



U.S. Department  
of Transportation  
**Federal Highway  
Administration**

FHWA Climate Resilience Pilot Program:

# Iowa Department of Transportation

The Federal Highway Administration's (FHWA)'s Climate Resilience Pilot Program seeks to assist state Departments of Transportation (DOTs), Metropolitan Planning Organizations (MPOs), and Federal Land Management Agencies (FLMAs) in enhancing resilience of transportation systems to extreme weather events and climate change. In 2013-2015, nineteen pilot teams from across the country partnered with FHWA to assess transportation vulnerability to extreme weather events and climate change and evaluated options for improving resilience. For more information about the pilot programs, visit: [http://www.fhwa.dot.gov/environment/climate\\_change/adaptation/](http://www.fhwa.dot.gov/environment/climate_change/adaptation/).

**R**iver floods can persist for days or weeks in river basins with gently sloping landscapes like those found in parts of Iowa. The basins drain slowly, creating an extended period over which new rainfall can amplify a flood pulse in the river system and flood bridges and adjacent roadways. To evaluate future flood conditions, Iowa DOT developed a methodology to integrate climate projections of rainfall within a river system model to predict river flood response to climate change. Iowa DOT tested this methodology in two river basins to evaluate its ability to produce scenarios of future flood conditions. They analyzed the potential impact of the predicted future floods on six bridges to evaluate vulnerability to climate change and extreme weather and inform the development of adaptation options.



## Scope

The Iowa DOT collaborated with Iowa State University and the University of Iowa Flood Center to create daily rainfall simulations and future peak discharge flows from 1960 to 2100. The basins chosen for detailed analysis represent one small basin (South Skunk River) with drainage time of about one day, and one larger basin (Cedar River) with drainage time of about one week (Figure 1). Both basins have experienced record flood events in recent years that have overtopped primary highways and the Interstate.

## Objectives

- Collect information, monitor, predict, and evaluate the performance of existing highway structures and roadway embankments with respect to flood inundation during severe rainfall events.
- Determine relevant precipitation metrics in climate projections for transportation infrastructure calculations.
- Quantify the sensitivity of simulated streamflow to projected precipitation change.
- Conduct an assessment of bridge vulnerability to simulated streamflow change using an integrated asset database and bridge-monitoring software application called BridgeWatch.
- Provide adaptation strategies for climate change impacts and review design policy to incorporate climate change.



I-80 overtopping at the Cedar River east of Iowa City, June 2008. Photo credit: Iowa DOT.



IA 1 flood damage by Cedar River near Mount Vernon, June 2008. Photo credit: Iowa DOT.



Close-up of I-80 overtopping at the Cedar River east of Iowa City, June 2008. Photo credit: Iowa DOT.

## Approach

**Asset inventory.** Iowa DOT already has a transportation asset database with information for all bridges in the project areas, including the age of the structure, elevation of roads and low beams, critical streamflow thresholds, scour vulnerability, current plan of action when the bridge is threatened by high streamflow, soils information, past damage from extreme streamflow, and maintenance records. The project team updated the database by performing hydraulic analysis at each of the 80 bridge locations within the two pilot basins to develop streamflow rating curves either based on U.S. Geological Survey (USGS) gauge data (where available) or USGS regression equations.

**Climate data.** The project team obtained historic annual peak flow data from USGS streamflow gauge records at each of the six pilot bridge locations. In addition, the team used historic data from the National Oceanic and Atmospheric Administration (NOAA) Stage IV precipitation analysis; and historic daily precipitation measurements that had been interpolated to a one-eighth-degree latitude-longitude grid across the entire U.S.<sup>1</sup>

The project team used modeled future precipitation data to produce simulations of streamflow, the primary infrastructure stressor. The project team extracted daily precipitation data from 19 climate projections (developed using a range of global climate models and greenhouse gas scenarios) that had been statistically downscaled at 22,781 grid points for 1960–2100. This approach and data source is consistent with the Gulf Coast Study, Phase 2: Temperature and Precipitation Projections for the Mobile Bay Region.<sup>2</sup>

**Streamflow modeling.** The project team used the modeled precipitation data as an input to the river networks analysis tool, CUENCAS hydrological model (a distributed rainfall-runoff hillslope model), to generate streamflow information. The CUENCAS hydrological model breaks the basin geography down into connected segments based on hill slopes to reflect the nature of the area and ensure consistent convex and concave areas within each analysis zone. Strong computing power and high-quality light detection and ranging (LiDAR) data was required for this approach.

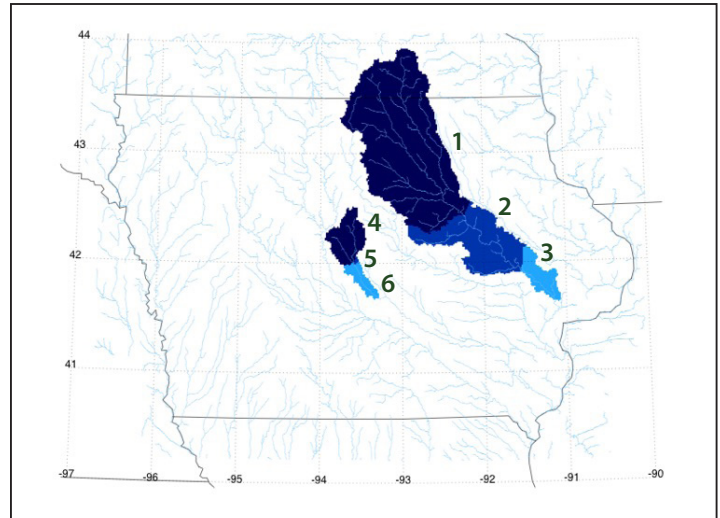


Figure 1: Cedar River Basin (larger area on the right) and South Skunk River Basin (smaller area on lower left) watershed locations. Numbers represent the location of the six bridges included in the analysis.

The project team used the model to independently calculate the percentage of daily rainfall that is absorbed into the soil and the percentage that turns into runoff for each unit of landscape. Because it is a continuous model, precipitation in the days or hours before a rainfall event is stored in the model. This allowed the project team to see that big storms have a larger impact when preceded by small events that increase the antecedent moisture content.

**Future flood estimation.** The project team used the climate model data to generate a continuous 140-year streamflow simulation and to estimate streamflow quantiles (estimates of instantaneous annual-maximum peak flows with recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years) using a modified version of the USGS protocol. The project team then contrasted the flood quantiles computed with and without future climate change to identify the vulnerability due to climate change.

**Credibility analysis.** The project team conducted a two-stage error analysis to determine whether the coarse resolution of the climate model precipitation data would result in unacceptable simulation errors, and to determine if the streamflow simulation error is smaller than the predicted streamflow change due to climate change.

<sup>1</sup> Maurer, E. P., A. W. Wood, J. C. Adam, D. P. Lettenmaier, and B. Nijssen. 2002. A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States. *Journal of Climate*. 15(22): 3237-3251.

<sup>2</sup> Hayhoe, K. and A. Stoner. 2012. Gulf Coast Study, Phase 2 Temperature and Precipitation Projections for the Mobile Bay Region. Climate Science Center, Texas Tech University. [www.fhwa.dot.gov/environment/climate\\_change/adaptation/ongoing\\_and\\_current\\_research/gulf\\_coast\\_study/phase2\\_task2/mobile\\_infrastructure/mblclmtrpt05.cfm](http://www.fhwa.dot.gov/environment/climate_change/adaptation/ongoing_and_current_research/gulf_coast_study/phase2_task2/mobile_infrastructure/mblclmtrpt05.cfm)

**Vulnerability and risk assessment.** The project team integrated projected streamflow statistics with the Iowa DOT bridge and roadway asset infrastructure database to evaluate change in exposure to critical streamflow levels. This allowed the project team to determine increased bridge vulnerability to overtopping (frequency) and

scour (severity) under projected climate change scenarios. The qualitative approach to risk assessment allowed the project team to determine the potential exposure of bridge and roadway sites to high streamflow. The analysis used the future 100-year flood as the key metric for indicating changes in potentially damaging streamflow.

## Key Results & Findings

**Model validation.** The project team had good results using climate projection data to generate a continuous 140-year hydrological simulation. They evaluated accuracy for basin-average annual maximum precipitation (AMP) over a historical climate scenario period (1960–1999) and a “future” climate scenario period (2000–2013). As expected, the project team found that the bias (mean error) was small in the historical period and much larger in the future scenario period. However, the projection range of AMP in the future period included an abrupt change of observed AMP, indicating the projection values are plausible and may serve as input values to hydrological models.

**Vulnerability findings.** Under the climate model projections, all six critical interstate and highway locations would be exposed to streamflow that exceeds current design standards. Each location is projected to have increased vulnerability from more frequent episodes of highway overtopping and potential bridge scour.

“Projected increases in precipitation will increase the vulnerability of our roads and bridges, either directly from flooding or indirectly from changes in annual peak flows deepening or widening the channel or increasing meandering.”

– Iowa DOT Pilot Project Team

**Need for adaptation.** Bridge and highway resilience would need to be improved in four of the six pilot bridge locations to withstand the projected increase in frequency of extreme streamflow conditions. In the South Skunk River Basin, the project team demonstrated that the most cost-effective resilient design is a grade raise of approximately 2 feet to prevent overtopping of the Interstate during a 200-year flood. This will be incorporated into the planned work for the I-35 bridges.

In the Cedar River Basin, the range of projected increase in future streamflow due to climate change roughly translates to an increase in the likelihood of overtopping of 1.6 percent to 10 percent annual probability. Potential impacts include significant disruption to commerce and the traveling public and possible flood damages to the road embankment, pavement, and bridge. One adaptation option for the I-80 bridge east of Iowa City would be to raise the interstate grade; however, an analysis of bridge scour is needed by raising the grade, more water would pass through the bridge opening.

**Communicating results.** Through discussion with the Iowa DOT bridge engineers, the project team created an innovative flood design graph that succinctly conveys vulnerability information to bridge engineers by providing the historical annual peak streamflow, the design metrics based on historical data, and the climate projection data. See Figure 2 for an example.

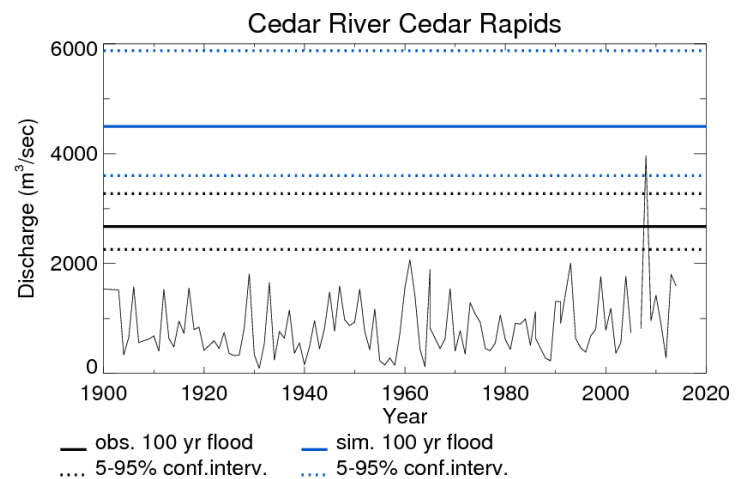


Figure 2: For the Cedar River Bridge at US 151 in Cedar Rapids, annual peak flow (bottom black plotted line), 100-year flood estimate from 1903–2013 measurements (solid black straight line) with confidence intervals from measurements (black dotted lines), and climate projections from 1960–2059 for the 100-year flood estimate (solid blue line) with confidence interval (dotted blue lines).

## Lessons Learned

**Select assets for study that have already experienced damage or disruption.** Iowa DOT found it useful to scope their pilot study by selecting bridges that have had disruptions or damage from recent streamflow extremes. These bridges likely have the most recent and possibly most relevant response information to use when evaluating projections of future streamflow.

**Engage a multidisciplinary team.** Dialogue between climate scientists, hydrologists, and bridge engineers was invaluable.

**Understand the required computing power.** Due to the complex modeling, the computing infrastructure for this pilot project was immense compared to the other vulnerability assessment pilot projects.

**Use a suite of climate change scenarios when developing streamflow projections.** There is significant variability in precipitation projections among climate change scenarios (e.g., A1B, A2, A1FI) and the rainfall response is not necessarily larger under the higher emissions scenarios. Additionally, variability in projected precipitation is large, and this variability can be amplified in river systems. For this reason, Iowa DOT recommends developing streamflow and engineering metrics (like the 100-year flood) using all climate change scenarios.

**Daily precipitation projections are suitable for flood analysis in large basins.** The project team found acceptably low error for simulated peak flow statistics for floods greater than twice the mean annual peak in basins larger than 100 square miles when generated from climate projection rainfall data having daily time step and grid spacing of one-eighth degree. These climate projection data are suitable for analysis of “big floods in big basins.”

## Next Steps

**Integrate findings into BridgeWatch and track damages.** The Iowa DOT will improve real-time monitoring of bridges and highway overtopping by including the infrastructure database information generated for this pilot project into the BridgeWatch program. This will be combined with real-time monitoring of USGS gauge and Next-Generation Radar (NEXRAD) to produce real-time alerts for maintenance staff. Iowa DOT staff will also be able to collect additional vulnerability information, including more precise estimates of maintenance costs associated with specific flood events.

**Conduct additional asset-specific vulnerability assessments.** The outcomes and resources of this pilot project will enable the Iowa DOT to conduct additional facility-level vulnerability assessments, particularly for assets that could be significantly impacted by increased flooding.

**Develop guidelines on estimating impacts of larger flood events.** Given the increase in projected vulnerability and streamflow, policy/guidelines should be developed for analyzing bridge scour when a superflood (greater than 500-year flood) occurs.

**Utilize climate data in cost-benefit analysis.**

Iowa DOT may consider the need to incorporate climate projections into policy considerations and needs determination for quantitative analysis of risk-based cost-benefit analysis.

### For More Information

**Final report available at:**  
[www.fhwa.dot.gov/environment/climate/adaptation/2015pilots/](http://www.fhwa.dot.gov/environment/climate/adaptation/2015pilots/)

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