Introduction to Hydrology

CE 413 – Environmental River Mechanics

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Hydrological Cycle

- What makes up the hydrological cycle?
  - **Precipitation**
  - Evaporation
  - Transpiration
  - **Infiltration/Percolation**
  - Subsurface Runoff
  - **Surface Runoff**

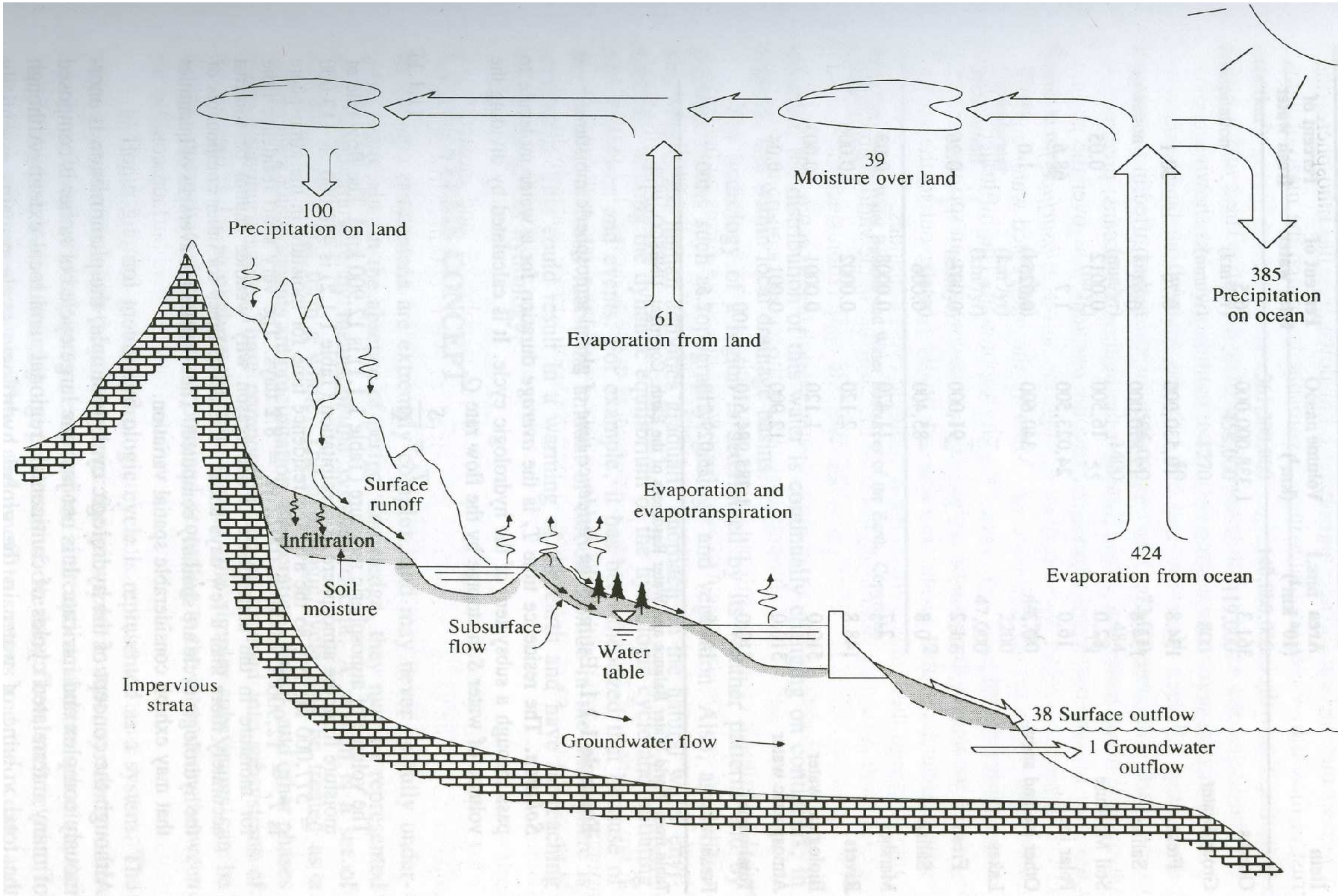


FIGURE 1.1.1
Hydrologic cycle with global annual average water balance given in units relative to a value of 100 for the rate of precipitation on land.

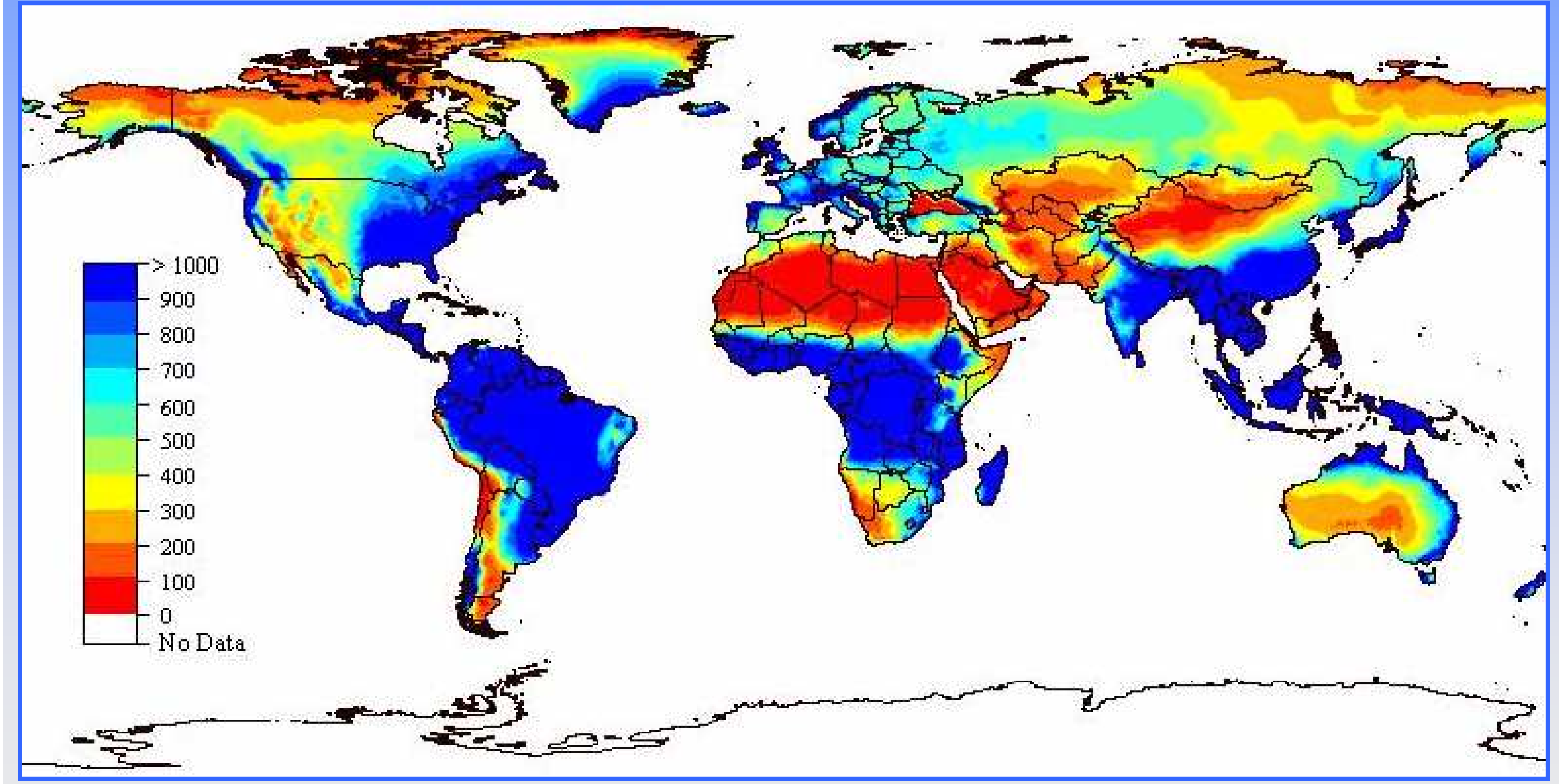
Source: Applied Hydrology

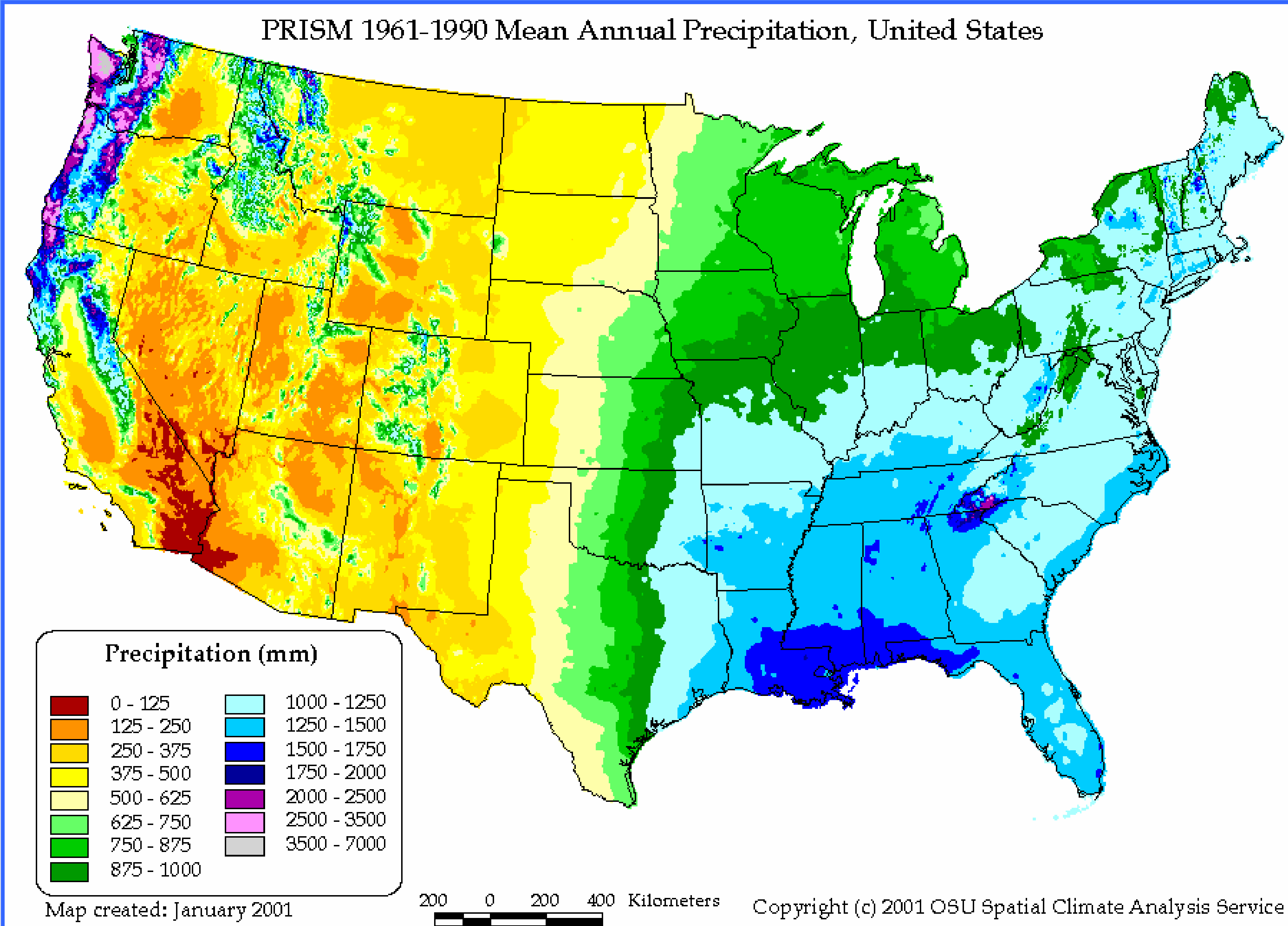
TABLE 1.1.1
Estimated world water quantities

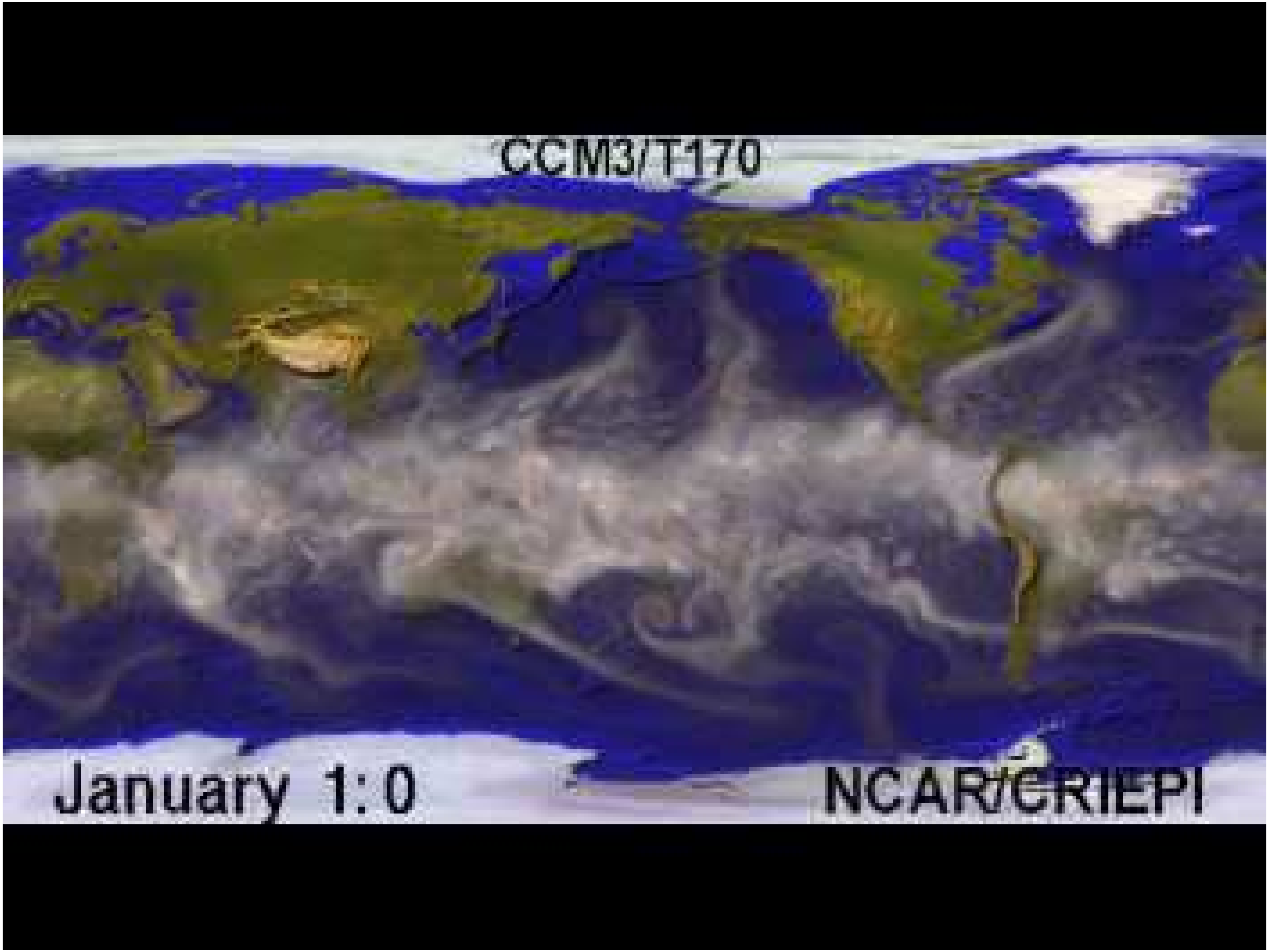
Item	Area (10^6 km^2)	Volume (km^3)	Percent of total water	Percent of fresh water
Oceans	361.3	1,338,000,000	96.5	
Groundwater				
Fresh	134.8	10,530,000	0.76	30.1
Saline	134.8	12,870,000	0.93	
Soil Moisture	82.0	16,500	0.0012	0.05
Polar ice	16.0	24,023,500	1.7	68.6
Other ice and snow	0.3	340,600	0.025	1.0
Lakes				
Fresh	1.2	91,000	0.007	0.26
Saline	0.8	85,400	0.006	
Marshes	2.7	11,470	0.0008	0.03
Rivers	148.8	2,120	0.0002	0.006
Biological water	510.0	1,120	0.0001	0.003
Atmospheric water	510.0	12,900	0.001	0.04
Total water	510.0	1,385,984,610	100	
Fresh water	148.8	35,029,210	2.5	100

Table from World Water Balance and Water Resources of the Earth, Copyright, UNESCO, 1978.

Average Annual Precipitation




PRISM 1961-1990 Mean Annual Precipitation, United States
Precipitation (mm)
0 - 125
125 - 250
250 - 375
375 - 500
500 - 625
625 - 750
750 - 875
875 - 1000
1000 - 1250
1250 - 1500
1500 - 1750
1750 - 2000
2000 - 2500
2500 - 3500
3500 - 7000
Map created: January 2001
200 0 200 400 Kilometers
Copyright (c) 2001 OSU Spatial Climate Analysis Service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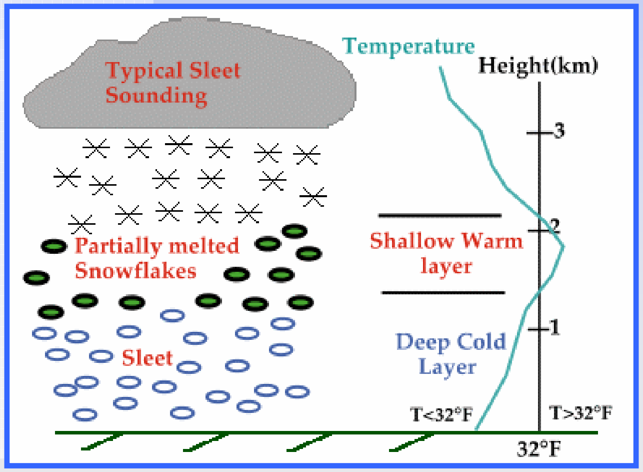
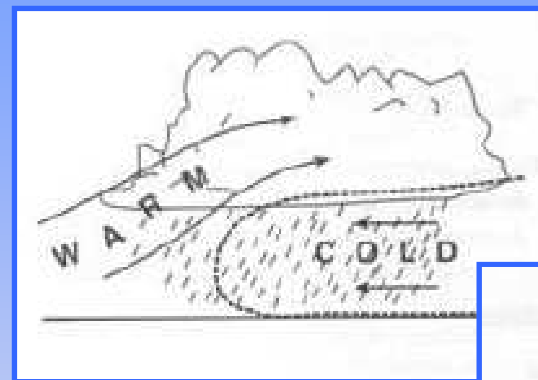
Different forms of Precipitation

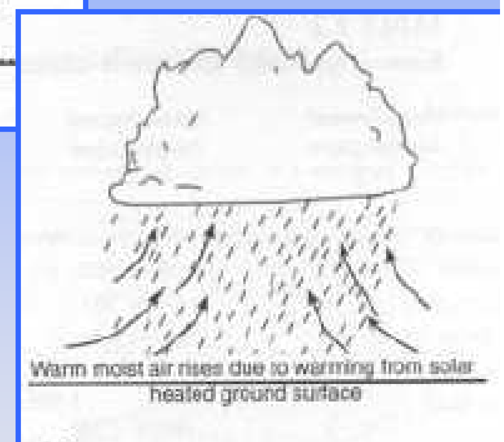
- Rain
- Drizzle
- Freezing Rain
- Hail
- Sleet
- Snow

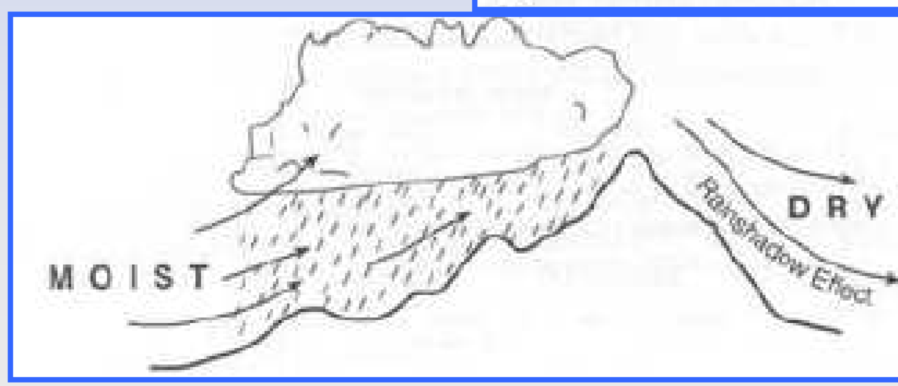


Precipitation Mechanisms
Frontal Activity

- Frontal Storm - results from warm air passing over cold air
- Convective Storm – caused by the sun heating the surface, thus resulting in warm moist air rises.
- Orographic Storm – caused by an air mass being forced from a low elevation to a higher elevation. As the air rises it cools, and cannot hold the moisture.







Examples of Rainfall Measurement Devices

Standard Rain Gauge

Weighing Gauge

Tipping Bucket

Characteristics of Precipitation

- Duration - Measured in units of minutes or hours
- Depth - Measured in units if mm or inches
- Rate Intensity - Measured in units of mm/hr or inch/hr
- Storm Frequency– Describe the probability of occurrence

Calculation of Maximum Precipitation

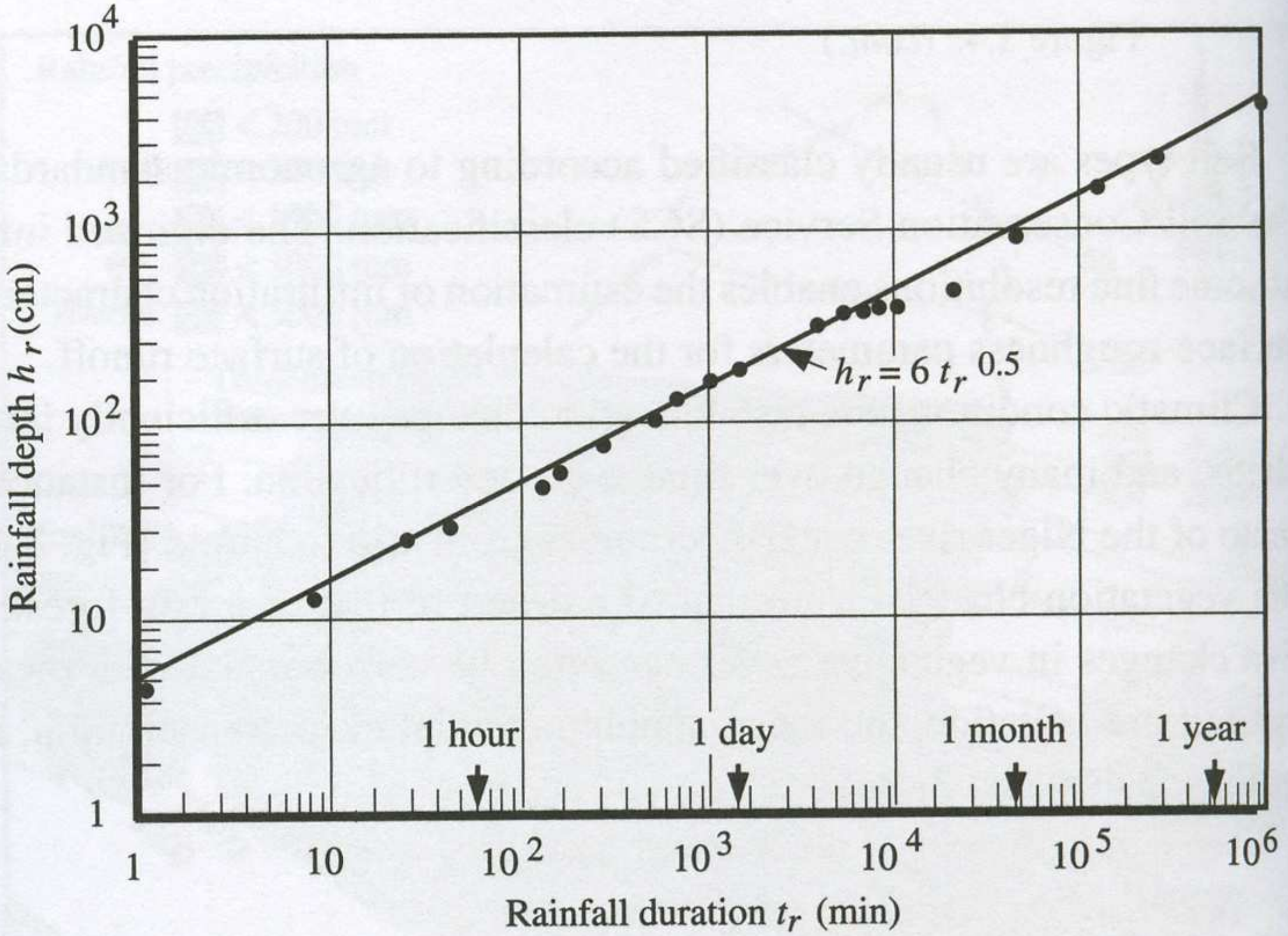
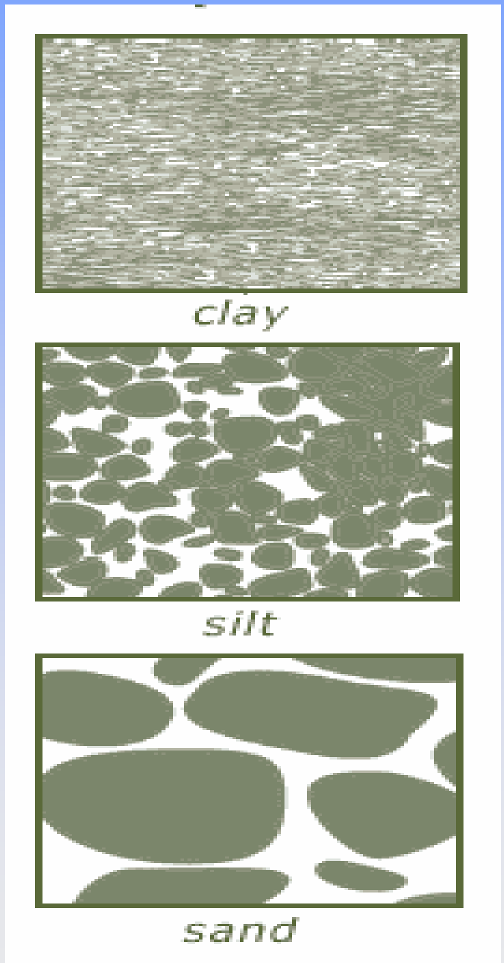


Figure 3.6. Maximum precipitation as a function of rainfall duration.

Infiltration

- Vegetative Cover
- Soil
  - Surface
  - Porosity
  - Hydraulic Conductivity
  - Moisture Content

Porosity



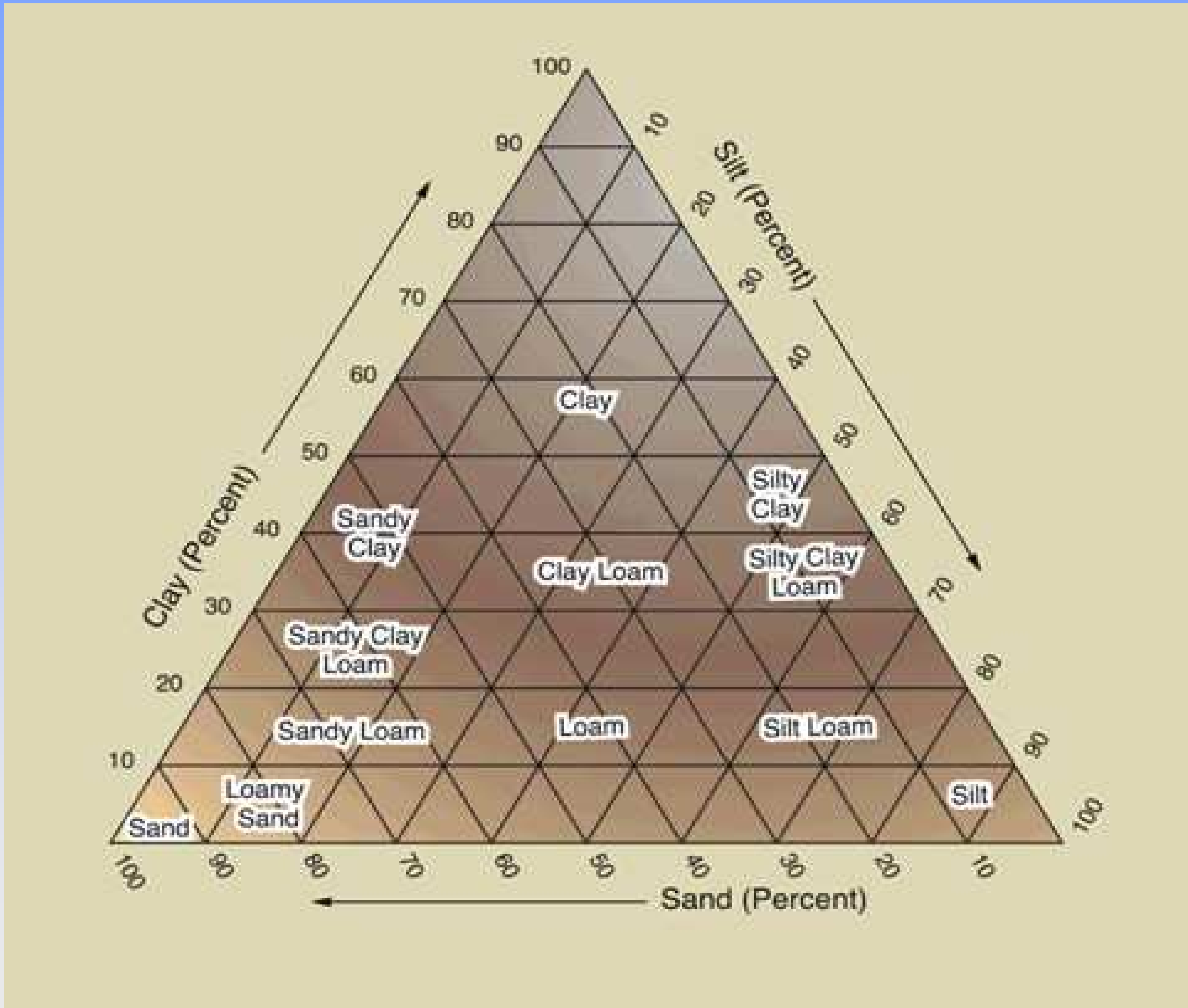
$$p_o = \frac{V_v}{V_t}$$

Porosity Ranges for Sediments

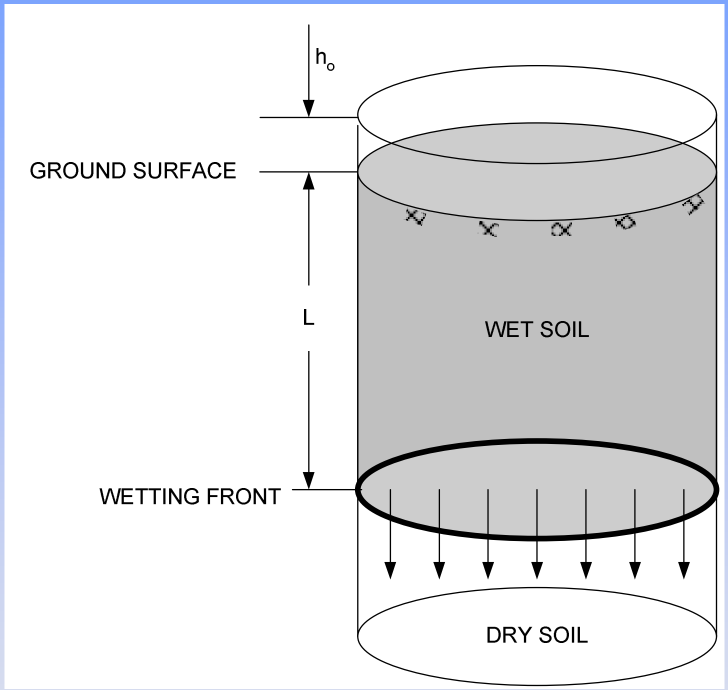
Material	Porosity (%)
well-sorted sand or gravel	25-50
sand and gravel, mixed	20-35
glacial till	10-20
silt	35-50
clay	33-60

(Based on Meinzer (1923a); Davis (1969); Cohen (1965); and MacCary and Lambert (1962) as quoted by C.W. Fetter [2])

Soil Texture



Green Ampt Method



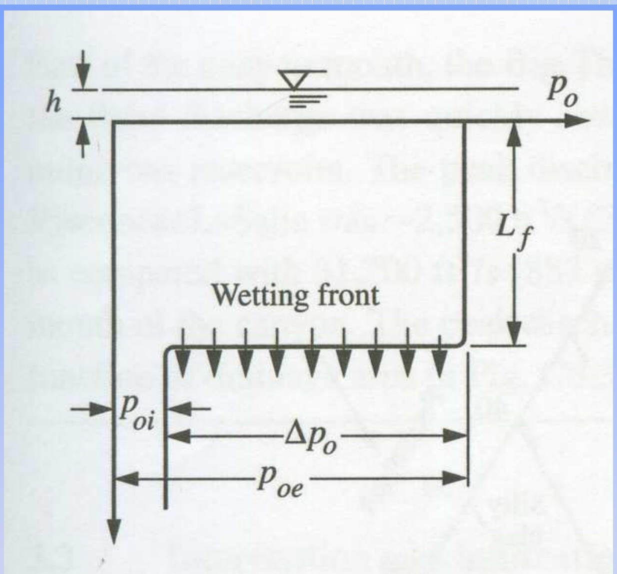


Figure 3.14. Piston-type infiltration approximation.

$$f(t) = K\left(\frac{h_p \Delta p_o}{F(t)} + 1\right)$$

$$F(t) = Kt + h_p \Delta p_o \ln\left(1 + \frac{F(t)}{h_p \Delta p_o}\right)$$

$$\Delta p_o = (1 - S_e) p_e$$

Parameters

TABLE 4.3.1
Green-Ampt infiltration parameters for various soil classes

Soil class	Porosity p_o	Effective porosity p_{oe}	Wetting front soil suction head h_p (cm)	Hydraulic conductivity K (cm/h)
Sand	0.437 (0.374–0.500)	0.417 (0.354–0.480)	4.95 (0.97–25.36)	11.78
Loamy sand	0.437 (0.363–0.506)	0.401 (0.329–0.473)	6.13 (1.35–27.94)	2.99
Sandy loam	0.453 (0.351–0.555)	0.412 (0.283–0.541)	11.01 (2.67–45.47)	1.09
Loam	0.463 (0.375–0.551)	0.434 (0.334–0.534)	8.89 (1.33–59.38)	0.34
Silt loam	0.501 (0.420–0.582)	0.486 (0.394–0.578)	16.68 (2.92–95.39)	0.65
Sandy clay loam	0.398 (0.332–0.464)	0.330 (0.235–0.425)	21.85 (4.42–108.0)	0.15
Clay loam	0.464 (0.409–0.519)	0.309 (0.279–0.501)	20.88 (4.79–91.10)	0.10
Silty clay loam	0.471 (0.418–0.524)	0.432 (0.347–0.517)	27.30 (5.67–131.50)	0.10
Sandy clay	0.430 (0.370–0.490)	0.321 (0.207–0.435)	23.90 (4.08–140.2)	0.06
Silty clay	0.479 (0.425–0.533)	0.423 (0.334–0.512)	29.22 (6.13–139.4)	0.05
Clay	0.475 (0.427–0.523)	0.385 (0.269–0.501)	31.63 (6.39–156.5)	0.03

The numbers in parentheses below each parameter are one standard deviation around the parameter value given. *Source:* Rawls, Brakensiek, and Miller, 1983.

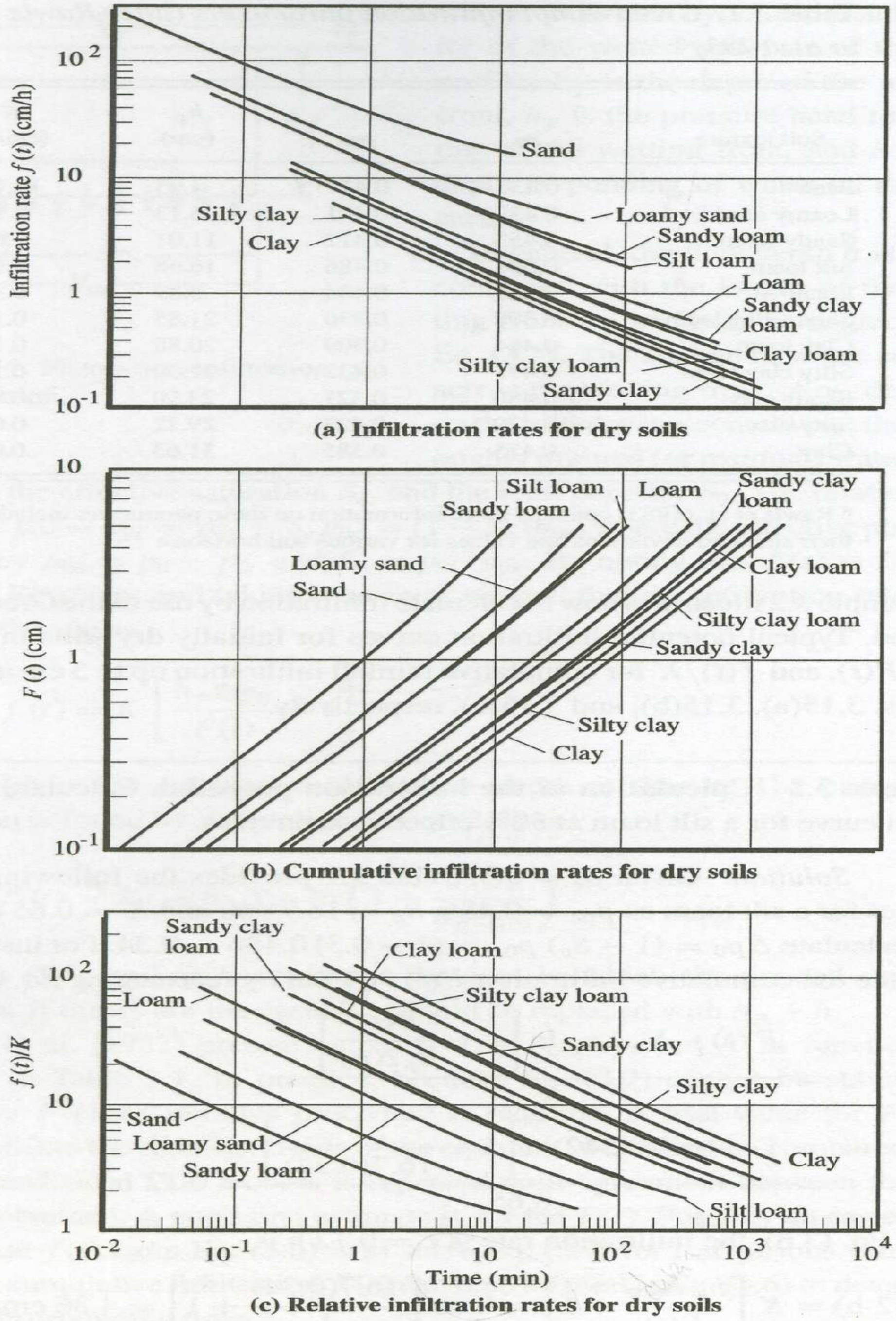
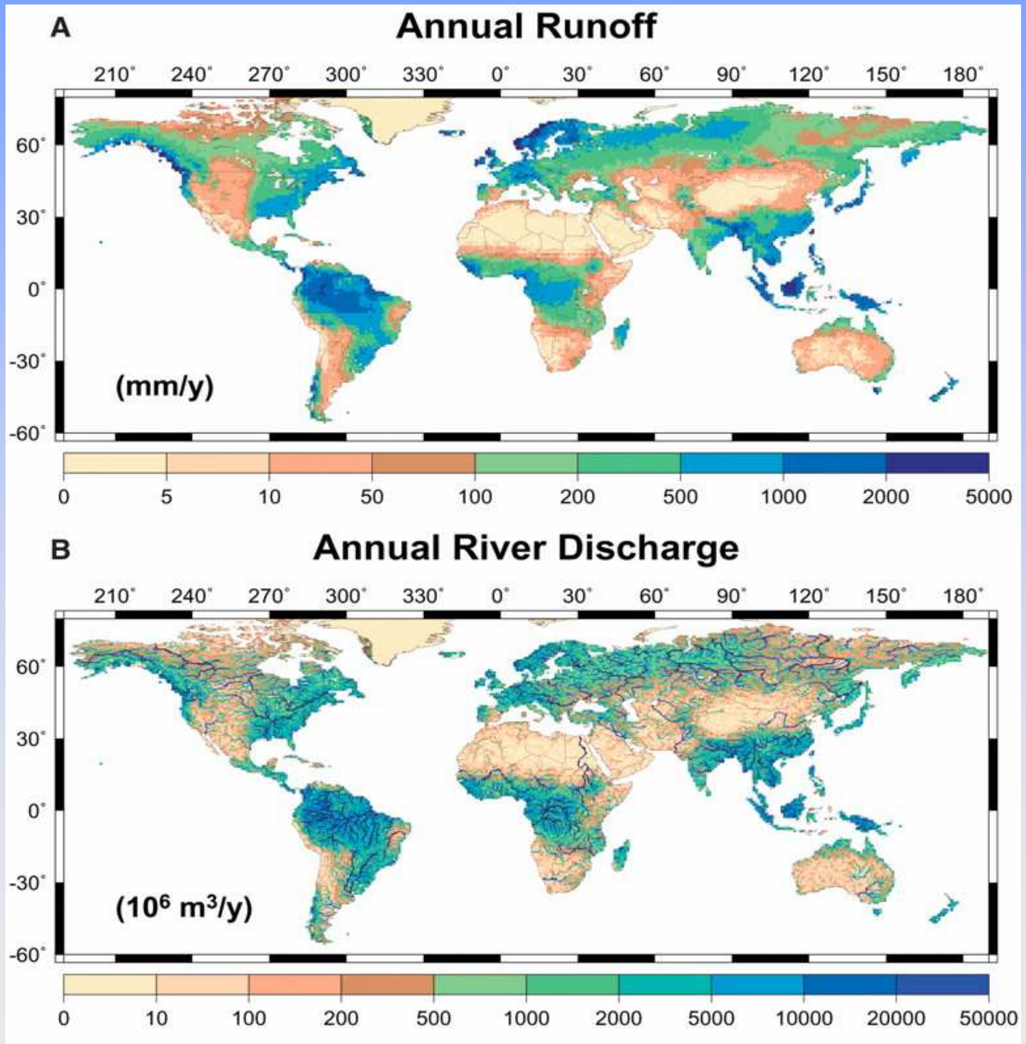


Figure 3.15. Infiltration characteristics for dry soils.

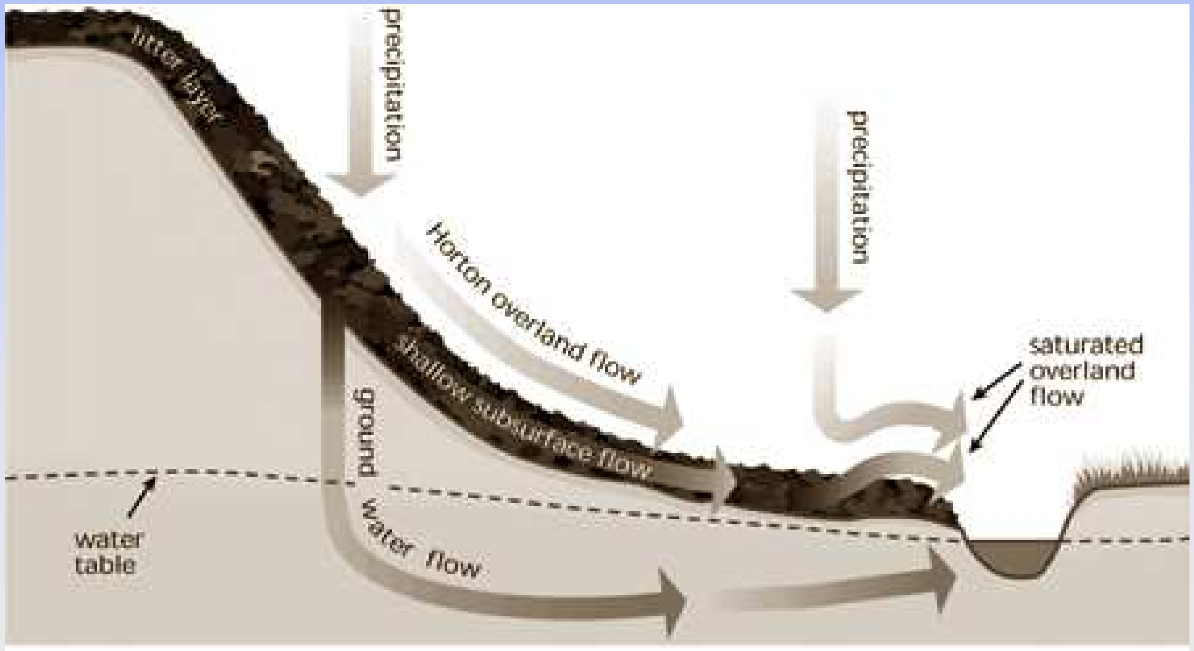
IN CLASS EXAMPLE

Surface Runoff



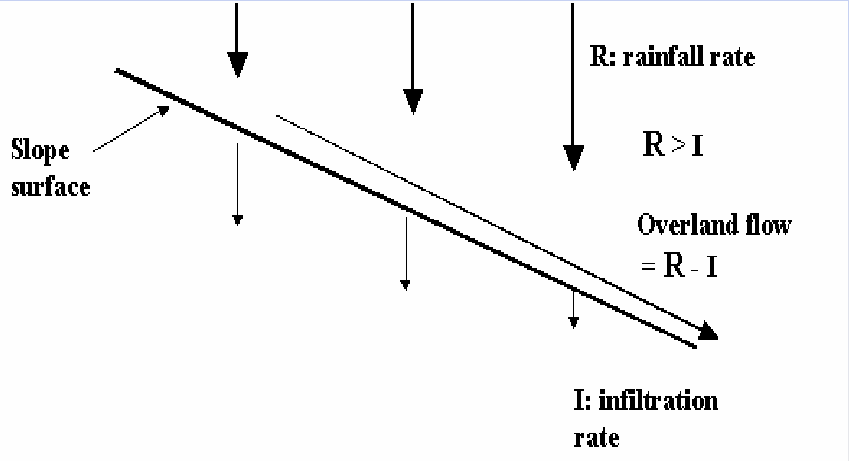
How Water Reaches the Stream

- Hortonian Flow
- Subsurface Flow
- Saturated Overland Flow



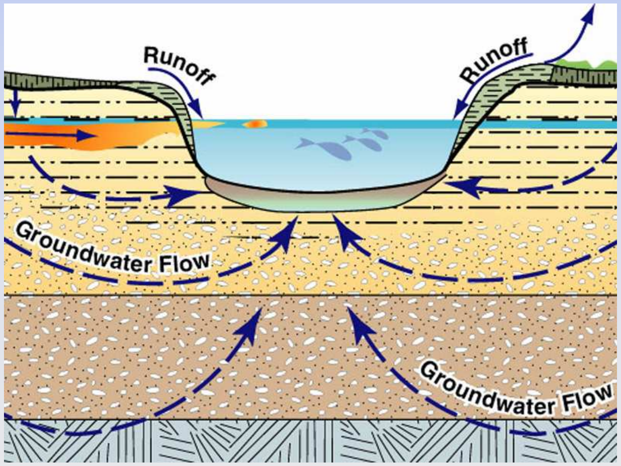
Hortonian Overland Flow

- Rainfall Intensity > Infiltration Rate
- Mode of ground saturation is flow precipitation
- Flow is transported as sheet flow
- There is detention sites located throughout the watershed which may result in flow infiltrating.
- Common in urban areas and natural areas where the soil layer is thin and has a low infiltration capacity
- Semiarid to Arid Regions



Subsurface Flow

- Rainfall intensity < Infiltration
- Flow is transported through pores in the soil
- Results in lower flows except when root holes and animal holes are present.
- Common in areas with higher vegetative cover
- Humid Environments



Saturated Overland Flow

- **Saturated Overland Flow**:
- Soil is completely saturated
- Mode of ground saturation is subsurface
- Flow is transported as sheet flow
- Common near the bottom of hill slopes and near channels.
- Continuous storm event

Rational Method

Rough calculation of the expected discharge at a given location

$$Q = CiA$$

Q - peak flow (cfs)

C - dimensionless runoff coefficient.

i - rainfall intensity (in/hr)

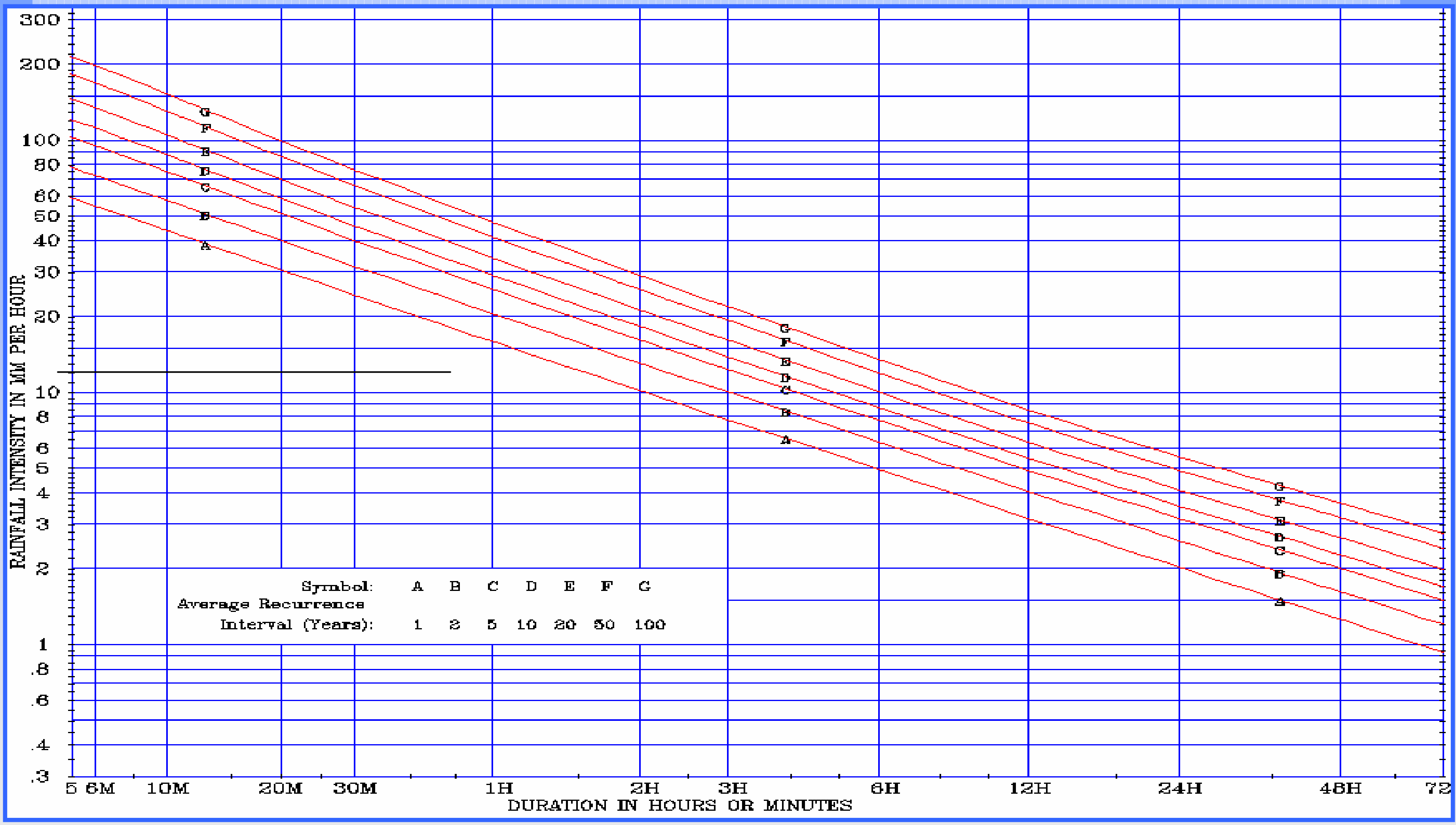
A - catchment area (acres)

Runoff Coefficient

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.)							
Poor condition (grass cover less than 50% of the area)							
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
Fair condition (grass cover on 50% to 75% of the area)							
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
Good condition (grass cover larger than 75% of the area)							
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

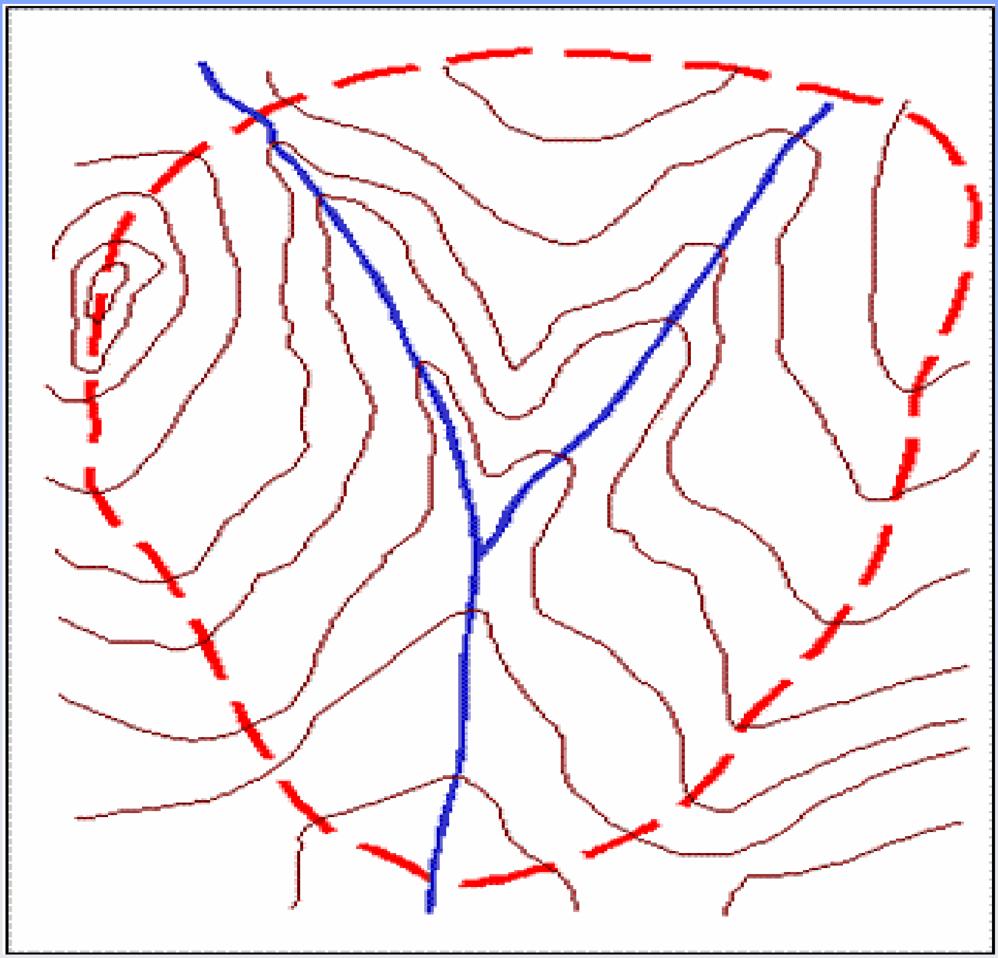
Note: The values in the table are the standards used by the City of Austin, Texas. Used with permission.

IDF Curve



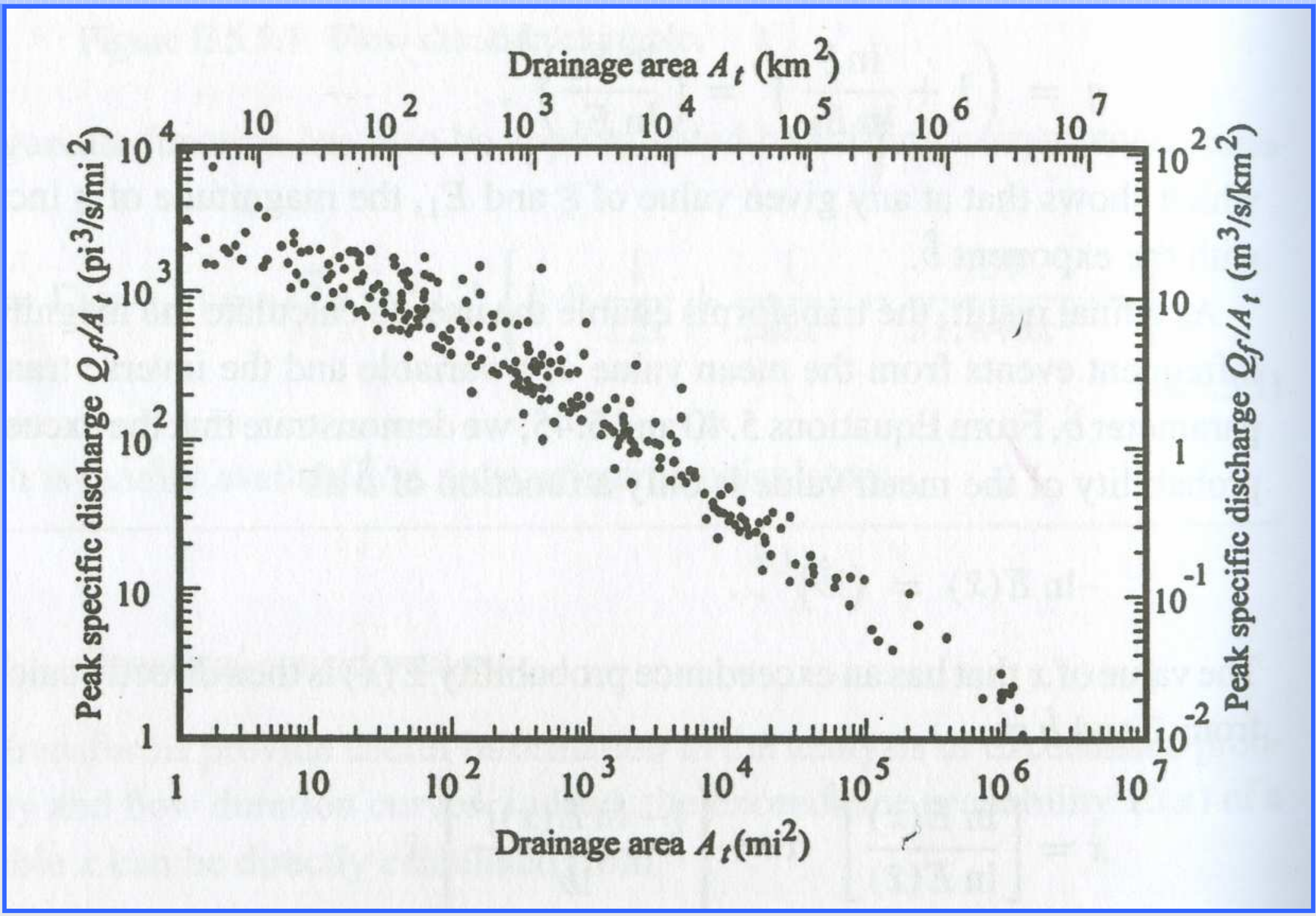
1 inch = 25.4 mm

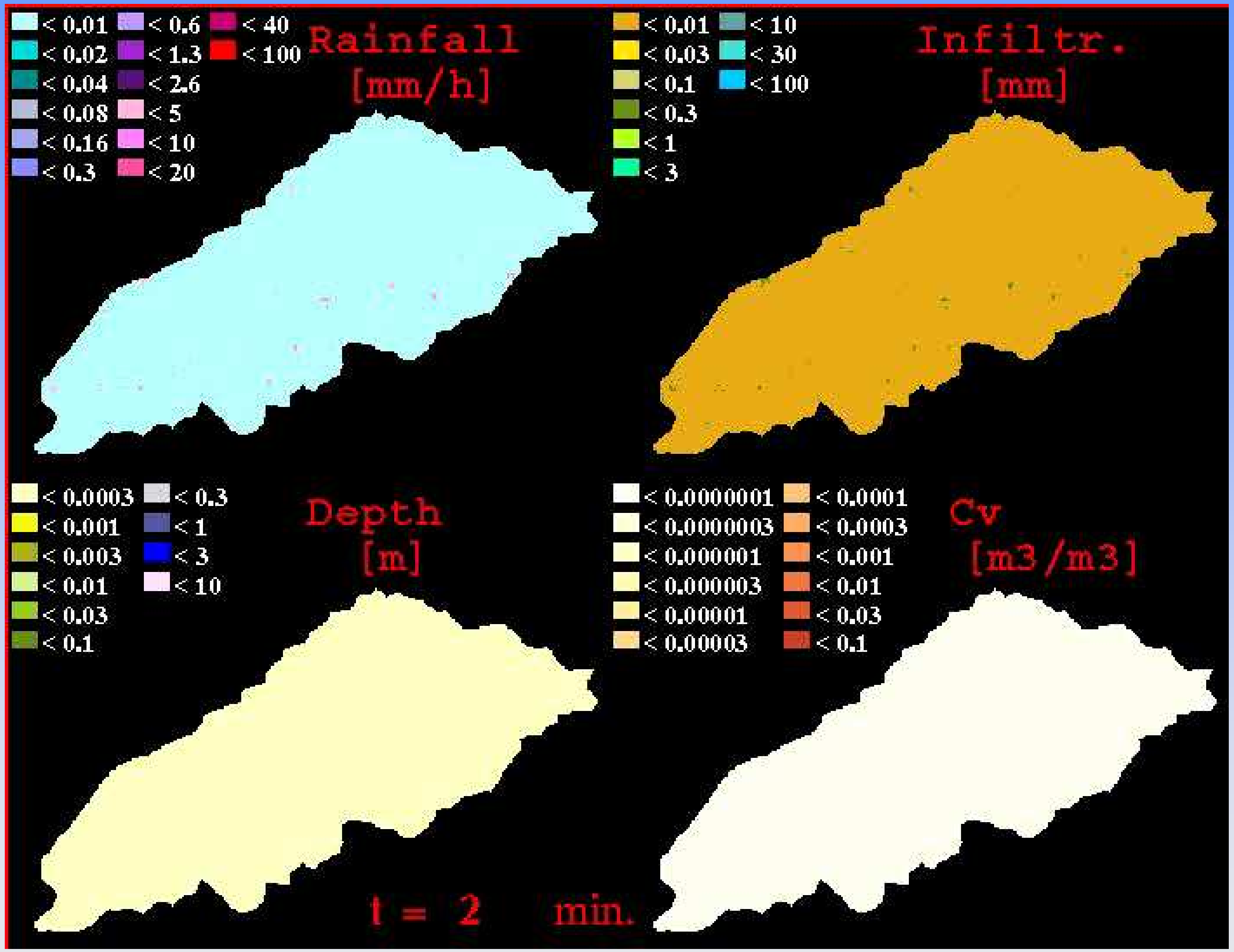
Watershed Delineation - Area



In Class Example

Extreme Specified-Discharge Conditions




Rainfall
[mm/h]
< 0.01
< 0.02
< 0.04
< 0.08
< 0.16
< 0.3
< 0.6
< 1.3
< 2.6
< 5
< 10
< 20
< 40
< 100
Infiltr.
[mm]
< 0.01
< 0.03
< 0.1
< 0.3
< 1
< 3
< 10
< 30
< 100
Depth
[m]
< 0.0003
< 0.001
< 0.003
< 0.01
< 0.03
< 0.1
< 0.3
< 1
< 3
< 10
Cv
[m3/m3]
< 0.0000001
< 0.0000003
< 0.000001
< 0.000003
< 0.00001
< 0.00003
< 0.0001
< 0.0003
< 0.001
< 0.01
< 0.03
< 0.1
t = 2 min.

Any Questions

CE 414 – ENVIRONMENTAL RIVER MECHANICS
Hydrology Homework Problems

1. Using the Figure 3.6, calculate the maximum precipitation for a 4 day storm.

2. Calculate the soil texture, cumulative infiltration depth and infiltration rate at time equals 2 hours. The soil is composed of 15% silt, 25% clay and 60% sand. The effective saturation (Se) is 50%.

3. Assume that the effective saturated hydraulic conductivity is zero. Use Figure 3.5 to determine the cumulative infiltration and infiltration rate. Explain why your results are different in question 2 and 3.

4. Using the rational method calculate the 100-year discharge caused by a 25-year rainfall storm which lasted 2 hours. The watershed is 50 acres. A detailed analysis has been performed to determine that 45% of the land area is concrete/roofs, 25% is good grass areas with flat slopes, 15% is cultivated agricultural area with flat slope and the remaining 15% is forested lands with steep slopes.

5. Using the Figure on extreme discharge fill in the following table.

Area (mi^2)	Specific Discharge ($ft^3/s/mi^2$)	Discharge (ft^3/s)
1		
10		
100		
1000		
10,000		

How does the specific discharge and discharge vary with increased area?