Engineering Hydrology

Class 13: Runoff, Peak Discharge and the Rational Method

Objectives

Be able to:

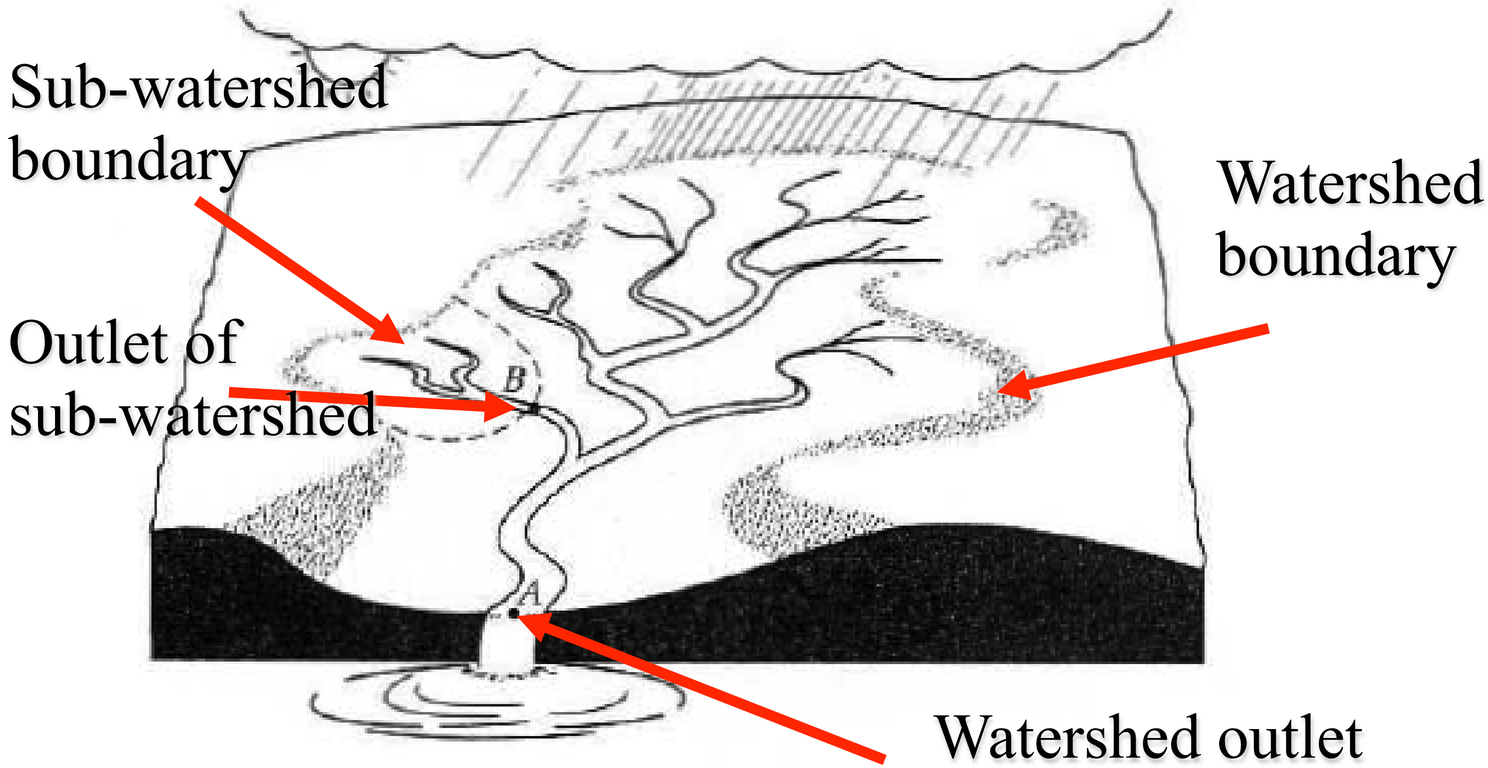
- define and describe runoff
- distinguish between runoff and discharge
- describe watershed characteristics that affect runoff and peak discharge
- calculate peak peak discharge

Reading Assignment

Optional Reading: Selected portions (to be identified in class) of Chapter 3 of McCuen "Hydrologic Analysis and Design" -- this will be posted on the course website.

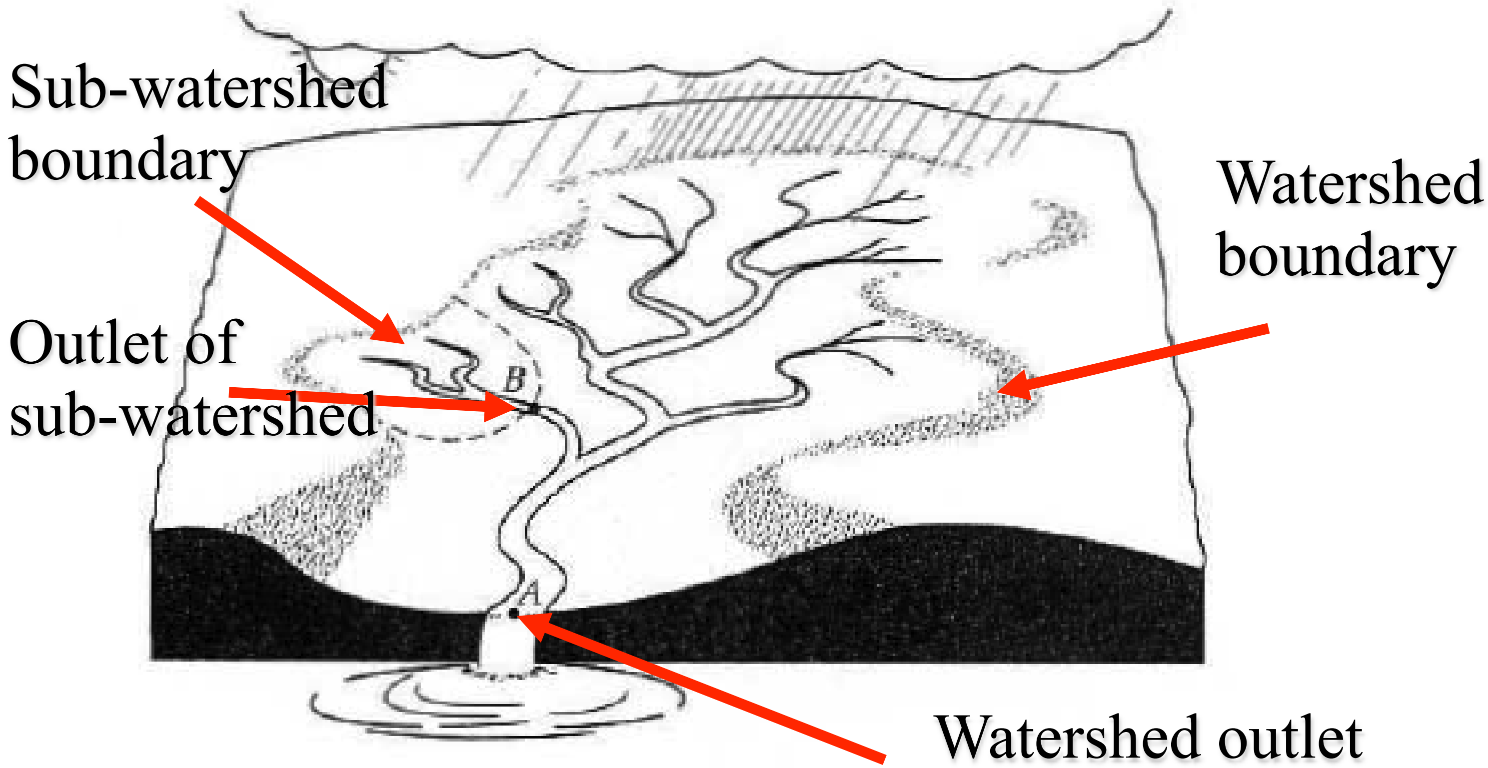
Review of the Watershed Concept

Recall the definition of a watershed: All points enclosed within an area from which rain falling at these points will contribute water to outlet



Review of the Watershed Concept

Watershed outlet: the location at which the engineering design is to be completed

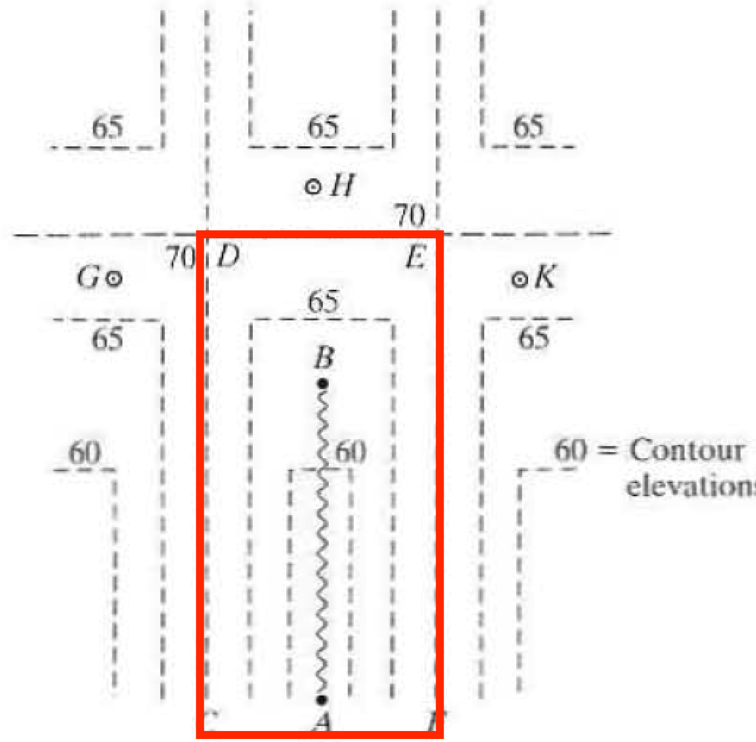


Review of the Watershed Concept

How does one delineate watershed boundaries?

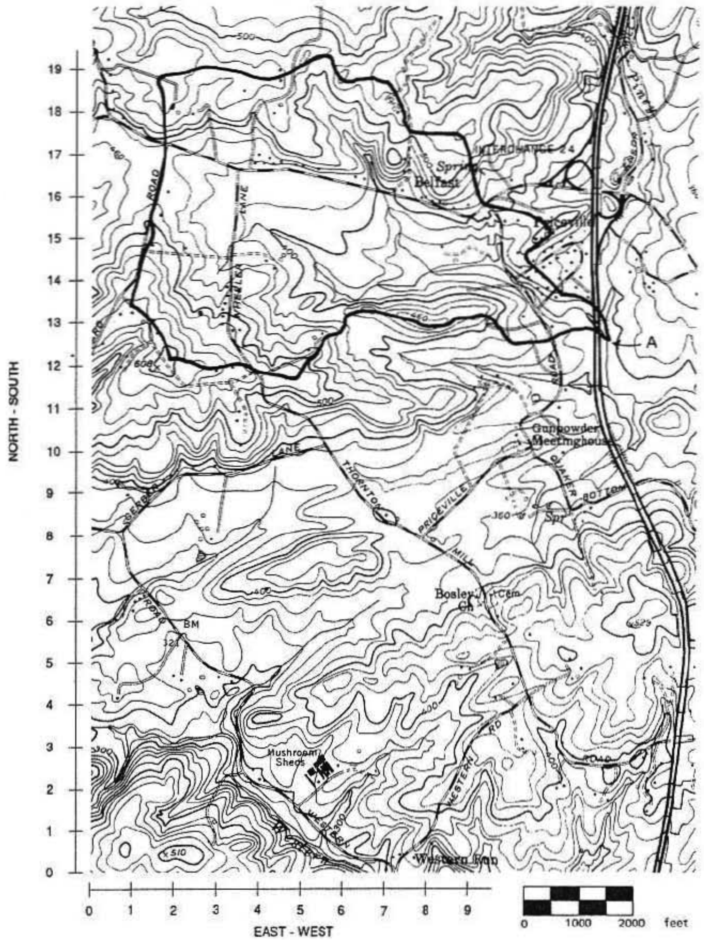
In this idealized case:
Runoff from D,E, and B flows to outlet A.

Runoff from G,H, and K does not flow to outlet A because the elevations of these points are less that that of watershed divide.



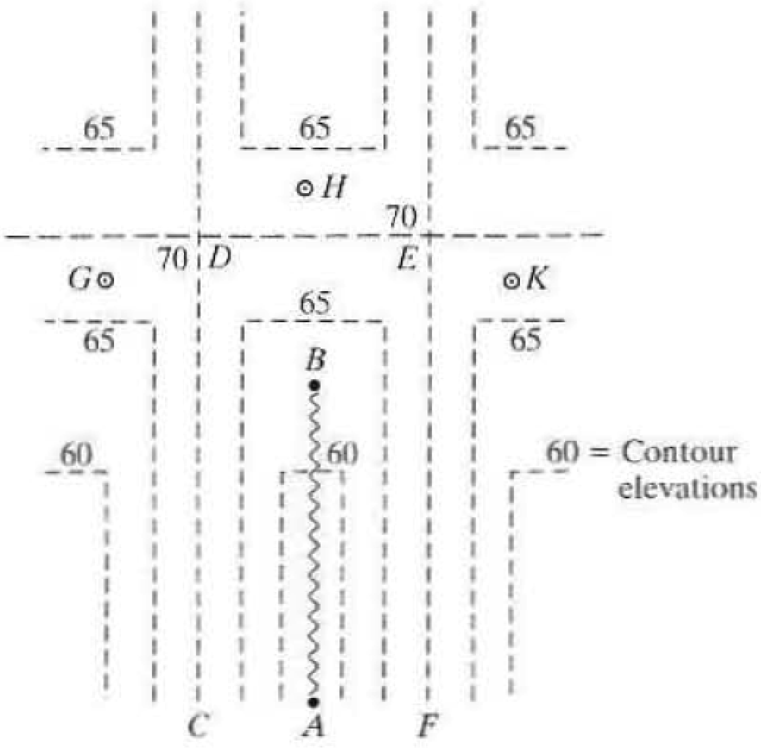
Review of the Watershed Concept

But, as you discovered, it can be difficult to delineate watershed boundaries for the actual (non-idealized) land surface

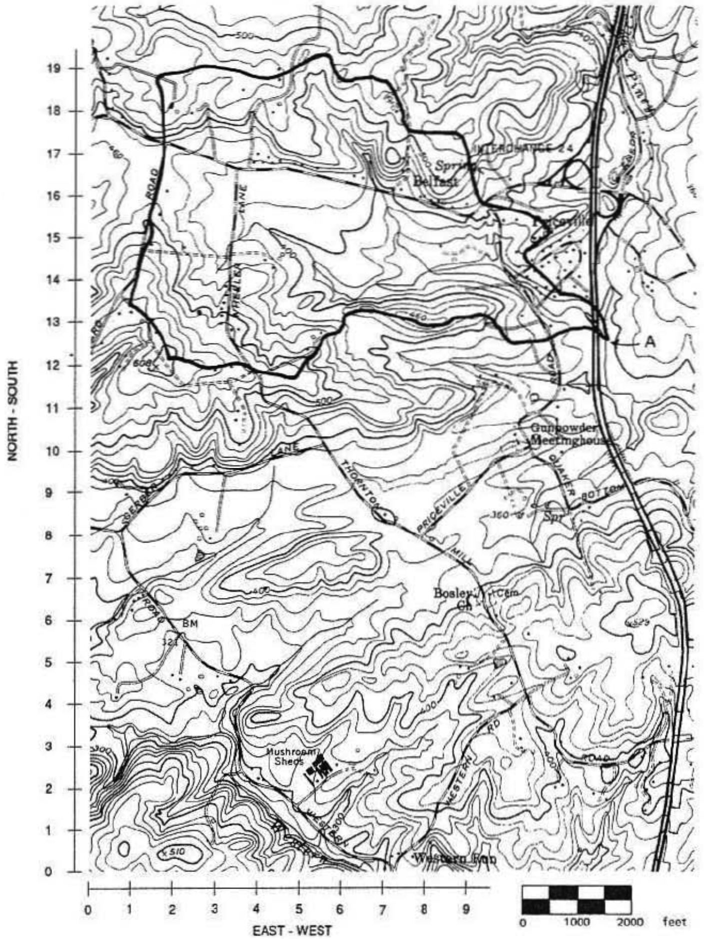


Review of the Watershed Concept

Watershed shape



Ideal



Real

- In general, runoff is defined as “the water flow that occurs when soil is infiltrated to full capacity and excess water from rain, meltwater, or other sources flows over the land”

- In mathematical terms, the variable Q is often used to represent the amount of runoff, and measure it in volume, but express it as depth (usually in inches). Depth is more easily understood in a relative sense, with conversion to true volume by multiplying times the area of the watershed.

- In general, discharge is defined as the volume rate of flow within a river or stream, or as the rate of flow of runoff that flows from (through) the exit point of a watershed

- In mathematical terms, the variable Q or q is also most often used to represent discharge, much like runoff (so be careful to note which is which in your textbook and other reference materials!). Discharge is typically expressed in units of cubic feet per second (cfs).

- Of particular importance is **peak discharge**

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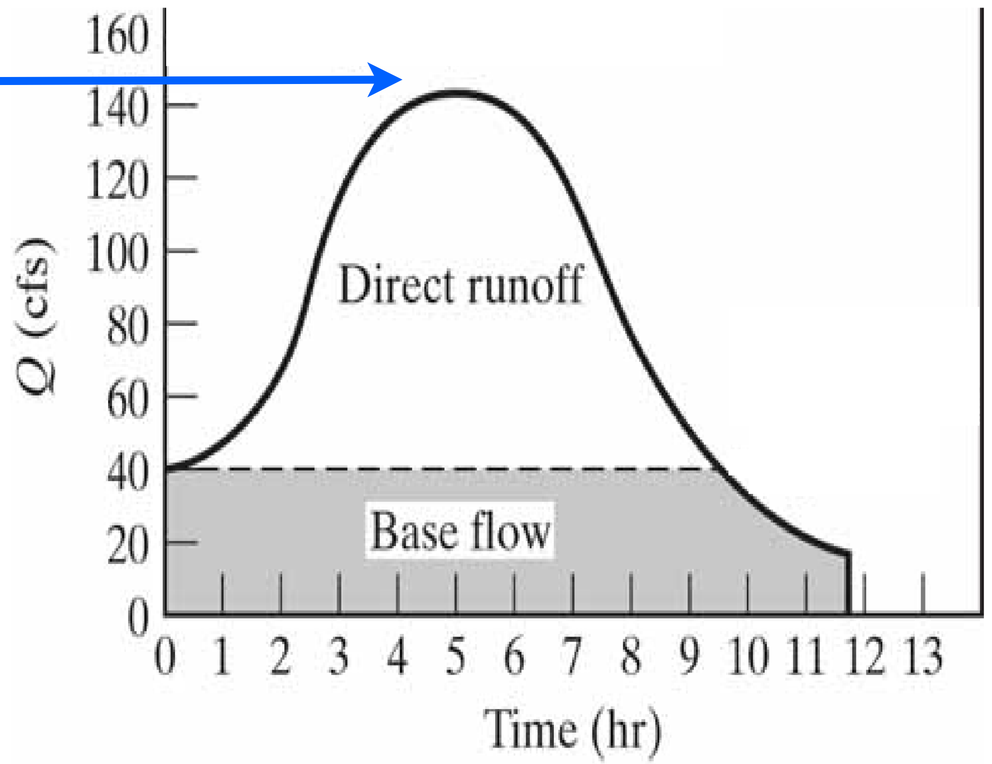


A plot of discharge vs time is a hydrograph. Integrating the area under the hydrograph yields the volume of runoff.

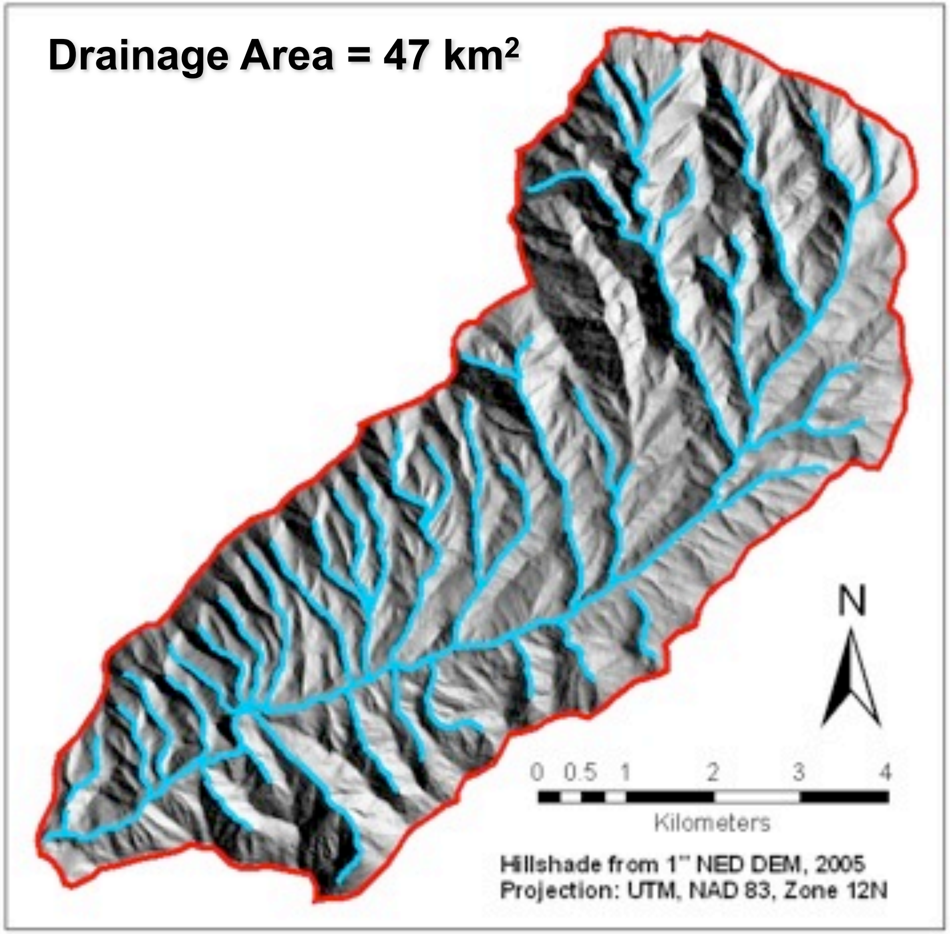
Which watershed characteristics affect runoff and peak discharge?

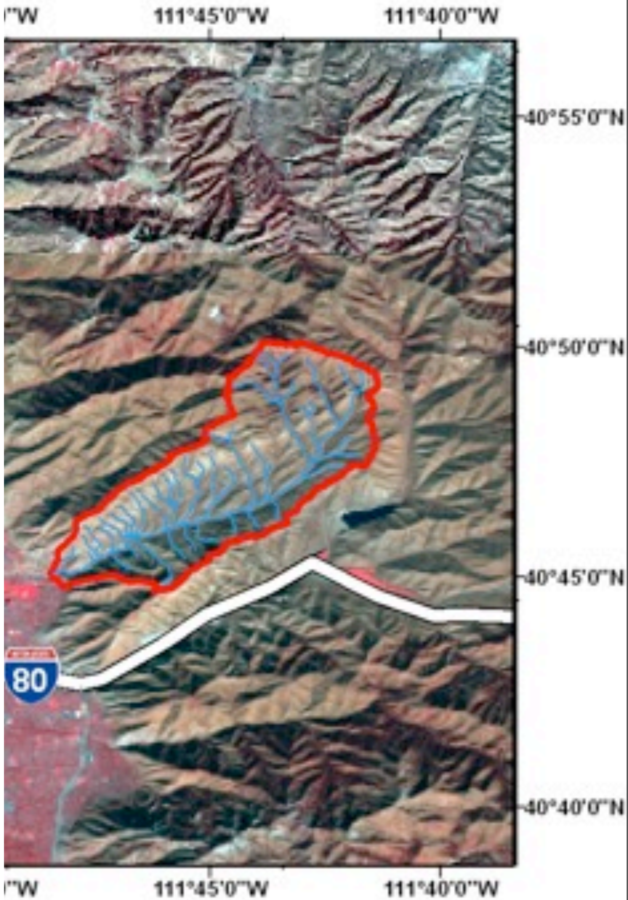
- Watershed geomorphology (drainage area, length, slope, hypsometry, shape)
- Channel morphology (length, slope, cross-section geometry)
- Land cover
- Roughness (watershed & channel)
- Soil properties
- Time-of-flow

These characteristics are also thus critical for engineering design

Drainage area

- **Most important watershed characteristic for hydrologic analysis**



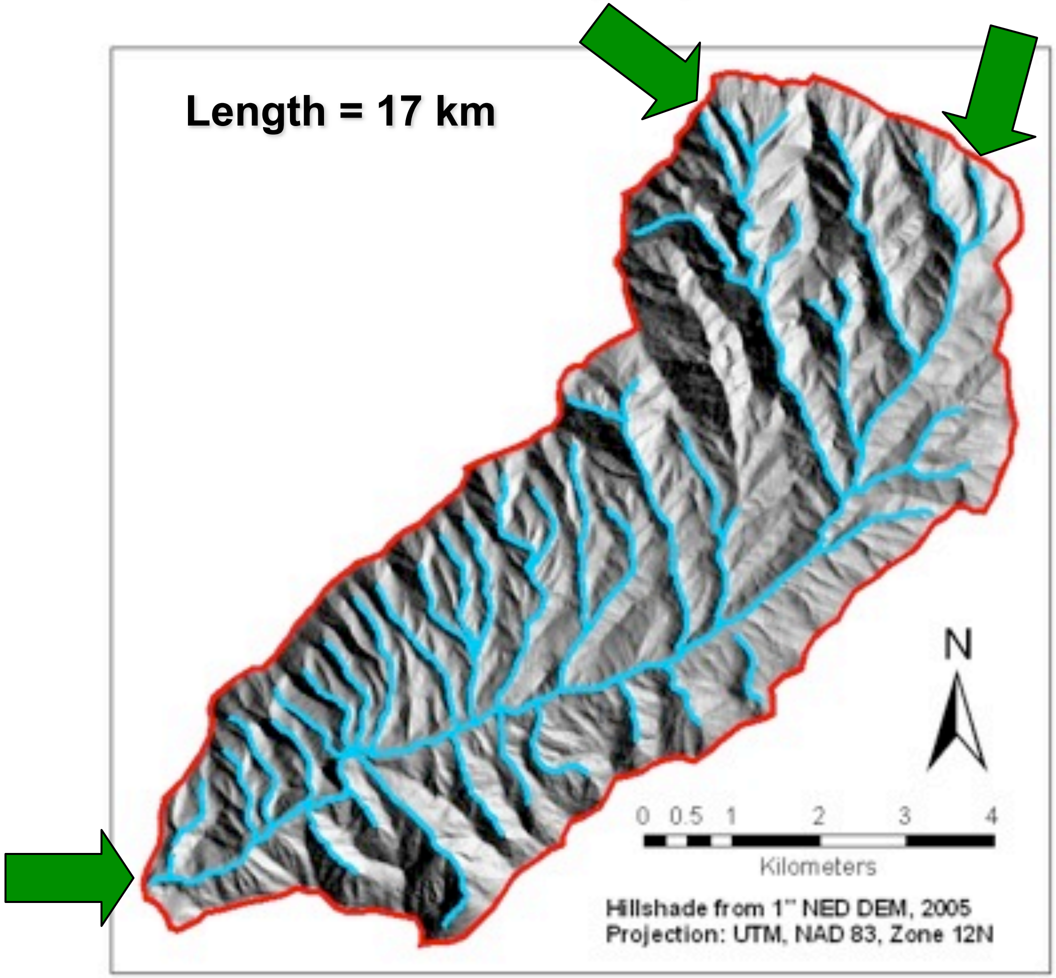


Drainage area

- Drainage area is related to predict runoff volume generated by precipitation
- Need to delineate watershed boundary
- Calculate the drainage area (commonly using Geographical Information System)
- Assume constant depth of rainfall depth
- Rainfall volume in a watershed = drainage area x rainfall depth

Watershed Length

- Distance along main channel from watershed outlet to basin divide (important for timing)



Watershed Length

- It is not a straight-line distance from outlet to farthest point on the watershed divide.
- This is a length measured along the principal flow path since we are interested in predicting the travel distance of flood water

Drainage area vs. Watershed length

- Drainage area: indicating volume of water generated by rainfall.
- Watershed length: indicating travel time of water through watershed

Watershed Slope

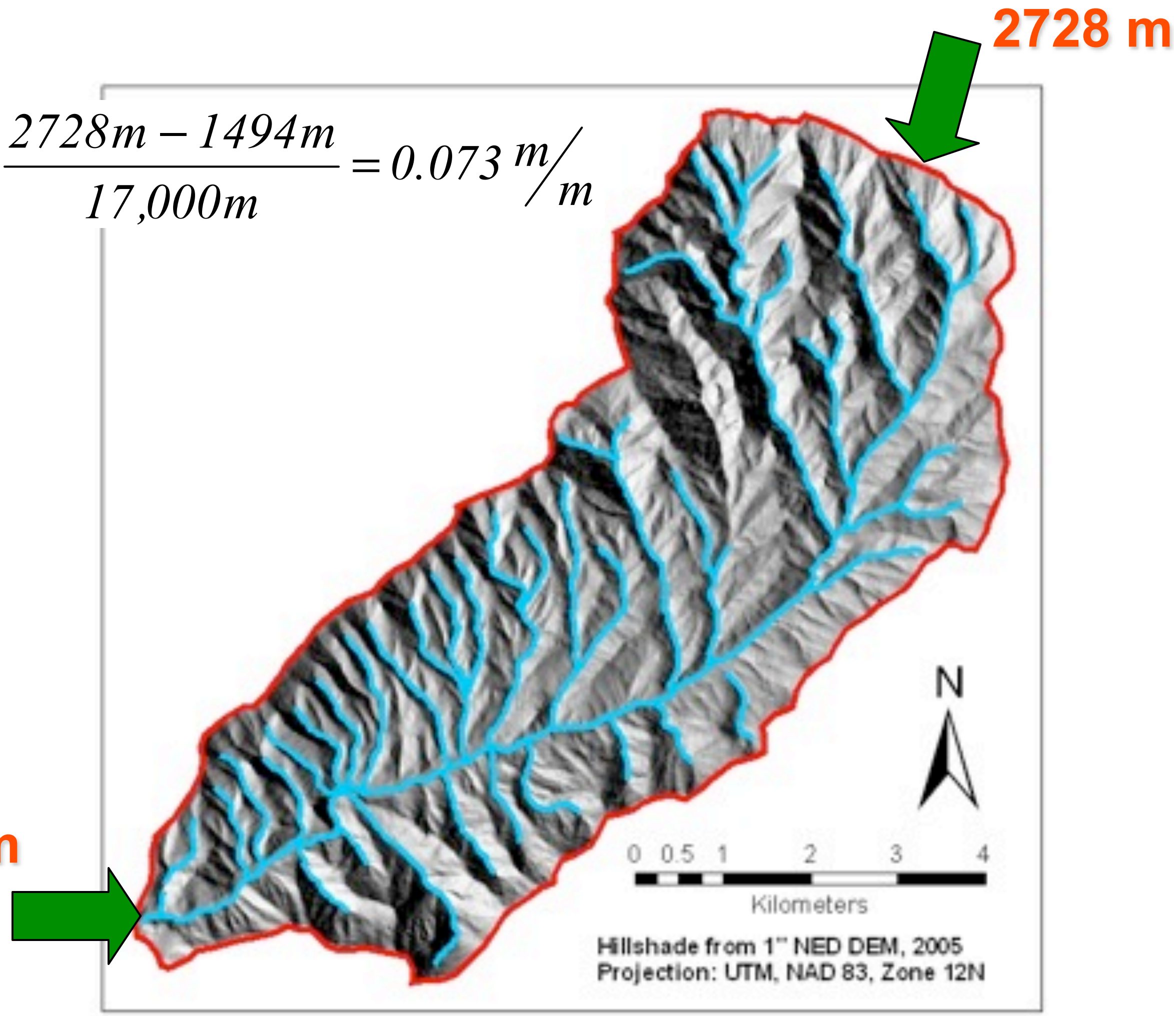
- Flood magnitude and timing depends on slope (S)
- Slope (S) is computed as the difference in elevation (E) between the end point of the principal flow path divided by the watershed length of the flow path

$$Slope = \frac{\Delta E}{L}$$

Watershed Slope

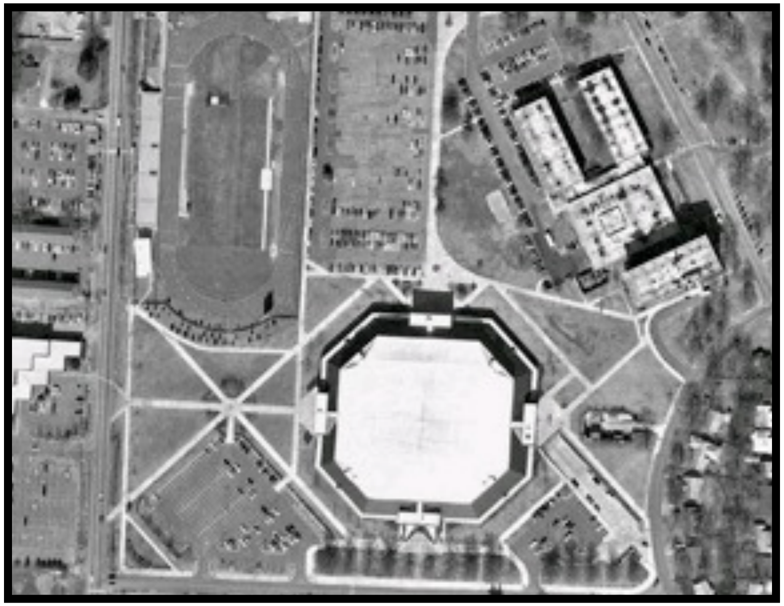
- **Flood magnitude and timing** depends on slope

$$Slope = \frac{\Delta E}{L} = \frac{2728m - 1494m}{17{,}000m} = 0.073\ {}^{m}/_{m}$$



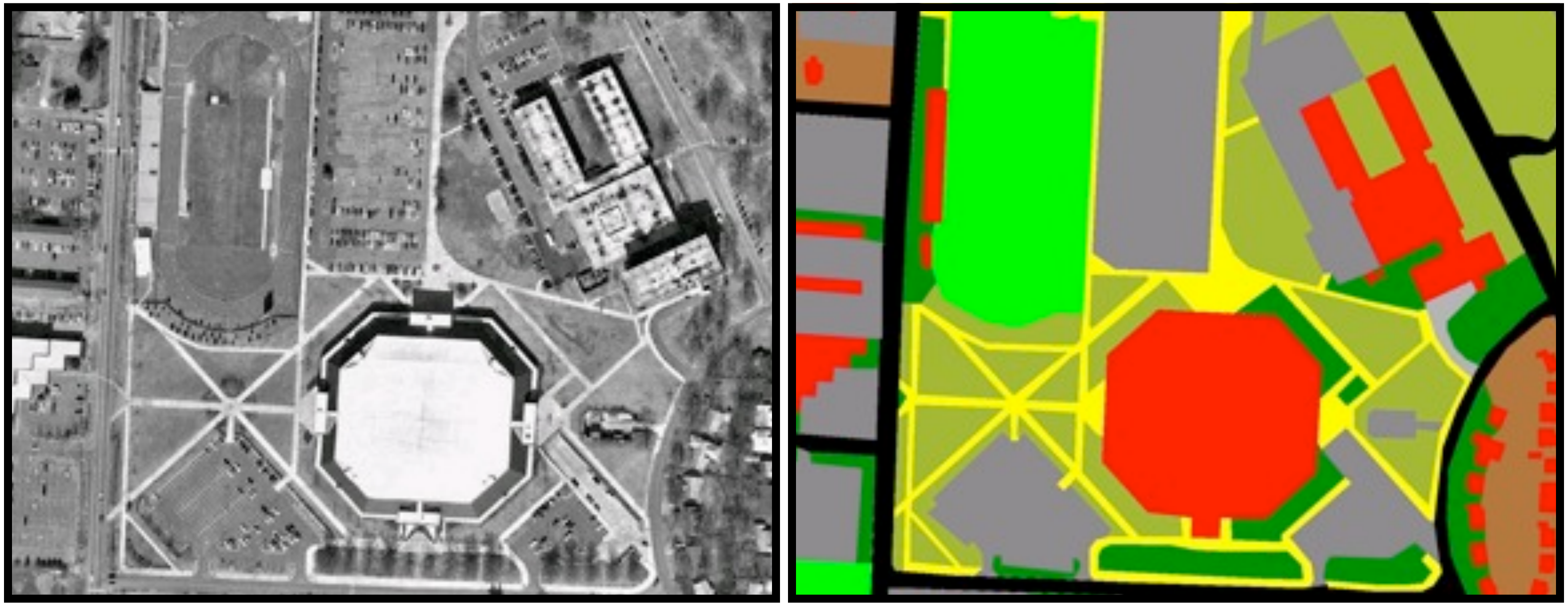
Land Cover

- Land cover significantly affect the runoff characteristics of a watershed
- A forested watershed would have less flood runoff than a watershed with no tree cover
- Grassy hill sheds water at a slower rate and has a smaller volume because some of water infiltrates into topsoil.
- Rational method: runoff coefficient
- Soil Conservation Service: runoff curve number



Land use refers to the specified purpose of land from a human perspective (e.g., residential, commercial, industrial)

- Residential
- Paved parking
- Commercial
- Educational
- Athletic field
- Urban lawn

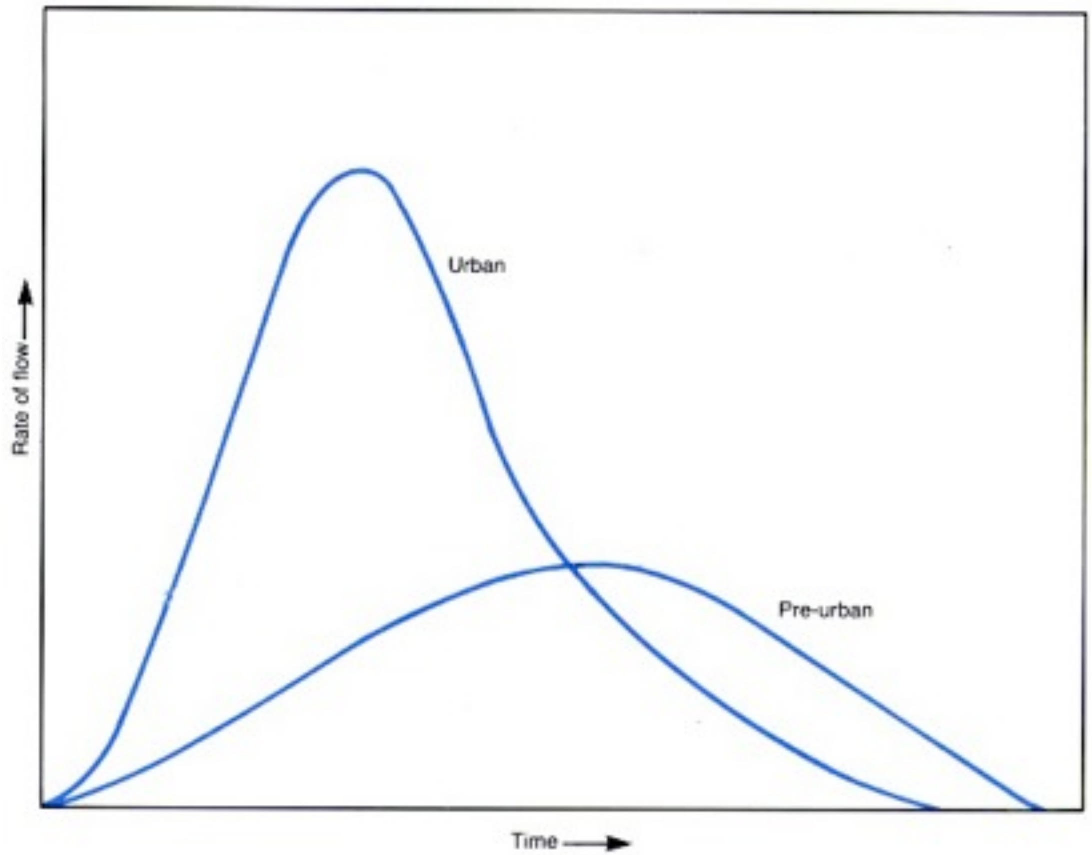


Land cover refers to the state or physical appearance of the land surface (e.g., grasslands, forest, bare soil, concrete, asphalt, metal roofing)

- Asphalt lot
- Asphalt road
- Rooftop
- Concrete walk
- Irrigated lawn
- Tree/brush
- Athletic turf
- Non-irrigated lawn

How do land use and land cover affect surface runoff?

- **For runoff modeling, a qualitative description of land cover is transformed into a quantitative index of runoff potential**
- **For urban areas, the percentage of impervious surfaces is an important parameter for hydrologic modeling**



Changes after Development:

- **Peak discharge**
- **Time to peak**
- **Runoff volume**

- **Roughness retards overland and channel flow**
- **Manning's roughness coefficient is the most frequently used index of roughness**

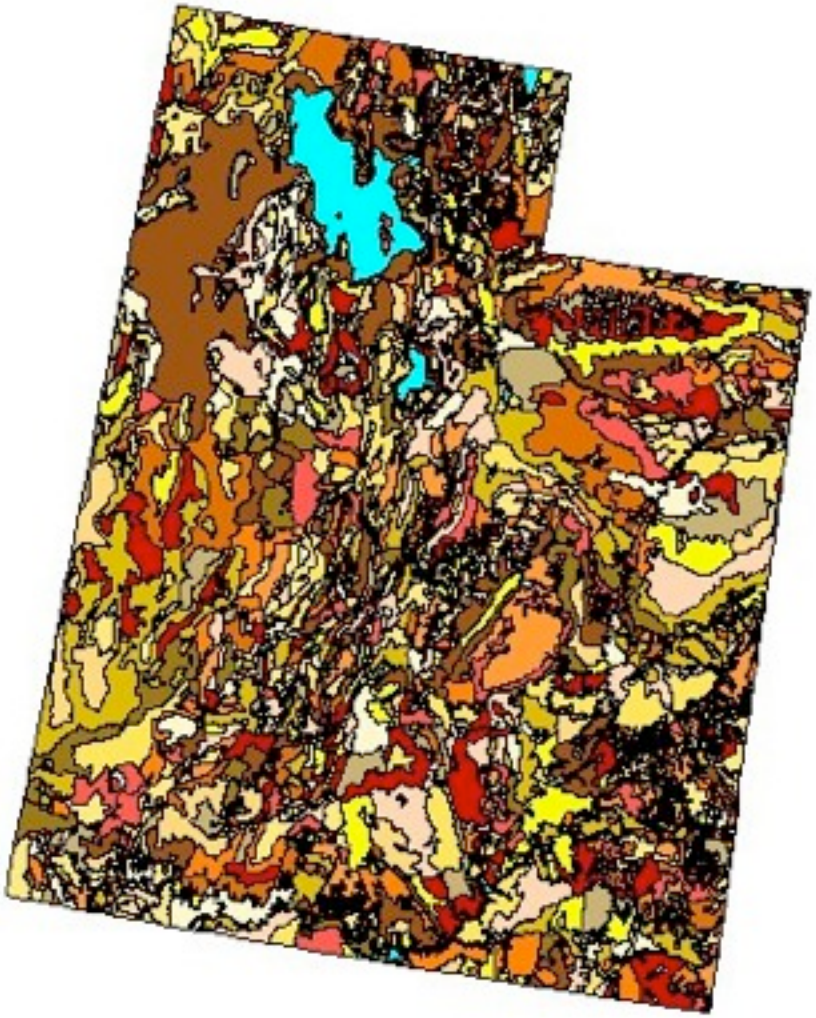
TABLE 3.3 Manning's Roughness Coefficient (n) for Sheet Flow

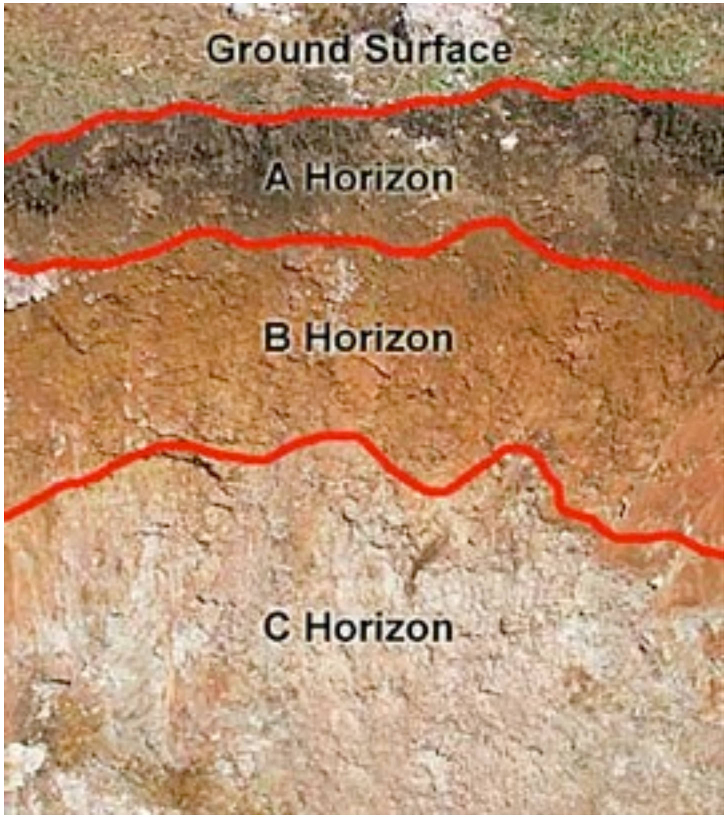
Surface	Recommended n	Range of n
Plastic, glass	0.009	0.008–0.010
Fallow	0.010	0.008–0.013
Bare land	0.010	0.008–0.013
Smooth concrete	0.011	0.010–0.014
Graveled surface	0.012	0.010–0.018
Asphalt	0.012	0.010–0.018
Bare clay	0.012	0.010–0.016
Ordinary concrete lining	0.013	0.011–0.015
Good wood	0.014	0.012–0.017
Brick with cement mortar	0.014	0.013–0.017
Unplanned timber	0.014	0.012–0.017
Vitrified clay	0.015	0.013–0.018
Cast iron	0.015	0.012–0.019
Smooth earth	0.018	0.015–0.021
Corrugated metal pipes	0.023	0.014–0.031
Cement rubble surface	0.024	0.015–0.032
Conventional tillage		
no residue	0.09	0.08–0.11
with residue	0.19	0.15–0.24
Grass		
Short	0.15	0.10–0.25
Dense	0.24	0.15–0.35
Bermuda grass	0.41	0.30–0.50
Woods		
No underbrush	0.20	0.1–0.3
Light underbrush	0.40	0.3–0.5
Dense underbrush	0.80	0.6–0.95
Rangeland	0.13	0.1–0.18

This month, we will discuss "time of concentration" in detail, for which we will utilize Manning's equation and these **Manning's roughness coefficients**.

Note that these are to be distinguished from **runoff coefficients** (discussed later in today's class).

- We know that soils vary spatially
- We also know that soils vary with depth (profile)





Generalized Soil Profile:

O-Horizon: surface litter - primarily organic matter

A-Horizon: topsoil - humus and organic minerals

E-Horizon: zone of leaching where percolating water dissolves water-soluble matter

B-Horizon: subsoil below A- or E-Horizons that contains minerals and humic compounds

C-Horizon: zone of undercomposed mineral particles and rock fragments

Soils vary spatially and with depth in composition, structure, texture, and color

- **Soil texture:** (1) size of mineral particles and (2) fraction in different size classes
- (1) Size of mineral particles
- Soil particles can be separated into three

Clay: $d < 0.002$ mm

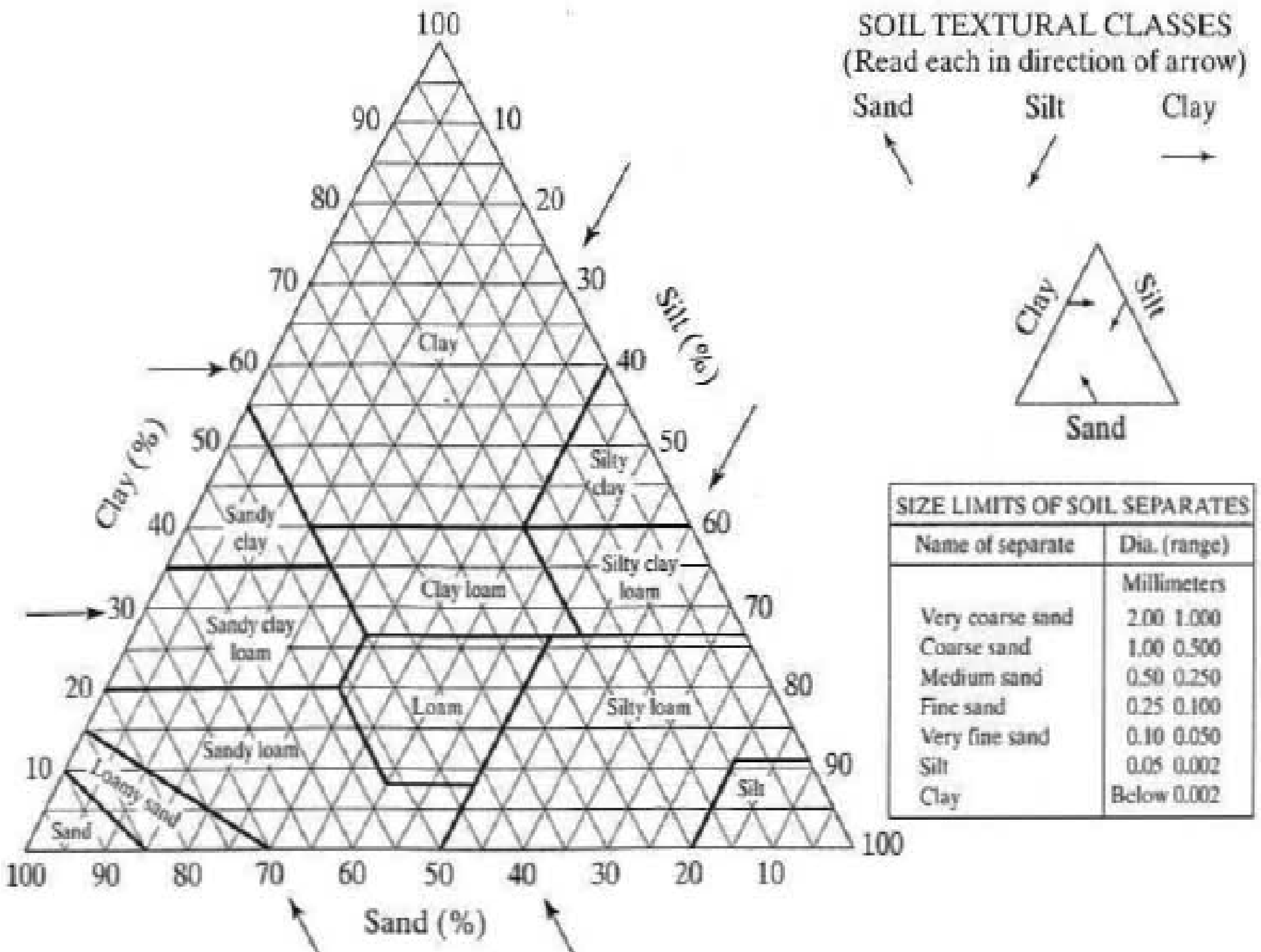
Silt: $0.002 \le d \le 0.02$ mm

Sand: $0.02 \le d \le 2$ mm

- Soil texture classifications have been developed based on the percentages of sand, silt, and clay

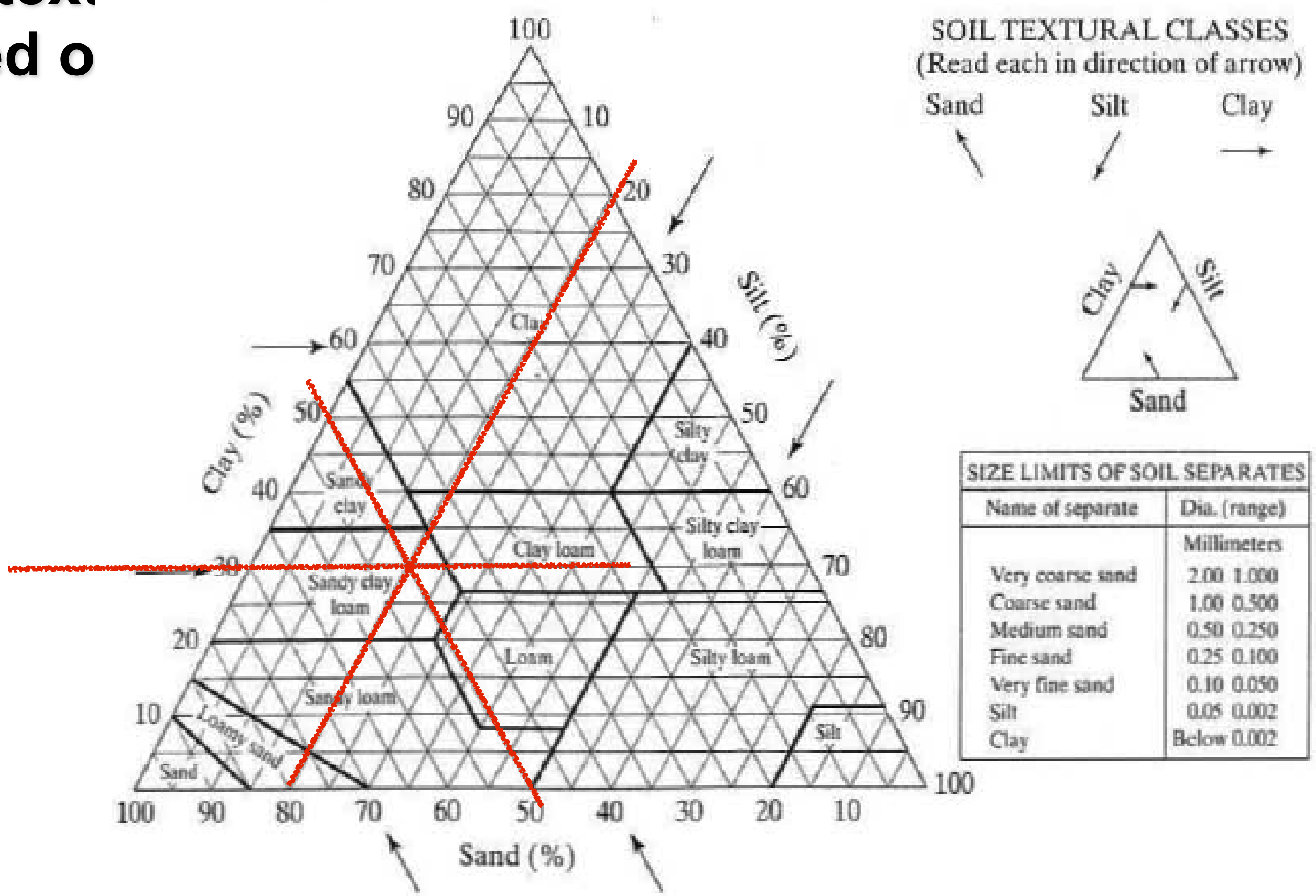
- **Soil texture:** **(1) size of mineral particles and (2) fraction in different size classes**
  - **Soil texture classifications have been developed based on the percentages of sand, silt, and clay**

Quick exercise: classify (assign name) to a soil with the following measured proportions:
- 30% Clay
- 50% Sand
- 20% Silt



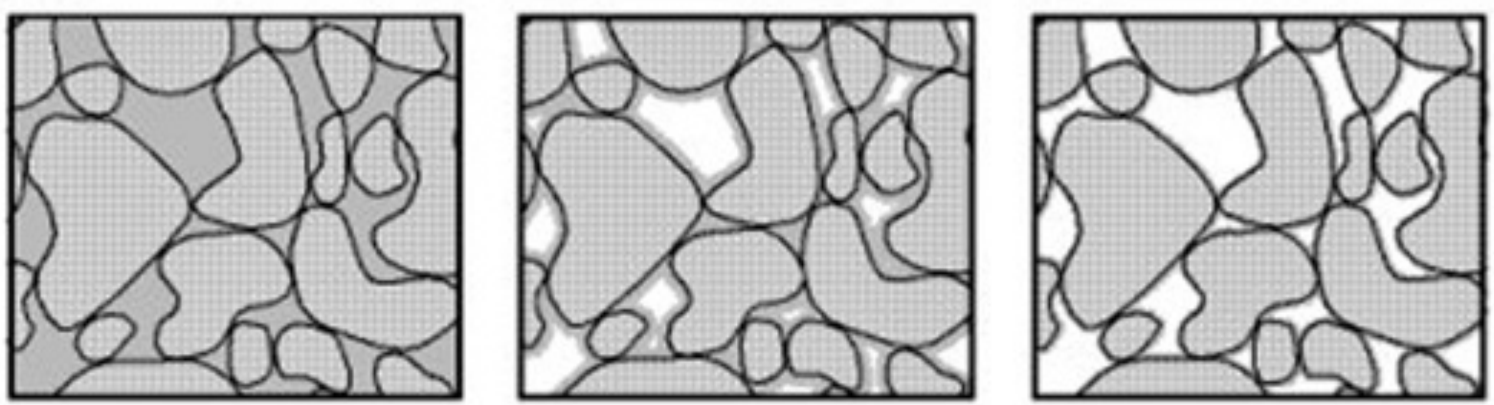
SIZE LIMITS OF SOIL SEPARATES	
Name of separate	Dia. (range)
	Millimeters
Very coarse sand	2.00 1.000
Coarse sand	1.00 0.500
Medium sand	0.50 0.250
Fine sand	0.25 0.100
Very fine sand	0.10 0.050
Silt	0.05 0.002
Clay	Below 0.002

- **Soil texture:** (1) size of mineral particles and (2) fraction in different size classes
- Soil texture classifications have been developed based o



Knowing soil characteristics is grand, but what is the meaning for hydrology?

- Soil texture is important for water-holding capacity and infiltration capacity

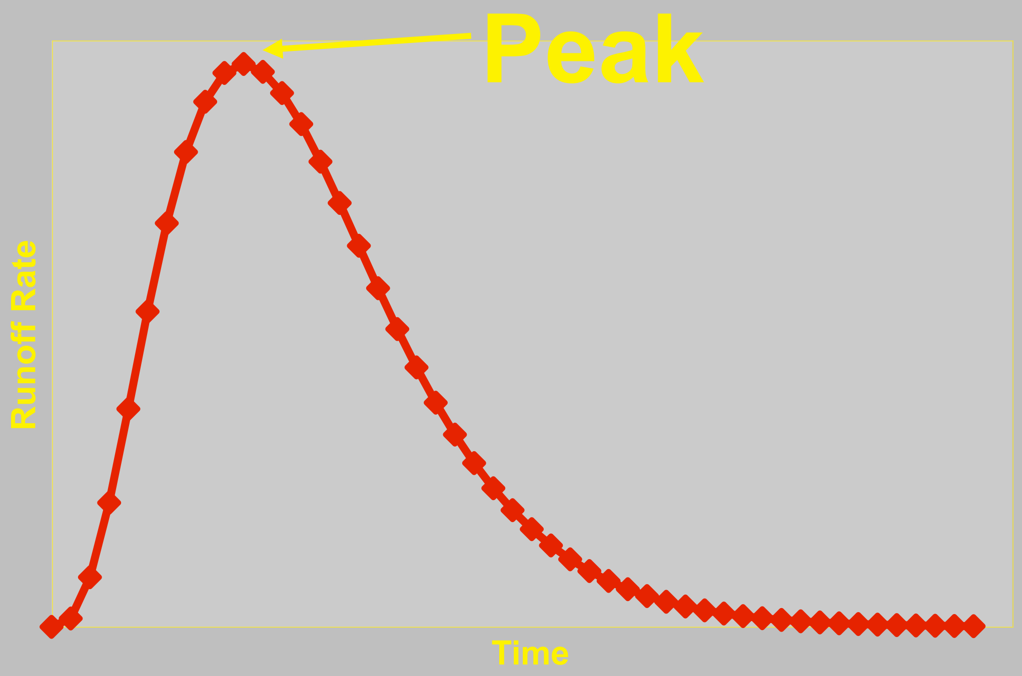


- As soil particle size increases, pore space increases, and infiltration capacity increases

Volumetric characteristics of soils

- **Total volume: $V=V_s+V_w+V_a$**
- **Porosity: $P_v=(V_w+V_a)/V$**
- **Specific yield: the proportion of the water that can drain under the force of gravity $P_e=V_g/V$ (V_g:the volume of water drain by gravity)**
- **Specific retention $R_s=V_r/V$ (V_r: the volume of water retained by surface tension)**
- **Porosity: $P_v=P_e+R_s$**

Please memorize these concepts (definitions), inasmuch as they dictate the trade-off between ***infiltration*** and runoff.



What design information does the hydrograph provide an engineer and what is it used for?

In more general terms, why do hydrologic engineers need runoff hydrographs, and especially PEAK DISCHARGE?

- Size detention basins
- Route flows to downstream location
- Predict time variation of flood inundation
- Design pump stations
- Analyze performance of system during storm event
- Real-time flood prediction and control
- The peak discharge is often calculated first, just because the full hydrograph takes more effort!

Rational Method

-The most frequently needed result in surface water modeling is an estimate of peak discharge.

-The simplest approach to predict the discharge is the Rational Method.

-This method was developed for small watersheds, usually undergoing urbanization (i.e. 40 hectares or 100 acres)

$$Q_p = CiA$$

- Q_p = peak flow (cfs)
- C = runoff coefficient
- i = rainfall intensity (in/hr)
- A = catchment area (ac)

The Rational Equation relates peak discharge to the runoff coefficient, rainfall intensity, and drainage area, based on watershed slope, land-use, and hydrologic soil type.

Assumptions

- Storm duration must be equal to the time of concentration of the watershed (the time needed for water to flow from the most remote point in a watershed to the watershed outlet).

- Rainfall intensity is uniform over watershed and over duration of storm.

- Runoff is invariant with time (i.e. soil conditions unchanging with time).

Procedure

Step 1: Compute time of concentration for drainage catchment (we'll discuss this procedure in 3 weeks).

Step 2: Select design storm rainfall intensity from an IDF curve given a design frequency and using the computed value for time of concentration as the duration.

Step 3: Determine the appropriate runoff coefficient.

Step 4: $$Q_p = CiA$$

Rational Method Example

Step 1: Consider a 2.4 acre parking area with a 1.5% slope, in Tallahassee, Fl. Using the method of segments you calculate a time of concentration of 10 minutes. Assume a 25-year design period requirement.

Step 2: Using the IDF in your textbook (next slide), you determine the design storm rainfall intensity.

Step 3: Determine the appropriate runoff coefficient from Table 7.9 (slide after next).

Step 4: Calculate peak discharge using $Q_p = CiA$

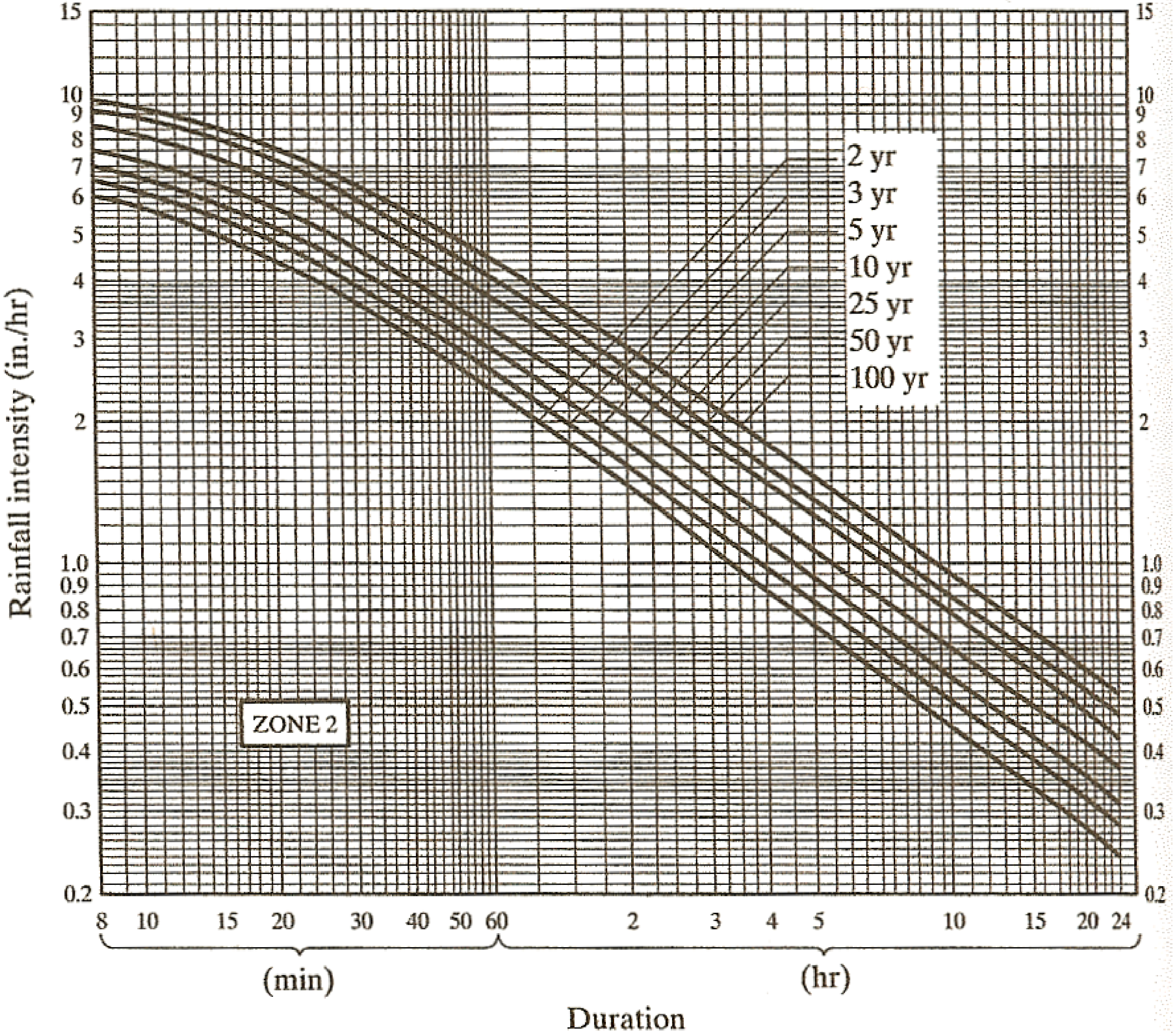


Figure 6–5 IDF curves for the Tallahassee, Florida, region. (From Weldon, 1985.)

TABLE 7.9 Runoff Coefficients for the Rational Formula versus Hydrologic Soil Group (A, B, C, D) and Slope Range

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

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

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