Water Cycle and Hydrology
Fundamentals of hydrology

Water Forum Suriname & GCCA+

Water Training

Integrated Water Resources Management

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Definition of Hydrology

- Hydrology is the science that deals with the movement, distribution and management of water on Earth and other planets, including the hydrological cycle, water resources and watershed sustainability.
- Water is central
  - Different forms of water: Ice, water, water vapour
- The transition from liquid, solid, gaseous, in the atmosphere and in the surface layers of land masses
- Also including the sea: source and storage of water,
  - important for life on Earth

Importance of Hydrology

The 4 compartments of the natural environment

- Air (atmosphere) => Meteorology
- Soil (lithosphere) => Geology, Soil Science
- Water (hydrosphere) => Hydrology
- Ecosystem (biosphere) => Ecology

Importance to living organism

- Humans and animals approx. 70% from moisture
- Plants about 80% from moisture
- Life on Earth is not possible without water
- Approx. 71% of the Earth's surface is covered by water

Importance of Hydrology

Importance of water and water users

- Drinking water and domestic purposes
- Shipping
- Irrigation and fishing
- Hydropower
- Recreation and tourism
- Industrial purposes
- Mining
- Drainage of excess and waste water
- Nature and environment

Water as medium (for water pollution)

- Water goes through and is in all compartments of it environment
- Water frequently is referred to as the universal solvent
- All forms of pollution finallyresults in water pollution

Hydrology and Watersystems

Water goes to all the compartments of the environment

- Airsystem (atmosphere)
- Soilsystem (lithoshere)
- Watersystem (hydrosphere),
- Ecosysteem (biosphere)

Branches in hydrology

Hydrosphere

- Potamology (hydrology of surface water)
- Limnology (hydrologie of lakes)
- Glaciology (hydrology of snow and ice)

Lithosphere

- Hydro-Geology (study of groundwater)
- Hydro-Pedologie (Inter-active processes within hydrolgy and soil science)

Biosphere

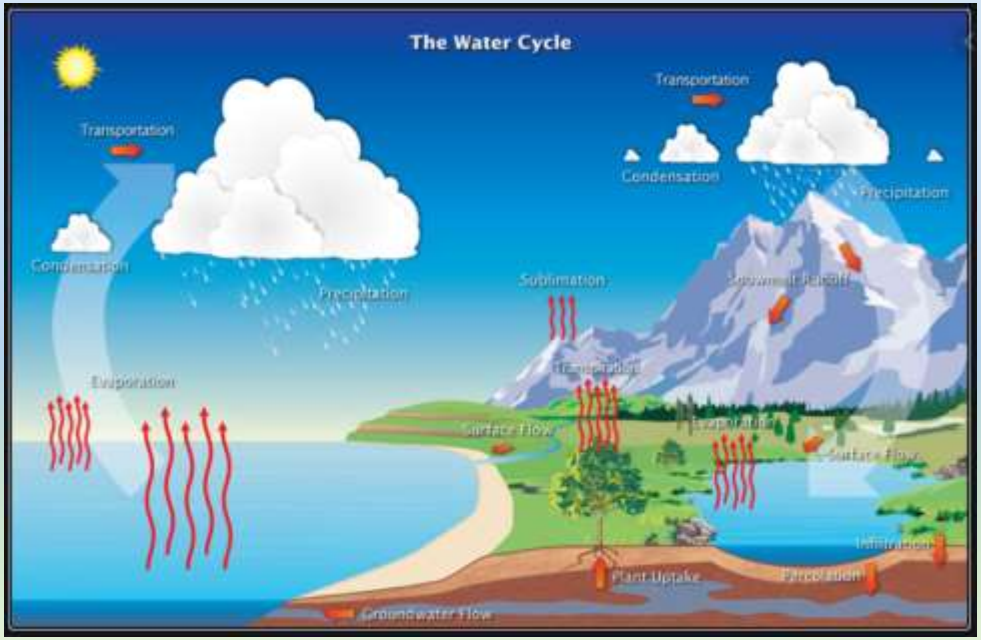
- Argro-Hydrology (hydrology of crops)
- Eco-Hydrology (study of inter-action between water and eco-systems)

Atmosphere

- Hydrometeorology (hydrological processen within the atmosphere, study of the atmospheric and land phase of the hydrological cycle with emphasis of the relationship involved)

The hydrological cycle (quantative)

- Water goes through a cycle
- Water evaporates from land and water systems to the atmosphere
- Clouds are formed and precipitation from atmosphere to Earth's surface occurs
- Water flows to canals, creeks, rivers, swamps/lakes, sea (surface water)
- Water penetrates the soil, enters soil and groundwater system, groundwater flow to canals, creeks, rivers, swamps/lakes, sea
- Water evaporates from land and water systems to the atmosphere



The hydrological cycle

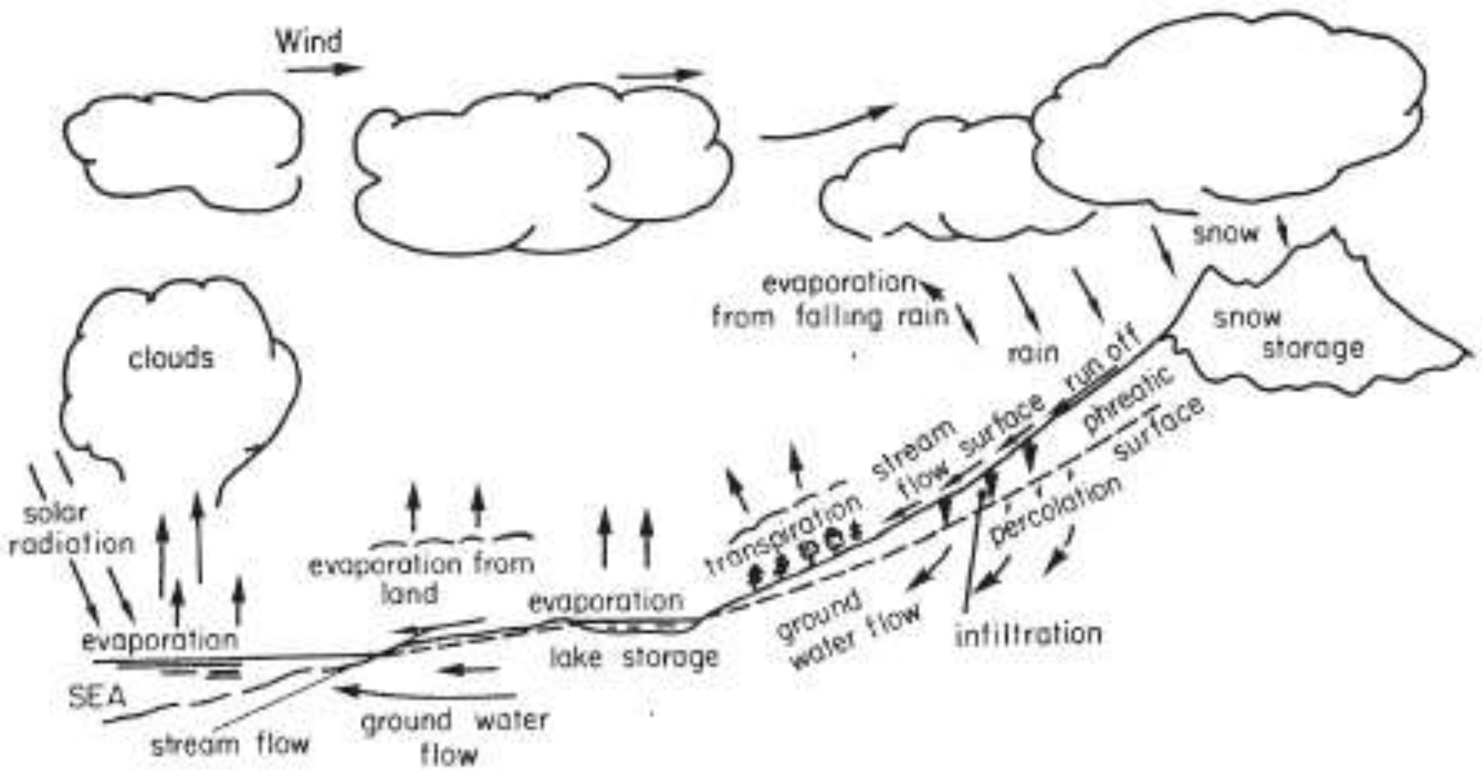
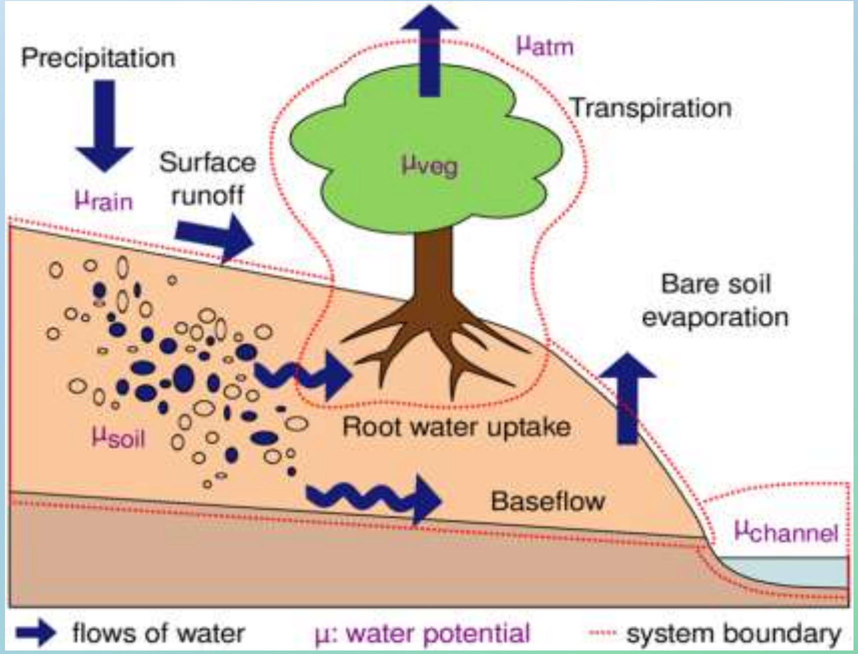


FIG. 1.1 *The hydrological cycle*

Source: Todd, 2005

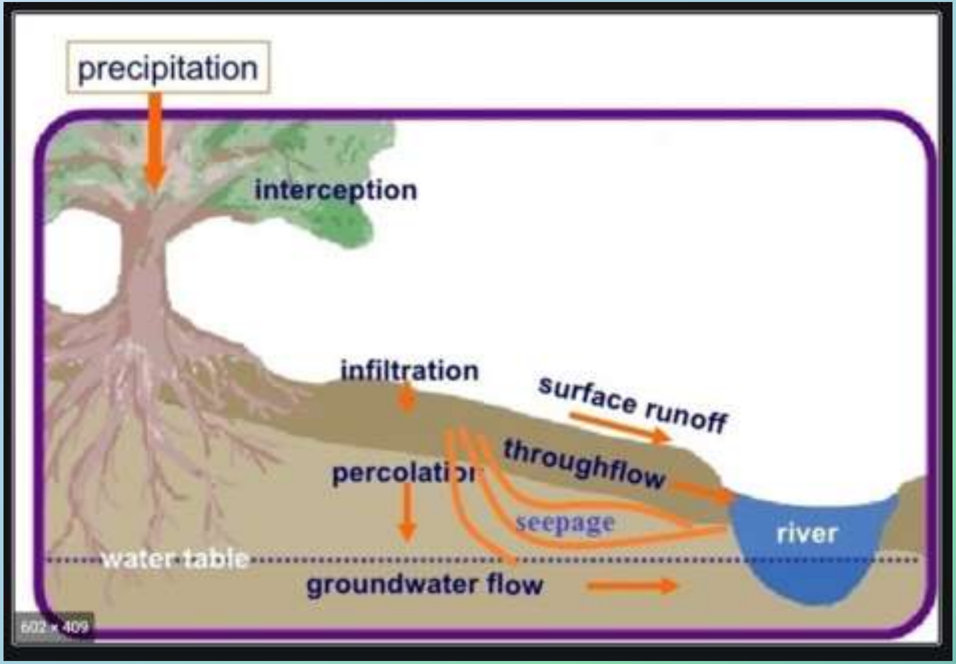
Components and processes of the hydrological cycle

- **Precipitation**
  - Rain, dew, snow, hail
- **Evapration, transpiration, evapo-transpiration**
- **Interception**
  - Temporary stored, evaporate at a later stage,
  - Canopy, grass, roof
  - Looses
- **Surface water**
  - Lakes, wetlands, channels, creeks, rivers, lake, sea
  - Flow
  - Storage
- **Infiltration**
  - Infiltration of water into the soil
- **Percolation**
  - Downward moving of water in the soil



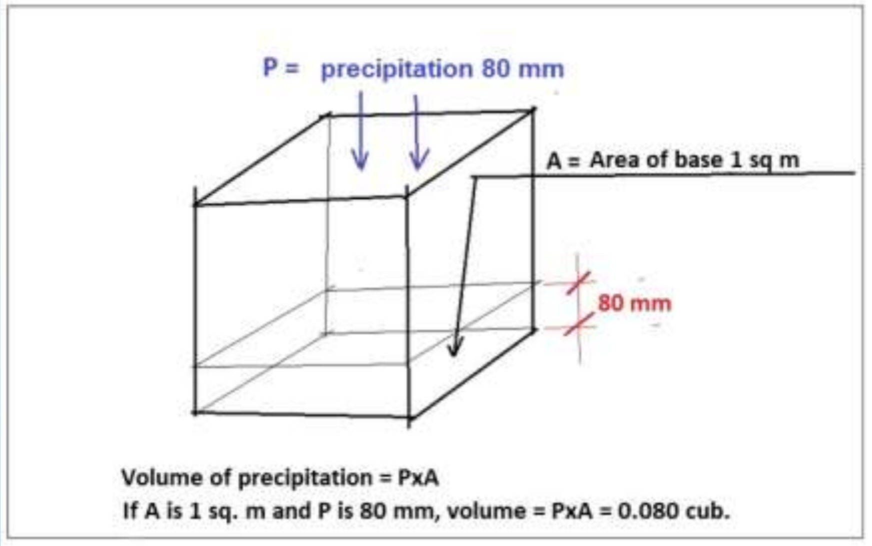
Components and processes of the hydrological cycle

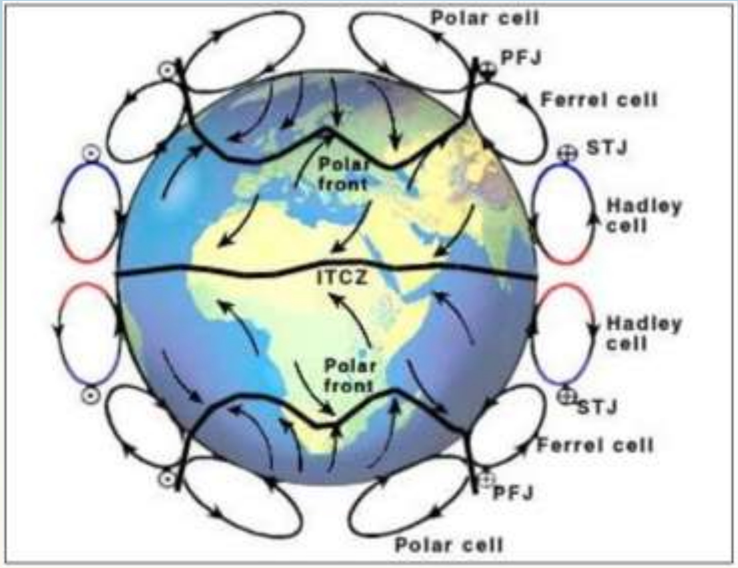
- **Unsaturared zone**
  - Soil moisture
  - storage
- **Groundwater**
  - Saturated zone in the soil
  - Aquifers (confined and unconfined)
  - Flow and storage
- **Discharge**
  - Surface runoff
  - Sub-surface runoff
  - Groundwater flow/seepage
- **Storage**
  - Storage of water
  - Frequently expressed in waterlevel or in volume of water
  - Also expressed in moisture content (in soils)

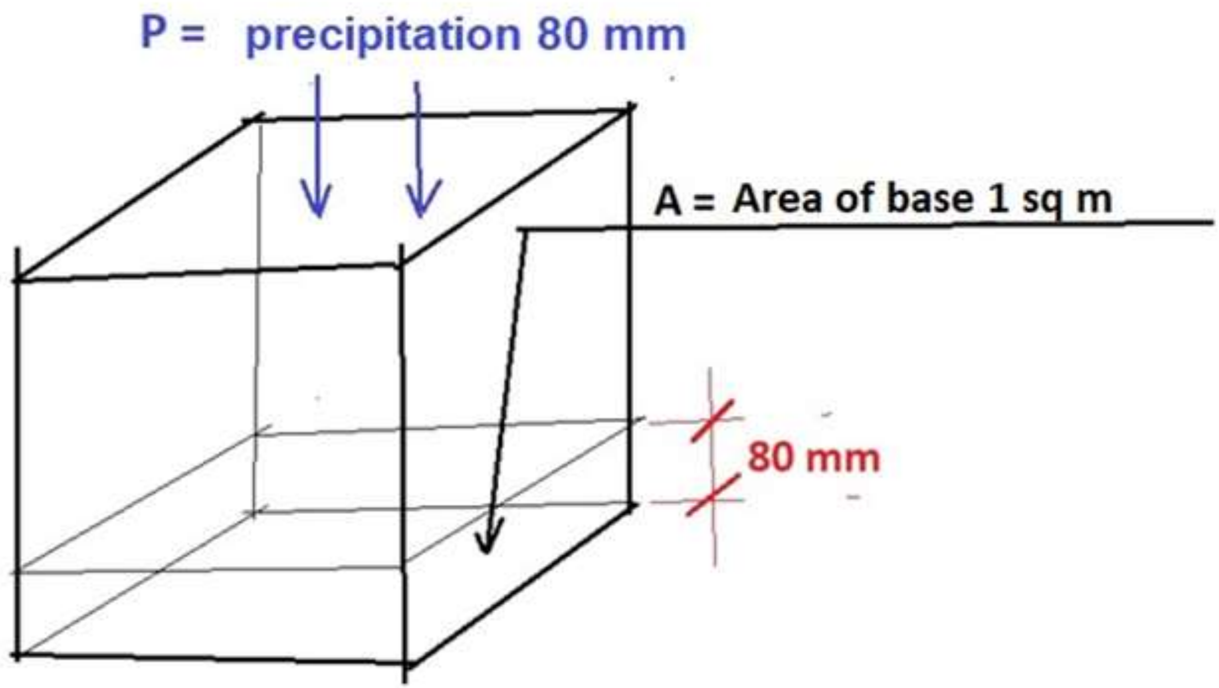


Precipitation (P)

- Expression: mm per time unit
- **Process**
  - Water evaporates from land and surface waters
  - Water vapor absorbed into the atmosphere
  - Water vapor condenses, if cooling occurs (higher air layers)
  - Maximum % moisture in air lower if temperature lower
  - Precipitated on the surface of the earth
  - Precipitation: rain, dew, hail, snow, sleet
- **Precipitation types**
  - Convective Precipitation
  - Orographic precipitation
  - Cyclonic and frontal precipitation
- **Seasons**
  - Governed by the ITCZ-zone (Intertropical Convergence Zone)



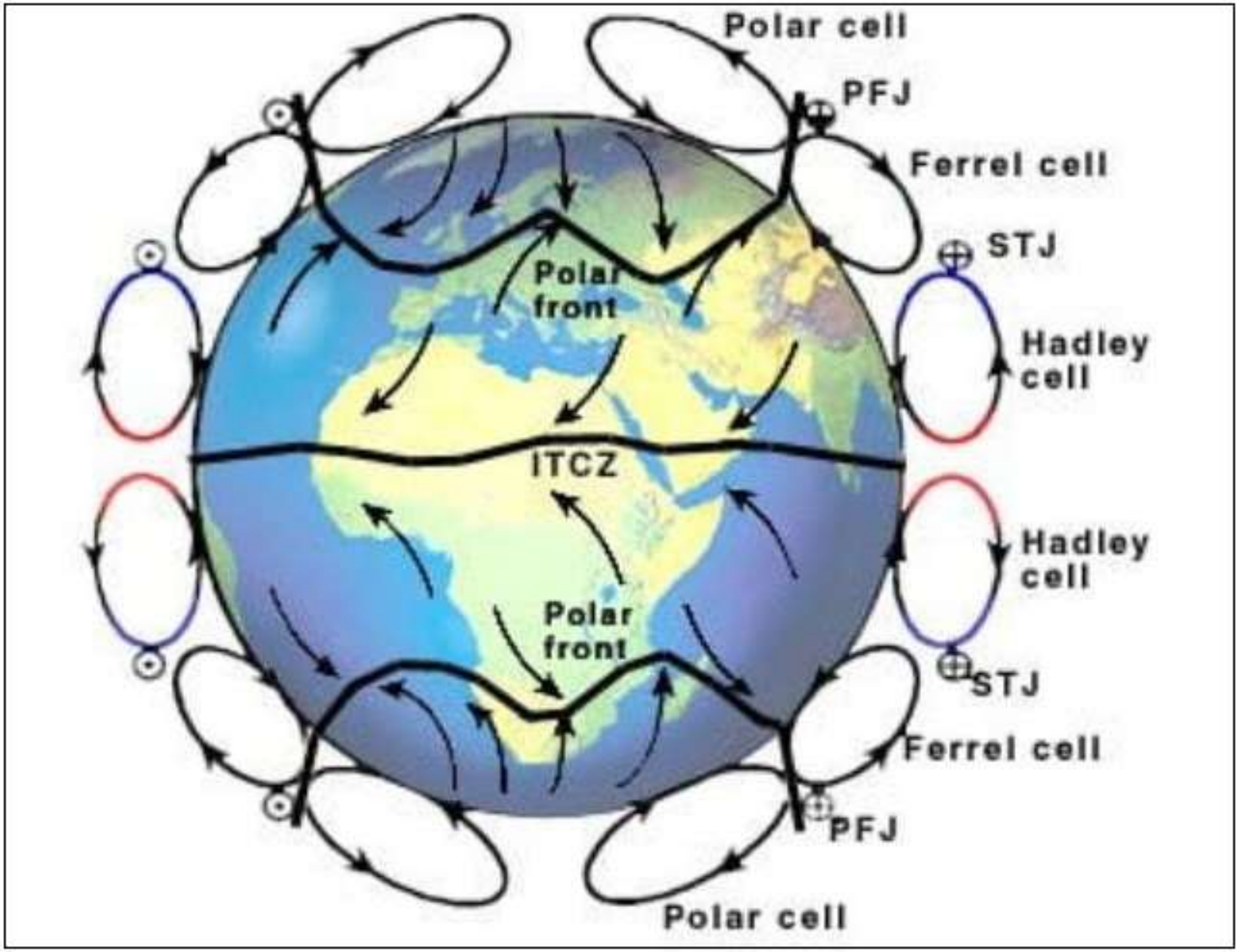




Volume of precipitation = PxA

If A is 1 sq. m and P is 80 mm, volume = PxA = 0.080 cub.

ITC-Z (Inter-Tropische Convergentie Zone)



Source: MetLink

Interception

- Expressed in mm
- Amount of precipitation that does not reach the ground
- Captured (retained) by foliage, turf, dry wood, roofing material, etc.
- Will evaporate over time
- A form of temporary storage
- Interception capacity: maximum amount of interception

Evapotranspiration

Expression: mm per time unit

Evaporation

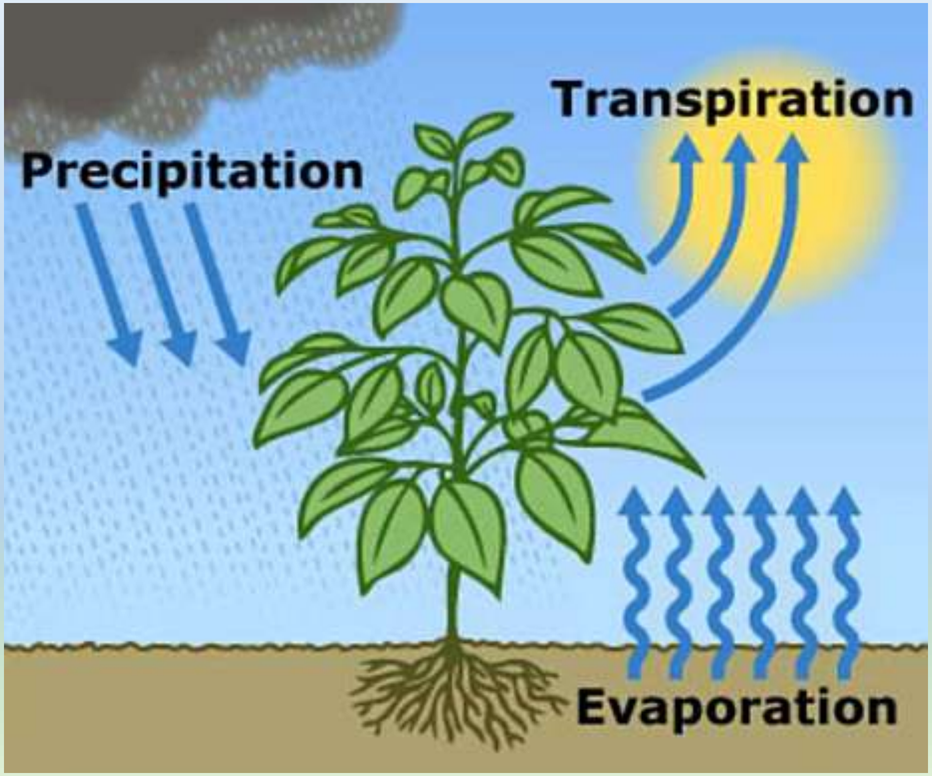
- Water transferred to the atmosphere as water vapor direct from surface water or the earth surface

Transpiration

- Water transferred to the atmosphere as water vapor by plants

Evapotranspiration

- Combination of evaporation and transpriration



Evapotranspiration Source picture: USGS

Evaporation

Potential evaporation

- Maximum evaporation under prevailing climatic conditions, where sufficient moisture is present

Actual evaporation

- Evaporation that actually occurs under the prevailing climatic conditions, where the moisture present is a limiting factor
- Is equal to or lower than potential evaporation

Evaporation

Depends on

Evaporating surface

- Color and reflective properties of evaporating surface are important
- In direct or indirect sunshine

Meteorological factors

- Solar radiation
  - Energy required for conversion of water to water vapour
- Wind
  - Water vapor in atmosphere due to evaporation
  - Water-atmosphere boundary layer saturated
  - In the case of an air flow boundary layer, water vapor is removed and dry air is supplied
  - Increase in flow of water vapor from the water

Evaporation

Meteorological factors

Relative air humidity (RH = Relative Humidity)

- Maximum possible humidity depending on temperature (saturated humidity)
- RH is actual air humidity divided by saturated air humidity
- Evaporation occurs at lower RH
- Airflow allows air with higher RH to be removed and air with lower RH to be brought in, increasing evaporation

Temperature

- Energy required for evaporation
- At higher temperature, higher saturated humidity, more moisture in the atmosphere possible, higher evaporation

Transpiration

- Water necessary for plants and other organisms
- Small portion of water required for building plant tissue
- Most water consumption for transpiration
- Process: water absorbed by roots (soil moisture), flows through trunk and transpires through leaves through the stomata (skin pores of leaves) (see Ecohydrology)
- Transpiration difficult to measure, usually evapotranspiration measured or calculated
- Can be measured with isothopes
- Amount of moisture transfered to the atmosphere depends on
  - Precipitation (presence/supply water for evaporation)
  - Climatic factors
  - Land use and vegetation

Transpiration

- **Potential transpiration**
  - the maximum amount of water that can transpire, if the availability of water is not a limiting factor
  - also depends on type of vegetation and growth stage
- **Actual transpiration**
  - Equals potential transpiration when soil is saturated with moisture or at field capacity, stomata fully open
- **Decrease in transpiration up to permanent wilting point**
  - due to closure of stomata
  - permanent wilting point: plant is no longer able to absorb moisture from the soil, due to too low moisture content

Soil moothe

Field capacity

Maximum soil moisture content, moisture retained by capillary forces against gravity.

- Is soil condition, in which maximum amount of moisture is retained in the soil, after excess water has drained off and has flowed down through the pores.
- Depending on soil type, pore content and grain distribution
- At field capacity, maximum amount of soil moisture is available for plants
- Evapotranspiration equals to potential if soil is at field capacity

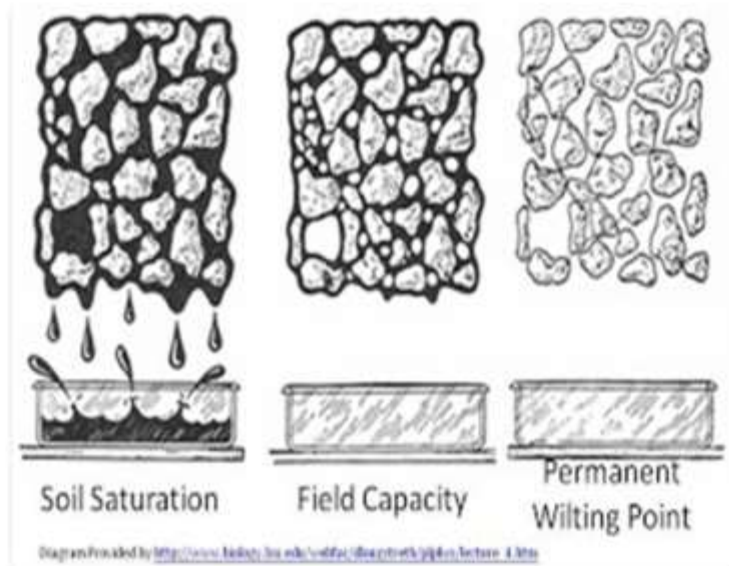
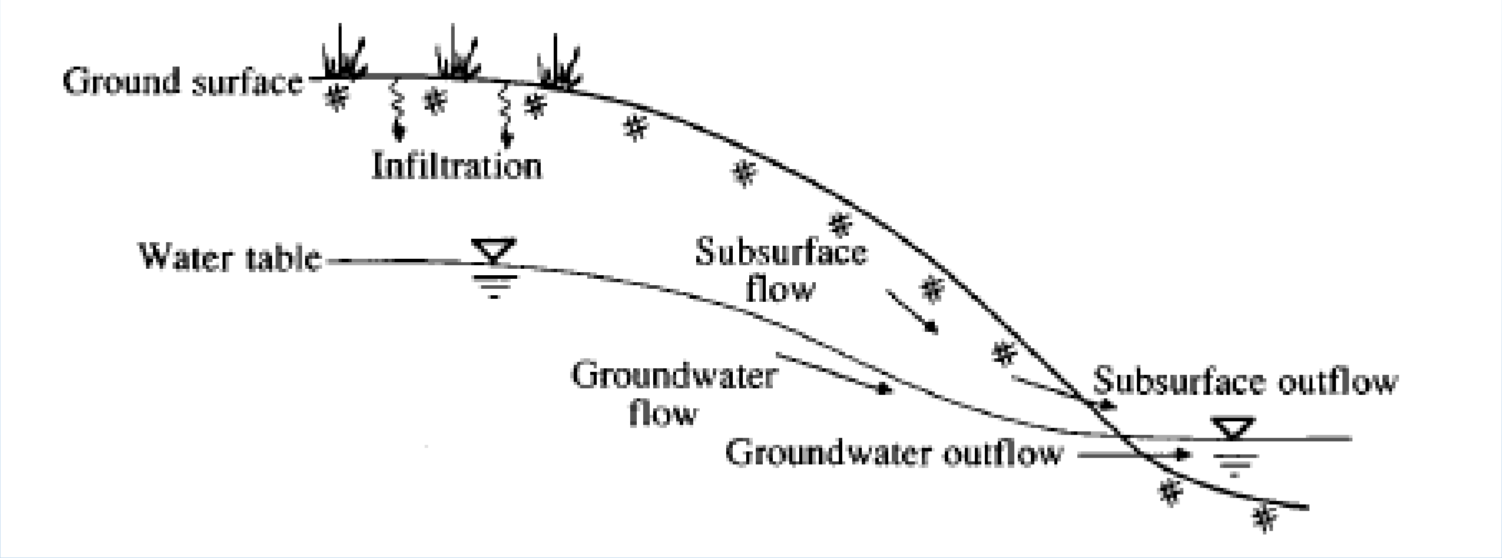


Figure 1: Differing terms regarding water holding capacity of soils.

scheduling-part-2-determining-water-holding-capacity

Infiltration



Picture: Chow 1988

Expressed in mm per time unit

Infiltration

- Penetration of water through the earth's surface into the soil
- After the interception capacity has been reached, water reaching the earth surface
- depending on the amount of precipitation

Infiltration capacity

- Maximum possible infiltration, not always constant
- Depending on the permeability of the soil and soil type

Percolation

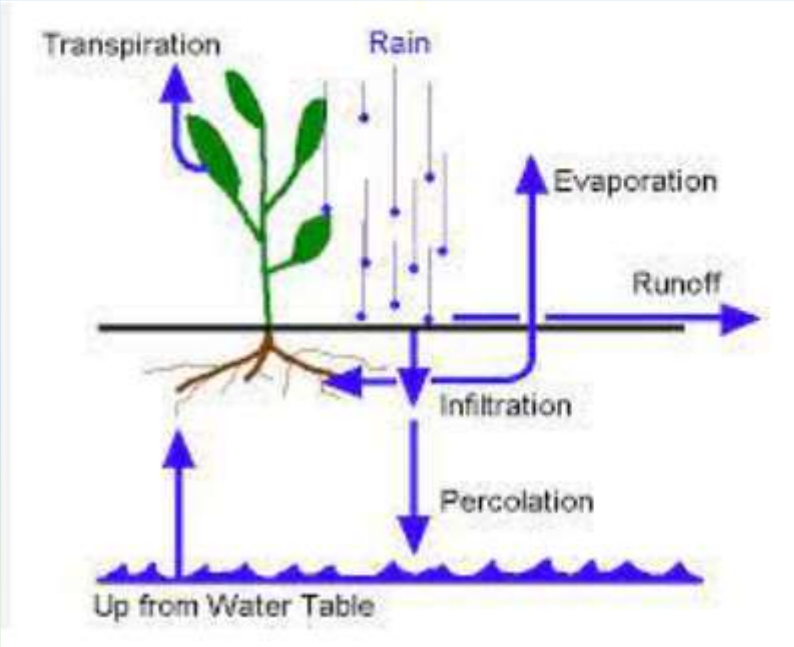
Expressed in mm per time unit

Percolation

- The downward flow of infiltrated water to the saturated zone (groundwater) due to gravity
- Occurs when soil is at field capacity.

Percolation capacity

- Maximum possible percolation
- Depending on soil type, pore content and grain distribution



Source: https://forestrypedia.com/infiltration-and-percolation/

Soil moisture and ground water

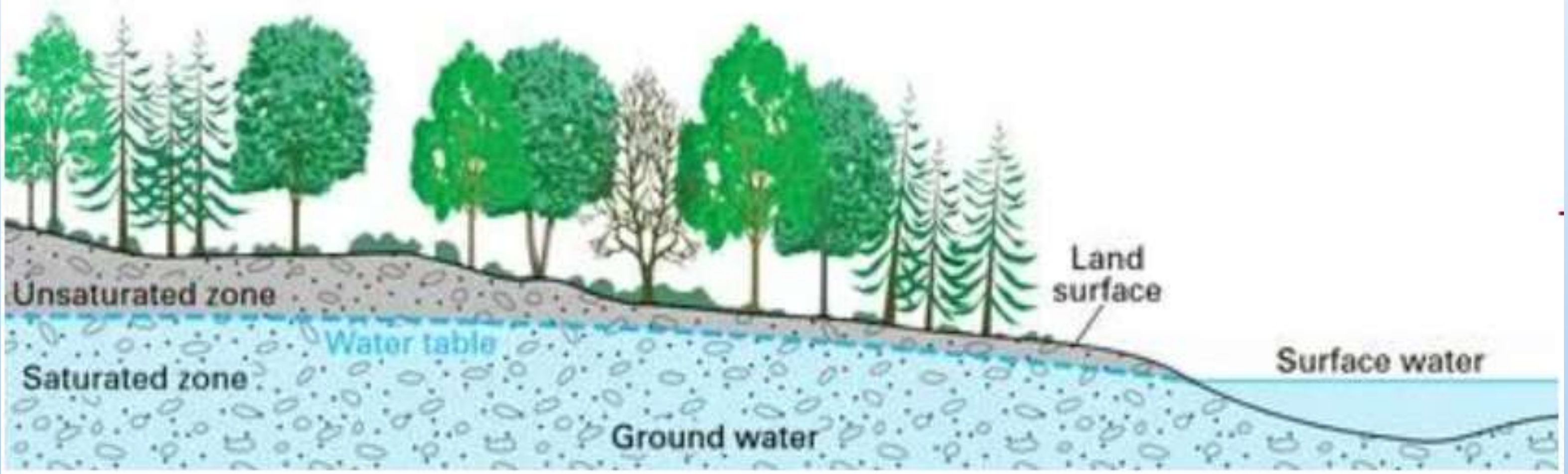


Illustration of groundwater location. (USGS)

- The unsaturated zone
- The saturated zone
    - Groundwater and groundwater level
- Groundwater-carrying layers (aquifers)

Soil moisture and ground water

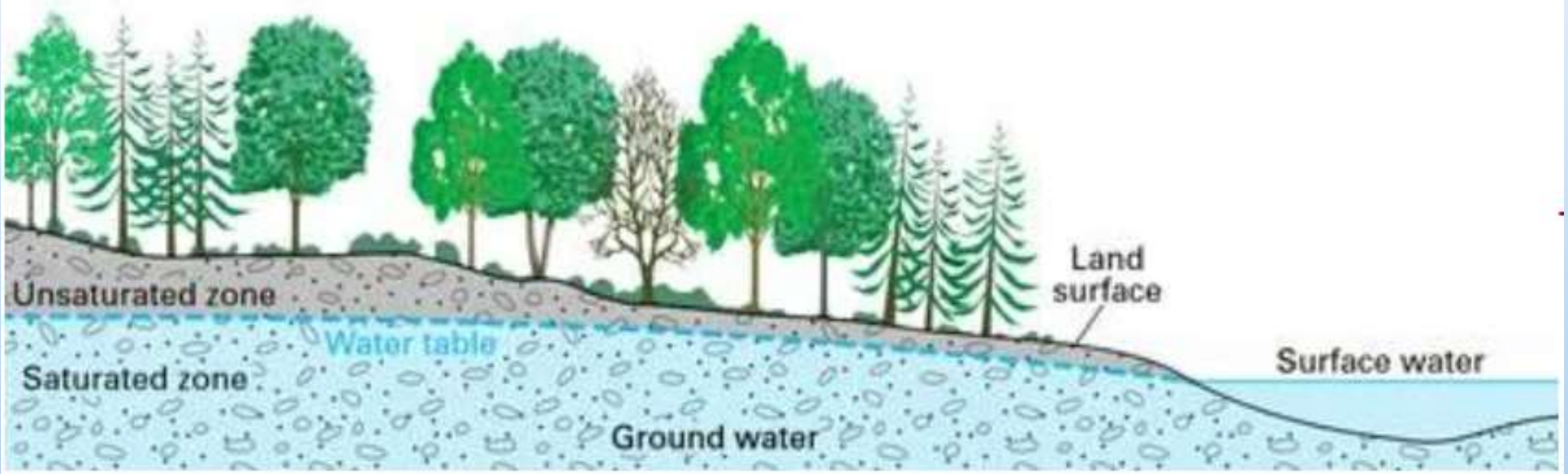


Illustration of groundwater location. (USGS)

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- The saturated zone
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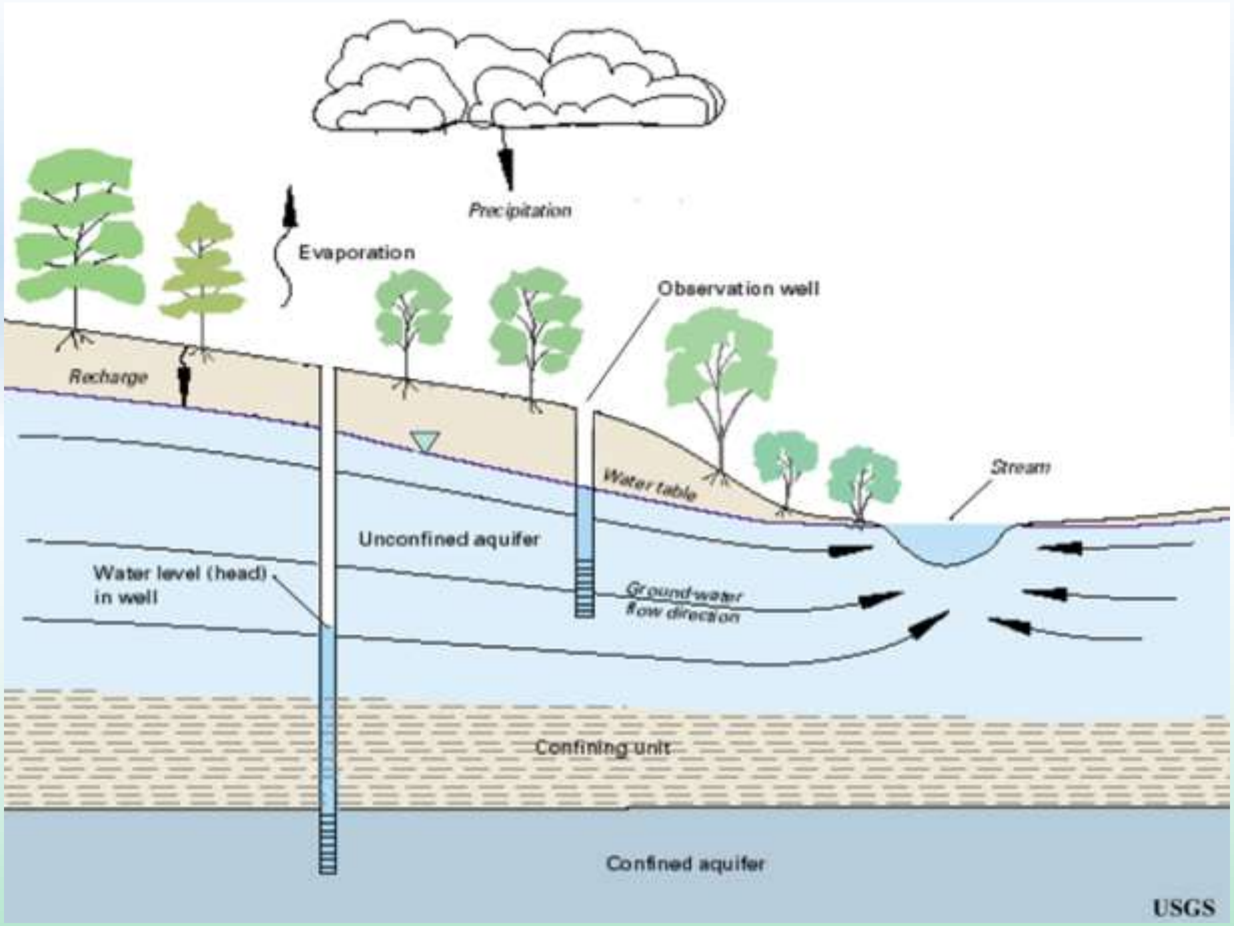
Groundwater system



Source picture: Research gate/ William M. Alley

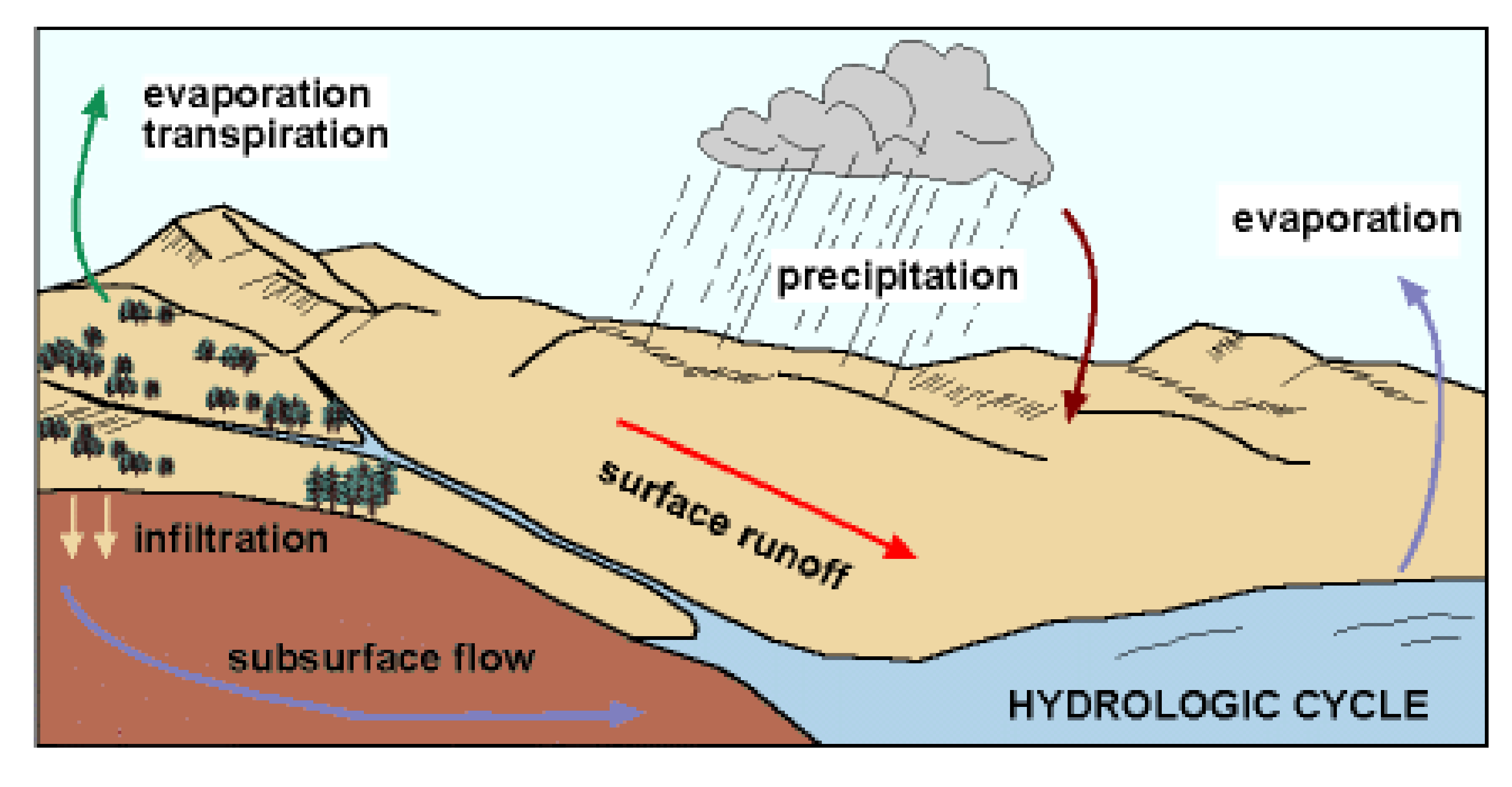
Soil moisture

Leaves the catchment through evaporation or evapotranspiration

Groundwater

Leaves the catchment through groundwater flow

Surface runoff en sub-surface flow



Source

http://geology.isu.edu/wapi/EnvGeo/EG7_water/EG_module_7pt1.htm

Groundwater system

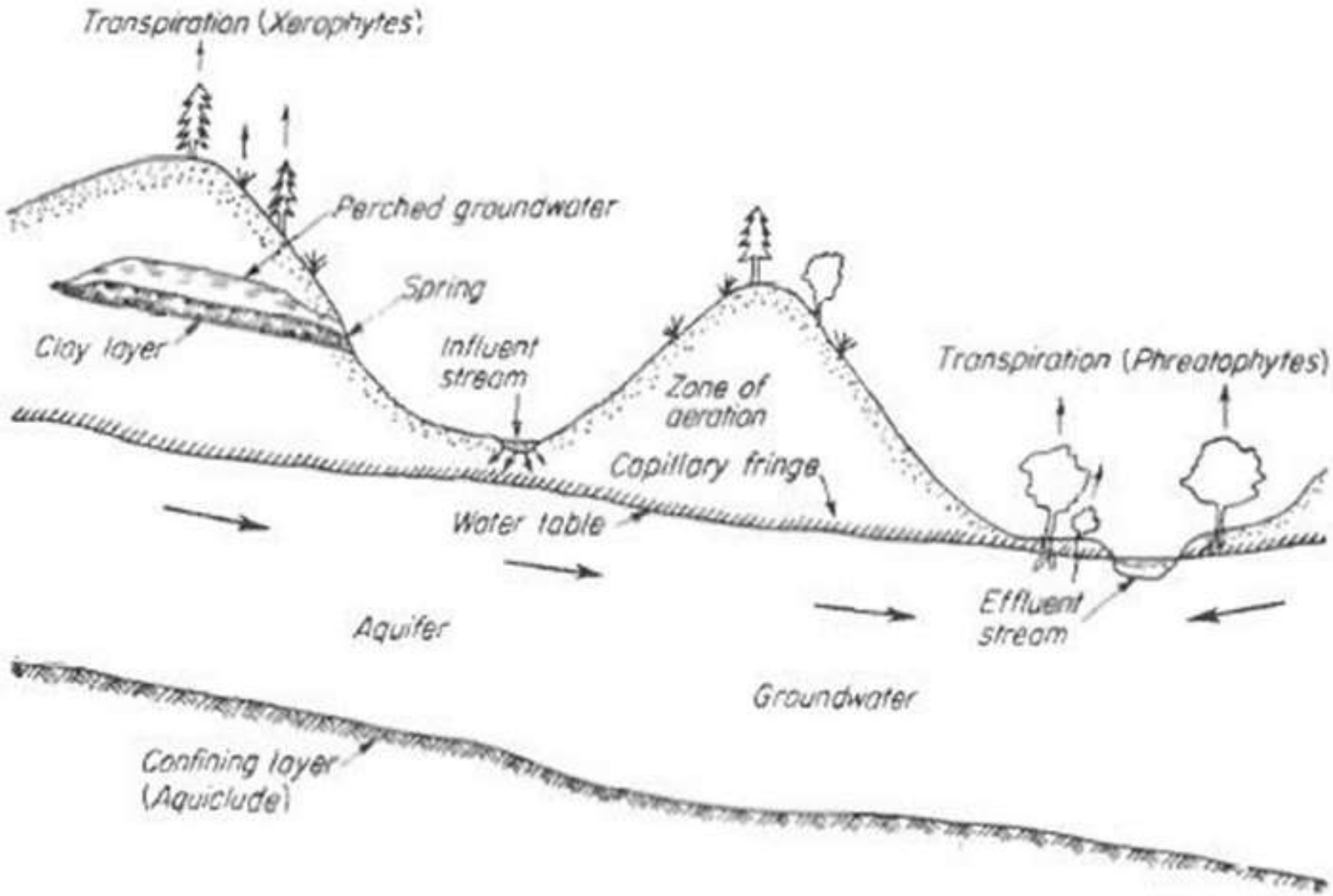
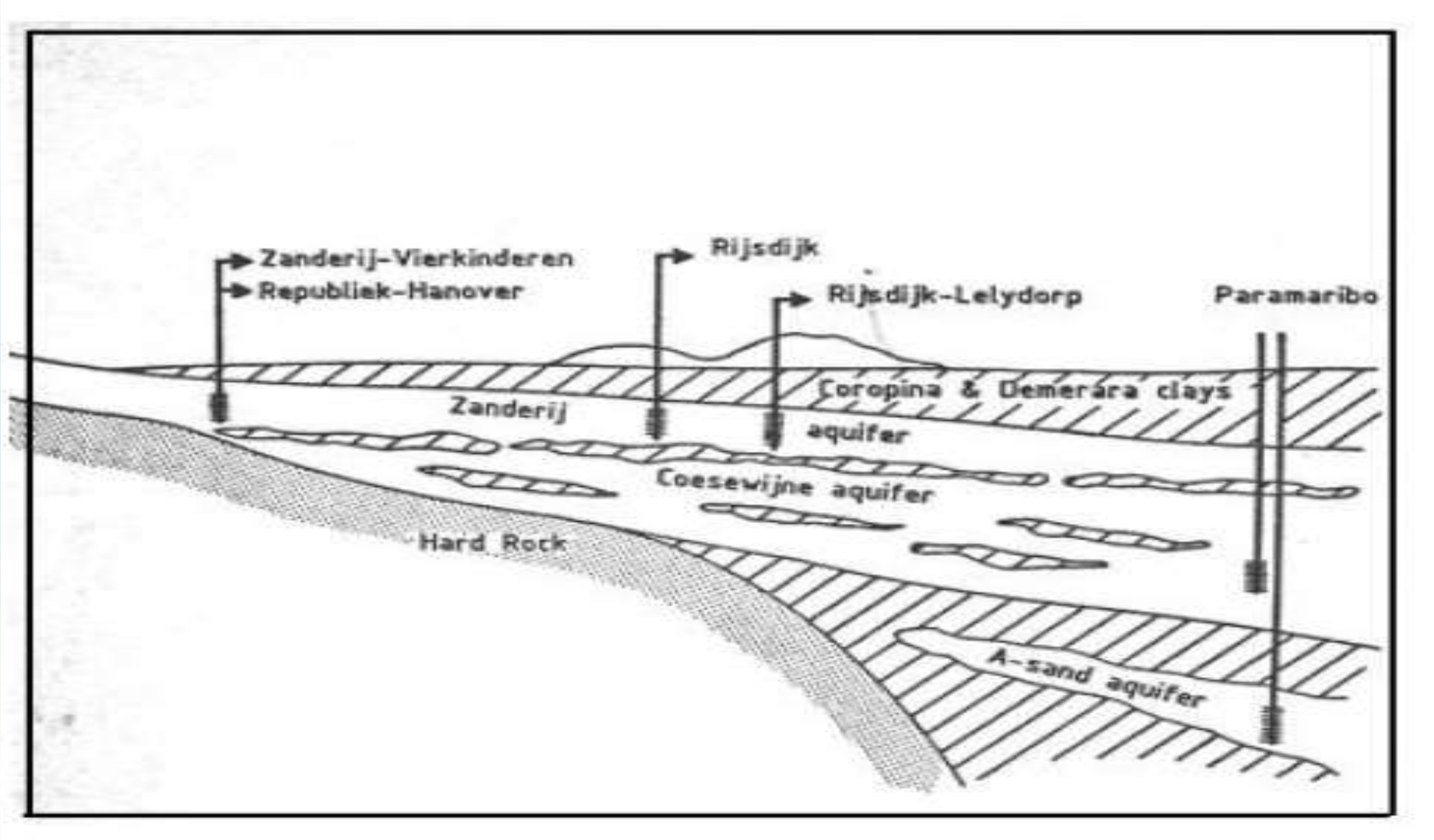


FIG. 6-1. Schematic cross section showing the occurrence of groundwater.

Source: Todd, 2005

Grondwater (aquifers) in Suriname



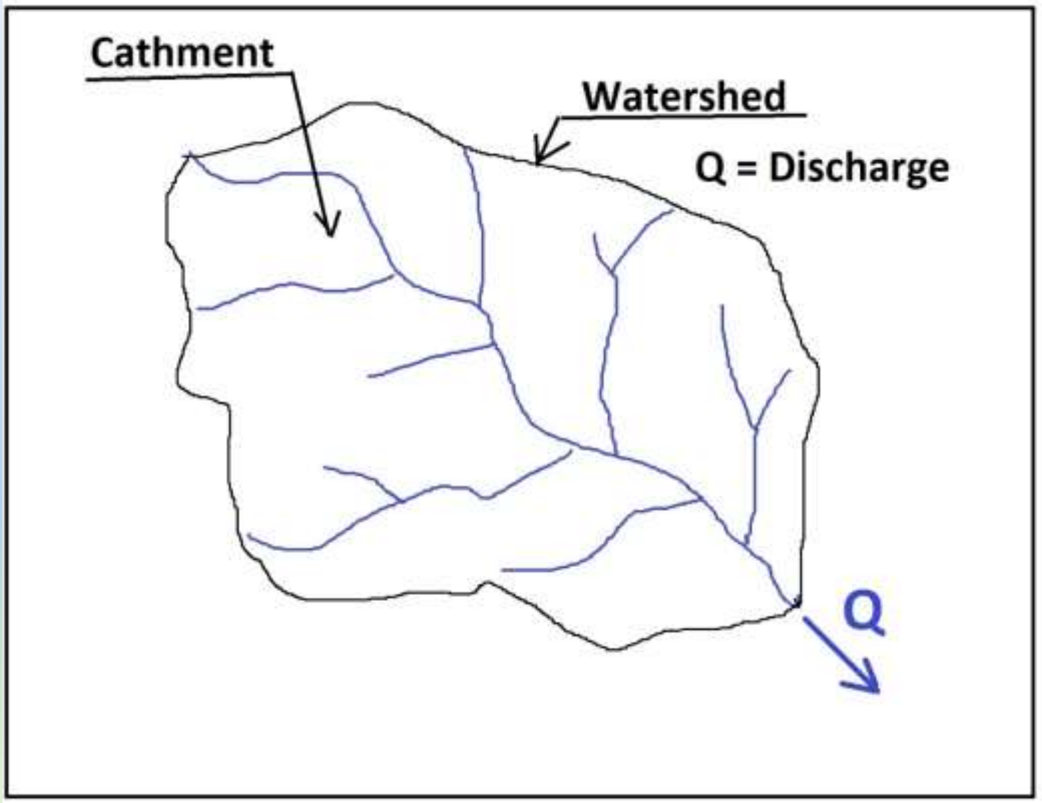
Cathment and Watershed

Cathment

- Area that drains its water through a watercourse (river/stream/canal).

Watershed

- Line which connects the highest (topographical) points between two catchments
- Ttopographical watershed is static. When the area near the watershed is inundated, the actual watershed is mobile, depending upon the water level. The same with groundwater, it depends on the groundwater level and will not always coincide with the geographical watershed, which is the watershed of surface water.



Discharge

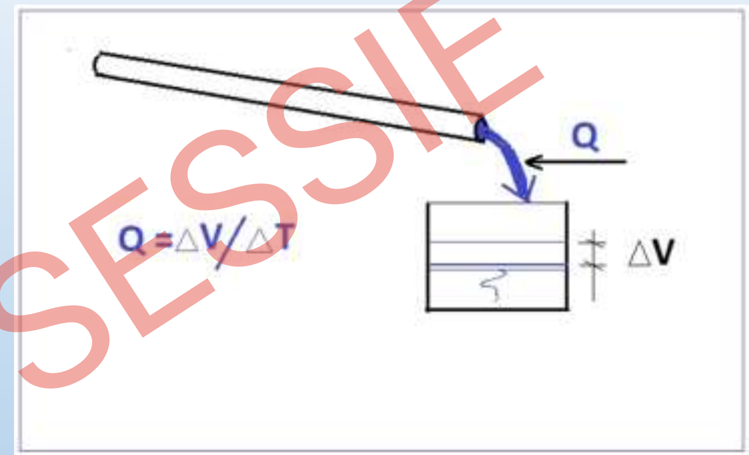
Discharge (Q)

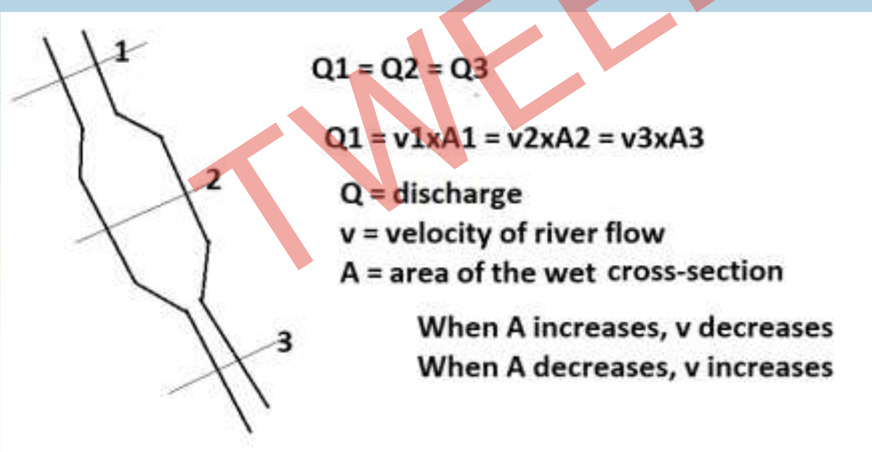
Volume of water flowing through a water course measured at any given point in m^3/sec or ft^3/sec.

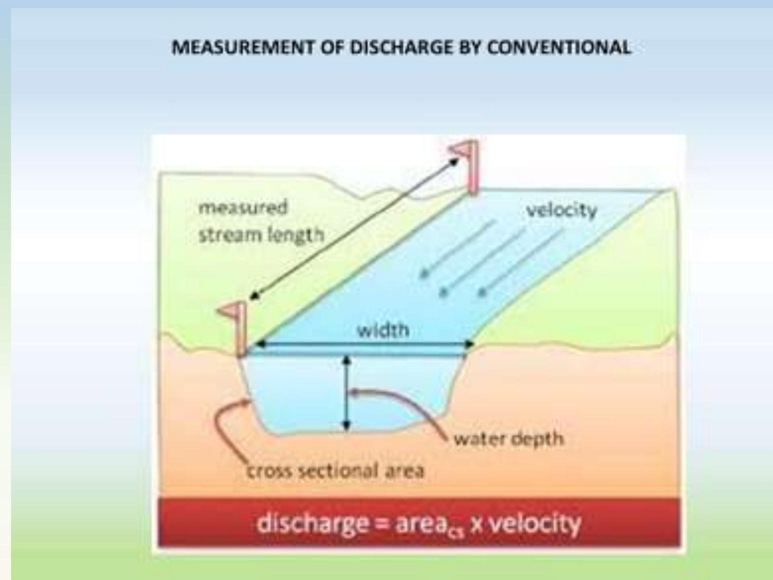
$Q = v \times A$

v = velocity of the river flow

A = area of the wet cross-section of the water course







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Discharge

Measured/calculated from a catchment

Components of the discharge (in m^3/sec or mm/day)

1. Surface runoff
2. Sub-surface runoff
3. Groundwater flow/seepage

Discharge to be divided in:

1. Direct Flow
   - Mainly surface runoff and sub-surface flow
   - Important for peak flow and high water level, during the wet season
2. Baseflow
   - Contribution by discharge from the groundwater system
   - Important for low flow during the dry periods

Componnent natural hydrographs
Discharge hydrograph due to a storm event

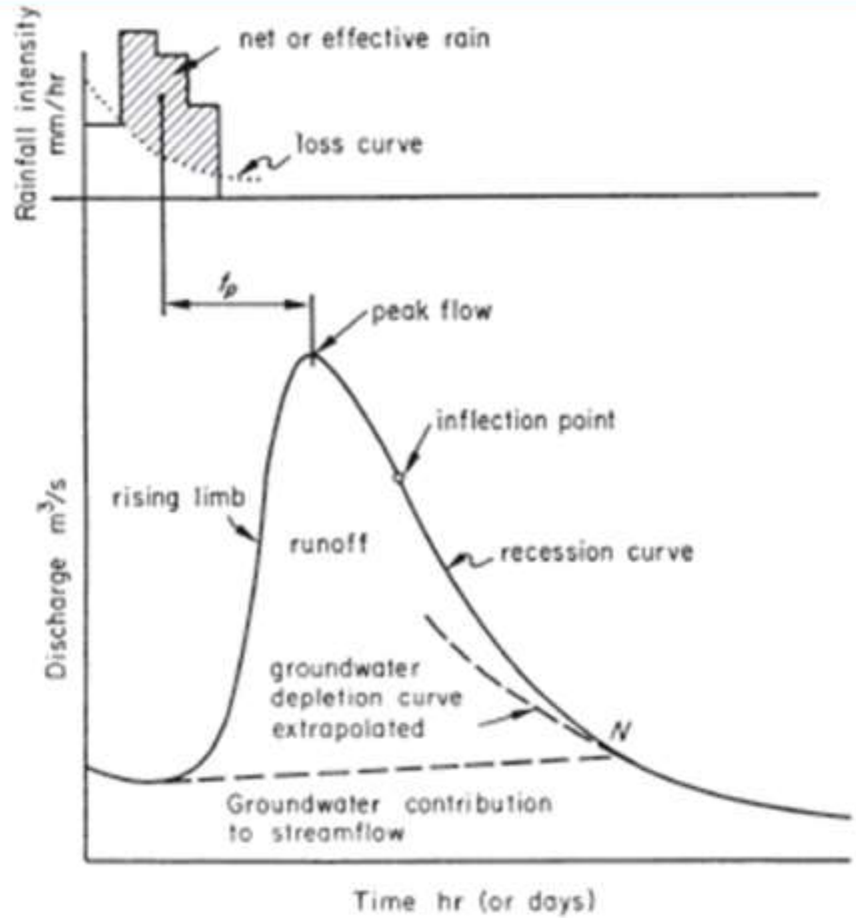


FIG. 7.1 *Component parts of a natural hydrograph*

Source: Todd, 2005

Componnent natural hydrographs

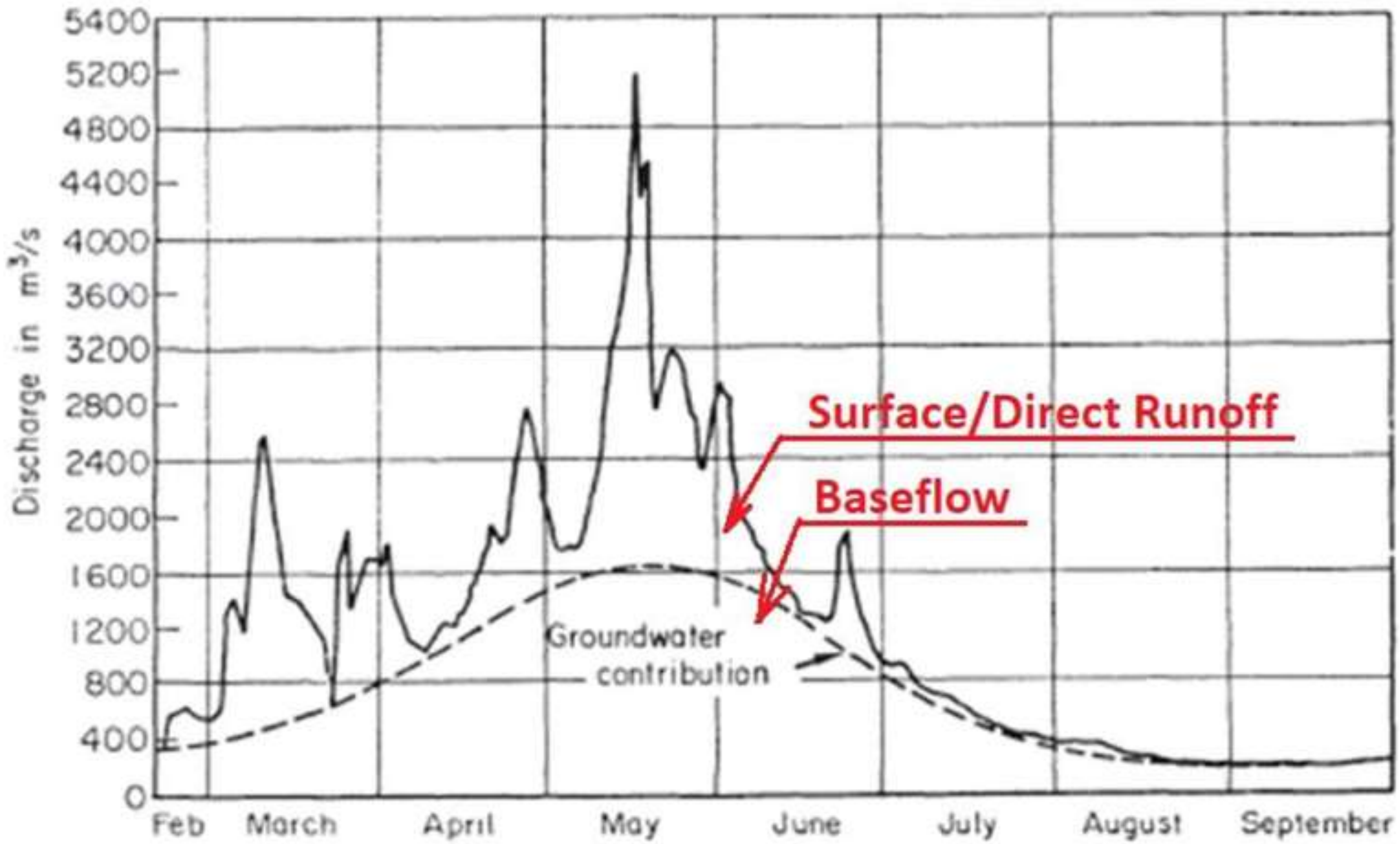
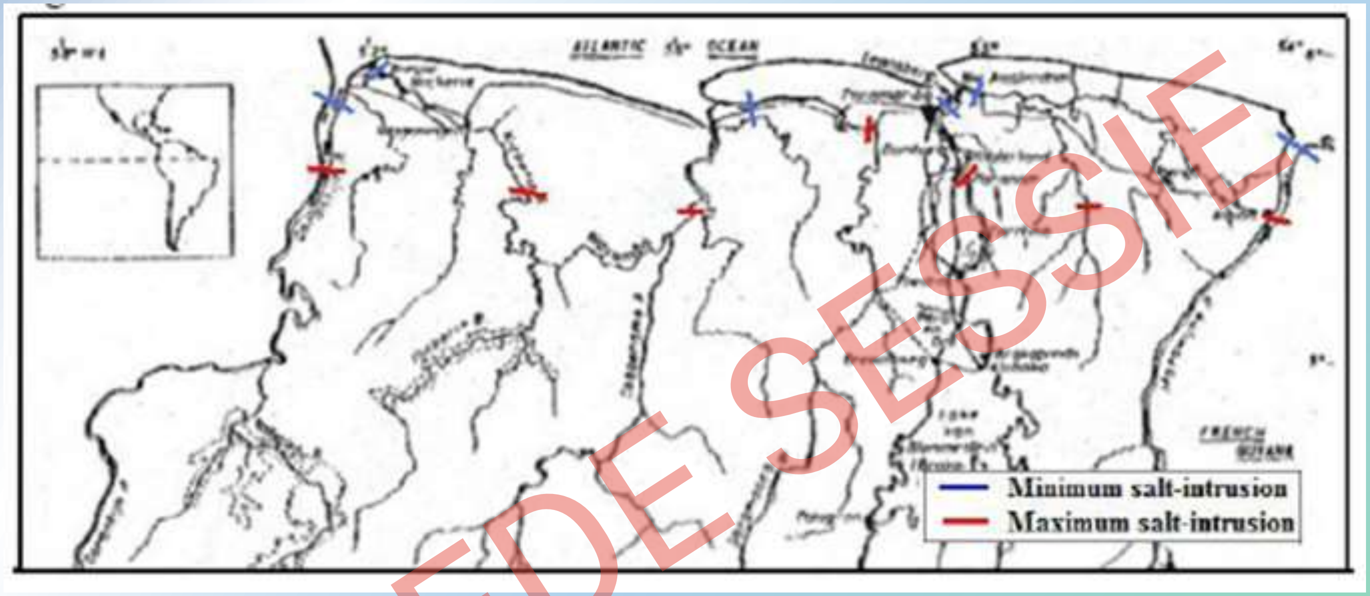


FIG. 6.5 *Hydrograph of R. Euphrates at Hit. Feb.–Sept. 1957 (after Directorate of Irrigation. Iraq)*

Source: Todd, 2005

Salt intrusion in the river



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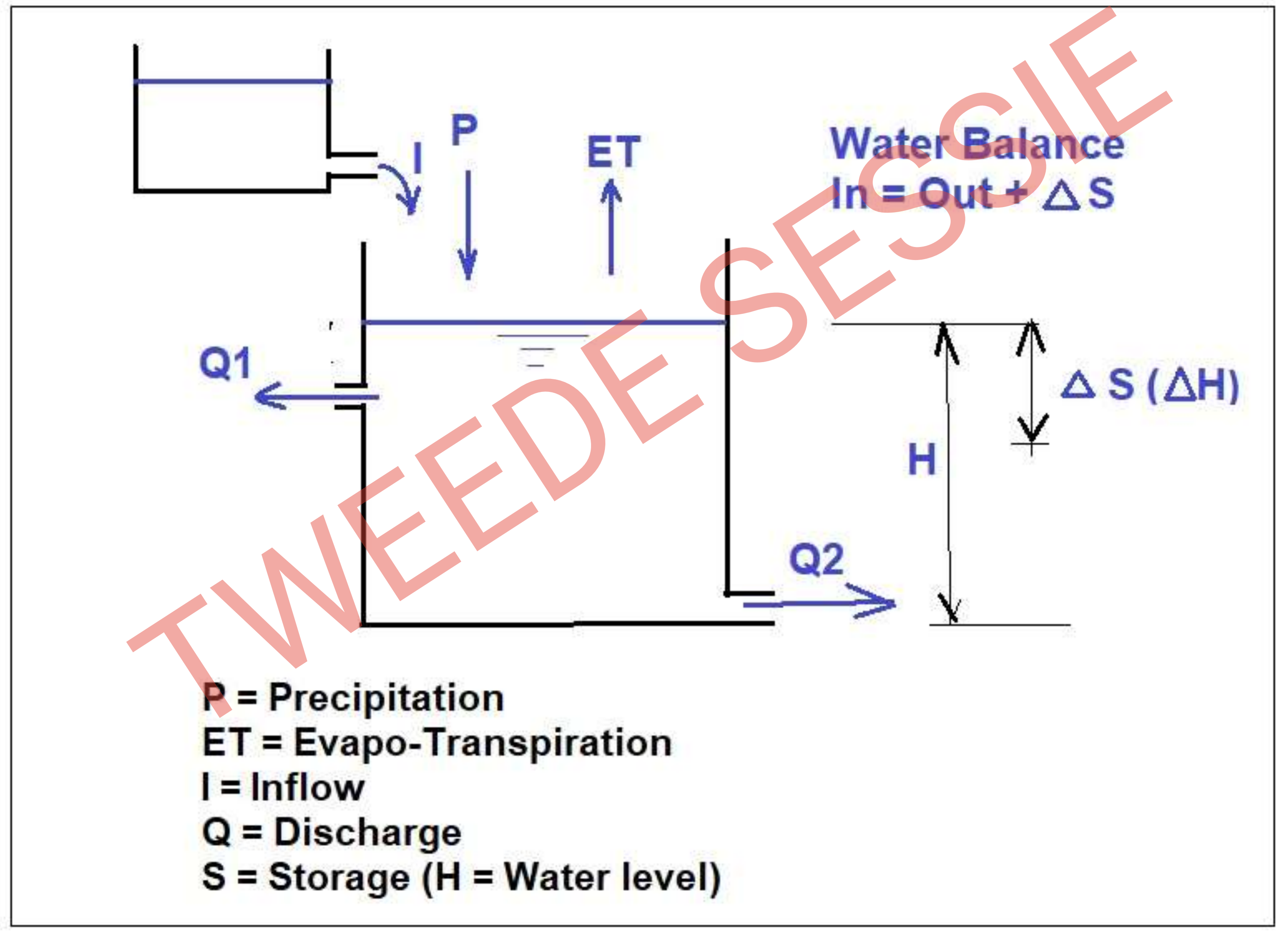
- Sea water (brackish water) enters the river.
- The discharge of freshwater from the river prevents the intrusion of seawater.
- The salt intrusion is highest during the day at high tide and lowest at low tide.
- In the dry season the salt intrusion is highest because the river discharge is smallest
- In the rainy season, salt intrusion is least because the river afooer is highest.
- Maximum salt content for freshwater crops (e.g. rice) is 300 mg Cl-/l and for drinking water 250 mg cl-/l

Water Balance



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How Trees Influence the Hydrological Cycle in Forest Ecosystems

Water balance:

- In = Out + ΔS
- $P + Q_{in} + L_{in} = Q_{out} + L_{out} + ET + \Delta S$
- P = (Areal) Precipitation
- Q_{in} = Recharge, inflowing water rate
- L_{in} = Water leaking into the catchment, including seapage
- Q_{out} = Discharge, outflowing water rate
- L_{in} = Water leaking from the catchment, including seapage
- ET = (Areal) Evapotranspiration
- ΔS = Change in storage
- The water balance is used to estimate the magnitute of the components of the hydrological cycle which is unknown.
- When the time period of the water balance calculation is long, the change in storage is negiglible.

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Appication of water balance

Example: lake, completely covered with water

Precipitation : 70 mm/day

Increase in water level: 6 cm

Area of the lake: 1600 km^2 (constant)

Evaporation: 4 mm/day

Calculate the discharge from the lake

There is no inflow of water into the lake from adjacent areas and streams.

Seepage and groundwater flow are negible

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Appication of water balance

Precipitation : 70 mm/day

Increase in water level: 6 cm

Area of the lake: 1600 km^2 (constant)

Evaporation: 4 mm/day

Calculate the discharge from the lake

In = uit + Δ S

P = (Q + E) + Δ S

70 mm = Q + 4 mm + 60 mm

Discharge (Q)= 70 – 60 – 4 = 6 mm/day

= 6.10^{-3} m x $1.600.10^3.10^3$ m^2= 9.600.000 m^3/etm

= 111 m^3/sec

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Regulation of a river/stream

- The discharge of the river/stream varies in time
- High discharge during wet season and low discharge during dry season
- Take measures to keep the discharge constant by establishing a storage lake (regulation of the river)
- Keep the discharge more or less constant
  - Availability of water constant throughout the year
  - No extreme low flow, less salt in trusion

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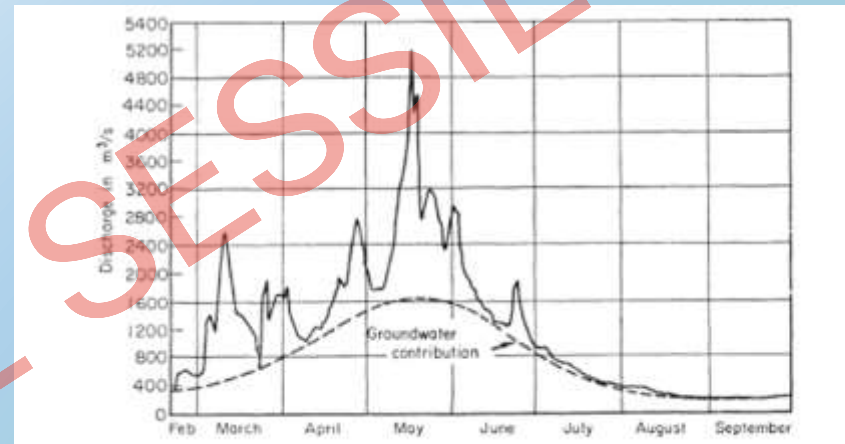

FIG. 6.5 *Hydrograph of R. Euphrates at Hit. Feb.–Sept. 1957 (after Directorate of Irrigation. Iraq)*

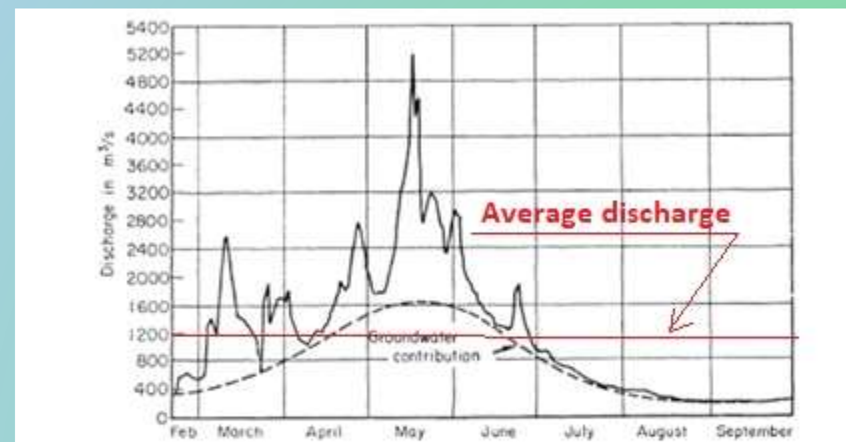

FIG. 6.5 *Hydrograph of R. Euphrates at Hit. Feb.–Sept. 1957 (after Directorate of Irrigation. Iraq)*

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FIG. 6.6 *Cumulative mass curve of runoff for R. Euphrates at Hit. Feb.–Sept. 1957*

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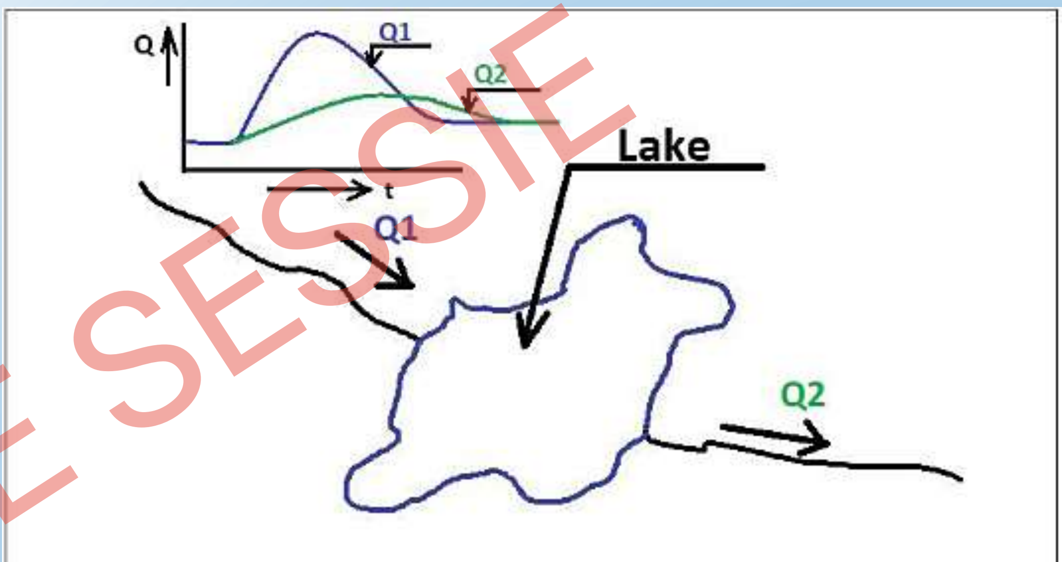
FIG. 6.6 *Cumulative mass curve of runoff for R. Euphrates at Hit. Feb.–Sept. 1957*

Calculation of the required storage in a reservoir, when the dischange from the reservoir is constant for a long period.

Flood Routing

- Many activities along river and other water courses and water bodies.
- Danger for flooding.
- Measures taken to decrease effects of floods.
- How will these measures behave when flooding occurs ?
- ***Flood routing***
  - Description applied to above processes
  - Process showing how a flood wave may be reduced and lengthened in time by the use of storage in the reach between two points.



Flood Routing through a (lake) reservoir

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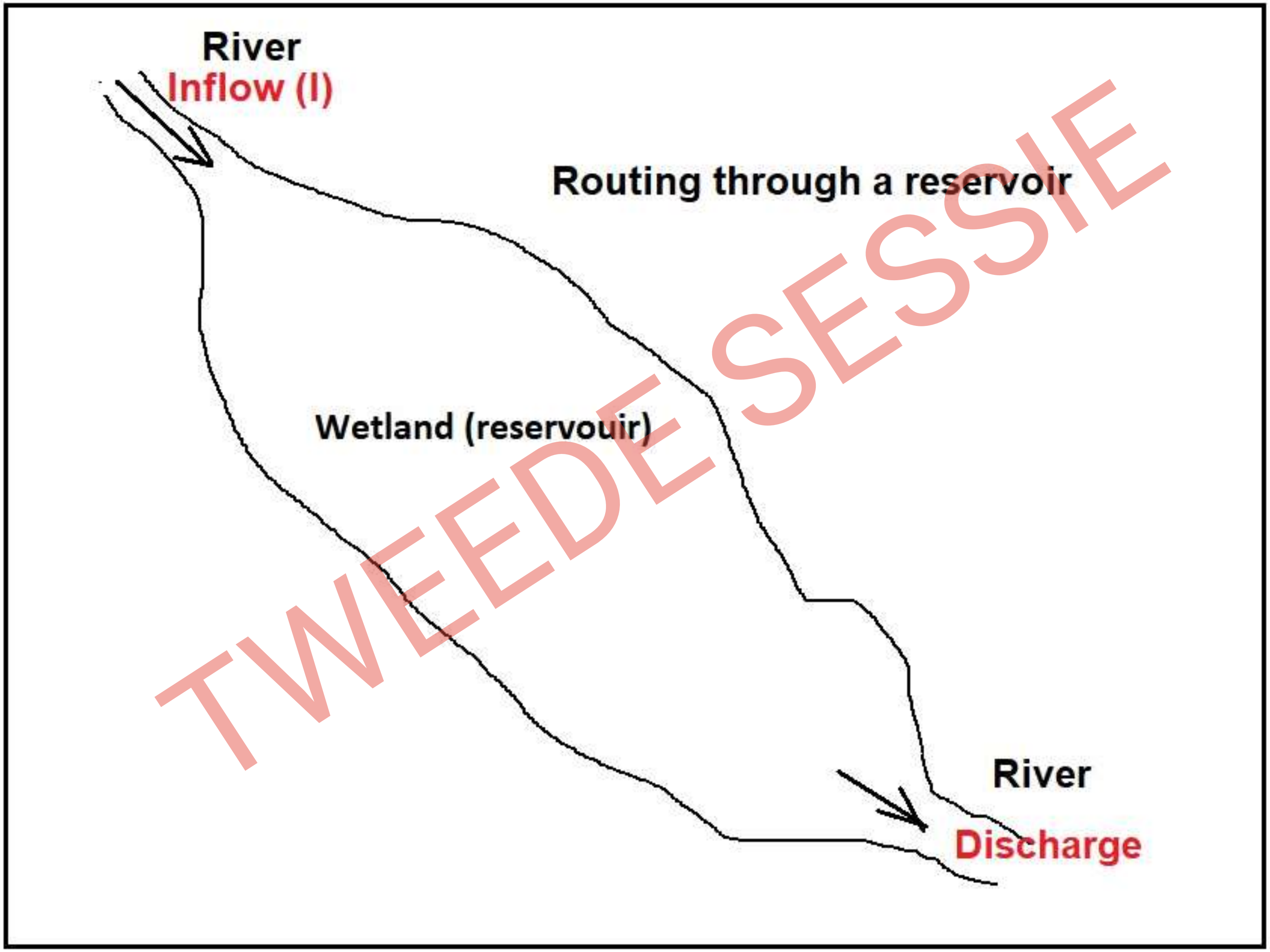

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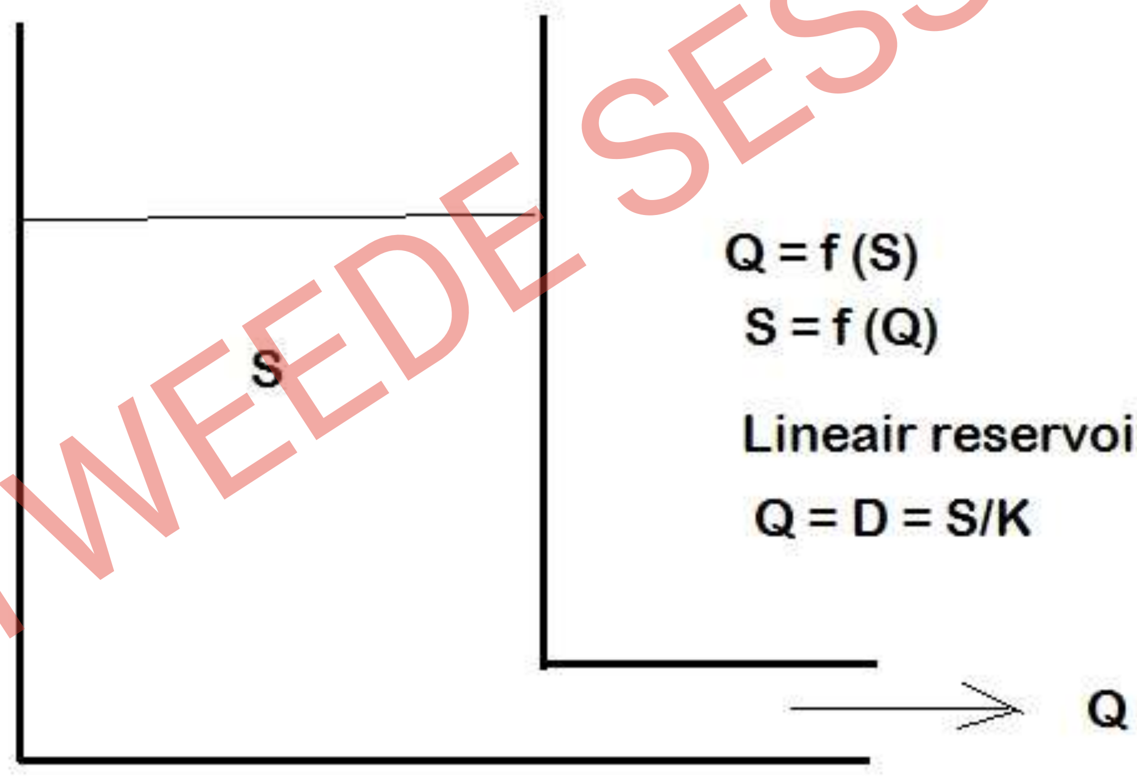
Flood Routing



Q = f (S)

S = f (Q)

Lineair reservoir S = KD

Q = D = S/K

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Flood Routing

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Routing in a river channel

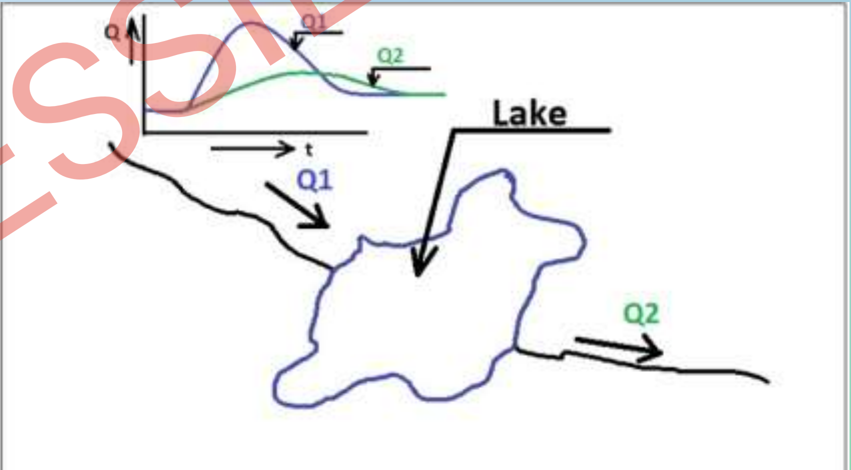
Muskingum method

Storage is expressed as function of inflow and discharge

$$S = K[xI + (1 - x)D]$$

x = dimensionless constant for a certain river reach

K = storage constant with dimension of time, to be found from observed hydrographs of I and D at both stations



Flood Routing through a (lake) reservoir

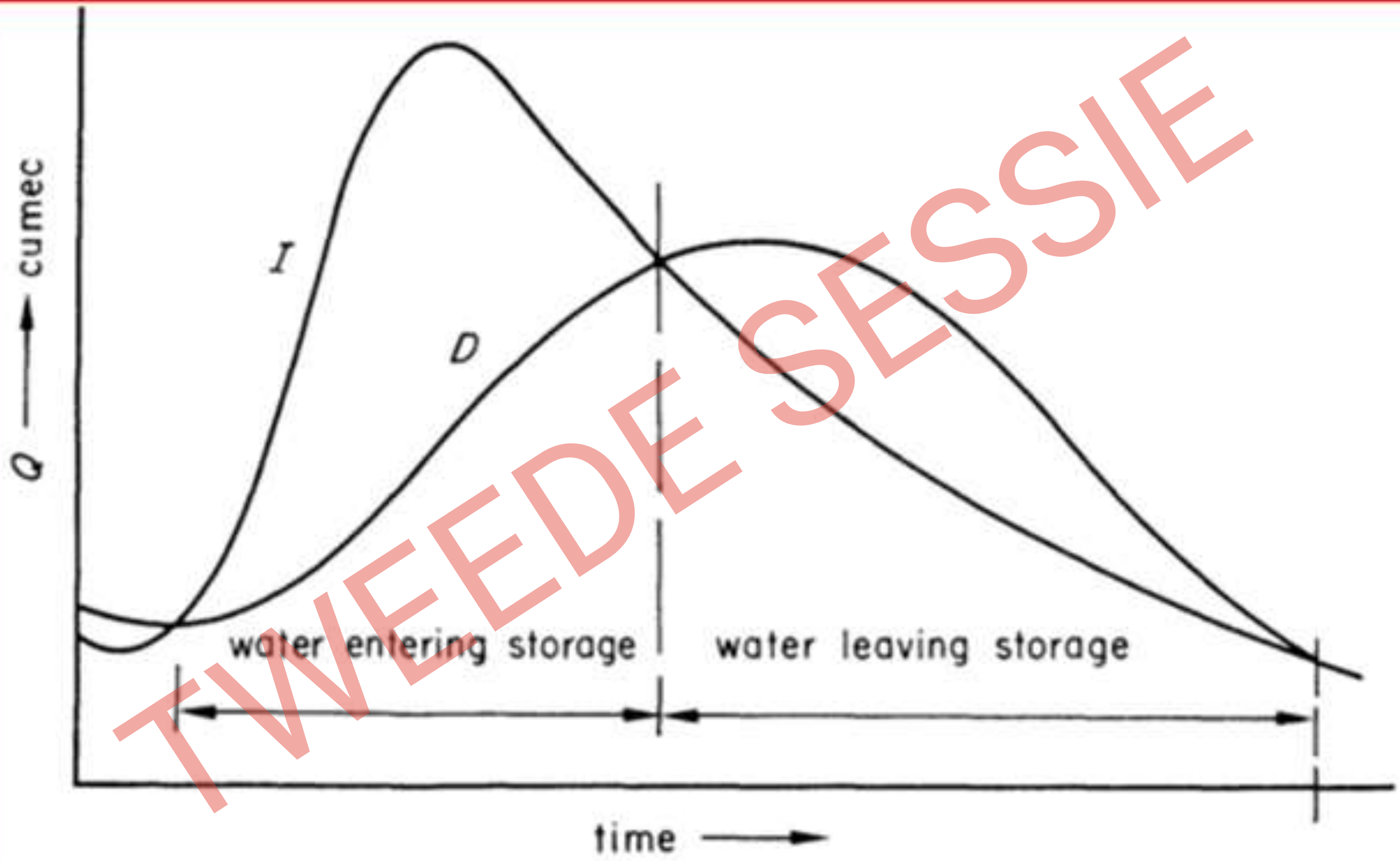


FIG. 8.5

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Storage Equation

Fig. 8.1 *Storage in a river reach*

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- **Needed Records**
  - Flow records at beginning and end of the reach and any tributary streams joining it
  - Rainfall records over area contributing direct runoff.

- **Storage in the reach**
  - Divided in prism and wedge
  - Slope of surface water during flood not uniform

Flood Routing

Continuity

In = uit + dS within a time interval; ds/dt is siacharge

$$I = D + \frac{dS}{dt}$$

I = inflow reach
D = Discharge from reach
dS/dt = rate of change in reach storage with respect to time

Idt = Ddt + dS → $(I_2 - I_1)t/2 = (D_2 - D_1)t/2 - (S_2 - S_1)$

$$\frac{I_1 + I_2}{2}t - \frac{D_1 + D_2}{2}t = S_2 - S_1$$

Approximation for time interval t
t = 1 is begin and t=2 is end
t = routing period; should be sufficient short, to satisfy above eq.
When t too long, inflow peak may be missed
When too short, greater computings

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Flood Routing

Reservoir Routing

Rearrange previous equation

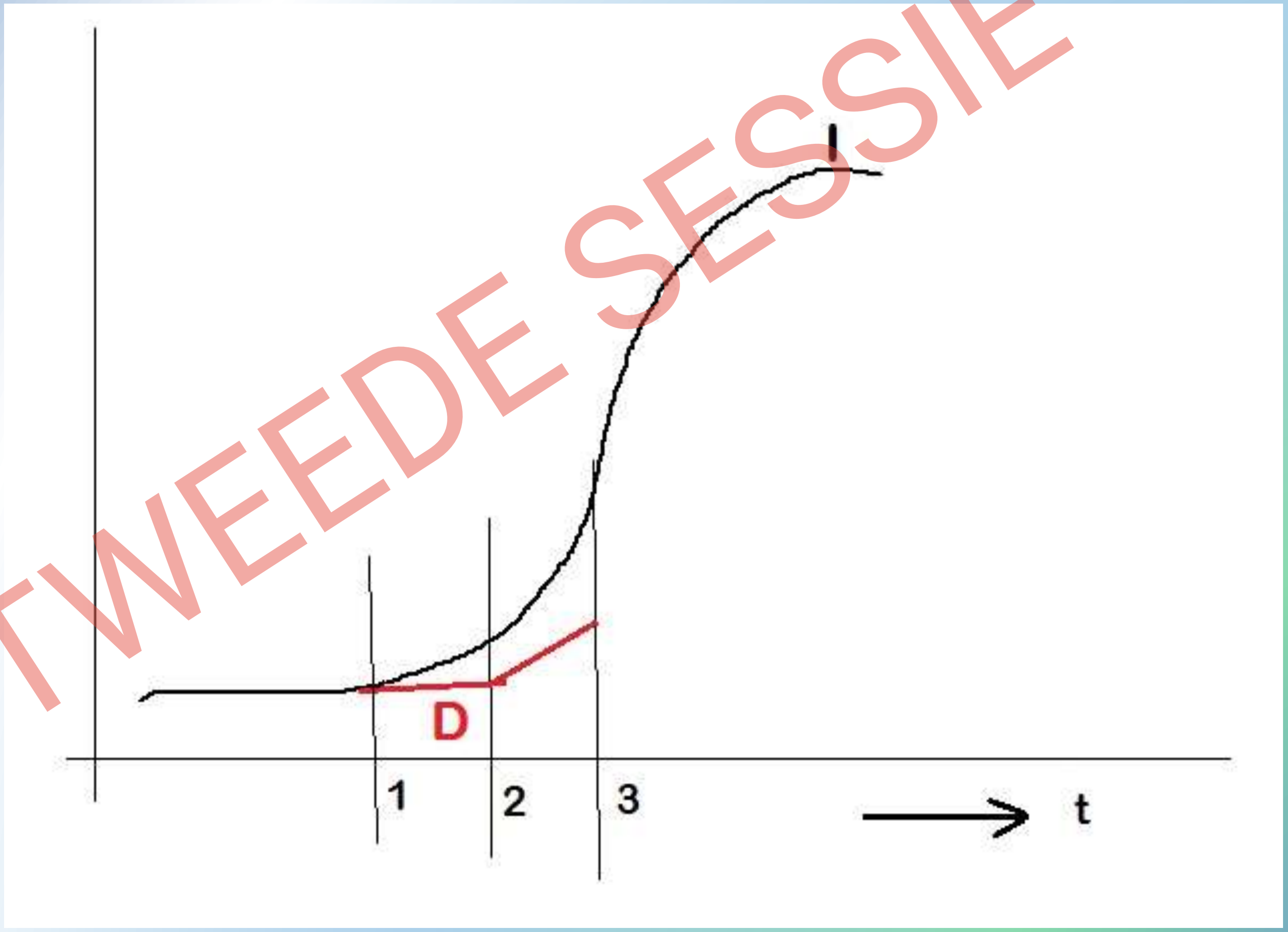
$$\frac{I_1 + I_2}{2} t - \frac{D_1 + D_2}{2} t = S_2 - S_1$$

$$\tfrac{1}{2}(I_1 + I_2)t + (S_1 - \tfrac{1}{2} D_1 t) = (S_2 + \tfrac{1}{2} D_2 t)$$

Purpose is to obtain the right term and deduce D2

TWEEDE SESSIE

Flood Routing



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END
Thank You