8.3 Design Criteria

8.3.1 Structural Alternatives

A myriad of structure alternatives are available for use in a highway-stream crossing system when all of the possible combinations of bridge lengths, spans, pier types and orientation, geometries, parapet designs, and superstructure designs are considered. In addition, at many crossings, multiple bridges or a single bridge may be viable alternatives or large culverts may be used in lieu of one or more bridges.

The hydraulics of the highway-stream crossing system should be given considerable study in choosing the preferred design from the long list of available alternatives.

8.3.2 Bridge or Culvert

Occasionally, the waterway opening(s) for a highway-stream crossing can be provided for by either culvert(s) or bridge(s). Estimates of costs and risks associated with each will indicate which structure alternative should be selected on the basis of cost, depth of cover, constructability, utility impact, environmental concerns, aesthetics, etc. It should be pointed out that the considerations outlined in Table 8-2 are not necessarily advantages or disadvantages but determine when it is appropriate to select a bridge or culvert. Other considerations which may influence structure-type selection are discussed in Section 8.5 and Chapter 9.

8.3.3 Allowable Headwater

Allowable headwater is the depth of water that can be ponded at the upstream end of the culvert during the design flood which will be limited by one or more of the following:

- non-damaging to upstream property
- 0.3 m (1 ft) below the established hydraulic control
- equal to an HW/D no greater than 1.5
- the elevation where flow is diverted from the area tributary to the culvert

8.3.4 Review Headwater

The culvert should be analyzed for a storm of greater frequency to ensure the level of inundation is tolerable to upstream property and the roadway (see Table 8-4).

Table 8-2

BRIDGE OR CULVERT

Bridges	
Advantages	Disadvantages
Less susceptible to clogging with drift, ice and debris Waterway generally increases with rising water surface until water begins to submerge superstructure Flowline is flexible Minimal impact on aquatic environment and wetlands Widening does not usually affect hydraulic capacity	Require more structural maintenance than culverts Fill slopes susceptible to erosion and scour damage Piers and abutments must be designed not to fail due to scour Susceptible to ice and frost formation on deck Bridge railing and parapets hazardous as compared to recovery areas when it is possible to extend the culvert beyond the safe recovery area Deck drainage may require frequent maintenance cleanout Buoyant, drag and impact forces are hazards to bridges Susceptible to damage from stream meander migration

Culverts	
Advantages	Disadvantages
Provides an uninterrupted view of the road Roadside recovery area can be provided Grade raises and widening projects sometimes can be accommodated by extending culvert ends Require less structural maintenance than bridges Frost and ice usually do not form before other areas experience the same problems Capacity increases with stage Capacity can sometimes be increased by installing improved inlets Usually easier and quicker to build than bridges Scour is localized, more predictable and easier to control Can be used to arrest headcutting Storage can be utilized to reduce peak discharge	Silting in multiple barrel culverts may require periodic cleanout No increase in waterway as stage rises above soffit as the bottom is fixed May clog with drift, debris or ice Possible barrier to fish passage Susceptible to erosion of fill slopes and scour at outlets Susceptible to abrasion and corrosion damage Extension may reduce hydraulic capacity Inlets of flexible culverts susceptible to failure by buoyancy Rigid culverts susceptible to separation at joints Susceptible to failure by piping and/or infiltration

8.3.5 Tailwater Relationship - Channel

- Evaluate the hydraulic conditions of the downstream channel to determine a tailwater depth for a range of discharges which includes the review or design discharge.
- Calculate backwater curves at sensitive locations or use a single cross section analysis.
- Use the critical depth and equivalent hydraulic grade line if the culvert outlet is operating with a free outfall.
- Use the headwater elevation of any nearby, downstream culvert if it is greater than the channel depth.

8.3.6 Tailwater Relationship - Confluence with a Main Stream or Large Water Body

The analysis of tributary crossings located at or within the influence of the confluence with a main stream or large water body shall utilize the following applicable tailwater conditions.

- Use the high water elevation that has the same frequency as the design flood if events are known to occur concurrently (statistically dependent).
- If statistically independent, evaluate the joint probability of flood magnitudes and use a likely combination resulting in the greater tailwater depth. For example, a main stream (receiving waters) and tributary (culvert outfall) have a drainage area ratio of 100 to 1 and a 50 year design for the culvert. Table 8-3 indicates that:
  1. when a 50 year storm is applied to the tributary, the highwater of the main stream should be determined for a 10 year storm frequency and be used as the design criteria.
  2. a 50 year highwater on the main stream should be applied to a 10 year storm frequency on the tributary. The analyses should include any additional drainage area that the outfall receives between the outlet and the receiving waters. This analysis is intended to be used as a check similar to the check frequency for the structure (Table 8-4 and 9-2). Modification to the design may be appropriate if there is likelihood of danger to persons, extensive property damage, etc. It should be noted that it may be impractical to provide an improved design due to the backwater of the main tributary.

- If tidal conditions are present, use the main stream high tide or normal depth in the downstream channel, whichever is greater.
- The worst case bridge scour event occurs when low tailwater conditions exist. When evaluating/analyzing scour, careful consideration is required when selecting the reasonable lowest tailwater conditions.
- Rating curves should be developed based on the same design/tailwater combinations.

Table 8-3 Joint Probability Analysis

AREA RATIO	FREQUENCIES FOR COINCIDENTAL OCCURRENCE							
	10-Year Design		25-Year Design		50-Year Design		100-Year Design	
	Main Stream	Tributary	Main Stream	Tributary	Main Stream	Tributary	Main Stream	Tributary
10,000 TO 1	2	10	2	25	2	50	2	100
	10	2	25	2	50	2	100	2
1,000 TO 1	2	10	2	25	5	50	10	100
	10	2	25	2	50	5	100	10
100 TO 1	5	10	5	25	10	50	25	100
	10	5	25	5	50	10	100	25
10 TO 1	10	10	10	25	25	50	50	100
	10	10	25	10	50	25	100	50
1 TO 1	10	10	25	25	50	50	100	100
	10	10	25	25	50	50	100	100

Notes: Shaded values denote design combination for coincidental frequency occurrence.
Non-shaded values denote check combination for coincidental frequency occurrence.

8.3.7 Minimum Culvert Size

Culverts providing for passage of storm runoff from one side of the highway to the other shall not be smaller than 600mm (24 in) for interstate systems and 450mm (18 in) for other systems.

8.3.8 Maximum Velocity

The maximum velocity at the culvert outlet shall be consistent with the velocity in the natural channel or shall be mitigated with outlet protection measures, energy dissipation and if required, channel stabilization. (See Section 8.7 and Chapter 7.)

8.3.9 Minimum Velocity

The minimum velocity in the culvert barrel shall result in a tractive force ($\tau=\gamma dS$) greater than critical τ of the transported streambed material at low flow rates, unless material is required to aid in fish passage. See Section 7.6.6 for a detailed discussion on tractive force.

8.3.10 Storage - Temporary or Permanent

If storage is being assumed upstream of the culvert, consideration shall be given to:

- limiting the total area of flooding
- limiting the average time that bankfull stage is exceeded for the design flood to 48 hr in rural areas or 6 hr in urban areas
- ensuring that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement

8.3.11 Flood Frequency

The flood frequency used to design or review culverts shall be based on:

- the level of risk associated with failure of the crossing, increasing backwater, or redirection of the floodwaters
- an economic assessment or analysis to justify the flood frequencies greater or lesser than the minimum flood frequencies listed herein
- location of FEMA and SCEL mapped floodplains
- ConnDOT design criteria (see Table 8-4)

Table 8-4

SUMMARY OF HYDRAULIC DESIGN CRITERIA FOR CULVERTS

CONNDOT STRUCTURE CLASS ***	DRAINAGE AREA km^2 (mi^2)	DESIGN FREQUENCY (year)	CHECK FREQUENCY (year)	BACKWATER m (ft)	MINIMUM ** FREEBOARD m (ft)
Minor	< 2.59 (1) (no established watercourse)	25	-	-	0.3 (1)
Small	< 2.59 (1)	50	100	-	0.3 (1)
Intermediate *	≥ 2.59(1) < 25.9(10)	100	500	≤ 0.3 (1)	0.3 (1)
Large *	≥ 25.9(10) < 2590(1000)	100	500	0.3 (1)	0.6 (2)

* The designer shall also consider bridge alternative (see 8.3.2 and Chapter 9) for this class when area > 2.59 km (1 mi^2)

** Freeboard is defined as the vertical distance between the design water surface and the upstream control such as the low point of the roadway edge, sill of a building or other controlling element.

*** See Section 9.3.3 through 9.3.6 for detailed discussions on structure classification.

8.3.12 Documentation

The following items shall be included in the documentation file (See Chapter 1, Section 1.6). The intent is not to limit data to only those items listed, but rather establish a minimum requirement consistent with the culvert design procedures as outlined in this chapter. If circumstances are such that the hydraulic design procedure is prepared other than the normal procedures or is governed by factors other than hydrologic or hydraulic factors, a narrative summary detailing the design basis shall appear with the other data.

The following items shall be included in the documentation file:

- design discharge values and discharge rating curves
- culvert performance curves
- allowable headwater elevation and basis for its selection
- type of culvert entrance conditions
- culvert outlet velocities and energy dissipation calculations and designs
- cross section(s) used in the design water surface determinations
- roughness coefficient assignments ("n" values)
- observed highwater marks with associated dates and discharges
- natural, existing and proposed conditions water surface profiles for intermediate structures or larger
- velocity measurements and locations or velocity estimates. Include both the through-bridge and channel
- copies of all computer analyses and standard computation sheets given in this chapter
- magnitude and frequency of overtopping flood if less than the design
- tailwater depth or starting water surface elevation
- roadway geometry plan and profile
- potential flood hazard to adjacent properties
- completed applicable forms (see Appendix C through F of this chapter)
- for culverts conveying drainage areas > 2.5 km^2 (1 mi^2) use the Hydraulic Data form in Appendix A of Chapter 9, Bridges.
- scour evaluation/analysis for bottomless structures for design 100 yr. flood and 500 yr. flood