Bringing Flood Resiliency into MassDOT Asset Management
ACKNOWLEDGEMENTS

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FHWA Asset Management, Extreme Weather, and Proxy Indicators Pilot Project
• **Where** is infrastructure vulnerable?

• **Why** are those assets vulnerable?

• **How** do we reduce risk?
<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major basins</td>
<td>8</td>
<td>From NHDPlus HR, USGS Hydrologic Unit Code 4 (HUC-4)</td>
</tr>
<tr>
<td>Watersheds</td>
<td>20</td>
<td>From NHDPlus HR, HUC-8</td>
</tr>
<tr>
<td>Stream channels</td>
<td>16,704 miles</td>
<td>From the NHDPlus-HR. Excludes intermittent streams. Includes stream orders 1 through 8.</td>
</tr>
<tr>
<td>State Roads</td>
<td>4,443 miles</td>
<td>Approximated from GIS.</td>
</tr>
<tr>
<td>State Culverts</td>
<td>1,171</td>
<td>State-owned structures from the MassDOT Culvert Database. Excludes culverts not on a mapped stream channel or that do not have a known width.</td>
</tr>
<tr>
<td>State Bridges</td>
<td>2,787</td>
<td>NBI and short-span bridges in the MassDOT Bridges Database owned by the state or a municipality. Excludes coastal bridges.</td>
</tr>
</tbody>
</table>

- MassDOT Road Inventory (MassDOT, 2018b): 55,977 miles of roads. The average road segment length is 0.1 miles.

- National Hydrography Dataset High-Resolution (NHDPlus HR) (USGS, 2018): 16,704 miles of GIS stream centerline segments. The average channel segment length is 0.2 miles.

- The MassDOT Culvert Database: 5,582 culverts. Focus on 1,171 culverts on perennial streams.

- The MassDOT Bridge Database: 3,120 structures. Focus on 2,787 bridges on perennial streams.
METHODS
GEOMORPHIC COMPATIBILITY

Percent-Bankfull Channel Width = \frac{\text{Structure Width (} W_{\text{structure}} \text{)}}{\text{Bankfull Channel Width (} W_{\text{bankfull}} \text{)}}

- **Percent Bankfull** as a proxy indicator for **Geomorphic Compatibility**
- Damages tend to occur structures that do not span the bankfull width

(MMI, UMass, MassDOT, 2017)
METHODS

GEOMORPHIC COMPATIBILITY

Percent-Bankfull Channel Width = \frac{\text{Structure Width (W}_{\text{structure}})}{\text{Bankfull Channel Width (W}_{\text{bankfull}})}

W_{\text{bankfull}} = 15.0418 \times \text{Drainage area}^{0.4038}

(Bent and Waite, 2013)
### METHODS

**GEOMORPHIC COMPATIBILITY**

<table>
<thead>
<tr>
<th>Percent Bankfull Width</th>
<th>Estimated Geomorphic Compatibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 49%</td>
<td>Low</td>
</tr>
<tr>
<td>50 – 100%</td>
<td>Moderate</td>
</tr>
<tr>
<td>&gt; 100%</td>
<td>High</td>
</tr>
</tbody>
</table>

(Mitchel Brook, Conway Road, Whately, MA) (AR and MADER, 2016)
Specific Stream Power $\times$ Predicted Bed Resistance

Proxy indicators for potential channel bed erosion

Damage more common in mid-range power ($100 – 300$ W/m²) with low resistance bed material
METHODS
POTENTIAL CHANNEL BED EROSION

Specific Stream Power (SSP) = \( \frac{\text{Weight of Water} \times \text{Flow}}{\text{X}} \times \text{Channel Slope} \) (Bagnold, 1966)

Potential geomorphic work to a unit area of the channel bed.

![Graph showing damaged structures by power](MMI, UMass, MassDOT, 2017)
METHODS
POTENTIAL CHANNEL BED EROSION

\[ Q_2(\text{ft}^3/\text{s}) = 10^\left(1.631 + 0.801 \times \log_{10}(\text{Area [mi}^2]) + 0.00589 \times (\text{Elev [m]}) - 0.01137 \times (\text{Storage [%]})\right) \]

Zarriello, 2017
METHODS

POTENTIAL CHANNEL BED EROSION
METHODS

POTENTIAL CHANNEL BED EROSION

“...balance between stream power and the bed resistance created by the sediment load and size”
- Lane, 1955; Rosgen and Silvey, 1996; FISRWG, 1998

<table>
<thead>
<tr>
<th>Geology Class</th>
<th>Predicted Bed Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand and Gravel</td>
<td>Low</td>
</tr>
<tr>
<td>Till or Bedrock</td>
<td>High</td>
</tr>
<tr>
<td>Sandy Till over Sand</td>
<td>Moderate</td>
</tr>
<tr>
<td>End Moraine</td>
<td>Moderate</td>
</tr>
<tr>
<td>Large Sand Deposit</td>
<td>Low</td>
</tr>
<tr>
<td>Fine-Grained Deposit</td>
<td>Low</td>
</tr>
<tr>
<td>Floodplain Alluvium</td>
<td>Low</td>
</tr>
</tbody>
</table>

(USGS, 1999)
### METHODS

#### SCORING

**Potential Channel Erosion Vulnerability**

<table>
<thead>
<tr>
<th>Estimated Specific Stream Power (W/m²)</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-29</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>30-59</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>60-99</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>100-199</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>200-299</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>300-599</td>
<td>High</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>600+</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

**Predicted Bed Resistance**

- Low
- Moderate
- High

**Estimated Structure Geomorphic Compatibility**

<table>
<thead>
<tr>
<th>Potential Channel Erosion Vulnerability (SSP and Bed Resistance)</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (%W&lt;bankfull &lt; 50)</td>
<td>M</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Moderate (%W&lt;bankfull &gt; 100)</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>High (%W&gt;bankfull &gt; 100)</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
</tbody>
</table>
RESULTS

ESTIMATED STRUCTURE GEOMORPHIC COMPATIBILITY

Estimated Geomorphic Compatibility of MassDOT Culverts

- Low: 80.3%
- Moderate: 14.7%
- High: 3.7%

Number of Culverts vs Percent Bankfull Width

Estimated Geomorphic Compatibility of MassDOT Bridges

- Low: 10%
- Moderate: 21%
- High: 32%

Number of Bridges vs Percent Bankfull Width
RESULTS

POTENTIAL CHANNEL EROSION VULNERABILITY

Potential Channel Erosion Vulnerability

<table>
<thead>
<tr>
<th>Miles of Stream</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12,823</td>
<td>2,973</td>
<td>906</td>
</tr>
</tbody>
</table>
RESULTS

ESTIMATED CULVERT AND BRIDGE VULNERABILITY

Estimated Culvert Vulnerability

- Low: 166
- Moderate: 753
- High: 252

Estimated Bridge Vulnerability

- Low: 1,854
- Moderate: 698
- High: 235
RESULTS

ESTIMATED CULVERT VULNERABILITY

Estimated Culvert Vulnerability
- Low (166)
- Moderate (966)
- High (371)
RESULTS

ESTIMATED BRIDGE VULNERABILITY

Estimated Bridge Vulnerability:
- Low (2,011)
- Moderate (800)
- High (309)
Resilient MA Climate Change Data Clearing House
Downscaled Massachusetts Projections for Consistent Planning

Mean annual precipitation increase 5 – 10% over next 50 years
The projected increase applied to estimates of bankfull discharge.

(Resilient MA Climate Change Data Clearinghouse, http://resilientma.org)
RESULTS

CLIMATE CHANGE IMPACTS

Predicted Increase in Culvert Vulnerability
- Low
  - 3 Culverts
- Moderate
  - 15
- High
  - 90

Predicted Increase in Bridge Vulnerability
- Low
  - 39 Bridges
- Moderate
  - 14
- High
RESULTS

CLIMATE CHANGE IMPACTS
CONCLUSIONS

- Most MassDOT culverts have low geomorphic compatibility
- \( \frac{1}{4} \) of channels have mod – high channel erosion vulnerability
- Most culverts have mod – high estimated vulnerability
- Most bridges have low – mod estimated vulnerability
- Vulnerable structures are spread across the state
- Estimated vulnerability will increase across state with climate change
- Culverts are of particular concern since less is known about location, size, condition, and geomorphic compatibility as compared to bridges.
1. Validate results of vulnerability screen with data from districts
2. Validate results of screen with field inspections at high-vulnerability crossings
3. Import results into GeoDOT to create online GIS maps
4. Add results of screen to MaPIT to improve project development and design
5. Complete development of the MassDOT Culvert Database
6. Coordinate with FHWA on culvert replacement and improvement program
7. Apply screen to culverts added to MassDOT Culvert Database in the future