7.0 Introduction

This chapter summarizes methods to evaluate runoff conveyance in various street cross sections and curb types in the City of Centennial and identifies acceptable upper limits of street capacity for minor and major storm events. Sections 7.1 through 7.6 address conventional curb-and-gutter street sections used in the City. The use of roadside ditches in rural portions of the City is covered in Section 7.8.

7.0.1 Stormwater Quality Considerations. A concept that holds promise for reducing urban runoff and pollutant loading consists of curbless (or intermittent curb) streets with adjacent grass swales. This concept gives street runoff a chance to infiltrate and get filtered and slowed in the vegetated swales. The use of curbless streets with grass swales for runoff reduction and enhanced water quality is discussed in Section 7.7.

7.1 Function of Streets in the Drainage System

7.1.1 Primary Function of Streets. Urban streets not only carry traffic, but stormwater runoff as well. The primary function of urban streets is for traffic movement; therefore, the drainage function is subservient and must not interfere with the traffic function of the street. When runoff in the street exceeds allowable limits, a storm sewer system or open channel is required to convey the excess flows.

7.1.2 Design Criteria Based on Frequency and Magnitude. The design criteria for the collection and conveyance of storm water runoff on public streets are based on an allowable frequency and magnitude of traffic interference. The primary design objective is to keep the depth and spread (encroachment) of stormwater on the street below an acceptable value for a given storm event.

7.1.3 Street Function in Minor (5-year) Storm Event. The primary function of streets in a minor storm event is to convey the nuisance flows quickly and efficiently to the next intended drainage conveyance system with minimal disruption to street traffic.

7.1.4 Street Function in Major (100-year) Storm Event. For the major storm event, the function of streets is to provide an emergency passageway for flood flows while maintaining public safety and minimizing flood damage. In the major event, the street becomes an open channel and must be analyzed to determine when flooding depths exceed acceptable levels.

7.2 Street Classification

7.2.1 City of Centennial Standard Roadway Sections. The current City of Centennial standard roadway sections were adopted from the1986 Arapahoe County Roadway Design and Construction Standards. Each roadway section has a different capacity, so it is important to use the section dimensions or capacity chart that applies to the particular street section of interest. The capacity charts located at the end of this chapter indicate the dimensions of the applicable roadway section. The use of these charts is discussed in Section 7.5.

7.2.2 Drainage Classification. The streets in the City are assigned a drainage classification of Type A, B, or C based on the average daily traffic (ADT) for which the street is designed or for the roadway classification.   In general, the higher the ADT or mobility that the roadway provides, the more restrictive the allowable drainage encroachment into the driving lanes. The following table summarizes the drainage classification for each City roadway section:

TABLE 7-1
DRAINAGE CLASSIFICATION FOR SEMSWATHE CITY OF CENTENNIAL STANDARD ROADWAY SECTIONS

Street Classification	Drainage Classification
Urban Local	A
60’ Minor Collector	B
80’ Major Collector	B
100’ Minor Arterial	C
120’ (4-Lane) Major Arterial	C
140’ (6-Lane) Major Arterial	C

7.3 Minor (5-year) Storm Allowable Street Flow

7.3.1 Allowable Flow Depth and Roadway Encroachment for Streets with Curb and Gutter. SEMSWA allows the use of streets for drainage conveyance in the minor storm with limitations on the depth of flow in the curb and gutter and the spread of flow onto the roadway. The following table summarizes these limitations for each drainage classification. The maximum allowable street capacity is determined by whichever limitation is more restrictive, based on the geometry of the street section.

TABLE 7-2
MINOR STORM ALLOWABLE FLOW DEPTH AND ROADWAY ENCROACHMENT FOR STREETS WITH CURB AND GUTTER

Drainage Classification	Allowable Flow Depth in Gutter Flowline[1]	Maximum Street Encroachment
Type A	No curb overtopping.	Flow may spread to crown of street.
Type B	No curb overtopping.	Flow spread must leave at least one 10-foot lane free of water. (5-feet either side of the street crown)
Type C	No curb overtopping.	Flow spread must leave at least two 10-foot lanes free of water. (10-feet each side of the street crown or median)

1 If a 4-inch curb with an attached sidewalk is used (i.e. combination or rollover curb), the allowable depth of flow is to the back of sidewalk.

7.4 Major (100-year) Storm Allowable Street Flow

7.4.1 Allowable Flow Depth for a Street with Curb and Gutter. SEMSWA allows the use of streets for drainage conveyance in the major storm with limitations on the depth of flow in the curb and gutter and the containment of flow within the roadway right-of-way or dedicated easements. The following table summarizes these limitations for each drainage classification. The maximum street capacity is determined by whichever of these criteria is first reached based on the geometry of the street section.

TABLE 7-3
MAJOR STORM ALLOWABLE DEPTH AND CONTAINMENT OF FLOW FOR STREETS WITH CURB AND GUTTER

Drainage Classification	Allowable Flow Depth	Containment of Flow
Type A, B and C	The depth of water at the gutter flowline shall not exceed 12-inches.	Flow must be contained within public right-of-way or dedicated drainage easements, AND All structures shall be a minimum of 1-foot above the 100-year water surface elevation[1].

1 For a structure with a finished floor elevation below the curb elevation, an 18-inch high berm must be constructed between the curb and the house, including at any driveways, to contain flow in the street section. If the flow is not contained within a berm, then the allowable flow in each side of the street shall not exceed the allowable flow shown for the minor (5-year) storm.

7.5 Hydraulic Evaluation of Street Capacity

Once the design discharge is calculated (see Chapter 6, Hydrology), hydraulic calculations are to be completed to determine the capacity of street gutters and the resulting encroachment onto the street section. All street capacity and encroachment calculations shall conform to the Streets/Inlets/Storm Sewers chapter of the UDFCD Manual unless otherwise noted herein. For more detailed information on the methodology used for the hydraulic evaluation of street capacity see Section 2.3 of the UDFCD Manual Streets/Inlets/Storm Sewers chapter.

7.5.1 Minor (5-year) Storm Street Capacity Worksheet. The Streets/Inlets/Storm Sewers chapter of the UDFCD Manual provides an analysis tool used for determining the minor storm street capacity and flow encroachment. The "Q-Allow" worksheet is contained within the UD-Inlet spreadsheet which can be accessed via the internet at www.udfcd.org. This worksheet completes a hydraulic evaluation of the theoretical street capacity for the minor storm by calculating the theoretical minor event street gutter flow capacity based on both 1) the allowable spread and 2) the allowable gutter depth. A reduction factor is then applied to the theoretical gutter flow based on allowable depth and the lesser of the allowable street capacities governs for the minor event.

7.5.2 Minor Storm Street Capacity Charts. The allowable minor storm street capacity for the City of Centennial standard street cross-sections have been calculated based on the "Q-Allow" worksheet and are presented at the end of this chapter**.** These charts shall only be used for streets that are consistent with all the referenced standard street parameters, including street width, pavement cross slope of 2%, and a depressed gutter consistent with the City's standard cross-section as noted. A Manning's n-value of 0.016 was used. These minor event capacity calculations were performed for various street slopes to generate the street capacity charts located at the end of this chapter. These charts present the allowable capacity for one-half of the street section, on one side of the street crown or the other. Standard capacity charts have not been provided for the High Speed Type 2 curb and gutter (CDOT M&S Standards), and therefore street capacities must be calculated when using this type of curb and gutter section. See Section 7.5.6 for more information.

7.5.3 Major (100-year) Storm Street Capacity Worksheet. Similar to the minor storm, the Streets/Inlets/Storm Sewers chapter of the UDFCD Manual provides an analysis tool used for determining the major storm street capacity. The "Q-Allow" worksheet is contained within the UD-Inlet spreadsheet which can be accessed via the internet at www.udfcd.org. This worksheet completes a hydraulic evaluation of the theoretical street capacity for the major storm and then applies the major storm reduction factor.

7.5.4 Major Storm Street Capacity Charts. The allowable major storm street capacity for the City of Centennial standard street cross-sections have been calculated based on the "Q-Allow" worksheet and are presented at the end of this chapter. These charts shall only be used for streets that are consistent with all the referenced standard street parameters, including street width, pavement cross slope of 2%, and a depressed gutter consistent with the City's standard cross-section as noted. A Manning's n-value of 0.016 was used. These charts present the allowable capacity for one-half of the street section, on one side of the street crown or the other.

The major storm street capacity charts at the end of this chapter contain two curves which represent the capacities at full curb depth and at 12-inches of depth at the gutter flowline, respectively. The 12-inch depth allowable capacity curve is based on the assumption of a vertical "wall" at the back of the curb. Although flow may be conveyed in the area behind the curb, the additional capacity is ignored to account for potential obstructions in the gutter and to allow for a reasonable capacity to be calculated, independent of the various grading scenarios and landscaping improvements that may be proposed adjacent to the roadway. The 12-inch depth curve may be used if the following conditions apply:

1. The major storm flow must be fully contained at the assumed depth within public right-of-way or easements.
2. A minimum of 1 foot above the assumed depth of 12-inches will be provided as freeboard to the lowest floor or window well openings for structures that are proposed adjacent to the roadway.
3. The grading behind the curb or sidewalk provides for the containment of the major storm flows at the assumed 12 inch depth, and there are no diversions at driveways, intersections or other locations prior to the designed outfall point.

It is the responsibility of the design engineer to verify that all of the conditions are satisfied. If these conditions are not met, the allowable capacity in each side of the street during the major storm shall be the same as shown for the minor storm. Both the minor and major curves are shown in order to assist the design engineer in determining the appropriate street capacity based on gutter flow depth in order to meet SEMSWA Criteria. Due to the large scale of the major storm capacity chart, the design engineer may refer to the minor storm street capacity chart to read a more accurate allowable capacity for the gutter full condition.

7.5.5 Major Storm Street Capacity with Flow Depth between Curb Full and 12-inches. There may be situations when the conditions in Section 7.5.4 can be satisfied when the major storm flow depth (at the gutter flowline) is between curb full and 12-inches of depth. An example of this situation would be when the lowest point of water entry into a structure is 20-inches above the gutter flowline. Since the finished floor elevation must be at least 1-foot above the assumed gutter flow elevation, the maximum gutter flow depth would be limited to 8-inches (20-inches minus 12-inches). The design engineer may use the "Q-Allow" worksheet in UD-Inlet to determine the street capacity at the specific depth between curb full and 12-inches of depth at the flowline, based on the other assumptions presented in Section 7.5.4.

7.5.6 Non-Standard Street Sections. When a City standard street section is not used, the design engineer should use the "Q-Allow" worksheet in the UDFCD Manual to determine the allowable gutter capacity. The engineer must enter the data appropriate for the street section and the minor/major storm criteria for the drainage classification for the worksheet to calculate the allowable gutter capacity based on the data and criteria provided.

7.6 Cross-Street Flow

7.6.1 Cross-Street Flow Conditions. Cross-street flow can occur in an urban drainage system under three conditions. One condition occurs when the runoff in a gutter spreads across the street crown to the opposite gutter. The second is when cross pans are used. The third condition is when the flow in a drainageway exceeds the capacity of a road culvert and/or bridge and subsequently overtops the crown of the street. Criteria for the first two conditions are discussed in the following sections. The third condition regarding allowable cross-street flow and overtopping at culvert crossings is limited by the criteria provided in Chapter 11, Culverts and Bridges.

7.6.2 Influence on Traffic. Whenever storm runoff, other than sheet flow, moves across a traffic lane, traffic movement is affected. The cross flow may be caused by super-elevation of a curve, by the intersection of two streets, by exceeding the capacity of the higher gutter on a street with cross fall, or street design that has not met the criteria provided herein. The problem associated with this type of flow is that it is localized in nature and vehicles may be traveling at speeds that are incompatible with the cross flow when they reach the location.

7.6.3 Allowable Cross-Street Flow Due to Spread Over the Street Crown. Allowable cross-street flow depths when the flow depth exceeds the street crown elevation are provided in Table 7-4. In the minor storm event, cross-street flow is NOT allowed based on the allowable flow depth and encroachment criteria provided in Table 7-2. In the major storm event, allowable cross-street flow is controlled by the criteria and limitations presented in Table 7-3 and Table 7-4. For example, if the maximum allowable gutter flow depth is 12-inches and the crown of the road is 7-inches above the flowline of the gutter, 5-inches (12-inches minus 7-inches) of cross-street flow is allowed during a major storm event, assuming all other criteria shown in Table 7-3 are met.

TABLE 7-4
ALLOWABLE CROSS-STREET FLOW DUE TO SPREAD OVER THE STREET CROWN FOR STREETS WITH CURB AND GUTTER

Drainage Classification	Minor Storm System Maximum Depth	Major Storm System Maximum Flow Depth
Type A, B and C	Not allowed	12-inches of depth at gutter flowline.

Note: All criteria in Table 7-3 must also be met for the major storm event.

7.6.4 Cross-Street Flow Analysis. The analysis to quantify the amount of cross-street flow can be complex due to the fact that the runoff is moving longitudinally down the street. In addition, it is often assumed that runoff being conveyed in the gutter will follow the path of the associated gutter at intersections, which generally requires the full flow to turn corners, without the appropriate consideration being given to the momentum that was established in one direction. There is potential for cross-street flow, if the flow isn't conveyed around the corner, as assumed. It is the responsibility of the design engineer to make conservative assumptions relative to cross-street flow and to design the downstream inlets and storm sewer accordingly. Even if the criteria stated above are met, SEMSWA will require inlets and storm sewers on the upstream side of the street to be designed to fully convey design flows assuming no cross-flow. Also, inlets and storm sewers on the downstream side of the street shall be increased in capacity by the amount of 1.5 times the estimated cross-flow.

7.6.5 Crosspans. Crosspans shall be designed to convey the minor and major storm event within the criteria presented in Sections 7.3 and 7.4. The design engineer shall evaluate the carrying capacity (with calculations provided) of water on the roadway being considered as well as the side street.

7.7 Curbless Streets with Roadside Swales for Enhanced Water Quality

7.7.1 Urban Roadside Swales. Urban roadside swales provide an opportunity to minimize directly connected impervious areas and thereby reduce the volume and peak rate of runoff and enhance stormwater quality. Roadside swales are used in conjunction with curbless (or intermittent curb) streets.

The use of urban roadside swales will need to be approved by SEMSWA prior to submittal. The engineer shall use the City standard street sections and the minimum urban swale criteria in the next section to determine the appropriate standard street section(s) for the project and seek approval for an alternate street section, as necessary.

Urban roadside swale sections should not be confused with rural street sections. Rural street sections incorporate a roadside ditch, which typically have a deeper section with steeper side slopes. Urban roadside swales shall be designed based on site-specific conditions. However, they will generally have a depth of 6- to 9-inches below the edge of pavement, a bottom width of at least 2-feet and side slopes of 8:1 or flatter. Swales shall be vegetated with irrigated bluegrass or irrigated sod-forming native grasses. The invert of the swale shall be parallel to the street slope to provide a constant depth.

7.7.2 Allowable Capacity. The allowable flow depth and roadway encroachment in the minor and major storm events for curbless streets can be found in Tables 7-2 and 7-3. Tables 7-2 and 7-3 reference allowable flow depth based on the gutter flow line; these tables should be used for curbless streets by applying the depth at the edge of pavement (rather than gutter flowline).

Flow in the grass swale is limited by capacity (this generally governs at low street slopes) and by velocity considerations (this governs at higher street slopes). To limit the potential for erosion during the 100-year event, allowable capacity for roadside grass swales is based on the major storm. Roadside swales shall be designed in accordance to the criteria for grass swales provided in Chapter 14 Stormwater Quality.

The lowest point of water entry (first floor or basement window) of any structure adjacent to the swale shall be at least 1.0-feet above the 100-year water surface, or generally 2.0 feet above the edge of the road.

7.7.3 Driveways and Street Cross-flow. In general, driveways or sidewalks that cross the swale are intended to conform to the swale cross section, such that flow will pass over the driveway as opposed to under it. Trench drains are generally required at the low point in the drive to convey any nuisance flows. Cross pans are typically used to convey swale flow across a street.

7.7.4 Downstream Facilities. At the point where the maximum capacity or slope of the swale is reached for the design event, runoff must be conveyed in an alternate system. The swale flow shall be diverted into a vegetated drainageway or picked up in an area inlet and storm sewer. Of the two, a vegetated drainageway is preferred to provide further contact of runoff with vegetation and soil. Drainageway design shall be in accordance with Chapter 12, Open Channel Design. Inlets and storm sewers shall be designed in accordance with Chapter 8, Inlets, and Chapter 9, Storm Sewers.

7.8 Rural Roadside Ditches

7.8.1 Roadside Ditches. Roadside ditches shall be used in lieu of curb and gutter when rural street sections are approved. Maintenance shall be considered when designing and using roadside ditches, including adequate area and side slopes to allow for maintenance access and vehicles. Maximum side slopes of 4 (horizontal) to 1 (vertical) are preferred, although maximum side slopes of 3 to 1 are acceptable if provided with erosion control blanket in accordance with SEMSWA GESC criteria. Roadside ditches shall be included in the street right-of-way section.

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7.8.2 Roadside Ditch Design Criteria. The allowable flow depth and roadway encroachment in the minor and major storm events for rural roadside ditches can be found in Tables 7-2 and 7-3. Tables 7-2 and 7-3 reference allowable flow depth based on the gutter flow line; these tables should be used for rural roadside ditches by applying the depth at the edge of pavement (rather than gutter flowline). The spread of flow shall not extend outside the street right-of-way and at least 12-inches of freeboard shall be provided from the major storm water surface elevation to the lowest point of water entry at any adjacent structures.

Rural roadside ditches shall be designed in accordance with the criteria for minor drainageway grass-lined channels shown in Chapter 12, Open Channel Design. Grade control structures are required to maintain velocities less than the maximum allowable or riprap lining (soil filled) shall be provided in accordance with the Major Drainage section of the UDFCD Manual.

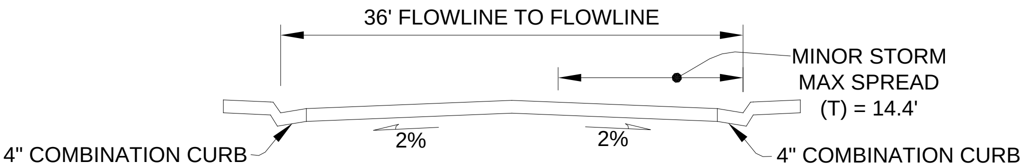
There are cases when the roadside ditch criteria may need to be more stringent due to the function of the rural road. Even if a rural road has a low traffic volume, it may be important for emergency access to several properties and therefore require special design criteria. SEMSWA reserves the right for more stringent criteria for single point access roads.

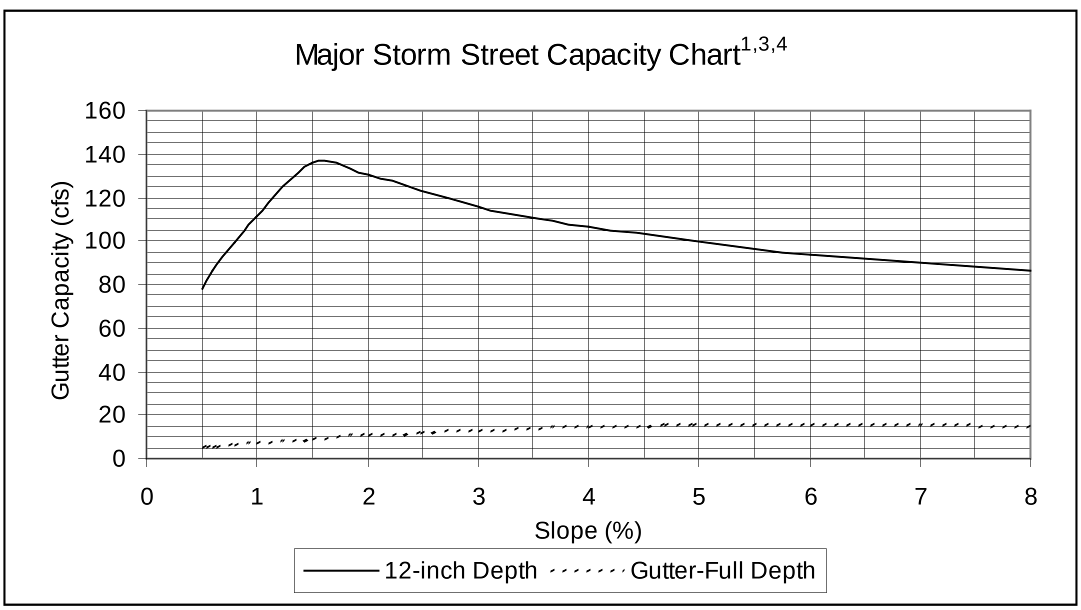
See Chapter 11, Culverts and Bridges, for design criteria pertaining to rural roadside ditch culverts.

FIGURE 7-1, SEMSWA STREET CAPACITY CHART

URBAN LOCAL (4" CURB)

Typical Cross Section





[1] The City of Centennial standard street section parameters must apply to use these charts. For non-standard sections, the street capacity shall be calculated using the UDFCD spreadsheets (see Section 7.5). The capacity shown is based on ½ the street section.

[2] The maximum spread width is limited by the curb height based on no curb overtopping allowable during a minor storm.

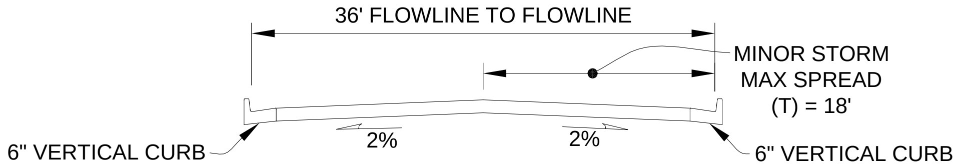
[3] Calculations for the 12-inch depth curve assume a vertical wall behind the top of curb. For the gutter-full depth case, the Minor Storm Capacity Chart may be used.

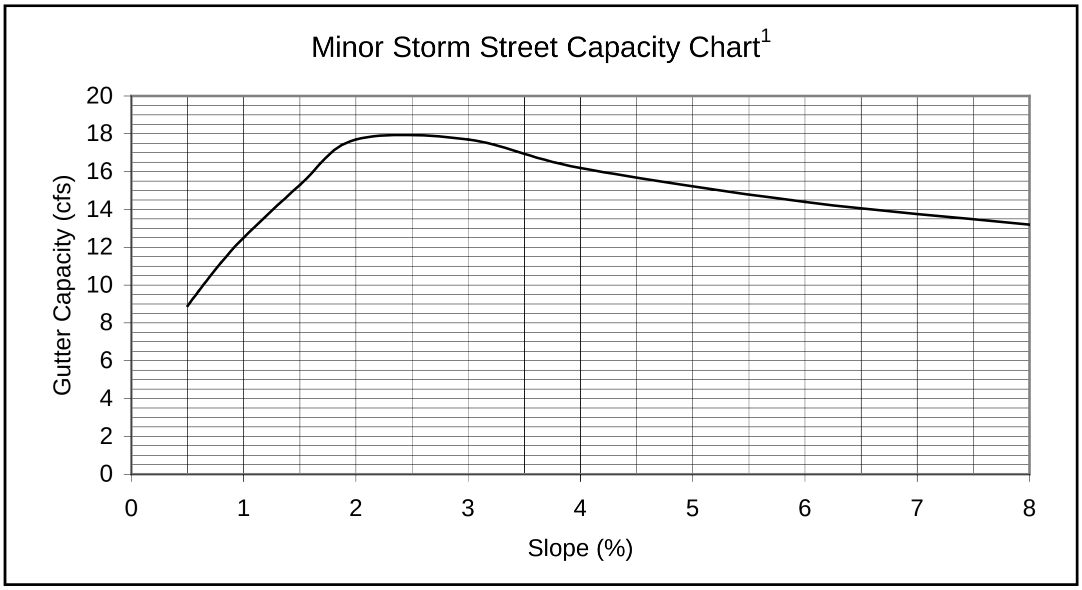
[4] The capacity shown assumes gutter-full depth of 5.0" to the back of the attached sidewalk. If a 4" curb without an attached sidewalk is used, the street capacity shall be calculated using the UDFCD spreadsheets.

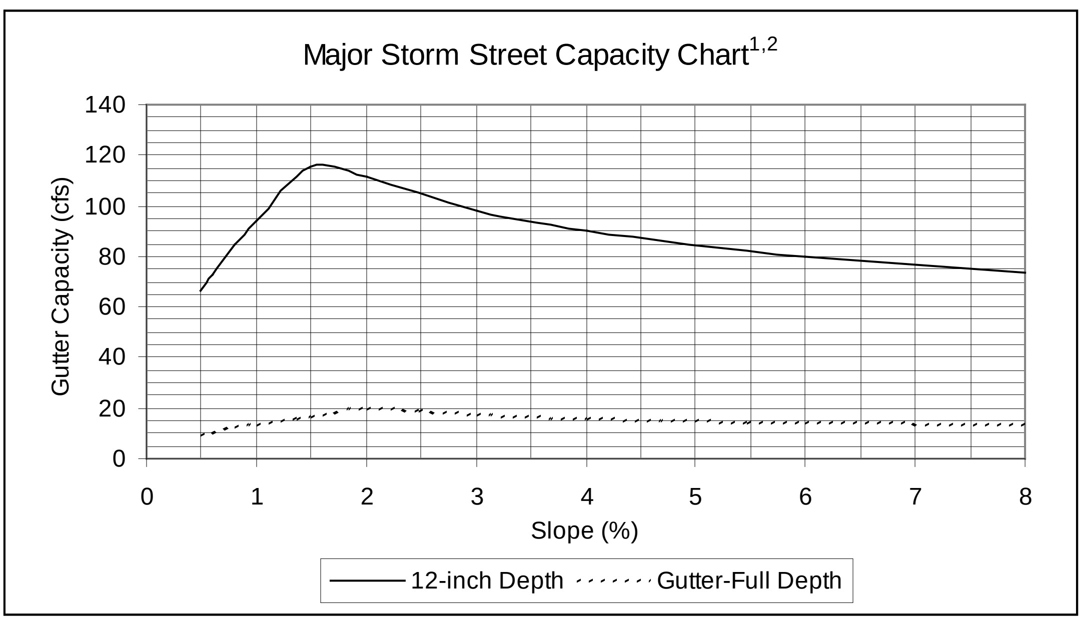
FIGURE 7-2, SEMSWA STREET CAPACITY CHART

URBAN LOCAL (6" CURB)

Typical Cross Section



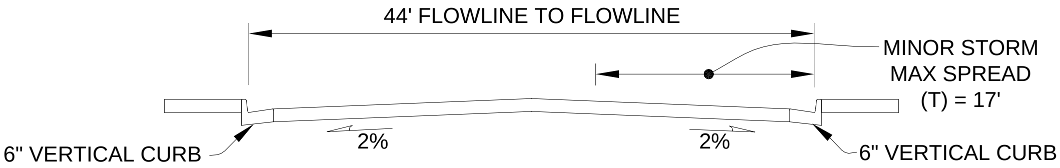


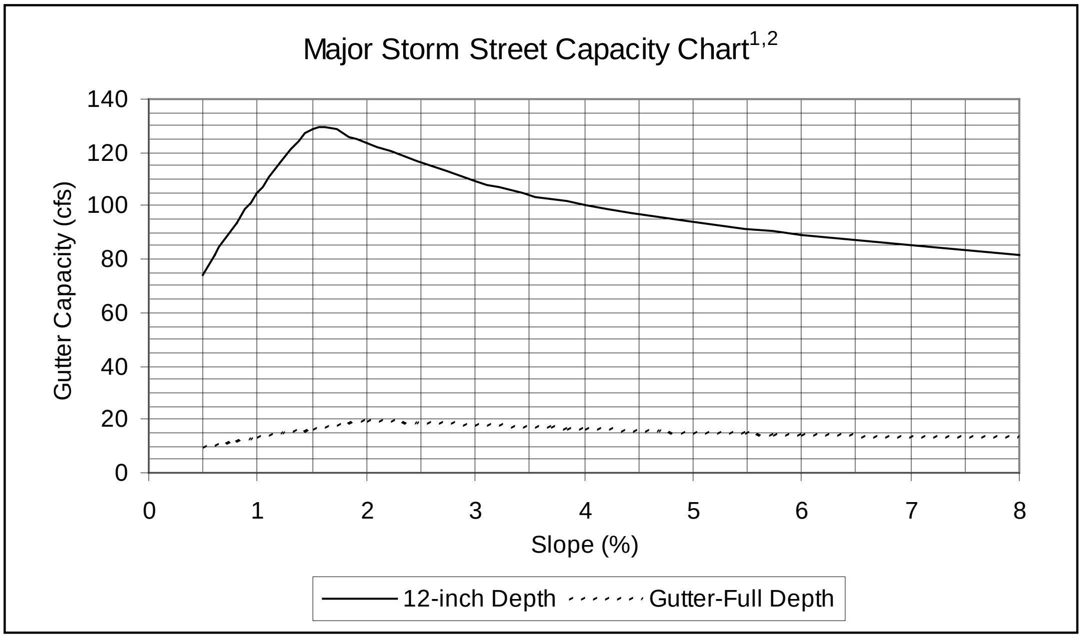


[1] The City of Centennial standard street section parameters must apply to use these charts. For non-standard sections, the street capacity shall be calculated using the UDFCD spreadsheets (see Section 7.5). The capacity shown is based on ½ the street section.
[2] Calculations for the 12-inch depth curve assume a vertical wall behind the top of curb. For the gutter-full depth case, the Minor Storm Capacity Chart may be used.

FIGURE 7-3, SEMSWA STREET CAPACITY CHART
60’ MINOR COLLECTOR

Typical Cross Section



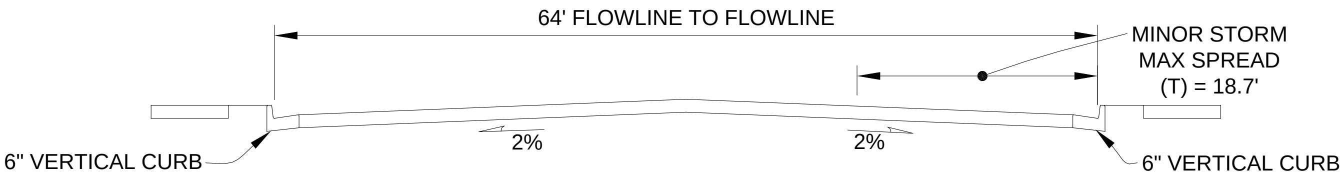


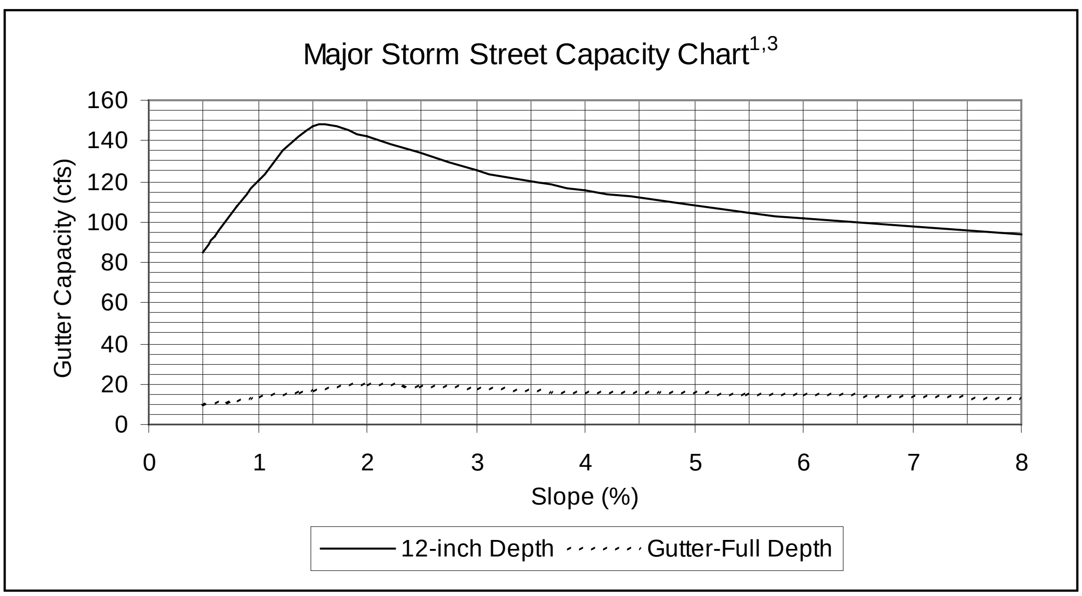
[1] The City of Centennial standard street section parameters must apply to use these charts. For non-standard sections, the street capacity shall be calculated using the UDFCD spreadsheets (see Section 7.5). The capacity shown is based on ½ the street section.
[2] Calculations for the 12-inch depth curve assume a vertical wall behind the top of curb. For the gutter-full depth case, the Minor Storm Capacity Chart may be used.

FIGURE 7-4, SEMSWA STREET CAPACITY CHART

80' MAJOR COLLECTOR

Typical Cross Section



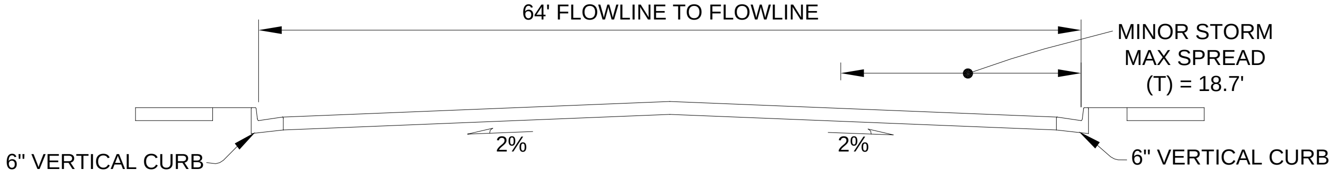


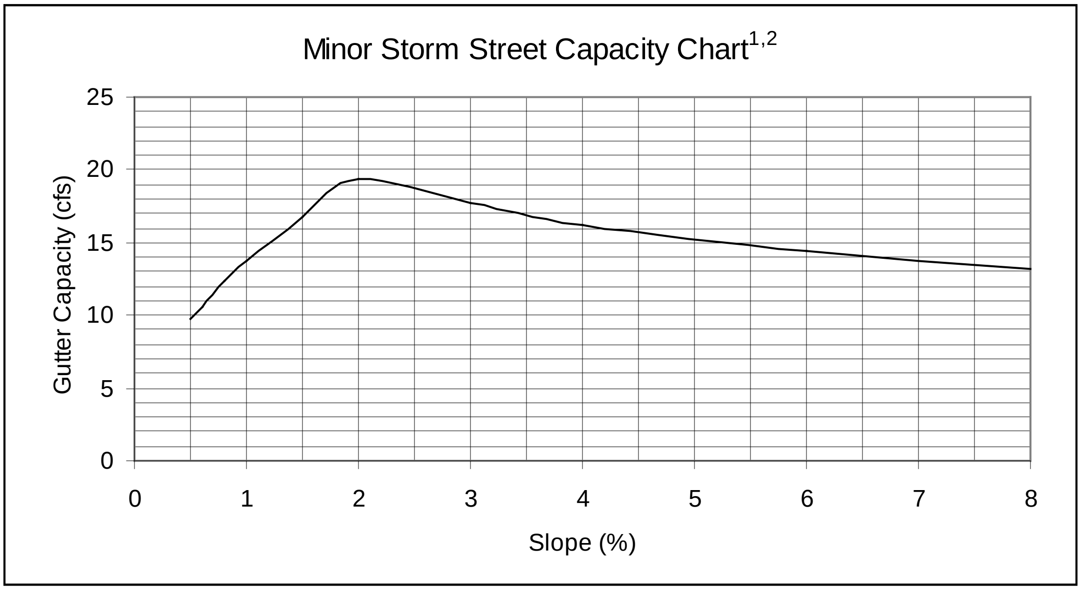
[1] The City of Centennial standard street section parameters must apply to use these charts. For non-standard sections, the street capacity shall be calculated using the UDFCD spreadsheets (see Section 7.5). The capacity shown is based on ½ the street section.
[2] The maximum spread width is limited by the curb height based on no curb overtopping allowable during a minor storm.
[3] Calculations for the 12-inch depth curve assume a vertical wall behind the top of curb. For the gutter-full depth case, the Minor Storm Capacity Chart may be used.

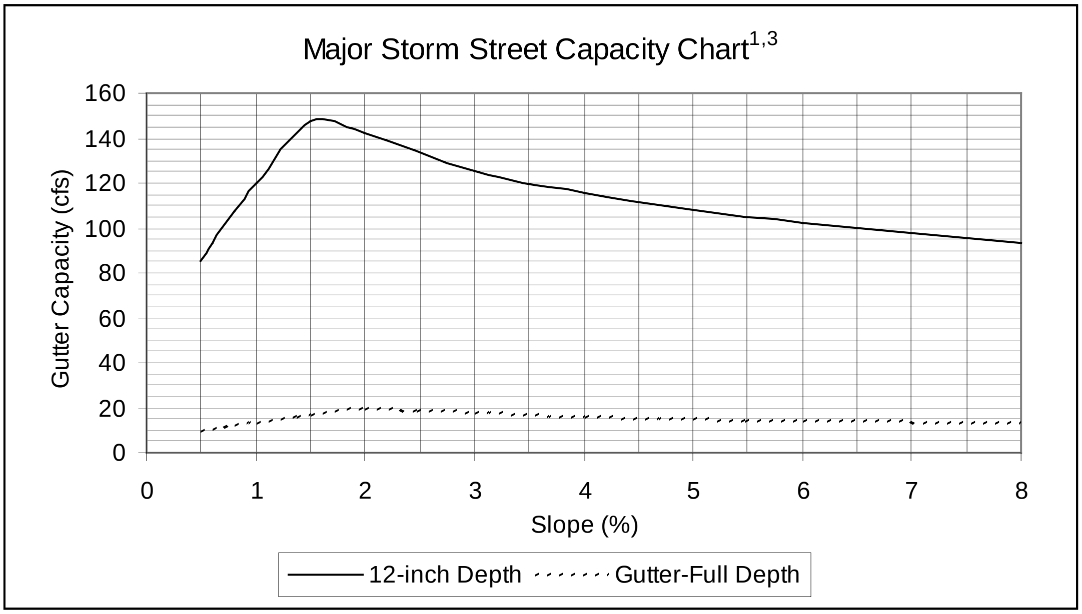
FIGURE 7-5, SEMSWA STREET CAPACITY CHART

100' MINOR ARTERIAL

Typical Cross Section





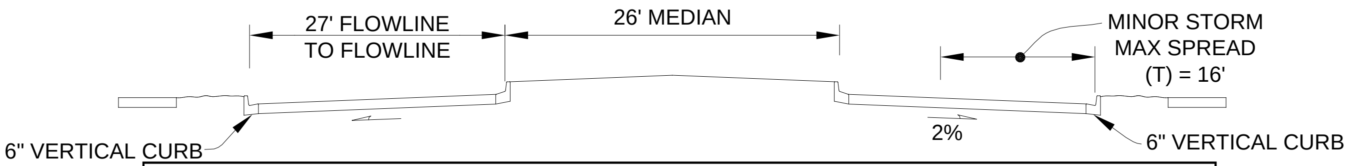


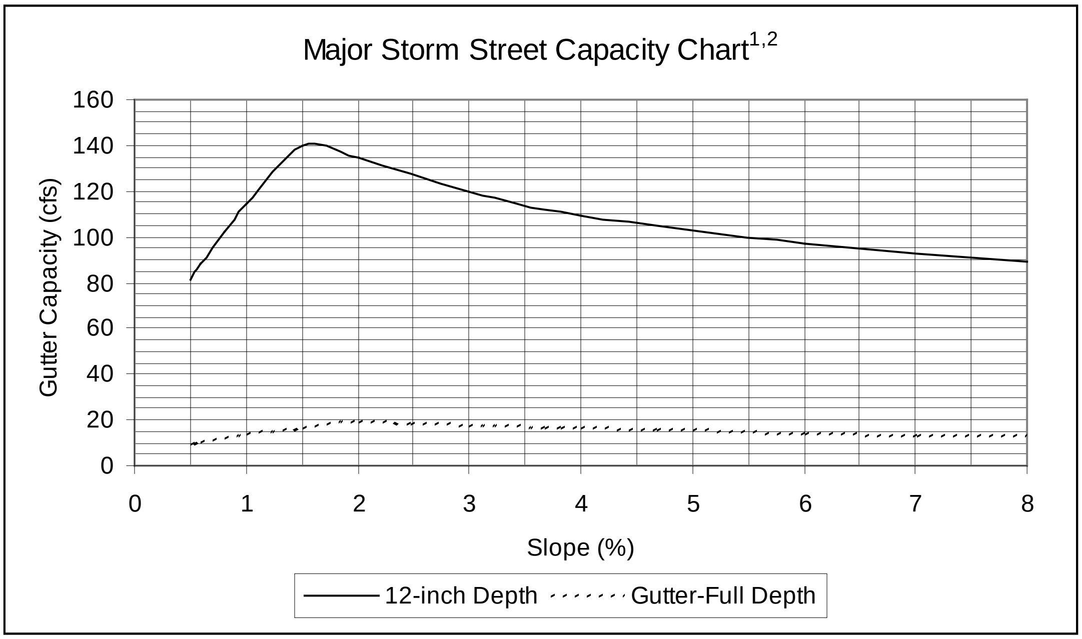
[1] The City of Centennial standard street section parameters must apply to use these charts. For non-standard sections, the street capacity shall be calculated using the UDFCD spreadsheets (see Section 7.5). The capacity shown is based on ½ the street section.
[2] The maximum spread width is limited by the curb height based on no curb overtopping allowable during a minor storm.
[3] Calculations for the 12-inch depth curve assume a vertical wall behind the top of curb. For the gutter-full depth case, the Minor Storm Capacity Chart may be used.

FIGURE 7-6, SEMSWA STREET CAPACITY CHART

120' (4 LANE) MAJOR ARTERIAL

Typical Cross Section





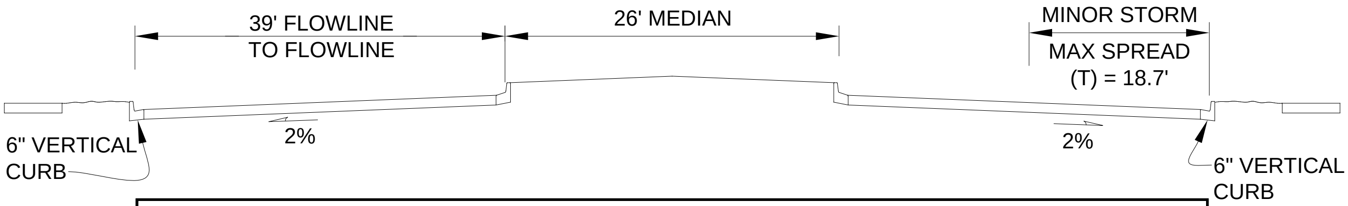
[1] The City of Centennial standard street section parameters must apply to use these charts. For non-standard sections, the street capacity shall be calculated using the UDFCD spreadsheets (see Section 7.5). The capacity shown is based on ½ the street section.

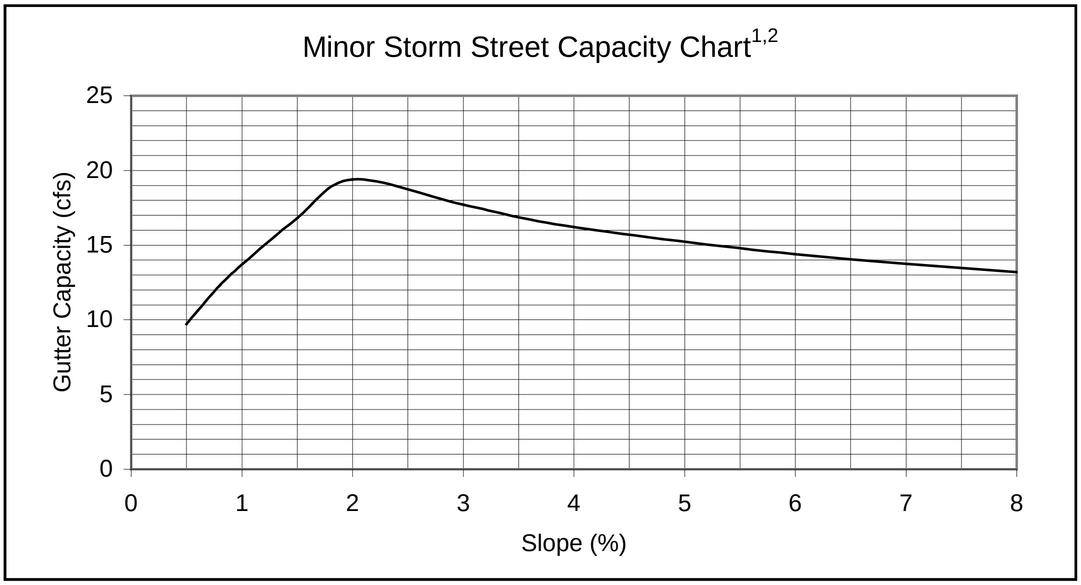
[2] Calculations for the 12-inch depth curve assume a vertical wall behind the top of curb. For the gutter-full depth case, the Minor Storm Capacity Chart may be used.

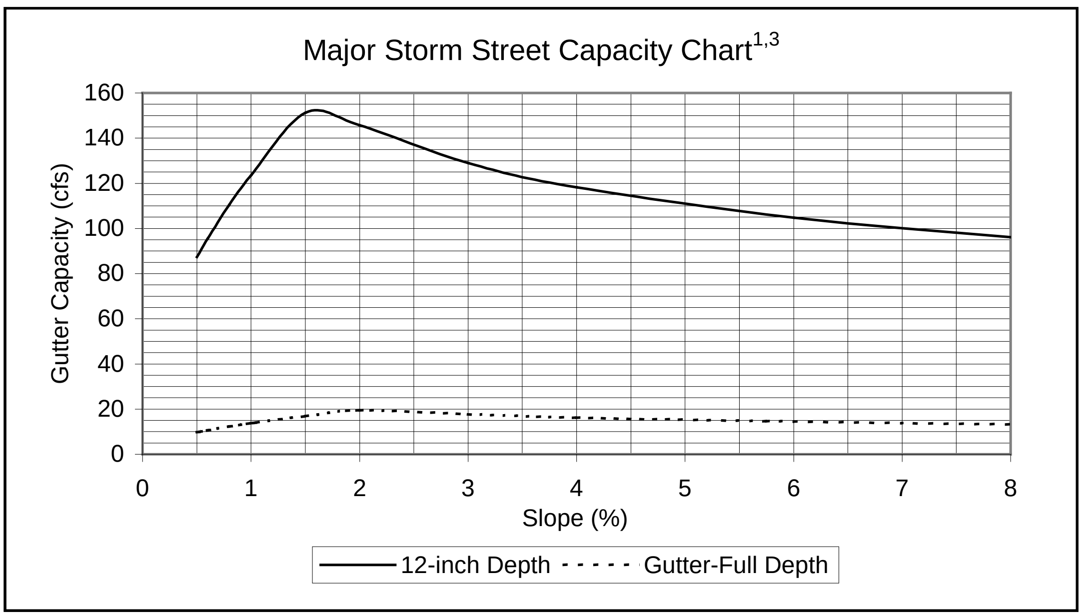
FIGURE 7-7, SEMSWA STREET CAPACITY CHART

140' (6 LANE) MAJOR ARTERIAL

Typical Cross Section







[1] The City of Centennial standard street section parameters must apply to use these charts. For non-standard sections, the street capacity shall be calculated using the UDFCD spreadsheets (see Section 7.5). The capacity shown is based on ½ the street section.

[2] The maximum spread width is limited by the curb height based on no curb overtopping allowable during a minor storm.

[3] Calculations for the 12-inch depth curve assume a vertical wall behind the top of curb. For the gutter-full depth case, the Minor Storm Capacity Chart may be used.