

HYDRAULICS

LECTURE 4: HYDROLOGY (PRECIPITATION, RUNOFF & FLOOD CALCULATIONS)



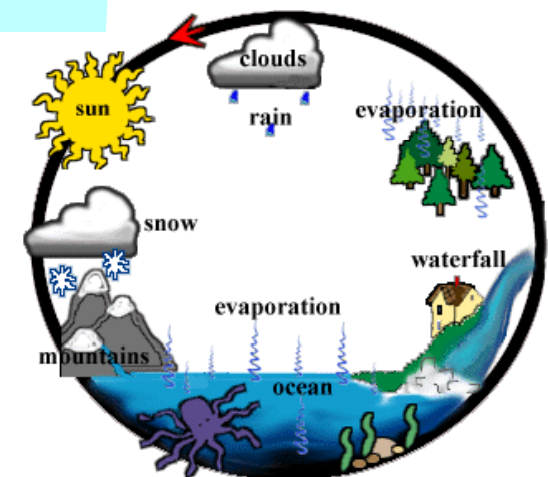
*PE REVIEW COURSE
PENN STATE BEAVER CONTINUING EDUCATION*

Uzair (Sam) Shamsi, Ph.D., P.E.

OUTLINE

Chapter 20: Meteorology, Climatology, and Hydrology

- ◆ Rainfall
- ◆ Design storms and flood frequency
- ◆ Time of Concentration
- ◆ Rational Method
- ◆ NRCS Curve Number Method
- ◆ Practice Problems
- ◆ Practice Exam
- ◆ Suggested Reading
- ◆ **Course Evaluation**



Text Book

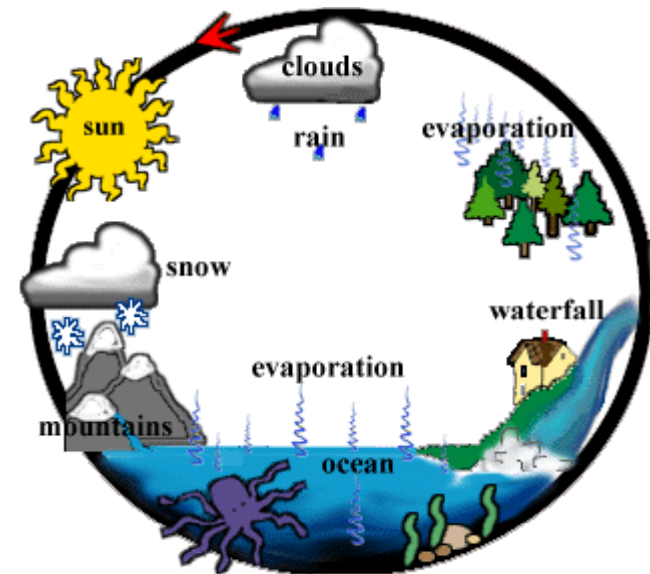
- ◆ **Title: Applied Hydrology**
- ◆ **Authors: Ven T Chow, David R Maidment, Larry W Mays**
- ◆ **Publisher: McGraw Hill**
- ◆ **Edition: 1988**
- ◆ **Type: Hardcover**
- ◆ **Pages: 572**
- ◆ **ISBN: 0070108102**

BASICS

HYDROLOGY



- ◆ Study of movement of water through:
 - ◆ atmosphere
 - ◆ land surface
 - ◆ waterways, and
 - ◆ soil (ground water)
- ◆ Study of movement of water through the hydrologic cycle:
- ◆ Hydrology: Science of water's:
 - ◆ Occurrence
 - ◆ Distribution, and
 - ◆ Movement



HYDROLOGIC CYCLE

Ten processes of hydrologic cycle

1. **Evaporation**
 - ♦ Water evaporates from oceans and land surface to become part of atmosphere (water vapor)
2. **Precipitation**
 - ♦ Water vapor is lifted and transported in the atmosphere until it condenses and precipitates on the land or oceans
3. **Interception**
 - ♦ Precipitated water intercepted by vegetation
4. **Overland flow**
 - ♦ Precipitated water overflowing on ground surface
5. **Infiltration**
 - ♦ Precipitated water infiltrated into ground
6. **Subsurface flow**
 - ♦ Precipitated water flowing through the soil near land surface
7. **Surface runoff (stream flow)**
 - ♦ Precipitated water discharged to streams
8. **Recharge**
 - ♦ Deep percolation to water table
9. **Groundwater flow**
 - ♦ Movement of water table deeper in soil or rock strata
10. **Overflow to oceans**
 - ♦ Surface and groundwater returning to oceans

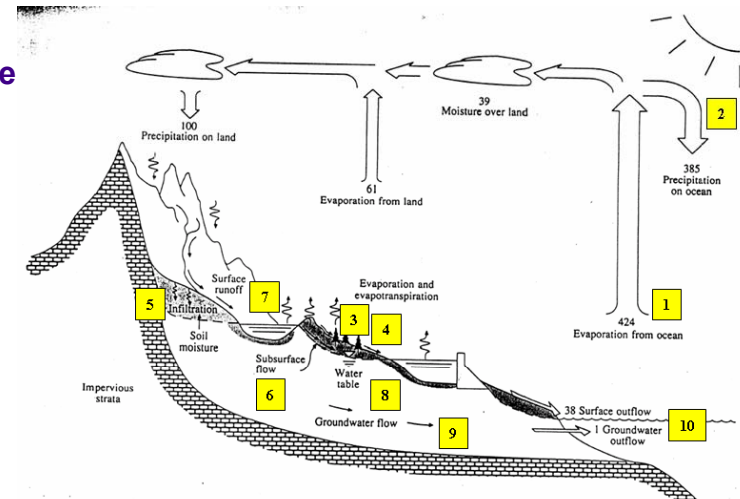


FIGURE 1.1.1
Hydrologic cycle with global annual average water balance given in units relative to a value of 100 for the rate of precipitation on land.

HYDROLOGIC CYCLE

Book: Applied Hydrology; Authors: Ven T Chow, David R Maidment, Larry W Mays
Publisher: McGraw Hill; Edition: 1988

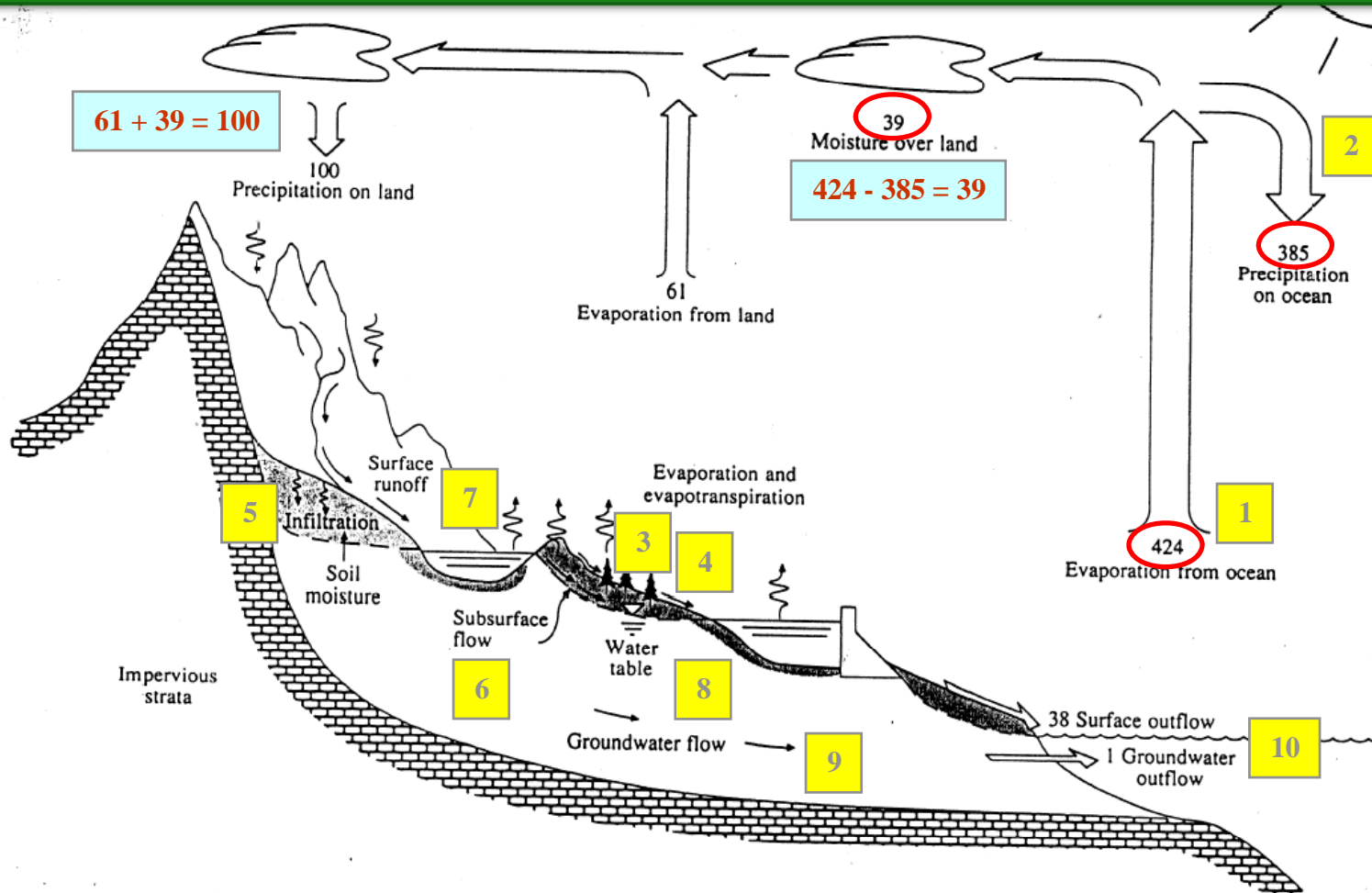
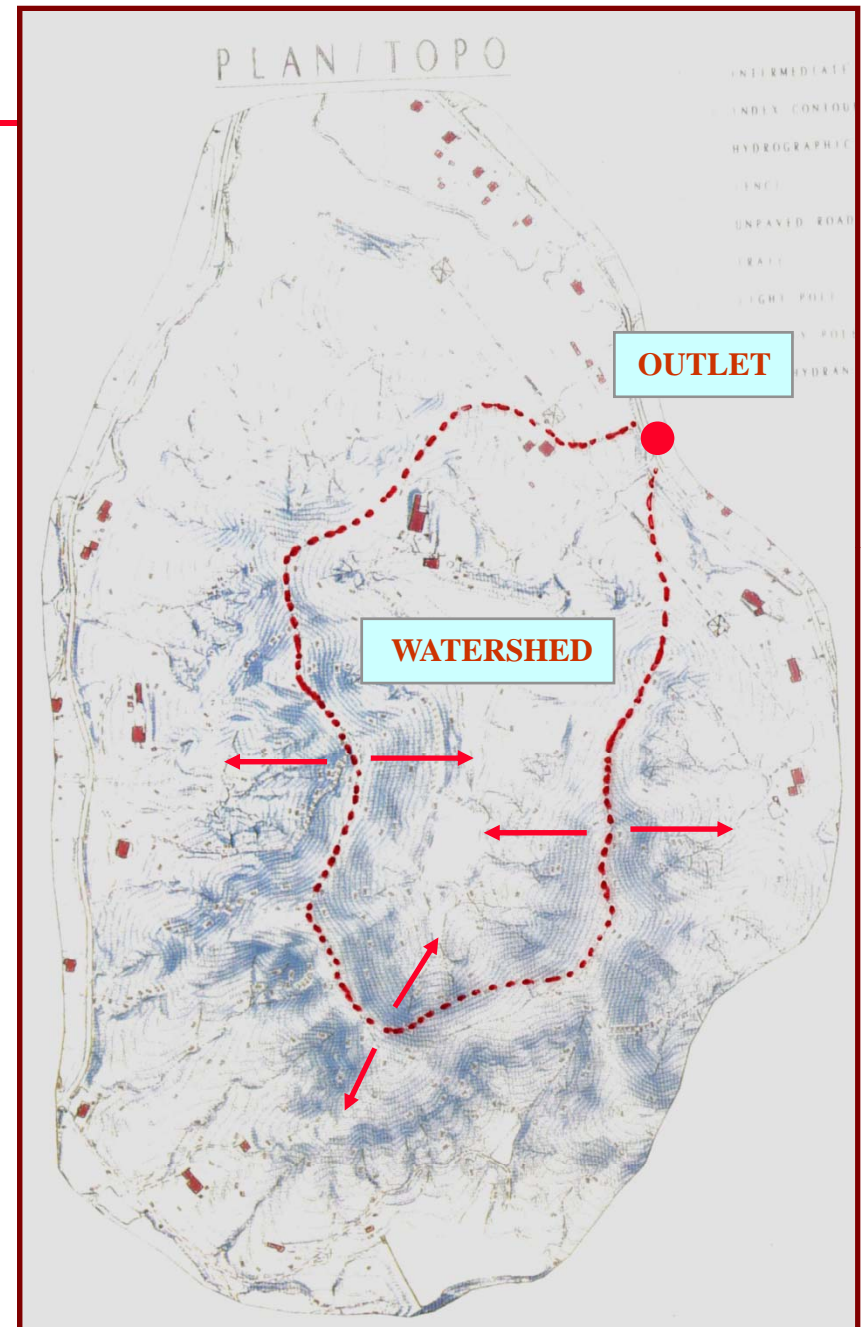


FIGURE 1.1.1

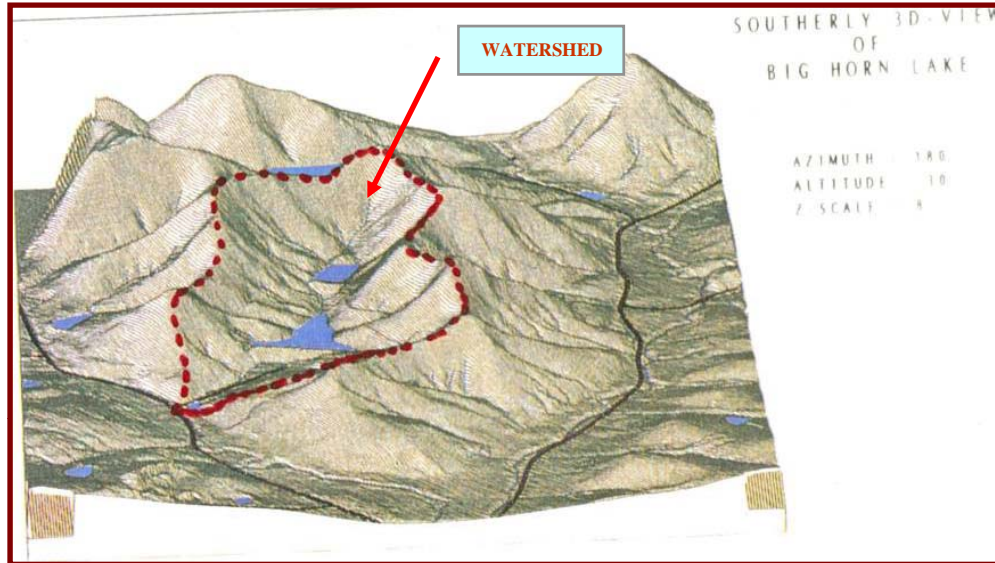
Hydrologic cycle with global annual average water balance given in units relative to a value of 100 for the rate of precipitation on land.

WATERSHEDS

- Watershed: area of land draining into a river at a given location (outlet)
 - Outlet: the most downstream point on the stream where the flow leaves the watershed and enters the river
- Sewershed: drainage area of sewer system
- Watershed divide: a line dividing
 - land draining towards the given stream, and
 - land draining away from that stream
- Manual delineation of watersheds is done by drawing drainage divides on topographic (contour) maps, which is cumbersome
- Automatic delineation of watersheds is done using Digital Elevation Models (DEMs) and Geographic Information Systems (GIS) software



WATERSHED EXAMPLES



RAINFALL

RAINFALL SPATIAL DISTRIBUTION

- Rain storms vary greatly in space and time
- Spatial distribution is shown by isohyetal maps
 - Rainfall contour maps created by interpolating “point” rainfall data from rain gages
 - Example: Figure 3.4.1
 - Johnstown storm produced the famous Johnstown flood and dam break in 1889 that killed 2000 people.

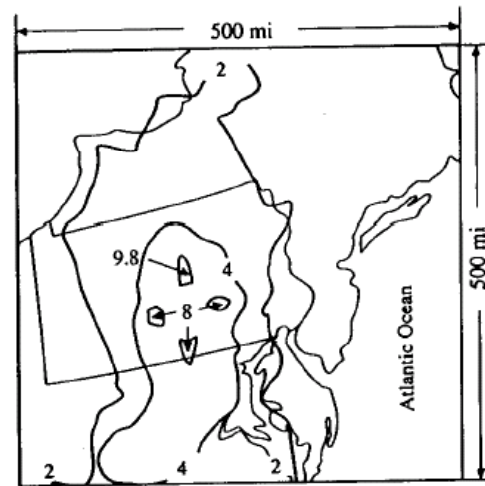
ISOHYETAL MAPS

Johnstown flood damage: 2000 deaths

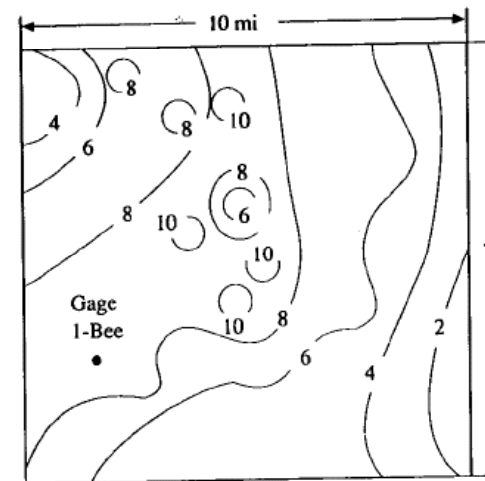
- **Smaller rainfall (9.8 in)**
- **Larger rainfall area**
- **Larger duration (18 hours)**

Austin flood damage: 13 deaths

- **Larger rainfall (11 in)**
- **Smaller rainfall area**
- **Smaller duration (3 hours)**



(a) Storm of May 30–June 1, 1889, which produced the **Johnstown flood** in Pennsylvania. Maximum rainfall of 9.8 in. recorded over 18 hour period at Wellsboro, Pennsylvania. Isohyets are in inches depth of total rainfall in the storm. (Source: U.S. Army Corps of Engineers, 1943.)



(b) Storm of May 24–25, 1981, in Austin, Texas. Maximum rainfall of 11 in. recorded over 3 hours. Isohyets are in inches depth of total rainfall in the storm. (Source: Massey, Reeves, and Lear, 1982.)

FIGURE 3.4.1

Isohyetal maps for two storms. The storms have about the same maximum depth of point rainfall, but the Johnstown storm covered a much larger area and had a longer duration than did the Austin storm.

RAINFALL ESTIMATION METHODS

- Areal Rainfall = Average rainfall over a watershed
- Three methods of areal rainfall estimation
 1. Arithmetic mean method (Figure 3.4.3.a)
 - Gages should be uniformly distributed
 - Gage data should not vary greatly about the mean (small standard deviation)



Station	Observed rainfall within or close to the area (mm or in)
P ₂	20.0
P ₃	30.0
P ₄	40.0
P ₅	50.0
	<u>140.0</u>

P ₂	20.0
P ₃	30.0
P ₄	40.0
P ₅	50.0
	<u>140.0</u>

$$\bar{P} = \frac{1}{n} \sum_{i=1}^n P_i$$

Average rainfall = $140.0/4 = 35.0$ mm or in

RAINFALL ESTIMATION

2. Thiessen method (Figure 3.4.3.b)

- Some gages are more representative of the watershed and should be assigned a higher “weight”
- Weights = area of Thiessen Polygons formed by drawing perpendicular bisectors to the lines joining adjacent gages
- Average rainfall = area weighted mean

$$P = \frac{1}{A} \sum_{j=1}^J A_j P_j$$

P = areal average rainfall

A = total watershed area

A_j = area of Thiessen Polygon for gage j

P_j = Rainfall at gage j

J = Total no. of gages



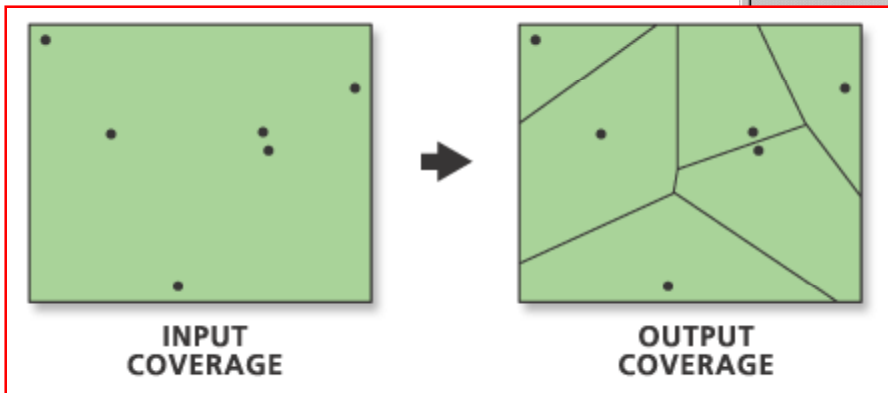
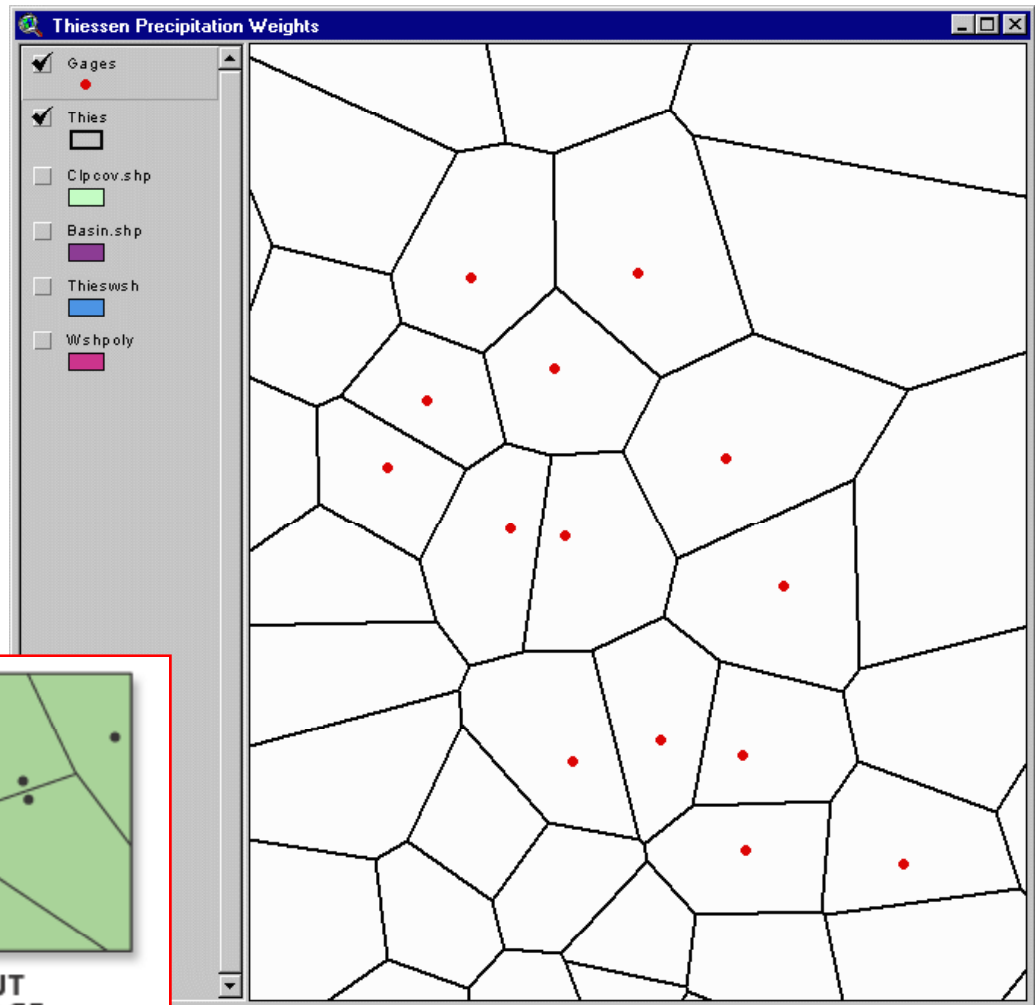
Station	Observed rainfall (mm or in)	Area (km ² or mi ²)	Weighted rainfall (mm or in)
P ₁	10.0	0.22	2.2
P ₂	20.0	4.02	80.4
P ₃	30.0	1.35	40.5
P ₄	40.0	1.60	64.0
P ₅	50.0	1.95	97.5
		9.14	284.6

$$\bar{P} = \frac{\sum A_i P_i}{\sum A_i}$$

Average rainfall = 284.6/9.14 = 31.1 mm or in

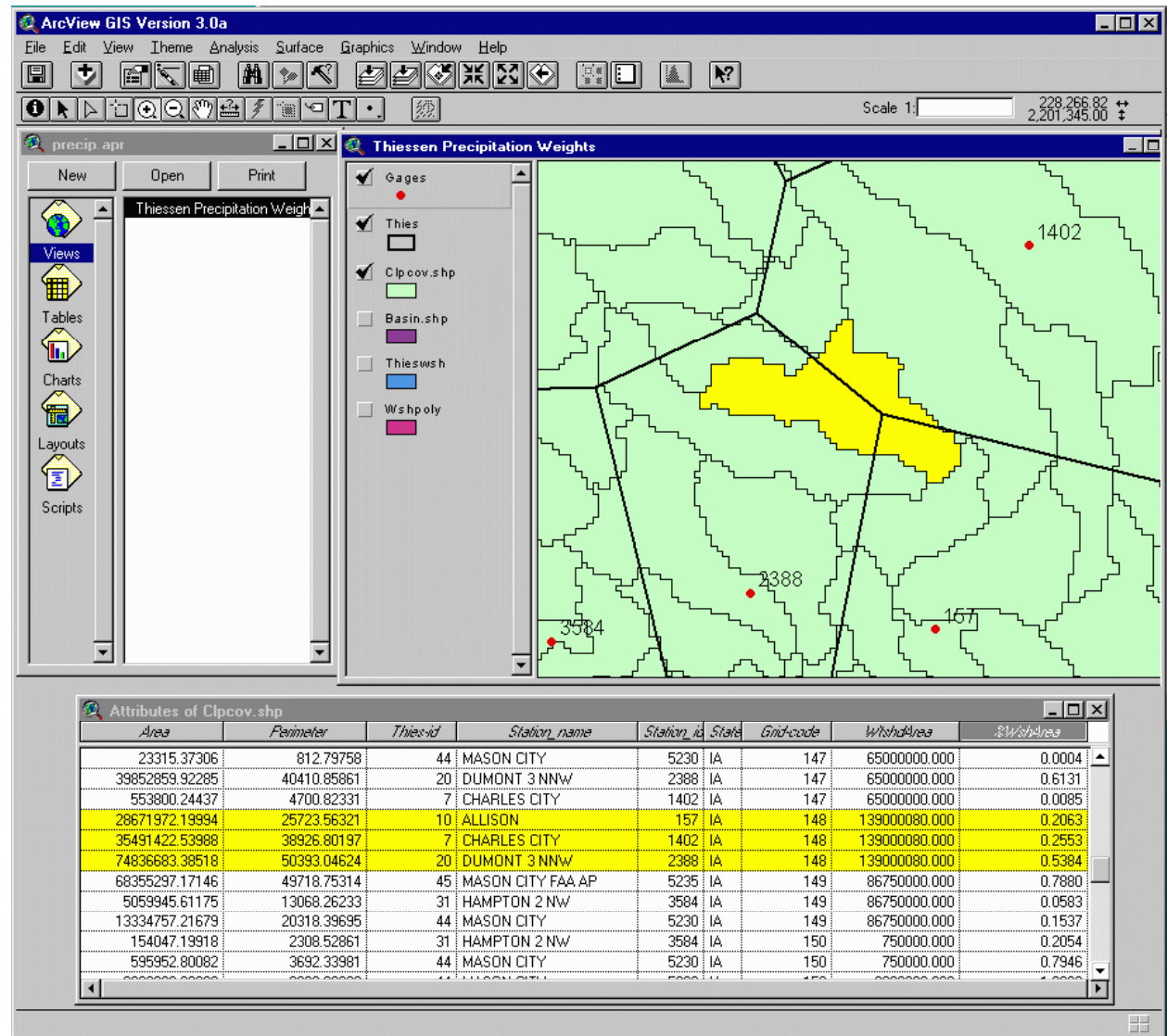
THEISSEN POLYGONS

- ◆ GIS application
- ◆ A Thiessen polygon is defined for each rain gage.



WATERSHED PRECIPITATION

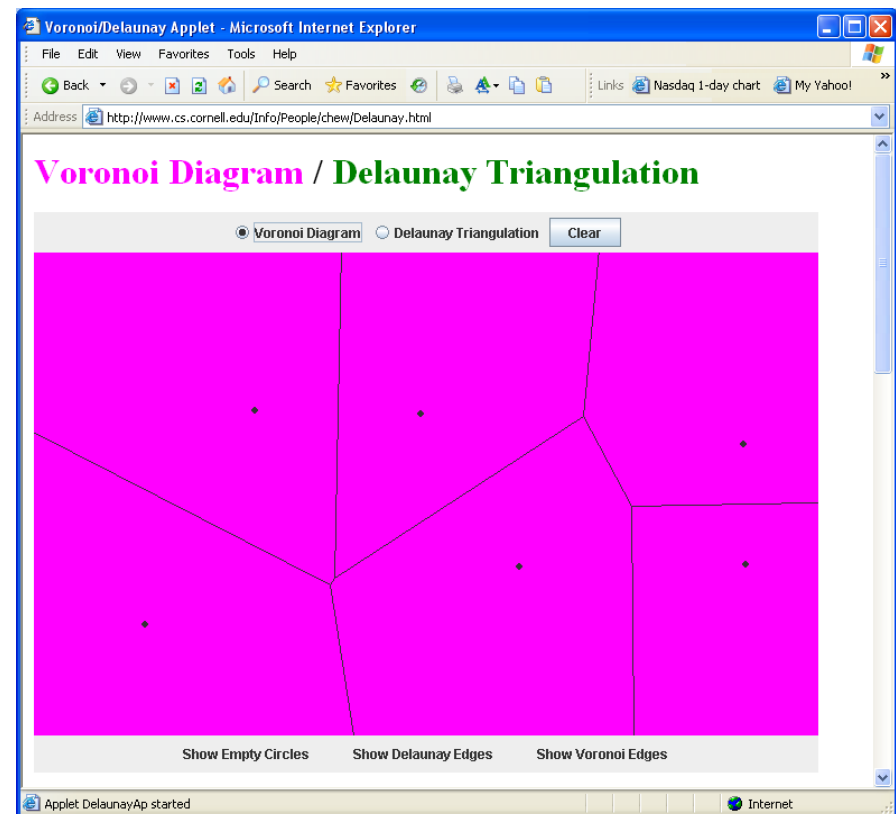
- ◆ GIS application
- ◆ The watershed precipitation is the weighted average (according to the Thiessen polygons) of the precipitation recorded at the neighbor stations.



THIESSEN POLYGON JAVA APPLET

11/4/09 link: <http://www.cs.cornell.edu/Info/People/chew/Delaunay.html>

- ◆ Here is a cool Java Applet that shows Delauney Triangulation and the formation of Thiessen (or Voronoi) polygons



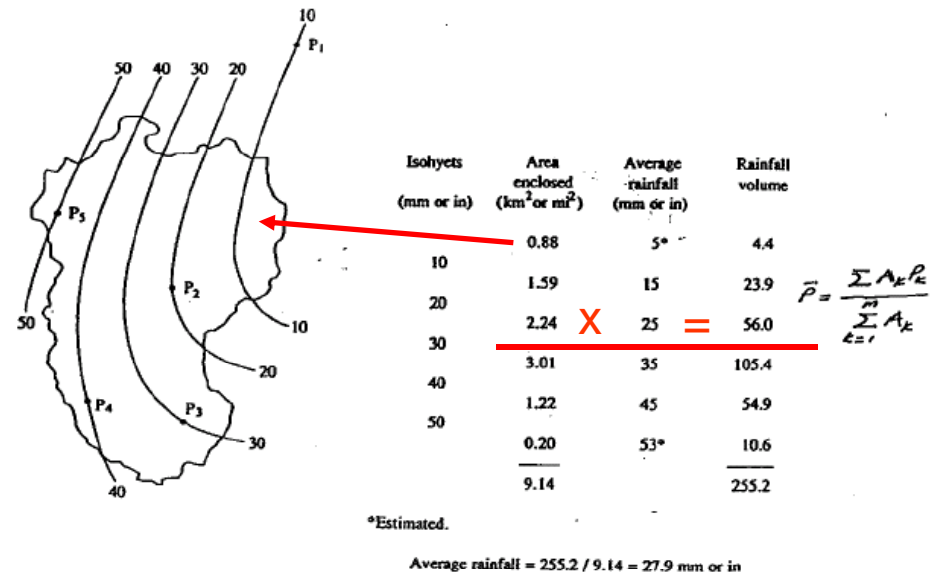
RAINFALL ESTIMATION

3. Isohyetal method (Figure 3.4.3.c)

- Weights = area between adjacent isohyets
- Average rainfall = area weighted mean

$$P = \frac{1}{A} \sum_{j=1}^J A_j P_j$$

- A_j = area between adjacent isohyets
- P_j = average rainfall of adjacent isohyets
- Should have a fairly dense network of gages



RAINFALL ESTIMATION

Which method to use?

- All methods give comparable results when time period is long (annual data)
- Thiessen method is most accurate, but was difficult to computerize
 - Not anymore, can be done in GIS
- Isohyetal method is less accurate but easy to automate because contouring programs exist throughout the engineering (CAD, GIS)

RAINFALL INTENSITY

- The time rate of precipitation, i.e., rainfall depth per unit time
- Units: in/h or mm/h
- Two types:
 - Instantaneous intensity: changes throughout the storm duration
 - Average intensity over the duration of rainfall: mean value over a duration t
 - Used commonly

$$I = \frac{P}{t}$$

$$P = I \times t \quad \dots \quad 20.18$$

Where

I = average intensity

P = rainfall depth (in or mm)

t = duration (usually in hours)

RAINFALL TEMPORAL DISTRIBUTION

- Temporal distribution is shown by hyetographs
 - A plot of “incremental” rainfall depth or intensity (depth/time) as a function of time
 - Example: Table 3.4.1 and Figure 3.4.2(a)
 - Rainfall mass curve = cumulative rainfall hyetograph
 - Maximum rainfall for a given interval is estimated by creating a series of running totals for that time interval

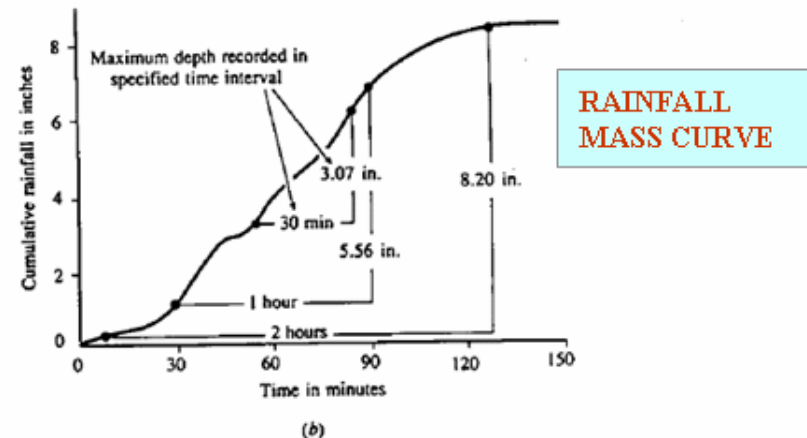
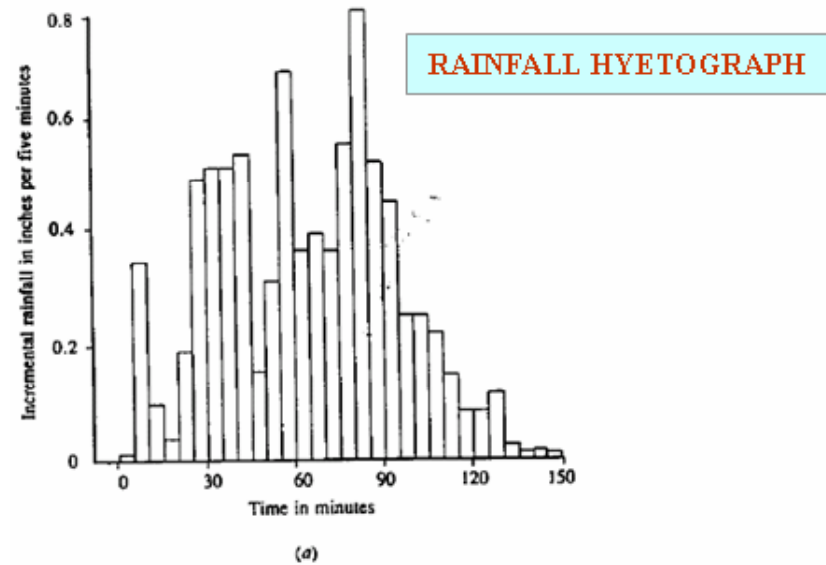


FIGURE 3.4.2 Incremental and cumulative rainfall hyetographs at gage I-Bee for storm of May 24–25, 1981 in Austin, Texas.

COMPUTATION OF RAINFALL DEPTH AND INTENSITY AT A POINT

76 APPLIED HYDROLOGY

30 MIN RUNNING TOTALS

TABLE 3.4.1
Computation of rainfall depth and intensity at a point

Time (min)	Rainfall (in)	Cumulative rainfall	Running Totals		
			30 min	1 h	2 h
0		0.00			
5	0.02	0.02			
10	0.34	0.36			
15	0.10	0.46			
20	0.04	0.50			
25	0.19	0.69			
30	0.48	1.17	1.17		
35	0.50	1.67	1.65		
40	0.50	2.17	1.81		
45	0.51	2.68	2.22		
50	0.16	2.84	2.34		
55	0.31	3.15	2.46		
60	0.66	3.81	2.64	3.81	
65	0.36	4.17	2.50	4.15	
70	0.39	4.56	2.39	4.20	
75	0.36	4.92	2.24	4.46	
80	0.54	5.46	2.62	4.96	
85	0.76	6.22	3.07	5.53	
90	0.51	6.73	2.92	5.56	
95	0.44	7.17	3.00	5.50	
100	0.25	7.42	2.86	5.25	
105	0.25	7.67	2.75	4.99	
110	0.22	7.89	2.43	5.05	
115	0.15	8.04	1.82	4.89	
120	0.09	8.13	1.40	4.32	8.13
125	0.09	8.22	1.05	4.05	8.20
130	0.12	8.34	0.92	3.78	7.98
135	0.03	8.37	0.70	3.45	7.91
140	0.01	8.38	0.49	2.92	7.88
145	0.02	8.40	0.36	2.18	7.71
150	0.01	8.41	0.28	1.68	7.24
Max. depth	0.76		3.07	5.56	8.20
Max. intensity (in/h)	9.12		6.14	5.56	4.10

$0.02 + 0.34 + 0.10 + 0.04 + 0.19 + 0.48 = 1.17$

$0.76 / (5/60)$

$8.20 / 2$

DESIGN STORMS

RETURN PERIOD

- The frequency of rainfall events is expressed in terms of return period (T) defined as
 - Average length of time (or average recurrence interval) between rainfall events of a specified magnitude
- Return period is inversely equal to the probability of occurrence of that event
 - Examples:
 - A 100-year rainfall event has a 1% (1/100) probability of occurrence in a given year
 - A 5-year rainfall event has a 20% (1/5) probability of occurrence in a given year

DESIGN STORMS

- Design storm is a precipitation pattern defined for use in the design of a hydraulic structure (culvert, detention pond, etc.)
- Usually a design hyetograph
 - 100-year / 24-hour
 - 2-year / 6-hour, etc.
- **Old source for rainfall frequency data:** U.S. Weather Bureau Rainfall Frequency Atlas (TP 40 or Technical Paper 40)
 - Six durations
 - 30 min
 - 1 hour
 - 3 hours
 - 6 hours
 - 12 hours
 - 24 hours
 - Seven return periods
 - 1 year
 - 2 years
 - 5 years
 - 10 years
 - 25 years
 - 50 years
 - 100 years
- Example: Figure 14.1.1 (100-year/24-hour)

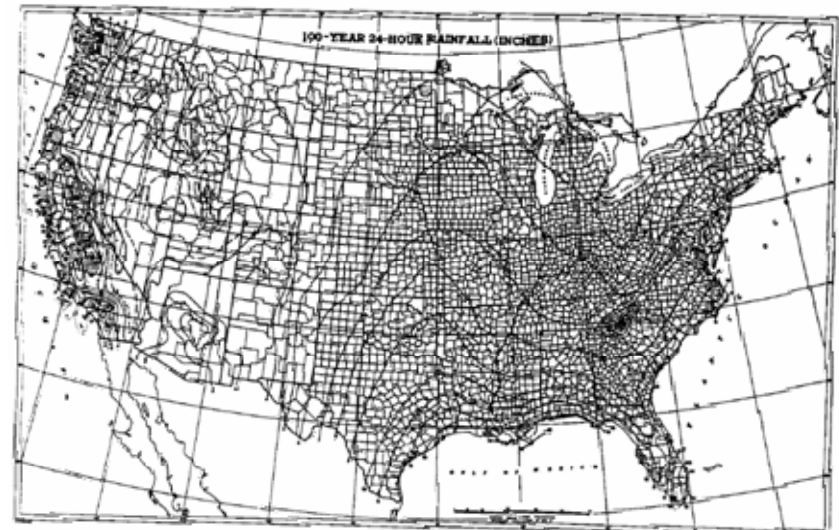


FIGURE 14.1.1
The 100-year 24-hour rainfall (in) in the United States, as presented in U. S. Weather Bureau technical paper 40. (Source: Hershfield, 1961.)

TP 40 RAINFALL ATLAS (SIMILAR TO FIG. 20.5 IN LINDEBURG)

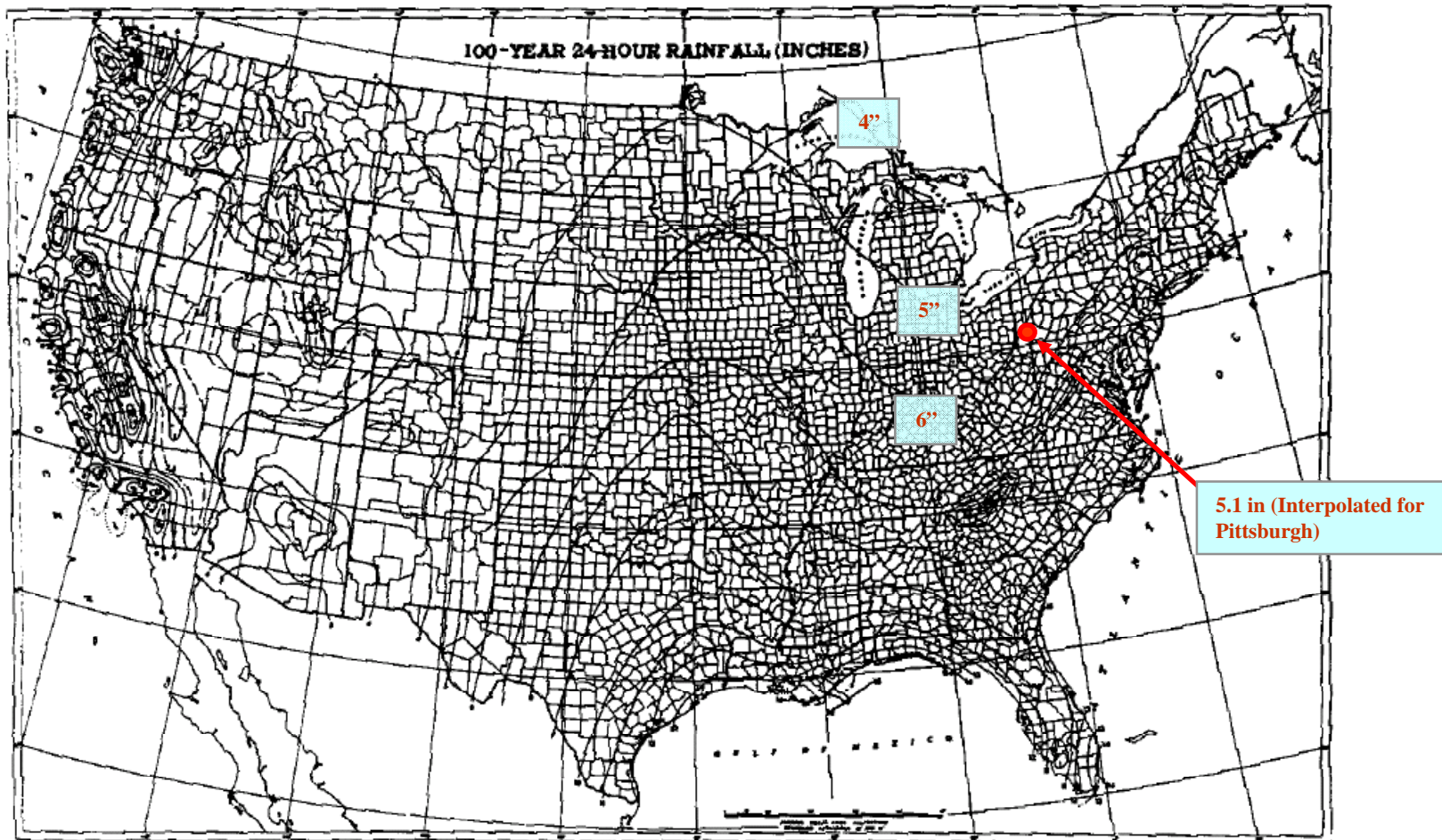


FIGURE 14.1.1

The 100-year 24-hour rainfall (in) in the United States as presented in U. S. Weather Bureau technical paper 40. (Source: Hershfield, 1961.)

NEW SOURCE FOR RAINFALL FREQUENCY DATA

- Precipitation-Frequency Atlas of the United States" NOAA Atlas 14
- Rainfall values different from TP40
- Available online at hdsc.nws.noaa.gov
- 18 durations from 5-min to 60-day
- 10 return periods from 1-year to 1000-year



POINT PRECIPITATION FREQUENCY ESTIMATES FROM NOAA ATLAS 14



PITTSBURGH WSCOM 2 AP, PENNSYLVANIA (36-6993) 40.5014 N 80.2311 W 1095 feet

from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 2, Version 3

G.M. Borimin, D. Martin, B. Liu, T. Parzybok, M. Yekta, and D. Riley

NOAA, National Weather Service, Silver Spring, Maryland, 2004

Extracted: Thu Nov 12 2009

[Confidence Limits](#)

[Seasonality](#)

[Location Maps](#)

[Other Info.](#)

[GIS data](#)

[Maps](#)

[Docs](#)

[Return to State Map](#)

Precipitation Frequency Estimates (inches)																		
ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	0.32	0.49	0.60	0.79	0.97	1.11	1.17	1.41	1.67	1.96	2.29	2.60	3.10	3.58	5.01	6.27	7.98	9.61
2	0.38	0.59	0.72	0.96	1.18	1.34	1.42	1.70	1.99	2.33	2.72	3.08	3.66	4.21	5.87	7.32	9.29	11.16
5	0.46	0.71	0.87	1.19	1.49	1.69	1.78	2.12	2.46	2.85	3.29	3.68	4.32	4.92	6.77	8.37	10.49	12.50
10	0.52	0.80	0.98	1.36	1.73	1.96	2.07	2.46	2.84	3.27	3.76	4.17	4.85	5.49	7.47	9.19	11.41	13.52
25	0.59	0.91	1.12	1.58	2.05	2.34	2.48	2.94	3.40	3.87	4.40	4.85	5.56	6.24	8.40	10.25	12.58	14.80
50	0.65	0.99	1.22	1.75	2.30	2.63	2.80	3.33	3.85	4.26	4.92	5.39	6.12	6.83	9.11	11.06	13.45	15.73
100	0.71	1.07	1.33	1.91	2.56	2.94	3.13	3.74	4.33	4.87	5.46	5.94	6.68	7.41	9.80	11.83	14.26	16.59
200	0.77	1.15	1.42	2.08	2.82	3.26	3.48	4.17	4.84	5.41	6.01	6.50	7.25	7.99	10.47	12.59	15.02	17.39
500	0.84	1.24	1.55	2.30	3.18	3.69	3.96	4.78	5.57	6.16	6.78	7.27	8.00	8.74	11.34	13.53	15.96	18.35
1000	0.90	1.31	1.64	2.46	3.46	4.02	4.34	5.27	6.16	6.76	7.38	7.87	8.57	9.31	11.97	14.21	16.62	19.00

**100 Year /
24-Hour
rainfall =
4.87 in**

**0.3 in (5%)
lower than
TP40 (5.2 in)**

NOAA ATLAS 14

- Three data retrieval options:
 - Select an existing NOAA rain gauge from the map or a drop-down list
 - Enter coordinates
 - Click on the map to select a location
- Provides interpolated results to user specified location

2. SELECT LOCATION:

Choose one of the following options:

2.1 Select site from list:

Select observing site

2.2 Enter location:

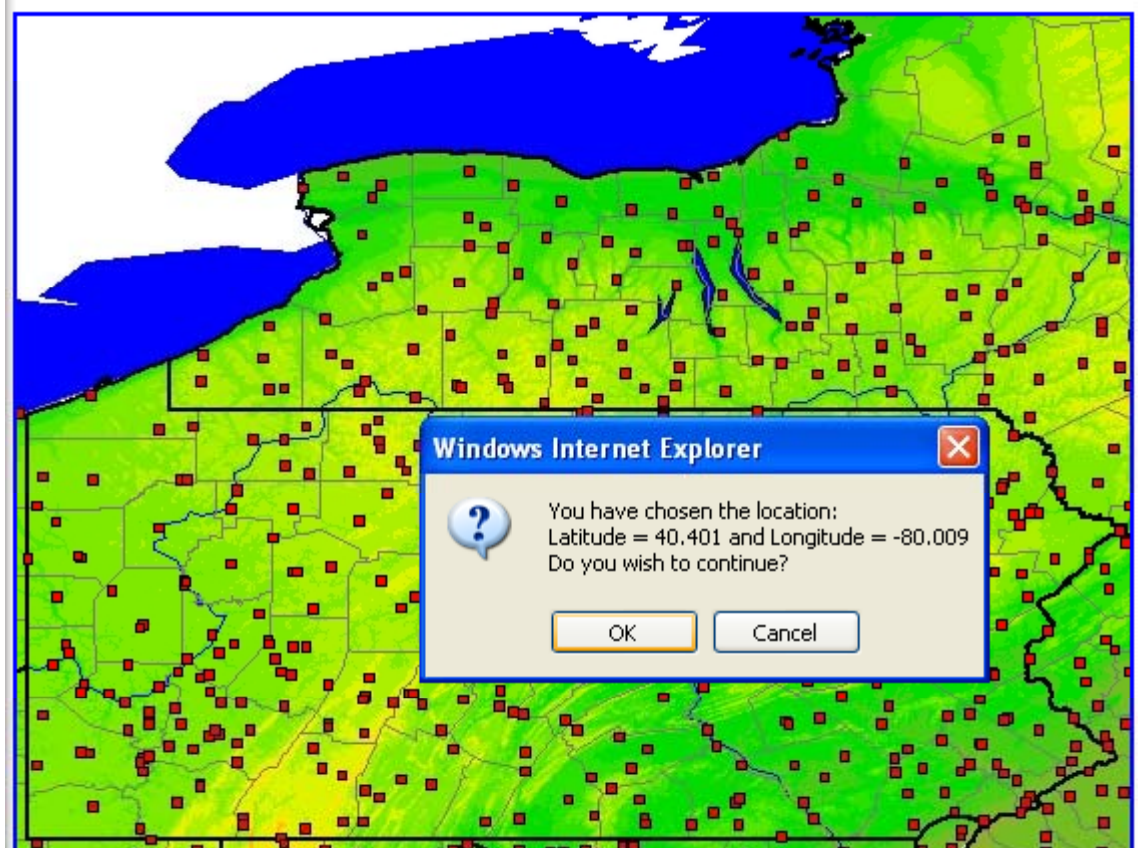
Latitude (decimal degrees):

Longitude (decimal degrees):

2.3 Click on map to select location information:

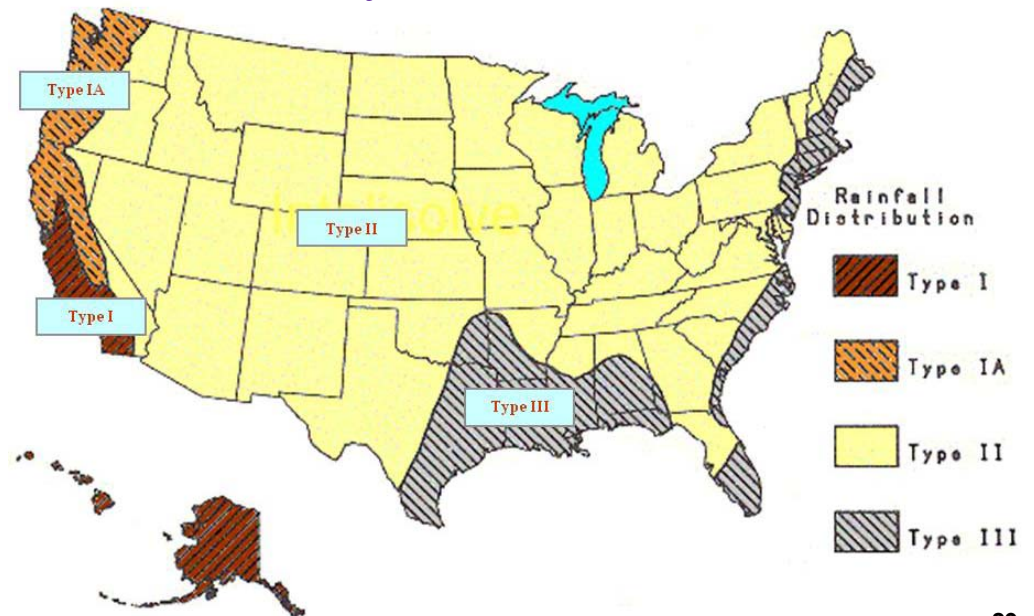
Latitude:

Longitude:



NRCS RAINFALL DISTRIBUTIONS

- Natural Resources Conservation Service (NRCS) formerly Soil Conservation Service (SCS)
 - Four NRCS rainfall distributions (Figure 14.3.3)
 - Type I and IA: West coast
 - Type III: East coast and Gulf of Mexico
 - Type II: Rest (most) of the country



SCS HYETOGRAPHS

- Table 14.3.1: 6 and 24-hour hyetograph tables
- Figure 14.3.2: 24-hour hyetograph plot

TABLE 14.3.1
SCS rainfall distributions

24-hour storm						6-hour storm		
Hour <i>t</i>	<i>t</i> /24	<i>P_t/P₂₄</i>				Hour <i>t</i>	<i>t</i> /6	<i>P_t/P₆</i>
		Type I	Type IA	Type II	Type III			
0	0	0	0	0	0	0	0	0
2.0	0.083	0.035	0.050	0.022	0.020	0.60	0.10	0.04
4.0	0.167	0.076	0.116	0.048	0.043	1.20	0.20	0.10
6.0	0.250	0.125	0.206	0.080	0.072	1.50	0.25	0.14
7.0	0.292	0.156	0.268	0.098	0.089	1.80	0.30	0.19
8.0	0.333	0.194	0.425	0.120	0.115	2.10	0.35	0.31
8.5	0.354	0.219	0.480	0.133	0.130	2.28	0.38	0.44
9.0	0.375	0.254	0.520	0.147	0.148	2.40	0.40	0.53
9.5	0.396	0.303	0.550	0.163	0.167	2.52	0.42	0.60
9.75	0.406	0.362	0.564	0.172	0.178	2.64	0.44	0.63
10.0	0.417	0.515	0.577	0.181	0.189	2.76	0.46	0.66
10.5	0.438	0.583	0.601	0.204	0.216	3.00	0.50	0.70
11.0	0.459	0.624	0.624	0.235	0.250	3.30	0.55	0.75
11.5	0.479	0.654	0.645	0.283	0.298	3.60	0.60	0.79
11.75	0.489	0.669	0.655	0.357	0.339	3.90	0.65	0.83
12.0	0.500	0.682	0.664	0.663	0.500	4.20	0.70	0.86
12.5	0.521	0.706	0.683	0.735	0.702	4.50	0.75	0.89
13.0	0.542	0.727	0.701	0.772	0.751	4.80	0.80	0.91
13.5	0.563	0.748	0.719	0.799	0.785	5.40	0.90	0.96
14.0	0.583	0.767	0.736	0.820	0.811	6.00	1.0	1.00
16.0	0.667	0.830	0.800	0.880	0.886			
20.0	0.833	0.926	0.906	0.952	0.957			
24.0	1.000	1.000	1.000	1.000	1.000			

Source: U. S. Dept. of Agriculture, Soil Conservation Service, 1973, 1986.

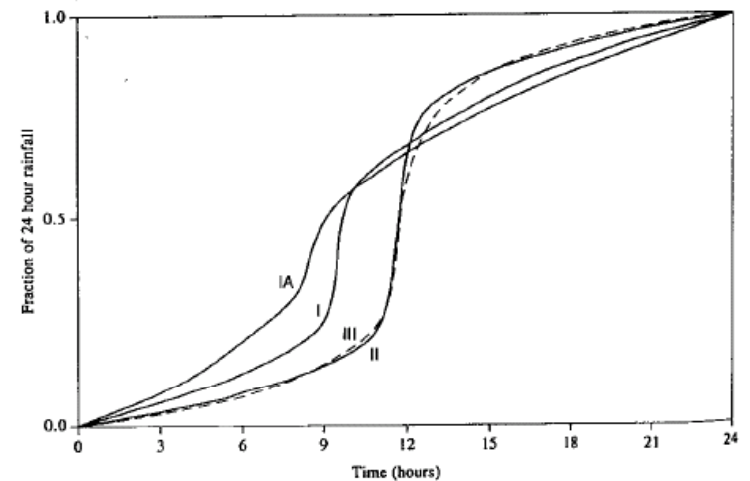
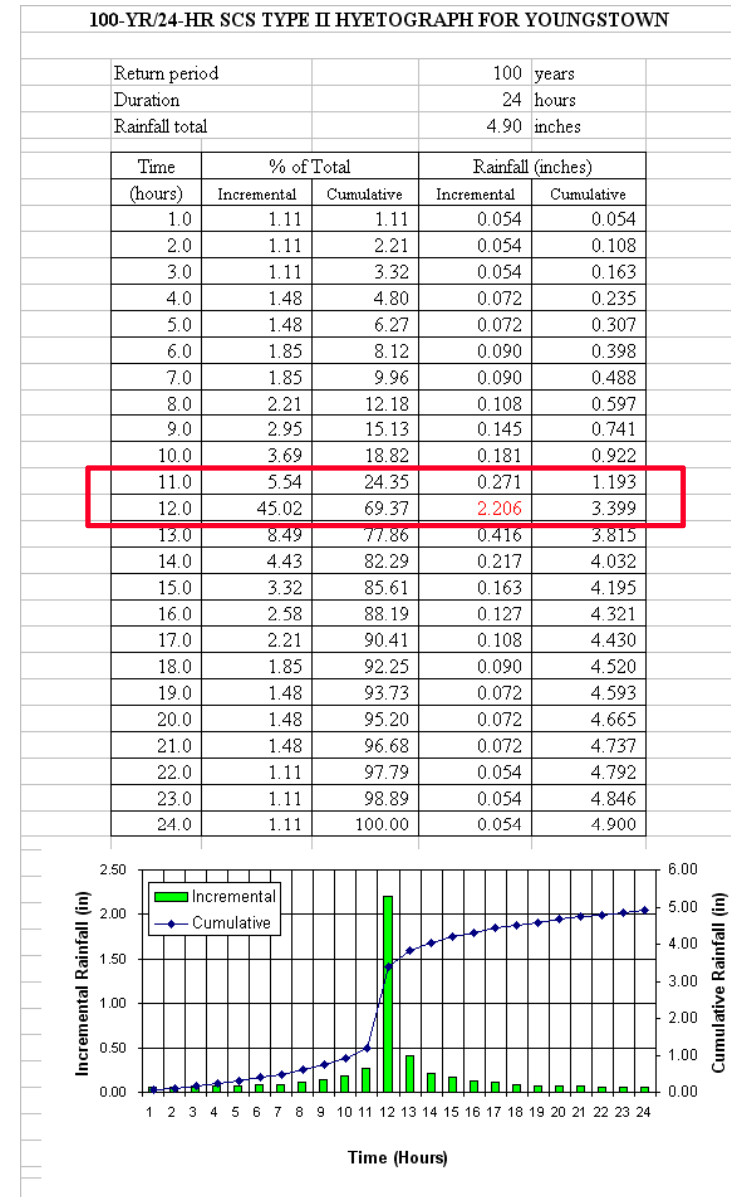


FIGURE 14.3.2
Soil Conservation Service 24-hour rainfall hyetographs. (Source: U. S. Dept. of Agriculture, Soil Conservation Service, 1986.)

EXAMPLE: SCS 24-HOUR HYETOGRAPH SPREADSHEET AND MANUAL CALCULATIONS

- Manual calculation example:
- If 24-hr rainfall = 4.9 in, what's the Type II rainfall at hour 12:00?
 - Cumulative % rainfall at Hr. 11:00 = 24.35%
 - Cumulative % rainfall at Hr. 12:00 = 69.37%
 - Incremental % rainfall from Hr. 11:00 to 12:00 = $69.37 - 24.35 = 45.02\% = 0.4502$
 - Rainfall at Hr. 12:00 = $4.9 \times 0.4502 = \boxed{2.206 \text{ in}}$ **ANSWER**



IDF CURVES

- Intensity-Duration-Frequency (IDF) Curves (design storm curves)
 - Intensity vs. duration for various return periods
 - Depth vs. duration for various return periods
 - Durations: 5 minute to 24 hour
 - Return periods: 1 year to 100 years
 - 1 year
 - 2 years
 - 5 years
 - 10 years
 - 25 years
 - 50 years
 - 100 years
- Usually state or region specific

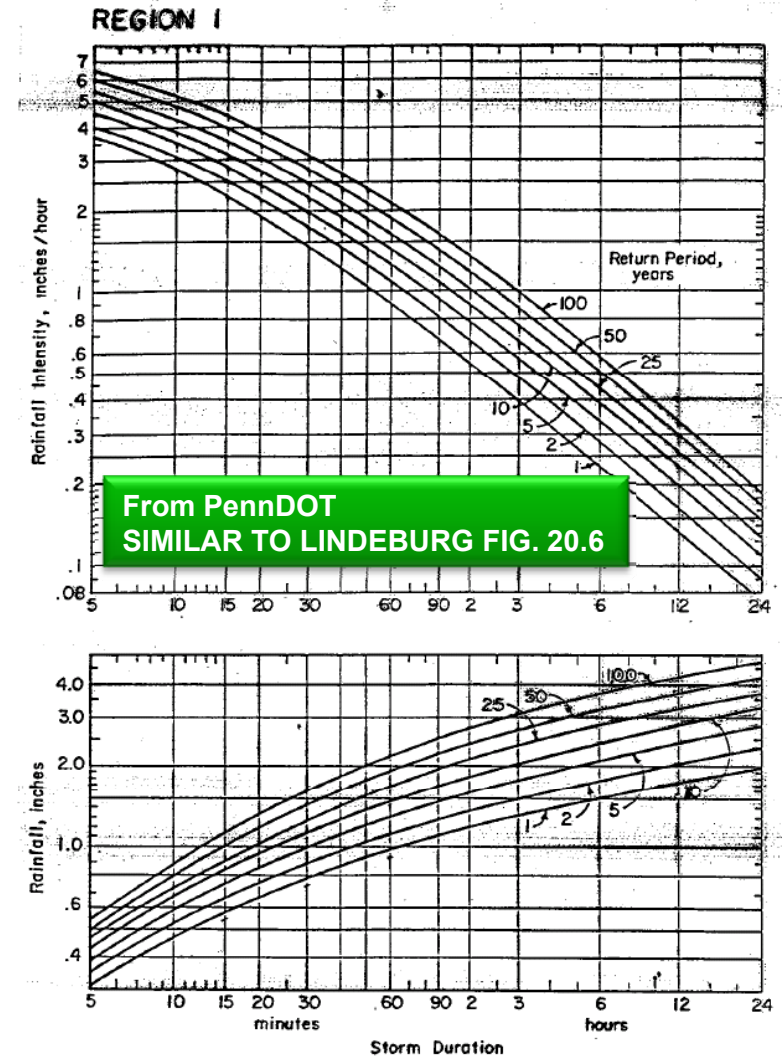
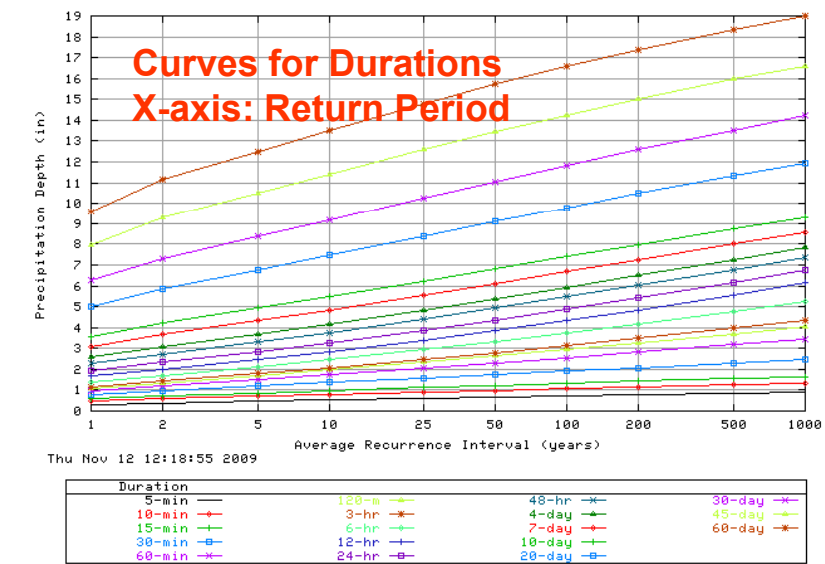
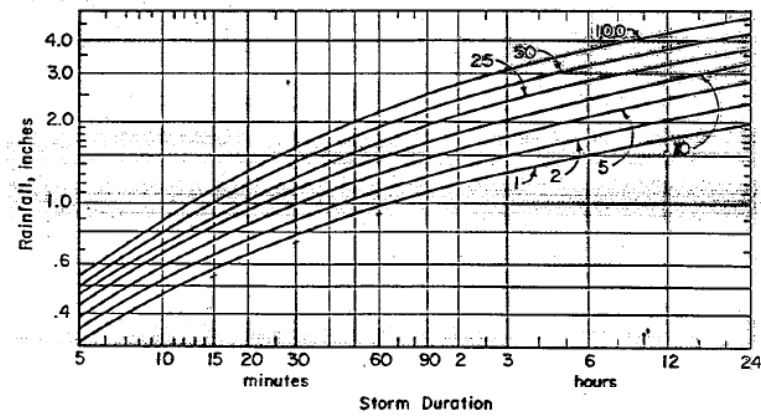
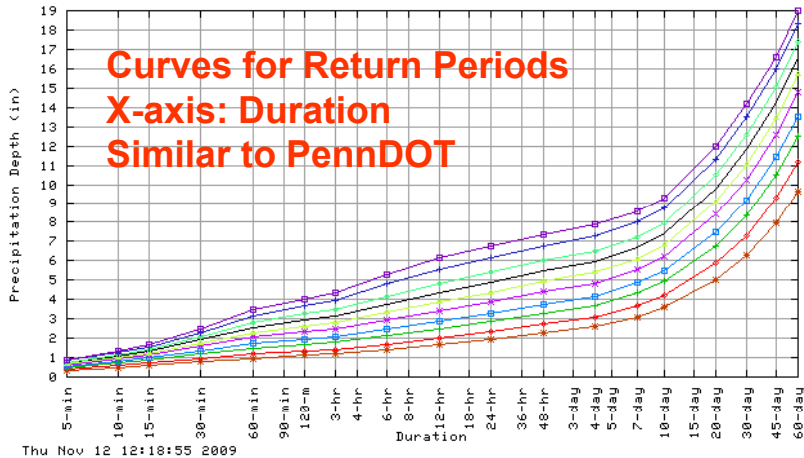


Fig. 2. Design Storm Curves for Region 1 (Pennsylvania)

ATLAS 14 IDF CURVES



- Are PennDOT and A14 IDF curve shapes different?
- Why?
- PennDOT curves are on a log-log plot.

IDF CURVES

◆ Typical equation for IDF curves

$$i = \frac{c}{(T_d)^e + f} \dots\dots\dots Eq.14.2.2$$

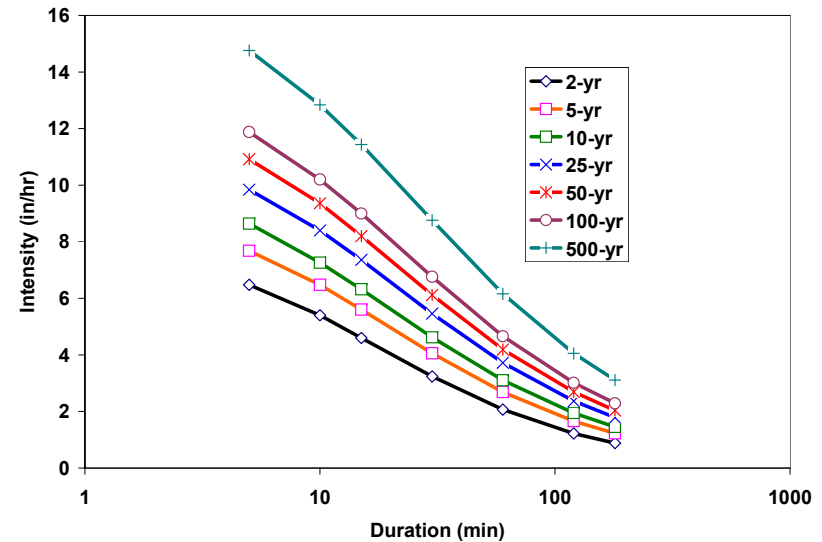
i = design rainfall intensity
 T_d = Duration of storm
 c, e, f = coefficients

◆ IDF Eq. for Austin, Texas

$$i = \frac{a}{(t+b)^c}$$

i = design rainfall intensity
 t = Duration of storm
 a, b, c = coefficients

Storm Frequency	a	b	c
2-year	106.29	16.81	0.9076
5-year	99.75	16.74	0.8327
10-year	96.84	15.88	0.7952
25-year	111.07	17.23	0.7815
50-year	119.51	17.32	0.7705
100-year	129.03	17.83	0.7625
500-year	160.57	19.64	0.7449



SAMPLE PROBLEM: IDF CURVES

- ◆ Determine the 10-year, 20-minute design rainfall intensity for Austin, Texas

Storm Frequency	a	b	c
10-year	96.84	15.88	0.7952

$$i = \frac{a}{(t+b)^c} = \frac{96.84}{(20+15.88)^{0.7952}} = \boxed{5.62 \text{ in/hr}} \text{ ANSWER}$$

FLOOD FREQUENCY

- Recurrence interval = mean time between flood (or storm) events of frequency F
- Probability of having a F -year event in any year
= p { F event in one year } = $1 / F$... 20.19

$$p \{ F \text{ event in } n \text{ years} \} = 1 - \left(1 - \frac{1}{F} \right)^n \quad \dots \quad 20.20$$



EXAMPLE 20.2: Flood Probability

A wastewater treatment plant has been designed to be in use for 40 yr. What is the probability that a 1% flood will occur within the useful lifetime of the plant?

➤ **Given Data:**

Design flood = 1% = 0.01

n = 40 years

➤ **Calculate (?):**

p {F event in 40 years }

- Solution: From Eq. 20.19

$$0.01 = 1/F$$

- $F = 1 / 0.01 = 100$ years

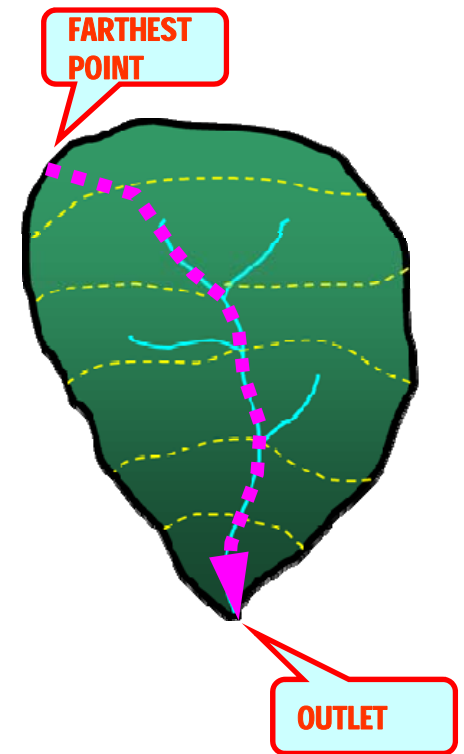
- From Eq. 20.20

$$p \{100 \text{ year flood in } 40 \text{ years}\} = 1 - \left(1 - \frac{1}{100}\right)^{40} = 0.33 \boxed{= 33\%} \text{ ANSWER}$$

TIME OF CONCENTRATION

TIME OF CONCENTRATION

- ◆ Different areas of a watershed contribute to runoff at different times after precipitation begins
- ◆ Time of concentration: The time required for storm water runoff to flow from the farthest point (time wise) in a drainage area (watershed) to a point of interest (watershed outlet, culvert, etc.)



TIME OF CONCENTRATION

- Time at which all parts of the watershed begin contributing to the runoff from the watershed
- Denoted by t_c
- For storm or combined sewers, t_c is calculated as the largest combination of
 1. Surface runoff time (overland or sheet flow)
 - ◆ For distance < 300 ft (100 m)
 2. Swale or ditch flow time (shallow concentrated flow)
 - ◆ For distance > 300 ft (100 m)
 3. Storm drain (or channel) flow time
- NRCS flow calculation: t_c should be at least 6 min
- Rational Method flow calculation: t_c should be at least 10 min
- t_c calculation equations: 20.5 to 20.12

TIME OF CONCENTRATION

$$\triangleright t_c = t_{sheet} + t_{shallow} + t_{channel} \dots 20.5$$

$$t_{sheet\ flow} = \frac{0.007(nL_o)^{0.8}}{\sqrt{P_2}(S_{decimal})^{0.4}} \dots 20.6$$

n = Manning's Roughness Coefficient for sheet flow

L_o = Ovreland flow length

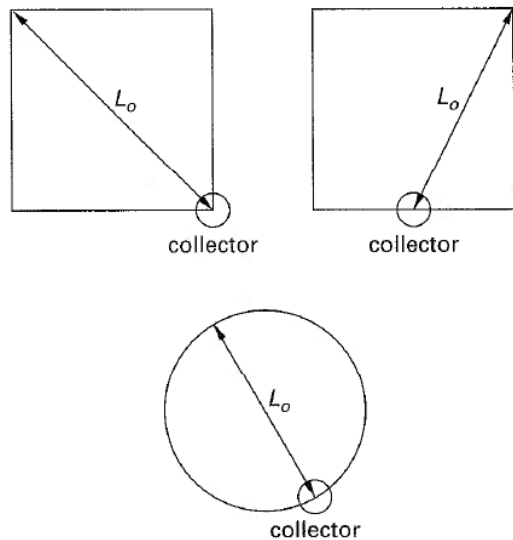
P_2 = 2 year, 24 hour rainfall in inches

S = Slope of hydraulic grade line in ft/ft (not in %)

Table 20.1 Manning Roughness Coefficient for Sheet Flow

surface	n
smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
fallow (no residue cover)	0.05
cultivated soils	
residue cover $\leq 20\%$	0.06
residue cover $> 20\%$	0.17
grasses	
short prairie grass	0.15
dense grass ^a	0.24
Bermuda grass	0.41
range, natural	0.13
woods ^b	
light underbrush	0.40
dense underbrush	0.80

Figure 20.2 Overland Flow Distances (L_o Definition)



TIME OF CONCENTRATION

- $t_{\text{shallow}} = L / V_{\text{shallow}}$
- L = length of shallow flow
- V_{shallow} = velocity of shallow flow

$$v_{\text{shallow}, ft / \text{sec}} = 16.1345 \sqrt{S_{\text{decimal}}} \quad [\text{unpaved}] \quad \dots \quad 20.7$$

$$v_{\text{shallow}, ft / \text{sec}} = 20.3282 \sqrt{S_{\text{decimal}}} \quad [\text{paved}] \quad \dots \quad 20.7$$

$$t_{\text{channel}} = \frac{\text{channel length}}{\text{channel velocity (measured or estimated from Manning's Eq. 19.12b)}}$$

RATIONAL METHOD

PEAK RUNOFF FROM THE RATIONAL METHOD

- ◆ An empirical equation to estimate peak surface runoff rate from rainfall intensity
 - ◆ Used in the design of storm sewers and culverts
 - ◆ Applicable to small watersheds less than several hundred acres. Seldom used for areas greater than 1-2 mi²

$$Q_p = C I A_d \dots 20.36$$

Q_p = Peak runoff rate (cfs)

C = runoff coefficient ($0 \leq C \leq 1$)

I = Peak rainfall intensity (in/hr) for duration equal to time of concentration of the watershed

A_d = Drainage area (acres)

RUNOFF COEFFICIENT

- ◆ Typical values in Appendix 20.A
 - ◆ C for lawns: 0.05 – 0.35
 - ◆ C for driveways: 0.75 – 0.85
- ◆ Higher C means higher imperviousness
- ◆ Higher C means higher peak flow (Q_p)
- ◆ Runoff coefficient is a function of the soil type, slope, vegetation, and other related factors

APPENDIX 20.A Rational Method Runoff C-Coefficients

categorized by surface

forested	0.059–0.2
asphalt	0.7–0.95
brick	0.7–0.85
concrete	0.8–0.95
shingle roof	0.75–0.95
lawns, well-drained (sandy soil)	
up to 2% slope	0.05–0.1
2% to 7% slope	0.10–0.15
over 7% slope	0.15–0.2
lawns, poor drainage (clay soil)	
up to 2% slope	0.13–0.17
2% to 7% slope	0.18–0.22
over 7% slope	0.25–0.35
driveways, walkways	0.75–0.85

categorized by use

farmland	0.05–0.3
pasture	0.05–0.3
unimproved	0.1–0.3
parks	0.1–0.25
cemeteries	0.1–0.25
railroad yards	0.2–0.35
playgrounds (except asphalt or concrete)	0.2–0.35
business districts	
neighborhood	0.5–0.7
city (downtown)	0.7–0.95
residential	
single family	0.3–0.5
multiplexes, detached	0.4–0.6
multiplexes, attached	0.6–0.75
suburban	0.25–0.4
apartments, condominiums	0.5–0.7
industrial	
light	0.5–0.8
heavy	0.6–0.9



EXAMPLE 20.5: RATIONAL METHOD

Two adjacent fields, as shown, contribute runoff to a collector whose capacity is to be determined. The storm intensity after 25 min is 3.9 in/hr. (a) Calculate the time to concentration. (b) Use the rational method to calculate the peak flow.

➤ **Given Data:**

$I = 3.9$ in/hr for 25-min duration

$A_1 = 2$ ac

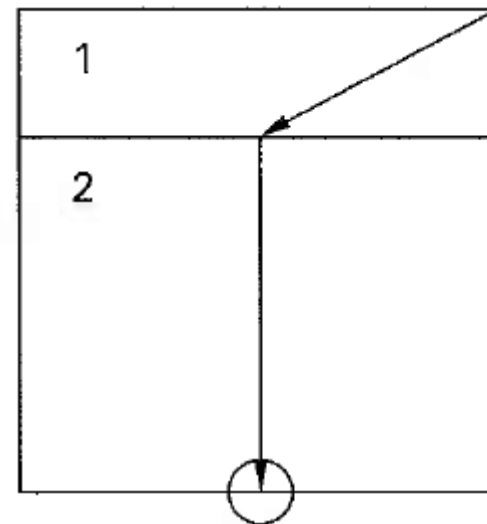
$C_1 = 0.35$

$t_1 = 15$ min

$A_2 = 4$ ac

$C_2 = 0.65$

$t_2 = 10$ min



$A_1 = 2$ ac
 $C_1 = 0.35$
 $t_1 = 15$ min

$A_2 = 4$ ac
 $C_2 = 0.65$
 $t_2 = 10$ min

➤ **Calculate (?):**

Peak flow to collector



EXAMPLE 20.5: SOLUTION

- ◆ Time of concentration = $t_1 + t_2 = 15 + 10 = 25$ min
- ◆ Weighted C for both areas =

$$\frac{(2 \times 0.35) + (4 \times 0.65)}{2 + 4} = 0.55$$

- ◆ From Eq. 20.36,
 $Q_p = C.I.A_d$
 $= 0.55 \times 3.9 \times (2+4)$
 $= 12.9 \text{ cfs}$ ANSWER



SAMPLE PROBLEM: RATIONAL METHOD

What is the peak discharge through a single culvert draining a forested watershed in Austin (TX) of 150 acres with average slope during a 10-year storm with a rainfall intensity of 6 in/hr?

Given data:

$A_d = 150$ acres

$I = 6$ in/hr

$T = 10$ -year (not a distractor)

Calculate: Q_p

Solution:

From Table 15.1.1 for $T=10$ year,

$C = 0.36$

From Eq. 20.3, $Q_p = C \cdot I \cdot A_d$

$Q_p = 0.36 \times 6 \times 150$

$Q_p = 324$ cfs **ANSWER**

TABLE 15.1.1
Runoff coefficients for use in the rational method

Character of surface	Return Period (years)						
	2	5	10	25	50	100	500
Developed							
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete/roof	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Grass areas (lawns, parks, etc.)							
<i>Poor condition (grass cover less than 50% of the area)</i>							
Flat, 0–2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average, 2–7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Steep, over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
<i>Fair condition (grass cover on 50% to 75% of the area)</i>							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
<i>Good condition (grass cover larger than 75% of the area)</i>							
Flat, 0–2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average, 2–7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Steep, over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
Undeveloped							
Cultivated Land							
Flat, 0–2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57
Average, 2–7%	0.35	0.38	0.41	0.44	0.48	0.51	0.60
Steep, over 7%	0.39	0.42	0.44	0.48	0.51	0.54	0.61
Pasture/Range							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Forest/Woodlands							
Flat, 0–2%	0.22	0.25	0.28	0.31	0.35	0.39	0.48
Average, 2–7%	0.31	0.34	0.36	0.40	0.43	0.47	0.56
Steep, over 7%	0.35	0.39	0.41	0.45	0.48	0.52	0.58

Note: The values in the table are the standards used by the City of Austin, Texas. Used with permission.

COMPOSITE RUNOFF COEFFICIENT

- ◆ For a watershed with multiple surface types (land use classes), sub-divide the watershed into subareas (or subcatchments) of uniform surface types and use Eq. 15.1.2

$$Q = i \sum_{j=1}^m C_j A_j \dots \text{Eq. 15.1.2/p497}$$

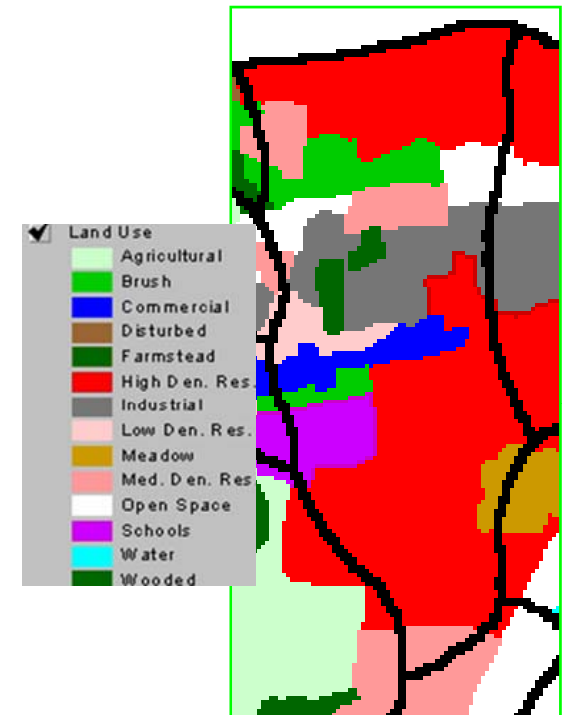
Q = Rate of peak discharge (cfs)

i = Rainfall intensity (in/hr)

C_j = runoff coefficient of j - th subarea

A_j = Area of j - th subarea (acres)

m = number of subareas in the watershed



Example 2: In the previous example, if 40% of the area is cultivated land on steep slope ($C = 0.44$) and 60% is asphalt parking ($C = 0.81$), the composite C is

$$C = (0.4 \times 0.44) + (0.6 \times 0.81), \text{ or} \\ = 0.176 + 0.486 = 0.662$$

$$Q_p = C \cdot i \cdot A_d$$

$$Q = 0.662 \times 6 \times 150$$

$$Q = 595.8 \text{ cfs}$$

**NRCS CURVE
NUMBER**

NRCS CURVE NUMBER METHOD

- ◆ Developed by Soil Conservation Service (SCS) in 1972
 - ◆ SCS is now called Natural Resources Conservation Service (NRCS)
- ◆ Computes abstractions from storm rainfall
- ◆ Estimates runoff as a function of cumulative precipitation, soil type, land use, and antecedent moisture
- ◆ Classifies soils (60 or 70 types) into four hydrologic soil groups: A, B, C, or D
- ◆ Initial Abstraction = I_a = depression storage + evaporation + interception losses

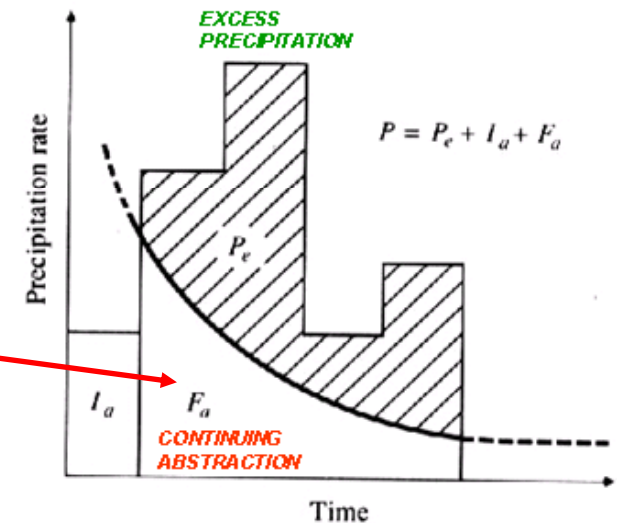


FIG. 5.5.1

THREE PRINCIPLES

1. This method assumes that initial abstraction = 20% of the storage capacity of soil (S)
 $I_a = 0.2 S \dots 20.38$
2. Runoff begins when gross rainfall (total rainfall without losses) P_g is greater than or equal to initial abstraction
 $P_g \geq I_a \dots 20.39$
3. The storage capacity of soil must be large enough to absorb the initial abstraction plus infiltration (F)
 $S \geq I_a + F \dots 20.40$

NRCS RUNOFF EQUATION

- **Total Q in inches (not in cfs) is computed from the NRCS runoff equation**

$$Q_{inches} = \frac{(P_g - 0.2S)^2}{P_g + 0.8S} \quad \dots \text{Eq. 20.44}$$

Q = Total (not instantaneous) runoff in inches (not in cfs)

P_g = Gross (not instantaneous) rainfall in inches

S = Storage capacity of soil in inches

$$S = \frac{1000}{CN} - 10 \quad \dots \text{20.43}$$

$$CN = \frac{1000}{10 + S}$$

(U.S. Units; $0 < CN < 100$)

CN = NRCS Runoff Curve Number

RUNOFF CURVE NUMBERS

- **Curve number = a dimensionless value ranging between 0 and 100**
- **For impervious and water surfaces CN = 100**
- **For natural surfaces CN < 100**
- **CN values tabulated in Table 20.4 for normal moisture conditions called Antecedent Runoff Conditions II (ARC II)**
 - **CN depends on land cover**
 - **CN depends on hydrologic soil group**

Table 20.4 Runoff Curve Numbers of Urban Areas (ARC II)

cover description	average percent impervious area	curve numbers for hydrologic soil			
		group A	group B	group C	group D
<i>fully developed urban areas (vegetation established)</i>					
open space (lawns, parks, golf courses, cemeteries, etc.)					
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
<i>impervious areas</i>					
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
<i>western desert urban areas</i>					
natural desert landscaping (pervious areas only)					
		63	77	85	88
artificial desert landscaping (impervious weed barrier, desert shrub with 1 to 2 in sand or gravel mulch and basin borders)					
		96	96	96	96
<i>urban districts</i>					
commercial and business					
	85	89	92	94	95
industrial					
	72	81	88	91	93
<i>residential districts by average lot size</i>					
$\frac{1}{8}$ acre or less (townhouses)					
	65	77	85	90	92
$\frac{1}{4}$ acre					
	38	61	75	83	87
$\frac{1}{3}$ acre					
	30	57	72	81	86
$\frac{1}{2}$ acre					
	25	54	70	80	85
1 acre					
	20	51	68	79	84
2 acres					
	12	46	65	77	82
<i>developing urban areas</i>					
newly graded areas (pervious areas only, no vegetation)					
		77	86	91	94

RUNOFF CURVE NUMBERS FOR AGRICULTURAL AREAS

Table 2-2c.—Runoff curve numbers for other agricultural lands¹

Cover description		Curve numbers for hydrologic soil group—			
Cover type	Hydrologic condition	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	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	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

¹Average 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.

⁴Actual curve number is less than 30; use $CN = 30$ for runoff computations.

⁵CN'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.

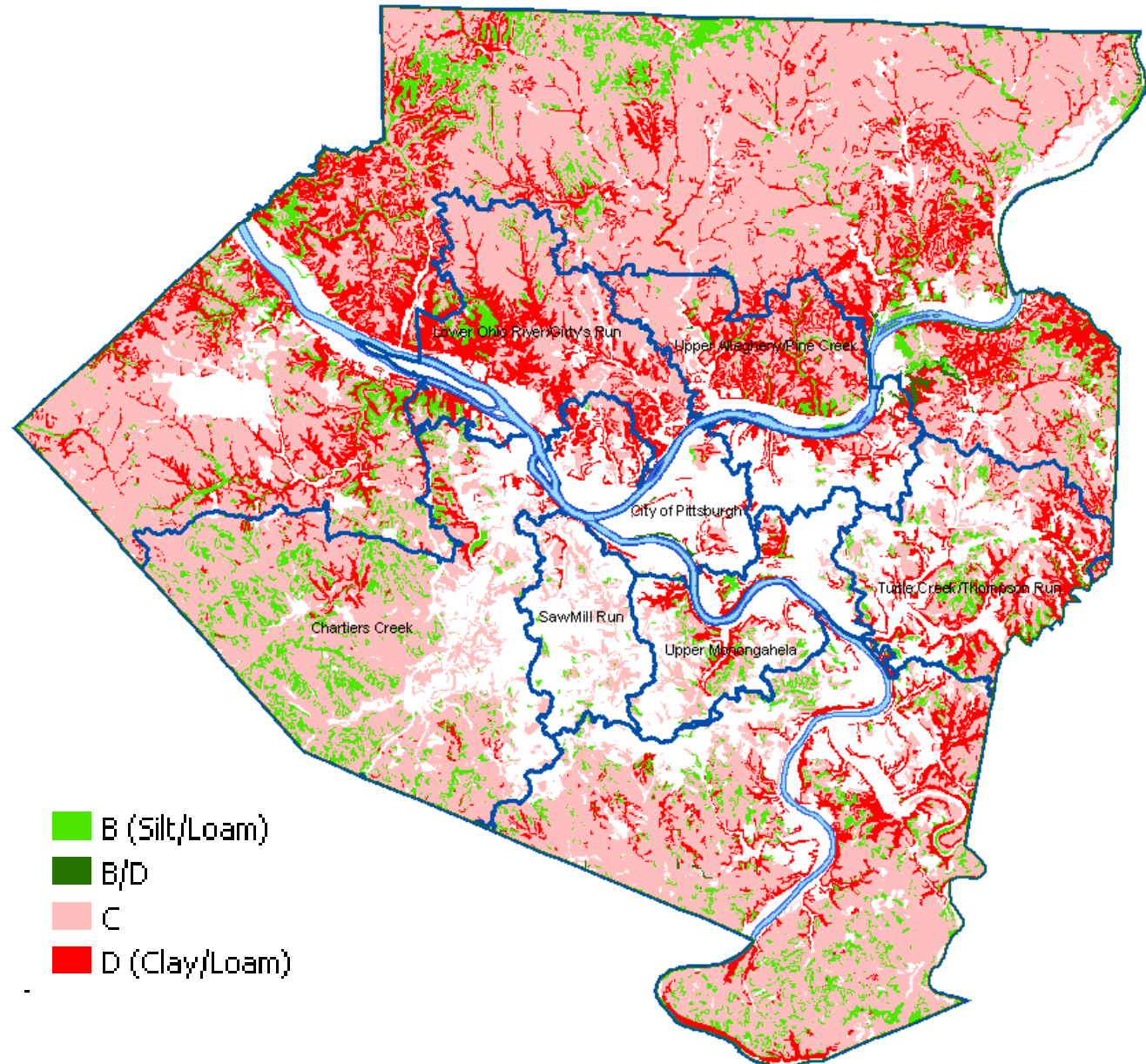
HYDROLOGIC SOIL GROUPS

◆ Curve Numbers depend on soil conditions

Group	Minimum Infiltration Rate (in/hr)	Soil type
A	0.3 – 0.45	High infiltration rates. Deep, well drained sands and gravels
B	0.15 – 0.30	Moderate infiltration rates. Moderately deep, moderately well drained soils with moderately coarse textures
C	0.05 – 0.15	Slow infiltration rates. Soils with layers, or soils with moderately fine textures
D	0.00 – 0.05	Very slow infiltration rates. Clayey soils, high water table, or shallow impervious layer

ALLEGHENY COUNTY SOILS

- Most (but not all) soils have a hydrologic soil group of C (sandy clay loam with low infiltration rates) or D (clay loam with low infiltration rate).
- Pockets of type B soil (silt loam or loam with moderate infiltration rate) are present.



SOURCE: USDA SSURGO GIS DATA, DATA DATE 9/14/06

HOW TO DETERMINE CURVE NUMBERS

- ◆ Use SCS Runoff Curve Number Table
- ◆ Relates CNs to land use and 4 hydrologic soil groups (HSG):
 - ◆ A: Most permeable (sand and silt)
 - ◆ B: shallow loess, sand loam
 - ◆ C: Clay loams, shallow sandy loam
 - ◆ D: Least permeable (clays)

TABLE 5.5.2
Runoff curve numbers for selected agricultural, suburban, and urban land uses (antecedent moisture condition II, $I_a = 0.2S$)

Land Use Description	Hydrologic Soil Group			
	A	B	C	D
Cultivated land ¹ : without conservation treatment	72	81	88	91
with conservation treatment	62	71	78	81
Pasture or range land: poor condition	68	79	86	89
good condition	39	61	74	80
Meadow: good condition	30	58	71	78
Wood or forest land: thin stand, poor cover, no mulch	45	66	77	83
good cover ²	25	55	70	77
Open Spaces, lawns, parks, golf courses, cemeteries, etc.				
good condition: grass cover on 75% or more of the area	39	61	74	80
fair condition: grass cover on 50% to 75% of the area	49	69	79	84
Commercial and business areas (85% impervious)	89	92	94	95
Industrial districts (72% impervious)	81	88	91	93
Residential ³ :				
Average lot size	Average % impervious ⁴			
1/8 acre or less	77	85	90	92
1/4 acre	61	75	83	87
1/3 acre	57	72	81	86
1/2 acre	54	70	80	85
1 acre	51	68	79	84
Paved parking lots, roofs, driveways, etc. ⁵	98	98	98	98
Streets and roads:				
paved with curbs and storm sewers ⁵	98	98	98	98
gravel	76	85	89	91
dirt	72	82	87	89

RUNOFF CURVE NUMBER CHART

- ◆ Plot of P_g vs. Q for various CN values
- ◆ Graphical solution of Eq. 20.44
- ◆ Example:
 $P_g = 5.9$ in
 $CN = 90$
 $Q = 4.8$ in

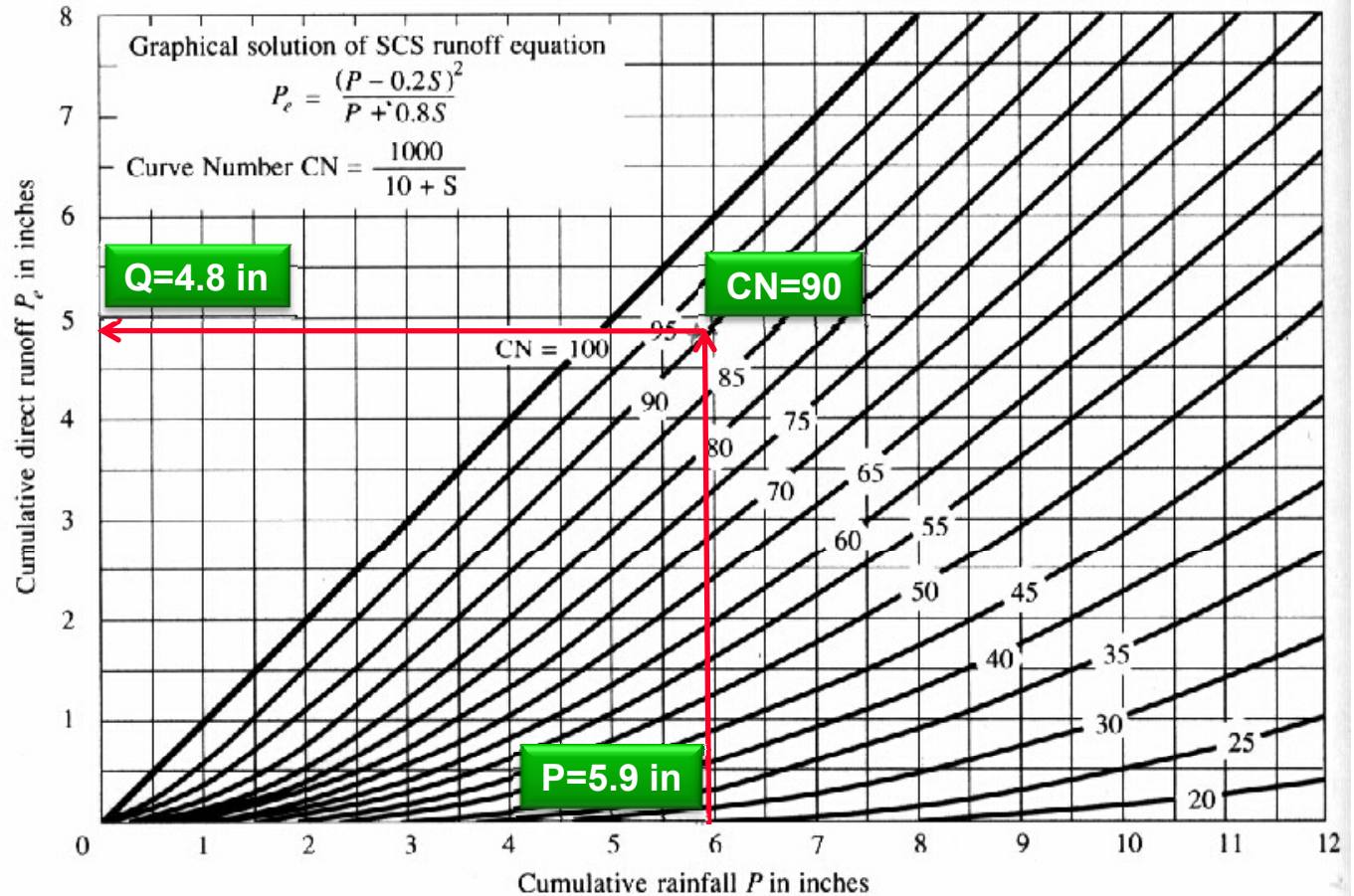


FIGURE 5.5.2

Solution of the SCS runoff equations. (Source: Soil Conservation Service, 1972, Fig. 10.1, p. 10.21)

ANTECEDENT MOISTURE CONDITIONS

- ◆ Table 20.4 values are valid for normal antecedent moisture conditions (ARC II).
- ◆ For abnormal conditions, modify CN values using
 - ◆ Eq. 20.41 for dry conditions (ARC I), or
 - ◆ Eq. 20.42 for wet conditions (ARC III).

TABLE 5.5.1
Classification of antecedent moisture classes (AMC)
for the SCS method of rainfall abstractions

Table 5.5.1 AMC Group	5-day antecedent rainfall (in)	
	Dormant season	Growing season
I (Dry)	< 0.50	< 1.4
II (Normal)	0.5 – 1.1	1.4 – 2.1
III (Wet)	> 1.1	> 2.1

$$CN_I = \frac{4.2CN_{II}}{10 - 0.058CN_{II}} \dots 20.41$$

$$CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}} \dots 20.42$$

HOW TO DETERMINE HYDROLOGIC SOIL GROUP VALUES FROM NRCS GIS DATA

- ◆ Soil Survey Geographic (SSURGO) data
- ◆ Scale: 1:12,000
- ◆ Like old County Soil Survey data
- ◆ Downloaded as GIS data shapefile
- ◆ Have Hydrologic Soil Group as an attribute

www.ncgc.nrcs.usda.gov/products/datasets/SSURGO/

The screenshot displays the ArcGIS interface. The main window shows a map of soil data with a yellow highlighted area. The 'Identify Results' window is open, showing the following properties for the selected area:

Shape	Polygon
Area	640101811.71042
Perimeter	294808.83459
Statsgo#	7
Statsgo-id	445
Muid	PA033
Major1	900
Minor1	33
Polyid	1156
Muhsg_dom	C
Muname	BERKS-WEIKERT-BEDINGTON
Mukind	
Mlra	147
Primfl	
Muacres	
Mu_perm	3.009
Mu_awc	3.662
Mu_kf	0.24
Muhsg_a	0.000
Muhsg_b	13.000
Muhsg_c	52.000
Muhsg_d	35.000
Mu_sand	0.00
Mu_silt	0.00
Mu_clay	0.00
Mu_bd	1.38
Mu_oc	0.000
Mu-permsurf	0.000000
Ids	033

The 'Attributes of Statsgo' table is also visible, with the following columns: Statsgo-id, Muid, Major1, Minor1, Polyid, Muhsg_dom, and Muname. The row for Statsgo-id 445 is highlighted in yellow, and a red callout box points to the 'Muhsg_dom' column, which contains the value 'C'. A red box also highlights the 'Muhsg_dom' column header.

Statsgo-id	Muid	Major1	Minor1	Polyid	Muhsg_dom	Muname
953	PA022	900	22	1201	C	HAZLETON-DEKALB-BUCHANAN (PA022)
971	PA056	900	56	903	C	GILPIN-BRINKERTON-CAVD
735	PA053	900	53	697	C	GILPIN-WHARTON-ERNEST
217	PA022	900	22	1197	C	HAZLETON-DEKALB-BUCHANAN (PA022)
440	PA054	900	54	1155	C	LECK KILL-CALVIN-KLINESVILLE (PA054)
445	PA033	900	33	1156	C	BERKS-WEIKERT-BEDINGTON (PA033)
981	PA027	900	27	912	B	CHENANGO-POPE-HOLLY (PA027)
445	PA033	900	33	1156	C	BERKS-WEIKERT-BEDINGTON (PA033)
366	PA022	900	22	1154	C	HAZLETON-DEKALB-BUCHANAN (PA022)
940	PA078	900	78	876	B	MORRISON-HAZLETON-CLYMER (PA078)
966	PA033	900	33	898	C	BERKS-WEIKERT-BEDINGTON (PA033)
846	PA078	900	78	876	B	MORRISON-HAZLETON-CLYMER (PA078)

FREE COUNTY SSURGO DATA

The screenshot shows the 'Soil Data Mart' website in a Microsoft Internet Explorer browser window. The address bar displays 'http://soildatamart.nrcs.usda.gov/'. The website header includes the NRCS logo and the text 'United States Department of Agriculture Natural Resources Conservation Service'. The current selection is 'OH099 - Mahoning County, Ohio Mahoning County Ohio'. Below the header, there are navigation links: 'Home', 'Select State', 'State Contacts', 'Template Databases', 'SSURGO Metadata', 'Status Map', 'Logon/Register', and 'Help'. The main content area prompts the user to 'Please select the class of data you wish to download: (Survey Area Version 6 , Tabular Version 6 , Spatial Version 3)'. Three radio buttons are present: 'Tabular Data Only', 'Tabular and Spatial Data' (which is selected), and 'Spatial Data Only'. Below this, there are two dropdown menus: 'Please select a spatial format:' with 'ArcView Shapefile' selected, and 'Please select a coordinate system:' with 'UTM Zone 17, Northern Hemisphere (NAD 83)' selected. A 'Reset Default' button is located to the right of these dropdowns. Below the dropdowns, there is a 'Please select a template database (optional):' section with a 'Clear Selection' button. A table lists available template databases for various states. The 'OH' row is highlighted. Below the table, a 'Description:' section provides details about the Ohio-specific template, including its compatibility with Microsoft Access 2002/2003 and Soil Data Viewer 5.0, and lists reports such as 'Source of Sand and Gravel (OH)' and 'Source of Reclamation Material, Roadfill, and Topsoil (OH)'. The browser's taskbar at the bottom shows the 'Internet' icon.

soildatamart.nrcs.usda.gov/

United States Department of Agriculture
NRCS Natural Resources Conservation Service

OH099 - Mahoning County, Ohio
Mahoning County
Ohio

Soil Data Mart

Home Select State State Contacts Template Databases SSURGO Metadata Status Map Logon/Register Help
US General Soil Map

Please select the class of data you wish to download: (Survey Area Version 6 , Tabular Version 6 , Spatial Version 3)

Tabular Data Only Tabular and Spatial Data Spatial Data Only Template Database Only

Please select a spatial format: ArcView Shapefile Please select a coordinate system: UTM Zone 17, Northern Hemisphere (NAD 83) Reset Default

Please select a template database (optional): Clear Selection

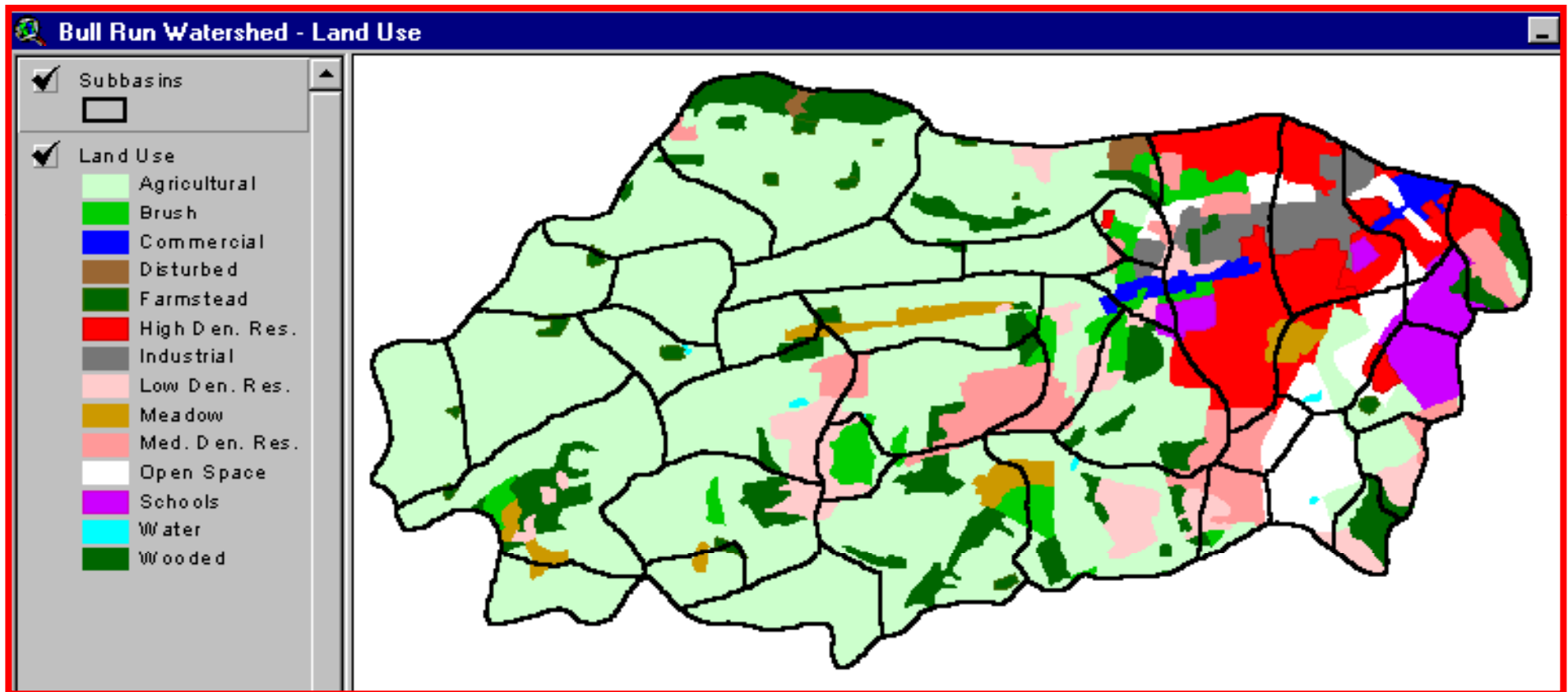
State	MS Access Version	Template DB Versio	Template DB Name	Size
MT	Access 97	31_1	soildb_MT_97	1.9M
NJ	Access 2002	32	soildb_NJ_2002	1.9M
NY	Access 2002	32.1	soildb_NY_2002	1.8M
OH	Access 2002	32	soildb_oh_2003	1.8M

Description: This template is customized so that the local (Ohio) versions of the reports are used and national reports that are not applicable to Ohio are hidden. It is for use with Microsoft Access 2002/2003. This database is compatible with Soil Data Viewer 5.0. This template includes Ohio versions of the following reports:

- Source of Sand and Gravel (OH)
- Source of Reclamation Material, Roadfill, and Topsoil (OH)

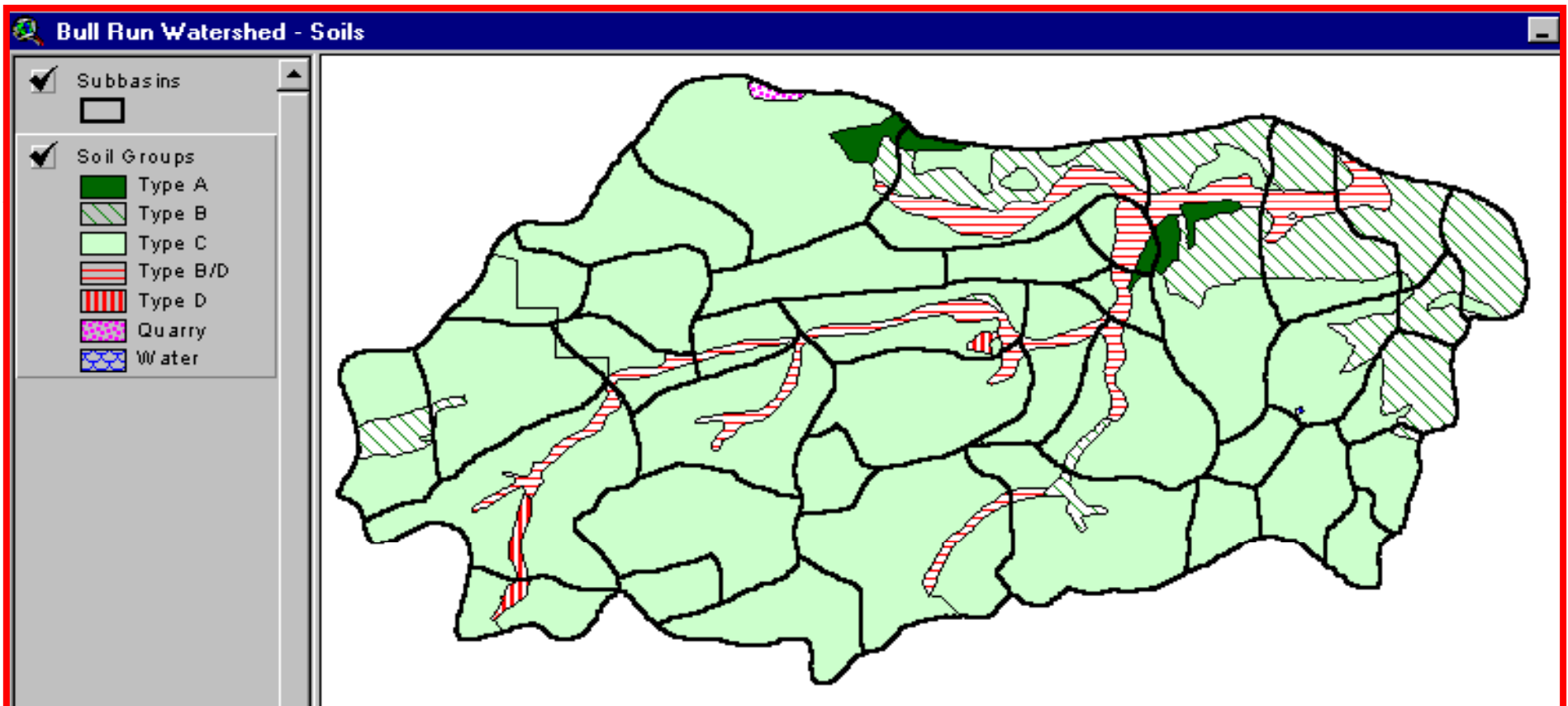
USING GIS FOR CN ESTIMATION

1. CREATE OR DOWNLOAD LAND USE LAYER



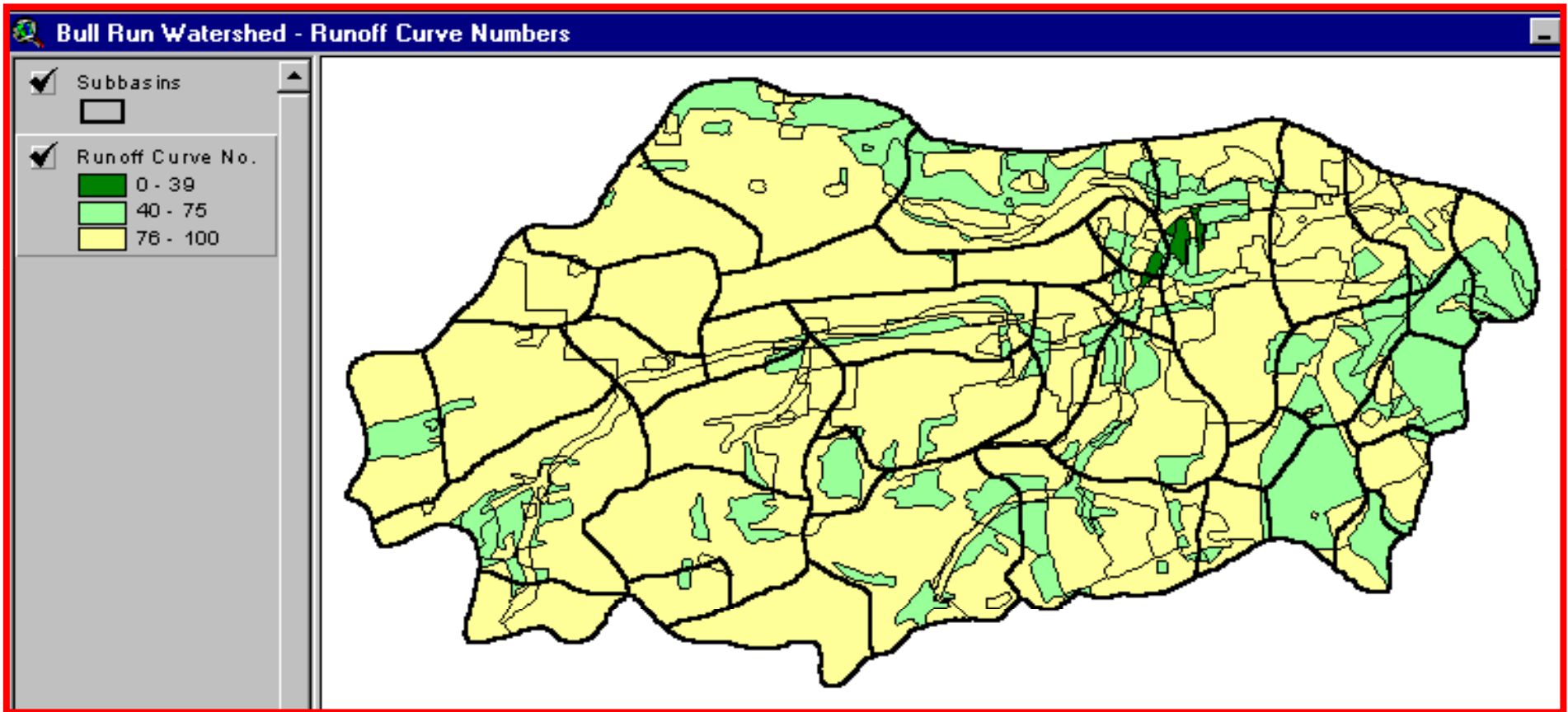
SCS HYDROLOGIC SOILS GROUPS

2. DOWNLOAD SSURGO SOILS LAYER AND MAP HSGs



RUNOFF CURVE NUMBERS

Intersect three layers: subbasins, soils (HSG), land use



Land Use	% Imp.	Runoff Curve Number for Hydrologic Soil			
		A	B	C	D
High density residential	51	69	80	87	90
Medium density residential	28	56	71	81	86
Low density residential	16	49	66	78	83

SOILS GIS DATA PAGES FROM MY BOOK

© Shamsi, 2009

GIS TOOLS FOR WATER, WASTEWATER, AND STORMWATER SYSTEMS



U.M. SHAMSI

ASCE
PRESS

SOILS GIS DATA

HOUSING AND URBAN DEVELOPMENT E-MAPS

U.S. Department of Housing and Urban Development (HUD) Healthy Communities Environmental Mapping E-Maps provide on-line information about HUD and EPA projects in communities throughout the United States. Data can be viewed from any community by using a variety of HUD and EPA categories. Maps can be scaled from a full region all the way down to the neighborhood level. E-Maps are an on-line interactive mapping service like USB's TIGER Map Service or EPA's Envirofacts. E-Maps consist of layers, which are discussed below.

HUD PROGRAM LAYERS

- Public and Native American housing
- Multifamily housing
- Community development projects

CENSUS BUREAU LAYERS

- Demographic data for states, counties, and census tracts

EPA LAYERS

- Superfund sites
- Brownfields site assessment pilots
- Brownfields tax incentive zones
- Air Releases/Aerometric Information Retrieval System (AIRS) facilities
- Toxic Releases/Toxic Release Inventory (TRI) facilities
- Hazardous waste handlers/Resource Conservation and Recovery Information System (RCRIS) facilities
- Discharges to water/Permit Compliance System (PCS) facilities
- Hazardous waste generators/Biennial Reporting System (BRS) facilities



E-Maps Web Site

HUD E-Maps	www.hud.gov/emaps
------------	--

NATURAL RESOURCES CONSERVATION SERVICE SOILS DATA

Soils data are used to estimate infiltration and erosion both of which affect the quantity and quality of runoff from watersheds and sewersheds.

Based on their resolution, there are three types of U.S. Natural Resources Conservation Service (NRCS) (formerly the U.S. Soil Conservation Service or SCS) soils data that are useful in GIS applications:

- National Soil Geographic (NATSGO)
- State Soil Geographic (STATSGO)
- Soil Survey Geographic (SSURGO)

SSURGO provides the highest resolution soils data at scales ranging from 1:12,000 to 1:63,360. This resolution is appropriate for watersheds a few squares miles in area. STATSGO data are digitized at 1:250,000 scale, which is useful when analyzing large regional watersheds. NATSGO data describe variations in soil type at the multi-state to regional scale, which is not suitable for wastewater and stormwater modeling applications (Moglen, 2000). Currently, the NRCS clearinghouse has approximately 1,100 digital soil datasets on-line with many more being processed.

STATSGO

STATSGO is a soil maps database designed for use in a GIS. This data set consists of georeferenced digital map data and attribute data. The map data are collected in 1- by 2-degree topographic quadrangle units and merged and distributed as statewide coverages. STATSGO represents a digital general soil association map developed by the National Cooperative Soil Survey.

STATSGO consists of a broad-based inventory of soils and non-soil areas that occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. The soil maps for STATSGO are compiled by generalizing more detailed soil survey maps. Where more detailed soil survey maps are not available, data on geology, topography, vegetation, and climate are assembled, together with LANDSAT satellite images. Soils of like areas are studied, and the probable classification and extent of the soils are determined. Map unit composition for a STATSGO map is determined by transecting or sampling areas on the more detailed maps and expanding the data statistically to characterize the whole map unit.

The STATSGO attributes are contained in the 16 relational tables shown in Table 5-6. File No. 2 (comp.dbf) contains data for hydrologic soils group (A, B, C, D). File No. 6 (layer.dbf) contains data for soil texture

SOILS GIS DATA

TOOLS FOR WATER, WASTEWATER, AND STORMWATER SYSTEMS

(sand, silt, and so on). The hydrologic soil group and texture data can be used to estimate watershed subbasin hydrologic parameters, such as runoff curve number and Green-Ampt infiltration parameters for input to hydrologic models.

Table 5-6. STATSGO Database Relational Tables

No.	Name	Description
1	codes.dbf	Database code: stores information on all codes used in the database
2	comp.dbf	Map unit component: stores information that will apply to a specific component of a soil map unit
3	compyld.dbf	Component crop yield: stores crop yield information for soil map unit components
4	forest.dbf	Forest understory: stores information for plant cover as forest understory for soil map unit components
5	interp.dbf	Interpretation: stores soil interpretation ratings (both limitation ratings and suitability ratings) to soil map unit
6	layer.dbf	Components layer: stores characteristics that apply to soil layers for soil map unit components
7	mapunit.dbf	Map unit: stores information that applies to all components of a soil map unit
8	plantcom.dbf	Plant composition: stores plant symbols and percentage of plant composition associated with components of soil map units
9	plantnm.dbf	Plant name: stores the common and scientific names for plants used in the database
10	rsprod.dbf	Range site production: stores range site production information for soil map unit components
11	taxclass.dbf	Taxonomic classification: stores the taxonomic classification for soils in the database
12	windbrk.dbf	Windbreak: stores information on recommended windbreak plants for soil map unit components
13	wlhabit.dbf	Wildlife habitat: stores wildlife habitat information for soil map unit components
14	woodland.dbf	Woodland: stores information on common indicator trees for soil map unit components
15	woodmgt.dbf	Woodland management: stores woodland management information for soil map unit components
16	yldunits.dbf	Yield units: stores crop names and the units used to measure yield

GIS TOOLS FOR WATER, WASTEWATER, AND STORMWATER SYSTI

149

Each STATSGO map is linked to the Soil Interpretations Record (SIR) attribute database. The attribute database gives the proportionate extent of the component soils and their properties for each map unit. The STATSGO map units consist of 1 to 21 components each. The SIR database includes more than 25 physical and chemical soil properties, interpretations, and productivity. Examples of information that can be queried from the database are available water capacity, soil reaction, salinity, flooding, water table, bedrock, and interpretations for engineering uses, cropland, woodland, rangeland, pastureland, wildlife, and recreation development.

Figure 5-14 shows a STATSGO soils map and database imported in ArcView GIS for a study area in southwestern Pennsylvania.

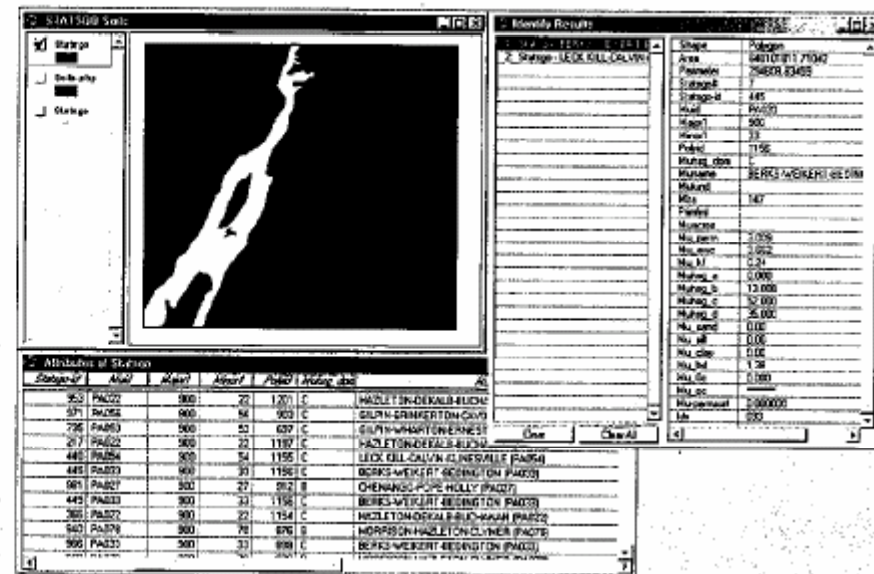


Figure 5-14. STATSGO Soils Map And Database Imported Into ArcView GIS for a Study Area In Pennsylvania

STATSGO data are available for the conterminous U.S., Hawaii, and Puerto Rico. STATSGO uses 1:250,000 USGS topographic quadrangles as basemap, so the mapping scale for the STATSGO geographic data is also 1:250,000. This scale is more suitable for regional planning applications covering state and multi-state areas. Each quadrangle area contains 100 to 400 soil polygons. The smallest mapped area is about

1,500 acres. STATSGO data are available in USGS DLG-3 optional distribution format, ArcInfo coverage, and GRASS vector formats (ASCE, 1999).

STATSGO data can be downloaded free from the local GIS data clearinghouse sites. For example, PASDA provides free STATSGO data for Pennsylvania in the ArcInfo exchange (E00) format. NRCS provides STATSGO data for 49 states and Puerto Rico on a CD-ROM for \$50. Data for Alaska is available on a separate CD-ROM.

SSURGO

SSURGO is the most detailed level of soil mapping done by NRCS. Field mapping methods using national standards are used to construct the soil maps in the SSURGO database. Mapping scales generally range from 1:12,000 to 1:63,360; SSURGO digitizing duplicates the original soil survey maps. This level of mapping is designed for use by landowners, townships, and county natural resource planning and management. SSURGO users are expected to be familiar with soils data and their characteristics.

Digitizing is done by line segment (vector) format in accordance with NRCS digitizing standards. The basemaps meet national map accuracy standards and are either orthophoto quadrangles or 7.5-min topographic quadrangles. SSURGO data are collected and archived in 7.5-min quadrangle units, and distributed as complete coverage for a soil survey area. Soil boundaries ending at quadrangle neatlines are joined by computer to adjoining maps to achieve an exact match.

SSURGO is linked to the National Map Unit Interpretation Records (MUIR) attribute database. The attribute database gives the proportionate extent of the component soils and their properties for each map unit. The SSURGO map units consist of one to three components each. MUIR data contain about 88 estimated soil physical and chemical properties, interpretations, and performance data. These include available water capacity; soil reaction; soil erodibility factors (K, Kf, and T); hydric soil ratings; ponding, flooding, water table depth and duration; bedrock; interpretations for sanitary facilities, building site development, engineering, cropland, woodland, and recreational development; and yields for common crops, site indices of common trees, and potential production of rangeland plants.

The map extent for a SSURGO data set is a soil survey area, which may consist of a county, multiple counties, or parts of multiple counties. A SSURGO data set consists of map data, attribute data, and metadata. SSURGO map data are available in modified DLG-3 optional and Arc interchange file formats. Attribute data are distributed in ASCII format

with DLG-3 map files and in ArcInfo interchange format with Arc interchange map files. Metadata are in ASCII format. SSURGO data can be downloaded from the NRCS Web site given below or ordered on a CD-ROM as described above for the STATSGO data.

STATSGO and SSURGO Data Applications

STATSGO and SSURGO data applications include the following:

- Soil mapping
- Estimation of soil infiltration parameters
- Estimation of runoff curve numbers
- Runoff estimation
- Hydrologic modeling



NRCS Web Sites

STATSGO	www.fw.nrcs.usda.gov/stat_data.html
SSURGO Download	www.fw.nrcs.usda.gov/ssurgo_fip3.html
SSURGO Data Access	www.fw.nrcs.usda.gov/ssur_data.html
National Soil Survey	www.statlab.iastate.edu/soils/nsdaf/

FEDERAL EMERGENCY MANAGEMENT AGENCY FLOOD DATA

The Federal Emergency Management Agency's (FEMA) Map Service Center (MSC) provides on-line distribution of their products. MSC products include: Digital Flood Insurance Rate Maps (DFIRM), Flood Insurance Rate Maps (FIRM), Flood Insurance Study (FIS) reports, Digital Q3 flood data, Community Status Book, Flood Map Status Information Service (FMSIS), Letters of Map Change (LOMC), and National Flood Insurance Program (NFIP) insurance Manuals. DFIRM and Q3 data have GIS applications and are described below.

DIGITAL FLOOD INSURANCE RATE MAPS DATA

The DFIRM is composed of all digital data required to create the hardcopy FIRM. This includes basemap information, graphics, text, shading, and other geographic and graphic data required to create the final hardcopy FIRM product to FEMA FIA-21 standards and specifications. This product serves the purpose of map design and provides the database from which the flood risk thematic data are extracted to create the DLG file for DFIRM. This product is generally produced in a county-wide format.

SAMPLE PROBLEM 1: COMPOSITE CURVE NO.

A 200 acre watershed is 40% agricultural and 60% urban land. The agricultural area is 40% cultivated land with conservation treatment, 35% meadow in good condition, and 25% forest land with good cover. The urban area is residential: 60% is 1/3 acre lots, 25% 1/4 acre lots and 15% is streets and roads with curbs and storm sewers. The entire watershed is in hydrologic soil group B. Compute the runoff from the watershed for 5 inches of rainfall. Assume AMC II conditions.



Solution:

Computation of the weighted curve number using Table 5.5.2.

LAND USE	%	% subarea	%	CN	Product
Agricultural	40%				
Cultivated land w/ conserv. treatm.		40%	16%	71	11.4
Meadow with good condition		35%	14%	58	8.1
Forest with good cover		25%	10%	55	5.5
Urban	60%				
1/3 acre lots		60%	36%	72	25.9
1/4 acre lots		25%	15%	75	11.3
Streets and roads w/ curbs and st. sw.		15%	9%	98	8.8
TOTAL			100%		71.0
					CN

$$CN := 71 \quad P := 5 \quad \text{inches}$$

$$S := \frac{1000}{CN} - 10 \quad S = 4.085$$

$$\begin{aligned}
 CN &= 0.40(0.40 \times 71 + 0.35 \times 58 + 0.25 \times 55) \\
 &+ 0.60(0.60 \times 72 + 0.25 \times 75 + 0.15 \times 98) \\
 &= 0.40(62.45) + 0.60(76.65) \\
 &= 24.98 + 45.99 \\
 &= 70.97 \\
 &\approx 71.0
 \end{aligned}$$

$$Q := \frac{(P - 0.2 \cdot S)^2}{(P + 0.8 \cdot S)} \quad Q = 2.116 \quad \text{inches}$$

$$\text{Direct runoff in acre-ft} = P_e \times A = (2.116/12) \times (200) = 35.27$$



SAMPLE PROBLEM 2: COMPOSITE CURVE NO.

Given Data

- ◆ Rainfall: 5 in.
- ◆ Area: 1000-ac
- ◆ Soils:
 - ◆ Class B: 50%
 - ◆ Class C: 50%
- ◆ Antecedent moisture: AMC(II)
- ◆ Land use
 - ◆ Residential
 - ◆ 40% with 30% impervious cover
 - ◆ 12% with 65% impervious cover
 - ◆ Paved roads: 18% with curbs and storm sewers
 - ◆ Open land: 16%
 - ◆ 50% fair grass cover
 - ◆ 50% good grass cover
 - ◆ Parking lots, etc.: 14%

Step 1. Calculate weighted (composite) curve number

Solution. Compute the weighted curve number using Table 5.5.2.

Land Use	Hydrologic soil group					
	B			C		
	%	CN	Product	%	CN	Product
Residential (30% impervious)	20	72	1440	20	81	1620
Residential (65% impervious)	6	85	510	6	90	540
Roads	9	98	882	9	98	882
Open land: Good cover	4	61	244	4	74	296
Fair cover	4	69	276	4	79	316
Parking lots, etc	7	98	686	7	98	686
	50		4038	50		4340

Calculate

- ◆ Runoff in inches

SAMPLE PROBLEM 2: COMPOSITE CURVE NO.

	Hydrologic Soil Group					
	B			C		
Land use	%	CN	Product	%	CN	Product
Residential (30% imp cover)	20	72	14.40	20	81	16.20
Residential (65% imp cover)	6	85	5.10	6	90	5.40
Roads	9	98	8.82	9	98	8.82
Open land: good cover	4	61	2.44	4	74	2.96
Open land: Fair cover	4	69	2.76	4	79	3.16
Parking lots, etc	7	98	6.86	7	98	6.86
Total	50		40.38	50		43.40

$$CN_{comp} = \sum_{j=1}^m C_j A_j$$

$$CN = 40.38 + 43.40 = 83.8$$

C_j = runoff curve number of j- th subarea

A_j = Area of j- th subarea (in acres or % in decimals (dimensionless))

m = number of subareas in the watershed

SAMPLE PROBLEM 2: COMPOSITE CURVE NO.

$$CN = 83.8$$

$$S = \frac{1000}{CN} - 10$$

$$S = \frac{1000}{83.8} - 10 = 1.93 \text{ in}$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(5 - 0.2 \times 1.93)^2}{5 + 0.8 \times 1.93} = 3.25 \text{ in}$$

Runoff = 3.25 in ANSWER



SAMPLE PROBLEM 3: WET AMC

◆ Previous Problem: Average AMC

◆ This Problem: Wet AMC or AMC III

◆ From Eq. 20.42

$$CN(III) = \frac{23CN(II)}{10 + 0.13CN(II)} = \frac{23 \times 83.8}{10 + 0.13 \times 83.8} = 92.3$$

CN in Pr. 1 = 83.8;
larger CN than for
AMC II (normal)
conditions.
Wet soil → more
imperviousness

$$S = \frac{1000}{92.3} - 10 = 0.83 \text{ in}$$

S in Pr. 1 = 1.93; less storage than for AMC II (normal) conditions.
Wet soil → less infiltration → less storage in soil

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} = \frac{(5 - 0.2 * 0.83)^2}{5 + 0.8 * 0.83} = \boxed{4.13 \text{ in}} \quad \text{ANSWER}$$

Q in Pr. 1 = 3.25; more runoff than for AMC II (normal) conditions.
Wet soil → less infiltration → more runoff

INTERNET RESOURCES

Runoff Tools - Microsoft Internet Explorer
Address: <http://danpatch.ecn.purdue.edu/~sprawl/Tools/index.htm>

Index of Erosion Control Structures

The following links provide design information on various erosion control and water management structures. After filling out a few forms, the programs will generate approximate sizes of the structure (size is based on the information you provide).

This site was developed by Keith Sullivan, Agricultural and Biological Engineering Department, Purdue University. Send comments and suggestions to sull@ecn.purdue.edu. Plans do include expanding the number of states.

- [Rational Method](#)
- [SCS Method](#)
- [Rainfall Depths for Midwest and North Carolina](#)
- [Grass Lined Channels](#)
- [Culverts](#)
- [Sediment Basins](#)

Design Runoff Rate Calculation - Microsoft Internet Explorer
Address: <http://danpatch.ecn.purdue.edu/~sprawl/Tools/SCS/input.htm>

Design Runoff Calculations Using the SCS CN Method

Run Name:

Number of similar hydrological response zones:

Other, please specify:

Source of design rainfall information:
P40 by county

Do you wish to calculate peak discharge?

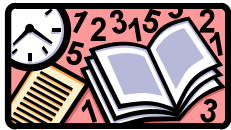
Which units would you prefer?

<http://danpatch.ecn.purdue.edu/~sprawl/Tools/index.htm>
11/12/09

SUGGESTED READING: CHAPTER 19

- ◆ 10 to 12. Unit Hydrographs
- ◆ 18 to 20. Reservoir sizing

PRACTICE EXAM



PRACTICE EXAM HYDROLOGY (CHAPTER 20)

Unlike a pond with a permanent pool of water, a dry basin fills during a storm and empties completely through an outlet at the bottom of the basin. Based on field studies by Environmental Protection Agency (EPA) it appears that a properly designed dry basin can be expected to remove 50% to 70% total suspended solids (TSS), 20% to 40% organic matter, and 75% to 90% lead.

A 100 acre residential development has a runoff coefficient of 0.50. The mean annual rainfall volume is 1.0 inches and the mean annual rainfall intensity is 0.2 inches/hour.

1. Volume of rainfall (cubic feet) is:

- (A) 181,500
- (B) 363,000
- (C) 0.0006
- (D) 4,356,000
- (E) 2,178,000

2. Volume of runoff (inches) is:

- (A) 1.0
- (B) 100.0
- (C) 0.50
- (D) 0.2
- (E) 20

3. Volume of runoff (cubic feet) is:

- (A) 181,500
- (B) 90,750
- (C) 0.0003
- (D) 2,178,000
- (E) 1,089,000

4. The "design" volume is defined as the volume of the dry basin required to detain the runoff from a storm which is twice as severe as an average

storm. The design volume (cubic feet) is:

- (A) 181,500
- (B) 0.0006
- (C) 4,356,000
- (D) 2,178,000
- (E) 363,000

5. Based on EPA data, the design volume (cubic feet) to remove 60% TSS, 30% organic matter, and 80% Lead is:

- (A) 363,000
- (B) 181,500
- (C) 2,178,000
- (D) 1,089,000
- (E) 4,356,000

6. Based on EPA data, the design volume (cubic feet) to remove 100% TSS is:

- (A) 605,000
- (B) 302,500
- (C) 363,000
- (D) 0
- (E) none of the above

7. The basin should overflow only when the design volume is exceeded. If only one acre of land is available to construct the basin and if the bottom of the basin is at an elevation of 100.00 feet, the crest elevation of an overflow weir (feet) should be most nearly:

- (A) 8
- (B) 104
- (C) 108
- (D) 4
- (E) 10

8. The overflow should be:

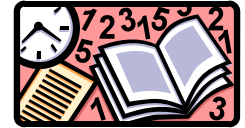
- (A) treated
- (B) discharged to river
- (C) recycled
- (D) spilled for overland flow
- (E) abandoned

9. If the detained water should drain in no less than 40 hours, the diameter (in inches) of the bottom outlet should be most nearly (assume hydraulic head = depth of the basin, and orifice discharge coefficient = 0.60):

- (A) 3
- (B) 6
- (C) 12
- (D) 24
- (E) 0

10. More pollutants can be removed from the design storm, if:

- (A) overflow elevation is increased
- (B) overflow elevation is decreased
- (C) size of the bottom outlet is increased
- (D) size of the bottom outlet is decreased
- (E) none of the above



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

Unlike a pond with a permanent pool of water, a dry basin fills during a storm and empties completely through an outlet at the bottom of the basin. Based on field studies by Environmental Protection Agency (EPA) it appears that a properly designed dry basin can be expected to remove 50% to 70% total suspended solids (TSS), 20% to 40% organic matter, and 75% to 90% lead.

A 100 acre residential development has a runoff coefficient of 0.50. The mean annual rainfall volume is 1.0 inches and the mean annual rainfall intensity is 0.2 inches/hour.

Ref.: Storm Water Detention For Drainage, Water Quality, and CSO Management. Peter Stahre and Ben Urbonas, Prentice Hall, 1990.

➤ **Given Data:**

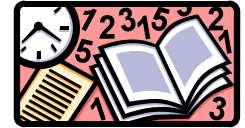
Dry basin pollutant removal rates: 50-70% TSS, 20-40% OM, 75-90% lead

$$A_d = 100 \text{ ac}$$

$$C = 0.50$$

$$P = 1.0 \text{ in}$$

$$I = 0.2 \text{ in/hr}$$



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

1. Volume of rainfall (cubic feet) is:

- A. 181,500
- B. 363,000
- C. 0.0006
- D. 4,356,000
- E. 2,178,000

Volume of rainfall (cubic feet)

= Depth of rainfall x area

= $(1/12)$ ft x $(100 \times 43,560)$ ft²

= 363,000 cubic feet

Correct Answer: B

2. Volume of runoff (inches) is:

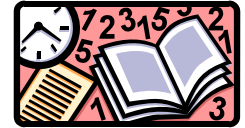
- A. 1.0
- B. 100.0
- C. 0.50
- D. 0.2
- E. 20

Volume of runoff in inches

= volume of rainfall in inches x runoff coefficient

= $1.0 \times 0.50 = 0.50$ inches

Correct Answer: C



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

3. Volume of runoff (cubic feet) is:

- A. 181,500
- B. 90,750
- C. 0.0003
- D. 2,178,000
- E. 1,089,000

Volume of runoff in cubic feet

= area (ft²) x rainfall (ft) x runoff coefficient

= (100 x 43560) x (1/12) x 0.50 = 181,500 cubic feet

Correct Answer: A

4. The "design" volume is defined as the volume of the dry basin required to detain the runoff from a storm which is twice as severe as an average storm. The design volume (cubic feet) is:

- A. 181,500
- B. 0.0006
- C. 4,356,000
- D. 2,178,000
- E. 363,000

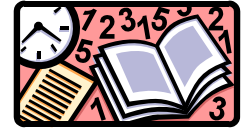
- **Runoff volume = 181,500 from Question 3**
- **Example of cascading question: If your answer for Q3 was wrong, this answer may also be wrong.**

Design volume

= 2 x volume of runoff from the average (mean annual) storm

= 2 x 181,500 (From Q3) = 363,000 cubic feet

Correct Answer: E



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

5. Based on EPA data given below, the design volume (cubic feet) to remove 60% TSS, 30% organic matter, and 80% Lead is:

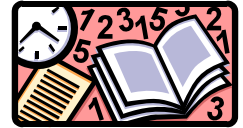
- A. 363,000
- B. 181,500
- C. 2,178,000
- D. 1,089,000
- E. 4,356,000

- *Basin design volume = 363,000 from Question 4*
- *Example of cascading question: If your answer for Q4 was wrong, this answer may also be wrong.*

Pollutant	Target Pollutant Removal Rate	EPA Removal Rates
TSS	60%	50% to 70%
Organic matter	30%	20% to 40%
Lead	80%	75% to 90%

- Since all the target removal rates are within EPA removal rate ranges, the design volume estimated in Q4 will be sufficient
- Design volume = 363,000 cubic feet (From Q4)

Correct Answer: A



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

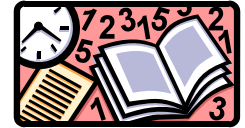
6. Based on EPA data, the design volume (cubic feet) to remove 100%

TSS:

- A. 605,000
- B. 302,500
- C. 363,000
- D. 0
- E. None of the above

➤ 100% removal of TSS is outside the 50% to 70% removal rate reported by EPA. Thus regardless of the design volume, this removal rate cannot be achieved.

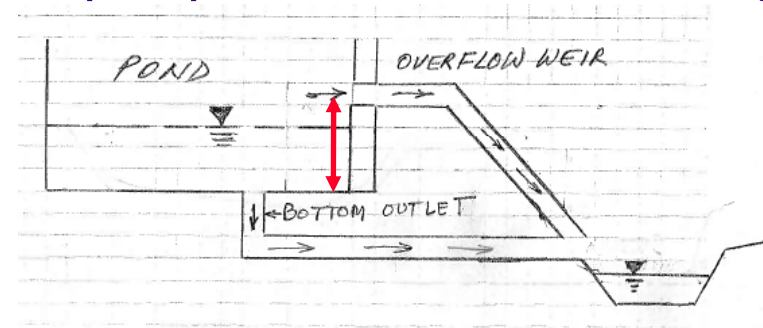
Correct Answer: E



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

7. The basin should overflow only when the design volume is exceeded. If only one acre of land is available to construct the basin and if the bottom of the basin is at an elevation of 100.00 feet, the crest elevation of an overflow weir (feet) should be most nearly:

- A. 8
- B. 104
- C. 108
- D. 4
- E. 10



➤ Depth of basin = design volume / surface area

$$= \frac{363,000}{(1 \times 43560)} \quad (1 \text{ acre} = 43,560 \text{ ft}^2)$$

$$= 8.33 \text{ ft}$$

➤ Overflow elevation = elevation at bottom of basin + depth of basin

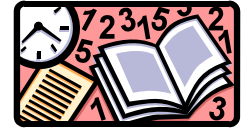
$$= 100 + 8.33$$

$$= 108.33$$

$$\approx 108$$

Correct Answer: C

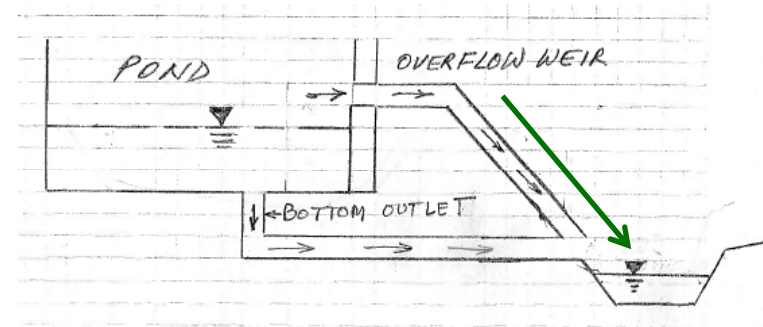
- *Basin design volume = 363,000 from Question 4*
- *Example of cascading question: If your answer for Q4 was wrong, this answer may also be wrong.*



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

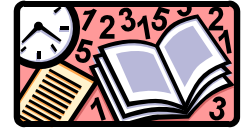
8. The overflow should be:

- A. Treated
- B. Discharged to river
- C. Recycled
- D. Spilled for overland flow
- E. Abandoned



- **A. Treated:** Not correct. If treatment was a feasible option, the detention basin would not have been considered.
- **B. Discharged to river:** Correct. Had there been no detention, the runoff was going to end up in the river anyways.
- **C. Recycled:** Not correct. Cannot recycle because there is no pumping.
- **D. Spilled for overland flow:** Not correct. Spilling on the ground is not a good option as it will cause flooding.
- **E. Abandoned:** Not correct. Overflow cannot be abandoned because it is an integral (required) part of the detention facility.

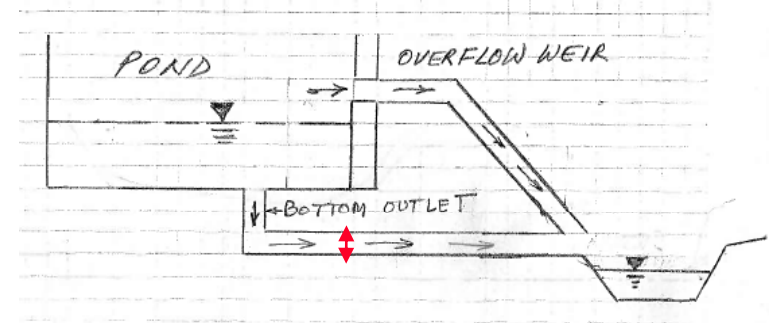
Correct Answer: B



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

9. If the detained water should drain in no less than 40 hours, the diameter (in inches) of the bottom outlet should be most nearly (assume hydraulic head = depth of the basin, and orifice discharge coefficient = 0.60):

- A. 3
- B. 6
- C. 12
- D. 24
- E. 0



➤ Maximum discharge rate from the bottom outlet

$$= (\text{design volume}) / (\text{detention time})$$

$$= \underline{363,000} / (40 \times 60 \times 60) = 2.52 \text{ ft}^3/\text{s (cfs)}$$

➤ Orifice equation for bottom outlet

$$Q_o = C_o \times A_o \times (2 \times g \times h)^{1/2} \dots \text{Eq. 17.75}$$

$$2.52 = 0.60 \times A_o \times (2 \times 32.2 \times \underline{8.33})^{1/2}$$

$$A_o = 0.18 \text{ ft}^2$$

$$(\pi/4) d_o^2 = 0.18$$

$$d_o = 0.47 \text{ ft} \approx 6 \text{ in}$$

Correct Answer: B

- *Basin design volume = 363,000 from Question 4*
- *Hydraulic head = 8.33 from Question 7*
- *Example of cascading question: If your answer s for Q4 and Q7 were wrong, this answer may also be wrong.*



PRACTICE EXAM: HYDROLOGY (CHAPTER 20)

10. More pollutants can be removed from the design storm, if:

- A. Overflow elevation is increased
 - B. Overflow elevation is decreased
 - C. Size of the bottom outlet is increased
 - D. Size of the bottom outlet is decreased
 - E. None of the above
- More pollutants can be removed if design storm is detained for a longer period of time. This is possible only by decreasing the size of the bottom outlet.

Correct Answer: D