Rational Problem – Incremental Rainfall

Time Minutes	Rainfall Inches	Incremental Rainfall, Inches	Incremental Rainfall, Inches
5	0.42	0.42	0.42
10	0.72	0.30	0.30
15	0.91	0.19	0.19
20			0.117
25			0.117
30	1.26	0.35	0.117
35			0.057
40			0.057
45			0.057
50			0.057
55			0.057
60	1.60	0.34	0.057

Rational Problem - Incremental Rainfall

Time Minutes	Incremental Rainfall, Inches	Incremental Rainfall, Inches
5	0.42	
10	0.30	0.72
15	0.19	
20	0.117	0.307
25	0.117	
30	0.117	0.233
35	0.057	
40	0.057	0.113
45	0.057	
50	0.057	0.113
55	0.057	
60	0.057	0.113

Rational Problem - Hyetograph

Time minutes	Incremental Rainfall Inches	Rainfall Intensity Inches/hr
10	0.72	4.32
20	0.307	1.84
30	0.233	1.40
40	0.113	0.68
50	0.113	0.68
60	0.113	0.68

Rational Problem - Hyetograph

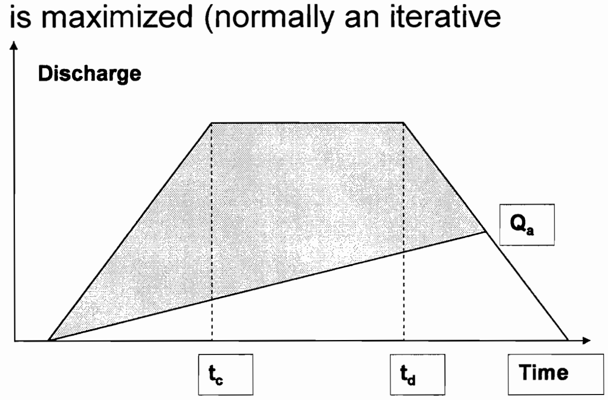
Time minutes	Rainfall Intensity inches/hr	Clock Time minutes	Rainfall Intensity inches/hr
0	0	0	0
10	4.32	10	0.68
20	1.84	20	1.84
30	1.40	30	4.32
40	0.68	40	1.40
50	0.68	50	0.68
60	0.68	60	0.68

Rational Problem - Hydrograph

Clock time minutes	Rainfall Intensity inches/hr	C * A	Q = CIA cfs
0	0	0.95 * 5	0.0
10	0.68	0.95 * 5	3.2
20	1.84	0.95 * 5	8.7
30	4.32	0.95 * 5	20.5
40	1.40	0.95 * 5	6.6
50	0.68	0.95 * 5	3.2
60	0.68	0.95 * 5	3.2

Modified Rational Method

- Can be used for estimation of storage volumes for detention calculations
- Rising and falling limbs have a duration equal to time of concentration (t_c)
- Q_a is allowable release rate
- t_d is critical duration of storm and is varied until the storage volume is maximized (normally an iterative procedure)



Modified Rational Method

- Allowable release rate:

  $Q_a = C_a * I * A$

  Where

  Q_a = allowable release rate (cfs)

  C_a = predevelopment Rational Method runoff coefficient

  I = rainfall intensity for corresponding time of concentration (in/hr)

  A = Area (acres)
- For the Ottumwa, IA example (using C_a = 0.2), Q_a = 11.9 cfs, t_d = 60 minutes, storage volume = 50,250 cubic feet

Modified Rational Method

- Critical duration of storm (for North Central Texas):

  $t_d = (2*C*A*a*b/Q_a)^{0.5} - b$

  Where

  t_d = critical storm duration (minutes)

  Q_a = allowable release rate (cfs)

  C = developed condition Rational Method runoff coefficient

  A = Area (acres)

  a, b = rainfall factors dependent on location and return period (see example table below)

Rainfall factor	1-year event	100-year event
a	90.5 - 108.7	298 - 350
b	13.1 - 15.7	22.7 - 26.7

Rainfall-Runoff Modeling: SCS Method

- We will use the SCS (NRCS) Curve Number Method presented in TR-55 to develop peak runoff and a hydrograph
- Q = runoff in inches (note that it is not in cfs)
- P = rainfall in inches (Q should always be < P)
- S = maximum potential retention after runoff begins
- I_a = initial abstraction
- CN = runoff curve number (0-100) depending on soils (hydrologic soil group A-D), slope and antecedent runoff conditions

SCS Method - Limitations

- Curve numbers describe average conditions - accuracy decreases if modeling a historical storm - also does not account for rainfall duration or intensity
- I_a accounts for interception, initial infiltration, surface depression storage, evapotranspiration and other factors; $I_a = 0.2S$ may not be appropriate
- Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures
- Curve Number method less accurate when Q < 0.5 inch
- Applies only to direct surface runoff - does not include a groundwater component
- Weighted CN > 40
- Watershed must be hydrologically homogeneous
- Accuracy of peak discharge reduced if $0.1 > I_a/P > 0.5$
- Tc < 2 hours

SCS Method - Limitations; Equations

Runoff Equations

- $S = (1000/CN) - 10$
- $Q = \frac{(P - I_a)^2}{(P - I_a) + S}$
- $I_a = 0.2\ S$ (but $0.1 \le I_a/P \le 0.5$)
- $Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$

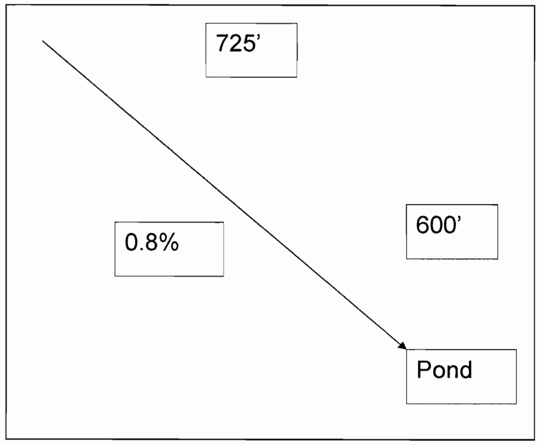
SCS Example - Runoff

- Example for a 10-acre lawn in good condition with soils in hydrologic soil group B (CN = 61) and for a 10-acre parking lot that will replace the lawn (CN = 98). Site is located in Ottumwa, Iowa (same as example for Rational Method). Find the 10-year runoff (in inches) for each condition. From "Rainfall Frequency Atlas of the Midwest", 10-year, 24-hour rainfall is 4.7 inches.
- For the lawn area:
- $S = (1000/CN) - 10 = (1000/61) - 10 = 6.39$
- $I_a = 0.2\ S = 0.2\ (6.39) = 1.28$ inches

  $I_a/P = 1.28/4.7 = 0.27$ OK
- $Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} = \frac{(4.7 - 0.2(6.39))^2}{(4.7 + 0.8(6.39))} = 1.19$ inches

SCS Example - Sketch

Parking Lot



SCS Example - Runoff

- For the paved area:
- $S = (1000/CN) - 10 = (1000/98) - 10 = 0.20$
- $I_a = 0.2\,S = 0.2\,(0.20) = 0.04$ inches

  $I_a/P = 0.04/4.7 = 0.01$ not OK

  use $I_a/P = 0.1$, so $I_a = 0.1 * P = 0.47$
- $Q = \dfrac{(P - I_a)^2}{(P - I_a) + S} = \dfrac{(4.7 - 0.47)^2}{(4.7 - 0.47 + 0.20)} = 4.04$ inches

SCS Example - Sheet Flow, Lawn

- Compute time of concentration (lawn).
  - Sheet flow (300 ft max), Tt (hours) = $\dfrac{0.007\ (nL)^{0.8}}{(P_2)^{0.5}\ S^{0.4}}$

    for lawn area, n = 0.24

    maximum length = 300 ft

    P_2 = 3.0 inches (2-year, 24-hour, as defined in SCS Method) from Bulletin 71

    S = 0.8% = 0.008 ft/ft

    $Tt = \dfrac{0.007\ (nL)^{0.8}}{(P_2)^{0.5}\ S^{0.4}} = \dfrac{0.007\ (0.24*300)^{0.8}}{(3.0)^{0.5}\ (0.008)^{0.4}}$

    Tt = 0.853 hours = 51.2 minutes

    Average velocity = 300/(51.2*60) = 0.10 ft/sec

SCS Example - Shallow Concentrated Flow, Lawn

- Compute time of concentration (continued).
  - Shallow concentrated flow: Tt = L/V

    From Figure 3-1, V = 1.4 ft/sec for S = 0.8%

    Total Length = $(725^2 + 600^2)^{0.5}$ = 941 ft

    Flow Length = 941 ft - 300 ft = 641 ft

    Tt = 641/(1.4*60) = 7.6 minutes

  Total travel time = ΣTt = 51.2 + 7.6 = 58.8 minutes (0.98 hour)

SCS Example - Sheet Flow, Paved

- Compute time of concentration (paved).
  - Sheet flow (300 ft max), $Tt \text{ (hours)} = \dfrac{0.007\,(nL)^{0.8}}{(P_2)^{0.5}\,S^{0.4}}$

    for asphalt parking lot, n = 0.016

    maximum length = 300 ft

    P_2 = 3.0 inches (2-year, 24-hour, as defined in SCS Method) from Bulletin 71

    S = 0.8% = 0.008 ft/ft

    $$Tt = \frac{0.007\,(nL)^{0.8}}{(P_2)^{0.5}\,S^{0.4}} = \frac{0.007\,(0.016*300)^{0.8}}{(3.0)^{0.5}\,(0.008)^{0.4}}$$

    Tt = 0.098 hours = 5.9 minutes

    Average velocity = 300/(5.9*60) = 0.85 ft/sec

  (note - Rational method answer was 5.0 minutes)

SCS Example - Shallow Concentrated Flow, Paved

- Compute time of concentration (continued).
  - Shallow concentrated flow: Tt = L/V

    From Figure, V = 1.8 ft/sec for S = 0.8%

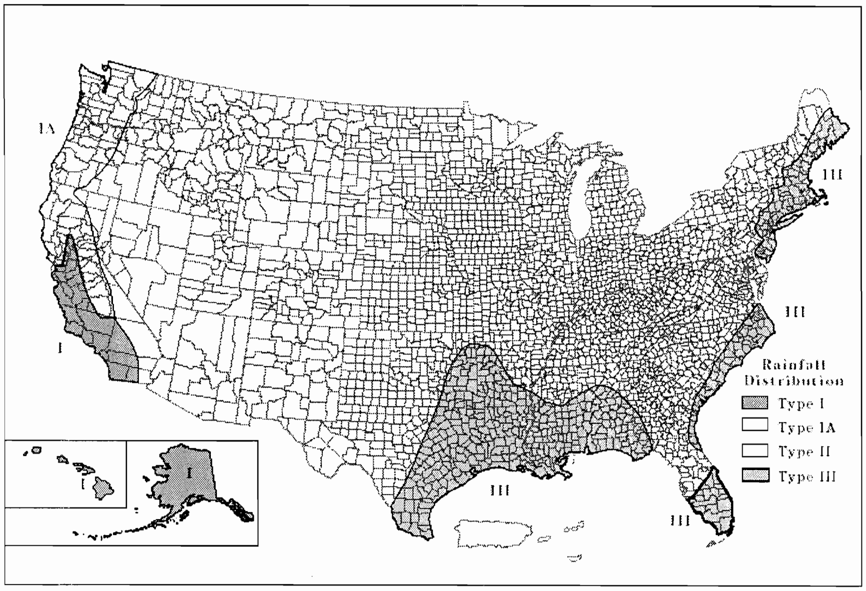
    Total Length = $(725^2 + 600^2)^{0.5}$ = 941 ft

    Flow Length = 941 ft - 300 ft = 641 ft

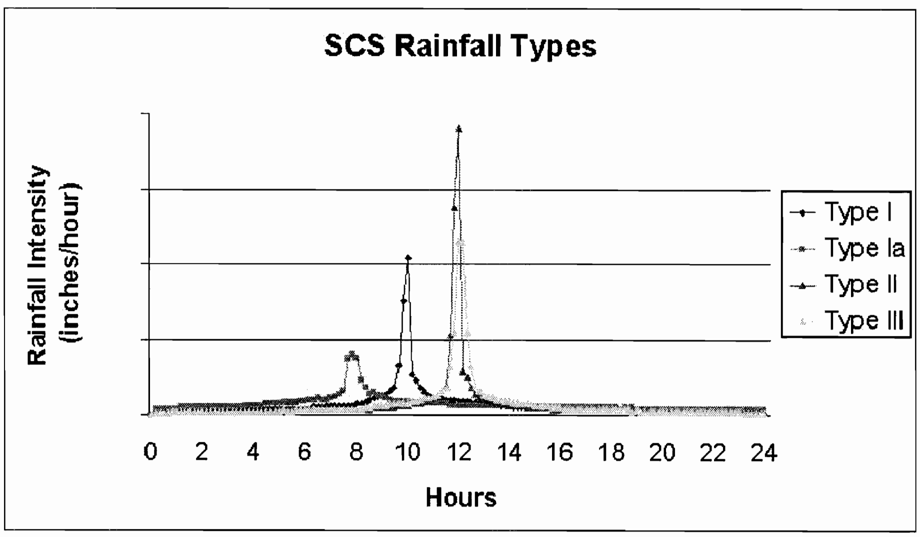
    Tt = 641/(1.8*60) = 5.9 minutes

  Total travel time = ΣTt = 5.9 + 5.9 = 11.8 minutes (0.2 hour)
- Type of Rainfall events (Type II for Iowa)

SCS Method - Rainfall Distribution Map



SCS Method - Rainfall Types



SCS Method - Class Problem

- Class Problem: For a 400' x 545' (5-acre) parking lot (CN = 98) in Red Wing, Minnesota (same as example for Rational Method). Find the 5-year runoff (in inches). From "Rainfall Frequency Atlas of the Midwest", 5-year, 24-hour rainfall is 3.5 inches. The 2-year, 24-hour rainfall is 2.8 inches (from Bulletin 71).
- S = (1000/CN) -10 = (1000/__) - 10 = ____
- I_a = 0.2 S = 0.2 (___) = ___ inches
  I_a/P = ___/___ = ___ OK?
  use I_a/P = __, so I_a = ___ * P = ___
- $Q = \dfrac{(P - I_a)^2}{(P - I_a) + S}$
- Q = _____

SCS Problem - Runoff

- S = (1000/CN) -10 = (1000/98) - 10 = 0.20
- I_a = 0.2 S = 0.2 (0.20) = 0.04 inches
  I_a/P = 0.04/3.5 = 0.01 not OK
  use I_a/P = 0.1, so I_a = 0.1 * P = 0.35
- $Q = \dfrac{(P - I_a)^2}{(P - I_a) + S} = \dfrac{(3.5 - 0.35)^2}{(3.5 - 0.35 + 0.20)} = 2.96$ inches

SCS Problem - Sheet Flow

- Compute time of concentration (paved).
  - Sheet flow (300 ft max), Tt (hours) = $\dfrac{0.007\,(nL)^{0.8}}{(P)^{0.5}\,S^{0.4}}$

  for asphalt parking lot, n = 0.016

  maximum length = 300 ft

  P = 2.8 inches (2-year, 24-hour, as defined in SCS Method) from Bulletin 71

  S = 0.8% = 0.008 ft/ft

  $$Tt = \frac{0.007\,(nL)^{0.8}}{(P)^{0.5}\,S^{0.4}} = \frac{0.007\,(0.016*300)^{0.8}}{(2.8)^{0.5}\,(0.008)^{0.4}}$$

  Tt = 0.101 hours = 6.1 minutes

  (note - Rational method answer was 5.7 minutes)

SCS Problem - Shallow Concentrated Flow

- Compute time of concentration (continued).
  - From Figure, V = 1.8 ft/sec for S = 0.8%

    Total Length = $(545^2 + 400^2)^{0.5}$ = 676 ft

    Flow Length = 676 ft - 300 ft = 376 ft

    Tt = 376/(1.8*60) = 3.5 minutes

  Total travel time = ΣTt = 6.1 + 3.5 = 9.6 minutes (0.16 hour)

SCS Example - Peak Flow

Continuing with Ottumwa Iowa example:

- Peak flow, q_p

  $q_p = q_u * A_m * Q * F_p$

  q_p = peak discharge, cfs

  q_u = unit peak discharge, csm/in (cfs square miles/inch)

  A_m = drainage area, square miles

  Q = runoff, inches

  F_p = pond and swamp adjustment factor
- From Exhibit 4-II (Type II rainfall event)

  q_u = 310 for Ia/P = 0.27 and Tc = 0.98 hour (lawn)

  q_u = 800 for Ia/P = 0.1 and Tc = 0.2 hour (paved)

SCS Example - Peak Flow

- Peak flow, q_p

  $q_p = q_u * A_m * Q * F_p$

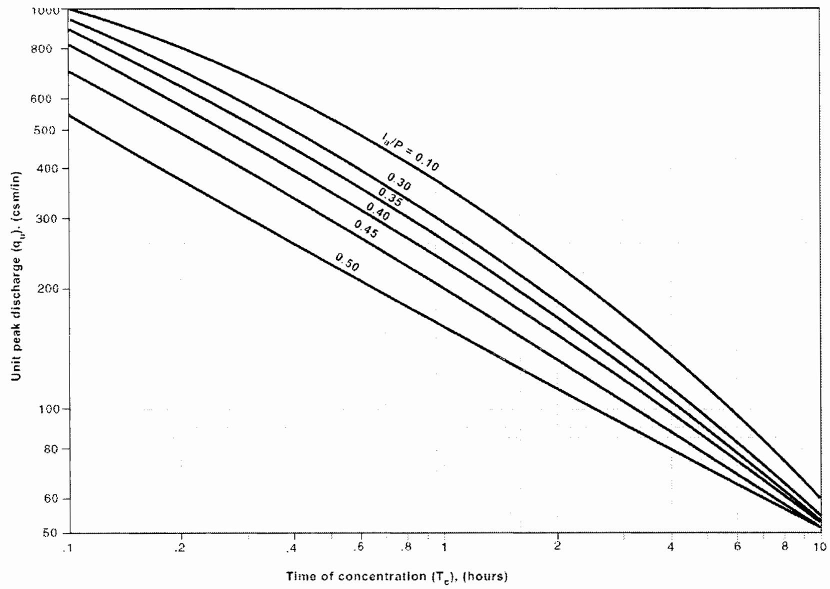
  $q_p = 310 * (10/640) * 1.19 * 1.0$

  q_p = 5.8 cfs for lawn area

  $q_p = 800 * (10/640) * 4.04 * 1.0$

  q_p = 50.5 cfs for parking lot

SCS Example - Unit discharge



SCS Example - Hydrograph

Using Tabular Hydrograph Method to develop a inflow hydrograph, the requirements include:

- Need to divide watershed into areas that are relatively homogeneous and have convenient routing reaches.
- Drainage area of each subarea in square miles
- Time of concentration, Tc for each subarea in hours
- Travel time, Tt for each routing reach in hours
- Weighted CN for each subarea
- Appropriate rainfall distribution
- 24-hour rainfall for the selected frequency
- Total runoff (Q)
- Ia for each subarea and Ia/P for each subarea

SCS Example - Hydrograph

- $q = q_t * A_m * Q$ (Equation 5-1)
- where:

  q = hydrograph coordinate (cfs) at hydrograph time t

  q_t = tabular hydrograph unit discharge from exhibit 5 (csm/in - cubic feet per second per square mile per inch)

  A_m = drainage area of individual subarea (square miles)

  Q = runoff (inches)
- Round actual values of Tt and Tc to values presented in Exhibit 5. For our example Tt = 0 (single basin).

SCS Example - Unit Hydrograph Table, Lawn

- From Exhibit 5-II, with Ia/P = 0.3 (actually 0.27), Tc = 1.00 (actually 0.98) and Tt =0.0:

Time	q_t	Time	q_t
11.0	0	12.6	195
11.3	0	12.7	243
11.6	0	12.8	271
11.9	0	13.0	292
12.0	1	13.2	227
12.1	4	13.4	178
12.2	16	13.6	143
12.3	42	13.8	117
12.4	83	14.0	98
12.5	137		

Exhibit 5-II: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10												* * * TC = 1.0 HR * * *																				
0.0	11	15	20	29	35	47	72	112	168	231	289	329	357	313	239	175	133	103	83	63	50	40	33	29	26	23	21	20	17	15	12	0
.10	10	13	17	24	27	33	42	62	95	144	202	260	306	340	293	222	165	126	98	72	56	43	35	30	27	24	22	20	18	15	12	0
.20	10	13	17	23	26	30	38	54	82	123	176	232	281	332	303	238	179	136	105	76	59	45	35	30	27	24	22	20	18	16	12	1
.30	9	12	16	22	24	28	35	48	70	105	152	205	256	323	310	254	193	146	113	81	61	46	36	31	27	24	22	20	18	16	12	1
.40	8	11	14	19	21	23	27	32	42	61	91	132	181	276	318	294	237	181	138	95	70	51	39	32	28	25	23	21	18	16	12	1
.50	8	10	13	18	20	22	25	30	38	53	78	114	159	253	311	300	251	195	149	102	74	53	40	33	29	25	23	21	18	16	12	1
.75	7	8	11	14	16	17	19	21	25	30	38	53	76	146	228	284	293	256	208	143	99	66	46	36	31	27	24	22	19	17	13	2
1.0	5	7	8	11	12	13	14	16	17	19	22	25	31	57	111	188	256	286	272	208	144	90	56	41	33	29	26	23	20	17	13	4
1.5	4	5	6	8	8	9	10	11	12	13	14	15	17	22	33	59	107	171	231	268	235	157	88	56	41	33	29	25	21	18	14	8
2.0	2	3	4	5	5	6	6	7	7	8	9	9	10	12	15	19	27	44	78	157	231	252	167	96	59	42	34	29	23	20	15	11
2.5	1	2	2	3	4	4	4	5	5	6	6	7	7	8	10	12	15	19	27	58	120	214	241	159	94	59	42	34	26	21	16	11
3.0	0	1	1	2	2	3	3	3	4	4	4	5	5	6	7	8	10	12	14	22	44	113	214	231	152	91	58	42	29	23	17	12
IA/P = 0.30												* * * TC = 1.0 HR * * *																				
0.0	0	0	0	0	1	4	16	42	83	137	195	243	271	292	227	178	143	117	98	79	66	55	47	42	38	34	31	30	27	23	19	0
.10	0	0	0	0	0	0	3	12	32	66	113	168	218	279	260	213	169	136	113	88	72	59	49	43	39	35	32	30	27	24	19	1
.20	0	0	0	0	0	0	2	9	24	52	93	143	193	271	271	225	180	145	119	92	75	60	50	44	39	35	32	30	27	24	19	1
.30	0	0	0	0	0	0	1	6	18	41	75	120	169	246	264	234	191	153	125	96	78	62	51	44	40	36	33	31	27	24	19	1
.40	0	0	0	0	0	0	0	1	4	14	32	61	100	190	251	259	222	181	146	109	86	67	53	46	41	37	33	31	28	25	19	2
.50	0	0	0	0	0	0	0	1	3	10	24	49	83	168	237	254	230	191	155	115	90	69	54	47	42	37	34	31	28	25	19	2
.75	0	0	0	0	0	0	0	0	0	1	4	12	25	76	150	213	239	228	198	149	112	82	61	50	44	39	35	32	29	26	20	4
1.0	0	0	0	0	0	0	0	0	0	0	0	1	2	15	51	113	182	226	234	197	150	104	72	56	47	42	38	34	30	27	20	7
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	18	51	104	162	220	210	158	102	71	56	47	42	37	31	28	22	13
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	20	49	121	187	209	152	100	70	55	47	41	34	29	23	17
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	7	32	87	171	199	146	98	69	54	46	37	31	24	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	13	62	158	192	151	103	73	56	41	34	26	18
IA/P = 0.50												* * * TC = 1.0 HR * * *																				
0.0	0	0	0	0	0	0	1	7	21	42	71	101	126	160	154	138	123	110	100	87	77	67	60	55	50	46	43	41	38	34	28	1
.10	0	0	0	0	0	0	0	1	5	15	33	58	87	134	156	149	134	120	108	93	82	71	62	57	52	47	44	42	38	34	28	1
.20	0	0	0	0	0	0	0	1	4	12	26	48	74	123	153	153	137	123	111	95	84	72	63	57	52	47	44	42	38	34	28	1
.30	0	0	0	0	0	0	0	0	3	9	20	38	62	111	143	150	140	127	114	98	86	73	63	58	53	48	45	42	39	35	28	1
.40	0	0	0	0	0	0	0	0	0	2	6	16	31	75	120	145	148	137	123	106	91	77	66	59	54	49	45	43	39	35	29	2
.50	0	0	0	0	0	0	0	0	0	1	5	12	25	64	109	139	146	139	127	108	94	79	67	60	55	50	46	43	39	36	29	3
.75	0	0	0	0	0	0	0	0	0	0	2	5	12	39	78	115	136	140	134	117	101	84	70	62	56	51	47	44	40	36	29	4
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	26	59	96	125	139	133	117	97	78	66	59	54	49	46	41	37	29	8
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	26	54	86	123	133	119	95	77	66	59	54	49	43	39	31	17
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	25	64	104	129	116	93	76	65	58	53	45	41	33	24
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	10	34	84	125	117	96	78	66	59	49	43	35	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	32	89	122	114	94	77	66	53	45	37	27

RAINFALL TYPE = II * * * TC = 1.0 HR * * * SHEET 7 OF 10

SCS Example - Hydrograph Table, Lawn

- $q = q_t * A_m * Q$, with A = 10/640 = 0.0156 and Q = 1.19 inches:

Time	q_t	q	Time	q_t	q
11.0	0	0.0	12.6	195	3.6
11.3	0	0.0	12.7	243	4.5
11.6	0	0.0	12.8	271	5.0
11.9	0	0.0	13.0	292	5.4
12.0	1	0.0	13.2	227	4.2
12.1	4	0.1	13.4	178	3.3
12.2	16	0.3	13.6	143	2.7
12.3	42	0.8	13.8	117	2.2
12.4	83	1.5	14.0	98	1.8
12.5	137	2.5			

Note - Peak flow is 5.4 cfs vs. 5.8 cfs by Runoff equations (due to I_a/P for hydrograph of 0.3 vs. 0.27)

SCS Example, Unit Hydrograph Table, Paved

- From Exhibit 5-II, with Ia/P = 0.1, Tc = 0.2 and Tt =0.0:

Time	q_t	Time	q_t
11.0	23	12.6	128
11.3	31	12.7	102
11.6	47	12.8	86
11.9	209	13.0	70
12.0	403	13.2	61
12.1	739	13.4	54
12.2	800	13.6	49
12.3	481	13.8	44
12.4	250	14.0	40
12.5	166		

Exhibit 5-II: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10												* * * TC = 0.2 HR * * *																	IA/P = 0.10			
0.0	23	31	47	209	403	739	800	481	250	166	128	102	86	70	61	54	49	44	40	35	33	30	27	24	21	20	19	18	16	13	12	0
.10	19	26	39	86	168	325	601	733	565	355	229	161	122	83	69	59	53	47	43	37	34	31	28	25	22	21	19	18	16	14	12	0
.20	17	23	32	49	74	136	262	488	652	594	435	298	207	115	81	67	58	51	46	40	35	32	29	26	23	21	20	19	16	14	12	0
.30	16	22	30	46	64	112	212	396	566	585	485	360	258	139	90	71	60	53	48	41	36	32	29	26	23	21	20	19	16	14	12	0
.40	14	19	25	37	43	57	94	173	322	485	551	507	409	227	129	87	68	58	52	44	38	33	30	27	24	21	20	19	17	14	12	0
.50	13	18	24	35	40	52	80	142	262	410	504	506	441	269	153	98	73	61	53	45	39	34	30	27	24	22	20	19	17	15	12	0
.75	10	13	17	23	26	30	34	40	55	86	150	247	349	438	360	240	151	101	75	57	47	39	33	29	26	23	21	20	18	15	12	0
1.0	9	11	14	19	21	24	26	30	35	44	62	101	167	337	413	353	245	157	104	68	53	42	35	31	28	24	22	20	18	16	12	0
1.5	6	8	10	13	14	15	17	19	21	23	26	30	37	73	166	288	356	337	264	154	91	57	42	35	30	27	24	22	19	17	13	3
2.0	4	5	7	8	9	10	10	11	12	14	15	16	18	23	31	55	114	206	291	324	239	125	63	44	35	31	28	24	20	18	14	9
2.5	3	4	5	6	6	7	7	8	9	9	10	11	12	15	18	22	32	58	111	227	298	246	122	63	43	35	31	27	22	19	15	11
3.0	1	2	3	4	4	4	5	5	6	6	7	7	8	9	11	13	16	19	27	59	138	280	248	137	70	46	36	31	25	21	16	11
IA/P = 0.30												* * * TC = 0.2 HR * * *																	IA/P = 0.30			
0.0	0	0	0	39	180	545	697	497	276	198	158	130	110	93	81	73	67	61	56	49	46	43	39	35	32	30	29	27	24	21	19	0
.10	0	0	0	2	27	129	407	600	532	361	252	190	150	108	90	79	71	65	59	52	48	44	41	36	32	31	29	28	25	21	19	0
.20	0	0	0	2	19	92	302	501	521	415	306	228	176	119	95	82	73	67	61	53	48	45	41	37	33	31	29	28	25	21	19	0
.30	0	0	0	0	1	13	66	223	408	484	438	350	269	163	114	93	80	72	65	57	51	46	42	38	34	31	30	28	25	22	19	0
.40	0	0	0	0	1	9	47	164	327	431	436	379	306	189	127	98	83	74	67	58	52	47	43	38	34	31	30	28	25	22	19	0
.50	0	0	0	0	0	0	6	33	120	258	374	415	391	271	173	121	95	81	72	62	55	48	44	40	35	32	30	29	26	22	19	0
.75	0	0	0	0	0	0	2	13	50	126	221	302	348	323	240	167	121	96	81	68	59	50	45	41	37	33	31	29	26	23	19	0
1.0	0	0	0	0	0	0	0	0	1	6	24	69	139	285	331	280	204	145	109	82	68	56	48	43	39	35	32	30	27	24	19	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	1	16	79	186	271	288	247	165	110	76	58	49	44	40	35	32	29	26	20	5
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	24	80	163	235	262	202	123	76	58	49	43	39	35	30	27	21	13
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	28	77	179	242	207	120	75	57	48	43	39	32	29	22	17
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	30	101	207	227	130	80	59	49	44	35	30	24	18
IA/P = 0.50												* * * TC = 0.2 HR * * *																	IA/P = 0.50			
0.0	0	0	0	0	7	98	371	322	221	182	158	137	120	104	94	86	80	74	69	62	60	57	52	47	44	42	40	39	35	30	28	0
.10	0	0	0	0	4	67	270	305	249	204	174	149	130	108	97	88	82	76	71	64	60	57	53	48	44	42	41	39	35	30	28	0
.20	0	0	0	0	0	3	45	195	268	255	221	189	163	125	106	95	87	80	75	67	62	58	54	49	45	43	41	39	35	31	28	0
.30	0	0	0	0	0	2	31	140	226	245	229	203	176	134	111	98	89	82	76	68	62	59	55	50	45	43	41	39	36	31	28	0
.40	0	0	0	0	0	1	21	101	184	225	228	211	188	144	117	101	91	84	78	69	63	59	55	50	45	43	41	40	36	31	28	0
.50	0	0	0	0	0	0	1	14	72	146	199	218	213	175	137	113	99	89	82	73	66	60	56	52	47	43	42	40	36	32	28	0
.75	0	0	0	0	0	0	0	5	28	71	121	162	186	193	161	133	112	98	88	78	70	62	57	53	48	44	42	41	37	33	28	0
1.0	0	0	0	0	0	0	0	0	0	2	13	38	77	154	186	174	147	122	105	89	78	68	60	56	51	46	43	42	38	34	28	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	2	22	71	129	163	168	150	120	98	80	67	60	55	51	46	43	40	36	28	4
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	25	65	112	146	157	134	103	79	67	60	55	50	46	41	38	29	14
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	26	60	117	148	136	101	79	66	59	54	50	43	39	31	24
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	40	90	142	130	99	78	66	59	54	45	41	33	26

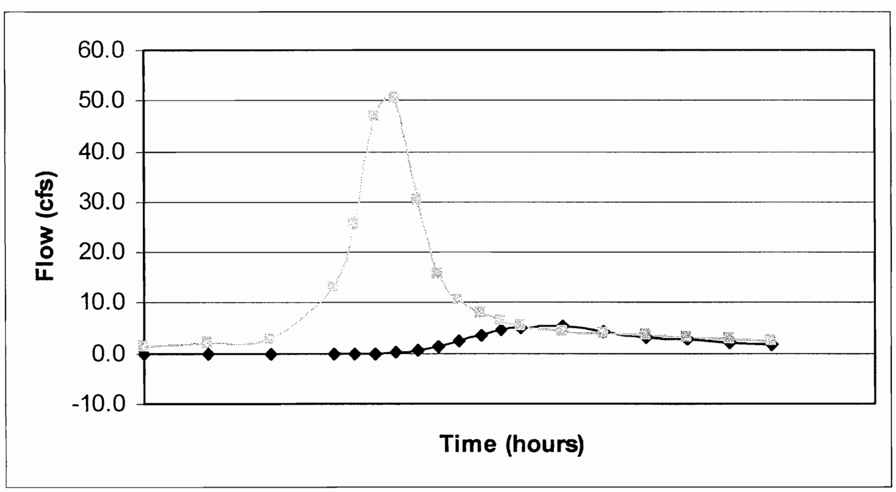
RAINFALL TYPE = II * * * TC = 0.2 HR * * * SHEET 2 OF 10

SCS Example - Hydrograph Table, Paved

- $q = q_t * A_m * Q$, with A = 10/640 = 0.0156 and Q = 4.04 inches:

Time	q_t	q	Time	q_t	q
11.0	23	1.5	12.6	128	8.1
11.3	31	2.0	12.7	102	6.4
11.6	47	3.0	12.8	86	5.4
11.9	209	13.2	13.0	70	4.4
12.0	403	25.4	13.2	61	3.9
12.1	739	46.6	13.4	54	3.4
12.2	800	50.5	13.6	49	3.1
12.3	481	30.4	13.8	44	2.8
12.4	250	15.8	14.0	40	2.5
12.5	166	10.5			

SCS Example - Hydrograph comparison



SCS Method - Class Problem

- Class Problem: for a 5-acre parking lot (CN = 98). Site is located in Red Wing, Minnesota (same as example for Rational Method). Find the 5-year hydrograph. From "Rainfall Frequency Atlas of the Midwest", 5-year, 24-hour rainfall is 3.5 inches. From earlier problem, Tc = 9.6 minutes (0.16 hour), Tt = 0, Ia/P = 0.1 and Q = 2.91 inches.

SCS Problem - Hydrograph

- $q = q_t * A_m * Q$, with A = 5/640 = 0.0078 and Q = 2.91 inches:

Time	q_t	q	Time	q_t	q
11.0	____	____	12.6	____	____
11.3	____	____	12.7	____	____
11.6	____	____	12.8	____	____
11.9	____	____	13.0	____	____
12.0	____	____	13.2	____	____
12.1	____	____	13.4	____	____
12.2	____	____	13.6	____	____
12.3	____	____	13.8	____	____
12.4	____	____	14.0	____	____
12.5	____	____			

Exhibit 5-II: Tabular hydrograph unit discharges (csm/in) for type II rainfall distribution—continued

HYDROGRAPH TIME (HOURS)

TRVL TIME (hr)	11.0	11.3	11.6	11.9	12.0	12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5	16.0	16.5	17.0	17.5	18.0	19.0	20.0	22.0	26.0
IA/P = 0.10																																
0.0	23	31	47	209	403	739	800	481	250	166	128	102	86	70	61	54	49	44	40	35	33	30	27	24	21	20	19	18	16	13	12	0
.10	19	26	39	86	168	325	601	733	565	355	229	161	122	83	69	59	53	47	43	37	34	31	28	25	22	21	19	18	16	14	12	0
.20	17	23	32	49	74	136	262	488	652	594	435	298	207	115	81	67	58	51	46	40	35	32	29	26	23	21	20	19	16	14	12	0
.30	16	22	30	46	64	112	212	396	566	585	485	360	258	139	90	71	60	53	48	41	36	32	29	26	23	21	20	19	16	14	12	0
.40	14	19	25	37	43	57	94	173	322	485	551	507	409	227	129	87	68	58	52	44	38	33	30	27	24	21	20	19	17	14	12	0
.50	13	18	24	35	40	52	80	142	262	410	504	506	441	269	153	98	73	61	53	45	39	34	30	27	24	22	20	19	17	15	12	0
.75	10	13	17	23	26	30	34	40	55	86	150	247	349	438	360	240	151	101	75	57	47	39	33	29	26	23	21	20	18	15	12	0
1.0	9	11	14	19	21	24	26	30	35	44	62	101	167	337	413	353	245	157	104	68	53	42	35	31	28	24	22	20	18	16	12	0
1.5	6	8	10	13	14	15	17	19	21	23	26	30	37	73	166	288	356	337	264	154	91	57	42	35	30	27	24	22	19	17	13	3
2.0	4	5	7	8	9	10	10	11	12	14	15	16	18	23	31	55	114	206	291	324	239	125	63	44	35	31	28	24	20	18	14	9
2.5	3	4	5	6	6	7	7	8	9	9	10	11	12	15	18	22	32	58	111	227	298	246	122	63	43	35	31	27	22	19	15	11
3.0	1	2	3	4	4	4	5	5	6	6	7	7	8	9	11	13	16	19	27	59	138	280	248	137	70	46	36	31	25	21	16	11
IA/P = 0.30																																
0.0	0	0	0	39	180	545	697	497	276	198	158	130	110	93	81	73	67	61	56	49	46	43	39	35	32	30	29	27	24	21	19	0
.10	0	0	0	2	27	129	407	600	532	361	252	190	150	108	90	79	71	65	59	52	48	44	41	36	32	31	29	28	25	21	19	0
.20	0	0	0	2	19	92	302	501	521	415	306	228	176	119	95	82	73	67	61	53	48	45	41	37	33	31	29	28	25	21	19	0
.30	0	0	0	0	1	13	66	223	408	484	438	350	269	163	114	93	80	72	65	57	51	46	42	38	34	31	30	28	25	22	19	0
.40	0	0	0	0	1	9	47	164	327	431	436	379	306	189	127	98	83	74	67	58	52	47	43	38	34	31	30	28	25	22	19	0
.50	0	0	0	0	0	0	6	33	120	258	374	415	391	271	173	121	95	81	72	62	55	48	44	40	35	32	30	29	26	22	19	0
.75	0	0	0	0	0	0	2	13	50	126	221	302	348	323	240	167	121	96	81	68	59	50	45	41	37	33	31	29	26	23	19	0
1.0	0	0	0	0	0	0	0	0	1	6	24	69	139	285	331	280	204	145	109	82	68	56	48	43	39	35	32	30	27	24	19	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	1	16	79	186	271	288	247	165	110	76	58	49	44	40	35	32	29	26	20	5
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	24	80	163	235	262	202	123	76	58	49	43	39	35	30	27	21	13
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	28	77	179	242	207	120	75	57	48	43	39	32	29	22	17
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	30	101	207	227	130	80	59	49	44	35	30	24	18
IA/P = 0.50																																
0.0	0	0	0	0	7	98	371	322	221	182	158	137	120	104	94	86	80	74	69	62	60	57	52	47	44	42	40	39	35	30	28	0
.10	0	0	0	0	4	67	270	305	249	204	174	149	130	108	97	88	82	76	71	64	60	57	53	48	44	42	41	39	35	30	28	0
.20	0	0	0	0	0	3	45	195	268	255	221	189	163	125	106	95	87	80	75	67	62	58	54	49	45	43	41	39	35	31	28	0
.30	0	0	0	0	0	2	31	140	226	245	229	203	176	134	111	98	89	82	76	68	62	59	55	50	45	43	41	39	36	31	28	0
.40	0	0	0	0	0	1	21	101	184	225	228	211	188	144	117	101	91	84	78	69	63	59	55	50	45	43	41	40	36	31	28	0
.50	0	0	0	0	0	0	1	14	72	146	199	218	213	175	137	113	99	89	82	73	66	60	56	52	47	43	42	40	36	32	28	0
.75	0	0	0	0	0	0	0	5	28	71	121	162	186	193	161	133	112	98	88	78	70	62	57	53	48	44	42	41	37	33	28	0
1.0	0	0	0	0	0	0	0	0	0	2	13	38	77	154	186	174	147	122	105	89	78	68	60	56	51	46	43	42	38	34	28	0
1.5	0	0	0	0	0	0	0	0	0	0	0	0	2	22	71	129	163	168	150	120	98	80	67	60	55	51	46	43	40	36	28	4
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	25	65	112	146	157	134	103	79	67	60	55	50	46	41	38	29	14
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	26	60	117	148	136	101	79	66	59	54	50	43	39	31	24
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	9	40	90	142	130	99	78	66	59	54	45	41	33	26

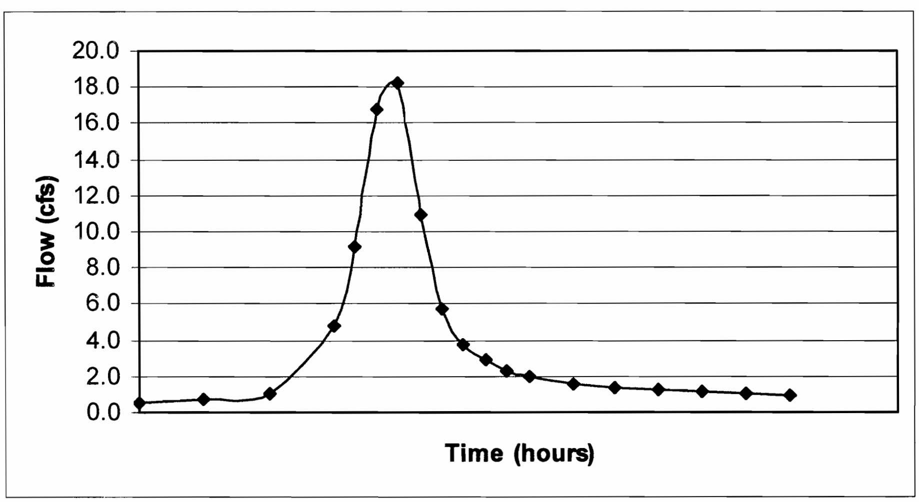
RAINFALL TYPE = II   * * * TC = 0.2 HR * * *   SHEET 2 OF 10

SCS Problem - Hydrograph

- $q = q_t * A_m * Q$, with A = 5/640 = 0.0078 and Q = 2.91 inches:

Time	q_t	q	Time	q_t	q
11.0	23	0.5	12.6	128	2.9
11.3	31	0.7	12.7	102	2.3
11.6	47	1.1	12.8	86	2.0
11.9	209	4.8	13.0	70	1.6
12.0	403	9.2	13.2	61	1.4
12.1	739	16.8	13.4	54	1.2
12.2	800	18.2	13.6	49	1.1
12.3	481	10.9	13.8	44	1.0
12.4	250	5.7	14.0	40	0.9
12.5	166	3.8			

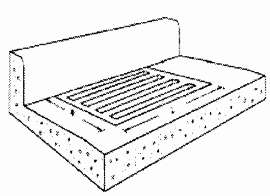
SCS Problem - Hydrograph



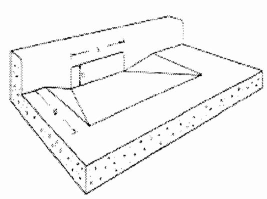
Inlet capacity analysis

- Inlet capacity can be a significant issue in design of storm drain systems and detention ponds. A very expensive piping system can be ineffective if there are not enough properly sized inlets.
- Factors affecting inlet capacity are depth of flow, width of flow, slope of gutter at inlet, inlet geometry and inlet type
- Inlets in sags can function in weir control or orifice control - compute both, lower capacity is limiting
- Inlet types
  - Grate inlets
  - Curb-opening inlets
  - Slotted inlets
  - Combination inlets

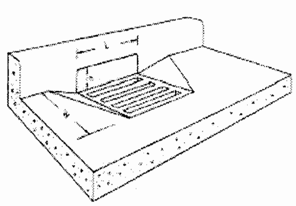
Inlet Types



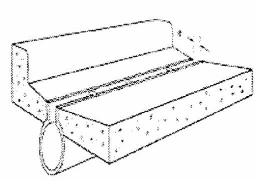
a. Grate



b. Curb-opening Inlet

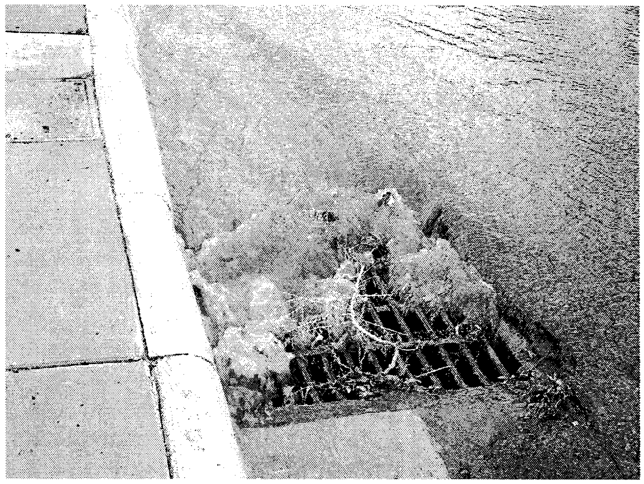


c. Combination Inlet



d. Slotted Drain Inlet

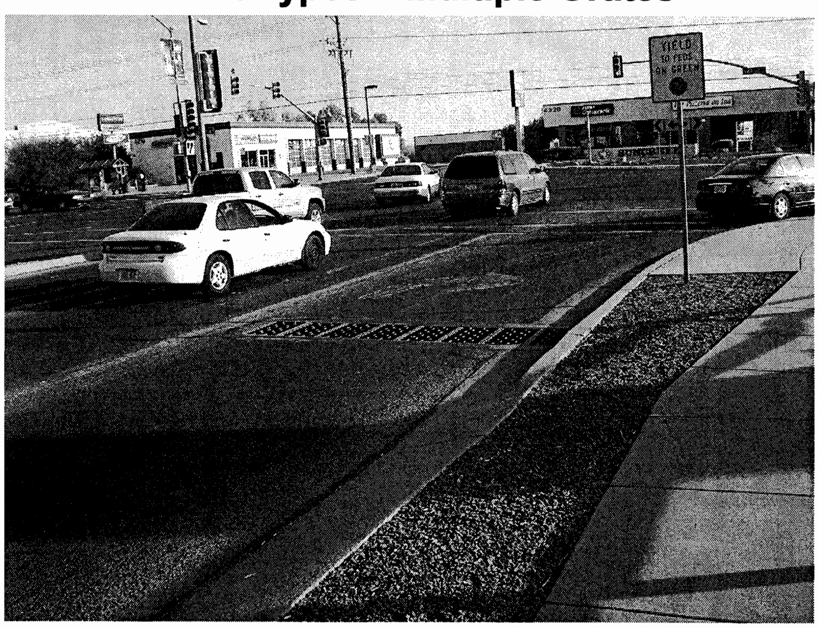
Inlet Types - Grate



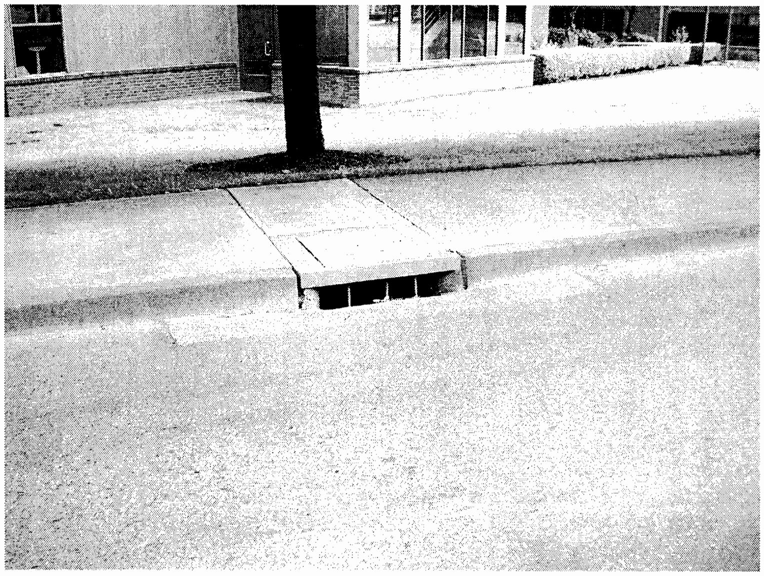
Inlet Types - Grate

Inlet Types - Grate, curved vane

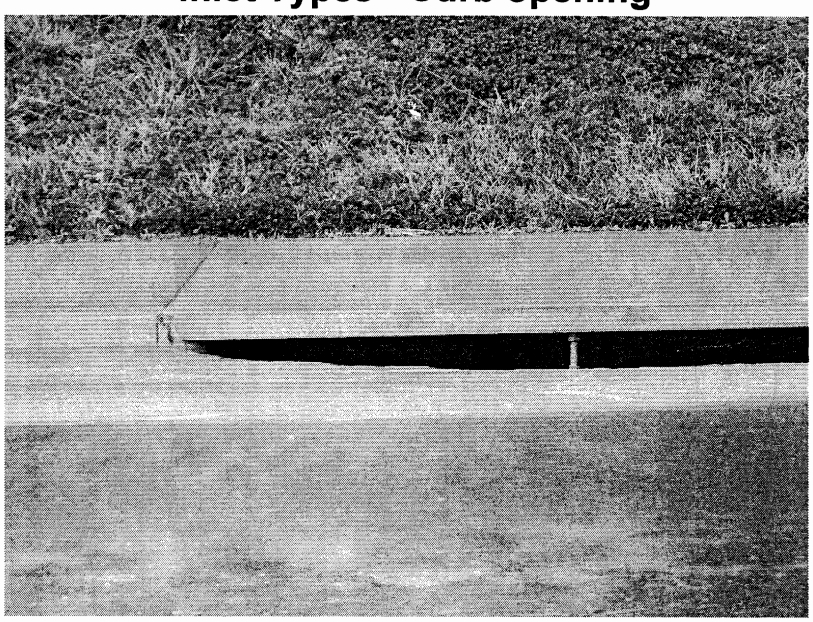
Inlet Types – Multiple Grates



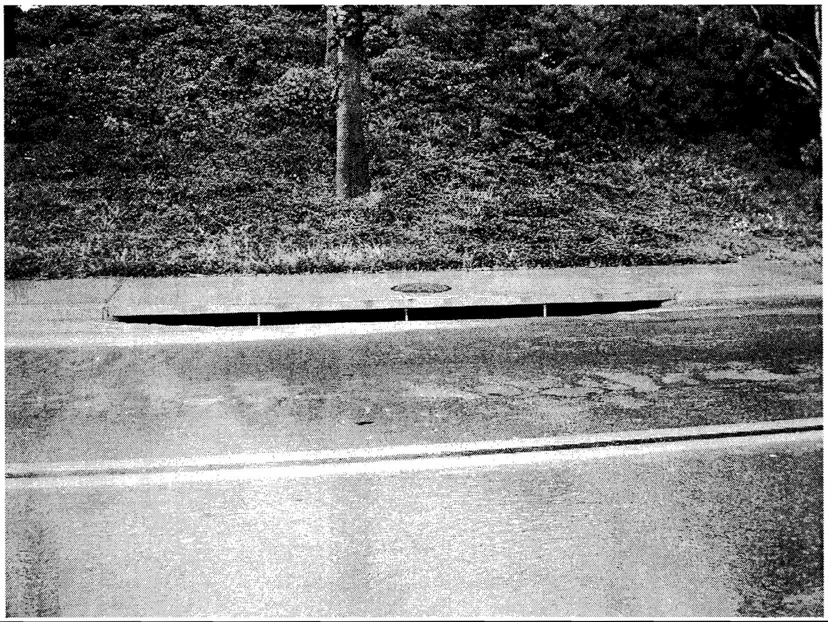
Inlet Types - Curb opening



Inlet Types - Curb opening

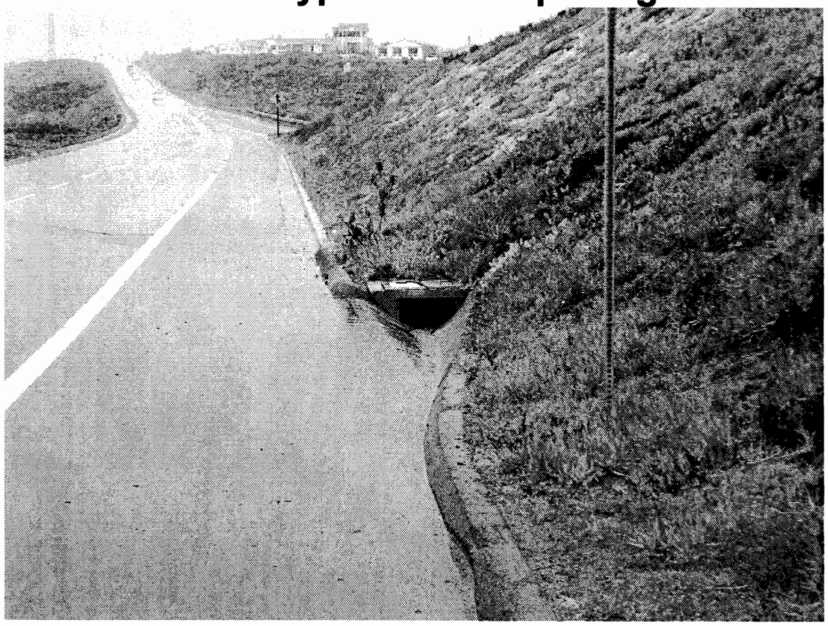


Inlet Types - Curb opening

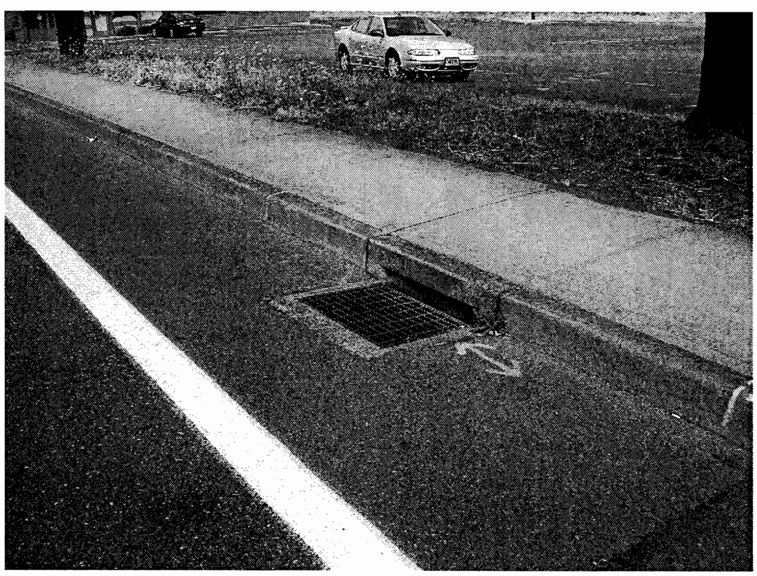


Inlet Types - Curb opening

Inlet Types - Curb opening

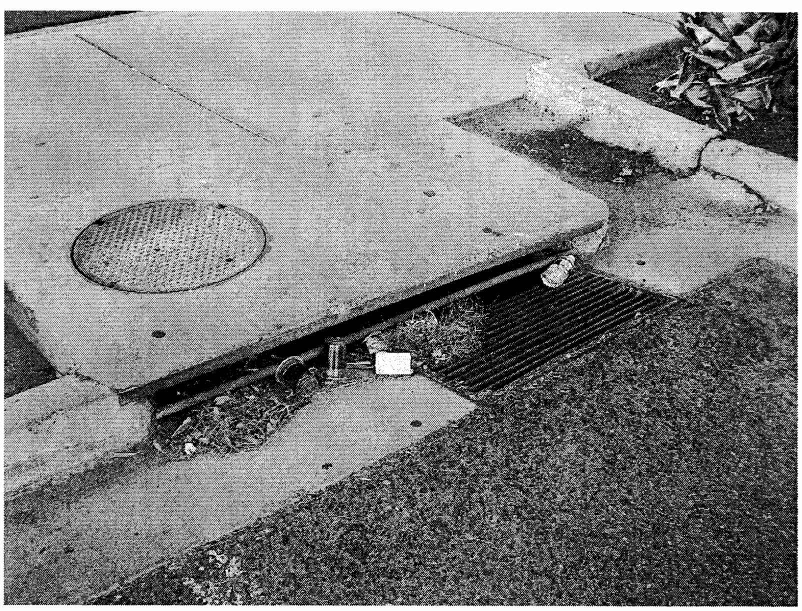


Inlet Types - Combination

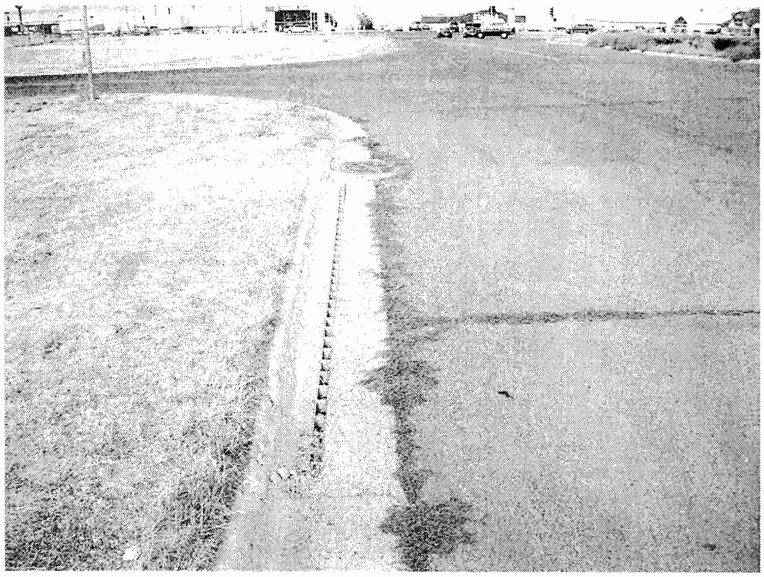


Inlet Types - Combination

Inlet Types - Combination



Inlet Types - Slotted Drain



Inlet Types - Slotted Drain