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING NORTH FROM OVERPASS

Photo 25. I-380 NEAR MP 14 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 26. I-380 NEAR MP 15 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 27. I-380 NEAR MP 16 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – SOUTHBOUND LANES LOOKING SOUTH

Photo 28. I-380 FROM US 30 EASTBOUND RAMP NEAR MP 16 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – FROM RAMP LOOKING SOUTH