13 Storm Drains

TABLE OF CONTENTS

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13.1 OVERVIEW

For a general discussion of policies and guidelines for storm drainage, the designer is referred to AASHTO's *A Policy on Geometric Design of Highways and Streets.* For more specific design and engineering guidance, refer to the AASHTO *Drainage Manual, Volume 1 – Policy,* and *Volume 2 – Procedures;* FHWA's HEC 21, *Design of Bridge Deck Drainage* and *HEC 22, Urban Drainage Design Manual;* and, the Denver Regional Council of Governments, Urban Drainage and Flood Control District's *Urban Storm Drainage Criteria Manual*.

This chapter is not a textbook on drainage design, nor is it a substitute for fundamental engineering knowledge or experience in drainage design. Storm drains should be designed by the CDOT hydraulics engineer or an experienced drainage engineering consultant. Hydraulic design of projects contracted to consultants must be reviewed by the CDOT hydraulics engineer.

13.1.1 Introduction

The primary aim of storm-drain design is to limit the amount of water flowing along gutters or ponding at sags to quantities which will not interfere with the passage of traffic for a common design storm. The storm-drain system consists of surface inlet structures connected to an underground-pipe system. The inlets are located at points spaced at intervals calculated 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 section to convey major-storm runoff through the roadway right of way in a manner which adequately drains the roadway, and minimizes potential for flooding and erosion to properties adjacent to the right of way.

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

- Damage to adjacent property from water overtopping curb and gutter;
- Risk and delays to the driving public caused by excessive ponding in sag vertical curves, or excessive spread along the roadway;
- Deterioration of pavement structure and subgrade due to saturation caused by frequent and long-duration ponding; and
- Creation of hydroplaning conditions for motorists.

Photo 13.2

13.1.2 Concept Definitions

The following are discussions of concepts important in storm drainage analysis and design. These concepts will be used throughout the remainder of this chapter.

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. It 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 inside top of a pipe, sometimes known as the soffit.

Culvert: 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. (e.g., 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 provide relief to the inlet at the low point.

Flow: 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. (e.g., Type C or D inlet)

Grate Perimeter: The sum of the lengths of all sides of a grate. 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 utilized to convey storm water runoff. It may include a portion of, or all of a traveled lane, shoulder, or parking lane. A limited width adjacent to the curb may be of different materials and have a different cross slope.

Hydraulic Grade Line: 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 inside bottom of a pipe.

Lateral Line: A line, sometimes referred to as a lead, which 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 used in storm-drain design as a basis for minimum-ponding depth and property-inundation calculations.

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

Panline: A line consisting of the lowest points of a curb and gutter section.

Pressure Head: The height of a column of water that would exert a 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 a 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 a curb or barrier is called a scupper.

Side-Flow Interception: Flow that is intercepted along the side of a grate inlet, in contrast 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 closed or open conduit that conveys stormwater 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: The 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: 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. It is the major conveyance element into which smaller pipes or laterals drain from the storm-drain inlets.

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

13.2 DESIGN FREQUENCY AND SPREAD WIDTH

13.2.1 Selection Considerations

The major consideration for selecting a design frequency and spread width is the highway classification. The highway classification can be found through the CDOT Online Transportation Information System (OTIS), by following the links to Highway Data, Highway Details, and System Classification. Highway classification defines requirements and reflects public expectations for encountering water on the pavement surface. Ponding is not expected to occur, and should be avoided on the traffic lanes of high-speed, high-volume highways.

Highway speed is another major consideration, because at speeds greater than 45 mph even a shallow depth of water on the pavement can cause hydroplaning and safety problems for motorists. Other considerations include inconvenience, hazards, and nuisances to pedestrian traffic and buildings adjacent to roadways located within the splash zone. In some locations (e.g., commercial areas) these considerations may assume major importance.

Design speed is recommended for use in evaluating hydroplaning potential. When the design speed has been selected, consideration should be given to the likelihood that legal posted speeds might be exceeded.

Selection of design criteria for intermediate types of facilities may be the most difficult. For example, some arterials with relatively high traffic volumes and high speeds may not have shoulders which will convey the design runoff without encroaching on the traffic lanes. In these instances, an assessment of the relative risks and costs of various design spreads may be helpful in selecting appropriate design criteria. Table 13.1 provides suggested minimum-design frequencies and spread based on the type of highway and traffic speed.

Table 13.1 Design Frequency Versus Spread Width

Road Classification	Design Frequency	Design Spread Width
Interstate, Principal Arterial – Freeways, Expressways	10 yr	Shoulder
Ramps	10 yr	Shoulder + 3 ft
Sag Point	50 yr	Shoulder + 3 ft
Principal and Minor Arterial		
< 45mph	10 yr	Shoulder + 3 ft
≥ 45 mph	10 yr	Shoulder
Sag Point	50 yr	Shoulder + 3 ft
Minor / Major Collectors		
< 45mph	10 yr	½ Driving Lane
≥ 45 mph	10 yr	Shoulder
Sag point	10 yr	½ Driving Lane
Local Streets		
Low ADT	Local Standards or 5 yr	Local Standards or ½ Driving Lane
High ADT	10 yr	½ Driving Lane
Sag Point	10 yr	½ Driving Lane

Table 13.1 criteria apply to shoulder widths of 4 ft or greater. Where curb and gutter exists with no parking lane or shoulder widths are less than 4 ft, a maximum design spread of 4 ft from flow line should be considered.

For roadways with curb and gutter and no parking lane, it is not practical to avoid all travel-lane flooding when longitudinal grades are flat (0.3% to 1%). For multi-lane roadways with curb and gutter, flow spread width must never exceed the lane width adjacent to the gutter for design conditions. For single-lane roadways with curb and gutter, flow spread width must leave at least one 8-ft lane free of water in each direction for design conditions. Flow spread width for municipal bridges with curb and gutter should also be based on this criterion.

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

13.2.2 Major Storm and Street Capacity

The effects of a major or 100-yr storm must be assessed for any storm-drain design. For this assessment the major storm's allowable depth and inundation must not exceed the following limitations:

- Residential dwellings, public, commercial, and industrial buildings must not be flooded at the foundation unless the buildings are floodproofed.

- The depth of water at the street crown on continuous-grade sections must not exceed 6 in., to allow the passage of emergency vehicles.
- The depth of water at the panline on continuous-grade sections must not exceed 18 in.
- For all highways except interstate highways, depth of ponding in sump areas must be kept to a minimum for the major storm. Major-storm inundation or closing of a sump area are not allowed if alternate detour routes are not available.

If major-storm criteria are not met, the size and design frequency of the minor storm-drain system must be increased to reduce major-storm flooding.

13.3 GENERAL DESIGN CRITERIA

13.3.1 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 with consideration of the potential for damage to adjacent property, and to secure as low a risk of traffic interruption by flooding as is consistent with the importance of the road, the design traffic-service requirements, and available funds.

Following is a summary of policies that should be followed for storm drain design and analysis.

13.3.2 Hydrology

The Rational Method is the recommended procedure to compute peak flows for storm-drain systems with drainage areas less than 200 ac. This limit is not a hard limit, and may need to be reduced based on watershed complexity. The Rational Method applies to the vast majority of small watersheds that are 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 existing-runoff conditions with an allowance for reasonably-foreseeable future developments and conditions. Future flow patterns and basin sizes should be based on present topographic conditions if specific plans for development modifications are unknown.

13.3.3 Bridge Decks

Many short bridges may not require any drainage facilities, while longer, wider decks may require drainage facilities to provide adequate traffic passage for the desired level of service. Bridge designs with sags, flat, or zero gradients should be avoided. Special attention is needed for decks with superelevation transitions. Approach slab drains must be provided on the high side of expansion devices to minimize flow over the joint. More information can be found in the CDOT *Bridge Design Manual*.

13.3.4 Inlets

Drainage inlets are sized and located to limit the spread of water in accordance with the design criteria specified in Table 13.1. The width of water spread on the pavement at sags should not be substantially greater than the width of spread encountered on continuous grades.

Grate inlets and depression of curb opening inlets should be located outside through-traffic lanes. All grate inlets must be bicycle safe where used on roadways that allow bicycle travel, and structurally designed to handle appropriate loads when subject to traffic loading. Curb inlets are preferred to grate inlets at major sag locations because of their debris-handling capabilities. When grate inlets are used at sag locations, assume that they are blocked 50% by debris and size them accordingly.

At locations where significant ponding may occur (e.g., underpasses or sag vertical curves in depressed sections), an inlet at the low point in the sag with flanking inlets on each side of the lowest inlet are required to provide relief from debris. As much as possible, sumps should be designed so that only the roadway drainage in the area of sump will contribute drainage to the lowest inlets.

Inlets are required at locations needed to collect runoff in conformity with design criteria in Section 13.2. 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 bypass. Examples of such locations include:

- All sag points in the gutter grade;
- Upstream of median breaks, entrance/exit ramp gores and crosswalks;
- Immediately upstream of bridge approaches;
- Immediately (~10 ft) upstream of superelevation transitions (cross-slope reversals);
- Immediately upstream of intersecting streets; and
- Immediately upstream on intersecting streets before storm runoff reaches the major highway.

Inlets should not be located in a path where pedestrians are likely to walk.

Inlets should be placed on tangent curb sections before the curb radius to avoid potential damage from large vehicles driving over the curb return. If an inlet has to be placed in the curb radius, the panline and inlet should be depressed to keep water in the gutter. Gutter profiles should be shown in the plans for all these locations. The use of a sidewalk chase (or curb chase) is discouraged due to maintenance issues.

Grated-inlet design must consider potential for obstruction by debris. The designer must evaluate a grate's geometry, location, debris potential, and adverse effects resulting from clogging. Experience and information about area drainage 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 13.2 may be used to determine flow reductions due to potential clogging of small grates. This table is not valid for culvert inlet grates.

Table 13.2 Capacity Reduction of Small Inlets Due to Debris

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

Approximately 70% to 80% of the design flow should be intercepted. Only part of the flow bypassing an inlet is added to the total for the next inlet, typically 50% of the bypass flow.

Using the concept of first-flush volume, UDFCD (2016) has developed an empirical decayed clogging factor when multiple inlets are used. This was to account for the fact that upgradient units of the inlet would be more susceptible to clogging. According to this approach, the single unit clogging factors are asymptotically reduced by a factor of 0.49 for 4 grate inlets and by a factor of 0.25 for 8 grate inlets. For curb opening inlets, for successive 20 percent curb opening lengths (L/5, 2L/5, 3L/5, 4L/5, L, etc.), the clogging coefficients are asymptotically reduced by factors of 1, 0.63, 0.44, 0.33, 0.26, up to 1.33/N (where N is defined as number of curb openings, L/5). According to UDFCD criteria, since the interception of an inlet on a grade is proportional to the inlet length, and, in a sump, is proportional to the inlet opening area, the clogging factor should be applied to inlet length or inlet area, accordingly.

13.3.5 Inlet Capacities

The main hydraulic criteria for inlet location design are the spread width, and inlet interception rate for the minor design storm. 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 depth, spread width, and interception rate for inlets commonly used by CDOT. The nomographs may only be used for certain sizes of inlets on continuous grades, and with specific cross slopes. For other situations, or for unique inlets, the designer must develop their own spreadsheets or nomographs based on criteria in Federal Highway Administration's *HEC 12, HEC-22,* or in the *Urban Drainage and Flood Control District Criteria Manual.*

Most recently, based on an extensive laboratory modeling study at Colorado State University, Guo and MacKenzie (*Urban Drainage and Flood Control District's Urban Storm Drainage Criteria Manual, USDCM 2016*) have found out that HEC-22 methodology on the average over-predicted the hydraulic efficiency of CDOT Type 13 inlet by an average of 20% and under-predicted the hydraulic efficiency of CDOT Type R inlet by 7 percent. These findings are reflected in UDFCD's charts and UDINLET software.

For inlet capacity equations for a specific inlet type and location, and for capacity computation examples, refer to the Volume 1, Chapter 7 of the *USDCM (2016),* the AASHTO *Drainage Manual,* FHWA's *HEC 12* or *HEC 22*. For CDOT Type C sump inlets, a nomograph is given in Appendix A. The CDOT Type R curb open inlet can intercept 1 cfs/ft of flow on a continuous slope, assuming 0.5 ft of ponding.

For major storm drain design, the designer must calculate depth and extent of flow into the street along with the flow intercepted by the inlets. A nomograph is provided in Appendix A that uses Manning's equation to calculate major-storm street capacity. The compound curb and gutter section with a depressed gutter should be used in calculations and for design as the depression in the gutter provides a significant increase in gutter capacity.

13.3.6 Storm Drains

Storm drains should be designed with future development or extension in mind if it is appropriate. The number of outfalls should be consolidated, and attention given to ensure that the potential for erosion is minimized.

The minimum pipe diameter for storm drain lines is 18 in. A 15-in minimum pipe diameter for laterals may be used to avoid utility conflicts or to meet cover requirements.

A minimum velocity of 3 ft/s is desirable in the storm drain to prevent sedimentation from occurring in the pipe.

Design the trunk line and lateral to convey runoff intercepted by the inlets. Surcharging may be allowed if accounted for in the design analysis. A hydraulic-grade-line analysis, including minor and major losses, should be performed for systems having large potential for junction losses.

Watertight joints are required for storm drainage pipes, inlets and manholes.

13.3.7 Maintenance Access (Manholes)

Manholes allow access to continuous underground storm drains for inspection and clean out. Where feasible, grate inlets should be used rather than manholes. When access to the system is provided at a grate inlet instead of at a manhole, additional storm-water interception is achieved with minimal additional cost.

Typical locations where maintenance access should be provided are:

- Where two or more storm drains converge;
- At intermediate points along tangent sections for maintenance access, as shown in Table 13.3; and
- At changes in pipe size, elevation and grade, alignment, or pipe material.

Maintenance access should not be located in traffic lanes, bike lanes and pedestrian pathways. If it is impossible to avoid locating a maintenance access in a traffic lane, care must be taken to insure it is not in the normal vehicle-wheel path.

Table 13.3 lists maximum spacing based on pipe size.

Table 13.3 Maintenance-Access Spacing

Size of Pipe, in	Maximum Distance, ft
≤ 48	300
> 48	600

13.3.8 Concrete Median Barrier

Concrete median barrier (CDOT Type 7 guardrail) is commonly used to separate opposing lanes of traffic on divided highways. Where median concrete barriers are used, particularly on horizontal curves associated with superelevations and in sag vertical curves, it is necessary to provide a means of drainage for water which accumulates against the barrier during major storms. This can be done on roads with 1 or 2 lanes of traffic each way with an opening slot in the concrete barrier as shown in Figure 13.1. Even with slots, ponding and closure of the highway can be expected where barriers crossing sag vertical curves are over-topped from major-drainage basins. The orifice and weir equations, assuming 50% debris blockage, must be used to analyze the number of slots required at any location.

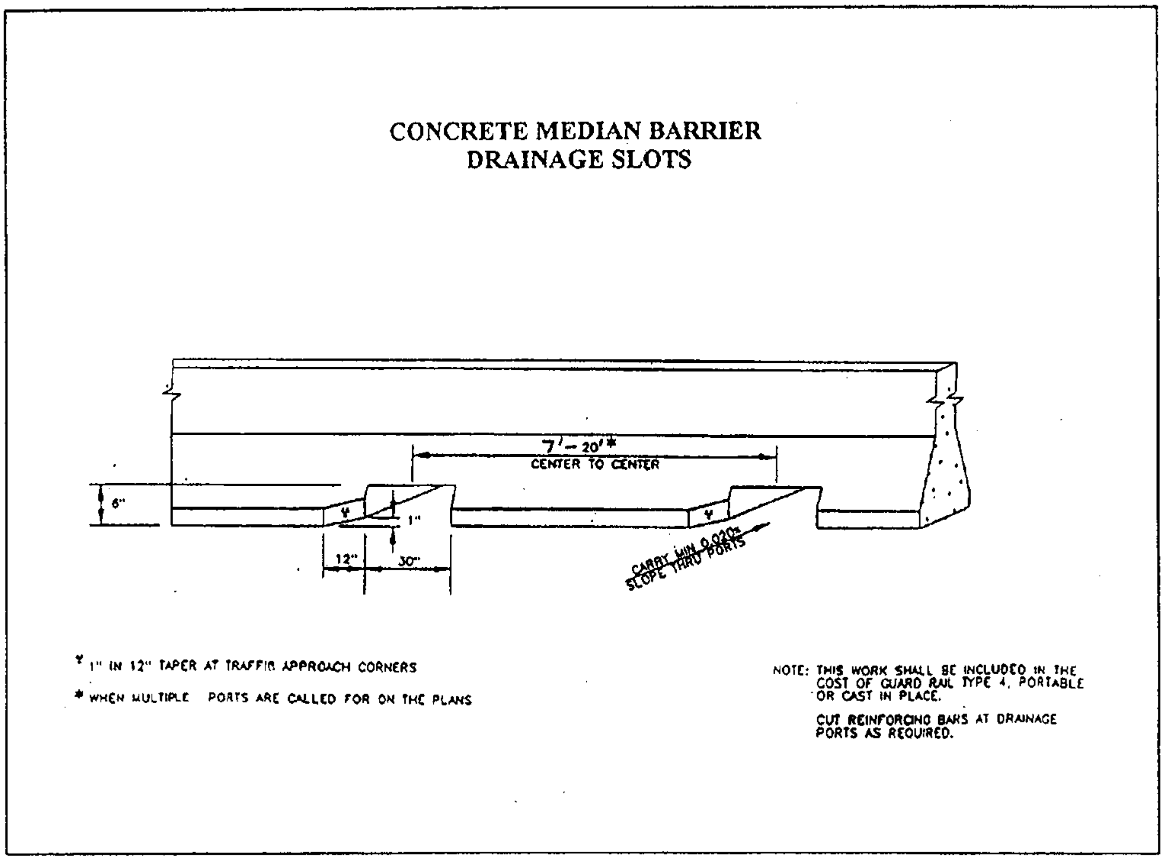

Figure 13.1 Concrete Median Barrier Drainage Slots

13.4 SOFTWARE FOR DESIGNING STORM DRAINAGE SYSTEMS

Essentially, a storm drainage system collects surface drainage with inlets and transports the water collected to an outfall in a system of pipes, the storm drain. Software is available for evaluating inlets, such as the FHWA Hydraulic Toolbox Curb and Gutter Calculator, or for evaluating an entire system, such as WMS or StormCAD. It should be noted that neither the FHWA Hydraulic Toolbox nor WMS includes a circular deck drain in their curb-and-gutter calculators. Current software for designing storm-drainage facilities is listed in Table 13.4. The software listed is public domain software, or software CDOT has purchased.

Table 13.4 Software for Designing Storm Drains

Software Name	Features	Source
FHWA Hydraulic Toolbox	The FHWA Hydraulic Toolbox Program is a stand-alone suite of calculators that perform routine hydrologic and hydraulic computations (see the Software section of Chapter 8 – Channels). The curb and gutter analysis feature can be used to size inlets.	FHWA website
WMS Curb and Gutter Calculator	The curb and gutter calculator is a feature of the WMS Hydrologic Modeling Module (see the WMS discussion in the Software section of Chapter 7 – Hydrology). Select "Calculators" on the menu tool bar to display available calculators. The curb and gutter calculator determines the width of spread for a given discharge, or the discharge for a given spread.	Aquaveo website
WMS Storm Drain	After the Map Module has been selected, an entire storm-drain model can be developed from the storm drain and optional-drainage coverages. The storm-drain coverage is used to define a pipe-network system and the attributes associated with each node. The storm-drain coverage can be connected to a surface-drainage coverage to pass the computed hydrograph to the linked nodes, or the specified Rational Method parameters may be used.	Aquaveo website
StormCAD	StormCAD is commercially-available software for design and analysis of storm-drain systems using a peak-flow (Rational Method) approach. StormCAD performs calculations for catchment runoff, gutters, inlets, conduit networks, and outfalls. Inlet capacity is calculated according to the methods described in HEC 22, 3rd Edition. Alternately, users can enter a maximum capacity, percent efficiency, gutter-flow-capture curve, or gutter-depth-capture curve to define the capacity of an inlet. A number of different methods are available for computing headloss at junctions, including HEC 22, flow-headloss curve, standard method, and generic method.	Bentley.com

The software shown in Table 13.4 are updated periodically. The most recent versions of these software are recommended for use. For current versions of software and documentation, the hydraulic engineer should consult the software source.

Available user and reference manuals are listed in the references. Additionally, many software developers provide extensive help within the software to supplement user's manuals.

REFERENCES

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4. Bentley, StormCAD V8i, "Easy Storm Sewer Design and Modeling."
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6. Federal Highway Administration, *Design Charts for Open Channel Flow,* Hydraulic Design Series No. 3, FHWA-EPD-86-102, U.S. Department of Transportation, Washington DC, 1961.
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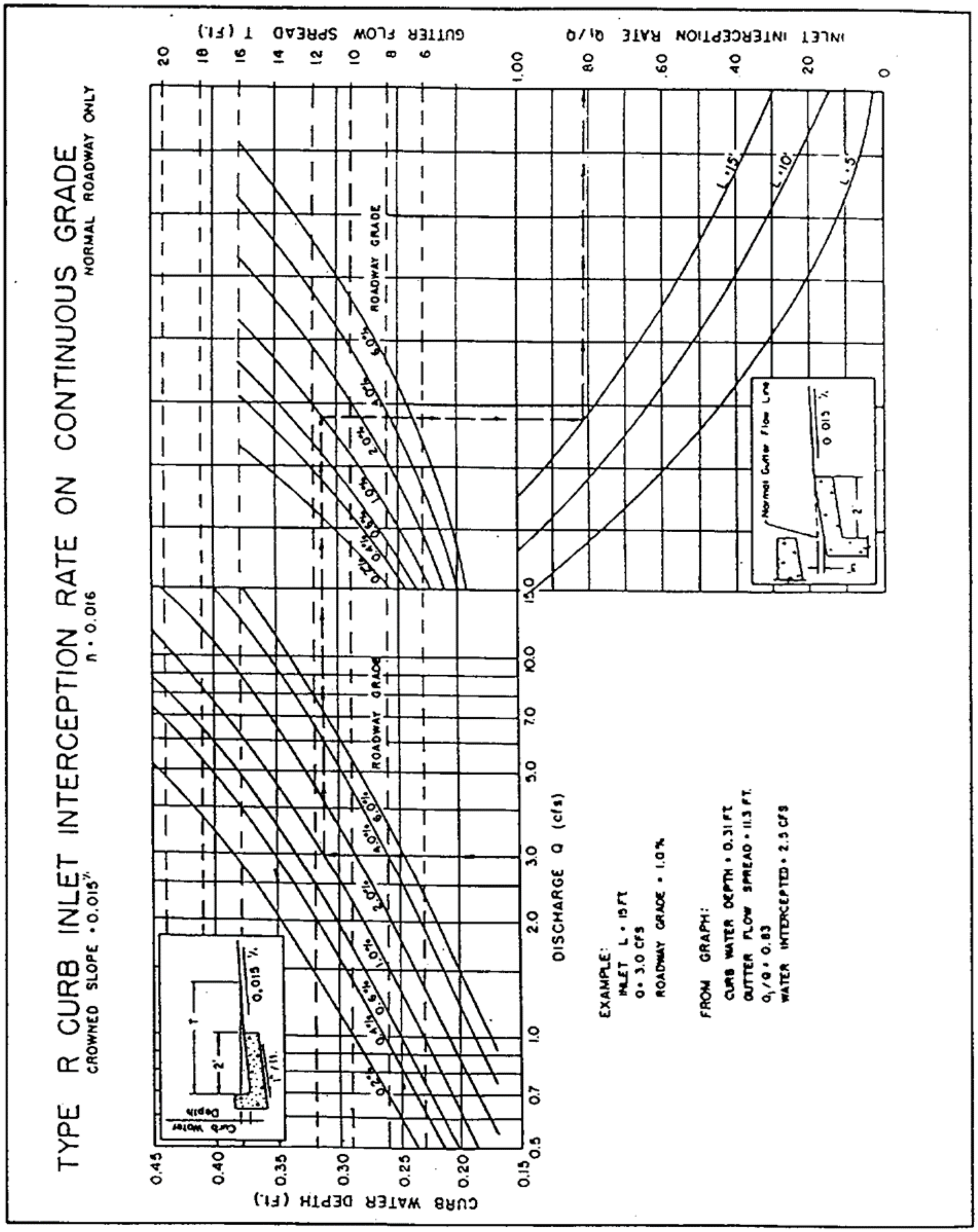
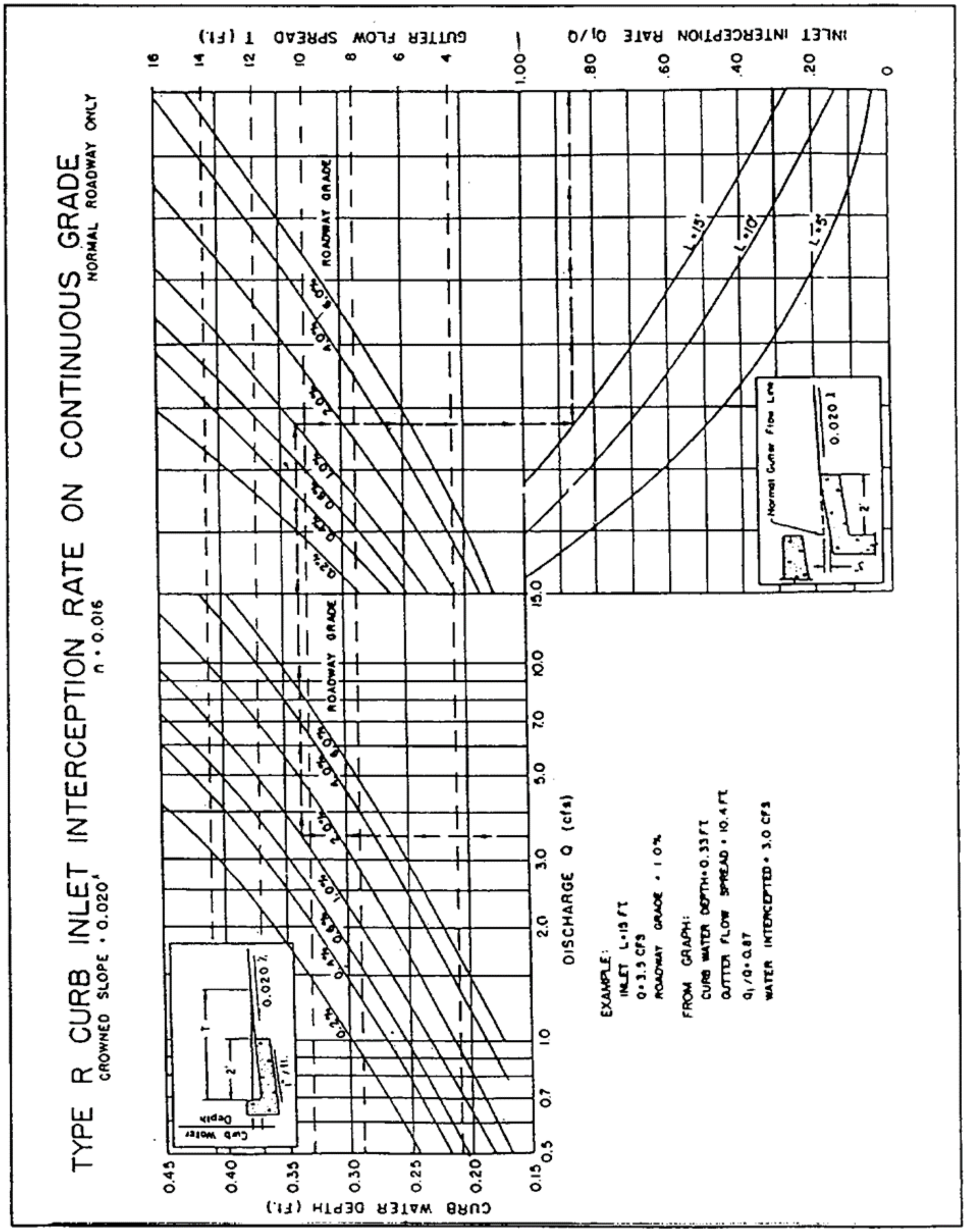
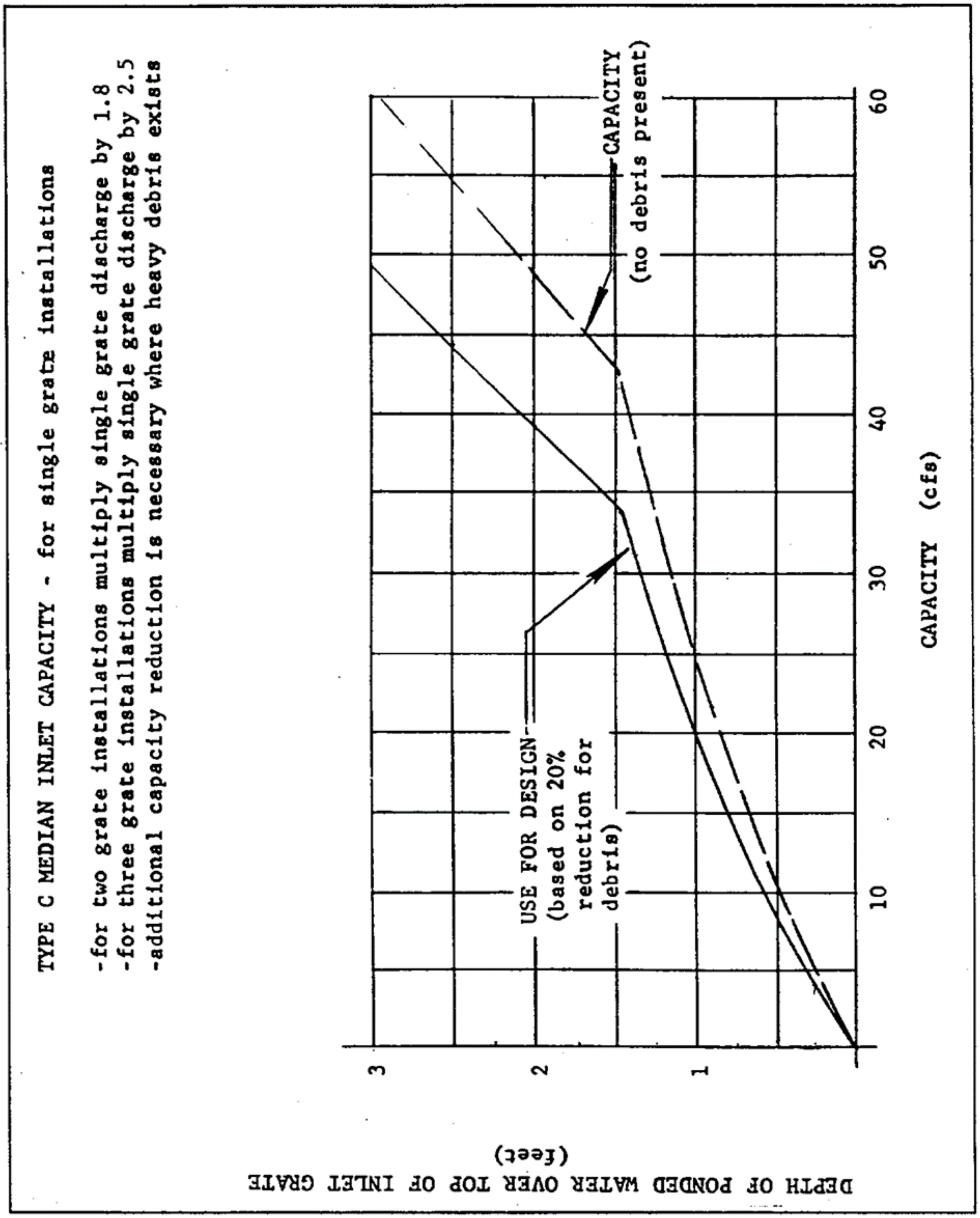
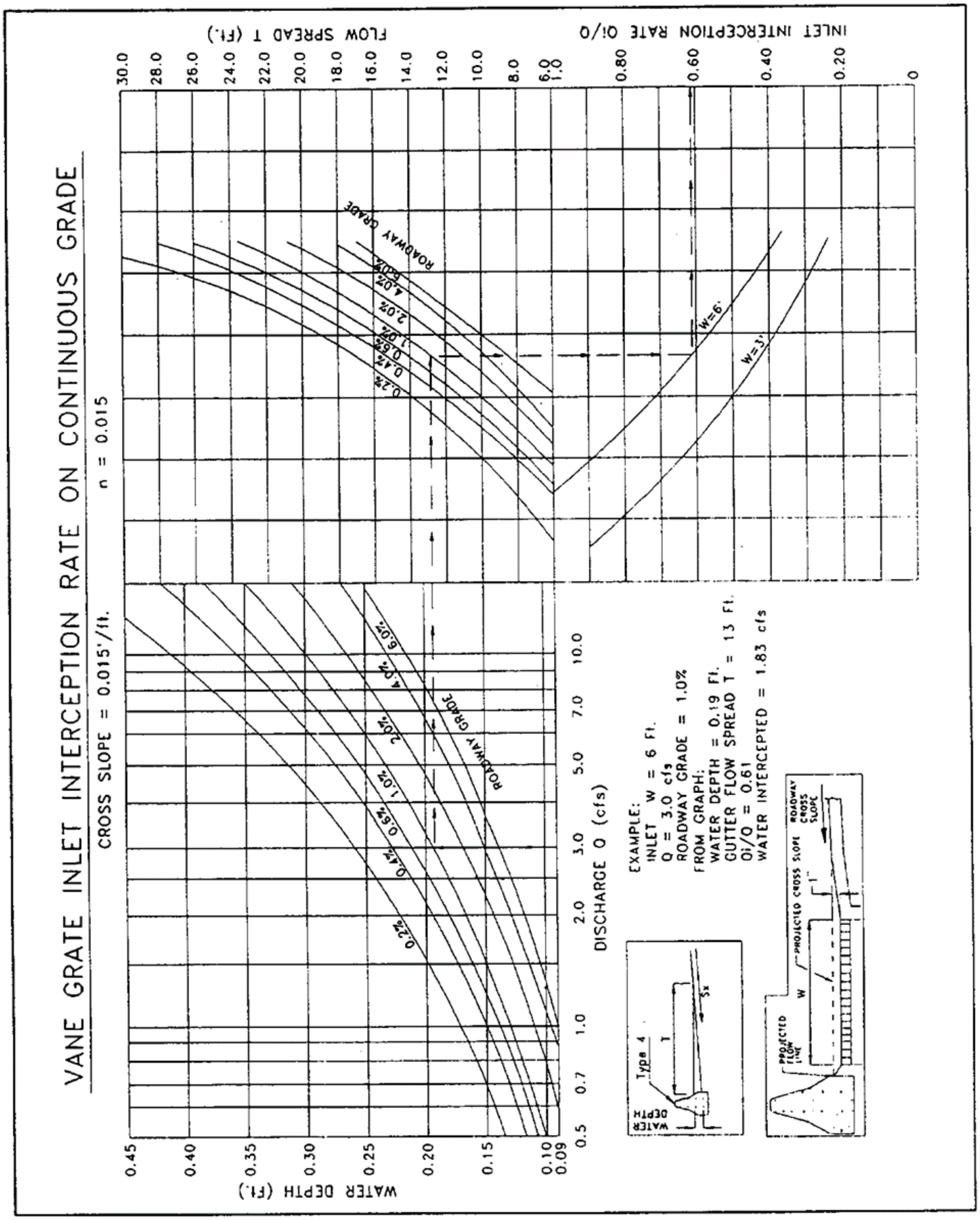
APPENDIX A - DESIGN NOMOGRAPHS

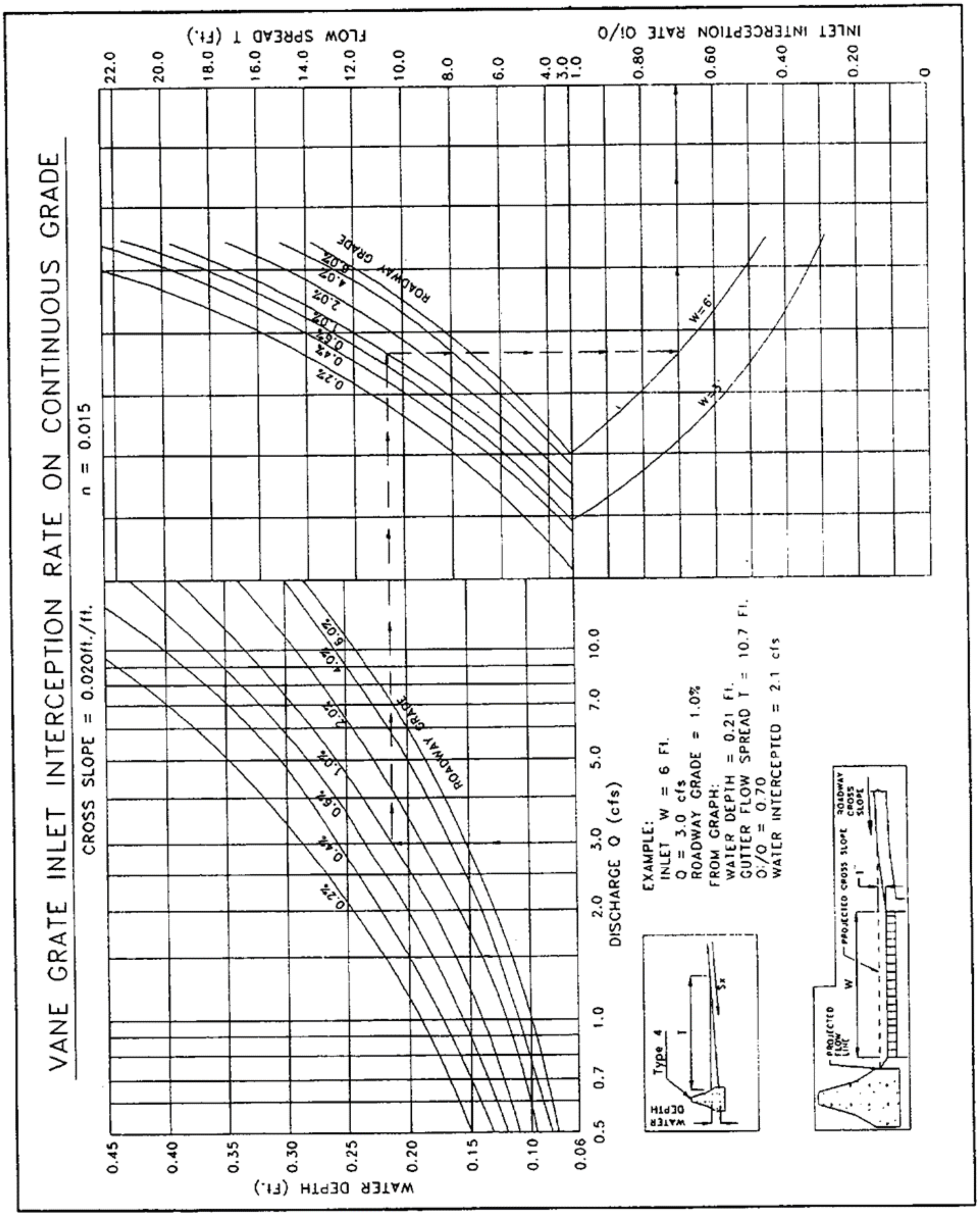


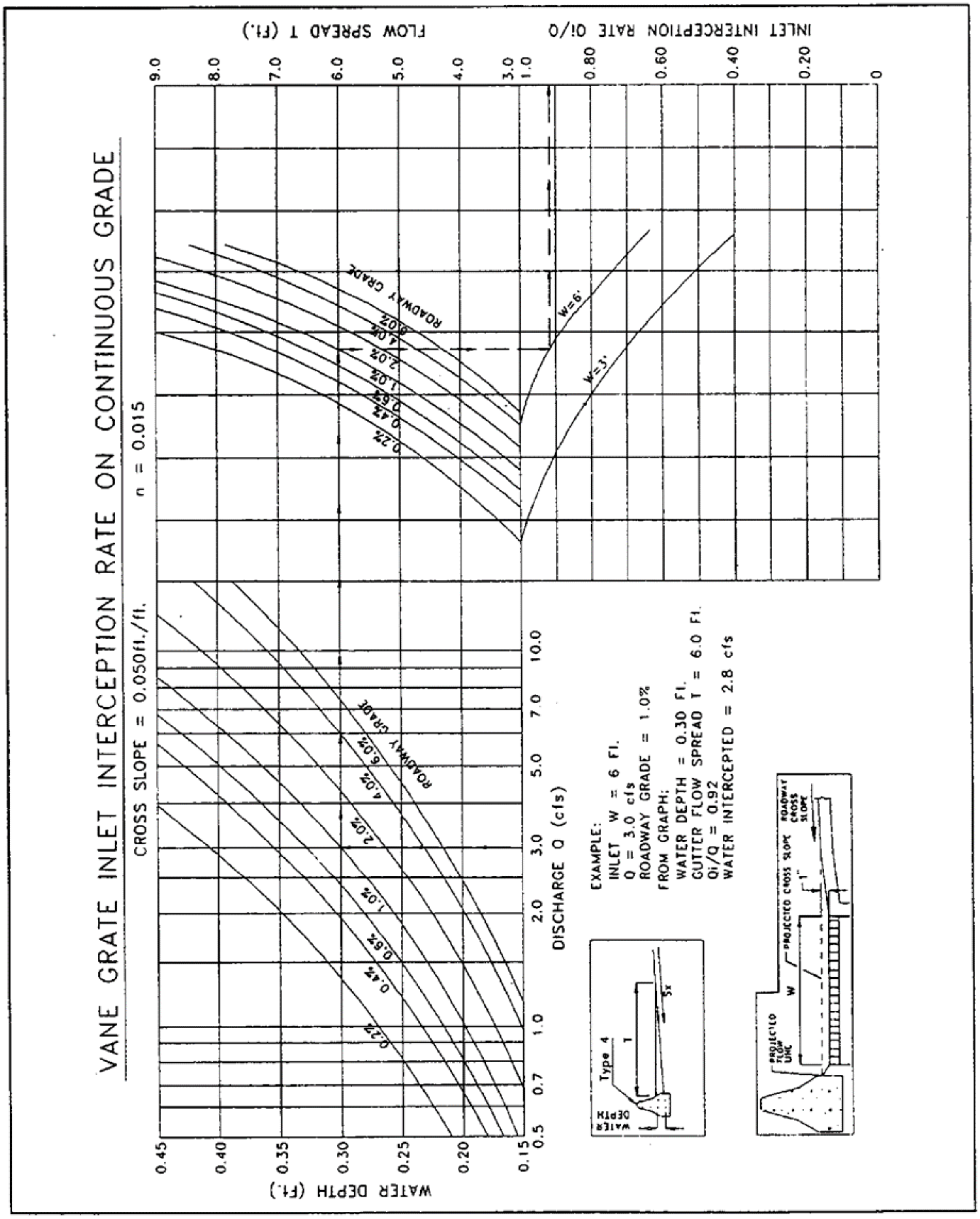

TYPE R CURB INLET INTERCEPTION RATE ON CONTINUOUS GRADE
CROWNED SLOPE = 0.020'
n = 0.016
NORMAL ROADWAY ONLY
CURB WATER DEPTH (Ft.)
GUTTER FLOW SPREAD T (Ft.)
INLET INTERCEPTION RATE Qi/Q
DISCHARGE Q (cfs)
ROADWAY GRADE
L=15'
L=10'
L=5'
Curb Water Depth
0.020 %
Normal Gutter Flow Line
EXAMPLE:
INLET 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)
10
20
30
40
50
60
CAPACITY (cfs)
1
2
3
DEPTH OF PONDED WATER OVER TOP OF INLET GRATE
(feet)


VANE GRATE INLET INTERCEPTION RATE ON CONTINUOUS GRADE
CROSS SLOPE = 0.015'/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 = 0.19 Ft.
GUTTER FLOW SPREAD T = 13 Ft.
Qi/Q = 0.61
WATER INTERCEPTED = 1.83 cfs
Type 4
WATER DEPTH
PROJECTED FLOW LINE
PROJECTED CROSS SLOPE
ROADWAY CROSS SLOPE


VANE GRATE INLET INTERCEPTION RATE ON CONTINUOUS GRADE
CROSS SLOPE = 0.020ft./ft.
n = 0.015
FLOW SPREAD T (Ft.)
INLET INTERCEPTION RATE Qi/Q
WATER DEPTH (Ft.)
DISCHARGE Q (cfs)
ROADWAY GRADE
0.2%
0.4%
0.6%
1.0%
2.0%
4.0%
6.0%
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
T
Sx
PROJECTED FLOW LINE
W
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
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
PROJECTED CROSS SLOPE
ROADWAY CROSS SLOPE
PROJECTED FLOW LINE