CHAPTER 13
STORM DRAINS

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13.1 OVERVIEW

13.1.1 Introduction

The primary aim of storm drain design is to limit the amount of water flowing along the gutters, or ponding at the sags, to quantities which will not interfere with the passage of traffic for a common design storm. The storm drain system consists of surface inlets structures connected to a underground pipe system. The inlets are located at points and at such intervals to intercept flows and control the water's spread width into the traveled lane.

Photo 13.1

Storm drain facilities should provide enough combined capacity in the storm drain and the street typical to convey the major storm runoff through the roadway right-of-way in a manner which adequately drains the roadway and minimizes the potential for flooding and erosion to properties adjacent to the right-of-way.

Storm drain design is one of the more cumbersome and difficult problems encountered in highway drainage. The complex network of inlets and conduits requires extensive evaluation to provide an efficient, balanced system.

Storm Drains should be designed by the CDOT Hydraulics Engineer or experienced drainage consultant. Hydraulic design of projects contracted to consultants should be reviewed and approved by the CDOT Hydraulics Engineer.

The most serious effects of an inadequate roadway drainage system are:

- damaging adjacent property from the water overtopping the curb and gutter;

- risk and delays to the driving public caused by excessive ponding in sags or excessive spread along the roadway;
- deterioration of the pavement structure and subgrade due to saturation caused by frequent and long duration ponding; and
- creating hydroplaning conditions for motorists.

Photo 13.2

Photo 13.3

13.1.2 Symbols And Definitions

To provide consistency within this Chapter and throughout this *Manual*, the symbols in Table 13.1 will be used. These symbols were selected because of their wide use in storm drainage publications.

13.1.3 Concept Definitions

Following are discussions of concepts that will be important in a storm drainage analysis and design. These concepts will be used throughout the remainder of this Chapter in addressing different aspects of storm drainage analysis:

Bypass Flow: Flow which bypasses an inlet on grade and is carried in the street or channel to the next inlet downgrade.

Check Storm: The use of a less frequent event (e.g., a 50-yr storm) to assess hazards at critical locations where water can pond to appreciable depths is commonly referred to as a check storm or check event.

Combination Inlet: A drainage inlet usually composed of a curb-opening inlet and a grate inlet.

Crown: The crown, sometimes known as the soffit, is the top inside of a pipe.

Culvert: A culvert is a closed conduit whose purpose is to convey surface water under a roadway, railroad or other impediment. It may have one or two inlets connected to it to convey drainage from the median area.

Curb-Opening: A drainage inlet consisting of an opening in the roadway curb. (ex. Type R inlet)

Drop Inlet: A drainage inlet with a horizontal or nearly horizontal opening.

Equivalent Cross Slope: An imaginary straight cross slope having conveyance capacity equal to that of the given compound cross slope.

Flanking Inlets: Inlets placed upstream and on either side of an inlet at the low point in a sag vertical curve. These inlets intercept debris as the slope decreases and act in relief of the inlet at the low point.

Flow: Flow refers to a quantity of water that is flowing.

Frontal Flow: The portion of the flow that passes over the upstream side of a grate.

Grate Inlet: A drainage inlet composed of a grate in the roadway section or at the roadside in a low point, swale or channel. (ex. Type C or D inlet)

Grate Perimeter: The sum of the lengths of all sides of a grate, except that any side adjacent to a curb is not considered a part of the perimeter in weir-flow computations.

Gutter: That portion of the roadway section adjacent to the curb which is utilized to convey storm water runoff. It may include a portion, or all, of a traveled lane, shoulder or parking lane, and a limited width, adjacent to the curb, may be of different materials and have a different cross slope.

Hydraulic Grade Line The hydraulic grade line is the locus of elevations to which the water would rise in successive piezometer tubes if the tubes were installed along a pipe run (pressure head plus elevation head).

Inlet Efficiency The ratio of flow intercepted by an inlet to total flow in the gutter.

Invert The invert is the inside bottom of the pipe.

Lateral Line A lateral line, sometimes referred to as a lead, has inlets connected to it but has no other storm drains connected. It is usually 2 ft or less in diameter and is tributary to the trunk line.

Lateral: The underground conduit that connects the inlet to the main trunkline of a storm drain.

Major Storm: The 50 to 100-year runoff to be assessed for with a storm drain design for minimum ponding depth and property inundation.

Minor Storm: The common storm that is used for designing the inlet size and location, the trunkline size and the spread width.

Panline: The lowest point in the curb and gutter section.

Pressure Head: Pressure head is the height of a column of water that would exert a unit pressure equal to the pressure of the water.

Runby/Bypass: Carryover flow that bypasses an inlet on grade and is carried in the street or channel to the next inlet downgrade. Inlets can be designed to allow a certain amount of runby for one design storm and larger or smaller amounts for other storms.

Sag Point/Major Sag Point: A low point in a vertical curve. A major sag point refers to a low point that can overflow only if water can pond to a depth of 2 ft or more.

Scupper: A vertical hole through a bridge deck for deck drainage. Sometimes, a horizontal opening in the curb or barrier is called a scupper.

Side-Flow Interception: Flow that is intercepted along the side of a grate inlet, as opposed to frontal interception.

Slotted Drain Inlet: A drainage inlet composed of a continuous slot built into the top of a pipe that serves to intercept, collect and transport the flow. Two types in general use are the vertical riser and the vane type.

Storm Drain: A storm drain is a closed or open conduit that conveys stormwater that has been collected by inlets to an adequate outfall. It generally consists of laterals or leads and trunk lines or mains. Culverts connected to the storm drainage system are considered part of the system.

Splash-Over: Portion of frontal flow at a grate that skips or splashes over the grate and is not intercepted.

Spread: The width of stormwater flow in the gutter or roadway measured laterally from the roadway curb.

Trunk Line: A trunk line is the main storm drain line. Lateral lines may be connected at inlet structures or access holes. A trunk line is sometimes referred to as a "main."

Trunkline: The underground pipe portion of a storm drain system. Major conveyance element into which the smaller pipes or laterals drain into from the storm drain inlets.

Velocity Head: Velocity head is a quantity proportional to the kinetic energy of flowing water expressed as a height or head of water ($V^2/2g$).

13.2 GENERAL DESIGN CRITERIA

13.2.1 Introduction

Highway storm drainage facilities collect stormwater runoff and convey it through the roadway right-of-way in a manner that adequately drains the roadway and minimizes the potential for flooding and erosion to properties adjacent to the right-of-way. Storm drainage facilities consist of curbs, gutters, storm drains, channels and culverts. The placement and hydraulic capacities of storm drainage facilities should be designed to consider the potential for damage to adjacent property and to secure as low a degree of risk of traffic interruption by flooding as is consistent with the importance of the road, the design traffic service requirements and available funds.

Storm drain systems have two separate drainage systems. One is the minor drainage system to handle the ordinary recurring storm (2 to 10-year storm events). The other is the major system to handle the large infrequent storm flows (100-year storm event). The minor system consists of underground piping that is connected to inlets draining roadway or offsite areas. The major system includes street flow, urban storm channels and other overflow provisions to pass the infrequent, large flows without excessive ponding or property damage.

Following is a summary of policies that should be followed for storm drain design and analysis. For a general discussion of policies and guidelines for storm drainage, the designer is referred to Reference *(1)*.

For more specific design and engineering guidance refer to the AASHTO "Drainage Manual", the Federal Highway Administration publication, HEC 21 and HEC 22. and the Denver Regional Council of Governments, "Urban Drainage and Flood Control District - Critenia Manual."

Table 13.1 Symbols and Definitions

Symbol	Definition	Units
A	Area of cross section	ft^2
A	Watershed area	acre
a	Depth of depression	inch
C	Runoff coefficient or coefficient	-
d	Depth of gutter flow at the curb line	ft
D	Diameter of pipe	ft
Eo	Ratio of frontal flow to total gutter flow (Qw/Q)	-
h	Height of curb-opening inlet	ft
H	Head loss	ft
I	Rainfall intensity	in/h
K	Coefficient	-
L	Length of curb-opening inlet	ft
L	Pipe length	ft
L	Pavement width	ft
L	Length of runoff travel	ft
n	Roughness coefficient in Manning's formula	-
P	Perimeter of grate opening, neglecting bars and side against curb	ft
P	Tire pressure	psi
Q	Rate of discharge in gutter	ft3/s
Qi	Intercepted flow	ft3/s
Qs	Gutter capacity above the depressed section (see Figure 13-1)	ft3/s
QT	Total flow	ft3/s
QW	Gutter capacity in the depressed section (see Figure 13-1)	
Rh	Hydraulic radius	ft
S or Sx	Pavement cross slope	ft/ft
S	Crown slope of pavement	ft/ft
S or SL	Longitudinal slope of pavement	ft/ft
Sw	Depressed section slope (see Figure 13-1)	ft/ft
T	Top width of water surface (spread on pavement)	ft
tc	Time of concentration	min
TD	Tire tread depth	min
Ts	Spread above depressed section	ft
TXD	Pavement texture depth	in
V	Vehicle speed	mph
V	Velocity of flow	ft/s
W	Width of depression for curb-opening inlets	ft
Wd	Rotational velocity on dry surface	rpm
WD	Water depth	in
Ww	Rotational velocity on flooded surface	rpm
y	Depth of flow in approach gutter	ft
Z	T/d, reciprocal of the cross slope	-

13.2.2 Hydrology

The Rational Method is the suggested procedure to compute the peak flows for storm drain systems with drainage areas less than 160 acres. It is the method that applies to the vast majority of small watersheds that are to be handled by storm drains. For more information on the Rational Method and other hydrological methods refer to Chapter 7 - Hydrology.

Estimated peak flows will be based on the existing runoff conditions and an allowance for the reasonably foreseeable future developments and conditions. The future flow patterns and basin sizes should be based on present topographic conditions if specific plans for developed modifications are unknown.

13.2.3 Design Frequency And Spread Width

The major consideration for selecting a design frequency and spread width is the highways classification, because it defines and reflects public expectations for finding water on the pavement surface.

Ponding should be avoided on the traffic lanes of high-speed, high-volume highways, where it is not expected to occur.

Highway speed is another major consideration, because at speeds greater than 45mph, even a shallow depth of water on the pavement can cause hydroplaning and safety problems to motorists.

Design speed is recommended for use in evaluating hydroplaning potential. When the design speed is selected, consideration should be given to the likelihood that legal posted speeds might be exceeded. It is clearly unreasonable to provide the same level of protection for low speed facilities as for high speed facilities.

For curb and guttered roadways with no parking, it is not practical to avoid all travel lane flooding when longitudinal grades are flat (0.3 to one percent). However, flow spread width shall never exceed the lane adjacent to the gutter for design conditions. Municipal bridges with curb and gutter should also use this criterion. For single lane roadways at least 8 ft of roadway shall remain unflooded for design conditions.

Storm drain systems are normally designed for full gravity flow conditions using the design frequency discharges.

The exceptions are depressed roadways and underpasses where ponded water can be removed only through pumps via the storm drain systems. In these situations, a larger design frequency is advisable for the inlets at the sag location and for sizing the main storm drain line.

Table 3.2 presents the Design Frequency vs. Spread Width.

13.2.4 Inlet Spacing

The time of concentration (t_c) for inlet spacing is the time for water to flow from the hydraulically most distant point of the drainage area to the inlet, which is known as the inlet time. Usually this is the sum of the time required for water to move across the pavement or overland back of the curb to the gutter, plus the time required for flow to move through the length of gutter to the inlet. For pavement drainage, when the total time of concentration to the upstream inlet is less than 5 min, a minimum t_c of 5 min should be used to estimate the intensity of rainfall. The time of concentration for the second downstream inlet and each succeeding inlet should be determined independently, the same as the first inlet. For a constant roadway grade and relatively uniform contributing drainage area, the time of concentration for each succeeding inlet could also be constant.

Table 13.2 Design Frequency vs. Spread Width.

Design Frequency vs. Spread Width.

Road Classification		Design Frequency	Design Spread Width
Interstate		2-5 year	Shoulder
		10 year	Shoulder + 3 ft
Arterials	< 45mph	2-5 year	Shoulder + 4 ft
		10 year	Shoulder + 3 ft
	> 45 mph	2-10 year	Shoulder
	sag point	50 year	Shoulder + 3 ft
Collectors	< 45 mph	2-10 year	1/2 Driving Lane
	> 45 mph	2-5 year	Shoulder + 4 ft
		10 year	Shoulder
	sag point	10 year	1/2 Driving Lane
Local Streets		2-10 year	1/2 Driving Lane
	sag point	10 year	1/2 Driving Lane

Note: These criteria applies to shoulder widths of 4 ft or greater. Where shoulder widths are less than 4 ft, a minimum design spread of 4 ft should be considered.

13.3 PAVEMENT DRAINAGE

13.3.1 Introduction

Roadway features considered during gutter, inlet and pavement drainage calculations include:

- Longitudinal and cross slope,
- Curb and gutter sections,
- Pavement texture/surface roughness,
- Roadside and median ditches, and
- Bridge decks.

The pavement width, cross slope, profile and pavement texture control the time it takes for stormwater to drain to the gutter section. The gutter cross section and longitudinal slope control the quantity of flow that can be carried in the gutter section.

13.3.2 Major Storm And Street Capacity

The effects of the major storm or 100-year has to be assessed for any storm drain design. For this assessment the major storm allowable depth and inundation shall not exceed the following limitations:

1. Residential dwellings, public, commercial and industrial buildings shall not be flooded around the foundation unless the buildings are flood proofed.
2. The depth of water at the street crown on continuous grade sections shall not exceed 6 in to allow the passage of emergency vehicles.
3. The depth of water at the panline on continuous grade sections shall not exceed 18in.
4. For interstate highways, on continuous grades and at sumps, the water shall not go out into the traveled lane more than 4ft for the 100-year storm.
5. For all highways except interstates, depth of ponding in sump areas shall be kept to a minimum for the major storm. Major storm inundation and closing of a sump area is not allowed if alternate detour routes are not available.

If the major storm criteria is not met the size and design frequency of the minor storm drain system shall be increased in size to reduce major storm flooding.

13.3.3 Longitudinal Slope

Desirable gutter grades should not be less than (0.3 percent) for curbed pavements. Minimum grades can be maintained in very flat terrain by use placing the flowline of the gutter at a steeper grade than the centerline profile of the roadway.

To provide adequate drainage for both crest and sag vertical curves, a minimum slope of 0.3 percent should be maintained within 50 feet of the level point in the curve. This is accomplished where the length of the curve divided by the algebraic difference in grades is equal to or less than 167.

Although ponding is not usually a problem at crest vertical curves, on extremely flat curves a similar minimum gradient should be provided to facilitate drainage.

13.3.4 Cross Slope

Reference *(1)* is standard practice and should be consulted prior to deviation from this *Manual*.

The design of pavement cross slope is often a compromise between the need for reasonably steep cross slopes for drainage and relatively flat cross slopes for driver comfort. Reference *(7)* reports that cross slopes of 2% have little effect on driver effort in steering, especially with power steering or on friction demand for vehicular stability. Use of a cross slope steeper than 2% on pavements with a central crown line is not desirable. In areas of intense rainfall, a somewhat steeper cross slope may be necessary to facilitate drainage. In such areas, the cross slope may be increased to 2.5%.

When three or more lanes are inclined in the same direction on multilane pavements, it is desirable that each successive pair of lanes, or the portion thereof outward from the first two lanes from the crown line, have an increased slope. The two lanes adjacent to the crown line should be pitched at the normal slope and successive lane pairs, or portions thereof outward, should be increased by approximately 0.5% to 1%. Where three or more lanes are provided in each direction, the maximum pavement cross slope should be limited to 4%.

It is preferable to slope median areas and inside shoulders to a center swale. This will prevent drainage and snow melt in the median area from running across the driving lanes. This is particularly important for high-speed facilities, and for facilities with more than two lanes of traffic in each direction. If used, temporary storage in shallow medians must be carefully engineered to handle high intensity rainfall and snow melt.

13.3.5 <u>Hydroplaning / Pavement Texture</u>

The pavement texture is an important consideration for roadway surface drainage. Although the hydraulic design engineer will have little control over the selection of the pavement type or its texture, it is important to know that pavement texture does have an impact on the buildup of water depth on the pavement during rain storms. A good macrotexture provides a channel for water to escape from the tire/pavement interface and, thus, reduces the potential for hydroplaning.

A high level of macrotexture may be achieved by tinning new portland cement concrete pavements while it is still in the plastic state. Re-texturing of an existing portland cement concrete surface can be accomplished through pavement grooving and cold milling. Both longitudinal and transverse grooving are very effective in achieving macrotexture in concrete pavement. Transverse grooving aids in surface runoff resulting in less wet pavement time. Combinations of longitudinal and transverse grooving provide the most adequate drainage for high-speed conditions.

The following considerations help reduce the potential for hydroplaning problems:

- Pavement cross slope is the dominant factor in removing water from the pavement surface. A minimum cross slope of 2 percent is recommended for two lanes and less.
- As a guideline, a wheel path depression in excess of 0.2 in should be considered as a threshold to indicate the potential for pavement drainage problems when dense asphaltic concrete or portland cement concrete pavements are used. The potential for hydroplaning is greater from wheel path depressions than from sheet flow depth. This is also true for most multi-laned facilities.
- Surface drains located parallel to the lane lines will not solve potential drainage problems caused by the creation of wheel path depressions.
- Grooving may be considered on portland cement concrete pavement as a corrective measure for severe localized hydroplaning problems. Grooving of the pavement is useful for removing small amounts of water such as in light drizzle.

13.3.6 <u>Curb and Gutter</u>

Curbing at the outside edge of pavements is normal practice for low-speed, urban highway facilities. They serve several purposes that include containing the surface runoff within the roadway and away from adjacent properties, preventing erosion, providing pavement delineation and enabling the orderly development of property adjacent to the roadway. Curbs may be either barrier or mountable type, and they are typically portland cement concrete, although bituminous curb is used occasionally.

13.3.7 Concrete Median Barrier

Concrete median barrier (CDOT Type 7 guard rail) is commonly used to separate opposing lanes of traffic on divided highways. Where median concrete barriers are used, particularly on horizontal curves associated with super-elevations and in sag vertical curves, it is necessary to provide for some relief for the water which can accumulate against the barrier during major storms. This can be done with an opening slot in the concrete barrier as shown in Figure 13.1. Even with the slots, ponding and closure of the highway can be expected for barriers that cross sags that get over-topped from major drainage basins. The onifice and wier equations, assuming 50% debris blockage, shall be used to analyze the number of slots required at any location.

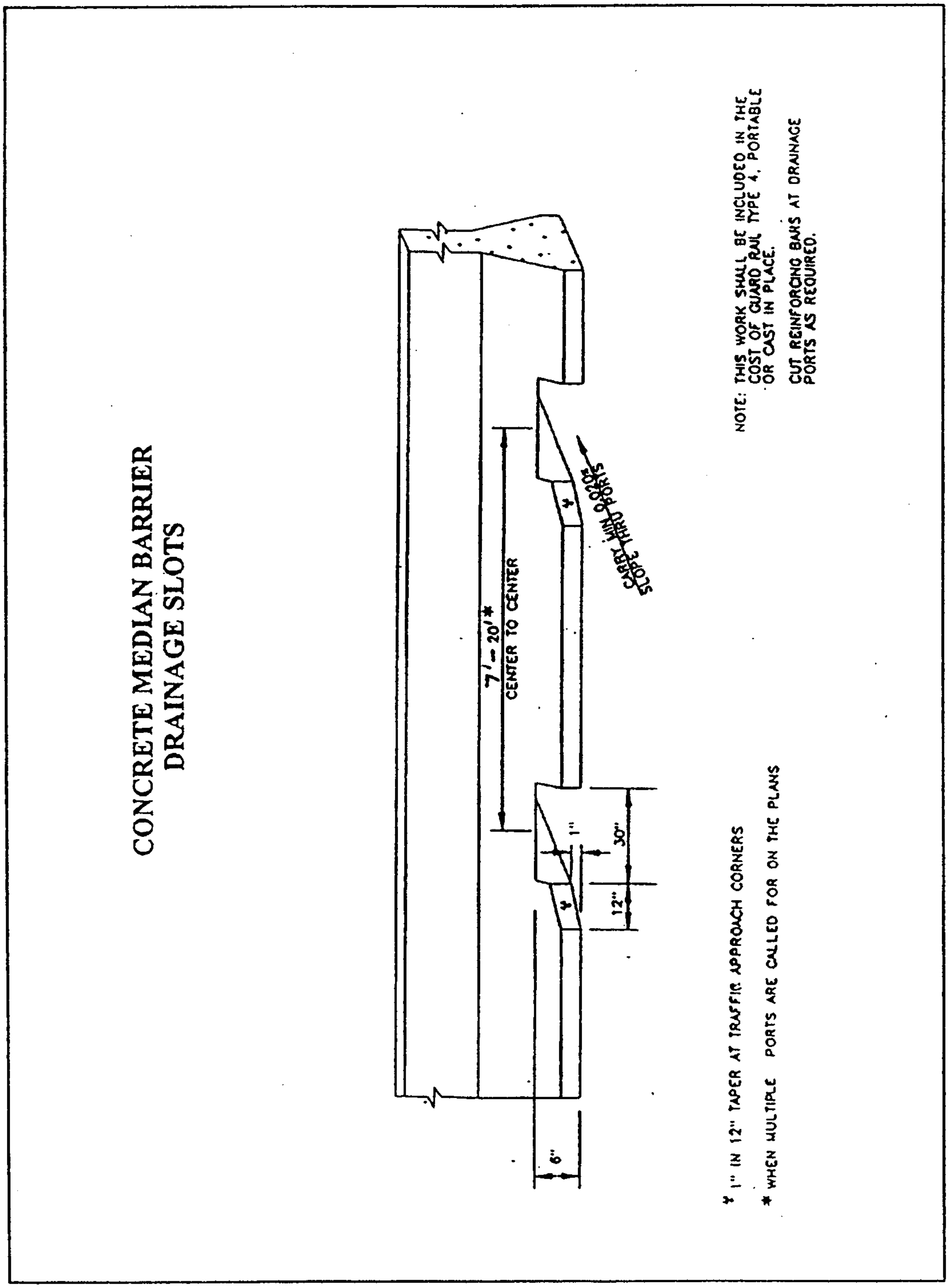

Figure 13.1 Concrete Median Barrier Drainage Slots

13.4 INLETS

13.4.1 General

Inlets are drainage structures utilized to collect surface water through grate or curb openings and convey it to storm drains or to culverts. Grate inlets should be bicycle safe, unless located on highways where bicycles (or wheelchair traffic) are not permitted.

This Section discusses the various types of inlets in use and recommends guidelines on the use of each type.

In general, the CDOT M&S standards show the typical inlets that should be used for CDOT projects.

13.4.2 Types

Inlets used for the drainage of highway surfaces can be divided into four major classes. These classes are as follows.

Grate Inlets

These inlets consist of an opening in the gutter covered by one or more grates. They are best suited for use on continuous grades. Because they are susceptible to clogging with debris, the use of standard grate inlets at sag points should be limited to minor sag point locations without debris potential. Special-design (oversize) grate inlets can be utilized at major sag points if sufficient capacity is provided for clogging. In this case, flanking inlets are definitely recommended. Grates should be bicycle safe where bike traffic is anticipated and structurally designed to handle the appropriate loads where subject to traffic.

Curb-Opening Inlets

These inlets are vertical openings in the curb covered by a top slab. They are best suited for use at sag points because they can convey large quantities of water and debris. They are a viable alternative to grates in many locations where grates would be hazardous for pedestrians or bicyclists. They are generally not recommended for use on steep continuous grades.

Combination Inlets

Various types of combination inlets are in use. Curb-opening and grate combinations are common, some with the curb opening upstream of the grate, and some with the curb opening adjacent to the grate. Slotted inlets are also used in combination with grates, located either longitudinally upstream of the grate or transversely adjacent to the grate. Engineering judgment is necessary to determine if the total capacity of the inlet is the sum of the individual components or a portion of each. The gutter grade, cross slope and proximity of the inlets to each other will be deciding factors. Combination inlets may be desirable in sags because they can provide additional capacity in the event of plugging.

Slotted Drain Inlets

These inlets consist of a slotted opening with bars perpendicular to the opening. Slotted inlets function as weirs with flow entering from the side. They can be used to intercept sheet flow, collect gutter flow with or without curbs, modify existing systems to accommodate roadway widening or increased runoff, and reduce ponding depth and spread at grate inlets. The two types of slotted inlets in general use are the vertical riser type and the vane type.

Inlet Locations

Inlets are required at locations needed to collect runoff within the design controls specified in the design criteria (see Section 13.4.3). In addition, there are a number of locations where inlets may be necessary with little regard to contributing drainage area. These locations should be marked on the plans prior to any computations regarding discharge, water spread, inlet capacity or runby. Examples of such locations are as follows:

1. sag points in the gutter grade;
2. upstream of median breaks, entrance/exit ramp gores, cross walks and street intersections;
3. immediately upstream and downstream of bridges;
4. immediately upstream of cross slope reversals;
5. on side streets at intersections;
6. at the end of channels in cut sections;
7. behind curbs, shoulders or sidewalks to drain low areas; and
8. where necessary to collect snow melt.
9. Inlets should not be located in the path where pedestrians are likely to walk.

13.4.3 Inlet Criteria and Design

Inlets are required at locations needed to collect runoff within the design controls specified below. Inlet locations should first be coordinated with other design features such as sags, driveways, crossroad intersections, pedestrian crosswalks, and interception points for concentrated flow from sources outside the pavement.

The placement of curb inlets is a trial and error process since both the spacing and size of inlets can be varied to a certain extent. However, many inlet locations are fixed using the following criteria:

Intersections

At intersections with side streets, it is desirable to remove 100 percent of the minor storm gutter flow from the side street to prevent cross street flow unto the state highway.

Place the upstream inlet as near to the intersection as possible without encroaching on pedestrian cross walk.

Inlets should be placed on tangent curb sections before the curb radius. If an inlet has to be placed in the curb radii, the panline and inlet should be depressed to help keep the water in the gutter. Gutter profiles should be shown in the plans for all these locations.

Superelevation Transition

Inlets are required 10 ft. before the point where the street cross slope begins to super-elevate toward the opposite side to prevent cross street flow.

Sumps

The sag vertical curve or sump area on a roadway requires an inlet at the lowest point and also flanking inlets on each side of the lowest inlet to provide relief from debris clogging. All sumps will be designed so that the 100-year drainage will not cause more than 4 feet of ponding. For Interstates no water ponding out of the shoulder area will be allowed for the 50-year storm.

All sumps shall be designed so that only the roadway drainage in the area of sump area will contribute drainage to the lowest inlets. Only the drainage from the immediate roadway area shall be allowed into a sump area low point. To keep offsite flow out of a sump either the flow shall be intercepted before entering the sump or the ground shall be raised around the sump area to divert the major flows around. Raising the area around the sump can be done by grading and berms. To keep water from the roadway draining into a sump short crest vertical curves in the roadway profile should be designed at each end of the roadway coming into the sump.

Tangents

Avoid placing inlets in locations objectionable to residents along the street. Avoid inlets in driveways or directly in front of store ftonts, pedestrian handicap ramps or private residences.

Major Side Drainage Entrances

Runoff from side drainage, such as parking lots usually enters the street at a specific location. An inlet should be placed downstream of this point when gutter capacity is inadequate. If there are ditches behind the curb and gutter area inlets should be provided in the ditch to intercept flows from offsite.

After Inlets are placed in fixed locations the hydraulic designer can go through and complete an inlet spacing analysis. The analysis begins at the upper most inlet in the drainage basin and the quantity of flow in the street is calculated. This calculated runoff is the sum of the street runoff and side drainage runoff reaching the inlet.

The inlet is then moved uphill or downhill, changing the drainage area until the computed runoff equals the street capacity within allowable water spread width. About 70 % to 80 % of the design flow should be intercepted as a rule of thumb. Only part of the flow bypassing an inlet is added to the total for the next inlet, a rule of thumb is 50 % of the bypass flow should be taken to the next inlet.

13.4.4 Inlet Capacities

The main hydraulic criteria for inlet location design is the spread width and inlet interception rate for the minor design storm. Therefore, it is important to accurately calculate the spread width of flow in the street and the depth of ponding in the gutter. Inlet design nomographs are given in Appendix A of this chapter. These nomographs give the depth, spread width and interception rate for common inlets used by CDOT. These nomographs can only be used for certain sized inlets on continuous grade and with the specific cross slopes. For other situations or for unique inlets the designer will need to develop their own spread sheets or nomographs based on the criteria in HEC-12 or on the criteria given in the Denver area "Urban Drainage and Flood Control District Criteria Manual".

For inlet capacity in low points or sag vertical curves the designer is referred to HEC-12 and the AASHTO Drainage Manual for the design of sump inlets using the orifice and weir equations. For CDOT Type C sump inlets a nomograph is given in Appendix A. The CDOT Type R curb open inlet can intercept 1cfs/foot of inlet, on a continuous slope, assuming 0.5ft of ponding.

For the major storm drain design the designer will have to calculate the depth and extent of flow out into the street along with the any flow intercepted by the inlets. (In Appendix A a nomograph is provided that uses the Manning's equation to figure the major storm street capacity.) The compound curb and gutter section With the depressed gutter should be used in the calculations and for design since the depression in the gutter does provide a significant increase in gutter capacity.

13.4.5 Inlet Debris

Grated inlet design shall consider the potential for debris obstruction. The designer must evaluate the grate's geometry, location, the debris potential and the adverse effects resulting from clogging.

Experience and history are essential to assess the characteristics and potential for debris. In Colorado ice, snow and hail can significantly reduce the capacity of inlets to intercept flow. Where there is sufficient information indicating the potential for debris clogging along a storm drain, Table 13.4 may be applied to determine the flow reductions due to potential clogging of small grates. This table is not valid for culvert inlet grates.

Table 13.4 Capacity Reduction Of Small Inlets Due To Debris

Net Size of Each Opening in^2	% Reduction Flow Due to Obstruction
Less than 20	30-60
20 to 60	20-50
Larger than 60	10-30

13.4.6 Maintenance Access (Manhole) Locations

Maintenance access (manholes) are utilized to provide access to continuous underground storm drains for inspection and clean-out. Where feasible, curb inlets should be used in lieu of manholes. When access to the system is provided at the curb inlet instead of at a manhole, there is a benefit of extra storm water interception achieved with minimal additional cost.

Typical locations where maintenance access should be provided are:

1. where two or more storm drains converge;
2. at intermediate points along tangent sections, for maintenance access;
3. where pipe size changes;
4. where an abrupt change in alignment occurs; and
5. where an abrupt change of the grade occurs.

Maintenance access should not be located in traffic lanes; however, when it is impossible to avoid locating a maintenance access in a traffic lane, care should be taken to insure it is not in the normal vehicle wheel path.

Pipes intersecting inside maintenance access shall not be aligned so that flows directly oppose each other.

Tee connections of laterals to trunk lines are generally discouraged due to cleaning difficulty. However, to save maintenance access costs, they are acceptable when large trunk lines and short laterals are encountered. The spring line (half way point of pipe) of the two pipes should intersect for ease of fabrication and construction.

Align the flowlines of pipes where a change of trunkline diameter is encountered.

Vertical and horizontal deflections in the pipe between maintenance access are discouraged but are occasionally necessary to avoid other underground conflicts.

13.4.7 Maintenance Access Spacing

The spacing of maintenance access should be in accordance with the criteria shown in Table 13.5.

Table 13.5 Maintenance Access Spacing

Size of Pipe, in	Maximum Distance, ft
15 - 24	400
30 - 36	500
42 - 54	700
60 - up	1000

13.4.8 <u>Curved Alignment</u>

Curved trunklines are permitted in special cases. The following criteria should be followed for curved storm drains 24 in and smaller in diameter.

1. Location: Curved alignments should follow the general alignment of streets.
2. Curve Type: Only simple curve design is acceptable.
3. Radius of Curvature: The minimum allowable radius of curvature is 300 ft.
4. Maintenance access: Maintenance access or inlets are required at the beginning and end of all curves.
5. Joints: Compression joints are required. The ASTM maximum allowable deflection of the pipe joints shall not be exceeded by a maximum of 25%.

For 24 in and larger curved storm drains the following criteria shall be followed:

1. Curved storm drains larger than 24 in in diameter shallmeet the requirements given above for smaller pipes except that the joints may be manufactured so that they fit together securely without deflection at the design curvature.
2. If curved storm drain alignments are contemplated, the local pipe manufacturer should be consulted regarding manufacturing and installation feasibility as well as availability of proper cleaning equipment for storm drain maintenance. Many manufacturers have standardized joint configurations and deflections for specific radii.

13.5 STORM DRAINS

13.5.1 Introduction

After the preliminary locations of inlets, connecting pipes and outfalls with tailwaters have been determined, the next logical step is the computation of the rate of discharge to be carried by each reach of the storm drain, and the determination of the size and gradient of pipe required to convey this discharge. This is done by starting at the upstream reach, calculating the discharge and sizing the pipe, then proceeding downstream, reach by reach, to the point where the storm drain connects with other drains or the outfall.

The rate of discharge at any point in the storm drain is not necessarily the sum of the inlet flow rates of all inlets above that section of storm drain. It is generally less than this total. The time of concentration is most influential and, as the time of concentration grows larger, the rainfall intensity to be used in the design grows smaller. In some cases, where a relatively large drainage area with a short time of concentration is added to the system, the peak flow may be larger using the shorter time even though the entire drainage area is not contributing. The prudent designer will be alert for unusual conditions and determine which time of concentration controls for each pipe segment.

For ordinary conditions, storm drains should be sized on the assumption that they will flow full or practically full under the design discharge but will not flow under pressure head. The Manning’s formula is recommended for capacity calculations. In locations such as depressed sections and underpasses where ponded water can be removed only through the storm drain system, a higher design frequency 50-yr should be considered to design the storm drain that drains the sag point. The main storm drain downstream of the depressed section should be designed by computing the hydraulic grade line and keeping the water surface elevations below the grates and/or established critical elevations for the design storm.

13.5.2 Trunkline Criteria And Design

The shape and slope of the storm drain drainage area generally determines the corridors or streets for the trunkline and laterals. The specific alignment is controlled by utilities, roadway typical sections, and ease of construction. If future widening is expected, the trunkline should be located outside the future travel lane.

13.5.3 Trunkline Velocity

All storm drains should be designed such that velocities of flow "Aill not be less than 3ft/s at the design flow. For very flat flow lines the general practice is to design components so that flow velocities all increase progressively throughout the length of the pipe system. The storm drainage system should be checked to be sure there is sufficient velocity in all of the drains to keep solids moving toward the outlet and deter settling of particles in the pipe system.

All storm drains should be designed such that velocities of flow will not be any greater than 22 ft/s at the major storm discharge (100-year). Any greater velocities may cause cavitation and destruction of the storm drain.

13.5.4 Hydraulic Design of Pipes

The procedure given below shows a step by step procedure for the preliminary hydraulic analysis of the underground pipe part of a storm drain system. Flow-line elevations at junction points must be estimated initially and adjusted later when pipe sizes are finalized. The designer is also referred to the Denver area Urban Storm Drainage and Flood Control criteria manual for more information.

Beginning at the upper end of the system, the following steps are required to determine pipe sizes:

1. **Using Mannings Formula**

The most widely used formula for determining the hydraulic capacity of storm drains is the Manning Formula and it is expressed by the following equation:

$$V = (1.486/n)\, R^{2/3} S^{1/2}$$

Where: V = mean velocity of flow ft/s; R = the hydraulic radius, ft, defined as the area of flow divided by the wetted flow surface or wetted perimeter (A/WP); S = the slope of hydraulic grade line, ft/ft; n = Mannings roughness coefficient where, n = 0.012 - 0.015, concrete or plastic.

In terms of discharge, the above formula becomes:

$$Q = (1.486/n) A R^{2/3} S^{1/2}$$

Where: Q = rate Of flow, cfs; A = cross sectional area of flow, ft^2.

For storm drains flowing full, the above equations become:

$$Q = (0.463/n) D^{8/3} S^{1/2}$$

Where: D = diameter of pipe, ft.

The Manning's equation can be written to determine friction losses for storm drains as:

$$H^f = [29\,(n^2)(L)(V^2)]/[R^{4/3} 2g]$$

Where: H^f = total head loss due to friction, ft; n = Manning's roughness coefficient; D = diameter of pipe, ft; L = length of pipe, ft; V = mean velocity, ft/s; R = hydraulic radius, ft; g = acceleration of gravity, 32.2 ft/s^{2}.

2. Assume a trial pipe size and solve Manning's formula for the slope, S. If the computed slope is greater than the actual slope, the pipe is flowing full and is pressurized. It is desirable to use a pipe size which flows nearly full, but is not pressurized. Therefore, two choices are available:

Either adjust the pipe flow line to a steeper slope, or choose a larger pipe size and repeat the calculation. Minimum pipe sizes criteria see Chapter 9 Culverts or inlet control may control in many cases.

3. Complete similar calculations for each segment of pipe in the system being careful to carry adjusted flow lines to subsequent calculations.

With the initial system tabulated, check for conflicts with utilities, minimum cover requirements, and additional maintenance access required. Maintenance access, or access points (Type R inlets), are required at intervals as specified in Table 13.5. Adjust and redesign as necessary.

13.5.5 Special Considerations

Consideration and planning should be directed toward avoidance of utilities and deep cuts.

Some instances may dictate a trunk line on both sides of the roadway with very few laterals while other instances may call for a single trunk line down one side of the highway with many laterals.

Except in very unusual circumstances, storm drains should discharge to a single outfall. For very steep storm drains the velocity at the outlet shall be reduced if possible by deepening and flattening the storm drain and dissipating the energy within the storm drain itself. If this is not possible, an energy dissipator should be placed at the outlet. The designer is referred to Chapter 11 Energy Dissipators for more information.

A storm drain which branches, thereby distributing the discharge, should be avoided.

Water Quality features like ponds and infiltration basins should be considered as part of any storm drain design. The designer is referred to CDOT Erosion Control and Stormwater Quality Guide for more information. Water tight joints shall be used to prevent contaminated groundwater infiltrating into the storm drain system.

13.6 PRELIMINARY SYSTEM PLANNING AND DESIGN

13.6.1 Basic Data

The proper design of any storm drainage system involves the accumulation of certain basic data, familiarity with the project site, and a basic understanding of the hydrologic and hydraulic principles and drainage policy associated with that design.

The designer should be familiar with the land use pattems, the nature of the physical development of the area to be served by the storm drainage system, and the ultimate pattern of drainage both overland and by storm drains to some existing outfall location. Furthermore, there should be an understanding of the nature of the outfall since it usually has a significant influence on the storm drainage system.

Actual surveys of these and other features are the most reliable means of gathering the required data. Photogrammetric mapping has become one of the most important methods of obtaining the large amounts of data required for drainage design, particularly for busy urban roadways with all the attendant urban development.

Existing topographic maps, available from the U. S. Geological Survey, the Natural Resources Conservation Service, many municipalities, county governments, and even private developers are also valuable sources of the kind of data needed for a proper storm drainage design.

Developers and governmental planning agencies should be consulted regarding plans for the area in question. Often, in rapidly growing urban areas, the physical characteristics of an area to be served by a storm drainage system may change drastically in a very short time. In such cases, the designer is to anticipate these changes and consider them in the storm drainage design. If there is significant drainage outside roadway ROW than cost sharing with the municipality in the area should be investigated, see Chapter 2 - Legal Aspects.

Good and reliable data is needed for a hydraulically sound and balanced storm drain system. The following is the basic data needs for the design of a storm drainage system.

1. Drainage Basin Map

The map of the storm drains area generally should be at a scale of 1" = 50' or 1" = 100' with two foot contours. A walking review of the area is necessary to determine drainage path on the contour map.

A USGS map with a scale of 1:24000 is necessary to determine large drainage areas and aerial photos are helpful to determine land use.

2. Typical section of roadway is needed for cross slopes and pavement width.

3. Plan Sheets

Obtain a layout of the immediate area to be storm drained, showing existing or proposed streets, intersections, and general topography.

4. Profiles

The grades of all streets, curbs and gutters are necessary to locate inlets, determine times of concentration, curb capacities, and velocities.

5. Location and Elevation of Outfall.

The location, nature and elevation of the outfall should be known. Any information on the water stage or tailwater at the outlet shall be located.

6. Rainfall Curves.

Rainfall intensity duration frequency curves are required for use in the Rational Method Equation.

7. Utility Information

Underground utilities often interfere with storm drains lines. Definite utility elevations must be known so that utilities can be avoided or relocated.

Sanitary sewers are generally avoided since adjustments can be difficult and expensive.

8. Soil and water table data is needed.

9. Obtain local design standards and land use information from the local governmental entities.

13.6.2 Preliminary Design

After the basic data is collected it is time for the designer to go through a rough design of the system. At this stage inlets will be roughly sized and located and a plan view of the trunkline will be completed. Later the designer will have to check the trunkline size and profile. Utilities will be a very important factor to address after the rough storm drain is completed. It is very important the designer weights the relocation of utilities and the design.

Determine limits of project and the basins for analysis. Classify probable future type of development within the basin as it will affect both hydrology and hydraulic design.

After selecting preliminary locations of inlets, storm drains, and outfalls, the next logical step is the computation of the rate of discharge to be carried by each storm drain trunk line and the determination of the size and gradient of storm drain required to carry this discharge. This is done by proceeding in steps from upstream of a storm drain to downstream to the point at which the storm drain connects with other storm drains or the outfall, whichever is applicable. The discharge for a storm drain is calculated, the storm drain serving that discharge is sized, and the process is repeated for the next storin drain downstream. Some additional issues to address are:

1. For these calculations it is recommended that safety be matched. It should be recognized that the rate of discharge to be carried by any particular section of storm drain is not necessarily the sum of the inlet design discharge rates of all inlets above that section of storm drain, but as a general rule is somewhat less than this total.
2. It is useful to understand that the time of concentration is most influential and as the time of concentration grows larger, the proper rainfall intensity to be used in the design grows smaller.
3. For ordinary conditions, storm drains should be sized on the assumption that they will flow full or practically full under the design discharge but will not be placed under pressure head. The Manning formula is recommended for capacity calculations.
4. The storm drainage system for sag vertical curves should have a higher level of flood protection to decrease the depth of ponding on the roadway and bridges.
5. Storm drains should be designed to protect the roadway from flooding at the appropriate return period. Reserve capacity should be available at critical locations such as vertical curve sags and at bridge approaches.

The following are the general steps required for the preliminary design of a storm drain system.

1. Layout Preliminary Conduit Alignment for Design Purpose. Layout shall include , location of storm drains, direction of flow, location of manholes, location of existing utilities such as water , gas or underground cables. Several preliminary layouts should be considered.

2. Divide Basin into Subbasins for Design points. The subbasins should vary according to the actual storm drain layout being considered. An actually map with the drainage areas delineated shall be used and kept in the design file.
3. Determine design frequency for initial design. Develop intensity-duration-frequency curves for both the minor design storm and the major (100-year storm).
4. Determine preliminary street grades and the cross slopes, beginning at the upper end of the basin in question. Calculate the quantity of flow in the street until the point is reached at which the allowable carrying capacity of the initial storm in the street matches the design runoff computed by the Rational Method, this is the sum of street runoff and side drainage runoff reaching the inlet. The inlet is then moved uphill or downhill, changing the drainage area until the computed runoff equals the street capacity. The initiation of the storm drain system starts at this point. Succeeding inlets are designed similarly. When the sum of the flow passing the previous inlet and the flow from the intervening street and side drainage equal the gutter capacity, an inlet is required.

The following is a part of preliminary design and represents the hydrology portion of the design, which establishes the flows which need to be carried in the system. To better explain the mechanics involved in a preliminary design of a storm sewer we will go through a column by column explanation of how to use the design worksheet shown in Figure 13.2. This work sheet is typical of the calculations required for a storm drain. Other similar design tools, like computer spreadsheets and storm drain design software, are also acceptable.

STORM DRAINAGE SYSTEM PRELIMINARY DESIGN DATA

LOCATION OF DESIGN POINT	NAME OF BASIN	LENGTH METERS	INLET TIME MINUTES	FLOW TIME		TIME OF CONCENTRATION MINUTES	COEFFICIENT "C"	INTENSITY "I" $m^3/s/ha$	AREA "A" ha	DIRECT RUNOFF m^3/s	OTHER RUNOFF m^3/s	SUMMATION RUNOFF m^3/s	STREET		PIPE			STREET		PIPE		REMARKS
				STREET MINUTES	PIPE MINUTES								SLOPE %	ALLOWABLE CAPACITY m^3/s	SLOPE %	SIZE mm	CAPACITY m^3/s	DESIGN m^3/s	VELOCITY mps	DESIGN m^3/s	VELOCITY mps	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23

Figure 13.2 Storm Drain Worksheet

Column 1 Deternine design point location and list. This design point should correspond to the subbasin illustrated on the preliminary drainage area layout map and should be the location for an inlet. The designer should be working from a drainage area map and a rough roadway alignment to find these design point. A walk through on the ground of the site is also recommended.

Column 2 List basins contributing runoff to this point which have not previously been analyzed.

Column 3 Enter length of flow path between the previous design point and the design point under consideration.

Column 4 Determine the inlet time for the particular design point. For the first design point on a system, the inlet time will be equal to thetime of concentration. For subsequent design points, inlet time should also be tabulated to determine if it may be of greater magnitude than the accumulated time of concentration from upstream basins. If the inlet time exceeds the time of concentration from upstream basin, and the area tributary to the inlet is of sufficient magnitude, the inlet time should be substituted for time of concentration and used for this and subsequent basins.

Column 5 Enter the appropriate flowline between the previous design pointand the design point under consideration. The flow time of the street should be used if a significant portion of the flow ftom the above basin is carried in the street.

Column 6 Pipe flow time should generally be used unless there is significantly carry over ftom above basins in the street.

Column 7 The time of concentration is summation of the previous design point time of concentration and the next flow time.

Column 8 Rational Method Runoff Coefficient, "C", for the basin listed in Column 2 should be determined and listed. The "C" value should be weighted if the basins contain areas with different "C" values see Chapter 7 - Hydrology.

Column 9 The intensity to be applied to the basins under consideration is obtained from the time-intensity-frequency curve developed for the specific area under consideration.

Column 10 The area in acres of the basins listed in Column 2 is tabulated here. Subtract ponding areas which do not contribute to direct runoff such as roof-top and parking lot ponding areas.

Column 11 Direct runoff from the tributary basins listed in Column 2 is calculated and tabulated here by multiplying Column 8, 9, and 10.

Column 12 Runoff from other sources, such as controlled release from rooftops, parking lots, base flows from groundwater, and any other sources, are listed here.

Column 13 The total of runoff from the previous design point summation plus the incremental runoff listed in Column 11 and 12 is listed here.

Column 14 The proposed street slope is listed in this column.

Column 15 The allowable capacity for the street is listed in this column.

Column 16 List the proposed pipe grade.

Column 17 List the required pipe size to convey the quantity of flow necessary in the pipe.

Column 16 List the capacity of the pipe flowing full with the slope expressed in Column 16.

Column 19 Tabulate the quantities of flow to be carried in the street.

Column 20 List the actual velocity of flow for the volume of runoff to be carried in the street.

Column 21 List the quantity of flow determined to be carried in the pipe.

Column 22 Tabulate the actual velocity of flow in the pipe for the design Q.

Column 23 Include any remarks or comments which may affect or explain the design. The allowable quantity of carryover across street intersection should often be listed for the initial design storm. When routing the major storm through the system, the requiredelevation for adjacent buildings can often be listed in this column.

Run the major storm runoff through the minor system and assess the 100-year effects using the worksheet. Determine if the combined capacity of the street and storm drain system are sufficient to maintain. surface flows within acceptable limits. The property adjacent to the CDOT property should not be inundated by the major flood and pond depths shall be within major storm criteria. The combined total of the allowable street carrying capacity for the major storm and the storm drain capacity should equal the major design runoff.

13.7 FINAL SYSTEM DESIGN

A Final hydraulic checking is necessary for a storm drain to ensure that the system is balanced and that the hydraulic grade line does not rise above the ground surface causing discharge to the street. Energy losses occurring at bends, junctions, and transitions are included in these calculations. Occasionally, these losses will be large enough to require pipe size increases.

The final step in designing a storm drain system is to check the hydraulic grade line (HGL). Computing the HGL will determine the elevation, under design conditions, to which water will rise in various inlets, maintenance access , junction, and etc.

The hydraulic gradient will determine if design flows can be accommodated without causing flooding at some locations or causing flows to exit the system at locations where this is unacceptable. This can be done manually with charts and calculators or using microcomputer software.

All head losses in a storm drainage system are considered in computing the hydraulic grade line to determine the water surface elevations, under design conditions in the various inlets, catch basins, manholes, junction boxes, etc.

The hydraulic grade line shall be computed for storm drain systems at underpasses and depressed roadways for higher frequency.

Hydraulic control is a set water surface elevation from which the hydraulic calculations are begun. All hydraulic controls along the alignment are established. If the control is at a main line upstream inlet, the hydraulic grade line is the water surface elevation minus the entrance loss minus the difference in velocity head. If the control is at the outlet, the water surface is the outlet pipe hydraulic grade line.

13.7.1 <u>Hydraulic Gradeline Procedure</u>

The following is the procedure and the steps recommended to calculate the hydraulic gradeline for the outlet control condition.

The head losses are calculated beginning from the control point to the first junction and the procedure is repeated for the next junction. The computation for an outlet control may be tabulated on Figure 13.3 using the following procedure:

Step 1

Enter in Col. 1 the station for the junction immediately upstream of the outflow pipe. Hydraulic grade line computations begin at the outfall and are worked upstream taking each junction into consideration.

Step 2

Enter in Col. 2 the outlet water surface elevation, if the outlet will be submerged during the design storm, or 0.8 diameter plus invert out elevation of the outflow pipe, whichever is greater.

Step 3

Enter in Col. 3 the diameter (D_o) of the outflow pipe.

Step 4

Enter in Col. 4 the design discharge (Q_o) for the outflow pipe.

Step 5

Enter in Col. 5 the length (L_o) of the outflow pipe.

Step 6

Enter in Col. 6 the friction slope (S_f) in ft/ft of the outflow pipe. This can be determined by using the following formula:

$S_f = [(Qn)/(1.49AR^{2/3})$ or $(Q^2)/K^2$

Where: S_f = friction slope; $K = (1.486/n)AR^{2/3}$.

Note: For an estimate, full flow conditions is assumed.

Step 7

Multiply the ffiction slope (S_f) in Col 6 by the length (L_o) in Col. 5 and enter the friction loss (H_f) in Col. 7. On curved alignments, calculate curve losses by using the formula $H_c = 0.002\ (A)(V_o^2/2g)$, where A = angle of curvature in degrees and add to the friction loss.

Step 8

Enter in Col. 8 the outlet pipe velocity of the flow (V_o).

Step 9

Enter in Col. 9 the contraction loss (H_o) by using the formula $H_o = [0.25\ (V_o^2)]/2g$, where $g = 32.2\ ft/s^2$.

Step 10

Enter in Col. 10 the design discharge (Q_i) for each pipe flowing into the junction, except lateral pipe with inflow of ten percent or less of the mainline outflow. Inflow must be adjusted to the mainline outflow duration time before a comparison is made.

Step 11

Enter in Col. 11 the velocity of flow (V_i) for each pipe flowing into the junction (for exception see Step 10).

Step 12

Enter in Col 12 the product of Q_i x V_i for each inflowing pipe. When several pipes inflow into a Junction, the line producing the greatest Q_i x V_i product is the line which will produce the greatest expansion loss (H_i). For exception, see Step 10.

Step 13

Enter in Col. 13 the controlling expansion loss (H_i) using the formula $H_i = [0.35\ (V_i^2)]/2g$.

Step 14

Enter in Col. 14 the angle of skew of each inflowing pipe to the outflow pipe (for exception, see Step 10).

Step 15

Enter in Col. 15 the greatest bend loss (H_j) calculated by using the formula $H_j = [KV_i^2)]/2g$ where K = the bend loss coefficient corresponding to the various angles of skew of the in flowing pipes.

Step 16

Enter in Col. 16 the total head loss (H_t) by summing the values in Col. 9 (H_o), Col. 13 (H_i), and Col. 15(H_j).

Step 17

If the junction incorporates adjusted surface inflow of ten percent or more of the mainline outflow, i.e., drop inlet, increase H, by 30 percent and enter 'the adjusted Ht in Col. 17.

Step 18

If the junction incorporates partial diameter inlet shaping, such as standard maintenance access holes, reduce the value of H_t by 50 percent and enter the adjusted value in Col. 18.

Step 19

Enter in Col. 19 the final H, the sum of H_f, and H_t, where H_t, is the final adjusted value of the H_t.

Step 20

Enter in Col. 20 the sum of the elevation in Col. 2 and the Final H in Col. 19. This elevation is the potential water surface elevation for the junction under design conditions.

Step 21

Enter in Col. 21 the rim elevation or the gutter flow line, whichever is lowest, of the junction under consideration in Col. 20. If the potential water surface elevation exceeds the rim elevation or the gutter flow line, whichever is lowest, adjustments are needed in the system to reduce the elevation of the H.G.L.

Step 22

Repeat the procedure starting with Step 1 for the next junction upstream.

HYDRAULIC GRADE LINE PROJECT

STATION	Outlet Water Surface Elev.	D_o	Q_o	L_o	S_{f_o} %	H_f	JUNCTION LOSS												Final H	Inlet Water Surface Elev.	Rim Elev.
							V_o	H_o	Q_i	V_i	Q_iV_i	$\frac{V_i^2}{2g}$	H_i	Angle	H_Δ	H_t	1.3 H_t	0.5 H_t			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)		(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)

$H_i = 0.35 \frac{V_i^2}{2g}$ $H_o = 0.25 \frac{V_o^2}{2g}$ $H_\Delta = K \frac{V_i^2}{2g}$ FINAL $H = H_f + H_t$

$H_t = H_o + H_i + H_\Delta$

For K values see Table 13-4

Figure 3.3 Hydraulic Gradeline Worksheet

13.8 REFERENCES

AASHTO, "*A Policy on Geometric Design of Highways and* Streets," Task Force on Geometric Design, 2001.

AASHTO, "*Highway Drainage Guidelines*, Chapter 9, "Storm Drain Systems," Task Force on Hydrology and Hydraulics, 2003.

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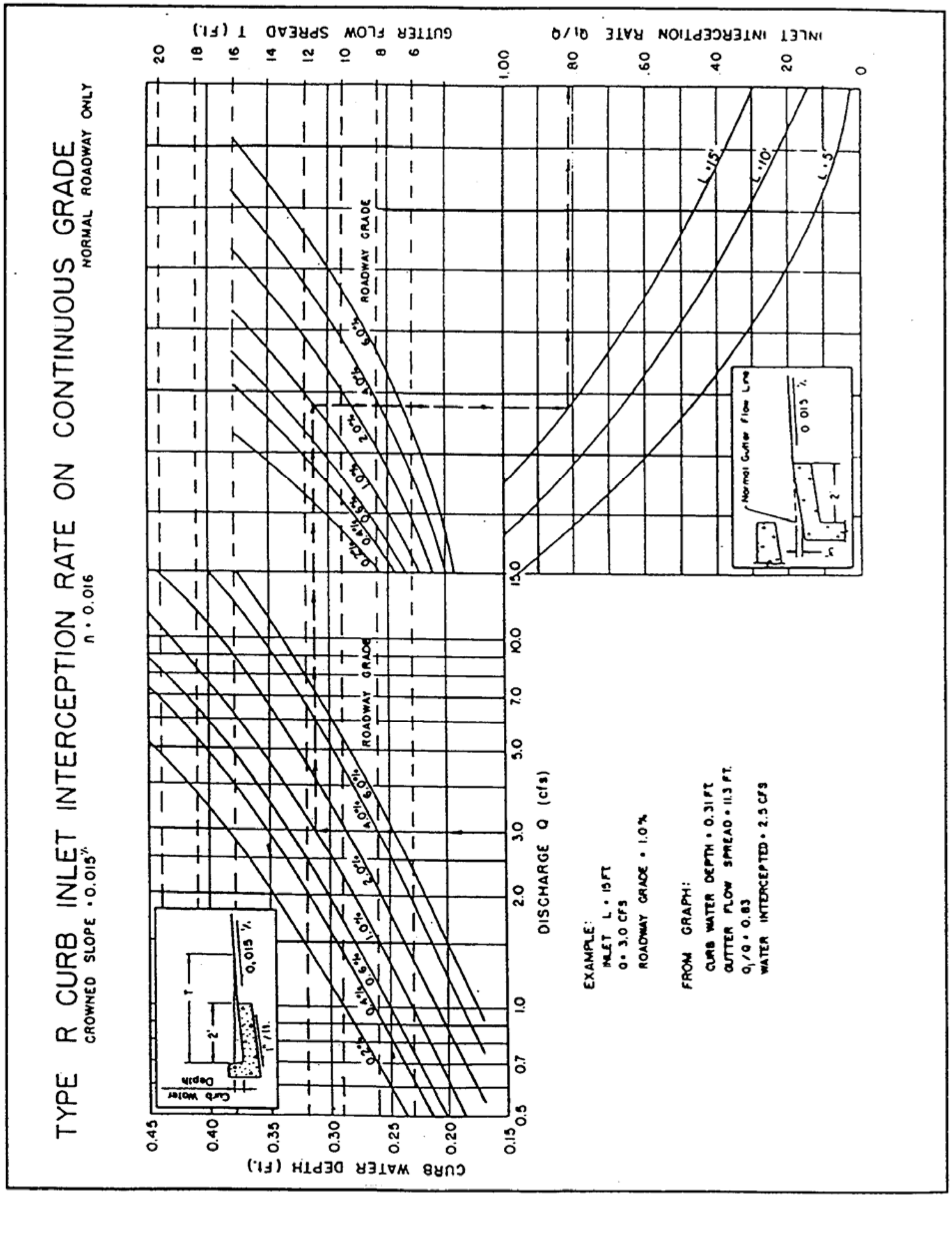
Federal Highway Administration, "*Urban Drainage Design Manual*,"Hydraulic Engineering Circular No. 22, FHWA-SA-96-078, 2001.

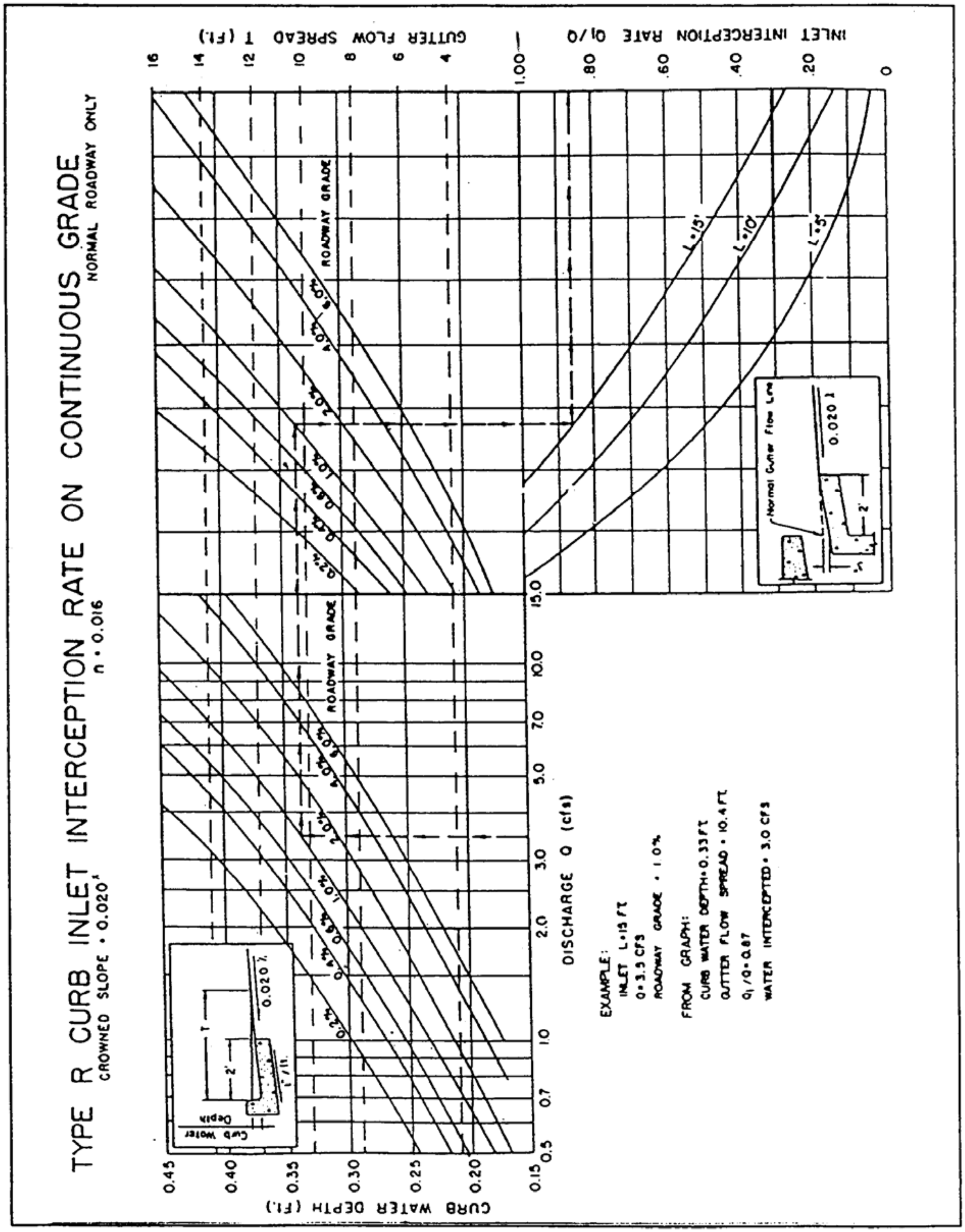
NCHRP Project 1-29, "*Improved Surface Drainage of Pavements*," Final Report, Pennsylvania Transportation Institute, July 1998.

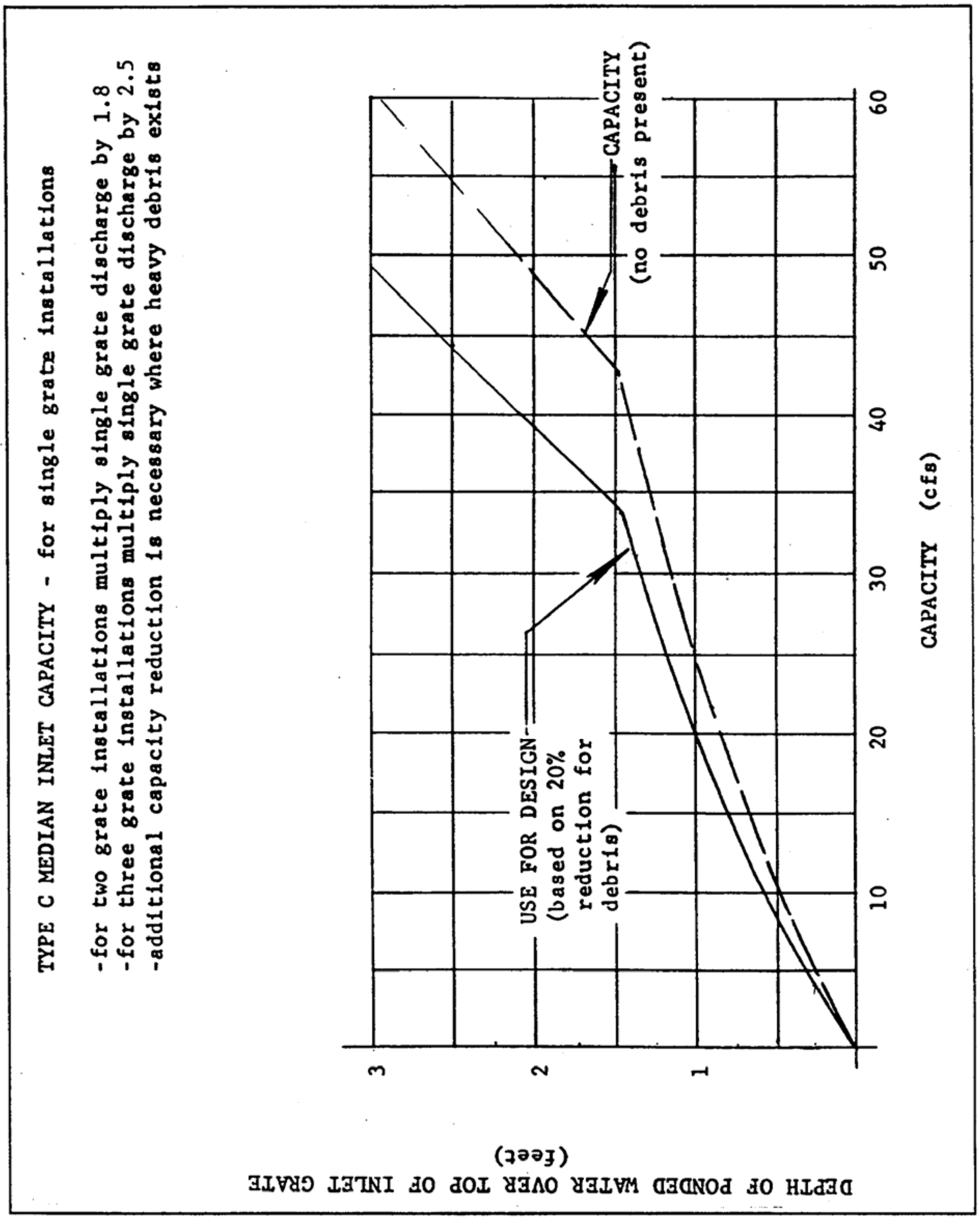
NCHRP Research Results Digest, Number 243, "*Proposed Design Guidelines for Reducing Hydroplaning on New and Rehabilitated Pavements*," September 1999.

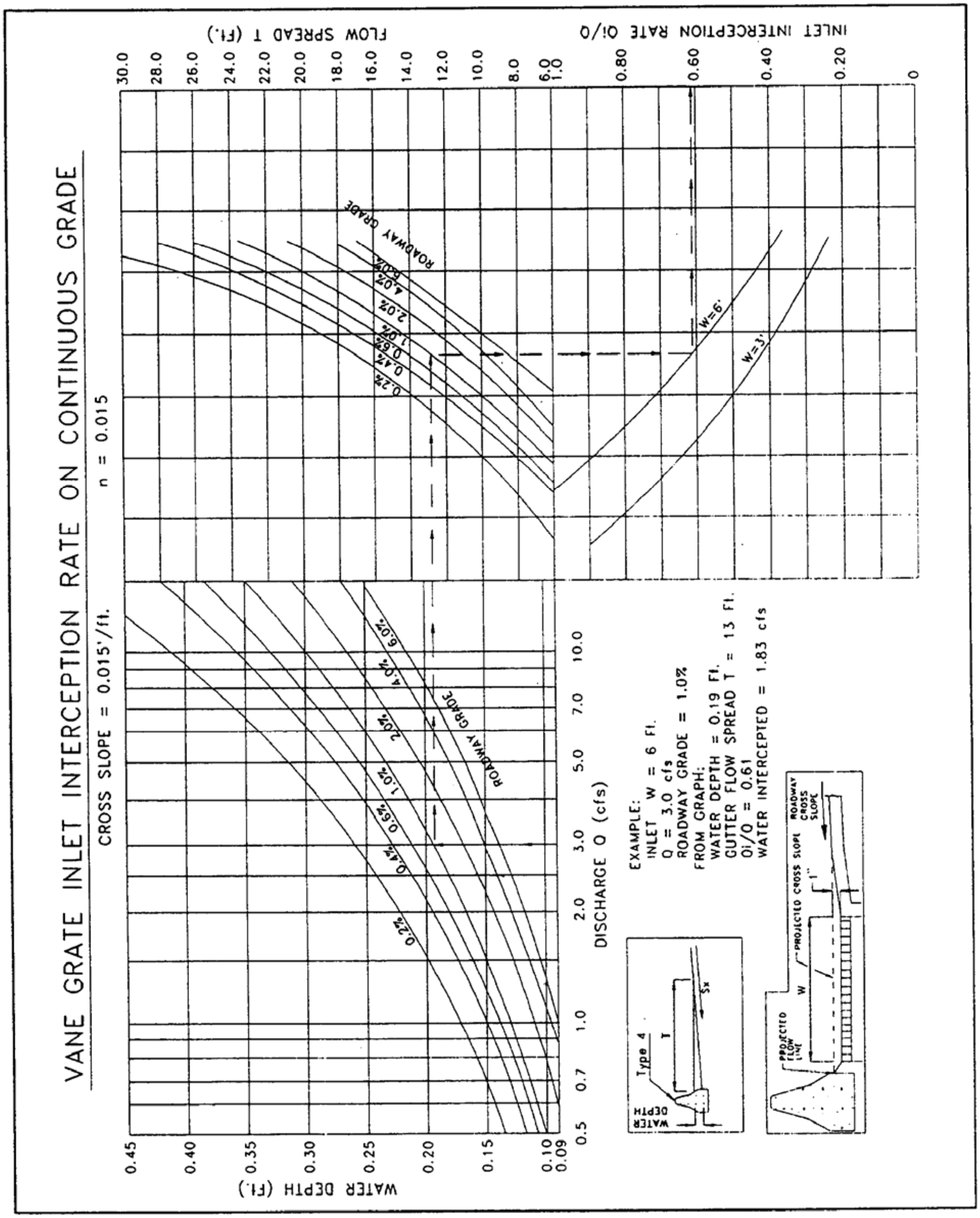
US Army Corps of Engineers

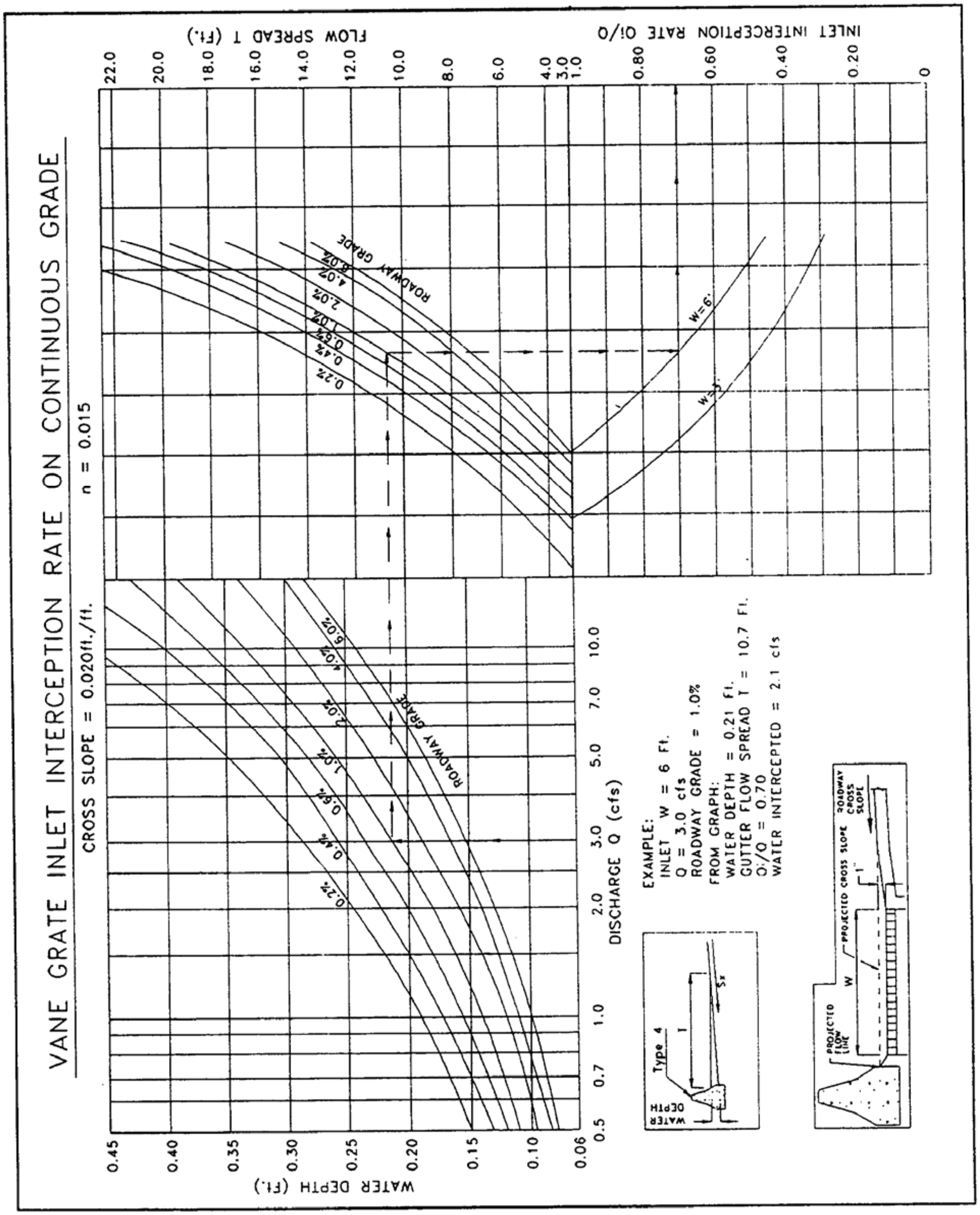
13.9 Appendix A Design Nomographs

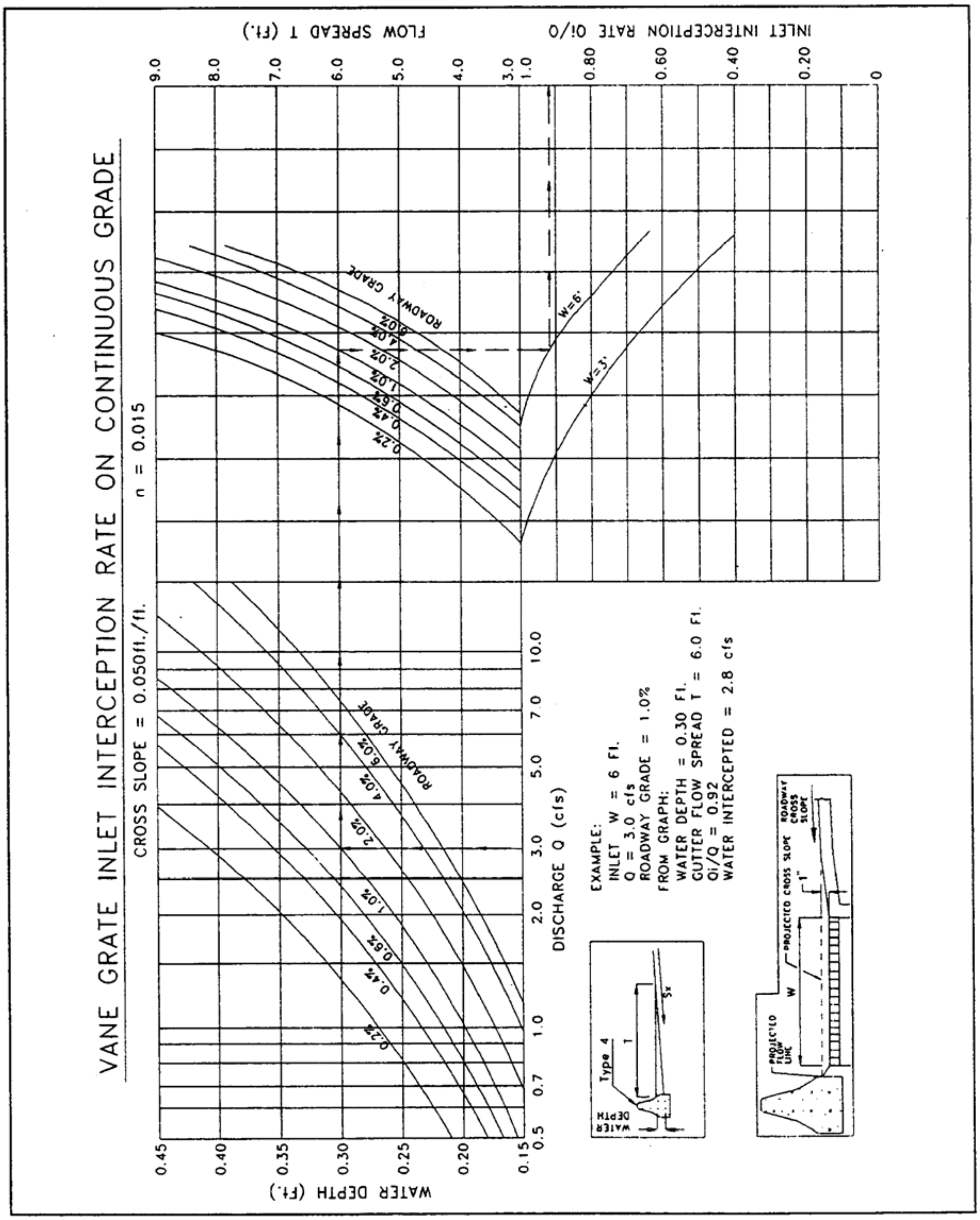

TYPE R CURB INLET INTERCEPTION RATE ON CONTINUOUS GRADE
CROWNED SLOPE • 0.015'/'
n • 0.016
NORMAL ROADWAY ONLY
CURB WATER DEPTH (FT.)
GUTTER FLOW SPREAD T (FT.)
INLET INTERCEPTION RATE Q,/Q
DISCHARGE Q (cfs)
ROADWAY GRADE
EXAMPLE:
INLET L • 15 FT
Q • 3.0 CFS
ROADWAY GRADE • 1.0%
FROM GRAPH:
CURB WATER DEPTH • 0.31 FT
GUTTER FLOW SPREAD • 11.3 FT.
Q,/Q • 0.83
WATER INTERCEPTED • 2.5 CFS


TYPE R CURB INLET INTERCEPTION RATE ON CONTINUOUS GRADE
NORMAL ROADWAY ONLY
CROWNED SLOPE = 0.020'
n = 0.016
CURB WATER DEPTH (Ft.)
DISCHARGE Q (cfs)
GUTTER FLOW SPREAD T (Ft.)
INLET INTERCEPTION RATE Qi/Q
ROADWAY GRADE
L=15'
L=10'
L=5'
EXAMPLE:
INLET L=15 FT
Q=3.5 CFS
ROADWAY GRADE = 1.0%
FROM GRAPH:
CURB WATER DEPTH = 0.33 FT
GUTTER FLOW SPREAD = 10.4 FT
Qi/Q = 0.87
WATER INTERCEPTED = 3.0 CFS


TYPE C MEDIAN INLET CAPACITY - for single grate installations
-for two grate installations multiply single grate discharge by 1.8
-for three grate installations multiply single grate discharge by 2.5
-additional capacity reduction is necessary where heavy debris exists
CAPACITY
(no debris present)
USE FOR DESIGN
(based on 20%
reduction for
debris)
DEPTH OF PONDED WATER OVER TOP OF INLET GRATE
(feet)
1
2
3
10
20
30
40
50
60
CAPACITY (cfs)


VANE GRATE INLET INTERCEPTION RATE ON CONTINUOUS GRADE
n = 0.015
CROSS SLOPE = 0.015'/ft.
FLOW SPREAD T (Ft.)
INLET INTERCEPTION RATE Qi/Q
WATER DEPTH (Ft.)
DISCHARGE Q (cfs)
ROADWAY GRADE
W=6'
W=3'
EXAMPLE:
INLET W = 6 Ft.
Q = 3.0 cfs
ROADWAY GRADE = 1.0%
FROM GRAPH:
WATER DEPTH = 0.19 Ft.
GUTTER FLOW SPREAD T = 13 Ft.
Qi/Q = 0.61
WATER INTERCEPTED = 1.83 cfs
Type 4
WATER DEPTH
PROJECTED CROSS SLOPE
ROADWAY CROSS SLOPE
PROJECTED FLOW LINE


VANE GRATE INLET INTERCEPTION RATE ON CONTINUOUS GRADE
CROSS SLOPE = 0.020ft./ft.
n = 0.015
FLOW SPREAD T (Ft.)
INLET INTERCEPTION RATE Qi/Q
WATER DEPTH (Ft.)
DISCHARGE Q (cfs)
ROADWAY GRADE
W=6'
W=3'
EXAMPLE:
INLET W = 6 Ft.
Q = 3.0 cfs
ROADWAY GRADE = 1.0%
FROM GRAPH:
WATER DEPTH = 0.21 Ft.
GUTTER FLOW SPREAD T = 10.7 Ft.
Qi/Q = 0.70
WATER INTERCEPTED = 2.1 cfs
Type 4
WATER DEPTH
PROJECTED FLOW LINE
PROJECTED CROSS SLOPE
ROADWAY CROSS SLOPE


VANE GRATE INLET INTERCEPTION RATE ON CONTINUOUS GRADE
CROSS SLOPE = 0.050ft./ft.
n = 0.015
FLOW SPREAD T (ft.)
INLET INTERCEPTION RATE Qi/Q
WATER DEPTH (ft.)
DISCHARGE Q (cfs)
ROADWAY GRADE
6.0%
4.0%
2.0%
1.0%
0.6%
0.4%
0.2%
W=6'
W=3'
EXAMPLE:
INLET W = 6 Ft.
Q = 3.0 cfs
ROADWAY GRADE = 1.0%
FROM GRAPH:
WATER DEPTH = 0.30 Ft.
GUTTER FLOW SPREAD T = 6.0 Ft.
Qi/Q = 0.92
WATER INTERCEPTED = 2.8 cfs
Type 4
WATER DEPTH
T
Sx
PROJECTED FLOW LINE
W
PROJECTED CROSS SLOPE
1"
ROADWAY CROSS SLOPE