The Geomorphic-Engineering Approach to Designing Bridges and Culverts

Presented By
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Undersized Culverts

Culvert Sizes
(~7,500 VT culverts)

Piscataquog River Watershed Culvert Sizes
(~361 culverts)
Comparing Culvert Size and Approximate Hydraulic Capacity Q50
Piscataquog River Watershed

Structure Width / Bankfull Channel Width (%) (Field Measurement)

<0.85 (Pass)  0.85 - 1.15 (Transition)  > 1.15 (Fail)

Approximate Hw/D Range (GIS Analysis)
Undersized Bridges

Geomorphologic Compatibility Screen
- Mostly Compatible
- Partially Compatible
- Mostly Incompatible
Geomorphic-Engineering Design

Start with the Vermont GP Design Requirement

\[ W_{\text{structure}} = 1.0 \times W_{\text{bankfull channel}} \]
\[ H_{\text{opening}} = 4 \times D_{\text{bankfull channel}} \]
\[ D_{\text{embed}} = 30\% H_{\text{opening}} \text{ or } D_{94} \text{ for boulder bed, whichever larger (min 1.5 feet, max 4.0 feet)} \]

Solve for Initial \( H_w \) for clear-flow hydraulic capacity

Q_{\text{design}} \text{ and } AHW \text{ requirement from Hydraulics Manual}

Check 1
Select Q, AHW, and % block to evaluate risk of structure failure due to material deposition.

Check 2
Select Q and AHW to evaluate risk of structure failure due to channel incision and scour.

Solve for \( H_w \) to verify adequate structure size considering deposition and scour. Analyze and compare results to clear-flow capacity. Consider:

- Flood level and velocity;
- Clogging potential;
- Incision and scour potential;
- Geomorphic compatibility;
- Aquatic organism passage (AOP); and
- Wildlife passage.

Larger structure width required

Evaluate \( W_{\text{structure}} \geq 1.2 \times W_{\text{bankfull channel}} \) such as

\[ W_{\text{structure}} = W_{\text{floodplain}} \]
- Sediment transport dominated reaches with large volume of coarse bedload.
- Actively incising sediment production reaches with or without slope failures.
- Confined of floodplain flows in the structure leading to high velocity and shear.
- Channel/structure with long damage history.
- Structure located near breaks in valley slope that is prone to clogging with sediment, woody debris, or ice.
- Wandering, braided, or fan stream types with frequently adjusting channel alignment.
- Channels with wide floodplain flow that would impact improved property if conveyance area is blocked.

**The proposed structure must meet the Equilibrium and Connectivity Performance Standards and requires approval from the Secretary of the Vermont Agency of Natural Resources for a General Permit or an application for an Individual Permit.

1. Adequate capacity and structure not likely to fail due to clogging or scour during flood.
   - Inlet/outlet design, headwall
   - Footing, scour analysis

2. Modified Stream Type OR excess capacity AND structure likely to fail due to clogging or scour

3. More capacity needed OR structure likely to erode or scour

H_{\text{opening}} < 4 \times D_{\text{bankfull channel}} \text{ if:}
- Low risk of impeding design flows and the passage of sediment and debris.
- Aquatic organism passage can be achieved.
- Larger streams.

D_{\text{embed}} < 30\% H_{\text{structure}} \text{ if:}
- Channel slope < 0.5%.
- Structure under outlet control, or backwatered.
- No sediment retention sills.

RE-EVALUATE

(Schiff et al., 2014)
“This will work”

“Waste of money”

Goodbye culvert

Flood-resilient culvert
Design – What is true structure capacity?
Assessment – Large Wood

(Furniss et al., 1998)
Large Wood at Bridges

Great Brook
Brook Road in Plainfield, VT
7/19/2015
Photo taken by B. Towbin

Great Brook
Brook Road in Plainfield, VT
5/27/2011
Photo taken by G. Springston
UVM Large Woody Debris Study

Small Pile: 1-5 Trees

- Completely Removed: 97
- Completely New: 94
- No Change: 58
- Debris Gained: 21
- Debris Lost: 3

(O’Neil-Dunne and Ahles, 2015)
Sediment Transport

- Equilibrium: Load ≈ Transport
- Deposition: Supply > Transport
- Erosion: Transport > Supply
- Local Scour: Bridges, bends, contractions

(MacBroom, 1998)
Identify Sediment Sources

Fulmer Creek
German Flatts, NY
(M. Carabetta, 2013)

Roaring Branch
Bennington, VT
(MMI, 2011)
### Assessment and Design Overview

<table>
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<tr>
<th><strong>Independent Variables</strong> (Assessment)</th>
<th><strong>Dependent Variables</strong> (Design)</th>
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<tbody>
<tr>
<td>- Physical Site Constraints</td>
<td>- Structure Slope / Channel Profile</td>
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<tr>
<td>- Valley / Channel Slope</td>
<td>- Structure Width and Height / Capacity</td>
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<tr>
<td>- Existing Channel and Floodplain Dimensions</td>
<td>- Hydraulics</td>
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<td>- Confinement</td>
<td>- Scour</td>
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<tr>
<td>- Flow</td>
<td>- Sediment in Structure</td>
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<tr>
<td>- Stream Power ((\Omega = \gamma QS))</td>
<td>- Natural</td>
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<tr>
<td>- Channel Pattern, Alignment, and Dynamics</td>
<td>- Embedded</td>
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<td>- Floodplain Connectivity</td>
<td>- Streambed Fill in Structure</td>
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<td>- Entrenchment</td>
<td>- AOP</td>
</tr>
<tr>
<td>- Incision</td>
<td>- Structure Design</td>
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<tr>
<td>- Sediment and Large Wood</td>
<td></td>
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<tr>
<td>- Channel Evolution</td>
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</table>

Increasing complexity and variables that may drop out of basic assessment during quick emergency repairs.
Floodplain Dimensions

(Q_{Bankfull} to Q_{10})

(Q_{100} to Q_{10})

Low Flow Channel

Bankfull Channel
(Q_{1.5} to Q_{2})

2-Year Floodplain

100-Year Floodplain

Colluvium or Ledge

Terrace

River Corridor

FEMA Floodway

Low Bench (~Q_{1})

Low Bench (~Q_{1})

(Adapted from Schiff et al., 2014)
Channel Dynamics

Assessment

(MMI, 2009)
THANK YOU.

Former culvert

New culvert

HIGH RESILIENCY = HIGH CONNECTIVITY

(MMI, 2015)
MA Culvert Vulnerability Screening

Specific Stream Power versus Bed Resistance

<table>
<thead>
<tr>
<th>Specific Stream Power (W/m²)</th>
<th>Silt</th>
<th>Sand</th>
<th>Gravel</th>
<th>Cobble</th>
<th>Boulder</th>
<th>Bedrock</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-60</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>60-100</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>100-300</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>300+</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Damaged Structures by Power

- Specific Stream Power (W/m²)
- Number of Structures

Legend:
- Highest Vulnerability
- Lowest Vulnerability

(MMI, 2016)
MA Culvert Vulnerability Screening

Vulnerability Screen

Number of Structures

Vulnerability Screen Score

- Red: 41%
- Yellow: 26%
- Blue: 14%

- Damaged Structures
- Undamaged Structures

(MMI, 2016)
MA Culvert Vulnerability Screening

Legend
Culvert and Bridge Vulnerability (197 Assessed Structures)
- Least Vulnerable
- Moderately Vulnerable
- Most Vulnerable
- Square marker indicates known past or current damage (51 Structures)

Project Culvert and Bridge Locations
- 812 Unassessed Structures

Specific Stream Power by Stream Order
0-30 W/m²

31-60 W/m²

51-200 W/m²

201-300 W/m²

301-600 W/m²

>600 W/m²

States for known culvert and bridge damages:
O = Overtopping
E = Embankment Failed
B = Blocked by Debris
S = Structural Failure
W = Washed Out
F = Roadway Flooding
L = Fluvial Erosion
* = Repeated Failures
Note: 21 damaged structures were not assessed for vulnerability due to lack of data or lack of access.

(MMI, 2016)
Poor Bridge Alignment

Roaring Brook
US Route 4 in Killington, VT
Photo by Lars Gange & Mansfield Heliflight, August 31, 2011)