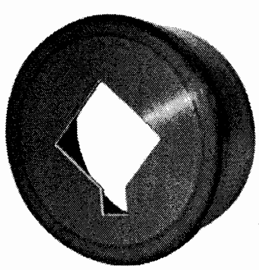
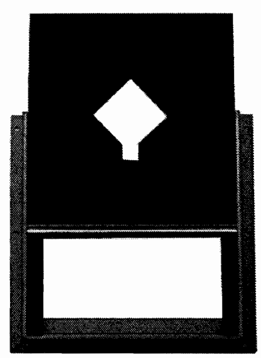
Inlet Types - debris

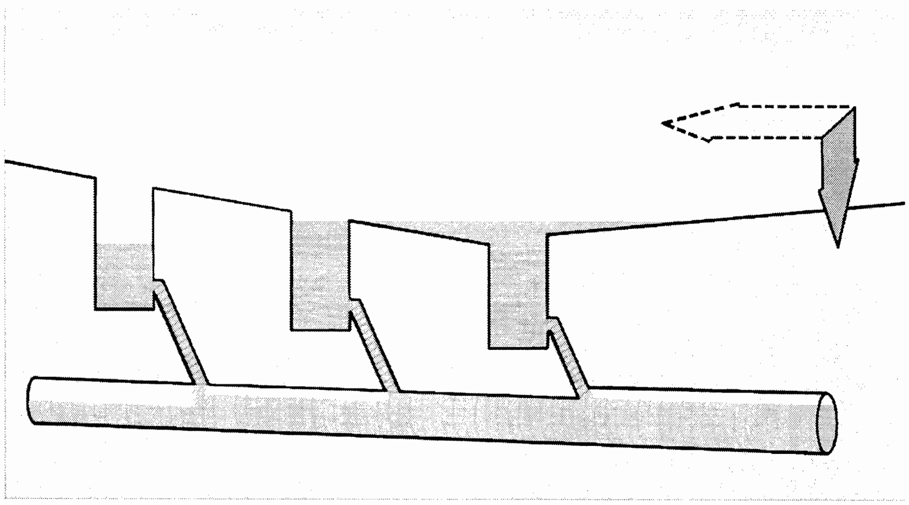
Inlet control devices

www.ipexinc.com





Inlet control devices

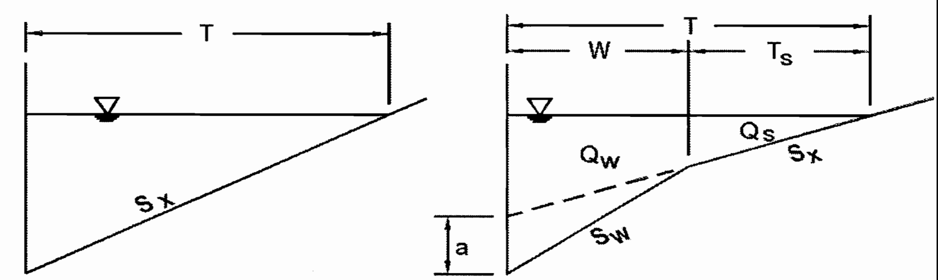


Inlet Types - location

Gutter Flow Analysis

- Gutter flow analysis to determine depth
  - Typical gutter is triangular in shape, cross-slope 2%-3%
  - Integrating Manning's equation across width of gutter section yields:
    - $Q = (Ku/n)\, S_x^{1.67}\, S_L^{0.5}\, T^{2.67}$ (4-2)
    - Where
      - Ku = 0.56
      - n = Manning's coefficient
      - S_x = Cross-slope, ft/ft
      - S_L = Longitudinal slope, ft/ft
      - T = Top width, ft

Gutter Cross-sections



1. Uniform Section   2. Composite Section

Gutter Roughness

Type of Gutter or Pavement	Manning's n
Concrete gutter, troweled finish	0.012
Asphalt Pavement:	
Smooth texture	0.013
Rough texture	0.016
Concrete gutter-asphalt pavement:	
Smooth	0.013
Rough	0.015
Concrete pavement:	
Float finish	0.014
Broom finish	0.016

Gutter flow depth and velocity

- Example - Find flow depth for a flow of 1.8 cfs, with S_L = 1%, S_x = 2% and n = 0.016
- Rearranging equation 4-2,
  $T = [(Qn)/(Ku\ S_x^{1.67}\ S_L^{0.5})]^{0.375}$
- $T = [(1.8)*(0.016)/(0.56\ (0.02)^{1.67}\ (0.01)^{0.5}\ )]^{0.375}$
- T = 9.0 ft
- $d = T * S_x$ where d = depth in ft.
- d = 9.0 * 0.02 = 0.18 ft.
- To find velocity,
  $V = (Kc/n)\ S_x^{0.67}\ S_L^{0.5}\ T^{0.67}$ (4-13)
  $V = (1.11/0.016)\ (0.02)^{0.67}\ (0.01)^{0.5}\ (9.0)^{0.67}$
  V = 2.20 ft/sec

Gutter depth and velocity - problem

- Class Problem - Find flow depth and velocity for a flow of 2.6 cfs, with S_L = 5%, S_x = 2% and n = 0.016
- Rearranging equation 4-2,
  $T = [(Qn)/(Ku\ S_x^{1.67}\ S_L^{0.5})]^{0.375}$
- T = [(__)*(___)/(0.56 (___)$^{1.67}$ (___)$^{0.5}$)]$^{0.375}$
- T = __ ft
- d = T * S_x where d = depth in ft.
- d = __ * ___ = ___ ft.
- To find velocity,
  $V = (Kc/n)\ S_x^{0.67}\ S_L^{0.5}\ T^{0.67}$
  V = (1.11/___) (___)$^{0.67}$ (___)$^{0.5}$ (___)$^{0.67}$
  V = ___ ft/sec

Gutter depth and velocity - problem

- Class Problem - Find flow depth and velocity for a flow of 2.6 cfs, with S_L = 5%, S_x = 2% and n = 0.016
- Rearranging equation 4-2,
  $T = [(Qn)/(Ku\ S_x^{1.67}\ S_L^{0.5})]^{0.375}$
- $T = [(2.6)*(0.016)/(0.56\ (0.02)^{1.67}\ (0.05)^{0.5}\ )]^{0.375}$
- T = 7.7 ft
- d = T * S_x where d = depth in ft.
- d = 7.7 * 0.02 = 0.15 ft.
- To find velocity,
  $V = (Kc/n)\ S_x^{0.67}\ S_L^{0.5}\ T^{0.67}$
  $V = (1.11/0.016)\ (0.02)^{0.67}\ (0.05)^{0.5}\ (7.7)^{0.67}$
  V = 4.42 ft/sec

Inlets - frontal flow

- On a slope, inlet capacity is determined by the amount of frontal flow and the amount of side flow
- The ratio of frontal flow to total gutter flow, Eo, for a uniform cross slope is expressed by equation 4-16:

  $Eo = (Qw/Q) = 1 - (1 - (W/T))^{2.67}$ (4-16)

  where:

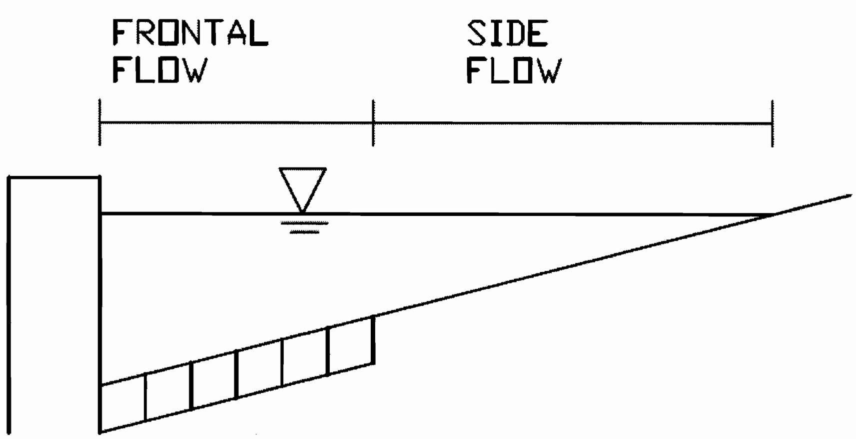
  Q = total gutter flow, ft^3/s

  Qw = flow in width W, ft^3/s

  W = width of depressed gutter or grate, ft

  T = total spread of water, ft

Inlets - frontal flow



Inlets - frontal and side flow

- For a flow of 1.8 cfs, with S_L = 1%, S_x = 2% and n = 0.016, find the amount of frontal flow and the amount of side flow, if the grate is 2.5 feet wide and 2 feet long. From earlier solution, T = 9.0.
- $Eo = 1 - (1 - (W/T))^{2.67}$ (4-16)
- $Eo = 1 - (1 - (2.5/9))^{2.67}$
- Eo = 0.58
- Frontal flow = 0.58 * 1.8 cfs = 1.04 cfs
- Side flow = 1.8 cfs - 1.04 cfs = 0.76 cfs

Inlet Problem - frontal and side flow

- Class Problem - For a flow of 2.6 cfs, with S_L = 5%, S_x = 2% and n = 0.016, find the amount of frontal flow and the amount of side flow, if the grate is 2.0 feet wide and 2.5 feet long. From earlier solution, T = 7.7.
- $Eo = 1 - (1 - (W/T))^{2.67}$ (4-16)
- $Eo = 1 - (1 - (\_\_/\_\_))^{2.67}$
- Eo = ___
- Frontal flow = ___ * ___ cfs = ___ cfs
- Side flow = ___ cfs - ___ cfs = ___ cfs

Inlet Problem - frontal and side flow

- Class Problem - For a flow of 2.6 cfs, with S_L = 5%, S_x = 2% and n = 0.016, find the amount of frontal flow and the amount of side flow, if the grate is 2.0 feet wide and 2.5 feet long. From earlier solution, T = 7.7.
- $Eo = 1 - (1 - (W/T))^{2.67}$ (4-16)
- $Eo = 1 - (1 - (2.0/7.7))^{2.67}$
- Eo = 0.55
- Frontal flow = 0.55 * 2.6 cfs = 1.43 cfs
- Side flow = 2.6 cfs - 1.43 cfs = 1.17 cfs

Inlet interception - frontal flow

- For a flow of 1.8 cfs, with S_L = 1%, S_x = 2% and n = 0.016, if the grate is 2.5 feet wide and 2 feet long (with a splash-over velocity of 4.1 ft/sec - from HEC-22, reticuline grate), find the amount of flow intercepted. From earlier solution, T = 9.0, Eo = 0.58, frontal flow = 1.04 cfs, side flow = 0.76 cfs, gutter velocity = 2.20 ft/sec.
- To determine ratio of frontal flow intercepted (Rf)

  Rf = 1 - Ku (V - Vo) (4-18)

  where:

  Ku = 0.09

  V = velocity of flow in the gutter, ft/s

  Vo = gutter velocity where splash-over first occurs, ft/s (Note: Rf cannot exceed 1.0)
- Rf = 1.0 because Vo > V

Inlets - splash over velocity

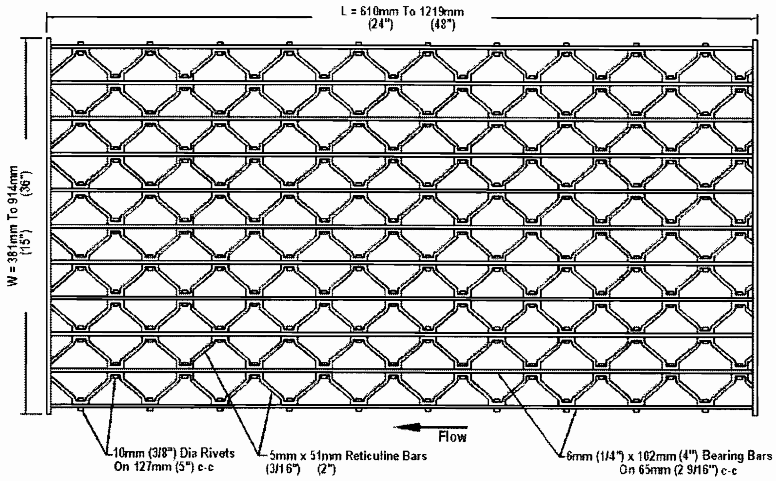
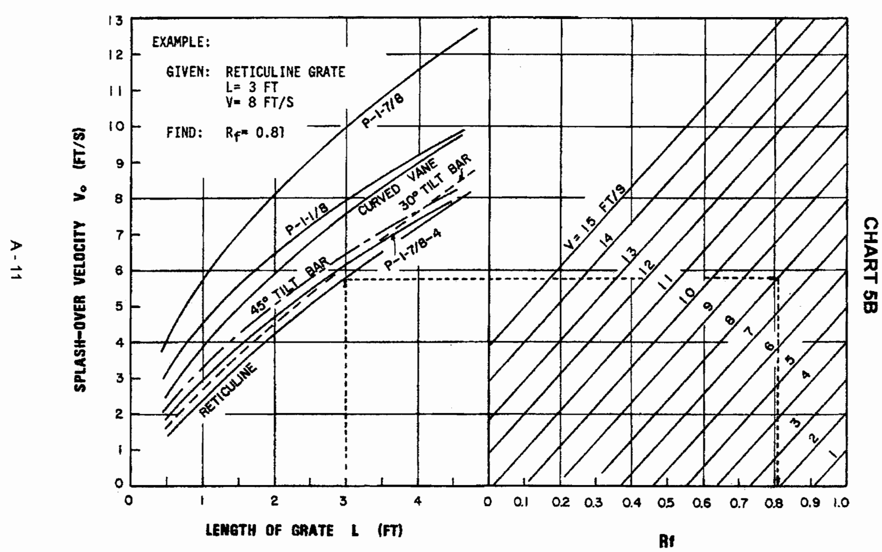


Figure 4-10. Reticuline grate.

Inlets - splash over velocity



Inlet interception - side flow

- If Rf = 1.0, 100% of frontal flow is intercepted, so frontal flow intercepted = 1.04 cfs
- To determine side flow interception
- $Rs = 1 / \{ 1 + [(Ks * V^{1.8})/(S_x * L^{2.3})]\}$ (4-19)

  where:

  Ks = 0.15
- $Rs = 1 / \{ 1 + [(0.15 * (2.2)^{1.8})/(0.02 * (2)^{2.3})]\}$
- Rs = 0.14, so 14% of side flow is intercepted
- Side flow intercepted = 0.14 * 0.76 cfs = 0.11 cfs
- Total flow intercepted by this inlet = 1.04 + 0.11 = 1.15 cfs, or about 64% of the total flow of 1.8 cfs
- Inlets should generally intercept about 80% of total flow

Inlet problem - frontal flow interception

- Class Problem - For a flow of 2.6 cfs, with S_L = 5%, S_x = 2% and n = 0.016, if the grate is 2.0 feet wide and 2.5 feet long (with a splash-over velocity of 4.7 ft/sec - from HEC-22, reticuline grate), find the amount of flow intercepted. From earlier solution, T = 7.7, Eo = 0.55, frontal flow = 1.43 cfs, side flow = 1.17 cfs, gutter velocity = 4.42 ft/sec.
- To determine ratio of frontal flow intercepted (Rf)

  Rf = 1 - Ku (V - Vo)

  Ku = 0.09

  Rf = 1 - 0.09 (__ - __)

  Rf = ___
- Frontal Flow intercepted = ___ * ___ = ___ cfs

Inlet problem - side flow interception

- To determine side flow interception
- $Rs = 1 / \{ 1 + [(Ks * V^{1.8})/(S_x * L^{2.3})]\}$
  where:
  Ks = 0.15
- $Rs = 1 / \{ 1 + [(0.15 * (\_\_)^{1.8})/(\_\_\_ * (\_\_)^{2.3})]\}$
- Rs = 0.__, so __% of side flow is intercepted
- Side flow intercepted = ___ * ___ cfs = ___ cfs
- Total flow intercepted by this inlet = ___ + ___ = ___ cfs, or about ___% of the total flow of 2.6 cfs

Inlet problem - interception

- To determine ratio of frontal flow intercepted (Rf)
- Rf = 1 - Ku (V - Vo)
  Rf = 1 - 0.09 (4.42 - 4.7)
  Rf = 1.00
- Frontal Flow intercepted = 1.00 * 1.43 = 1.43 cfs
- To determine side flow interception
- $Rs = 1 / \{ 1 + [(Ks * V^{1.8})/(S_x * L^{2.3})]\}$
- $Rs = 1 / \{ 1 + [(0.15 * (4.42)^{1.8})/(0.02 * (2.5)^{2.3})]\}$
- Rs = 0.07, so 7% of side flow is intercepted
- Side flow intercepted = 0.07 * 1.17 cfs = 0.08 cfs
- Total flow intercepted by this inlet = 1.43 + 0.08 = 1.51 cfs, or about 58% of the total flow of 2.6 cfs

Curb Opening Inlet

- Length of curb-opening for total interception:
  $L_T = Kc\ Q^{0.42}\ S_L^{0.3}\ [1/(n\ S_x)]^{0.6}$ (4-22)
  - $Kc = 0.6$
  - L_T = curb opening length
  - Q = gutter flow, cfs
  - S_L = longitudinal slope
  - S_x = transverse slope
- Efficiency for shorter lengths:
  $E = 1 - [1 - (L/L_T)]^{1.8}$ (4-23)
- Efficiency increases by 40-50% if curb opening is depressed 1 inch (see equation 4-24)

Curb Opening Inlet

- Find required length of curb opening for a flow of 2.6 cfs, with S_L = 5%, S_x = 2% and n = 0.016
  $L_T = 0.6\ (2.6)^{0.42}\ (0.05)^{0.3}\ [1/(0.016 * 0.02)]^{0.6}$
  L_T = 46 ft
- Find required length of curb opening for a flow of 2.6 cfs, with S_L = 2%, S_x = 2% and n = 0.016
  $L_T = 0.6\ (2.6)^{0.42}\ (0.02)^{0.3}\ [1/(0.016 * 0.02)]^{0.6}$
  L_T = 35 ft
- Find the flow intercepted by 20 feet of curb opening, if total flow is 2.6 cfs, with S_L = 5%, S_x = 2% and n = 0.016
  $E = 1 - [1 - (20/46)]^{1.8}$
  E = 0.64 (or 64% efficiency)
  Q = 0.64 * 2.6 = 1.66 cfs

Sag Inlet capacity

- In a sag, inlet capacity is determined by either orifice flow or weir flow
- The capacity of grate inlets operating as weirs is:

  $Q_i = C_w P d^{1.5}$ (4-26)

  where:

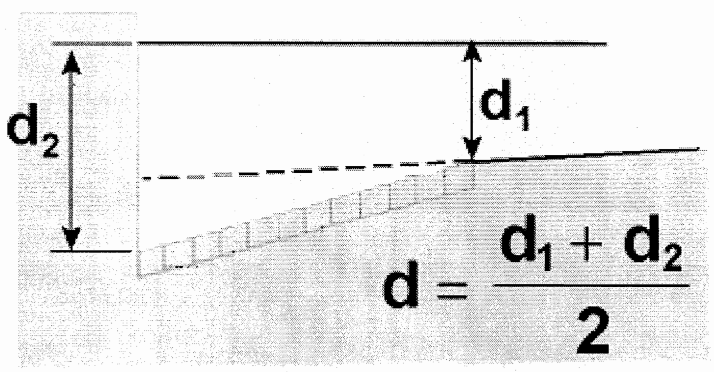
  P = perimeter of the grate in ft disregarding the side against the curb

  Cw = 3.0 in English units

  d = average depth across the grate;

  0.5 (d1 + d2), ft

Sag Inlet capacity



Sag Inlet Capacity - weir flow

- Example - inlet grate is 2.5 feet wide, 2 feet long, S_x = 0.02 and the grate has a clear opening area of 4 square feet. What is the capacity in weir flow at a depth of flow of 0.25 feet?
- d2 = 0.25 ft
- d1 = d2 - W * S_x = 0.25 - (2.5 * 0.02) = 0.20
- d = 0.5 * (d1 + d2) = 0.5 * (0.25 + 0.20) = 0.225
- $Qi = \Sigma Cw\ P\ d^{1.5}$
- $Qi = \{3.0 * (2.5 + 2.5) * (0.225)^{1.5}\} + \{3.0 * (2) * (0.2)^{1.5}\}$
- Qi = 1.60 + 0.54
- Qi = 2.14 cfs

Sag Inlet Capacity - orifice flow

- The capacity of grate inlets operating as orifices is:
- $Qi = Co\ Ag\ (2\ g\ d)^{0.5}$ (4-27)

  where:

  Co = orifice coefficient = 0.67

  Ag = clear opening area of the grate, ft^2

  g = 32.16 ft/s^2
- Example - inlet grate is 2.5 feet wide, 2 feet long, S_x = 0.02 and the grate has a clear opening area of 4 square feet. What is the capacity in orifice flow at a depth of flow of 0.25 feet?
- $Qi = 0.67 * 4 * (2 * 32.2 * 0.225)^{0.5}$
- Qi = 10.2 cfs > 2.14 cfs, so inlet operates as a weir

Sag Inlet Problem

- Class problem - inlet grate is 1.5 feet wide, 2 feet long, S_x = 0.02 and the grate has a clear opening area of 2 square feet. What is the capacity at a depth of flow of 0.3 feet?
- Weir flow capacity:

  d2 = __ ft

  d1 = d2 - W * S_x = ___ - (__ * __) = ___

  d = 0.5 * (d1 + d2) = 0.5 * (__ + __) = ___

  Qi = {Cw P $d^{1.5}$} + {Cw P $d^{1.5}$}

  Qi = {3.0 * (__ + __) * $(\_\_\_)^{1.5}$} + {3.0 * (__) * $(\_\_\_)^{1.5}$}

  Qi = ___ cfs
- Orifice flow capacity:

  Qi = Co Ag $(2 \text{ g d})^{0.5}$

  Qi = 0.67 * __ * (2 * 32.2 * ___) $^{0.5}$ = ___ cfs

Sag Inlet Problem

- Class problem - inlet grate is 1.5 feet wide, 2 feet long, S_x = 0.02 and the grate has a clear opening area of 2 square feet. What is the capacity at a depth of flow of 0.3 feet?
- Weir flow capacity:

  d2 = 0.3 ft

  d1 = d2 - W * S_x = 0.3 - (1.5 * 0.02) = 0.27

  d = 0.5 * (d1 + d2) = 0.5 * (0.30 + 0.27) = 0.285

  Qi = Cw P $d^{1.5}$

  Qi = {3.0 * (1.5 + 1.5) * $(0.285)^{1.5}$} + {3.0 * (2.0) * $(0.27)^{1.5}$}

  Qi = 1.37 + 0.84 cfs

  Qi = 2.22 cfs

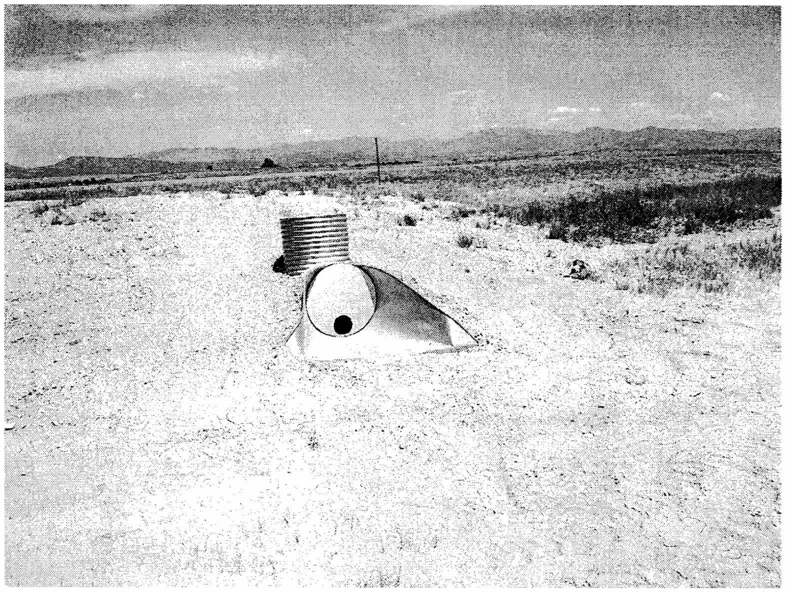
Sag Inlet Problem

- Orifice flow capacity:
  $Qi = Co\ Ag\ (2\ g\ d)^{0.5}$
  $Qi = 0.67 * 2 * (2 * 32.2 * 0.285)^{0.5} = 5.74$ cfs
- Weir flow capacity = 2.22 cfs, so inlet operates in weir flow

Outlet capacity analysis

- Detention pond outlets ALMOST NEVER have a constant outflow rate.
- Outlets are commonly some type of culvert or perforated pipe, often with a trash rack
- For culverts, use hydraulic design software (carefully) - should solve inlet control and outlet control
- For perforated pipe, analyze each perforation (or set of perforations) separately
- In either case, develop a stage-discharge relationship

Outlet capacity - Pipe with orifice



Outlet capacity - Overflow

Outlet capacity - Orifice and overflow

- Orifice size = 10 inches
- Overflow pipe size = 36 inches
- Invert of orifice to overflow pipe = 5 feet
- For orifice capacity: $Qo = Co\ Ag\ (2\ g\ h)^{0.5}$ where:
  Co = orifice coefficient = 0.60
  Ag = opening area of the orifice, ft^2
  $= \pi\ r^2 = \pi * (5/12)^2 = 0.545\ ft^2$
  $g = 32.16\ ft/s^2$
  h = depth from water surface to center of orifice
- For weir capacity: $Qw = Cw\ P\ d^{1.5}$ where:
  Cw = weir coefficient = 3.0
  P = perimeter of weir, ft
  $= \pi\ d = \pi * (36/12) = 9.42\ ft$
  d = depth from water surface to top of weir

Outlet capacity - Orifice and overflow

- $Qo = Co\ Ao\ (2\ g\ h)^{0.5}$
  $Co = 0.60$; $Ao = 0.545\ ft^2$; $g = 32.16\ ft/s^2$

Depth above Bottom	Depth above orifice center (h)	Q (cfs)
0.0 ft	0.0 ft	0.0
1.0 ft	0.58 ft	2.0
2.0 ft	1.58 ft	3.3
3.0 ft	2.58 ft	4.2
4.0 ft	3.58 ft	5.0
5.0 ft	4.58 ft	5.6
5.5 ft	5.08 ft	5.9
6.0 ft	5.58 ft	6.2

Outlet capacity - Orifice and overflow

- $Qw = Cw\ P\ d^{1.5}$

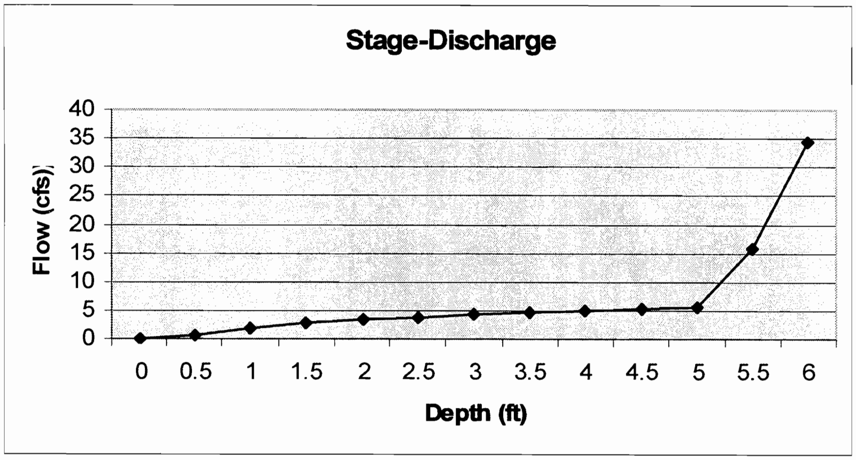
  $Cw = 3.0$; $P = 9.42$ ft

Depth above Bottom	Depth above weir (d)	Q (cfs)
0.0 ft	0.0 ft	0.0
5.0 ft	0.0 ft	0.0
5.5 ft	0.5 ft	10.0
6.0 ft	1.0 ft	28.3

Outlet capacity - Orifice and overflow

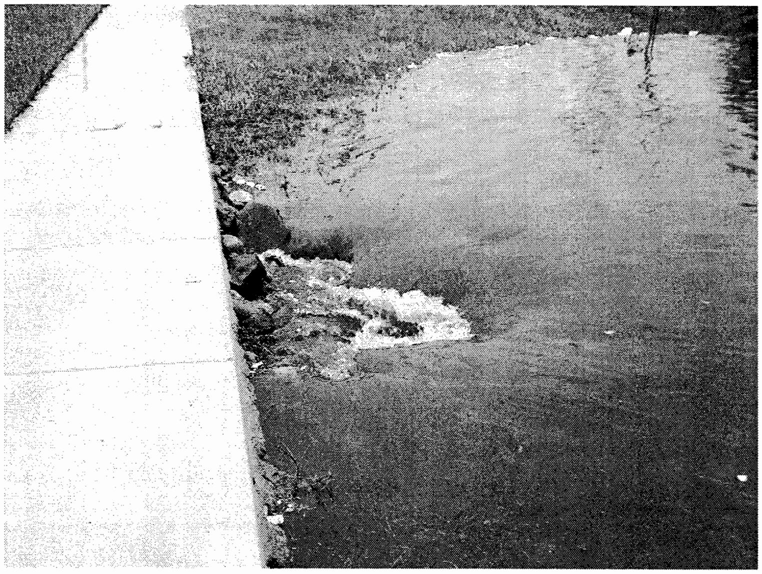
Depth above Bottom	Orifice flow (cfs)	Weir flow (cfs)	Total flow (cfs)
0.0 ft	0.0	0.0	0.0
1.0 ft	2.0	0.0	2.0
2.0 ft	3.3	0.0	3.3
3.0 ft	4.2	0.0	4.2
4.0 ft	5.0	0.0	5.0
5.0 ft	5.6	0.0	5.6
5.5 ft	5.9	10.0	15.9
6.0 ft	6.2	28.3	34.5

Outlet capacity - Orifice and overflow

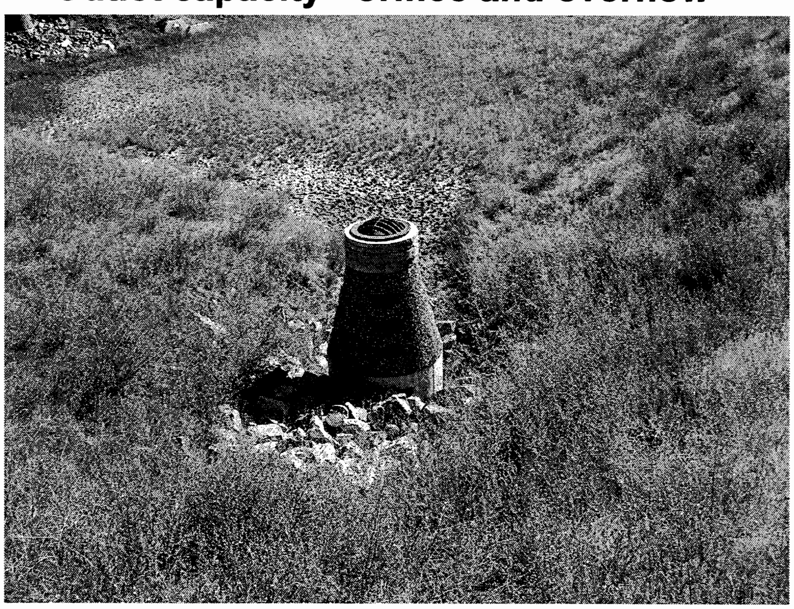


Outlet capacity - grate

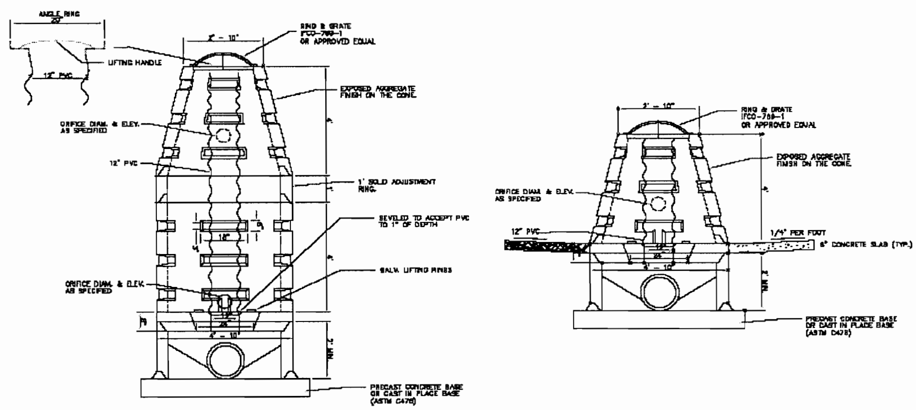
Outlet capacity - grate in operation



Outlet capacity - orifice and overflow



Outlet capacity - orifice and overflow



RETENTION DISCHARGE OUTLET CONTROL STRUCTURE.
NO SCALE

Outlet capacity - Multiple perforations

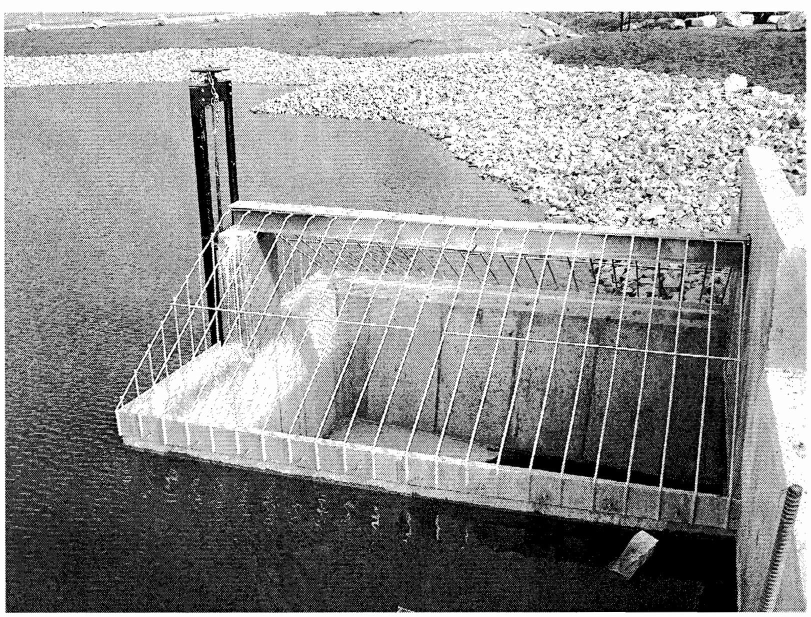
- For outlet with a series of perforations/orifices - solve for flow through each perforation/orifice using orifice equation (same as for an inlet) for varying depths, then sum each row of perforations
- For Mansion Heights Pond, two orifices: #1, elevation 3690, 7" diameter (Ao = 0.27); #2, elevation 3695, 5" diameter (Ao = 0.14); Co = 0.60

Water Elevation	Head on Orifice	Orifice#1 flow	Orifice#2 flow	Total flow
3690	0.0'/0.0'	0.0	0.0	0.0
3691	0.7'/0.0'	1.1	0.0	1.1
3696	5.7'/0.8'	3.1	0.6	3.7
3697	6.7'/1.8'	3.3	0.9	4.2

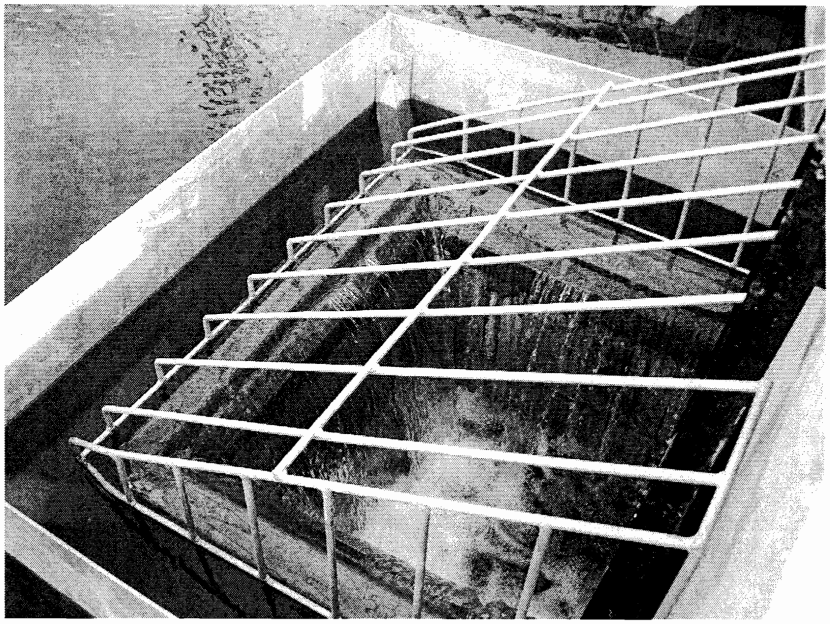
Outlet capacity - Multiple perforations

Elevation	Low Orifice Flow, cfs	High Orifice Flow, cfs	Total Flow cfs
3690	0	0	0
3691	1.1	0	1.1
3692	1.7	0	1.7
3693	2.1	0	2.1
3694	2.5	0	2.5
3695	2.8	0	2.8
3696	3.1	0.6	3.7
3697	3.3	0.9	4.2
3698	3.6	1.1	4.7
3699	3.8	1.3	5.1

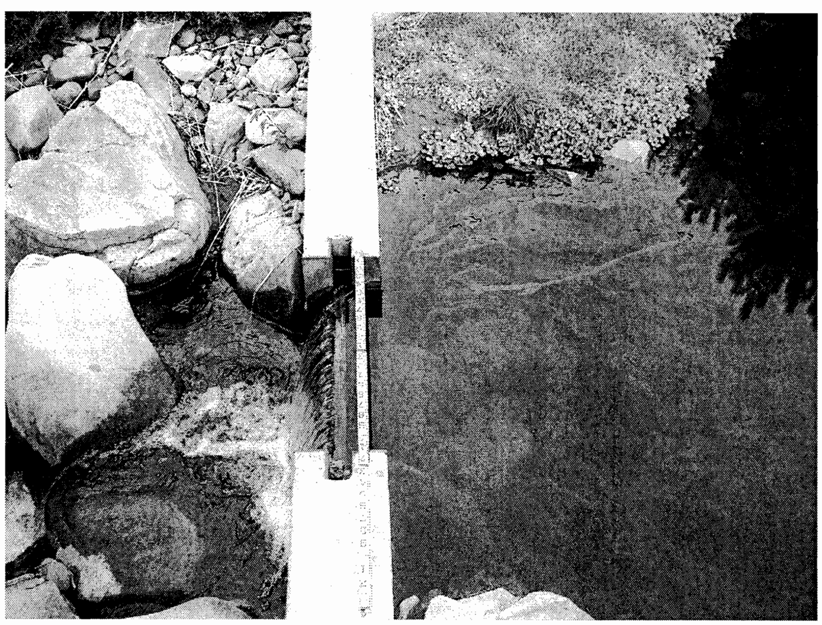
Outlet capacity - weir and gated orifice



Outlet capacity - weir



Outlet capacity - weir



Outlet capacity - pipe and overflow

Outlet capacity - overflow

Outlet capacity – low flow

Outlet capacity - pipes with fence

Outlet capacity - inlet control equations

From FHWA HDS-5:

- UNSUBMERGED:

  Form (2) $Hw_i/D = K*[(Ku*Q)/(A*D^{0.5})]^M$

  Hw_i = Headwater depth above inlet invert, ft

  D = Interior height of culvert barrel, ft

  Q = Discharge, cfs

  A = Full cross-sectional area of barrel, ft^2

  S = Culvert barrel slope, ft/ft

  K, M, c, Y = Constants from Table 9

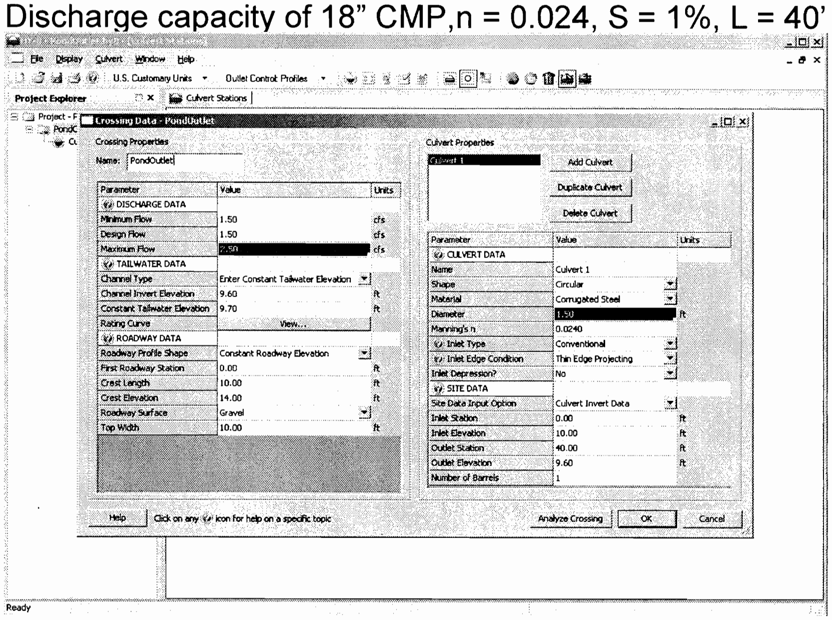
  Ku = 1.0 (English units)

- SUBMERGED:

  $Hw_i/D = c*[(Ku*Q)/(A*D^{0.5})]^2 + Y - 0.5S^2$

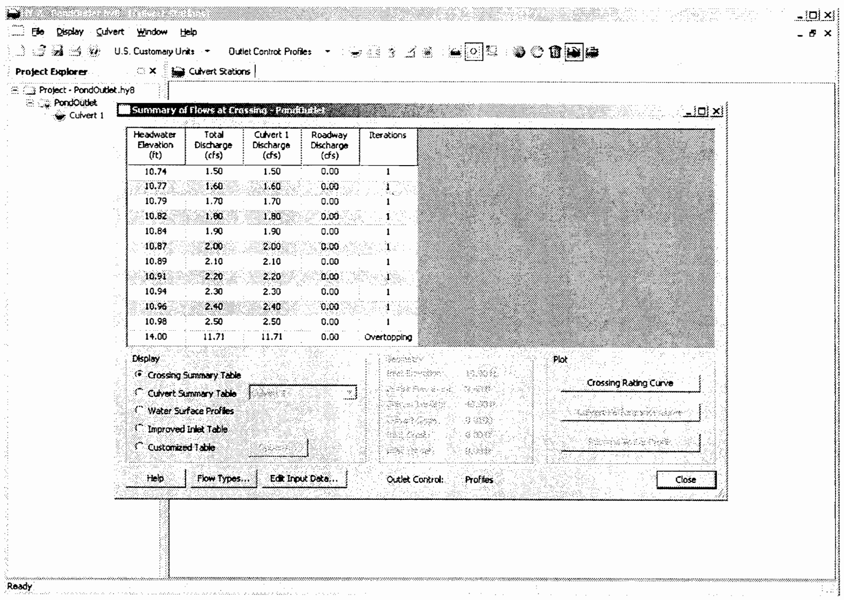
Outlet capacity

Discharge capacity of 18" CMP, n = 0.024, S = 1%, L = 40'



Outlet capacity

Discharge capacity of 18" CMP,n = 0.024, S = 1%, L = 40'

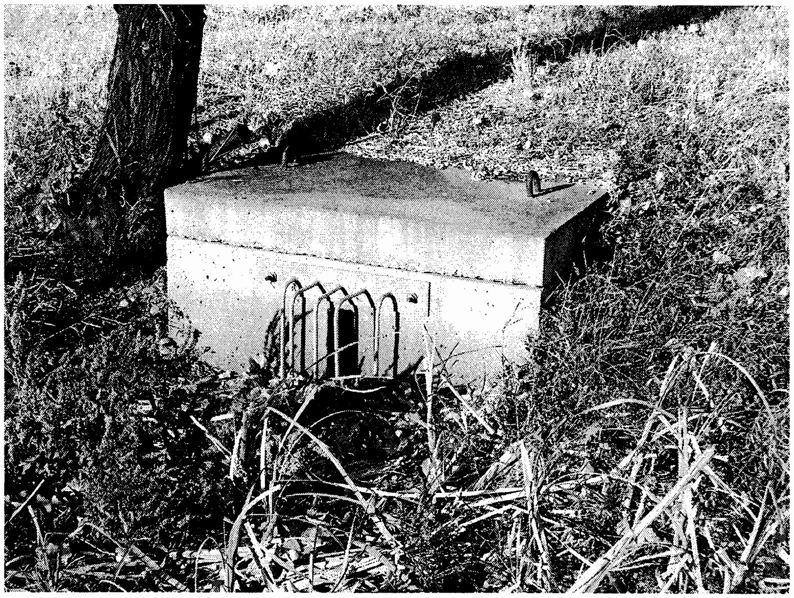


Outlet capacity

- Discharge capacity of 18" CMP, from HY-8 Program (with n = 0.024, S = 1%, L = 40'):

Depth	Flow	Depth	Flow	Depth	Flow	Depth	Flow
0.1	0.1	1.1	3.0	2.1	7.6	3.1	9.9
0.2	0.1	1.2	3.5	2.2	7.8	3.2	10.1
0.3	0.2	1.3	4.1	2.3	8.1	3.3	10.3
0.4	0.5	1.4	4.6	2.4	8.3	3.4	10.5
0.5	0.7	1.5	5.1	2.5	8.5	3.5	10.7
0.6	1.0	1.6	5.6	2.6	8.8	3.6	10.9
0.7	1.3	1.7	6.1	2.7	9.0	3.7	11.1
0.8	1.7	1.8	6.6	2.8	9.3	3.8	11.3
0.9	2.1	1.9	7.0	2.9	9.5	3.9	11.5
1.0	2.6	2.0	7.3	3.0	9.7	4.0	11.7

Outlet capacity - concrete structure



Outlet capacity - grate

Outlet capacity - maintenance

Small Outlet