# CHAPTER 4 ENCLOSED SYSTEMS

Enclosed conveyance systems consisting of inlets, conduits and manholes may be used to convey storm water runoff where site conditions will not permit the stable and non-erosive use of natural or engineered channels. Where used, such systems must be designed in accordance with design criteria and performance standards given below.

## 4.1 General Guidance

**4.1.1** Where storm drainage along the side lot lines of residential property is to be in conduit, the conduit shall extend to a point at least forty (40) feet to the rear of the front building line or ten (10) feet beyond the rear line of the structure, whichever is greater.

**4.1.2** Where culverts are placed under roadways, they shall extend to at least the limits of the right-of-way or the toe of the roadway embankment, whichever is greater, except that culverts shall not outlet on hillsides.

**4.1.3** Pipe drains or culverts constructed to intercept the flow of ditches or channels, which may be enclosed in a conduit at a future time, shall be installed at adequate depth to permit their extension at the same required depth.

**4.1.4** Curb inlets shall be installed at or near intersections where they are deemed necessary for the safety of pedestrian and vehicular traffic. Curb inlets shall be placed to intercept the storm water before it reaches the crosswalks. No curb inlet shall be located within a crosswalk or within curb radius at the intersection.

**4.1.5** Concentrated discharges should not discharge directly onto or across public sidewalks or to the street gutter. Likewise, sheet flow of large turf areas (greater than 9000 square feet) or paved areas (greater than 3000 square feet) or a proportional combination thereof, should not discharge across public sidewalks or into the street.

**4.1.6** All plans for drainage systems shall indicate the overflow path for the portion of the 100 year (1% annual chance) storm that the system cannot accommodate.

**4.1.7** Stormwater collection systems on private property and not in a public drainage easement (such as for internal parking lots/driveways) shall be designed to the 10 year (10% annual chance) storm for property in a residential zoning district and the 25 year (4% annual chance) storm for property in all other zoning districts.

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## 4.2 Existing Drainage Systems

Existing on-site drainage system pipes, structures, and appurtenances within the project limits may be retained as elements of an improved system providing:

- They are in sound structural condition.
- Their hydraulic capacity, including surcharge, is equal to or greater than the capacity required by these criteria.
- Easements exist or are dedicated to allow operation and maintenance.

Discharge from an existing upstream storm drainage system shall be computed assuming its capacity is adequate to meet the performance criteria given below. The computed discharge shall be used to design the new downstream system even if the actual capacity of the existing upstream system is less.

## 4.3 Inlet Design

### 4.3.1 Type

Only curb opening inlets shall be used on public streets for design flows. Other inlets or combinations of inlets must be approved by the Director.

### 4.3.2 Design Method

Inlets shall be designed using Figures 4.1 and 4.2 at the end of this chapter or calculations within appropriate engineering software. Note that the Theoretical Captured Discharge (left side of chart) is the design capacity. A 20% reduction for clogging factor shall be used for all inlets. Deflectors may be used when the street grade is greater than or equal to 4%.

### 4.3.3 Location/Spread of flow in streets

Inlets shall be located to provide clear driving lanes for various street classifications as specified below.

### 4.3.4 Spread in streets

| Road Classification | | Design Storm Frequency | Design Spread |
|---|---|---|---|
| High Volume | > 4000 ADT | 10 year | Gutter + 3 feet |
| | sag point | 25 year | Gutter + 3 feet |
| Collector | <4000 and > 1500 ADT | 10 year | Gutter + 1/2 driving lane |
| | sag point | 25 year | Gutter + 1/2 driving lane |
| Local Streets | < 1500 ADT | 10 year | Gutter + 1/2 driving lane |
| | sag point | 10 year | Gutter + 1/2 driving lane |

Table is modified from Table 8-1 Municipal Storm Water Management by Debo and Reese

**A.** In addition to the inlet spacing requirements for limiting width of flow, inlets shall be located to limit gutter flow from crossing the street centerline at the time of peak discharge for the design storm to the following limits:

| CONDITION CAUSING FLOW TO CROSS STREET CENTERLINE | MAXIMUM DISCHARGE, (CFS) |
|---|---|
| Transitions to super elevation | 1.0 |
| Sump at midblock | Not Allowed |
| Overflow of non-gutter flow | See 4.5 |

Note: For new development, any inlets at intersections shall be positioned outside the curb return and sidewalk ramps.

### 4.3.6 Freeboard Requirements

Any opening through which surface water is intended to enter (or may backflow from) the system shall be at or above the hydraulic grade line in the inlet during the design storm, specified in Table 4.1 on page 5 of this chapter, where such calculation must include junction (so-called “minor”) losses.

## 4.4 Gutter Flow

### 4.4.1 Gutter Capacity

Gutter capacity may be determined from Izzard's Formula below (see Figure 4.3 at the end of this chapter for graphical solution):

$$Q = \frac{0.56z \cdot S_O{}^{1/2} \cdot D^{8/3}}{n} \quad \text{where:}$$

$Q$ = The gutter capacity in cubic feet per second

$z$ = The reciprocal of the average cross-slope, including gutter section, in feet per foot

$S_O$= The longitudinal street grade in feet per foot

$D$ = The depth of flow at curb face in feet

$n$ =Manning's "n", see Table 3.9 at the end of Chapter 3

**A. Street Grade on Vertical Curves, *$S_O$***

The following formula shall be used to determine the street grade at any point on a vertical curve using plus for grades ascending forward and minus for grades descending forward, in feet per foot.

$$S_O = S_1 + \frac{x \cdot (S_2 - S_1)}{L} \quad \text{where:}$$

$S_O$ = The street grade on a vertical curve at point x, in feet per foot

$S_1$ = The street grade at the PC of a vertical curve, in feet per foot

$S_2$ = The street grade at the PT of a vertical curve, in feet per foot

$x$ = The distance measured from the PC to point x on a vertical curve, in feet

$L$ = The total length of a vertical curve, in feet

## 4.5 Protection for Streets

### 4.5.1 Street Crossings

Concentrated flow not conveyed in the gutter system, shall be conveyed under streets to prevent vehicles from being swept from the roadway in infrequent storms. These crossings ( bridges, culverts or underground systems) must be designed to completely convey flood flows without street overtopping in accordance with the following table:

**TABLE 4.1**
**DESIGN STORM CAPACITY FOR STREETS**

| **Street Classification** | **Min. Design Storm Capacity** | **Design Storm Return Interval** |
|---|---|---|
| Arterial | 2% | 50 year |
| Collector/Commercial | 4% | 25 year |
| Local | 10% | 10 year |

### 4.5.2 Roadway Overtopping

Overflow depths at low points in roadways during the 100 year (1% annual chance) storm will be limited to 7 inches measured at the high point in the roadway cross section; except that it also shall not exceed 14 inches at the deepest point in the roadway cross section. Depths may be limited where necessary by lengthening the vertical curve of the roadway, by reducing roadway crown, or by other similar means. Roadway overtopping depths shall be determined by integrating the broad crested wier formula across the roadway profile. Each incremental flow can be determined by using the formula:

$$q = Clh^{3/2}$$

where:
$q$ = the flow for an increment of profile length (width of flow)
$l$ = the incremental width
$C$ = a flow coefficient that shall not exceed 3.0
$H$= the average depth of flow at each increment

The total flow $Q$ is the sum of the incremental flows. Depth determinations can be made through an iterative process where successive depths are chosen, Q is calculated for each depth and then compared to the known Q at the overtopping point.

Overflow protection criteria provides additional accessibility criteria at major stream crossings for emergency personnel, and provides the public with protection against injury and property damage.

## 4.6 Enclosed Pipe Systems

### 4.6.1 General Requirements and Guidance

**A.** The crown(s) of pipe(s) entering a drainage structure should be at or above the crown of the pipe exiting from the structure and must provide a minimum fall of the invert in the structure of 0.1 feet.

**B.** The maximum spacing between manholes shall be 400 feet for 30 inch diameter or less; 600 feet for pipes more than 30 inch diameter.

**C.** Instead of a manhole junction, prefabricated wye and tee connections may be utilized provided at least one of the pipes is greater than 30 inches in diameter.

**D.** Select pipe size and slope so that the velocity of flow will not appreciably decrease, at inlets, bends or other changes in geometry or configuration.

**E.** Pipes shall be installed in a straight line and grade.

**F.** Do not discharge the contents of a larger pipe into a smaller one, even though the capacity of the smaller pipe may be greater due to steeper slope.

**G.** Conduits are to be checked at the time of their design with reference to critical slope. If the slope on the line is greater than critical slope, the unit will likely be operating under entrance control instead of the originally assumed normal flow. Conduit slope should be kept below critical slope if at all possible. This also removes the possibility of a hydraulic jump within the line.

**H.** Pipes should be parallel or perpendicular with the centerline of streets unless otherwise unavoidable.

### 4.6.2 Capacity

Capacity shall be determined in accordance with Chapter 3. Minimum design pipe size shall be 18-inch in diameter for pipe under street pavement. For partially full pipe flow, Figure 4.4 can be used to obtain hydraulic parameters of the flow.

### 4.6.3 Pressure Flow

After considering the discussion presented at the beginning of Chapter 3, an enclosed system may be designed to operate with pressure flow, for the design storms specified in Table 4.1 (page 5 of this chapter) if all the following conditions are met:

**A.** The Hydraulic Grade Line (HGL) must be at or below any openings to the ground or street at all locations.

**B.** Appropriate energy losses for bends, transitions, manholes, inlets, and outlets, are used in computing the HGL. This is addressed in the hydraulics section.

**C.** Energy methods (Bernoulli's equation) must be used for the computations.

### 4.6.4 Outfalls and Energy Dissipation

**A.** The outfall of all enclosed systems shall include energy dissipation sufficient to transition outlet flows to velocities and applied shear stresses consistent with the normal flow conditions in the receiving channel for the range of flows up to and including the 100 year (1% annual chance) storm. Calculations, at a minimum, shall include the 1 year (100% annual chance), the 10 year (10% annual chance) and the 100 year (1% annual chance) storms.

**B.** Figure 4.5 provides guidance for riprap aprons for various size pipes and limitations on the use of aprons.

**C.** Outfalls shall not be permitted on slopes of greater than 5%. Flow shall be piped or run in an engineered channel to a point as outlined in Section 5.1.5.

**D.** Energy dissipation for lateral outflows to natural streams and edge of buffer outfalls to riparian buffers shall follow the guidance in Section 5.1.5.

**E.** Effective energy dissipating structures shall be provided to meet the requirements stated in Table 5.1 (end of Chapter 5) when conditions are beyond the limitations of rock aprons. Examples of energy dissipating structures are:

- Hydraulic Jump Basins
- Impact Baffle Basins
- Plunge Pool and Plunge Basin

- Slotted-Grating or Slotted Bucket Dissipators
- Stilling Basins
- Internal Pipe Rings

1. The suitability of each method is site dependent. The FHWA computer program HY8 Energy (downloadable free from the FHWA hydraulics website) lists methods and applicability. Energy dissipaters shall be designed according to the criteria and procedures defined in professionally acceptable references. Several such references include:

   - United States. Department of the Interior. Bureau of Reclamation. Design of Small Dams. 1987 ed. Denver: GPO, 1987.

   - United States. Department of the Interior. Bureau of Reclamation. A Water Resource Technical Publication. Engineering Monograph No. 25. Hydraulic Design of Stilling Basins and Energy Dissipaters. 1978 ed. GPO, 1978.

   - Federal Highway Administration (FHWA), 1983. Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular (HEC) No. 14, along with HY8Energy design software

   - US Army Corps of Engineers, 1994. Hydraulic Design of Flood Control Channels, US Army Corps of Engineers Engineer Manual EM 1110-2-1601.

   - Bridge Scour and Stream Instability Countermeasures Experience, Selection, and Design Guidance (Latest Edition), National Highway Institute,HEC No. 23.

   - River Engineering for Highway Encroachments, Highways in the River Environment, U.S. Department of Transportation, Federal Highway Administration, Publication No. FHWA NHI 01-004, December 2001.

2. Grade control shall be provided downstream of the dissipator or shall be constructed integrally with it. In addition, the developing agencies' recommendations for armoured transition to natural channel shall be included as part of the design.

### 4.6.5 Minimum Pipe Slope

Unless approved by the director of public works, the minimum allowable pipe slope for any pipe is 0.4 %.

### 4.6.6 Velocity Within the System

The velocity within the system shall be between 2 and 15 feet per second for the design flow.

## 4.7 Overflow Provisions

Each conveyance element of the stormwater drainage system (whether open, enclosed, or detention) shall include an overflow element if the in-system capacity is less than the 100 year (1% annual chance) storm flows. Overflow systems shall:

**4.7.1** Be designed to route downstream any amount of the 100 year (1% annual chance) storm exceeding the in-system design capacity specified in Table 4.1 (page 5 of this chapter), while providing 1 foot of freeboard to low exterior sill or low opening of adjacent structures.

**4.7.2** Include streets, engineered channels, redundant piping, spillways, parking lots, drives or combinations thereof.

**4.7.3** Limit the maximum water surface elevation generated by the 100 year (1% annual chance) storm as specified in Section 4.5.2.

**4.7.4** Conform to local standards regarding dedicated easements and/or restricted uses for overflow systems; consult with the City for requirements.

**4.7.5** Be limited to the natural drainage basins. Transfer of overflow out of a natural drainage basin (e.g. a thoroughfare straight-graded through a drainage basin with a sump in another drainage basin) may sometimes be allowed at the discretion of the Director. These overflows must be added to the overflows in the receiving drainage basin and the combined overflow must still meet the criteria within this chapter.

## 4.8 Easements

Easements are required per the Stormwater Management Ordinance. The minimum easement width is 15 feet or the sum of the conduit diameter and twice the cover depth, whichever is greater. However, the easement width shall increase if necessary to encompass the overflow spread from the 100 year (1% annual chance) rainfall event. Easements should be centered on the pipe or overflow path.

### 4.8.1 Permanent

The Director may require wider easements when other utilities are located within the same easement and/or when the depth of cover is substantial or the conduit is very large.

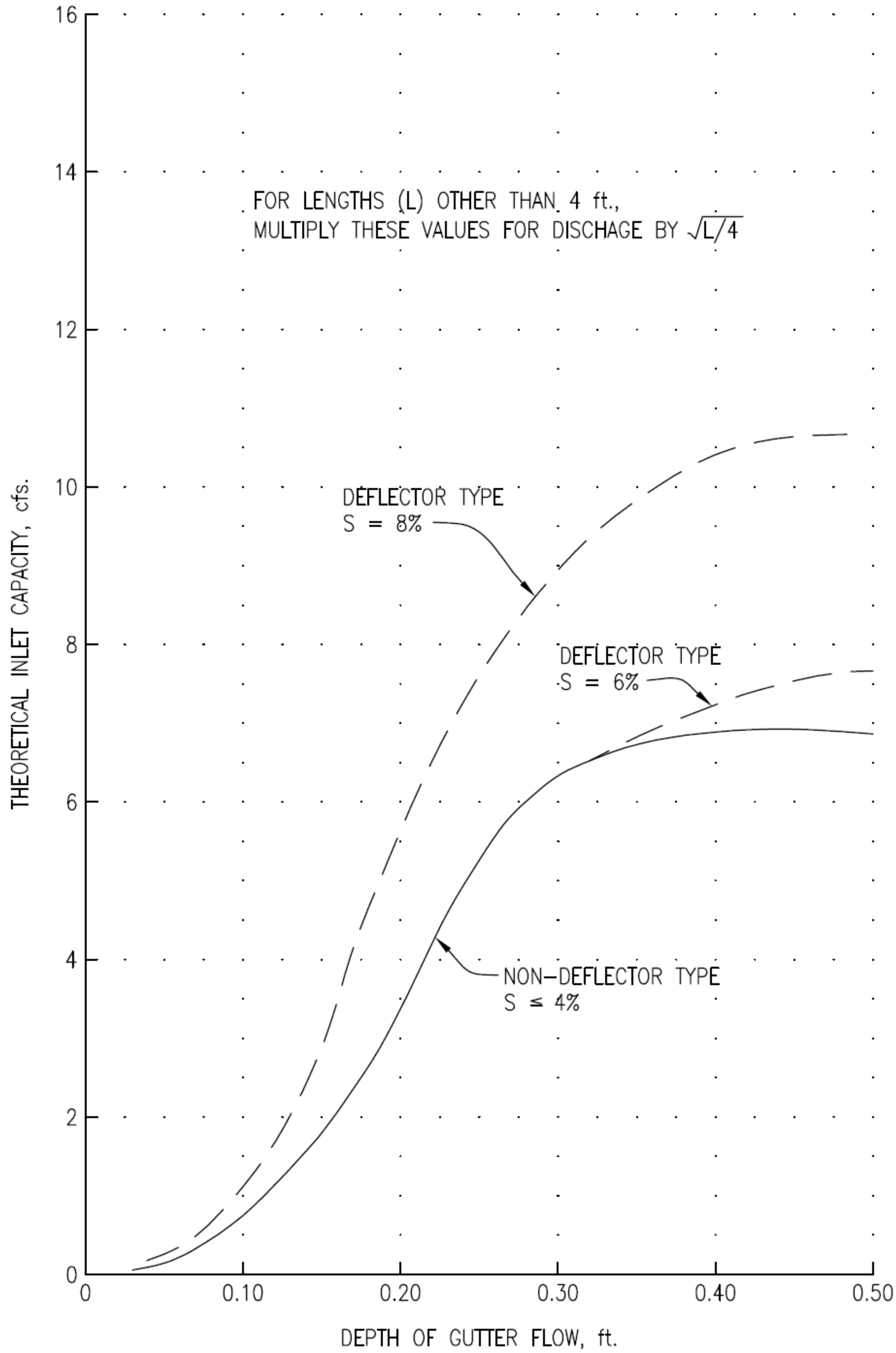
### 4.8.2 Temporary

Temporary construction easements of sufficient width to provide access for construction shall be acquired when the proposed work is located in areas developed prior to construction.

# Figure 4.1

## THEORETICAL INLET CAPACITY

### 4'-0" LONG DEPRESSED CURB OPENING INLET



# Figure 4.2
# Inlet Capacity
# (3 Pages)

## Curb Inlets In Sump

For the design of a curb-opening inlet in a sump location, 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 capacity of curb-opening inlets in a sump location can be determined from Figure 8-9 which accounts for the operation of the inlet as a weir and as an orifice at depths greater than 1.4h. This figure is applicable to depressed curb-opening inlets and the depth at the inlet includes any gutter depression. The height (h) in the Figure assumes a vertical orifice opening (see sketch on Figure 8-9). The weir portion of Figure 8-9 is valid for a depressed curb-opening inlet when $d \leq (h + a/12)$.

The capacity of curb-opening inlets in a sump location with a vertical orifice opening but without any depression can be determined from Figure 8-10. The capacity of curb-opening inlets in a sump location with other than vertical orifice openings can be determined by using Figure 8-11.

Steps for using Figures 8-9, 8-10, and 8-11 in the design of curb-opening inlets in sump locations are given below.

(1) Determine the following input parameters:
Cross slope = $S_x$ (ft/ft)
Spread of water on pavement = T (ft) from Figure 8-1
Gutter flow rate = Q (cfs) or dimensions of curb-opening inlet [L (ft) and H (in.)]
Dimensions of depression if any [a (in.) and W (ft)]

(2) To determine discharge given the other input parameters, select the appropriate Figure (8-9, 8-10, or 8-11 depending whether the inlet is in a depression and if the orifice opening is vertical).

(3) To determine the discharge (Q), given the water depth (d), locate the water depth value on the y-axis and draw a horizontal line to the appropriate perimeter (p), height (h), length (L), or width times length (hL) line. At this intersection draw a vertical line down to the x-axis and read the discharge value.

(4) To determine the water depth given the discharge, use the procedure described in step 3 except you enter the figure at the value for the discharge on the x-axis.

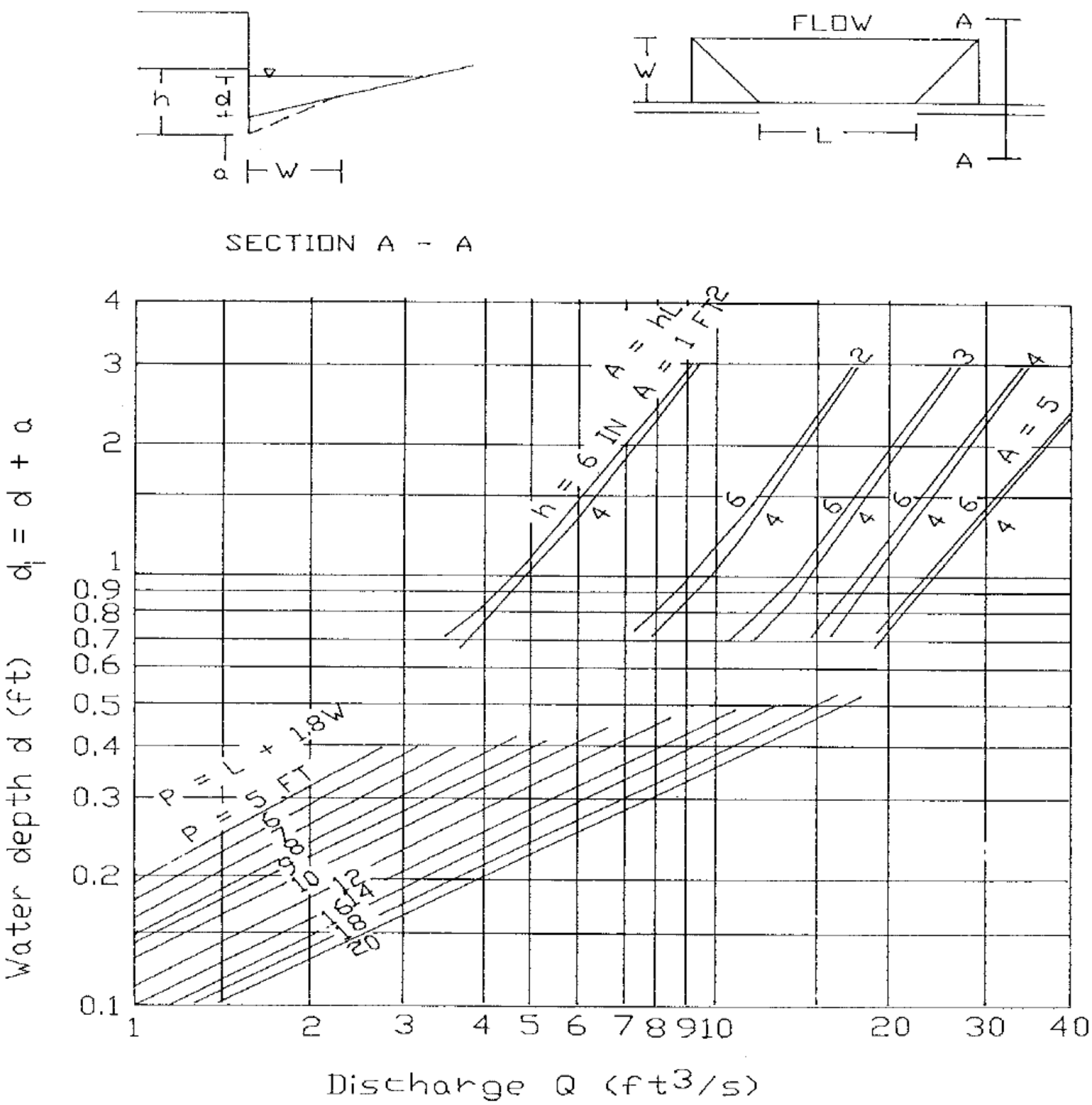



**Figure 8-9 Depressed Curb-Opening Inlet Capacity In Sump Locations**

**Source: AASHTO Model Drainage Manual, 1991**

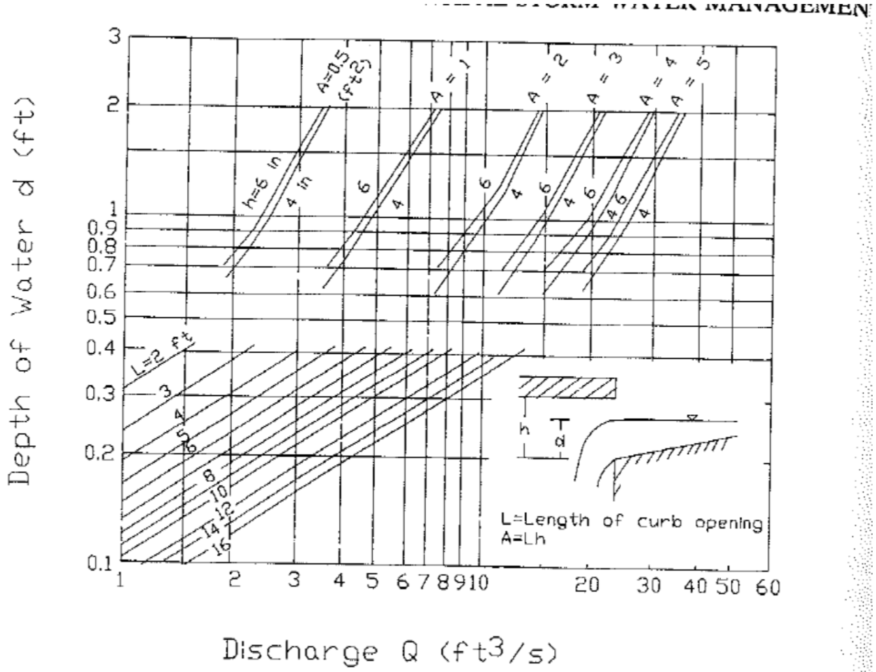



**Figure 8-10 Curb-Opening Inlet Capacity In Sump Locations**
Source: AASHTO Model Drainage Manual, 1991

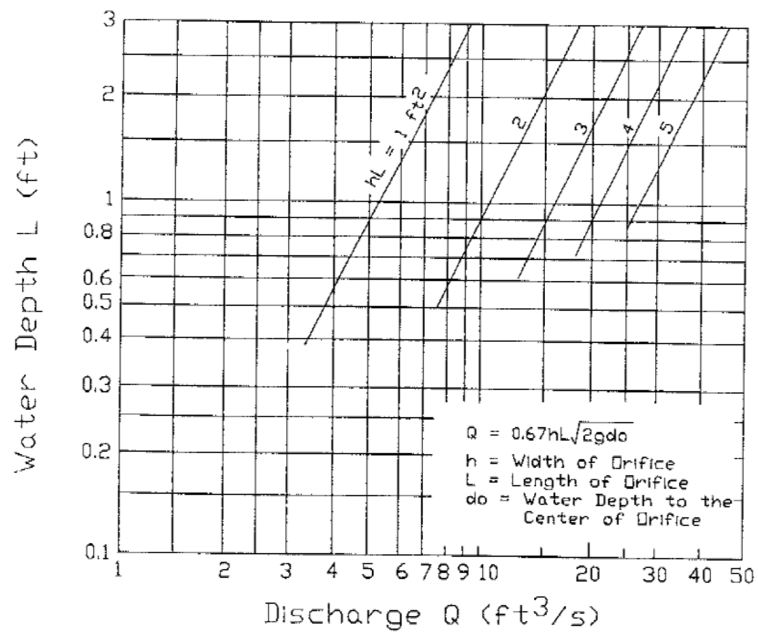
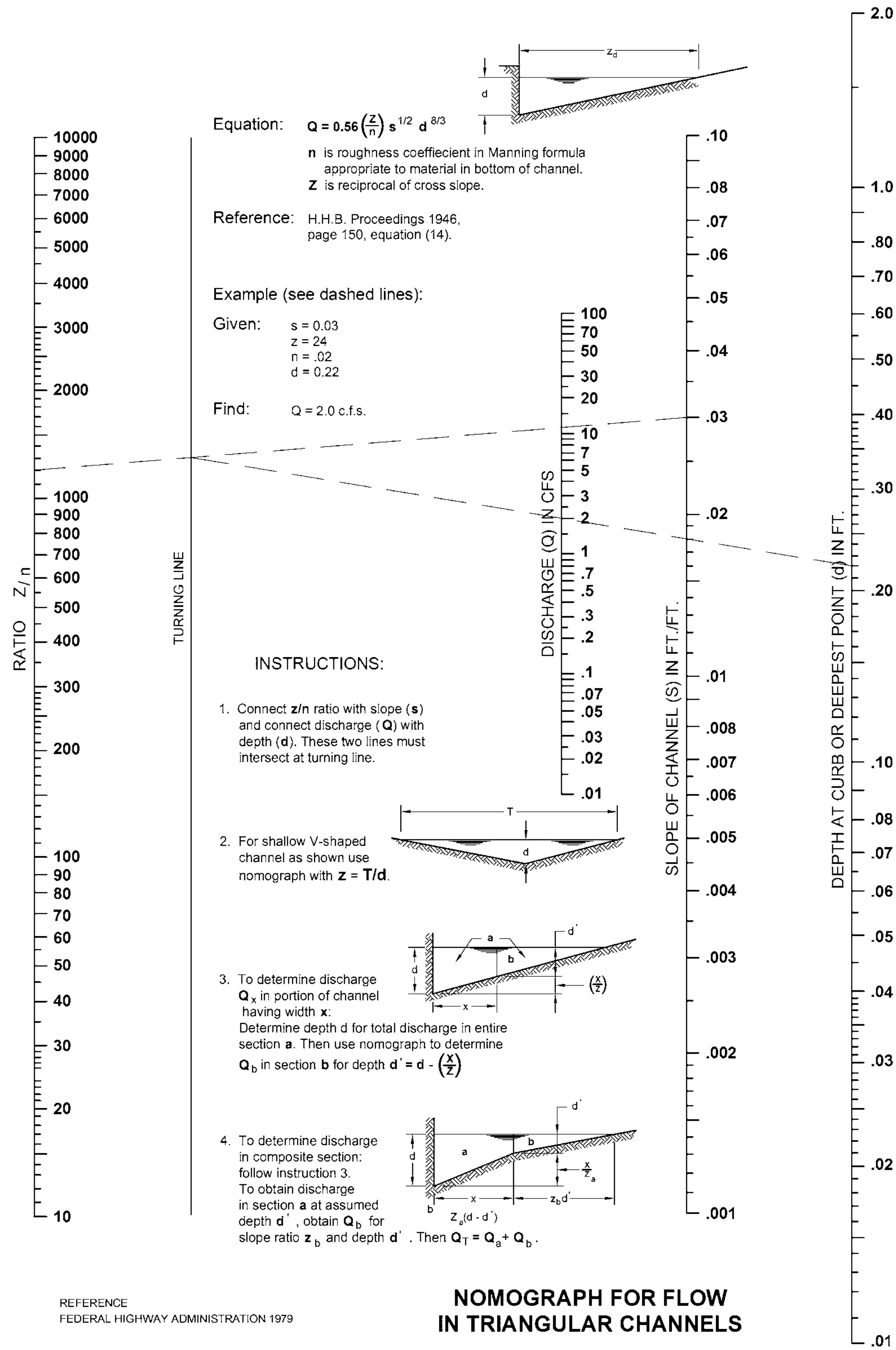



**Figure 8-11 Curb-Opening Inlet Orifice Capacity - Inclined And Vertical Orifice Throats**
Source: AASHTO Model Drainage Manual, 1991

# Figure 4.3


Equation: $Q = 0.56\left(\frac{z}{n}\right) s^{1/2} d^{8/3}$
n is roughness coeffiecient in Manning formula appropriate to material in bottom of channel.
Z is reciprocal of cross slope.
Reference: H.H.B. Proceedings 1946, page 150, equation (14).
Example (see dashed lines):
Given: s = 0.03
z = 24
n = .02
d = 0.22
Find: Q = 2.0 c.f.s.
RATIO Z/n
TURNING LINE
DISCHARGE (Q) IN CFS
SLOPE OF CHANNEL (S) IN FT./FT.
DEPTH AT CURB OR DEEPEST POINT (d) IN FT.
INSTRUCTIONS:
1. Connect z/n ratio with slope (s) and connect discharge (Q) with depth (d). These two lines must intersect at turning line.
2. For shallow V-shaped channel as shown use nomograph with z = T/d.
3. To determine discharge $Q_x$ in portion of channel having width x: Determine depth d for total discharge in entire section a. Then use nomograph to determine $Q_b$ in section b for depth $d' = d - \left(\frac{x}{z}\right)$
4. To determine discharge in composite section: follow instruction 3. To obtain discharge in section a at assumed depth d', obtain $Q_b$ for slope ratio $z_b$ and depth d'. Then $Q_T = Q_a + Q_b$.
REFERENCE
FEDERAL HIGHWAY ADMINISTRATION 1979
NOMOGRAPH FOR FLOW
IN TRIANGULAR CHANNELS

# Figure 4.4
## RIP RAP APRON

| Pipe Size (in) | Maximum Pipe Slope (%) | Length L (ft) | Bottom Width BW Minimum (ft) | Top Width TW Minimum (ft) | Thickness T Minimum (ft) |
|---|---|---|---|---|---|
| 12 | 3.50 | 12 | 4 | 8 | 2 |
| 15 | 2.60 | 15 | 4 | 9 | 2 |
| 18 | 2.00 | 16 | 4 | 10 | 2 |
| 24 | 1.70 | 20 | 4 | 12 | 2 |
| 30 | 1.40 | 24 | 6 | 16 | 2 |
| 36 | 1.00 | 28 | 6 | 18 | 2 |
| 42 | 0.80 | 32 | 6 | 20 | 3 |
| 48 | 0.65 | 36 | 6 | 22 | 3 |
| 54 | 0.55 | 40 | 8 | 26 | 3 |
| 60 | 0.45 | 44 | 8 | 28 | 3 |
| 72 | 0.40 | 48 | 8 | 32 | 3 |

Rip rap to be MoDOT Type I: 50% of particles greater than or equal to 1 foot in diamenter. Rock must be angular, hard and durable.

Rock Liner Fabric shall consist of a non-woven polypropylene type fabrice: Amoco 4553 or SI Geosolutions Geotex 801 or approved equal. Alternatively, an 8 inch bed of well graded sand and gravel with gravel up to 3" is acceptable.