Comparing Life Cycle Costs of Fish- and Wildlife-Friendly Culverts with Conventional Culvert Designs

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The Caltrans Division of Research and Innovation (DRI) receives and evaluates numerous research problem statements for funding every year. DRI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

Caltrans is interested in identifying methods to estimate and compare costs for designing, constructing and maintaining culverts designed to provide safe passage of aquatic organisms with conventional culvert designs. Also of interest are culvert design requirements common to both fish and wildlife.

To aid in this effort, this Preliminary Investigation aims to examine completed and in-process research, federal guidance and state practices related to the application of life cycle cost analysis (LCCA) to culvert design to address the following questions:

- What tools and methods are available for performing LCCA on culvert design that allow for the comparison of conventional culvert design with designs that permit fish and wildlife passage?
- What costs are associated with the design, construction, operation and support of conventional and alternative culvert designs over the anticipated life cycle?
- What design requirements are common to both fish and wildlife? Conversely, what conflicts may arise?

Summary of Findings

We found much in the literature that addresses culvert design, with a wealth of recommendations on the design, construction and maintenance of conventional culverts as well as designs that accommodate fish passage. What the current literature appears to fail to address in any significant way are cost comparisons of conventional and fish-friendly culverts.

Limiting our focus to publications that relate at least tangentially to cost comparisons, we gathered information in four topic areas associated with our examination of life cycle costs of conventional and fish- and wildlife-friendly culverts:

- National Guidance.
- State Research and Practices.

- Related Publications.
- Research in Progress.

Following is a summary of findings by topic area.

National Guidance

- A 2008 Forest Service publication on stream simulation includes a discussion of cost considerations, tips for choosing structures and comparative costs for three types of structures.
- Design and implementation guidelines that describe the effectiveness, benefit and ranking of mitigation measures for wildlife passage are provided in an October 2008 Federal Highway Administration (FHWA) report to Congress.
- In 2007, FHWA published a synthesis report that includes a brief discussion of the life cycle cost for fish passage culverts. The report notes that such comparisons are difficult given the experimental nature of some design techniques and the long-term monitoring that has yet to occur to assess the full impact and implications of a selected design.
- Engineering standards produced by ASTM International provide life cycle costing methods for conventional concrete and metal pipe culverts that might provide a template for an expanded cost analysis.
- A software tool prepared for the U.S. Air Force that prepares cost estimates related to environmental investigations and cleanup projects could be applied to other cost estimating needs.

State Research and Practices

- We highlight tools, manuals and research results from six states—Colorado, Maine, Minnesota, Oregon, Pennsylvania and Washington—that address to varying degrees cost estimations or comparisons of culvert designs that provide for fish passage:
    - A user manual for the spreadsheet-based cost estimating tool developed by Colorado's Urban Drainage and Flood Control District includes costs and other data needed to implement the tool.
    - A 2010 article describes Maine's study of 2007 culvert installations that applied a net present value analysis to compare the cost of fish-friendly arch culverts to undersized round culverts. Lower average annual costs for the fish-friendly culverts were due in part to financial assistance obtained through a state agency.
    - Minnesota DOT analyzed costs associated with alternative culvert installations in a 2009 report.
    - A chapter in a 2004 AASHTO committee report describes Oregon DOT's program of culvert installation and maintenance, noting that baffle and weir designs significantly reduced the cost of improving fish passage at Oregon DOT culverts.
    - While the 2010 edition of PennDOT's Drainage Manual notes that "life cycle costs generally are not needed to determine cost-effective designs," the manual does provide recommendations for long-term cost components that can be used if an LCCA is requested. A PennDOT design manual provides a sample present worth analysis that is used to permit economic comparison between alternatives.
    - While somewhat dated, the fish passage project costs identified in a 2003 Washington State DOT manual may be of interest.

Related Publications

- The safe passage of wildlife is the focus of a 2010 book that also addresses technologies for mitigating the impacts of highways on wildlife and fish.
- A 2007 conference paper considered passage designs that are effective for both terrestrial and aquatic species.

Research in Progress

- A project expected to conclude in 2012 is examining culverts in Vermont for their cost-effectiveness and the efficacy of new culvert design criteria to enhance fish passage.

Gaps in Findings

We noted a common theme when the topic of life cycle costing for culvert design appears in the literature: More data are needed. For example, a 2009 Minnesota DOT report concluded that additional research is required to determine if benefits such as reduced erosion and reduced maintenance costs will offset the additional costs associated with the larger culverts designed for fish passage. A 2007 FHWA report comes to a similar conclusion, noting that development of a database of standardized costs would allow agencies to compare costs for culvert operations on a life cycle basis, and recommending that state DOTs adopt a standard procedure when describing design and maintenance costs of culverts.

We contacted Eric Ross (eric.ross@dot.gov, (202) 366-3975), liaison for LCCA in FHWA's Office of Pavement Technology, to determine if LCCA was being applied to culvert design. Mr. Ross is aware of a 2007 PennDOT survey on the use of LCCA for pipe culverts but was unable to provide the survey for our review. His requests to PennDOT staff for the survey were unsuccessful at the time of publication of this Preliminary Investigation.

Next Steps

Caltrans might consider the following in its evaluation of the comparative costs of culverts designed to allow fish passage with conventional designs:

- Examining ASTM standards that apply LCCA to conventional culvert designs to assess the expandability of the models to include comparisons with alternative culvert designs.
- Contacting Minnesota DOT to determine if further research is planned or in process to expand on the 2009 cost analysis of alternative culvert installation practices.
- Reviewing PennDOT's use of present worth analysis to determine its possible applicability as a method to compare conventional and fish-friendly culvert designs. Long-term cost components identified in the PennDOT Drainage Manual may also provide a template for the types of costs to be addressed in an LCCA model that compares conventional and alternative culvert designs.
- Contacting Washington State DOT to determine the availability of fish passage project costs more recent than those reflected in a 2003 report.
- Contacting Vermont Agency of Transportation to identify the status of the project in process that will evaluate the cost-effectiveness of fish-friendly culverts.

National Guidance

We found no guidance at the national level that is specific to life cycle cost comparisons of conventional and fish-friendly culvert designs. The citations we provide below offer some degree of input into an eventual cost comparison model, including cost factors that affect choice of structure, best practices for wildlife passage, and an examination of current culvert design techniques and how they relate to costs and fish passage.

We also include links to ASTM engineering standards for LCCA of concrete and metal pipe culvert designs that may inform development of a model that compares conventional and alternative culvert design. Finally, we cite a cost estimating tool developed by the U.S. Air Force that generates location-specific program cost estimates for environmental investigations and cleanup operations.

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings, Forest Service, U.S. Department of Agriculture, May 2008.
http://www.stream.fs.fed.us/fishxing/publications/PDFs/AOP_PDFs/08771801.pdf
A discussion of cost considerations associated with crossing structure selection begins on page 315 of the PDF. Table 7.3 provides cost factors that affect choice of structure; Table 7.4 on page 316 lists the durability factors that affect choice of structure. Data in Table 7.5 on page 317 are taken from Oregon DOT's 2005 Hydraulics Manual (Parts 1 and 2 of the 2005 manual are available at http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/hyd_manual_info.shtml; see ftp://ftp.odot.state.or.us/techserv/geo-environmental/Hydraulics/Hydraulics%20Manual/Table_of_Contents_rev_Nav.pdf for a draft of the 2011 manual) and provide an example of the type of information that may be available when choosing a structure material appropriate for the site.

Other sections of interest include:

- 7.2.4, Tips for Choosing Structures, which begins on page 318.
- G.3, Estimated Project Costs: Comparing Different Structure Types and Sizes, which begins on page 567 of the PDF, compares estimated costs for three types of structures.
- G.4, Tips from Engineers and Biologists Experienced in Stream-Simulation Construction, which begins on page 576 of the PDF, addresses common problems in placing embedded pipes and their solutions. Included in the discussion are advantages and disadvantages of various options, including cost.

Wildlife Vehicle Collision Reduction Study: Best Practices Manual, FHWA, Report to Congress, October 2008.
http://environment.fhwa.dot.gov/ecosystems/wvc/wvc.pdf
This manual provides design and implementation guidelines for wildlife fencing, wildlife underpasses and overpasses, animal detection systems, vegetation management and wildlife culling. The FHWA Project Committee for this study categorized each measure as either best practice or not, based on effectiveness in reducing wildlife-vehicle collisions, costs and benefits, and availability of alternatives. See page 46 of the PDF for Table 2, Effectiveness, Benefit, and Ranking of Mitigation Measures.

Design for Fish Passage at Roadway-Stream Crossings: Synthesis Report, FHWA, Publication No. FHWA-HIF-07-033, June 2007.
http://www.fhwa.dot.gov/engineering/hydraulics/pubs/07033/07033.pdf
This document places current culvert design techniques into four categories based on design premise and objectives:

- No impedance techniques.
- Geomorphic simulation techniques, which create fish passage by matching natural channel conditions within the culvert crossing.
- Hydraulic simulation techniques, which attempt to mirror hydraulic diversity found in the natural channels with the use of natural and oversized substrate.
- Hydraulic design techniques, which may utilize roughness elements such as baffles and weirs to meet species-specific fish passage criteria during periods of fish movement.

Included in the report are design examples and case histories for a selection of design techniques.

Page 101 of the PDF addresses the life cycle cost for fish passage culverts:

> Total life cycle cost for fish passage culverts is therefore difficult to compare for different design methods. It should not be assumed, for example, that one method is more costly than another based on culvert span. A complete cost analysis must be made for each crossing.
>
> Many design techniques are still considered experimental, and long-term monitoring is still required to understand the true impacts and implications of a selected method (Chapter 10). Careful consideration of goals and requirements should be taken before selecting design criteria.

Life cycle costs are addressed again on page 257 of the PDF:

> **11.3 Life Cycle Costs**
> There are insufficient data available that describe the total life cycle costs of culverts. For example, there are only qualitative statements in this report that state wider-span culvert expenses may be offset by lower maintenance and stream-channel protection costs following construction. Work is required to populate a database with standardized costs for culvert operations on a life cycle basis. This will require State DOTs to cooperate in following consistent procedures for describing all costs, including both design and maintenance of the culvert and the local stream reach.

Engineering Standards

ASTM C1131 - 10e1, Standard Practice for Least Cost (Life Cycle) Analysis of Concrete Culvert, Storm Sewer, and Sanitary Sewer Systems, ASTM International, 2010.
http://www.astm.org/Standards/C1131.htm
From the web site:

> **Significance and Use**
>
> The significance of the LCA method is that it is a comprehensive technique for taking into account all relevant monetary values over the project design life and provides a measure of the total cost of the material, system, or structure.
>
> The LCA method can be effectively applied in both the preconstruction and bid stages of projects. After bids are taken, real costs can be used instead of estimates.
>
> **1. Scope**
>
> 1.1 This practice covers procedures for least cost (life cycle) analysis (LCA) of materials, systems, or structures proposed for use in the construction of concrete culvert, storm sewer, and sanitary sewer systems.
>
> Note 1—As intended in this practice, examples of analyses include, but are not limited to the following: (1) materials-pipe linings and coatings, concrete wall thicknesses, cements, additives, etc.; (2) systems-circular pipe, box sections, multiple lines, force mains, etc.; and (3) structures-wet and dry wells, pump and lift stations, etc.

1.2 The LCA method includes costs associated with planning, engineering, construction (bid price), maintenance, rehabilitation, replacement, and cost deductions for any residual value at the end of the proposed project design life.

1.3 For each material, system, or structure, the LCA method determines in present value constant dollars, the total of all initial and future costs over the project design life, and deducts any residual value.

1.4 Major factors in the LCA method include project design life, service life, and relevant interest and inflation rates.

ASTM A930 - 09, Standard Practice for Life-Cycle Cost Analysis of Corrugated Metal Pipe Used for Culverts, Storm Sewers, and Other Buried Conduits, ASTM International, 2009.
http://www.astm.org/Standards/A930.htm
From the web site:

Significance and Use

LCC analysis is an economic method for evaluating alternatives that are characterized by differing cash flows over the designated project design life. The method entails calculating the LCC of each alternate capable of satisfying the functional requirement of the project and comparing them to determine which has (have) the lowest estimated LCC over the project design life.

The LCC method is particularly suitable for determining whether the higher initial cost of an alternative is economically justified by reductions in future costs (for example, operating maintenance, rehabilitation, or replacement) when compared to an alternative with lower initial costs but higher future costs. If a design alternative has both a lower initial cost and lower future costs than other alternatives, an LCC analysis is not necessary to show that the former is the economically preferable choice.

1. Scope

1.1 This practice covers a procedure for using life-cycle cost (LCC) analysis techniques to evaluate alternative drainage system designs using corrugated metal pipe that satisfies the same functional requirements.

1.2 The LCC technique measures the present value of all relevant costs of installing, operating, and maintaining alternative drainage systems, such as engineering, construction, maintenance, rehabilitation, or replacement, over a specified period. The practice also accommodates any remaining residual or salvage value.

1.3 Using the results of the LCC analysis, the decision maker can then identify the alternative(s) with the lowest estimated total cost based on the present value of all costs.

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Cost Estimating Tools

Remedial Action Cost Engineering Requirements (RACER) System, Version 10.4, Federal Remediation Technologies Roundtable, October 2010.
http://www.frtr.gov/ec2/ecracersystem.htm
RACER, initially developed by the U.S. Air Force, addresses environmental investigations and cleanup projects and can be applied to other environmental cost estimating needs. While this software system is not specific to culvert design, the system's approach to generating location-specific program cost estimates might provide a helpful perspective on the cost analyses Caltrans wishes to conduct.

State Research and Practices

Below we highlight tools, manuals and research results from six states—Colorado, Maine, Minnesota, Oregon, Pennsylvania and Washington—that address to varying degrees cost estimations or comparisons for culvert designs that provide for fish passage.

Colorado

User Manual, Cost Estimator for Master Planning (UD-MP Cost), Version 1.1, Urban Drainage and Flood Control District, December 2010.
http://www.udfcd.org/downloads/software/UD-MP%20COST%20User's%20Guide%20-%20V1.1.pdf
The concept for the cost estimating tool, Cost Estimator for Master Planning (UD-MP Cost), described in this manual includes:

- Developing a master planning cost estimate spreadsheet for use on all master planning projects.
- Developing comprehensive cost data.
- Providing support for streamlined table creation for master plan reports.
- Creating a flexible tool.

Appendices to the report include data and details needed to implement the tool:

- Appendix A, Cost Data (page 26).
- Appendix B, Standard Details (page 28).
- Appendix C, Calculation Design Aids (page 36).

Maine

"The Economics of Culvert Replacement: Fish Passage in Eastern Maine," John Long, State Economist, Maine Natural Resources Conservation Service, revised March 2010.
ftp://ftp-fc.sc.egov.usda.gov/Economics/Technotes/EconomicsOfCulvertReplacement.pdf
This case study assessed the potential cost impacts of installing properly sized arch culverts and crossings in place of undersized round culverts that do not allow for fish passage. Researchers used data from projects installed during 2007 in Washington County, ME, to develop four scenarios for analysis.

Elements of the cost analysis include the following:

- A net present value (NPV) of 25 years of undersized culvert operation, maintenance and replacement costs were calculated using a 4.2 percent discount rate.
- The NPV was amortized over 25 years to arrive at an average annual cost.
- The average annual cost was compared with the amortized installation cost of the arch culvert over the same period.

In all four cases, researchers found a lower average annual cost for the fish-friendly arch culvert compared to the undersized round culvert. It is important to note that significant financial assistance from Maine's Natural Resources Conservation Service to help install the properly sized culverts contributed to the cost savings.

Minnesota

Cost Analysis of Alternative Culvert Installation Practices in Minnesota, Minnesota Department of Transportation, Report No. MN/RC 2009-20, June 2009.
http://www.lrrb.org/PDF/200920.pdf
In this project, researchers performed a cost analysis of four alternative culvert designs. The following alternatives are not designed as replacements for conventional culvert designs but as additions to in-place culverts to help facilitate fish passage:

- Baffles, which use panels inside the culvert to slow down water flow.
- Roughened channels, which add a graded mix of rock and sediment to create diversity in flow rates.
- Backwater weirs, which are dams placed downstream to slow water flow.

The fourth alternative design—MESBOAC (Match, Extend, Set, Bury, Offset, Align, Consider)—is a stream-simulation technique designed to mimic the natural channel characteristics through the culvert.

Findings include the following:

- Tying the cost of alternative designs to the cost of the culvert as a percentage should allow an estimate of alternative design costs as the scale of the project increases or decreases.
- For all cases examined, the MESBOAC design added -5 percent to 33 percent to the culvert cost. Researchers observed that if proposed additional benefits beyond improved fish passage of reduced erosion and maintenance costs prove to be true, those benefits could offset the additional costs associated with the larger culvert needed for MESBOAC. More research is needed to make such a determination.
- Baffles cost an average of 12.5 percent of the bankfull culvert cost, roughened channels 10 percent and backwater weirs 15.1 percent.

Oregon

ODOT Culvert Program Strategy Report: Final Draft, Oregon Department of Transportation, MB&G Project No. 1355, January 9, 2007.
ftp://ftp.odot.state.or.us/Culvert_Program/Work%20Plan/Culvert%20Strategy_Report_Final_Draft.pdf
This strategy report identifies both short- and long-term goals for culvert management, recommended actions and desired outcomes. Page 17 of the PDF describes the need for an economic sustainability analysis of culvert programming that would examine the cost/benefit of incrementally larger culverts. Such an examination might be extended to address the types of culvert designs that allow for fish passage.

Chapter 3, Designing for Environmental Stewardship in Construction & Maintenance, Environmental Stewardship Practices, Procedures, and Policies for Highway Construction and Maintenance, AASHTO Standing Committee on the Environment, September 2004.
http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/25-25(4)_FR.pdf
This publication does not provide specific cost comparisons but does speak to the cost savings associated with certain types of culverts designed for fish passage. A description of Oregon DOT's ongoing program of culvert installation and maintenance begins on page 191 of the PDF; the program seeks to make all Oregon DOT culverts passable to fish. After research monitoring results demonstrated the effectiveness of baffle and weir designs in culverts, Oregon DOT modified its culvert replacement programs to use these designs, significantly reducing the cost of improving fish passage at Oregon DOT culverts.

Pennsylvania

Chapter 9, Culverts, PennDOT Drainage Manual, Pennsylvania Department of Transportation, Publication 584, 2010 edition.
ftp://ftp.dot.state.pa.us/public/bureaus/design/PUB584/PDMChapter09.pdf
From page 46 of the PDF:

> Life cycle costs generally are not needed to determine cost-effective designs. Culverts are expected to last without maintenance for the design life specified. However, the following long-term cost components (reduced to an annual cost based on the anticipated service life) may be considered if a life cycle cost analysis is requested under an unusual circumstance.
>
> - Initial cost of the culvert.
> - Expected cost of damage to the roadway.
> - Expected cost of damage to the culvert and associated appurtenances.
> - Expected cost of damage to the stream (approach and exit).
> - Expected cost of damage to upstream and downstream private or public property.
> - Expected cost of traffic detours.
> - Debris removal.

Section 12 – Buried Structures and Tunnel Liners, Design Manual – Part 4, Volume 1, Structures (Publication 15M), Pennsylvania Department of Transportation, September 2007.
ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%2015M.pdf
A discussion of present worth analysis begins on page 1,031 of the PDF. This method is used to adjust all annual and future costs to a present cost to permit economic comparison between alternatives. The manual indicates that the present worth method of analysis is restricted to alternatives that perform the same function. The example provided in the Commentary section of the manual may prove helpful in framing Caltrans' examination of cost comparisons of conventional and fish-friendly culvert designs.

Washington

Design of Road Culverts for Fish Passage, Washington Department of Fish and Wildlife, 2003.
http://wdfw.wa.gov/publications/00049/wdfw00049.pdf
Since 1991, the Washington Department of Fish and Wildlife has tracked fish passage project costs relative to design parameters. See Appendix G, Construction Unit Cost, which begins on page 101 of the PDF, for a unit-cost comparison for fish passage construction projects. The figures reported represent the cost of construction only. The costs have been inflated by 3 percent per year to produce 2003 costs. Other factors affecting cost:

- These costs should only be used for initial project-planning purposes to compare project types; site conditions will greatly affect actual project costs.
- Variables that significantly affect costs include site access, requirements to detour traffic, removal and end-hauling of road fill material and additional work required, such as grade control and road repair.
- Unit cost of culvert replacement may vary according to the length of the culvert, since an increase of length requires not only a longer pipe and excavation but also implies the need for removal, hauling and replacement of a higher fill and wider open cut.

Related Publications

The publications below examine safe wildlife passage, including a 2007 conference paper that expanded on other analyses of wildlife passage to consider practices effective for both terrestrial and aquatic species.

Safe Passages: Highways, Wildlife, and Habitat Connectivity, Jon P. Beckmann, Anthony P. Clevenger, Marcel P. Huijser, Jodi A. Hilty, Island Press, September 2010.
Publisher's information available at http://islandpress.org/bookstore/details6de2.html
It is not clear from the publisher's description if the authors examine comparative costs in this handbook of tools and examples designed to assist those interested in reducing road-wildlife impacts. The book provides current planning approaches and technologies for mitigating the impacts of highways on both terrestrial and aquatic species, case studies that highlight successful implementation of ecological and engineering solutions, and recent innovative highway-wildlife mitigation developments.

"Combining Aquatic and Terrestrial Passage Design into a Continuous Discipline," Sandra Jacobson, Robert Gubernick, Michael Furniss, *Proceedings of the 2007 International Conference on Ecology and Transportation*, North Carolina State University, 2007: 136-142.
http://escholarship.org/uc/item/6w6573r8.pdf
While a cost comparison is not provided in this paper, the focus on identifying barriers to simultaneous consideration of passage needs for all vertebrate species and the solutions suggested for a new paradigm broadly considering all species may be of interest to Caltrans. The authors aimed to identify:

- Characteristics of passages effective for both aquatic and terrestrial species.
- Practices effective for either aquatics or terrestrials but not both.
- Practices that cause problems for one group while solving problems for the other group.
- Planning solutions to obtaining passages effective for all taxonomic categories.

Research in Progress

A project expected to conclude in 2012 is examining culverts in Vermont for their cost-effectiveness and the efficacy of new culvert design criteria to enhance fish passage.

"An Assessment of Culvert Replacements Modified for Fish Passage," Vermont Agency of Transportation, expected completion date: September 28, 2012.
http://rip.trb.org/browse/dproject.asp?n=14184
From the abstract: Over the past several years, the Vermont Agency of Transportation (VTrans) has begun to incorporate project design criteria for the enhancement of fish passage through newly constructed culverts. Many different modifications have been utilized by VTrans during the design and implementation of fish-friendly culverts with consideration to ecologically sized culverts that allow for sufficient water depth, flow, and velocities that are intended to permit the passage of fish. Many factors can affect these parameters including the slope, length, width, roughness and placement of a culvert. The objective of this research project is to determine the effectiveness of fish passage restoration. An examination of representative fish passage structures will define the character, durability and stability of the constructed habitats and improved connectivity upstream and downstream of the culvert. Researchers will also evaluate the cost-effectiveness of these fish-friendly structures.