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Improving Flood Resilience Using Stream Simulation Crossings: A Case Study from Wisconsin

Flood damage to road-stream crossings presents a safety hazard and is expensive to repair. While crossing structure design has progressed over time to address flood resilience, little research has been conducted to evaluate the performance of culverts and bridges after floods. In 2016, an extreme flood in northwestern Wisconsin created an opportunity to address this knowledge gap.

On July 11 and 12, parts of the Great Divide Ranger District of the Chequamegon-Nicolet National Forest received 9 inches of rainfall in 6 hours. The resulting flooding produced peak flows at 21 sites that were, on average, 4.6 times greater than a flood with only a 1 percent chance of occurring in any year. These flows greatly exceeded even the highest design standards for road-stream crossings.

Before the flood, some crossing structures had been replaced with new structures designed using the stream simulation approach, which requires structures to be at least as wide as the bankfull width of the stream, among other criteria. The storm provided an opportunity for personnel from U.S. Department of Agriculture, Forest Service, to team up. Hydrologist Dale Higgins and staff at the Chequamegon-Nicolet National Forest and ecologist Deahn Donner of the Northern Research Station assessed the impact of flooding on traditional and stream simulation road-stream crossings and determined the landscape characteristics that were more closely associated with flood vulnerability. They gathered peak flood flows estimates on 26 road-stream crossings—9 traditional crossings and the 17 stream simulation culverts and bridges—and published the results of the case study.

PUBLIC BENEFITS

Flood-resilient, stream simulation road-stream crossings protect roads from damage and in turn reduce repair costs, increase access to recreation areas, and improve road safety. These crossings also allow aquatic organisms to pass through and support fish populations, thereby protecting wildlife that depend on fish for food and supporting recreation opportunities.

Success of Stream Simulation Crossings

Between 2001 and 2015, the Chequamegon-Nicolet National Forest staff replaced 17 traditional crossings with stream simulation crossings. The stream simulation design approach was developed to allow aquatic organisms to pass under roads; it designs a stream channel through the crossing, and a culvert or bridge is built around the channel. This approach differs from the traditional approach, which sets the design of the structure around flood flow rate estimates and results in the smallest crossing that meets the specified headwater-to-depth ratio for those estimates. Many road management agencies set design standards using this traditional approach.

In 2016, the stream simulation structures survived the flood at a higher rate than the traditional culverts. Of 17 stream simulation structures, 1 structure failed and 13 of the surviving structures were overtopped during the flood. Of the 9 traditional structures in the study, 5 were overtopped and 4 of these failed. Notably, the 13 stream simulation structures that

A stream simulation crossing at the Chequamelon-Nicolet National Forest that did not overtop during the 2016 flood. USDA Forest Service photo by Dale Higgins.

were overtopped but did not fail were bankfull width or greater, and all had measures to prevent erosion including riprap around the structure and dense vegetative ground cover.

The 2020 construction cost estimates for the 17 stream simulation crossings were higher than for traditional crossings. The cost difference varied by type. Stream simulation culverts were 21 percent more expensive, on average, than traditional culverts. Stream simulation bridge-type crossings were nearly five times (479 percent) more expensive. Costs varied with site characteristics, such as the degree to which the previous crossing was undersized.

Taken together, the researchers concluded that stream simulation culverts offered both environmental benefits and greater flood resiliency, which offset the small increase in cost. Bridge-type structures were more expensive largely because the previous structures were undersized, but the new structures provided substantial flood resilience.

Landtype Association and Watershed Characteristics

The team also used differences in peak flow measurements at the stream crossings in the study to assess vulnerability to flooding, and they explored relationships among landtype association (units of land defined by topography, geology, soil, vegetation, and climate) and watershed characteristics. They found that higher peak flows were associated with the following characteristics:

A failed traditional crossing at the Chequamegon-Nicolet National Forest following the 2016 flood. USDA Forest Service photo by Dale Higgins.

- Steeper main channel slopes
- Decreased natural water storage capacity in the form of lakes and wetlands
- Increased drainage density (i.e., density of streams per unit area)
- Finer soils

Flood vulnerability was highly correlated with landtype association; in particular, the Penokee/Gogebic Iron Range landtype association—with shallow silt soils, greater topographic relief, and less natural water storage compared to other landtype associations—was the most vulnerable. These relationships could be explained in part by relationships between watershed characteristics and peak flood flow.

Designing Flood-Resilient Road Crossings

Using the correlations among landtype association and flood runoff, the team extrapolated those results across Wisconsin and categorized flood vulnerability into four classes based on drainage density, storage, flood flow rates, and professional judgment. Drawing upon these results and years of professional experience, the team provided guidance on adjusting crossing design based on overall vulnerability and specific hydrology and topography of sites (Fig. 1).

Overall, results of this case study demonstrate that stream simulation crossings are more resilient to flooding and that landtype associations and watershed characteristics can predict vulnerability to increased flooding. Although stream simulation crossings cost more up front, replacing traditional crossings and adjusting the design based on site-specific vulnerabilities could improve resilience to intense rainfall and extreme floods.

KEY MANAGEMENT IMPLICATIONS

- During an extreme flood in 2016, 16 of 17 structures designed using the stream simulation method survived.
- Stream simulation structures are more flood resilient because they are at least as wide as the bankfull channel width.
- Areas with steep slopes, less water storage capacity, and finer soils had more rapid runoff.
- Landtype associations, which are ecological land units defined by their topography, soils, and other factors, were highly correlated with flood vulnerability.

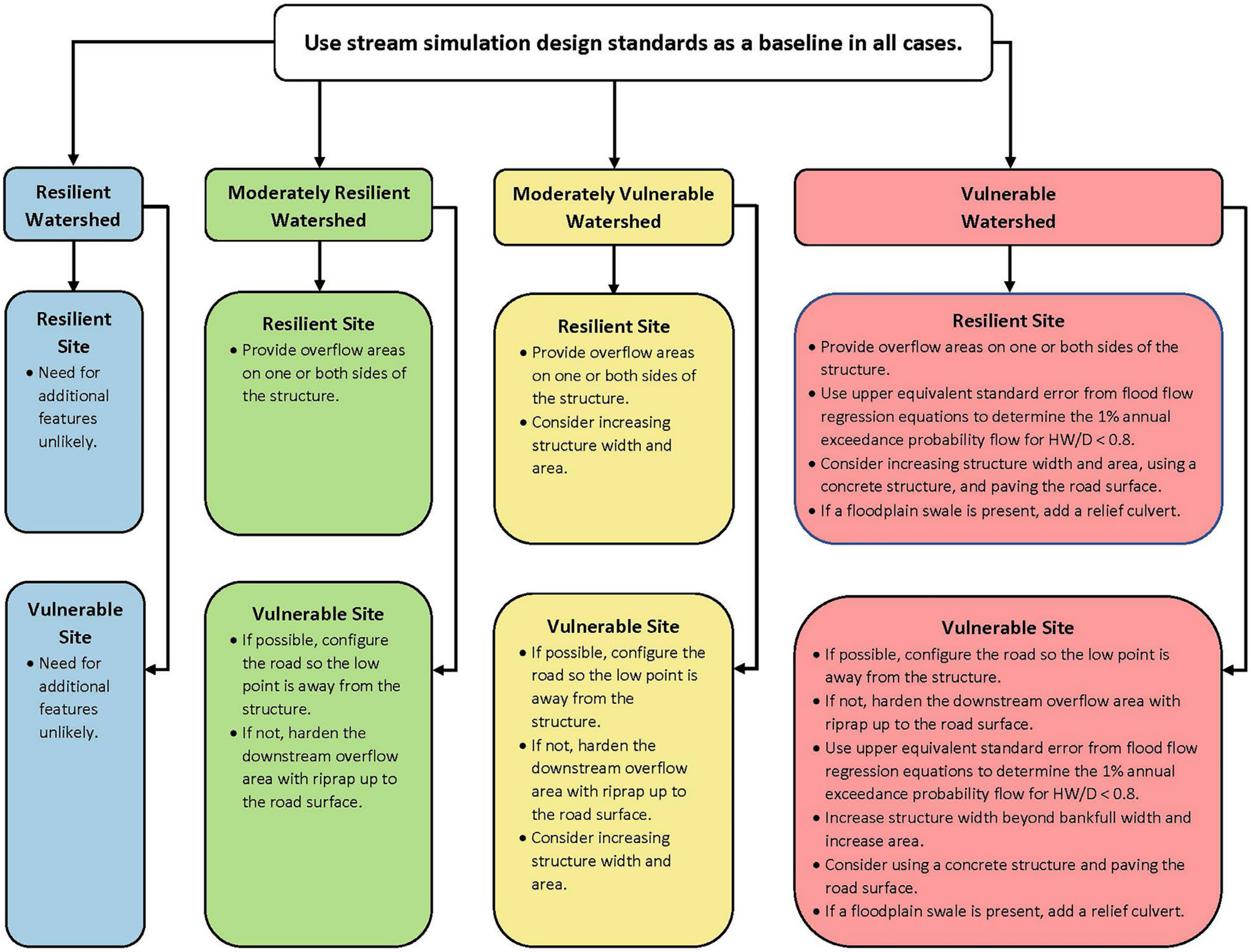

Figure 1.—Baseline and supplement design features to enhance flood resiliency. HW/D = headwater-to-depth ratio. Source: Higgins and Donner (2025).

PROJECT LEADS

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Jenna Zukswert is the author of this Rooted in Research science brief.

FURTHER READING

Higgins, Dale; Donner, Deahn M. 2025. Designing flood resilient road-stream crossings: a case study from the July 2016 northwest Wisconsin flood. Gen. Tech. Rep. NRS-231. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 69 p. https://doi.org/10.2737/NRS-GTR-231.

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