

Chapter 11. Culverts and Bridges

11.0 Introduction

This section addresses design criteria for culverts and bridges as they relate to drainageways in the City of Centennial. Generally, a culvert is a conduit for the passage of surface drainage water under a highway, railroad, canal, or other embankment, and a bridge is a structure carrying a pathway, roadway, or railway over a waterway. Further discussions and descriptions of both of these structure types are included in the following sections.

11.1 General Design Information

11.1.1 Design Criteria. The procedures and basic data to be used for the design and hydraulic evaluation of culverts shall be consistent with the Culverts Chapter of Volume 2 of the UDFCD Manual, except as modified herein. The reader is also referred to the many texts covering the subject for additional information, including Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5 (FHWA 1985).

Bridges are typically designed to cross the waterway with minimal disturbance to the flow. However, for practical reasons, abutment encroachments and piers are often located within the waterway. Consequently, the bridge structure can cause adverse hydraulic effects and scour potential that must be evaluated and addressed as part of each design. The design of a bridge is very specific to site conditions and numerous factors must be considered.

There are many acceptable manuals that are available and should be used in bridge hydraulic studies and river stability analysis. The Bridges Section 4.0 in the Hydraulic Structures chapter of the UDFCD Manual shall be consulted for basic design criteria and information regarding other publications and resources. Some excellent references include the CDOT Drainage Design Manual, FHWA Highways in the River Environment, FHWA Evaluating Scour at Bridges, FHWA The Design of Encroachments on Floodplains using Risk Analysis, and FHWA Stream Stability at Highway Structures.

11.1.2 Design Flows. Culverts and bridges shall be designed for future fully developed basin conditions as outlined in Chapter 6, Hydrology. The design flows shall be consistent with the design flows of the drainageway in which the improvement is being made. Specific requirements for several of the structure types are contained in their respective sections.

11.1.3 UDFCD Maintenance Eligibility. Culverts and bridges for road and highway construction are generally considered to be a part of the transportation system and are usually not eligible for UDFCD maintenance assistance. In some cases, however, the major drainageway reach where the crossing is located may be eligible for UDFCD maintenance assistance. In addition, culvert outlet improvements and channel stabilization improvements associated with the

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roadway crossing may be eligible for UDFCD maintenance assistance. Culvert outlet and channel improvements shall be designed in accordance with SEMSWA and UDFCD criteria to ensure that those improvements are eligible for UDFCD maintenance assistance. Culvert and Bridge designs will be referred to UDFCD for comment in all cases, to ensure that the major drainageway remains eligible for UDFCD maintenance assistance, where applicable

- 11.1.4 Permitting and Regulations.** Designers of stream crossings must be cognizant of relevant local, State, and Federal laws and permit requirements. Permits for construction activities in navigable waters are under the jurisdiction of the U.S. Army Corps of Engineers. Applications for Federal permits may require environmental impact assessments under the National Environmental Policy Act of 1969. In Colorado provisions of Senate Bill 40 need to be addressed on any stream crossing. A 404 permit from the U.S. Army Corps of Engineers concerning wetlands mitigation is an example of an additional permit.

SEMSWA requires a Floodplain Development Permit for any stream crossing constructed in a floodplain. Refer to Chapter 5, Floodplain Management for a complete description of impacts to floodplains.

- 11.1.5 Aesthetics and Safety.** The appearance and safety of structures are important considerations for SEMSWA's acceptance of the design. Structure geometry, materials, and the texture, patterning, and color of structure surfaces shall be selected to blend with the adjacent landscape and provide an attractive appearance.

The safety of the public, especially in areas of recreational use, shall be considered when selecting the appropriate structure and handrail treatment for a given area. Prior to final selection of a structure, the applicant should meet with SEMSWA to ensure that the structure is appropriate for the area in which it is proposed.

- 11.1.6 Easement, Ownership and Maintenance Requirements.** Culverts and bridges within the City are generally within the public right-of-way for the road. Additional easement or right-of-way, beyond the normal street width may be required to facilitate the construction, operation and/or maintenance of the structure. Design plans for the structure shall include the proposed easement and/or right-of-way limits. Maintenance issues and access shall be considered in the structure design, and appropriate measures should be included to facilitate proper maintenance (i.e. access road if necessary, etc.). Where culverts and bridges are not within a public right-of-way, the easement, ownership and maintenance requirements for structures shall be consistent with the requirements defined for open channels in Chapter 12.

- 11.1.7 Trail Coordination.** Culverts and bridges often provide an opportunity for trails to cross roadways with a grade separation, avoiding conflicts between pedestrians and vehicles. Advance coordination with SEMSWA is required to

determine if the proposed culvert or bridge location is compatible with an existing or proposed trail plan. If the location is determined by SEMSWA to be compatible from a planning standpoint, and the crossing is physically possible, final design requirements for trail width, vertical clearance, surfacing, lighting and safety improvements shall be coordinated to match the existing or proposed trail design. Where a trail may be proposed, but not yet designed, a 12-foot minimum width bench shall be provided within the culvert or under the bridge in accordance with the SEMSWA'S trail recommendations. A minimum height from the bench up to the lowest point on the structure of 9-feet is required, with additional height if equestrian traffic is expected. The low flow channel adjacent to the bench shall pass as much flow as practicable, considering the duration of the flooding, inconvenience to the public, and available alternate routes. As a minimum the low flow should be designed to accommodate the 2-year flood flow if the duration of the hydrograph is less than 24 hours. If the duration of the hydrograph is longer than 24 hours, a 10-year channel shall be provided below the bench. Connections to the roadway grade should be considered.

11.2 Culvert and Bridge Sizing Criteria

11.2.1 Culvert and Bridge Sizing Factors. The sizing of a culvert or bridge is dependent upon several factors including whether the drainageway is major or minor, the street drainage classification (i.e., Type A, Type B, or Type C), the allowable street overtopping, and the allowable headwater. For minor drainageways, the allowable street overtopping for the various street classifications is identified below. No overtopping is allowed for any street classification at major drainageway crossings.

**TABLE 11-1
ALLOWABLE BRIDGE AND CULVERT OVERTOPPING
FOR MINOR DRAINAGEWAYS**

NOTE: No Overtopping Allowed for Major Drainageways

Drainage Classification	10-Yr. Storm Event Runoff	Major Storm Event Runoff
Type A (Local, Minor Collector)	No overtopping allowed	Overtopping at crown governed by maximum depth of 12-inches at gutter flowline ¹
Type B (Major Collector)	No overtopping allowed	Overtopping at crown governed by maximum depth of 12-inches at gutter flowline ¹
Type C (Arterial)	No overtopping allowed	No overtopping allowed
Type C (Arterial by Functional Classification) ²	No overtopping allowed	No overtopping allowed

¹ See Chapter 7, Street Drainage, for further discussion regarding allowable flow depth in the street based on Drainage Classification.

² Functional classification identifies the type of transportation service provided by a roadway. Roadways providing a high level of mobility have a high functional classification such as a freeway or arterial. Roadways having a high level of accessibility have a low functional classification such as a local street. For example, a two-lane low volume roadway may provide high mobility between areas of low-density land use and could have a Functional Classification of Arterial.

Actual overtopping depth at the street crown will depend on the width of the street and cross slope. No overtopping is allowed if a street has a raised median.

SEMSWA may consider lesser criteria for rural areas or low volume roadways on a case-by-case basis, if there is adequate justification. Any variance from the table above will have to be approved by SEMSWA.

These Criteria are considered the minimum design standard and must be modified where other factors are considered more important, such as impacts to the floodplain and adjacent structures or properties, availability of alternate routes, excessive channel velocities, and other factors pertinent to a specific site.

11.2.2 Sizing Procedure for Type A and B Streets When Overtopping is Allowed.

The following procedure shall be used when overtopping is allowed:

1. Using the future developed condition 100-year runoff, the allowable flow over the street shall be determined based on the allowable overtopping depth and the roadway profile, treating the street crossing as a broad-crested weir.
2. The culvert is then sized for the difference between the 100-year runoff and the allowable flow over the street.
3. If the resulting culvert is smaller than that required to pass the 10-year storm runoff without overtopping, the culvert size shall be increased to pass the 10-year storm runoff.

11.2.3 Headwater Considerations. For all Type A and B roads, the maximum headwater to depth ratio for the 100-year design flows will be 1.5 times the culvert or bridge opening height. For a culvert through a Type C road, the maximum headwater to depth ratio for the 100-year design flows will be 1.2 times the culvert opening height. Refer to Section 11.6.4 for Bridge Freeboard guidelines.

11.3 Culvert Design Standards

11.3.1 Construction Material. Culverts designed and built in the City shall be made of reinforced concrete in round or elliptical cross-sections or reinforced concrete box shapes that are either cast-in-place or supplied in precast sections. In rural areas, corrugated metal pipe culverts in round or arch cross sections may be accepted on a case by case basis. All corrugated metal pipe must be galvanized or aluminized steel or aluminum pipe.

11.3.2 Minimum Pipe Size. The minimum pipe size for culverts within a public right-of-way (ROW) shall be 24 inches diameter round, or shall have a minimum cross sectional area of 3.3 ft² for arch or elliptical shapes. Box culverts shall be as tall as physically possible, but shall not have less than a 3-foot high inside dimension. An exception is made for private driveway culverts, which may have a minimum diameter of 18”.

11.3.3 Culvert Sizing and Design. Culvert design involves an iterative approach. Two references are particularly helpful in the design of culverts. The UDFCD Manual provides design aids and guidance taken from FHWA (1985) Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts. The FHWA circular explains inlet and outlet control and the procedure for designing culverts.

11.3.4 Capacity Curves. There are many charts, tables, and curves in the literature for the computation of culvert hydraulic capacity. To assist in the review of the culvert design computations and to obtain uniformity of analysis, the Capacity Charts and Nomographs provided in the Culverts chapter of the UDFCD Manual shall be used for determining culvert capacity.

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The procedures for using the capacity charts and nomographs are provided in Sections 3.2 and 3.3 of the Culverts section in the UDFCD Manual. Care must be exercised in the use of these nomographs as certain design elements are built into the nomographs, such as roughness coefficients and entrance coefficients. Selection of the appropriate entrance coefficients shall be based on the information presented in Table CU-1 in the Culverts section of the UDFCD Manual or in Table 12 of Hydraulic Design of Highway Culverts, (FHWA 1985). When non-standard design elements are utilized, the designer should return to the reference Hydraulic Design of Highway Culverts, (FHWA 1985) for information on treating special cases.

11.3.5 Design Forms. Standard Form CU-8 in the Culverts Chapter of the UDFCD Manual or other versions of this form shall be used to present and document the culvert design process when spreadsheets or computer programs are not used for culvert sizing and design. Form CU-8 or the equivalent must be included in the drainage report when used to document the culvert design.

11.3.6 UD-Culvert Spreadsheet. The UDFCD has prepared a spreadsheet to aid with the calculations for the more common culvert designs. The spreadsheet applications utilize the FHWA nomographs. FHWA's HY-8 Culvert Analysis program is another computer application used to design culverts. Other computer programs or software, which are based on the methodologies presented in Hydraulic Design of Highway Culverts, (FHWA 1985), may also be used for culvert design. The latest versions of the UD-Culvert Spreadsheet and the FHWA's HY-8 Culvert Analysis programs are available on the UDFCD web site www.udfcd.org.

11.3.7 Velocity Considerations. In design of culverts, both the minimum and maximum velocities must be considered.

A minimum flow velocity of 4-feet per second is required when the culvert conveys runoff from frequently occurring storm events. Assuming that the culvert has been designed to flow near full, a flow depth equal to 25-percent of the culvert diameter or height and the corresponding flow rate shall be used to check the minimum velocity. If the culvert is operating under inlet control and not flowing full, a flow depth equal to 25-percent of the design flow depth and the corresponding flow rate shall be used to check the minimum velocity. The intent of this requirement is to reduce the potential for sediment accumulation in the culvert. The culvert slope must be equal to or greater than the slope required to achieve the minimum velocity. The slope should be checked for each design, and if the proper minimum velocity is not achieved, the pipe diameter may be decreased, the slope steepened, a smoother pipe used, or a combination of these may be used.

The velocity in the culvert during the 100-year event shall be kept as close as feasible to the 100-year velocity in the drainageway, but shall not exceed 15-fps.

11.3.8 Structural Design. As a minimum, all culverts shall be designed to withstand an HS-20 loading in accordance with the design procedures of AASHTO, "Standard Specifications for Highway Bridges," and with the pipe manufacturer's recommendation. It is the engineer's responsibility to determine if a culvert installation needs to be designed to withstand a loading other than HS-20.

11.3.9 Alignment. The alignment of the culvert with respect to the natural channel is very important for proper hydraulic performance. Culverts may pass beneath the roadway normal to the centerline or they may pass at an angle (skewed). Culverts shall be aligned with the natural channel. This reduces inlet and outlet transition problems.

Where the natural channel alignment would result in an exceptionally long culvert, modification of the natural channel alignment may be necessary. Modifications to the channel alignment or profile affect the natural stability of the channel and proposed modifications shall be thoroughly investigated. In many cases where the channel alignment is modified, grade control or drop structures are needed to achieve stable channel slopes upstream or downstream of the culvert. Although the economic factors are important, the hydraulic effectiveness of the culvert and channel stability must be given major consideration. Improper culvert alignment and poorly designed outlet protection may cause erosion to adjacent properties, increased instability of the natural channel and sedimentation of the culvert.

11.3.10 Minimum Cover. The vertical alignment of roadways relative to the natural existing channel profile may define the maximum culvert diameter/height that can be used. Low vertical clearance may require the use of elliptical or arched culverts, or the use of a multiple-barrel culvert system. All culverts shall have a minimum of 1.5-feet of cover from the subgrade elevation to the outside of the top of the pipe. A variance will be required for culverts with less than 1.5-feet of cover to subgrade. When analyzing the minimum cover over a culvert, consideration should be given to potential treatment of the subgrade for mitigation of swelling soils, the placement of other utilities, live loading conditions, and other factors that may affect the pipe cover

11.3.11 Multiple-Barrel Culverts. If the available fill height limits the size of culvert necessary to convey the flood flow, multiple culverts can be used. The number of separate culvert barrels shall be kept to a minimum to minimize clogging potential and maintenance costs. If each barrel of a multiple-barrel culvert is of the same type and size and constructed such that all hydraulic parameters are equal, the total flow shall be assumed to be equally divided among each of the barrels.

11.3.12 Trash Racks/Safety Grates. The use of trash/safety racks at inlets to culverts and long underground pipes should be considered on a case-by-case basis, when there is sufficient justification for considering the use of a trash rack or safety grate. Alternatives to limit access or catch debris upstream of the culvert

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inlet should be thoroughly investigated prior to considering improvements on the culvert inlet. While there is a sound argument for the use of racks for safety reasons, field experience has clearly shown that when the culvert is needed the most, that is, during the heavy runoff, trash racks often become clogged and the culvert is rendered ineffective. A general rule of thumb is that a trash/safety rack will not be needed if one can clearly “see daylight” from one side of the culvert to the other, if the culvert is of sufficient size to pass a 48” diameter object and if the outlet is not likely to trap or injure a person. By contrast, at entrances to longer culverts and long underground pipes and for culverts not meeting the above-stated tests, a trash/safety rack may be necessary.

Trash racks or grates used to limit access will not be allowed on the downstream ends of culvert or pipe outlets.

Table 11-2 provides guidelines when to use, and when not to use a trash/safety rack.

**TABLE 11-2
USE OF TRASH/SAFETY RACKS**

Use a trash/safety rack when:	Do not use a trash/safety rack when:
<ul style="list-style-type: none">▪ Debris may cause plugging of the culvert inlet▪ A bend, drop, or obstruction is located in the culvert▪ An unsafe condition is located at the outlet▪ Culvert is smaller than 48-inches in diameter▪ Culvert is longer than 200 feet	<ul style="list-style-type: none">▪ Daylight can be seen through the culvert▪ At culvert or storm sewer outlets

If a trash/safety grate is necessary, the following criteria shall be met.

1. Rack shall be designed for full hydrostatic load
2. Minimum grate area shall be four times pipe opening area
3. Maximum velocity through rack shall be 2 fps
4. The rack slope shall be 3:1 maximum
5. Maximum bar spacing of 4 ½ to 5 inches
6. Bars shall be parallel to flow
7. Provide a clear opening of 9-12 inches at the bottom
8. Maintenance requirements shall be addressed by hinging the rack or providing a method for equipment removal of the rack
9. Man access to the underside of the rack shall be provided
10. A separate rack upstream of the structure is an acceptable alternative
11. Collapsible racks are discouraged

11.3.13 Inlets and Outlets. Culvert inlets will require erosion protection where stable channel velocities are exceeded. If needed, riprap erosion protection shall be designed according to the procedures outlined in the Major Drainage section of

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the UDFCD Manual. In addition, culvert outlets are discussed in Chapter 10, of this manual, Conduit Outlet Structures.

11.4 Driveway Culverts

- 11.4.1 Applicable Criteria.** The requirements in this section apply to rural areas and rural residential subdivisions where the roadside ditch has depth. Urban roadside swales, used to incorporate the Minimizing Directly Connected Impervious Area concept into a development, are treated in a different manner. See Chapter 14 Stormwater Quality for design guidelines and criteria for the urban swale/driveway interface.
- 11.4.2 Construction Material.** Within the City right-of-way, driveway culverts shall be constructed from concrete (RCP) or galvanized corrugated metal (CMP/CMPA).
- 11.4.3 Minimum Size.** Driveway culverts for new developments or subdivisions shall be sized to pass the 5-year ditch flow capacity without overtopping the driveway. The minimum size for driveway culverts shall be 18-inches in diameter for round pipe or shall have a minimum cross sectional area of 1.8-square feet for arch or elliptical shapes.
- 11.4.4 Minimum Cover.** Driveway culverts shall be provided with the minimum cover recommended by the pipe structural design requirements, or 1-foot, whichever is greater.
- 11.4.5 Culvert End Treatments.** All driveway culverts shall be provided with end treatments on the upstream and downstream ends of the culvert to protect and help maintain the integrity of the culvert opening. Flared end sections or headwalls and/or wingwalls are acceptable end treatments.
- 11.4.6 Minimum Slope.** A minimum slope shall be provided to achieve the minimum velocities outlined in Section 11.3.7 or a minimum slope of 2% is required, whichever is greater.
- 11.4.7 Design and Construction of Driveway Culverts.** Additional information must be included in the drainage report and on the construction drawings for new subdivisions, where the use of roadside ditches and driveway culverts is proposed. Driveway culverts shall be sized for each lot in the subdivision drainage report, based on the tributary area at the downstream lot line. The construction drawings shall include information regarding sizes, materials, locations, lengths, grades, and end treatments for all driveway culverts. Typical driveway crossing/culvert details shall be included in the construction drawings. In general, typical roadside ditch sections do not have adequate depth to accommodate driveway culvert installations, which meet the criteria outline in this section. The construction drawings must address the roadside ditch section in detail to ensure that adequate depth is provided to accommodate the driveway culverts, including the minimum cover, and considering overtopping of the

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driveway when the culvert capacity is exceeded.

11.4.8 Driveway Culvert Permit. A Stormwater Public Improvement Permit (SPIP) is required for all driveway culverts located in City right-of-way.

11.5 Low Water Crossings/Pedestrian Bridges

11.5.1 Pedestrian Bridges. Where practical, a pedestrian bridge shall be designed to span the 100-year floodplain, and shall meet the general intent of the design criteria for bridges described in Section 11.6. It is recognized that in some cases, the width of the floodplain would require a structure that is not practical, aesthetic, in character with the general surroundings, nor economically feasible. SEMSWA shall consider the use of low-water crossings on a case-by-case basis, when it can be demonstrated, that a 100-year structure is not practical.

11.5.2 Minimum Conveyance. When a pedestrian bridge with capacity less than the 100-year runoff is permitted by the variance procedure, pedestrian bridge low-water crossings shall be designed to convey the runoff from the 10-year storm event as a minimum.

11.5.3 Minimum Clearance. To allow for debris passage, and variations in the channel invert, a minimum clearance of 3 ft. shall be provided between the channel invert and the lowest member of the pedestrian bridge.

11.5.4 Structural Design/Tethering. A structure within the floodplain has the potential to become dislodged and, therefore may become debris contributing to clogging of downstream facilities. Pedestrian bridges/low water crossings must demonstrate that they will be constructed to withstand the forces of flows higher than the conveyance capacity, or that they will be tethered or restrained from being carried downstream.

11.5.5 Handrails. Handrails are required on every pedestrian bridge, in accordance with the criteria presented in Section 10.1.2 of the Conduit Outlet Structures chapter. Handrails may be eliminated if hydraulic problems are present, SEMSWA agrees with the request, and mitigating factors are considered. Mitigating factors for eliminating handrail include widening of the sidewalk at the crossing, addition of curbs or alternate barriers, or an increase in the width of the crossing allowing additional shoulder width on the walk.

Breakaway railings are also a possible solution to hydraulic modeling difficulties. These railings will only be considered on a case-by-case basis, and with proper structural design to show that the railings will breakaway in a flood, yet be strong enough when standing. If allowed, breakaway railings shall be submitted with a maintenance plan showing who is responsible for resetting breakaway railings and the schedule with which they will be checked and repaired.

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Handrails on pedestrian bridges with multiple openings of less than two square feet in area shall be treated as a total blockage in hydraulic models. Handrails with openings in excess of two square feet shall be treated as if they are 50% blocked in hydraulic models.

11.5.6 Maintenance. Because of the potential for frequent debris accumulation, possible overtopping, etc., a maintenance plan must be developed to address maintenance concerns associated with the structure.

11.6 Bridge Design Guidance

11.6.1 General. As presented in Section 11.1.1, the design of a bridge is very specific to site conditions and numerous factors must be considered. A partial list of these factors includes location and skew, structural type selection, water surface profiles and required freeboard, floodplain management and permitting, scour considerations, deck drainage, and environmental permitting. The consideration of these factors requires that every bridge project be a unique design. The following Bridge Design Guidelines are presented to provide basic guidance in the design of bridges within the City of Centennial. It is understood that the following criteria is presented as guidance, and the unique aspects of bridge design may warrant additional consideration of the outlined criteria.

11.6.2 Location of Stream Crossing. Although many factors, including non-technical ones, enter into the final location of a stream crossing system, the hydraulics of the proposed location must have a high priority. Hydraulic considerations in selecting the location include floodplain width and roughness, flow distribution and direction, stream type (braided, straight, or meandering), stream regime (aggrading, degrading, or equilibrium), and stream controls. Bridge skew should be minimized provided it does not change regime or flow patterns. The hydraulics of a proposed location also affects environmental considerations such as aquatic life, wetlands, sedimentation, and stream stability, impacts to the floodplain, reduction of flooding losses, and preservation of wetlands.

The stream crossing system shall avoid encroachment into the FEMA regulated floodway.

11.6.3 Structural Design. As a minimum, all bridges shall be designed to withstand an HS-20 loading in accordance with the design procedures of AASHTO, "Standard Specifications for Highway Bridges". The Colorado Department of Transportation is using the Load and Resistance Factor Design (LRFD) method for new bridges and this method is acceptable for State Highway structures. The method may be acceptable for use on other City structures. Please check with SEMSWA before selecting a structural design method.

11.6.4 Freeboard. A minimum clearance, or freeboard shall be provided between the design approach water surface elevation and the low girder of the bridge. The freeboard is required to allow for wave action, ice, debris, and uncertainty in

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estimated stage. The freeboard requirements for each situation will vary, depending upon many factors, including the expected amount of debris, the geometry of the channel and/or floodplain, the availability of hydrologic data for the reach, etc. The bridge designer shall consider and discuss the required freeboard in the preliminary design report. Guidelines for the minimum requirements are provided below. These minimums shall not be used to set the freeboard for the design. They shall only be used when the recommended design freeboard is less than the minimum.

Minimum Freeboard Guidelines*

1. For a high debris stream, freeboard should be 4 feet or more.**
2. For low to moderate debris streams, the freeboard given in the equation below should be used.

$$\text{Freeboard} = 0.1Q^{0.3} + 0.008V^2$$

In which:

Q = the design discharge (cfs)

V = the main velocity of flow through the bridge (ft/sec)

* Do not use to establish design criteria – Freeboard for the individual structure must be determined by the engineer during the design of the bridge. Use the minimum above only when the proposed bridge design freeboard is less.

** High debris streams are generally found in urban environments and highly vegetated watersheds.

Another important consideration with freeboard is the location of the freeboard on the structure. Freeboard for a structure with a low girder that is not flat is taken at the one-third point between the lowest point and highest point on the low girder.

The water surface 50 to 100 feet upstream of the face of the bridge should be the elevation to which the freeboard is added to set the bottom or low girder of the bridge. The water surface elevation can be estimated by interpolating between the section at the bridge and the upstream section.

If the structure's upstream girder can be made rounded or tapered to facilitate debris passage, the freeboard requirements may be reduced by one foot, if approved by SEMSWA.

Debris deflector walls to divert the debris around a pier are recommended for all bridges on high debris streams. An alternative to a debris wall is to extend the upstream face of the wall pier out, flush with the deck. This design does not divert the debris but does move the debris out in front of the bridge for easier removal by maintenance personnel.

Other issues that need to be addressed when designing a bridge for debris are how quickly maintenance equipment can get to the structure to remove debris

and how important the route is for emergencies. All of these issues must be clearly addressed in the design report for the structure.

11.6.5 Flow Distribution. An analysis of the flow patterns at a proposed stream crossing should be made to determine the flow distribution and to establish the location of bridge opening(s). The proposed facility shall not cause a significantly adverse change in the existing flow distribution or direction. A range of flow distributions should be investigated for any bridge design because a bridge location might function well for one flood stage but not at other flow stages.

Relief openings in the approach roadway embankment shall be investigated if there is more than a 10% redistribution of flow in the overbanks (see Section 11.6.9).

11.6.6 Bridge Scour. A hydraulic analysis of a bridge requires an assessment of the proposed bridge's vulnerability to scour. Because of the extreme hazard and economic hardships posed by a catastrophic bridge collapse, special considerations must be given to the scour and foundation analysis of any new bridge.

An evaluation and design of a highway stream crossing or encroachment should begin with a qualitative assessment of stream stability. This involves application of geomorphic concepts to identify potential problems and alternative solutions. This analysis should be followed with a quantitative analysis using basic hydrologic, hydraulic, and sediment transport engineering concepts. Such analyses should include evaluation of flood history, channel hydraulic conditions (water surface profile analysis) and basic sediment transport analyses (watershed sediment transport, incipient motion analysis, and scour calculations). An analysis of this type is adequate for most locations in the City. If not, a more complex quantitative analysis based on detailed mathematical modeling and/or physical hydraulic models should be considered.

Designers should consult FHWA Publications HEC-18 "Evaluating Scour at Bridges" and HEC-20 "Stream Stability at Highway Structures" for a more thorough treatise on scour and scour prediction methodologies. HEC-18 includes several examples of scour calculations and a procedure to plot scour depths.

Data requirements for bridge scour analysis include:

- Bed Material
- Geometry
- Historic Scour
- Hydrology
- Stream Morphology

A plot of the design and 500-year scour depths shall be included in the design plans. Scour shall be on the Bridge General Layout Sheet.

11.6.7 Deck Drainage. Improperly drained bridge decks can cause numerous problems including corrosion, icing and hydroplaning. Ideally bridges shall be placed on crest vertical profile grades and bridges on sags vertical curves should be avoided. A superelevation transition on a bridge is not acceptable because of cross flow problems.

Whenever possible, bridge decks should be watertight and all deck drainage should be carried to the ends of the bridge. Drains at the end of the bridge should have sufficient inlet capacity to carry all of the minor drainage. A curb roll is required from the bridge ends to the end of the guardrail. At the end of this curb roll an inlet and pipe (preferred design) or well-depressed rundown with a transition from the curb roll is required to convey the drainage down the fill slope.

Where it is necessary to intercept deck drainage at intermediate points along the bridge, the design of the interceptors shall conform to the HEC-21, "Design of Bridge Deck Drainage" procedures.

11.6.8 Waterway Enlargement. There are situations where roadway and structural constraints dictate the vertical positioning of a bridge and result in a small vertical clearance between the low chord and the channel flowline or overbank. Significant increases in span length provide small increases in effective waterway opening in these cases.

It is possible to increase the effective area by excavating a flood channel through the reach affecting the hydraulic performance of the bridge. There are, however, several factors that must be accommodated when this action is taken.

1. The flow line of the new enlarged channel should be set above the stage elevation of the ordinary high water. (see AASHTO Highway Drainage Guidelines).
2. The flood channel must extend far enough up and downstream of the bridge to establish the desired flow regime through the affected reach.
3. The flood channel must be stabilized to prevent erosion, scour, and to prevent aggradation within the newly excavated flood channel.

11.6.9 Auxiliary Opening. The need for auxiliary waterway openings, or relief openings as they are commonly termed, arises on streams with wide floodplains. The purpose of openings on the floodplain is to pass a portion of the flood flow in the floodplain when the stream reaches a certain stage. It does not provide relief for the principal waterway opening in the sense that an emergency spillway as a dam does, but has predictable capacity during flood events. Basic objectives in choosing the location of auxiliary openings include:

1. Maintenance of flow distribution and flow patterns,
2. Accommodation of relatively large flow concentrations on the floodplain,
3. Avoidance of floodplain flow along the roadway embankment for long distances, and

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4. Accommodation of Colorado Division of Wildlife requests for minimal flows for wildlife.

The most complex factor in designing auxiliary openings is determining the division of flow between the two or more structures. If incorrectly proportioned, one or more of the structures may be overtaxed during a flood event. The design of auxiliary openings should usually be generous to guard against that possibility.