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U.S. Department of Transportation
Federal Highway Administration

FHWA Climate Resilience Pilot Program:

Minnesota Department of Transportation

The Federal Highway Administration's (FHWA) Climate Resilience Pilot Program seeks to assist state Departments of Transportation (DOTs), Metropolitan Planning Organizations (MPOs), and Federal Land Management Agencies (FLMAs) in enhancing the resilience of transportation systems to extreme weather and climate change. In 2013–2015, 19 pilot teams from across the country partnered with FHWA to assess transportation vulnerability to climate change and extreme weather events, and evaluate options for improving resilience. For more information about the pilots, visit **http://www.fhwa.dot.gov/environment/climate_change/adaptation**.

Minnesota Department of Transportation (MnDOT) planners and engineers have long considered minimizing the risk of flash flooding in the siting and design of the state's roadway network; however, they are now working to integrate the potential for increased flooding as the climate changes. In two Districts, the pilot project team conducted a vulnerability assessment of bridges, culverts, pipes, and roads paralleling streams to flooding related to increased heavy precipitation. Based on preliminary vulnerability assessment results, they selected two culverts in which to conduct case studies of facility-level adaptation planning that considered the potential for damage and economic losses associated with flash flooding. The project findings and recommendations are informing MnDOT's ongoing asset management planning.

Scope

In conjunction with state, local, and MnDOT stakeholders, the project team assessed the vulnerability of 1,819 assets (including bridges, large culverts, pipes, and roads paralleling streams) on Minnesota's trunk highway system to flash flood risks from increased heavy precipitation.

The project team conducted the study in two MnDOT districts that have experienced particularly severe flooding in recent years: District 1 in northeast Minnesota and District 6 in the southeastern portion of the state.

Objectives

- Better understand the vulnerability of the state's trunk highway system (including interstates, U.S. routes, and state roads) to flash flooding events.
- Develop a process to identify cost-effective planning and design solutions for specific facilities to increase resiliency.
- Support MnDOT's asset management planning efforts.
- Provide FHWA with feedback and lessons learned on the assessment process.

Roadway erosion following flooding event. Photo credit: MnDOT.

Bridge filled with debris during flood event. Photo credit: MnDOT.

Roadway collapse during flood event. Photo credit: MnDOT.

Approach

Form advisory committees. The project team relied on a Technical Advisory Committee (consisting of hydrologists and engineers from MnDOT District offices, counties, and the state) to provide critical input on the approach; a Climate Advisory Committee (consisting of climate experts from state agencies) to provide guidance on the climate projections; and an overarching Core Advisory Panel of engineers and planners to provide strategic direction throughout the project.

Develop and apply vulnerability metrics. For each asset type, the project team developed a unique set of metrics for exposure, sensitivity, and adaptive capacity to assist in understanding vulnerability to flash flood risks (see Figure 1 for examples). The team drew vulnerability metrics data from a mix of hydraulic analysis (using U.S. Geological Survey StreamStats), work sessions with district staff, geographic information system analysis, and existing MnDOT databases. Some of the most important metrics to the analysis (e.g., the percentage change in design flow required for overtopping) were developed with the aid of a hydraulics tool that interfaces with MnDOT's asset management system developed as part of this project.

Weight and score vulnerability. The project team scaled each of the metrics to a common zero- to 100-point scale. The scale varied based on the district. Then, the project team weighted the metric, using higher weights for metrics perceived as more important to characterizing vulnerability. The project team combined the weighted metrics to produce composite exposure, sensitivity, adaptive capacity, and vulnerability scores for each asset. For bridges, large culverts, and pipes, each vulnerability component was weighted equally. For roads paralleling streams, exposure was given the highest weight (43.3 percent), followed by adaptive capacity (33.3 percent) and sensitivity (23.3 percent).

Tier the vulnerability results. At the district level, the project team identified statistical clusters in the data distribution and grouped assets with similar scores into five tiers of vulnerability. By not combining the weighting and binning process across the two districts, the analysis supports district-level capital planning and allows future districts to replicate this process without having to recalculate the results for Districts 1 and 6.

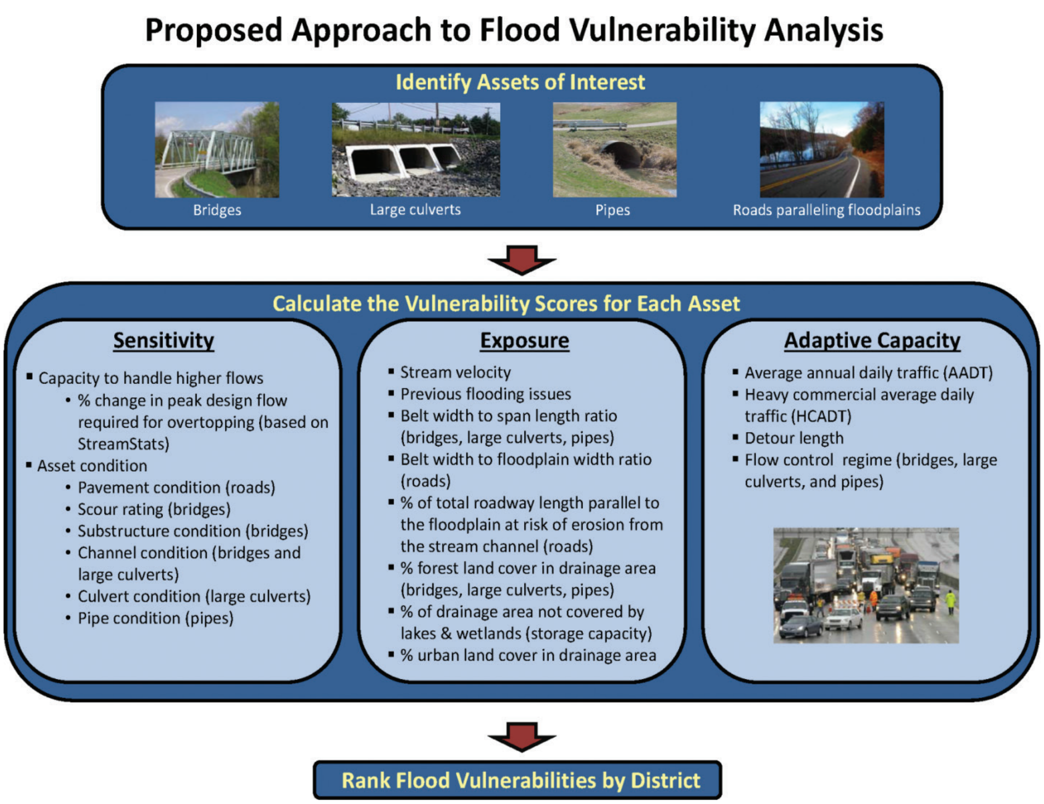

Figure 1: Flood Vulnerability Analysis Approach.
Figure source: MnDOT Flash Flood Vulnerability. and Adaptation Assessment Pilot Project: Final Report

Conduct facility-level assessment. The project team selected a vulnerable large culvert from each district for a facility-level assessment. The assessments follow the *General Process for Transportation Facility Adaptation Assessments* (the 11-Step Process) developed by the U.S. Department of Transportation for the Gulf Coast Study, Phase 2.

MnDOT took the following approach to the 11-Step Process:

1. **Describe the site context**. Included information on annual average daily traffic, location, major uses, and hydrologic setting.
2. **Describe the existing/proposed facility**. Included information on facility geometry, materials, useful life, and current conditions.
3. **Identify climate stressors that may impact Infrastructure Components**. Focused on flash flooding.
4. **Decide on climate scenarios and determine the magnitude of changes**. Created three future precipitation scenarios using outputs from 22 global climate models based on RCP4.5, RCP6, and RCP8.5. These data were downscaled[1] using SimCLIM, and the modeled percent changes in precipitation depths were applied to the historic National Oceanic and Atmospheric Administration Atlas 14 data.
5. **Assess performance of the existing/proposed facility**. Used hydrologic models to project peak flows for various storm events and determine whether the existing structure would meet the freeboard requirements and the potential for scour.
6. **Identify adaptation option(s)**. Based on the 2100 peak flow projections, designed one adaptation option for each climate scenario.
7. **Assess Performance of the adaptation option(s)**. Analyzed the degree of flooding during the 50-year storm event under each climate scenario.
8. **Conduct an economic analysis**. Used the COAST benefit-cost tool to analyze physical damage costs, travel time delay costs, and potential for motorist injury, and compared the results to an analysis including only physical damage costs.
9. **Evaluate additional decision-making considerations**. Evaluated broader project sustainability, project feasibility and practicality, ongoing maintenance needs, capital funds availability, and stakeholders' tolerance for risk of service interruption.
10. **Select a course of action**. Provided preliminary recommendations based on the cost-benefit results.
11. **Plan and conduct ongoing activities**. Recommended continuing to monitor the facilities after construction and to record ongoing costs.

[1] Downscaling refers to the process of translating coarse geographic resolution climate projections from global climate models into higher geographic resolution projections more relevant for site-level analyses.

Key Results & Findings

Vulnerability results. The most vulnerable assets in District 1 are bridges and pipes. In District 6, roads paralleling streams and bridges are most vulnerable.

District 1 Silver Creek case study results. The existing two-cell box culvert, built in 1936, is at the end of its useful life, with a replacement planned in 2020. MnDOT analyzed the performance of four replacement options: a base case replacement designed to today's standards, and three alternative options, each designed to perform optimally in the year 2100 under three different climate precipitation scenarios. These alternatives included a larger two-cell culvert and two different bridge designs.

If the social costs of detours and injuries are included in the cost estimates, an expanded two-cell culvert, designed to meet a low precipitation scenario, is the most cost-effective design under all future precipitation scenarios. However, when social costs are excluded, the most cost-effective option varies between replacing the existing culvert with one designed to today's standards and replacing it with the expanded two-cell culvert.

Based on these results, the project team initially recommended the expanded two-cell culvert for this site; however, other decision-making considerations will have to be explored before a final recommendation can be made.

District 6 Spring Valley case study results. The project team analyzed the performance of the existing three-cell box culvert, built in 1937, and three replacement options: expanding the culvert from three cells to five (both with and without floodplain enhancement efforts) and replacing the culvert with a three-span bridge. Only replacing the culvert with a three-span bridge would eliminate the risk of overtopping under today's 50-year storm.

Whether or not the social costs of detours and injuries were included, an expanded five-cell culvert without floodplain enhancement is the most cost-effective design in all future rainfall scenarios. However, additional conditions, such as upstream flooding of private property, water quality, and the project permitting requirements, need to be fully considered before a final course of action can be selected.

Lessons Learned

Vulnerability components can be isolated and/or variably weighted. The FHWA vulnerability framework merges exposure, sensitivity, and adaptive capacity into one vulnerability score. It may be more appropriate to calculate a range of risk factors, both with and without adaptive capacity measures.

Downscaled precipitation data is not very refined. The uncertainty in the projected local precipitation data is uncomfortable for engineers who have worked primarily with statistically derived data from the past to identify asset risk. The pilot project team ultimately deemed the downscaled data not appropriate for decision-making.

StreamStats is an acceptable replacement for Light Detection and Ranging data (LIDAR). Though StreamStats uses a coarser elevation dataset, LIDAR data could not be used to generate drainage areas for each asset because of "digital dams" in the dataset (i.e., instances where water is conveyed through an embankment by a culvert that is not recognized in the LIDAR data).

Next Steps

Mainstream project results. Use this study to illustrate the threat posed by climate change in the long-range transportation plan. Incorporate identified risks into culvert and bridge improvement programs, asset management databases, the asset management plan, and MnDOT's risk registers. Develop emergency action plans and real-time monitoring and warning systems for vulnerable assets. Incorporate cost-effective adaptation projects into the capital plan and prioritize funding for vulnerable assets.

Expand the analysis. Complete vulnerability assessments in other districts and other types of "assets" (i.e., slopes). Conduct facility-level adaptation assessments on major projects or corridors with a large number of vulnerable assets, as well as assets that are under-capacity, have high social costs of failure, and are not planned for replacement.

"Flooding is not the only threat to the state's highway system posed by climate change, but it is likely to be one of the most significant and has already caused extensive disruptions in many areas."

-Philip Schaffner, MnDOT Project Team

Monitor and refine. Test the sensitivity of vulnerability scoring to different criteria weighting and the exclusion of the adaptive capacity component. Gather data on waterway opening dimensions and other relevant variables. Monitor updates to climate projections and advances in climate downscaling methodologies.

For More Information

Resources:

MnDOT Flash Flood Vulnerability and Adaptation Assessment Pilot Project: Final Report

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