SECTION 3 - STREET FLOW

3.1.0 GENERAL

The location of inlets and permissible flow of water in streets should be related to the extent and frequency of interference to traffic and the likelihood of flood damage to surrounding property for the 25-and 100-year frequency storms. Interference to traffic is regulated by design limits of the spread of water into traffic lanes, especially in regard to arterials. Flooding of surrounding property from streets is controlled by limiting curb buildup to the top of curb for a 25-year storm, which is designated as the design storm. Conveyance provisions for the 100-year storm must also be made within defined right-of-way and easements.

3.1.1 Interference Due to Flow in Streets

Water which flows in a street, whether from rainfall directly onto the pavement surface or overland flow entering from adjacent land areas, will flow in the gutters of the street until it reaches an overflow point or some outlet, such as a storm sewer inlet. As the flow progresses downhill and additional areas contribute to the runoff, the width of flow will increase and progressively encroach into the traffic lane. On streets where parking is not permitted, as with many arterial streets, flow widths exceeding one traffic lane become a traffic hazard. Field observations show that vehicles will crowd adjacent lanes to avoid curb flow.

As the width of flow increases, it becomes impossible for vehicles to operate without moving through water in an inundated lane. Splash from vehicles traveling in the inundated lane obscures the vision of drivers of vehicles moving at a higher rate of speed in the open lane. Eventually, if width and depth of flow become great enough, the street loses its effectiveness as a traffic-carrier. During these periods it is imperative that emergency vehicles such as fire trucks, ambulances and police cars be able to traverse the street by moving along the crown of the roadway.

3.1.2 Interference Due to Ponding

Storm runoff ponded on the street surface because of grade changes or because of the crown slope of intersecting streets has a substantial effect on the street-carrying capacity. The manner in which ponded water affects traffic is essentially the same as for curb flow; that is, the width of spread into the traffic lane is critical. Ponded water will often completely halt all traffic. Ponding in streets has the added hazard of surprise to drivers of moving vehicles, producing erratic and dangerous responses.

3.1.3 Street Cross Flow

Whenever storm runoff, other than limited sheet flow, moves across a traffic lane, a serious and dangerous impediment to traffic flow occurs. Cross-flow is allowed only in case of superelevation of a curve or overflow from the higher gutter on a street with cross fall. No more than three (3) cubic feet per second for the 25-year storm shall be allowed to cross flow from the higher elevation to the lower elevation.

3.1.4 Allowable Flow of Water Through Intersections

As the storm-water flow approaches a ~~an arterial~~ street or tee intersection (except alleys), an inlet is required if more than three (3) cubic feet per second for the 25-year storm shall ~~enter~~ flow across the intersection. No more than three (3) cfs for the 25-year storm shall be allowed to enter the bulb of a cul-de-sac or corner bubble. In both situations, the inlet cannot be placed inside the curb return.

3.1.5 Valley Gutter

Valley gutters can be useful in diminishing the deterioration of pavements, particularly at intersections where flows tend to concentrate. At the intersection of two (2) arterial streets, a valley gutter cannot be used. At the intersection of two (2) collector streets or local streets, the valley gutter may be used. At an intersection of two (2) different types of streets, the valley gutter may be used across the smaller street only. Valley gutters must be constructed out of reinforced concrete.

3.2.0 PERMISSIBLE SPREAD OF WATER

The flow of water in gutters of typical ~~various~~ streets during the 25-year storm ~~of different categories~~ shall be contained below the top of curb and shall maintain the clear width requirements listed in Table 3-1. The flow of water shall be limited to a maximum of 6" above the top of crown during the 100-year storm event and must be contained within the defined right-of-way and easements~~. limited by those values found on Table 3-1.~~ These clear widths at the crown of the roadway or at the high point on a divided roadway are necessary to provide access for vehicles in the event of an emergency.

Equation 3-1 (from equations presented in HEC-22, FHWA-NHI-10-009, modified to solve for depth rather than flow or spread) may be used to determine the depth ~~spread~~ of gutter flow for a specific street width and flow spread ~~depth~~.

$$y = 4H(S/W) - 4H(S^2/W^2) \qquad \text{(Eq. 3-1)}$$

Where,

y = Water depth in the gutter (feet) (limited to 0.5ft)

W = Street width (feet)

H = Crown height (feet)

S = Spread on one side of street (feet)

~~$$\text{Spread} = W/2 - [(W^2/4) - 30y_o W^2/(30 + W)]^{1/2}, \qquad \text{(Eq. 3-1)}$$~~

~~Where,~~

~~W = Street Width, feet~~
~~y_o = Water depth in the gutter, feet~~

3.3.0 DESIGN METHOD

3.3.1 Gutter Flow Velocities

To ensure ~~insure~~ scouring velocities for low flows, the gutter shall have a minimum slope of 0.004 feet per foot ~~(0.4 percent)~~.

3.3.2 Straight Crowns

Flow in gutters on straight crown pavements is normally assumed to be uniform, with Manning's Equation being used to determine the flow. However, because the hydraulic radius assumption in the Manning's Equation is not able to adequately describe the hydraulic characteristics of the gutter cross section, modification of the equation is necessary to accurately compute the flow. The modified Manning's Equation (HEC-22 Manual, FHWA-NHI-10-009) is:

$$Q_o = 0.56\ (z/n)\ S_o^{1/2} Y_o^{8/3} \qquad \text{(Eq. 3-2)}$$

Where,

Q_o = Gutter discharge, cfs
z = Reciprocal of the crown slope, ft/ft
S_o = Street or gutter slope, ft/ft
n = Roughness coefficient
Y_o = Depth of flow in gutter, feet

The nomograph in Figure 3-1 in Appendix D of this manual provides a direct solution for flow conditions in triangular channels. For a concrete pavement gutter, an n value equal to 0.016 is recommended. For gutters with small slope (less than one (1) percent) where sediment may accumulate, an n value of 0.02 is recommended.

Table 3-1
Minimum Clear Widths for Roadway Design When ~~Due to~~ Gutter is Flowing Full*

Roadway Type		Minimum Clear Width (ft)
Local		0
Collector	Residential or Neighborhood All others	12 12 in each direction
Arterial	4 lanes one way or 8 lanes divided All others	24 in each direction 12 in each direction

~~**Roadway Type**~~	~~Proposed Usage~~	~~Minimum Clear Width (Feet)~~
~~1. Local Street~~	~~a. General~~ ~~b. Loop~~ ~~c. Elbow~~	~~0~~ ~~0~~ ~~0~~
~~2. Collector~~	~~a. Residential~~ ~~b. Neighborhood~~ ~~c. Commercial~~ ~~d. Industrial~~ ~~e. Primary, 4 Lanes~~ ~~5 Lanes~~ ~~4 Lanes Divided~~ ~~6 Lanes Divided~~	~~8~~ ~~11~~ ~~24~~ ~~24~~ ~~22~~ ~~24~~ ~~12 (each way)~~ ~~12 (each way)~~
~~3. Arterial~~	~~a. 4 Lanes, Undivided~~ ~~b. 3 Lanes, One way~~ ~~c. 4 Lanes, One way~~ ~~d. 4 Lanes, with continuous left turn lane~~ ~~e. 4 Lanes, Divided~~ ~~f. 6 Lanes, Divided~~ ~~g. 8 Lanes, Divided~~	~~24~~ ~~12~~ ~~24~~ ~~24~~ ~~12 (each way)~~ ~~12 (each way)~~ ~~24 (each way)~~
~~* See Reference 3-2 for typical cross-sections of the roadways described here.~~		
~~Source: City of Austin, Department of Public Works and Transportation~~		

~~The nomograph in Figure 3-1 in Appendix E of this manual provides a direct solution for flow conditions in triangular channels. For a concrete pavement gutter, an n value equal to 0.016 is recommended. For gutters with small slope less than one (1) percent where sediment may accumulate, an n value of 0.02 is recommended.~~

3.3.3 Parabolic Crowns

Flows in the gutter of a parabolically crowned pavement are calculated from a variation of Manning's Equation, which assumes steady flow in a prismatic open channel. However, this equation is complicated and difficult to solve for each design case.

To provide a means of determining the flow in the gutter, generalized gutter flow equations for combinations of parabolic crown heights, curb splits and street grades of different street widths have been prepared. All of these equations have a logarithmic form.

Note: The street width used in this section is measured from face-of-curb to face-of-curb.

A. Streets Without Curb Split. Curb split is the vertical difference in elevation between curbs at a given street cross section. The gutter flow equation for parabolic crown streets without any curb split is:

$$\log Q = K_o + K_1 \log S_o + K_2 \log y_o \qquad \text{(Eq. 3-3)}$$

Where,

Q = Gutter flow, cfs
S_o = Street grade, ft/ft
y_o = Water depth in the gutter, feet
K_o, K_1, K_2 = Constant coefficients shown in Table 3-2 for different street widths:

Table 3-2
Coefficients for Equation 3-3, Streets Without Curb Split

Street Width* (ft)	Coefficients		
-	K_o	K_1	K_2
30	2.85	0.50	3.03
36	2.89	0.50	2.99
40	2.85	0.50	2.89
44	2.84	0.50	2.83
48	2.83	0.50	2.78
60	2.85	0.50	2.74
*Note: Based on the Transportation Criteria Manual, the street width is measured from face-of-curb to face-of-curb (FOC-FOC).			
Source: City of Austin, Watershed Engineering Division			

B. Streets With Curb Split - Higher Gutter. The gutter flow equation for calculating the higher gutter flows is as follows:

$$\log Q = K_0 + K_1 \log S_0 + K_2 \log y_o + K_3 (CS) \qquad \text{(Eq. 3-4)}$$

Where,

Q = Gutter flow, cfs
S_0 = Street grade, ft/ft
y_0 = Water depth in the gutter, feet
C_S = Curb split, feet
K_o, K_1, K_2, K_3 = Constant coefficients shown in Table 3-3 for different street widths:

Table 3-3
Coefficients for Equation 3-4, Streets With Curb Split - Higher Gutter

Street Width (ft)	Coefficients				Curb Split Range (ft)
-	K_0	K_1	K_2	K_3	-
30	2.85	0.50	3.03	-0.131	0.0-0.6
36	2.89	0.50	2.99	-0.140	0.0-0.8
40	2.85	0.50	2.89	-0.084	0.0-0.8
44	2.84	0.50	2.83	-0.091	0.0-0.9
48	2.83	0.50	2.78	-0.095	0.0-1.0
60	2.85	0.50	2.74	-0.043	0.0-1.2
Source: City of Austin, Watershed Engineering Division					

C. Streets with Curb Split - Lower Gutter.

The gutter flow equation for the lower gutter is:

$$\log Q = K_0 + K_1 \log S_0 + K_2 \log y_0 + K_3 (CS) \qquad \text{(Eq. 3-5)}$$

Where,

Q = Gutter flow, cfs
S_0 = Street grade in ft/ft
y_0 = Water depth in the gutter in feet
CS = Curb split in feet
K_0, K_1, K_2, K_3 = Constant coefficients shown in Table 3-4 for different street widths:

Table 3-4
Coefficients for Equation 3-5, Streets With Curb Split - Lower Gutter

Street Width (ft)	Coefficients				Curb Split Range (ft)
-	K_0	K_1	K_2	K_3	-
30	2.70	0.50	2.74	-0.215	0.0-0.6
36	2.74	0.50	2.73	-0.214	0.0-0.8

40	2.75	0.50	2.73	-0.198	0.0-0.8
44	2.76	0.50	2.73	-0.186	0.0-0.9
48	2.77	0.50	2.72	-0.175	0.0-1.0
60	2.80	0.50	2.71	-0.159	0.0-1.2
Source: City of Austin, Watershed Engineering Division					

~~All the crown heights for different street widths are calculated by the following equation:~~

~~Crown Height (feet) = 0.5 + [(W – 30)/120] (Eq. 3-6)~~

~~Where,~~

~~W = street width, feet~~

D. Parabolic Crown Location**.**

The gutter flow equation presented for parabolic crowns with split curb heights is based on a procedure for locating the street crown. The procedure allows the street crown to shift from the street center line toward the high ¼ point of the street in direct proportion to the amount of curb split. The maximum curb split occurs with the crown at the ¼ point of the street. The maximum allowable curb split for a street with parabolic crowns is 0.02 feet per foot of street width.

Example: Determination of Crown Location

Given: 0.4 feet Design split on 30-foot wide street.

Maximum curb split = 0.02 x street width
= 0.02 x 30 feet = 0.6 feet
Maximum Movement = ¼ street width for 30 foot street
= ¼ x 30 feet = 7.5 feet
Split Movement =(Design split x W/Maximum Split x 4)
= (0.4 x 30/.6 x 4) = 5 feet

Curb splits that are determined by field survey, whether built intentionally or not, should be considered when determining the capacity of the curb flow.

Special consideration should be given when working with cross sections which have the pavement crown above the top of curb. When the crown exceeds the height of the curb the maximum depth of water is equal to the height of the curb, not the crown height. It should be noted that a parabolic section where the crown equals the top of curb will carry more water than a section which has the crown one (1) inch above the top of curb.

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SECTION 4 - INLETS

4.1.0 GENERAL

The primary purpose of storm drain inlets is to intercept surface runoff so that flows will be conveyed safely in an engineered storm drain system.

~~The primary purpose of storm drain inlets is to intercept excess surface runoff and deposit it in a drainage system, thus reducing the possibility of surface flooding.~~

The most common location for inlets is at the curb line of streets where surface flow collects. Inlets must be designed to avoid conflicting with the movement of vehicular traffic and to provide travel space free of surface flow in accordance with Section 3 of this manual.

~~The most common location for inlets is in streets which collect and channelize surface flow, making it convenient to intercept. Because the primary purpose of streets is to carry vehicular traffic, inlets must be designed so as not to conflict with that purpose.~~

The following guidelines shall be used in the design of inlets to be located in streets:

A. Curb inlets shall be used to intercept surface runoff for curb and gutter streets unless the use of an alternative type inlet has been approved in writing by the Director of the Watershed Protection Department. The use of an alternative type inlet also needs to be approved by the Quality and Standards Management Division (QSMD) with respect to any effect that the layout of the inlet might have on the remainder of the right of way.

B. All curb inlets, whether in a sump or on grade, shall be a minimum of five (5) feet in length and be designed and constructed in accordance with the City's standard details for curb inlets. In all cases, the size and layout of inlets shall be such that all applicable requirements of the City street drainage criteria will be met.

C. Curb inlets in excess of ten feet in length shall be designed and constructed with a modified top in accordance with the City's standard details for curb inlets.

D. The standard curb inlet transition length is 9'-8" as shown in the standard details. Transition lengths may be reduced to a minimum of 7'-6" for curb inlets having a standard depth of depression only when the inlet is located on the outside lane of a street where the outside lane is clearly designated for parking only.

E. The use of a reduced throat inlet may be considered on travel lanes where a proposed inlet is less than ten feet from an existing driveway or street corner. Hydraulic requirements must be satisfied. All reduced throat inlets must be designed and constructed in accordance with the City's standard details. Approval in writing by the Director of the Watershed Protection Department is required in all cases where a reduced throat inlet is proposed.

F. The use of recessed inlets is encouraged on any street where space is available and subsurface utility lines can be accommodated. The advantage of recessed inlets is that they minimize the dip in the travel lane; the disadvantage is that they can make subsurface utility placement more difficult due to the increased potential for location conflicts. The width of the sidewalk shall not be decreased whenever a recessed inlet is used.

G. Grate inlets, combination inlets and slotted drains are discouraged from use due to the tendency of grates and slotted drains to clog, the increased maintenance needed to keep them free of debris, the hazards caused by broken or missing grates, and the difficulties associated with replacing broken or missing

grates. When the use of a grate inlet, combination inlet or slotted drain is being considered, a written request to allow the proposed grate inlet, combination inlet or slotted drain may be made when accompanied by supporting information that clearly demonstrates that the proposed grate inlet, combination inlet or slotted drain is the only feasible solution. If approved in writing by the Director of the Watershed Protection Department, the selection and use of a grate inlet, combination inlet or slotted drain shall be in strict accordance with the manufacturer's design guidelines.

H. Trench drains with grates, when approved for use in writing by the Director of the Watershed Protection Department, shall be designed and constructed in accordance with the City's standard details for trench drains with grates. All trench drains with grates shall be designed for HS-20 loading. For all trench drains with grates located within City right-of-way, two additional sets of the full grate length shall be provided at the time of construction for City maintenance crews to have on hand for emergency replacement of the grate.

I. Inlet design and location must be in accordance with the criteria established in Section 3 of this manual.

J. The selection, use and maintenance of water treatment systems at inlets to improve water quality shall be in accordance with the manufacturer's recommendations. Inlet structures shall be sized so that the peak rate of flow entering the inlet from the surface will pass over or around the treatment device when the device is fully clogged. Flow that enters the inlet from the surface and flow in the storm drain system that is passing through the inlet structure shall not be hindered by the presence of a treatment device. The designer of the storm drain system must account for all increased headlosses due to the presence of a fully-clogged treatment device.

~~A. Grated curb inlets are discouraged from use due to their increased tendency to clog and problems with replacement. In all instances where a curb inlet can be used in lieu of a grated curb inlet it shall be required unless approval is given from the Director of the Watershed Protection and Development Review Department.~~

~~B. Minimum transition for recessed inlets shall be ten (10) feet, in accordance with the Public Works Department standard detail for recessed inlets (Standard No. 508-5).~~

~~C. All curb inlets (whether in a sump or on grade) incorporate a standard five (5) inch depression, and must be designed and constructed in accordance with the Public Works Department standard detail for curb inlets (Standard No. 508-3). Unless otherwise approved in writing by the Director of the Watershed Protection and Development Review Department, all curb inlets shall be a minimum of ten (10) feet in length.~~

~~D. When recessed inlets are used, they shall not decrease the width of the sidewalk. Also, it should be noted that the use of recessed inlets is optional for all streets.~~

~~E. Design and location of inlets shall take into consideration pedestrian and bicycle traffic. In particular, grate inlets shall be designed to assure safe passage of bicycles.~~

~~F. Inlet design and location must be compatible with the criteria established in Section 3 of this manual.~~

~~G. The use of slotted drains is discouraged except in instances where there is no alternative. If used, the manufacturer's design guidelines should be followed.~~

4.2.0 INLET CLASSIFICATIONS

Inlets are classified into two (2) major groups: 1) inlets in sumps where flow contributes from two (2) or more sides (Type S) and 2) inlets on grade (Type G). The following list references the various inlet types. (See Figures 4-1 through 4-7 in Appendix ~~E~~ D of this manual).

Inlets in Sumps

(1) Curb Opening	Type S-1
(2) Grate*	Type S-2

(3) Combination (Grate and Curb Opening)* Type S-3
(4) Area Without Grate Type S-4

Inlets on Grade
(1) Curb Opening Type G-1
(2) Grate* Type G-2
(3) Combination (Grate and Curb Opening)* Type G-3

Recessed inlets are identified by the suffix (R), i.e.: S-1(R).

* For the flow capacity through the grate inlets, engineer should check appropriate vendor catalog.

4.3.0 STORM INLET HYDRAULICS

4.3.1 Inlets In Sumps

Inlets in sumps are inlets at low points with gutter flow contributing from two (2) or more sides. The capacity of inlets in sumps must be known in order to determine the depth and width of ponding for a given discharge. ~~Sump inlets should be designed using Figure 4-8 in Appendix E of this manual for an unsubmerged inlet or Figure 4-9 in Appendix E of this manual for submerged conditions, regardless of what depth of depression exists at the inlet.~~

A. Curb Opening Inlets (Type S-1) and Area Inlet Without Grate (Type S-4).

~~Unsubmerged curb opening inlets (Type S-1) and area inlets without grates (Type S-4) in a sump function as rectangular weirs with a coefficient of discharge of 3.0. Their capacity shall be based on the following equation:~~

~~$Q = 3.0h^{1.5}L$ (Eq. 4-1)~~

~~Where,~~

~~Q = Capacity of curb opening inlet or of area inlet, cfs~~
~~h = Head at the inlet, feet, = a + Y_o~~
~~L = Length of opening through which water enters the inlet, feet~~

~~Figure 4-8 in Appendix E of this manual provides for direct solution of the above equation.~~

~~Curb opening inlets and drop inlets in sumps have a tendency to collect debris at their entrances. For this reason, the calculated inlet capacity shall be reduced by ten (10) percent to allow for clogging.~~

Source: Hydraulic Engineering Circular No. 22, Third Edition, FHWA, Sept. 2009

The capacity of a curb-opening inlet in a sag depends on water depth at the curb, the curb opening length, and the height of the curb opening. The inlet operates as a weir to depths equal to the curb opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

The depth of flow shall be measured upstream of the inlet at the curb at the point of maximum spread.

The weir location for a depressed curb-opening inlet is at the edge of the gutter, and the effective weir length is dependent on the width of the depressed gutter and the length of the curb opening. The weir location for a curb-opening inlet that is not depressed is at the lip of the curb opening, and its length is equal to that of the inlet, as shown in Fig. 4-9.

The equation for the interception capacity of a depressed curb-opening inlet operating as a weir is:

$Q_i = C_w (L + 1.8 W) d^{1.5}$ (Eq. 4-1)

where:

$C_w = 2.3$

L = Length of curb opening (ft)

W = Lateral width of depression (ft)

d = Depth at curb measured from the normal cross slope (ft), i.e., $d = T S_x$.

Note that the depth is measured at the curb at the beginning of the transition. This is the undepressed depth. To avoid over-estimating the weir capacity of the inlet, do not use the depth from the water surface to the depressed inlet throat.

The weir equation is applicable to depths at the curb approximately equal to the height of the opening plus the depth of the depression. Thus, the limitation on the use of Equation 4-1 for a depressed curb-opening inlet is:

$d \leq h + a / 12$ (Eq. 4-2)

where:

h = Height of curb-opening inlet (ft)

a = Depth of depression (in)

Experiments have not been conducted for curb-opening inlets with a continuously depressed gutter, but it is reasonable to expect that the effective weir length would be as great as that for an inlet in a local depression. Use of Equation 4-1 will yield conservative estimates of the interception capacity.

The weir equation for curb-opening inlets without depression becomes:

$Q_i = C_w L d^{1.5}$ (Eq. 4-3)

Without depression of the gutter section, the weir coefficient, Cw, becomes 3.0. The depth limitation for operation as a weir becomes $d \leq h$.

At curb-opening lengths greater than 12 ft, Equation 4-3 for non-depressed inlet produces intercepted flows which exceed the values for depressed inlets computed using Equation 4-1. Since depressed inlets will perform at least as well as non-depressed inlets of the same length, Equation 4-30 should be used for all curb-opening inlets having lengths greater than 12 ft.

Curb-opening inlets operate as orifices at depths greater than approximately 1.4 times the opening height. The interception capacity can be computed by Equation 4-4a and Equation 4-4b. These equations are applicable to depressed and undepressed curb-opening inlets. The depth at the inlet includes any gutter depression.

$Q_i = C_o h L(2 g do)^{0.5}$ (Eq. 4-4a)

Or

$Q_i = C_o A_g \{2g [d_i – (h/2)]\}^{0.5}$ (Eq 4-4b)

where:

C_o = Orifice coefficient (0.67)

d_o = Effective head on the center of the orifice throat (ft)

L = Length of orifice opening (ft)

A_g = Clear area of opening (ft2)

d_i = Depth at lip of curb opening (ft)

h = Height of curb-opening orifice (ft)

The height of the orifice in Equations 4-4a and 4-4b assumes a vertical orifice opening. As illustrated in Figure 4-8, other orifice throat locations can change the effective depth on the orifice and the dimension (di - h/2). A limited throat width could reduce the capacity of the curb-opening inlet by causing the inlet to go into orifice flow at depths less than the height of the opening.

Fig. 4-8 depicts typical cross-sections of various types of curb-opening inlets.

For curb-opening inlets with other than vertical faces (Fig. 4-8), Equation 4-4a can be used with:

h = orifice throat width (ft)

d_o = effective head on the center of the orifice throat (ft)

Fig. 4-9 provides solutions for Equations 4-1 and 4-4 for depressed curb-opening inlets, and Fig. 4-10 provides solutions for Equations 4-3 and 4-4 for curb-opening inlets without depression. Fig. 4-11 is provided for use for curb openings with other than vertical orifice openings.

Example 4-1 illustrates the use of Figs. 4-10 and 4-11.

Example 4-1

Given: Curb-opening inlet in a sump location with

L = 8.2 ft

h = 0.43 ft

(1) Undepressed curb opening

S_x = 0.02

T = 8.2 ft

(2) Depressed curb opening

S_x = 0.02

a = 1 in. local

W = 2 ft.

T = 8.2 ft.

Find: Q_i

Solution (1): Undepressed

Step 1. Determine depth at curb.

$d = T S_x = (8.2)(0.02)$

$d = 0.16$ ft

$d = 0.16$ ft $< h = 0.43$ ft,

therefore weir flow controls

Step 2. Use Equation 4-3 or Fig. 4-10 to find Q_i.

$Q_i = C_w L d^{1.5}$

$Q_i = (3.0)(8.2)(0.16)^{1.5}$

$= 1.6$ ft$_3$/s

Solution (2): Depressed

Step 1. Determine depth at curb, d_i

$d_i = d + a$

$d_i = Sx\ T + a$

$d_i = (0.02)(8.2) + 1/12$

$d_i = 0.25$ ft

$d_i = 0.25$ ft $< h = 0.43$ ft,

therefore weir flow controls

Step 2. Use Equation 4-1 or Fig. 4-9 to find Q_i.

$P = L + 1.8\ W$

$P = 8.2 + (1.8)(2.0)$

$P = 11.8$ ft

$Q_i = C_w (L + 1.8\ W) d^{1.5}$

$Q_i = (2.3)(11.8)(0.16)^{1.5}$

$Q_i = 1.7$ ft^3/s.

The depressed curb-opening inlet has 10% more capacity than an inlet without depression.

B. Grate Inlets (Type S-2).

~~An area inlet with a grate (Type S-2) in a sump functions as an orifice with a coefficient of discharge of 0.60. Therefore, the orifice equation becomes:~~

~~$Q = 4.82Ah^{0.5}$ (Eq. 4-2)~~

~~Where,~~

~~Q = Capacity, cfs~~
~~h = Depth of flow at inlet, feet~~
~~A = Area of grate opening, square feet~~

~~The curves shown in Figure 4-9 in Appendix E of this manual provide for direct solution of the above equation.~~

~~Area inlets with grates in sumps have a tendency to clog from debris which becomes trapped by the inlet. For this reason, the calculated inlet capacity of a grate inlet shall be reduced by 50 percent to allow for clogging. Since the clogging problems require maintenance, grate inlets in sumps are discouraged.~~

Grate Inlets in Sags

Grate inlets in sumps have a tendency to clog from debris which becomes trapped by the grate. Since the clogging problems require increased maintenance to keep the inlets free of debris and functioning as designed, the use of grate inlets is discouraged and will only be allowed with written approval from the Director of the Watershed Protection Department.

Source: Hydraulic Engineering Circular No. 22, Third Edition, FHWA, Sept. 2009

A grate inlet in a sag location operates as a weir to depths dependent on the size of the grate and as an orifice at greater depths. Grates of larger dimension will operate as weirs to greater depths than smaller grates.

$Q_i = C_w P d^{1.5}$ (Eq. 4-5)

where:

P = Perimeter of the grate in ft, disregarding the side against the curb

$C_w = 3.0$

d = Average depth across the grate; 0.5 (d1 + d2) (ft)

See Fig. 4-12 for a depiction of the average depth at a grate inlet.

The capacity of a grate inlet operating as an orifice is:

$Q_i = C_o A_g (2 g d)^{0.5}$ (Eq. 4-6)

where:

C_o = Orifice coefficient = 0.67

A_g = Clear opening area of the grate (ft^2)

g = 32.16 ft/s^2)

Use of Equation 4-6 requires the clear area of opening of the grate. Tests of three grates for the Federal Highway Administration showed that for flat bar grates, such as the P-50x100 and P-30 grates, the clear opening is equal to the total area of the grate less the area occupied by longitudinal and lateral bars. The curved vane grate performed about 10% better than a grate with a net opening equal to the total area less the area of the bars projected on a horizontal plane. That is, the projected area of the bars in a curved vane grate is 68% of the total area of the grate leaving a net opening of 32%; however, the grate performed as a grate with a net opening of 35%. Tilt-bar grates were not tested, but exploration of the above results would indicate a net opening area of 34% for the 30-degree tilt-bar and zero for the 45-degree tilt-bar grate. Obviously, the 45-degree tilt-bar grate would have greater than zero capacity.

Tilt-bar and curved vane grates are not recommended for sump locations where there is a chance that operation would be as an orifice. Opening ratios for the grates are given on Fig. 4-13.

Fig. 4-13 is a plot of Equations 4-5 and 4-6 for various grate sizes. The effects of grate size on the depth at which a grate operates as an orifice is apparent from the chart. Transition from weir to orifice flow results in interception capacity less than that computed by either the weir or the orifice equation. This capacity can be approximated by drawing in a curve between the lines representing the perimeter and net area of the grate to be used.

Example 4-2 illustrates use of Equations 4-5 and 4-6 and Fig. 4-13.

Example 4-2

Given: Under design storm conditions, a flow to the sag inlet is 6.71 ft^3/s. Also,

$S_x = S_w = 0.05$ ft/ft

n = 0.016

$T_{allowable} = 9.84$ ft

Find: Find the grate size required and depth at curb for the sag inlet assuming 50% clogging where the width of the grate, W, is 2.0 ft.

Solution:

Step 1. Determine the required grate perimeter.

Depth at curb, d2

d2 = T Sx = (9.84) (0.05)

d2 = 0.49 ft

Average depth over grate

d = d2 - (W/2) SW

d = 0.49 - (2.0/2)(.05)

d = 0.44 ft

From Equation 4-5 or Fig. 4-13

$P = Qi / [Cw\ d^{1.5}]$

$P = (6.71)/[(3.0)(0.44)^{1.5}]$

P = 7.66 ft

Some assumptions must be made regarding the nature of the clogging in order to compute the capacity of a partially clogged grate. If the area of a grate is 50% covered by debris so that the debris-covered portion does not contribute to interception, the effective perimeter will be reduced by a lesser amount than 50%. For example, if a 2 ft by 4 ft grate is clogged so that the effective width is 1 ft, then the perimeter, P = 0.3 + 1.2 + 0.3 = 6 ft, rather than 7.66 ft, (the total perimeter), or 4 ft, (half of the total perimeter). The area of the opening would be reduced by 50% and the perimeter by 25%.

Therefore, assuming 50% clogging along the length of the grate, a 4 ft by 4 ft, 2 ft by 6 ft, or a 3 ft by 5 ft grate would meet requirements of a 7.66 ft perimeter 50% clogged.

Assuming 50% clogging along the grate length,

$P_{effective} = 8.0 = (0.5)\ (2)\ W + L$

if W = 2 ft then L □6 ft

if W = 3 ft then L □5 ft

Step 1. Select a double 2 ft by 3 ft grate.

$P_{effective} = (0.5)\ (2)\ (2.0) + (6)$

$P_{effective} = 8$ ft

Step 2. Check depth of flow at curb using Equation 4-5 or Fig. 4-13.

$d = [Q/(Cw\ P)]^{0.67}$

$d = [6.71/((3.0\ (8.0)]^{0.67}$

d = 0.43 ft

Therefore, ok

Conclusion:

A double 2 ft by 3 ft grate 50% clogged is adequate to intercept the design storm flow at a spread which does not exceed design spread. However, as stated previously in 4.1.0.G, grate inlets are discouraged from use due to their tendency to clog. A curb-opening inlet should be used when feasible.

C. Combination Inlets (Type S-3).

The use of combination inlets is discouraged as stated in 4.1.0.G. When a combination inlet is considered to be the only feasible solution, the capacity of the combination inlet shall be determined using the procedures provided in Hydraulic Engineering Circular No. 22, Third Edition, FHWA, Sept. 2009. The calculated inlet capacities shall be reduced by 10% for the curb opening and 50% for the grate inlet.

~~The capacity of a combination inlet Type S-3 consisting of a grate and curb opening in a sump shall be considered to be the sum of the capacities obtained from Figures 4-8 and 4-9 in Appendix E of this manual. When the capacity of the gutter is not exceeded, the grate inlet accepts the major portion of the flow.~~

~~Combination inlets in sumps have a tendency to clog and collect debris at their entrances. For this reason, the calculated inlet capacities shall be reduced by their respective percentages indicated previously (which are 10% for a curb opening and 50% for grate inlets).~~

D. Recessed Inlets in Sumps (Type S-1(R), Type S-3(R)).

Recessed inlets shall be the curb-opening type whenever feasible. Combination inlets may be considered if there is no other feasible solution to provide the required inlet capacity. The clogging factors shall remain the same for recessed or non-recessed inlets.

~~Recessed inlets can be either curb-opening or combination types. The clogging factors shall remain the same for recessed or non-recessed inlets.~~

4.3.2 Inlets On Grade With Gutter Depression

A. Curb-Opening Inlets on Grade (Type G-1).

~~The capacity of a depressed curb inlet should be determined by use of Figures 4-10 and 4-11 in Appendix E of this manual. Because the inlet is on a slope and there is no grate to catch debris, the majority~~

~~of the debris will be carried downstream; therefore, no reduction for clogging is necessary.~~

Source: Hydraulic Engineering Circular No. 22, Third Edition, FHWA, Sept. 2009

Curb-opening inlets are effective in the drainage of highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently. Curb openings are less susceptible to clogging and offer little interference to traffic operation.

Curb opening heights vary in dimension; however, a typical maximum height is approximately 4 to 6 in. The length of the curb-opening inlet required for total interception of gutter flow on a pavement section with a uniform cross slope is expressed by Equation 4-7:

$L_T = K_u Q^{0.42} S_L^{0.3} [1 / (n Sx)]^{0.6}$ (Eq. 4-7)

where:

$K_u = 0.6$ in

L_T = Curb opening length required to intercept 100% of the gutter flow (ft)

S_L = Longitudinal slope

Q = Gutter flow (ft3/s)

The efficiency of curb-opening inlets shorter than the length required for total interception is expressed by Equation 4-8.

$E = 1 – [1 – (L / L_T)]^{1.8}$ (Eq. 4-8)

where:

L = Curb-opening length (ft)

Fig. 4-14 is a nomograph for the solution of Equation 4-7, and Fig. 4-15 provides a solution of Equation 4-8.

The length of inlet required for total interception by depressed curb-opening inlets or curb-openings in depressed gutter sections can be found by the use of an equivalent cross slope, Se, in Equation 4-7 in place of Sx. Se can be computed using Equation 4-9.

$S_e = S_x + S'_w E_o$ (Eq. 4-9)

where:

S'_w = Cross slope of the gutter measured from the cross slope of the pavement,

S_x (ft/ft)

$S'_w = a / [12 W]$, for W in ft or $= S_w - S_x$

a = Gutter depression (in)

E_o = Ratio of flow in the depressed section to total gutter flow determined by the gutter configuration upstream of the inlet.

Figure 4-16 shows the depressed curb inlet for Equation 4-9.

As seen from Fig. 4-14, the length of curb opening required for total interception can be significantly reduced by increasing the cross slope or the equivalent cross slope. The equivalent cross slope can be increased by use of a continuously depressed gutter section or a locally depressed gutter section.

Using the equivalent cross slope, Se, Equation 4-7 becomes:

$L_T = K_T Q^{0.42} S_L^{0.3} [1 / (n S_e)]^{0.6}$ (Eq. 4-10)

where:

$K_T = 0.6$

Equation 4-8 is applicable with either straight cross slopes or composite cross slopes.

Figs. 4-14 and 4-15 are applicable to depressed curb-opening inlets using Se rather than Sx.

Equation 4-9 uses the ratio, Eo, in the computation of the equivalent cross slope, Se.

Example 4-3

Given: A curb-opening inlet with the following characteristics:

$S_L = 0.01$ ft/ft

$S_x = 0.02$ ft/ft

Q = 1.77 ft3/s

n = 0.016

Find:

(1) Q_i for a 9.84 ft curb-opening.

(2) Q_i for a depressed 9.84 ft curb opening inlet with a continuously depressed curb section.

a = 1 in

W = 2 ft

Solution:

Step 1. Determine the length of curb opening required for total interception of gutter flow using Equation 4-7 or Fig. 4-14.

$L_T = K_u Q^{0.42} SL^{0.3} (1/(n Sx))^{0.6}$

$L_T = 0.6(1.77)^{0.42}(0.01)^{0.3}(1/[(0.016)(0.02)])^{0.6}$

$L_T = 23.94$ ft

Step 2. Compute the curb-opening efficiency using Equation 4-8 or Chart 4-15.

$L / L_T = 9.84 / 23.94 = 0.41$

$E = 1 - (1 - L / L_T)^{1.8}$

$E = 1 - (1 - 0.41)^{1.8}$

E = 0.61

Step 3. Compute the interception capacity.

$Q_i = E Q$

= (0.61)(1.77)

Q_i = 1.08 ft^3/s

Example 4-4

The following information is given:

S_L = 0.01 ft/ft

S_x = 0.02 ft/ft

T = 8.2 ft

Q = (2.26 ft^3/s

n = 0.016

W = 2.0 ft

a = 2.0 in

E_O = 0.70

Find: The minimum length of a locally depressed curb-opening inlet required to intercept 100% of the gutter flow.

Solution:

Step 1. Compute the composite cross slope for the gutter section using Equation 4-9.

$S_e = S_x + S'_w E_o$

S_e = 0.02 + (2/ 12 / 0.6) 0.60

S_e = 0.07

Step 2. Compute the length of curb opening inlet required from Equation 4-10.

$L_T = K_T Q^{0.42} S_L^{0.3} (1 / n S_e)^{0.6}$

$L_T = (0.60)(2.26)^{0.42}(0.01)^{0.3}[1/ (0.016) (0.07)]^{0.6}$

L_T = 12.5 ft

B. Grate Inlets on Grade (Type G-2).

The depression of the gutter at a grate inlet decreases the flow past the outside of the grate. The effect is the same as that caused by the depression of a curb inlet.

The bar configuration of grate inlets greatly affects the hydraulic efficiency of the inlet. To determine the hydraulic capacity of a grate inlet on grade, consult with the grate manufacturer regarding the grate design, clear openings, laboratory test results for capacity, recommended coefficients, etc.

~~The bar arrangements for grate inlets greatly affect the efficiency of the inlet. In order to determine the capacity of a grate inlet on grade the appropriate vendor catalog should be checked (see Reference 4-3).~~

Grate inlets have a tendency to trap debris such as leaves and paper which results in increased ponding in the street. A reduction factor of 35% to allow for clogging shall be applied. Since clogging problems require additional maintenance to keep the inlets free of debris and functioning as designed, the use of grate

inlets is discouraged and will only be allowed with written approval from the Director of the Watershed Protection Department.

~~Grate inlets have a tendency to trap debris such as leaves and paper being carried by the gutter flows. This causes traffic problems from ponding water and requires maintenance. A reduction factor of 35 percent to allow for clogging should be applied.~~

C. Combination Inlets on Grade (Type G-3).

Combination inlets (curb-opening plus grate) have greater hydraulic capacity than curb-opening inlets or grate inlets of the same length. Generally speaking, combination inlets are the most efficient of the three (3) types of inlets on grade presented in this manual. The basic difference between a combination inlet and a grate inlet is that the curb opening receives the carry-over flow that passes between the curb and the grate. The reduction factor for clogging of this type of inlet shall be 0% for the curb opening and 35% for the grate inlet. Since clogging problems require additional maintenance to keep the inlets free of debris and functioning as designed, the use of combination inlets on grade is discouraged and will only be allowed with written approval from the Director of the Watershed Protection Department.

D. Recessed Inlets on Grade (Type G-1R, G-3R).

Capacities for recessed inlets on grade shall be calculated as 0.75 times the capacity for non-recessed inlets. The clogging factors shall remain the same for the various types of inlets.

~~4.3.3 Example 4-1~~

~~Given: Parabolic crown street width = 30 feet~~
~~Cross Slope = 0 ft/ft~~
~~Street Grade = 5.0 percent~~
~~Q_a in one gutter = 12 cfs~~

~~Find: Capacity of a ten (10) foot curb inlet on grade (Type G-1) with a five (5) inch gutter depression.~~

~~Step 1. From Equation 3-3 (Section 3) depth of flow in gutter is y_e = 0.43 feet, of 5.1inches.~~

~~Step 2. Enter Fig. 4-10 with y_e = 0.43 feet and a = 5 inches and find corresponding Q_a/L_a = 0.90~~

~~Step 3. Compute L_a = 12/0.90 = 13.33.~~

~~Step 4. Compute L/L_a = 10/13.33 = 0.75.~~

~~Step 5. Enter Figure 4-11 (in Appendix E of this manual) with L/L_a 0.75 and a/y = 0.98 and find corresponding Q/Q_a = 0.84.~~

~~Step 6. Determine Q from Q/Q_a.~~
~~Q = 0.84 (12) = 10.1 cfs~~

~~Step 7. Determine Q_{pass}.~~
~~Q_{pass} = 12 - 10.1 = 1.9 cfs~~

~~Step 8. The by-pass flow is 1.90 cubic feet per second.~~

4.4.0 INLET SYSTEM LAYOUT

The following is a general step-by-step procedure for designing the layout of an inlet system using information provided in Sections 3 and 4. The procedure is not a precise requirement for design, and is provided solely as a guideline for the designer.

~~The following is intended to provide a general step by step procedure for the layout of an inlet system~~

~~utilizing the information that has been provided in Chapters 3 and 4. This information is in no way a requirement for design and is provided solely for the benefit of the engineer or designer.~~

4.4.1 Preliminary Design Considerations

A. Prepare a drainage map of the entire contributing drainage area to be served by the proposed improvements. Recent topographic maps obtained through the use of aerial photogrammetry having contours every one or two feet are usually sufficient when supplemented by field verification of the drainage patterns.

~~A. Prepare a drainage map of the entire area to be drained by proposed improvements. Contour maps serve as excellent drainage area maps when supplemented by field observation.~~

B. Identify on a plan the location of inlets that are needed regardless of any contributing drainage area. These would be inlets at (1) low points, (2) immediately upstream of median breaks, entrance/exit ramps, cross walks and street intersections, i.e., at any location where water could flow onto the travelway, (3) immediately upgrade of bridges to prevent drainage from flowing onto the bridge decks, (4) immediately downgrade of bridges to intercept bridge deck drainage, (5) immediately upgrade of pedestrian cross walks, (6) at the ends of channels in cut sections, (7) on side streets immediately upgrade of intersections, (8) behind curbs, shoulders or sidewalks to drain low areas.

~~B. Outline the drainage area for each inlet in accordance with present and future street development. Show all existing underground utilities.~~

C. Select as a first trial the assumed locations for additional inlets needed to intercept runoff to meet drainage criteria requirements. The location of the additional inlets will be refined in subsection 4.4.2.

~~C. Make a tentative layout of the proposed storm drainage system, locating all inlets, manholes, mains, laterals, ditches, culverts, etc.~~

D. Select the design rainfall frequency using design criteria in the City's Drainage Criteria Manual.

~~D. Establish the design rainfall frequency.~~

E. Calculate the time of concentration at each design point.

~~E. Establish the minimum inlet time of concentration~~.

F. Identify the cross-section applicable to each street within the proposed project limits.

~~F. Establish the typical cross section of each street.~~

G. Identify the permissible spread of water on each street within the project limits.

~~G. Establish the permissible spread of water on all streets within the drainage area.~~

H. For each subarea, show on the drainage map the subarea identification number, the limits of the subarea, the size of the subarea in acres, the travel path used to calculate the time of concentration, the time of concentration, and the runoff coefficient or runoff curve number.

~~H. Indicate each drainage area, the size of area, the direction of surface runoff by small arrows and the coefficient of runoff for the area.~~

4.4.2 Inlet System Design

Determining the size and location of inlets is largely a trial and error procedure. Based on criteria outlined in sections 2, 3 and 4 of this manual, the following steps will serve as a guide to the procedure to be used.

Step 1: Delineate the boundaries of the contributing subarea for the assumed location of the inlet at the

upstream end of the project and calculate the peak rate of runoff.

~~**Step 1.** Beginning at the upstream end of the project drainage basin, outline a trial subarea and calculate the runoff from it.~~

Step 2: Compare the calculated peak rate of runoff to the allowable rate of flow in the street, taking into consideration allowable spread in the street and required clear widths. If the calculated peak rate of runoff is greater than the rate of flow that cannot be exceeded to meet spread and clear width requirements, adjust the inlet location so that the contributing subarea is smaller. If the calculated peak rate of runoff is less than the rate of runoff in the street that cannot be exceeded, adjust the inlet location so that the contributing subarea is larger. Repeat this procedure until the calculated peak rate of runoff is close to, but does not exceed, the flow rate needed to achieve spread and clear width requirements. This is the first point at which a portion of the flow must be removed from the street. The amount of flow to be removed will depend on the clear width requirements (DCM 3.2.0), street cross flow limitations (DCM 3.1.3), and restrictions on the amount of flow allowed through intersections (DCM 3.1.4).

~~**Step 2.** Compare the calculated runoff to allowable street capacity. If the calculated runoff is greater than the allowable street capacity, reduce the size of the trial subarea. If the calculated runoff is less than street capacity, increase the size of the trial subarea. Repeat this procedure until the calculated runoff equals the allowable street capacity. This is the first point at which a portion of the flow must be removed from the street. The percentage of flow to be removed will depend on street capacities versus runoff entering the street downstream.~~

Step 3: Record the drainage area, time of concentration, runoff coefficient or runoff curve number and calculated peak rate of runoff for the subarea. This information shall be recorded on the drainage map or in tabular format.

~~**Step 3**. Record the drainage area, time of concentration, runoff coefficient and calculated runoff for the subarea. This information shall be recorded on the plans or in tabular form similar to that shown in Table 4-1 which is convenient for review.~~

Step 4: If an inlet is proposed to remove flow from the street, determine and record the inlet size, amount of intercepted flow and the amount of bypass flow.

~~**Step 4.** If an inlet is to be used to remove water from the street, determine and record the inlet size, amount of intercepted flow and amount of flow carried over (bypassing the inlet).~~

Step 5: Continue the procedure above, working toward the system low point, until a complete system of inlets has been established. Remember to account for carry over (bypass) flow from one inlet to the next.

~~**Step 5.** Continue the above procedure for other subareas until a complete system of inlets has been established. Remember to account for carry-over from one inlet to the next.~~

Step 6: Record the information in steps 3 and 4 for all inlets.

~~**Step 6.** After a complete system of inlets has been established, modification should be made to accommodate special situations such as point sources of large quantities of runoff, and variation of street alignments and grades.~~

Step 7: After the inlets have been located and sized, the storm drain pipes can be designed (See Section 5).

~~**Step 7.** Record information as in Steps 3 and 4 for all inlets.~~

~~**Step 8.** After the inlets have been located and sized the inlet pipes can be designed (see Section 5).~~

4.4.3 Inlet Flow Calculation Table

A suggested procedure for inlet flow design is provided below. A table of 18 columns can be used to record the value for each step in the procedure.

~~An example of a calculation table for inlet flow design is shown in Table 4-1.~~

~~The following is an explanation of each column in Table 4-1~~:

Column 1. Inlet number. All inlets are classified with a designated number.

Column 2: Drainage area number. List the identification number of all subareas draining to the inlet identified in Column 1.

~~**Column 2.** Drainage area number. List all numbers of the drainage areas which drain stormwater into inlet number in Column 1.~~

Column 3.The corresponding discharge from the drainage areas in Column 2.

Column 4: The carry-over flow (Q_{pass}) in this column is the rate of flow (cfs) which bypassed the inlet immediately upstream of the inlet under consideration.

~~**Column 4.** The carry-over flow (Q_{pass}) in this column is the quantity of water which has passed by the last preceding inlet to the inlet under consideration.~~

Column 5. The total run-off, Q_a, is the run-off from Column 3 plus the carry-over from preceding drainage areas.

Column 6. The slope, S, expressed in percentage, is obtained from established grade lines as shown on the plan-profile sheets, or from specified data.

Column 7. Gutter depression.

Column 8. The water depth, y_o, in the gutter is expressed in feet. "y_o" can be determined from Equation 3-1 or Figure 3-1 (in Appendix ~~E~~ D of this manual) for the straight crown streets and determined from Equations 3-3, 3-4 or 3-5 for the parabolic crown streets.

Column 9. The value of the ponded width is the product of the water depth (in Column 7) and the reciprocal of the cross slope (z) in the Equation 3-2. The ponding width must be kept within the maximum permissible ponded limit of the streets.

Column 10. The reduction factor for each inlet as specified in Section 4.3.0.

Column 11. Q_a/L_a is read from Figure 4-10 in Appendix ~~E~~ D of this manual by the gutter depression and gutter flow depth.

Column 12. L_a is calculated from Qa divided by the value in Column 11. L_a represents the length of an inlet for 100 percent interception.

Column 13. Length of the inlet L.

Column 14.The ratio of L/L_a.

Column 15. The ratio of gutter depression (in feet) to water depth in the gutter (in feet).

Column 16. The ratio of Q/Q_a. The value is read from Figure 4-11 in Appendix ~~E~~ D of this manual.

Column 17. Q is the flow intercepted by the inlet of length L.

Column 18. The carry-over flow (Q_{pass}) is the result of Q_a-Q.

~~**Column 19.** This column is used to specify the inlet information.~~

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