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801 INTRODUCTION

The criteria presented in this section shall be used to design and evaluate storm drain systems in Boulder County. “Storm drain system” refers to the system of inlets, pipes, manholes or junctions, outlets, and other appurtenant structures that are designed to collect and convey the minor storm runoff and discharge it to a major drainage system. The storm drain system is a part of the local drainage system, which may also include curb and gutter, streets, roadside ditches, swales, and channels. This section presents both technical criteria and the general procedure for design and evaluation of pipes and inlets. Allowable roadway encroachment is discussed in Section 900, Roadways.

802 DESIGN CRITERIA

802.1 Design Storm Frequency

A storm drain system is required when the allowable street capacity is exceeded during the 5-year event.

802.2 Construction Materials

Pipes, materials, and related items that are suitable for roadway cross culverts in accordance with Section 1000 are also suitable for storm drain systems. These requirements limit pipe materials to reinforced concrete.

802.3 Horizontal and Vertical Alignment

Storm drains shall be designed with enough cover to support the vehicular bridge loadings listed in the Boulder County Multimodal Standards and with the pipe manufacturer’s recommendations. The minimum cover shall be 12 inches. Trench installations shall be in accordance with the most recent edition of the CDOT M&S Standard Plans. Manholes will be required whenever there is a change in size, vertical or horizontal alignment, elevation, grade, and at all junctions.

The minimum clearance between a storm drain and a water main shall be 12 inches, regardless of which is higher. Concrete encasement or bridging of the water line will be required for clearances of 12 inches or less. The work shall be in accordance with the CDOT M&S Standard Plans, Boulder County Standard Drawings, or other approved details, and the design must be approved by both the county and the utility owner.

The minimum clearance between a storm drain and a sanitary sewer shall also be 12 inches. When a sanitary sewer lies above a storm drain, the sanitary sewer shall have an impervious encasement or be constructed of structural drain pipe for a minimum of 10 feet on each side of where the storm drain crosses. When a sanitary sewer is below a storm drain and has less than 18 inches clearance, concrete encasement or bridging of the sanitary line will be required. The work shall be in accordance with the

CDOT M&S Standard Plans, Boulder County Standard Drawings, or other approved details, and the design must be approved by both the county and the utility owner.

Storm drain alignment between manholes shall be straight. Manholes shall be spaced no more than 400 feet apart for trunk lines 36 inches in diameter and smaller and 500 feet for trunk lines larger than 36 inches in diameter.

802.4 Pipe Size

Storm drain trunk lines shall have a minimum diameter of 18 inches or the hydraulic equivalent if using a shape other than circular. Storm drain laterals from inlets shall have a minimum diameter of 15 inches or the hydraulic equivalent if using a shape other than circular.

802.5 Storm Inlets

The standard inlets permitted for use in Boulder County streets are a CDOT Type R curb opening inlet, a CDOT Type C grated inlet, and a Denver Type 16 combination inlet. Type R and Type 16 inlets shall be used with a 6-inch vertical curb and gutter section, and Type C inlets shall be used in roadside ditches. Type C inlets shall be installed in accordance with the CDOT standard plans, including creating a sump condition where one does not naturally exist.

802.6 Storm Drain Capacity and Velocity

The storm drain system shall be designed to convey the minor storm without resulting in pressure flow. The minor storm capacity and velocity shall be calculated using the Manning's *n* values in Table 800-1.

Table 800-1. Manning's *n* Values for Capacity and Velocity

Pipe Material	Manning's *n* Value	
	Capacity Calculation	Velocity Calculation
RCP (newer)	0.013	0.011
RCP (older)	0.015	0.012
RCP (preliminary design)	0.015	0.012
Smooth Plastic	0.011	0.009

The maximum full flow velocity shall be less than 15 feet per second (fps). The energy grade line (EGL) for the 5-year design flow shall be at or below finished grade at all manholes, inlets, or other junctions. The EGL and hydraulic grade line (HGL) for both the 5-year and 100-year events shall be calculated for all storm drain systems. Hydraulic losses will include friction, expansion, contraction, and junction losses at a minimum. The methods for estimating these losses are presented in the following sections. If the 100-year HGL is above any manhole or inlet cover, or if the manhole or inlet is located in a floodplain, manhole and inlet covers shall be bolted down.

802.7 Storm Drain Outlets

All storm drain outlets into open channels shall be constructed with a headwall and wingwalls or a flared end section. Riprap shall be provided at the outlet in the form of a blanket or low tailwater basin. Storm drain outlets shall meet the requirements of Section 1000 for culvert outlets.

803 HYDRAULICS OF STORM DRAINS

Presented in this section are the general aspects of hydraulic design and evaluation of storm drains that need to be considered. Hydraulic design calculations can be done manually with a spreadsheet or by using a computer model. Both methods are briefly discussed below. The user is assumed to possess a basic working knowledge of storm drain hydraulics and is encouraged to review technical literature available on the subject as needed.

803.1 Manual Hydraulic Calculations

Manual storm drain hydraulic calculations shall be performed in accordance with the HEC-22 (Brown et al., 2013). Procedures and coefficients presented in HEC-22 shall be used for system design unless they are specifically included in this MANUAL. HEC-22 includes discussion on open channel flow, where the water surface within the pipe remains open to the atmosphere, and pressure flow, where there is no exposed water surface within the pipe. It also includes a design example.

Two of the critical design elements of a storm drain system are the HGL and the EGL. The HGL is a line that represents the water surface elevation at any point along an open channel. In pressure flow situations, the HGL is the level to which water would rise in a vertical tube at any point along the pipe. The EGL is an imaginary line that represents the total energy at any point in the system. Total energy includes elevation head, velocity head, and pressure head and is the HGL plus the velocity head ($V^2/2g$). The total energy at any section equals the energy at any downstream section plus the losses that occur between the two points.

Losses are typically classified as either friction or form losses. Friction losses occur as water flows along the length of a pipe. Form losses occur at the exit from the system and at junctions such as manholes within the system. Because the county does not allow transitions or bends outside of manholes, form losses will be restricted to exit losses when flow leaves the system, and structure losses, such as through inlets or manholes and are referred to by HEC-22 as inlet and access hole losses. Although rare, losses due to hydraulic jumps in storm drains are discussed in Section 700, Open Channels.

803.2 Hydraulic Calculations Using a Computer Model

Computer models are often used to calculate the HGL and EGL of storm drain systems. The benefits of using a computer model include consistency, speed, and the ability to check the validity of the model with relative ease. This section provides specific guidance for UD-Sewer 2009; however, other programs such as StormCAD may be used if specifically approved by the county.

UD-Sewer is a computer model that assists in the design and flow analysis of storm drain systems. The program uses Manning's equation to analyze and size storm sewer systems. The program can also use the Rational Method to calculate runoff, perform hydraulic and EGL calculations, and provide plots of the storm drain, ground line, HGL, and EGL. The USDCM (UDFCD, 2016) provides additional information, as does the UD-Sewer user's manual. The user's manual is embedded in the software, which can be obtained from the UDFCD website (*http://udfcd.org/software*) or via an internet search for "UDFCD UD-Sewer."

803.2.1 Rational Method

UD-Sewer uses the Rational Method to calculate runoff based on input parameters provided by the user. The user can override Rational Method calculations by manually entering known flows that have been calculated separately; however, values must be entered for Rational Method parameters or the program will give an error.

803.2.2 Bend and Lateral Loss Coefficients

UD-Sewer requires bend and lateral loss coefficients for each storm drain segment within a model. Bend and lateral losses both occur at a manhole or inlet junction. Bend losses are the result of the angle between the incoming storm drain and the exiting trunk line at a junction. Lateral losses are the result of turbulence or eddies that occur from lateral flows joining a trunk line. These coefficients are calculated by the program based on user inputs that define the geometry of the system.

To calculate the bend loss coefficient, the user must select the shape of the manhole invert and enter the angle between the incoming and downstream pipe segments. To calculate the lateral loss coefficient, the user must enter the angle between the incoming lateral and downstream trunk line. When entering the angle, the user must select main line or lateral line. Lateral loss is only applied to the main lines of a storm sewer system in UD-Sewer. For all lateral lines, the user should select lateral line and the program will default to zero. If more than one lateral enters a manhole, the user must exercise judgment to determine the appropriate loss coefficient.

804 HYDRAULICS OF STORM INLETS

Presented in this section are the general procedures for sizing and spacing of inlets in a storm drain system. Design calculations can be done manually, but this section will focus on the use of UD-Inlet to calculate street and inlet capacity. The USDCM provides additional details on the equations and methodologies that have been incorporated into the UD-Inlet spreadsheet.

804.1 Introduction

Inlets on a continuous grade are located so that ponding will not occur once the inlet is at capacity. Flow will instead bypass the inlet. Sump inlets are located at roadway sags or similar low points that will not allow water to bypass after the inlet reaches capacity. A sump condition can occur at a change in street grade from positive to negative or at an intersection due to the crown slope of a cross street.

804.2 Inlet Capacity

Inlet capacity may be calculated using the UD-Inlet spreadsheet developed by the UDFCD, with exceptions noted below. UD-Inlet is an Excel-based program that calculates both street and inlet capacities based on several parameters entered by the user. In general, the procedure consists of defining the amount and depth of flow in the gutter and determining the theoretical flow interception by the inlet. The calculations within the spreadsheet program are based on physical research completed at Colorado State University. The most recent version of UD-Inlet can be obtained via an internet search for "UD-Inlet UDFCD" or from the UDFCD website (*http://udfcd.org/software*). Additional information specific to inlets on grade and in a sump condition is included in the following sections.

Information required by the spreadsheet includes design flow; height of curb; distance from curb face to street crown; gutter width; street cross and longitudinal slopes; gutter cross slope; Manning's *n* for the street; maximum allowable spread from gutter flow line; maximum allowable depth at gutter flow line; and allowable flow depth at the street crown. Additionally, if flow is allowed behind the curb, the allowable spread width behind the curb and side slope behind the curb, and Manning's *n* behind the curb must be entered. The spreadsheet can use the Rational Method to calculate a design flow or will accept a flow entered by the user. If the inlet receives bypass from an upstream inlet, the bypass flow can be entered or retrieved from another UD-Inlet spreadsheet. Default clogging factors included in the UD-Inlet spreadsheet shall be used to account for potential debris clogging, pavement overlaying, and varying design assumptions.

804.3 Continuous Grade Condition

The capacity of an inlet on grade is dependent on street slope, depth of flow in the gutter, height and length of curb opening, street cross slope, and the amount of depression at the inlet. Cost effective inlet design will allow for some bypass. The amount of carryover must be included in the drainage facility evaluation as well as in the design of the inlet. Boulder County allows Type R and Type 16 inlets in a continuous grade condition.

804.4 Sump Condition

The capacity of each sump inlet is dependent on depth of flow in the gutter, height and length of curb opening, street cross slope, and the amount of local depression at the inlet. Type R and Type 16 inlets are allowed for a sump inlet on curb and gutter system. A Type C inlet can be used in a ditch or as an area inlet.

At the time of publication of this MANUAL, UD-Inlet either overestimated or underestimated the capacity of inlets in sumps, leading to the installation of both oversized and undersized inlets throughout Colorado. A study done in 2007 entitled "Sump Inlet Hydraulics" found that current design procedures utilized by UD-Inlet were not consistent due to the application of inconsistent design parameters used to size a sump inlet under various conditions. Laboratory tests of several different inlet types were completed by the UDFCD in partnership with Colorado State University, and the data was used to modify design procedures for inlets in sumps. The USDCM provides modified design procedures for grate, curb opening, and combination inlets located in sumps that shall be used to design sump inlets in Boulder County.

804.5 Inlet Spacing

The optimum spacing of storm inlets is dependent upon several factors, including traffic requirements, contributing land use, street slope, allowable street capacity, and distance to the nearest outfall system.

The suggested sizing and spacing of the inlets is based on an ideal interception rate of 70 percent to 80 percent. This spacing has been found to be more efficient than a spacing using a 100 percent interception rate; although, the downstream-most inlet will still need to be designed to intercept 100 percent of the flow. Considerable improvements in overall system efficiency can be achieved if the inlets are located in the local sumps created by street intersections.

Inlet spacing is typically an iterative process, and the designer may have to move inlet locations multiple times before determining the appropriate spacing to meet design criteria and maintain efficiency. After initial inlet locations are determined, the designer should recalculate the peak flow to each inlet and check that the allowable street capacity has not been exceeded. If the actual flow is less than the allowable street capacity, inlets may be spaced further apart to prevent overdesign of a system. Locating inlets is a balance between meeting criteria and efficient design. It is not usually possible to have optimum inlet spacing throughout an entire storm drain system.

804.6 Inlet Grates

All grates used on storm inlets in Boulder County will be bicycle-safe grates in accordance with the *Guide for the Development of Bicycle Facilities* (AASHTO, 1999).

805 DESIGN OF STORM DRAIN SYSTEM

This section presents the general procedure used to design a storm drain system from preliminary through final design. Using the Rational Method for sizing the drain system is also discussed. A typical local drainage system consists of flow in the storm drain and allowable flow in the gutter. These flows are ultimately discharged to a larger drainage system or an open channel with capacity for a much larger event.

805.1 Preliminary Design

The preliminary design of the storm drain system begins after a preliminary development plan has been prepared that delineates the general development areas, major drainage paths, and drainage outfall locations. Allocation of space for drainage facilities and considerations shall be incorporated into the preliminary development plan. The drainage engineer must have input into the development plan to ensure proper drainage planning.

1. **Gather Basic Data.** The first step in any drainage project is the collection of basic data. Information typically required is as follows:
    a. Topographic maps of the development and drainage basins that show existing and proposed roadways, existing and proposed land uses, major drainage features such as creeks and streams, development area, and property boundaries
    b. Typical street cross sections
    c. Preliminary grading information, such as contours, profiles, and control elevations
    d. Soils information
    e. Existing and proposed utilities

f. Existing irrigation and raw water facilities and requirements for maintaining facilities

g. Rainfall information.

2. **Perform Hydrologic Analysis.** Perform the hydrologic evaluation of the basin(s) for both the minor and major storms, typically using the Rational Method. Divide each basin into smaller subbasins, and calculate the peak design flow for each hydrologic point of interest. The degree of basin subdivision will depend on the detail of information available and the experience of the licensed professional drainage engineer. Some general guidelines are included in Section 600.

3. **Complete Preliminary Sizing.** Preliminary sizing should be completed for the minor storm. Beginning at the upper end of the basin, calculate the quantity of flow in the street until the allowable capacity of the street matches the design runoff. The storm drain system will start at this point, provided that no alternate method of removing runoff from the street exists. Removal of all the street flow by the storm drain system is not required, except at sump areas, and is typically not economical. The sum of the flow in the storm drain plus the flow in the street must be less than or equal to the allowable capacity of the street and storm drain.

   For preliminary sizing purposes, the diameter, type of pipe, and slope is generally sufficient. Manning's *n* values should be those in Table 800-1. In some instances, a profile may be required to check utility conflicts or to assure compatibility with the major drainage system. The preliminary vertical alignment should not be steeper than the proposed street grade. The designer should also be aware of utility considerations, especially when crossing water and sanitary main and service lines.

4. **Route the Major Storm.** After sizing the storm drain, route the major storm through the system and compare the flows to the allowable capacity. The combined total of the allowable street capacity during the major storm and the storm drain capacity during the major storm should equal or exceed the 100-year runoff. A plan and profile of the pipes, EGL, and HGL will be required. If the combined allowable capacity is less than the design flow, some or all of the following actions may be taken:

   a. Increase storm drain size

   b. Increase street grade within acceptable limits or revise street classification to allow additional capacity

   c. Revise major drainage system such that the runoff is collected further upstream

   d. Provide additional onsite detention within the development to decrease peak flow.

5. **Evaluate the Preliminary Design.** In addition to a cost estimate for the design, the preliminary system can also be evaluated by developing alternatives and comparing the total benefits. The impact of the system outfall on downstream properties must be identified and mitigated if problems exist.

805.2 Final Design

Final design consists of final revisions to the system model and preparation of plans, profiles, and specifications for the storm drain system in sufficient detail for construction. Basic data, hydrologic analysis, and inlet sizing performed for the preliminary design should be reviewed and verified. Drainage subbasin boundaries should be confirmed or revised as necessary, and design peak flows should be recalculated accordingly. The drain pipe and inlet sizes and locations are then finalized while taking into account final street and storm drain grades, locations of existing and proposed utilities, and the design of the major drainage system. The EGL and HGL should be revised accordingly including energy losses at manholes and any other structures. If special transitions are required to reduce losses, the structural design of the facilities must include energy loss considerations.

806 REFERENCES

American Association of State Highway and Transportation Officials, 1999. *Guide for the Development of Bicycle Facilities,* prepared by the AASHTO Task Force on Geometric Design, Washington, D.C.

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