## Rainfall and Hydrology Factors Affecting Erosion Rates

- Rainfall energy (rain intensity and duration)
- Tractive force (shear stress) of sheet and channel flow
- Runoff depth and velocity (to calculate shear stress for specific site conditions)

1

## Hydrology Parameters Needed for the Design of Construction Site Erosion Control Practices

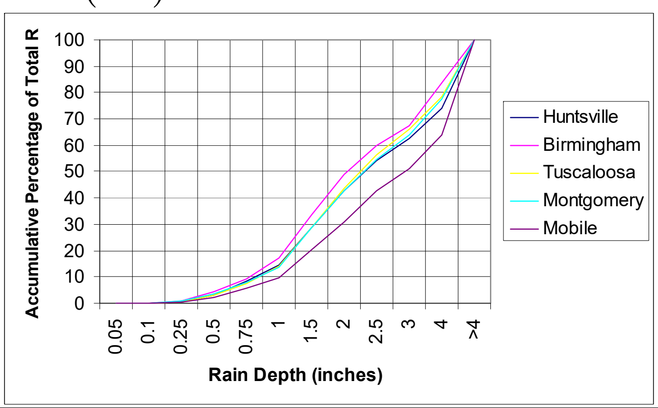
- Mulches – water velocities and water depth
- Ditch liners – water velocities and water depth
- Slope down shoots – peak flow rates
- Diversion dikes and swales – peak flow rates
- Filter fabric fences – water velocities and hydrographs
- Sediment ponds – water volume and hydrographs

2

Thronson (1973) presented the following equation to estimate the erosion potential for individual rains:

$$R = \frac{19.25(P)^{2.2}}{(dur)^{0.4672}}$$

P = rain depth in inches and,
dur = rain duration in hours



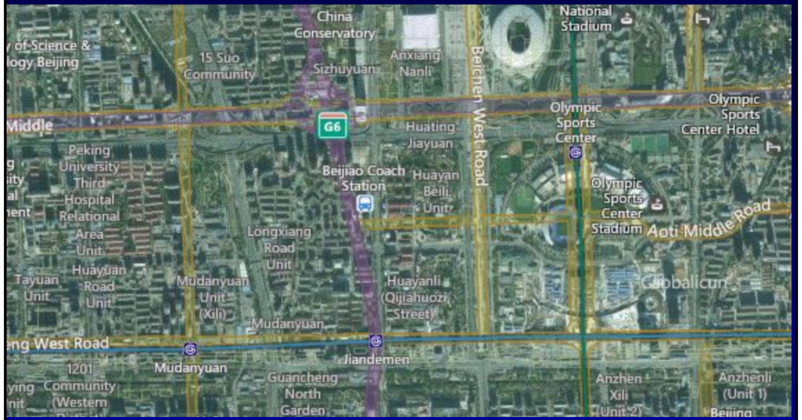

3

## Factors Affecting Runoff

- Rainfall – The duration of the storm and the distribution of the rainfall during the storm are the two major factors affecting the peak rate of runoff. The rainfall amount affects the volume of runoff.
- Soil conditions – antecedent moisture conditions generally affects the infiltration rate of the rainfall falling on the ground. Soil texture and compaction (structure) usually has the greatest effect on the infiltration.
- Surface cover – the type and condition of the soil surface cover affects the rain energy transferred to the soil surface and can affect the infiltration rate also.

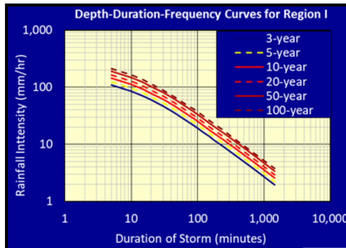
4

# Typical Dense Urbanized Area in Central Beijing

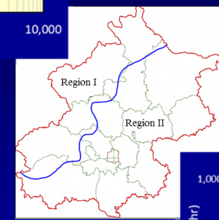



Aerial photo from Google maps

5

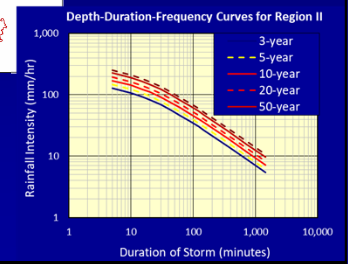



Traditional IDF design storms for design of stormwater collection systems, focusing on 3 to 100-yr reoccurring events (1 to 33% probability of occurring in any one year).

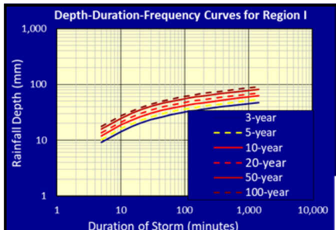



Flatter topography, lower elevations and closer to sea results in greater intensities in Region II compared to Region I, especially for longer duration events.

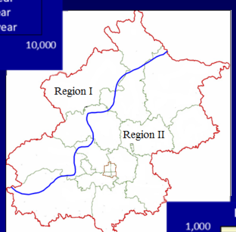
| intensity (mm/hr) associated with: | 5 yr rain frequency | | 20 yr rain frequency | | 100 yr frequency | |
|---|---|---|---|---|---|---|
| Beijing rain region: | 1 | 2 | 1 | 2 | 1 | 2 |
| short duration (5 minutes) | 124 | 146 | 163 | 194 | 210 | 252 |
| one hour (60 minutes) | 32 | 54 | 43 | 72 | 55 | 92 |
| one day (1440 minutes) | 2.6 | 7.2 | 3 | 8.2 | 3.8 | 11 |



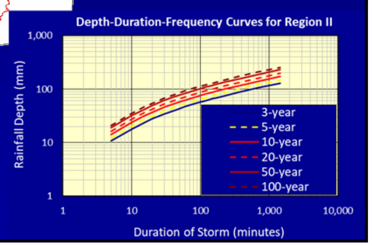

6




**Similar plots showing rain depth vs. duration and reoccurrence interval.**




| rainfall depth (mm) associated with: | 5 yr rain frequency | | 20 yr rain frequency | | 100 yr frequency | |
|---|---|---|---|---|---|---|
| Beijing rain region: | 1 | 2 | 1 | 2 | 1 | 2 |
| short duration (5 minutes) | 10 | 12 | 14 | 16 | 18 | 21 |
| one hour (60 minutes) | 32 | 54 | 43 | 72 | 55 | 92 |
| one day (1440 minutes) | 54 | 148 | 71 | 197 | 91 | 254 |




7

# Urban Stormwater Hydrology

- Early focus of urban stormwater was on storm sewer and flood control design using the Rational Method and TR-55 (both single event, "design storm" methods).
- The Curve Number procedure was developed in the 1950s by the (then) SCS as a simple tool for estimating volumes generated by large storm events in agricultural areas, converted to urban uses in mid 1970s (TR55 in SCS 1976). Data based on many decades of observations of large storms in urban areas, at Corps of Engineers monitoring locations. Data available from the Rainfall-Runoff database report prepared by the Univ. of Florida for the EPA.
- Water quality focus results form Public Law 92-500, the Clean Water Act, 1972. Stormwater quality research started in the late 1960s, with a few earlier interesting studies. Big push with Nationwide Urban Runoff Program (NURP) in late 70s and early 80s. Most still rely on earlier drainage design approaches. Distributed infiltration systems demonstrated in the 1960s.

8

## Importance of Site Hydrology in the Design of Stormwater Controls

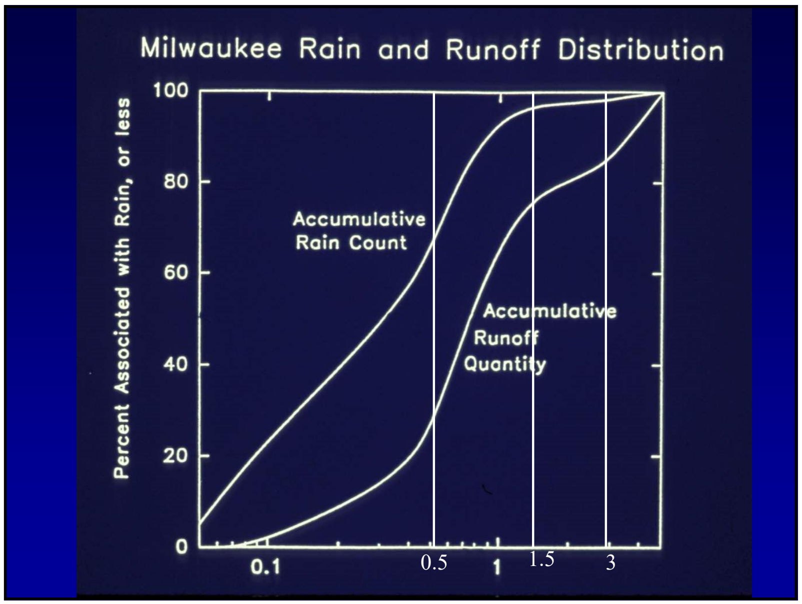
- Design of stormwater management programs requires knowledge of site hydrology
- Understanding of flows (variations for different storm conditions, sources of flows from within the drainage area, and quality of those flows), are needed for effective design of source area and outfall controls.

9

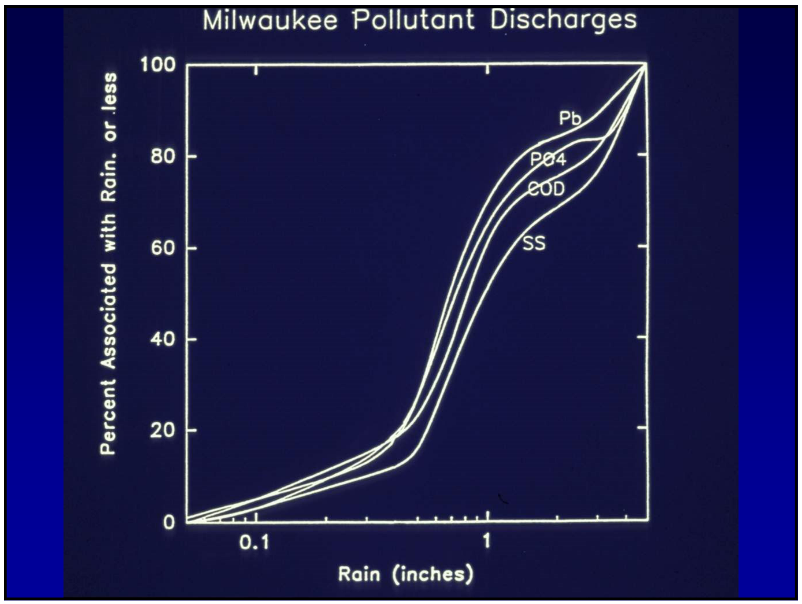
## Design Issues for Stormwater Quality Management

- Recognize different objectives of storm drainage systems
- Recognize associated rainfall conditions affecting different objectives
- Select appropriate tools for evaluation and design
- Example - 4 major rainfall categories for Milwaukee, WI (as monitored during NURP):
  - <0.5 in (<12 mm) (median rain by count)
  - 0.5 to 1.5 in (12 to 40 mm) (most of the runoff)
  - 1.5 to 3 in (40 to 75 mm) (few events)
  - >3 in (>75 mm) (drainage design and flooding)

10

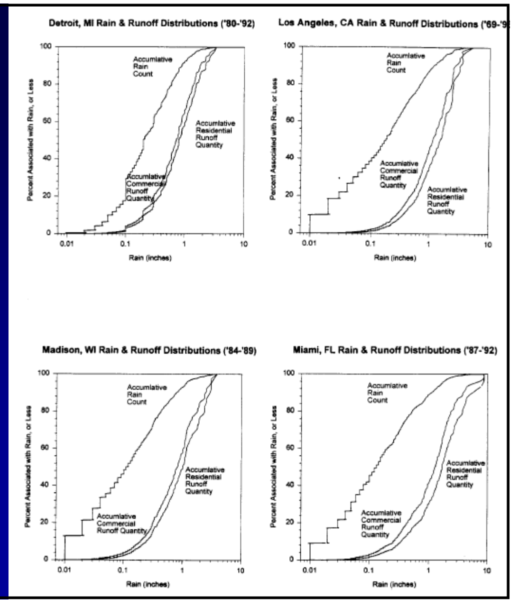



11




12

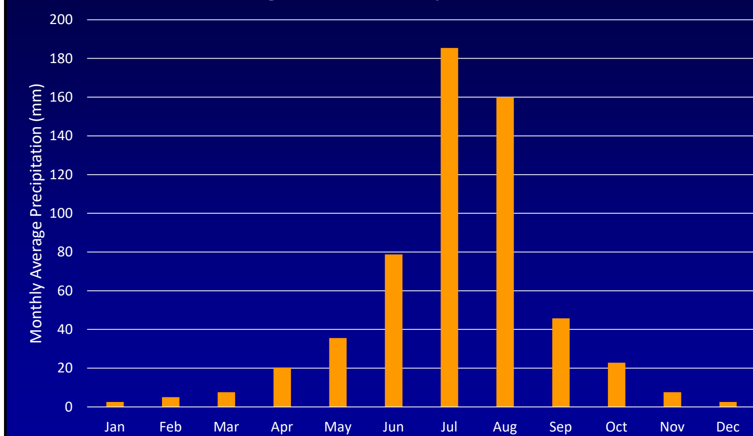
Same pattern in other parts of the country, just shifted.




Pitt, *et al.* (2000)

13

## Long-Term Average Beijing Rainfall (China Meteorological Bureau, years not shown)




https://www.weather-atlas.com/en/china/beijing-climate

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Li Miao, Xia Jun, and Meng Dejuan. "Long-Term Trend Analysis of Seasonal Precipitation for Beijing, China." *Journal of Resources and Ecology*. March 2012, Vol. 3, Issue 1, pgs. 64- 72.

This was a comprehensive precipitation trend and periodic analysis at the seasonal scale for a 286–year rainfall data series (1724–2009) for Beijing. They found that in the past 300 years, precipitation has increased, except during winter. However, based on their cyclic trend analyses, they expect Beijing will experience less rainfall in the 2009 to 2030 time period.

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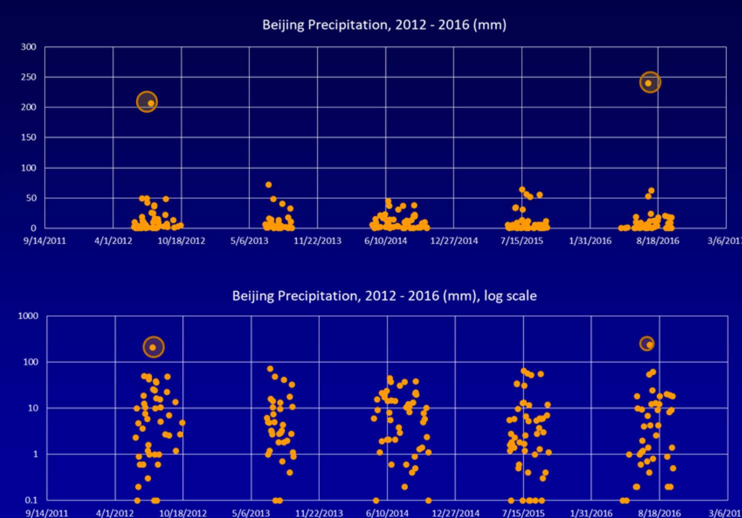


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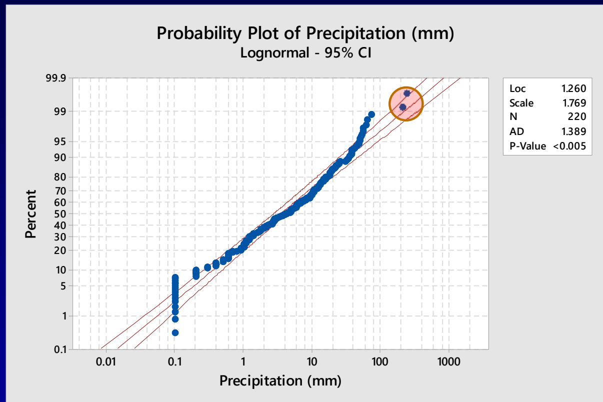
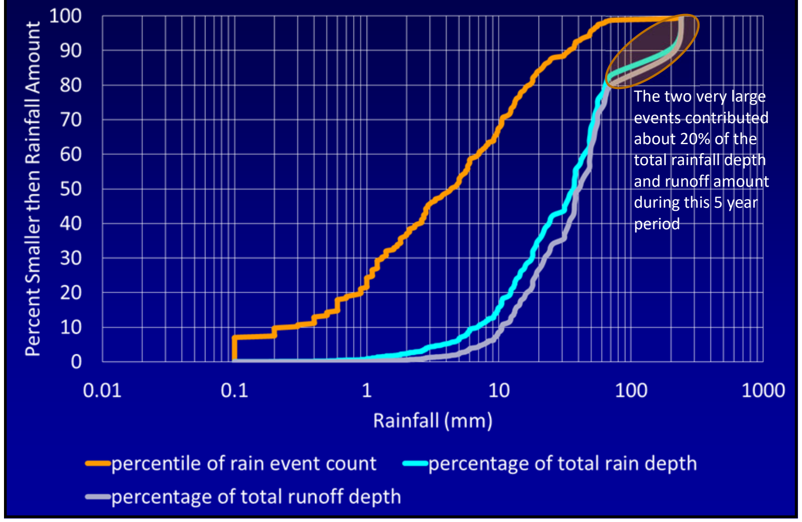
## 2012 though 2016 Daily Rainfall in Beijing




In this 5 year period, the median rain depth was about 4.4 mm, the 90th percentile rain depth was about 90 mm, and the largest rain depth was about 240 mm (second largest was 207 mm and 3rd largest dropped to 72 mm). Recall the 24-hr/5-yr event was 54-148 mm and the 100 yr/24 hr rain event was 91 to 254 mm).

17

Beijing 2012 - 2016 Daily Rains and Runoff (high density urban areas)

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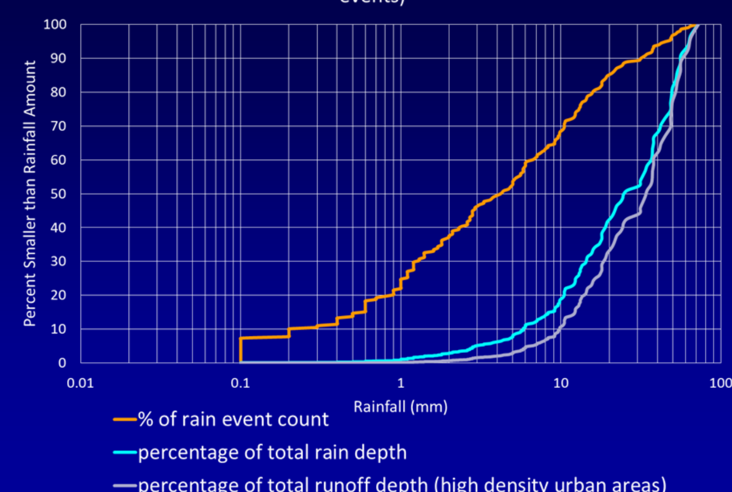
## Importance of Small and Intermediate Sized Rains

| | Beijing 2012 through 2016 rains (including 2 very large events) |
|---|---|
| % of rain events, by count, <10 mm depth: | 68% |
| Rain depth associated with 10% of annual runoff: | <10.5 mm |
| Rain depth associated with 50% of annual runoff: | <40.9 mm |
| Rain depth associated with 80% of annual runoff: | <72 mm |
| Large rains >70 mm therefore contributed about 20% of the annual runoff for this 5 year monitoring period (unusually large?) | |

19

Beijing 2012 - 2016 Daily Rains (w/o 207 and 240 mm large events)




20

## Importance of Small and Intermediate Sized Rains (especially when two unusually large and rare rains are not considered in this five year period)

| | Beijing 2012 through 2016 rains excluding 207 and 240 mm rains) |
|---|---|
| % of rain events, by count, <10 mm depth: | 68% |
| Rain depth associated with 10% of annual runoff: | <9.8 mm |
| Rain depth associated with 50% of annual runoff: | <34.5 mm |
| Rain depth associated with 80% of annual runoff: | <52 mm |

This may be more representative of typical rain periods (without the two very large rains)

21

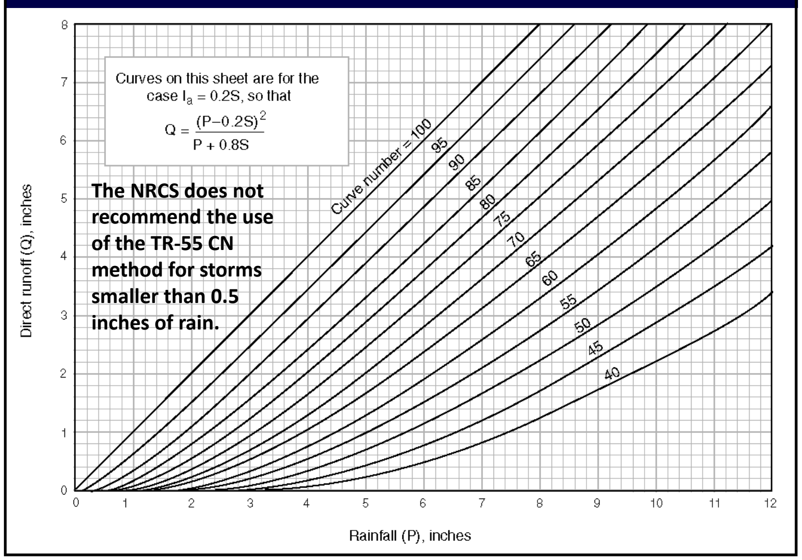
| Cover description: Cover type and hydrologic condition | Average percent impervious area [2] | Curve numbers for hydrologic soil group: A | B | C | D |
|---|---|---|---|---|---|
| *Fully developed urban areas (vegetation established)* | | | | | |
| Open space (lawns, parks, golf courses, cemeteries, etc.) [3]: | | | | | |
| Poor condition (grass cover < 50%) | | 68 | 79 | 86 | 89 |
| Fair condition (grass cover 50% to 75%) | | 49 | 69 | 79 | 84 |
| Good condition (grass cover > 75%) | | 39 | 61 | 74 | 80 |
| Impervious areas: | | | | | |
| Paved parking lots, roofs, driveways, etc. (excluding right-of-way) | | 98 | 98 | 98 | 98 |
| Streets and roads: | | | | | |
| Paved; curbs and storm sewers (excluding right-of-way) | | 98 | 98 | 98 | 98 |
| Paved; open ditches (including 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 |
| Western desert urban areas: | | | | | |
| Natural desert landscaping (pervious areas only) [4] | | 63 | 77 | 85 | 88 |
| Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders) | | 96 | 96 | 96 | 96 |
| Urban districts: | | | | | |
| Commercial and business | 85 | 89 | 92 | 94 | 95 |
| Industrial | 72 | 81 | 88 | 91 | 93 |
| Residential districts by average lot size: | | | | | |
| 1/8 acre or less (town houses) | 65 | 77 | 85 | 90 | 92 |
| 1/4 acre | 38 | 61 | 75 | 83 | 87 |
| 1/3 acre | 30 | 57 | 72 | 81 | 86 |
| 1/2 acre | 25 | 54 | 70 | 80 | 85 |
| 1 acre | 20 | 51 | 68 | 79 | 84 |
| 2 acres | 12 | 46 | 65 | 77 | 82 |
| *Developing urban areas* | | | | | |
| Newly graded areas (pervious areas only, no vegetation) [5] | | 77 | 86 | 91 | 94 |
| Idle lands (CN's are determined using cover types similar to those in table 2-2c). | | | | | |

1 Average runoff condition, and $I_a = 0.2S$.
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

**The SCS (NRCS) curve number method presented in TR-55 (and also used in WinTR-55 and many stormwater models) is the most common urban hydrology method used in the US. Typical curve number (CN) values for urban areas are shown on this table from TR-55. The same curve number is used for all storms in a given area.**

22

## SCS (NRCS) TR-55 Curve Number Model of Rainfall vs. Runoff



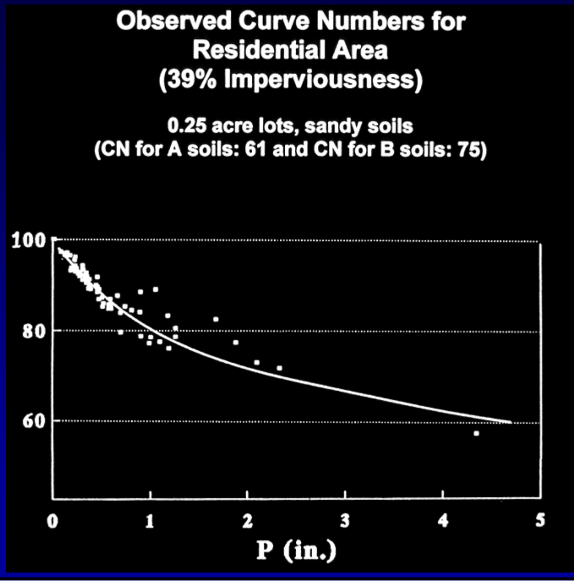

23

## 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:

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

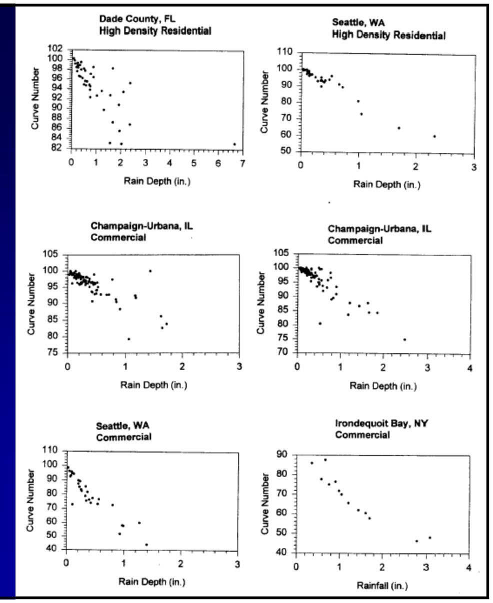
**The following example plots use rainfall and runoff data from the EPA's NURP projects in the early 1980s (EPA 1983), and from the EPA's rainfall-runoff-quantity data base (Huber, *et al.* 1982).**

24

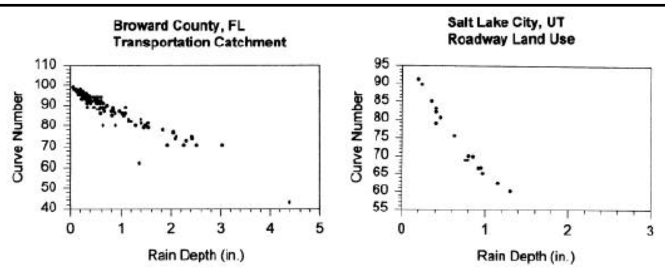



25

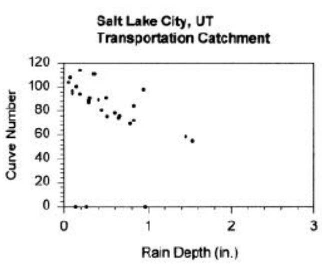
High Density Residential Sites




26



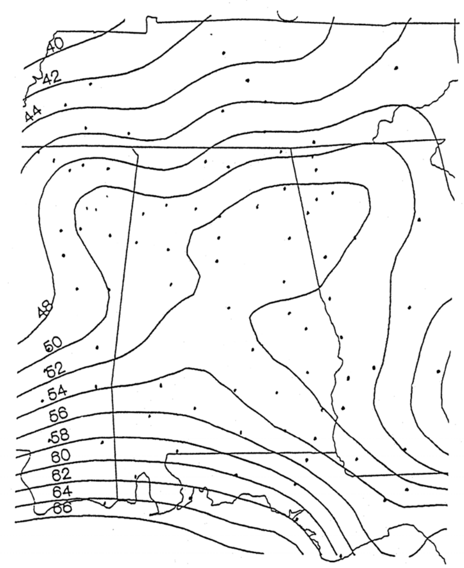

## Highway Sites




Actual runoff relationships do not follow the commonly used NRCS curve number method. For small and intermediate rains, the actual curve numbers are much higher than the table values in TR-55 and only reach those assumed constant CN values as the rain depth approaches drainage design storm depths (as intended when the method was developed).

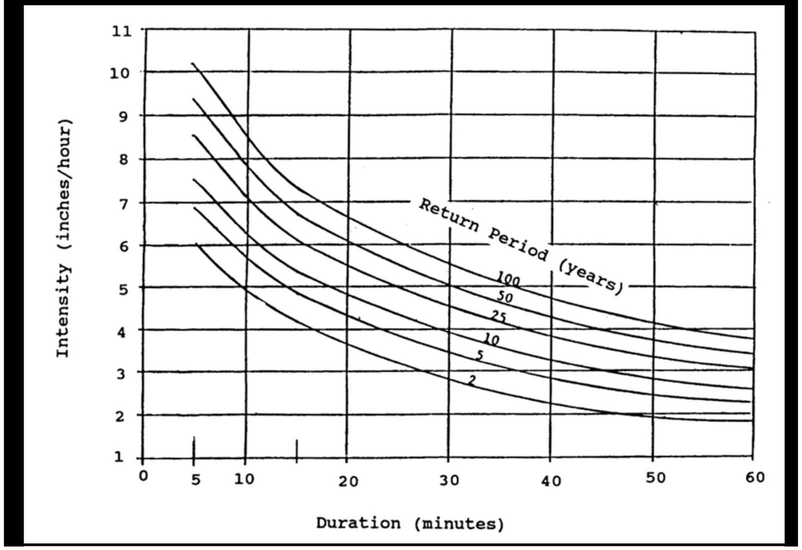
27

**Annual rainfall variations over Alabama (inches). The dots show the locations of the rain gages used in the analysis.**




28

## Birmingham Intensity - Duration - Frequency (IDF) Curve




29

# Time of Concentration ($t_c$)

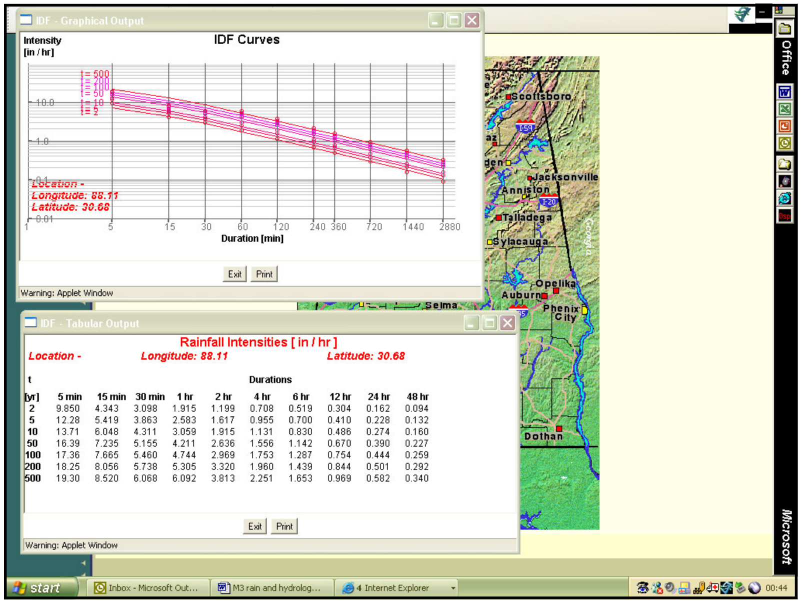
- The duration must be equal to the time of concentration for the drainage area.
- The time of concentration ($t_c$) is equal to the longest flow path (by time).
- If the $t_c$ is 5 min for a storm having a return period of 25 years, the associated peak intensity (which has a duration of 5 min) would be about 8.6 in/hr.
- If the $t_c$ for this same return period was 40 min, the peak rain intensity would be "only" 3.8 in/hr.

30

# Rainfall Frequency

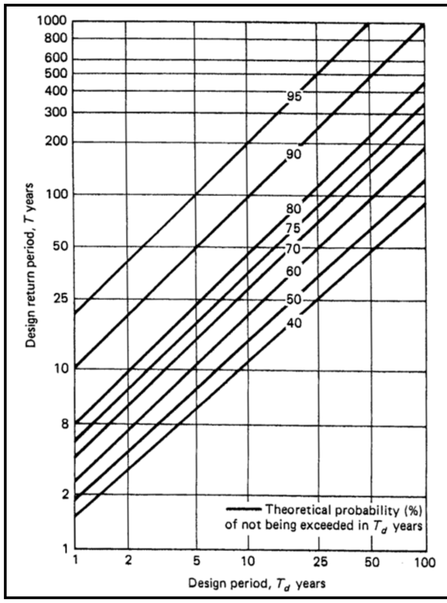
- Rainfall frequency is commonly expressed as the average return period of the event.
- The value should be expressed as the probability of that event occurring in any one year.
- As an example, a 100-yr storm, has a 1% chance of occurring in any one year, while a 5-yr storm has a 20% chance of occurring in any one year.
- Multiple rare events may occur in any one year, but that is not very likely.

31




| t [yr] | 5 min | 15 min | 30 min | 1 hr | 2 hr | 4 hr | 6 hr | 12 hr | 24 hr | 48 hr |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 9.850 | 4.343 | 3.098 | 1.915 | 1.199 | 0.708 | 0.519 | 0.304 | 0.162 | 0.094 |
| 5 | 12.28 | 5.419 | 3.863 | 2.583 | 1.617 | 0.955 | 0.700 | 0.410 | 0.228 | 0.132 |
| 10 | 13.71 | 6.048 | 4.311 | 3.059 | 1.915 | 1.131 | 0.830 | 0.486 | 0.274 | 0.160 |
| 50 | 16.39 | 7.235 | 5.155 | 4.211 | 2.636 | 1.556 | 1.142 | 0.670 | 0.390 | 0.227 |
| 100 | 17.36 | 7.665 | 5.460 | 4.744 | 2.969 | 1.753 | 1.287 | 0.754 | 0.444 | 0.259 |
| 200 | 18.25 | 8.056 | 5.738 | 5.305 | 3.320 | 1.960 | 1.439 | 0.844 | 0.501 | 0.292 |
| 500 | 19.30 | 8.520 | 6.068 | 6.092 | 3.813 | 2.251 | 1.653 | 0.969 | 0.582 | 0.340 |

32




**Probability of design storm (design return period) not being exceeded during the project life (design period).**

**As an example, if a project life was 5 years, and a storm was not to be exceeded with a 90% probability, a 50 year design return period storm must be used.**

33

| Probability of storm not being exceeded in a one year ($T_d$) construction period | Design storm return period (T) |
|---|---|
| 50% | 1.9 year |
| 75% | 6.5 |
| 90% | 10 |
| 95% | 20 |

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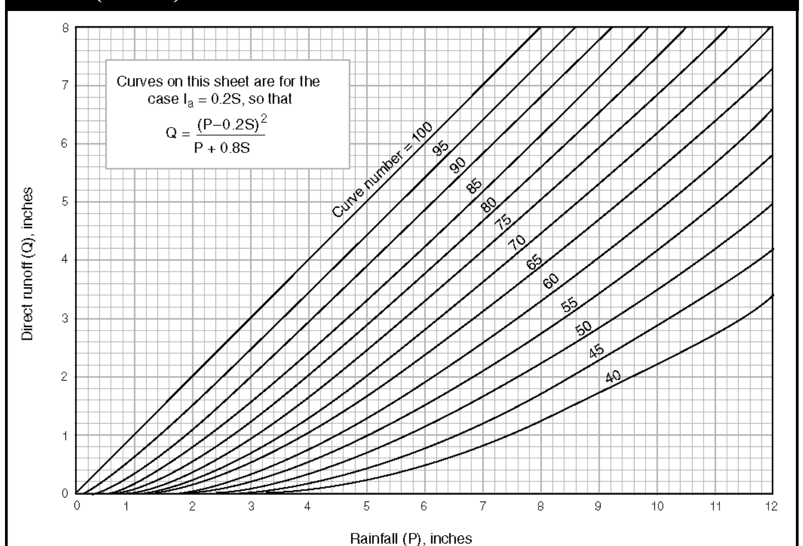
## Example Hydrologic Calculation Methods

| Output Requirements | Drainage Area | Appropriate Method | | | | |
|---|---|---|---|---|---|---|
| Peak Discharge Only | Up to 20 acres | 1 | | 3 | 4 | 5 |
| | Up to 2,000 acres | | 2 | 3 | 4 | 5 |
| | Up to 5 square miles | | 2 | 3 | | 5 |
| | Up to 20 square miles | | 2 | 3 | | 5 |
| Peak Discharge and Total Runoff Volume | Up to 2,000 acres | | 2 | 3 | 4 | 5 |
| | Up to 5 square miles | | 2 | 3 | | 5 |
| | Up to 20 square miles | | 2 | 3 | | 5 |
| Runoff Hydrograph | Up to 5 square miles | | 2 | 3 | | 5 |
| | Up to 20 square miles | | 2 | 3 | | 5 |

1 Rational Method 2 SCS TR-20 Method
3 SCS TR-55 Tabular Method 4 SCS TR-55 Graphical Peak Discharge Method
5 COE HEC-1 Method (HEC-HMS)

35

## SCS (NRCS) TR-55 Curve Number Model of Rainfall vs. Runoff




36

| Cover description: Cover type and hydrologic condition | Average percent impervious area [2] | Curve numbers for hydrologic soil group: A | B | C | D |
|---|---|---|---|---|---|
| *Fully developed urban areas (vegetation established)* | | | | | |
| Open space (lawns, parks, golf courses, cemeteries, etc.) [3]: | | | | | |
| Poor condition (grass cover < 50%) | | 68 | 79 | 86 | 89 |
| Fair condition (grass cover 50% to 75%) | | 49 | 69 | 79 | 84 |
| Good condition (grass cover > 75%) | | 39 | 61 | 74 | 80 |
| Impervious areas: | | | | | |
| Paved parking lots, roofs, driveways, etc. (excluding right-of-way) | | 98 | 98 | 98 | 98 |
| Streets and roads: | | | | | |
| Paved; curbs and storm sewers (excluding right-of-way) | | 98 | 98 | 98 | 98 |
| Paved; open ditches (including 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 |
| Western desert urban areas: | | | | | |
| Natural desert landscaping (pervious areas only) [4] | | 63 | 77 | 85 | 88 |
| Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders) | | 96 | 96 | 96 | 96 |
| Urban districts: | | | | | |
| Commercial and business | 85 | 89 | 92 | 94 | 95 |
| Industrial | 72 | 81 | 88 | 91 | 93 |
| Residential districts by average lot size: | | | | | |
| 1/8 acre or less (town houses) | 65 | 77 | 85 | 90 | 92 |
| 1/4 acre | 38 | 61 | 75 | 83 | 87 |
| 1/3 acre | 30 | 57 | 72 | 81 | 86 |
| 1/2 acre | 25 | 54 | 70 | 80 | 85 |
| 1 acre | 20 | 51 | 68 | 79 | 84 |
| 2 acres | 12 | 46 | 65 | 77 | 82 |
| *Developing urban areas* | | | | | |
| Newly graded areas (pervious areas only, no vegetation) [5] | | 77 | 86 | 91 | 94 |
| Idle lands (CN's are determined using cover types similar to those in table 2-2c). | | | | | |

1 Average runoff condition, and $I_a = 0.2S$.
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

## Typical curve number (CN) values for urban areas.

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## 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.

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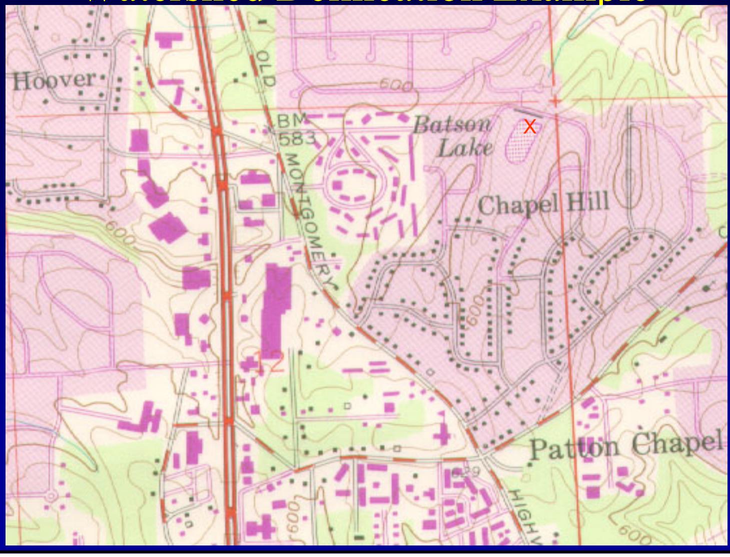
## Watershed Delineation Example

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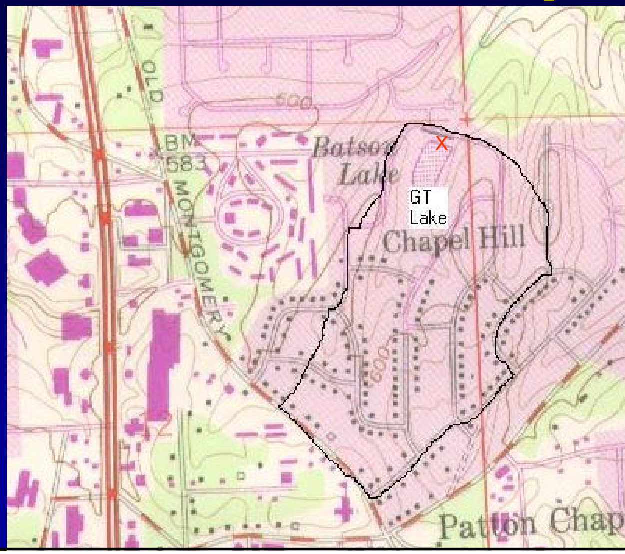
## Watershed Delineation Example






## Watershed Delineation Hints

The determination of a watershed's area begins with the analysis of a topographic map of the region. The most downstream point of interest (a potential dam site, a culvert location, the outlet of a stream, where a stream reaches a river, etc.) is located. The area contributing flow to that site is then identified by application of a few simple rules:

- Water flows downhill
- Water tends to flow perpendicularly across the contour lines
- Ridges are indicated by contour "V"s pointing downhill
- Drainages are indicated by contour "V"s pointing upstream.



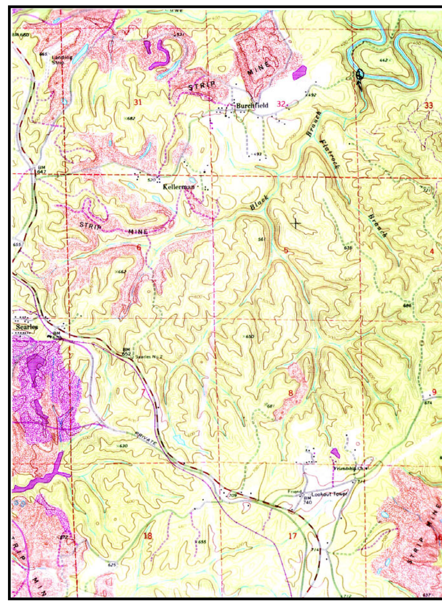
## Watershed Delineation Process

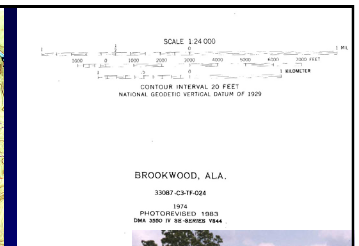
**Information Sources**

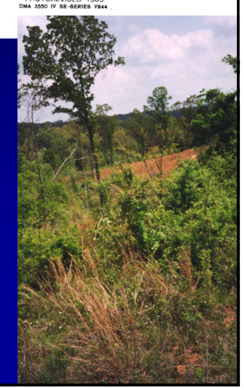
Topographic Maps

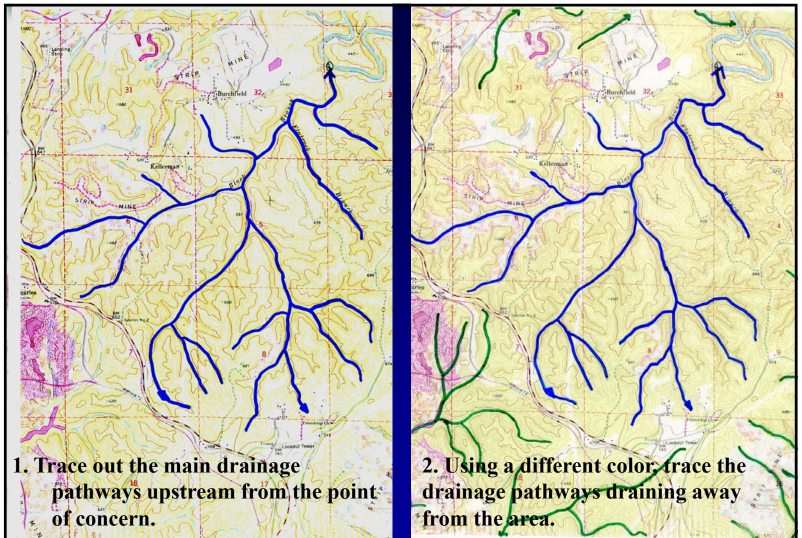
- The fundamental sources of data for delineating and studying watersheds are topographic maps. Generally, each map covers 7.5 minutes of longitude and latitude.
- These maps give a wealth of information including topographic contour lines, locations of cities, buildings, roads, road types, railroads, pipelines, water bodies, forested land, and stream networks.
- These maps typically have a scale of 1:24,000 (i.e. 1 meter on the map = 24,000 meters on land)
- Detailed site maps having 0.1 to 2 m contour intervals are usually required for final analyses.



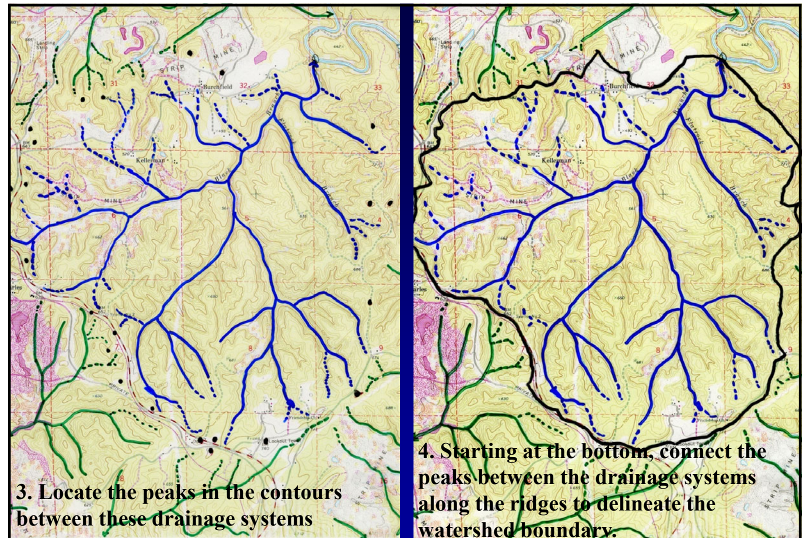







45

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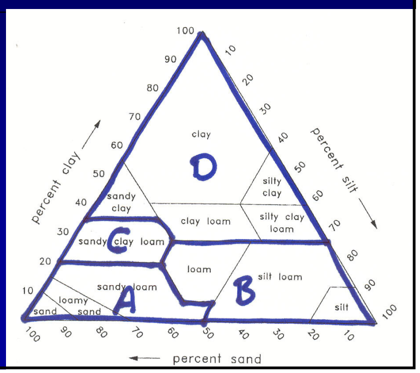
| HSG | Soil Textures |
|---|---|
| A | Sand, loamy sand, or sandy loam |
| B | Silt, silt loam or loam |
| C | Sandy clay loam |
| D | Clay loam, silty clay loam, sandy clay, silty clay, or clay |

**Site soil information also needed for TR-55**

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Group A soils have low runoff potential and high infiltration rates, even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission (greater than 8 mm/hr).

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils, with moderately fine to moderately coarser textures. These soils have a moderate rate of water transmission (4 to 8 mm/hr).

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Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine textures. These soils have a low rate of water transmission (1 to 4 mm/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly imperious material. These soils have a very low rate of water transmission (< 1 mm/hr).

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# Soil Surveys

Information typically available in a soil survey:

- Soil type by general area
- Descriptions of the various soil types
- Tables of information regarding the various soil types
- Soil classification (Hydrologic Soil Group A, B, C, and D)

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# Time of Concentration ($t_c$)

- The duration must be equal to the time of concentration for the drainage area.
- The time of concentration ($t_c$) is equal to the longest flow path (by time).
- If the $t_c$ is 5 min for a storm having a return period of 25 years, the associated peak intensity (which has a duration of 5 min) would be about 8.6 in/hr.
- If the $t_c$ for this same return period was 40 min, the peak rain intensity would be "only" 3.8 in/hr.

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# Time of Concentration Estimates

- The TR-55 procedures estimate $t_c$ using three flow segment types:
  - Sheetflow (maximum of 300 ft; WinTR-55 has a maximum of 150 ft now, similar to some state agency restrictions)
  - 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 of each pathway are calculated.
- The $t_c$ for the drainage area is the longest travel time calculated.

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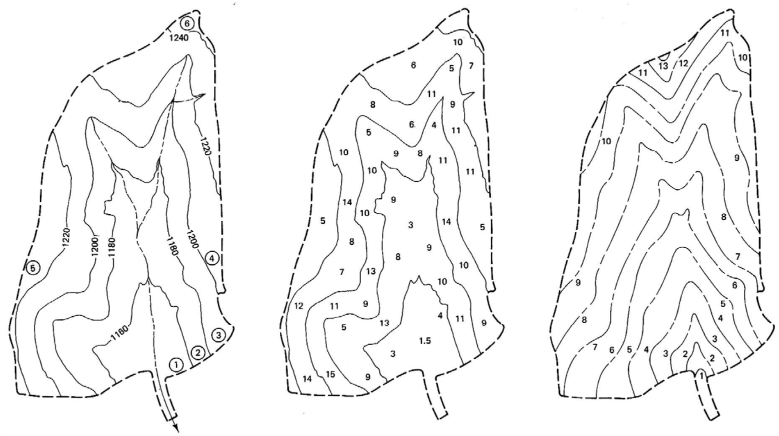


(a) Topographic map (b) Slope (c) Iso-time lines

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

McCuen 1989

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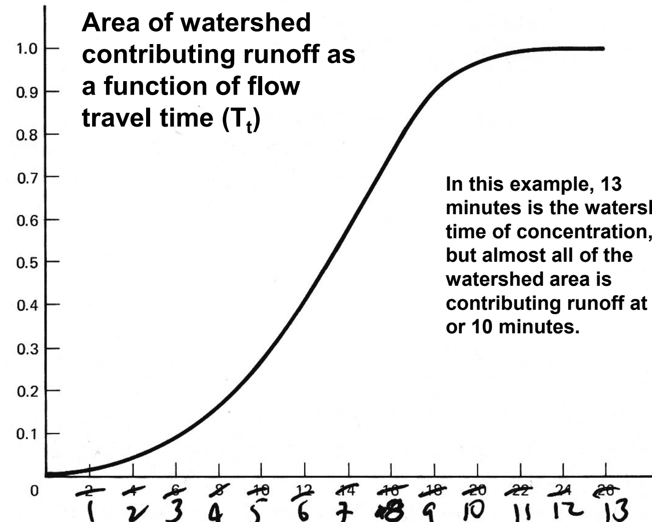
**Area of watershed contributing runoff as a function of flow travel time ($T_t$)**




**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

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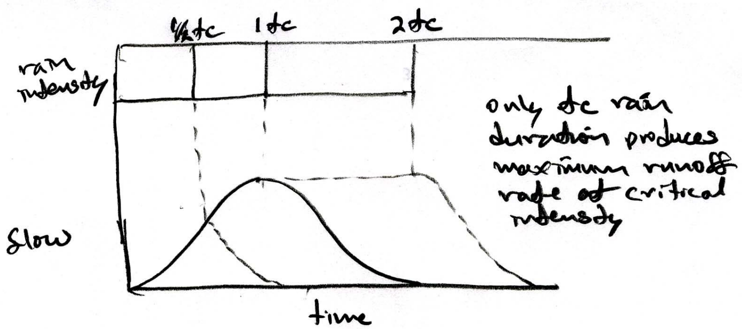
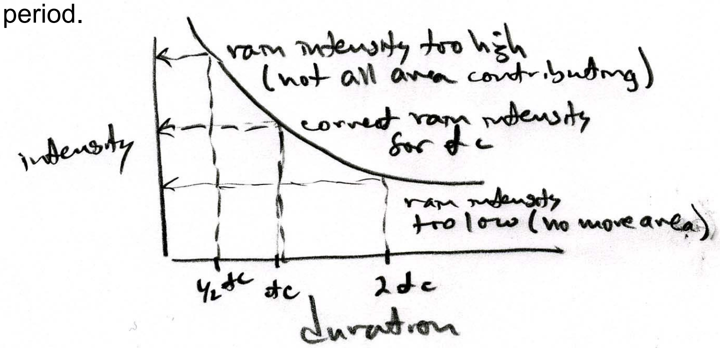
Only a rain duration equal to the $T_c$ produces the maximum peak runoff rate at the critical rain intensity. Shorter duration rains do not produce runoff from the complete area, while longer duration rains do not have any additional contributing areas.




55

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.

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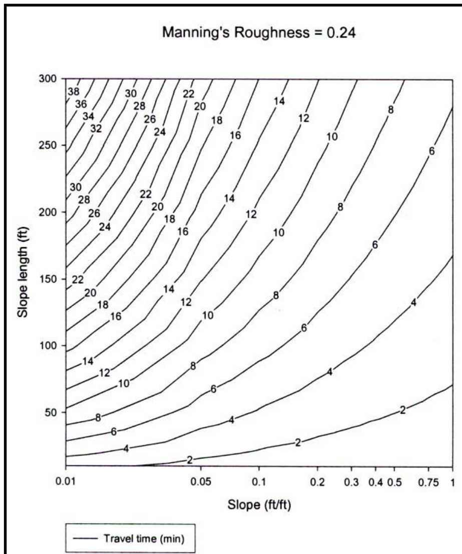


Grass, dense (weeping lovegrass, bluegrass, buffalo grass, blue gama grass, and native grass

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

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

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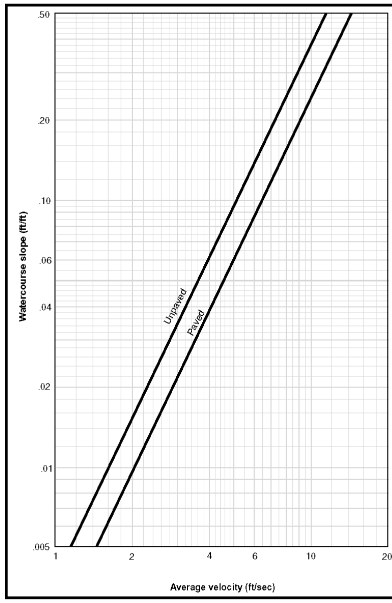


**Figure illustrating shallow concentrated flow velocities for paved and unpaved surfaces and for different slopes.**

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## Channel Flow using Manning's Equation:

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

V = average velocity (ft/s), and
r = hydraulic radius (ft) and is equal to a/pw
a = cross sectional flow area (ft2)
pw = wetted perimeter (ft)
s = slope of hydraulic grade line (channel slope, ft/ft)
*n* = Manning roughness coefficient (for open channel flow)

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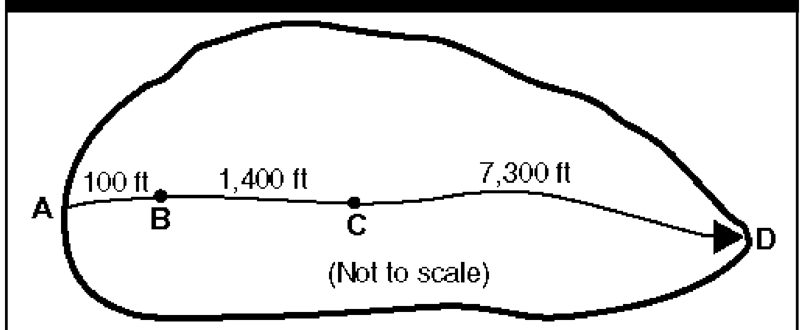
**NRCS Travel Time Example:**
**A-B sheetflow (100 ft)**
**B-C shallow concentrated flow (1,400 ft)**
**C-D channel flow (7,300 ft)**

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**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 |

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# 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)

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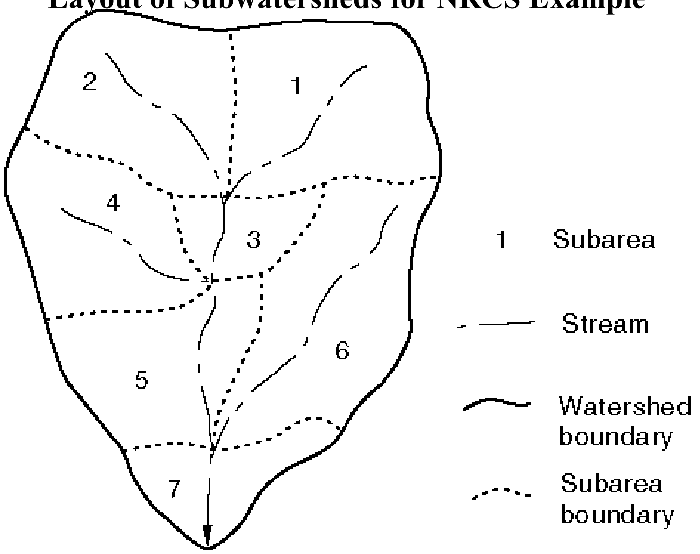
# Layout of Subwatersheds for NRCS Example

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**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 $\Sigma T_t$ (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

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| Curve number | $I_a$ (in) | Curve number | $I_a$ (in) |
|---|---|---|---|
| 40 | 3.000 | 70 | 0.857 |
| 41 | 2.878 | 71 | 0.817 |
| 42 | 2.762 | 72 | 0.778 |
| 43 | 2.651 | 73 | 0.740 |
| 44 | 2.545 | 74 | 0.703 |
| 45 | 2.444 | 75 | 0.667 |
| 46 | 2.348 | 76 | 0.632 |
| 47 | 2.255 | 77 | 0.597 |
| 48 | 2.167 | 78 | 0.564 |
| 49 | 2.082 | 79 | 0.532 |
| 50 | 2.000 | 80 | 0.500 |
| 51 | 1.922 | 81 | 0.469 |
| 52 | 1.846 | 82 | 0.439 |
| 53 | 1.774 | 83 | 0.410 |
| 54 | 1.704 | 84 | 0.381 |
| 55 | 1.636 | 85 | 0.353 |
| 56 | 1.571 | 86 | 0.326 |
| 57 | 1.509 | 87 | 0.299 |
| 58 | 1.448 | 88 | 0.273 |
| 59 | 1.390 | 89 | 0.247 |
| 60 | 1.333 | 90 | 0.222 |
| 61 | 1.279 | 91 | 0.198 |
| 62 | 1.226 | 92 | 0.174 |
| 63 | 1.175 | 93 | 0.151 |
| 64 | 1.125 | 94 | 0.128 |
| 65 | 1.077 | 95 | 0.105 |
| 66 | 1.030 | 96 | 0.083 |
| 67 | 0.985 | 97 | 0.062 |
| 68 | 0.941 | 98 | 0.041 |
| 69 | 0.899 | | |

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

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## 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**

| 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 * * * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 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 * * * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 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 * * * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| .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

(210-VI-TR-55, Second Ed., June 1986) 5-37

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### 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

| Subarea name | Subarea $T_c$ (hr) | $\Sigma T_t$ to outlet (hr) | $I_a/P$ | $A_mQ$ (mi²—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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basic watershed data used 1/ | | | | Select and enter hydrograph times in hours from exhibit 5-II 2/ — Discharges at selected hydrograph times 3/ (cfs) | | | | | | | | | | | |
| 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.

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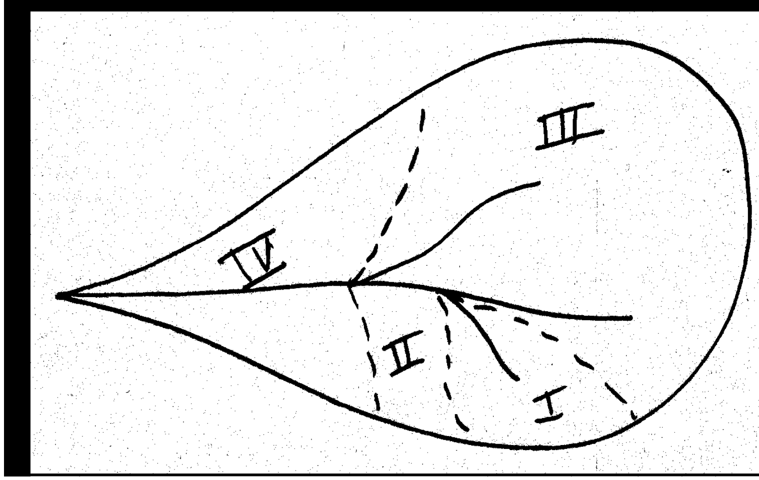
## Example Urban Watershed

**1) subdivide the watershed into relatively homogeneous subareas**

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2) calculate the drainage area for each subarea:

| | |
|---|---|
| I | 0.10 mi$^2$ |
| II | 0.08 |
| III | 0.6 |
| IV | 0.32 |
| Total: | 1.12 |

3) calculate the time of concentration (Tc) for each subarea

| | |
|---|---|
| I | 0.2 hrs |
| II | 0.1 |
| III | 0.3 |
| IV | 0.1 |



4) calculate the travel time (Tt) from each subarea discharge location to the location of interest (outlet of total watershed in this example):

| | |
|---|---|
| I | 0.1 hrs |
| II | 0.05 |
| III | 0.05 |
| IV | 0 |

5) select the curve number (CN) for each subarea:

| | | |
|---|---|---|
| I | Strip commercial, all directly connected | CN = 97 |
| II | Medium density residential area, grass swales | CN = 46 |
| III | Medium density residential area, curbs and gutters | CN = 72 |
| IV | Low density residential area, grass swales | CN = 40 |



6) rainfall distribution: Type II for all areas

7) 24-hour rainfall depth for storm: 4.1 inches

8) calculate total runoff (inches) from CN and rain depth (from SCS fig. 2-1)

| | | | |
|---|---|---|---|
| I | CN = 97 | P = 4.1 in. | Q = 3.8 in. |
| II | CN = 46 | P = 4.1 in. | Q = 0.25 |
| III | CN = 72 | P = 4.1 in. | Q = 1.5 |
| IV | CN = 40 | P = 4.1 in. | Q = 0.06 |



9) determine Ia for each subarea (assumes Ia = 0.2 S) (SCS table 5-1):

| | | |
|---|---|---|
| I | CN = 97 | Ia = 0.062 in. |
| II | CN = 46 | Ia = 2.348 in. |
| III | CN = 72 | Ia = 0.778 in. |
| IV | CN = 40 | Ia = 3.000 in. |

10) calculate the ratio of Ia to P

| | |
|---|---|
| I | Ia/P = 0.062/4.1 = 0.015 |
| II | Ia/P = 2.348/4.1 = 0.57 |
| III | Ia/P = 0.778/4.1 = 0.19 |
| IV | Ia/P = 3.000/4.1 = 0.73 |

11) use worksheets SCS 5a and 5b to summarize above data and to calculate the composite hydrograph

Project: example urban | Location: Jefferson Co. | By: | Date:
Check one: ☐ Present ☑ Developed | Frequency (yr): 2 yr | Checked: | Date:

| Subarea name | Drainage area $A_m$ (mi²) | Time of concentration $T_c$ (hr) | Travel time through subarea $T_t$ (hr) | Downstream subarea names | Travel time summation to outlet $\Sigma T_t$ (hr) | 24-hr rainfall P (in) | Runoff curve number CN | Runoff Q (in) | $A_mQ$ (mi²—in) | Initial abstraction $I_a$ (in) | $I_a/P$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 0.10 | 0.2 | — | — | 0.1 | 4.1 | 97 | 3.8 | 0.38 | 0.062 | 0.015 |
| II | 0.08 | 0.1 | — | — | 0.05 | 4.1 | 46 | 0.25 | 0.02 | 2.348 | 0.57 |
| III | 0.62 | 0.3 | — | — | 0.05 | 4.1 | 72 | 1.5 | 0.93 | 0.778 | 0.19 |
| IV | 0.32 | 0.1 | — | — | 0 | 4.1 | 40 | 0.06 | 0.019 | 3.000 | 0.73 |
| Σ = | 1.12 | | | | | | | | | | |

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Project: example urban | Location: Jefferson Co. | By: | Date:
Check one: ☐ Present ☑ Developed | Frequency (yr): 2 yr. | Checked: | Date:

| Subarea name | Basic watershed data used 1/: Subarea $T_c$ (hr) | $\Sigma T_t$ to outlet (hr) | $I_a/P$ | $A_mQ$ (mi²—in) | Select and enter hydrograph times in hours from exhibit 5-II 2/ → Discharges at selected hydrograph times 3/ (cfs) | 11.0 | 11.6 | 12 | 12.2 | 12.3 | 13 | 14 | 16 | 18 | 26 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | 0.2 | 0.1 | ~~0.15~~ 0.10 | 0.38 | csm/in: | 19 | 39 | 168 | 601 | 733 | 83 | 43 | 25 | 18 | 0 | pg 5-30 |
| | | | | | cfs: | 7.2 | 14.2 | 63.8 | 228 | 278 | 31.5 | 16.3 | 9.5 | 6.8 | 0 | |
| II | 0.1 | ~~0.05~~ 0 | ~~0.57~~ 0.5 | 0.02 | csm/in: | 0 | 0 | 70 | 377 | 196 | 99 | 67 | 46 | 38 | 0 | pg 5-29 |
| | | | | | cfs: | 0 | 0 | 1.4 | 7.5 | 3.9 | 2.0 | 1.3 | 0.9 | 0.8 | 0 | |
| III | 0.3 | ~~0.05~~ 0 | ~~0.19~~ 0.1 | 0.93 | csm/in: | 20 | 41 | 235 | 676 | 676 | 80 | 42 | 24 | 18 | 0 | pg 5-31 |
| | | | | | cfs: | 18.6 | 38.1 | 218 | 628 | 628 | 74.4 | 39.1 | 22.3 | 16.7 | 0 | |
| IV | 0.1 | 0 | ~~0.73~~ 0.5 | 0.019 | too small | | | | | | | | | | | |
| Composite hydrograph at outlet | | | | | | 25.8 | 52.3 | 283 | 863 | 910 | 108 | 56.7 | 32.7 | 24.3 | 0 | |

910 ← peak flow

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.

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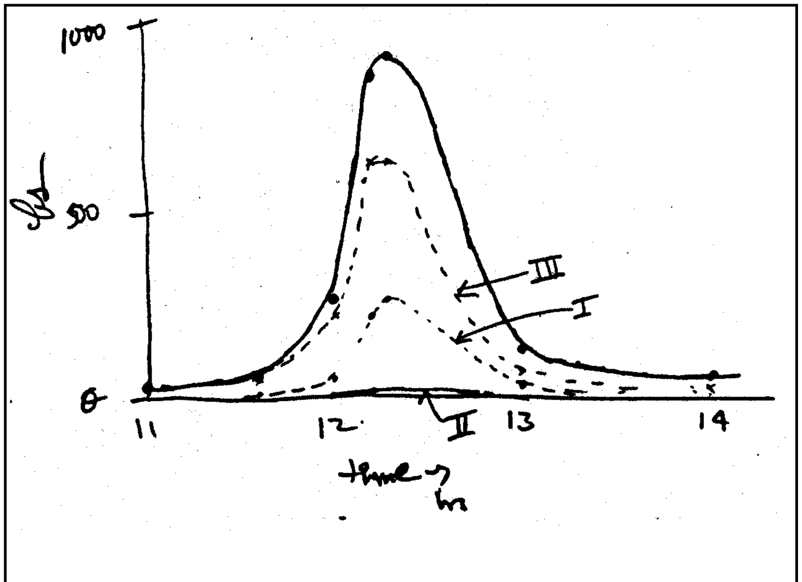


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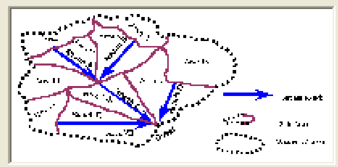
# About WinTR-55 Small Watershed Hydrology



## 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

Some international locations now included in WinTR-55

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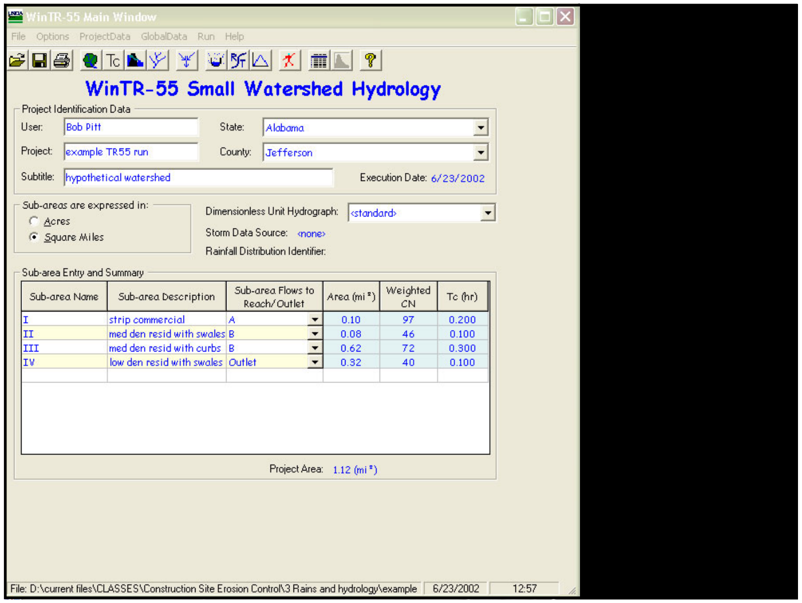
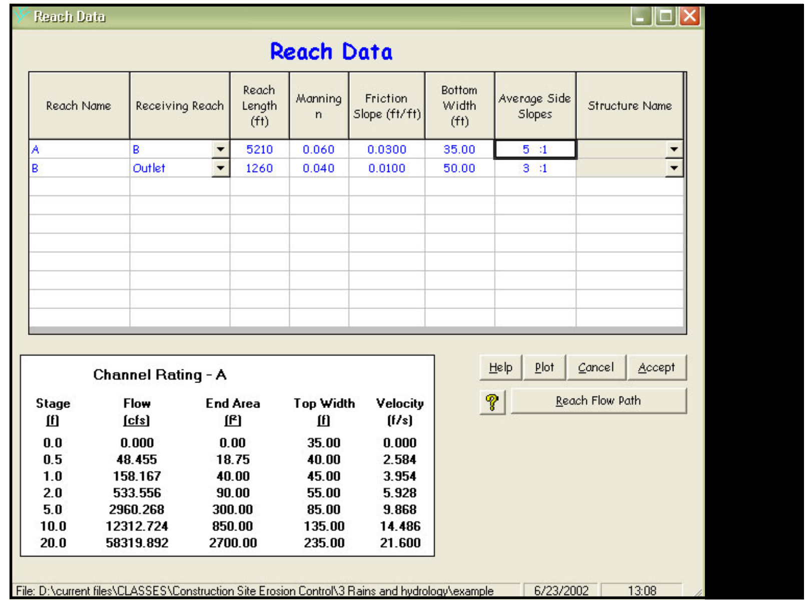

WinTR-55 Main Window
File Options ProjectData GlobalData Run Help
WinTR-55 Small Watershed Hydrology
Project Identification Data
User: Bob Pitt
State: Alabama
Project: example TR55 run
County: Jefferson
Subtitle: hypothetical watershed
Execution Date: 6/23/2002
Sub-areas are expressed in:
Acres
Square Miles
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 (mi²) | 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 (mi²)
File: D:\current files\CLASSES\Construction Site Erosion Control\3 Rains and hydrology\example 6/23/2002 12:57

77


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
Help Plot Cancel Accept
Reach Flow Path
Channel Rating - A
Stage (ft) | Flow (cfs) | End Area (ft²) | Top Width (ft) | Velocity (ft/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
File: D:\current files\CLASSES\Construction Site Erosion Control\3 Rains and hydrology\example 6/23/2002 13:08

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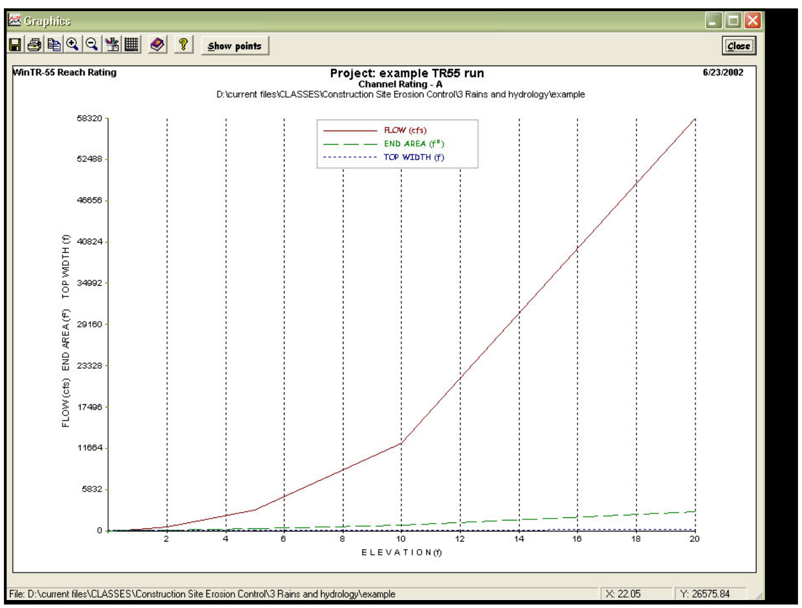
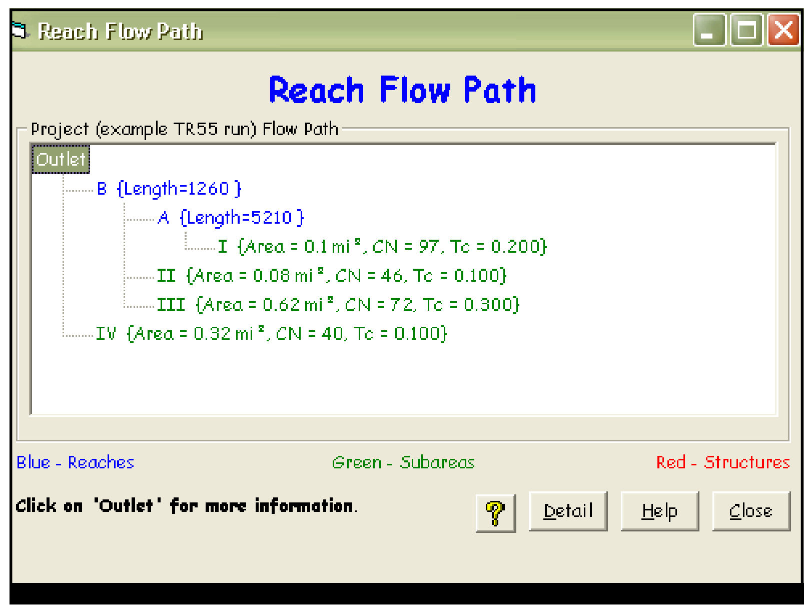
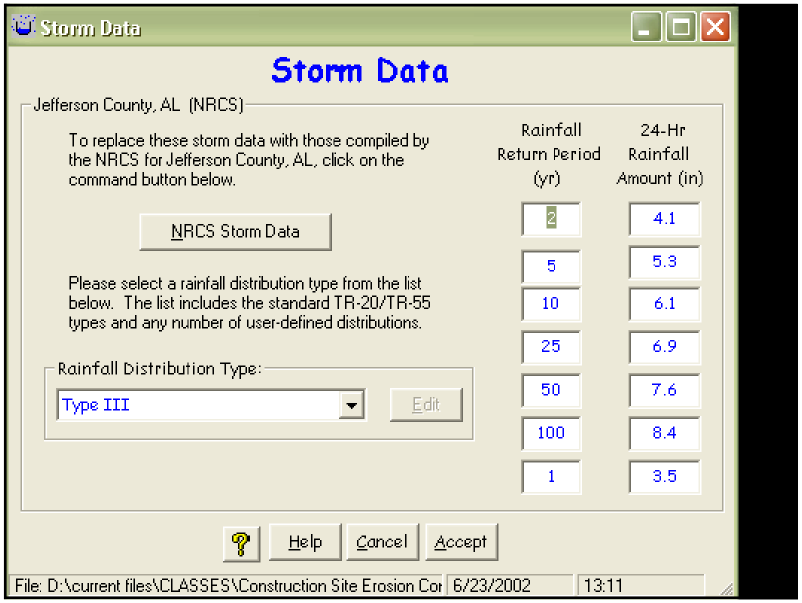

Graphics
Show points
Close
WinTR-55 Reach Rating
Project: example TR55 run
Channel Rating - A
D:\current files\CLASSES\Construction Site Erosion Control\3 Rains and hydrology\example
6/23/2002
FLOW (cfs)
END AREA (ft²)
TOP WIDTH (ft)
FLOW (cfs) END AREA (ft²) TOP WIDTH (ft)
58320
52488
46656
40824
34992
29160
23328
17496
11664
5832
0
2 4 6 8 10 12 14 16 18 20
ELEVATION (ft)
File: D:\current files\CLASSES\Construction Site Erosion Control\3 Rains and hydrology\example
X: 22.05
Y: 26575.84

79

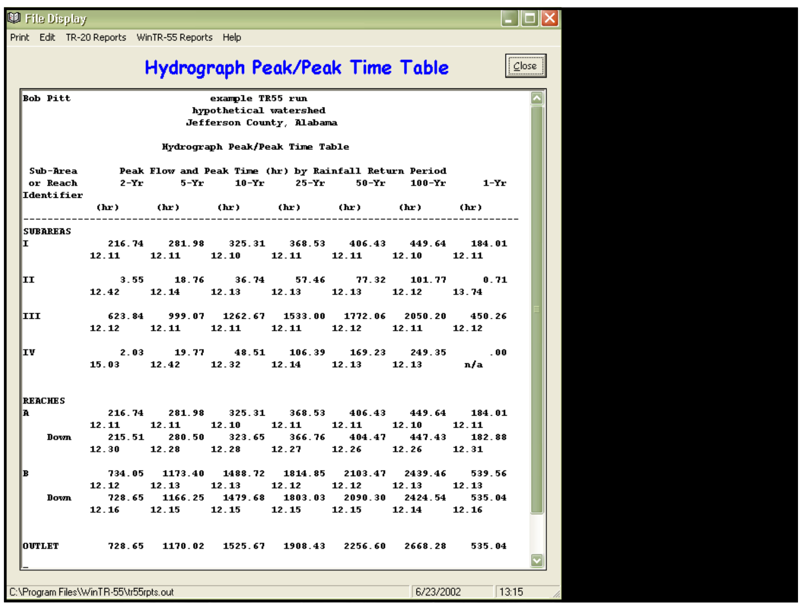

Reach Flow Path
Reach Flow Path
Project (example TR55 run) Flow Path
Outlet
B {Length=1260 }
A {Length=5210 }
I {Area = 0.1 mi², CN = 97, Tc = 0.200}
II {Area = 0.08 mi², CN = 46, Tc = 0.100}
III {Area = 0.62 mi², CN = 72, Tc = 0.300}
IV {Area = 0.32 mi², CN = 40, Tc = 0.100}
Blue - Reaches
Green - Subareas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

80



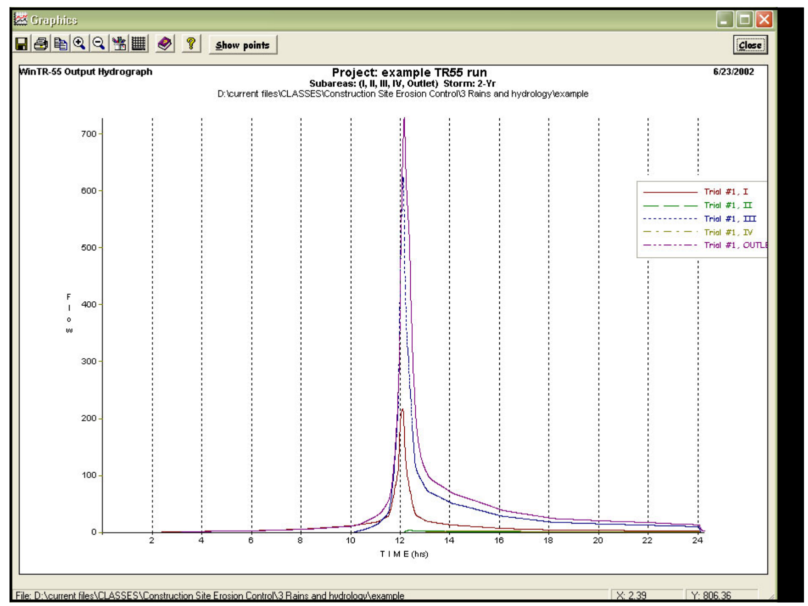

81


82




| Sub-Area or Reach Identifier | 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 |

83

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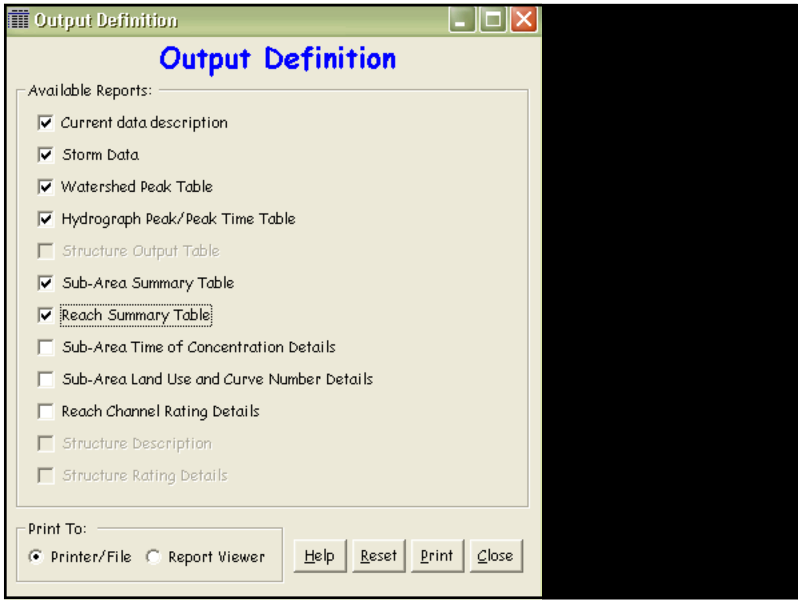


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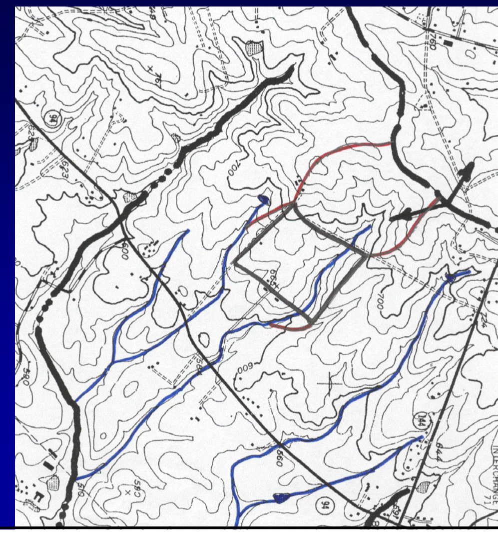
## Example Applications to Construction Sites



Upslope and downslope drainage areas for construction site.

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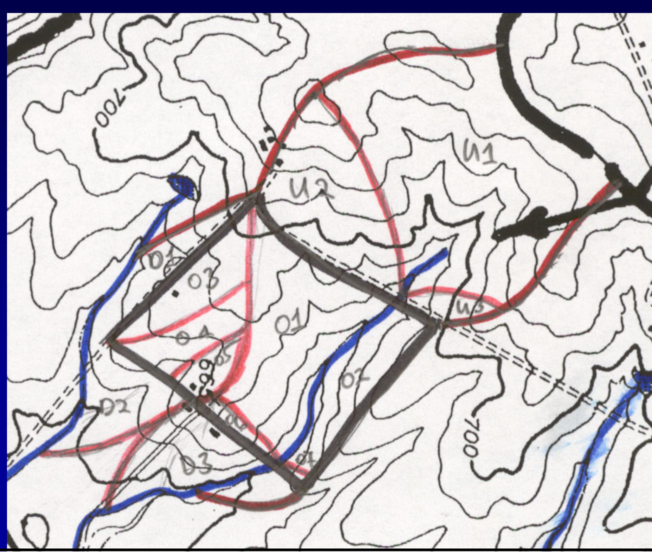
## Subdrainages on and near construction site affecting control design.

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## Upslope Subdrainage Area Characteristics

| | | Calculation objective | Acres | Cover n | Flow path slope | CN | $t_c$ (min) |
|---|---|---|---|---|---|---|---|
| U1 | Direct to site | Hydrograph (to be combined with U2 and U3) | 37.4 | 0.4 | 8 % | 73 | 29 |
| U2 | Diversion to site stream | Peak flow rate and hydrograph (to be combined with U1 and U3) | 14.6 | 0.4 | 11.5 | 73 | 25 |
| U3 | Diversion to site stream | Peak flow rate and hydrograph (to be combined with U1 and U2) | 2.4 | 0.4 | 12.7 | 73 | 20.7 |

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## Upslope Subdrainage Area TR-55 Calculations ("5-year" storm)

| Area Notation | Location | Direct Runoff, Q (inches) | area-depth (AmQ), ($mi^2$-inches) | Peak unit area flow rate (csm/in) | Peak discharge ($ft^3$/sec) |
|---|---|---|---|---|---|
| U1 | Upslope – direct to on site stream | 2.8 | 0.16 | 411 | 66 |
| U2 | Upslope – diversion to on site stream | 2.8 | 0.064 | 449 | 29 |
| U3 | Upslope – diversion to on site stream | 2.8 | 0.011 | 449 | 4.9 |

Etc.

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**Calculations for areas draining to sediment pond**

WinTR-55 Current Data Description

--- Identification Data ---

User: Bob Pitt
Project: site diversions
SubTitle: construction site example
State: Alabama
County: Tuscaloosa
Filename: C:\Documents and Settings\rpitt.000\Application Data\WinTR-55\example erosion file.w55

Date: 7/21/2003
Units: English
Areal Units: Acres

--- Sub-Area Data ---

| Name | Description | Reach | Area(ac) | RCN | Tc |
|---|---|---|---|---|---|
| U1 | upslope to site stream | A | 37.4 | 73 | 0.480 |
| U2 | upslope to diversion | A | 14.6 | 73 | 0.420 |
| U3 | upslope to diversion | A | 2.4 | 73 | 0.350 |
| O1 | on site to pond | A | 12.6 | 91 | 0.100 |
| O2 | on site to pond | A | 7.1 | 91 | 0.100 |

Total area: 74.10 (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>

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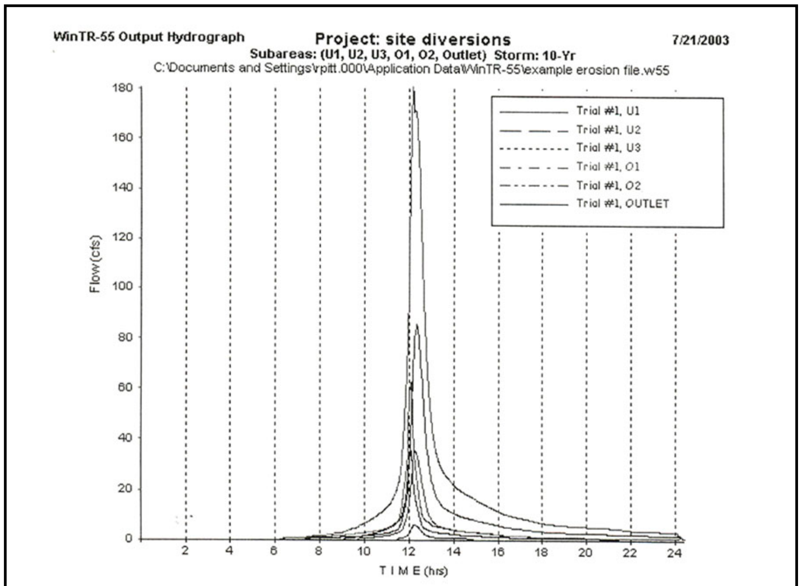


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## Acceptable Levels of Protection for Different Site Activities (1 year construction period)

| | Example Acceptable Failure Rate | Design Storm Return Period | 24-hr Rain Depth |
|---|---|---|---|
| Diversion channels | 25% | 6.5 years | 5.5 inches |
| Main site channel | 5% | 20 | 6.6 |
| Site slopes | 10% | 10 | 6.0 |
| Site filter fence | 50% | 1.9 | 4.0 |
| Sediment pond | 5% and 1% | 20 and 100 | 6.6 and 8.4 |

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# Runoff Water Depth

(needed for sheetflow calculations on slopes for slope protection)

$$y = \left( \frac{qn}{1.49 s^{0.5}} \right)^{\frac{3}{5}}$$

y is the flow depth (in feet),
q is the unit width flow rate (Q/W, the total flow rate, in $ft^3$/sec, divided by the slope width, in ft.)
n is the sheet flow roughness coefficient, and
s is the slope (as a fraction)