Runoff Calculations

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Time of Concentration (T_c or t_c)

Time of Concentration and Travel Time (based on Chapter 3 of TR-55)

- **Time of Concentration (T_c):** time required for runoff to travel from the most hydraulically distant point in the watershed to a point of interest (drainage point) within the watershed.
- **Travel Time (T_t):** time required for water to travel from one location to another within a watershed. Travel time is summed within a watershed (to the hydraulically most distant point) to determine the watershed's time of concentration.

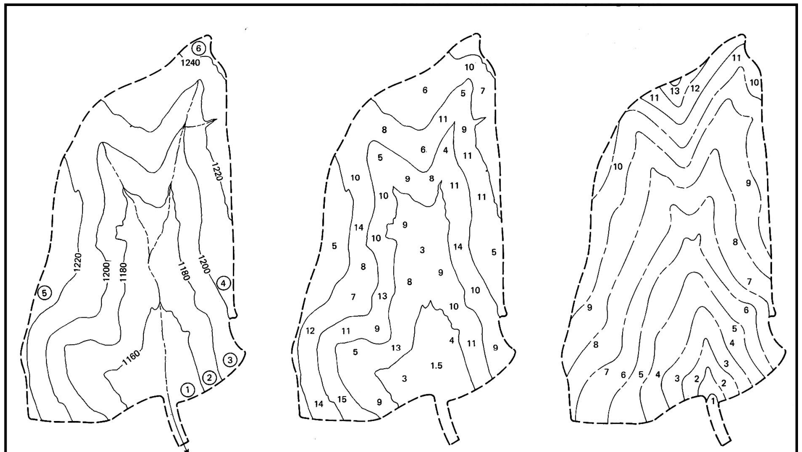
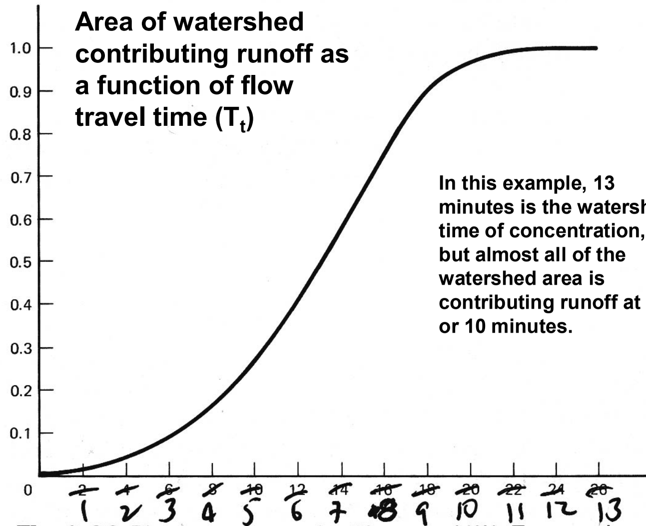


Fig. 8-22 Watershed W1, Treynor, Iowa (A = 74.5 acres).

McCuen 1989

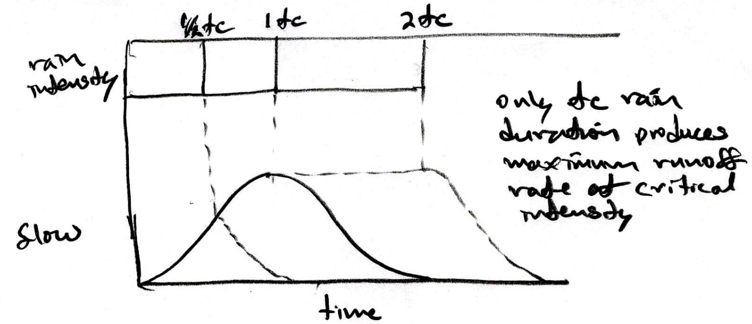
Area of watershed contributing runoff as a function of flow travel time (T_t)



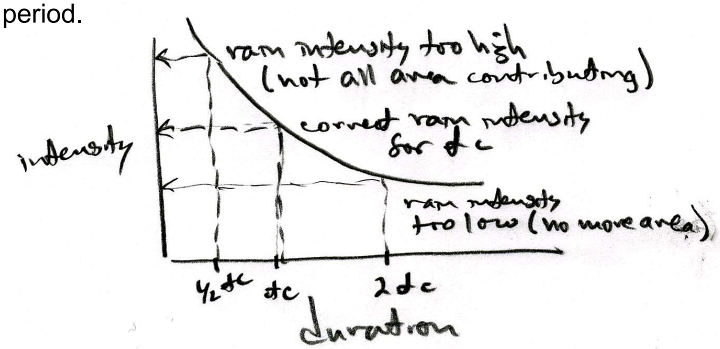
In this example, 13 minutes is the watershed time of concentration, but almost all of the watershed area is contributing runoff at 9 or 10 minutes.

Fig. 8-23 Time–area curve for Watershed W1, Treynor, Iowa.
McCuen 1989

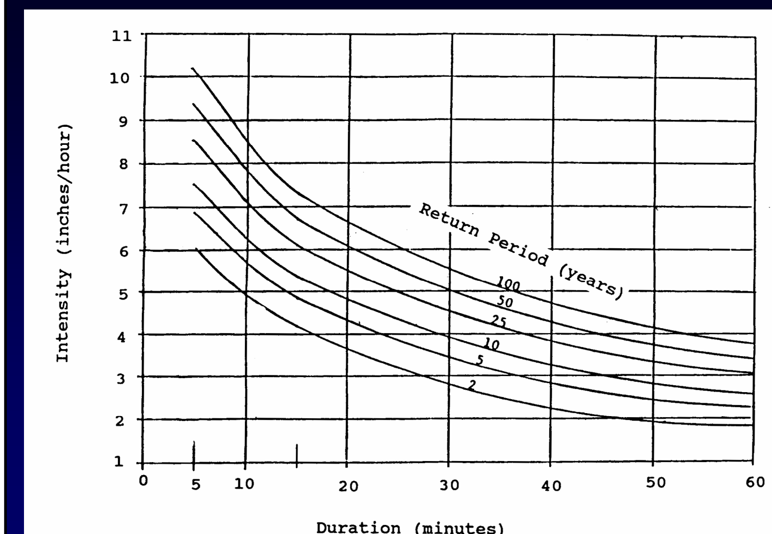
Only a rain duration equal to the T_c produces the maximum peak runoff rate at the critical rain intensity. Shorter duration rains do not produce runoff from the complete area, while longer duration rains do not have any additional contributing areas.



Rains having durations equal to the T_c must be used in drainage designs as they produce the critical intensity for the area and the level of service (likelihood of failure in any one year). Longer duration rains have lower intensities for the same service, while shorter duration rains do not have the complete drainage area contributing flows during that time period.



Example Intensity - Duration - Frequency (IDF) Curve



Time of Concentration Estimates using NRCS (Natural Resources Conservation Service) TR-55 Methods

- TR-55 (Technical Reference #55: *Urban Hydrology for Small Watersheds*, 1975 and 1986) includes procedures to estimate t_c using three flow segment types:
  - Sheetflow (maximum of 300 ft, limited to shorter lengths by many states and now limited to 150 ft. in WinTR-55)
  - Shallow concentrated flow (paved or unpaved surfaces
  - Channel flow (using Manning's equation)
- Candidate t_c pathways are drawn on the site map and the travel times for the three flow segments are calculated and summed.
- The t_c for the watershed area is the longest travel time calculated.

Factors affecting Time of Concentration and Travel Time:

- Surface Roughness
- Channel Shape and Flow Pattern
- Slope

Travel time is the ratio of the flow length to the flow velocity. The general form of the travel time equation is:

$$T_t(hr) = \frac{L(ft)}{(3600\,sec/hr)(V[ft/sec])}$$

Time of Concentration is the sum of the Travel Times for the various Consecutive Flow Segments that make up the time of concentration pathway.

$$T_c(hr) = T_{t1}(hr) + T_{t2}(hr) + \ldots + T_{tm}(hr)$$

Definitions of Flow Regimes Potentially Involved in Time of Concentration Calculations

- **Sheet Flow**: flow over plane surfaces (generally occurs for less than 300 feet of flow). Water depth is less than 0.1 ft.
- **Shallow Concentrated Flow**: flow depth is greater than 0.1 ft. Shallow concentrated flow generally occurs when water flows over land (no definable channel), but after sheetflow has occurred.
- **Open Channel Flow**: flow in open channels (exposed to the atmosphere). It is assumed to begin where survey information is available or where channels are visible on an aerial photograph.
- **Reservoirs or Lakes**: travel time in reservoirs or lakes is assumed to be very small comparatively and therefore is assumed to be zero.

Equations used for calculation of time of concentration (T_c or t_c)

Sheet flow:

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5} S^{0.4}}$$

where T_t = travel time (hr)
n = Manning's roughness coefficient (for sheet flow)
L = flow length (ft)
P_2 = 2-year, 24-hour rainfall (in) [4.2 inches for central AL area]
S = slope of hydraulic grade line (approximated by land slope)

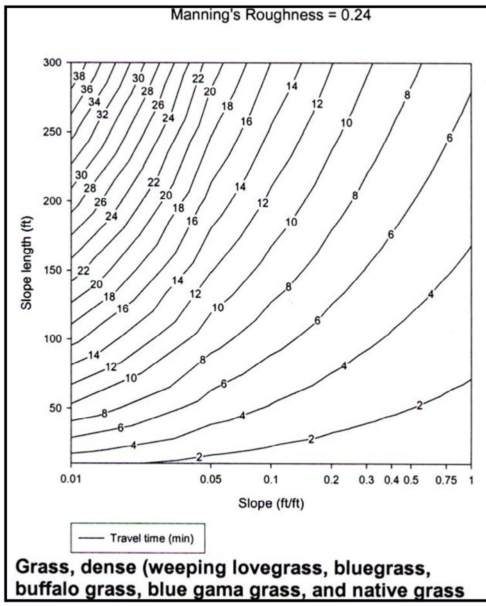


Figure illustrating sheetflow travel time for dense grass surfaces, for varying slopes and flow lengths.

Equations used for calculation of time of concentration (T_c or t_c)

- Assumptions for sheet flow equation:
  - Shallow steady uniform flow
  - Constant intensity of rainfall excess
  - Rainfall duration of 24 hours
  - Minor effect of infiltration on travel time

Table 3-1 (from TR55) – Roughness coefficients (Manning's n) for sheet flow

Surface description	Manning's n
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated soils:	
Residue cover <= 20%	0.06
Residue cover > 20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses	0.24
Bermudagrass	0.41
Range (natural)	0.13
Woods:	
Light underbrush	0.40
Dense underbrush	0.80

Equations used for calculation of time of concentration (T_c or t_c)

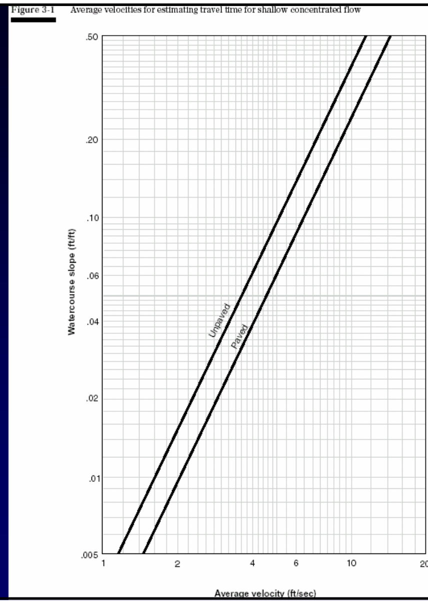
Shallow Concentrated Flow:

$$T_t(hr) = \frac{L(ft)}{(3600\sec/hr)(V[ft/\sec])}$$

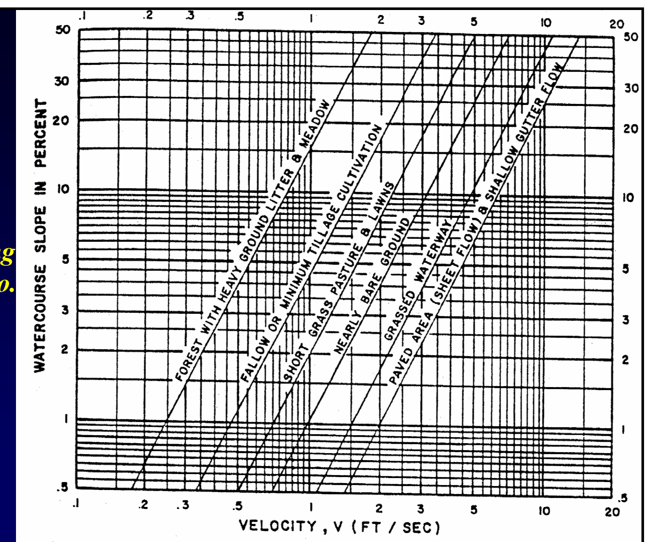
where: T_t = travel time (hr)
L = flow length of shallow concentrated flow (ft)
V = average velocity of flow (ft/sec)

Velocity Graph (from TR-55)

Figure 3-1 Average velocities for estimating travel time for shallow concentrated flow



Velocity Graph (from *FHWA Hydraulic Engineering Circular No. 19*)



Source: U.S. Department of Transportation, Federal Highway Administration, Hydrology, Hydraulic Engineering Circular, No. 19, 1984.

Equations used for calculation of time of concentration (T_c or t_c)

Open Channel Flow (Manning's Equation)

- Calculations based on bank full conditions

$$V = \frac{1.49 r^{2/3} s^{1/2}}{n}$$

where V = average velocity (ft/sec)
r = hydraulic radius = A/P
P = wetted perimeter (ft)
s = slope of the hydraulic grade line (ft/ft)
n = Manning's roughness coefficient

Manning's Roughness Coefficient Table

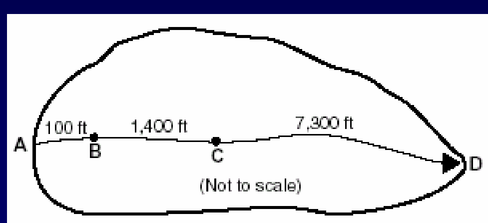
(from Viessman and Hammer, Fifth Edition, 1993)

Material description	Manning's n
Concrete	0.013
Cast-Iron Pipe	0.015
Vitrified Clay	0.014
Brick	0.016
Corrugated Metal Pipe	0.022
Bituminous Concrete	0.015
Uniform, Sodded Earth	0.025

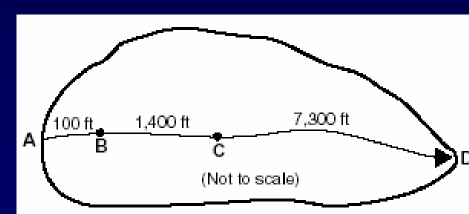
NOTE: These Manning's n values cannot be used for sheet flow; they are only used for deep channel flow

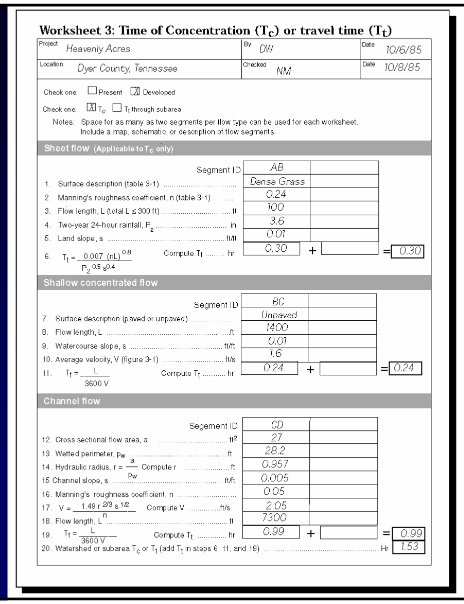
Example 3-1 from TR-55

- The sketch below shows a watershed in Dyer County, Tennessee. The problem is to compute T_c at the outlet of the watershed (point D). The 2-year, 24-hour rainfall depth is 3.6 inches. All three types of flow occur from the hydraulically most distant point (A) to the point of interest (D). To compute T_c, first determine T_t for each segment from the following information.



- Segment AB
  - Sheet flow
    - Dense grass
    - Slope = 0.01 ft/ft
    - Length = 100 ft
- Segment BC
  - Shallow concentrated flow
    - Unpaved
    - Slope = 0.01 ft/ft
    - Length = 1400 ft
- Segment CD
  - Channel flow
  - n = 0.05
  - A = 27 ft^2
  - P = 28.2 ft
  - s = 0.005 ft/ft
  - L = 7,300 ft





Worksheet 3: Time of Concentration (T_c) or travel time (T_t)

Project: Heavenly Acres	By: DW	Date: 10/6/85
Location: Dyer County, Tennessee	Checked: NM	Date: 10/8/85

Check one: ☐ Present ☒ Developed

Check one: ☒ T_c ☐ T_t through subarea

Notes: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to T_c only)

Segment ID	AB		
1. Surface description (table 3-1)	Dense Grass		
2. Manning's roughness coefficient, n (table 3-1)	0.24		
3. Flow length, L (total L ≤ 300 ft) ... ft	100		
4. Two-year 24-hour rainfall, P_2 ... in	3.6		
5. Land slope, s ... ft/ft	0.01		
6. $T_t = \frac{0.007\,(nL)^{0.8}}{P_2^{0.5}\,s^{0.4}}$ Compute T_t ... hr	0.30	+	= 0.30

Shallow concentrated flow

Segment ID	BC		
7. Surface description (paved or unpaved)	Unpaved		
8. Flow length, L ... ft	1400		
9. Watercourse slope, s ... ft/ft	0.01		
10. Average velocity, V (figure 3-1) ... ft/s	1.6		
11. $T_t = \frac{L}{3600\,V}$ Compute T_t ... hr	0.24	+	= 0.24

Channel flow

Segement ID	CD		
12. Cross sectional flow area, a ... ft^2	27		
13. Wetted perimeter, p_w ... ft	28.2		
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r ... ft	0.957		
15 Channel slope, s ... ft/ft	0.005		
16. Manning's roughness coefficient, n	0.05		
17. $V = \frac{1.49\,r^{2/3}\,s^{1/2}}{n}$ Compute V ... ft/s	2.05		
18. Flow length, L ... ft	7300		
19. $T_t = \frac{L}{3600\,V}$ Compute T_t ... hr	0.99	+	= 0.99
20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) ... Hr			1.53

Runoff Calculations

Runoff can be related to Rainfall through the following relationship:

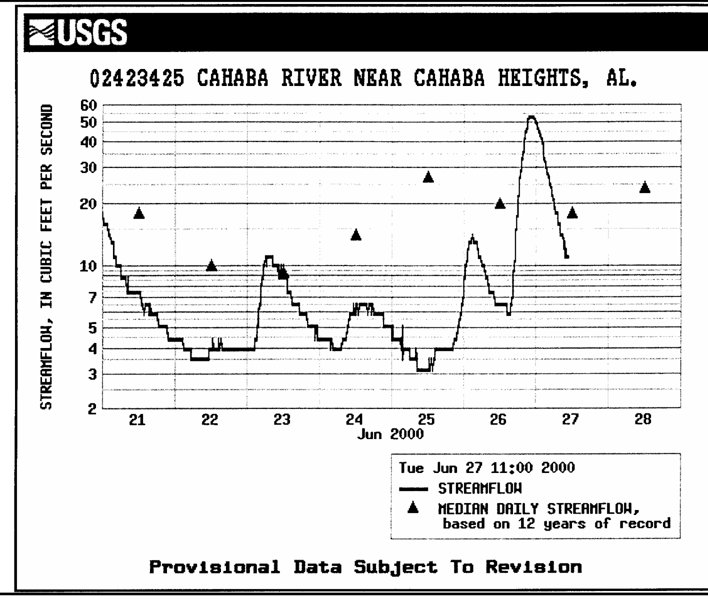
Runoff = (Proportionality Constant)(Rainfall)

Two major factors that will affect the amount of surface runoff that occurs are slope and infiltration. Infiltration will be based upon the soil type. Soil types can be determined from Soil Surveys of the appropriate area.

Assumptions for all runoff calculation methods:

- Actual stream gage information that can be related to individual precipitation events is always preferred for calibration of rainfall-runoff model, but is rarely available.
- Only a portion of the rainfall that lands on a watershed will appear as runoff, due to:
  - Vegetative interception
  - Depression storage
  - Infiltration

- **Yield**: Portion of precipitation on a watershed that can be collected for use
- **Safe yield**: The minimum recorded yield in the past
- **Hydrograph**: Graphical record of flow at a point versus time



Developing Design Storms for Drainage Design

- Constant Intensity Design Storms
- Unit Hyetograph Storms (such as the 24-hour NRCS Storm Design Distribution)

Design Storm Selection Guidelines

(Source: *Model Drainage Manual*, American Association of State Highway and Transportation Officials, Washington, D.C. 1991 as given in Garber and Hoel. *Traffic and Highway Engineering, Second Edition.* PWS Publishing Company, 1997).

Roadway Classification	Exceedence Probability	Return Period
Rural principal arterial system	2%	50 year
Rural minor arterial system	2 – 4%	25 – 50 year
Rural collector system, major	4%	25 year
Rural collector system, minor	10%	10 year
Rural local road system	10 – 20%	5 – 10 year
Urban principal arterial system	2 – 4%	25 – 50 year
Urban minor arterial street system	4%	25 year
Urban collector street system	10%	10 year
Urban local street system	10 – 20%	5 – 10 year

NOTE: Federal law requires interstate highways to be provided with protection from the 2% flood event, and facilities such as underpasses, depressed roadways, etc. where no overflow relief is available should be designed for the 2% event.

Methods Used to Calculate Runoff in Urban Areas for Drainage Design

- Rational Method (Mulvaney, 1851, in Ireland; Kuichling, 1889, in the US)
- NRCS TR-20 and TR-55 (SCS 1975; 1982; 1986)
- US EPA SWMM (Stormwater Management Model) (Metcalf & Eddy, *et al.*, 1971; CDM 2003)
- Many currently available proprietary models use these methods.

Rational Method for Calculating Runoff

- Equation:

$$Q_p = CiA$$

Where Q_p = peak discharge (ft^3/sec, cfs)
i = rainfall intensity (in/hr) – selected for storm duration equal to T_c [common error to incorrectly select i simply based on 24 hour period]
A = drainage area (acres)
C = runoff coefficient

Rational Method best used for:

- Small urban watersheds for sizing inlets and culverts
- Small drainage areas with short times of concentration and homogeneous surfaces with simple drainage networks (not extensive branching of lines)

Runoff Coefficients for the Rational Method
(from McCuen, Hydrologic Analysis and Design. Prentice-Hall, Inc. 1998)

Description of Area	Range of Runoff Coefficients	Recommended Value
Business		
Downtown	0.70 – 0.95	0.85
Neighborhood	0.50 – 0.70	0.60
Residential		
Single-family	0.30 – 0.50	0.40
Multiunits, detached	0.40 – 0.60	0.50
Multiunits, attached	0.60 – 0.75	0.70
Residential (suburban)	0.25 – 0.40	0.35
Apartment	0.50 – 0.70	0.60
Industrial		
Light	0.50 – 0.80	0.65
Heavy	0.60 – 0.90	0.75
Parks, cemeteries	0.10 – 0.25	0.20
Playgrounds	0.20 – 0.35	0.30
Railroad yard	0.20 – 0.35	0.30
Unimproved	0.10 – 0.30	0.20

"It is often desirable to develop a composite runoff coefficient based on the percentage of different types of surface in the drainage area. This procedure is often applied to typical 'sample' block as a guide to selection of reasonable values of the coefficient for an entire area. Coefficients with respect to surface type currently in use are listed below."

Character of Surface	Range of Runoff Coefficients	Recommended Value
Pavement		
Asphaltic and Concrete	0.70 – 0.95	0.85
Brick	0.75 – 0.85	0.80
Roofs	0.75 – 0.95	0.85
Lawns, sandy soil	0.30 – 0.50	0.40
Flat, < 2%	0.05 – 0.10	0.08
Average, 2 to 7%	0.10 – 0.15	0.13
Steep, > 7%	0.15 – 0.20	0.18
Lawns, heavy soil	0.50 – 0.70	0.60
Flat, < 2%	0.13 – 0.17	0.15
Average, 2 to 7%	0.18 – 0.22	0.20
Steep, > 7%	0.25 – 0.35	0.30

The coefficients in these two tabulations are applicable for storms of 5- to 10-year frequencies. Less frequent, higher intensity storms will require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on runoff. The coefficients are based on the assumption that the design storm does not occur when the ground surface is frozen.

Runoff Coefficients for the Rational Formula versus Hydrologic Soil Group (A, B, C, D) and Slope Range
(from McCuen, Hydrologic Analysis and Design. Prentice-Hall, Inc. 1998)

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%+
Residential Lot, ⅛ acre	0.25[a]	0.28	0.31	0.27	0.30	0.35	0.30	0.33	0.38	0.33	0.36	0.42
	0.33[b]	0.37	0.40	0.35	0.39	0.44	0.38	0.42	0.49	0.41	0.45	0.54
Residential Lot, ¼ acre	0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
	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, ⅓ acre	0.19	0.23	0.26	0.22	0.26	0.30	0.25	0.29	0.34	0.28	0.32	0.39
	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, ½ acre	0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
	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, 1 acre	0.14	0.19	0.22	0.17	0.21	0.26	0.20	0.25	0.31	0.24	0.29	0.35
	0.22	0.26	0.29	0.2	0.28	0.34	0.28	0.32	0.40	0.31	0.35	0.46
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	0.90	0.89	0.89	0.90

[a] Runoff coefficients for storm recurrence intervals less than 25 years.
[b] Runoff coefficients for storm recurrence intervals of 25 years or longer.

Example of Rational Method Calculation of Peak Discharge from a Watershed

- Drainage Area (25-year storm)
  - Drainage Area: 1.14 mi^2
  - Watershed Slope: 0.021
  - Hydrologic Soil Group C
  - Land Use Description: ½ acre lots
  - Time of Concentration: calculated previously
- Using T_c = ? hours, i = ? in/hr for 25-year storm
- Using ½-acre lot size, 2 – 6% slope, C soil, C = ?
- Peak Discharge = Q_p = CiA
  $Q_p = (?)(?\text{ in/hr})(1.14\text{ mi}^2)(640\text{ acres/mi}^2) = ?\text{ cfs}$

Methods Used to Calculate Runoff in Urban Areas for Drainage Design

- NRCS TR-20 and TR-55 (SCS 1975; 1982; 1986)
  - Graphical Peak Discharge Method (Chapter 4 of TR-55 Manual)
    - Uses a term called "Curve Number" or "CN" as a measure of proportionality to determine the fraction of the rainfall that becomes runoff

Runoff Curve Numbers for Urban Areas
(Average runoff conditions, Ia = 0.2S)

Cover Description		CNs for Hydrologic Soil Group			
Cover Type	Average Percent Impervious Area	A	B	C	D
Urban districts					
Commercial and business	89	92	94	95	85
Industrial	81	88	91	93	72
Residential district by average lot size					
⅛ acre or less (town houses)	98	77	85	90	92
¼ acre	38	61	75	83	87
⅓ acre	30	57	72	81	86
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82

Runoff Curve Numbers for Urban Areas
(Average runoff conditions, Ia = 0.2S)

Cover Description		CNs for Hydrologic Soil Group			
Cover Type	Average Percent Impervious Area	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)					
Poor condition (grass < 50%)		68	79	86	89
Fair condition (grass 50% to 75%)		49	69	79	84
Good condition (grass > 75%)		39	61	74	80
Impervious areas					
Paved parking lots, roofs, driveways, etc. (exc. right-of-way)		98	98	98	98
Streets and roads					
Paved; curbs and storm sewers (exc. right-of-way)		98	98	98	98
Paved; open ditches (inc. right-of way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89

Typical CN Values for Pastures, Grasslands, and Woods

Cover description: Cover type	Hydrologic condition	Curve numbers for hydrologic soil group: A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. 2/	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. 3/	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 4/	48	65	73
Woods—grass combination (orchard or tree farm). 5/	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. 6/	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 4/	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

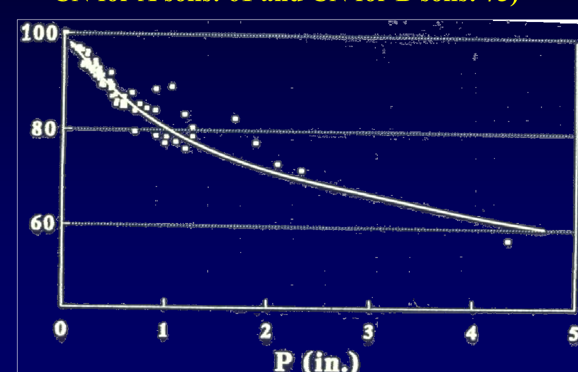
1 Average runoff condition, and $I_a = 0.2S$.
2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.
3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
4 Actual curve number is less than 30; use CN = 30 for runoff computations.
5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.
6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

The following equation can be used to calculate the actual NRCS curve number (CN) from observed rainfall depth (P) and runoff depth (Q), both expressed in inches:

$$CN = \frac{1000}{\left[10 + 5P + 10Q - 10\left(Q^2 + 1.25QP\right)^{1/2}\right]}$$

Observed Curve Numbers for Residential Area (39% Imperviousness)

0.25 acre lots, sandy soils
CN for A soils: 61 and CN for B soils: 75)

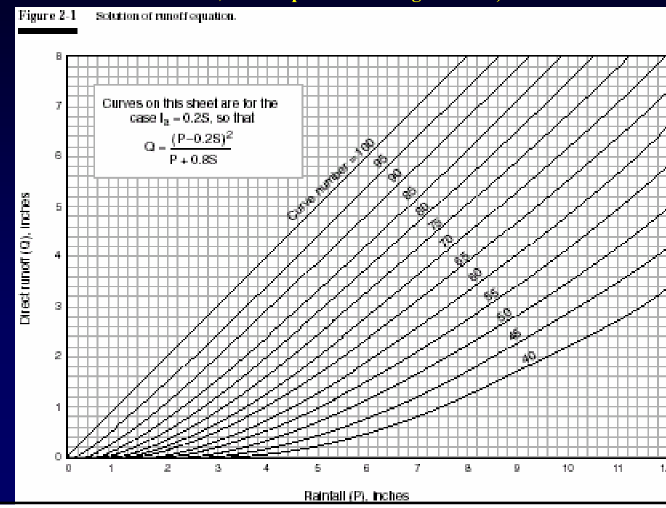


Limitations of Curve Numbers

- Curve numbers describe average conditions that are useful for design purposes. If the rainfall event used is a historical storm, the modeling accuracy decreases.
- Use the runoff curve number equation with caution when re-creating specific features of an actual storm. The equation does not contain an expression for time and, therefore, does not account for rainfall duration and intensity.
- The user should understand the assumption reflected in the initial abstraction term (Ia) and should ascertain that the assumption applies to the situation.
- Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures.
- The CN procedure is less accurate when runoff is less than 0.5 inch. As a check, use another procedure to determine runoff.
- The SCS runoff procedures apply only to direct surface runoff.
- When the weighted CN is less than 40, use another procedure.

Solution of the SCS Runoff Equation

(from TR-55, *Urban Hydrology for Small Watersheds*, Soil Conservation Service, U.S. Department of Agriculture):



Curve number	I_a (in)
40	3.000
41	2.878
42	2.762
43	2.651
44	2.545
45	2.444
46	2.348
47	2.255
48	2.167
49	2.082
50	2.000
51	1.922
52	1.846
53	1.774
54	1.704
55	1.636
56	1.571
57	1.509
58	1.448
59	1.390
60	1.333
61	1.279
62	1.226
63	1.175
64	1.125
65	1.077
66	1.030
67	0.985
68	0.941
69	0.899

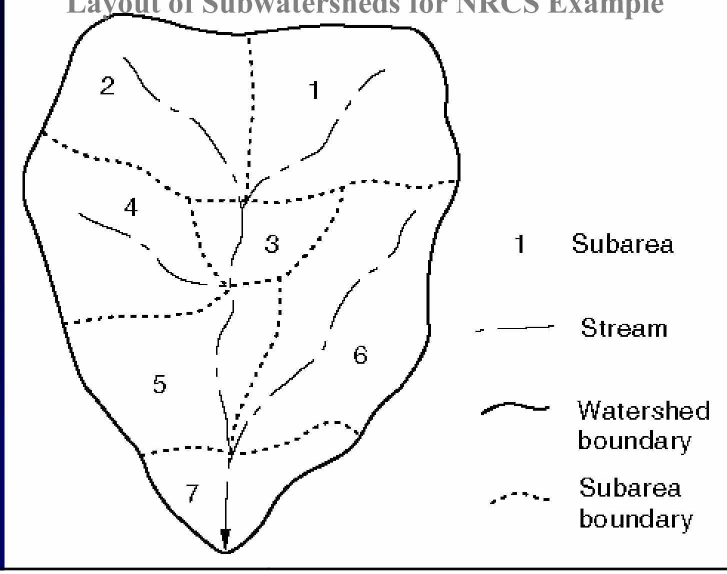
Curve number	I_a (in)
70	0.857
71	0.817
72	0.778
73	0.740
74	0.703
75	0.667
76	0.632
77	0.597
78	0.564
79	0.532
80	0.500
81	0.469
82	0.439
83	0.410
84	0.381
85	0.353
86	0.326
87	0.299
88	0.273
89	0.247
90	0.222
91	0.198
92	0.174
93	0.151
94	0.128
95	0.105
96	0.083
97	0.062
98	0.041

The initial abstraction values (mostly detention storage) are a direct function of the curve number.

Tabular Hydrograph Method

- The NRCS TR-55 Tabular Hydrograph Method uses watershed information and a single design storm to predict the peak flow rate, the total runoff volume, and the hydrograph.
- Information needed includes:
  - Drainage area (square miles)
  - Time of concentration (hours)
  - Travel time through downstream segments (hours)
  - 24-hr rainfall total for design storm
  - Rainfall distribution type
  - Runoff curve number (and associated initial abstraction)

Layout of Subwatersheds for NRCS Example



Worksheet 5a: Basic watershed data

Project: Fallswood | Location: Dyer County, Tennessee | By: DW | Date: 10/1/85
Check one: ☒ Present ☐ Developed | Frequency (yr): 25 | Checked: NM | Date: 10/3/85

Subarea name	Drainage area A_m (mi^2)	Time of concentration T_c (hr)	Travel time through subarea T_t (hr)	Downstream subarea names	Travel time summation to outlet ΣT_t (hr)	24-hr rainfall P (in)	Runoff curve number CN	Runoff Q (in)	A_mQ (mi^2—in)	Initial abstraction I_a (in)	I_a/P
1	0.30	1.50	--	3, 5, 7	2.50	6.0	65	2.35	0.71	1.077	0.18
2	0.20	1.25	--	3, 5, 7	2.50	6.0	70	2.80	0.56	0.857	0.14
3	0.10	0.50	0.50	5, 7	2.00	6.0	75	3.28	0.33	0.667	0.11
4	0.25	0.75	--	5, 7	2.00	6.0	70	2.80	0.70	0.857	0.14
5	0.20	1.50	1.25	7	0.75	6.0	75	3.28	0.66	0.667	0.11
6	0.40	1.50	--	7	0.75	6.0	70	2.80	1.12	0.857	0.14
7	0.20	1.25	0.75	--	0	6.0	75	3.28	0.66	0.667	0.11
		From worksheet 3				From worksheet 2				From table 5-1	

The dimensionless unit hydrograph is selected from tables in TR-55

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												* * * TC = 1.5 HR * * *																IA/P = 0.10				
0.0	9	11	15	21	25	31	41	58	82	112	147	184	216	255	275	236	198	159	129	98	76	57	43	35	30	25	23	21	18	16	12	1
.10	8	10	13	18	20	23	28	37	51	72	98	131	166	226	265	254	226	187	151	113	86	63	46	37	31	26	23	21	19	16	13	2
.20	8	10	13	17	19	22	26	33	45	63	87	116	149	212	259	259	233	197	160	119	90	66	48	38	32	27	24	22	19	16	13	2
.30	7	9	12	16	18	21	24	30	40	55	76	103	134	197	244	255	238	206	169	125	95	68	49	38	32	27	24	22	19	17	13	2
.40	7	8	11	14	15	17	19	23	28	36	49	67	91	151	208	247	252	230	196	146	109	77	54	41	34	29	25	22	19	17	13	3
.50	6	8	10	13	15	16	18	21	26	33	43	59	80	136	194	238	249	235	204	154	115	81	56	42	34	29	25	23	20	17	13	3
.75	5	7	8	11	12	13	14	16	18	21	25	32	42	76	125	179	222	240	233	193	148	102	67	48	38	32	27	24	20	18	13	5
1.0	4	5	7	8	9	10	11	12	13	14	16	18	22	34	59	101	152	201	236	230	193	135	86	59	44	35	30	26	21	18	14	7
1.5	3	4	5	6	6	7	8	8	9	10	11	12	13	16	22	34	58	95	141	203	226	197	131	84	58	43	35	29	23	20	15	10
2.0	1	2	3	4	4	5	5	6	6	7	7	8	9	10	12	16	22	34	56	110	172	218	187	126	82	57	43	34	25	21	16	11
2.5	1	1	2	2	3	3	3	4	4	4	5	5	6	7	8	9	11	14	18	34	69	141	210	190	133	87	60	44	30	23	17	12
3.0	0	0	1	1	2	2	2	2	3	3	3	3	4	5	5	6	8	9	11	16	27	66	149	204	181	128	85	58	35	25	18	12
IA/P = 0.30												* * * TC = 1.5 HR * * *																IA/P = 0.30				
0.0	0	0	0	0	0	1	6	15	31	53	80	112	144	193	225	208	186	157	134	108	89	70	56	48	42	37	34	31	28	25	20	2
.10	0	0	0	0	0	0	1	4	12	25	43	68	97	157	198	219	203	178	151	120	98	77	60	50	44	38	35	32	28	25	20	3
.20	0	0	0	0	0	0	0	1	3	9	19	35	57	114	168	201	213	196	171	135	108	84	64	53	46	40	36	33	29	26	20	4
.30	0	0	0	0	0	0	0	1	2	7	15	29	48	100	155	193	210	200	177	140	113	87	66	54	46	41	36	33	29	26	20	5
.40	0	0	0	0	0	0	0	0	2	5	12	23	39	87	141	184	207	202	182	146	117	89	68	55	47	41	36	33	29	26	20	5
,50	0	0	0	0	0	0	0	0	0	1	4	9	18	51	101	153	190	205	197	164	131	99	73	58	49	43	38	34	30	26	20	7
.75	0	0	0	0	0	0	0	0	0	0	2	4	9	30	68	116	160	189	197	179	147	110	80	62	52	45	39	35	30	27	21	8
1.0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	20	49	92	138	175	195	178	137	97	72	57	48	42	37	31	28	21	12
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	21	47	85	145	187	178	133	95	71	57	48	42	34	29	23	16
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	13	45	97	162	180	138	99	74	58	49	38	32	25	18
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	31	89	161	174	133	97	72	58	42	34	26	18
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	29	98	160	169	129	95	71	48	37	28	19
IA/P = 0.50												* * * TC = 1.5 HR * * *																IA/P = 0.50				
.0	0	0	0	0	0	0	0	3	8	16	27	42	59	92	116	128	130	121	112	100	90	78	67	60	55	50	46	43	39	35	29	4
.10	0	0	0	0	0	0	0	2	6	12	22	35	51	84	110	125	128	123	114	102	91	79	68	61	55	50	46	43	39	35	29	4
.20	0	0	0	0	0	0	0	0	1	4	10	18	29	60	91	114	126	128	120	108	97	83	71	63	57	52	47	44	40	36	29	5
.30	0	0	0	0	0	0	0	0	1	3	8	14	24	52	83	108	123	126	122	110	98	85	72	63	57	52	48	44	40	36	29	6
.40	0	0	0	0	0	0	0	0	0	1	2	6	12	31	60	90	112	124	126	116	104	90	75	66	59	54	49	45	41	37	29	8
.50	0	0	0	0	0	0	0	0	0	0	2	4	9	26	53	83	106	121	125	118	106	91	77	67	60	54	49	46	41	37	29	8
.75	0	0	0	0	0	0	0	0	0	0	1	2	5	16	36	62	88	108	119	122	112	97	81	69	62	56	51	47	42	38	30	11
1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	10	26	49	75	98	118	121	108	90	76	66	59	54	49	43	39	31	16
1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	11	25	45	80	107	118	106	89	75	65	59	53	45	41	32	23
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	11	32	63	100	115	104	87	74	65	58	48	42	34	26
2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	16	48	94	113	105	89	76	66	53	45	36	27
3.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	15	54	96	111	103	88	75	58	48	38	28
RAINFALL TYPE = II												* * * TC = 1.5 HR * * *																SHEET 9 OF 10				

Worksheet 5b: Basic watershed data

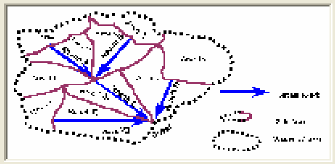
Project: Fallswood | Location: Dyer County, Tennessee | By: DW | Date: 10/1/85
Check one: ☒ Present ☐ Developed | Frequency (yr): 25 | Checked: NM | Date: 10/3/85

Basic watershed data used 1/ — Select and enter hydrograph times in hours from exhibit 5-II 2/ — Discharges at selected hydrograph times 3/ (cfs)

Subarea name	Subarea T_c (hr)	ΣT_t to outlet (hr)	I_a/P	A_mQ (mi^2—in)	12.7	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.3	14.6	15.0	15.5
1	1.50	2.50	0.10	0.71	4	4	5	6	6	8	10	113	24	49	100	149
2	1.25	2.50	0.10	0.56	3	4	4	6	7	8	11	16	32	64	110	127
3	0.50	2.00	0.10	0.33	5	5	6	8	12	21	41	67	98	92	60	29
4	0.75	2.00	0.10	0.70	8	9	11	14	20	34	62	106	172	192	149	81
5	1.50	0.75	0.10	0.66	21	28	50	83	118	147	158	154	127	98	67	44
6	1.50	0.75	0.10	1.12	36	47	85	140	200	249	269	261	216	166	114	75
7	1.25	0	0.10	0.66	169	187	205	176	140	108	85	69	51	40	31	24
Composite hydrograph at outlet					246	284	366	433	503	575	636	686	720	701	631	529

1/ Worksheet 5a. Rounded as needed for use with exhibit 5.
2/ Enter rainfall distribution type used.
3/ Hydrograph discharge for selected times is A_mQ multiplied by tabular discharge from appropriate exhibit 5.

About WinTR-55 Small Watershed Hydrology



WinTR-55 Small Watershed Hydrology

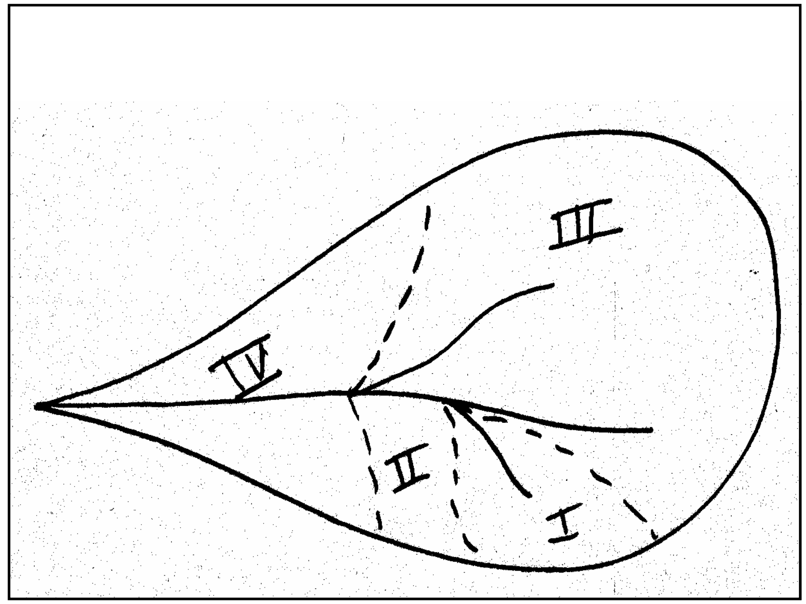
32-bit Window Based Application
Version 2002.00.17
Compiled on 06/14/2002

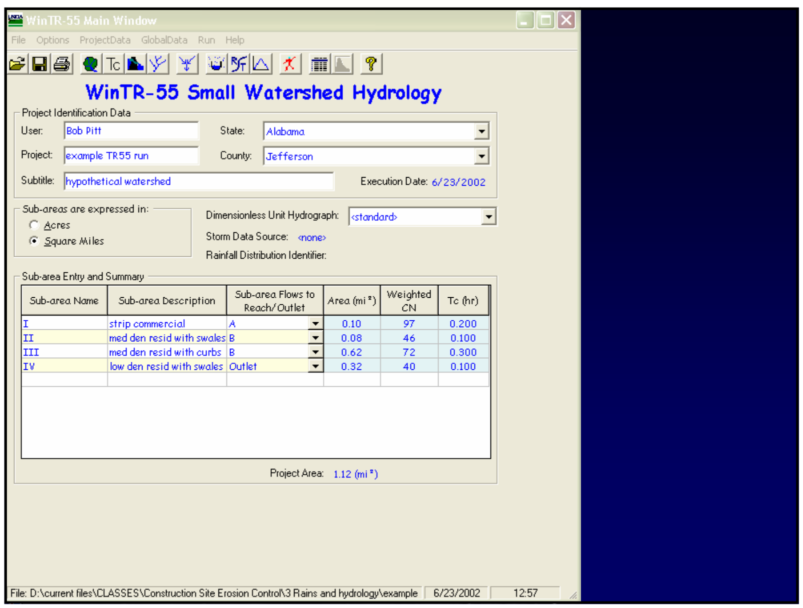
WinTR-55 is a single event rainfall-runoff small watershed model. The model applies to both urban and agricultural areas generating hydrographs from land areas and at selected points along the stream system. Multiple sub-areas can be modeled within a watershed.

Although WinTR-55 has been tested by its developers, NO warranty, expressed or implied, is made as to the accuracy and functioning of the program and related program material nor shall the fact of distribution constitute any such warranty, and NO responsibility is assumed by the developers in connection therewith.

Close

To contact us, please send email to: tr55team@wcc.nrcs.usda.gov





WinTR-55 Main Window

File Options ProjectData GlobalData Run Help

WinTR-55 Small Watershed Hydrology

Project Identification Data

User: Bob Pitt State: Alabama
Project: example TR55 run County: Jefferson
Subtitle: hypothetical watershed Execution Date: 6/23/2002

Sub-areas are expressed in: Acres / Square Miles (selected)

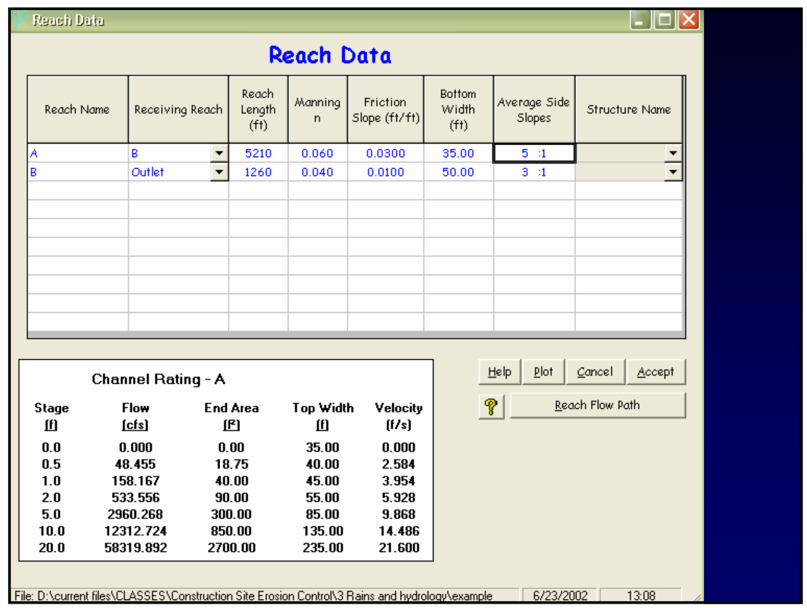
Dimensionless Unit Hydrograph: <standard>
Storm Data Source: <none>
Rainfall Distribution Identifier:

Sub-area Entry and Summary

Sub-area Name	Sub-area Description	Sub-area Flows to Reach/Outlet	Area (mi^2)	Weighted CN	Tc (hr)
I	strip commercial	A	0.10	97	0.200
II	med den resid with swales	B	0.08	46	0.100
III	med den resid with curbs	B	0.62	72	0.300
IV	low den resid with swales	Outlet	0.32	40	0.100

Project Area: 1.12 (mi^2)

File: D:\current files\CLASSES\Construction Site Erosion Control\3 Rains and hydrology\example 6/23/2002 12:57



Reach Data

Reach Data

Reach Name	Receiving Reach	Reach Length (ft)	Manning n	Friction Slope (ft/ft)	Bottom Width (ft)	Average Side Slopes	Structure Name
A	B	5210	0.060	0.0300	35.00	5 :1	
B	Outlet	1260	0.040	0.0100	50.00	3 :1	

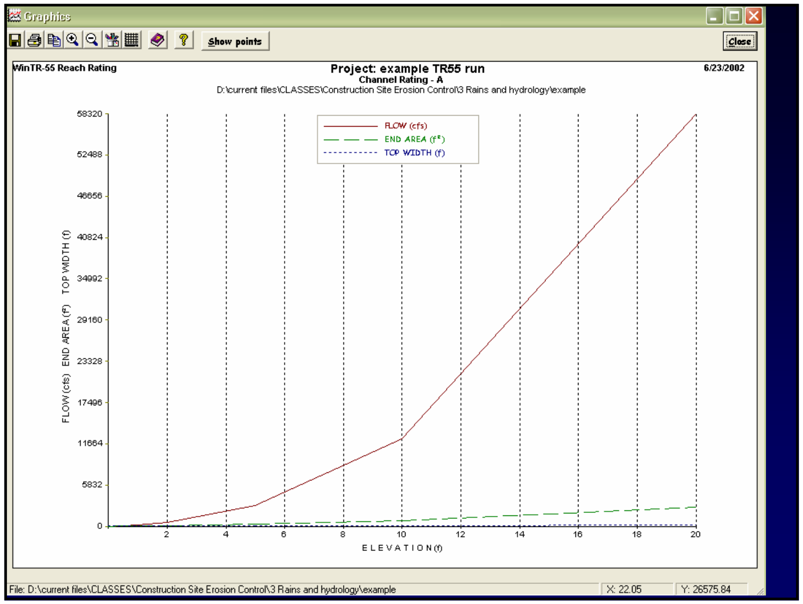
Channel Rating - A

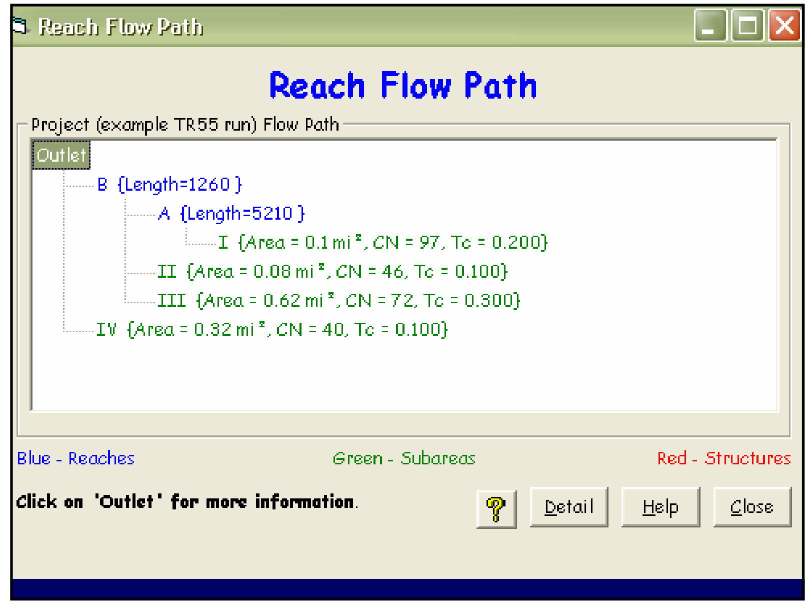
Stage [ft]	Flow [cfs]	End Area [ft²]	Top Width [ft]	Velocity [f/s]
0.0	0.000	0.00	35.00	0.000
0.5	48.455	18.75	40.00	2.584
1.0	158.167	40.00	45.00	3.954
2.0	533.556	90.00	55.00	5.928
5.0	2960.268	300.00	85.00	9.868
10.0	12312.724	850.00	135.00	14.486
20.0	58319.892	2700.00	235.00	21.600

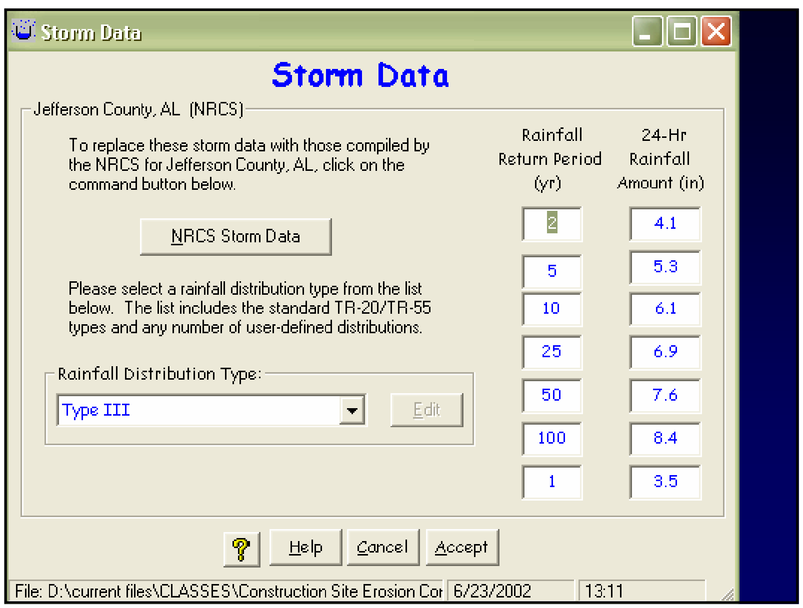
Help Plot Cancel Accept

Reach Flow Path

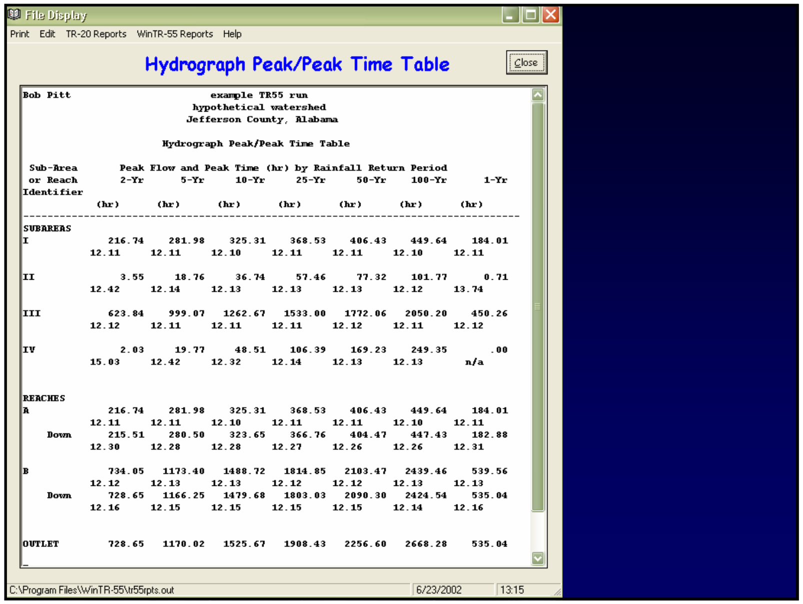
File: D:\current files\CLASSES\Construction Site Erosion Control\3 Rains and hydrology\example 6/23/2002 13:08


Graphics
Show points
Close
WinTR-55 Reach Rating
Project: example TR55 run
Channel Rating - A
D:\current files\CLASSES\Construction Site Erosion Control\3 Rains and hydrology\example
6/23/2002
FLOW (cfs)
END AREA (ft²)
TOP WIDTH (ft)
ELEVATION (ft)
File: D:\current files\CLASSES\Construction Site Erosion Control\3 Rains and hydrology\example
X: 22.05
Y: 26575.84


Reach Flow Path
Reach Flow Path
Project (example TR55 run) Flow Path
Outlet
B {Length=1260 }
A {Length=5210 }
I {Area = 0.1 mi², CN = 97, Tc = 0.200}
II {Area = 0.08 mi², CN = 46, Tc = 0.100}
III {Area = 0.62 mi², CN = 72, Tc = 0.300}
IV {Area = 0.32 mi², CN = 40, Tc = 0.100}
Blue - Reaches
Green - Subareas
Red - Structures
Click on 'Outlet' for more information.
Detail
Help
Close


Storm Data
Storm Data
Jefferson County, AL (NRCS)
To replace these storm data with those compiled by the NRCS for Jefferson County, AL, click on the command button below.
NRCS Storm Data
Please select a rainfall distribution type from the list below. The list includes the standard TR-20/TR-55 types and any number of user-defined distributions.
Rainfall Distribution Type:
Type III
Edit
Rainfall Return Period (yr)
24-Hr Rainfall Amount (in)
2
4.1
5
5.3
10
6.1
25
6.9
50
7.6
100
8.4
1
3.5
Help
Cancel
Accept
File: D:\current files\CLASSES\Construction Site Erosion Cor
6/23/2002
13:11


Run WinTR-55
Run WinTR-55
Check storm(s) to evaluate:
2-Yr
25-Yr
5-Yr
50-Yr
10-Yr
100-Yr
1-Yr
Help
Cancel
Run


File Display

Print Edit TR-20 Reports WinTR-55 Reports Help

Hydrograph Peak/Peak Time Table

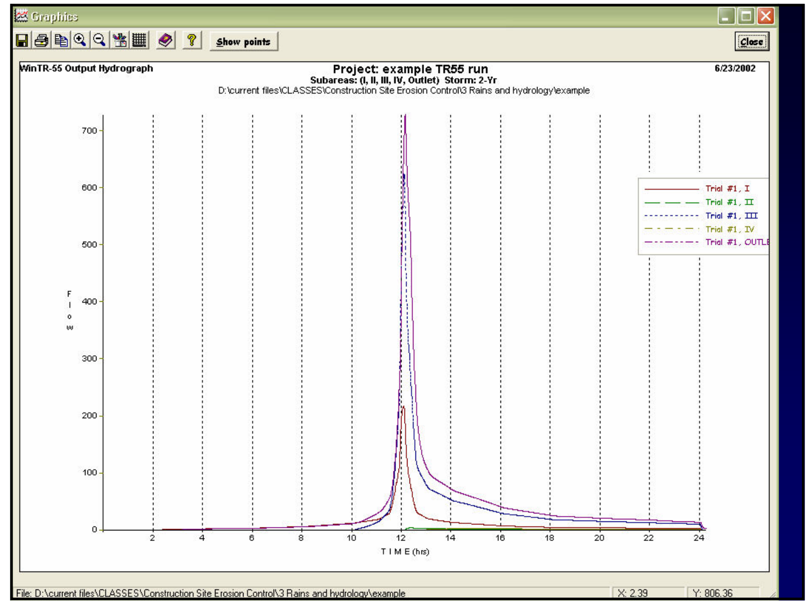
Bob Pitt

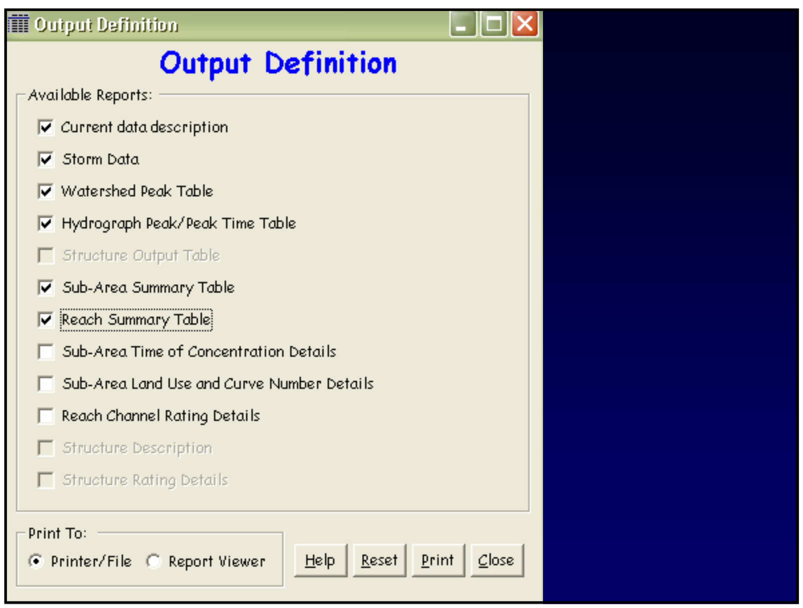
example TR55 run
hypothetical watershed
Jefferson County, Alabama

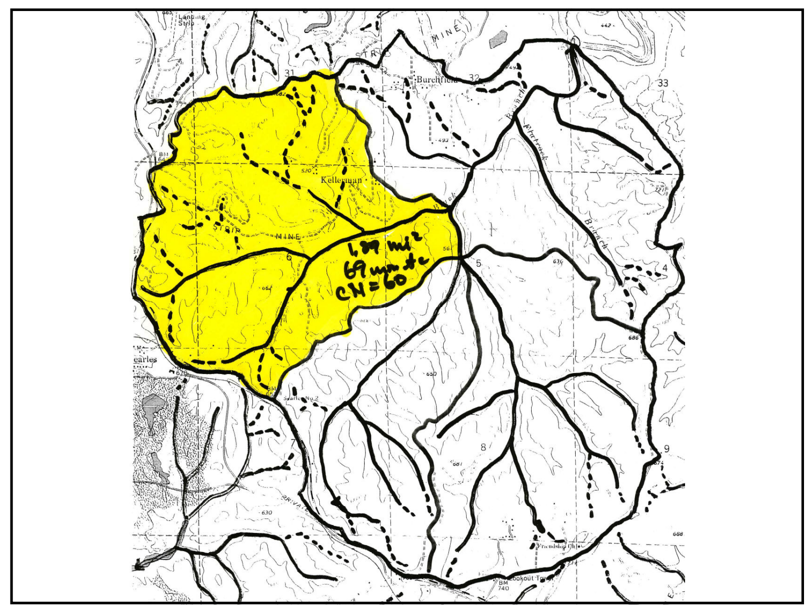
Hydrograph Peak/Peak Time Table

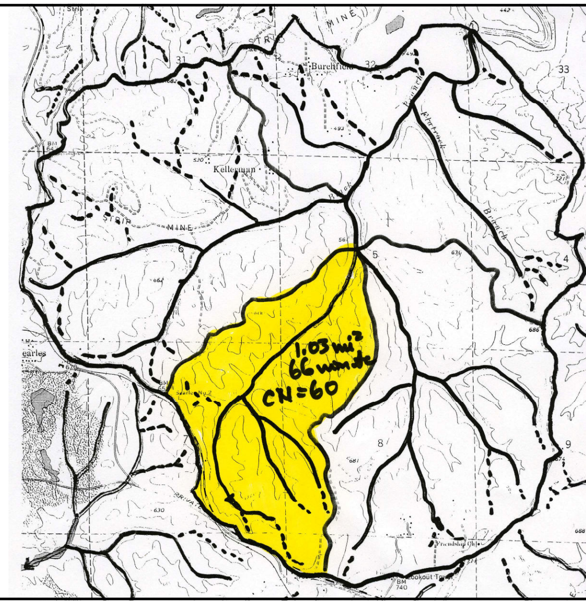
Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 2-Yr (hr)	5-Yr (hr)	10-Yr (hr)	25-Yr (hr)	50-Yr (hr)	100-Yr (hr)	1-Yr (hr)
SUBAREAS							
I	216.74	281.98	325.31	368.53	406.43	449.64	184.01
	12.11	12.11	12.10	12.11	12.11	12.10	12.11
II	3.55	18.76	36.74	57.46	77.32	101.77	0.71
	12.42	12.14	12.13	12.13	12.13	12.12	13.74
III	623.84	999.07	1262.67	1533.00	1772.06	2050.20	450.26
	12.12	12.11	12.11	12.11	12.12	12.11	12.12
IV	2.03	19.77	48.51	106.39	169.23	249.35	.00
	15.03	12.42	12.32	12.14	12.13	12.13	n/a
REACHES							
A	216.74	281.98	325.31	368.53	406.43	449.64	184.01
	12.11	12.11	12.10	12.11	12.11	12.10	12.11
Down	215.51	280.50	323.65	366.76	404.47	447.43	182.88
	12.30	12.28	12.28	12.27	12.26	12.26	12.31
B	734.05	1173.40	1488.72	1814.85	2103.47	2439.46	539.56
	12.12	12.13	12.13	12.12	12.12	12.13	12.13
Down	728.65	1166.25	1479.68	1803.03	2090.30	2424.54	535.04
	12.16	12.15	12.15	12.15	12.15	12.14	12.16
OUTLET	728.65	1170.02	1525.67	1908.43	2256.60	2668.28	535.04

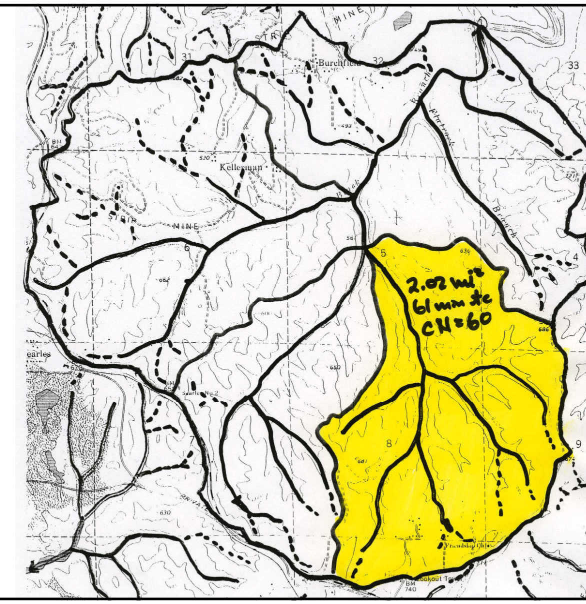
C:\Program Files\WinTR-55\tr55rpts.out 6/23/2002 13:15

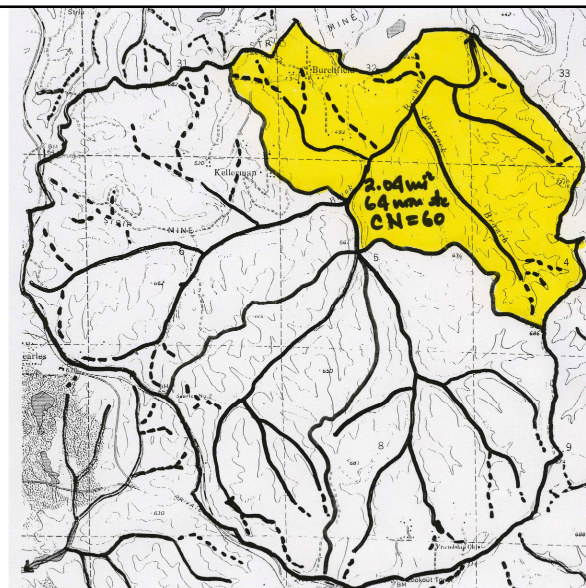


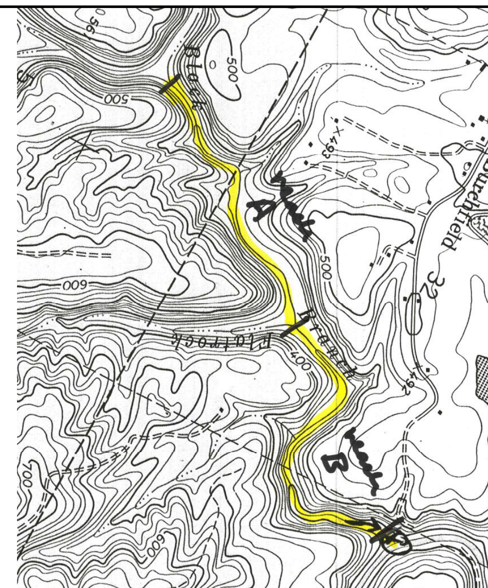





1.03 mi²
66 min tc
CN=60
Kelleman
MINE


2.02 mi²
61 min tc
CN=60
Kelleman
MINE


2.04 mi²
64 min tc
CN=60
Kelleman
MINE


Burchfield
Black
Branch
Flatrock
A
B

Subwatershed Characteristics

- Common sheetflows for all areas: 15% slope, woods, dense undergrowth with n 0.80, 35 min. for 300 ft. Common shallow concentrated flows for all areas: 5% slope unpaved, 3.5 ft/sec for 200 ft. = 9.5 min.
- Woods, B soils: CN = 60
- Subarea 1 (1212 acres)
  - Soil 25 (B) and 40 (B)
  - Tc: 44.5 min plus 4800 ft at 6.8 ft/sec (11.8 min) and 5200 ft at 7.0 ft/sec (12.4 min) = 1.1 hour
- Subarea 2 (661 acres)
  - Soil 22 (D/B) and 40 (B)
  - Tc: 1.1 hour
- Subarea 3 (1293 acres)
  - Soil 40 (B), 3 (B), and 6 (B)
  - Tc = 1.0 hour
- Subarea 4 (1302 acres)
  - Soil 22 (D/B), 12 (B), and 23 (B)
  - Tc = 1.1 hour

Channel Flow Travel Time

- Reach A: 3290 ft, n = 0.04, S_f = 0.008, bottom width = 20 ft, side slope = 2:1
- Reach B: 3390 ft, n = 0.02, S_f = 0.0158, bottom width = 10 ft, side slope = 2:1

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

```
User:     Pitt                                          Date:         4/7/2004
Project:  Brookwood                                     Units:        English
SubTitle:                                               Areal Units:  Acres
State:    Alabama
County:   Tuscaloosa
Filename: &lt;new file&gt;
```

--- Sub-Area Data ---

Name	Description	Reach	Area(ac)	RCN	Tc
Subarea 1		A	1212	60	1.100
Subarea 2		A	661	60	1.100
Subarea 3		A	1293	60	1.000
Subarea 4		Outlet	1302	60	1.100

Total area: 4468 (ac)

--- Storm Data --

Rainfall Depth by Rainfall Return Period

2-Yr (in)	5-Yr (in)	10-Yr (in)	25-Yr (in)	50-Yr (in)	100-Yr (in)	1-Yr (in)
4.2	5.4	6.3	7.1	7.8	8.6	3.6

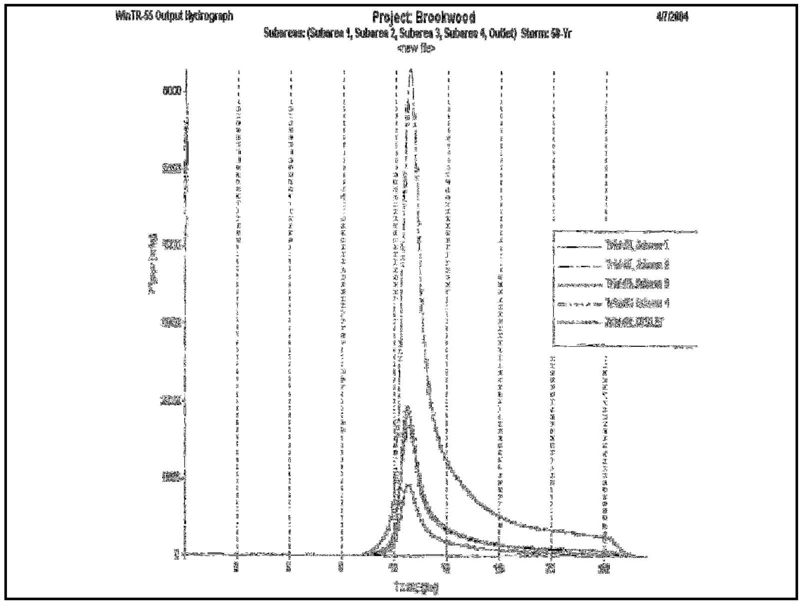
Storm Data Source: Tuscaloosa County, AL (NRCS)
Rainfall Distribution Type: Type III
Dimensionless Unit Hydrograph: <standard>

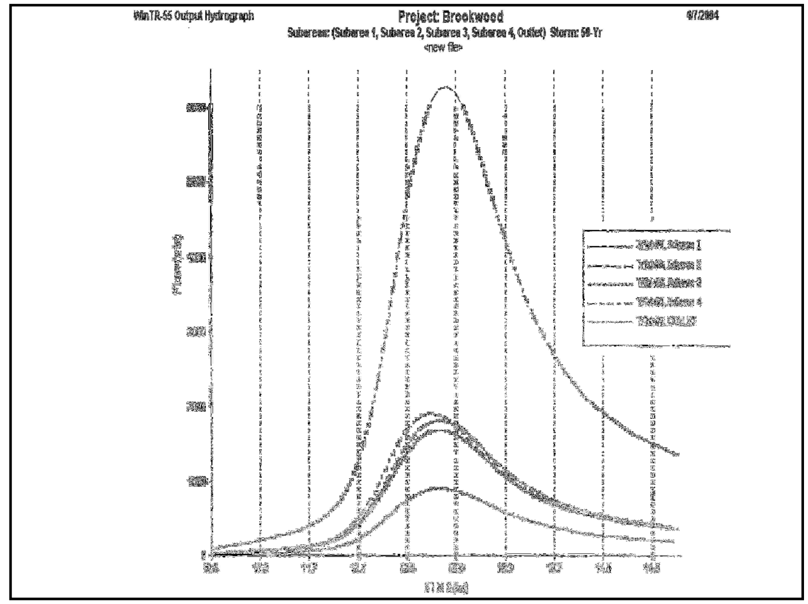
Pitt — Brookwood

Tuscaloosa County, Alabama

Watershed Peak Table

Sub-Area or Reach Identifier	Peak Flow by Rainfall Return Period 50-Yr (cfs)
SUBAREAS	
Subarea 1	1691.40
Subarea 2	922.45
Subarea 3	1915.57
Subarea 4	1817.00
REACHES	
A	4509.75
Down	4487.89
B	4487.89
Down	4487.89
OUTLET	6291.12


WinTR-55 Output Hydrograph
Project: Brookwood
4/7/2004
Subareas: (Subarea 1, Subarea 2, Subarea 3, Subarea 4, Outlet) Storm: 50-Yr
<new file>


WinTR-55 Output Hydrograph
Project: Brookwood
Subareas: (Subarea 1, Subarea 2, Subarea 3, Subarea 4, Outlet) Storm: 50-Yr
<new file>