Long Term Construction and Maintenance Cost Comparison for Road Stream Crossings: Traditional Hydraulic Design vs. Aquatic Organism Passage Design

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Research Objectives

• Quantify the long-term costs of road stream crossings that span the bankfull width of a waterway (aquatic organism passage design or AOP) in order to provide an accurate picture of the total life-cycle cost of the structure.

• Compare long-term costs of AOP design-based structures to the long-term costs of traditional hydraulic design structures.

• Provide guidance for DOTs to track culvert life-cycle costs and develop a template for a standardized database.
APPROACHES TO STREAM CROSSING DESIGN

Traditional Hydraulic Design: Crossing designed with only hydraulic and practical structural criteria taken into account. Structures are the largest practical design and typically smaller and less costly than AOP design.

AOP Design: Crossing designed with hydraulic, sediment transport and habitat criteria taken into account to facilitate passage of fish and other aquatic species. This approach typically leads to a smaller crossing width than under stream simulation (HEC-26 and Bankfull width times a safety factor, such as 1.2).

Stream simulation design (geomorphic design): Crossing designed with hydraulic, sediment transport and stream geomorphology criteria taken into account to mimic functions of a natural stream and floodplain to maximize stream continuity.
Traditional Design

AOP Design
Performance
Recent extreme rainfall events have documented performance differences in traditional hydraulic design culverts versus AOP designed culverts

- Tropical cyclone Irene 2011
- St. Louis County, Duluth, Minnesota, June 2012
- Empirical evidence from both events showed that AOP culverts survived event with limited damage
METHODS
Methodology developed with Panel oversight

- Literature Survey
- Initial Survey of select DOTs on culvert design, use of AOP design methods, and maintenance practices
- Follow up surveys of DOTs for detailed project cost information and maintenance costs
- Research and develop supporting cost data for model
- Develop and Run Benefit-Cost Analysis (BCA) model
SURVEY RESULTS

- 94 AOP crossing project examples provided by eight agencies
- 65 had sufficient data available for use in analysis
  - 13 3-sided box culverts
  - 20 4-sided box culverts
  - 32 pipes (25 are metal arches or pipes)
SURVEY RESULTS
Summary of Key Findings from Initial and Follow-up Surveys of Practitioners

• Regulatory compliance is the main driver for use of AOP culverts.
• Some State DOTs and Consultants are still on the learning curve for AOP culvert design/installation.
• Most DOTs have not been incorporating risk reduction (resiliency) and reduced maintenance cost benefits in project planning and decision making.
• DOTs identified technical barriers for AOP culvert use:
  • Increasing flood elevations on downstream properties
  • Conflicts with utilities, ROW requirements, roadway geometry
  • Funding: higher costs of AOP culverts limit the number of projects that can be funded
## Summary of Recent Culvert Cost Comparisons

<table>
<thead>
<tr>
<th>Source</th>
<th>Location</th>
<th>Number of Projects</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minnesota DOT (Hansen et al, 2009)</td>
<td>Minnesota</td>
<td>11</td>
<td>AOP culvert cost -3% to +33% compared to THC design estimate. Most of cost difference driven by increased size of structures</td>
</tr>
<tr>
<td>Wisconsin DNR (Christiansen et al, 2014)</td>
<td>Wisconsin</td>
<td>495</td>
<td>Cost-Benefit analysis for AOP culvert replacements; net fiscal benefit -$4700/culvert; net social benefit $7800/culvert.</td>
</tr>
<tr>
<td>Gillespie, et al, 2014</td>
<td>Vermont</td>
<td>3</td>
<td>AOP culvert cost +9% to +12% higher than HC design estimate</td>
</tr>
<tr>
<td>MA DER, 2015</td>
<td>Massachusetts</td>
<td>3</td>
<td>Long term cost savings for AOP culvert replacement: -$41K, 180K and $520K</td>
</tr>
</tbody>
</table>
**Benefit-Cost Analysis**

Monte Carlo Simulation (@Risk module for Excel)

- Risk analysis method that builds models of possible results by substituting a range of values that have inherent uncertainty to create a probability distribution.
- Method used a normal distribution approach to estimate a range of outcomes.
- Each simulation is composed of ten thousand iterations to obtain a stability and consistency in output of values.
Benefit-Cost Analysis: Computation

- Lifetime Costs = One Time Costs + Annual Costs
- Net Benefit/Costs = Lifetime Costs AOP Culvert – Lifetime Costs Traditional Culvert
- Culvert Lifetimes:
  - 50 years for Box
  - 25 years for Pipes
Benefit-Cost Analysis Variables

- One Time Costs: Design and Construction Costs
- Long Term Economic Factors
  - Maintenance costs
  - Replacement costs
- Ecosystem Services
  - Acres of reconnected stream habitat
  - Regionally important species habitat (Salmon and brook trout)
- Social Benefits
  - Flood protection
  - Risk reduction of culvert failure
  - Road user delays
  - Recreational benefit
Precipitation Trends

Projected change in frequency of heavy precipitation events.
Source: U.S. Global Change Research Program, 2014

Observed change in heavy precipitation
Source: U.S. Global Change Research Program, 2014

Projections for North America estimate a 20-year storm will occur on average every 12-to 15 years by 2050, and every 7-8 years by 2100 (U.S. Climate Change Science Program, 2008; Kharin, et al., 2007)
Benefit-Cost Analysis Results: 3-Sided Culverts

• Net cost benefits are achieved in 78% of culvert replacements with an AOP design.
Benefit-Cost Analysis Results: 4-Sided Culverts

• Net cost benefits are achieved in 82% of culvert replacements with an AOP design.
Benefit-Cost Analysis Results: Pipe Culverts

- Net cost benefits are achieved in 100% of culvert replacements with an AOP design.
Benefit-Cost Analysis Results: Sensitivity Analysis

- **Shortened Life Spans:**
  - Box Culverts: Costs breakeven with a reduced life span to 40 years.
  - Pipe Culverts: Costs breakeven with a reduced life span of 10 years.

- **Recreational Benefits:**
  - Box culvert – reduced the benefit value by 50% before affecting the outcome.
  - Pipe culverts – removal of benefit value had a minimal affect compared to capital costs

- **Ecosystem Services Benefits:**
  - Box and pipe culverts - removal of values had no effect on outcome.
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