Hydrology I

Hydrology I

- Hydrology and its issues
- Water sources and hydrological cycle
- Water budget
- Surface water topics: Watershed, hydrograph, runoff coefficient

Hydrology

- Definition

  A multidisciplinary subject that deals with the question of how much water can be expected at any particular time and location

- Application of hydrology
  - ensure adequate water supply for drinking, irrigation, industrial uses, etc.
  - prevent flooding

Issues of hydrology

- Flood and droughts

Issues of hydrology

- Climate change

Issues of hydrology

- Water use sustainability

Aral Sea, Kazakhstan & Uzbekistan, change from 1989 to 2008

Particularly significant

- For dry regions
- In regions with high water demand (high population, significant agricultural activities, etc.)
- Rely on water resources with long residence time
- Rely on water resources shared by multiple countries

Issues of hydrology

- Water use sustainability

Land subsidence due to groundwater pumping

Issues of hydrology

- Hot in Korea - sinkholes

Water balance and residence time

Table 1.1 Estimate of the Water Balance of the World

Parameter	Surface area $(km^2) \times 10^6$	Volume $(km^3) \times 10^6$	Volume (%)	Equivalent depth (m)*	Residence time
Oceans and seas	361	1370	94	2500	~4000 years
Lakes and reservoirs	1.55	0.13	<0.01	0.25	~10 years
Swamps	<0.1	<0.01	<0.01	0.007	1–10 years
River channels	<0.1	<0.01	<0.01	0.003	~2 weeks
Soil moisture	130	0.07	<0.01	0.13	2 weeks–1 year
Groundwater	130	60	4	120	2 weeks–10,000 years
Icecaps and glaciers	17,8	30	2	60	10–1000 years
Atmospheric water	504	0.01	<0.01	0.025	~10 days
Biospheric water	<0.1	<0.01	<0.01	0.001	~1 week

SOURCE: Nace, 1971.

*Computed as though storage were uniformly distributed over the entire surface of the earth.

- Water useful for humans: i) lakes & reservoirs, ii) rivers, iii) (shallow) groundwater
- These waters constitute only a small fraction

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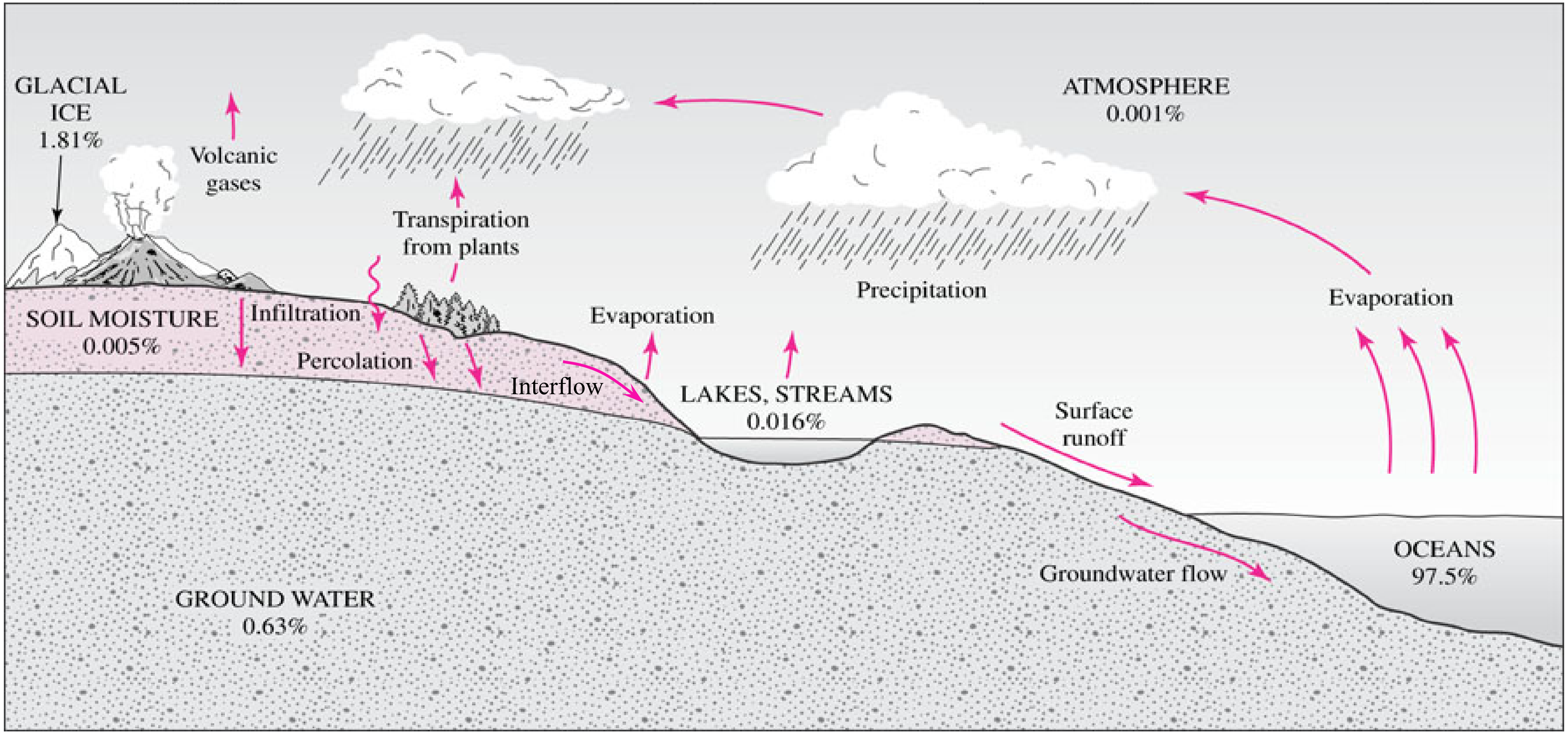
- Long residence time for groundwater – once depleted, it takes a long time to recover (effectively nonrenewable)
- Significant temporal and spatial variation of freshwater availability & water needs → dams, reservoirs, pipelines, etc. needed

Hydrological cycle



Processes in the hydrological cycle

- Earth's surface → atmosphere
  - evaporation: conversion of liquid water from lakes, streams, and other bodies of water to water vapor
  - transpiration: the process by which water is emitted from plants through the stomata

    * evapotranspiration = evaporation + transpiration

- Earth's atmosphere → surface
  - precipitation (rain+snow+hail+…)

Processes in the hydrological cycle

- Within Earth's surface
  - surface (direct) runoff: water running over the ground into streams and rivers
  - interflow: portion of precipitation that infiltrates into the soil and moves horizontally through the shallow soil horizon without ever reaching the water table
  - infiltration (percolation): vertical movement of water from the surface into the soil

Water budget

- Water budget: mass balance for water

  (rate of accumulation) = (rate in) – (rate out)

$$\frac{\Delta S}{\Delta t} = \sum (rate\ \ in)\ - \sum (rate\ \ out)$$

ΔS/Δt = change in storage over time [L^3/T]

ex) For a lake: define the control volume as the lake itself

- possible "in" processes: flow of streams entering the lake, precipitation, runoff, seepage into the lake
- possible "out" processes: flow of streams exiting the lake, evapotranspiration, seepage out of the lake

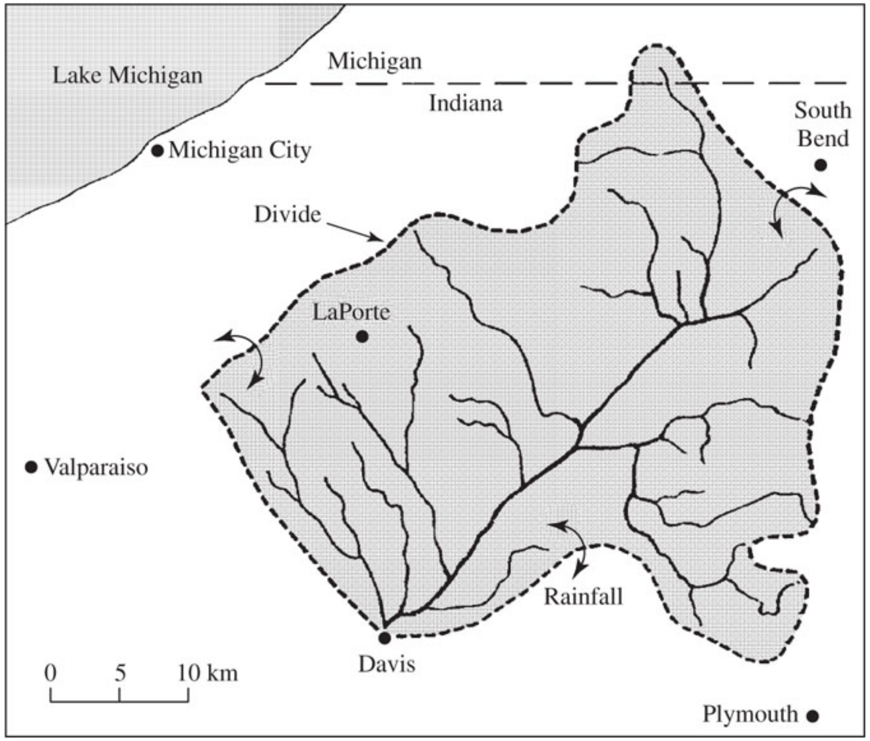
$$\frac{\Delta S}{\Delta t} = (Q_{in} + P + R + I_{in}) - (Q_{out} + E_T + I_{out})$$

Water budget

Q: Sulis Lake has a surface area of 708,000 m^2. Okemos Brook flows into the lake at a flow rate of 1.5 m^3/s and the Tamesis River flows out of the lake at a flow rate of 1.25 m^3/s during the month of June. The evaporation rate was measured as 19.4 cm/month. Transpiration is ignored because there are few water plants. A total of 9.1 cm of precipitation fell this month. Seepage and runoff is negligible. The average depth in the lake at the beginning of the month was 19 m. Calculate the **average depth at the end of the month**.

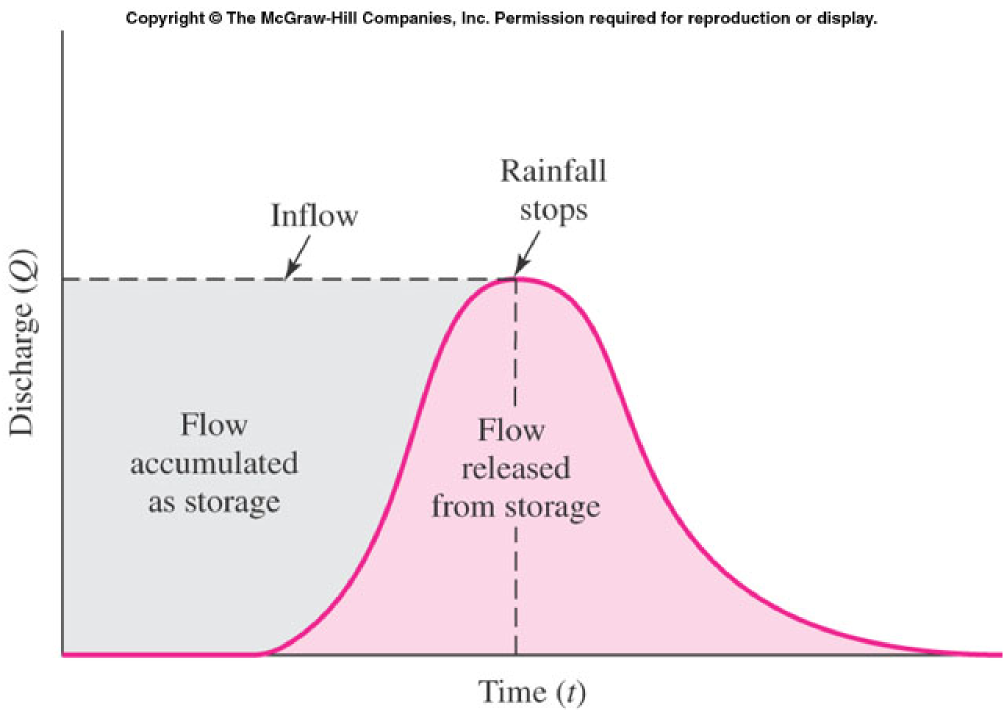
Watershed

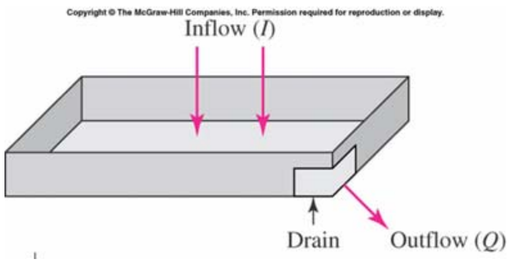
- **Watershed (basin)**: the area of land where all of the water that is under it or drains off of it goes to the same place
- **Divide**: the boundary of the watershed



Hydrograph

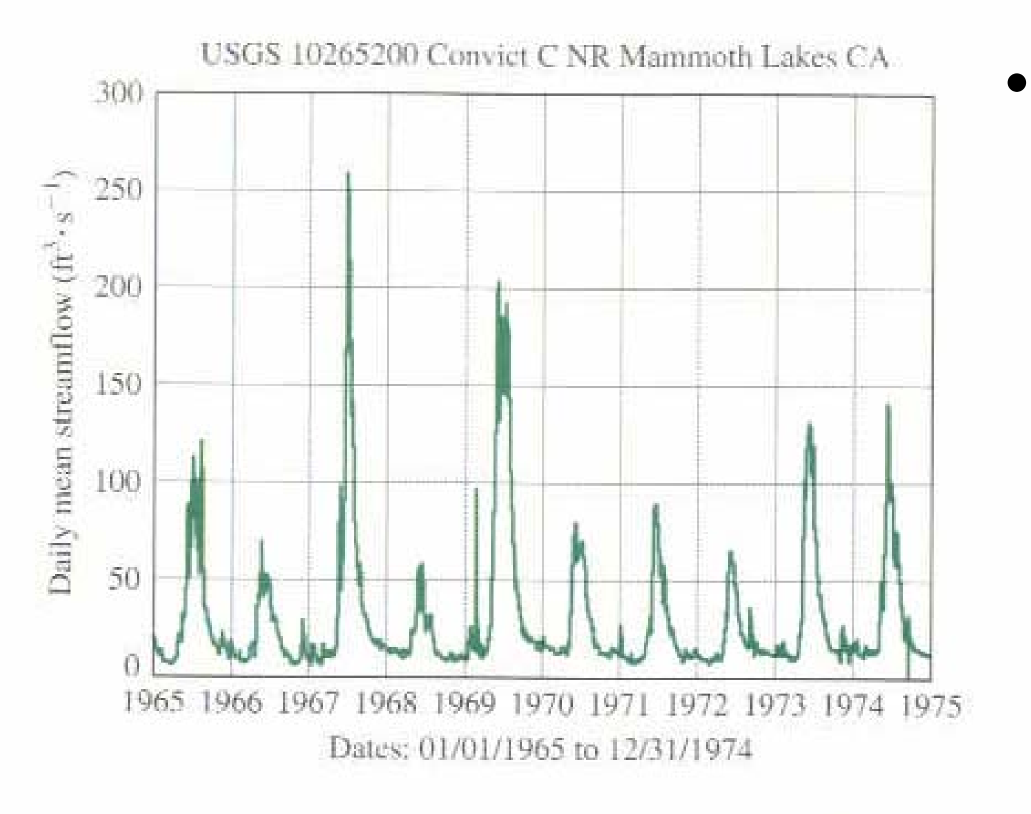
- A chart in which flow rate is plotted vs. time





An example hydrograph for a simple parking lot

Hydrograph



10-year hydrograph for a creek (example)

- The shape of the hydrograph is affected by various factors such as: precipitation, weather, topography of the watershed, density and type of ground cover, ...

Runoff coefficient

- Runoff coefficient

  = {rate of runoff (R)} / {rate of precipitation (P)}

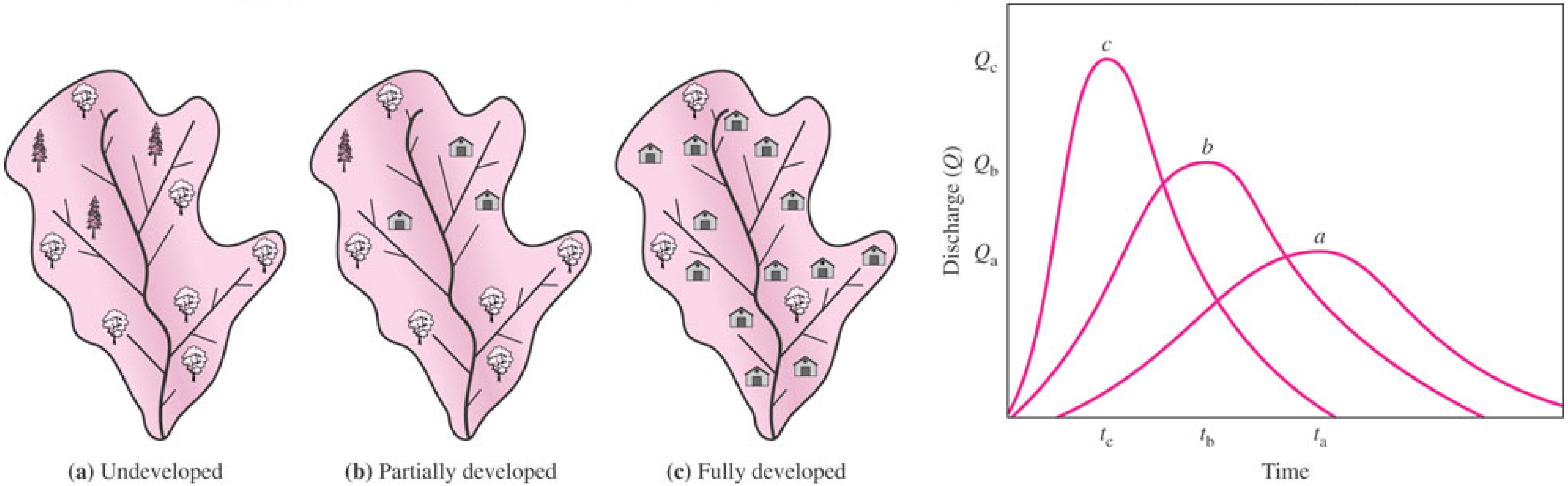
Typical Runoff Coefficients

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, 1969.

The more developed, the bigger runoff coefficient

Runoff coefficient



$Q_c > Q_b > Q_a$, $t_c < t_b < t_a$

- Urban & industrial development increases the impact of flood

Runoff coefficient

Q: A watershed with an area of 4530 km^2 received 77.7 cm of precipitation in 2013. The average rate of flow measured in a river which drained the watershed was 39.6 m^3/s. Infiltration occurred at an average rate of 9.2×10^{-7} cm/s and evapotranspiration was estimated to be 45 cm/year. What was the change in storage in the watershed in 2013? What was the runoff coefficient?

Reading assignment

- Textbook Ch 7, p. 258-267

Water budget

Slide #15 solution)

The control volume is the lake.

Input processes

$Q_{in} = 1.5\ m^3/s$

$P = 9.1$ *cm/month*

No seepage in, no runoff into the lake

Output processes

$Q_{out} = 1.25\ m^3/s$

$E = 19.4$ *cm/month*

No transpiration, no seepage out

Water budget

$$\frac{\Delta S}{\Delta t} = (Q_{in} + P) - (Q_{out} + E)$$

Need a unit of m/month

$$\frac{\Delta h}{\Delta t} = \frac{\Delta S}{A_{lake}\Delta t}$$

$$= \frac{(1.5-1.25)\ m^3/s \times 86400\ s/day \times 30\ days/month}{708000\ m^2} + (9.1 - 19.4)\ cm/month\ \times 10^{-2}\ m/cm$$

$$= 0.8\ m$$

$$h = h_0 + \frac{\Delta h}{\Delta t} \cdot \Delta t = 19.0\ m + 0.8\ m = \mathbf{19.8\ m}$$

Runoff coefficient

Slide #21 solution)

The control volume is the watershed.

Input processes

$P = 77.7$ *cm/year*

No other input processes for a watershed

Output processes

$Q_{out} = 39.6\ m^3/s$ *(this is the "runoff" from the watershed!)*

$I_{out} = 9.2 \times 10^{-7}\ m/s$

$E_T = 45$ *cm/year*

Runoff coefficient

$$\frac{\Delta S}{\Delta t} = P - (Q_{out} + I_{out} + E_T)$$

$$= (77.7\ cm/year - 9.2 \times 10^{-7}\ cm/s\ \times 86400\ s/day\ \times 365\ days/year - 45\ cm/year)$$
$$10^{-2}\ m/cm \times 4530\ km^2\ \times\ 10^6\ m^2/km^2 - 39.6\ m^3/s\ \times\ 86400\ s/day\ \times 365\ days/year$$
$$= \mathbf{-1.08 \times 10^9\ m^3/year}$$

Converting the Q_{out} into cm/year:

$$\frac{39.6\ m^3/s \times 86400\ s/day \times 365\ days/year}{4530\ km^2 \times 10^6\ m^2/km^2} \times 10^2\ cm/m = 27.6\ cm/year$$

Runoff coefficient = $\frac{27.6\ cm/year}{77.7\ cm/year} = \mathbf{0.36}$