IOWA DOT
I-80 Planning Study

INTERSTATE 80
PLANNING STUDY (PEL)

Evaluation of I-80 Resiliency and Vulnerability
Office of Location and Environment | June 2017

EXECUTIVE SUMMARY

This technical memorandum analyzes information from previous studies that have identified historic climate trends, future projected climate trends, and the impacts of future climate variability on the I-80 transportation infrastructure across the state of Iowa. Using this information, this technical memorandum identifies resiliency recommendations to be considered in subsequent environmental and engineering studies of the I-80 corridor. This study relies on existing literature and available historical climate record and projected climate information. The study region evaluated focuses on rural and non-urban areas. Studies of developed urban areas will be completed at a future time. Also, greenhouse gas (GHG) emissions are generally thought by some to be a contributing factor to climate variability. The change in GHG emissions as a result of the planned I-80 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.
2. Identify and understand vulnerabilities – based on historical closure events and surrogate factors that may suggest a risk of impact resulting from an extreme weather event.
3. Identify strategies – to adapt and minimize the risk of traffic interruption along the corridor as a result of an extreme weather event.
4. Provide recommendations – for consideration in future studies.

Historic climate data show strong trends in increasing temperature, precipitation, streamflow and flooding and decreasing snowfall and wind throughout the I-80 corridor. These trends are expected to continue into the future and will impact the I-80 corridor in various ways. Available information on historical weather-related impacts and closure events along the I-80 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 to extreme weather conditions are summarized in Table ES-1 and Figure ES-1.

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

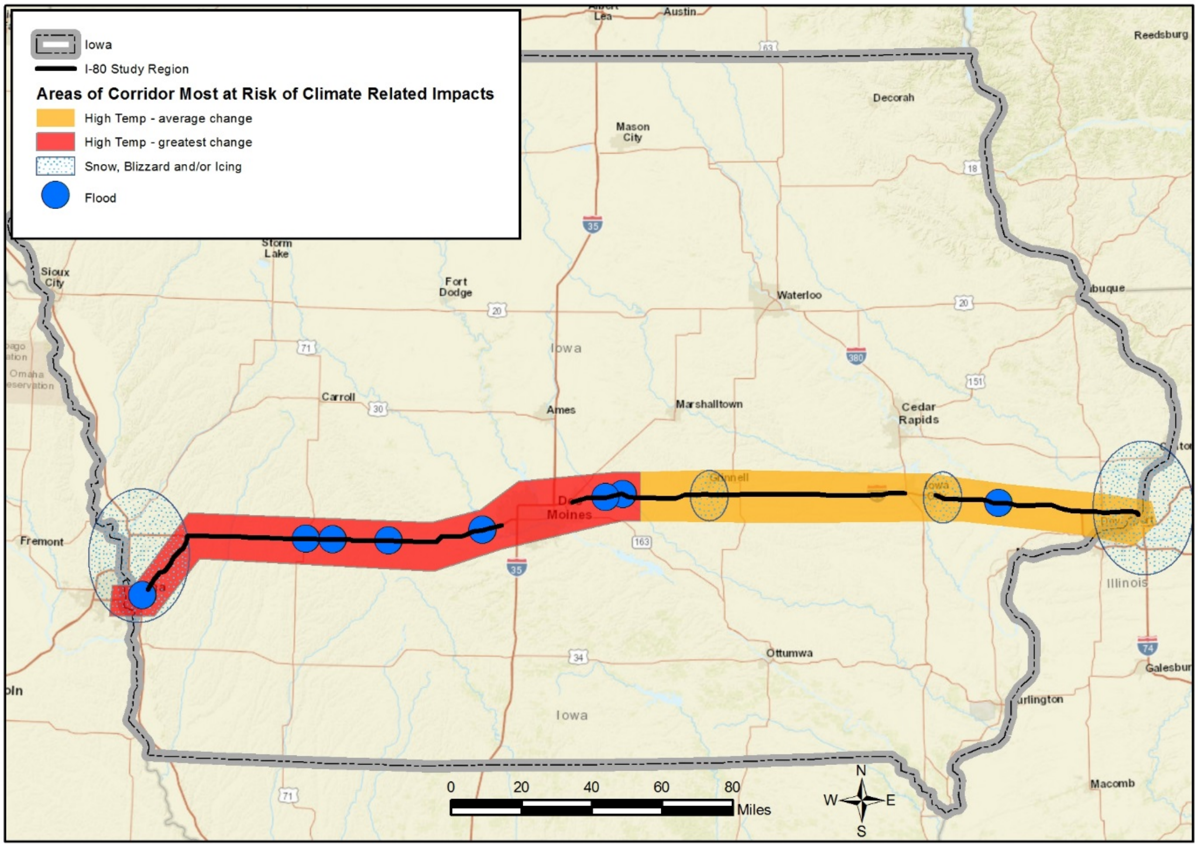
Feature Name	I-80 Mile Post [Range]	Impact Type	Notes
	0 to 150	High Temp – greatest change	Approximate range; temperature increase is expected to be greatest on the western side of the state.
	0 to 30	Snow, Blizzard	Approximate range; heavier snow has historically been recorded on the western side of Iowa. However, historical and projected trends in this area show decreasing snow.
Mosquito Creek	5.4 [5.3 to 27.4]	Flooding	AE[a] Floodplain Zone; creek crossing of I-80 outside study region, but creek and associated floodplain parallels portions of I-80 study region from approximately Mile Post (MP) 10 to MP 27, with approximately 6 miles of that section of I-80 immediately adjacent to or within the mapped floodplain.
East Nishnabotna River	61 [61.1 to 61.2]	Flooding	History of flood elevation near bridge deck.
Crooked Creek	68.7 [68.7 to 68.8]	Flooding	History of flood closures.
Middle River	84.8	Flooding	History of flood near closure.
North Raccoon River	112.4 [112.4 to 112.5]	Flooding	AE[a] floodplain zone; history of flood closures.
South Skunk River	152.6 [112.4 to 112.5]	Flooding	History of flooding and possible closures.
Indian Creek	157.8 [156.8 to 158.8]	Flooding	History of flooding and possible closures.
	182	Blizzard, Icing	History of wind, blowing snow and icing near Grinnell.

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

Feature Name	I-80 Mile Post [Range]	Impact Type	Notes
	248 to 254	Blizzard, Icing	History of wind, blowing snow, and icing between Iowa City and West Branch.
Cedar River	265.8	Flooding	History of flood closures.
	280 to 306	Snow, Blizzard	Approximate range; some evidence of increasing snowfall on eastern side of state.
	150 to 306	High Temp – average change	Approximate range; average temperature increase is expected on the eastern side of the state.

Note: [a] Zone AE is designated by FEMA on flood insurance maps, and indicates that these areas are inundated by the 1 percent annual chance of flood and have documented base flood elevations. This is further described in Section 2.3.

Figure ES-1. AREAS OF THE I-80 CORRIDOR MOST AT RISK OF CLIMATE RELATED IMPACTS.



The U.S. DOT provides guidelines for transportation and infrastructure climate resiliency planning. Their recommendations are discussed as they relate to Iowa's changing climate conditions and projected future impacts. They include design, operational, and cost and economic planning strategies. Engineering and design considerations include pavement compositions that are more durable at higher temperatures, raising roadway embankments and bridges above projected flood levels, 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/year and expanding infrastructure monitoring programs. Economic planning strategies include evaluating road-user costs from climate and weather-related impacts.

This technical memorandum makes the following four recommendations for climate resiliency planning along the I-80 corridor:

1. Develop a road closure monitoring and documentation program with a more comprehensive understanding of weather-related events disrupting the flow of I-80 traffic. 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. For stream crossings with long asset design life, use the most recent discharge data for hydraulics analysis, 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-80. Perform an economic evaluation as part of the risk analysis to compare the cost of mitigation to the impact created by disrupting I-80 traffic.

The findings of this memorandum are high-level in that they provide guidance for areas of I-80 where traffic flow could be disrupted by an extreme weather event. However, further, more-detail project-level studies is encouraged regarding existing infrastructure, the risk of impact at specific locations, possible strategies to remedy identified weaknesses of the I-80 corridor, and a benefit-cost evaluation on a location-by-location basis. The eventual outcome of additional analysis will be the safe mobility of the I-80 corridor.

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1. INTRODUCTION

The purpose of this technical memorandum is to summarize existing information associated with observed and projected future climate along the Iowa Interstate 80 (I-80) corridor and to evaluate the overall resiliency of the I-80 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-80 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 Iowa Department of Transportation's (DOT's) I-80 Planning and Environmental Linkages (PEL) Project. Additional supporting documentation about this evaluation are included as Appendixes, which 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 – Map Book of Areas of the I-80 Corridor Most At Risk of Climate Related Impacts
Appendix E – 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 will be addressed or evaluated within the framework of required NEPA studies is not clearly defined.

Regarding resiliency of a major transportation corridor like I-80, 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-80 planning study transitions from program-level evaluations to more-detailed, project-level studies.

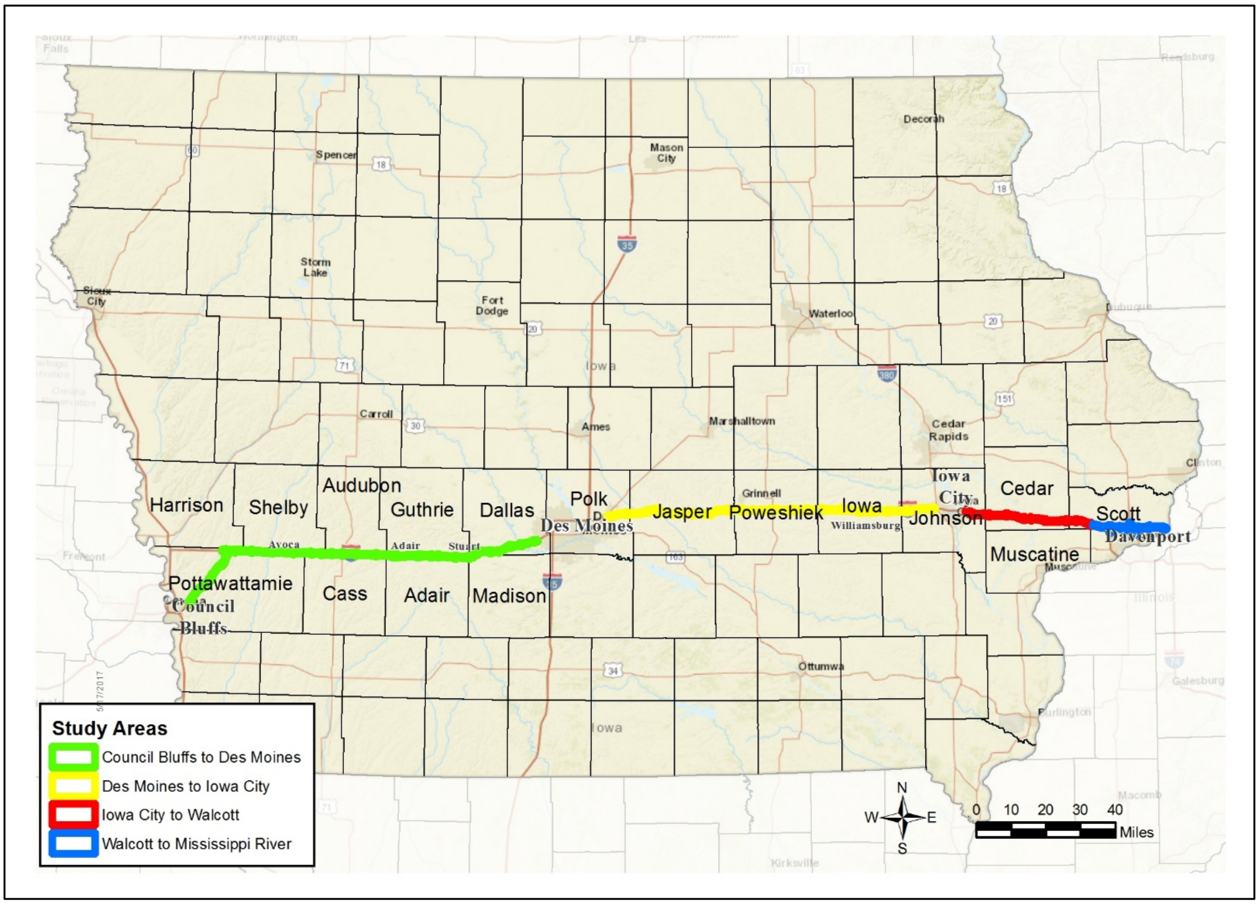
2. GEOGRAPHIC DESCRIPTION OF STUDY REGION

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

2.1 STUDY REGION

The study region (Figure 1) extends along the existing I-80 corridor across Iowa, approximately 306 miles across 12 counties from the western border with Nebraska and the Missouri River to the eastern border with Illinois and the Mississippi River. This technical memorandum is limited to rural areas only, and excludes urban areas including Council Bluffs, Des Moines, Iowa City, and the Quad City metro areas. These urban areas will be studied separately. Also, discussion of possible climate risks (such as, floodplains, rivers, traffic incidents and other factors) are limited to the study region. Figure 1 summarizes the portions of the rural I-80 corridors included in this study.

Figure 1. MAP OF STUDY REGION



2.2 WATERSHED BASINS

The Iowa I-80 corridor crosses 4 major watershed basins (Hydrologic Unit 4, or HU4) and 14 minor (HU8) subbasins (Figure 2). These basins are part of the Upper Mississippi and Missouri watersheds, and generally drain northwest to southeast. Within these 4 basins and within the study region, the corridor crosses 22 larger creeks and rivers (Figure 3 and Table 1), with mean annual flow above 10 cubic feet per second (cfs) as approximated by the National Hydrography Dataset Plus (NHDPlus) dataset (Horizon Systems, 2017). These creeks and rivers range from the Mosquito Creek that parallels the western portion of the I-80 study region, to Sugar Creek approximately 35 miles from Iowa's eastern border and the Mississippi. Other larger rivers (mean annual flow above 1,000 cfs) include the South Raccoon River, North Raccoon River, Des Moines River, and Cedar River. The Missouri River, Iowa River, and Mississippi River are outside the study region. Combined, the 22 rivers and creeks in the study region have a mean annual flow of approximately 14,000 cfs.

Figure 2. MAJOR (HU4) AND MINOR (HU8) WATERSHEDS ALONG THE I-80 CORRIDOR (FROM U.S. GEOLOGICAL SURVEY [USGS] WATERSHED BOUNDARY DATASET)

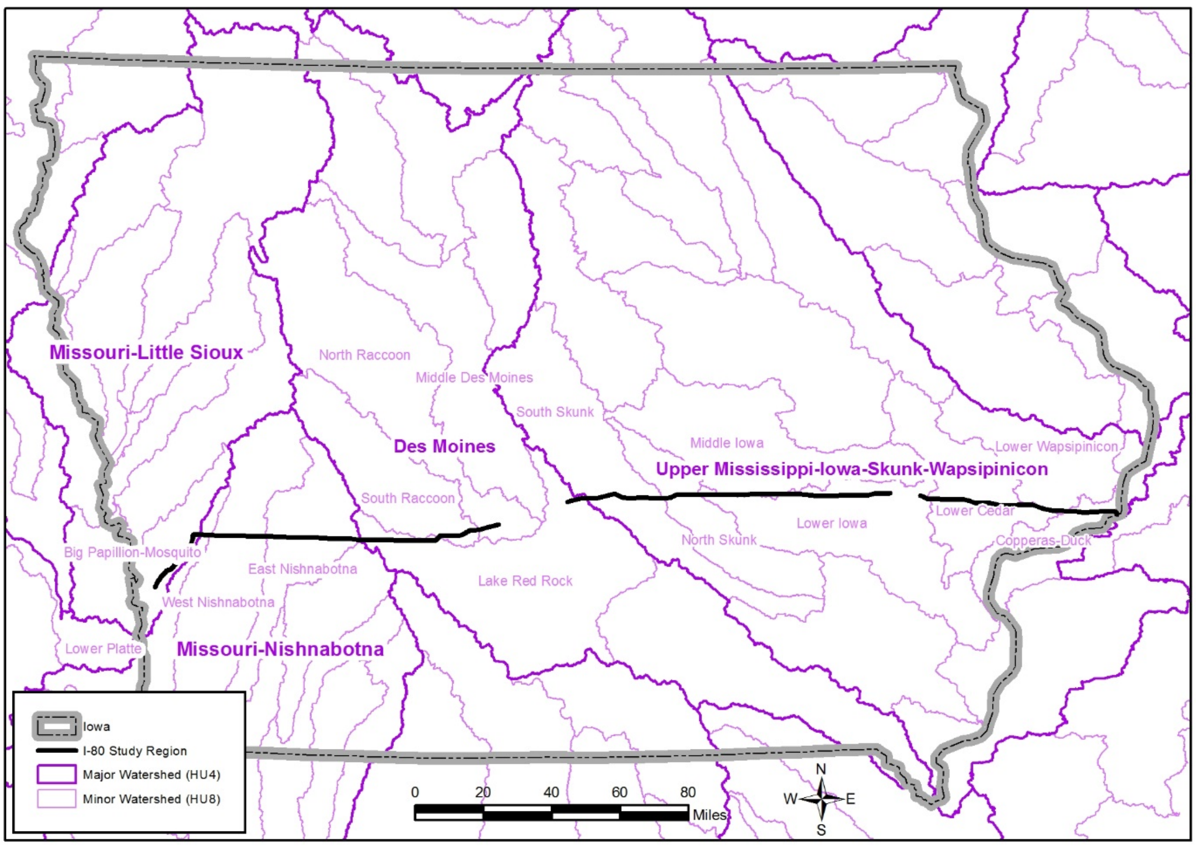
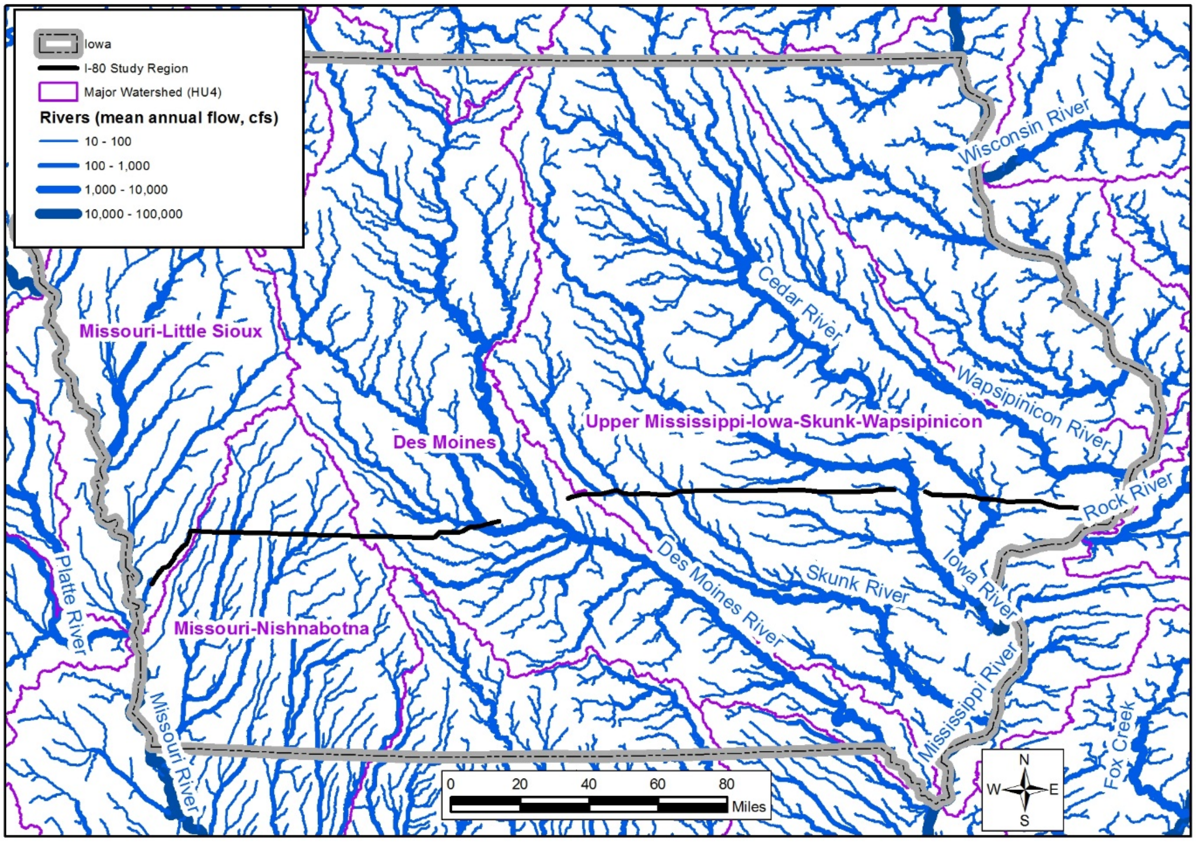


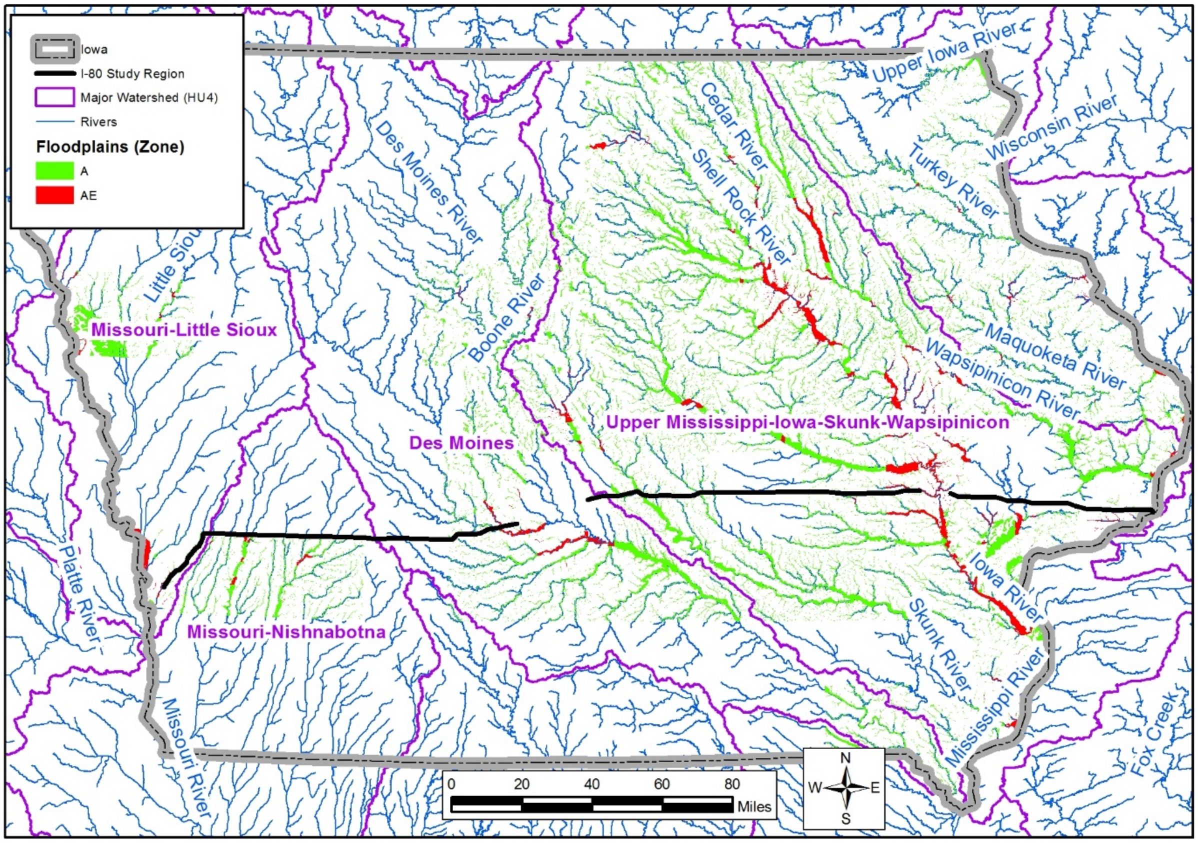
Figure 3. RIVERS AND CREEKS CROSSING THE I-80 CORRIDOR, CATEGORIZED BY MEAN ANNUAL FLOW (FROM NHDPLUS)



2.3 FLOODPLAINS

Of the 22 large creeks and rivers with NHDPlus approximated mean annual flow above 10 cfs, 18 have Federal Emergency Management Agency (FEMA) floodplains (Figure 4 and Table 1). The remaining 4 large creeks and rivers may be in counties without floodplains mapped on the National Flood Hazard Layer (FEMA, 2013), and may have active floodplains. Most FEMA floodplains that intersect I-80 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. Two floodplains that intersect I-80 are mapped as Zone AE, which means these are areas inundated by the 1 percent annual chance of flood (100-year recurrence interval) and have documented base flood elevations. Approximately 31,000 linear feet of I-80 crosses mapped floodplains, with an additional 30,000 feet immediately adjacent to floodplain along Mosquito Creek from MP 10 to 27.

Figure 4. FEMA FLOODPLAINS CROSSING THE I-80 CORRIDOR, CATEGORIZED BY ZONE



3. EXISTING DATA COLLECTION SUMMARY

Existing data, studies, and reports were used to understand historical and projected future climate, hydrology and weather patterns. These studies 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 the I-80 corridor. Temperature increases are more apparent during certain seasons and certain times of day – winter temperatures are increasing more than annual averages (+0.18 degrees Fahrenheit [°F]/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). Extreme precipitation events have also trended upward during the observed record. Historical flooding has occurred most frequently in the late spring and summer, 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 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. 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 26 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 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 compares 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 two eastern Iowan basins, general trends and conclusions from this study are most likely to be found 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 (Figure A-22) signify that the 1 percent annual exceedance-probability discharge (AEPD) increased 37 to 67 percent for Cedar River Basin and 9 to 50 percent for South Skunk River Basin (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 of 24 and 32 percent in precipitation (and accompanying warming) can lead to drainage flow increase of 35 to 80 percent, respectively (Jha et al., 2004). However, the Skunk and Cedar River Basin model analyses show percent 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

4.1 HISTORICAL I-80 IMPACTS DUE TO WEATHER-RELATED EVENTS

The resilience of I-80 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-80 event type, frequency, and location is important for projecting future corridor resilience.

Historical I-80 closure event information is limited. A 2015 database of traffic incidents on all Iowa highways was filtered to I-80 only. This database includes traffic incidents, many of which did not result in full closures, and many that were not weather related. In general, accidents (which may be weather related) are most frequent in the more urban and heavily trafficked segments of I-80 (urban sections of I-80 are excluded from the study region in this report). Three weather-related closures were explicitly recorded in 2015:

- Winter closure at MP 1A, Pottawattamie County, near Council Bluffs, closed for about 8 hours on December 26, 2015. Greatest observed extreme snowfall (28 inches in 2 days in 1903) was also at Council Bluffs; this may be hot spot for snow closures.
- Flood closure at MP 120 in Dallas County, for about 1 hour on November 11, 2015 (specific stream or creek unknown).
- Flood closure at MP 112 in Dallas County, for about 28 hours on June 25, 2015 at North Raccoon River.

Additional limited flood closure information was provided by the Iowa DOT through communications with maintenance staff, and is summarized by river crossing location in Table 1 with flooding information from USGS. Rivers with historical I-80 flooding issues include:

- East Nishnabotna River (MP 61)
- Crooked Creek (MP 68.5)
- Middle River (MP 84.8)
- North Raccoon River (MP 112.4)
- South Skunk River (MP 152.6)

- Indian Creek (MP 157.8)
- Cedar River (MP 265.8)

Additional non-flood closure information includes: issues with wind in District 4 (southwest portion of I-80); and issues with wind, blowing snow, and icing near Grinnell (MP 182) and between Iowa City (MP 248) and West Branch (MP 254) in eastern Iowa.

4.2 POTENTIAL CHANGE IN CLIMATE RELATED IMPACTS

Climate-related impacts to the I-80 corridor are most likely to increase in occurrence due to projected changes in temperature and precipitation. These impacts are most likely to occur from extreme weather events that the I-80 infrastructure cannot withstand, such as bridge design range for flood flows, or pavement design range for freeze-thaw cycles and high temperature. It is most likely that future impacts to the I-80 infrastructure will occur where historical impacts have been observed. Available historical weather-related closure and impacts are presented in Section 4.1, but are limited and incomplete. Because historical weather-related closures and impacts information is limited, 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 are most likely to occur along the I-80 corridor. Figure 5 summarizes the geographic extent of these impacts. Larger maps showing these impacts along with more detailed study region and location information are provided in Appendix D. 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* (NRC, 2008) and the *Transportation Climate Change Sensitivity Matrix* (ICF, 2014). Appendix E shows a I-80 photo log of areas identified most at risk of possible climate related impacts.

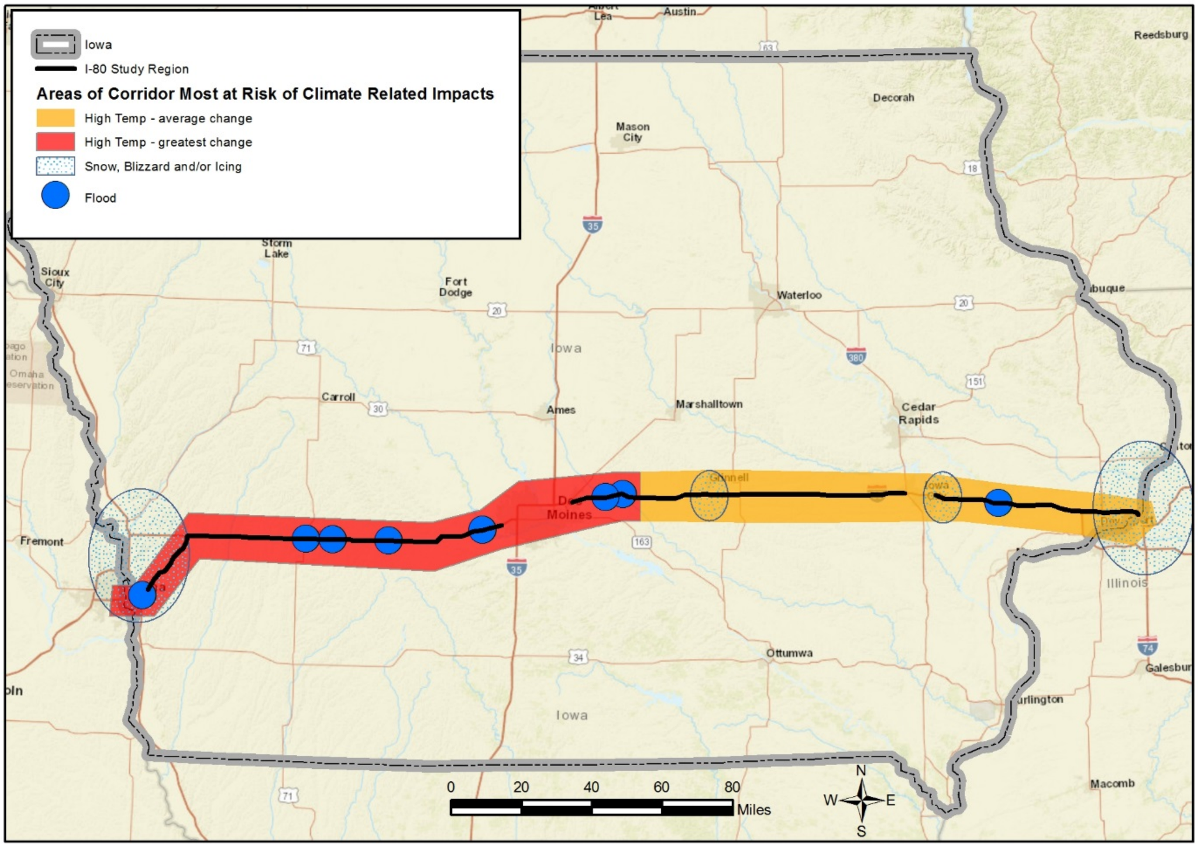


Figure 5. AREAS OF THE I-80 CORRIDOR MOST AT RISK OF CLIMATE RELATED IMPACTS.

Table 1. AREAS MOST AT RISK OF CLIMATE RELATED IMPACTS

Feature Name	I-80 Mile Post [Range]	Impact Type	Notes
	0 to 150	High Temp – greatest change	Approximate range; temperature increase is expected to be greatest on the western side of the state.
	0 to 30	Snow, Blizzard	Approximate range; heavier snow has historically been recorded on the western side of Iowa. However, historical and projected trends in this area show decreasing snow.

Table 1. AREAS MOST AT RISK OF CLIMATE RELATED IMPACTS

Feature Name	I-80 Mile Post [Range]	Impact Type	Notes
Mosquito Creek	5.4 [5.3 to 27.4]	Flooding	AE Floodplain Zone; creek crossing of I-80 outside study region, but creek and associated floodplain parallels portions of I-80 study region from approximately MP 10 to MP 27, with approximately 6 miles of that section of I-80 immediately adjacent to or within the mapped floodplain.
East Nishnabotna River	61 [61.1 to 61.2]	Flooding	History of flood elevation near bridge deck.
Crooked Creek	68.7 [68.7 to 68.8]	Flooding	History of flood closures.
Middle River	84.8	Flooding	History of flood near closure.
North Raccoon River	112.4 [112.4 to 112.5]	Flooding	AE floodplain zone; history of flood closures.
South Skunk River	152.6 [112.4 to 112.5]	Flooding	History of flooding and possible closures.
Indian Creek	157.8 [156.8 to 158.8]	Flooding	History of flooding and possible closures.
	182	Blizzard, Icing	History of wind, blowing snow and icing near Grinnell.
	248 to 254	Blizzard, Icing	History of wind, blowing snow, and icing between Iowa City and West Branch.
Cedar River	265.8	Flooding	History of flood closures.
	280 to 306	Snow, Blizzard	Approximate range; some evidence of increasing snowfall on eastern side of state.
	150 to 306	High Temp – average change	Approximate range; average temperature increase is expected on the eastern side of the state.

LOW TEMPERATURE AND FREEZE-THAW IMPACTS

An increase in freeze-thaw cycles may occur in some localized areas and isolated periods. 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 occur more 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.

Approximately 20 more frost-free days are expected by 2041-2070 than occurred during 1980-2000. Similarly, the number of days below 10°F historically have been observed between 10 to 20 days per year and are expected to decrease to 0 to 10 (2041-2070). The freeze-free season (period of time between the last spring frost and first autumn frost) may increase by 26 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-80 corridor.

HIGH TEMPERATURE IMPACTS

High temperature extremes are expected to impact transportation infrastructure nationwide. High temperature extremes primarily affect pavement longevity and maintenance. The number of days above 95°F are expected to increase from 20 to 40 days per year (1980-2000) to 40 to 70 days per year by 2041-2070. 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 entire I-80 corridor, but will potentially be most impactful in the western portion of the state where the greatest changes are expected to occur. Specific locations or portions of I-80 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-80 project. These existing sections of I-80 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 (described in the Flood Impacts section), as well as potential for increase in fog intensity and frequency. Foggy weather conditions lead to greater risks in traffic incidents.

FLOOD IMPACTS

The I-80 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 from 4 to 6 days per year (1980-2000) to 4 to 8 days per year (2041-2070). Future flooding for the Skunk River and Cedar River 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, however, precipitation changes are projected to be more severe in the eastern portion of the I-80 corridor. 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-80 and possibly other routes.

River and creek crossings that have a history of flooding are described in Table 1. Table 2 summarizes I-80 river crossings that have historical flood closure issues or are otherwise susceptible to flooding. Given the history of flooding at these locations, future flooding impacts are more likely at these locations. Recommendations for location and project specific hydrologic and hydraulic modeling are included in Section 6.

SNOW AND BLIZZARD IMPACTS

Snow and blizzards can cause closure events, generally as a safety precaution and to protect motorists. Decreases in annual snowfall along the I-80 corridor have been observed and are expected to continue. The documented highest historical snowfall along I-80 occurred at the southwestern corner near Council Bluffs. Although annual snowfall is generally expected to decrease, extreme blizzard events may still occur, and may still follow historical patterns resulting in closures of sections of I-80, particularly those areas with a history of snow related closures like I-80 near Council Bluffs.

4.3 POTENTIAL RISK MITIGATION AND CLIMATE ADAPTATION STRATEGIES

Risk mitigation and climate adaptation strategies related to climate-caused I-80 closure events are unique to specific climate impacts, and 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.
- Revise highway drainage design standard 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-80 during closure events. Develop pre-identified detour routes and provide reliable real-time information to all road users, vehicle navigation systems and aids (GPS systems, Iowa 511, 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-80 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.

5. USER COSTS DUE TO ROAD CLOSURE EVENTS

5.1 INTRODUCTION TO ROAD USER COSTS

In the event of an extreme weather occurrence, the I-80 transportation corridor may be unable to meet future travel demands with interruption of service along a section or sections of the corridor. These weather-related issues could have a significant economic impact to the state and surrounding region. To improve resiliency of the I-80 corridor and maintain acceptable levels of mobility, certain design features may be appropriate to consider as part of the individual I-80 expansion projects to mitigate locations susceptible to 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, 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-80.

Section 5.2 summarizes the evaluation of user costs for the purposes of this I-80 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-80 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 a portion of I-80 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. 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-80 and serve as the foundation for future studies as individual I-80 projects progress.

I-80 locations potentially at risk of closure due to an extreme weather event were identified through coordination with Iowa DOT maintenance and operations staff, existing literature, and other surrogate factors such as proximity to floodplains per FEMA maps and Iowa Flood Center information. The scope of the user cost evaluation was kept to roadway flooding due to the limited historic information available regarding other weather events impacting I-80 travel such as, high wind, dense fog, or snowfall.

To estimate out-of-distance travel, possible detour routes were identified for various locations of I-80 considered at risk of extreme weather-related impacts. These routes assumed a preference to maintain traffic on the National Highway System primary road network, maintain traffic on a four-lane divided facility when possible, and avoid urban corridors with frequent at-grade intersections and traffic signals. The out-of-distance travel for each detour route was calculated by comparing the length of the assumed detour route to the length of travel along I-80 over a given segment of the corridor assuming a through trip along I-80 (i.e., additional out-of-distance travel created by backtracking for a local trip destined for or originating from a section of I-80 that is closed to through traffic). This out-of-distance travel was converted to added travel time using currently posted speed limits along I-80 and the respective detour route(s).

Table 2 summarizes the results of the user cost analysis with the two calculation methods; 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 (Appendix C). From this high-level user cost estimate calculation, it is clear that economic impacts of between $500,000 and $1,000,000 per day are possible over majority of the rural I-80 corridor areas. These impacts will likely only increase in dollar value 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.

Table 2. CALCULATED USER COSTS FOR EACH LOCATION

ID	Location	County	Assumed Detour Route	Distance Along I-80 (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-80 Closure: Iowa DOT ABC Evaluation Method	Estimated Daily Economic Impact of I-80 Closure: Hourly Rate with Census and Labor Statistics Method
1	Keg Creek	Pottawattamie	South on I-29; East on US 34; North on US 59	37.0	70.8	33.8	0.7	22,400	7,900	$484,185	$367,298
2	Silver Creek	Pottawattamie	South on I-29; East on US 34; North on US 59	37.0	70.8	33.8	0.7	21,800	7,800	$474,045	$357,108
3	West Nishnabotna River	Pottawattamie	South on I-29; East on US 34; North on US 59	37.0	70.8	33.8	0.7	21,800	7,800	$474,045	$357,108
4	East Branch West Nishnabotna River	Pottawattamie	South on US 59; East on US 34; North on US 71	20.3	95.3	75.0	1.4	20,200	7,600	$995,625	$694,619
5	Indian Creek	Cass	South on US 59; East on US 34; North on US 71	20.3	95.3	75.0	1.4	20,200	7,700	$1,001,250	$693,954
6	Buck Creek	Cass	South on US 59; East on US 34; North on US 71	20.3	95.3	75.0	1.4	19,700	7,600	$981,563	$676,174
7	East Nishnabotna River	Cass	North on US 71; East on US 30; South on US 169	49.4	123	73.6	1.5	19,700	7,600	$963,240	$717,381
8	Troublesome Creek	Cass	North on US 71; East on US 30; South on US 169	49.4	123	73.6	1.5	19,700	7,600	$963,240	$717,381
9	Crooked Creek	Cass	North on US 71; East on US 30; South on US 169	49.4	123	73.6	1.5	19700	7600	$963,240	$717,381
10	Middle River	Adair	North on US 71; East on US 30; South on US 169	49.4	123	73.6	1.5	20,900	7,800	$1,007,400	$762,935
11	South Raccoon River	Dallas	South on US 169; East on IA 92; North on I-35	12.9	42.6	29.7	0.5	26,800	8,300	$483,368	$341,056
12	North Raccoon River	Dallas	South on US 169; East on IA 92; North on I-35	12.9	42.6	29.7	0.5	26,800	8,300	$483,368	$341,056
13	South Skunk River	Jasper	South on US 65; East on IA 163; North on IA 14	23.5	40.9	17.4	0.4	34,700	9,000	$343,868	$304,903
14	Indian Creek	Jasper	South on US 65; East on IA 163; North on IA 14	23.5	40.9	17.4	0.4	33,100	8,900	$332,123	$290,321
15	Prairie Creek	Jasper	South on US 65; East on IA 163; North on IA 14	23.5	40.9	17.4	0.4	31,400	8,900	$321,030	$274,651
16	Cherry Creek	Jasper	South on US 65; East on IA 163; North on IA 14	23.5	40.9	17.4	0.4	31,400	8,900	$321,030	$274,651

Table 2. CALCULATED USER COSTS FOR EACH LOCATION

ID	Location	County	Assumed Detour Route	Distance Along I-80 (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-80 Closure: Iowa DOT ABC Evaluation Method	Estimated Daily Economic Impact of I-80 Closure: Hourly Rate with Census and Labor Statistics Method
17	North Skunk River	Jasper	North on IA 14; East on US 30; South on US 63	27.3	69.2	41.9	0.8	27,400	8,700	$703,920	$559,567
18	Rock Creek	Jasper	North on IA 14; East on US 30; South on US 63	27.3	69.2	41.9	0.8	27,400	8,700	$703,920	$559,567
29	Sugar Creek	Jasper	North on IA 14; East on US 30; South on US 63	27.3	69.2	41.9	0.8	27,800	8,700	$710,205	$568,232
20	West of US Hwy 151	Iowa	North on US 63; East of US 30; South on I-380	48	87.8	39.8	0.7	31,200	9,300	$743,265	$536,669
21	East of US Hwy 151	Iowa	North on US 63; East of US 30; South on I-381	48	87.8	39.8	0.7	30,600	9,500	$740,280	$525,107
22	218 interchange	Johnson	North on US 151; East on Us 30; South on IA 1	22	59.8	37.8	0.7	34,800	9,500	$762,615	$614,908
23	Cedar River	Cedar	North on I-380; East on US 30; South on US 61	56.3	91.2	34.9	0.7	33,700	11,500	$742,061	$577,465
24	Sugar Creek	Cedar	North on I-380; East on US 30; South on US 61	56.3	91.2	34.9	0.7	32,400	11,400	$722,430	$554,058
25	Northwest blvd Interchange	Scott	South and East on I-280; North on I-74	8.6	28.3	19.7	0.3	36,000	12,000	$443,250	$243,484
26	Northwest blvd Interchange	Scott	South and East on I-280; North on I-74	8.6	28.3	19.7	0.3	36,000	12,000	$443,250	$243,484
27	Spencer Creek	Scott	South on I-74; West on I-280	19.8	19.8	0	0.0	30,900	9,100	$0	$0
28	Wells Fr. Road	Scott	South on I-74; West on I-280	19.8	19.8	0	0.0	30,900	9,100	$0	$0

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

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

6. RECOMMENDATIONS

Because of the minimal availability of documented weather-related I-80 events, the evaluation of projected climate impacts along the I-80 corridor is guided by historical closure events, existing literature, and surrogate factors that may indicate future risk. Based on the available information, the following recommendations are suggested for future I-80 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-80 traffic. 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. 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. For stream crossings with long asset design life, use most recent discharge data for hydraulics analysis and consider projected increases in discharge within the asset design life. One of the largest projected impacts on I-80 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 was 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.

4. For vulnerable locations, perform risk analysis during future planning studies and design development. This risk analysis should incorporate location specific features, possible detours, strategies to improve the resiliency of I-80 to minimize the likelihood of disruption of traffic due to a weather event, and the economic benefit cost of implementing a mitigation strategy.

7. REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). 2010. *Highway Safety Manual.*

Anderson, C.J. 2013. *Extreme Weather and Climate Change in Iowa: Now and Future Trends.* December.

California Department of Transportation. 2016. Life-Cycle Benefit-Cost Analysis Economic Parameters 2016. http://dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html. Accessed May 7, 2017.

CH2M HILL, Inc. (CH2M) and Iowa Department of Transportation (IDOT). 2017. *I-80 History*.

Council on Environmental Quality (CEQ). 2016. CEQ Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews. August.

Eash, D. A. 2014. Summary of USGS Reports Documenting Flood Profiles of Streams in Iowa, 1963-2012.

Executive Order 137873. 2017. Promoting Energy Independence and Economic Growth. From the Trump Administration.

Federal Emergency Management Agency (FEMA). 2013. National Flood Hazard Layer. July.

Federal Highway Administration (FHWA). 2005. *Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries.* Publication Number FHWA-HRT-05-051. October.

Francis, J., and S. Vavrus. 2012. Evidence linking Arctic amplification to extreme weather in mid-latitudes. *Geophysical Research Letters*. doi: 10.1029/2012GL051000. March.

Hans, Z., N. Hawkins, K. Gkritza, M. Shaheed, and I. Nlenanya. 2014. *Safety and Mobility Impacts of Winter Weather – Phase 3.*

Horizon Systems. 2017. NHDPlus. http://www.horizon-systems.com/nhdplus/. Accessed May 7, 2017.

ICF International for U.S. Department of Transportation (ICF). 2014. *Transportation Climate Change Sensitivity Matrix*. June.

Intergovernmental Panel on Climate Change (IPCC). 2000. *IPCC Special Report Emissions Scenarios*. https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf. Accessed May 7, 2017.

Iowa Climate Change Impacts Committee. 2010. *Climate Change Impacts on Iowa 2010: Report to the Governor and the Iowa General Assembly*. January.

Iowa Department of Transportation (DOT). 2014. *Truck Traffic.* https://iowadot.gov/maps/msp/pdf/TruckTrafficMap.pdf.

Iowa Department of Transportation (DOT). 2015. *Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot*. March.

Iowa Department of Transportation (DOT). 2016. *2015 Iowa Traffic Incidents*.

Iowa Department of Transportation (DOT). 2017a. *Office of Bridges and Structures LRFD Design Manual*. https://iowadot.gov/bridge/design-policies/bridge-design-manual. Accessed May 7, 2017.

Iowa Department of Transportation (DOT). 2017b. *Maps Cartography and Traffic Data.* https://www.iowadot.gov/maps/digital%20maps/traffic%20maps/county.

Iowa Flood Center. 2017. http://iowafloodcenter.org/. Accessed May 7, 2017.

Jha, M., Z. Pan, E. S. Takle, R. Gu. 2004. *Impacts of climate change on streamflow in the Upper Mississippi River Basin: A regional climate model perspective*. May.

Liang Ning and Raymond S. Bradley. 2015. *Snow Occurrence Changes over the Central and Eastern U.S. Under Future Warming Scenarios*.

Mann, M., S. Rahmstorf, K. Kornhuber, B. Steinman, S. Miller, D. Coumou. 2017. "Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events". *Scientific Reports 7*. Article No. 45242. doi:10.1038/srep45242. March.

Maze, T., Michael Crum., and Garrett Burchett. 2005. *An Investigation of User Costs and Benefits of Winter Road Closures*. June. http://lib.dr.iastate.edu/intrans_reports/21/. Accessed May 7, 2017.

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. August. http://link.springer.com/article/10.1007%2Fs10584-011-0156-z. Accessed May 2016.

Minnesota Department of Transportation (MnDOT). 2016. *Benefit-Cost Analysis for Transportation Projects*. http://www.dot.state.mn.us/planning/program/appendix_a.html. Accessed May 7, 2017.

National Oceanic and Atmospheric Administration (NOAA). 2013. *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*. January.

National Oceanic and Atmospheric Administration (NOAA). 2016. *Comparative Climatic Data for the United States Through 2015.*

National Oceanic and Atmospheric Administration (NOAA). 2017a. *National Weather Service (NWS) Home Page*. https://www.weather.gov/. Accessed May 7, 2014.

National Oceanic and Atmospheric Administration (NOAA). 2017b. *Snowfall Extremes – Iowa.* https://www.ncdc.noaa.gov/snow-and-ice/snowfall-extremes/IA. Accessed May 7, 2014.

National Research Council of the National Academies (NRC). 2008*. Potential Impacts of Climate Change on U.S. Transportation.* The National Academies Press. 978-0-309-11905-4.

New York Department of Transportation (DOT). 2012. *Value of Time for Work Zone Delay Cost Calculations Using 2012 Income Data.* https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm/hdm repository/Recommended%20Value%20of%20Time.pdf. Accessed May 7, 2017.

Ohio Department of Transportation. 2017. *Work Zone User Cost Calculations.* http://www.dot.state.oh.us/Divisions/ConstructionMgt/Admin/Innovative Contracting/RoadUserCostsRevised041515.xls. Accessed May 7, 2017.

Pryor, S.C., R.J. Barthelmie, D.T. Young, E.S. Takle, R.W. Arritt. 2009. *Wind speed trends over the contiguous US*. July.

Takle, E. S. 2011. *Assessment of Potential Impacts of Climate Changes on Iowa Using Current Trends and Future Projections.* October.

Takle, E.S., Professor in Agriculture and Life Science at Iowa State University. 2017. Personal communication (email correspondence) with Kensey Daly, CH2M. April 21.

Texas Department of Transportation. 2017. *Road User Costs.* http://www.txdot.gov/inside-txdot/division/construction/road-user-costs.html. Accessed May 7, 2017.

U.S. Environmental Protection Agency (EPA). 2014. *Greenhouse Gas Emissions from a Typical Passenger Vehicle.* May.

U.S. Geological Survey (USGS). 2016. The Global Climate Change Viewer (GCCV). https://www.usgs.gov/software/global-climate-change-viewer-gccv. Accessed May 7, 2017.

United States Census Bureau. 2017. Iowa Quick Facts. https://www.census.gov/quickfacts/table/PST045216/19. Accessed May 7, 2017.

United States Department of Labor, Bureau of Labor Statistics. 2017. May 2016 *National Occupational Employment and Wage Estimates.* https://www.bls.gov/oes/current/oes_nat.htm#53 0000. Accessed May 7, 2017.

Appendix A

EXISTING DATA COLLECTION SUMMARY

EXISTING DATA COLLECTION SUMMARY

Appendix A summarizes the data collection effort conducted to support the I-80 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 Iowa I-80 corridor. 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 the 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-80 corridor. A full list of documents and data reviewed are included in Appendix B.

SOURCES

Within the study region, existing climate, climate impacts, variability, resiliency and adaptation has been documented by the Iowa DOT, National Oceanic and Atmospheric Administration (NOAA), Iowa State University, U.S. Federal Highway Administration, Iowa Climate Change Advisory Council (ICCAC), 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-80 corridor. Because of the statewide nature of I-80, local studies that pertain to only a portion of Iowa or the study region were generally avoided or, if used, were only used to provide an example of detailed location information that may be available. These local resources may prove beneficial for review when the I-80 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's National Climatic Data Center, and the Iowa Environmental Mesonet. 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-80. 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).

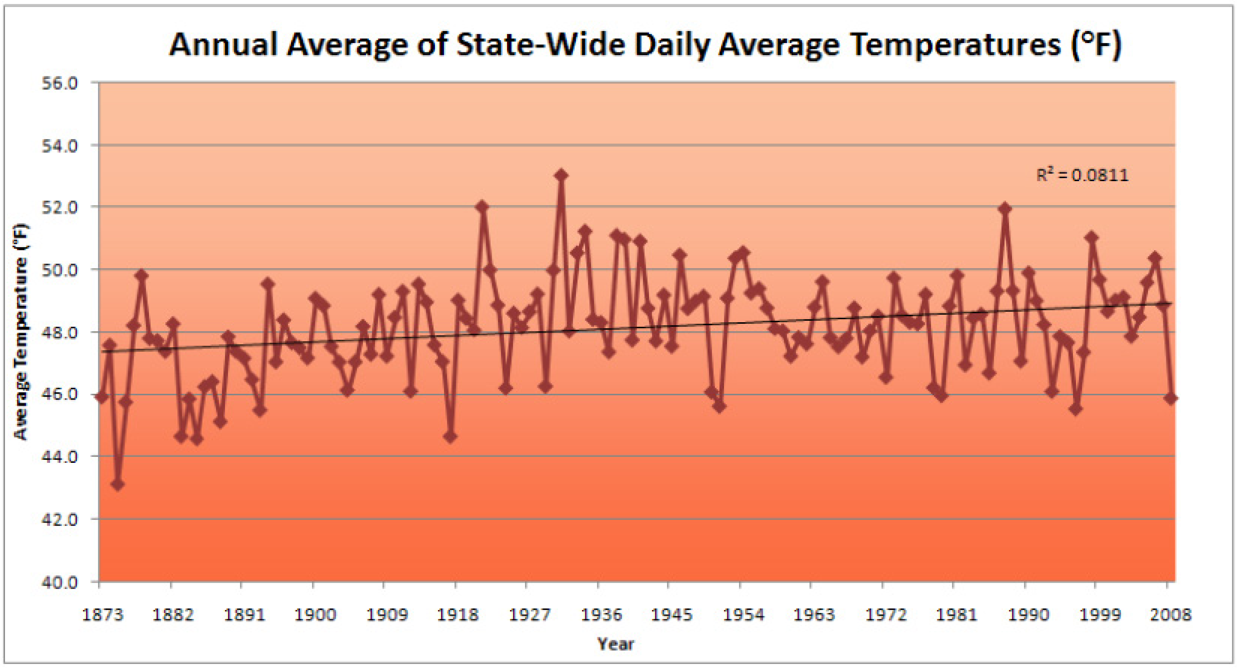
OBSERVED CLIMATE, HYDROLOGY, AND WEATHER TRENDS

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 Iowa I-80 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 are included in this memorandum as they are important in understanding trends in extreme weather events.

Figure A-1. ANNUAL AVERAGE STATEWIDE DAILY AVERAGE TEMPERATURES (°F) FROM 1873-2008



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/decade in the winter and +0.03°F/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).

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 normals to provide the range of temperature extreme months. The I-80 corridor study region has been overlaid on the figures to provide context.

Figures A-2 to A-8 indicate an annual high temperature normal ranging from 57°F to 63°F along the corridor region. The annual average ranges from 48°F to 52°F, and the annual low ranges from 37°F to 42°F. Winter high and low temperature normals range from 31°F to 35°F and 10°F to 18°F, respectively. Summer high and low temperature normals range from 81°F to 85°F and 61°F to 64°F, respectively.

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

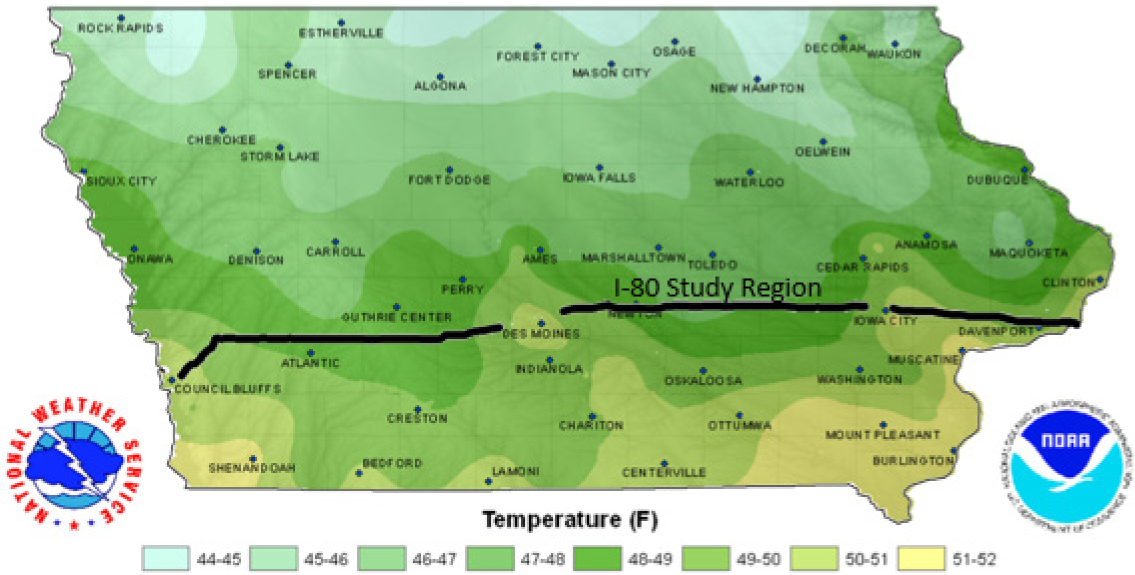


Figure A-3. IOWA ANNUAL HIGH TEMPERATURE NORMAL (1981-2010) PROVIDED BY NOAA NWS

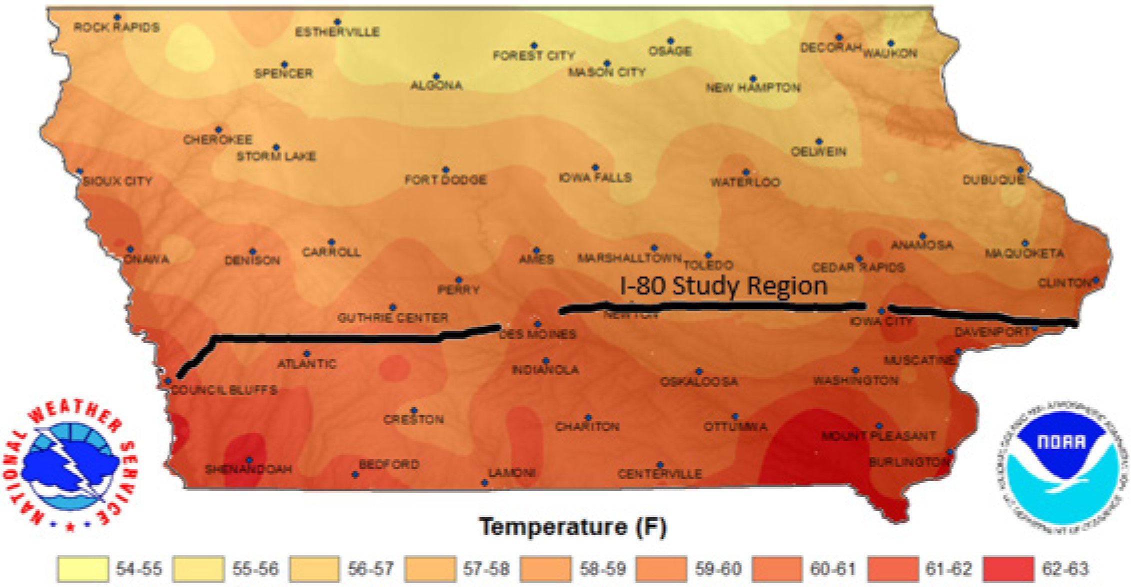


Figure A-4. IOWA ANNUAL LOW TEMPERATURE NORMAL (1981-2010) PROVIDED BY NOAA NWS

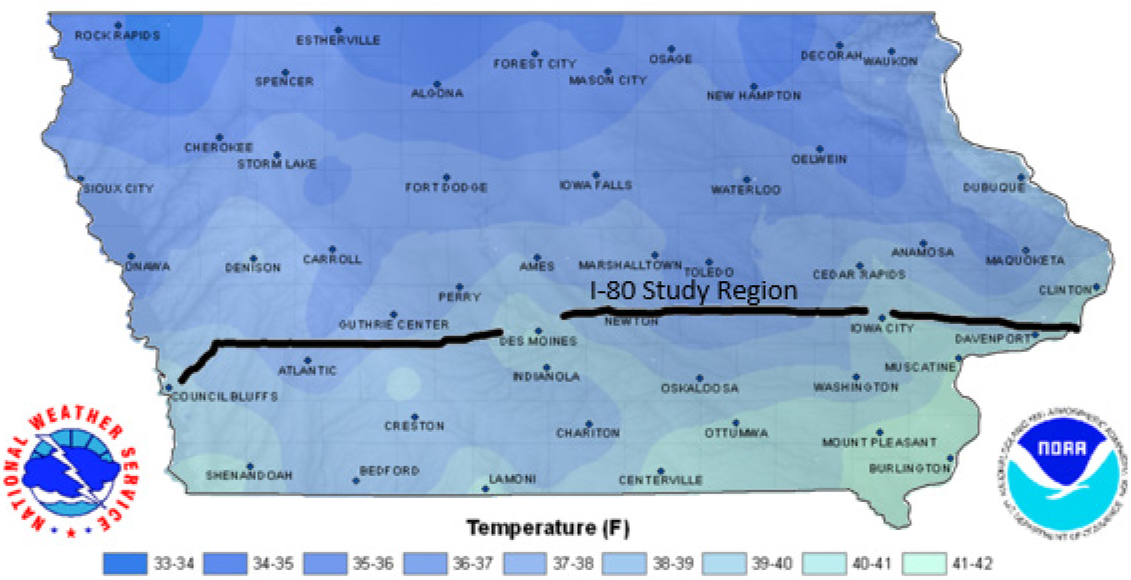


Figure A-5. IOWA WINTER HIGH TEMPERATURE NORMAL (1981-2010) PROVIDED BY NOAA NWS

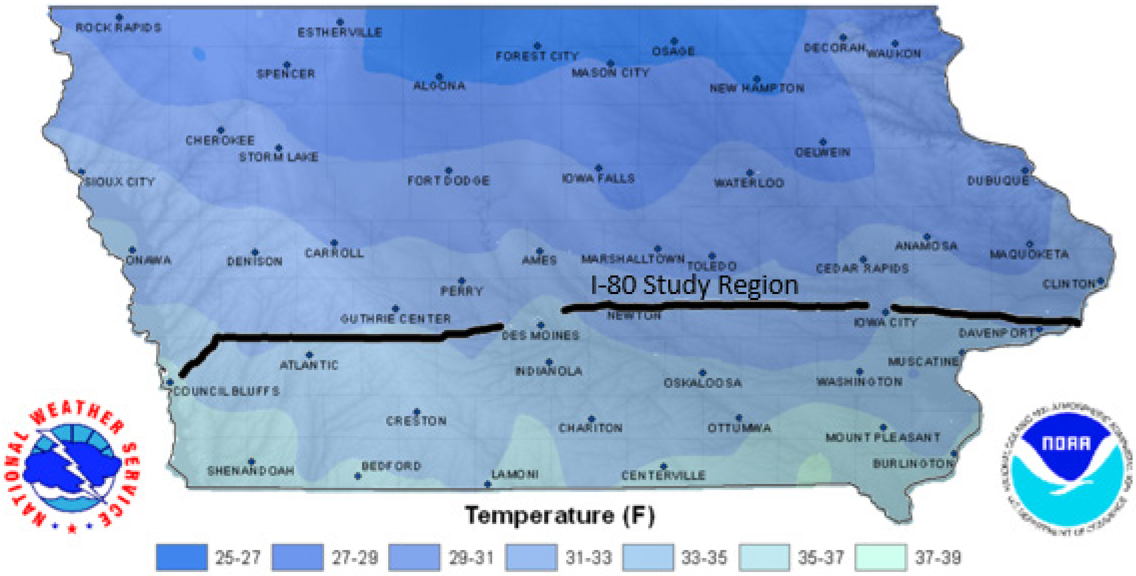


Figure A-6. IOWA WINTER LOW TEMPERATURE NORMAL (1981-2010) PROVIDED BY NOAA NWS

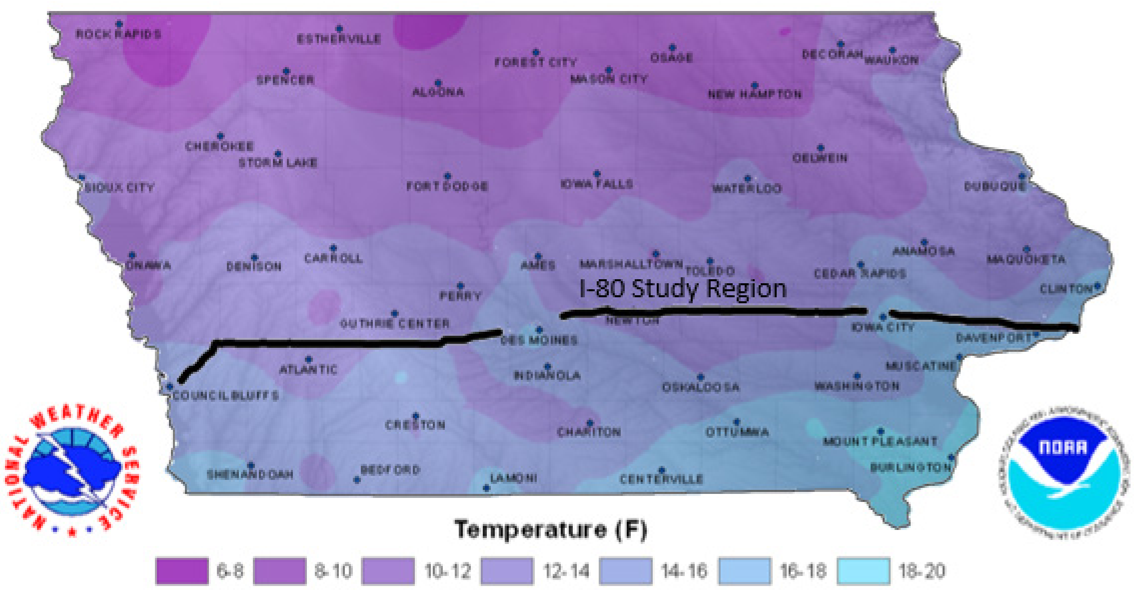


Figure A-7. IOWA SUMMER HIGH TEMPERATURE NORMAL (1981-2010) PROVIDED BY NOAA NWS

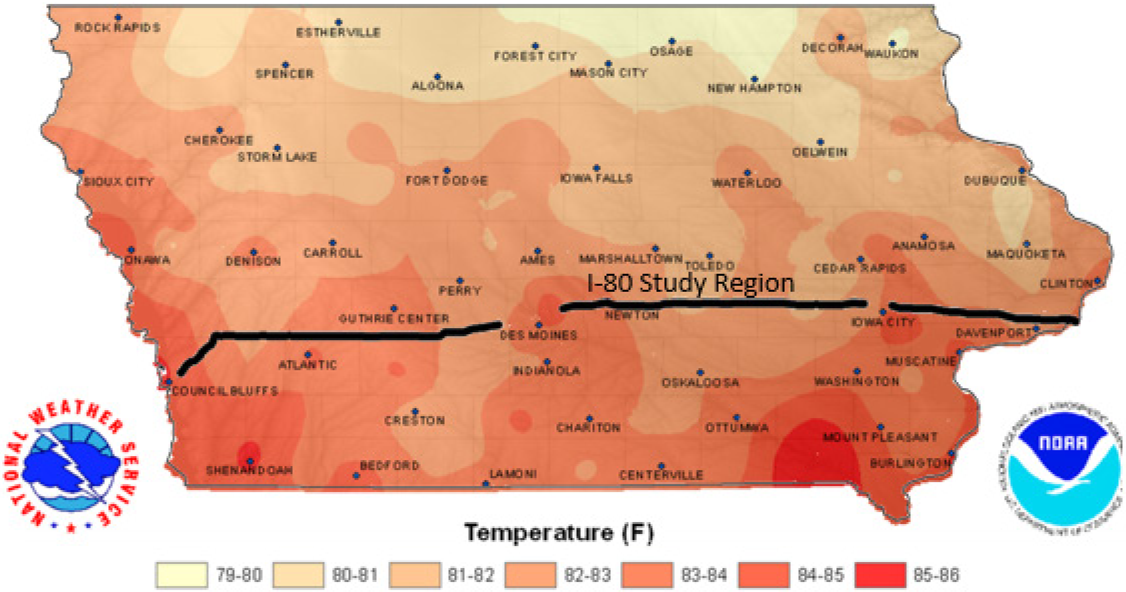
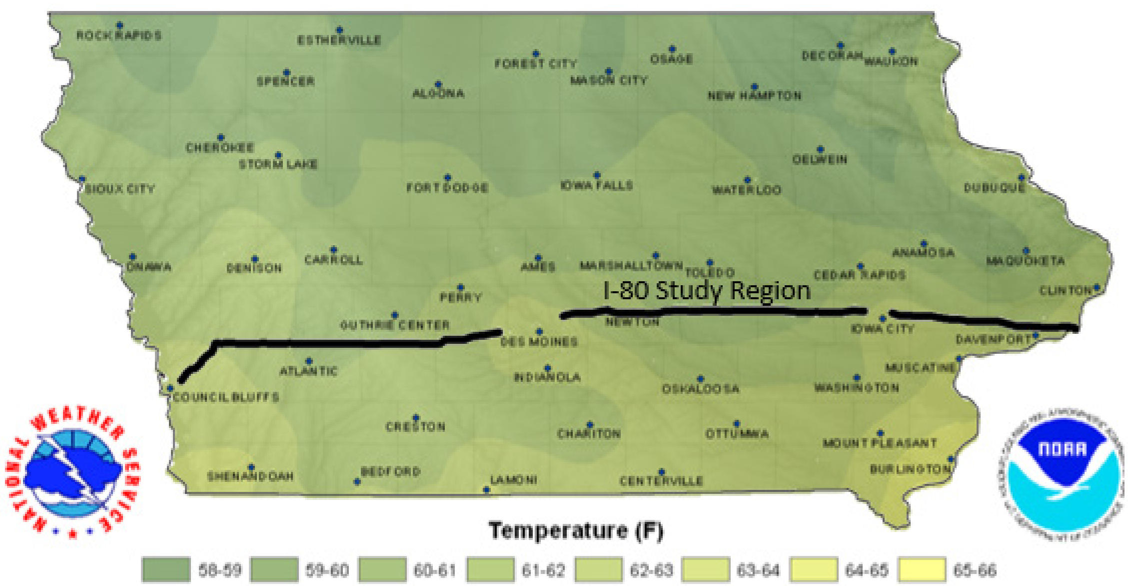


Figure A-8. IOWA SUMMER LOW TEMPERATURE NORMAL (1981-2010) PROVIDED BY NOAA NWS

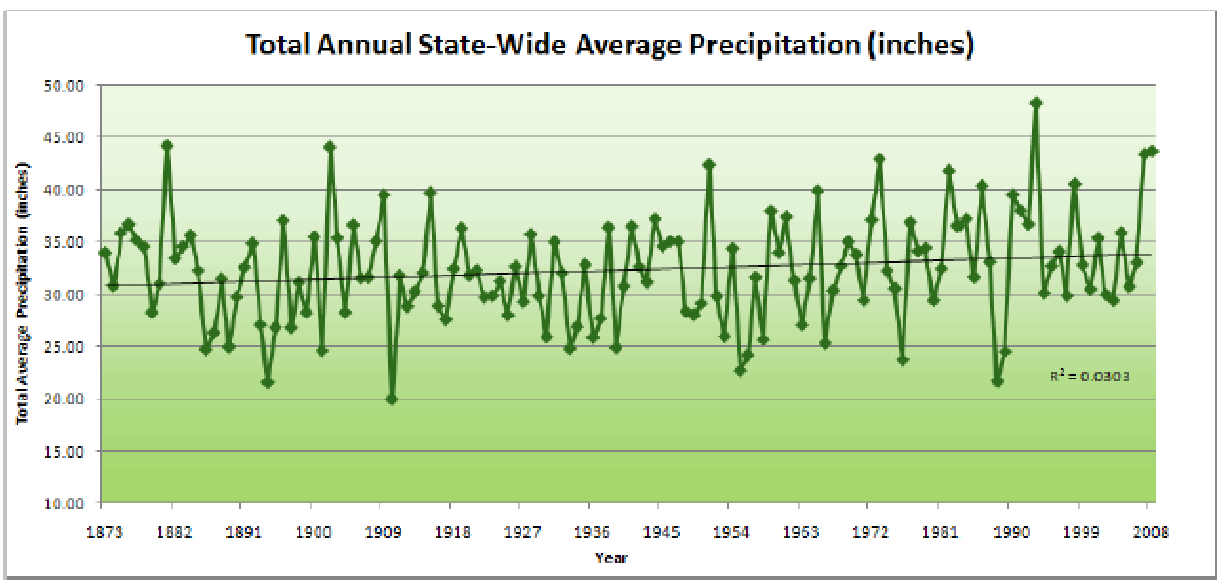


PRECIPITATION

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.

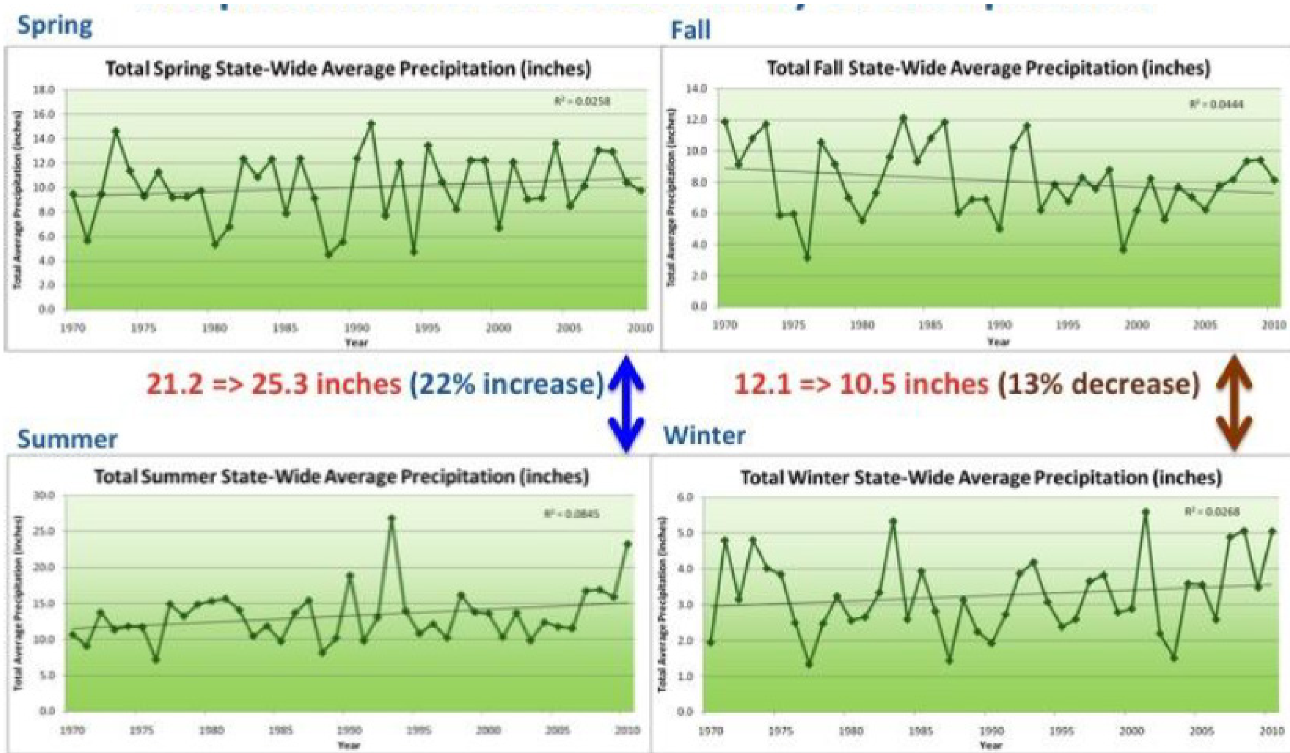
Increasing trends in historical precipitation are evident through increased intensity and frequency of rainfall events. The number of days with relatively high rainfall intensity (days with more than 1.25 inches) has also been found to increase for many regions throughout the state. This threshold relates 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.

Figure A-9. IOWA ANNUAL STATEWIDE PRECIPITATION IN INCHES FROM 1873-2008.



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

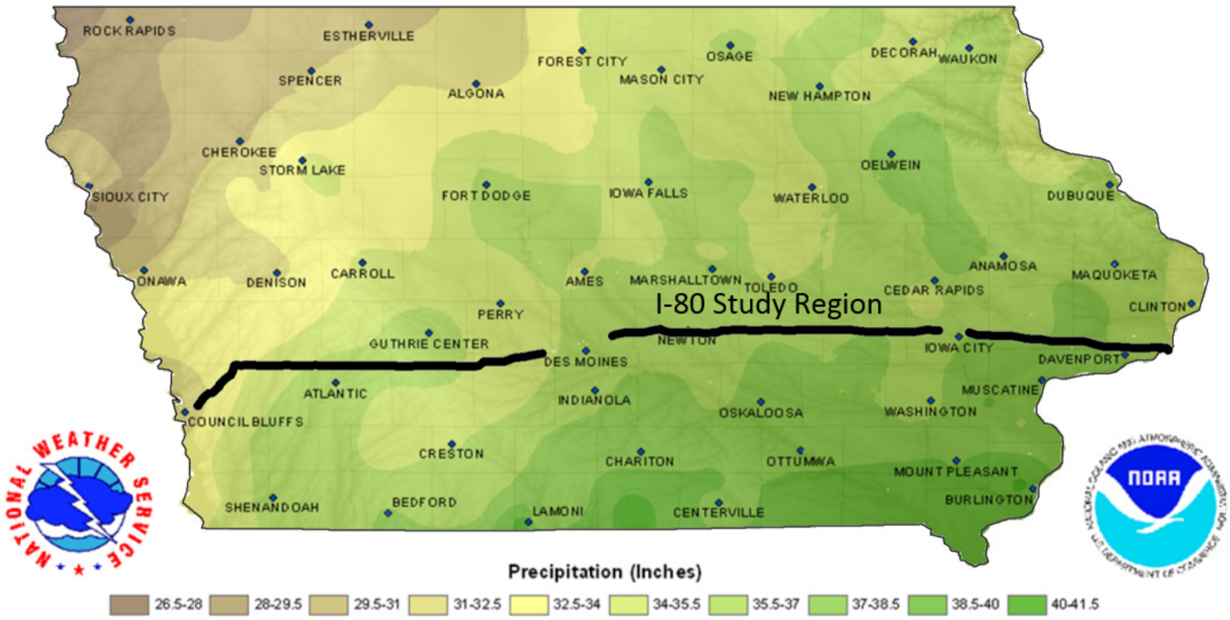
Figure A-10. IOWA STATEWIDE PRECIPITATION SHOWING A SHIFT IN SEASONALITY TOWARD MORE RAIN IN SPRING AND SUMMER (MARCH-AUGUST) AND LESS IN FALL AND WINTER (SEPTEMBER-FEBRUARY).



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 ranges from 30 to 38 inches per year along the I-80 corridor. An increasing trend from northwest to southeast is also demonstrated in Figure A-11.

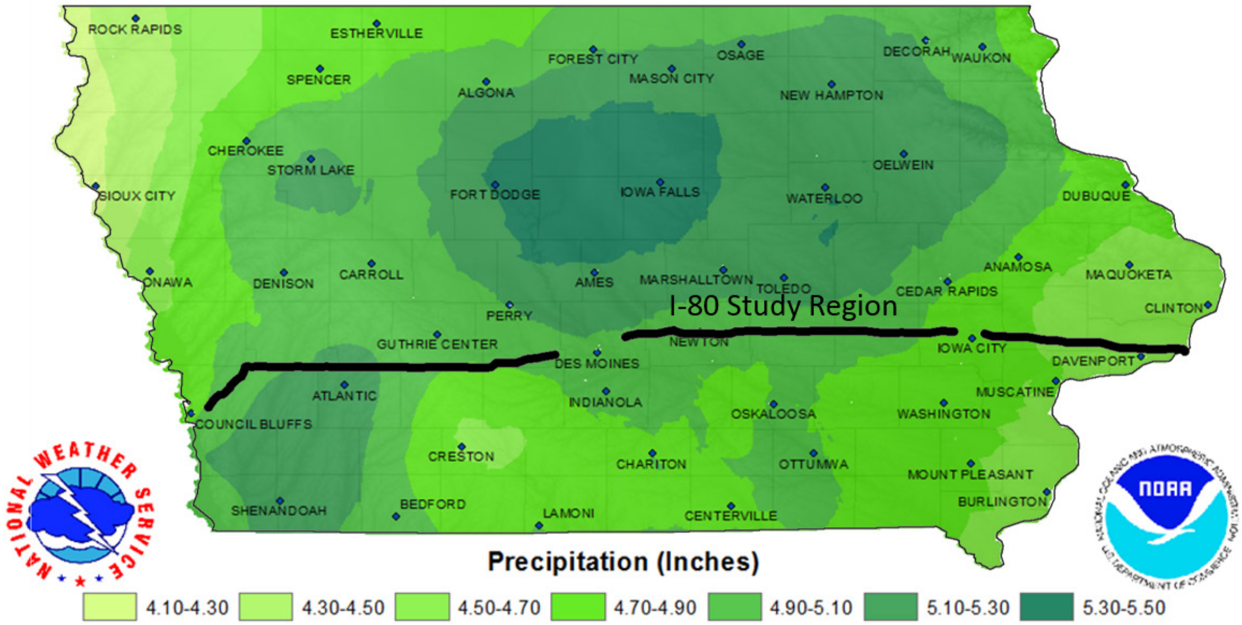
Figure A-11. IOWA ANNUAL AVERAGE PRECIPITATION NORMAL (1981-2010)



Source: Graphic is from the NOAA NWS (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-80 corridor. June is also the month in which flooding in Iowa has occurred most often. Figure A-12 indicates June precipitation normals ranging from 4.5 to 5.3 inches.

Figure A-12. IOWA JUNE PRECIPITATION NORMALS (1981-2010)



Source: Graphic is from the NOAA NWS (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-80 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-80 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. A summary of rivers and larger creeks crossing the I-80 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. The collection of USGS profile reports (Eash, 2014) analyzes flood events impacting I-80 on the following rivers:

- East Nishnabotna River (July 1998, September 1972)
- North Raccoon River (July 1993, March 1979)
- South Skunk River (August 2010, July 1993, May 1 944, and June 1975)
- Cedar River (June 2008)

Table A-1 summarizes additional information about these flood events in relation to I-80, namely the approximate freeboard between the flood peak and I-80 bridge low chord. Even though a given event may have multiple feet of freeboard between the flood profile and a bridge low chord, bridges tend to be raised above nearby terrain, and thus flooding at lower lying sections of nearby highway may be imminent or occur.

Other rivers may have flooded during these or other events, but were not explicitly analyzed as part of the collection of reports summarized by Eash (2014). Iowa DOT reports identified two additional I-80 locations that have been closed due to flooding:

- Crooked Creek (July 1993)
- North Raccoon River (July 1993)

Other I-80 flooding closures may have occurred but were not included in available records. Figure A-13 shows the years and months of flood events profiled in the Eash (2014) report.

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

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				

	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-80. However, this table highlights the seasonal trends of much of the riverine flooding along Iowa rivers, a trend that also applies to rivers crossing I-80.

Table A-1. RIVER CROSSINGS, FLOODPLAIN CROSSINGS, AND FLOOD INFORMATION ALONG THE I-80 CORRIDOR STUDY REGION

Reach Name	Crossing Mile Post	Mean Annual Flow (cfs)[a]	Mean June Flow (cfs)[a]	Drainage Area (square miles)[a]	Floodplain – Zone[b]	Approximate Floodplain Width (feet, [MP range])[b]	Upstream Base Flood Elevation (feet, NAVD88)[b]	Flooding Notes[c,d,e, and f]
Mosquito Creek	5.4	106	170	226	AE	3300 [MP 5.3 to MP 27.4]	1000	Creek crossing of I-80 outside study region, but creek and associated floodplain parallels portions of I-80 study region from approximately MP 10 to MP 27, with approximately 6 miles of that section of I-80 immediately adjacent to or within the mapped floodplain.
Keg Creek	30	33	53	53	A	200 [30.1 to 30.2]	N/A*	N/A**
Silver Creek	35	32	49	48	A	1200 [35.1 to 35.4]	N/A*	N/A**
West Nishnabotna River	39.4	183	272	358	A	5600 [38.7 to 39.8]	N/A*	N/A**
East Branch West Nishnabotna River	41.4	114	167	205	A	2700 [41.1 to 41.7]	N/A*	N/A**
Indian Creek	50.5	75	109	122	A	400 [50.4 to 50.5]	N/A*	N/A**
Buck Creek	56.5	18	28	23	A	500 [56.5 to 56.6]	N/A*	N/A**
East Nishnabotna River	61	129	191	226	A	500 [61.1 to 61.2]	N/A*	USGS: June 1998 at or just below low chord; September 1972 at or just below low chord; RM 99.19, 1189.77 National Geodetic Vertical Datum of 1929 (NGVD29).
Troublesome Creek	65	47	70	70	A	800 [64.9 to 65.1]	N/A*	N/A**
Crooked Creek	68.7	19	29	24	A	200 [68.7 to 68.8]	N/A*	Iowa DOT: I-80 was closed in 1993 due to flooding.
Middle River	84.8	51	60	74		Not mapped as floodplain[b]		Iowa DOT: Water has been to the edge of shoulder
South Raccoon River	111.5	663	1,194	1,113	A	1300 [111.5 to 111.8]	N/A*	N/A**
North Raccoon River	112.4	1,299	2,585	2,288	AE	500 [112.4 to 112.5]	868	USGS: July 1993 – closed eastbound and westbound. At low chord of bridge. March 1979 about 6 feet below low chord. Iowa DOT: closed for 28 hours on June 25, 2015. Iowa DOT: Watch spot; may be addressing with grade raise and bridge replacement project.
Des Moines River	133	3,868	7,649	16,136		Not mapped as floodplain[b]		N/A**

Table A-1. RIVER CROSSINGS, FLOODPLAIN CROSSINGS, AND FLOOD INFORMATION ALONG THE I-80 CORRIDOR STUDY REGION

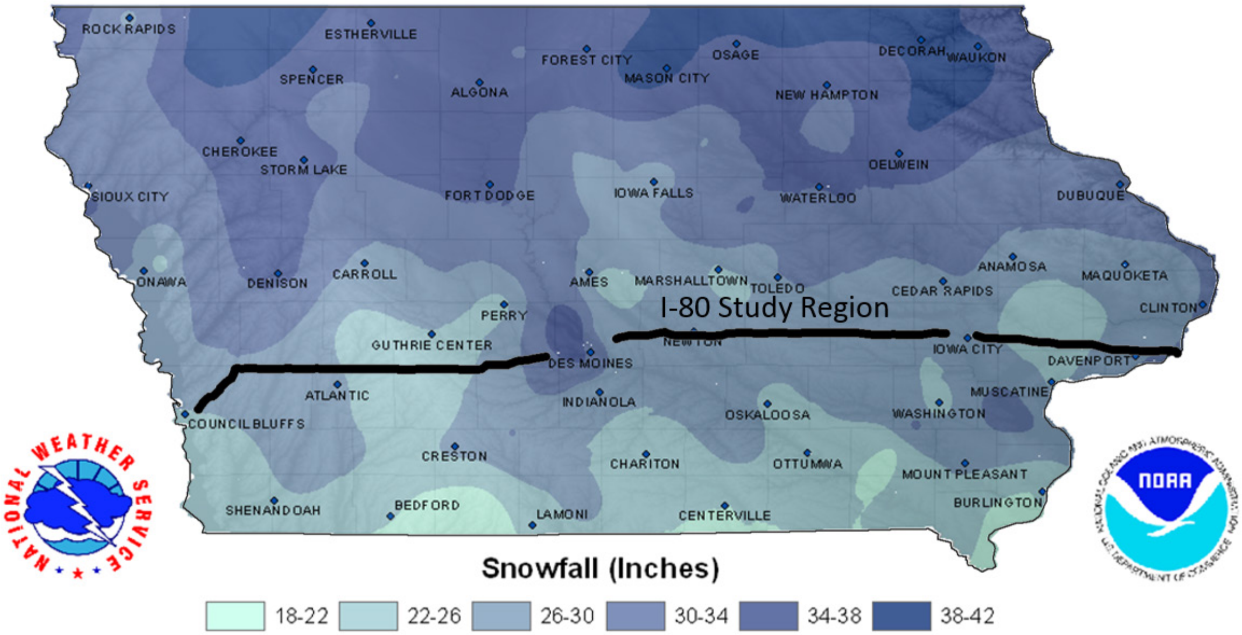
Reach Name	Crossing Mile Post	Mean Annual Flow (cfs)[a]	Mean June Flow (cfs)[a]	Drainage Area (square miles)[a]	Floodplain – Zone[b]	Approximate Floodplain Width (feet, [MP range])[b]	Upstream Base Flood Elevation (feet, NAVD88)[b]	Flooding Notes[c,d,e, and f]
South Skunk River	152.7	553	1,228	767	A	400 [152.7 to 152.8]	N/A*	USGS: August 2010 – approximately 6-feet freeboard from low chord; 9-feet freeboard to July 1993, May 1944, and June 1975 floods. Iowa DOT: Historical flooding near MP 155. Possible east bound closure of east bound entrance ramp at IA 117. May also be affected by confluence with Indian Creek. Iowa DOT: Studied as part of Iowa DOT Pilot (Iowa DOT, 2015) – projected increase in flooding. Currently estimated to overtop at >27,000 cfs, equivalent to >500-year event.
Indian Creek	157.8	322	720	411	A	11200 [156.8 to 158.8]	N/A*	Iowa DOT: Historical flooding near MP 155. Possible east bound closure of east bound entrance ramp at IA 117. May also be affected by confluence with South Skunk River.
Prairie Creek	159.5	20	21	26		Not mapped as floodplain[b]		N/A**
Cherry Creek	163	20	21	26	A	100 [163.0]	N/A*	N/A**
North Skunk River	175.5	130	157	181	A	1200 [175.5 to 175.7]	N/A*	N/A**
Rock Creek	176.5	41	44	48	A	200 [176.5]	N/A*	N/A**
Sugar Creek	179.8	27	28	28	A	200 [179.8]	N/A*	N/A**
Cedar River	265.8	5,678	9,033	7,245		Not mapped as floodplain[b]		USGS: June 2008, above low chord (-2 feet), 4 feet below deck – closed; March 1961, approximately 4 feet freeboard from low chord. RM 39.71; 658.28 ft. during June 2008 Iowa DOT: Historical flooding Iowa DOT: Studied as part of Iowa DOT Pilot (Iowa DOT, 2015) – projected increase in flooding. Currently estimated to overtop at 84,000 cfs, equivalent to 60-year event.
Sugar Creek	269.5	79	89	93		Not mapped as floodplain[b]		N/A**

Sources and Notes:
Streams and rivers crossing Iowa I-80 but not in the Study Region are not included in this table.
[a] Horizon Systems, 2017
[b] FEMA, 2013
[c] USGS, 2016
[d] Iowa DOT I-80 History (CH2M HILL, Inc. and Iowa DOT, 2017)
[e] Iowa DOT 2015 Iowa Traffic Incidents (Iowa DOT, 2016)
[f] *Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot* (Iowa DOT, 2015)
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.

SNOWFALL

Snowfall throughout Iowa generally shows a south to north increasing trend. Figure A-14 shows average annual snowfall normals ranging from 22 to 38 inches along the I-80 corridor.

Figure A-14. IOWA ANNUAL AVERAGE SNOWFALL NORMAL (1981-2010)

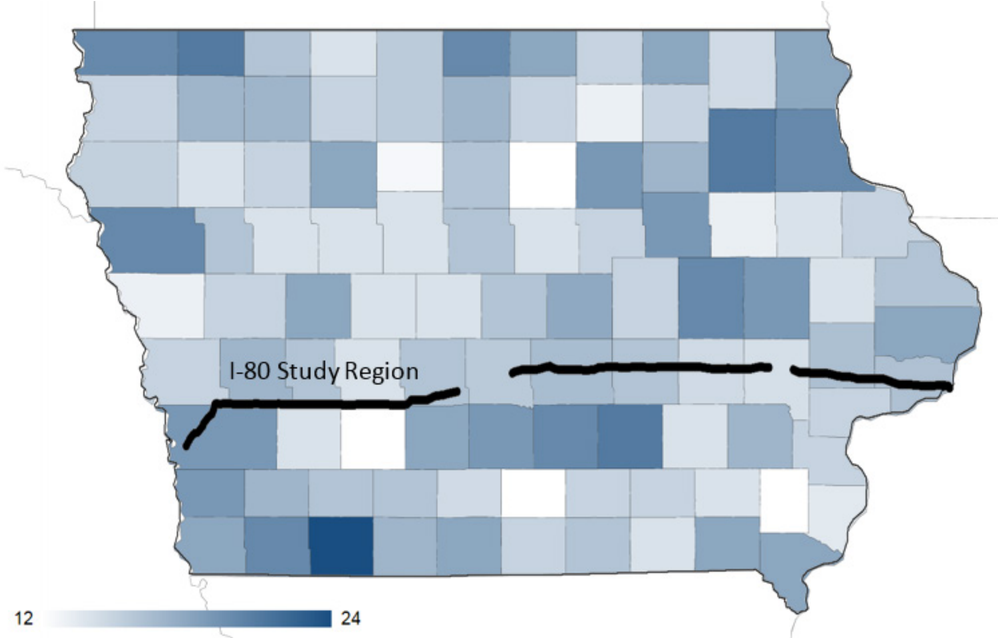


Source: Graphic is from the NOAA NWS (2017a).

As it relates to I-80 closure events, extreme snowfall is most relevant. 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-80 corridor shows typical 1-day extreme snowfall in the range of 14 to 18 inches, 2-day extreme snowfall in the range of 16 to 20 inches, and 3-day extreme snowfall in the range of 18 to 22 inches. A few extreme exceptions include:

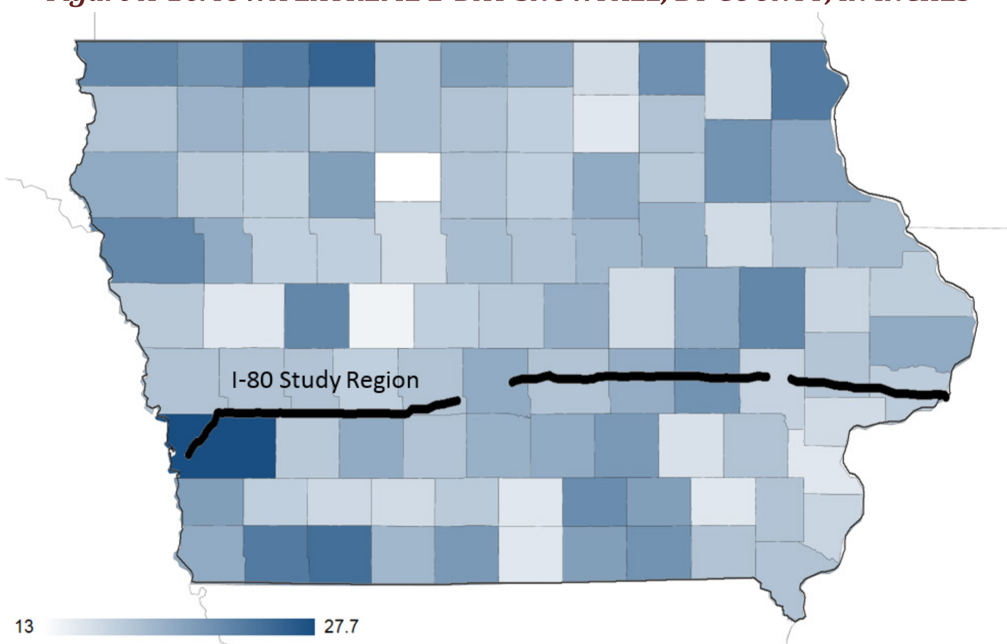
- 1-day extremes: 19 inches on February 11, 1965 at Council Bluffs in Pottawattamie County.
- 2-day extremes: 28 inches on February 4, 1903 at Council Bluffs in Pottawattamie County, and 22 inches on January 14, 1979 at Williamsburg in Iowa County.
- 3-day extremes: 28 inches on February 4, 1903 at Council Bluffs in Pottawattamie County, and 25-inches on January 14, 1979 at Williamsburg in Iowa County.

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



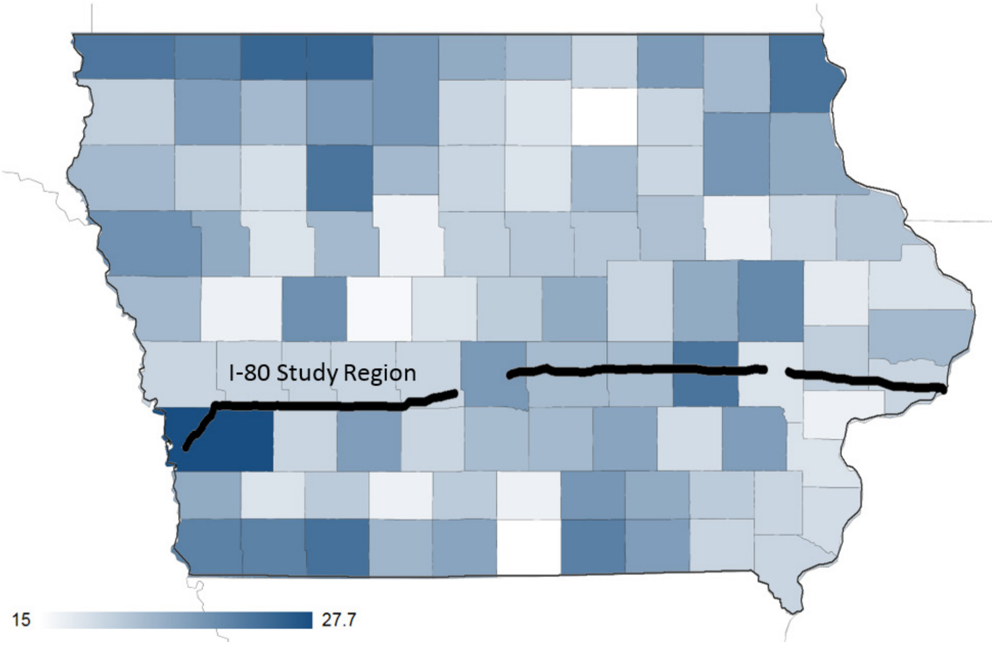
Source: Graphic is from the NOAA NWS (2017b).

Figure A-16. IOWA EXTREME 2-DAY SNOWFALL, BY COUNTY, IN INCHES



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

Figure A-17. IOWA EXTREME 3-DAY SNOWFALL, BY COUNTY, IN INCHES



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

WIND

Wind trends have been analyzed much less than the above climate components, and much less information is available throughout the I-80 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).

Past I-80 closures resulted from high wind speeds occurring during snowfall events, which resulted in blizzard conditions too dangerous for drivers to endure. Records in Des Moines and other Iowa weather stations show that extreme winds can exceed 80 miles per hour, with the highest wind speeds generally in June and July (NOAA, 2016). Other months generally have experienced extreme winds above 60 miles per hour.

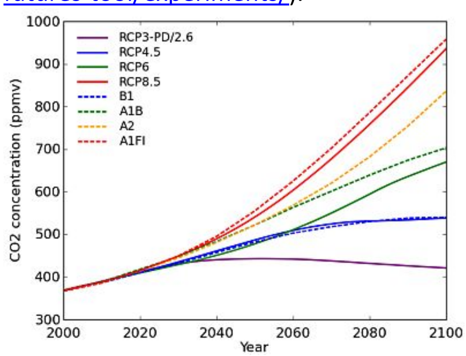
Only minimal information has been found regarding observed historical trends of extreme wind events that have impacted travel on I-80. Anderson (2013) reports that tornado and wind loss events increased about 30 to 40 percent from 2000-2004 to 2008-2012, respectively. However, these periods are too short for meaningful trend analysis. Over longer periods, Anderson (2013) reports EF2-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. Iowa DOT maintenance personnel indicated a history of some trucks being blown over in western Iowa.

FUTURE CLIMATE AND HYDROLOGY PROJECTIONS

Future climate projections described in this section refer to a report by the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) (NOAA, 2013); this information was in turn used to inform the Mid-West portion of the National Climate Assessment. Greenhouse gas emission 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 Intergovernmental Panel on Climate Change (IPCC) Special Report (2000) on Emission Scenarios[1]. 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 data sets including CMIP3, downscaled CMIP3, and the North American Regional Climate Change Assessment Program (NARCCAP). These climate models use projected atmospheric concentrations of greenhouse gasses 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).

[1] Climate models developed as part of CMIP3 use multiple pre-defined greenhouse gas emission scenarios, defined by the IPCC's Special Report on Emissions Scenarios (SRES) (IPCC, 2000). These include high (A2) and low (B1), with A2 assuming a general increase in global greenhouse gas emissions throughout the 21st Century, B1 assuming relatively constant greenhouse gas emissions through mid-century, and eventual decrease in emissions by end of century. The more recent CMIP5 climate modeling effort uses a different and new set of emissions scenarios known as Representative Concentration Pathways (RCPs) (Meinshausen et al., 2011). While there are many distinctions between SRES and RCPs, SRES A2 is generally similar to RCP 8.5, and SRES B1 is generally similar to RCB 4.5. Atmospheric CO_2 concentrations for SRES and RCP scenarios are shown in the below graph, used from Climate Change in Australia (https://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-futures-tool/experiments/).



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-80 PEL 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 2021-2050, 2041-2070, and 2070-2099. 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 1971-1999, 1971-2000, or 1980-2000.

TEMPERATURE PROJECTIONS

Temperatures are expected to continue to increase throughout the entire I-80 corridor region. NOAA/NESDIS multi-model analysis found annual average temperatures can potentially rise by about 3°F between 2021-2050, between 4°F to 5°F for 2041 to 2070, and between 5°F to 8.5°F for 2070 to 2099 with respect to 1971 to 2000. 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 of 48°F to 55°F for 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 2041 to 2070.

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, 3-4.5°F for 2055, and 4-9.5°F for 2085 for both high and low emission scenarios from CMIP3. NARCCUP projects seasonal average increases for 2055 to be 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. 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.

High temperature extremes are often categorized as number of days above 95°F. In general, the number of high temperature extremes are expected to increase throughout the I-80 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-80 corridor ranged from 20 to 40 days/year in 1980 to 2000 and are projected to increase to 40 to 70 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 are expected to decrease throughout the I-80 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-80 corridor ranged from 10-20 days/year in 1980-2000 and are projected to decrease to 0 to 10 days per year for the 2041-2070 period. Similarly, the number of days less than 32°F are expected to decrease from 70-110 days/year in 1980 to 2000 to 50 to 90 days/year in 2041 to 2070 along the I-80 corridor (NOAA, 2013).

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 26 additional days by 2041 to 2070, according to the NARCCUP projections. All models and scenarios are in agreement of this projected trend.

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 NARCCUP MULTI-MODEL MEAN HIGH EMISSIONS SCENARIO.

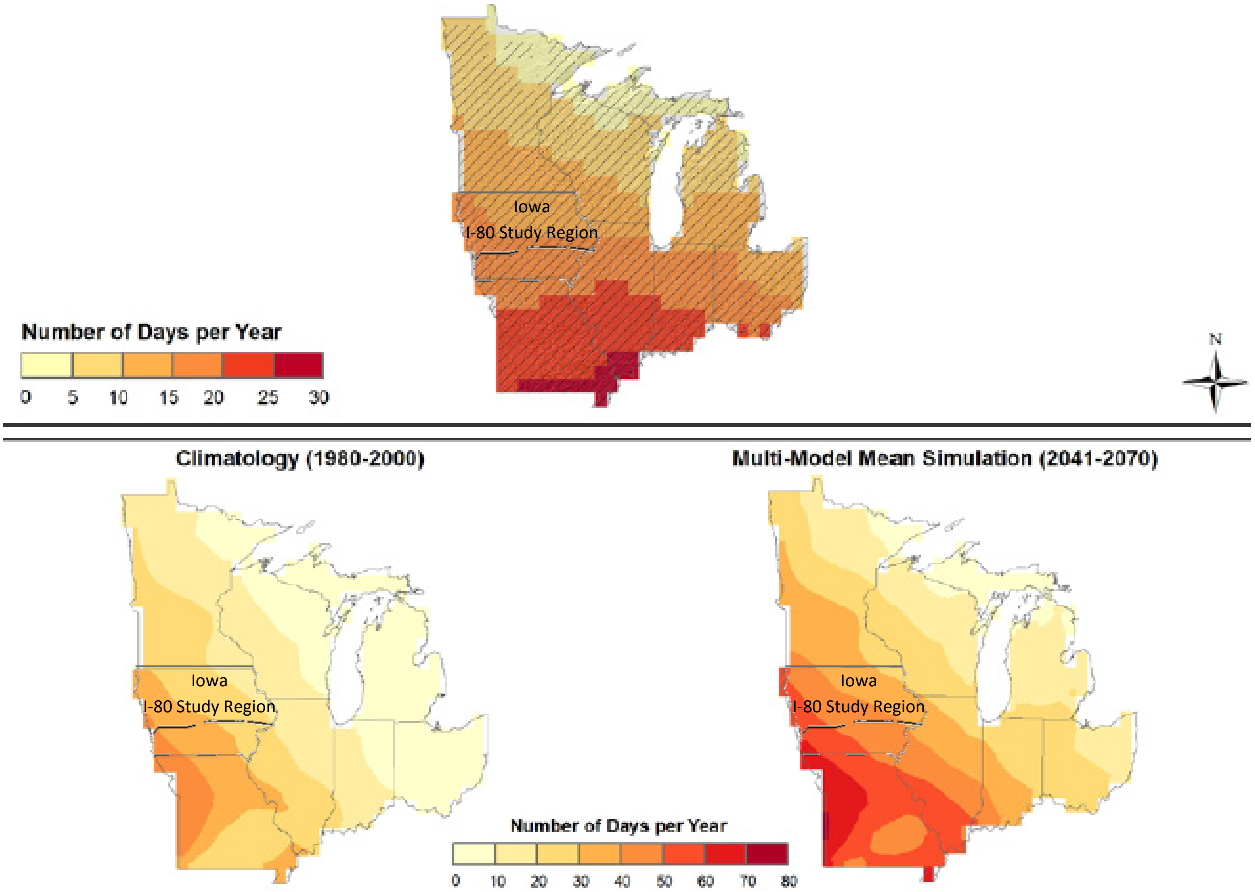
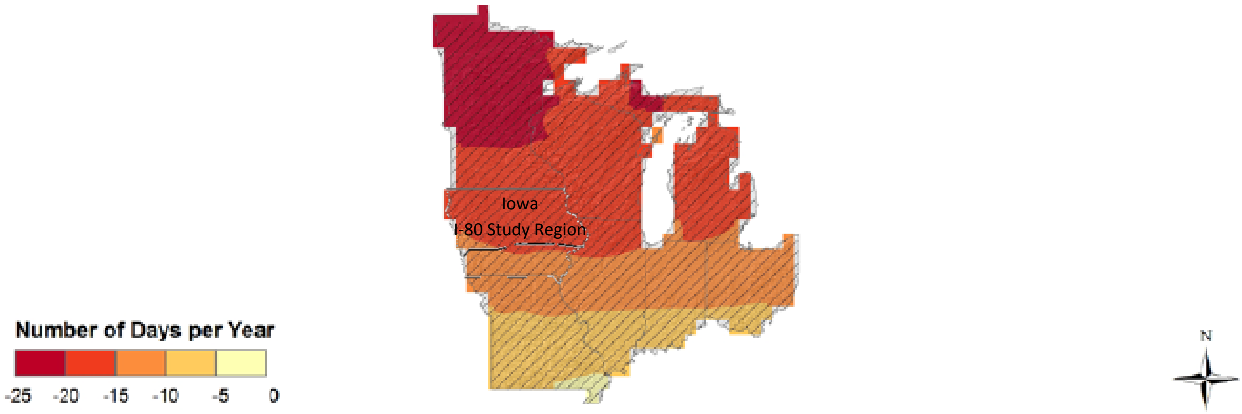
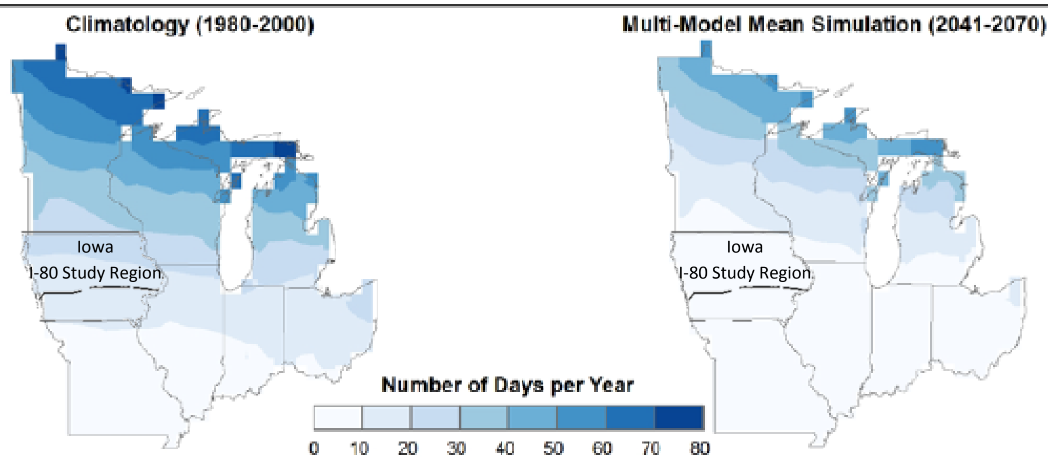


Figure A-19. MIDWEST REGION SIMULATED DIFFERENCE IN THE MEAN ANNUAL NUMBER OF DAYS WITH A MINIMUM TEMPERATURE LESS THAN 10°F, FOR THE 2041-2070 TIME PERIOD IN REFERENCE TO 1980-2000 FOR THE NARCCUP MULTI-MODEL MEAN HIGH EMISSIONS SCENARIO.





PRECIPITATION PROJECTIONS

Precipitation is expected to continue increasing throughout the entire I-80 corridor, although much greater variation and uncertainty is inherent in the multiple models analyzed in the NOAA/NESDIS report. There is particular discrepancies amongst models in southern Iowa, where the I-80 corridor occurs. 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 an east-west increasing gradient in precipitation changes. 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 are expected to increase throughout the I-80 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-80 corridor ranged from 4 to 6 days/year from 1980 to 2000 and are projected to increase to 4 to 8 days/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).

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 expected to increase throughout the I-80 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-80 corridor ranges from 35 to 50 days per year in 1980 to 2000 and is projected to increase by about 2 days along the corridor region, with a larger increase in frequency in the western region of the corridor for the 2041 to 2070 period. This is a relatively small increase compared to the variability of the current trends.

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.

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 NARCCUP MULTI-MODEL MEAN HIGH EMISSIONS SCENARIO.

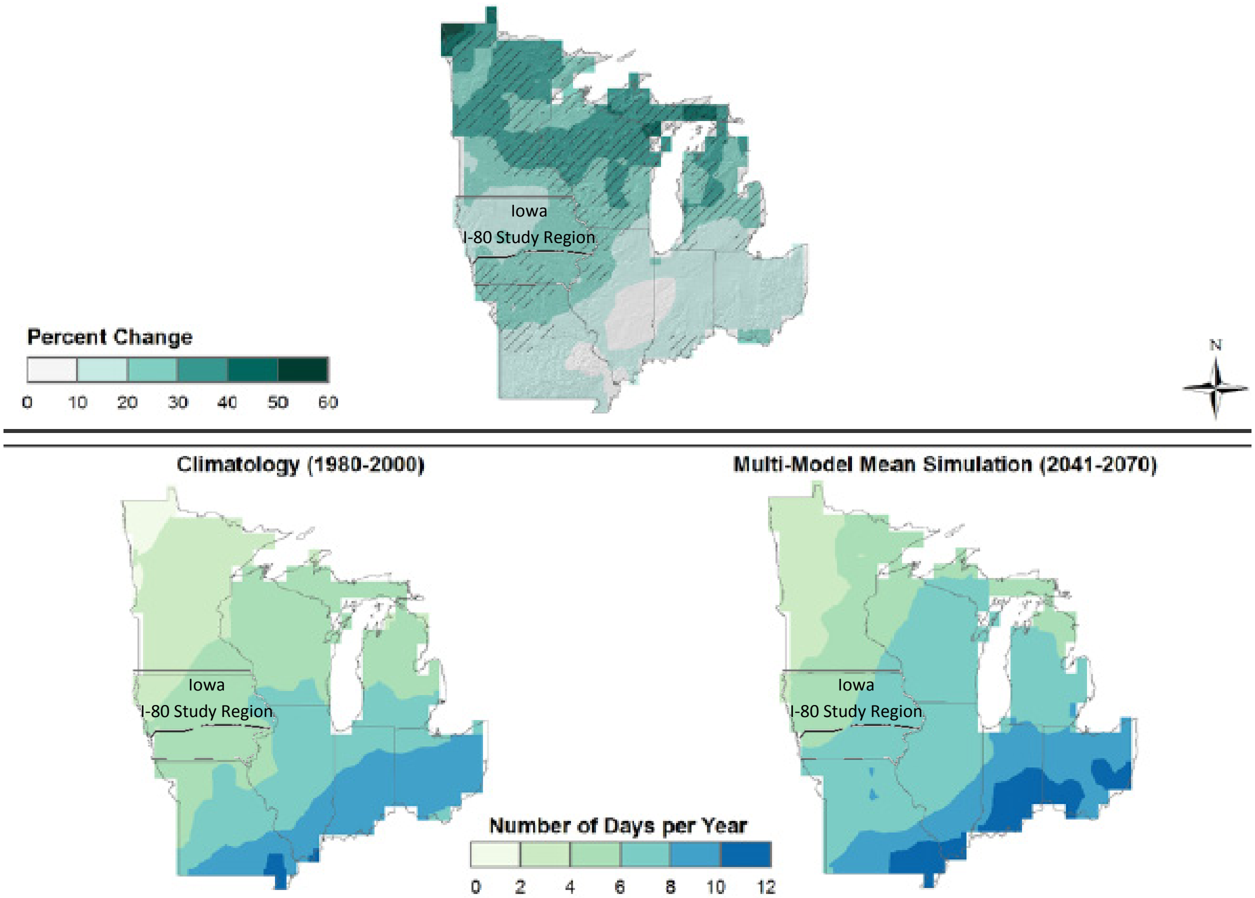
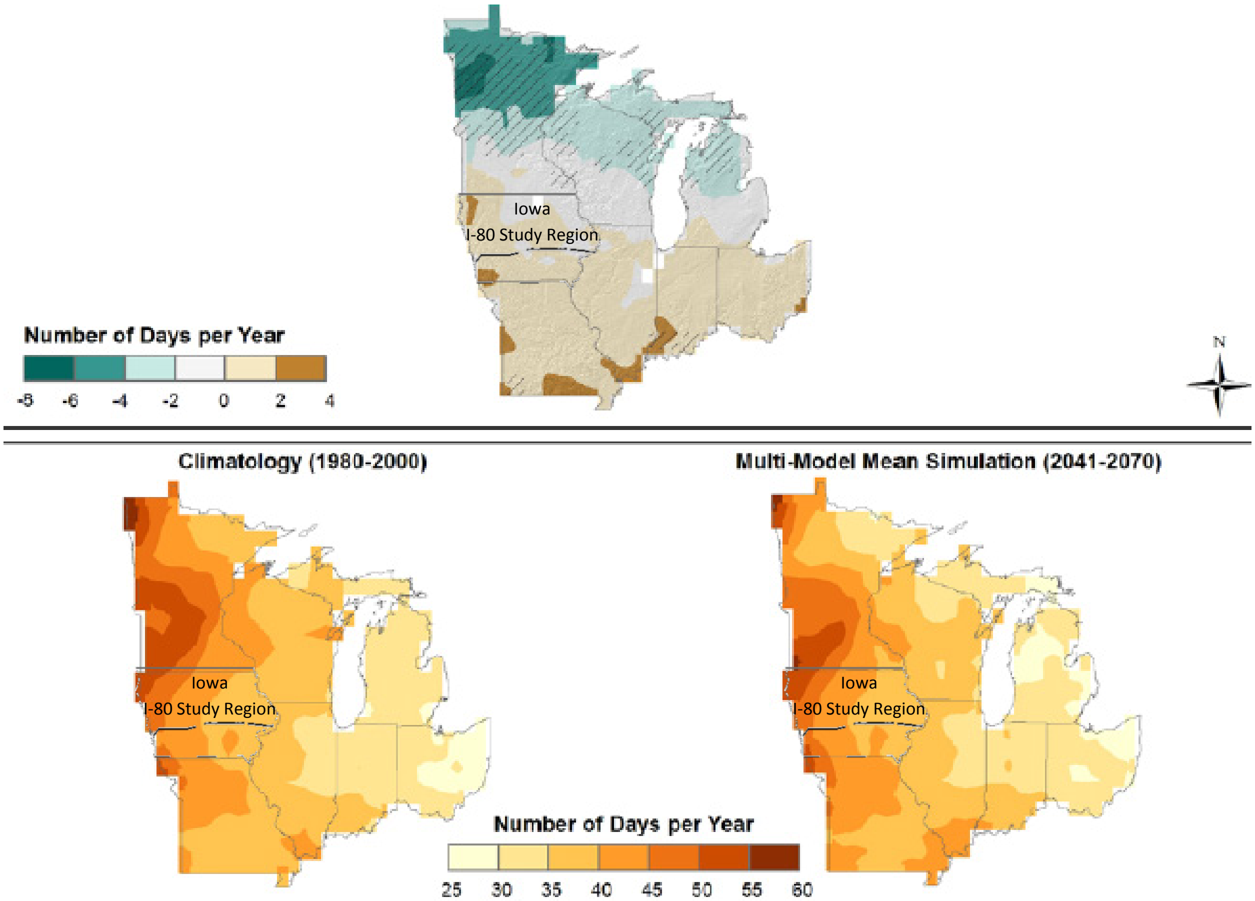


Figure A-21. MIDWEST REGION SIMULATED DIFFERENCE IN THE MEAN ANNUAL MAXIMUM NUMBER OF DAYS WITH PRECIPITATION LESS THAN 0.1 INCHES, FOR THE 2041-2070 TIME PERIOD IN REFERENCE TO 1980-2000 FOR THE NARCCUP MULTI-MODEL MEAN HIGH EMISSIONS SCENARIO.



STREAMFLOW AND FLOODING PROJECTIONS

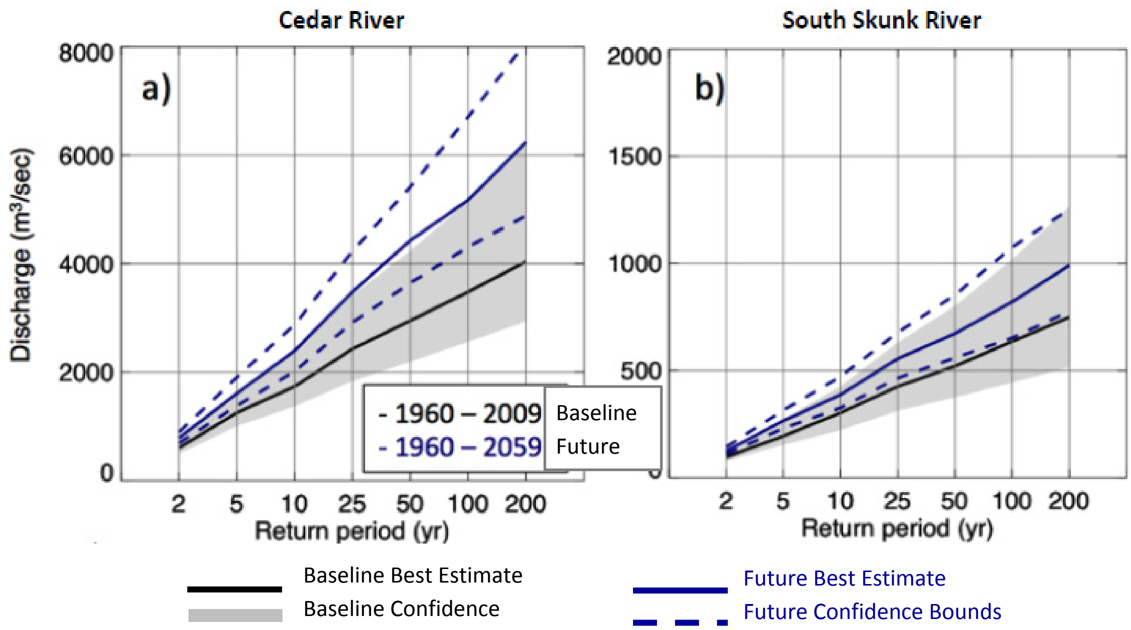
Precipitation intensity increases that are projected to continue will lead to greater instances of flood events, increasing stress on the I-80 corridor's bridges, culverts, and other infrastructure. Climate variability impacts on streamflow and flood projections inherently include greater level of uncertainties. 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 analyses compares streamflow simulations for a historical period (1960 to 2009) and historical/future period (1960 to 2059). 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 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, shown in Figure A-22, from the study signify that the 1 percent annual exceedance-probability discharge (AEPD) increased 37 to 67 percent for Cedar River Basin and 9 to 50 percent for South Skunk River Basin (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 of 24 and 32 percent in precipitation (and accompanying warming) can lead to drainage flow increase of 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 be 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.



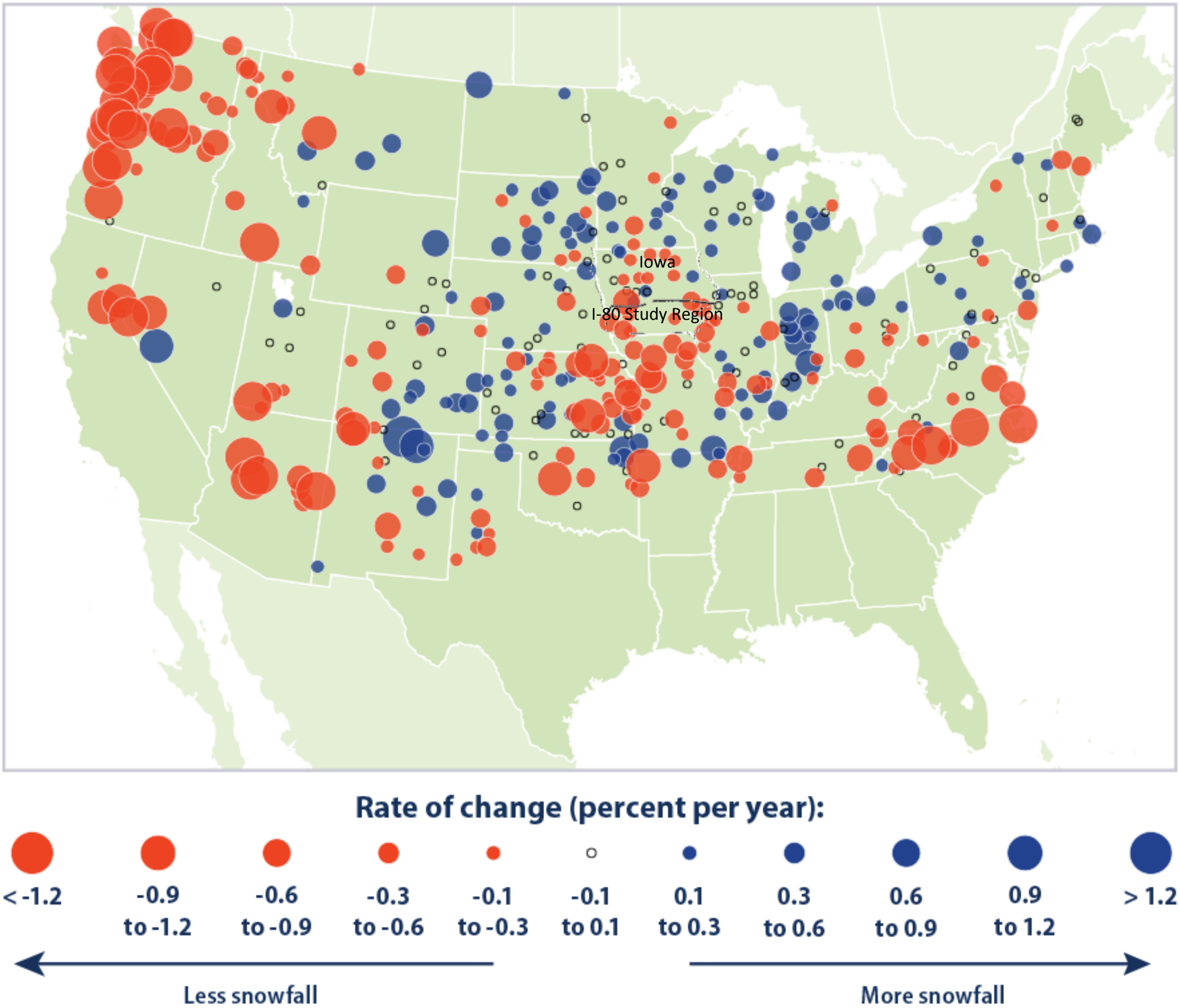
Source: Graphic is from Iowa DOT, 2015.

SNOWFALL PROJECTIONS

A decreasing trend of total annual snowfall has been observed along the I-80 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 0.1 to 0.9 percent per year throughout most of the I-80 corridor. Figure A-24 indicates that this manifested in a 2 to 30 percent decrease of snow-to-rain ratio in 2016 compared to 1949. Both of these trends are apparent in most of the I-80 corridor, with a few exceptions in the very eastern region. A small region near Clinton shows slight increases in snowfall. This region is closest to Wisconsin and northern Illinois, both of which show increasing trends in snowfall.

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, pers. comm). 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 of 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.

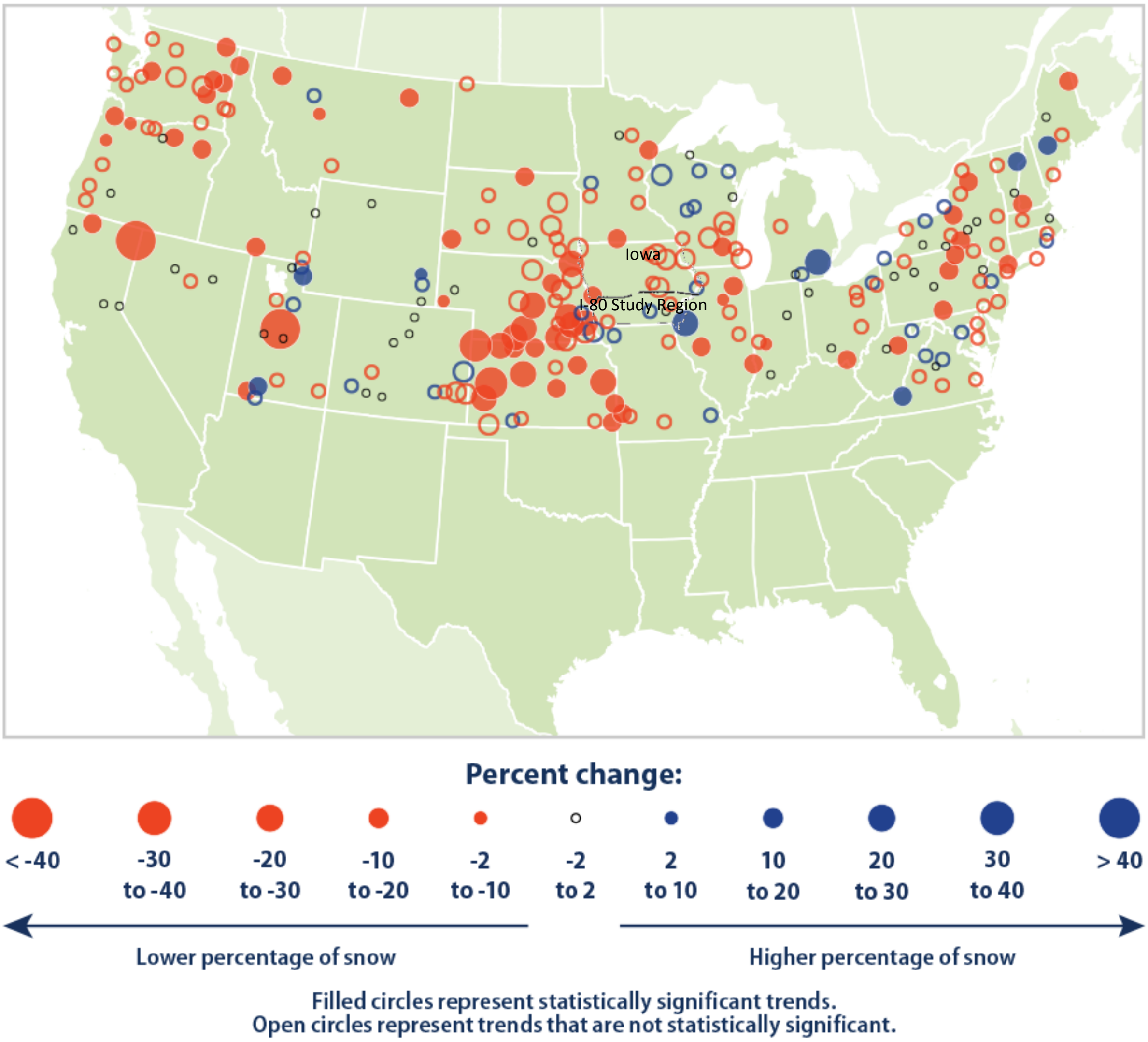


Data source: Kunkel, K.E., M. Palecki, L. Ensor, K.G. Hubbard, D. Robinson, K. Redmond, and D. Easterling. 2009. Trends in twentieth-century U.S. snowfall using a quality-controlled dataset. J. Atmos. Ocean. Tech. 26:33–44.

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 EPA, 2014.

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.

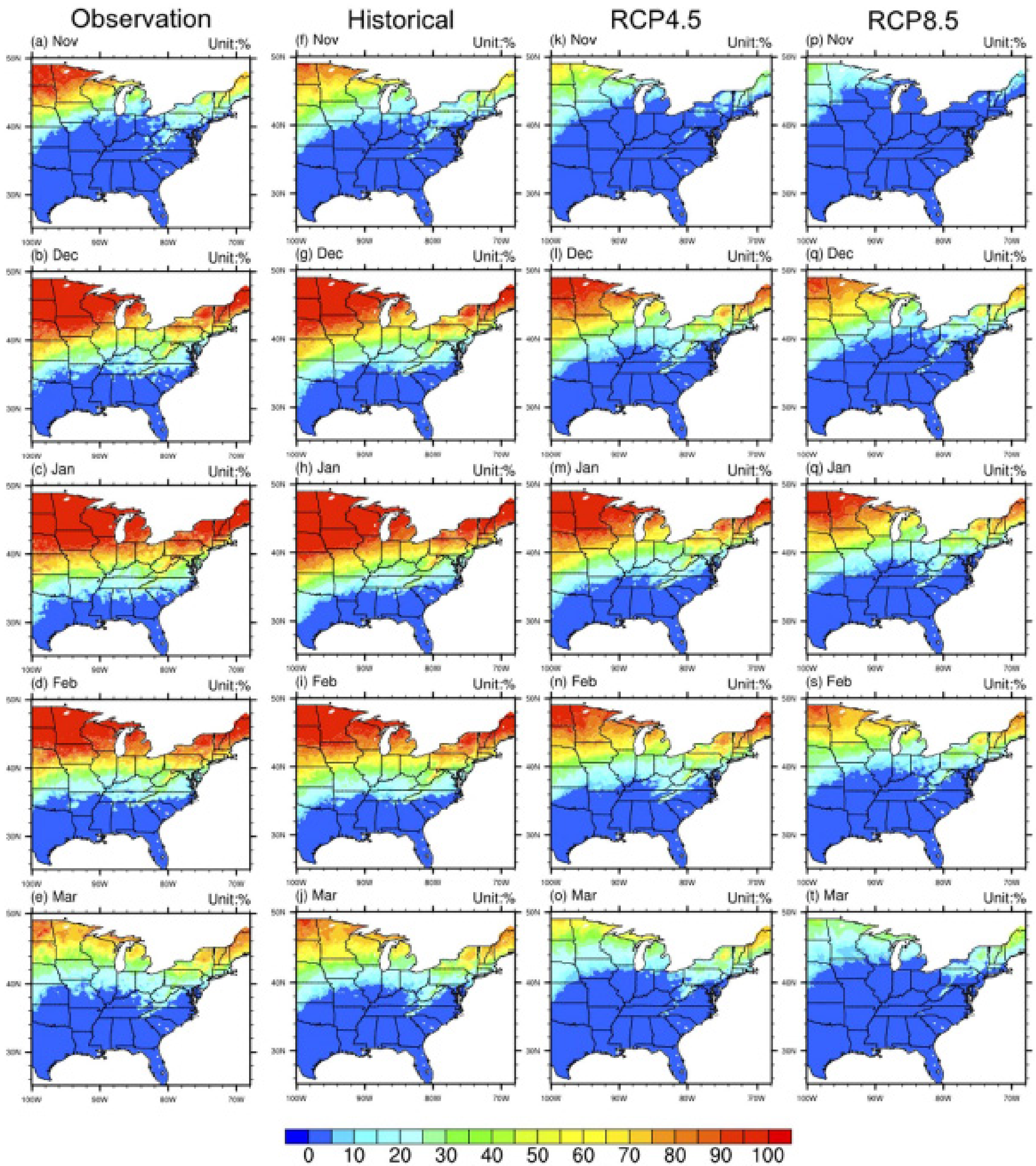


Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. National Centers for Environmental Information. Accessed June 2016. www.ncdc.noaa.gov.

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, 2014.

Figure A-25. CHANGE IN SNOW OCCURRENCE BY MONTH, FROM NOVEMBER THROUGH MARCH, FOR THE EASTERN UNITED STATES. COLORS INDICATES PERCENTAGE OF TOTAL PRECIPITATION OCCURRING AS SNOW.



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-80 roadway infrastructure.

Appendix B

LIST OF ALL SOURCES AND DATA REVIEWED

Row	Author	Document Name	Date
1	American Association of State Highway and Transportation Officials (AASHTO)	Highway Safety Manual	2010
2	Anderson, C., R. Arritt, B. Gutowski, G. Takle	Climate Science and Public Policy in Iowa	
3	Anderson, C.J.	Extreme Weather and Climate Change in Iowa: Now and Future Trends (presentation)	12/11/2013
4	Barnes, K. K. and D. A. Eash	Flood of August 11-16, 2010, in the South Skunk River Basin, Central and Southeast Iowa	2012
5	Bernhard, C.J.	Iowa DOT Email Thread re: Draft Response to EPA's US 30 Letter	12/28/2015
6	CH2M and Iowa Department of Transportation	Flood Map Location Limits (spreadsheet)	8/25/2015
7	CH2M and Iowa Department of Transportation	I80 History (spreadsheet)	2017
8	Council on Environmental Quality (CEQ)	CEQ Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews	8/1/2016
9	Eash, D. A.	Summary of USGS Reports Documenting Flood Profiles of Streams in Iowa, 1963-2012	2014
10	Eash, D. A. and A. J. Heinitz	Floods in the Nishnabotna River Basin, Iowa	1991
11	Eash, D. A. and B. A. Koppensteiner	Flood of July 9-11, 1993, in the Raccoon River Basin, West-Central Iowa	1997
12	Executive Order 137873	Promoting Energy Independence and Economic Growth	2017
13	Federal Highway Administration (FHWA)	Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries	2005
14	Federal Highway Administration (FHWA)	FHWA Climate Resilience Pilot Program: Iowa Department of Transportation	2015
15	Fisher, E. E.	Flood of June 15-17, 1998, Nishnabotna and East Nishnabotna Rivers, Southwest Iowa	1999
16	Francis, J., and S. Vavrus	Evidence linking Arctic amplification to extreme weather in mid-latitudes. Geophysical Research Letters.	2012
17	Hans, Z., N. Hawkins, K. Gkritza, M. Shaheed, and I. Nlenanya	Safety and Mobility Impacts of Winter Weather - Phase 3	2014
18	ICF International for U.S. Department of Transportation (ICF)	Transportation Climate Change Sensitivity Matrix (Excel File)	June 2014
19	Intergovernmental Panel on Climate Change (IPCC)	IPCC Special Report Emissions Scenarios	2000
20	Iowa Climate Change Advisory Council (ICCAC)	Iowa Climate Change Advisory Council's Final Report (part 1)	2008
21	Iowa Climate Change Advisory Council (ICCAC)	Iowa Climate Change Advisory Council's Final Report (part 2 - Appendices)	2008
22	Iowa Climate Change Impacts Committee	Climate Change Impacts on Iowa 2010: Report to the Governor and the Iowa General Assembly	1/1/2010
23	Iowa Department of Transportation (DOT)	Iowa In Motion - Planning Ahead 2040	5/8/2012

Row	Author	Document Name	Date
24	Iowa Department of Transportation (DOT)	Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot	March 2015
25	Iowa Department of Transportation (DOT)	2015 Iowa Traffic Incidents (spreadsheet)	2016
26	Iowa Office of Energy Independence	2010 Energy Independence Plan	2010
27	Iowa State University Center for Earthworks Engineering Research	Western Iowa Missouri River Flooding - Geo-Infrastructure Damage Assessment, Repair, and Mitigation Strategies	September 2013
28	Iowa State University Center for Transportation Research and Education	Iowa's Renewable Energy and Infrastructure Impacts	April 2010
29	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
30	Liang Ning & Raymond S. Bradley	Snow Occurrence Changes over the Central and Eastern U.S. Under Future Warming Scenarios	2015
31	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
32	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
33	Maze, T., Michael Crum., and Garrett Burchett.	An Investigation of User Costs and Benefits of Winter Road Closures	2005
34	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
35	Minnesota Department of Transportation (MnDOT)	Benefit-Cost Analysis for Transportation Projects	2016
36	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
37	National Oceanic and Atmospheric Administration (NOAA)	9th Annual Climate Prediction Applications Science Workshop Report	3/1/2011
38	National Oceanic and Atmospheric Administration (NOAA)	Comparative Climatic Data for the United States Through 2015	2016
39	National Research Council of the National Academies (NRC)	Potential Impacts of Climate Change on U.S. Transportation	2008
40	Parsons Brinckerhoff and Sarah J. Siwek & Associates	Climate Change: Impacts, Challenges, and Strategies (Workshop Presentation)	6/22/2010
41	Pryor, S.C., R.J. Barthelmie, D.T. Young, E.S. Takle, R.W. Arritt	Wind speed trends over the contiguous US	2009
42	Takle, E. S.	Assessment of Potential Impacts of Climate Changes on Iowa Using Current Trends and Future Projections	10/26/2011
43	Takle, E. S.	Personal communication	4/21/2017
44	Takle, E. S. et al.	Iowa Climate Statement 2013: A Rising Challenge to Iowa Agriculture	2013

Row	Author	Document Name	Date
45	Transportation Research Board (TRB)	Surface Transportation System Resilience to Climate Change and Extreme Weather Events	2/1/2016
46	U.S. Department of Transportation (USDOT)	US Department of Transportation Climate Adaptation Plan 2014 - Ensuring Transportation Infrastructure and System Resilience	2014
47	U.S. Department of Transportation (USDOT)	US DOT Climate Adaptation Plan - Ensuring Transportation Infrastructure and System Resilience	2013
48	U.S. Environmental Protection Agency (EPA)	Greenhouse Gas Emissions from a Typical Passenger Vehicle	May 2014
49	U.S. Environmental Protection Agency (EPA)	Iowa Climate Change Adaptation & Resilience Report	2011

Row	Author	Website Name	Date	URL
50	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
51	California Department of Transportation.	Life-Cycle Benefit-Cost Analysis Economic Parameters 2016	7/9/1905	http://dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html
52	Federal Highway Administration (FHWA)	Tools: Climate Change Adaptation	2017	https://www.fhwa.dot.gov/environment/sustainability/resilience/tools/index.cfm
53	Iowa Department of Agriculture and Land Stewardship	Climatology Bureau Home Page	2017	http://www.iowaagriculture.gov/climatology.asp
54	Iowa Department of Natural Resources	Climate Change	2017	http://www.iowadnr.gov/Conservation/Climate-Change
55	Iowa Department of Transportation (DOT)	511 Information: Iowa Winter Travel Condition Definitions	2015	http://www.iowadot.gov/511/road_condition_terms.html
56	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
57	Iowa Department of Transportation (DOT)	Truck Traffic	2014	https://iowadot.gov/maps/msp/pdf/TruckTrafficMap
58	Iowa Department of Transportation (DOT)	Office of Bridges and Structures LRFD Design Manual.	2017	https://iowadot.gov/bridge/design-policies/bridge-d
59	Iowa Department of Transportation (DOT)	Maps Cartography and Traffic Data	2017	https://www.iowadot.gov/maps/digital%20maps/tra
60	Iowa Flood Center	Iowa Flood Center Home Page	2017	http://iowafloodcenter.org/
61	Iowa Flood Center and Iowa Department of Natural Resources	Iowa Statewide Floodplain Mapping Project	2017	http://www.iihr.uiowa.edu/iowafloodmaps/
62	Iowa State University Climate Science Program	Data Archive Page	2017	http://climate.engineering.iastate.edu/DataArchive.html
63	Iowa State University Climate Science Program	Education and Presentations Page	2017	http://climate.engineering.iastate.edu/CSPPresentations.html
64	Iowa State University Climate Science Program	Publications and Presentations by the CSP Research Team	2017	http://climate.engineering.iastate.edu/CSPPublications.html
65	Iowa State University Climate Science Program	Publications Page - Impacts of Climate Change	2017	http://climate.engineering.iastate.edu/ImpactsResearch.html
66	Iowa State University Climate Science Program	Publications Page - Regional Climate Model Development and Regional Analysis	2017	http://climate.engineering.iastate.edu/RCMResearch.html

Row	Author	Website Name	Date	URL
67	Iowa State University Climate Science Program	Resources Page	2017	http://climate.engineering.iastate.edu/Resources.html
68	Iowa State University of Science and Technology	Roadway Weather Information System	2017	https://mesonet.agron.iastate.edu/RWIS/
69	National Climate Assessment (NCA)	Climate Change Impacts in the United States	2014	http://nca2014.globalchange.gov/report/regions/midwest#intro-section-2
70	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
71	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
72	National Oceanic and Atmospheric Administration (NOAA)	Regional Snowfall Index	2017	https://www.ncdc.noaa.gov/snow-and-ice/rsi/societal-impacts
73	National Oceanic and Atmospheric Administration (NOAA)	Snowfall Extremes - Iowa	2017	https://www.ncdc.noaa.gov/snow-and-ice/snowfall-extremes/IA
74	New York Department of Transportation	Value of Time for Work Zone Delay Cost Calculations Using 2012 Income Data	2012	
75	Ohio Department of Transportation (DC	Work Zone User Cost Calculations.	2017	http://www.dot.state.oh.us/Divisions/ConstructionM
76	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
77	Texas Department of Transportation	Road User Costs	2017	http://www.txdot.gov/inside-txdot/division/construct
78	The Center for Climate Strategies	Documents Library	2017	http://www.climatestrategies.us/library/library/index/39
79	Transportation Research Board (TRB)	Climate Change: Activities of the Transportation Research Board	2017	http://www.trb.org/Main/SpecialtyPageClimateChange.aspx
80	U.S. Environmental Protection Agency (USEPA)	Climate Change Indicators: Snowfall	2014	https://www.epa.gov/climate-indicators/climate-change-indicators-snowfall
81	U.S. Environmental Protection Agency (USEPA)	Climate Impacts in the Midwest	2017	https://www.epa.gov/climate-impacts/climate-impacts-midwest
82	United States Census Bureau	Iowa Quick Facts	2017	https://www.census.gov/quickfacts/table/PST0452
83	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#53 0
84	U.S. Geological Survey (USGS)	The Global Climate Change Viewer (GCCV)	2016	https://www.usgs.gov/software/global-climate-change-viewer-gccv

Row	Data Source	Date	Author
85	NHDPlus. http://www.horizon-systems.com/nhdplus/.	2017	Horizon Systems
86	National Flood Hazard Layer	7/16/2013	FEMA
87	I-80 - ESRI ArcMap 10.4 Template data - highways	2016	Environmental Systems Research Institute (ESRI)

Appendix C

USER COSTS DUE TO ROAD CLOSURE EVENTS

USER COSTS DUE TO ROAD CLOSURE EVENTS

INTRODUCTION TO ROAD USER COST

The I-80 corridor is important to the economic health of the state, the surrounding region and beyond, and society as a whole. 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-80 corridor and maintain acceptable levels of mobility, certain design features may be appropriate to consider as part of the individual I-80 expansion projects 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, 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 is placed on the effects and consequences of a crash intended to consider the comprehensive economic impact and loss. 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	http://www.txdot.gov/inside-txdot/division/construction/road-user-costs.html
Minnesota	2016	$16.80	$28.30	http://www.dot.state.mn.us/planning/program/appendix_a.html
New York (intercity)	2012	$31.06-$ 36.41	$26.74	https://www.dot.ny.gov/divisions/engineering/design/dqab/hdm/hdm-repository/Recommended%20Value%20of%20Time.pdf
California	2016	$13.65	$31.40	http://dot.ca.gov/hq/tpp/offices/eab/benefit_cost/LCBCA-economic_parameters.html
Ohio	2017	$22.42	$60.52	http://www.dot.state.oh.us/Divisions/ConstructionMgt/Admin/Innovative Contracting/RoadUserCosts – Revised041515.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, Crum, 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 Redbook, software applications like HERS-ST, 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 Load and Resistance Factor 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 construction.

DRUC = (AADT + 2xADTT + OODT) x Mileage Rate

where:

DRUC = Direct Road User Cost ($)

AADT = Average Annual Daily Traffic (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 mileage rate is not provided in the design manual guidance.

CALCULATING USER COSTS FOR I-80

For the purposes of this memorandum, road user costs for the I-80 corridor were considered at a high level to gain a sense of possible economic impacts of the I-80 closure. Because of the general lack of information regarding existing problem spots along I-80 with a documented history of closure due to weather events, this memorandum assumes those locations with existing closure data available, anecdotal information received from District maintenance staff, and locations of the corridor shown to be potentially impacted by flooding events per FEMA maps and Iowa Flood Center information. Locations identified through FEMA maps (2013) and the Iowa Flood Center (2017) information are considered surrogate locations for the purposes of this memorandum in lieu of the lack of detailed historic events along the corridor readily available at the time of this study. Because of the lack of available information documenting historic impacts to the I-80 corridor as a result of other weather-related events (snow/ice, and high wind), the road user costs and potential economic impacts calculated for this memorandum only consider locations potentially at risk for flooding.

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 construction 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-80 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-80 and the assumed detour routes.

For the purposes of this study, detour routes assumed for the various locations along I-80 follow the National Highway System primary road network and were identified at a very high conceptual level. A more detailed evaluation of all possible alternate routes to identify those most suitable to serve the transportation needs in the event of an I-80 closure is warranted. Iowa DOT is currently undertaking this detailed effort. However, results were not available at the time this memorandum was prepared. When evaluating a possible detour route, a desire to maintain traffic on four-lane divided facilities and avoid travel through urban areas with at-grade intersections and traffic signals was followed when possible. Out-of-distance travel for each detour route was calculated comparing the length of the assumed detour route to the length of travel along I-80 over a given segment of the corridor assuming a through trip along I-80 (i.e., does not consider backtracking, additional out-of-distance travel, potentially required for a local trip destined for or originating at some location along the section of I-80 closed to through traffic). If more than one route was identified as a potentially accepted detour, the route with the least amount of out-of-distance travel was assumed.

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-80 and the available alternate routes.

Table C-2 summarizes the calculated user costs for each location noted as in a floodplain or with available information of past closures/impacts. The assumed detour route, daily volume of traffic, and percentage of trucks is also provided.

Table C-2. CALCULATED USER COSTS FOR EACH LOCATION

ID	Location	County	Assumed Detour Route	Distance Along I-80 (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-80 Closure	
										Iowa DOT ABC Evaluation Method	Hourly Rate with Census and Labor Statistics Method
1	Keg Creek	Pottawattamie	South on I-29; East on US 34; North on US 59	37.0	70.8	33.8	0.7	22,400	7,900	$484,185	$367,298
2	Silver Creek	Pottawattamie	South on I-29; East on US 34; North on US 59	37.0	70.8	33.8	0.7	21,800	7,800	$474,045	$357,108
3	West Nishnabotna River	Pottawattamie	South on I-29; East on US 34; North on US 59	37.0	70.8	33.8	0.7	21,800	7,800	$474,045	$357,108
4	East Branch West Nishnabotna River	Pottawattamie	South on US 59; East on US 34; North on US 71	20.3	95.3	75.0	1.4	20,200	7,600	$995,625	$694,619
5	Indian Creek	Cass	South on US 59; East on US 34; North on US 71	20.3	95.3	75.0	1.4	20,200	7,700	$1,001,250	$693,954
6	Buck Creek	Cass	South on US 59; East on US 34; North on US 71	20.3	95.3	75.0	1.4	19,700	7,600	$981,563	$676,174
7	East Nishnabotna River	Cass	North on US 71; East on US 30; South on US 169	49.4	123	73.6	1.5	19,700	7,600	$963,240	$717,381
8	Troublesome Creek	Cass	North on US 71; East on US 30; South on US 169	49.4	123	73.6	1.5	19,700	7,600	$963,240	$717,381
9	Crooked Creek	Cass	North on US 71; East on US 30; South on US 169	49.4	123	73.6	1.5	19700	7600	$963,240	$717,381
10	Middle River	Adair	North on US 71; East on US 30; South on US 169	49.4	123	73.6	1.5	20,900	7,800	$1,007,400	$762,935
11	South Raccoon River	Dallas	South on US 169; East on IA 92; North on I-35	12.9	42.6	29.7	0.5	26,800	8,300	$483,368	$341,056
12	North Raccoon River	Dallas	South on US 169; East on IA 92; North on I-35	12.9	42.6	29.7	0.5	26,800	8,300	$483,368	$341,056
13	South Skunk River	Jasper	South on US 65; East on IA 163; North on IA 14	23.5	40.9	17.4	0.4	34,700	9,000	$343,868	$304,903
14	Indian Creek	Jasper	South on US 65; East on IA 163; North on IA 14	23.5	40.9	17.4	0.4	33,100	8,900	$332,123	$290,321
15	Prairie Creek	Jasper	South on US 65; East on IA 163; North on IA 14	23.5	40.9	17.4	0.4	31,400	8,900	$321,030	$274,651
16	Cherry Creek	Jasper	South on US 65; East on IA 163; North on IA 14	23.5	40.9	17.4	0.4	31,400	8,900	$321,030	$274,651

Table C-2. CALCULATED USER COSTS FOR EACH LOCATION

ID	Location	County	Assumed Detour Route	Distance Along I-80 (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-80 Closure: Iowa DOT ABC Evaluation Method	Estimated Daily Economic Impact of I-80 Closure: Hourly Rate with Census and Labor Statistics Method
17	North Skunk River	Jasper	North on IA 14; East on US 30; South on US 63	27.3	69.2	41.9	0.8	27,400	8,700	$703,920	$559,567
18	Rock Creek	Jasper	North on IA 14; East on US 30; South on US 63	27.3	69.2	41.9	0.8	27,400	8,700	$703,920	$559,567
29	Sugar Creek	Jasper	North on IA 14; East on US 30; South on US 63	27.3	69.2	41.9	0.8	27,800	8,700	$710,205	$568,232
20	West of US Hwy 151	Iowa	North on US 63; East of US 30; South on I-380	48	87.8	39.8	0.7	31,200	9,300	$743,265	$536,669
21	East of US Hwy 151	Iowa	North on US 63; East of US 30; South on I-381	48	87.8	39.8	0.7	30,600	9,500	$740,280	$525,107
22	218 interchange	Johnson	North on US 151; East on Us 30; South on IA 1	22	59.8	37.8	0.7	34,800	9,500	$762,615	$614,908
23	Cedar River	Cedar	North on I-380; East on US 30; South on US 61	56.3	91.2	34.9	0.7	33,700	11,500	$742,061	$577,465
24	Sugar Creek	Cedar	North on I-380; East on US 30; South on US 61	56.3	91.2	34.9	0.7	32,400	11,400	$722,430	$554,058
25	Northwest blvd Interchange	Scott	South and East on I-280; North on I-74	8.6	28.3	19.7	0.3	36,000	12,000	$443,250	$243,484
26	Northwest blvd Interchange	Scott	South and East on I-280; North on I-74	8.6	28.3	19.7	0.3	36,000	12,000	$443,250	$243,484
27	Spencer Creek	Scott	South on I-74; West on I-280	19.8	19.8	0	0.0	30,900	9,100	$0	$0
28	Wells Fr. Road	Scott	South on I-74; West on I-280	19.8	19.8	0	0.0	30,900	9,100	$0	$0

Mileage Rate (Iowa DOT, 2017a)	$0.375
Average Annual Income in Iowa (United States Census Bureau, 2017)	$53,183
Average Hourly Rate per Average Annual Income (United States Census Bureau, 2017)	$25.57
Average Truck Driver Hourly Rate (United States 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-2, the calculated values vary between the two calculation methods. However, it is clear that economic impacts of between $500,000 and $1,000,000 per day are possible over the vast majority of the rural I-80 corridor areas. 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. 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.

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

I-80 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-3 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-80. 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.

Little data were available regarding I-80 snow and ice events aside from some anecdotal data provided by Iowa DOT maintenance staff and snowfall history and future projections documented in existing literature. Iowa DOT has a comprehensive crash database available and the location, frequency, and severity of crashes related to snow and ice can be queried and summarized. The past 5 years of snow- and ice-related crash data were requested from Iowa DOT for this evaluation but the information was not available at the time this memorandum was prepared. The use of this crash data and further coordination with Iowa DOT maintenance staff may be appropriate at the project level to identify specific areas where I-80 may benefit from implementation of strategies to minimize the impact of snow and ice on daily travel. The values noted in Table C-3 could be used to assess benefit-cost tradeoffs of improvements at the project level.

Table C-3. 2001 COMPREHENSIVE CRASH COSTS BY INJURY SEVERITY (HSM, 2010)

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

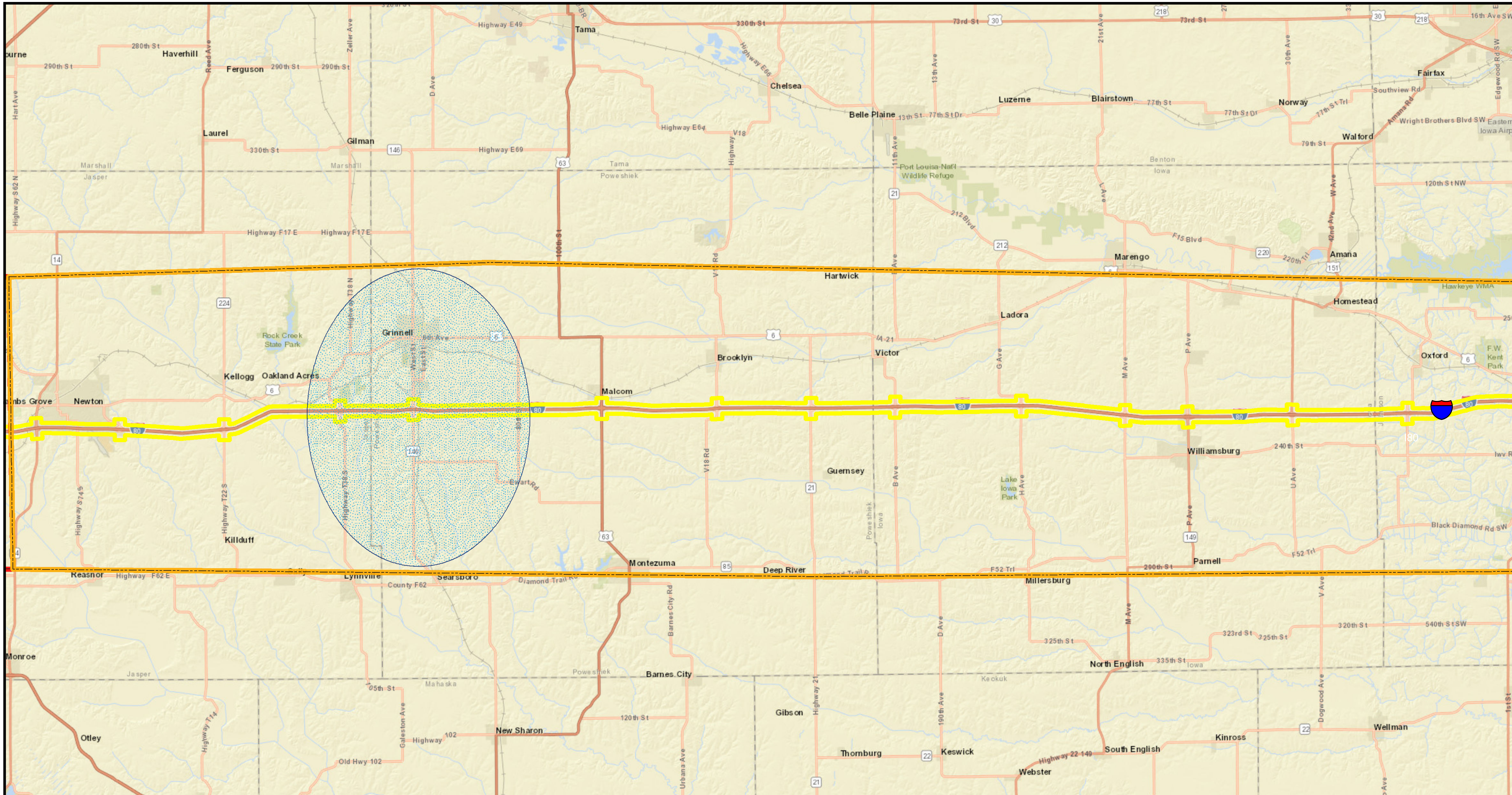
PROJECT LEVEL NEXT STEPS

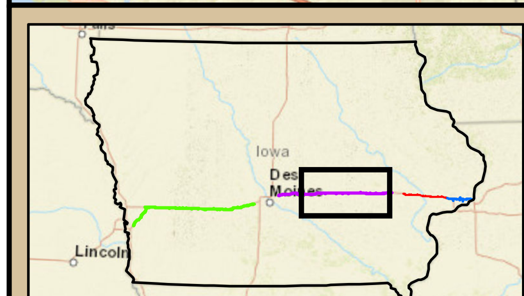
Based on the findings of the high level analyses, it would appear that weather-related closures or capacity reductions in the rural corridors of I-80 can have significant economic ramifications to road users and the Iowa and Midwest Region economy, particularly if the events are frequent and/or sustained events disrupting traffic for days at a time. Considering the volume of traffic along I-80 on a daily basis, which is projected to increase in the future, the large percentage of heavy vehicles using corridor, and the out-of-distance travel required for a suitable I-80 alternate route, it is anticipated that improvements to increase the resiliency of the I-80 corridor will have some level of viability in most cases.

As the I-80 project moves from programmatic level analyses to project level analyses, 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. Better 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 given route; 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-80 and added infrastructure capital investment.

Appendix D

MAP BOOK OF AREAS OF THE I-80 CORRIDOR MOST AT RISK OF CLIMATE RELATED IMPACTS





Study Areas

- Council Bluffs to Des Moines
- Des Moines to Iowa City
- Iowa City to Walcott
- Walcott to Mississippi River

Areas of Corridor Most at Risk of Climate Related Impacts

- High Temp - average change
- High Temp - greatest change
- Snow, Blizzard and/or Icing
- Flood

N
W E
S

0 1.5 3 4.5 6 Miles

Appendix D
Areas of the I-80 Corridor Most at Risk of Climate Related Impacts
Page 1 of 4

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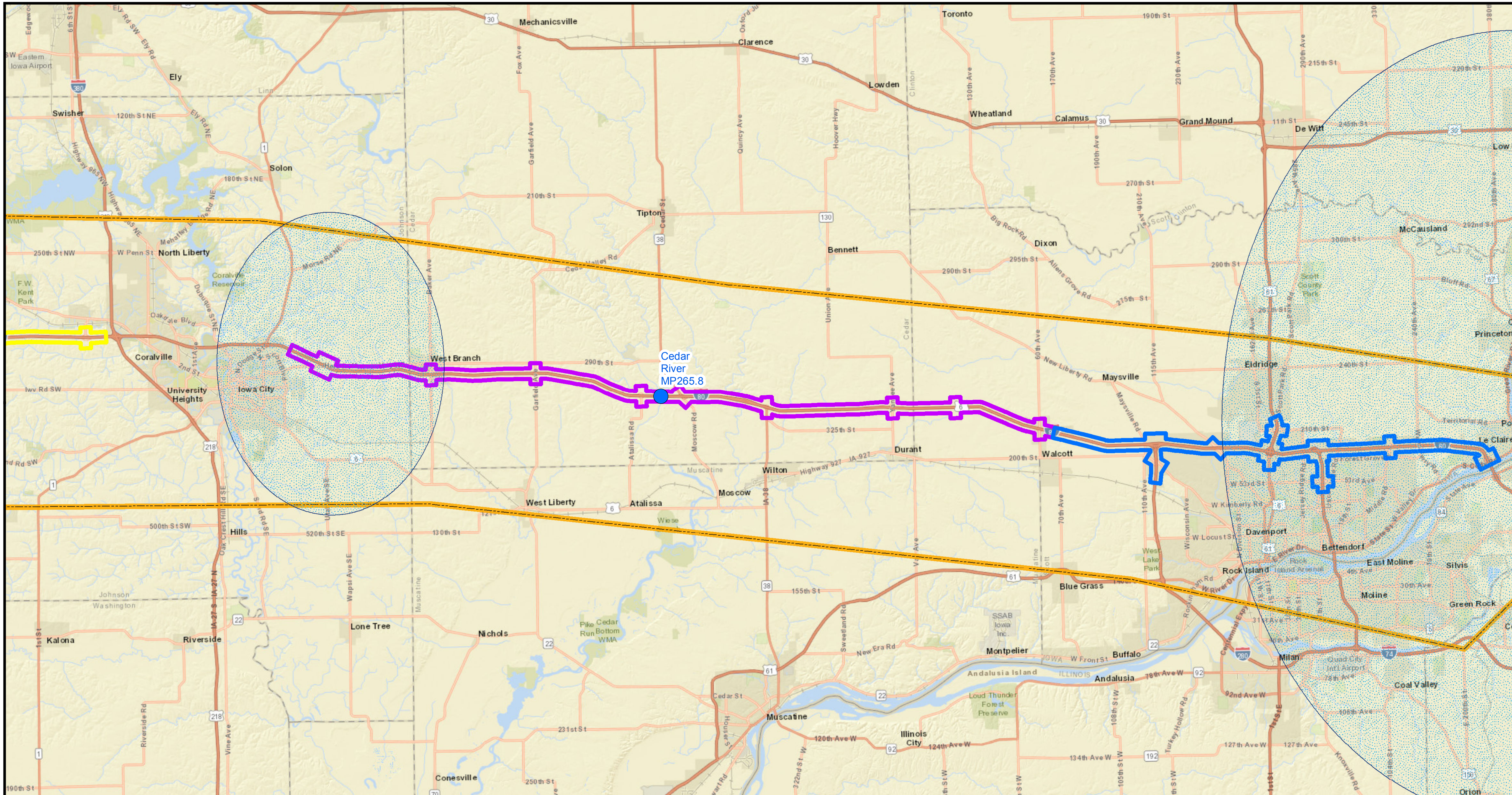

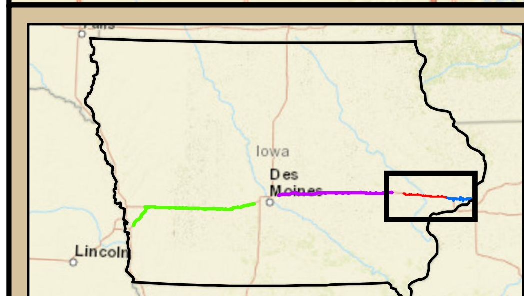

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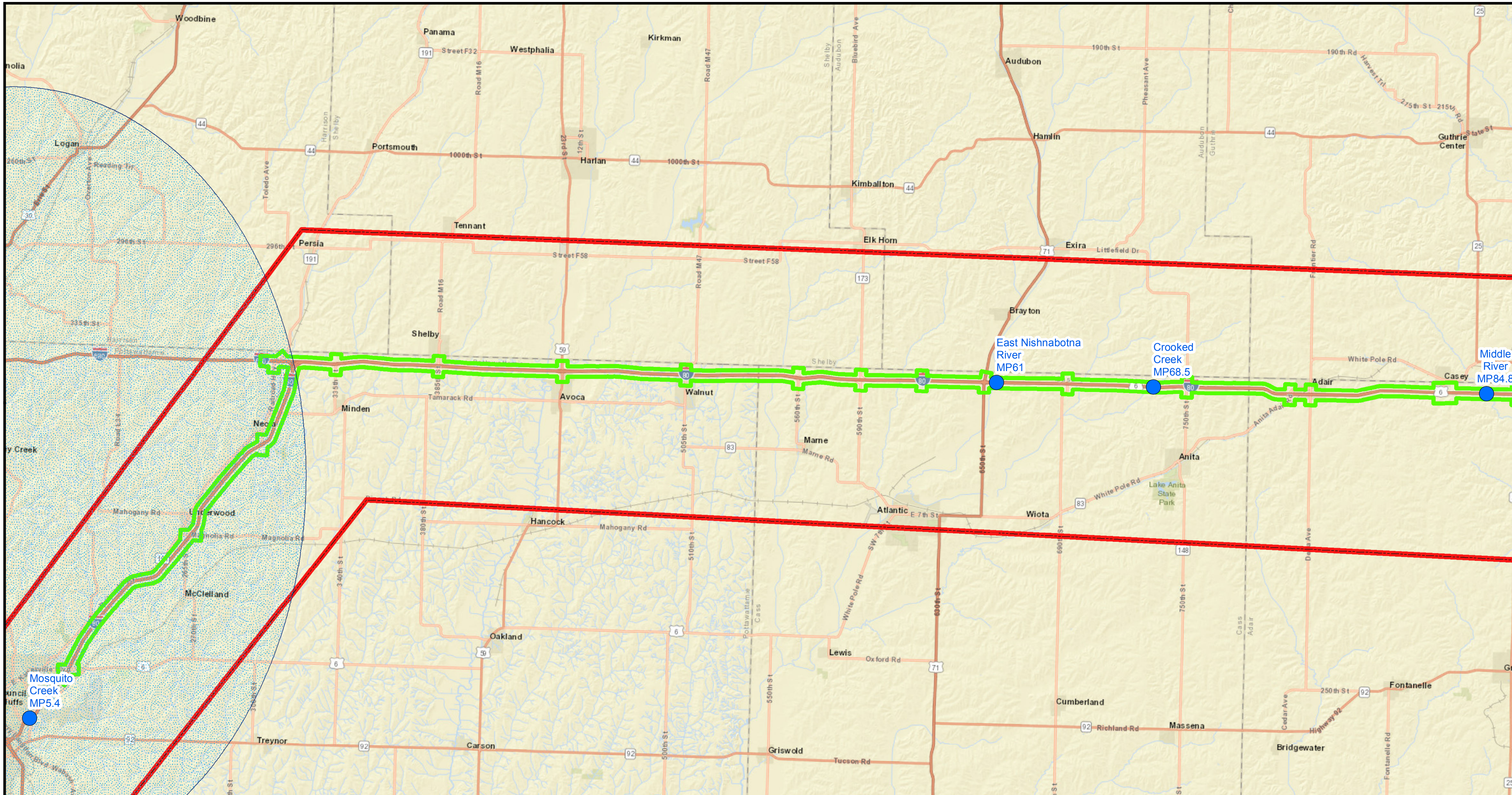

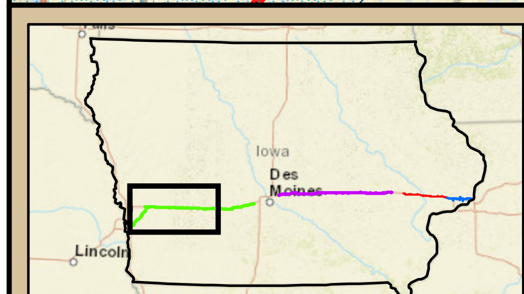

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0 1.5 3 4.5 6 Miles

Appendix D
Areas of the I-80 Corridor Most at Risk of Climate Related Impacts
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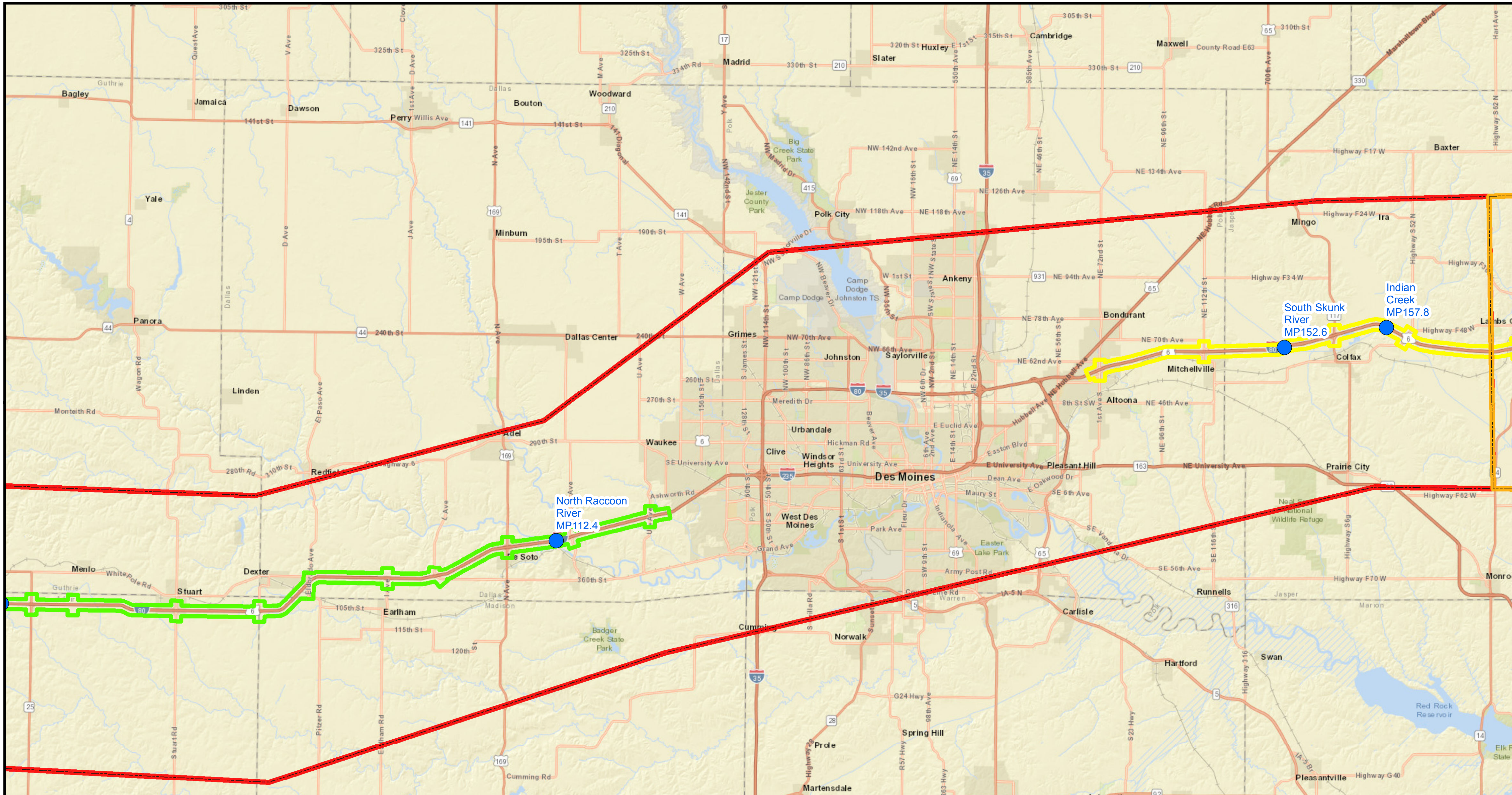

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Areas of Corridor Most at Risk of Climate Related Impacts

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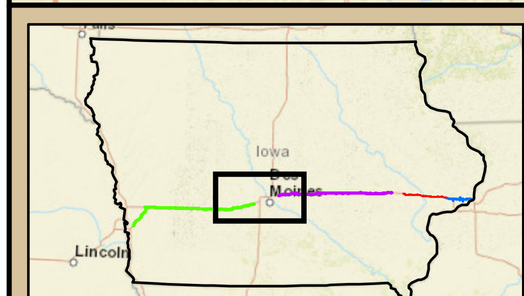

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Appendix D
Areas of the I-80 Corridor Most at Risk of Climate Related Impacts
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Appendix E

PHOTO LOG OF AREAS MOST AT RISK OF CLIMATE RELATED IMPACTS

POTTAWATTAMIE COUNTY

Photo 1. POTTAWATTAMIE COUNTY NEAR MILE POST (MP) 30 (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE) – LOOKING EAST FROM 335 STREET (EXIT 29)

Photo 2. POTTAWATTAMIE COUNTY NEAR MP 35/SILVER CREEK (HIGH TEMPERATURE CHANGE) – I-80 WESTBOUND LANES LOOKING WEST

Photo 3. POTTAWATTAMIE COUNTY NEAR MP 5.4/MOSQUITO CREEK (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE, FLOODING) – TAKEN FROM VALLEY VIEW DRIVE LOOKING NORTH

Photo 4. POTTAWATTAMIE COUNTY NEAR MP 5.4/MOSQUITO CREEK (SNOW, BLIZZARD, HIGH TEMPERATURE CHANGE, FLOODING) – TAKEN FROM VALLEY VIEW DRIVE LOOKING NORTH

Photo 5. POTTAWATTAMIE COUNTY NEAR MP 41/EAST BRANCH OF WEST NISHNABOTNA RIVER (HIGH TEMPERATURE CHANGE) – I-80 WESTBOUND LOOKING WEST

CASS COUNTY

Photo 6. CASS COUNTY NEAR MP 50/INDIAN CREEK (HIGH TEMPERATURE CHANGE) – I-80 WESTBOUND LOOKING WEST

Photo 7. CASS COUNTY NEAR MP 61/EAST NISHNABOTNA RIVER (FLOODING, HIGH TEMPERATURE CHANGE) – LOOKING EAST FROM US 6/US 71 WESTBOUND EXIT RAMP

Photo 8. CASS COUNTY NEAR MP 69/CROOKED CREEK (FLOODING, HIGH TEMPERATURE CHANGE) – LOOKING WEST FROM 740 STREET OVERPASS

ADAIR COUNTY

Photo 9. ADAIR COUNTY NEAR MP 85/MIDDLE RIVER (FLOODING, HIGH TEMPERATURE CHANGE) – I-80 WESTBOUND LOOKING WEST

DALLAS COUNTY

Photo 10. DALLAS COUNTY NEAR MP 111/SOUTH RACCOON RIVER (HIGH TEMPERATURE CHANGE) – LOOKING WEST FROM OLD PORTLAND ROAD

Photo 11. DALLAS COUNTY NEAR MP 112/NORTH RACCOON RIVER (FLOODING, HIGH TEMPERATURE CHANGE) – LOOKING EAST FROM OLD PORTLAND ROAD

JASPER COUNTY

Photo 122. JASPER COUNTY NEAR MP 153/SOUTH SKUNK RIVER (FLOODING) – LOOKING EAST FROM W. 128 STREET OVERPASS

Photo 133. JASPER COUNTY NEAR MP 158/INDIAN CREEK (FLOODING) – I-80 EASTBOUND LOOKING EAST

Photo 14. JASPER COUNTY RCB CULVERT AT EXIT 159 EASTBOUND EXIT RAMP NEAR INDIAN CREEK (FLOODING)– LOOKING WEST FROM F-48W EASTBOUND OFF RAMP

JASPER/POWESHIEK COUNT

Photo 145. JASPER/POWESHIEK COUNTY NEAR MP 180 (BLIZZARD, ICING) – LOOKING EAST FROM T-39N OVERPASS

JOHNSON COUNTY

Photo 156. JOHNSON COUNTY NEAR MP 245 (BLIZZARD, ICING) – I-80 EASTBOUND LOOKING EAST

CEDAR COUNTY

Photo 167. CEDAR COUNTY NEAR MP 266/CEDAR RIVER (FLOODING) – I-80 EASTBOUND LOOKING EAST

Photo 18. CEDAR COUNTY NEAR MP 266/CEDAR RIVER (FLOODING) – LOOKING WEST FROM 306 STREET

SCOTT COUNTY

Photo 19. SCOTT COUNTY NEAR MP 293/GOOSE CREEK (SNOW, BLIZZARD) – LOOKING EAST

Photo 20. SCOTT COUNTY NEAR MP 301/SPENCER CREEK (SNOW, BLIZZARD) – I-80 EASTBOUND LOOKING EAST

Photo 17. SCOTT COUNTY NEAR MP 303/WELLS FERRY ROAD (SNOW, BLIZZARD) – I-80 WESTBOUND LOOKING WEST