Planning and Development Services

City of Aurora

Planning Division
15151 E. Alameda Parkway, Ste. 2300
Aurora, Colorado 80012

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May 20, 2020

Steven Marshall
Western Transport, LLC
625 East Main Street Suite #1028
Aspen, CO 81611

Re: Fourth Submission Review -	Transport Colorado – Sub-Area Master Plan 1
Application Number:	**DA-1793-04**
Case Number:	2005-7008-03

Dear Mr. Marshall:

Thank you for your latest submission, which we started to process on Friday, May 1st, 2020. We reviewed it and attached our comments along with this cover letter. The first section of our review highlights our major comments. The following sections contain more specific comments, including those received from other city departments and community members.

Since several important issues still remain, you will need to make another submission. Please revise your previous work and send us a new submission.

Note that all our comments are numbered. When you resubmit, include a cover letter specifically responding to each item. The Planning Department reserves the right to reject any resubmissions that fail to address these items. If you have made any other changes to your documents other than those requested, be sure to also specifically list them in your letter.

Feel free to contact me if you have any questions or concerns. I can be reached at, 303.739.7186 or srodrigu@auroragov.org.

Sincerely,

Stephen Rodriguez

Stephen Rodriguez, Planning Supervisor
City of Aurora Planning Department

cc: Jennifer Carpenter – LAI Design Group 88 Inverness Circle East, Building J, Ste. #101 Englewood, CO 80112
Susan Barkman, Neighborhood Services
Jacob Cox, ODA
Filed: K:\$DA\1793-04rev4.rtf

Fourth Submission Review

SUMMARY OF KEY COMMENTS FROM ALL DEPARTMENTS

- See the comment redlines from Engineering, Traffic (contact directly), Aurora Water, Life Safety, and PROS.
- Please contact the Colorado Department of Transportation (CDOT) for any comments as none were received.
- See the attached letter from Mile High Flood District.

PLANNING DEPARTMENT COMMENTS

Reviewed by: Stephen Rodriguez srodrigu@auroragov.org/ 303-739-7186 / PDF comment color is teal.

1. Community Comments

1A. No additional comments were received from surrounding neighborhoods.

2. Completeness and Clarity of the Application

2A. No additional comments.

3. Zoning, Land Use Comments and Transportation Issues

Open Space, Recreation, and Land Dedication

3A. Continue to work with Porter Ingrum regarding the required avigation easements for the Master Planned development. (Re: Jason Mann email dated 7/19/19)

REFERRAL COMMENTS FROM OTHER DEPARTMENTS AND AGENCIES

4. Civil Engineering

Reviewed by: Kristin Tanabe, ktanabe@auroragov.org / 303-739-7306 / Comments in green.

PIP

4A. Page 1 - The FDP will not be approved by public works until the overall master drainage study and the master drainage study for Sub Area 1 are approved.

4B. Page 6 – Please add that the PUC will be approached as each planning area is developed and include an updated model on when the thresholds will be met. This will require an updated model for each planning area shall be provided to the PUC and City of Aurora to see if the horizon dates change

4C. Page 9 - Include reference to the previous comment regarding updated submissions to the PUC with each planning area, typical.

4D. Page 27 (Sheet 1) - This is identified as a potential signalized intersection in the overall FDP. Include the symbol at all identified intersections on all exhibits.

4E. Please add a note regarding the no rise certificate/CLOMR for construction in the floodplain, and the IGA if annexation has not occurred (per previous comment) on all exhibits.

4F. Where is the drainage channel section?

5. Traffic Engineering

Reviewed by: Brianna Medema ccampuza@auroragov.org / bmedema@auroragov.org 303-739-7309 Comments in gold.

TIS

5A. Please contact the reviewer directly for comments. No redlines were received by staff.

PIP

5B. Please contact the reviewer directly for comments. No redlines were received by staff.

6. Aurora Water

Casey Ballard / / (303) 739-7382) Comments in red.

Master Utility Report
Please address redline comments:
6A. Subarea Master Plan 1 is acceptable but cannot be approved until the MUS is approved. A folder for this has been opened for the developer to submit the MUS for final signature.

7. Life Safety
Reviewed by: William Polk / wpolk@auroragov.org / 303-739-7371 Comments in blue.
Please see Marked-Up (In Blue) FDP for Specific Comments.
7A. Land Matrix Comments
Page 5

- Include the permanent fire station within the PA-15B label/section or make a reference to the permanent fire station land dedication in section 2.

PIP Page 18

- Please revise to "dedicated for public land use (temporary fire station) and dedicated for public land use (permanent fire station).
- After recent discussions with COA Fire & Rescue, it was determined that the temporary fire station shall be the modular structure instead of a portion of a proposed onsite building. Please revise this statement to "the developer will provide the temporary fire station by the means of a modular structure at the direction of the Fire Chief or his or her designee.

8. Parks and Recreation (PROS)
8A. Detention Pond Ineligibility for Open Space Credit – Although the applicant's response to PROS' comments on this topic indicate the item has been addressed, the mapping for PA-36 in Tab #9 and what is shown in the PIP map for Tab #13 are still inconsistent. If a detention pond in the northern part of PA-36 remains an element of the proposed stormwater management system, the acreage associated with the pond should not be symbolized as open space nor should the acreage be counted toward the land dedication acreage. Please refer to the redlines in Tab #9 and rectify.

Tab #9, Open Space, Circulation & Neighborhood Plan – The proposed stormwater infrastructure (i.e., detention pond) should be excepted out of PA-36 for both the maps and the acreage calculations.

Tab #9, Form J – The proposed stormwater infrastructure (i.e., detention pond) should be excepted out of PA-36 for both the maps and the acreage calculations.

9. Mile High Flood District (MHFD)
Reviewed by: Teresa Patterson 303 / 455-6277
9A. See the attached letter dated May 12, 2020.

10. Colorado Department of Transportation (CDOT)
10A. No comments received to date. Contact Marilyn Cross directly for comments.

Roadway Crossings for High functioning, Low Maintenance Streams

2018

Prepared for:

Urban Drainage and Flood Control District
2480 W 26th Ave. Suite 156-B
Denver, CO 80211
(303) 455-6277

Prepared by:

ICON ENGINEERING, INC.

7000 S. Yosemite Street, Suite 120
Centennial CO 80112
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www.iconeng.com

Table of Contents

Table of Figures

SECTION 1 - INTRODUCTION

1.1 Purpose

The purpose of this paper is to present the concept of roadway crossing for high functioning, low maintenance streams as an alternative to traditional hydraulic sizing for the design of stream crossings. Roadway crossings sized to compliment high functioning streams are safer, more resilient to large flood events, better convey sediment and debris, require less maintenance over time, and also provide better conditions for aquatic passage than traditionally designed crossings. The Urban Drainage and Flood Control District (UDFCD) supports this concept but understands that in some cases, site conditions will limit the design.

This paper is the result of a literature review that included academic journals, technical presentations, and stream crossing guidance documents from many state transportation, wildlife, and environmental protection agencies. Additionally, phone interviews with many of the authors were conducted. We would like to thank those who took the time to speak with us and offer their guidance, your contributions are appreciated.

1.2 Usage

For new stream crossings within developing areas, and also for the replacement of old structures at already established crossings, geomorphic crossing design should be the first alternative investigated. Section 5 of this document outlines key geomorphic design criteria that should be followed to the greatest extent possible. It is also recognized that geomorphic design is not possible for all stream crossing situations. Economically, Gynomorphically Sized Crossing (GSCs) are more expensive initially than traditional designs. Additionally, GSCs generally require more space than traditional crossings. Sometimes these or other constraints may limit geomorphic design. In these instances, the reasons why a geomorphic design is not feasible at a particular site, should be clearly demonstrated prior to undertaking a different design approach.

SECTION 2 - STREAM PRINCIPLES

2.1 Stream Input and Function

Streams are a fundamental part of the natural environment. Streams act as agents of erosion, moving water and sediment from the land to the ocean (Knighton, 1998). Figure 1 depicts the longitudinal zones of sediment source, transfer, and deposition within a mountain to ocean river system. In the Colorado Front Range, we have river systems that have characteristics of all three zones.

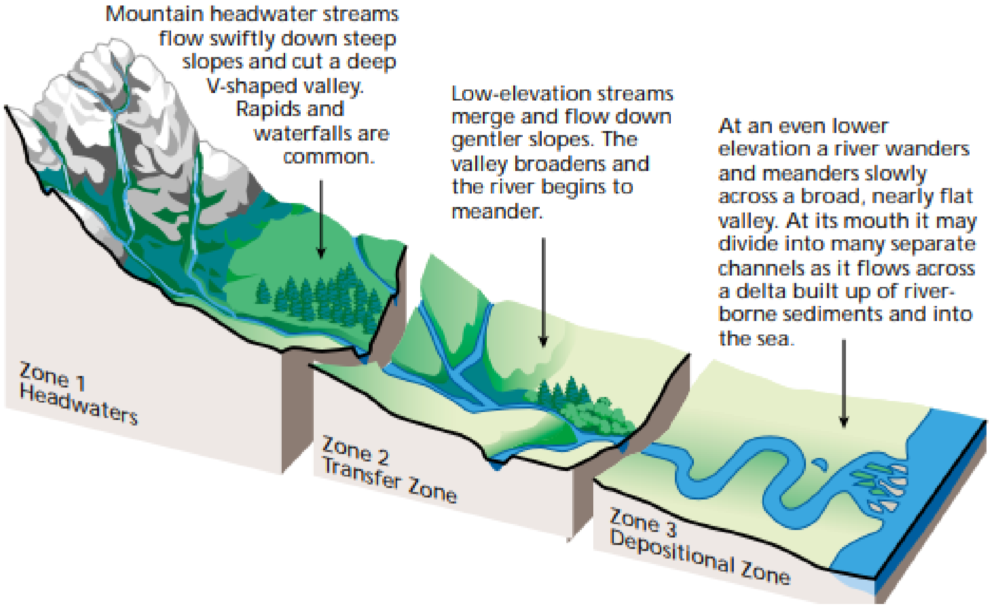

Figure 1: Longitudinal Profile Zones (Federal Interagency Stream Restoration Working Group, 1998)

There are many variables influenced by climate and geology that interact to create the form of a stream channel. These variables include: discharge, sediment supply, sediment size, vegetation, longitudinal slope, and channel roughness (Leopold, 1994).

2.2 Stream Adjustments and Stability

Streams are dynamic systems that change their form over time to changing inputs and anthropogenic constraints. Characteristics of a stream can alter in response to changes in input include, but are not limited to: width, depth, slope, sediment gradation, planform and bedforms. Commonly, aggradation (the deposition of sediment) and degradation (the erosion of sediment) are two responses a stream may have in response to changing flow and sediment regimes. A common depiction of this relationship is known as Lane's Balance (Figure 2). Lane (1955) conceptualized this relationship in an easy to understand manner.

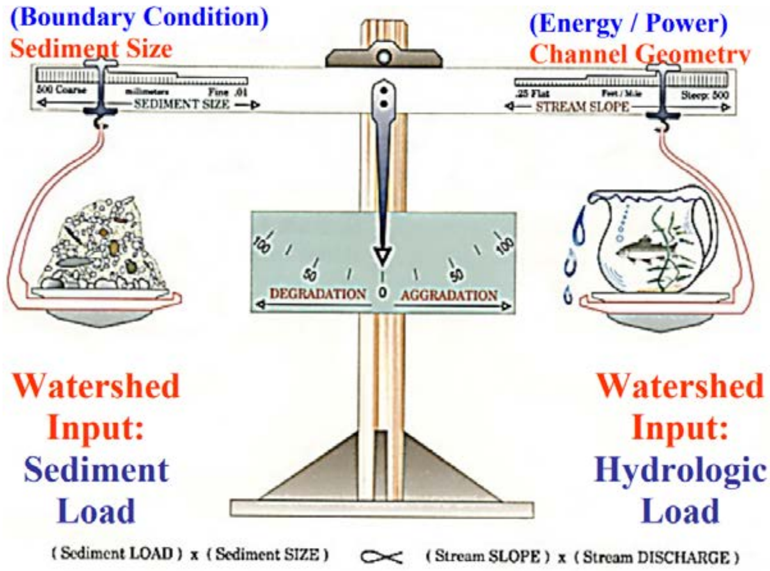

Figure 2: Lane's Balance (1955) from Rosgen 1996

Lane's balance is very useful, but inherently limited because it does not account for changes in cross sectional geometry, bedforms, or planform (Wohl, 2014). A more detailed look at the complex response has been provided by others (Dust and Wohl, 2012; Schumm, 1973).

A stable river, from a geomorphic perspective, is one that has adjusted its width, depth, and slope such that there is no significant aggradation or degradation of the stream bed or significant planform changes (e.g., meandering to braided) within the engineering time frame, which is generally about 50 years (Biedenharn et al., 1997). The goal of geomorphic stream crossing design is to apply this sense of stability to the road-stream intersection in order to increase flood resiliency and minimize maintenance.

SECTION 3 - TRADITIONAL SIZING OF STREAM CROSSINGS

3.1 Traditional Hydraulic Design

Engineers have traditionally designed stream crossings with the primary objective of passing a specified peak discharge with either no overtopping of the roadway or a pre-determined acceptable depth of overtopping. Often times the peak discharge may be the estimated 100-, 50-, or 25-year discharge depending on the level of service of the roadway. Perhaps only second to the goal of passing the design discharge, is minimizing the construction cost of the crossing. These objectives have historically led engineers to design roadway crossings that are very efficient at passing large volumes of water through the smallest possible structure. Considering only the hydraulic performance of a stream crossing alone can be detrimental to the upstream and downstream stability of the system.

3.2 Stream Crossing Problems

3.2.1 Undersized Crossings

Flow through culverts can be very efficient from a hydraulic perspective. However, to achieve this efficiency, water velocity and pressure are often increased to levels far beyond what is found naturally in the stream. This can create a myriad of geomorphic effects on streams. Excessive stream velocity and pressure within a culvert can cause scour and erosion problems at the downstream side of a culvert (Furniss et al., 1998) while simultaneously causing sediment deposition at the upstream end of the culvert.

Undersized culverts are also prone to collecting debris that can't fit into or through the culvert (Minnesota Department of Transportation, 2014). Large pieces of wood and other floatable items can collect on the entrance to the culvert reducing the structure's efficiency and increasing risk of overtopping. High stream velocity and pressure with a culvert during periods of high flow can also cause a temporary barrier to aquatic organisms.

Figure 3: Debris accumulation at entrance to undersized culvert (Minnesota Department of Natural Resources, 2014).

3.2.2 Oversized Crossings

Often to reach a desired hydraulic capacity, a single culvert or bridge may need to be widened beyond the width of the upstream channel. Or similarly, the hydraulic design may require multiple culverts to be placed at the same elevation across the width of the channel. In these situations an increase in the active flow width (from the upstream channel to the crossing) may cause a decrease in flow depth and sediment deposition. Removing sediment deposition from within a culvert (Figure 4) crossing can become a costly maintenance requirement in these situations.

Figure 4: Sediment deposition at river crossing on Poudre River in Greeley, Colorado.

3.2.3 Other Stream Crossing Problems

Other stream crossing problems include perched crossings and unnatural beds. Perched crossings present a physical barrier to the movement of aquatic organisms (Connecticut Department of Environmental Protection, 2008). Even small amount of perching at a roadway crossing can entirely segment a stream for fish and amphibians preventing them from accessing different parts of their environment. Similarly unnatural bed materials such as concrete and metal also create a barrier. In order to maintain natural aquatic passage, the bed of the crossing should match the bed material of the stream.

Figure 5: Perched Culverts (Connecticut Department of Environmental Protection, 2008).

SECTION 4 - GEOMORPHICALLY SIZED STREAM CROSSINGS (GSCs)

4.1 Principles of Geomorphic Sizing

The key principle of GSCs is that rather than being sized primarily on a hydraulic basis where the primary goal is to pass a design discharge, the crossing is sized based on the dimensions and characteristics of the upstream and downstream channel and floodplain. A few overlapping schools of thought for geomorphic-centric stream crossing design exist.

4.1.1 Stream Simulation

The stream simulation approach for design culverts was developed by the United States Forest Service. The methodology was pioneered and developed by engineers and biologists in Alaska and the Pacific Northwest who were concerned about barriers to anadromous fish. Stream simulation aims to create a structure that is as similar as possible to the natural channel. This method assumes that when channel dimensions, slopes, and streambed structure is similar, water velocities, and depths will also be similar. Thus the simulated channel will present not more of an obstacle to aquatic organisms than the natural channel (USDA Forest Service, 2008).

4.1.2 MESBOAC

'MESBOAC' is a stream crossing design methodology that was developed in the State of Minnesota. MESBOAC is based on the principles of fluvial geomorphology and aims to allow geomorphic processes to occur through a stream crossing. Where aquatic passage is a specific goal of the stream simulation methodology, MESBOAC simply assumes that aquatic passage will occur as a byproduct of successful geomorphic design (Minnesota Department of Natural Resources, 2014).

MESBOAC stands for:

Match culvert width to bankfull stream width.

Extend culvert length through the side slope toe of the road.

Set culvert slope the same as stream slope.

Bury the culvert.

Offset multiple culverts.

Align the culvert with the stream channel.

Consider headcuts and cutoffs.

4.2 Continuum of Connectivity

A particular stream crossing design and its design methodology offers a distinct level of connectivity. Depending on the design of the crossing the level of connectivity may lie anywhere on a continuum of connectivity as depicted in Figure 6. At the bottom of the continuum is traditional hydraulic design for flood capacity. Traditional hydraulic design for flood capacity may meet hydraulic goals for the passage of peak flow, but restrict the movement of aquatic organisms, sediment, debris, and encroach on the floodplain.

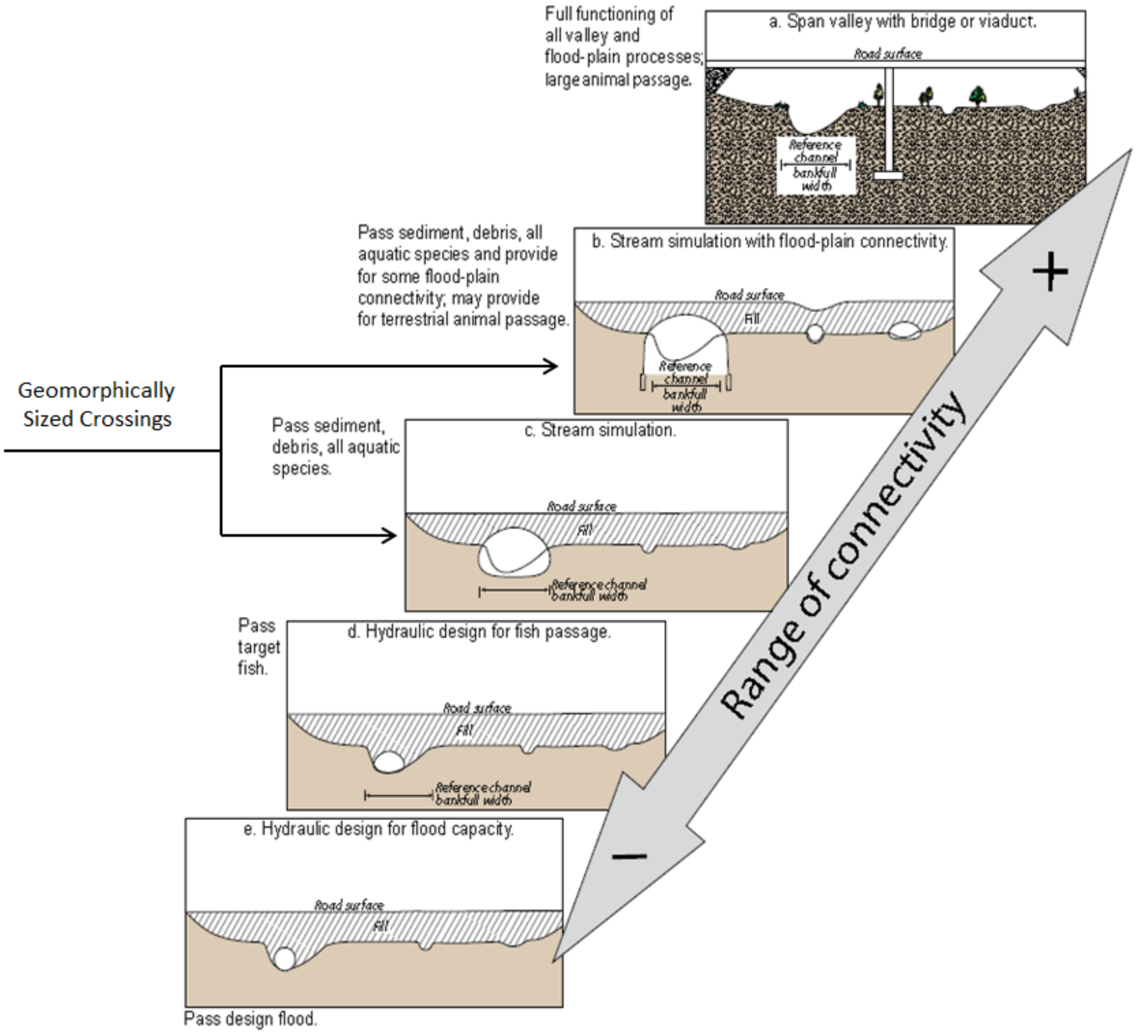

Figure 6: Stream Crossing Design Continuum of Connectivity (Adapted From: Forest Service, 2008)

Hydraulic design for fish passage improves on traditional hydraulic design by restricting velocity in the crossing to levels within the ability of a target species. This allows the target species to be able to traverse the crossing during the design discharge. Crossings hydraulically designed for fish passage may still restrict passage of other aquatic organisms, sediment, or debris as they generally do not provide for the bankfull width. With these designs, the floodplain is still encroached.

Geomorphic sizing improves on the hydraulic design for fish passage by providing a bankfull width passage through the road. By mimicking the upstream characteristics of the bankfull channel, the crossing provides the same level of sediment transport, debris conveyance, and aquatic passage as the channel itself. In order to also provide floodplain connectivity, smaller, auxiliary culverts can be placed in the floodplain. These auxiliary culverts encourage natural floodplain functions while also increasing hydraulic capacity of the total crossing. The level of connectivity provided by GSCs is a great improvement on hydraulic design methodologies.

The highest level of connectivity is provided by a valley spanning bridge. Valley spanning bridges allow for passage of flood waters, sediment, debris, aquatic organisms, and also large animals. While they provide excellent function, valley spanning bridges are cost prohibitive, or impractical on many small to mid-size rivers.

4.3 Benefits of Geomorphic Sizing

4.3.1 Economic

Replacing conventional culverts with GSCs yields a positive economic benefit. Although GSCs have higher initial construction costs (FHWA, 2011), GSCs are also more resilient to floods and catastrophic failure, require less maintenance, and are more durable (Christiansen et. al., 2014). The long lifespan and reduction in maintenance provides a net fiscal benefit (Christiansen et. al., 2014).

Typical service lifetimes for conventional metallic culverts range from 25 to 50 years, while GSCs can achieve lifetimes of 50 to 75 years (Gillespie et al., 2014). GSCs culverts have a longer lifetime primarily because:

1. their increased size results in less likelihood of catastrophic failure during large flood events (O'Shaughnessy et al., 2016) (Figure 7);
2. they transport sediment more efficiently reducing scour and abrasion which can damage the culvert (Christiansen et. al., 2014).

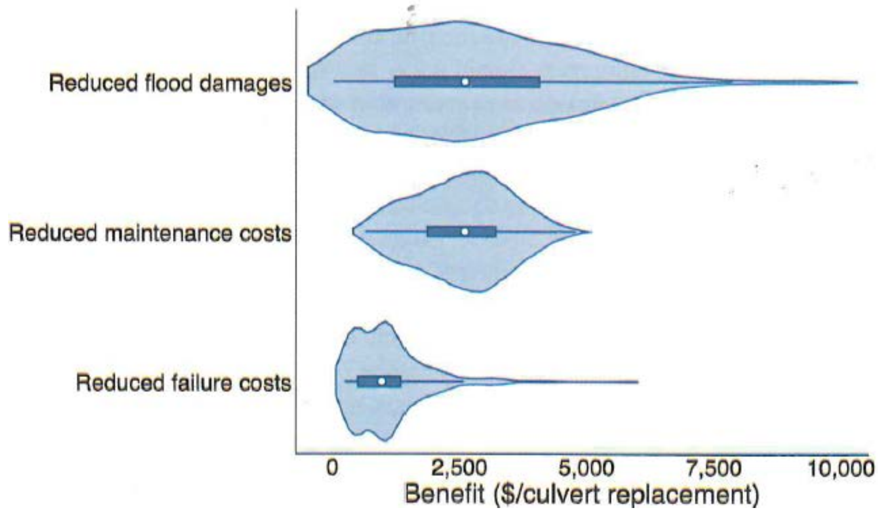

Figure 7: Area plots depicting the distribution of different measured culvert in dollars per culvert (O'Shaughnessy et al., 2016)

The lifecycle of three different culverts for a theoretical watershed is conceptualized in Figure 8 below. In this figure, traditional culverts are depicted with blue and orange lines whereas a GSC (Stream Simulation) is shown as a range of costs between the two green lines. The GSC has the highest initial construction cost. However, because the GSC doesn't need to be replaced after a large flood event, and has minimal to no maintenance costs, it has the lowest lifecycle cost.

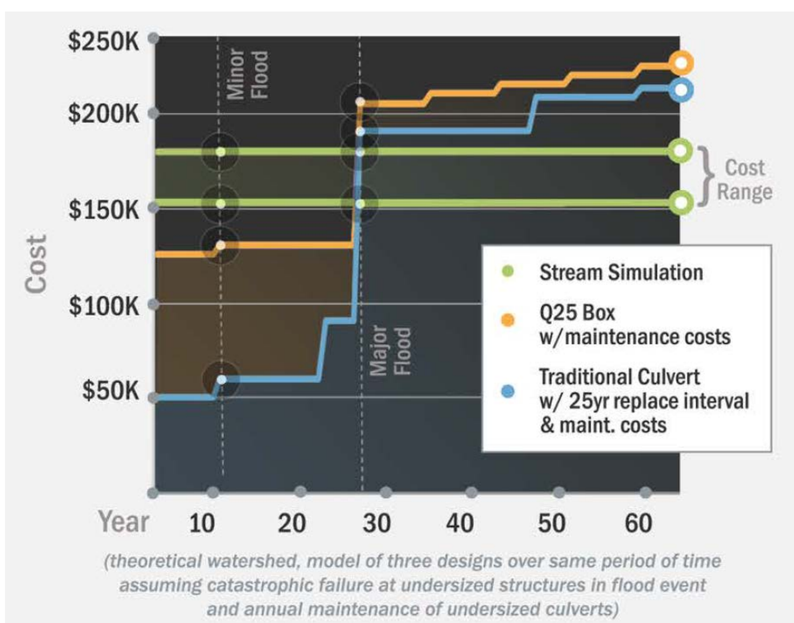

Figure 8: Theoretical stream crossing cost over time (Trout Unlimited, 2018)

4.3.2 Safety

During flooding events, overtopped roadways, and washed out road crossings present a major danger. Vehicles that attempt to drive through floodwaters can be swept away. In the United States, most flooding deaths are drivers and passengers who become trapped in their vehicles (Yale et al., 2010).

Creating a more resilient road system will help keep people safer during floods. GSCs are less likely to clog with debris, overtop, or catastrophically fail than traditional crossings (O'Shaughnessy et al., 2016). GSCs are one tool that may be used to increase human safety during floods.

4.3.3 Environmental

Traditional road crossing culverts present barriers to the passage of aquatic organisms causing fragmented ecosystems. Fragmenting ecosystems limits species access to critical spawning habitats and reduces aquatic populations (Fausch et al., 2002; Letcher at al., 2007). Other methods of culvert design that account for geomorphic sizing criteria (USFS Stream Simulation, MESBOAC) have been shown to greatly improve aquatic passage at road crossings for multiple species (Rathburn, 2015).

4.3.4 Social

Social benefits associated with geomorphic stream crossings include increased safety and recreational opportunities. Adequately sized and designed stream crossings improve the safety of public roads during times of flooding (Levine, 2013). Upgraded stream crossings also improve opportunities for recreational endeavors such as fishing (Levine, 2013).

4.4 Geomorphic Sizing Constraints

Although there are many potential benefits to using GSCs, it may be difficult to implement GSCs due to a variety of constraints. Common constraints may include economics, right of way, utilities, lack of information, and general unfamiliarity with the concept.

State highway departments and local municipalities operate on fixed budgets. This may make it hard to justify a large increase in upfront construction and installation costs for GSCs, especially when multiple culvert replacements are being considered. For urban areas, right-of-way and utilities may also pose considerable constraints to design. Existing utilities can impact the elevation and slope of GSC designs unless further expense is incurred to move such utilities. Lastly, lack of suitable geomorphic information or knowledge of how to apply such information may be a limitation to GSC design.

4.5 Usage

Stream simulation stream crossing design was pioneered and developed by engineers and biologists in Alaska and the Pacific Northwest who were concerned about barriers to anadromous fish. Today, Washington, Alaska, Oregon, California all require stream simulation design elements to be incorporated into culvert design. The United States Forest Service also uses stream simulation design criteria as much as possible to facilitate aquatic passage through road crossings on National Forests. The state of Minnesota also uses geomorphic sizing criteria in the design of stream crossings on a limited basis.

In the Northeast United States, geomorphic sizing parameters have been incorporated into standard criteria and best management practices in many states. Massachusetts, Vermont, and Connecticut have geomorphic sizing procedures in place statewide. For some of these states the turning point was Hurricane Irene in 2011. Hurricane Irene created huge amounts of runoff that damaged or destroyed thousands of stream crossings across a multi-state area. In Vermont, where storm damages were catastrophic, a few stream simulation culverts had been designed and built in 2006. These culverts showed little to no damage from Hurricane Irene. This result led to Vermont adopting stream simulation design concepts on a statewide basis for flood resiliency and safety.

SECTION 5 - DESIGN GUIDANCE FOR GEOMORPHICALY SIZED ROADWAY CROSSINGS

5.1 Site Reconnaissance

Before beginning the design, visit your project site and conduct a field reconnaissance. Begin by walking the channel at least 30-50 channel widths upstream and downstream of the crossing. Extend even further for instances where the streambed is more mobile (Forest Service, 2008). Look for instabilities such as headcuts, knickpoints, eroding streambanks, areas of aggradation, and debris jams. Unstable reaches upstream of your project site could dramatically increase sediment or debris loading to your site. Be aware of recent floods that may affect your interpretation of the channel (Forest Service, 2008). Take note of the condition and function of the channel. Are there any areas that could be considered for reference sites?

5.2 Geomorphic Analysis

5.2.1 Selection of Reference Reach

The "reference reach" is a natural channel in the same vicinity of the project that can be used as a real-world model for the design of your channel through the road crossings (CalTrans, 2007). It is important to select an appropriate reference reach for your stream crossing location. The best case scenario is that you have a suitable reference reach immediately upstream of your project. However, because this is not always the case, sometimes one must look to more distant sections of the same river, or even a different river to provide a suitable reference reach. Ideal reference reaches have the following similarities with the design site (Bledsoe et al., 2017):

- Location (ideally the same river)
- Flow and sediment regime (absence of dams, tributaries, flow extractions in between reference and design site)
- Valley energy (driven by valley slope)
- Lateral constraints (dikes, roads, urban encroachment)
- Land use
- Geology and bed material

Once you have selected the general location of your reference reach using the guidance provided above, a more detailed approach can be taken (Harrelson et al., 1994).

1. Choose sites with evident natural features. These features may include floodplains, terraces, bars, and natural vegetation.
2. Look for evidence of physical impact on the stream from roads, bridges, buildings, and diversions. Ideally, your reference reach should be free of such impacts.
3. The reference reach should include an entire meander (two bends) if possible. The length should be at least 20 times the bankfull width of the channel.

5.2.2 Observations of Reference Reach

Once you have selected your reference reach, there are a few observations that need to be made.

(i) Bankfull Stage

The term "bankfull stage" was coined by Wolman and Leopold (1957) to describe the elevation at which flow begins to leave the channel banks and enter the floodplain. Bankfull discharge is one of the most important and influential terms in fluvial geomorphology because it has widely been interpreted as the most important flow magnitude for controlling channel process and form (Wolman and Miller, 1960; Dunne and Leopold, 1978). Bankfull discharge has since been equated with a recurrence interval of 1-2 years for most channels (Leopold et al., 1964, Castro and Jackson, 2001).

Identifying the bankfull stage and associated geometry of your stream is a critical component to designing your GSC. Active floodplains are the best indicator of bankfull stage and are seen as flat, depositional surfaces (Harrelson et al., 1994). Other indicators of bankfull elevation are (Harrelson et al., 1994):

- a change in vegetation (especially the lower limit of perennial species);
- slope breaks along the bank;
- a change in the particle size of bank material, such as the boundary between coarse cobble or gravel with fine-grained sand or silt;
- undercuts in the bank, which usually reach an elevation slightly below bankfull stage.

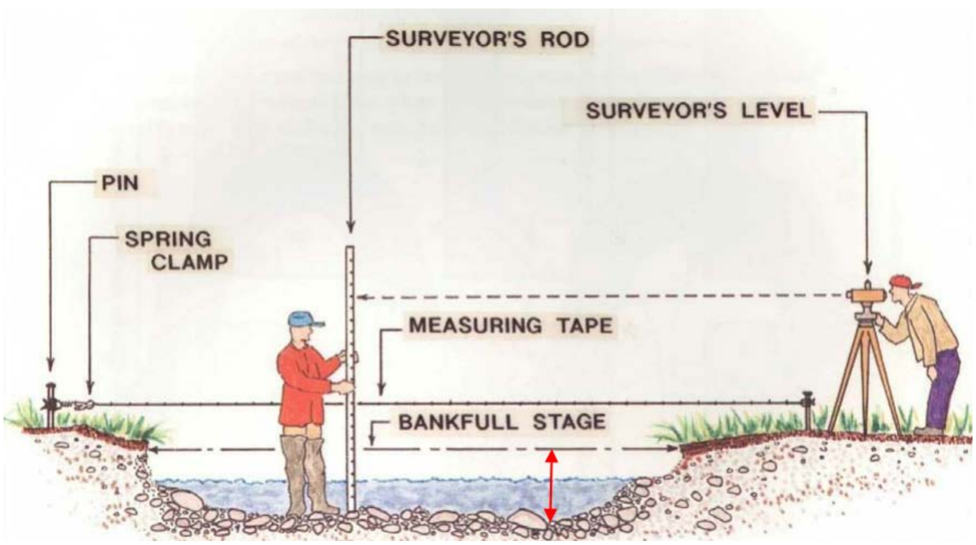

Figure 9: Measurement of Bankfull Stage (Natural Resource Conservation Service, 2009)

For more information on identification of bankfull stage, and the processes that create these indicators see: Dunne and Leopold (1978), Harrelson et. al. (1994), and Rosgen (1996).

(ii) Longitudinal Profile

The longitudinal profile of the stream should be surveyed during the field visit to the reference reach. The longitudinal profile should extend at last 20 times the bankfull channel width. While measuring the profile, elevation of the channel thalweg, water surface, and bankfull elevation should be made (Harrelson et. al., 1994).

(iii) Characterization of Bed Material

The composition of the stream bed and banks is an important facet of stream character, influencing channel form and hydraulics, erosion rates, sediment supply, and other parameters (Harrelson et. al., 1994). An understanding of the sediment gradation of the channel bed is a necessary component of geomorphic crossing design. For streams with sediment gravel sized or larger, the Wolman Pebble Count (1954) is the most efficient and simple technique for characterizing the size of the bed. The Wolman Pebble Count involves traversing a stream riffle and randomly selecting 100 pieces of sediment. The intermediate axis of each piece of sediment should be measured and recorded. This data can then be organized to obtain a representative sediment gradation (Harrelson et. al., 1994).

For streams with finer sediment, a sieve analysis is needed. Consult the U.S. Soil Conservation Service, Soil Survey Handbook (1982) for more information on this procedure.

5.3 Alignment

Establishing the crossing alignment is one of the first steps in geomorphic culvert design. The crossing alignment is the two-dimensional plan view that connects the upstream and downstream channel. The crossing profile, which is designed next, is a longitudinal view of the elevation change of the crossing over its length from upstream to downstream. The alignment and profile of the crossing must be considered together as they are interdependent.

In the past, culverts were aligned to be perpendicular to the road in order to minimize culvert length, and thus cost. However, in some situations, perpendicular alignments can create instabilities in the upstream and downstream channel by shortening the length of the channel and thus increasing the slope and stream power. Additionally, in order to create a perpendicular alignment, often the stream has to be forced into unnatural bends (MDNR, 2008).

Considerations for selection of design alignment:

- Consider the natural channel location through the crossing. Ideally, the culvert should be parallel to the upstream channel as much as is possible without overlengthening the culvert (Forest Service, 2008).

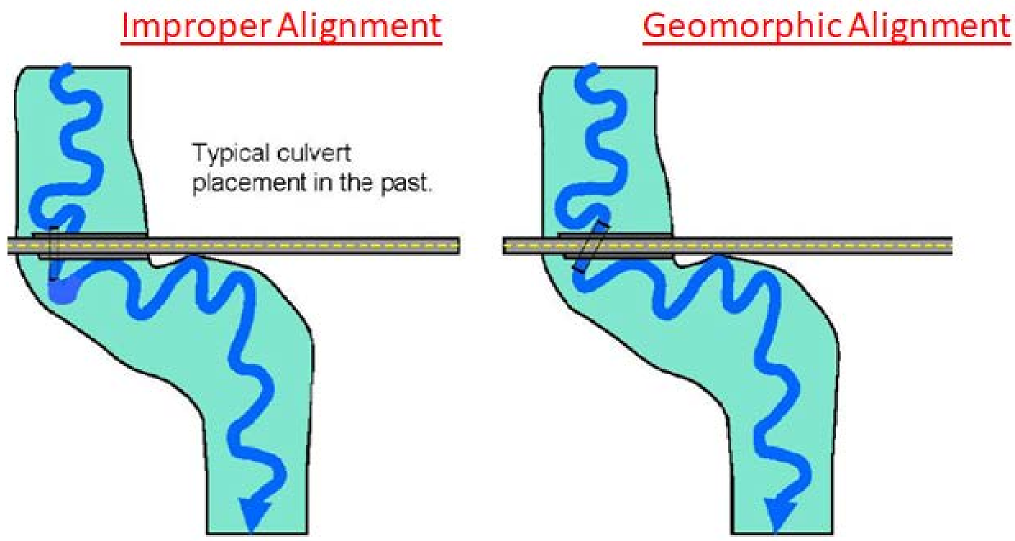

Figure 10: Improper and Correct Crossing Alignment (adapted from MDNR, 2008)

- Shorter culverts are better than longer culverts. Longer culverts carry more risk that hydraulic energy is not adequately dissipated within the culvert. Additionally, longer culverts on meandering streams may be more likely to cutoff channel bends and steepen the channel (Forest Service, 2008). Using vertical headwalls rather than fill slopes are recommended to reduce the total length of the culvert (Connecticut Department of Environmental Protection, 2008).
- Where it is not possible to match the culvert alignment with the upstream alignment without significantly lengthening the culvert, consider overwidening the culvert to reduce risk of culvert failure (Forest Service, 2008). Also, consider using headwalls in conjunction with an overwide culvert (Figure 11).

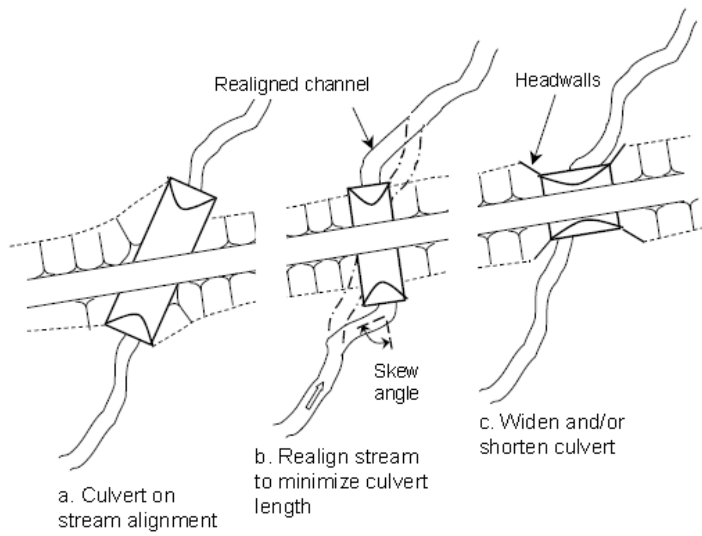

Figure 11: Alignment Options for Skewed Culvert (Bates and Kirn, 2009)

- The relationship between the radius of curvature (R_c) of the upstream bend and bankfull width is an indicator of the level of risk posed by a skewed alignment. When R_c is greater than 5 times bankfull width, sediment and debris transport are essentially the same as on a straight channel. As R_c decreases to a point where it is equal or less than 2 times bankfull width, the risk of impeding sediment and debris transport is substantial (Forest Service, 2008).

5.4 Profile

Because the crossing alignment and profile are interdependent, designing these components needs to be an iterative process.

Considerations for selection of design profile:

- Use the survey of longitudinal profile of the reference reach to ensure the culvert matches the slope of the reference reach. The slope of the reference reach should be from stable grade control features including bedrock outcrops, highly stable step drops, or riffle crests (Forest Service, 2008).

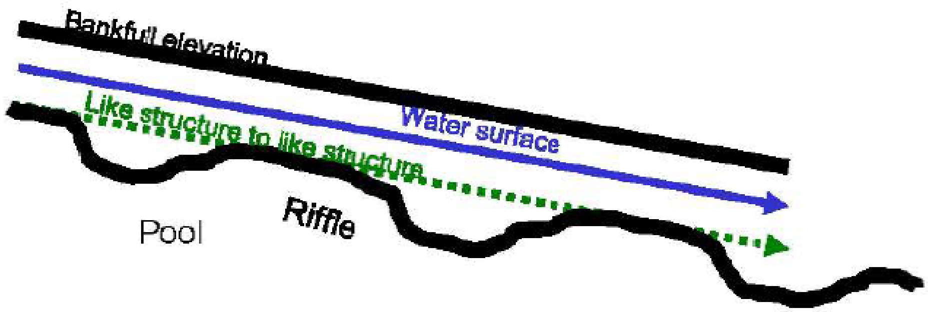

Figure 12: Set Culvert Slope to Match Riffle Slope (MDNR, 2014)

- The culvert gradient should be no steeper than the streambed gradient upstream or downstream of the culvert and should match the overall stream gradient as closely as possible. Gradient for sunken culverts should not exceed 3%. Bottomless arch culverts or clear span bridges should be used where the gradient exceeds 3% (Connecticut Department of Environmental Protection, 2008).

5.5 Design of the Channel Bed

Bed material inside the stream crossing is important for maintaining flow resistance, bed forms, and cross sectional shape similar to that which is upstream and downstream of the channel. From a hydraulic perspective, this helps ensure that aggradation/degradation, a costly maintenance problem, does not occur through the culvert. Placing bed material within the stream crossing also allows for a diverse array or flow depths and velocities which provide the best conditions for aquatic passage (Forest Service, 2008). For these reasons, spans (bridges, 3-sided box culverts, open arches) are strongly preferred (Jackson et. al., 2011) stream crossing alternatives. However, the channel bed can be simulated by placing material on the bottom of an enclosed stream crossing.

Considerations for creation of channel bed within culvert:

- When placing the channel bed, it is best to use material of a similar origin and gradation to the upstream channel bed material.
- The culvert should be buried at a depth of 1/6th the bankfull width (up to 2 feet), 1/5th for steeper streams with larger cobble substrate (MDNR, 2014).
- Culverts should be embedded a minimum of 2 feet for all culverts, a minimum of two feet and at least 25 percent for round pipe culverts (Jackson et. al., 2011).
- The minimum thickness of the bed over the culvert flood should be 1.5 times the diameter of the largest immobile particles or four times the size of the largest mobile particle, whichever is greater (Bates and Kirn, 2009).

- Material placed within the crossing should be formed into a cross section resembling the bankfull channel. The banks of the bankfull channel should be constructed with immobile material. To accomplish this, you may need to use material up to twice the size of the D95 of the reference reach. Gaps in the large bank material should be packed with smaller material (Forest Service, 2008).
- For very mobile bed streams such as those with sand beds, the initial channel can be a simple V-shaped section with a 5:1 (H:V) slope. This will keep the thalweg off the culvert walls until time in which a bankfull channel can form (Forest Service, 2008).

5.6 Structure Size and Elevation

Only after the crossing alignment, profile, and bed have been determined does the crossing designer then consider the dimensions and elevation of the structure itself.

5.6.1 Structure Width

The first estimate of structure width can be estimated by the bankfull width plus the size of the largest rocks used to construct the channel banks within the crossing. This allows channel forming flows to pass through the culvert without being narrowed. Wider structures can be used where a floodplain bench is desired through the culvert (Forest Service, 2008). Others suggest culverts should have a width that spans an area 1.2 times the bankfull width of the stream (Connecticut Department of Environmental Protection, 2008).

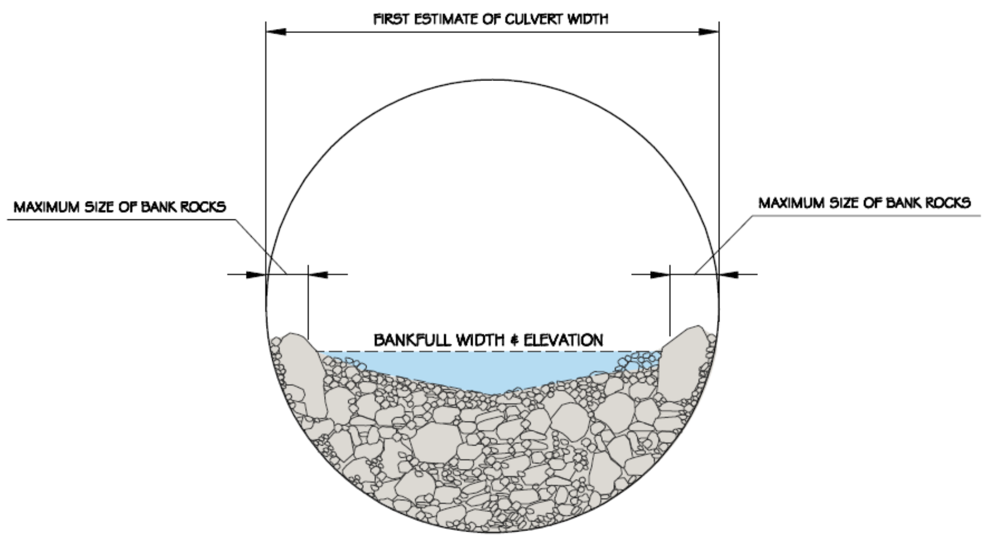

Figure 13: Estimate of Crossing Width (Forest Service, 2008)

5.6.1 Structure Height

Determining the culvert height can be a challenging part of the design process. To size the height of the structure, the Forest Service (2008) first recommends determining the bed-design flow. The bed-design flow is the highest flow that immobile bed particles are designed to sustain without moving. To determine the bed-design flow, an incipient motion analysis needs to be performed on the D_{84} of the channel bed material to determine the discharge rate which entrains the D_{84}. The discharge that entrains the D_{84} is the bed-design flow. The structure height should allow passage of the bed-design flow without more than 80% submergence of the structure, 67% submergence if woody debris is a significant concern (Forest Service, 2008). This requirement helps keep the simulated streambed from washing out during high flow events.

Other guidance documents don't require an incipient motion analysis and rather provide more general recommendations for the minimum culvert height. In these cases, the culvert height is set to provide flood conveyance and the guidelines guard against a small culvert height. For example: the state of Minnesota minimum culvert height should be at least 1/3 the bankfull width (MDNR, 2014). In Massachusetts, a minimum height of 6 feet is recommended (Jackson et. al., 2011).

5.6.2 Openness Ratio

The openness ratio should be used as a check on the cross sectional area of your culvert. The openness ratio is calculated by dividing a culvert's cross sectional area (ft^2) by its length (ft). The resulting value has units of feet. For embedded culverts, only the cross sectional area open to flow conveyance should be used in the calculations. Different agencies have varying recommendations for minimum openness ratio. An openness ratio of at least 0.25 feet is recommended for the State of Connecticut (Connecticut Department of Environmental Protection, 2008) for passage of aquatic organisms. When stream crossings are in important wildlife corridors, where passage of terrestrial animals is a consideration, a ratio of at least 1.0 is preferred (Brudin, 2003). Other states, such as Massachusetts recommend a minimum value of 0.82 feet (Jackson et. al., 2011) as a general requirement for all crossings, while saying that 1.64 is preferred. For stream crossings in Colorado, an openness ratio of at least 0.82 is recommended by the Urban Drainage and Flood Control District.

5.6.3 Multiple Culverts and Floodplain Relief Culverts

Floodplain relief culverts are auxiliary culvert crossings placed adjacent to the stream within the floodplain (Figure 14). Floodplain relief culverts are a useful option for meeting flood conveyance targets without exceeding the maximum submergence (80%) of the primary bankfull crossing. The auxiliary openings increase stream stability while reducing the likelihood of road washout (MDNR, 2014). Because floodplain culverts are primarily for increased hydraulic capacity and floodplain connectivity, they do not need to conform to any geomorphic sizing criteria, nor do they need to have a natural bed.

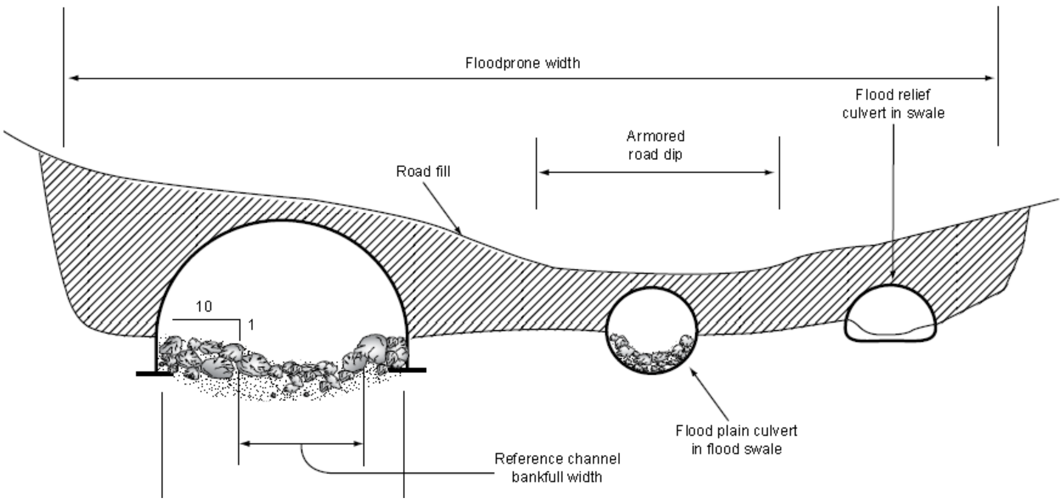

Figure 14: Geomorphically Sized Crossing with Floodplain Relief Culverts (Forest Service, 2008)

Considerations for creation off floodplain relief culverts:

- Floodplain culvert should be located at, or above, bankfull elevation (Zytkovicz and Murtada, 2013)
- Floodplain culverts should be sized large enough to allow for maintenance as needed.
- From a floodplain function perspective, many small floodplain culverts are better than just one large floodplain culvert (Zytkovicz and Murtada, 2013)

SECTION 6 - DEMONSTRATION DESIGNS

6.1 First Creek at E. 26th Ave.

<This section will demonstrate the design of a geomorphically sized culvert. Comparisons will be made against a traditional design culvert for performance and estimates cost.>

6.2 Demonstration Design #2

<This section will demonstrate the design of a geomorphically sized culvert. Comparisons will be made against a traditional design culvert for performance and estimates cost.>

SECTION 7 - CONCLUSIONS

<Section to be completed after UDFCD roundtable discussion>

SECTION 8 - REFERENCES

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