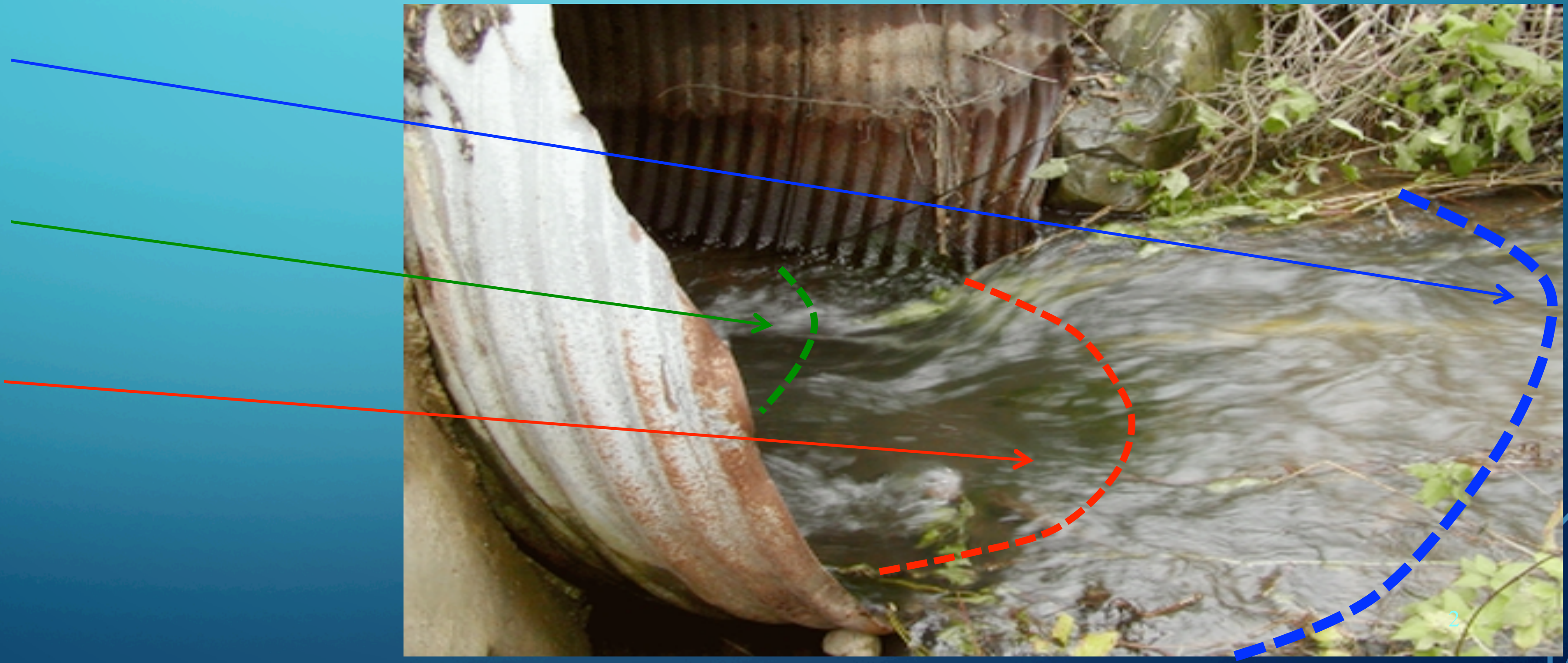
CE 3372 WATER SYSTEMS DESIGN

LESSON 16: STORM SEWERS, INLETS, AND CONDUITS

REVIEW

- Supercritical, Critical, or Subcritical



- Location A ?
- Location B ?
- Location C ?

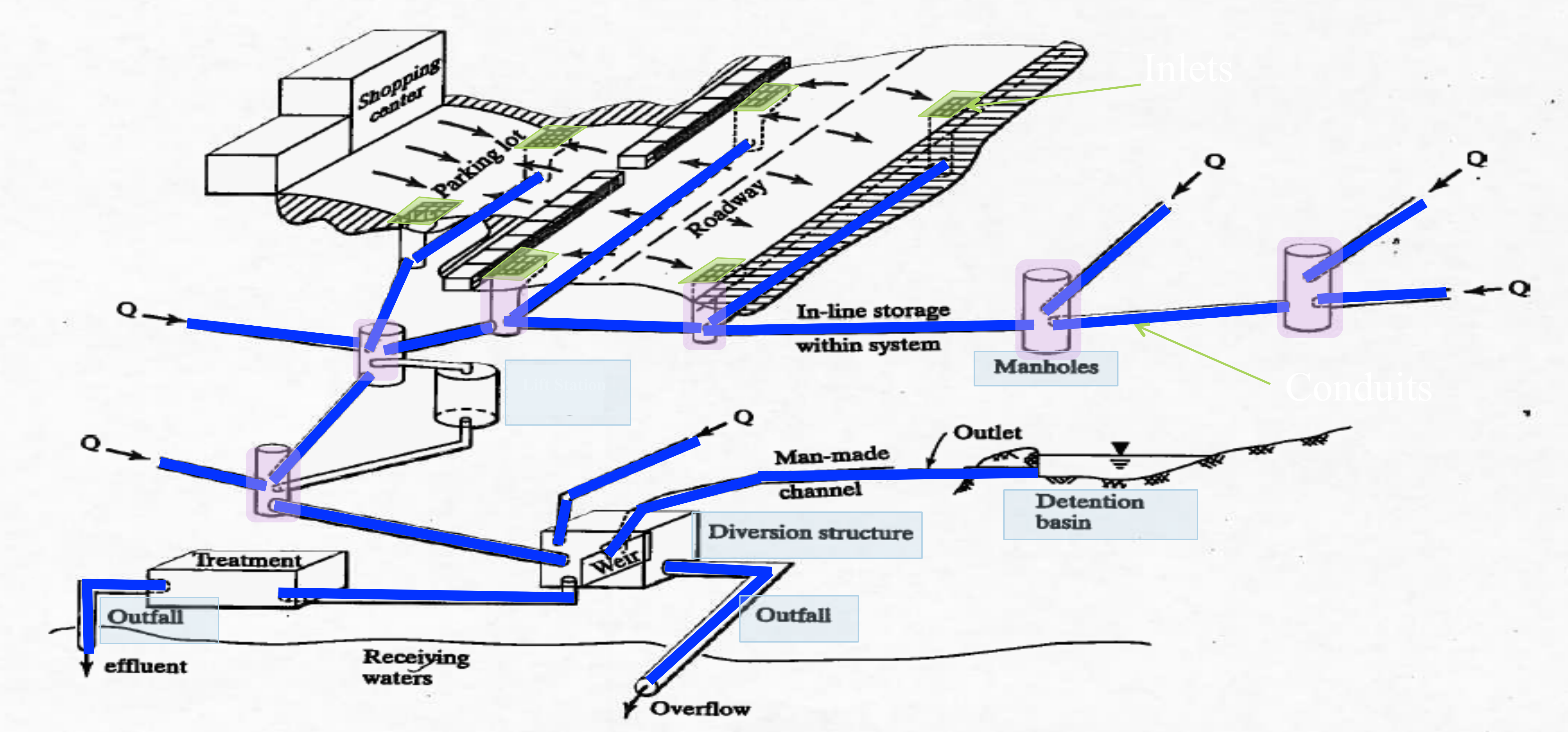
OUTLINE

- Storm sewer overview
- Inlets
  - Design using FHWA methods
    (as specified in TxDOT Hydraulic Design Manual)
  - Representative of typical design computations involved, change to fit your jurisdiction

STORM SEWERS

- Inlets to capture runoff
- Conduits to convey to outfall
  - Lift Stations if cannot gravity flow to outfall
  - Detention and diversions
- Outfall release back into environment

STORM SEWER SYSTEMS



STORM SEWER INLETS

- Spread width
- Combination Inlet
  - Curb+Grate
- Carryover
  - Flow that passes beyond the inlet (none in this picture – complete capture)

STORM DRAINS

- A storm drain is a system of curbs and gutters, inlets, and pipe networks that receives runoff and conveys it to some point where it is discharged into a pond, channel, stream, or another pipe system.

- A storm drain may be comprised of a closed-conduit, an open conduit, or some combination of the two

DESIGN CHALLENGES

- Drainage in urban areas is challenging because of:
  - Heavy traffic and subsequent higher risks
  - Wide roadway sections
  - Relatively flat grades, both longitudinal and transverse
  - Shallow water courses
  - Absence of side ditches
  - Concentrated flow

DESIGN CHALLENGES

- Drainage in urban areas is challenging because of:
  - *Potential for costly property damage from water ponding or flow through built-up areas*
  - Roadway section must carry traffic and serve as a channel to carry water to a discharge point
  - Limited ROW to place drainage infrastructure
  - Outfalls not convenient
  - Infrastructure impacts multiple jurisdictions
  - Water quality

STORM DRAIN DESIGN

- Establish design parameters and criteria
- Decide layout, component location, and orientation
- Use appropriate design tools
- Comprehensive documentation
- The process is iterative

STREETS AND FLOW IN STREETS

- Curb-and-gutter sections

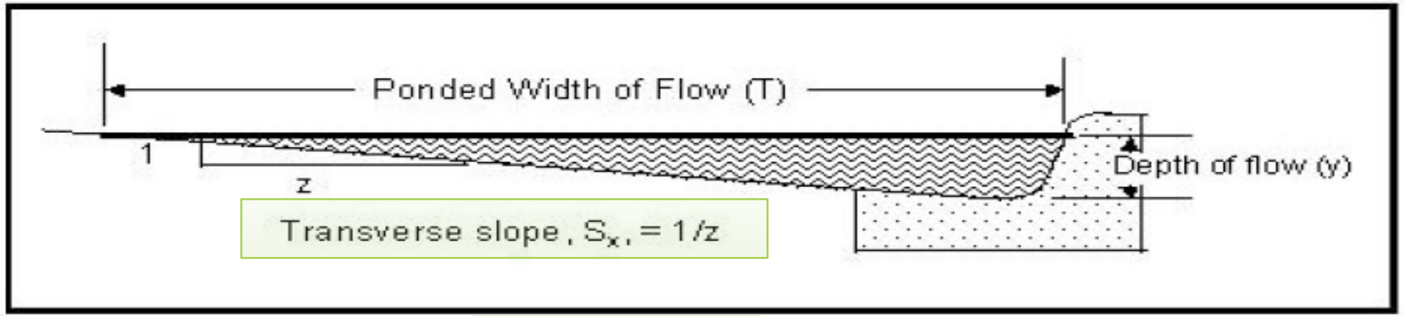
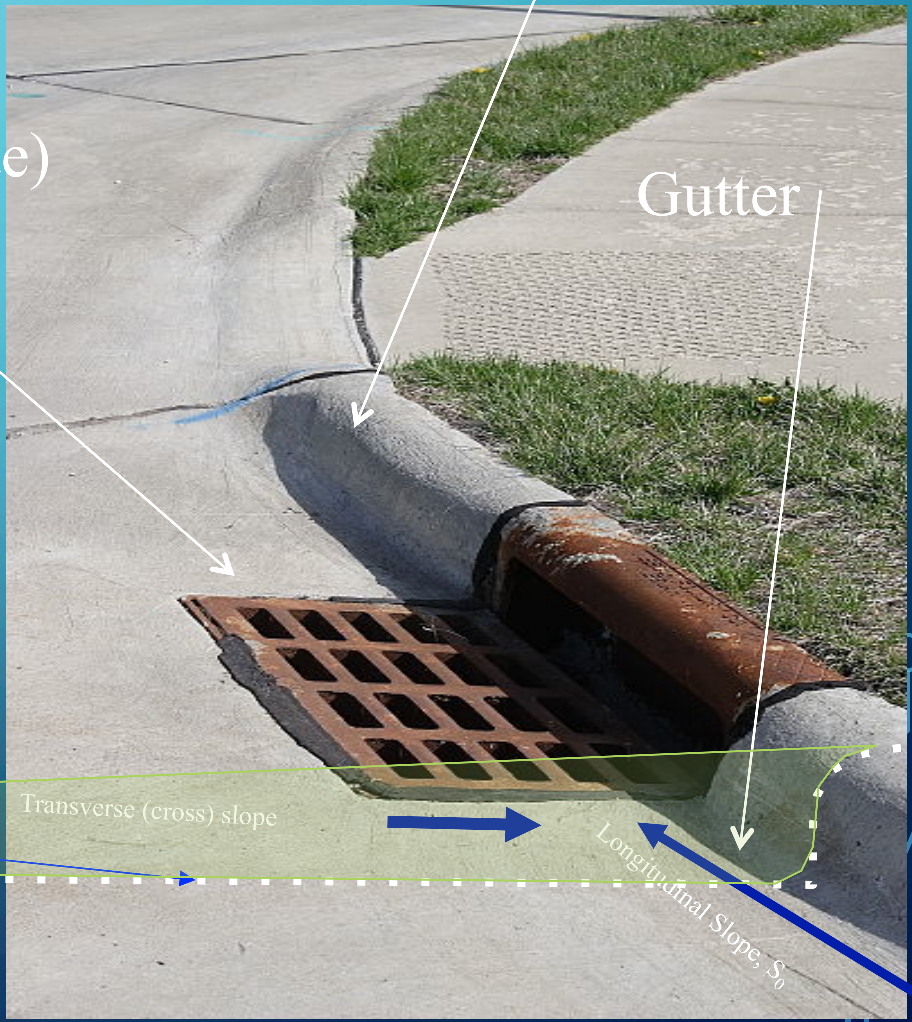


Figure 10-2. Gutter Flow Cross Section Definition of Terms



STREETS AND FLOW IN STREETS

- Ditch sections

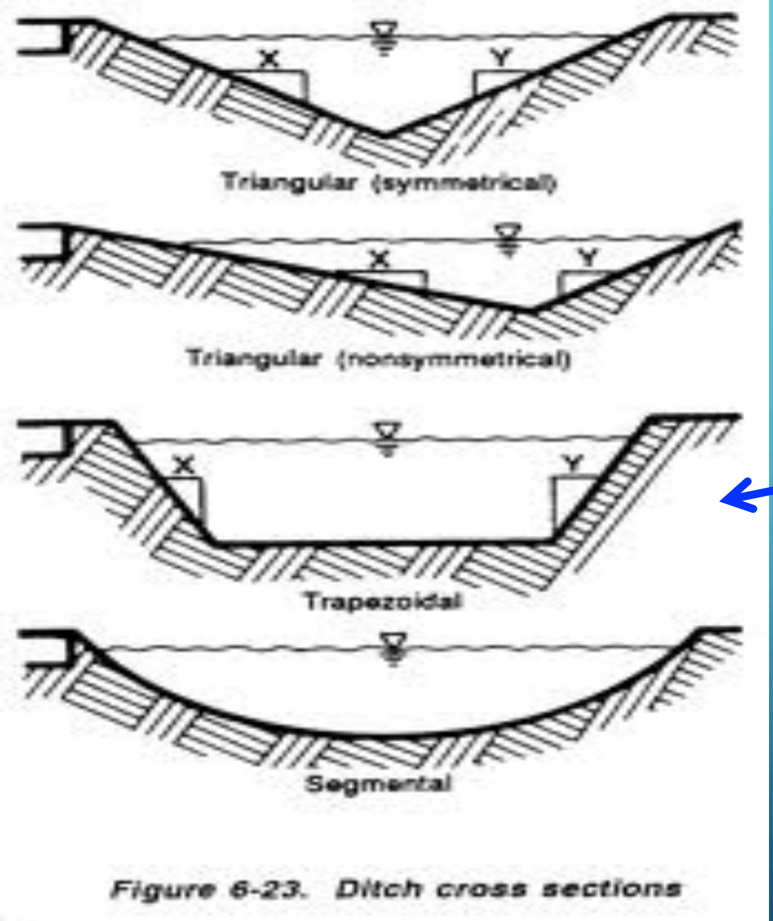


Figure 6-23. Ditch cross sections

STREETS AND FLOW IN STREETS

- Flow in curb-and-gutter sections

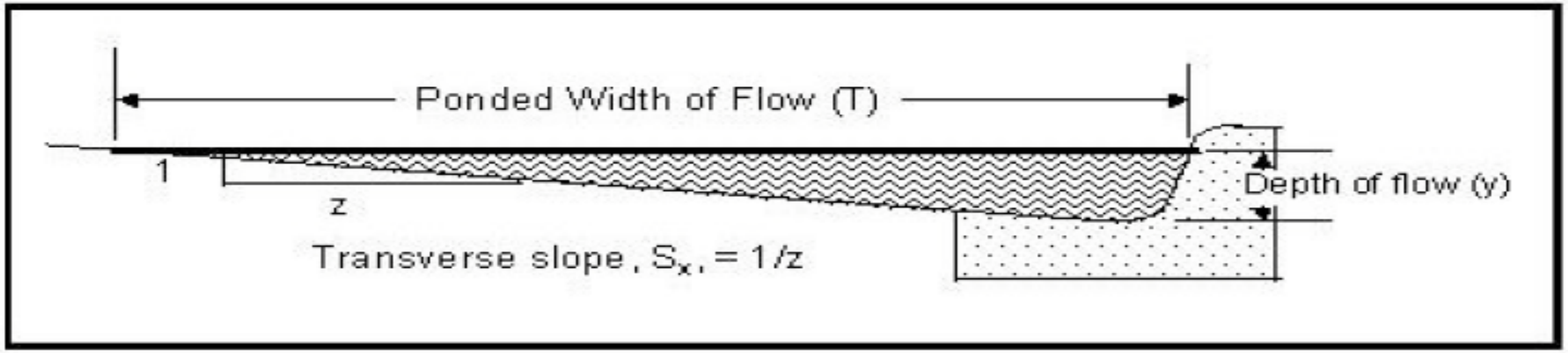


Figure 10-2. Gutter Flow Cross Section Definition of Terms

$$y = z\left(\frac{QnS_x}{S^{1/2}}\right)^{3/8}$$

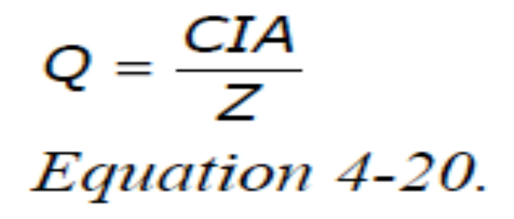
Equation 10-1.

$$T = 1.24\left(\frac{Qn}{S_x^{5/3}S^{1/2}}\right)^{3/8}$$

Equation 10-4

RATIONAL & MODIFIED RATIONAL

- The “Rational Equation” is an equation that is used in the vast majority of urban storm drain designs.
- The basic equation (HDM) is:



$$Q = \frac{CIA}{Z}$$

Equation 4-20.

  - Z is a dimensions correction coefficient
  - C is a “runoff coefficient”
  - I is rainfall intensity for an appropriate duration and frequency
  - A is contributing area, in acres.

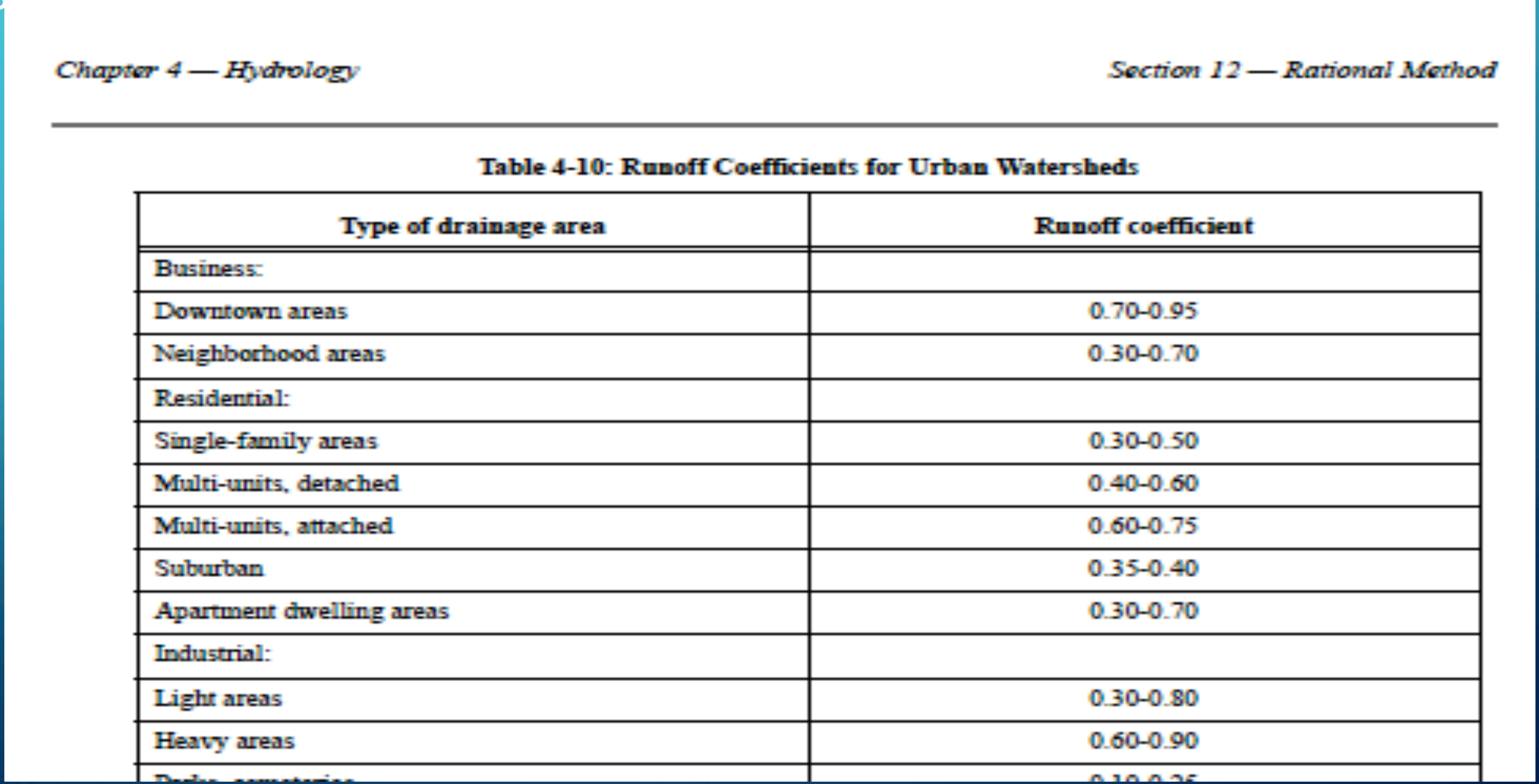
INTENSITY-DURATION-FREQUENCY

- Intensity is the ratio of an accumulated depth to some averaging time usually the time of concentration.
- Called “inlet time” for inlet design.

$$i_{avg} = \frac{D}{T_C}$$

RUNOFF COEFFICIENTS

- Runoff coefficients are tabulated, and selected from a land use description

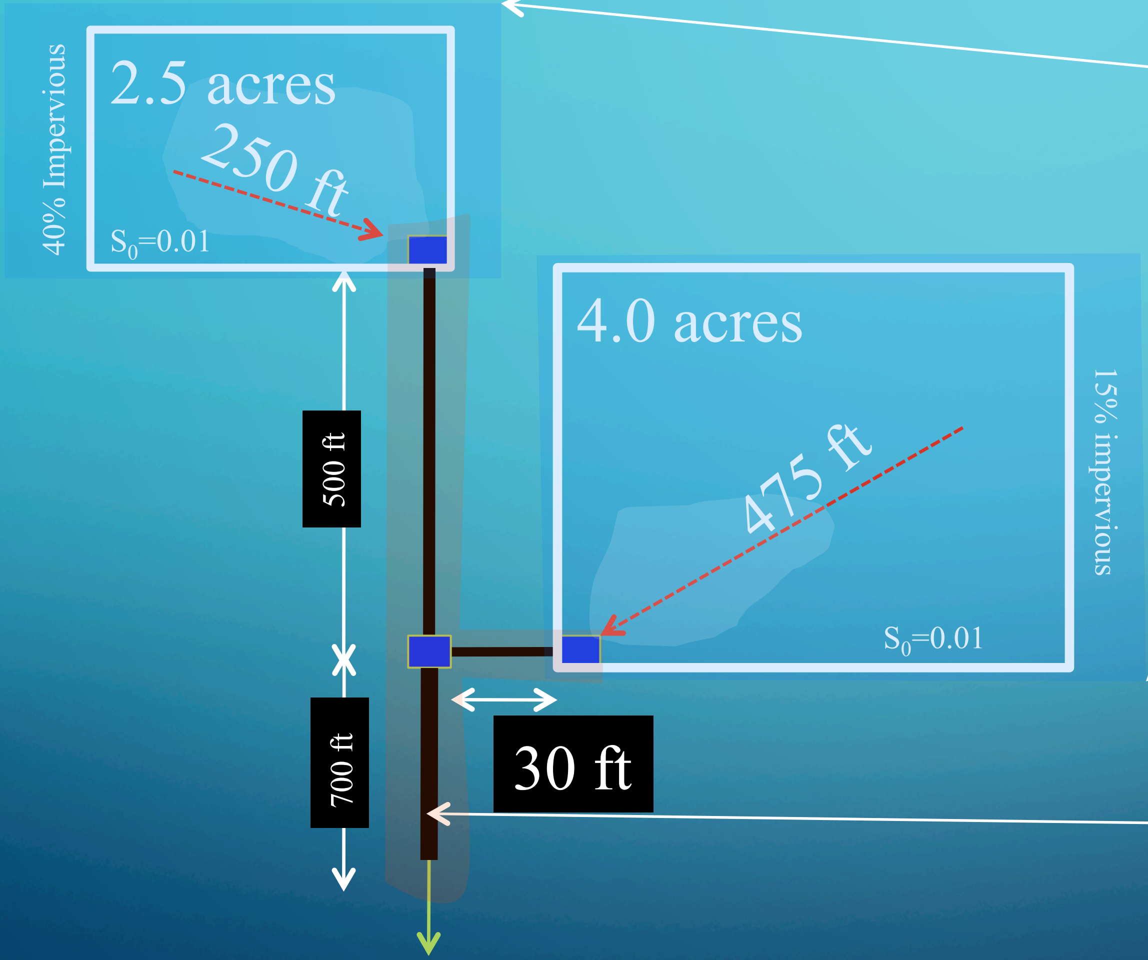


Chapter 4 — Hydrology *Section 12 — Rational Method*

Table 4-10: Runoff Coefficients for Urban Watersheds

Type of drainage area	Runoff coefficient
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25

TC APPLIES WHERE?



Use NRCS or Kerby-Kirpich;
channel flow only if appropriate

Travel time based on conduit hydraulics

CURBS

- Curbs are the usual roadway bounding feature in urban areas.
  - Vary in height from negligible to as much as 8 inches

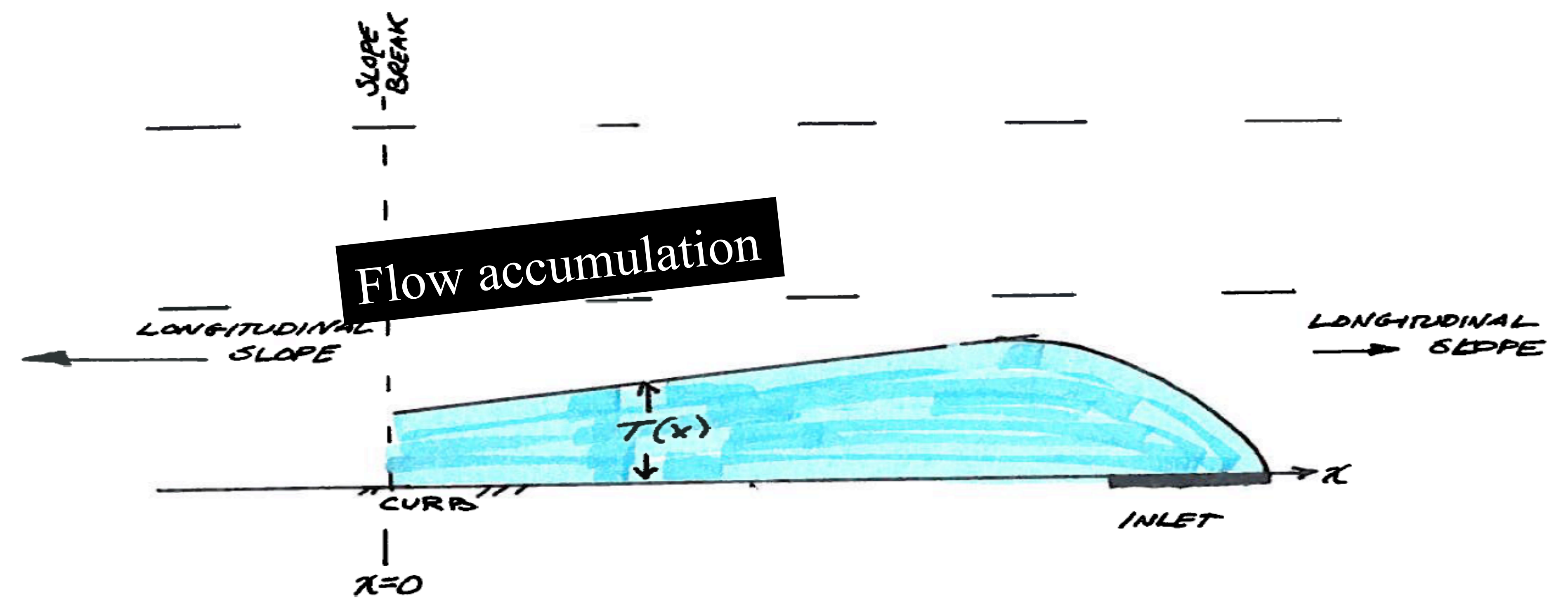
- Curbs serve multiple purposes
  - Minor redirection for errant vehicles
  - Bounding feature for water running in the roadway as an open channel

- Curbs provide constraint that allows them to become a part of inlets.

ROADWAY PONDING WIDTH

- The primary design criterion for urban storm drainage systems is usually "ponded width" in the roadway
    - Ponded width is the width of the roadway covered by ponded water
    - What remains is considered usable roadway
- The portion with water ponded is considered to be a traffic hazard
- In the design process, each side of the roadway must is considered separately with respect to ponding.

INCREASE IN PONDED WIDTH

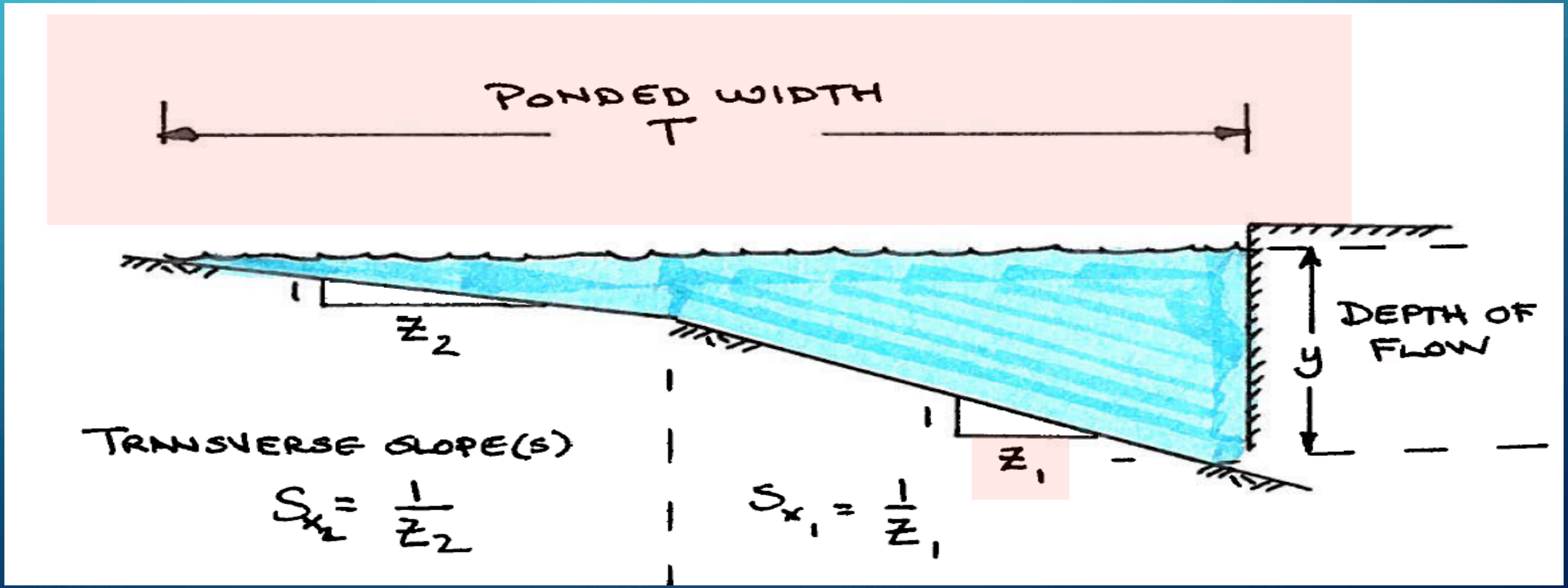

Flow accumulation

VELOCITY AND TRAVEL TIME

- As average velocity of contribution increases, travel time for a given distance decreases
- All other things being equal, as travel time decreases, critical duration decreases, and the intensity associated with it increases

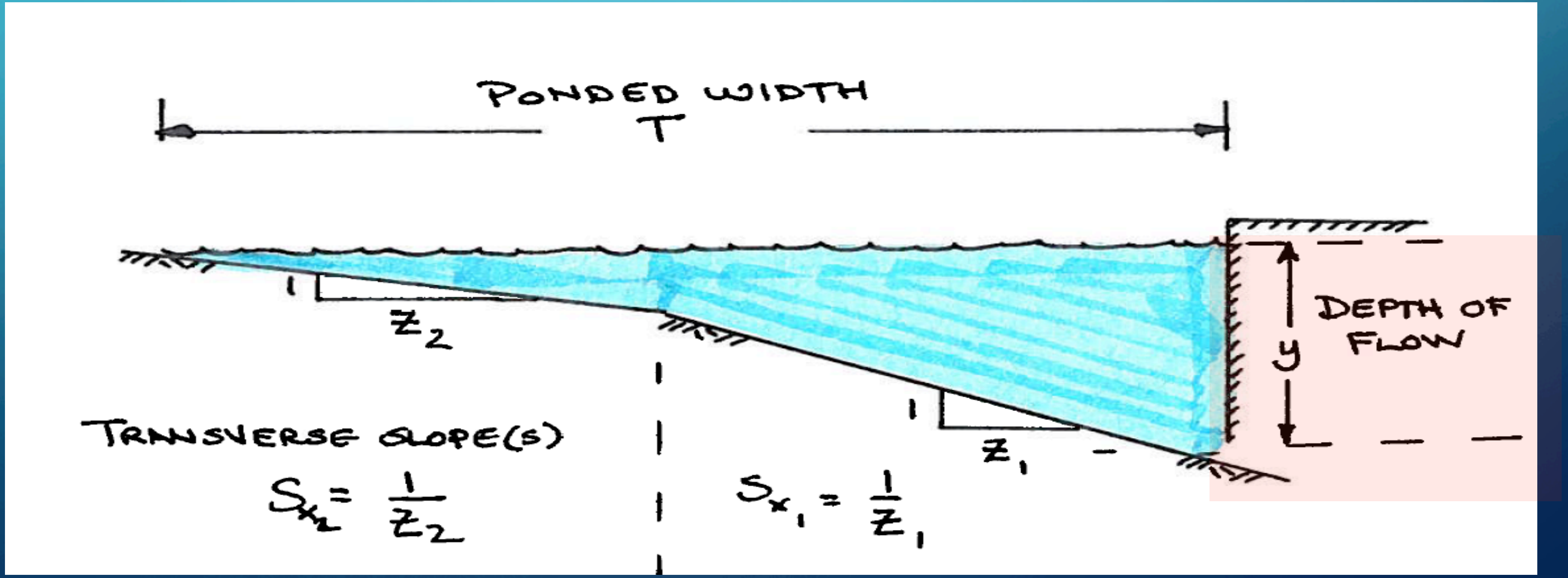
PONDED WIDTH

- Ponded width computations will usually involve all "Z" values in the typical section.
- Z_1 is usually the slope closest to the curb and gutter.



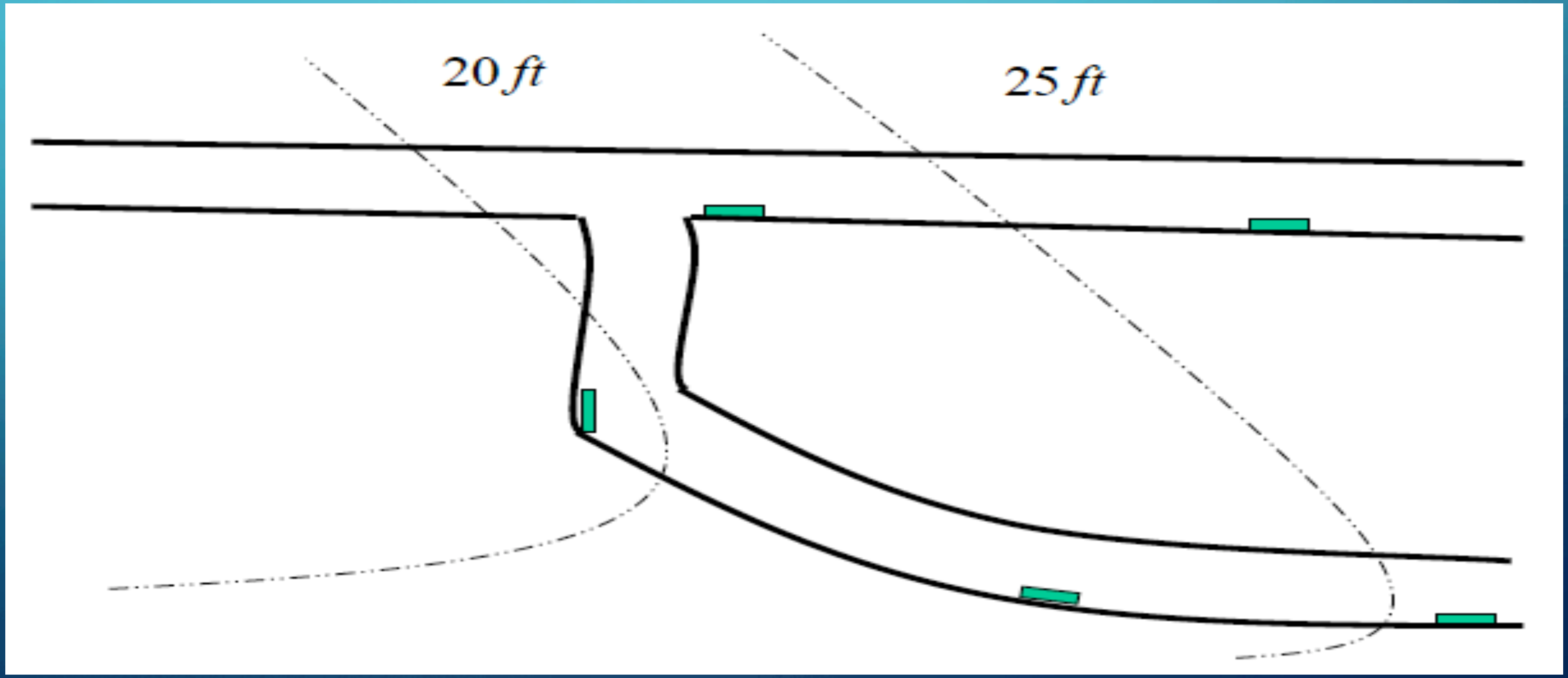
PONDED DEPTH

- Ponded depth is the depth at the curb (or edge).
- If at an inlet, the depth would be measured from the lip of the inlet.



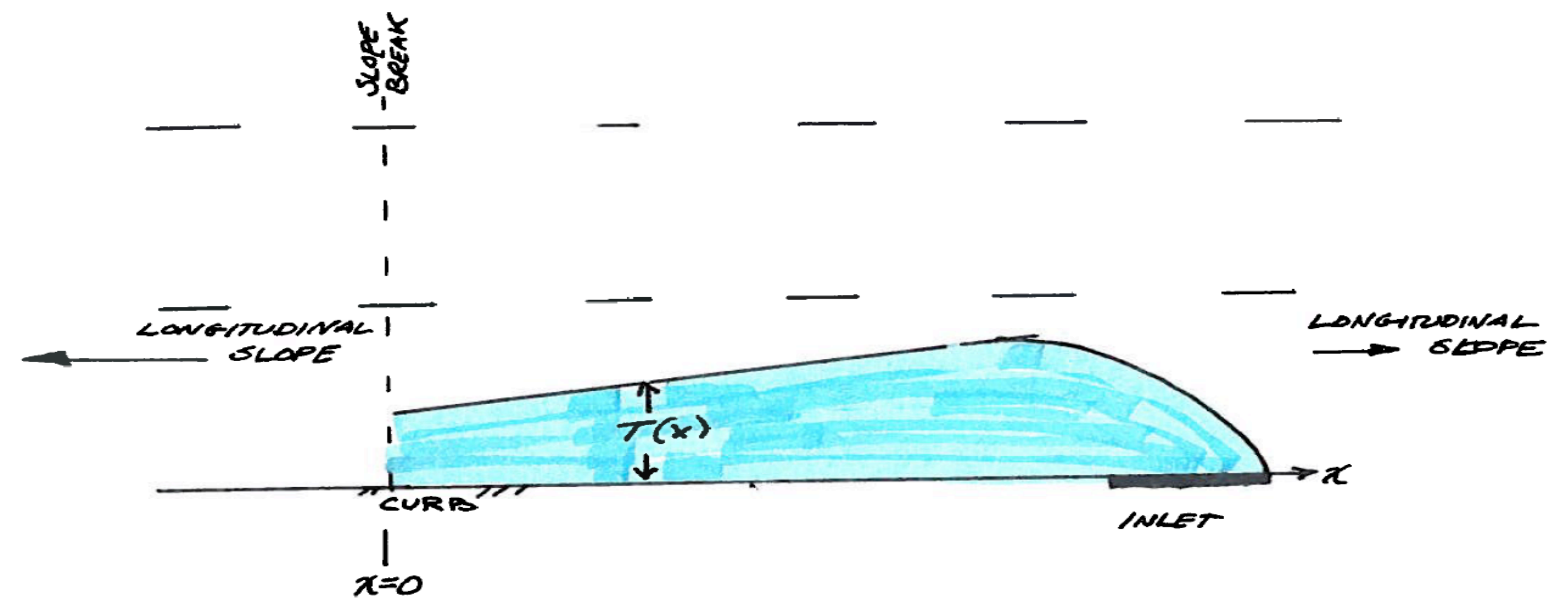
INLET PLACEMENT TO REDUCE WIDTH

- Inlets are placed in low points
- Consider intersections
- Acceptable ponding widths



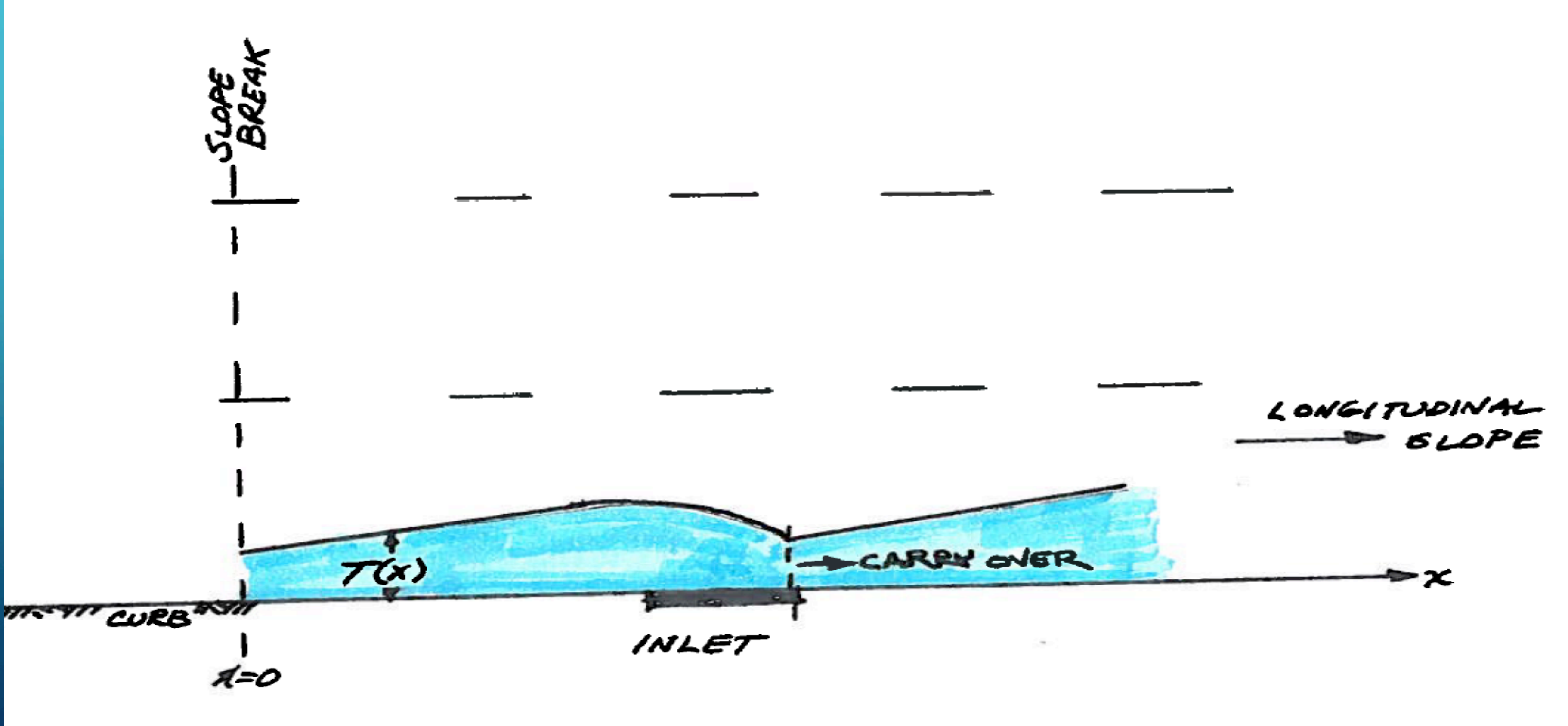
INLET PLACEMENT TO REDUCE WIDTH

- Ponding width



INLET PLACEMENT TO REDUCE WIDTH

- Partial capture with carryover



INLET PLACEMENT

- Locations dictated by physical demands, hydraulics, or both
- Logical locations include:
  - Sag configurations
  - Near intersections
  - At gore islands
  - Super-elevation transitions
- Allowable ponded width guides location selection

ALLOWABLE PONDED WIDTH

- Typical Transportation Guidelines
  - Limit ponding to one-half the width of the outer lane for the main lanes of interstate and controlled access highways
  - Limit ponding to the width of the outer lane for major highways, which are highways with two or more lanes in each direction, and frontage roads
  - Limit ponding to a width and depth that will allow the safe passage of one lane of traffic for minor highways

CURB INLET ON GRADE

- Compute length of inlet for total interception
- Subjective decision of actual length
- Estimate carryover

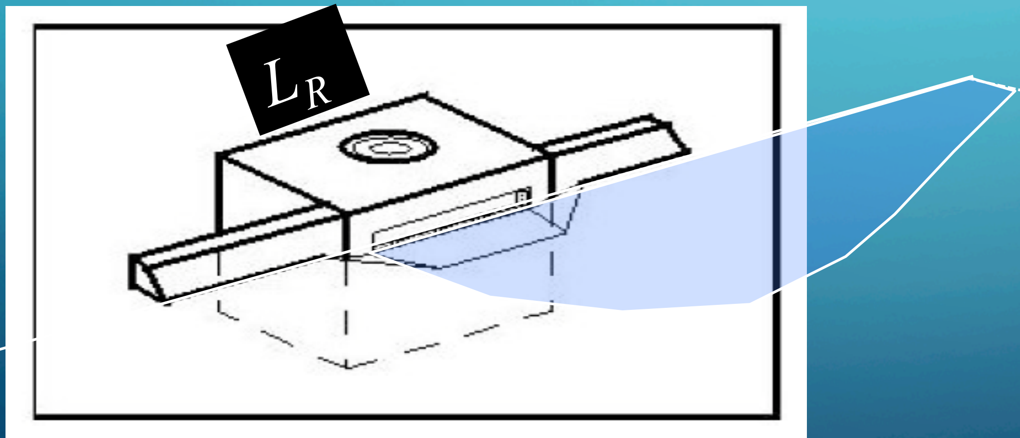
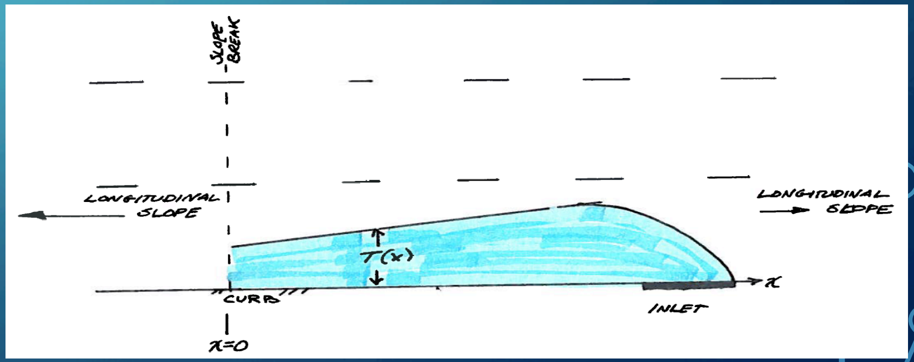


Figure 10-3. Curb Opening Inlet



CURB INLET ON GRADE

- Design guidance in HDM pp. 10-30 – 10-35.
- Formula for estimating required length
  - Need geometry
  - Need desired flow (to capture)
  - Calculate equivalent cross slope
    - Inlet height used here
  - Apply formula for required inlet length

CURB INLET ON GRADE

- Value of carryover
  - Uses more of inlet open area – hence may be able to use shorter inlet (if there is compelling need)

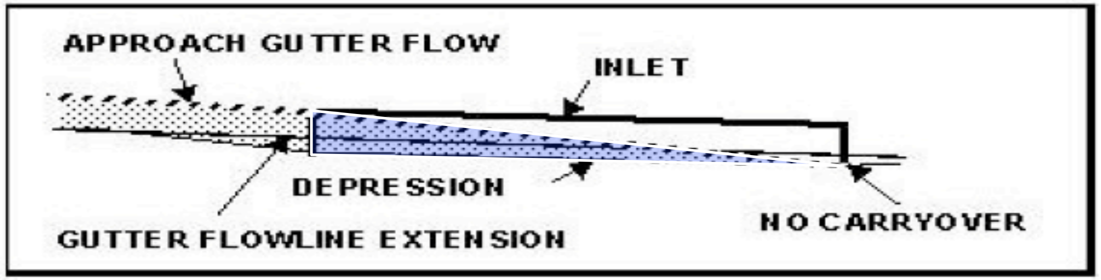


Figure 10-12. Inlet Designed with No Carryover

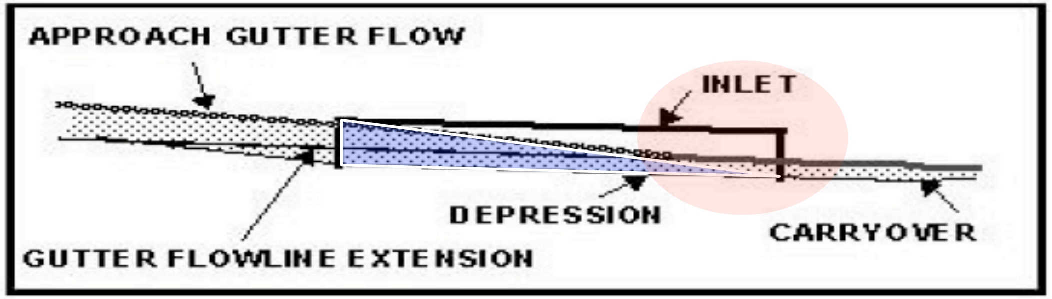
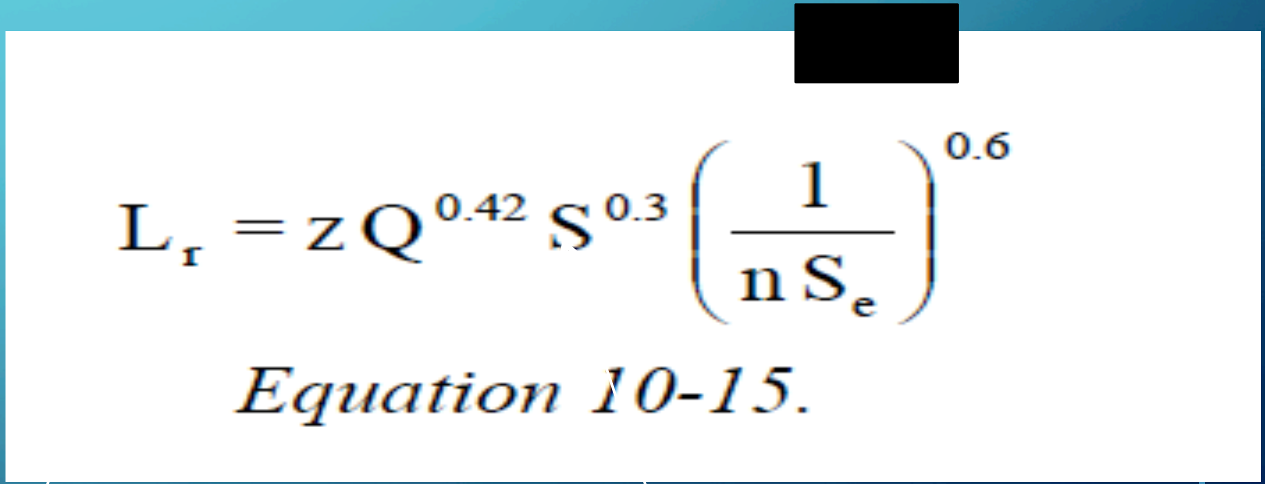


Figure 10-13. Inlet Designed with Carryover

PROFILE GRADE VS. INLET LENGTH

- Inlet length is proportional to longitudinal slope
- As slope increases, required length increases

$$L_R \propto S^{0.3}$$



[redacted]

$$L_r = z\,Q^{0.42}\,S^{0.3}\left(\frac{1}{n\,S_e}\right)^{0.6}$$

Equation 10-15.

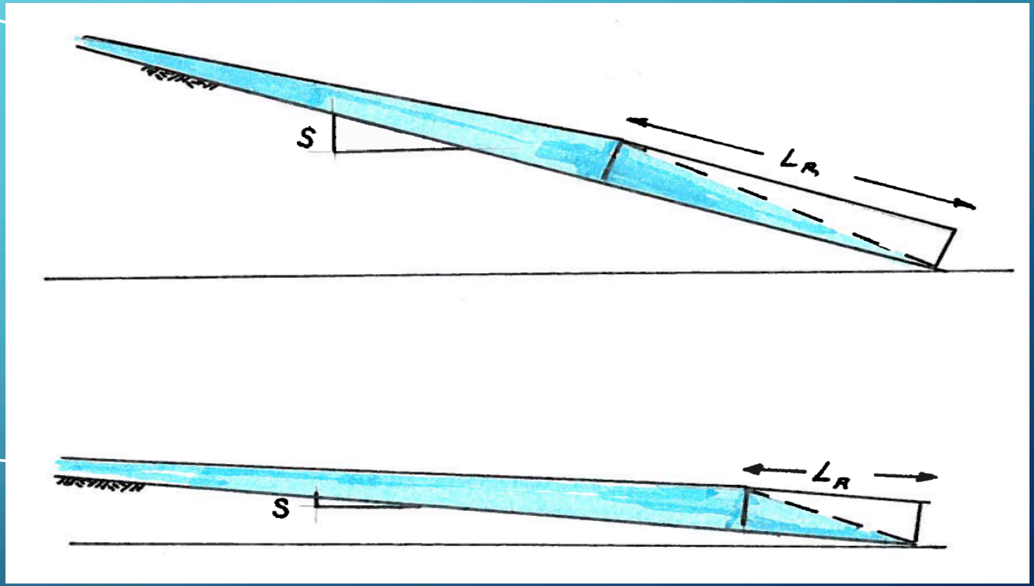
Length for complete capture

Longitudinal slope

PROFILE GRADE VS. INLET LENGTH

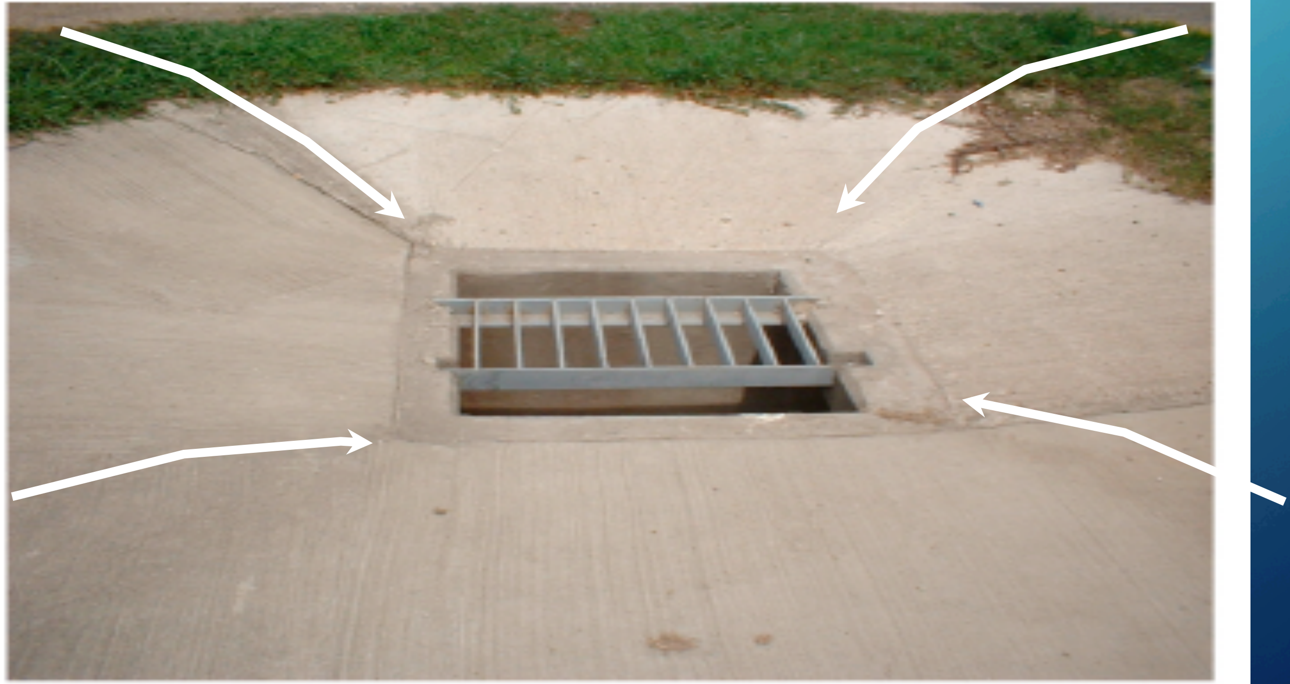
- Inlet length is proportional to longitudinal slope
- As slope increases, required length increases

$$L_R \propto S^{0.3}$$



SAG INLETS

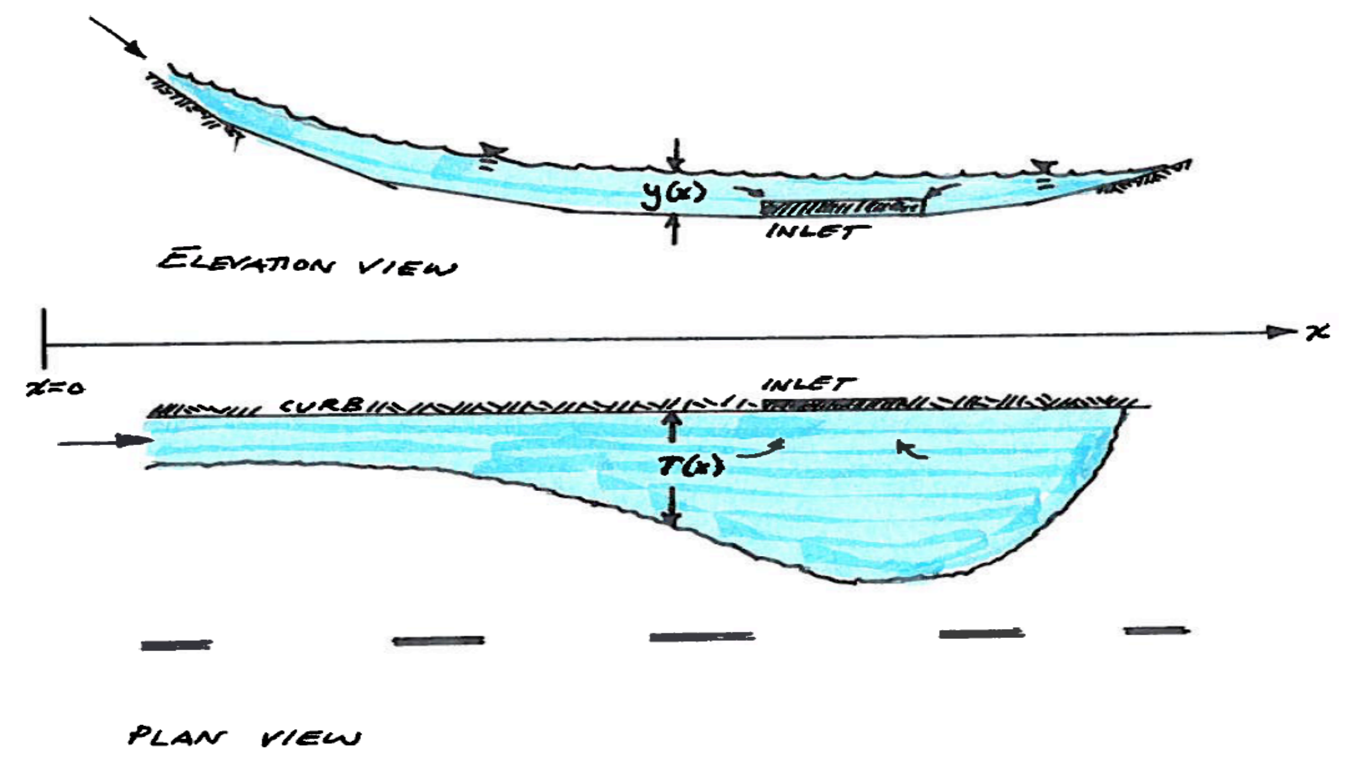
- Inlets placed at low point of a vertical curve.
- Various actual geometries, lowest point is the key feature.



Type-H (IL-H-G) In sag condition

PONDED WIDTH VS. VERTICAL CURVATURE

- As slope of vertical curve decreases, spread width increases



PONDED WIDTH VS. VERTICAL CURVATURE

- Median inlet configuration

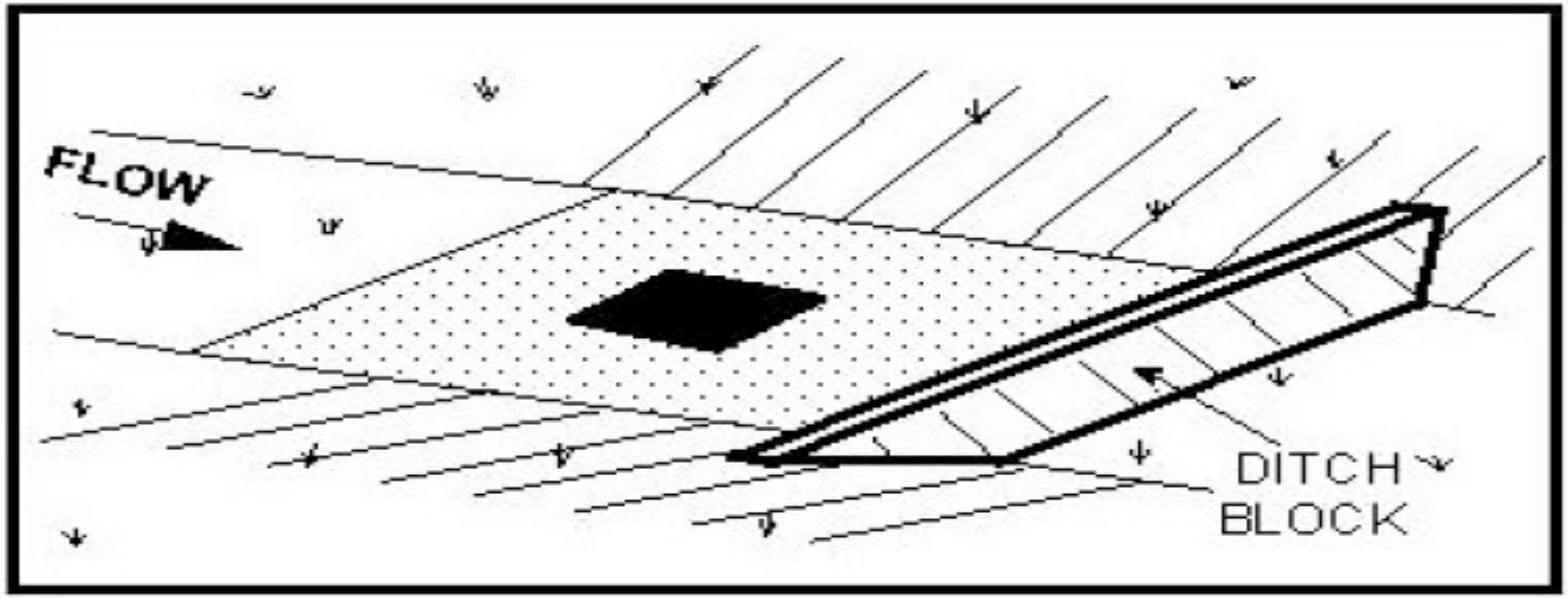
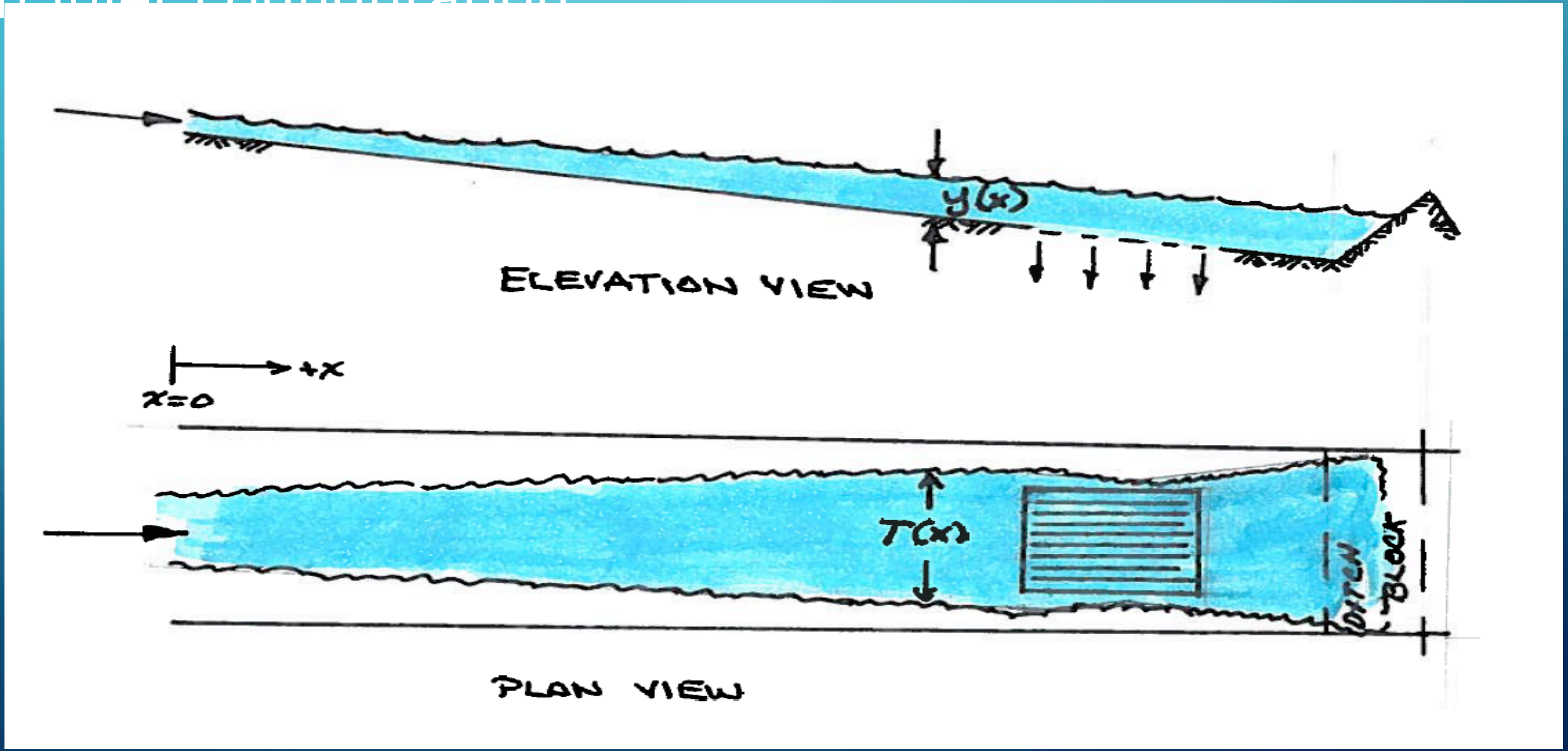


Figure 10-8. Median/Ditch Inlet

PONDED WIDTH VS. VERTICAL CURVATURE

- Median inlet configuration



INLETS AND INLET PERFORMANCE (*VIDEOS*)

- Grate On-Grade

INLETS AND INLET PERFORMANCE (*VIDEOS*)

- Grate with Ditch Block (Sag Condition)

NLETS AND INLET PERFORMANCE (*VIDEOS*)

- Tandem Grate Inlets On Grade

- Tandem Grate Inlets with Ditch Block (Sag Condition)

DESIGN DISCHARGE

- The design discharge to the inlet is based on the desired risk (AEP), the surface area that drains to the inlet, and the time of concentration
- The time of concentration in this context is also called the inlet time

DESIGN DISCHARGE (1 OF 2)

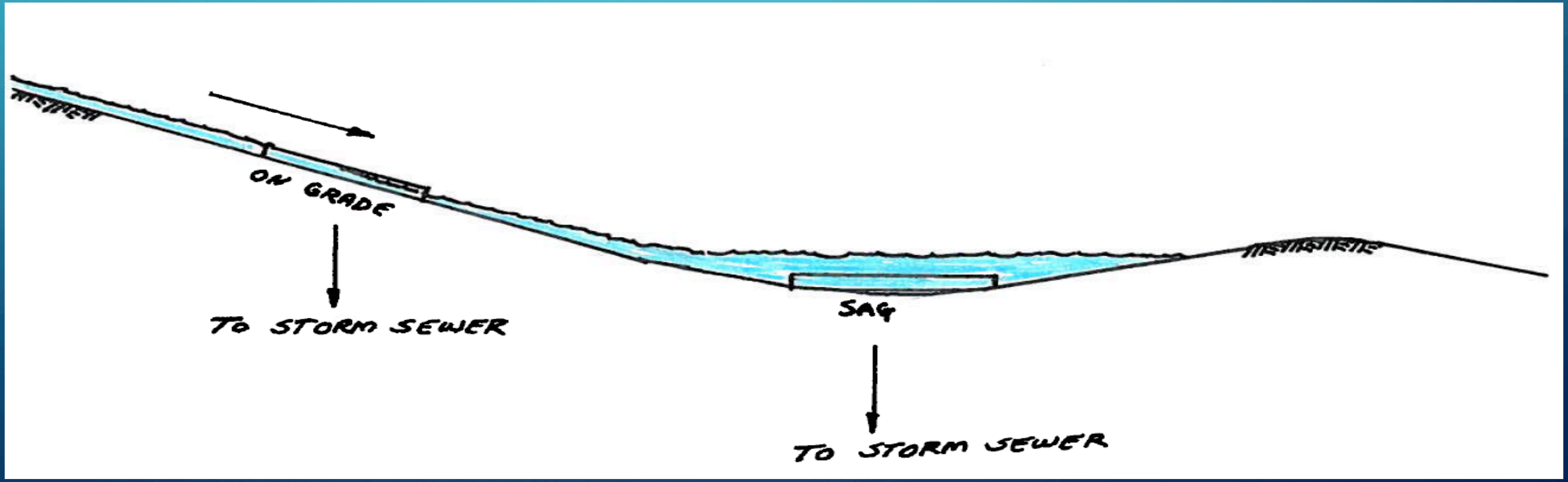
- The “steps” for the inlet are:
  - State the desired risk (typically 10-50% AEP)
  - Determine the area that drains to the inlet
  - Determine the T_c appropriate for the area
    - If T_c<10 min., then use 10 min as the averaging time.

DESIGN DISCHARGE (2 OF 2)

- The “steps” for the inlet are:
  - Compute intensity from T_c.
    - EBDLKUP.xls, or equation in HDM – be sure to check time units with either tool!
  - Estimate a reasonable runoff coefficient, C.
  - Apply rational equation to estimate design discharge, Q

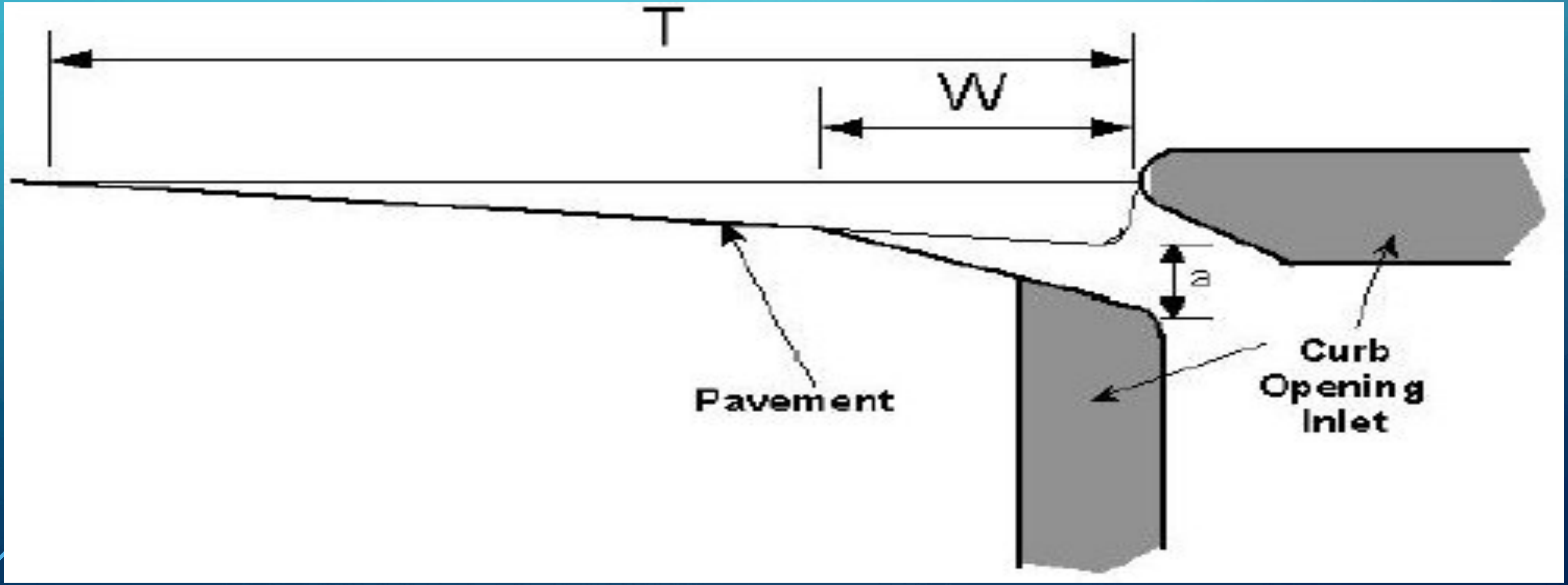
CAPACITY COMPUTATIONS

- Based on the design flow, gutter geometry, longitudinal and cross slope, and inlet length and height.
- Computations for Inlet On-grade
- Computations for Inlet in Sag



CURB OPENING INLET DESIGN VARIABLES

- Ponding width = T
- Gutter depression = a
- Gutter depression width = W



DETERMINING INLET LENGTH

- Use HDM Equations 10-8 through 10-16

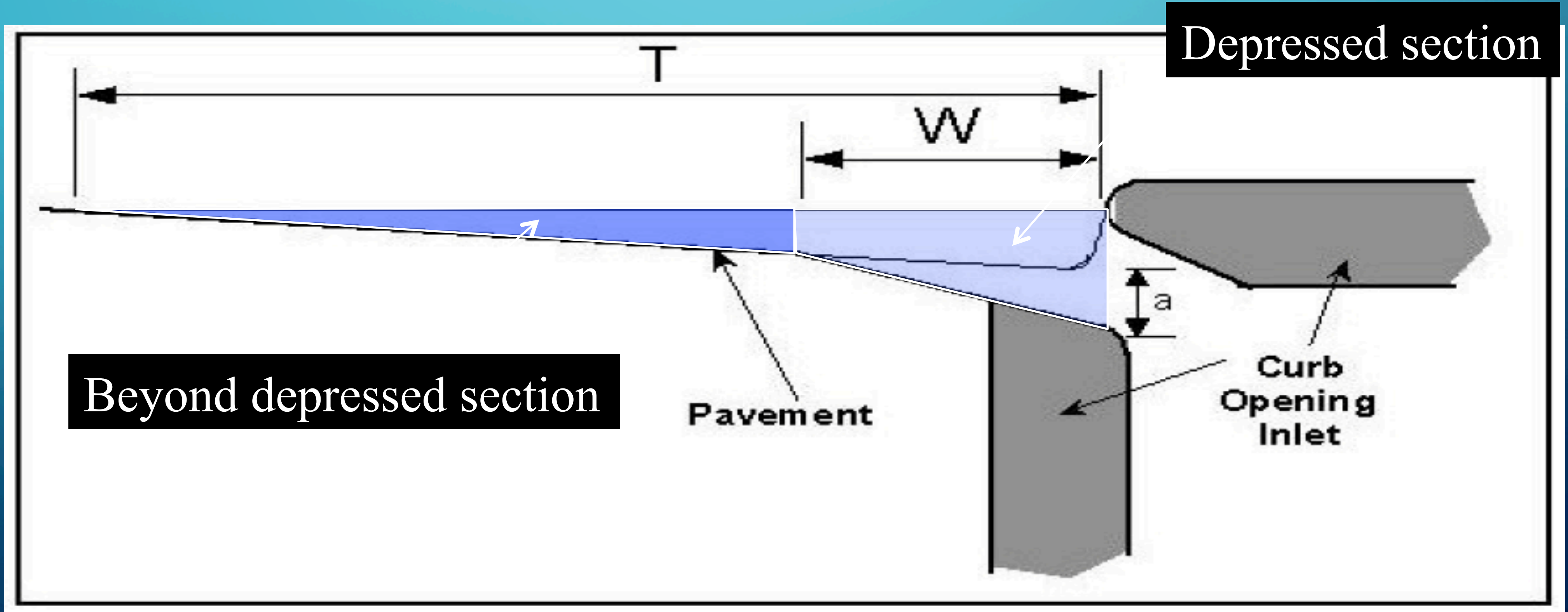


Figure 10-14. Gutter Cross-Section Diagram

NORMAL DEPTH

- TxDOT HDM Eq 10-1

$$d = 1.24\left(\frac{QnS_x}{S^{1/2}}\right)^{3/8}$$

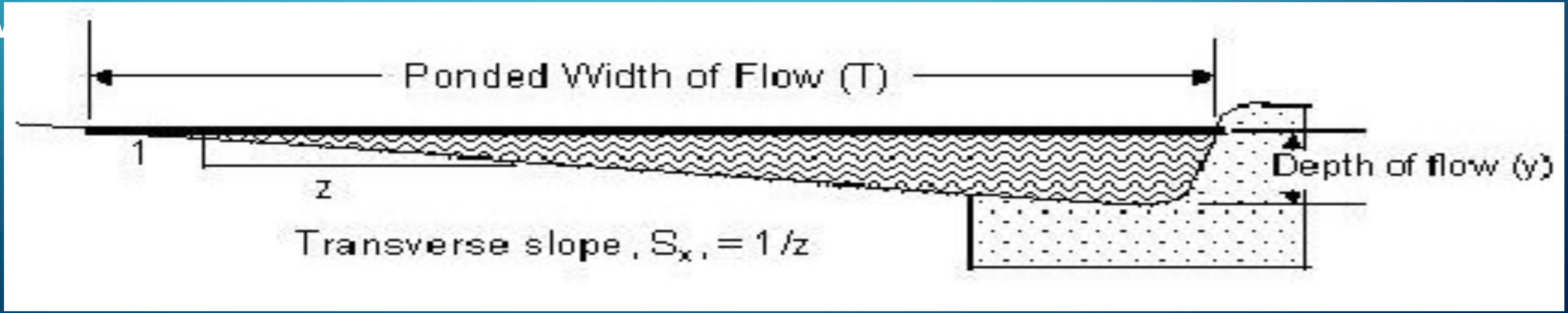
where

Q = design flow (cfs);
n = Manning’s roughness coefficient;
S_x = pavement cross slope;
S = friction slope; d = ponded depth (ft).

PONDED WIDTH

- TxDOT HDM Eq 10-2

$$T = \frac{d}{S_x}$$



RATIO OF DEPRESSED SECTION FLOW TO TOTAL FLOW

- TxDOT HDM Eq 10-8

$$E_o = \frac{K_w}{K_w + K_o}$$

where

K_w = conveyance in depressed section (cfs);
K_o = conveyance beyond depressed section (cfs);
E_o = ratio of depressed section flow to total flow.

CONVEYANCE

- TxDOT HDM Eq 10-9

$$K = \frac{1.486A^{5/3}}{nP^{2/3}}$$

where

A = cross section area (sq ft);
n = Manning roughness coefficient;
P = wetted perimeter (ft);
K = conveyance.

AREA OF THE DEPRESSED GUTTER SECTION

- TxDOT HDM Eq 10-10

$$A_W = WS_x\left(T - \frac{W}{2}\right) + \frac{1}{2}aW$$

where

W = depression width (ft);
S_x = pavement cross slope;
T = ponded width (ft);
a = curb opening depression (ft);
A_w = area of depressed gutter section(sq.ft.).

WETTED PERIMETER OF THE DEPRESSED GUTTER SECTION

- TxDOT HDM Eq 10-11

$$P_W = \sqrt{(WS_x + a)^2 + W^2}$$

where

W = depression width (ft);
S_x = pavement cross slope;
a = curb opening depression (ft);
P_w = wetted perimeter of depressed gutter section (ft).

AREA OF CROSS SECTION BEYOND THE DEPRESSION

- TxDOT HDM Eq 10-12

$$A_o = \frac{S_x}{2}(T - W)^2$$

where

S_x = pavement cross slope;
T = ponded width (ft);
W = depression width (ft);
A_o = area of cross section beyond depression.

WETTED PERIMETER OF CROSS SECTION BEYOND THE DEPRESSION

- TxDOT HDM Eq 10-13

$$P_o = T - W$$

where

T = ponded width (ft);
W = depression width (ft);
P_o = wetted perimeter of cross section beyond depression (ft).

EQUIVALENT CROSS SLOPE

- TxDOT HDM Eq 10-14

$$S_e = S_x + \frac{a}{W} E_o$$

where

S_x = pavement cross slope;
a = curb opening depression (ft);
W = depression width (ft);
E_o = ratio of depression flow to total flow;
S_e = equivalent cross slope.

LENGTH OF CURB INLET REQUIRED

- TxDOT HDM Eq 10-15

$$L_r = 0.6Q^{0.42}S^{0.3}\left(\frac{1}{nS_e}\right)^{0.6}$$

where

Q = flow (cfs);

S = longitudinal slope;

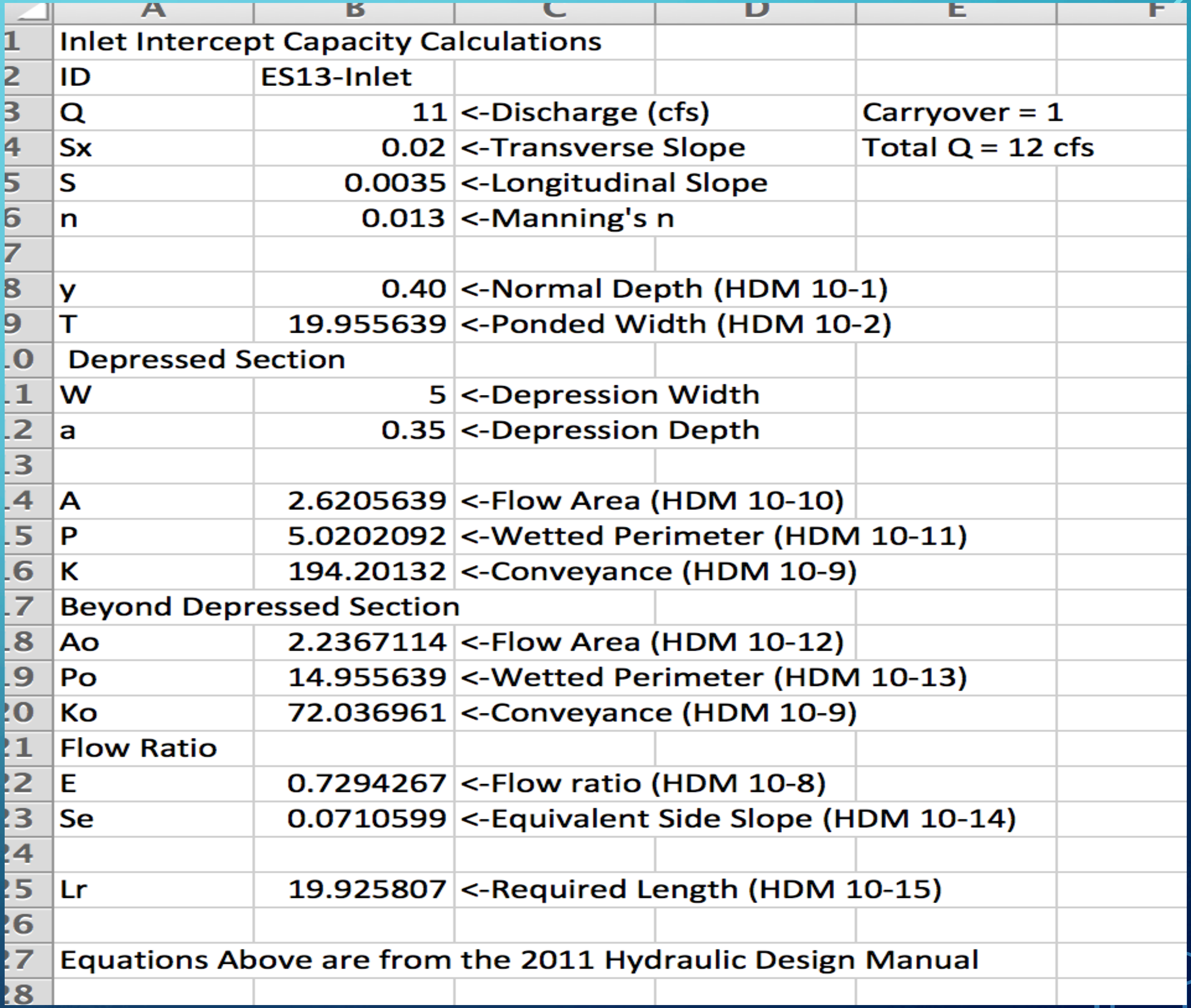
n = Manning's roughness coefficient;

S_e = equivalent cross slope;

L_r = length of curb inlet required.

USE SPREADSHEET TOOL

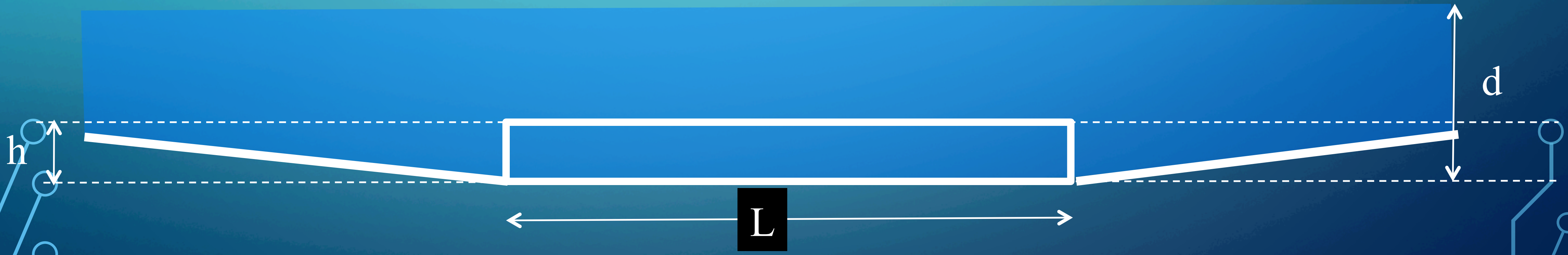
- Implements inlet computations
- Need to think about what trying to accomplish; the tool is not yet nbr ena



A	B	C	D	E
Inlet Intercept Capacity Calculations				
ID	ES13-Inlet			
Q	11	<-Discharge (cfs)		Carryover = 1
Sx	0.02	<-Transverse Slope		Total Q = 12 cfs
S	0.0035	<-Longitudinal Slope		
n	0.013	<-Manning's n		
y	0.40	<-Normal Depth (HDM 10-1)		
T	19.955639	<-Ponded Width (HDM 10-2)		
Depressed Section				
W	5	<-Depression Width		
a	0.35	<-Depression Depth		
A	2.6205639	<-Flow Area (HDM 10-10)		
P	5.0202092	<-Wetted Perimeter (HDM 10-11)		
K	194.20132	<-Conveyance (HDM 10-9)		
Beyond Depressed Section				
Ao	2.2367114	<-Flow Area (HDM 10-12)		
Po	14.955639	<-Wetted Perimeter (HDM 10-13)		
Ko	72.036961	<-Conveyance (HDM 10-9)		
Flow Ratio				
E	0.7294267	<-Flow ratio (HDM 10-8)		
Se	0.0710599	<-Equivalent Side Slope (HDM 10-14)		
Lr	19.925807	<-Required Length (HDM 10-15)		
Equations Above are from the 2011 Hydraulic Design Manual				

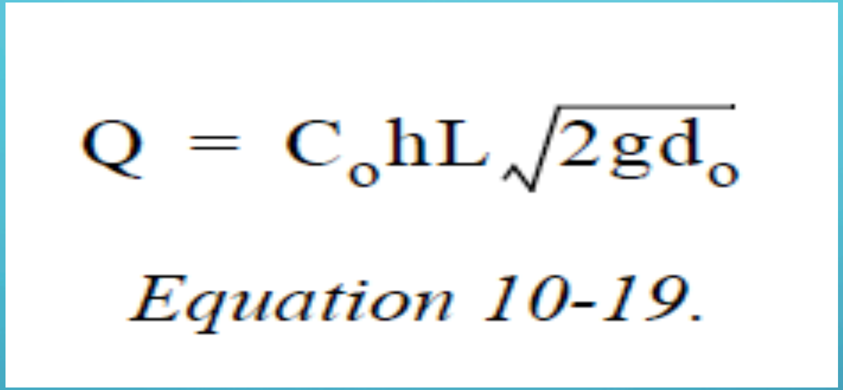
CAPACITY IN SAG PLACEMENT

- Depends on water depth at opening and opening height
- Determine if orifice-only flow ($d>1.4h$)
- If $d<1.4h$ compute using a weir flow equation and orifice flow equation for the depth condition, then choose the larger length



ORIFICE FLOW

- d>1.4h
- Use equation 10-19



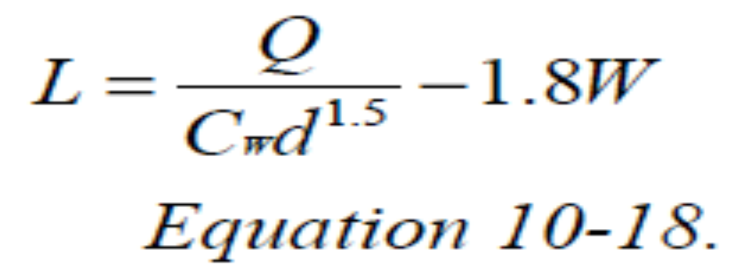
$$Q = C_o hL\sqrt{2gd_o}$$

Equation 10-19.

$$L = \frac{Q}{C_0 h\sqrt{2gd_0}}$$

WEIR FLOW

- d<1.4h
- Use equation 10-18



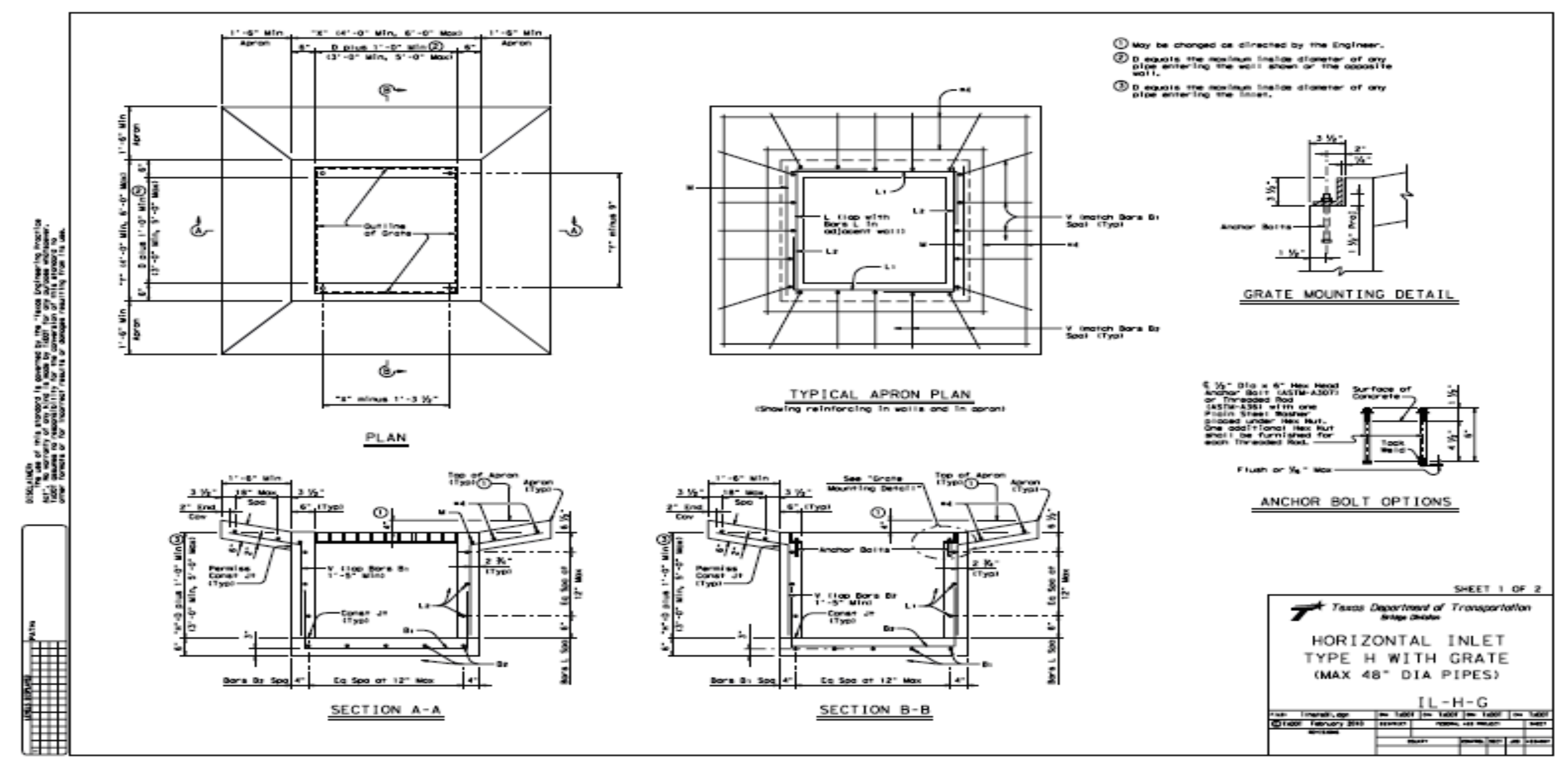
$$L = \frac{Q}{C_w d^{1.5}} - 1.8W$$

Equation 10-18.

DROP INLETS ON GRADE AND SAG

INLETS AND INLET PERFORMANCE

- Choose grate of standard dimension (e.g. Type-H, etc. from standards and specifications server)



① May be changed as directed by the Engineer.

② D equals the maximum inside diameter of any pipe entering the wall shown or the opposite wall.

③ D equals the maximum inside diameter of any pipe entering the inlet.

SHEET 1 OF 2

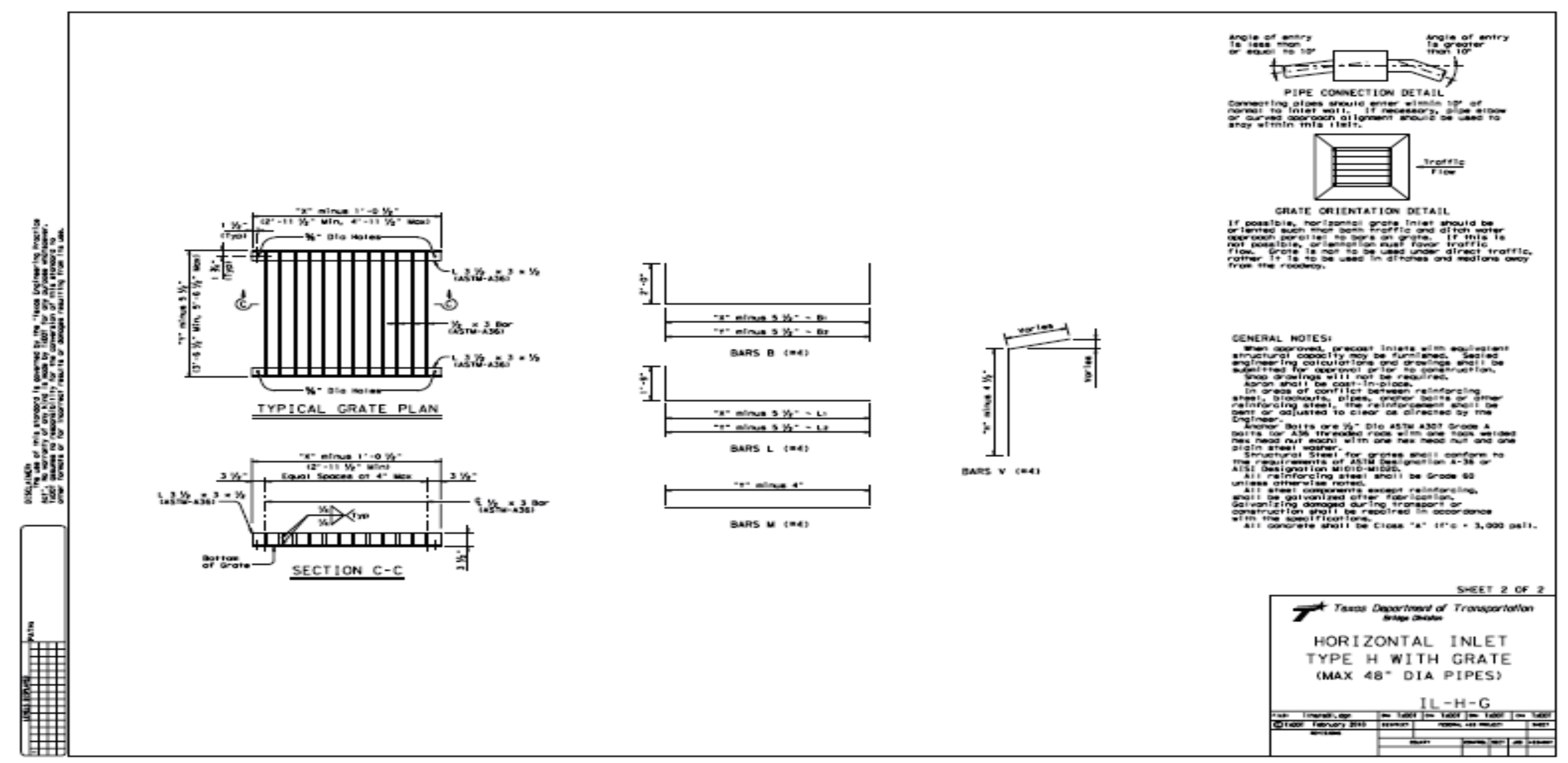
Texas Department of Transportation
Bridge Division

HORIZONTAL INLET
TYPE H WITH GRATE
(MAX 48" DIA PIPES)

IL-H-G

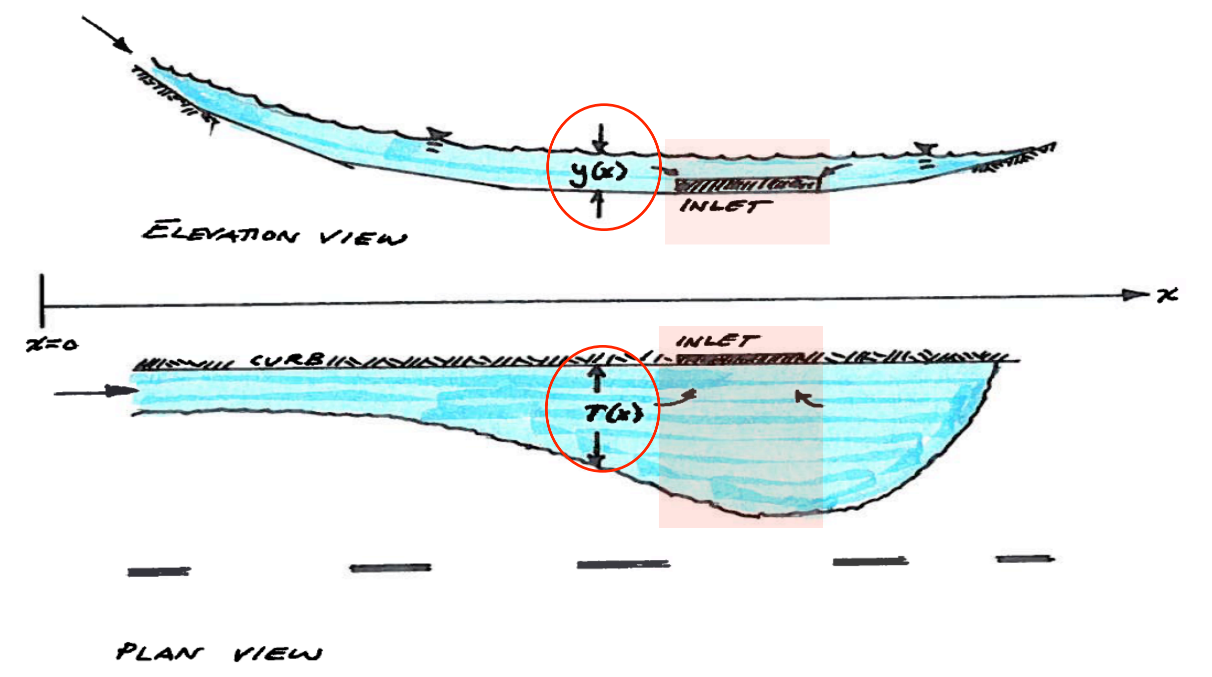
INLETS AND INLET PERFORMANCE

- Choose grate of standard dimension (e.g. Type-H, etc. from standards and specifications server)



INLETS AND INLET PERFORMANCE

- Determine allowable head (depth) for the inlet location. Lower of the curb height and depth associated with allowable pond width

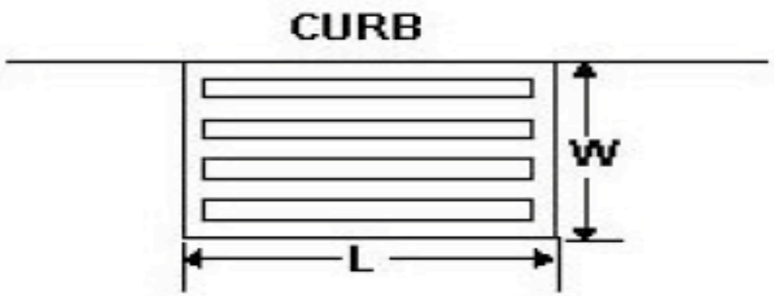


INLETS AND INLET PERFORMANCE

- Determine the capacity of the grate inlet opening as a **weir**.
- Perimeter controls the capacity.

$$Q_w = C_w P^{1.5}$$

Equation 10-32.

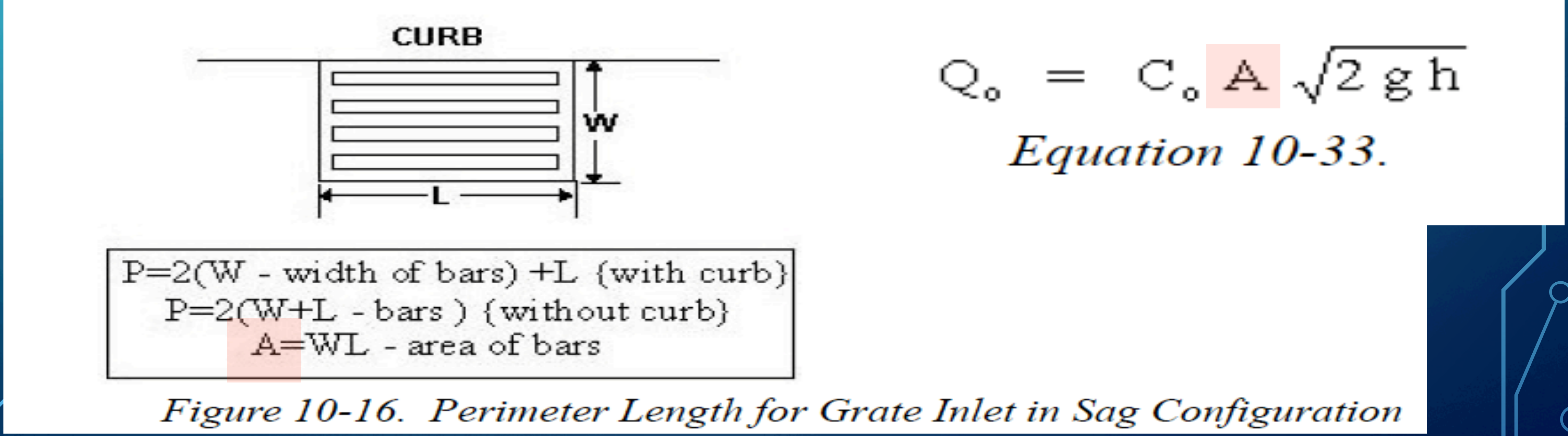


P=2(W - width of bars) +L {with curb}
P=2(W+L - bars) {without curb}
A=WL - area of bars

Figure 10-16. Perimeter Length for Grate Inlet in Sag Configuration

INLETS AND INLET PERFORMANCE

- Determine the capacity of the grate inlet opening as an **orifice**.
- Area controls the capacity.



$$Q_o = C_o A \sqrt{2 g h}$$

Equation 10-33.

P=2(W - width of bars) +L {with curb}
P=2(W+L - bars) {without curb}
A=WL - area of bars

Figure 10-16. Perimeter Length for Grate Inlet in Sag Configuration

INLETS AND INLET PERFORMANCE

- Compare the weir and orifice capacities, choose the lower value as the inlet design capacity.

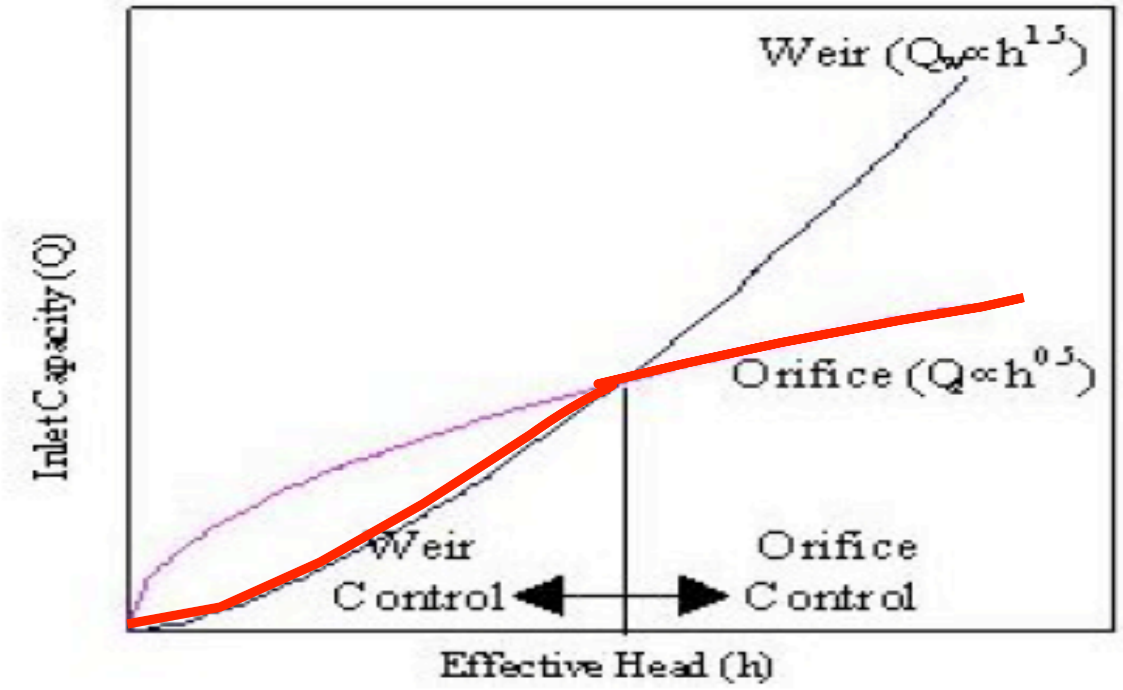
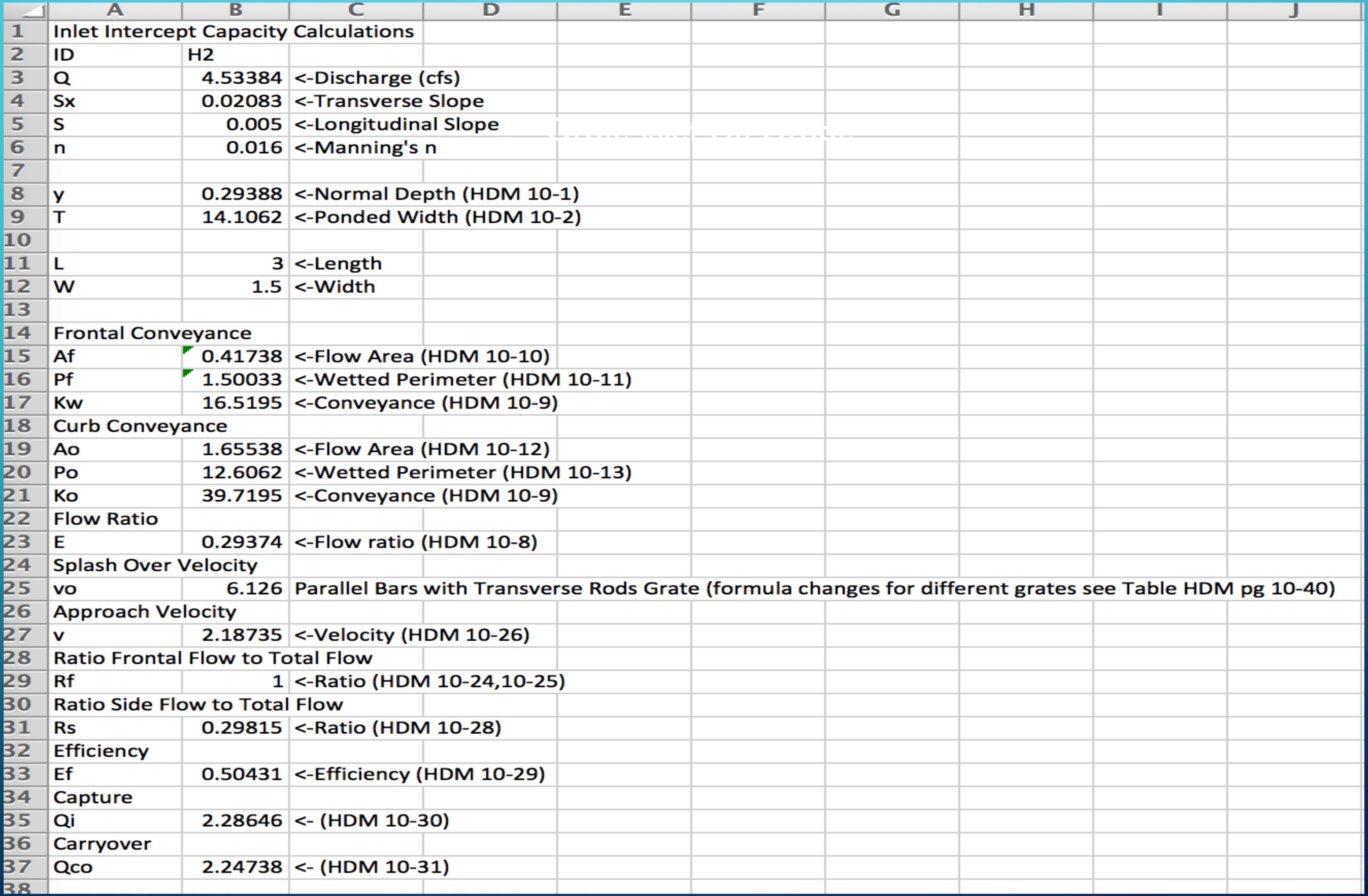


Figure 10-17. Relationship between Head and Capacity for Weir and Orifice Flow

SPREADSHEET TOOLS



	A	B	C
1	Inlet Intercept Capacity Calculations		
2	ID	H2	
3	Q	4.53384	<-Discharge (cfs)
4	Sx	0.02083	<-Transverse Slope
5	S	0.005	<-Longitudinal Slope
6	n	0.016	<-Manning's n
7			
8	y	0.29388	<-Normal Depth (HDM 10-1)
9	T	14.1062	<-Ponded Width (HDM 10-2)
10			
11	L	3	<-Length
12	W	1.5	<-Width
13			
14	Frontal Conveyance		
15	Af	0.41738	<-Flow Area (HDM 10-10)
16	Pf	1.50033	<-Wetted Perimeter (HDM 10-11)
17	Kw	16.5195	<-Conveyance (HDM 10-9)
18	Curb Conveyance		
19	Ao	1.65538	<-Flow Area (HDM 10-12)
20	Po	12.6062	<-Wetted Perimeter (HDM 10-13)
21	Ko	39.7195	<-Conveyance (HDM 10-9)
22	Flow Ratio		
23	E	0.29374	<-Flow ratio (HDM 10-8)
24	Splash Over Velocity		
25	vo	6.126	Parallel Bars with Transverse Rods Grate (formula changes for different grates see Table HDM pg 10-40)
26	Approach Velocity		
27	v	2.18735	<-Velocity (HDM 10-26)
28	Ratio Frontal Flow to Total Flow		
29	Rf	1	<-Ratio (HDM 10-24,10-25)
30	Ratio Side Flow to Total Flow		
31	Rs	0.29815	<-Ratio (HDM 10-28)
32	Efficiency		
33	Ef	0.50431	<-Efficiency (HDM 10-29)
34	Capture		
35	Qi	2.28646	<- (HDM 10-30)
36	Carryover		
37	Qco	2.24738	<- (HDM 10-31)
38			

NEXT TIME

- Conduit design
  - Rational method for storm sewer conduit sizing (by-hand)
  - Used to obtain initial estimates of required diameters, flowlines, and hydraulic grade lines.