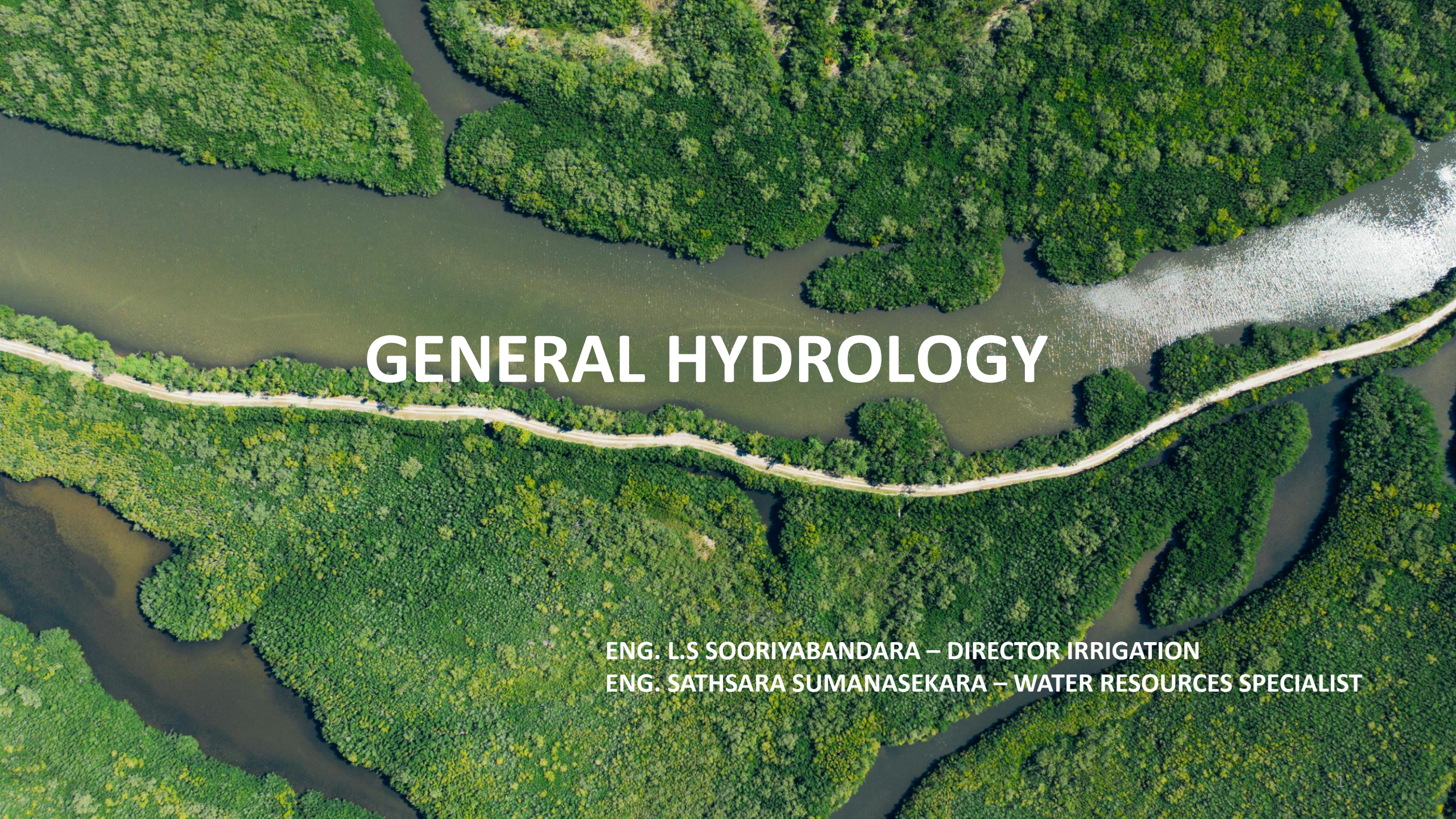
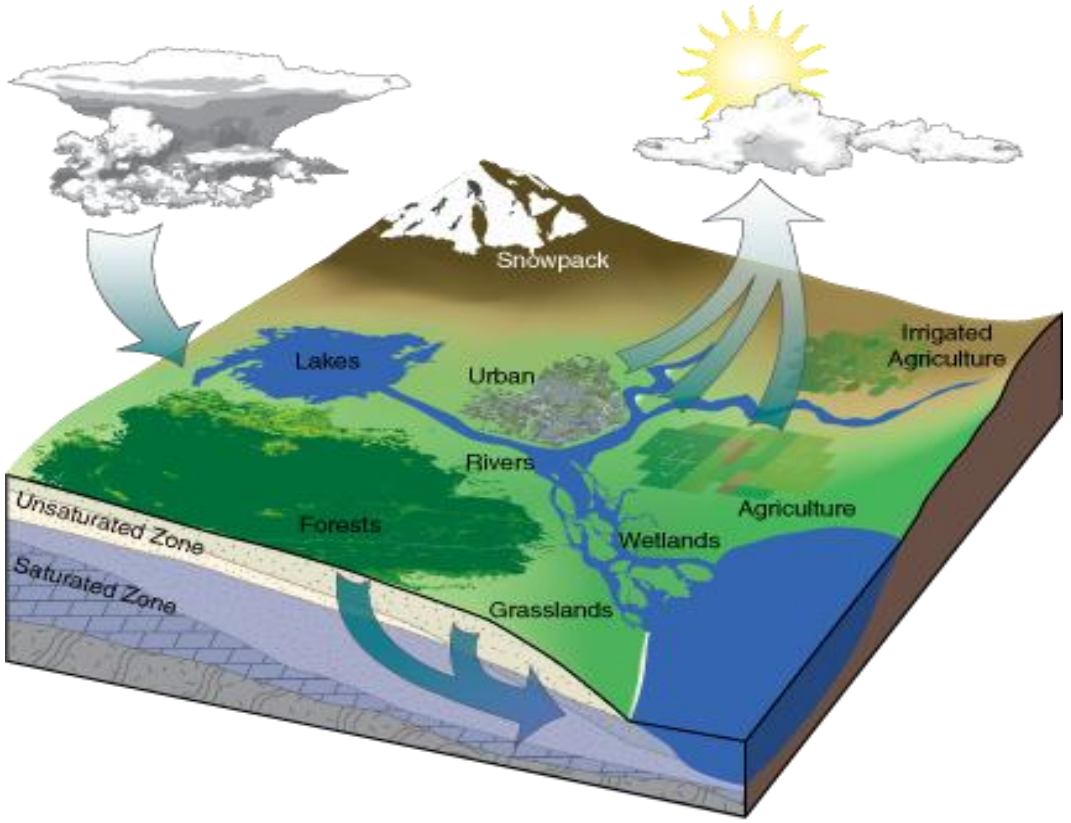


GENERAL HYDROLOGY

ENG. L.S SOORIYABANDARA – DIRECTOR IRRIGATION
ENG. SATHSARA SUMANASEKARA – WATER RESOURCES SPECIALIST

Hydrology: An Introduction

- Hydrology as a science
  - Precipitation and Evaporation: Climatology and Meteorology
  - Infiltration: Soil science
  - Groundwater: Geology
  - Surface runoff: Geomorphology
  - Stream flow: Fluid mechanics
- Hydrology as a profession
- What do hydrologists do
  - Water use
  - Water control
  - Pollution control
  - Flood mitigation/flood modelling



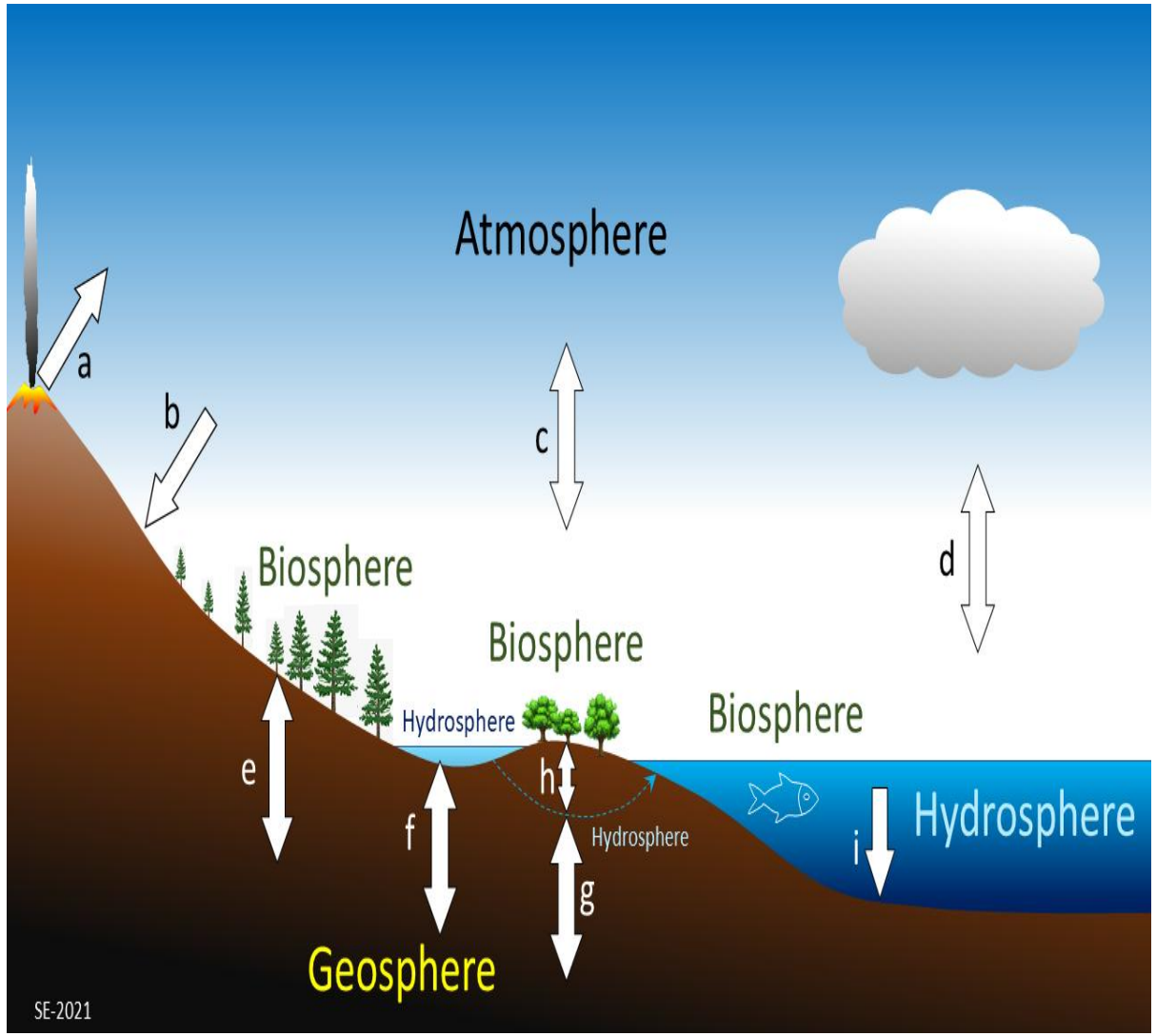
Weather and Hydrology: definitions

Weather – a set of all phenomena occurring in a given atmosphere at a given time. It refers to current activity.

Climate – average of prevailing conditions at a particular time. It refers to the average of a longer period of time.

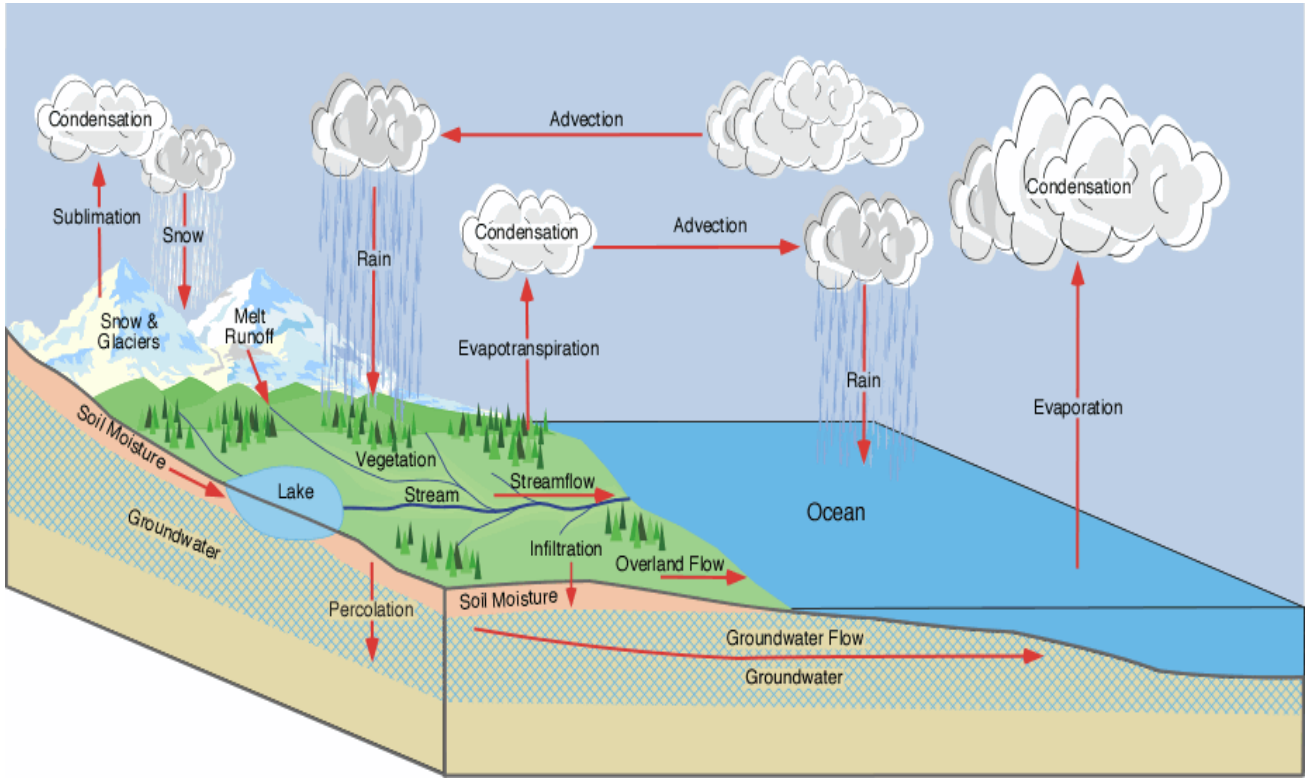
Hydrology is the science that treats waters of the Earth, their occurrence, circulation and distribution, their chemical and physical properties, and their reactions with their environment, including their relation with living things

Meteorology is the study of the atmosphere with a special interest in weather and climate conditions

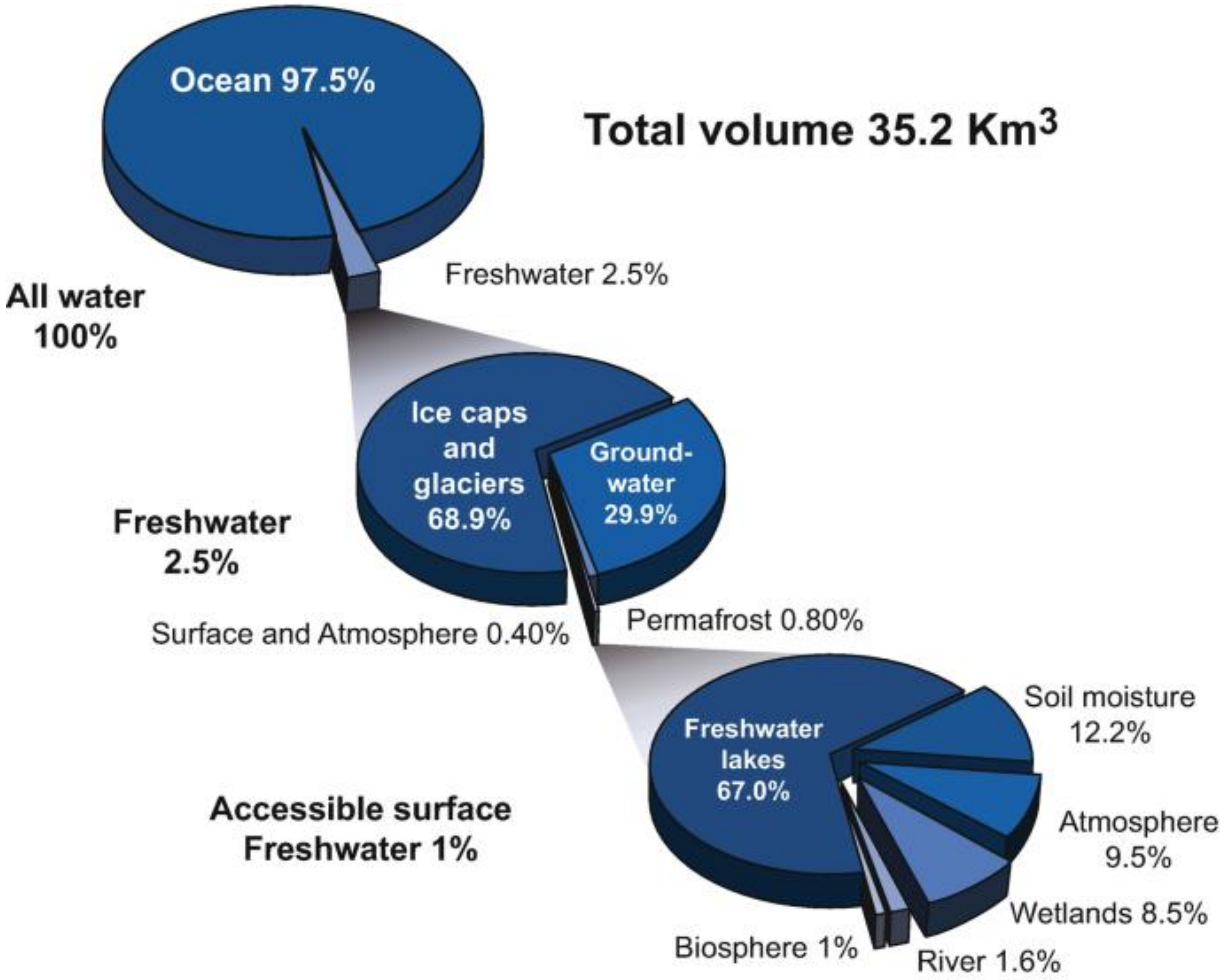


Hydrologic cycle

- Five processes to keep Earth's water moving in a cycle
  - Condensation
  - Precipitation
  - Infiltration
  - Runoff
  - Evapotranspiration
- All occur simultaneously and constantly except precipitation

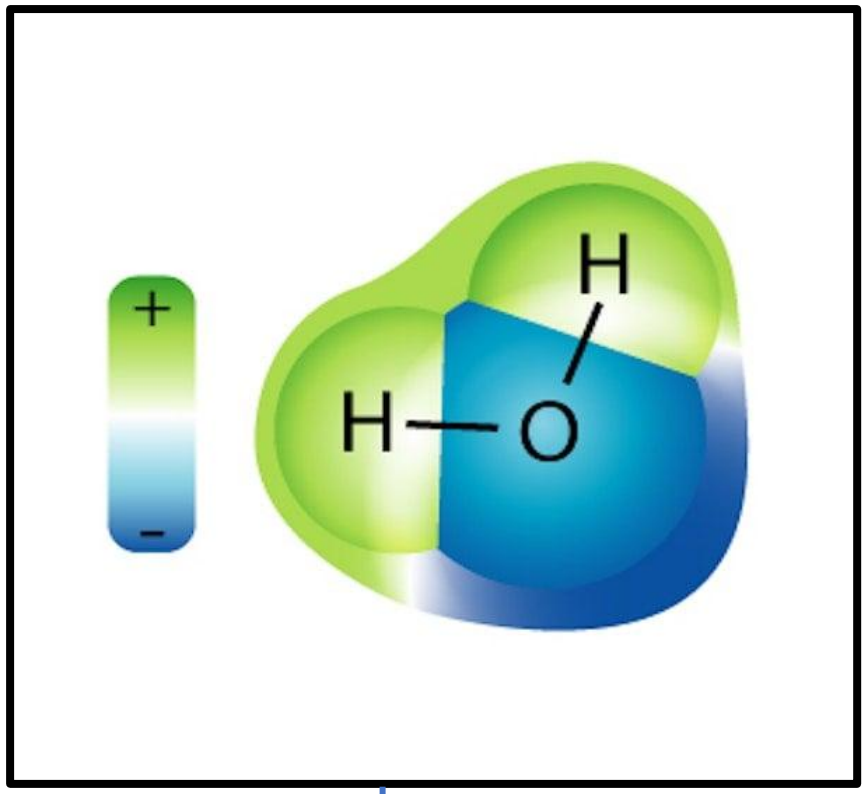


Global Water Resources in various phases

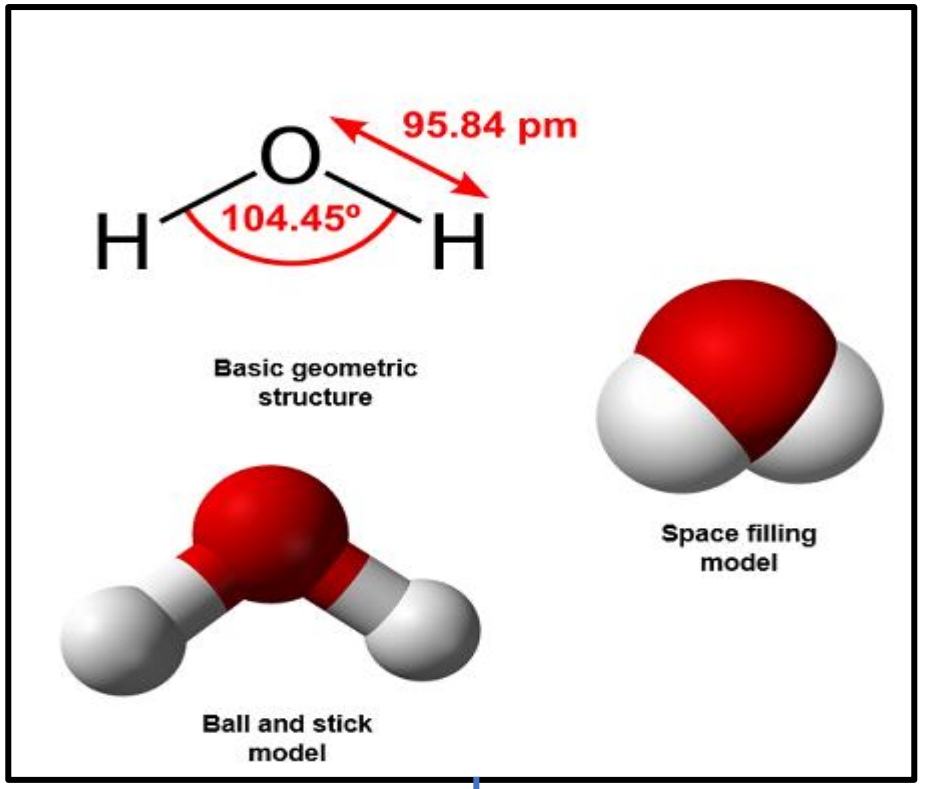


Source - https://link.springer.com/chapter/10.1007/978-3-030-31684-6_2

Water as a Physical Substance



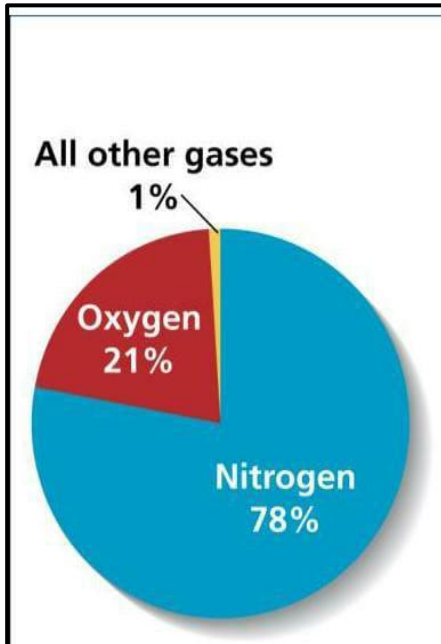
Approx. shape and charge distribution of a water molecule



Water molecule diagram with dimensions

Atmosphere

- The gaseous envelope surrounding the Earth
- Sustains life by cycling chemicals and water
- Gases in the atmosphere can affect temperature



Gas	Percentage by Volume
Nitrogen (N_2)	78.084
Oxygen (O_2)	20.946
Argon (Ar)	0.934
Carbon dioxide (CO_2)	0.037
Neon (Ne)	0.00182
Helium (He)	0.00052
Methane (CH_4)	0.00015
Krypton (Kr)	0.00011

Temperature

- Related to the occurrence and distribution of water on Earth, Influences – precipitation, evaporation, transpiration, and snowmelt
- Average, mean and normal; mean daily; normal daily; daily range; mean monthly; mean annual temperature
- Degree-day is a departure of one degree for one day in the mean daily temp. from a specified base temp.

Measurement:
Stevenson's Screen (shelter) 1.4 m height;
› min. thermometer;
› max. thermometer

Water Vapor and Wind

Water Vapor

The pressure that vapor would exert in the absence of other gases is known as vapor pressure

Relative humidity is the ratio of actual vapor pressure to that at saturation for a given temperature (RH ~ 100%)

Wind

Movement of air, speed, and direction

Winds provide the forces to sustain the moist air flow

Due to Earth's rotation, air mass (frontal) movements are from west to east

Weather Systems

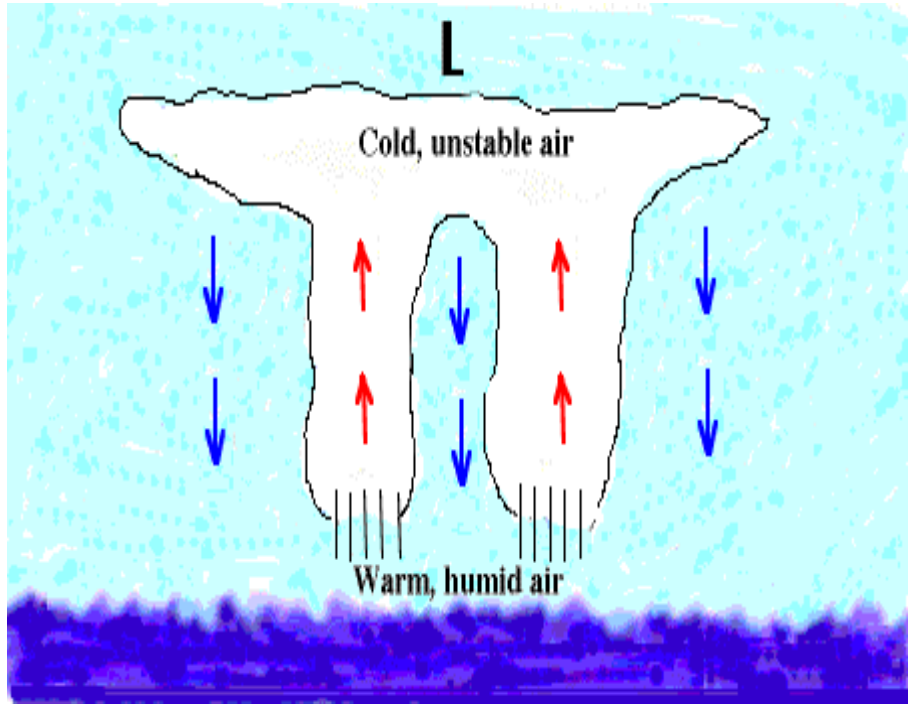
- Related to types of precipitation, air masses, and storms.
- Air mass is a large air body whose physical properties (temp., vapor, wind and pressure) are constant in a horizontal plane
- Border between air masses FRONT
  - Cold front = If cold air replaces warm air
  - Warm front = warmer air moves into an area

Four types of storms

- Convective storms
- Orographic storms
- Cyclonic storms
- Tropical cyclones

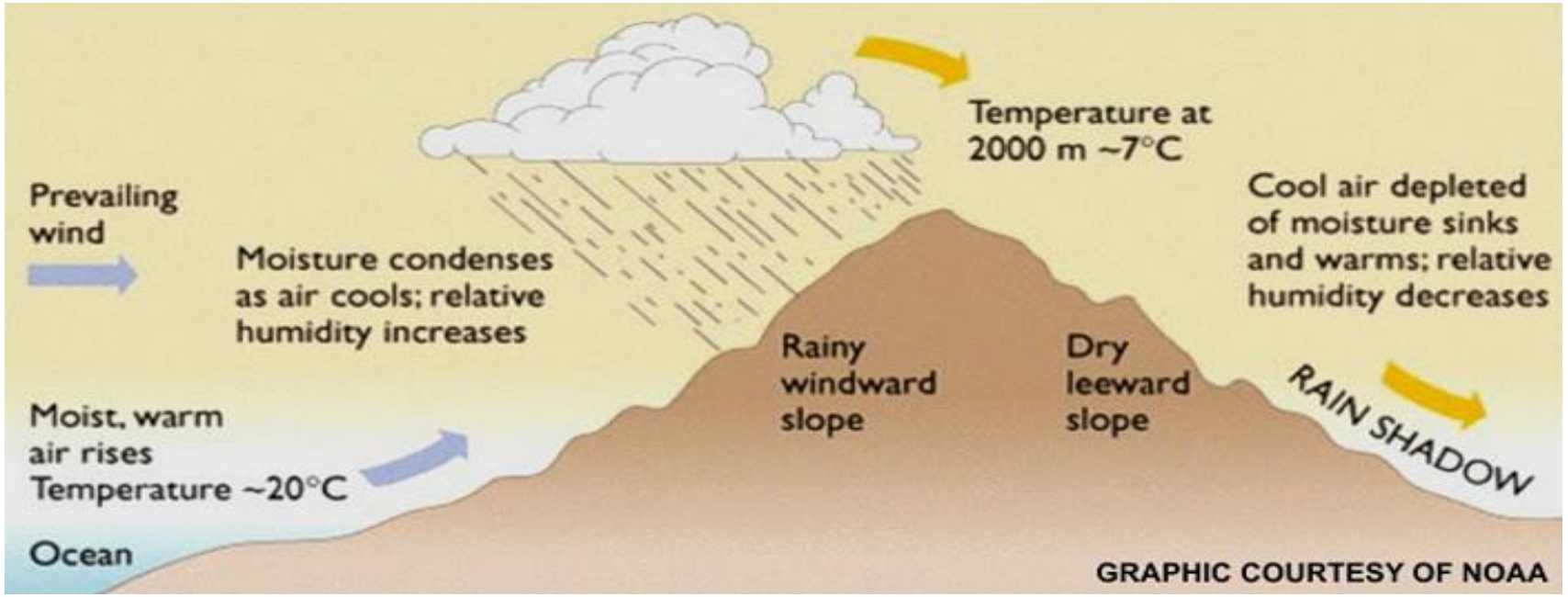
Convective Storms

- Caused by warm, humid air rising into cooler overlying air
- A common form of convective precipitation is the summer thunderstorm
- These storms are very intense, short-duration, and have a wide area distribution



Orographic Storms

Caused due to warmer air rising over a high geographic feature and meeting cooler air

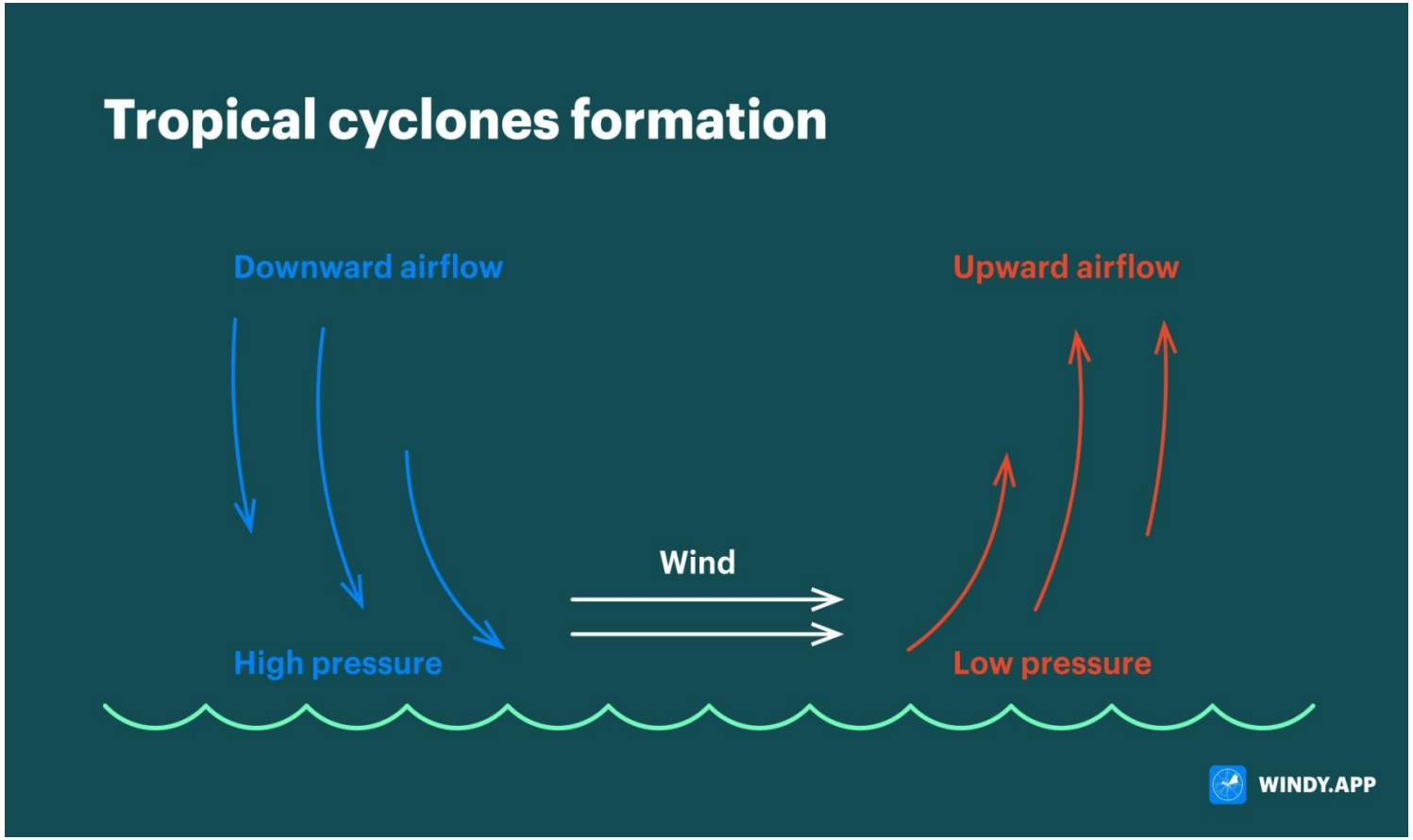


Cyclonic Storm

Caused by the rising of air as it converges on an area of low pressure

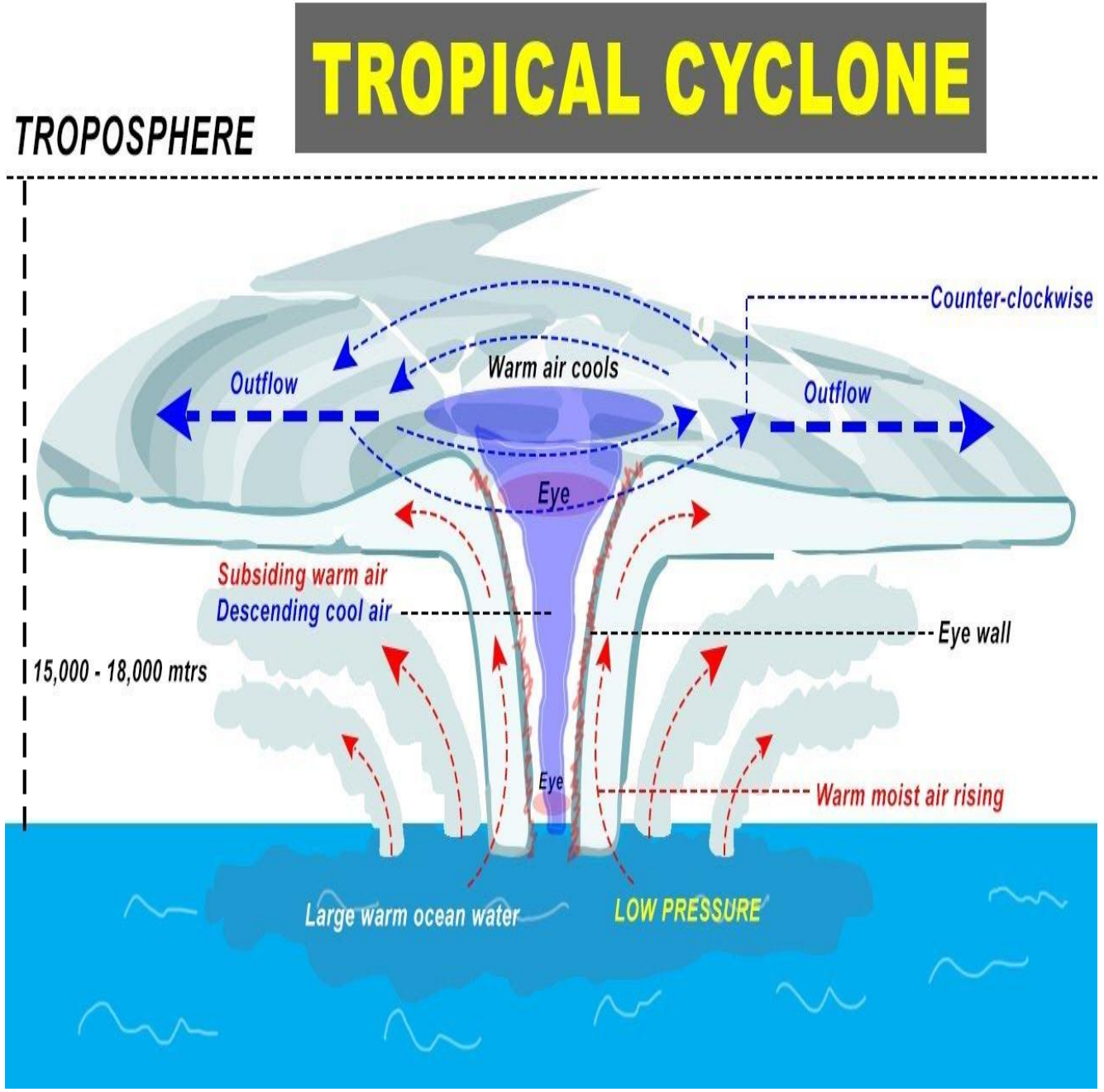
Cold fronts => cold air advancing under warmer air.
Warm front => warm air advancing over colder air.

A cold front is heavy and covers a small area.
Cold fronts move faster than warm fronts, and, thus, warm air is lifted at a faster rate, causing a higher intensity of precipitation



Tropical cyclone

- An intense cyclone with its source in the tropical regions where the surface water temperature is more than 29°C, wind speed of 75 mph
- Common name: Hurricane, typhoon, cyclone
- Tropical cyclones may cause more than 25 cm of rain in 12-24 hr
- https://www.youtube.com/watch?v=gjBlJgL-a8Q&ab_channel=WowPlay



PRECIPITATION

Precipitation occurs when 3 conditions are met

The atmosphere is saturated

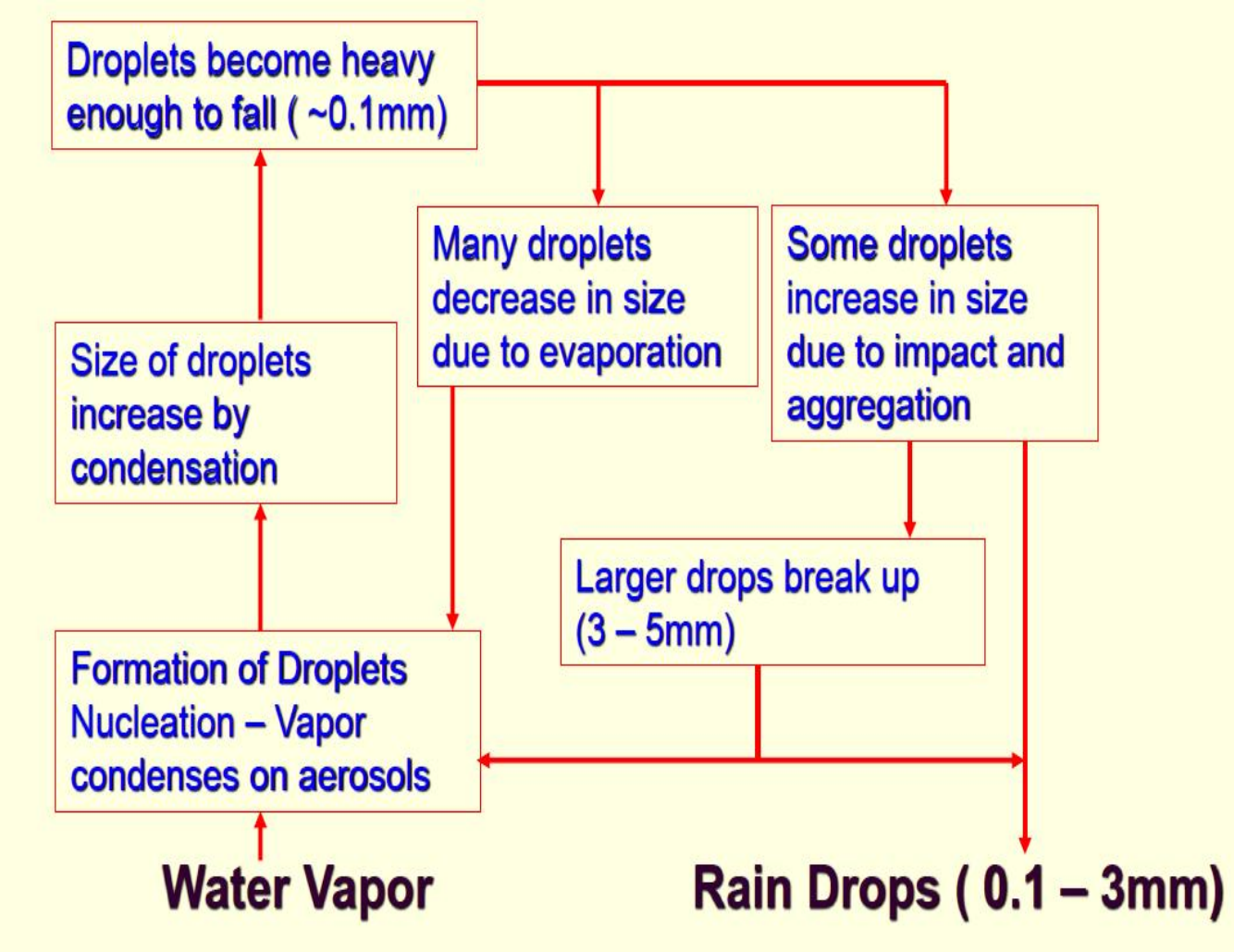
- Air mass cooled by lifting (Frontal systems, orographic effects, convection)

Small particles are present

- Dust, Aerosols, Salts (N, S, compounds)

Drops are big enough to reach the surface

- Condensation and Aggregation



Precipitation Measuring Devices

Rain Gauge (Non-Recording)

- **Description**: A Simple container to collect rainfall.
- **Example**: Symons Rain Gauge.

Recording Rain Gauges

- **Tipping Bucket Rain Gauge**
  - Small buckets tip when filled; counts converted to rainfall.
- **Weighing Bucket Rain Gauge**
  - Measures the weight of rainfall over time.
- **Float Recording Rain Gauge**
  - Float rises with rainfall; movement recorded on chart.

Automatic Weather Stations (AWS)

- Use electronic sensors to measure and transmit rainfall data in real time.

Radar-Based Measurement

- Weather radar detects precipitation intensity over wide areas.

Satellite-Based Measurement

- Remote sensing to estimate precipitation globally (e.g., TRMM, GPM).

(a) Tipping bucket rain gauge (b) Weighing bucket rain gauge (c) Optical rain gauge

(d) Present weather detector

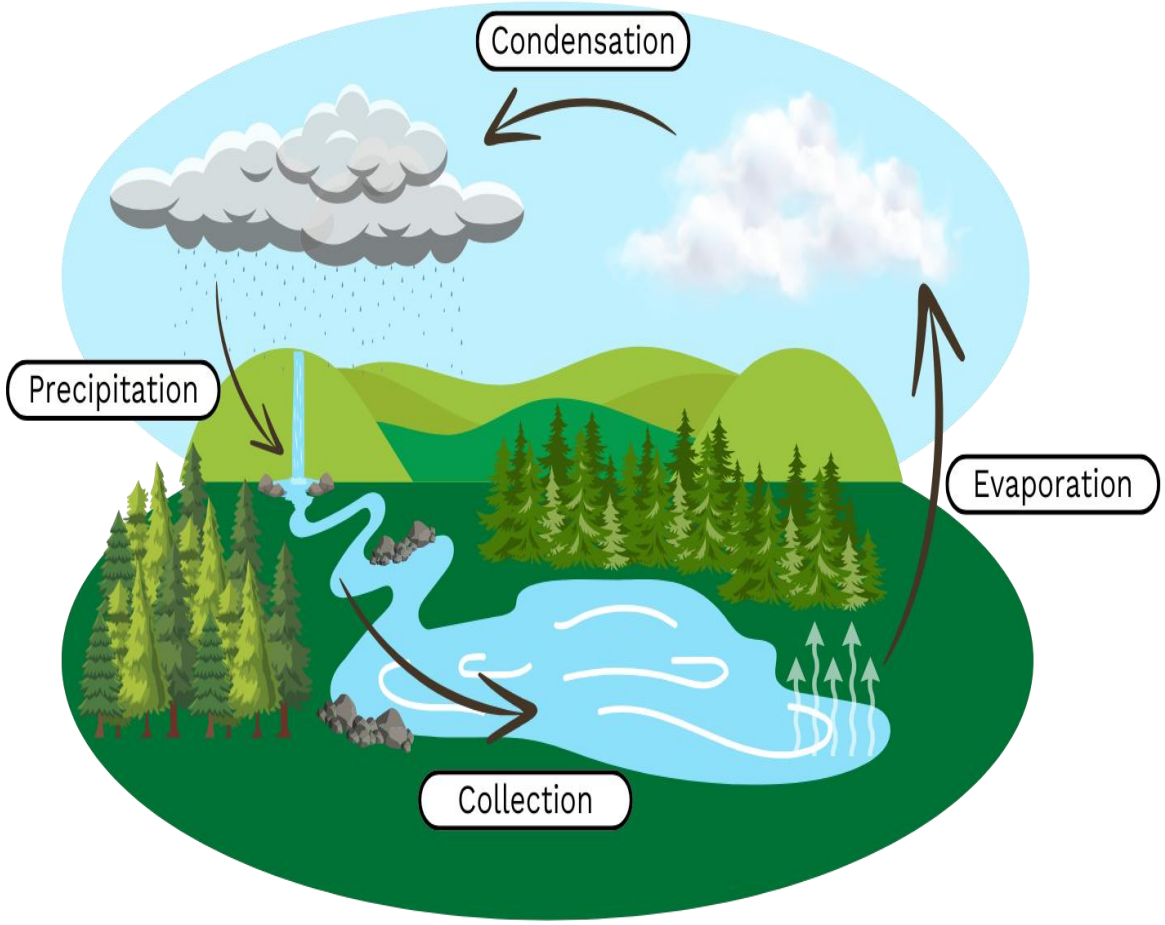
(e) Joss-Waldvogel disdrometer

(f) 2D video disdrometer

Condensation & Aggregation Leading to Precipitation

Condensation:
• The process where smaller molecules or ions combine to form larger molecules by releasing a small molecule (often water).
• In solutions, condensation of dissolved ions can lead to precipitation of insoluble compounds.

Aggregation:
• The clustering of dissolved or suspended particles or molecules to form larger structures.
• Aggregation of these particles can lead to precipitation, forming a solid phase that separates from the liquid phase.



SPATIAL ESTIMATION OF RAINFALL

Arithmetic mean method

The Arithmetic Mean Method calculates average rainfall across an area by taking the simple average of values recorded at multiple rain gauge stations.

Formula

$$\bar{P} = (P_1 + P_2 + P_3 + \ldots + P_n) / n$$

Where:

- $\bar{P}$: Average rainfall
- $P_1, P_2, \ldots, P_n$: Rainfall at each station
- n: Number of stations

Example

Rainfall data from 3 stations:

- Station A: 60 mm
- Station B: 55 mm
- Station C: 65 mm

$\bar{P} = (60 + 55 + 65) / 3 = 180 / 3 = 60$ mm

- Average Rainfall Over the Area = 60 mm

SPATIAL ESTIMATION OF RAINFALL

Thiessen polygon method

The Thiessen Polygon Method calculates weighted average rainfall using areas of influence defined by polygons around each station.

Formula

$$P = (A_1P_1 + A_2P_2 + \ldots + A_nP_n) / A$$

Where:

- P: Weighted average rainfall
- $A_1, A_2, \ldots, A_n$: Area of influence for each station
- $P_1, P_2, \ldots, P_n$: Rainfall at each station
- A: Total area

Example

3 Stations:

- Station A: 50 mm, 40 km²
- Station B: 60 mm, 30 km²
- Station C: 70 mm, 30 km²

$P = (40\times50 + 30\times60 + 30\times70) / 100 =$

$(5900 / 100) = 59$ mm

- Average Rainfall Over the Area = 59 mm

SPATIAL ESTIMATION OF RAINFALL

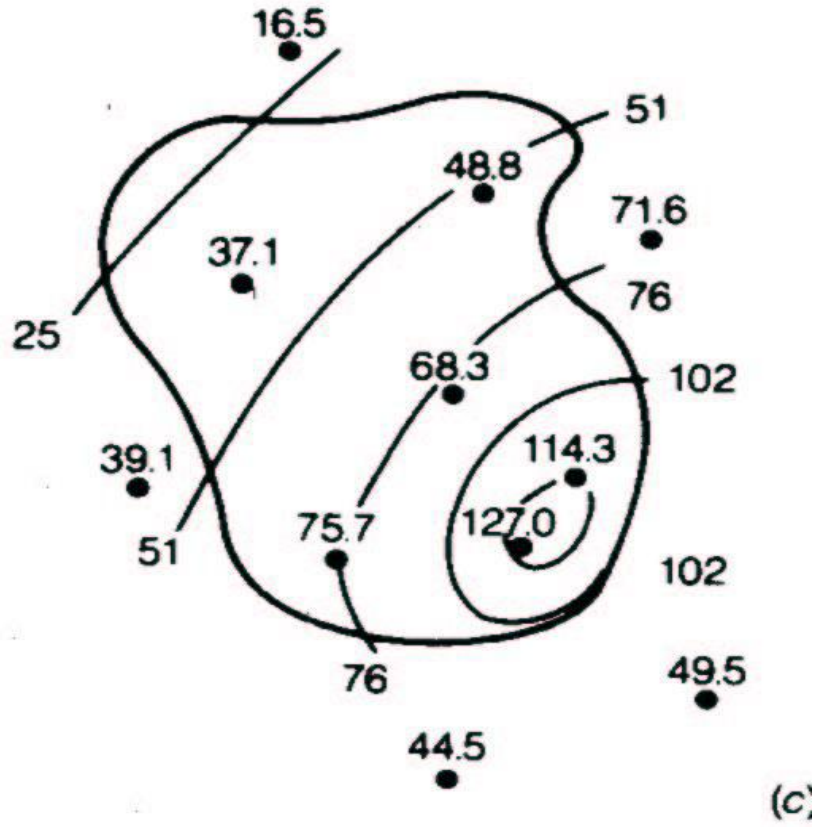
Isohyetal method

The **Isohyetal Method** estimates average rainfall over an area using **contours (isohyets)** of equal rainfall. It is considered the **most accurate** among the three standard methods (Arithmetic Mean, Thiessen, Isohyetal) as it accounts for the **spatial variation** of rainfall.

Isohyet	Area* enclosed (sq.km)	Net area (sq.km)	Avg. Prec. (mm)	Prec. volume (Col.3xCol.4)
127	34	34	135	4590
102	233	199	117	23283
76	534	300	89	26700
51	1041	508	64	32448
25	1541	500	38	19000
<25	1621	80	20	1600
				107621

Average = 107621 / 1621 = 66 mm

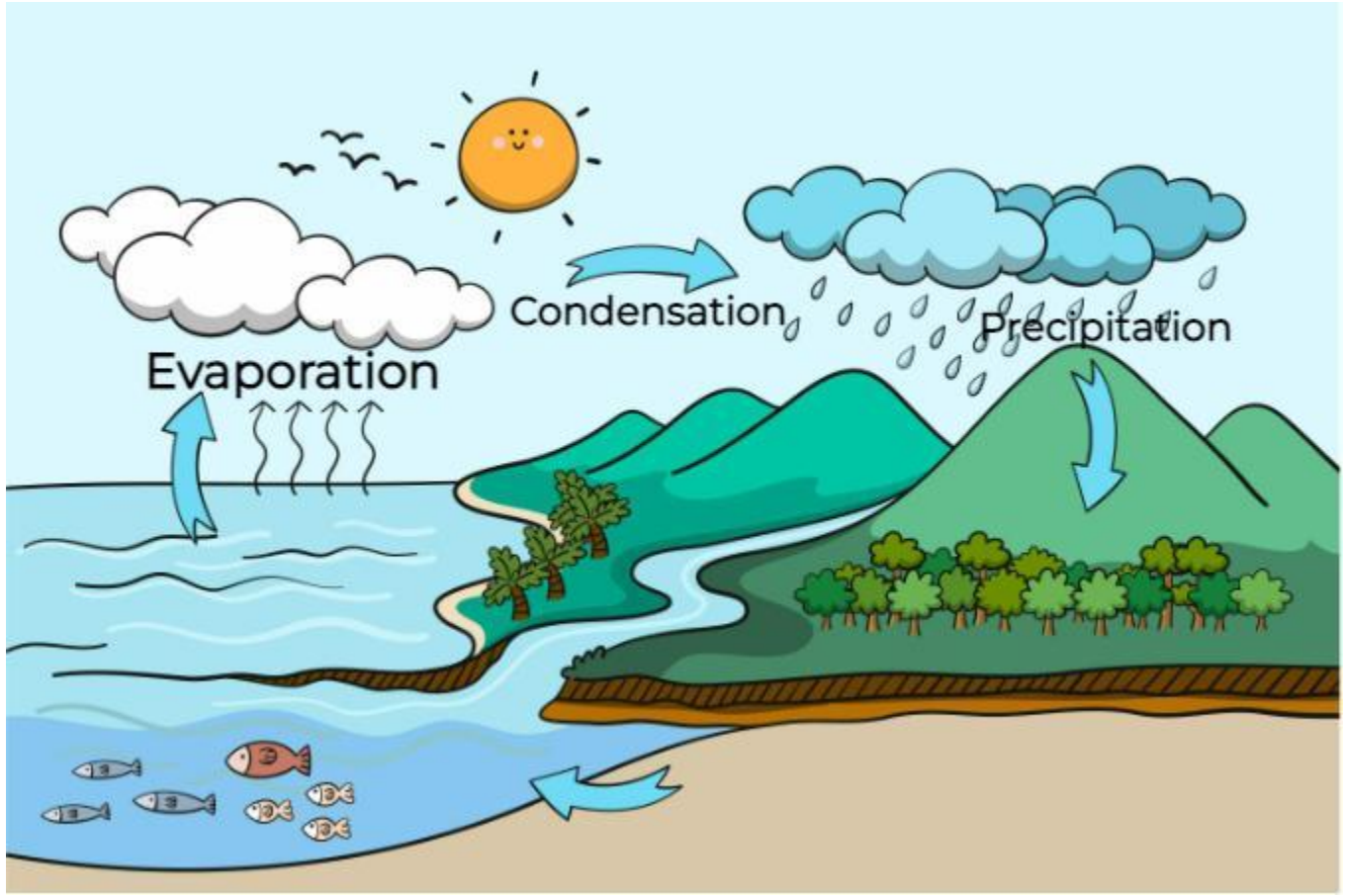
* Within basin boundary



Evaporation: Theory and Measurement

What is Evaporation?

- The process of water changing from liquid to vapor.
- Driven by solar radiation, temperature, wind, humidity, and pressure.



Evaporation: Theory and Measurement cont.

Key Factors Affecting Evaporation

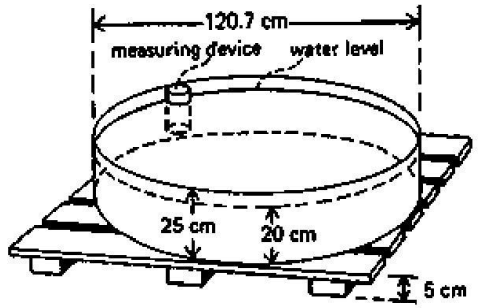
- Solar Radiation: The primary energy source.
- Temperature: Higher temp = more evaporation.
- Humidity: Lower humidity = more evaporation.
- Wind Speed: Removes water vapor.
- Surface Area: Larger = more evaporation.

Methods to Measure Evaporation

- Evaporation Pan (e.g., Class A Pan)
- Lysimeter
- Common Instrument
- Class A Pan: Diameter 120.7 cm, Depth 25.4 cm

EVAPORATION PAN

- CLASS *A* EVAPORATION PAN



INFILTRATION AND SOIL WATER MOVEMENT

Infiltration

Process of water entry into a soil from rainfall, snowmelt, or irrigation

Soil water movement

The process of water flow from one point to another within the soil

Key Importance of Infiltration

Recharges groundwater

Reduces surface runoff & erosion

Supports plant growth

What Controls Infiltration?

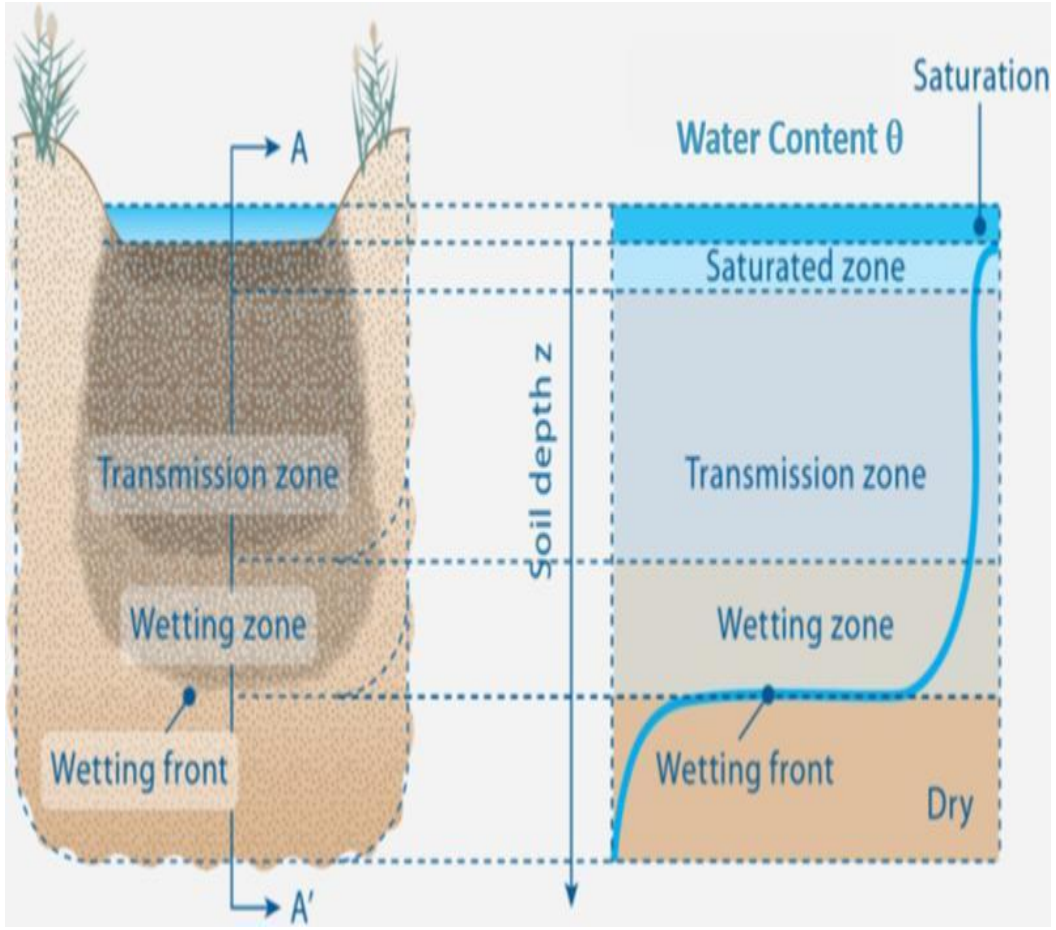
Content:

Soil Texture (Sandy soils infiltrate faster than clay).

Soil Structure (Well-aggregated soils allow better infiltration).

Land Cover (Vegetation & roots enhance infiltration).

Rainfall Intensity (Heavy rain may exceed infiltration capacity).



MOISTURE ZONES DURING INFILTRATION

PROPERTIES AFFECTING SOIL WATER MOVEMENT

Major influencing properties

- **Hydraulic conductivity**
  - Measure of soil's ability to transmit water
- **Water retention characteristics**
  - Ability of soil to store and release water

Both of these influencing properties are closely related to

- Soil Physical Properties

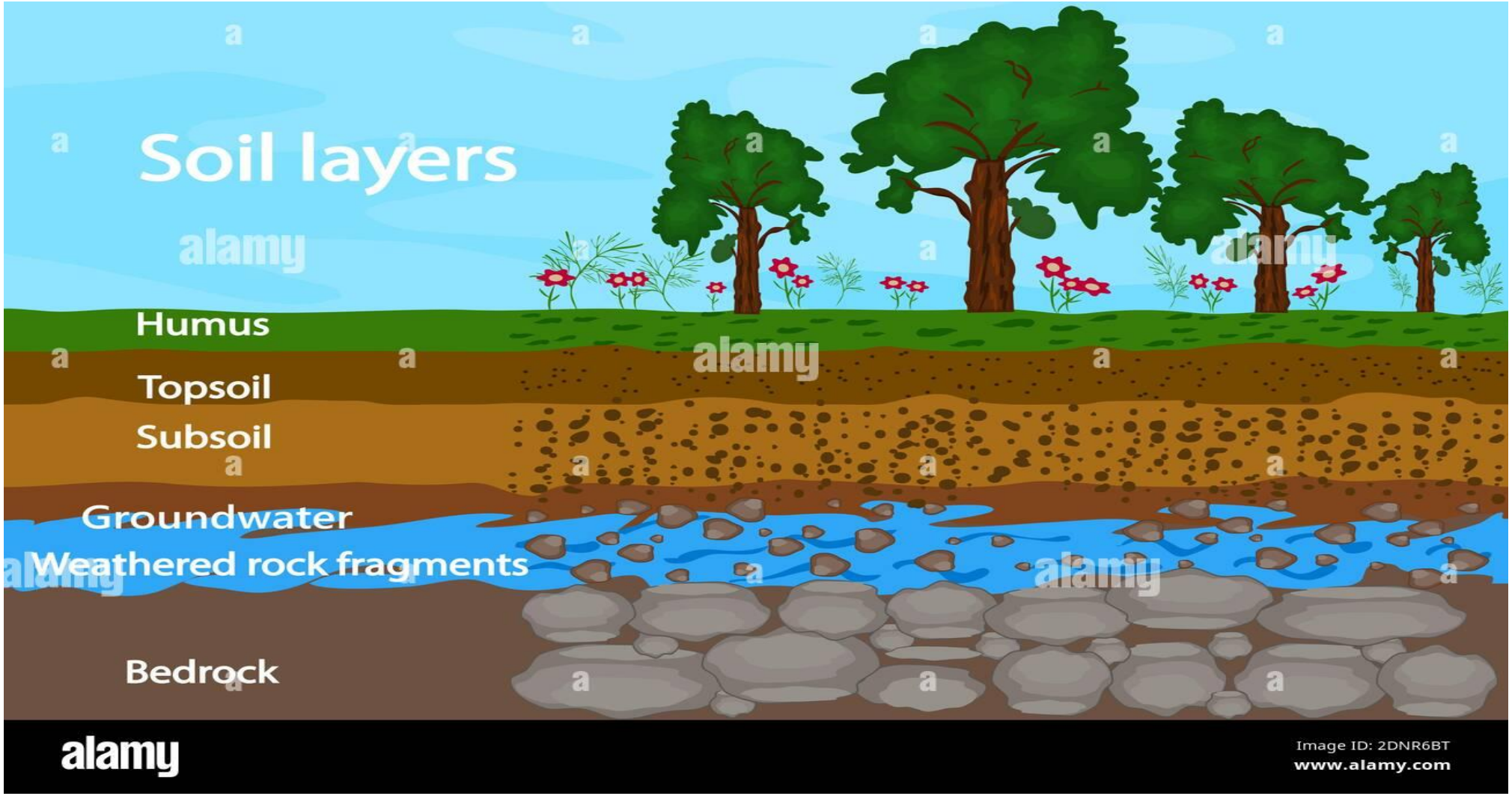
Soil Physical Properties

- **Particle size properties**

Percentage of sand, silt, and clay

- **Morphological properties**
  - **Bulk density:** As bulk density increases, water retention and hydraulic conductivity near saturation decrease
  - **Organic matter:** More organic matter, more water retention
  - **Clay type:** Expandable clays (montmorillonite) have lower hydraulic conductivity and water retention, compared to non-expandable clays (kaolinite)

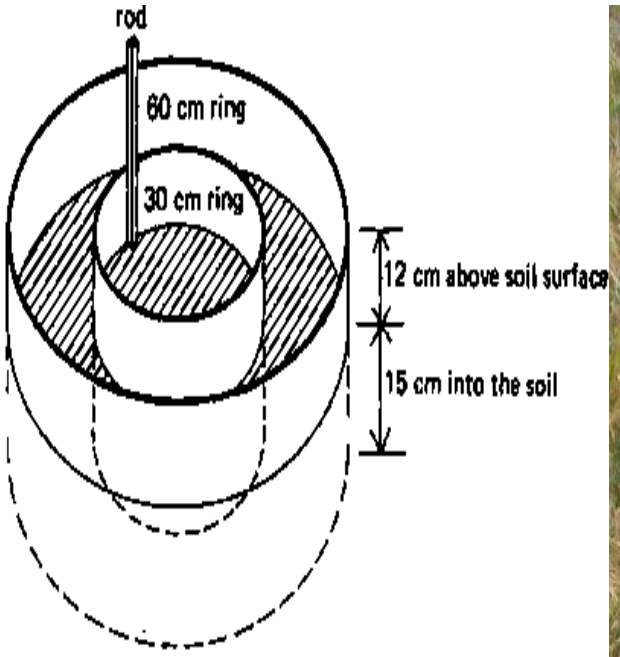
INFILTRATION AND SOIL WATER MOVEMENT cont.

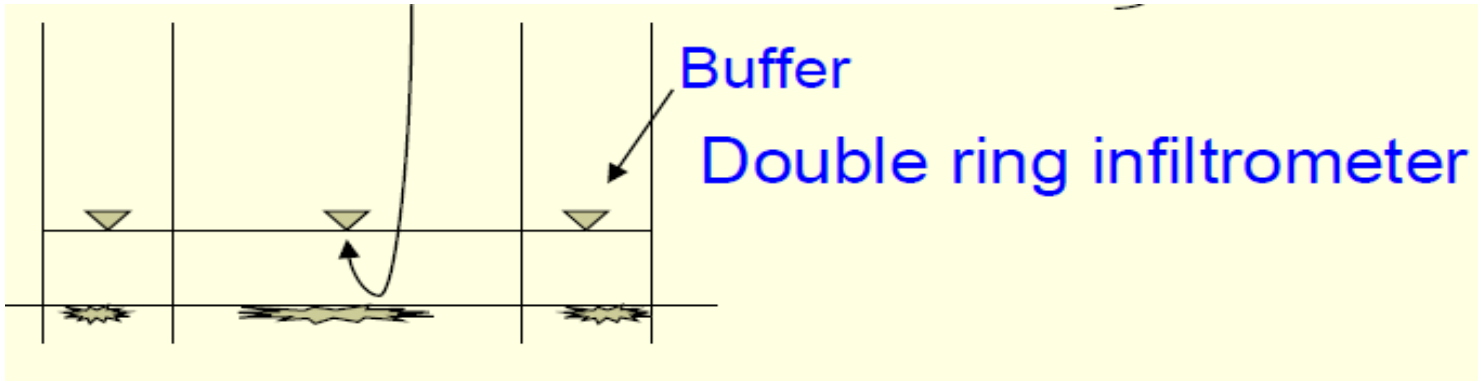


INFILTRATION MEASUREMENT

Point Measurements

- Ponded-water ring or cylinder type infiltrometer
- Sprinkler-type infiltrometer
- Tension-type infiltrometer
- Furrow-type infiltrometer





FACTORS AFFECTING INFILTRATION

Soil factors

- Particle size distribution, bulk density, particle density, porosity, water content, water retention characteristics, and hydraulic conductivity

Surface factors

- Bare soil or with a crust formation on bare soil

Management factors

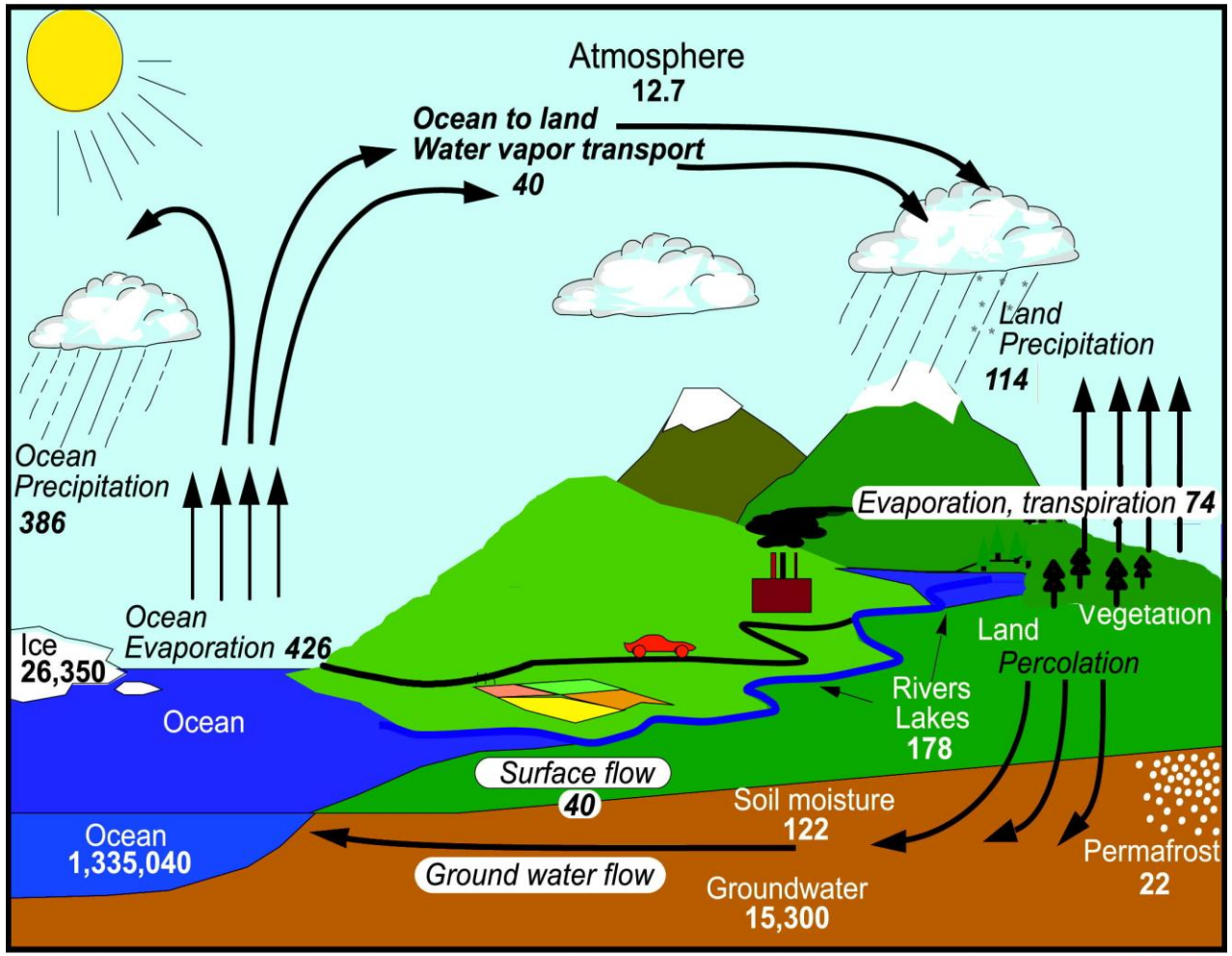
- Types of tillage, vegetation, and surface cover
- The MB plow increases porosity by 10-20%
  - OM to BD to porosity to infiltration

Natural factors

Rainfall intensity, seasons, temperature (viscosity of water), and moisture

What is Groundwater?

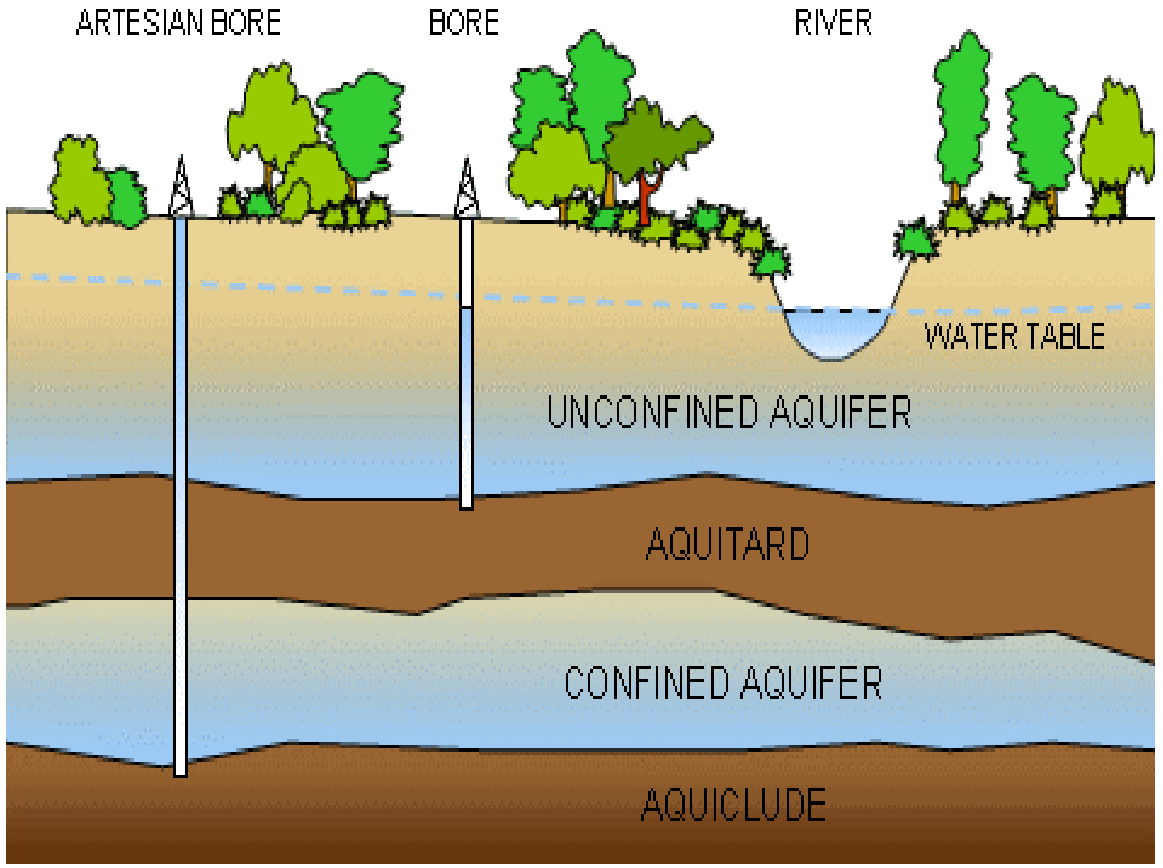
- Definition: Water found beneath the Earth's surface in soil pore spaces and fractures of rock formations.
- Sources: Recharged by precipitation, rivers, and lakes via infiltration.
- Importance:
  - Supplies drinking water for ~50% of the global population.
  - Supports agriculture (irrigation) and industries.
  - Maintains ecosystems (e.g., wetlands).



Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges *1990s

How Does Groundwater Flow?

- **Aquifer**: Permeable rock/sediment storing water (e.g., sandstone).
- **Aquitard**: Low-permeability layer (e.g., clay) restricting flow.
- **Porosity & Permeability**:
  - *Porosity*: Volume of empty spaces (storage capacity).
  - *Permeability*: Ability to transmit water.
- Darcy's Law:
  - Flow rate depends on permeability and hydraulic gradient.



Protecting Groundwater Resources

- **Threats**:
  - Over-pumping (depletion, land subsidence).
  - Pollution (agricultural runoff, industrial waste).

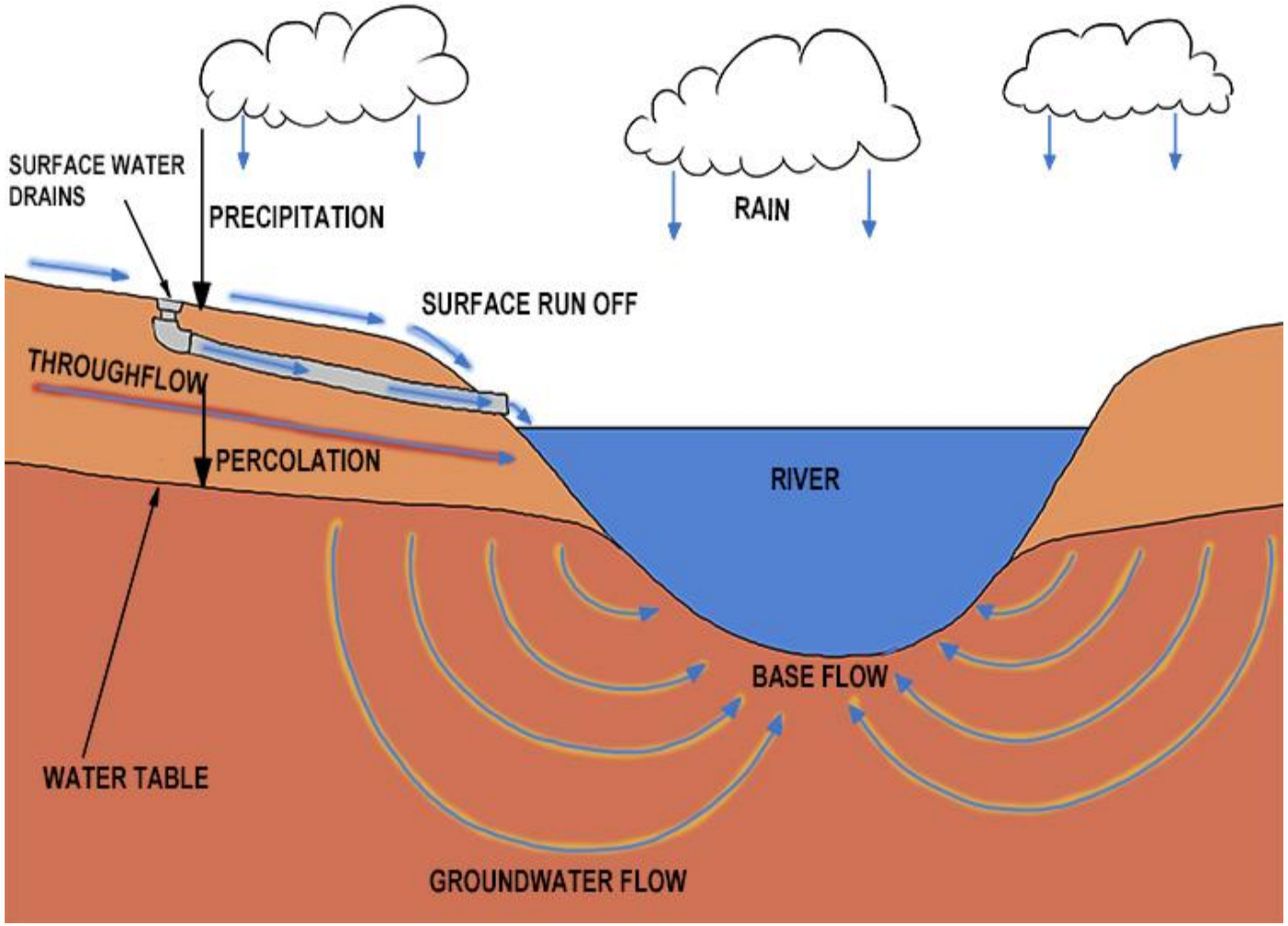
- **Sustainable Management**:
  - Artificial recharge.
  - Monitoring usage.
  - Pollution control regulations.

Definition of streamflow

Streamflow is the flow rate (discharge) of water along a defined natural channel

Streamflow is generated by a combination of

- Base flow
- Interflow
- Saturated overland flow



Channel Network

- Channel network reflects hydrologic processes and partially controls them through channel flow resistance
- Stream ordering: **Strahler system** (topologic characteristics)
- Drainage area is commonly related to hydrology; Basin slope is also **correlated** with drainage area
- Mean annual flood/runoff **increases** with drainage area
- Streamflow per unit area is **inversely proportional** to drainage area

Stream-flow measurement

Measurement involves

- Measuring stage or water level above a datum
- Establishing stage-discharge curve (Rating Curve)
- Transforming stage to discharge using the rating curve

Selection of a site for a gauging station

Hydraulic controls

- Natural and hydraulic structures (weirs and flumes)
- Stable and sensitive to changes in Q; Q-h relation should not change over time

Accessibility of the site (high flood flows)

Unaffected by backwater conditions

Section control

- Natural constriction, sloppy channel, artificial constriction

Artificial control

- Groins/sills across the streambed

Channel control (friction control)

- Natural roughness of the channel perimeter controls velocity and depth

Stream-flow measurement cont.

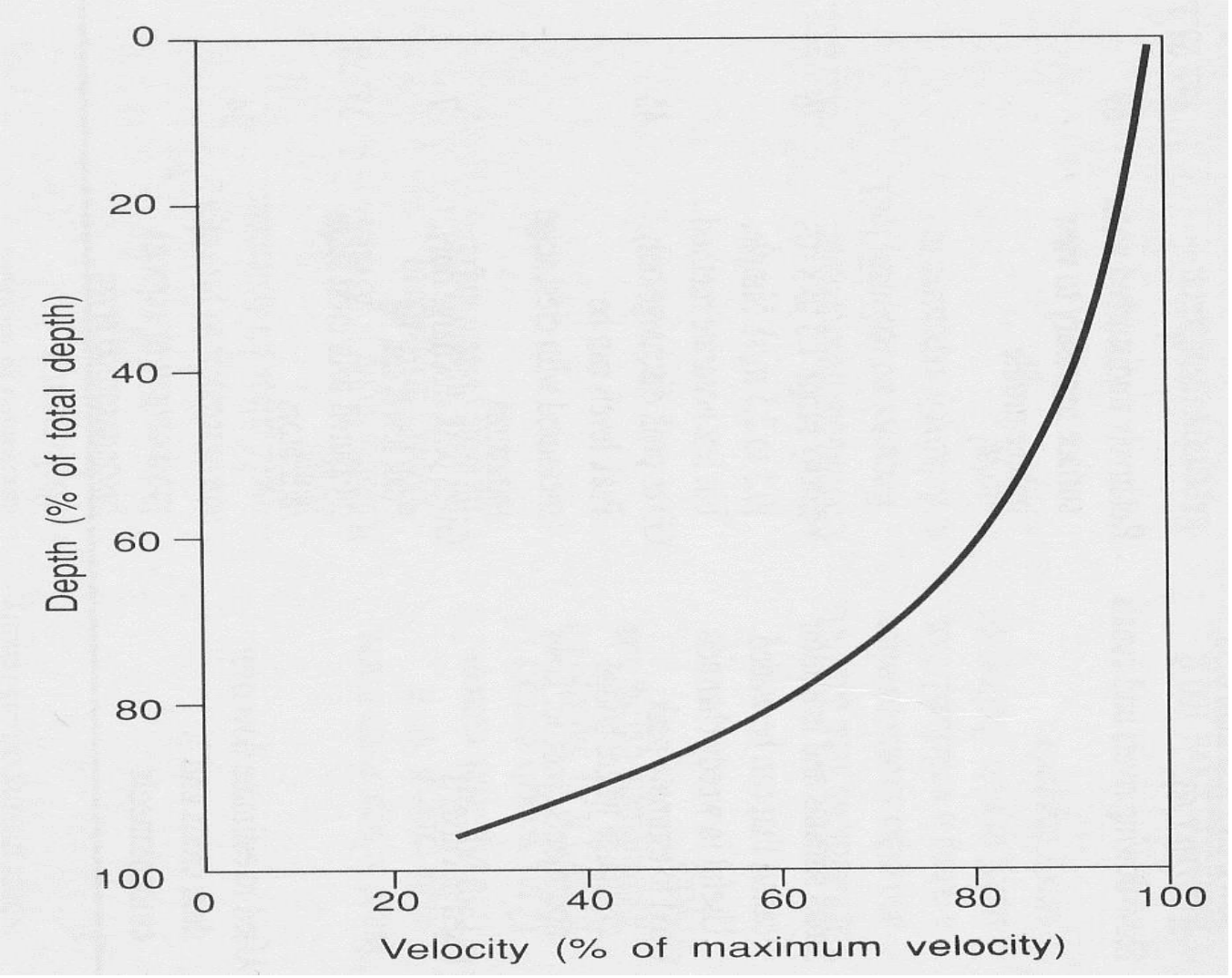
Discharge measurement

- **Velocity and depth**
  - In verticals by the current meter

Mean velocity

- Velocity measured at 0.6 depth from the surface for depths less than 0.76 m
- Average of velocity measured at 0.2 and 0.8 depth in water more than 0.76 m deep

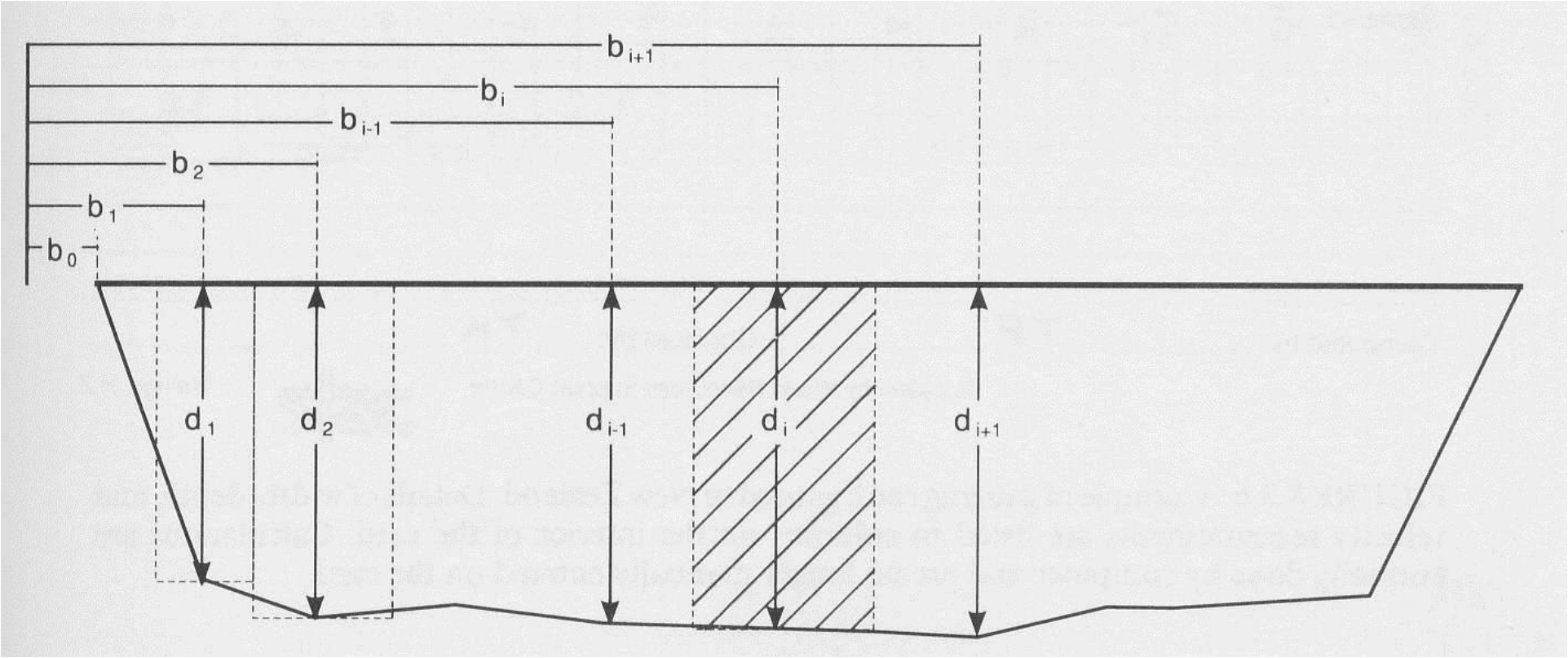
Typical vertical velocity curve



Stream-flow measurement cont.

Velocity area method of discharge measurement

Mid-section method



$$q_i = v_i\left(\frac{b_{i+1}-b_i}{2}+\frac{b_i-b_{i-1}}{2}\right)d_i$$

$$= v_i\left(\frac{b_{i+1}-b_{i-1}}{2}\right)d_i$$

q = Discharge
v = Velocity
b = Width from the bank
d = Depth

Stream-flow measurement cont.

Discharge measurement of the channel is carried out using a current meter

Stream-flow measurement cont.

Thank you!