ASCE American Society of Civil Engineers

Introduction to Detention Pond Design: Parking Lots and Urban Drainage

2008

Introduction to Detention Pond Design: Parking Lots and Urban Drainage

Learning Outcomes

At the conclusion of the course, you will be able to:

- Use the Rational equation to determine runoff, including selection of appropriate rainfall intensity values and runoff coefficients
- Use the NRCS (SCS) Method to determine runoff, including selection of appropriate rainfall distributions and Curve Number values
- Determine capacities of various outlet configurations
- Determine capacities of various storm drain inlet types
- Determine appropriate volumes for detention ponds
- Route a hydrograph through a detention pond
- Understand some of the water quality improvements possible by use of detention ponds

Assessment of Learning Outcomes

Students' achievement of the learning outcomes will be assessed through a series of problem-solving exercises.

ASCE

Introduction to Detention Pond Design

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Overview

Thursday:

- Facility Logistics
- Introductions and Disclaimers
- Rainfall data sources, including NWS publications (when it doesn't rain, we don't have any storm drain problems - compared to other utilities)
- Time of concentration
- Rainfall runoff modeling - using the Rational Method to generate an inflow hydrograph
- Rainfall runoff modeling - using the NRCS (SCS) Method to generate an inflow hydrograph
- Inlet capacity analysis

Overview (cont.)

Friday:

- Inlet capacity analysis (continued)
- Outlet capacity design and analysis - why assuming a constant outflow is a very bad assumption
- Detention pond volumes - frustums, contours, average end areas
- Routing a hydrograph through a detention pond
- Impacts of ponds on water quality
- Underground detention facilities
- Maintenance requirements
- Hazards of Detention Ponds (including the West Nile virus) and when not to use them
- Risks
- Software

Introduction

Reasons for Detention Ponds

- reduce peak flows
- promote sedimentation
- pollutant removal
- regulatory requirement (WA: post-development peak = ½ pre-development peak for 2-yr pond discharge)

Detention Ponds detain (slow down) the flow

Retention Ponds retain all of the water until it evaporates, infiltrates or is pumped out

Types of Detention Ponds

Dry Detention Ponds

Dry Extended Detention Ponds (12-48 hours)

Wet Detention Ponds

Rainfall Amount

- Best data source - local regulatory agency
- National Weather Service - Technical Paper No. 40 (1961) - Eastern US, 2 yr to 100 yr, 1 hour to 24 hours
- National Weather Service - NOAA Atlas 2 (1973) - Western US, 2 yr to 100 yr, 5 minutes to 24 hours
- National Weather Service - NOAA Technical Memorandum NWS Hydro 35 (1977) - Eastern US, 2 yr to 100 yr, 5 minutes to 60 minutes
- More recent information for a 9-state region of the Midwest US (Bulletin 71, 1992) is available at http://www.sws.uiuc.edu/pubdoc/B/ISWSB-71.pdf. This includes Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio and Wisconsin.

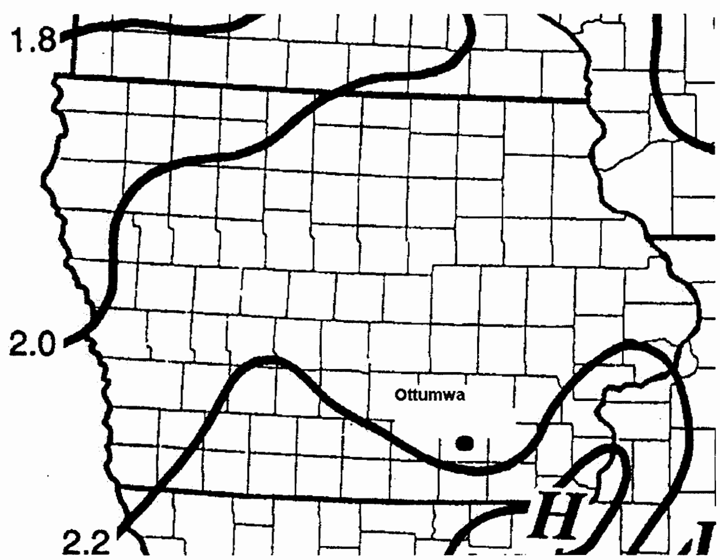
Rainfall Amount (cont.)

- More recent information (1995) for a 12-state region of the Northeastern US is available for ordering at http://met-www.cit.cornell.edu/reports/RR_93-5.html. This includes Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia and parts of Ohio, Virginia, Ontario and Quebec.
- National Weather Service - NOAA Atlas 14, Vol. 1 (2003), UT, NV, AZ, NM & southern CA - Precipitation Frequency Data Server - http://hdsc.nws.noaa.gov/hdsc/pfds/
- National Weather Service – NOAA Atlas 14, Vol. 2 (2004), DE, IL, IN, KE, MD, NJ, NC, OH, PA, SC, TN, VA, WV, DC
- NOAA Atlas 14, Vol. 3 (2006), PR & VI; Vol. 4 (12/2008?), HI, Vol. 5 (7/2009?), northern CA

Computing Rainfall Amounts

- Example
  - Compute the rainfall intensities for durations of 60 minutes and less for a 10-year event for Ottumwa Iowa.
  - From Part 2, Figure 1, "Rainfall Frequency Atlas of the Midwest", 10-year, 1-hour rainfall is 2.2 inches (see next slide). Note degree of accuracy of data and maps

Rainfall Amount - 10-year, 1 hour



Computing Rainfall Intensity

For shorter durations:

rainfall amount = factor * 1-hour amount
30-minutes = 0.79 * 2.2 inches = 1.74 inches
15-minutes = 0.57 * 2.2 inches = 1.25 inches
10-minutes = 0.45 * 2.2 inches = 0.99 inches
5-minutes = 0.26 * 2.2 inches = 0.57 inches

(Ratios applicable to all areas covered by Bulletin)

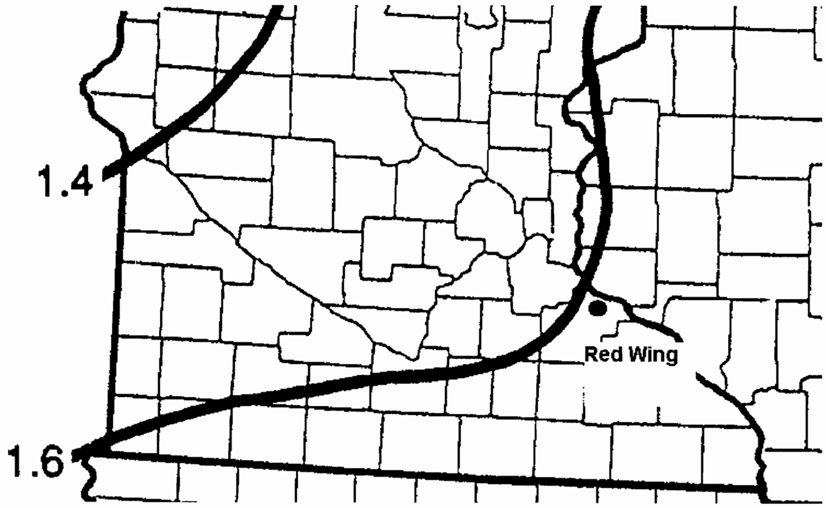
Note that the above values are rainfall amounts (in inches), NOT rainfall intensities (in inches/hour).

30-minutes = 1.74 * (60/30) = 3.48 in/hr
15-minutes = 1.25 * (60/15) = 5.00 in/hr
10-minutes = 0.99 * (60/10) = 5.94 in/hr
5-minutes = 0.57 * (60/5) = 6.84 in/hr

Computing Rainfall Intensity

- Class Problem
  - Compute the rainfall intensities for durations of 60 minutes and less for a 5-year event for Red Wing, Minnesota.
  - From Part 2, Figure 1, “Rainfall Frequency Atlas of the Midwest”, 5-year, 1-hour rainfall is __ inches (see next slide).

Rainfall Amounts - 5-year, 1 hour



Computing Rainfall Intensity

For shorter durations:

rainfall amount = factor * 1-hour amount
30-minutes = 0.79 * ____ = ____ inches
15-minutes = 0.57 * ____ = ____ inches
10-minutes = 0.45 * ____ = ____ inches
5-minutes = 0.26 * ____ = ____ inches

Note that the above values are rainfall amounts (in inches), NOT rainfall intensities (in inches/hour).

30-minutes = ____ * (60/30) = ____ in/hr
15-minutes = ____ * (60/15) = ____ in/hr
10-minutes = ____ * (60/10) = ____ in/hr
5-minutes = ____ * (60/5) = ____ in/hr

Computing Rainfall Intensity

5-year one-hour rainfall is 1.6 inches

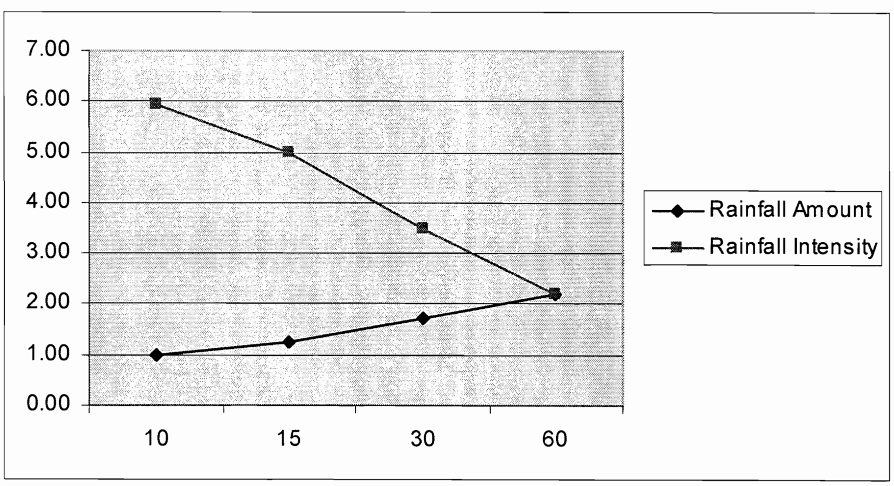
For shorter durations:

30-minutes = 0.79 * 1.6 = 1.26 inches
15-minutes = 0.57 * 1.6 = 0.91 inches
10-minutes = 0.45 * 1.6 = 0.72 inches
5-minutes = 0.26 * 1.6 = 0.42 inches

Note that the above values are rainfall amounts (in inches), NOT rainfall intensities (in inches/hour).

30-minutes = 1.26 * (60/30) = 2.52 in/hr
15-minutes = 0.91 * (60/15) = 3.64 in/hr
10-minutes = 0.72 * (60/10) = 4.32 in/hr
5-minutes = 0.42 * (60/5) = 5.04 in/hr

Computing Rainfall Intensity



Rainfall Intensity

Rainfall Interpolation:

30 minute intensity = 2.52 inches/hour (amount = 1.26)

60 minute intensity = 1.60 inches/hour (amount = 1.60)

Interpolating 50 minute intensity

= 1.60 + {(2.52 - 1.60) / 3}

1.60 + (0.92/3)

1.91 inches per hour

50 minute rainfall amount = 1.91 * (50/60)

1.59 inches

60 minute rainfall amount = 1.60 inches

Interpolating 50 minute rainfall amount

= 1.60 - {(1.60 - 1.26)/3}

1.49 inches

50 minute intensity = 1.49 * (60/50) = 1.79 inches/hour

Time of Concentration

- Definition - Time of concentration is the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed. Travel time (Tt) is the time it takes water to travel from one location to another in a watershed. Tt is a component of time of concentration (Tc). Tc is computed by summing all the travel times for consecutive components of the drainage conveyance system.
- Factors - surface roughness, channel shape and flow patterns, slope

Time of Concentration - Sheet Flow

- Components:
  - Sheet flow (300 ft max), $Tt = \dfrac{0.933\,(nL)^{0.6}}{(I)^{0.4}\,S^{0.3}}$

    (Manning's kinematic solution)

    (Tt in minutes, L in feet, I in inches/hour)
  - Shallow concentrated flow (see figure on next page)

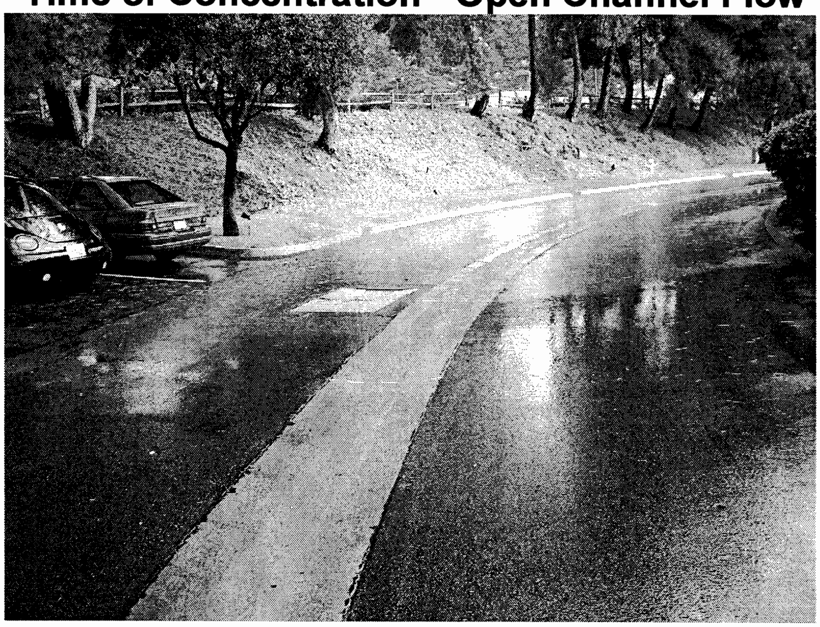
    $Tt = L / V$
  - Open channel flow, generally use Manning's equation

    $V = (1.49/n)\,R^{2/3}\,S^{1/2}$

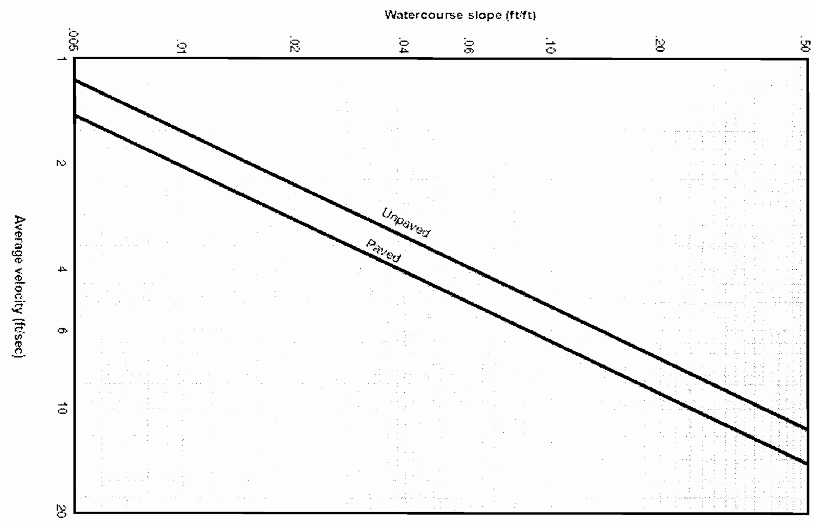
    $Tt = L / V$

  $Tc = \Sigma\,Tt$

Time of Concentration - Open Channel Flow



Time of Concentration - Shallow Concentrated Flow



Time of Concentration: FAA Equation

- FAA equation: $t = 1.8\ (1.1 - C)\ L^{0.5}\ S^{-0.333}$

  Where
  - C = Rational Formula runoff coefficient
  - L = Longest watercourse length in the watershed, ft
  - S = Slope of the watershed, %
  - t = Time of concentration, minutes
- The FAA method was developed from data obtained from airport runoff but has been successfully applied to overland flow in urban areas.

Time of Concentration: Kerby-Hathaway Equation

- Kerby-Hathaway equation: $t = 0.83\ (nL/S^{0.5})^{0.47}$

  Where
  - n = Manning's roughness coefficient
  - L = Longest watercourse length in the watershed, ft
  - S = Slope of the watershed, ft/ft
  - t = Time of concentration, minutes
- The Kerby-Hathaway equation was developed from data obtained in watersheds having watercourses less than 1200 ft., slopes less than 1% and areas less than 10 acres. It is for watersheds where overland flow dominates.

Time of Concentration: Kirpich Equation

- Kirpich equation: $t = 0.0078\ L^{0.77} S^{-0.385}$

  Where
  - L = Longest watercourse length in the watershed, ft
  - S = Slope of the watershed, ft/ft
  - t = Time of concentration, minutes
- The Kirpich equation was developed from data obtained in seven rural watersheds in Tennessee. The watersheds had well-defined channels, slopes between 3% and 10% and areas 1 to 112 acres. It is for watersheds in which channel flow dominates.
- The computed time of concentration should be multiplied by 0.4 for watersheds where the overland flow path is either concrete or asphalt and by 0.2 where the channel is concrete lined.

Rainfall-Runoff Modeling: Rational

- Q = CIA
- C is runoff coefficient, 0.0 - 1.0
- I = intensity for a duration equal to time of concentration, in inches per hour
- A = area in acres
- unit conversion factor of 1 acre-in/hr = 1.008 cfs

Rainfall-Runoff Modeling: Runoff Coefficients

Sample Runoff coefficients *

Type of Drainage Area	C
Downtown Business Area	0.70 - 0.95
Residential single family areas	0.30 - 0.50
Streets and Parking Lots	0.70 - 0.95

- from "Urban Drainage Design Manual", FHWA HEC-22, 2001

Rainfall-Runoff Modeling: Runoff Coefficients

Runoff Coefficients for the Rational Formula versus Hydrologic Soil Group (A, B, C, D) and Slope Range

Land use	A			B			C			D		
	0-2%	2-6%	>6%	0-2%	2-6%	>6%	0-2%	2-6%	>6%	0-2%	2-6%	>6%
Cultivated land	0.08[a]	0.13	0.16	0.11	0.15	0.21	0.14	0.19	0.26	0.18	0.23	0.31
	0.14[b]	0.18	0.22	0.16	0.21	0.28	0.20	0.25	0.34	0.24	0.29	0.41
Pasture	0.12	0.20	0.30	0.18	0.28	0.37	0.24	0.34	0.44	0.30	0.40	0.50
	0.15	0.25	0.37	0.23	0.34	0.45	0.30	0.42	0.52	0.37	0.50	0.62
Meadow	0.10	0.16	0.25	0.14	0.22	0.30	0.20	0.28	0.36	0.24	0.30	0.40
	0.14	0.22	0.30	0.20	0.28	0.37	0.26	0.35	0.44	0.30	0.40	0.50
Forest	0.05	0.08	0.11	0.08	0.11	0.14	0.10	0.13	0.16	0.12	0.16	0.20
	0.08	0.11	0.14	0.10	0.14	0.18	0.12	0.16	0.20	0.15	0.20	0.25
Residential lot	0.25	0.28	0.31	0.27	0.30	0.35	0.30	0.33	0.38	0.33	0.36	0.42
size 1/8 acre	0.33	0.37	0.40	0.35	0.39	0.44	0.38	0.42	0.49	0.41	0.45	0.54
Residential lot	0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
size 1/4 acre	0.30	0.34	0.37	0.33	0.37	0.42	0.36	0.40	0.47	0.38	0.42	0.52
Residential lot	0.19	0.23	0.26	0.22	0.26	0.30	0.25	0.29	0.34	0.28	0.32	0.39
size 1/3 acre	0.28	0.32	0.35	0.30	0.35	0.39	0.33	0.38	0.45	0.36	0.40	0.50
Residential lot	0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
size 1/2 acre	0.25	0.29	0.32	0.28	0.32	0.36	0.31	0.35	0.42	0.34	0.38	0.48
Residential lot	0.14	0.19	0.22	0.17	0.21	0.26	0.20	0.25	0.31	0.24	0.29	0.35
size 1 acre	0.22	0.26	0.29	0.24	0.28	0.34	0.28	0.32	0.40	0.31	0.35	0.46
Industrial	0.67	0.68	0.68	0.68	0.68	0.69	0.68	0.69	0.69	0.69	0.69	0.70
	0.85	0.85	0.86	0.85	0.86	0.86	0.86	0.86	0.87	0.86	0.86	0.88
Commercial	0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	0.88	0.88	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.90
Streets	0.70	0.71	0.72	0.71	0.72	0.74	0.72	0.73	0.76	0.73	0.75	0.78
	0.76	0.77	0.79	0.80	0.82	0.84	0.84	0.85	0.89	0.89	0.91	0.95
Open Space	0.05	0.10	0.14	0.08	0.13	0.19	0.12	0.17	0.24	0.15	0.21	0.28
	0.11	0.16	0.20	0.14	0.19	0.26	0.18	0.23	0.32	0.22	0.27	0.39
Parking	0.85	0.86	0.87	0.85	0.86	0.87	0.85	0.86	0.87	0.85	0.86	0.87
	0.95	0.96	0.97	0.95	0.96	0.97	0.95	0.96	0.97	0.95	0.96	0.97

[a] Runoff coefficients for storm recurrence intervals less than 25 years

[b] Runoff coefficients for storm recurrence intervals of 25 years or longer

From: McCuen, R.H., *Hydrologic Analysis and Design*, 3rd ed., Prentice Hall, Upper Saddle River, New Jersey, 07458, 2004.

Rainfall-Runoff Modeling: Rational Example

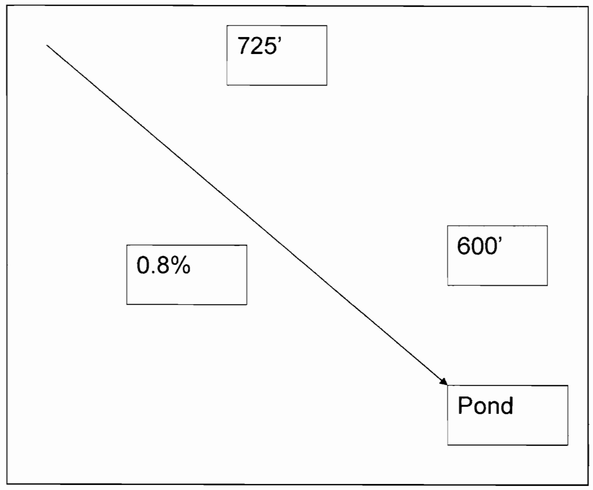
- Example:

  Compute the peak flow from a 10-year, 1-hour rainfall event for a 600' x 725' (10-acre parking lot in Ottumwa, Iowa.

  From Part 2, Figure 1, "Rainfall Frequency Atlas of the Midwest", 10-year, 1-hour rainfall is 2.2 inches (see earlier slides).

Rational Example - Sketch

Parking Lot



Rational Example - Sheet Flow

- Step 1 - compute time of concentration.
  - Sheet flow (300 ft max), $Tt = \dfrac{0.933\,(nL)^{0.6}}{(I)^{0.4}\,S^{0.3}}$

    for asphalt parking lot, n = 0.016

    maximum length = 300 ft

    I = 5.94 inches per hour (10-yr 10-minute)

    S = 0.8% = 0.008 ft/ft

    $$Tt = \frac{0.933\,(nL)^{0.6}}{(I)^{0.4}\,S^{0.3}} = \frac{0.933\,(0.016*300)^{0.6}}{(5.94)^{0.4}\,(0.008)^{0.3}}$$

    Tt = 5.0 minutes

Rational Example - Shallow Concentrated Flow

- Step 1 - compute time of concentration (continued).
  - Shallow concentrated flow: Tt = L/V

    From Figure 3-1, 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 = 5.0 + 5.9 = 10.9 minutes,

    compared to original assumption of 10 minutes

  Needs to be accurate to nearest 0.1 hour

Rational Example – Alternate Tc Values

- FAA equation: $t = 1.8\,(1.1 - C)\,L^{0.5}\,S^{-0.333}$
  - C = 0.95, L = 941, S = 0.8%
  - $t = 1.8\,(1.1 - 0.95)\,941^{0.5}\,0.8^{-0.333}$ = 8.9 minutes
- Kerby-Hathaway equation: $t = 0.83\,(nL/S^{0.5})^{0.47}$
  - n = 0.016, L = 941, S = 0.8%
  - $t = 0.83\,(0.016 * 941/(0.008)^{0.5})^{0.47}$ = 9.2 minutes
- Kirpich equation: $t = 0.0078\,L^{0.77}S^{-0.385}$
  - L = 941, S = 0.8%
  - $t = 0.0078 * 941^{0.77} * 0.008^{-0.385}$ = 9.8 minutes
  - Overland flow path is asphalt, so
    t = 0.4 * 9.8 = 4.0 minutes

Rational Example - Design Intensity

- Step 2 - Estimate rainfall intensity for time of concentration of 11 minutes.
  - 10 minute rainfall amount = 0.99 inches
  - 15 minute rainfall amount = 1.25 inches
  - 11 minute rainfall amount = 0.99 + (1/5)*(0.26)
    11 minute rainfall amount = 1.04 inches
    11 minute intensity = (1.04"/11 min) * 60 minutes/hr
    11 minute intensity = 5.67 inches/hour
- Step 3 - Estimate runoff coefficient
  - For a parking lot, referring to table from HEC-22, C = 0.95

Rational Example - Peak flow and hydrograph

- Step 4 - Compute peak flow using Rational Equation
  - Q = CIA = 0.95 * 5.67 in/hr * 10 acres
  - Q = 54 acre-in/hr = 54 cfs

- Develop hydrograph for one-hour duration design storm
  - Similar to Chicago Method for hyetograph development (includes 5-minute, 15-minute, 60-minute, etc. intensities within overall design storm)
  - Use time increments approximately equal to time of concentration

- Place peak of hydrograph near center of storm event

Rational Example - Incremental Rainfall

Time Minutes	Rainfall Inches	Incremental Rainfall, Inches	Incremental Rainfall, Inches
5	0.57	0.57	0.57
10	0.99	0.42	0.42
15	1.25	0.26	0.26
20			0.163
25			0.163
30	1.74	0.49	0.163
35			0.077
40			0.077
45			0.077
50			0.077
55			0.077
60	2.20	0.46	0.077

Rational Example - Incremental Rainfall

Time Minutes	Incremental Rainfall, Inches	Incremental Rainfall, Inches
5	0.57	
10	0.42	0.99
15	0.26	
20	0.163	0.423
25	0.163	
30	0.163	0.327
35	0.077	
40	0.077	0.153
45	0.077	
50	0.077	0.153
55	0.077	
60	0.077	0.153

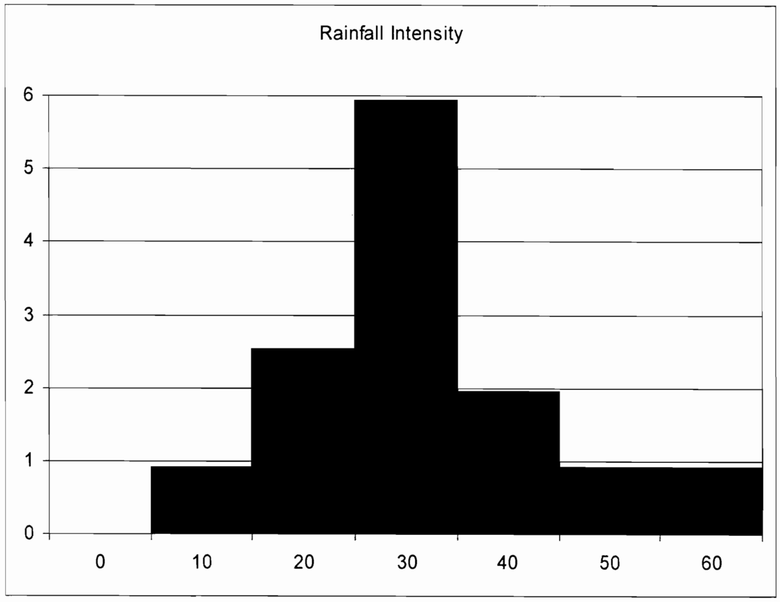
Rational Example - Rainfall Intensity

Time minutes	Incremental Rainfall Inches	Rainfall Intensity Inches/hr
10	0.99	5.94
20	0.423	2.54
30	0.327	1.96
40	0.153	0.92
50	0.153	0.92
60	0.153	0.92

Rational Example - Hyetograph

Time minutes	Rainfall Intensity inches/hr	Clock Time minutes	Rainfall Intensity inches/hr
0	0	0	0
10	5.94	10	0.92
20	2.54	20	2.54
30	1.96	30	5.94
40	0.92	40	1.96
50	0.92	50	0.92
60	0.92	60	0.92

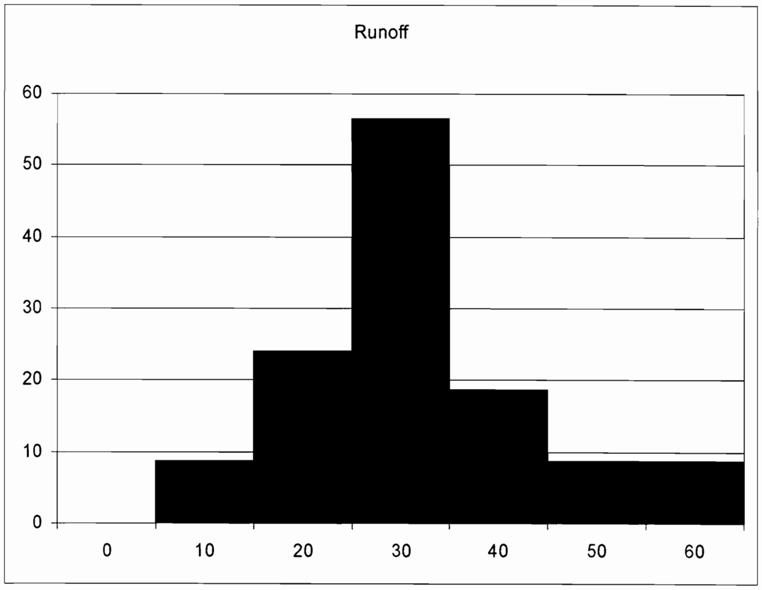
Rational Example - Hyetograph



Rational Example - Hydrograph

Clock time minutes	Rainfall Intensity inches/hr	C * A	Q = CIA cfs
0	0	0.95 * 10	0.0
10	0.92	0.95 * 10	8.7
20	2.54	0.95 * 10	24.1
30	5.94	0.95 * 10	56.4
40	1.96	0.95 * 10	18.6
50	0.92	0.95 * 10	8.7
60	0.92	0.95 * 10	8.7

Rational Example - Hydrograph



Rational - Class Problem

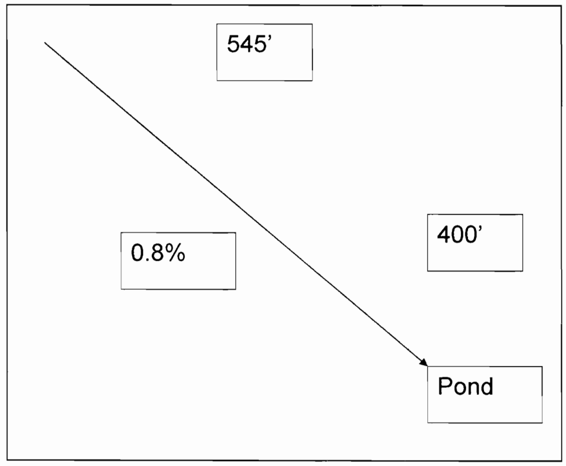
Class Problem

Compute the peak flow from a 5-year, 1-hour rainfall event for a 400' x 545' (5-acre) parking lot in Red Wing, Minnesota.

From Part 2, Figure 1, "Rainfall Frequency Atlas of the Midwest", 5-year, 1-hour rainfall is 1.6 inches (see earlier slides).

Rational - Problem Sketch

Parking Lot



Rational Problem - Sheet Flow

- Step 1 - compute time of concentration.
  - Sheet flow (300 ft max), $T_t = \dfrac{0.933\,(nL)^{0.6}}{(I)^{0.4}\,S^{0.3}}$

    for asphalt parking lot, n = 0.016

    maximum length = 300 ft

    I = _____ inches per hour (5-yr 10-minute)

    S = __% = ___ ft/ft

    $T_t = \dfrac{0.933\,(nL)^{0.6}}{(I)^{0.4}\,S^{0.3}} = \dfrac{0.933\,(0.016*300)^{0.6}}{(\_\_\_)^{0.4}\,(\_\_\_)^{0.3}}$

    Tt = ___ minutes

Rational Problem - Sheet Flow

- Step 1 - compute time of concentration.
  - Sheet flow (300 ft max), $Tt = \frac{0.933\,(nL)^{0.6}}{(I)^{0.4}\,S^{0.3}}$

    for asphalt parking lot, n = 0.016

    maximum length = 300 ft

    I = 4.32 inches per hour (5-yr 10-minute)

    S = 0.8% = 0.008 ft/ft

    $Tt = \frac{0.933\,(nL)^{0.6}}{(I)^{0.4}\,S^{0.3}} = \frac{0.933\,(0.016*300)^{0.6}}{(4.32)^{0.4}\,(0.008)^{0.3}}$

    Tt = 5.7 minutes

    Average Velocity is 300/(5.7*60) = 0.88 ft/sec

Rational Problem - Shallow Concentrated Flow

- Step 1 - compute time of concentration (continued).
  - Shallow concentrated flow: Tt = L/V

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

    Total Length = $(\_\_^2 + \_\_^2)^{0.5}$ = __ ft

    Flow Length = __ ft - 300 ft = __ ft

    Tt = ___/(___*60) = ___ minutes

  Total travel time = ΣTt = __ + __ = ___ minutes,

    compared to original assumption of 10 minutes

Rational Problem - Shallow Concentrated Flow

- Step 1 - compute time of concentration (continued).
  - Shallow concentrated flow: Tt = L/V

    From Figure 3-1, 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 = 5.7 + 3.5 = 9.2 minutes,

    compared to original assumption of 10 minutes

Rational Problem - Rainfall Amount and Intensity

- Step 2 - Estimate rainfall intensity for time of concentration of __ minutes.
  - __ minute rainfall amount = ___ inches
  - __ minute rainfall amount = ___ inches
  - __ minute rainfall amount = ___ + (_/_)*(___)

    __ minute rainfall amount = ___ inches

    __ minute intensity = (__"/__ min) * 60 minutes/hr

    __ minute intensity = ___ inches/hour
- Step 3 - Estimate runoff coefficient
  - For a parking lot, referring to table from HEC-22, C = 0.95

Rational Problem - Rainfall Amount and Intensity

- Step 2 - Estimate rainfall intensity for time of concentration of 9 minutes.
  - 5 minute rainfall amount = 0.42 inches
  - 10 minute rainfall amount = 0.72 inches
  - 9 minute rainfall amount = 0.42 + (4/5)*(0.30)
    9 minute rainfall amount = 0.66 inches
    9 minute intensity = (0.66"/9 min) * 60 minutes/hr
    9 minute intensity = 4.40 inches/hour
- Step 3 - Estimate runoff coefficient
  - For a parking lot, referring to table from HEC-22, C = 0.95

Rational Problem - Peak and Hydrograph

- Step 4 - Compute peak flow using Rational Equation
  - Q = CIA = 0.95 * ___ in/hr * __ acres
  - Q = __ acre-in/hr = __ cfs
- Develop hydrograph for one-hour duration event
  - Use time increments approximately equal to time of concentration

Rational Problem - Peak Flow

- Step 4 - Compute peak flow using Rational Equation
  - Q = CIA = 0.95 * 4.40 in/hr * 5 acres
  - Q = 21 acre-in/hr = 21 cfs

Rational Problem – Incremental Rainfall

Time Minutes	Rainfall Inches	Incremental Rainfall, Inches	Incremental Rainfall, Inches
5			
10			
15			
20			
25			
30			
35			
40			
45			
50			
55			
60			

Rational Problem - Incremental Rainfall

Time Minutes	Incremental Rainfall, Inches	Incremental Rainfall, Inches
5		
10		
15		
20		
25		
30		
35		
40		
45		
50		
55		
60		

Rational Problem - Hyetograph

Time minutes	Incremental Rainfall Inches	Rainfall Intensity Inches/hr
10		
20		
30		
40		
50		
60		

Rational Problem - Hyetograph

Time minutes	Rainfall Intensity inches/hr	Clock Time minutes	Rainfall Intensity inches/hr
0		0	
10		10	
20		20	
30		30	
40		40	
50		50	
60		60	

Rational Problem - Hydrograph

Clock time minutes	Rainfall Intensity inches/hr	C * A	Q = CIA cfs
0			
10			
20			
30			
40			
50			
60			