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RESEARCH PROJECT TITLE

Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot

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The mission of the Institute for Transportation (InTrans) at Iowa State University is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, reliability, and sustainability while improving the learning environment of students, faculty, and staff in transportation-related fields.

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tech transfer summary

An interactive and proactive process is desired to collect, monitor, predict, and evaluate performance of existing Iowa highway structures and roadway embankments during flood inundation, to assist in proactively mitigating these events, and to prepare and plan for future highway improvements.

Background

The Iowa Department of Transportation (DOT) is responsible for approximately 4,100 bridges and structures that are a part of the state's primary highway system, which includes the Interstate, US, and Iowa highway routes. Many of these primary highway structures are impacted during flooding. The expected lifetime of bridges means they may experience different flood conditions under future extreme weather events.

Problem Statement

River floods can persist for days to weeks in river basins with gently sloping landscapes, because the basins drain slowly, creating an extended period over which rainfall can feed into a flood pulse in the river system. This complicated rainfall and streamflow timing mechanism was clearly responsible for the 2008 Cedar Rapids, Iowa flood that exceeded 1.4 times its 500-year flood level and for which Interstate 80 (I-80) was closed.



Closure of I-35 and US 30 for several days due to South Skunk River floods in and around Ames in 2010 (Image: ©James Moreland, retired from Iowa DOT Office of Motor Vehicle Enforcement)

To evaluate future flood conditions, climate projections of rainfall must be integrated within a river system model to predict river flood response to climate change. This is an innovative methodology within bridge design.

Goal

The goal of this project for the Iowa DOT was to develop the necessary building blocks of an interactive and proactive planning process for maintenance, repair, and replacement of Iowa's primary highway structures.

Research Description and Methodology

A pilot study was conducted in two Iowa river basins—the Cedar River Basin and the South Skunk River Basin—to evaluate strengths and weaknesses of technology to produce scenarios of future flood conditions.

Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot project is the only one of the 19 Federal Highway Administration (FHWA) Climate Change Vulnerability Assessment Pilots to link climate projections of precipitation with streamflow simulation to enable vulnerability assessment under climate change scenarios.

The methodology extracts climate model daily precipitation data from 19 climate projections at 22,781 grid points for 1960 – 2100 (22,118,072,900 precipitation data points). It generates continuous 140-year streamflow simulation and uses U.S. Geological Survey (USGS) protocol for estimating streamflow quantiles.

To evaluate change in exposure to critical streamflow levels and assess change in bridge vulnerability, projected streamflow statistics are integrated with the Iowa DOT bridge and roadway asset infrastructure database.



IA 150 near Vinton during 2008 flooding (Image: ©Iowa Department of Transportation)

The pilot methodology assesses the following.

- Spatial and temporal precision needed for climate model data to be credible for hydrologic simulation
- Accuracy of predicted changes in rainfall
- Sensitivity of hydrologic simulation to variability in climate projection data
- Practical considerations for the approach to translate simulated hydrology into engineering metrics
- Vulnerability of six bridge and highway locations
- Solutions to increase resilience of existing hydraulic design for bridges based on current methodologies

Key Findings

Finding 1: Simulated peak flow statistics have acceptably low error 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.”

Finding 2: The credibility of climate projection data for use as input data to generate a continuous 140-year hydrological simulation is confirmed with analysis of prediction error. Accuracy is evaluated for basin-average annual maximum precipitation (AMP) over a historical climate scenario period (1960 – 1999) and a future climate scenario period (2000 – 2013).

Bias is small in the historical period and much larger in the future scenario period, as expected. The projection range of AMP in the future climate scenario period, however, enveloped an abrupt change of observed AMP, indicating the projection values are plausible and may serve as input values to hydrological models.

Finding 3: Streamflow simulation data have larger bias than climate model precipitation data because the lack of correspondence in sequences of precipitation from observed and climate model datasets create different annual peak flow statistics.

Streamflow simulation error is tractable in vulnerability analysis because it is smaller than the predicted streamflow change due to greenhouse gas increases.

Finding 4: An approach was developed to maintain consistency with USGS protocol for calculating flood quantiles by defining two estimation periods for which full simulated streamflow records are used: historical period (1960 – 2009) and hypothetical bridge lifetime period (1960 – 2059).

The primary engineering metric of interest is the 100-year flow (1% annual exceedance-probability discharge or AEPD). Confidence intervals are used to evaluate change in 1% AEPD estimates for the historical period and hypothetical bridge lifetime period.

The analysis showed a median of the 19 climate projection 1% AEPD estimates for each period increases more in the Cedar River Basin compared to the smaller South Skunk River Basin.

Finding 5: 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.

For instance, I-80 over the Cedar River currently overtops for the 1.6% AEPD (60-year flood), but the same discharge is projected to be approximately a 10% AEPD (10-year flood) over the lifetime of the bridge.

Potential impacts include significant disruption to commerce and the traveling public and possible flood damages to the road embankment, pavement, and bridge.

Finding 6: 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.

Balance must be obtained between the disruption to the traveling public and damage associated with highway overtopping versus the integrity of a bridge to accept all the flow from an extreme flood event.

We illustrate cost-effective bridge design based on the 100-year flood (1% AEPD) estimate from measurements, using the flexible streamflow scenario analysis approach described in Findings 3 through 5.



IA 6 (top) and IA 24 bridge in Winneshiek County (bottom) during 2008 flood (Images: ©Iowa Department of Transportation)

Implementation Readiness and Benefits

This project supports the effort to prepare and plan for future highway improvements through evaluation of simulated streamflow to precipitation change based on climate scenarios. Assessment of the vulnerability of various highway sites was analyzed for future infrastructure design and mitigation based on climate scenarios.

The Iowa DOT plans to use the results of this project to help in assessing impacts and integrating information into the BridgeWatch program to provide a proactive alert system to enhance safety for the traveling public.

It is anticipated that this effort will lead to dialogue with the FHWA on the effective use of climate scenarios in climate vulnerability assessment and adaptation planning.

Project Successes and Accomplishments

Iowa's Bridge and Highway Climate Change and Extreme Weather Vulnerability Assessment Pilot project developed insights, resources, and infrastructure that could be expanded upon by the Iowa DOT and translated into use by other transportation agencies as follows:

- Determined that the leading edge of downscaled climate projection data resolution (one-eighth degree and daily increments) was sufficient for vulnerability analysis of “Big Basins and Big Floods,” quantitatively defined as basins exceeding 100 square miles with floods exceeding twice the mean annual peak flow.
- Determined engineering design metrics could be developed from streamflow simulation over a long, continuous period spanning historical and future climate conditions (e.g., continuous streamflow for 1960 – 2059).
- Determined the annual peak streamflow response to climate change likely will be basin-size dependent. The larger basin had a larger response in flood quantiles. This could motivate a screening strategy for expansion of vulnerability analysis to other bridges across Iowa.
- Developed an innovative flood design graph for bridge vulnerability analysis that conveys succinctly to bridge engineers the historical annual peak streamflow as well as design metrics based on historical data and climate projection data.
- Determined that under climate projections, four of six pilot study bridges would be exposed to increased frequency of extreme streamflow and would have higher frequency of overtopping.
- Determined the proposed design for replacing the I-35 bridges over the South Skunk River is resilient to climate change. The cost-effective design ensures the bridge would not overtop I-35 for the current 0.5% AEPD (200-year flood) and would not change flood elevations up to the 0.2% AEPD (500-year flood).
- Created the software and database infrastructure to perform this analysis statewide and to link it with real-time bridge monitoring and alert systems.
- Identified Iowa DOT bridge design policies that could be reviewed for consideration of incorporating climate change information.



Four-day closure of I-80 across the eastern half of Iowa in 2008, which caused 120-mile detour between Davenport and Des Moines (Image: ©Keven Arrowsmith, Iowa Department of Transportation)

Planned and Anticipated Next Steps

We have several planned activities to integrate into other facets of Iowa DOT bridge design, planning, and maintenance of the resources and information from this pilot study.

- 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) rainfall data to produce real-time alerts for maintenance staff. Iowa DOT staff will also be able to build-out new facets of vulnerability and more precise estimates of costs by documenting and capturing in real-time the flood damages and maintenance costs associated with alerted events.
- The outcomes and resources of this pilot project will enable the Iowa DOT to consider broader assessment of facility-level vulnerability, particularly for assets that could be significantly impacted by increased flooding.
- Policy/guidelines should be developed for analyzing bridge scour when a superflood (greater than 500-year flood) occurs, given the increased vulnerability that became apparent with this project's streamflow projections.
- The pilot outcomes may motivate discussions to incorporate climate projections into policy considerations and needs determination for quantitative analysis of risk-based cost-benefit analysis. Topics of discussion may include: list of relevant costs, definition of risk for bridge-potential traffic interruption or bridge failure, identification of adaptation alternatives, and policy regarding flood quantile thresholds for critical infrastructure.