11.0 Introduction

This section addresses design criteria for culverts and bridges as they relate to drainageways in the County. Generally, a culvert is a conduit for the passage of surface drainage water under a highway, railroad, canal, or other embankment; 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 and economic 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 Volume 2 of the *UDFCD Manual* shall be consulted for basic 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 Flood Plains 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 culverts and bridges 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 part of the transportation system and are not eligible for UDFCD maintenance assistance. In some cases however the major drainageway reach where the crossing is proposed may be eligible for UDFCD maintenance assistance. In addition, culvert outlet improvements and channel stabilization improvements associated with the roadway crossing may be eligible for UDFCD maintenance assistance. Culvert outlet and channel

improvements shall be designed in accordance with Douglas County and UDFCD criteria to ensure that those improvements are eligible for UDFCD maintenance assistance and that the major drainageway remains eligible for UDFCD maintenance assistance, where applicable.

Improvements constructed within the County outside of the UDFCD boundaries are not eligible for UDFCD maintenance assistance. However, all drainage facilities associated with roadway crossings shall be designed in accordance with County and UDFCD criteria. Contact the County if there are any questions regarding eligibility for maintenance assistance.

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 Section 404 permit from the U.S. Army Corps of Engineers, required for the discharge of dredged or fill material in waters of the United States, is an example of an additional permit.

The County requires a Floodplain Development Permit for any stream crossing constructed in a designated floodplain. Refer to Chapter 5, Floodplain Management for information regarding construction of improvements in floodplains.

11.1.5 Aesthetics and Safety. The appearance and safety of structures, including headwalls and wingwalls, are important considerations for the County'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. Consideration of structure geometry, materials, and texture, patterning, and color of structure surfaces should be given in selection to blend with the adjacent landscape and arrive at attractive appearance.

11.1.6 Easement, Ownership and Maintenance Requirements. Culverts and bridges constructed in the County are generally within the public Right-of-Way for the roadway or a combination of easements and Right-of-Way. In some cases they may be constructed in private roadway easements. Additional easement or Right-of-Way beyond the normal roadway Right-of-Way or easement 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.).

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 the County Parks and Trails Division is recommended to determine if the proposed culvert or bridge location has been identified as a potential location for a separated grade trail crossing. If the location is determined by the County to be compatible from a planning standpoint, and the crossing is physically possible, final design requirements for trail width, vertical clearance, surfacing, and lighting and safety improvements, shall be coordinated with the Douglas County Parks and Trails Division. The low flow channel adjacent to the trail bench shall pass as much flow as practicable, considering the duration of the flooding, inconvenience to the public, and available alternate routes. Connections of the trail 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. No overtopping is allowed for any street classification at major drainageway crossings. For minor drainageways, the allowable street overtopping for the various street classifications is identified in Table 11-1.

TABLE 11-1
ALLOWABLE BRIDGE AND CULVERT OVERTOPPING
FOR MINOR 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)	No overtopping allowed	No overtopping allowed

Note: No Overtopping Allowed for Major Drainageways
[1] See Chapter 7, Street Drainage, for further discussion regarding allowable flow depth in the street based on Drainage Classification.

Functional classification identifies the type of transportation service provided by a facility. Facilities providing a high level of mobility have a high functional classification such as a freeway or an arterial. Facilities providing 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 street and cross slope. No overtopping is allowed if a street has a raised median. The County may approve lesser criteria for rural areas or low volume roadways. Any variance from the table above will have to be considered and approved by the County.

These *Criteria* are considered the minimum design standard and may be modified where other factors are considered more important. For example, the designer shall consider flooding of adjacent structures or private property, excessive channel velocities, availability of alternate routes, 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:

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 using the allowable overtopping elevation as the maximum headwater elevation.
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. For a bridge on a Type C road, freeboard shall be applied to the water surface for the recommended design frequency. Freeboard requirements shall be considered on an individual basis due to the numerous factors or conditions that must be considered in any bridge installation. The profile grade of the bridge and roadway, the potential for debris accumulation, and predicted sedimentation are just a few of the factors that must be considered when developing freeboard requirements. The CDOT Drainage Design Manual and other publications should be consulted for discussion and guidance regarding freeboard.

11.3 Culvert Design Standards

11.3.1 Construction Material. Culverts designed and built in the County 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 or low-volume roadways, corrugated metal pipe culverts in round or arch cross sections may be accepted. All corrugated metal pipe must be galvanized or aluminized steel or aluminum pipe.

11.3.2 Minimum Pipe Size. The minimum pipe size for a cross culvert within a public Right-of-Way shall be 24-inches diameter round culvert, or shall have a minimum cross sectional area of 3.3 ft^2 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.

11.3.3 Culvert Sizing and Design. Culvert design involves an iterative approach. Two references are particularly helpful in the design of culverts. The Culverts chapter of Volume 2 of the *UDFCD Manual* provides design aids and guidance taken from the 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 Volume 2 of the *UDFCD Manual* shall be used for determining culvert capacity.

The procedures for using the capacity charts and nomographs are provided in the Culverts chapter of Volume 2 of 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 chapter of Volume 2 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 Volume 2 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 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. 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. Designs that include trash racks or grates on culvert inlets will be reviewed on a case-by-case basis when there is sufficient justification for considering the use of a trash rack or grate. Alternatives to limit access or catch debris well upstream of the culvert inlet should be thoroughly investigated prior to considering improvements on the culvert inlet. Trash racks or grates to limit access will not be allowed on culvert or pipe outlets. See the Culverts chapter in Volume 2 of the *UDFCD Manual* for additional discussion and requirements regarding these structures.

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 chapter in Volume 1 of the *UDFCD Manual*. In addition, culvert outlets are discussed in Chapter 10 Conduit Outlet Structures of these *Criteria*.

11.4 Driveway Culverts

11.4.1 Applicable Criteria. The requirements in this section apply to new rural residential subdivisions where the roadside ditch has some 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 County Right-of-Way, driveway culverts shall be constructed from concrete (RCP) or 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 15-inches in diameter for round pipe or shall have a minimum cross sectional area of 1.2-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. Headwalls and/or wingwalls and flared end sections 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.

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 don't have adequate depth to accommodate driveway culvert installations, which meet the criteria outlined 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 driveway when the culvert capacity is exceeded. See Figure 11-1 for additional information.

11.5 Bridges Design Criteria

11.5.1 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 with variable criteria.

11.6 Low Water Crossings/Pedestrian Bridges

11.6.1 General. The crossings for pedestrian use can vary greatly from small low-use crossings to regional trail crossings. The crossings can have impacts on the floodplain, wetlands, and habitat. For those reasons, the County will treat pedestrian and low water crossings on an individual basis, with criteria set upon submittal of a request for the crossing.

Consideration shall be given to floodplain impacts, debris accumulation and passage, structural design, tethering of the structure or potential blockage of other conveyance structures, clearances to water levels and structural members, maintenance responsibility and cost, and construction and replacement cost of the structure.

FIGURE 11-1
ROADSIDE DITCH MODIFICATION FOR DRIVEWAY CULVERTS