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CEE 370 Environmental Engineering Principles

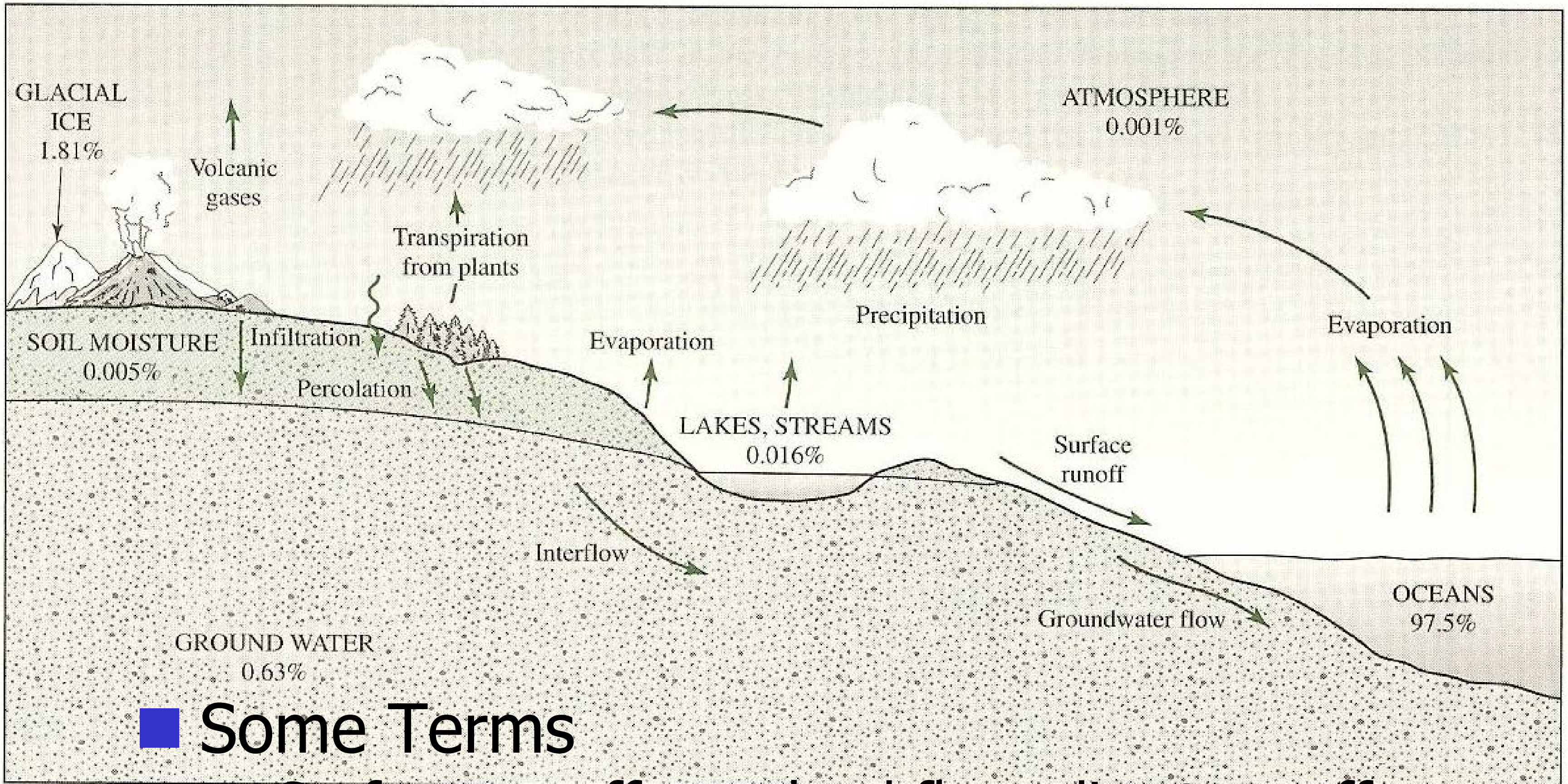
Lecture #19

Water Resources & Hydrology I: Fundamentals

Reading: Mihelcic & Zimmerman, Chapter 7

Hydrologic Cycle

D&M, Fig 6-1



- Some Terms
  - Surface runoff, overland flow, direct runoff
  - Interflow
  - Infiltration, percolation

Beneficial uses of water

- Home Use
  - ~200 gal/cap/day
- Power Plants
  - ~800 gal/cap/day
- Industry
  - ~200 gal/cap/day
- Agriculture
  - ~600 gal/cap/day
- Recreation

Home Use: Drinking, cooking, bathing, cleaning, waste disposal

Recreation: Swimming, boating, fishing, etc.

Drinking Waters

Ground vs Surface

About 20% of all community water systems in the US use surface water; the remaining 80% uses groundwater. However, the surface water systems tend to be much larger, so that the population served by surface water sources is about two-thirds of the total.

Community vs Individual

Community water systems serve about 83% of the total US population. Most of these employ some form of treatment to make the water microbiologically and chemically safe.

Global Water Balance

- Showing global mass fluxes
  - In 10^{12} m^3/yr

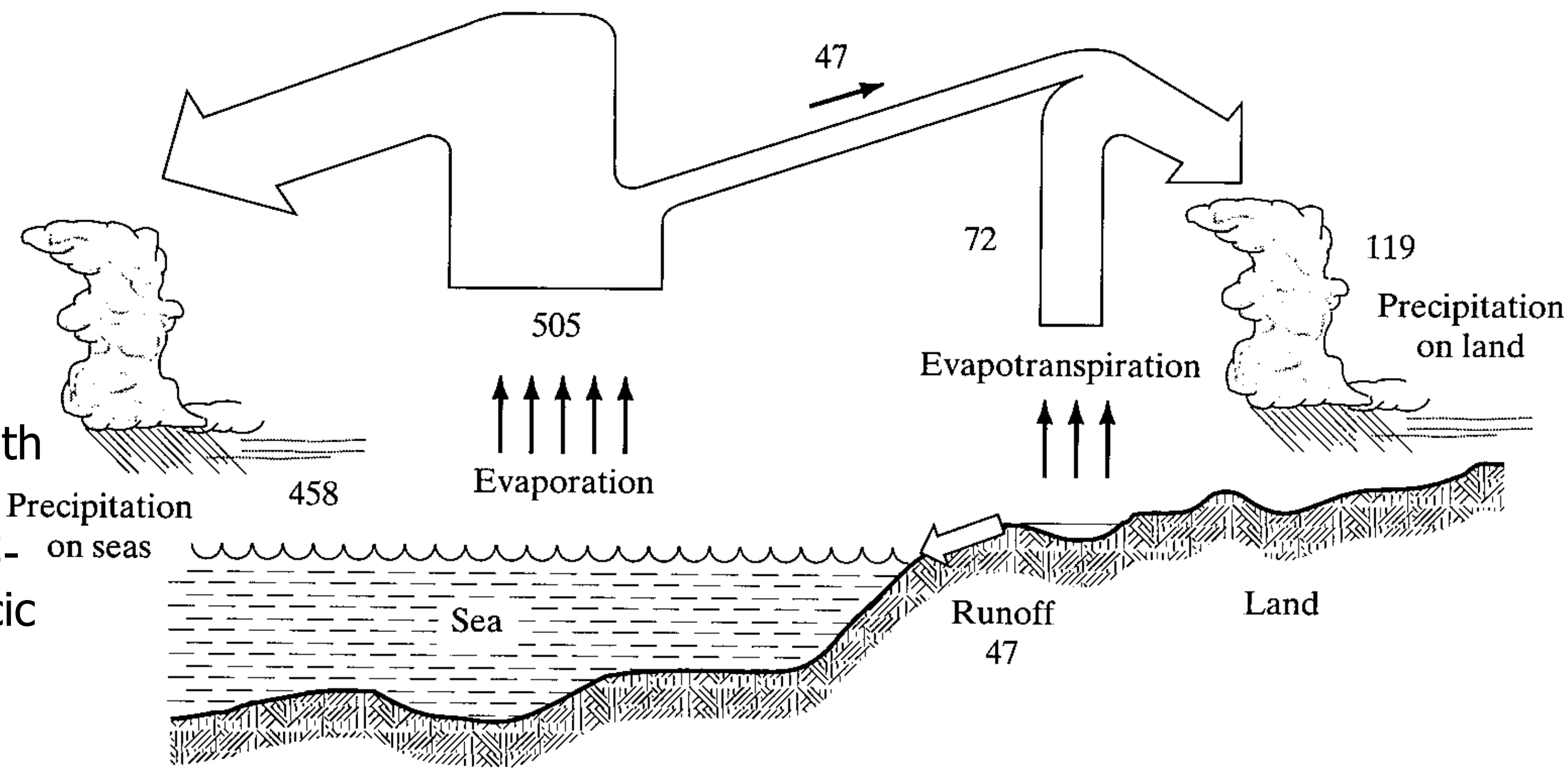


Fig. 5.3 in Masters, Compare with Fig. 6.1 in D&M; Fig. 5-27 in Mihelcic Fig 7.1 in M&Z

Shown earlier in the course

Local Water Balance

- Change in storage = inputs – outputs

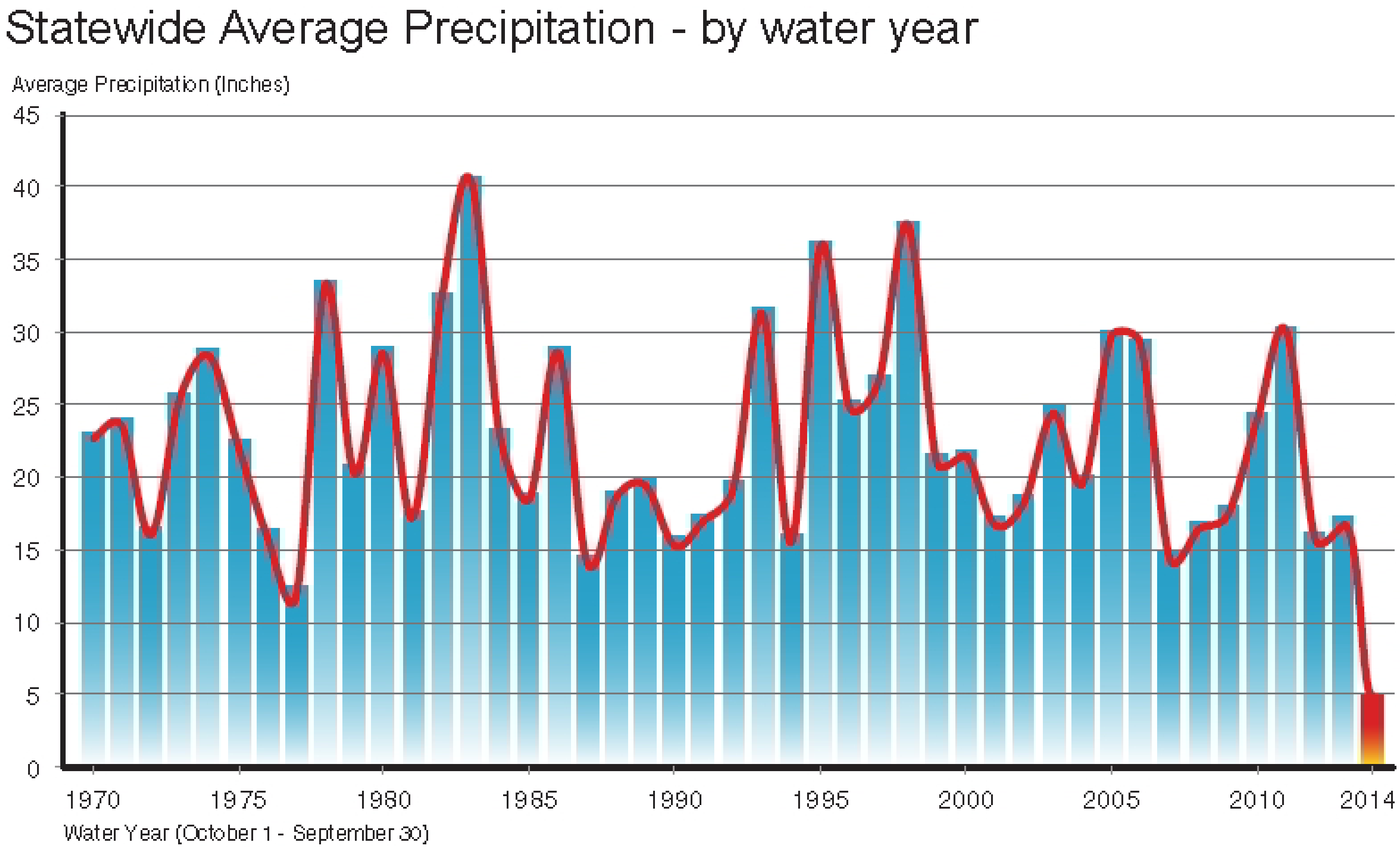
$$\frac{dS}{dt} = P - R - E - I$$

  - Where:
    - S = storage
    - P = precipitation rate
    - E = evapotranspiration rate
      - Includes transpiration from plants and direct evaporation from water bodies, soil, etc.
    - R = runoff rate
    - I = infiltration rate (or leachate for a landfill)

What is average annual rainfall in Amherst?

A. 15-20 in
B. 20-25 in
C. 25-30 in
D. 30-35 in
E. >35 in

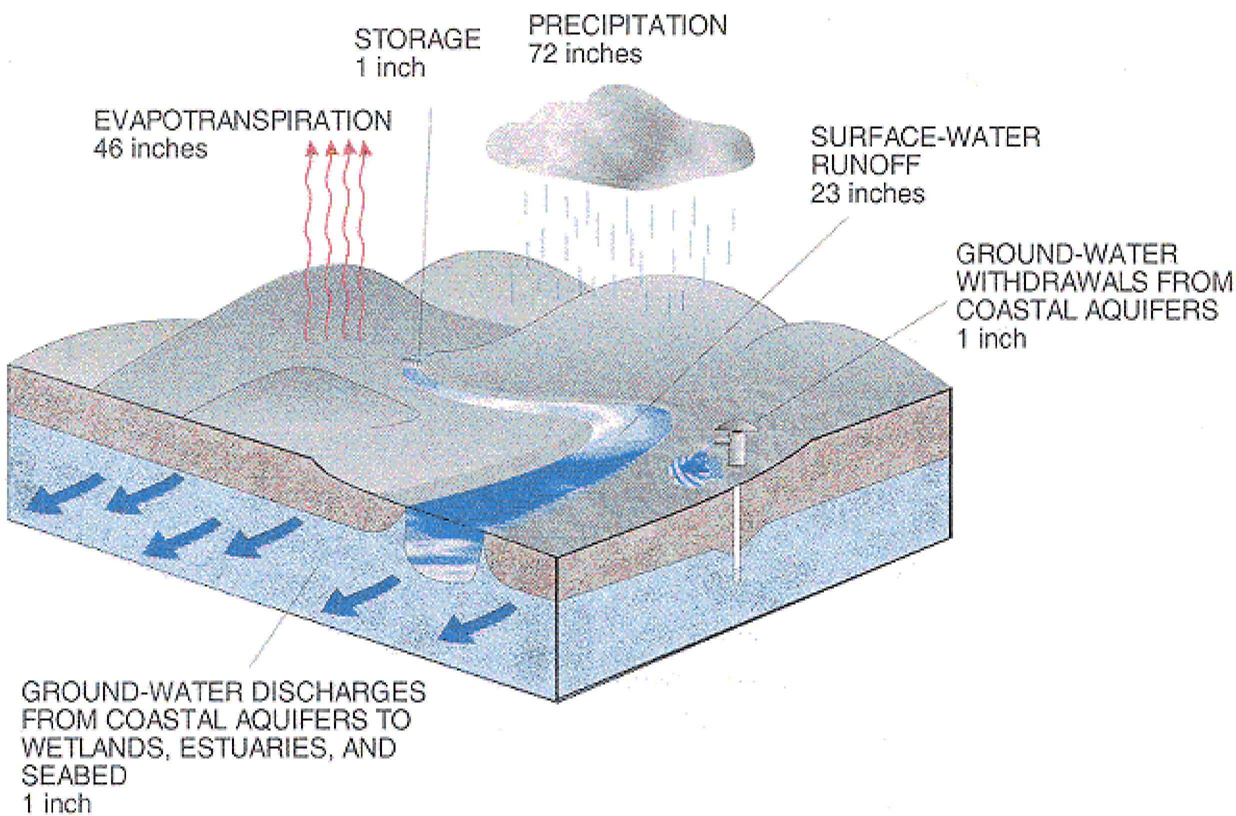
California



Source: Forbes

Local water balance

- Annual Water budget for Puerto Rico



From USGS site: http://pr.water.usgs.gov/public/water_use/water_balance.html

Puerto Rico (cont.)

- In this case, the USGS includes coastal aquifers within the "control volume" for the mass balance, so:

$$\frac{dS}{dt} = P - R - E - I$$

  - Becomes:

$$\frac{dS}{dt} = P - R - E - GW_W - GW_D$$

  - Where groundwater withdrawals (GW_W) and groundwater discharge (GW_D) are two loss processes from the aquifers
  - And now:

$$1\frac{in}{yr} = 72\frac{in}{yr} - 23\frac{in}{yr} - 46\frac{in}{yr} - 1\frac{in}{yr} - 1\frac{in}{yr}$$

Example 1 (start)

Hvarekhshaeta Lake has a surface area of 708,000 m^2. Based on collected data, Drvaspa Brook flows into the lake at an average rate of 1.5 $m^3 \cdot s^{-1}$ and the Vouruskasha River flows out of Hvarekhshaeta Lake at an average rate of 1.25 $m^3 \cdot s^{-1}$ during the month of June. The evaporation rate was measured as 19.4 $cm \cdot month^{-1}$. Evapotranspiration can be ignored because there are few water plants on the shore of the lake. A total of 9.1 cm of precipitation fell this month. Seepage is negligible. Due to the dense forest and the gentle slope of the land surrounding the lake, runoff is also negligible. The average depth in the lake on June 1 was 19 m. What was the average depth on June 30th?

The first step to solving this problem is to determine what we know. We know that the inputs to the lake are

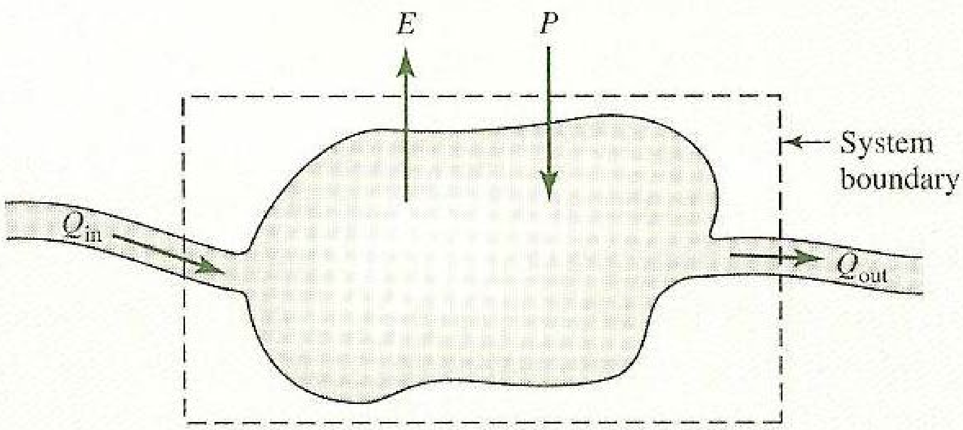
$$Q_{\text{in}} = 1.5\ m^3 \cdot s^{-1}$$
$$P = 9.1\ cm \cdot month^{-1}$$
$$I_{\text{in}} = 0 \text{ (because we were told that seepage is negligible)}$$
$$R' = 0 \text{ (because we were told that runoff is negligible)}$$

We also know that the outputs from the lake are

$$Q_{out} = 1.25\ m^3 \cdot s^{-1}$$
$$E = 19.4\ cm \cdot month^{-1}$$
$$E_T = 0$$

We also know that surface area of the lake is 708,000 m^2 and the average depth of the lake on June 1 is 19 m.

The following is a picture of the lake as a system



Using the average values given earlier and the most general form of the mass-balance equation (6–2), the mass-balance for this lake can be reduced to

$$\text{Volumetric rate of accumulation} = Q_{in} - Q_{out} + P - E$$

The volumetric rate of accumulation is often referred to as the **change in storage** (ΔS) and

$$\Delta S = Q_{in} - Q_{out} + P - E$$

Because the units for Q and P and E are different, we must ensure that the proper conversions are performed, yielding the same set of units.

Example 1 (conclusion)

Therefore,

$$\Delta S = (1.5\ \text{m}^3 \cdot \text{s}^{-1})(86{,}400\ \text{s} \cdot \text{day}^{-1})(30\ \text{days} \cdot \text{month}^{-1})$$
$$- (1.25\ \text{m}^3 \cdot \text{s}^{-1})(86{,}400\ \text{s} \cdot \text{day}^{-1})(30\ \text{days} \cdot \text{month}^{-1})$$
$$+ (9.1\ \text{cm} \cdot \text{month}^{-1})(\text{m} \cdot 100\ \text{cm}^{-1})(708{,}000\ \text{m}^2)$$
$$- (19.4\ \text{cm} \cdot \text{month}^{-1})(\text{m} \cdot 100\ \text{cm}^{-1})(708{,}000\ \text{m}^2)$$
$$= 3{,}888{,}000\ \text{m}^3 \cdot \text{month}^{-1} - 3{,}240{,}000\ \text{m}^3 \cdot \text{month}^{-1}$$
$$+ 64{,}428\ \text{m}^3 \cdot \text{month}^{-1} - 137{,}352\ \text{m}^3 \cdot \text{month}^{-1}$$

Solving the preceding equation, yields

$$\Delta S = 575{,}076\ \text{m}^3 \cdot \text{month}^{-1}$$

Because $\Delta S = 575{,}076\ \text{m}^3 \cdot \text{month}^{-1}$ and the average surface area is $708{,}000\ \text{m}^2$, the change in depth during the month of June is

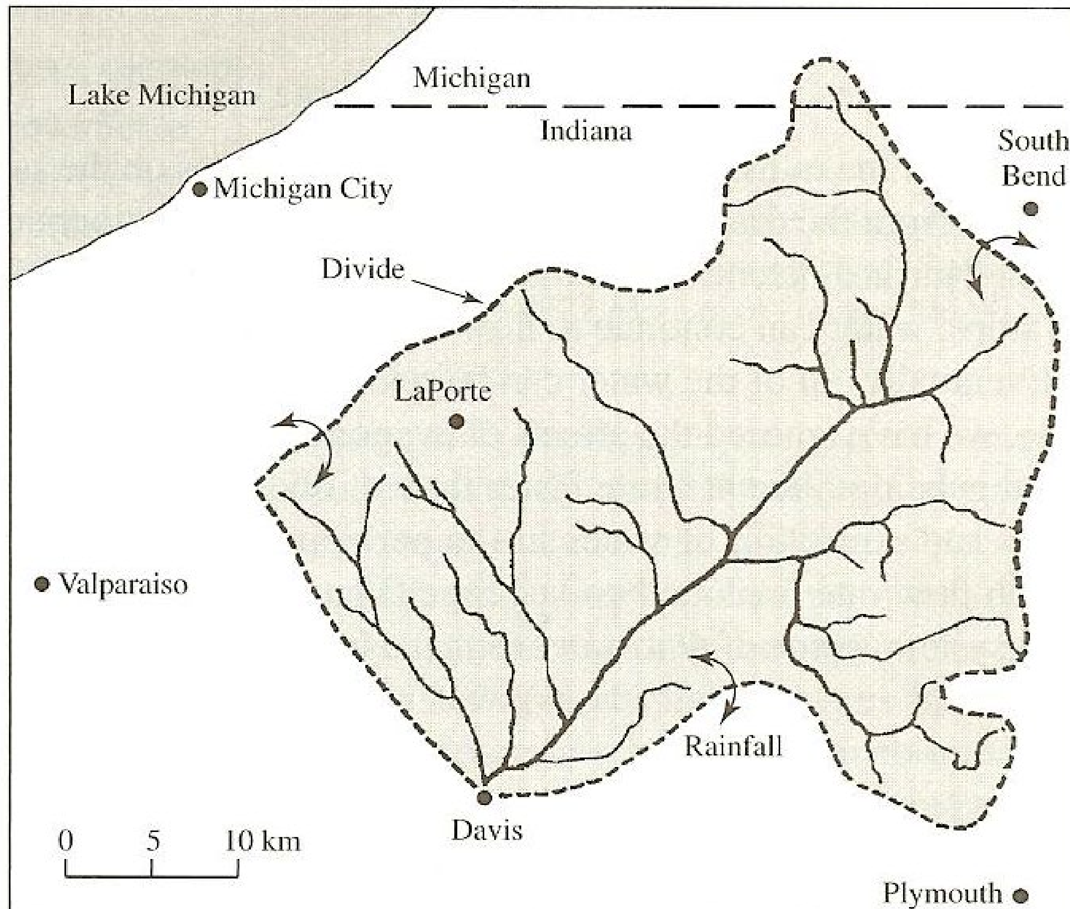
$$(575{,}076\ \text{m}^3 \cdot \text{month}^{-1})/708{,}000\ \text{m}^2 = 0.81\ \text{m}$$

Note that ΔS is positive. As such, the volume in the lake increased during June and, therefore, the depth increases. The new average depth on June 30 would be 19.81 m. Had a negative value for storage been calculated, then the depth of the lake would have decreased.

Drainage Basins

- Kankakee River basin above Davis, IN

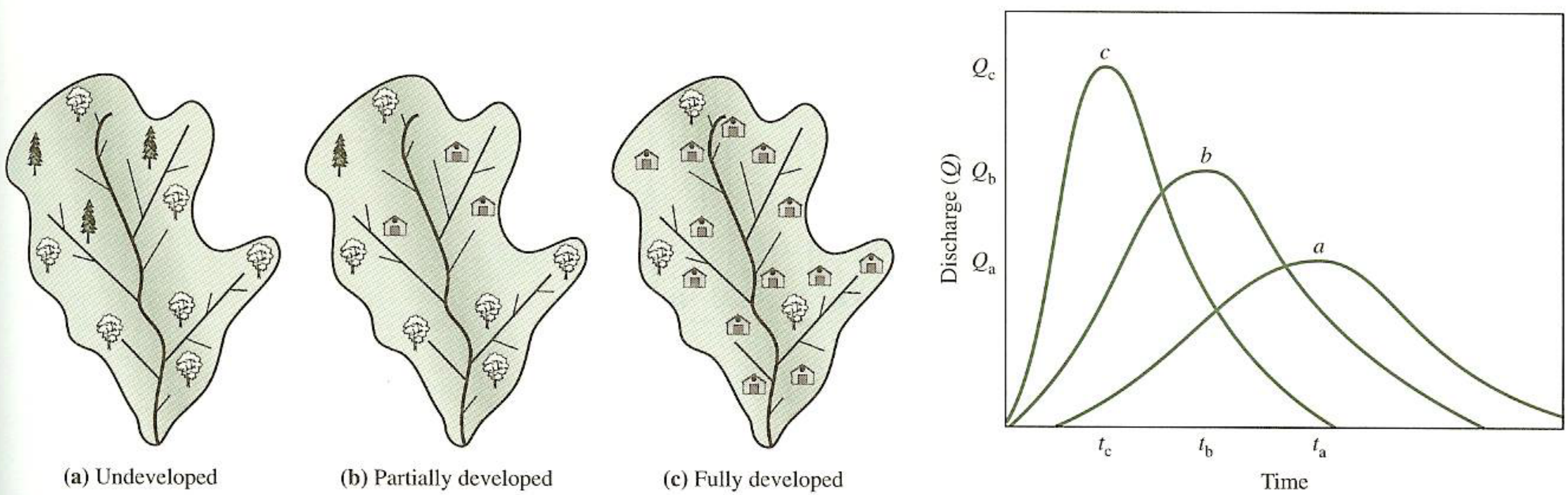
- Dashed line is the basin "divide"
  - Water that falls on one side eventually flows into the Kankakee
  - Water that falls on the other side goes outside the basin



Effect of development

FIGURE 6–5

Effect of the watershed on a hydrograph. $Q_c > Q_b > Q_a$ and $t_c < t_b < t_a$.



Typical Runoff Coefficients

Description of Area or Character of Surface	Runoff Coefficient	Description of Area or Character of Surface	Runoff Coefficient
Business		Railroad yard	0.20–0.35
Downtown	0.70–0.95	Natural grassy land	0.10–0.30
Neighborhood	0.50–0.70	Pavement	
Residential		Asphalt, concrete	0.70–0.95
Single-family	0.30–0.50	Brick	0.70–0.85
Multi-units, detached	0.40–0.60	Roofs	0.75–0.95
Multi-units, attached	0.60–0.75	Lawns, sandy soil	
Residential, suburban	0.25–0.40	Flat (< 2%)	0.05–0.10
Apartment	0.50–0.70	Average (2–7%)	0.10–0.15
Industrial		Steep (> 7%)	0.15–0.20
Light	0.50–0.80	Lawns, heavy soil	
Heavy	0.60–0.90	Flat (< 2%)	0.13–0.17
Parks, cemeteries	0.10–0.25	Average (2–7%)	0.18–0.22
Playgrounds	0.20–0.35	Steep (> 7%)	0.25–0.35

Source: Joint Committee of the American Society of Civil Engineers and the Water Pollution Control Federation. *Design and Construction of Sanitary and Storm Sewers* (ASCE Manuals and Reports on Engineering Practice No. 37, or WPCF Manual of Practice No. 9), American Society of Civil Engineers, New York, (1969), p. 51.

Rational Formula

$Q = C*I*A$

- Simplified view of runoff; no time resolution
  - Runoff is some fraction of the total rainfall
    - The fraction is the runoff coefficient

$$R = C*P$$

Runoff (in)

Runoff Coefficient

Precipitation (in)

$$Q = \left(\frac{1hr}{3600s}\frac{10^6 m^2}{km^2}\frac{1m}{100cm}\right)C*I*A$$

Streamflow (m^3/s)

Rainfall intensity (cm/hr)

Basin Area (km^2)

Land Use, Crop, and Management	Hydrologic Soil Group A	B	C	D
CULTIVATED, with crop rotations				
Row Crops, poor management	.55	.65	.70	.75
Row Crops, conservation mgmt	.50	.55	.65	.70
Small Grains, poor management	.35	.40	.45	.50
Small Grains, conservation mgmt	.20	.22	.25	.30
Meadow	.30	.35	.40	.45
PASTURE, permanent w/moderate grazing	.10	.20	.25	.30
WOODS, permanent, mature, no grazing	.06	.13	.16	.20
Urban residential				
30 percent of area impervious	.30	.40	.45	.50
70 percent of area impervious	.50	.60	.70	.80

Hydrologic Soil Group Descriptions:

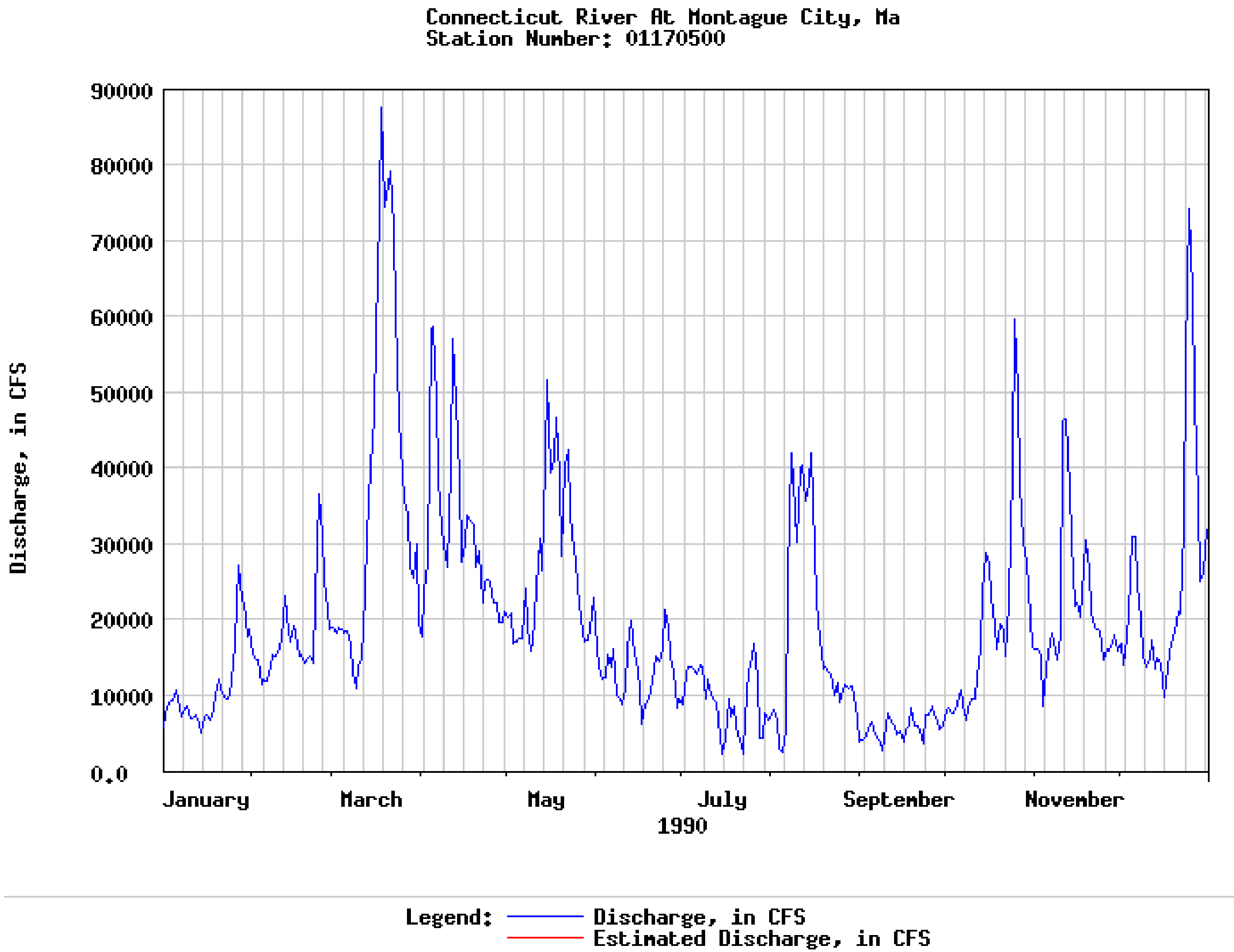
A -- Well-drained sand and gravel; high permeability.

B -- Moderate to well-drained; moderately fine to moderately coarse texture; moderate permeability.

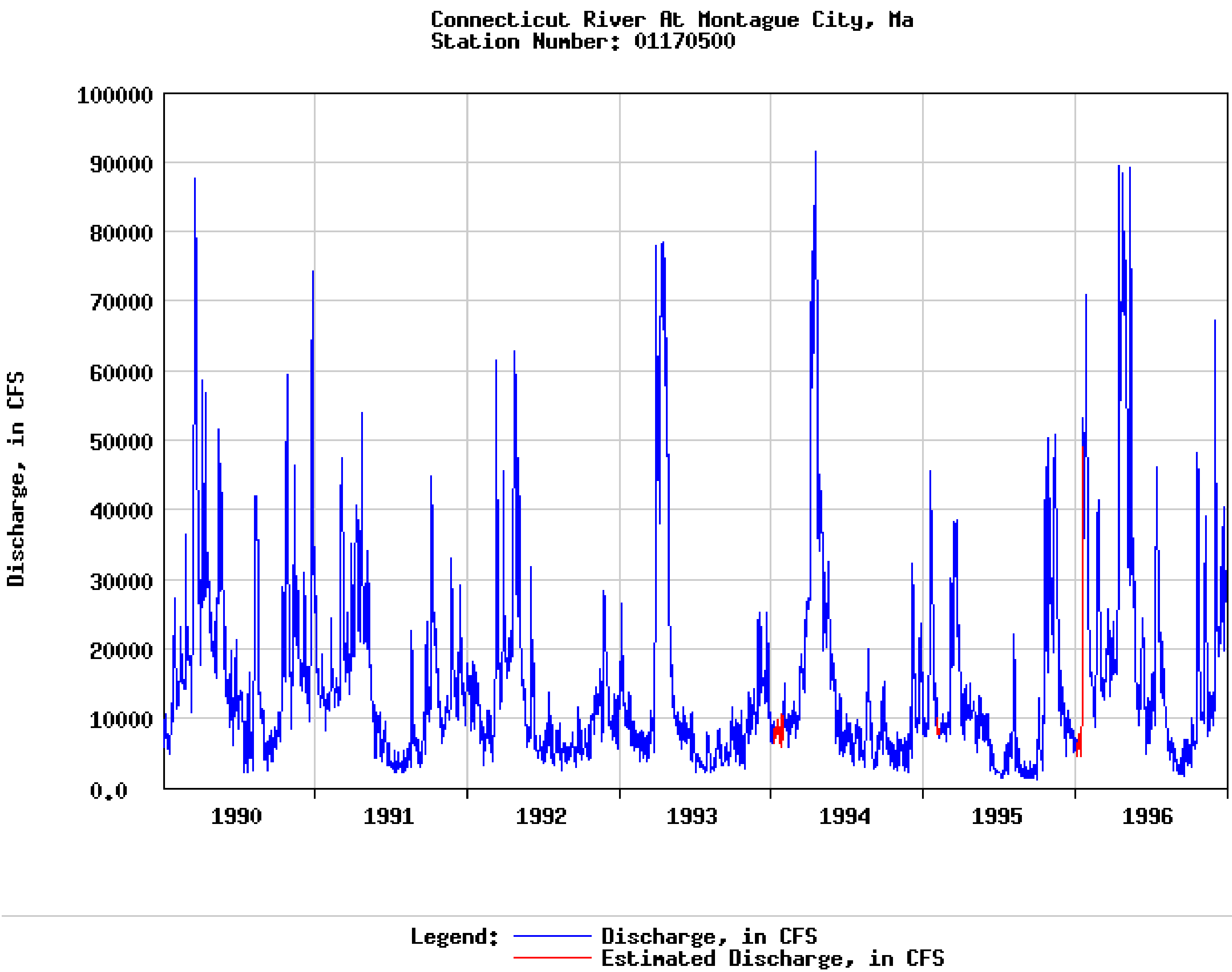
C -- Poor to moderately well-drained; moderately fine to fine texture; slow permeability.

D -- Poorly drained, clay soils with high swelling potential, permanent high water table, claypan, or shallow soils over nearly impervious layer(s).

CT River: one year

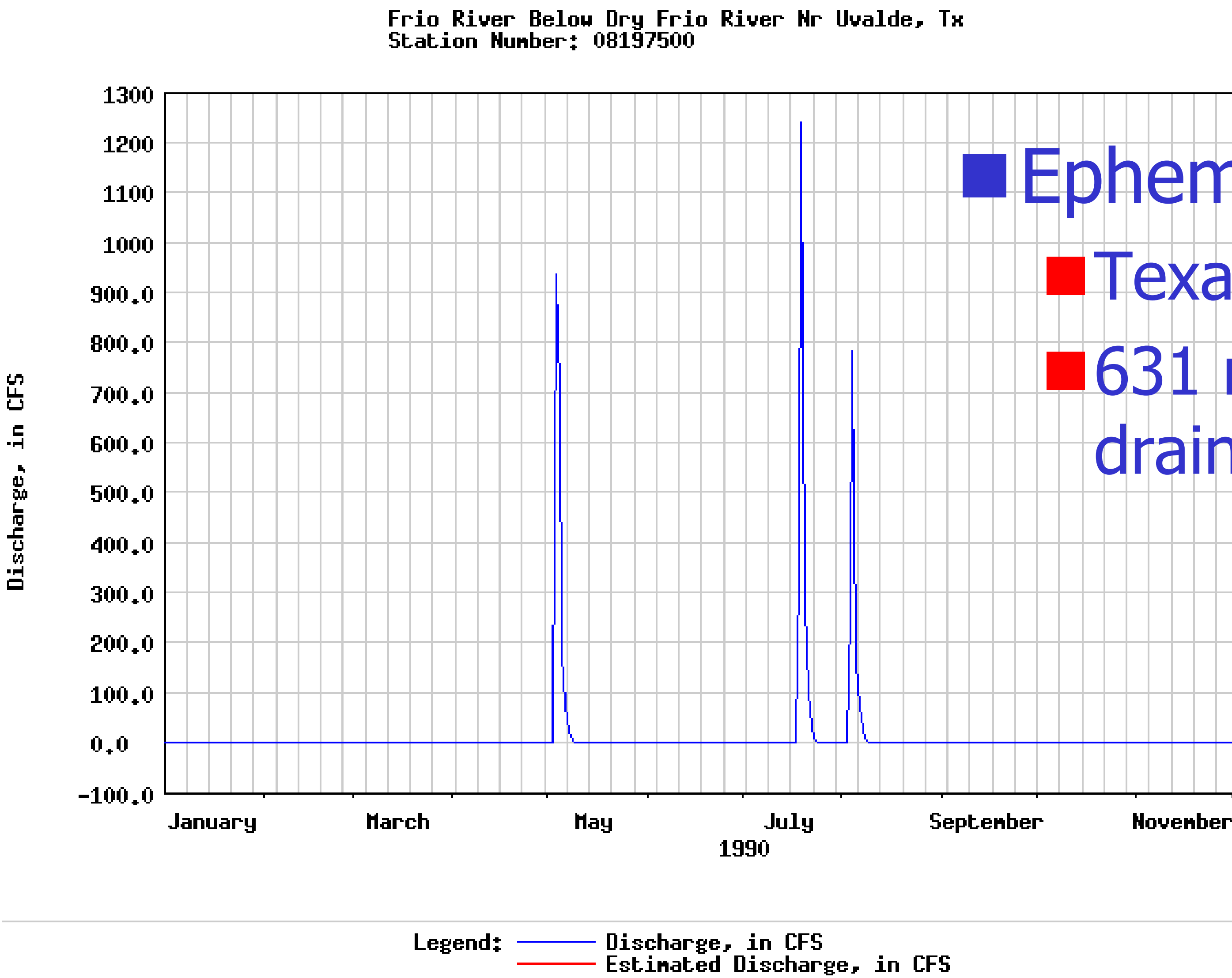


CT River: Multi-year



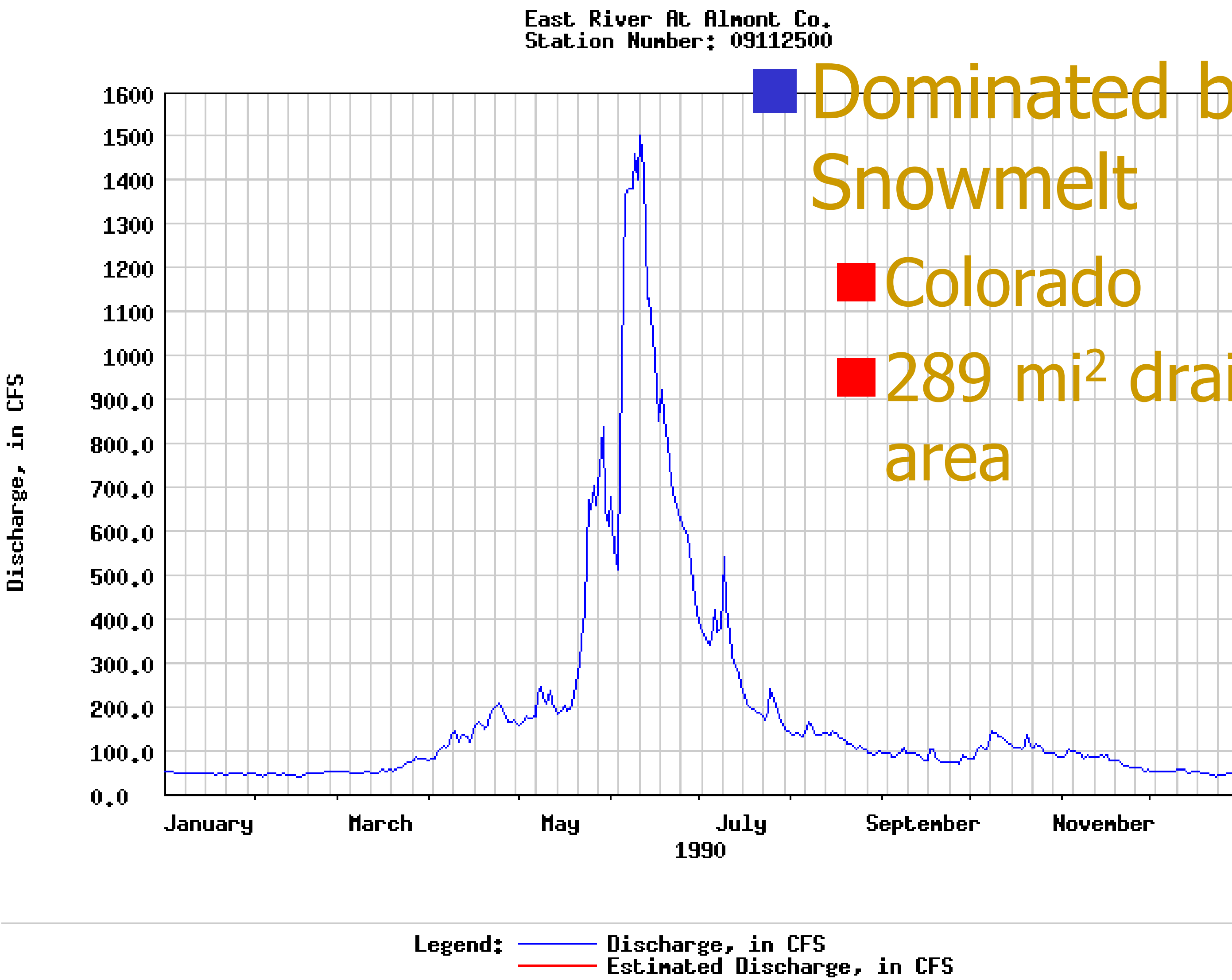
- Annual flow patterns

Frio River



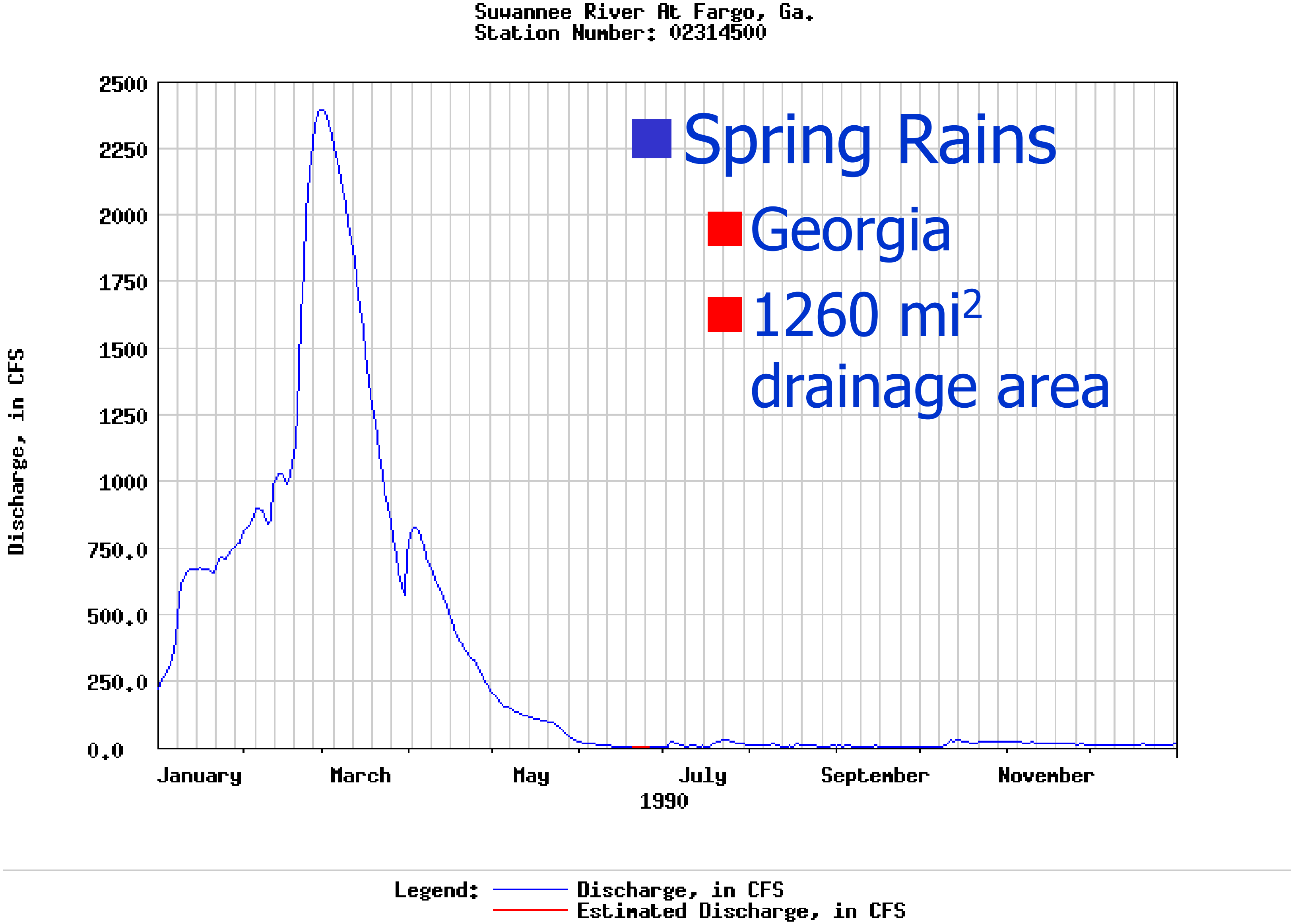
- Ephemeral
  - Texas
  - 631 mi^2 drainage basin

East River



- Dominated by Snowmelt
  - Colorado
  - 289 mi^2 drainage area

Suwanee River



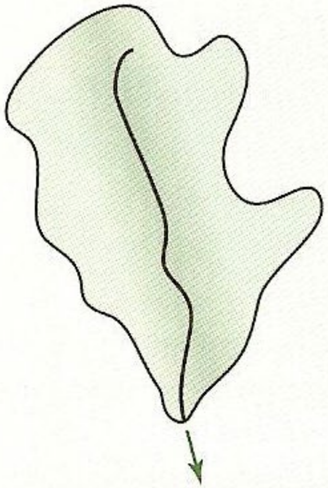
- Spring Rains
  - Georgia
  - 1260 mi^2 drainage area

Example 2

In 1997, the Upper Grand watershed near Lansing, Michigan, with an area of 4530 km^2 received 77.7 cm of precipitation. The average rate of flow measured in the Grand River, which drained the watershed, was 39.6 $m^3 \cdot s^{-1}$. Infiltration was estimated to occur at an average rate of 9.2×10^{-7} $m \cdot s^{-1}$. Evapotranspiration was estimated to be 45 cm $\cdot$ $year^{-1}$. What is the change in storage in the watershed?

To solve this problem, we should draw a picture, list the information we know and that which we are seeking and write the question in symbolic form.

A simple picture of the watershed is shown here.



We know the following information:

$$\text{Area} = 4530 \text{ km}^2$$

$$P = 77.7 \text{ cm} \cdot \text{year}^{-1}$$

$$\text{Infiltration} = G = 9.2 \times 10^{-7} \text{ cm} \cdot \text{s}^{-1}$$

$$E_T = 45 \text{ cm} \cdot \text{year}^{-1}$$

To solve this problem we assume that all of the flow in the river is due to runoff, so that, $R = Q_{out}$.

In words, the mass-balance equation for this system can be written as

Change in storage = rate of precipitation − rate of evapotranspiration − rate of infiltration − rate of water flowing from the stream.

Symbolically, this can be represented as

$$\Delta S = P - E_T - G - R$$

$$= 77.7 \text{ cm} \cdot \text{year}^{-1} - 45 \text{ cm} \cdot \text{year}^{-1} - (9.2 \times 10^{-7} \text{ cm} \cdot \text{s}^{-1})(60 \text{ s} \cdot \text{min}^{-1})(60 \text{ min} \cdot \text{h}^{-1})$$

$$\times (24 \text{ h} \cdot \text{day}^{-1})(365 \text{ day} \cdot \text{year}^{-1}) - R$$

We must convert R from units of cubic meters per second as given to units of centimeters per year as all other terms are given. To accomplish this we must divide the flow rate by the area of the watershed it drains and perform all of the necessary unit conversions. Thus, substituting now for R

$$\Delta S = 77.7 \text{ cm} \cdot \text{year}^{-1} - 45 \text{ cm} \cdot \text{year}^{-1} - 29 \text{ cm} \cdot \text{year}^{-1}$$

$$- \frac{(39.6 \text{ m}^3 \cdot \text{s}^{-1})(86{,}400 \text{ s} \cdot \text{day}^{-1})(365 \text{ day} \cdot \text{year}^{-1})(100 \text{ cm} \cdot \text{m}^{-1})}{(4530 \text{ km}^2)(1000 \text{ m} \cdot \text{km}^{-1})^2}$$

Solving this equation, yields

$$\Delta S = 77.7 - 45 - 29 - 27.6 = -23.9 \text{ cm} \cdot \text{year}^{-1}$$

The negative storage means that there is a net loss of water from the watershed during this period.

We can also calculate the runoff coefficient for this watershed. Remembering that the runoff coefficient equals R/P, then

$$\frac{R}{P} = \frac{27.6 \text{ cm}}{77.7 \text{ cm}} = 0.36$$

This value (from Table 6–1) is typical of that one would observe in a suburban area.

- To next lecture