Louis Berger

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

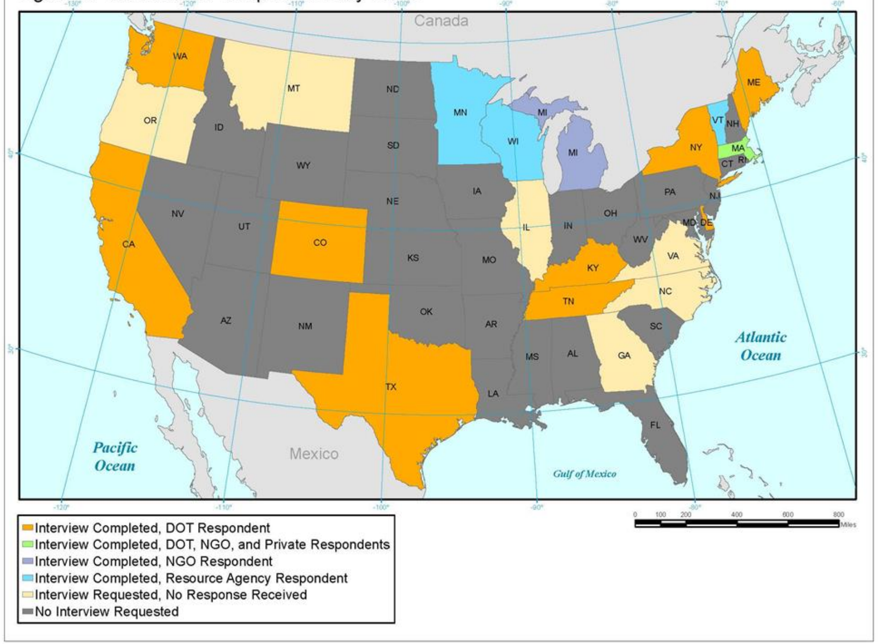
Recent extreme rainfall events have documented performance differences in traditional hydraulic design culverts versus AOP designed culverts

- 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

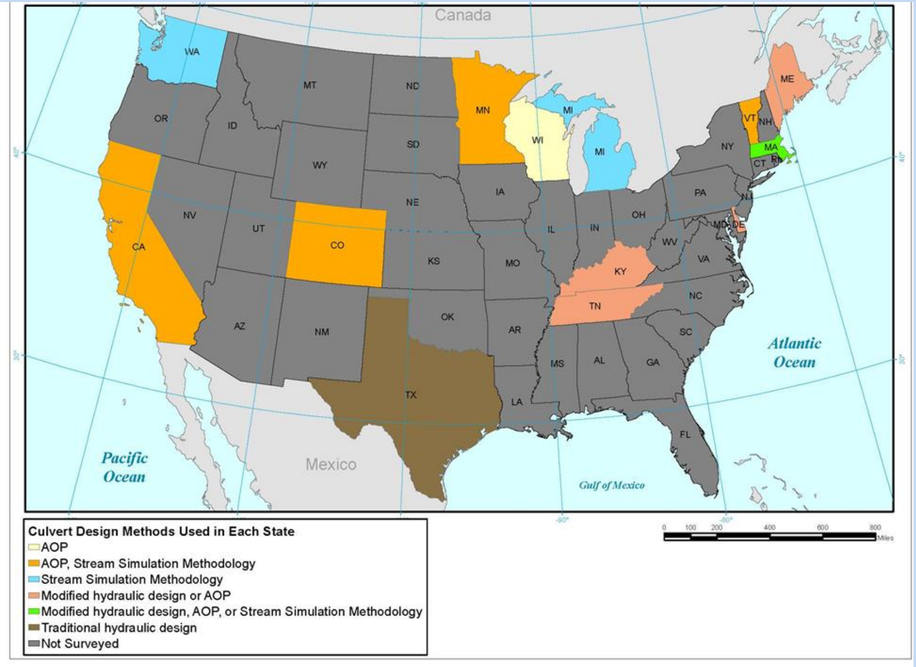
Methodology developed with Panel oversight

Figure 1: "Stakeholder Respondents by State"



- 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

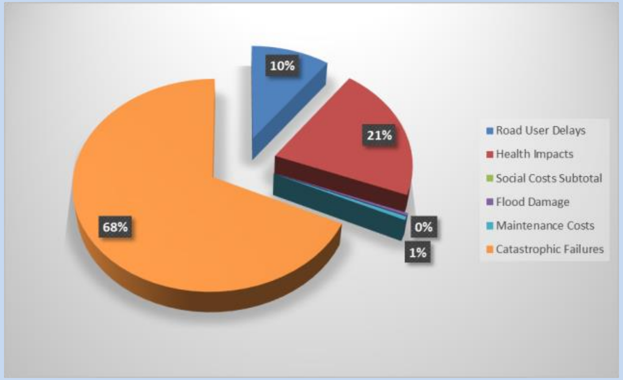
Summary of Key Findings from Initial and Follow-up Surveys of Practioners

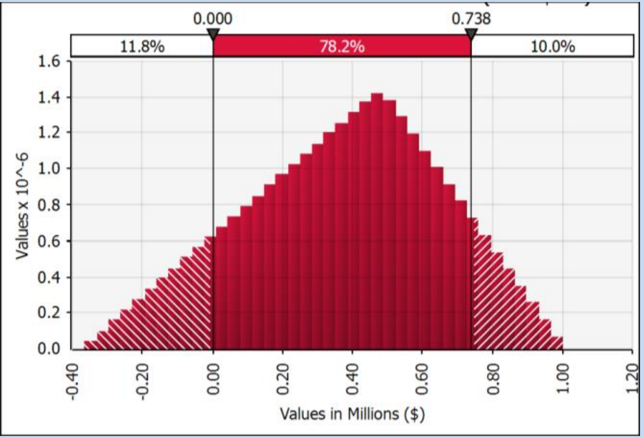
- Regulatory compliance is the main driver for use of AOP culverts.
- Some State DOTs and Consultants are still on the learning curve for AOP culvert design/installation.
- Most DOTs have not been incorporating risk reduction (resiliency) and reduced maintenance cost benefits in project planning and 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

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

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**

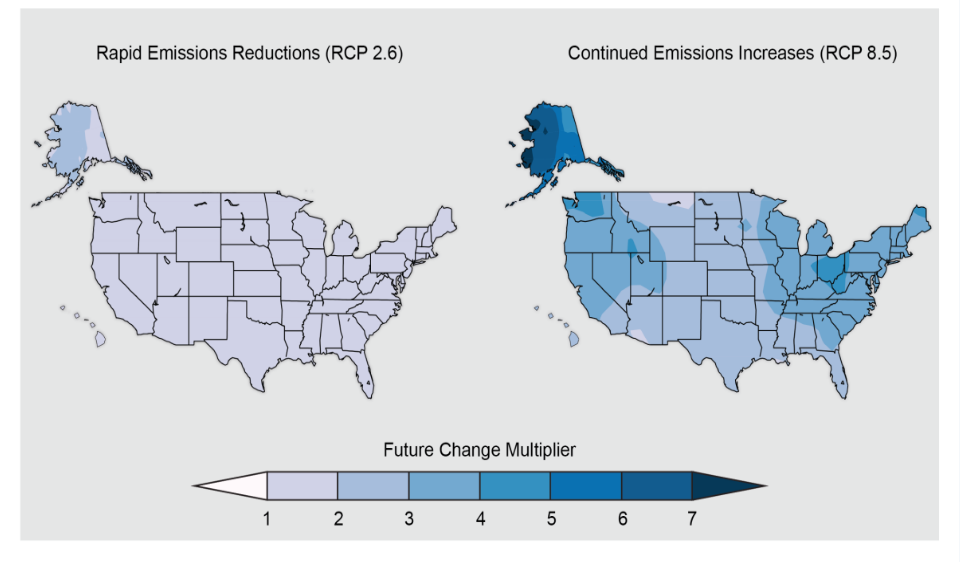
- **Culvert Lifetimes:**
  - **50 years for Box**
  - **25 years for Pipes**

Benefit-Cost Analysis Variables

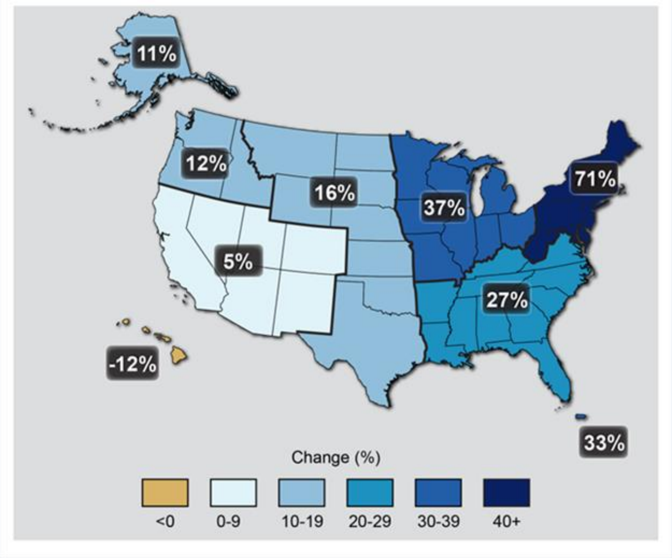
- One Time Costs: Design and Construction Costs
- Long Term Economic Factors
  - Maintenance costs
  - Replacement costs
- Ecosystem Services
  - Acres of reconnected stream habitat
  - Regionally important species habitat (Salmon and brook trout)
- Social Benefits
  - Flood protection
  - Risk reduction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

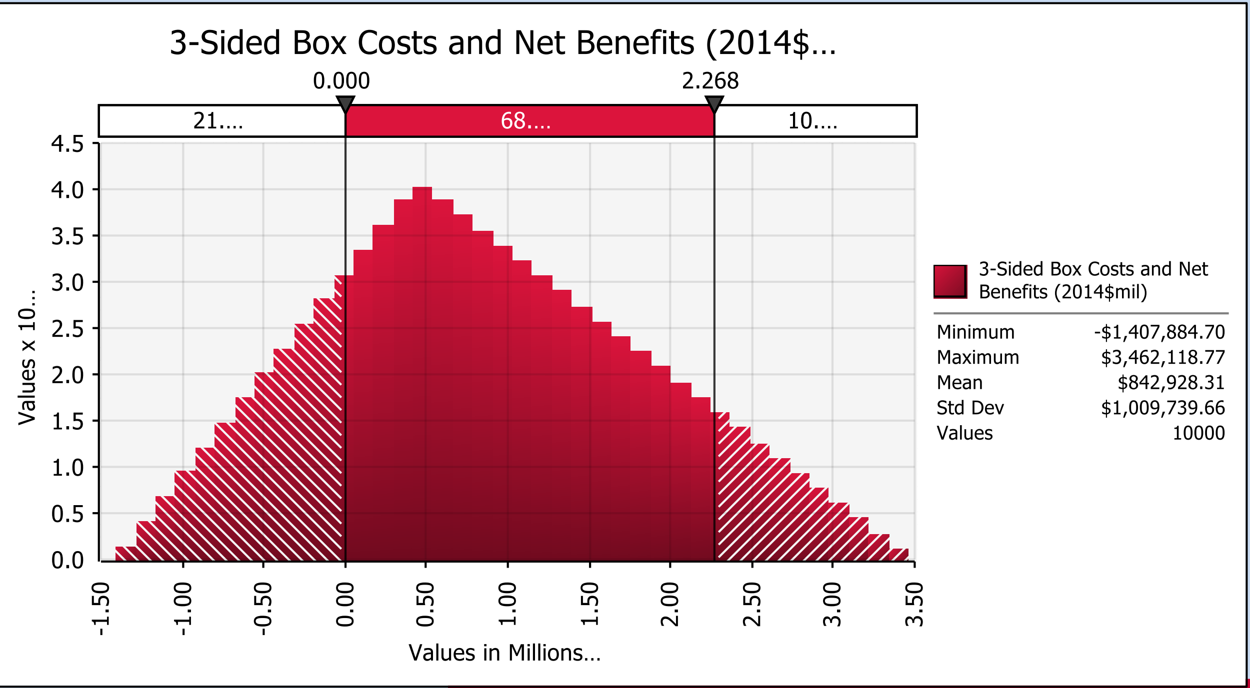


Observed change in heavy precipitation
Source: U.S. Global Change Research Program, 2014



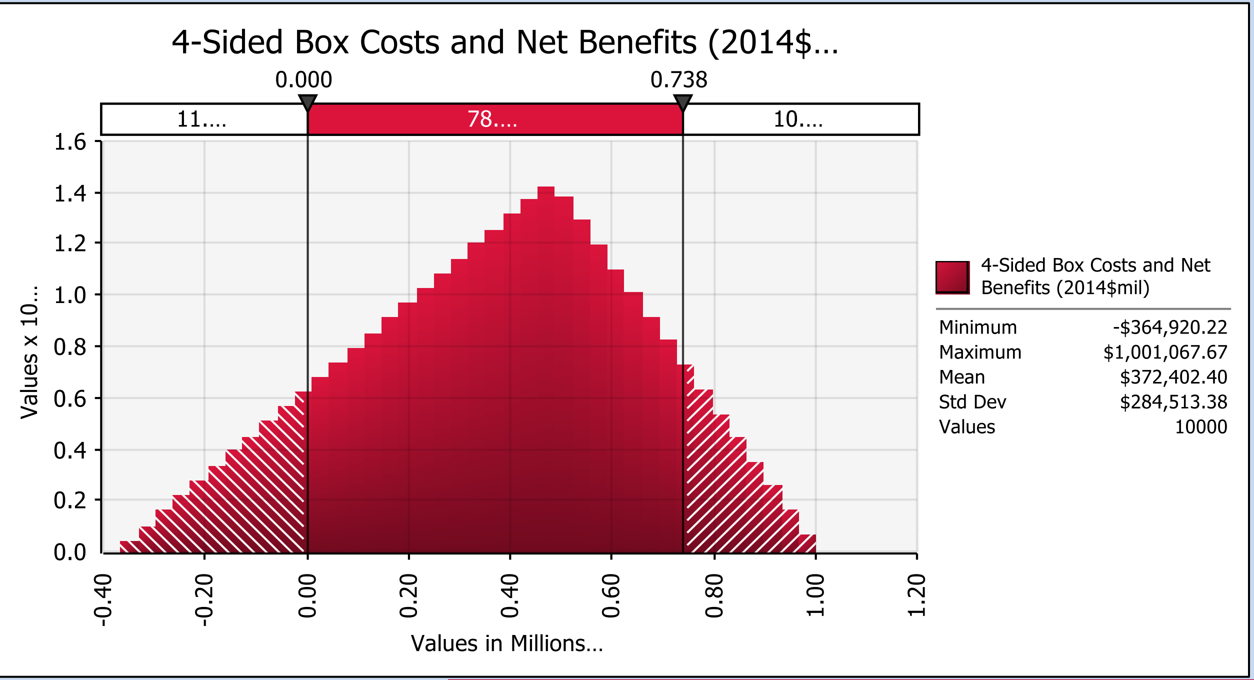
Projections for North America estimate a 20-year storm will occur on average every 12-to 15 years by 2050, and every 7-8 years by 2100 (U.S. Climate Change Science Program, 2008; Kharin, et al., 2007)

Benefit-Cost Analysis Results: 3-Sided Culverts



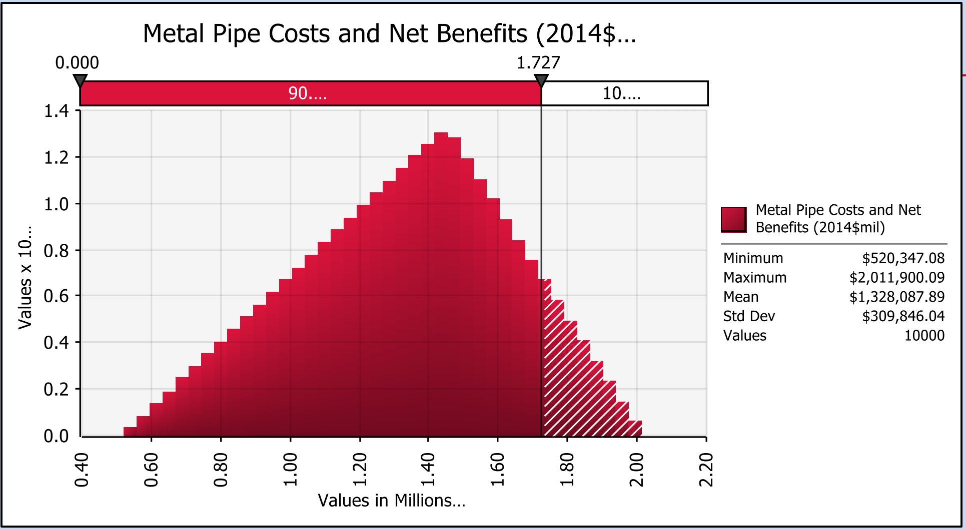
- Net cost benefits are achieved in 78% of culvert replacements with an AOP design.

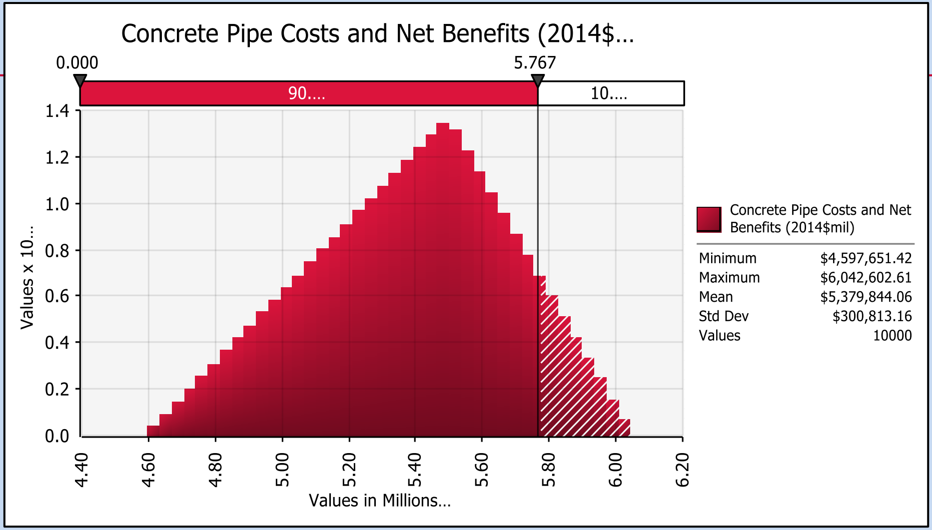
Benefit-Cost Analysis Results: 4-Sided Culverts



- 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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