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

FHWA Climate Resilience Pilot Program:

Connecticut 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/**.

Extreme precipitation events have been more frequent and intense in Connecticut in recent years, resulting in damage to Connecticut DOT (CTDOT) infrastructure and posing safety concerns. CTDOT conducted a systems-level vulnerability assessment of bridge and culvert structures from inland flooding associated with extreme rainfall events. The assessment included data collection and field review, hydrologic and hydraulic evaluation, criticality assessment, and hydraulic design criteria evaluation. This project complements numerous other facility assessments CTDOT has conducted both independently and jointly with other state agencies in the past as well as the tri-state *Hurricane Sandy Follow-up and Vulnerability Assessment and Adaption Analysis* (focused on coastal assets and adaptation efforts transportation infrastructure).

Scope

The project evaluated the hydrologic and hydraulic performance of CTDOT bridge and culvert structures (six feet to 20 feet in length) located in the (primarily rural) northwest corner of Connecticut from inland flooding associated with extreme precipitation events. This information fed into a systems-level vulnerability and criticality assessment that considered the adaptive capacity of the structures to future changes in precipitation patterns due to climate change.

Objectives

- Develop information on vulnerability and criticality that can be used to assist CTDOT in identifying and prioritizing replacement and reconstruction efforts where needed.
- Conduct an assessment of facilities and assets in a part of the state that has not been comprehensively studied and has limited detour and accessibility options in the event of a structure failure.

Two cell box culvert in rural Connecticut. Photo credit: ConnDot Hydraulics and Drainage Section.

Severe roadway damage during a storm. Photo credit: Foothills Media Group, 2011.

Culvert with surrounding vegetation. Photo credit: ConnDot Hydraulics and Drainage Section.

Approach

Data Collection and Field Review

Collect historical precipitation data. The project team used a suite of precipitation data for the hydraulic evaluations, including NOAA TP-40, NOAA Technical Memorandum NWS HYDRO-35, U.S. Geological Survey (USGS) Regression Equations, and NRCC-NRCS ("Precip.net"). All of these sources rely on historical data and do not take into account future changes in precipitation patterns due to climate change.

Table 1 shows the difference between the old TP-40 and the newer Precip.net data. The differences between the data sets become larger as the storm frequency becomes more remote (decreases in probability) and precipitation depth more extreme.

	24-Hour Precipitation (Inches)			
	50-Year		100-Year	
	Min.	Max.	Min.	Max.
TP-40	6.2	6.2	7.0	7.0
Precip.net	7.0	7.5	8.3	9.0
Difference (%)	12.9	21.0	18.6	28.6

Table 1: Approx. Min./Max. Precipitation Estimates Within Project Limits

Identify culvert/bridge structures for field evaluation. The project team used the state's bridge inventory to identify 60 culvert/bridge structures that met at least one of the following criteria:

- Poor structural condition rating;
- High average daily traffic (ADT);
- Not recently built or reconstructed;
- On a "Designated National Network" (national network for trucks); and
- A Waterway Adequacy rating of 5 or lower.

Additionally, the project team sought to identify structures in a varied range of drainage areas (from 0.1 to 6 square miles, as determined by USGS StreamStats).

The project team conducted field reviews for the selected structures to gather additional site information, assess the site conditions, verify watershed limits, and obtain measurements for the hydraulic evaluations. Following the field reviews, the team selected 52 structures for advancement.

Hydrologic and Hydraulic Evaluations

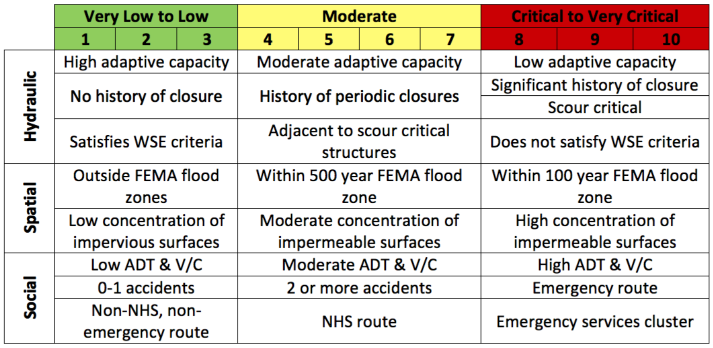
The team evaluated the structures for hydraulic adequacy based on the current design criteria. Depending on watershed size, the team performed hydrologic calculations using the Rational Method, SCS Unit Hydrograph, or USGS Regression Equations (StreamStats) to determine design and check discharges. Each of these methods uses precipitation as an input parameter.

The project team used FHWA's Culvert Analysis Program HY-8 and peak discharge information from StreamStats to evaluate the hydraulic adequacy of the structures and to develop rating (performance) curves illustrating the hydraulic performance of the structures over a range of flow conditions. Structures were determined to be hydraulically adequate if the hydraulic design criteria were satisfied for the current design discharge estimate (using the Precip.net data). Additionally, the headwater (flood) elevations in relation to the roadway or any adjacent buildings, as well as the flow velocity in relation to potential erosion and scour, were examined under a range of flows.

If a structure was determined to be hydraulically adequate, the project team assessed whether the structure has additional hydraulic capacity that would make it more adaptive to variations in the discharge estimate. This additional hydraulic capacity provides a cushion for uncertainties in the hydrologic/hydraulic calculations and for changes in precipitation and extreme weather events due to climate change.

Criticality Assessment

The project team evaluated the criticality of the structures that underwent the hydraulic and hydrologic assessment using the approach piloted by the Washington State DOT in their 2011 Climate Impacts Vulnerability Assessment report. In creating their own Criticality Matrix (see Table 2) the project team included both quantitative and qualitative criteria. These criteria are grouped under three categories



	Very Low to Low			Moderate				Critical to Very Critical		
	1	2	3	4	5	6	7	8	9	10
Hydraulic	High adaptive capacity			Moderate adaptive capacity				Low adaptive capacity		
	No history of closure			History of periodic closures				Significant history of closure		
								Scour critical		
	Satisfies WSE criteria			Adjacent to scour critical structures				Does not satisfy WSE criteria		
Spatial	Outside FEMA flood zones			Within 500 year FEMA flood zone				Within 100 year FEMA flood zone		
	Low concentration of impervious surfaces			Moderate concentration of impermeable surfaces				High concentration of impermeable surfaces		
Social	Low ADT & V/C			Moderate ADT & V/C				High ADT & V/C		
	0-1 accidents			2 or more accidents				Emergency route		
	Non-NHS, non-emergency route			NHS route				Emergency services cluster		

Table 2: CTDOT Criticality Matrix

that pertain directly to the capacity and characteristics of the structures: hydraulic, spatial, and social.

While many of the inputs into the criticality matrix were quantitative in nature, the overall judgment of a structure's criticality was assessed qualitatively by the project team. Merely providing numerical weights to various factors did not allow for nuanced and context-sensitive understanding of the criticality of each structure within the system. In many cases, mapping the structure, the surrounding emergency services, land uses, and accidents was a useful tool for determining ratings. Based on the combined values of each factor, the project team assigned structures overall Criticality Rankings of Low, Moderate, or Critical.

Key Results & Findings

The hydraulic evaluations showed that 34 of the 52 structures evaluated (65 percent) satisfied the design water surface elevation criteria for the specified design frequency discharge based on the current precipitation estimates. Thirteen of these structures may require some corrective action due to scour, however. Eighteen of the 52 structures (35 percent) do not satisfy the hydraulic design criteria and are therefore hydraulically inadequate based on the current precipitation estimates. Four of these structures would have been considered hydraulically adequate if the project team had used the old TP-40 precipitation estimates rather than the Precip.net data.

> "The results of this project will aid in determining where limited resources can best be directed to limit road closures in communities where closures have an immediate and significant impact on residents' daily lives."
>
> – CTDOT Pilot Team

Sixteen of the 34 hydraulically adequate structures were determined to have sufficient additional capacity to be considered adaptive to potential increases in discharge. Most of the structures that were not considered adaptive have sufficient additional headwater capacity to exceed their design flood frequency; however, increased velocity and potential scour is a concern.

There are no clear observations to indicate that CTDOT's existing structures, which were designed using older data and methods, are now significantly under-designed based on their performance over the last few decades. At this point, age and deteriorating condition are more likely to contribute to a structure's vulnerability than climate change. However, when exceptions to one or more of today's design standards are made for reasons such as site constraints, reducing environmental and property impacts, project scope and funding limitations, the structures may become less adaptable.

Based on the qualitative criticality scoring process, the bulk of the structures (20) received moderately critical ratings, while 19 structures were rated critical or very critical. See Figure 1 for a distribution of scores across structures.

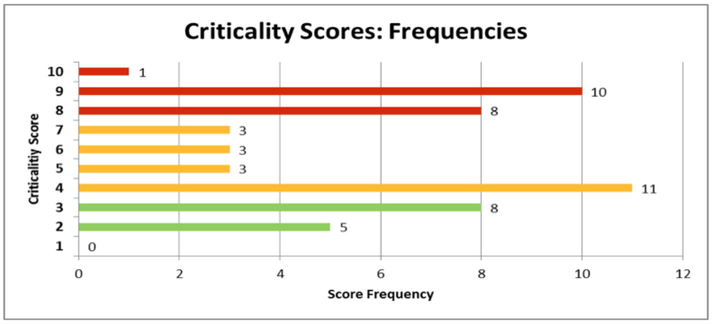


Figure 1: Frequency of Criticality Scores

Lessons Learned

Seek earlier and continued coordination with local emergency responders. Obtain their input on the criticality of roadways and structures.

Develop the data collection process and final presentation format early in a project. Doing so allows for increased automation and more budget for evaluations and analyzing results.

Include a cost factor in future criticality assessments. The hydraulic, spatial, and social criteria support the identification and prioritization of structures critical to preserving life and safety during an emergency event. A cost factor would assist in assessing the risk of the structure in monetary terms and, therefore, assessing the value or financial need to prioritize replacement.

Upsizing structures should not become the de facto approach to addressing climate trends. There needs to be a common understanding of purpose among all stakeholders due to the potential for increased downstream flooding when structures are upsized.

Conduct risk evaluation coupled with an economic cost analysis to address the risks and costs associated with extreme flood events at critical highway structures. A more strict, blanket adjustment of design flood frequencies is not recommended to address potential climate change trends due to the uncertainty surrounding precipitation projections.

Next Steps

Disseminate design-related findings and recommendations. Prepare a technical memorandum providing recommendations to department staff and consulting engineers. This memo will include guidance on using Precip.net and NOAA Atlas 14 data (when available), and other lessons learned from the project.

Integrate the results into existing datasets and practices. This integration should be twofold:

- Coordinate with the Bridge Management group to determine how to integrate the results of the hydraulic evaluations and criticality assessments into the bridge inventory.
- Outline a plan and process for how the department can better incorporate risk assessment/life cycle cost-benefit analysis into hydraulic design and asset management.

Coordinate with federal, state, and local partners. Coordination will require the following actions:

- Discuss with USGS updates to the regression equations for estimating stream flows.
- Conduct outreach to determine if there is interest in re-establishing a hydrology committee to develop more consistent practices in hydrology on a statewide basis and facilitate discussion of climate adaptation and resiliency strategies.
- Work with municipalities on context-dependent adaptation strategies and other tools to expand the adaptive capacity of at-risk structures.

For More Information

Final report available at:
www.fhwa.dot.gov/environment/climate/adaptation/2015pilots/

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