



HYDROLOGY

INTRODUCTION



Professor Ranjana. U.K. Piyadasa

Professor in Hydrogeology

(PhD- Hydrogeology), MSc- Engineering Geology)

Head- Department of Environmental Technology

University of Colombo,

Colombo 03, Sri Lanka

HYDROLOGY | definition

hydrology

The term *hydrology* is from Greek: *hydōr*, "water"; and, *logos*, "study".

noun

the science dealing with the **occurrence, circulation, distribution, and properties** of the waters of the earth and its atmosphere.



1. Basic Hydrology Concept

1.1. Introduction

- Water is vital for all living organisms on Earth.
- For centuries, people have been investigating where water comes from and where it goes, why some of it is salty and some is fresh, why sometimes there is not enough and sometimes too much. All questions and answers related to water have been grouped together into a discipline.
- The name of the discipline is hydrology and is formed by two Greek words: "hydro" and "logos" meaning "water" and "science".

- **What is Hydrology?**
 - It is a science of water.
 - It is the science that deals with the occurrence, circulation and distribution of water of the earth and earth's atmosphere.
- A good understanding of the hydrologic processes is important for the assessment of the water resources, their management and conservation on global and regional scales.

World Water resources

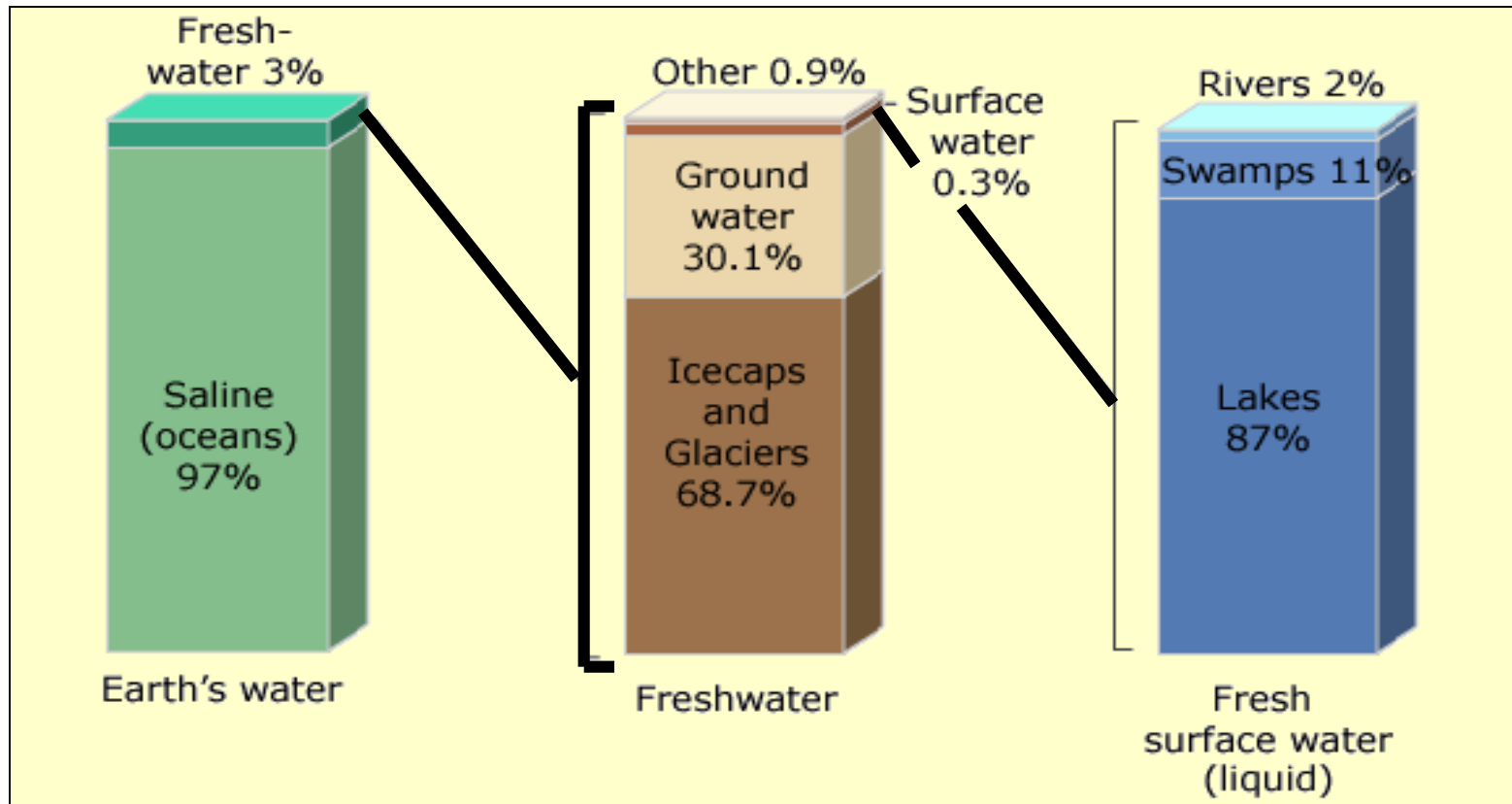
distribution



Sea water saline and not usable for domestic purposes



WATER DISTRIBUTION OF THE EARTH



Imaging glass of water





**It covers most of the planet,
but just 3% is freshwater.**



A global crisis

- **884 million people in the world do not have access to safe water. This is roughly one in eight of the world's population. (WHO/UNICEF)**
- **2.5 billion people in the world do not have access to adequate sanitation, this is almost two fifths of the world's population. (WHO/UNICEF)**
- **1.4 million children die every year from diarrhea caused by unclean water and poor sanitation - 4,000 child deaths a day or one child every 20 seconds. (WHO/WaterAid)**



Millennium Development Goal (MDG), agreed to by all 191 United Nations member countries declared from 2005- 2015 Decade

“WATER FOR LIFE”

Decade



Scarcity of fresh water

- **On a global basis, fresh water is an increasingly scarce resource. It is partially caused by increasing population coupled by change of consumption pattern and climate changes.**



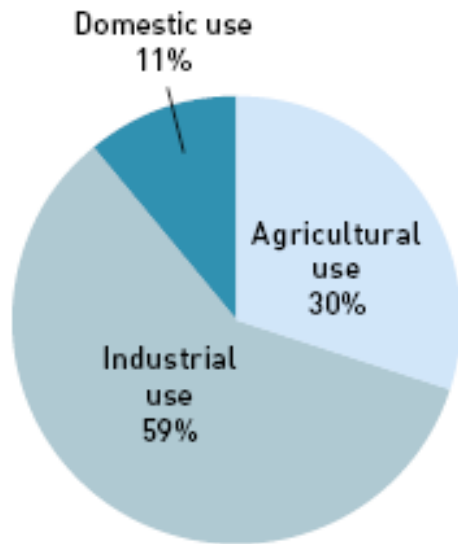
Water consumption for food production

Product	Unit	Equivalent water in cubic metres
Bovine, cattle	head	4,000
Sheeps and goats	head	500
Meat bovine fresh	kilogram	15
Meat sheep fresh	kilogram	10
Meat poultry fresh	kilogram	6
Cereals	kilogram	1.5
Citrus fruit	kilogram	1
Palm oil	kilogram	2
Pulses, roots and tubers	kilogram	1

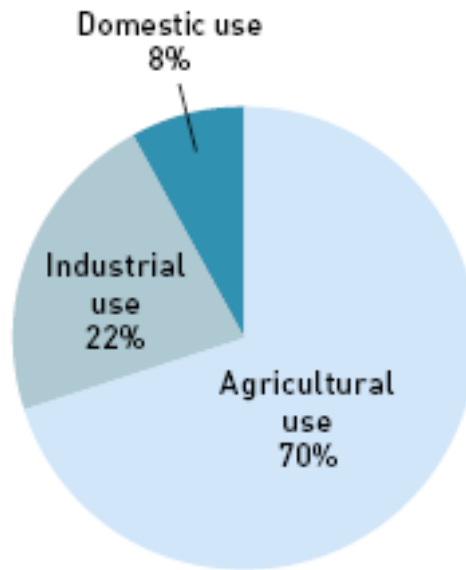
Source: FAO, 1997b.



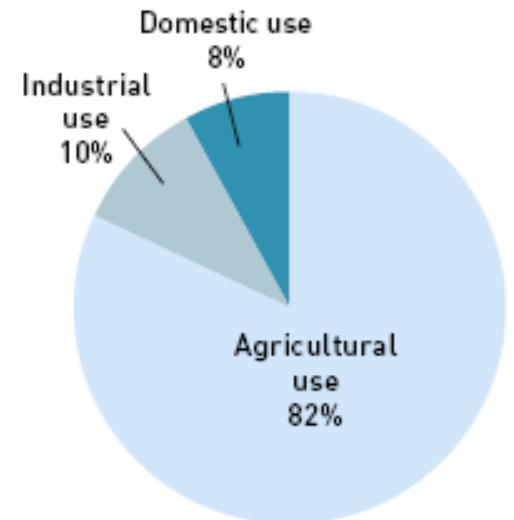
Competing water uses



Competing water uses
(high-income countries)



Competing water uses
(world)

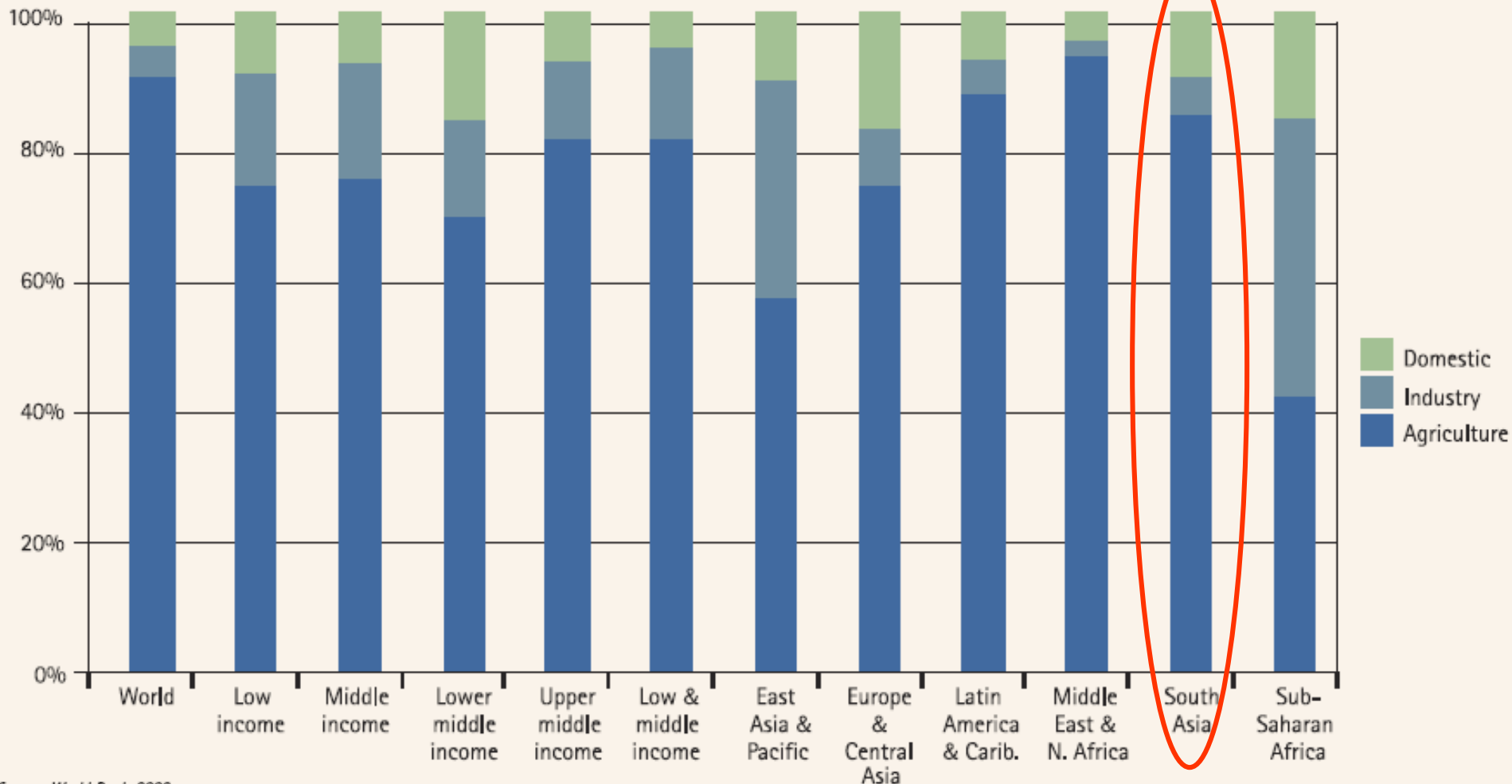


Competing water uses
(low- and middle-income
countries)



Water use by industry vs. domestic use and agriculture

Uses of water among sectors



Source: World Bank, 2002.



Competing water uses

- Industrialized / developed countries tend to use more water in their industrial production.
- Other countries tend to use more water for agricultural uses.



- What is Hydrology?
 - It is a science of water.
 - It is the science that deals with the occurrence, circulation and distribution of water of the earth and earth's atmosphere.
- A good understanding of the hydrologic processes is important for the assessment of the water resources, their management and conservation on global and regional scales.

- In general sense engineering hydrology deals with
 - Estimation of water resources
 - The study of processes such as precipitation, evapotranspiration, runoff and their interaction
 - The study of problems such as floods and droughts and strategies to combat them

Hydrology

- literally "**water science**," encompasses the study of the occurrence and movement of water on and beneath the surface of the Earth
- finite though renewable resource
 - finite in quantity, unlimited in supply, use rate is limited by 'recycling times'
- hydrologic sciences have pure and applied aspects
 - how the Earth works
 - scientific basis for proper management of water resources (or any natural resource...)



HYDROLOGY | history



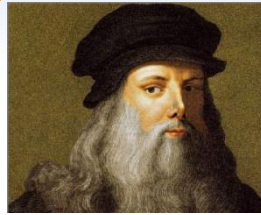
4000 BC

Along the Indus River, Pakistan, the Tigris and Euphrates in Mesopotamia, Hwang Ho in China, and the Nile in Egypt that the first hydraulic engineers created canals, levees, dams, subsurface water conduits, and wells

The Romans constructed numerous aqueducts to bring water from distant sources into their cities and towns. Waste water was removed by complex sewage systems and released into nearby bodies of water. Some aqueducts also provided water for mining, processing, manufacturing, and agriculture.



200 AD



1500

Leonardo da Vinci and Bernard Palissy independently reached an accurate representation of the hydrologic cycle

Perault

Linked rainfall to flow of the river Seine

Marriotte

Combined velocity and river cross section to obtain discharge of the river Seine

1800

Pitot

Bernoulli

Euler

Chezy

Dalton

Made progress in applications of mathematics, fluid mechanics, and hydraulics

Darcy

Worked on groundwater hydrology

1850

Poiseuille

Stokes

Manning

Reynolds

Mead

Meyer

Hazen

Gumbel

Hurst

Meinzer

Hubbert

Prandtl

Chow

Thornthwaite

Penman

Horton

1900



HYDROLOGY | branches

Chemical Hydrology

Study of chemical characteristics of water

Water Quality

Chemistry of water in rivers and lakes, both of pollutants and natural solutes

Eco Hydrology

Study of interactions of living organisms and the hydrologic cycle

Hydrogeology

Study of the distribution and movement of groundwater in the soils and rocks of the Earth's crust

Hydrometeorology

Study of the transfer of water and energy between land and water body surfaces and the lower atmosphere

Surface Hydrology

Study of hydrologic processes that operate at or near Earth's surface

Drainage Basin Management

Covers water-storage, in the form of reservoirs, and flood-protection



HYDROLOGY | themes | atmospheric water

“Water present in the atmosphere either as a solid (snow, hail), liquid (rain) or gas (fog, mist)”

Topics

- Cloud formation
- Precipitation types
- Measuring precipitation
- Evaporation types
- Estimating evaporation



HYDROLOGY | themes | surface water

“Water at the surface, whether stagnant in the form of surface storage or flowing in rivers, or as overland flow on slopes”

Topics

- Bernoulli's equation
- Measuring water velocity and flow
- Hydrograph analysis
- Pollutant loads



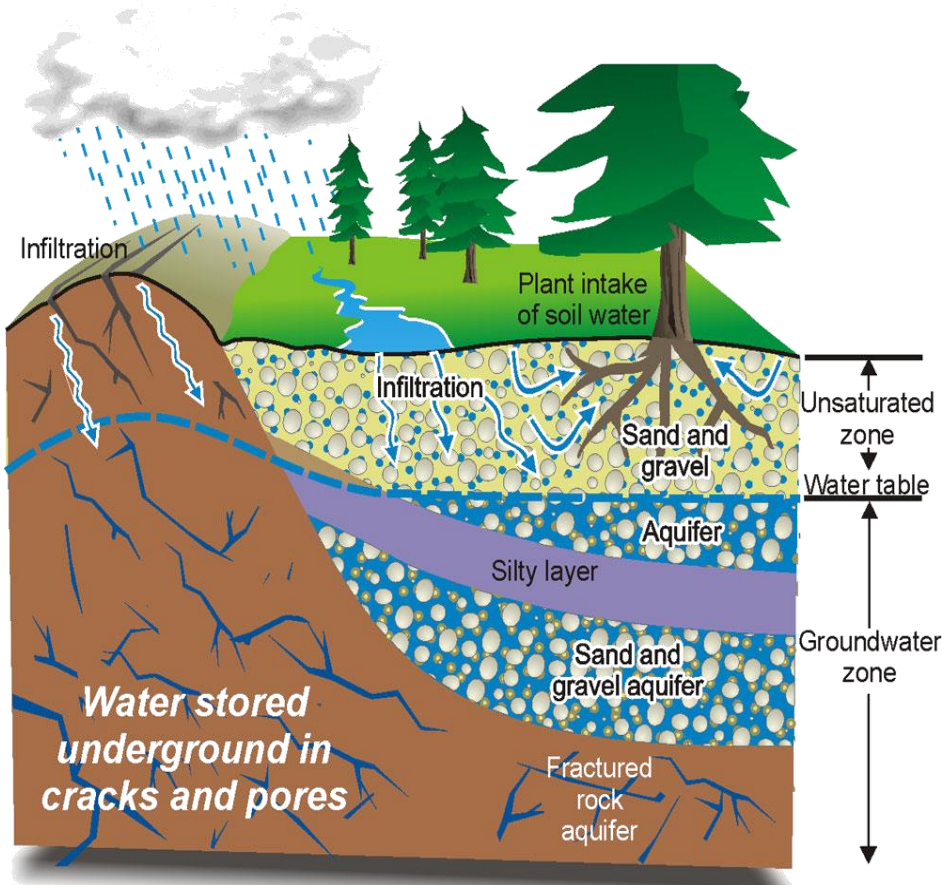
HYDROLOGY | themes | groundwater & soil water

“Water beneath the land surface that fully saturates the pores in the ground is called groundwater”

“Water stored in the unsaturated zone above the water table is called soil water”

Topics

- Aquifers
- Darcy's Law
- Soil moisture
- Capillary rise & evaporation
- Infiltration & percolation



HYDROLOGY | applications

Assessing impacts
of natural and
human induced
environmental
change on water
resources

Determining the
water balance
for a region

Designing
irrigation
schemes

Designing
drainage
systems

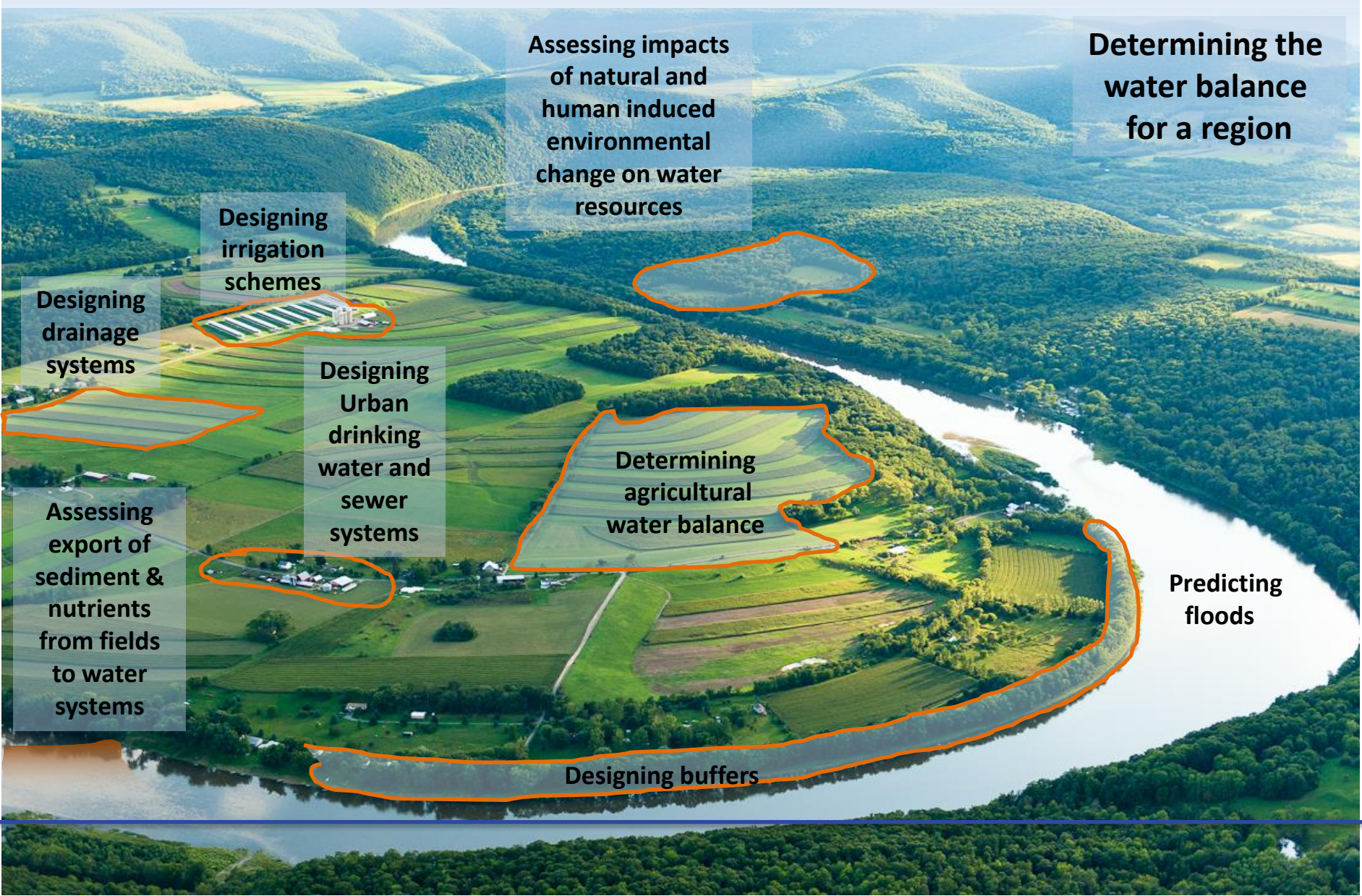
Designing
Urban
drinking
water and
sewer
systems

Assessing
export of
sediment &
nutrients
from fields
to water
systems

Determining
agricultural
water balance

Predicting
floods

Designing buffers



The Water Cycle (in detail)

- The volume (M) of water at the surface of the Earth is enormous: $1.37 \times 10^9 \text{ km}^3$! (total reservoir) – The Oceans cover 71% of the Earth's surface (29% for the continent masses above sea level)

Reservoir	Volume (km^3)	% Total
Biosphere	0.6×10^3	0.00004
Rivers	1.7×10^3	0.0001
Atmosphere	13×10^3	0.001
Lakes	125×10^3	0.01
Groundwater	9500×10^3	0.68
Glacial and other land ice (?)	29000×10^3	2.05
Oceanic water and sea ice	$1,370,000 \times 10^3$	97.25
Total	$1,408,640 \times 10^3$	100

Adapted from Berner & Berner (*The Global Water Cycle*; Prentice Hall, 1987)

Hydrologic Cycle

- Water exists on the earth in all its three states, viz. liquid, solid, gaseous and in various degrees of motion.





Water never leaves the Earth. It is constantly being cycled through the atmosphere, ocean, and land. This process, known as the **water cycle**, is driven by energy from the sun. The water cycle is crucial to the existence of life on our planet.



Hydrologic cycle....

- Water, irrespective of different states, involves dynamic aspect in nature.
- The dynamic nature of water, the existence of water in various state with different hydrological process result in a very important natural phenomenon called **Hydrologic cycle**.

The Water Cycle (in detail)

- The volume (M) of water at the surface of the Earth is enormous: $1.37 \times 10^9 \text{ km}^3$! (total reservoir) – The Oceans cover 71% of the Earth's surface (29% for the continent masses above sea level)

Reservoir	Volume (km^3)	% Total
Biosphere	0.6×10^3	0.00004
Rivers	1.7×10^3	0.0001
Atmosphere	13×10^3	0.001
Lakes	125×10^3	0.01
Groundwater	9500×10^3	0.68
Glacial and other land ice (?)	29000×10^3	2.05
Oceanic water and sea ice	$1,370,000 \times 10^3$	97.25
Total	$1,408,640 \times 10^3$	100

Adapted from Berner & Berner (*The Global Water Cycle*; Prentice Hall, 1987)

Hydrologic Cycle Contd.

- The vapour is carried by moving air masses which upon proper conditions is condensed to form clouds which in turn falls as precipitation to the earth.
- The greater part of the water which falls on the land is temporarily retained in the soil and returns to the atmosphere by evaporation and transpiration by plants.

Hydrologic Cycle Contd.

- A portion of the water which enters the soil forms part of the groundwater and flows back to the stream.
- Another portion of it flows parallel to the soil surface and enters the stream. This portion of water does not hit the water table and is called lateral flow (see Fig. 1.1).
- There is also the overland flow which just moves on the surface of the soil into the stream.

Hydrologic Cycle Concluded

- The overland flow (surface flow), the lateral flow and the groundwater under the influence of gravity move towards lower elevations from where they may eventually discharge into the ocean.
- A lot of this water is lost to the atmosphere by evaporation and transpiration before reaching the ocean.

COMPONENTS OF THE HYDROLOGIC CYCLE

- The hydrologic characteristics of a given region are determined largely by its climate and its geological structure, the climate playing a dominant part.
- The climatic factors that affect the hydrological features of an area or region are:
- Amount and Distribution of Precipitation,
- The occurrence of Snow and Ice (in Temperate Regions),
- The Effects of Wind, Temperature and Humidity on Evaporation.

COMPONENTS OF THE HYDROLOGIC CYCLE CONTD.

- The design and operation of hydrologic projects involve meteorological considerations.
- Hydrologic problems in which meteorology plays an important role include the
- Determination of probable maximum precipitation for spillway design,
- Forecasts of precipitation for reservoir operation, and
- Determination of probable maximum winds over water surfaces for evaluating resulting waves in connection with the design of dams.

Weather and Climate

- Hydrology depends on Climate then topography, Geology
- Climate factor depends on Geography position of the surface.
- With climate factor depend temperature, wind, humidity which directly affect to evaporation and EVT
- Weather is the condition of the atmosphere at a particular place over a short period of time
- climate refers to the weather pattern, using statistical data, of a place over a long enough period to yield meaningful averages

Temperature Scales

The three temperature scales compared:

	$^{\circ}\text{F}$	$^{\circ}\text{C}$	K
Boiling point of water	212	100	373
Freezing point of water	32	0	273
Freezing point of dry ice (CO_2)	-109	-78	195
Boiling point of nitrogen	-321	-196	77
Absolute zero	-460	-273	0

Temperature

- Temperature can be measured using the maximum and minimum thermometers.
- **Temperature Terminologies**
- **(a) Mean daily temperature:** This is the average of the maximum and minimum temperatures.
- **(b) Mean monthly temperature:** The average of the mean monthly daily maximum and minimum temperatures.

Temperature

- Thermometer housed on open boxes above 1.5 m.
- Normal daily temperature= Daily mean
$$=T_{\max}+T_{\min}/2$$
- Mean monthly $T = 24 \text{ hours } T/24$
- Mean annual $T =$ average of the monthly

Temperature Terminologies

Continued

- **(c) Mean annual temperature:** The average of the monthly means for the year.
- **(d) Normal temperature:** The average daily mean temperature for a specified time usually 30 years. Every 10 years, the data for the first 10 years is dropped.

Temperature Terminologies

Concluded

- **(e) Daily Range in Temperature:** The difference between the highest and lowest temperatures recorded on a particular day.

Lapse rate

- **Lapse Rate or Vertical Temperature Gradient:**
- The rate of change of T with height is called lapse rate
- This is the drop of temperature with rise in elevation
- Mean value 6.5 C per 1000 meters height

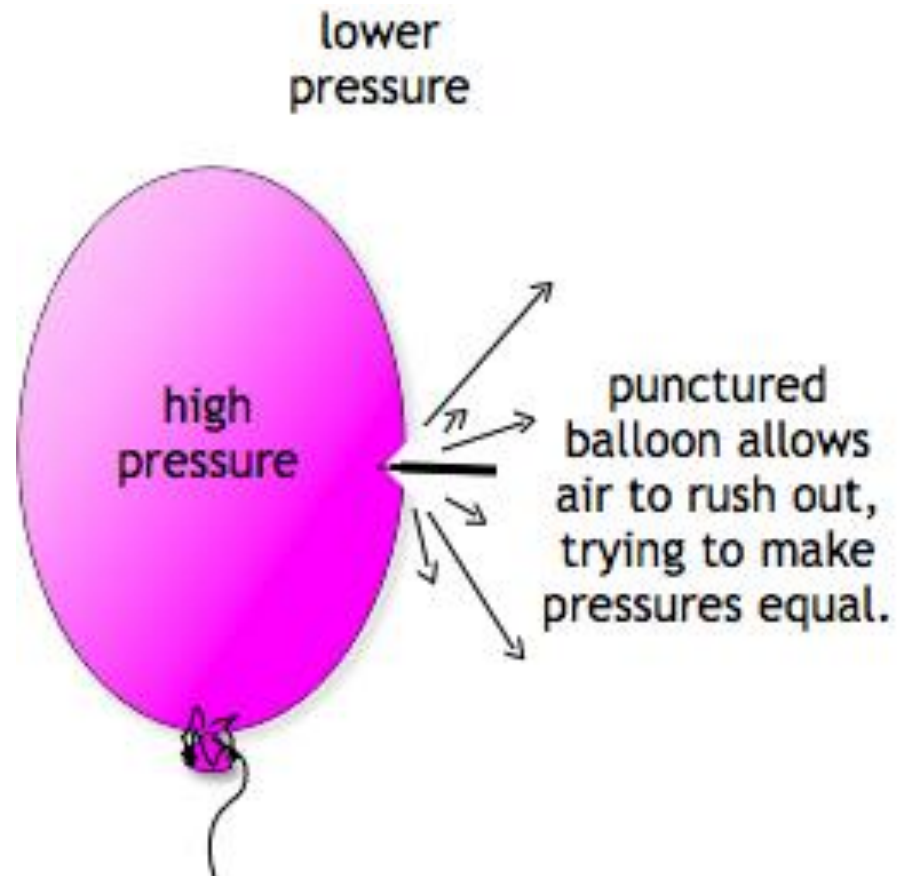
WIND

- The important parameters of wind are wind speed, wind run and wind direction.
- The wind speed is measured using an anemometer while its direction is measured with a wind vane.
- Wind speed is given in miles per hour, metres per second or knots($1 \text{ knot} = 1.151 \text{ miles/hr}$).

Wind

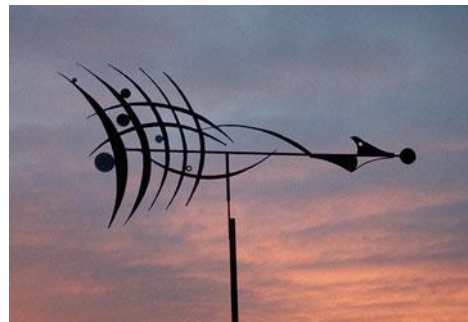
- Air moves from areas of **HIGH** pressure to areas of **LOW** pressure.
- This movement of the air is the wind

Example: *When you blow up a balloon, you increase the air pressure inside the balloon. When you let go of the end, the air rushes out of the balloon*



Measuring Wind Speed and Direction

- Wind speed is measured using an anemometer
- Wind direction is measured with a wind vane



Hand-Held Anemometer



Wind contd.

- The conventional anemometer is the cup anemometer made up of 3 or 4 cups arranged in a circular form rotating around a vertical axis.
- The wind speed is the speed of rotation of the cups while the wind run, which is the distance a particular parcel of air is moving through in a given time, is given by the total revolutions around the axis of the cups.

Wind Measurement Concluded

- The particular height of wind speed measurement should be specified. An empirical relationship exists between wind speed and height:

$$U/U_0 = (Z/Z_0)^{0.15}$$

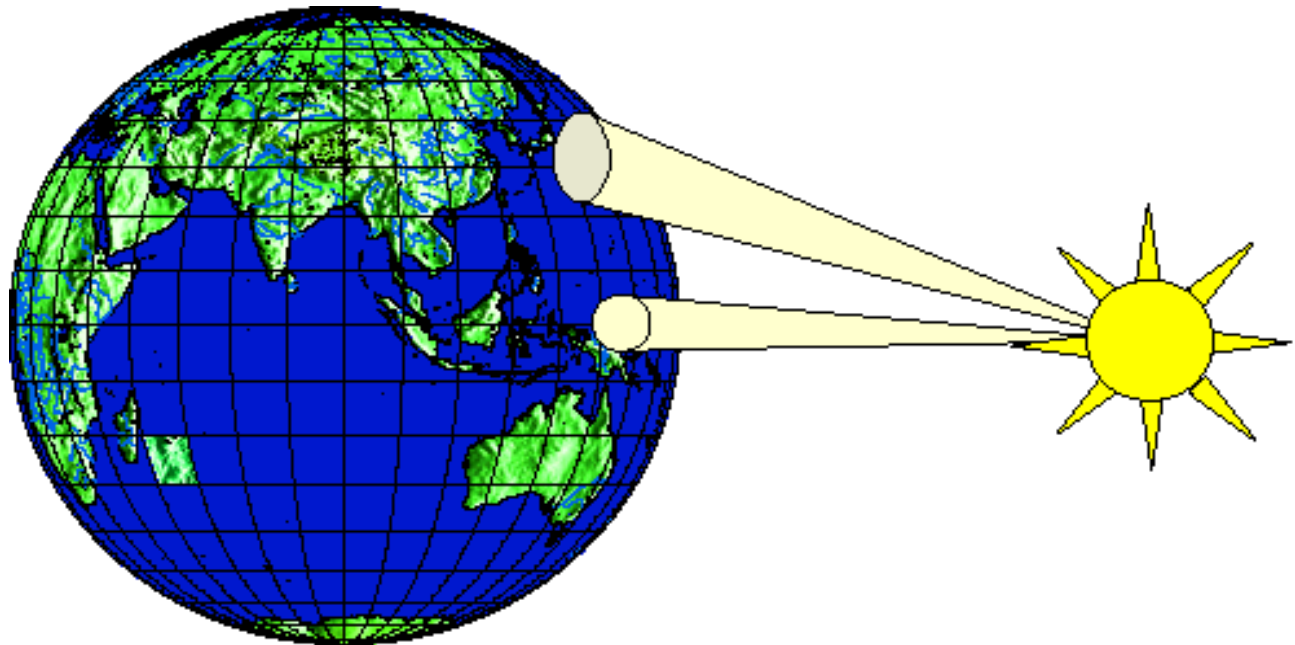
- U_0 is the wind speed at height Z_0 and U is that at higher level Z .

Wind speed and direction measurments

- $U/U_o=(Z/Z_o)^k$
- U_o = Wind speed at anemometer at height Z_o
- U = Wind speed at anemometer at height Z_o
- K = Surface roughnees usually 0.15
- Wind speed given in km/hour or knots
- $1 \text{ km/hr} = 0.54\text{hrs} = 0.278\text{m/s}$

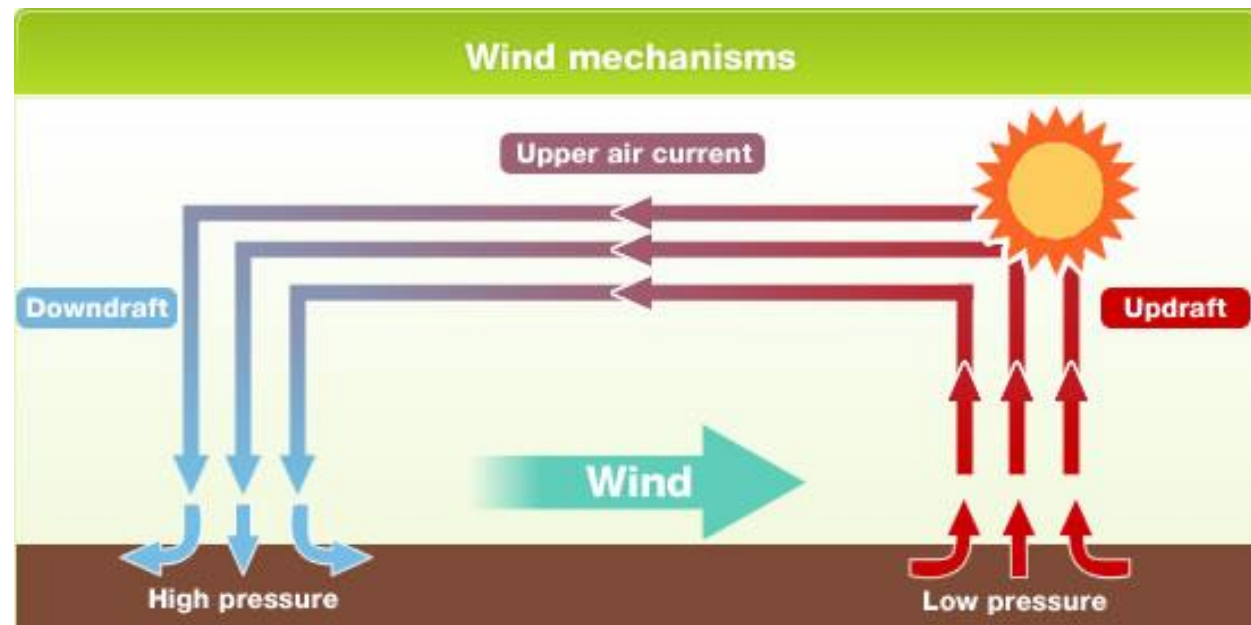
What causes differences in air pressure?

- Differences in air pressure are caused by UNEVEN HEATING of the Earth's surface by the sun.
- Therefore, the sun and solar energy is the ultimate cause of the wind.

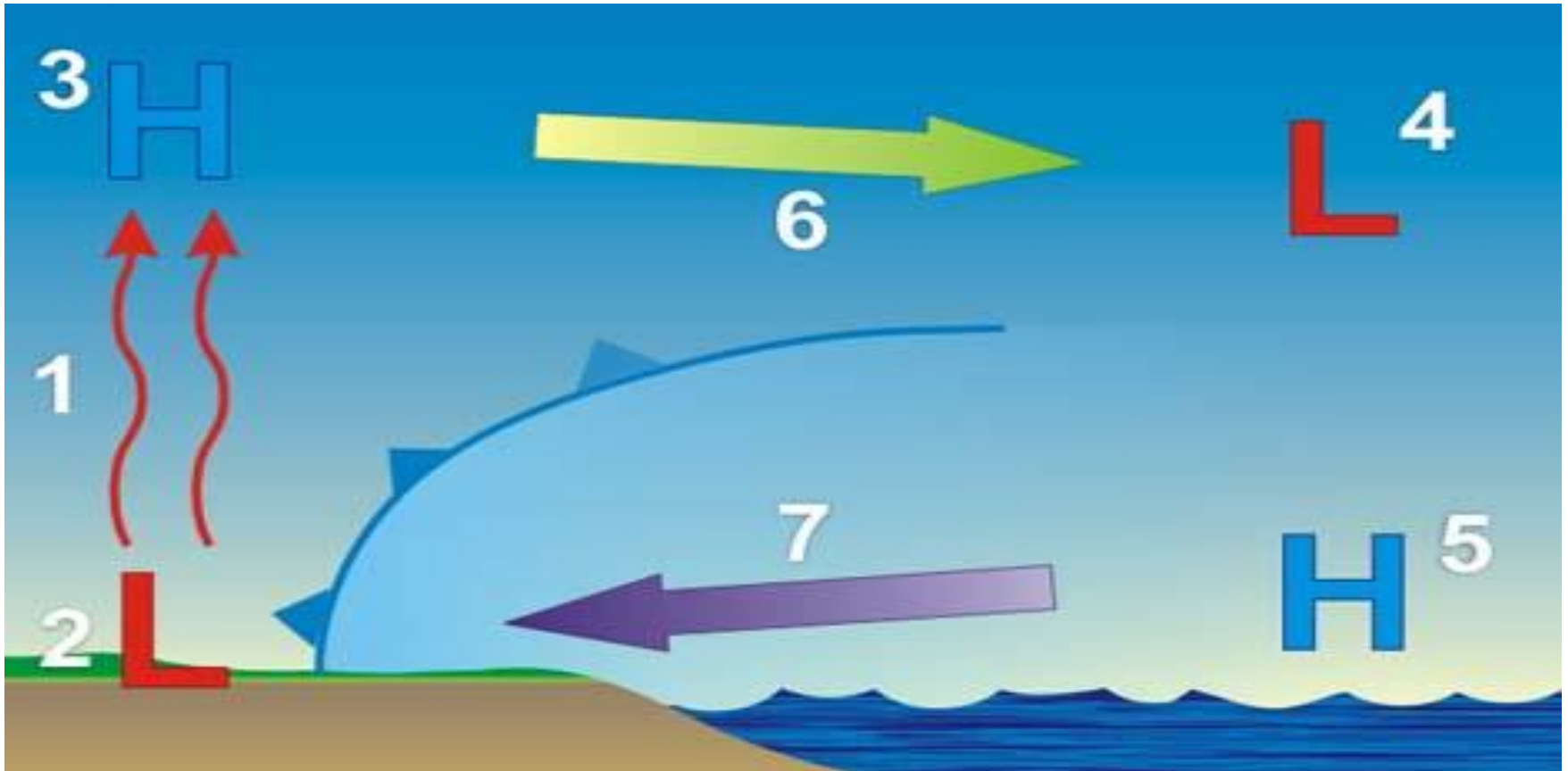


Local Winds

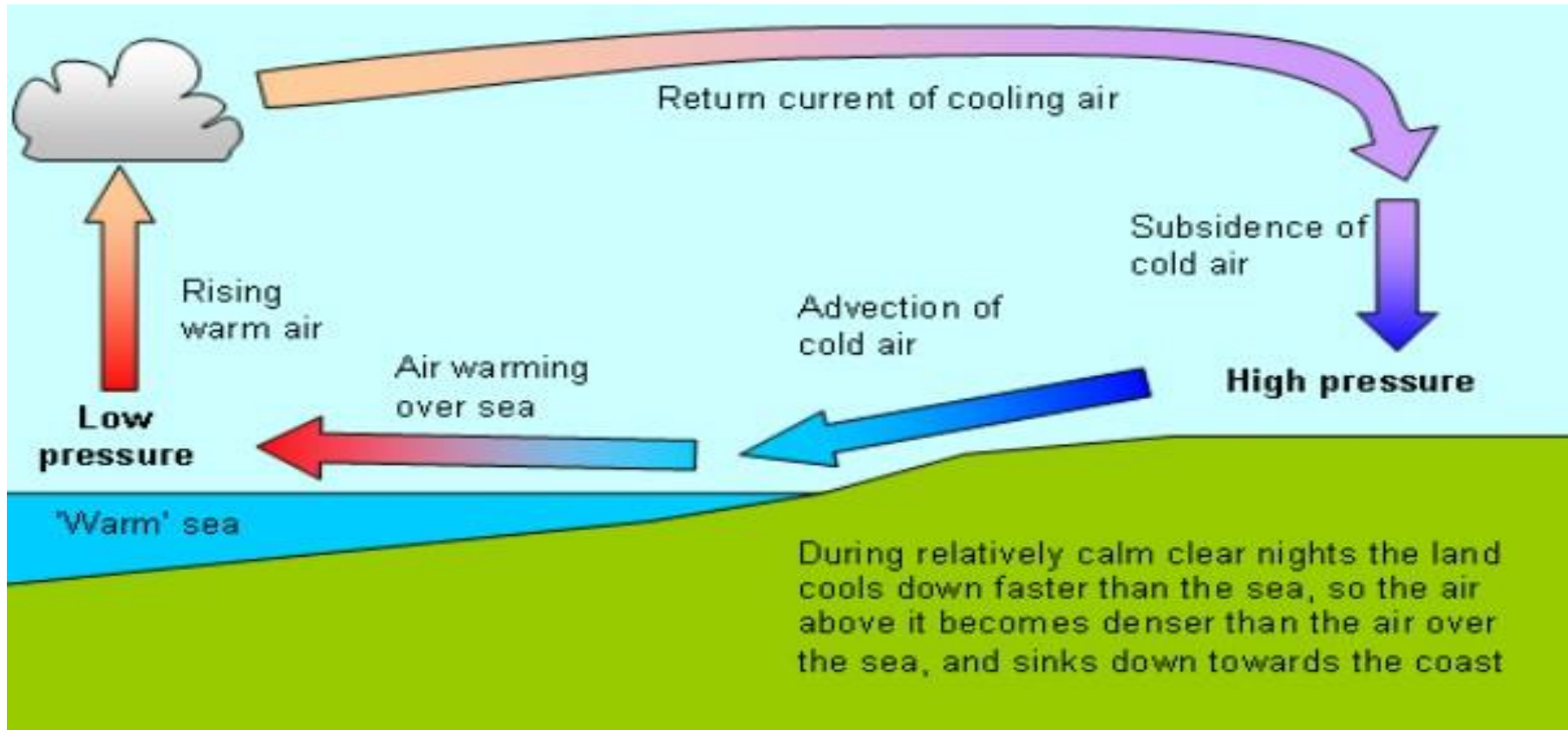
- The **land** *heats and cools* **faster** than the sea. **Water retains heat longer** than land, and *also takes longer to heat and cool*.
- This causes temperature differences between the land and the sea, which leads to a ***thermal circulation*** (or **wind based on temperature differences**).



- During the day, the land heats up faster, the hot air rises, creating an area of lower pressure. Wind blows from the sea to the land. This is a **sea breeze**.



- At night, the land cools off faster than the sea. Cooler air descends creating an area of higher pressure. Wind blows from the land to the sea. This is a land breeze.



- Assume you have a lapse rate of $6.5^{\circ}\text{C km}^{-1}$. An air mass, at an elevation of 4000m and a temperature of 4°C move into the area. The ground level temperature is 75°F . Will the air mass rise or sink in the new environment?
- A tower anemometer shows a wind speed of 20 m/s at 100m above the ground surface. What is the estimated speed in m/s, 10m above the ground indicated by the power law profile with values for K (surface roughness)? $1/7$ and $1/2$
- Anemometer at 5m and 60m on a tower records wind speeds of 5 and 10 m/s, respectively. Compute the wind speed at 10 and 30 m?

Humidity

- Humidity is the amount of water vapor in the air. Too much or too little humidity can be dangerous. For example, high humidity combined with hot temperatures is a combination that can be a health risk, especially for the very young and the very old.

- Absolute humidity is the amount of water vapor divided by the amount of dry air in a certain volume of air at a particular temperature.
- A relative humidity of 100% means that the air can't hold any more water vapor. It's totally saturated. When this occurs, it can rain. In fact, the relative humidity must be 100% where clouds are forming for it to rain. However, at ground level where the rain lands, the relativehumidity can be less than 100%.

Dew point

- The dew point is the temperature at which air is saturated with water vapor, which is the gaseous state of water.
- When air has reached the dew-point temperature at a particular pressure, the water vapor in the air is in equilibrium with liquid water, meaning water vapor is condensing at the same rate at which liquid water is evaporating.

- The dew point temperature determines what combinations of temperature and RH will be possible in the storage environment.
- Below the dew point, liquid water will begin to condense on solid surfaces (such as blades of grass) or around solid particles in the atmosphere (such as dust or salt), forming clouds or fog

- At a constant dew point, when the temperature goes up, the RH goes down and when the temperature goes down, the RH goes up. Controlling the dew point is key to managing the risk of material decay. What's your dew point? If you know the T & RH in your space you can use the DP Calculator to get the DP. If your building does not have humidification or dehumidification, the indoor dew point is the same as the outdoor dew point.



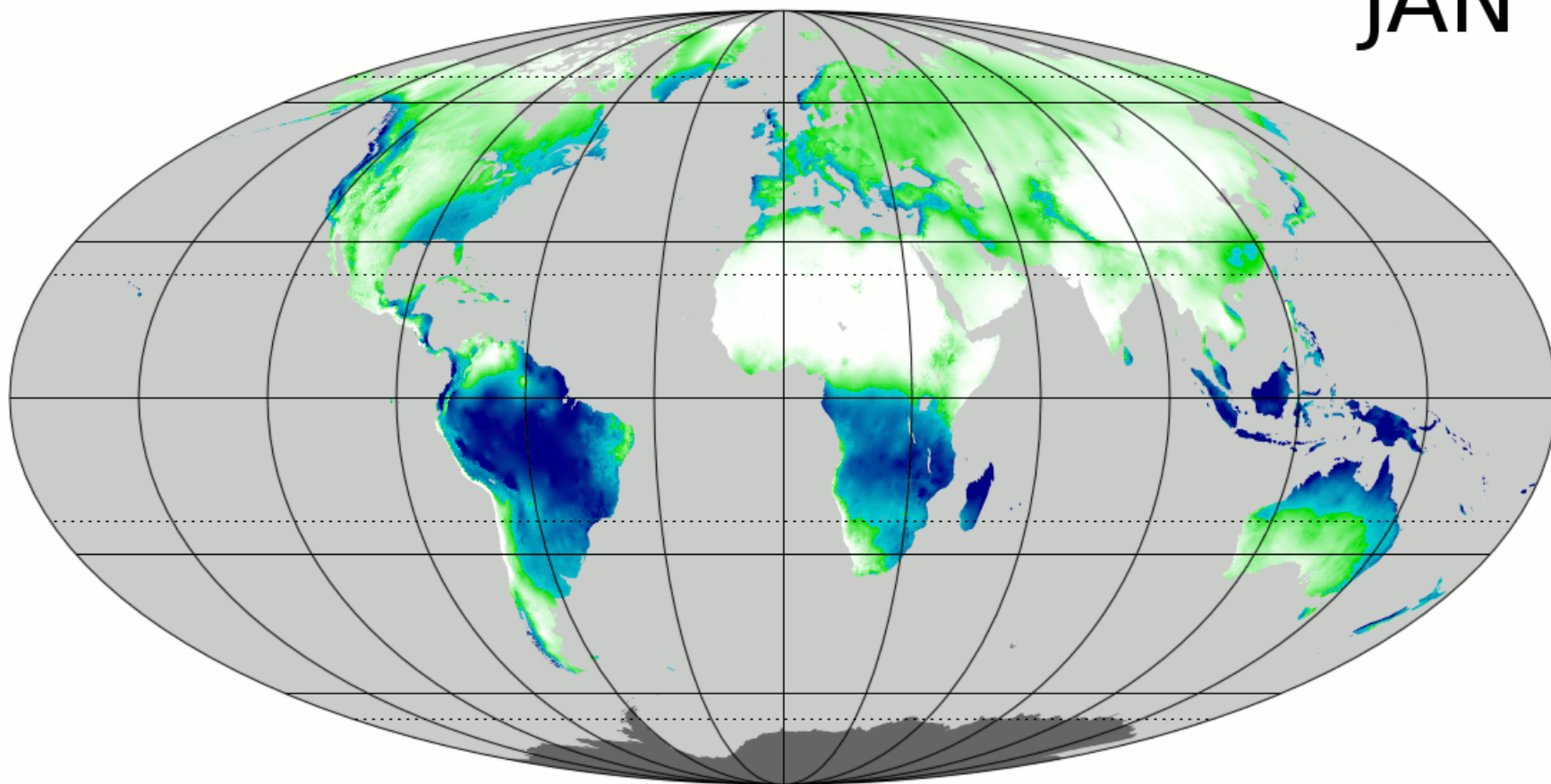
What is precipitation?



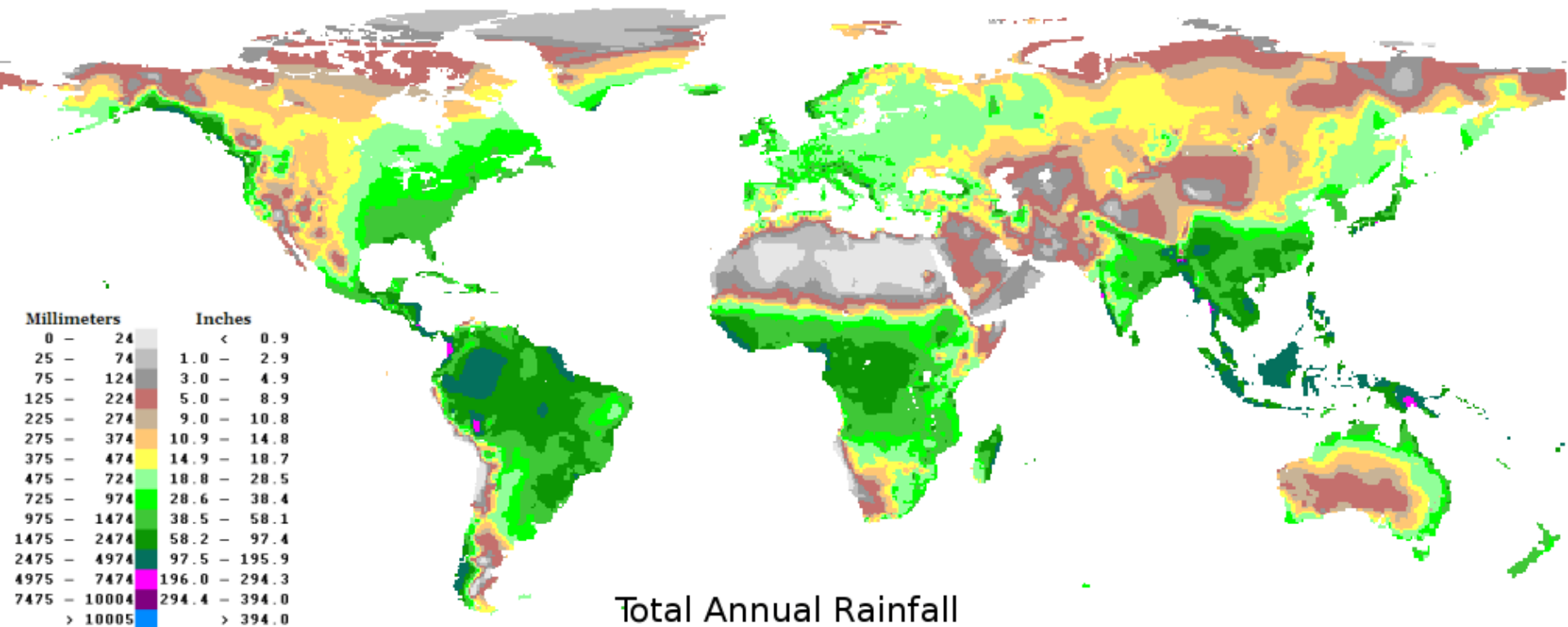
Dr. Ranjana. U.K. Piyadasa
(PhD- Hydrogeology), MSc- Engineering Geology)
Department of Geography
University of Colombo,
Colombo 03, Sri Lanka



JAN



Global Precipitation



Precipitation averages just about 1 meter per year over Earth but, like wealth, varies widely from place to place and over time. Rainfall is generally greatest near the Equator where the air rises, small in the subtropics where the air sinks, and tiny in the polar regions where the frigid air has a tiny vapor capacity. The next slide shows how precipitation varies over the year, as the main rain belts follow the Sun north and south with the seasons.

What are the forms of precipitation?



What are the forms of precipitation?



Forms of Precipitation

➤ **1. Rain** - liquid deposits falling from the atmosphere to the surface



- with a diameter > 0.5 mm

- < 0.5 mm: drizzle

- max. size: about 5 - 7 mm

(too large to remain suspended)

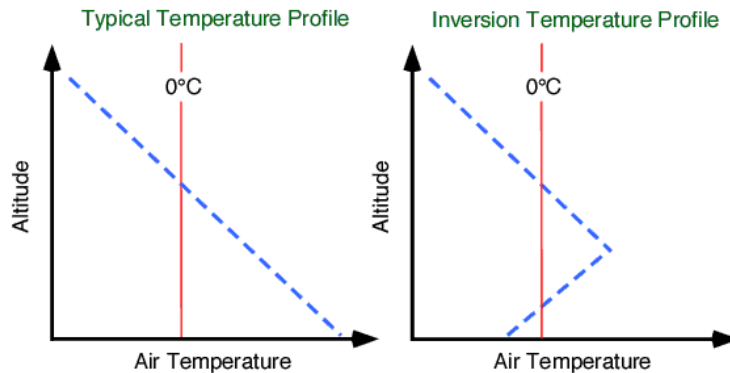
- beyond this size, inter-molecular cohesive forces become too weak to be held in the mass of water together as a single drop



Forms of Precipitation

➤ 2. Freezing rain

- when falling liquid water droplets reaches a surface with a temperature below freezing point
- so, the rain droplets quickly turn into ice
- another * condition: where the rain develops, the temperature of rain develops must be above freezing



e.g. within a temperature inversion

Forms of Precipitation

- 3. **Sleet / ice pellets**

- transparent / translucent spheres of frozen water
- with a diameter > 5 mm
- develop first as raindrops in relatively warm atmosphere (Temp: $>$ freezing),
- then raindrops descend into a colder layer of the atmosphere (Temp: $< 0^{\circ}\text{C}$)
- causing the freezing into ice pellets while reaching the ground surface
- like freezing rain, an air temperature inversion is required

Forms of Precipitation

➤ 4. Snow

- commonly found in the mid- and high- latitudes
- it develops when water vapour deposits itself directly to a six-sided (**hexagon**) deposition nuclei as a solid crystal, at temperature below freezing (what is this process called?)
- why is this unique form?
- snow is usually associated frontal uplifting with **mid-latitude cyclones**



Forms of Precipitation

➤ 5. Hail

- a frozen form of precipitation with a diameter > 5 mm
- hailstones: concentric shells of ice with alternating white cloudy appearance & those that are clear
- cloudy white: contain partially melted snowflakes that freeze on to the to the surface of the growing hailstone
- clear shell: develops when liquid water freezes onto the hailstone



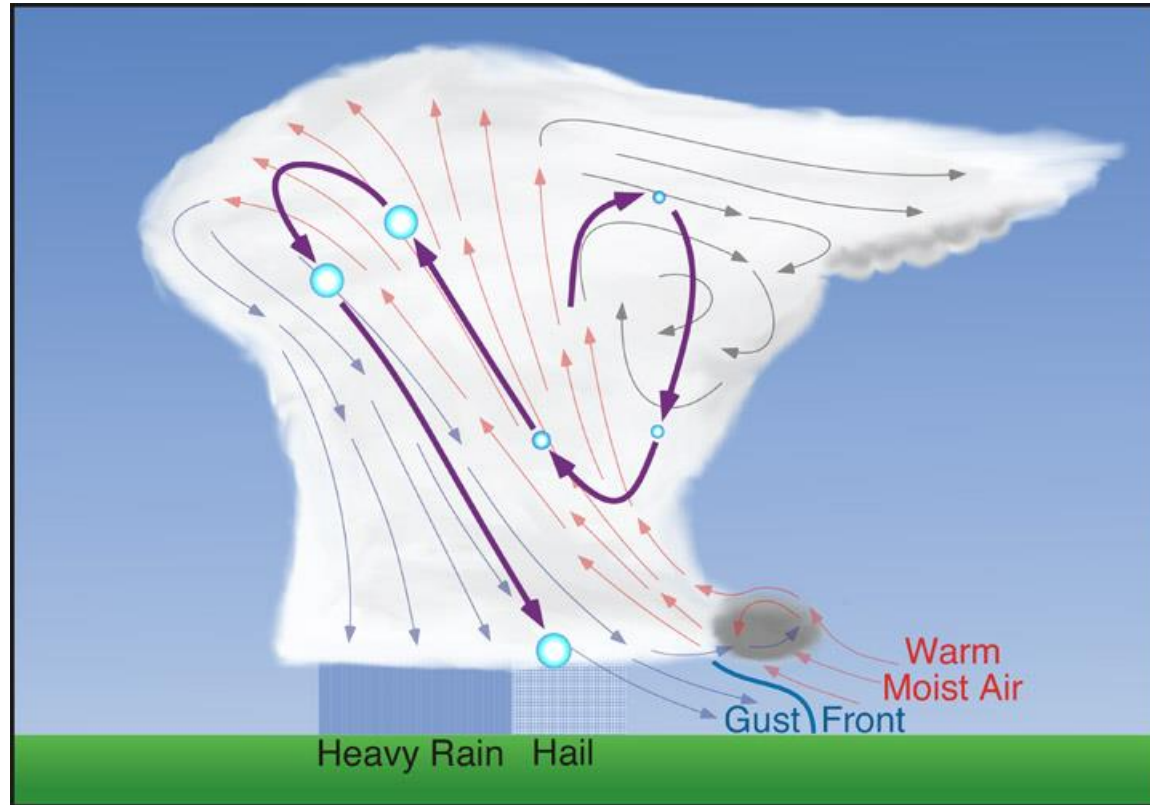
Forms of Precipitation

➤ 5. Hail

- Strong uprising currents in thunderstorm clouds provide the mechanism for forming hail
- the updrafts move hailstone embryos (e.g. large frozen raindrops) upward through the storm cloud
- where they encounter layers of ice crystals, snow & supercooled rain
- each encounter causes the hailstone to grow larger
- hailstones can grow very large in size with repeated updrafts
- until being too heavy to be supported by updrafts, it begins falling under gravity
- on descending, it can lose great mass due to melting

Forms of Precipitation

➤ 5. Hail



A typical hailstone growth path through a thunderstorm cloud. Hailstones add most of their mass during updrafts.

Necessary conditions?

- When clouds form in the atmosphere, they are non-precipitating in 99% of cases.



Necessary conditions?

- 1. cooling of air (e.g. convective / orographic / cyclonic (frontal) uplifting)
- 2. condensation and cloud formation
- 3. an accumulation of moisture
- 4. the growth of cloud droplets
 - the most critical stage!!
- **Water droplets and ice crystals** of clouds need to be transformed into heavier particles if they are to fall out of clouds as precipitation. **Why?**

Necessary conditions?

- **Water droplets and ice crystals** of clouds need to be transformed into heavier particles if they are to fall out of clouds as precipitation. **Why?**
- As we know, water droplets & ice crystals can only fall to the Earth's surface if they grow to a sufficiently large size that can overcome updrafts

Necessary conditions?

➤ **Raindrop size:**

drizzle	about 0.2 mm
light rain	about 0.5 mm
small rain	about 1.0 mm
rain	about 5.0 mm
rainstorm	up to about 7.0 mm

➤ How about the condensed size generated from **condensation**? (Make a guess?)

Necessary conditions?

➤ **Raindrop size:**

drizzle	about 0.2 mm
light rain	about 0.5 mm
small rain	about 1.0 mm
rain	about 5.0 mm
rainstorm	up to about 7.0 mm

➤ **From condensation alone:**

- Between 50 – 200 μm (size of drizzle only)
- (where 1 mm = 1000 μm)

Precipitation

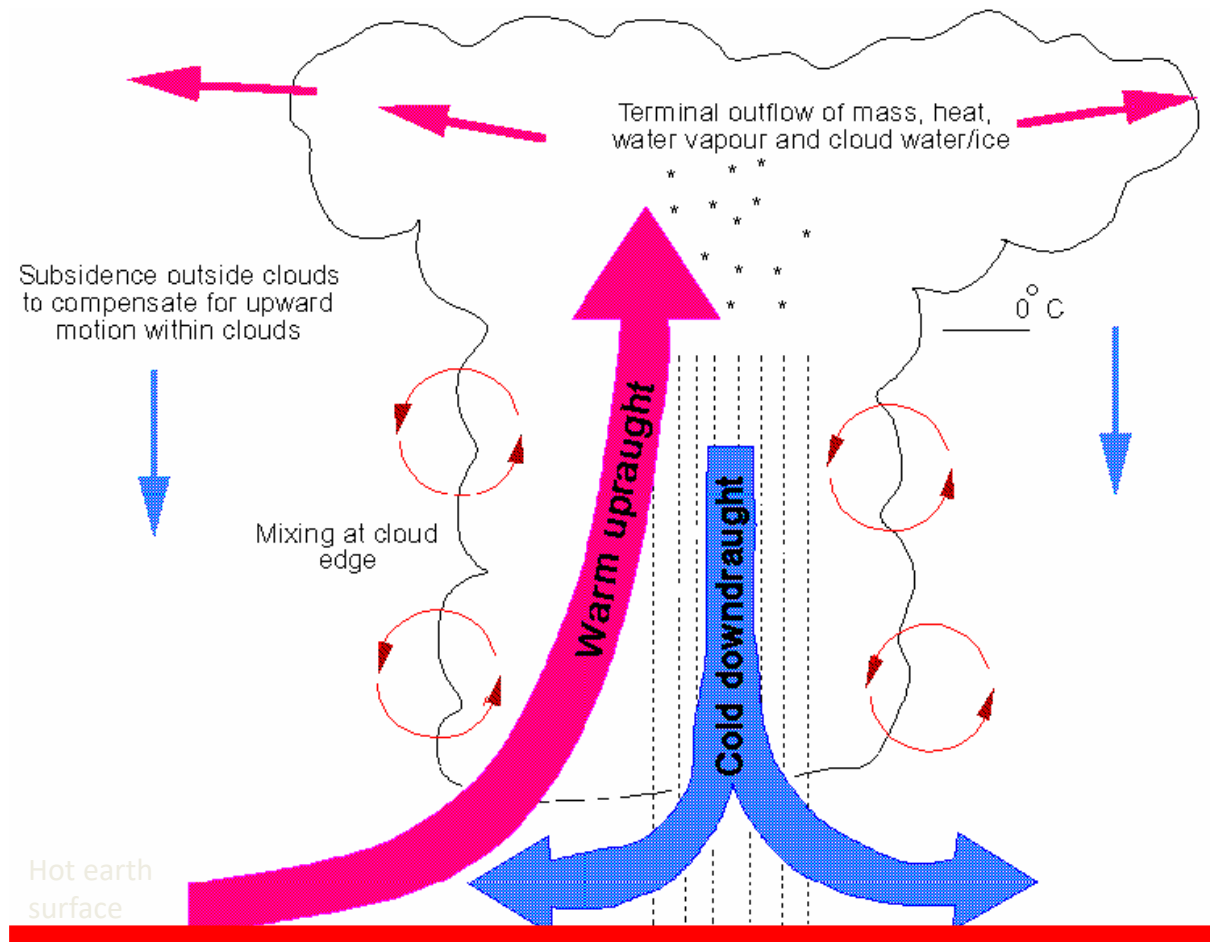
- Types
 - Convective
 - Cyclonic
 - Orographic
- Important for Real Time Input and Forecasting

Convective

- *Heating of air at the interface with the ground.* The heated air expands with a result of reduction of weight and the air will rise. Dynamic cooling takes place with precipitation resulting.
- ***High intensity, short duration precipitation*** develops as the warm air rises and cools rapidly. A summer thunderstorm is the typical convective storm.

Convective lifting

Convective precipitation occurs when the air near the ground is heated by the earth's warm surface. This warm air rises, cools and creates precipitation.



Cyclonic

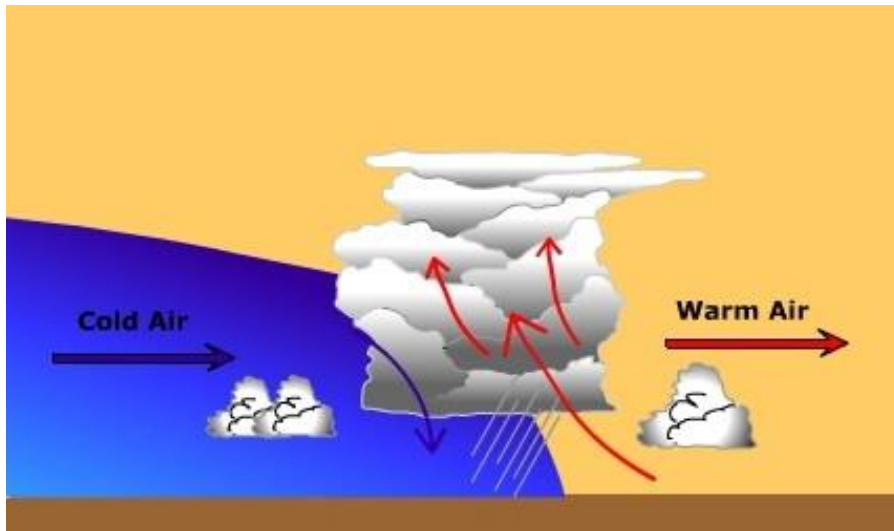
- Air masses from high pressure regions to low pressure regions-cold fronts, warm fronts, stable fronts.
- Cyclonic storms result from convergence of air masses of different temperatures and characteristics. Two fronts develop: a cold front in which cold air moves under the warm air, and a warm front in which warm air moves over the cold air.

Cyclonic

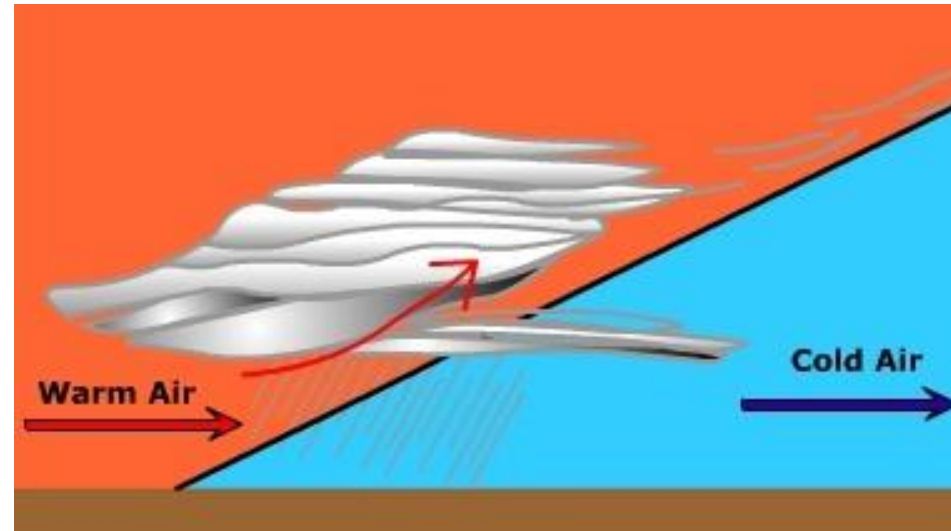
- Rainfall takes place along both fronts as the warm air rises at the interfaces.

Frontal Lifting

- Boundary between air masses with different properties is called a *front*
- *Cold front* occurs when cold air advances towards warm air
- *Warm front* occurs when warm air overrides cold air



Cold front (produces cumulus cloud)



Warm front (produces stratus cloud)

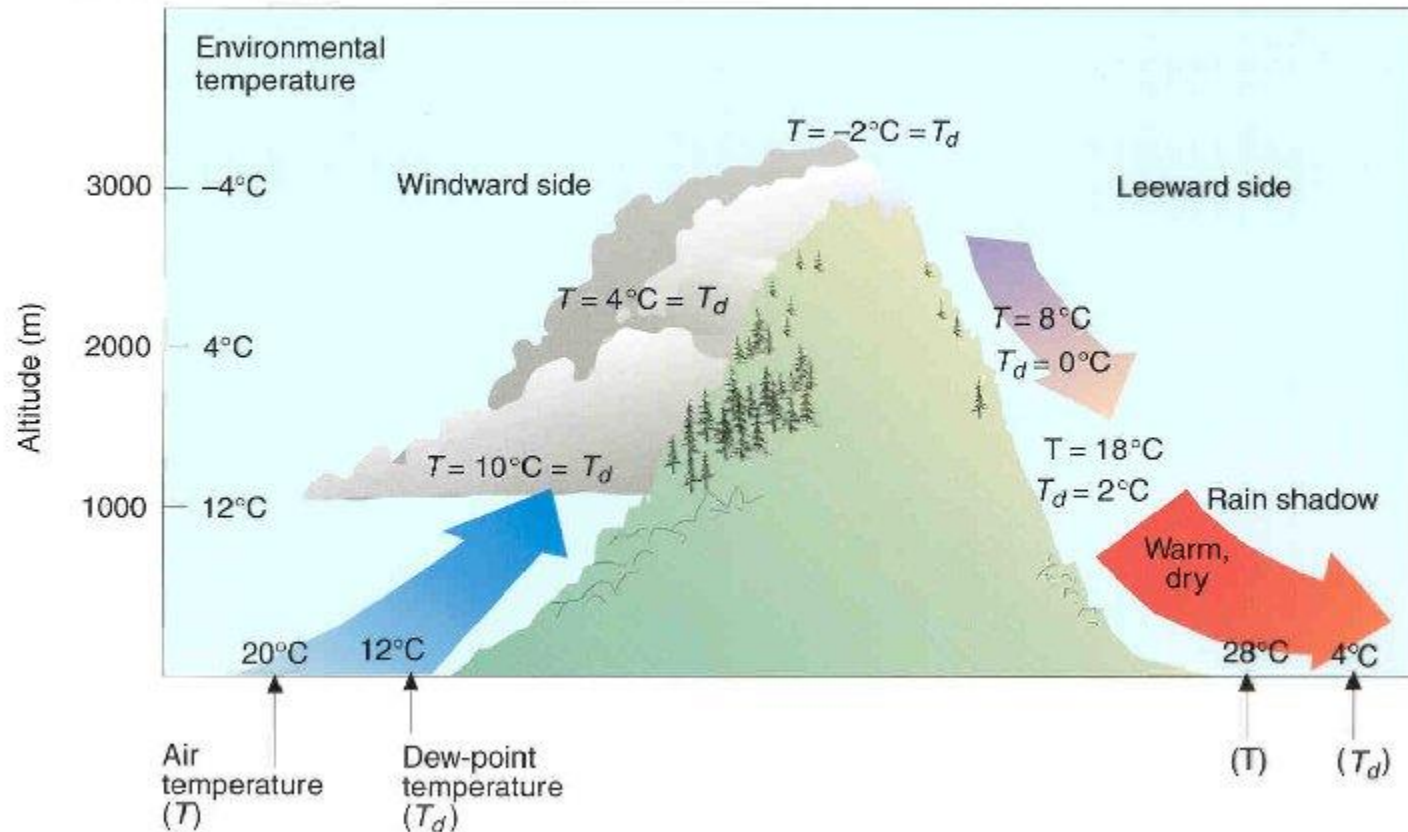
Orographic

- *Mechanical lifting of moist air masses over natural barriers such as mountains.*
- Orographic storms develop as the wind forces moist air to rise near a mountain range. The slope facing the wind (windward side) receives more precipitation than the opposite slope (leeward side).

Orographic lifting

Orographic uplift occurs when air is forced to rise because of the physical presence of elevated land.

Orographic uplift, cloud development, and the formation of a rain shadow



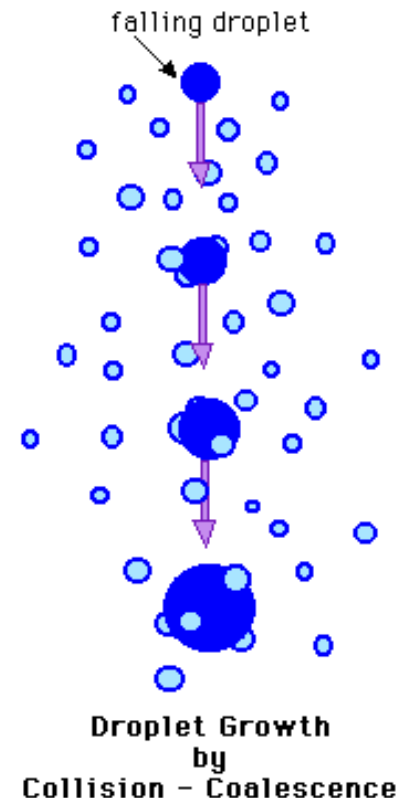
Mechanism of Precipitation Development

- 1. Coalescence theory
- 2. Bergeron-Findeisen process

Mechanism of Precipitation Development

➤ 1. **Collision - Coalescence theory**

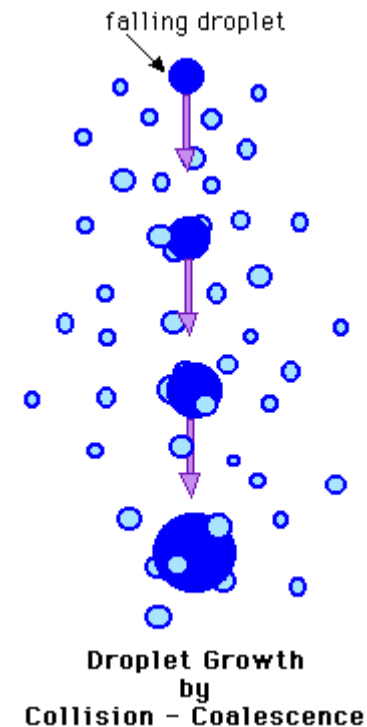
- A droplet may continue to grow by diffusion beyond 20 micrometers in diameter, however, once a droplet attains this size, growth is slow and inefficient.
- Droplets this large begin to collide and coalesce with other droplets as they fall through the cloud, meaning they will bump into and bond to one another and form larger drops.



Mechanism of Precipitation Development

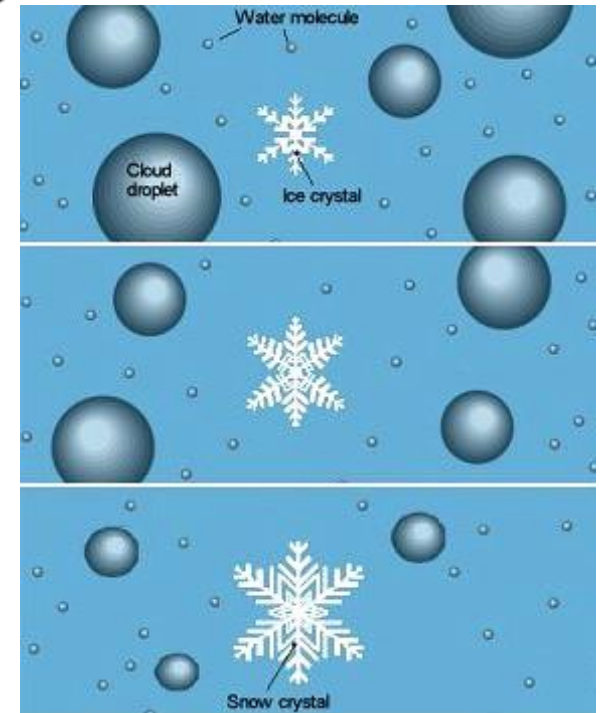
➤ 1. **Collision - Coalescence theory**

- Updrafts in a cloud can transport a droplet upward repeatedly allowing it many opportunities to fall back down through the cloud and collide and coalesce with other droplets.
- Tiny aerosol nuclei grow into large water droplets more than 10,000 times their initial size.



Mechanism of Precipitation Development

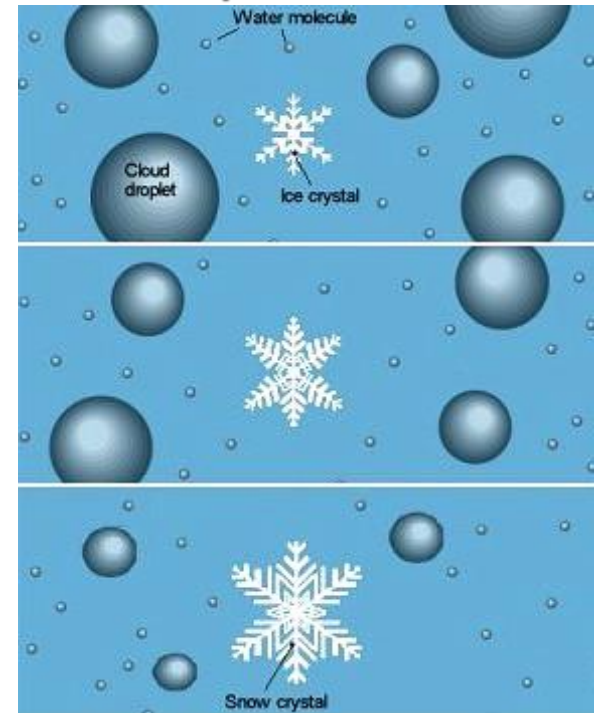
- **2. Bergeron – Findeisen process**
- also known as the **cold rain** or **ice crystal process**
- As the formation of precipitation in the cold clouds of the mid and upper latitudes by ice crystal growth.
- The equilibrium vapor pressure over water is greater than the saturation vapor pressure over ice, at the same temperature.



Mechanism of Precipitation Development

➤ 2. **Bergeron – Findeisen process**

- Therefore in a mixed phase cloud, the liquid water will be out of vapor pressure equilibrium and will evaporate to reach equilibrium.
- The water droplets will move toward the lower pressure over the ice and diffuse onto the ice crystals.
- The vapour will be condensed and freeze onto the ice crystal, causing it to grow larger.



Precipitation

Precipitation includes mainly:

Rainfall,

Dew,

Fog drip,

Hail and

Drizzle, also called mist.

MEASUREMENT OF PRECIPITATION

Rain gauges are used, There are two rain gauge types.

- (a) Non-recording gauges for taking daily values
- (b) Recording gauges.
- If the volume of water entering the rain gauge is known, divide it by the area of the catching device to get the depth of rain.
- ie. $\text{depth per unit area} = \frac{\text{Volume}(\text{mm}^3)}{\text{Area}(\text{mm}^2)}$

Non-Recording Gauges

- Non-Recording gauges measure only the *total amount of rainfall* and not the *intensity* of the rainfall from time to time.
- A typical non-recording gauge is the *Rain Gauge*.

Rain Gauge



Rain Gauge

- All measurements are made with the USWB(United States Weather Bureau) rain gauge in order to effect standardization.
- The rain gauge is approximately 20 cm in diameter and has 4 components:
 - (a) Collector or receiver - 20 cm diameter
 - (b) Cylindrical measuring tube
 - (c) Overflow can
 - (d) Measuring stick.

Rain Gauge Concluded

- Water enters the receiver and goes into the measuring tube through the funnel.
- To measure precipitation, the funnel is removed and the precipitation measured with a measuring stick.
- The overflow can is 10 times the size of the measuring tube so as to collect excess water when the need arises.

Recording Gauges

- Recording gauges measure both the *amount of rainfall* and the *intensity*.
- Two main types exist: tipping bucket and the weighing gauge types.
- **(a) Tipping Bucket Gauge:** There are two conical compartments fixed at a point.
- When rain that enters the equipment from the receiver reaches 0.25 mm, it tips and empties its contents to the reservoir below.
- This tipping is recorded by a needle on a paper wrapped round a rotating cylinder.

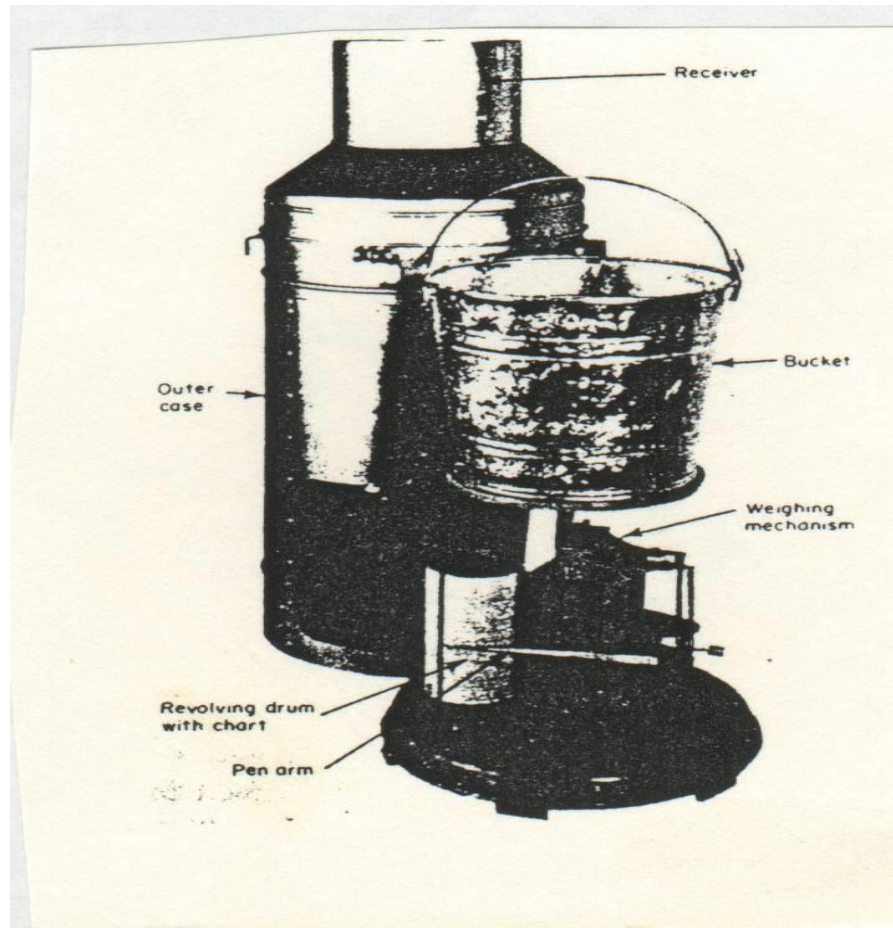
Tipping Bucket Gauge



b) Weighing Type Recording Gauge

- This is similar to the non-recording type gauge but the overflow can rests on a scale.
- The weight of rainfall is measured on the scale and transmitted to a Lab's rotating shaft through an electric wire.
- There is a calibration to get the amount of precipitation.
- Alternatively, a bucket can be set on a platform of a spring or lever balance.
- The increasing weight of the bucket and its contents is recorded on a chart.
- The record then shows the accumulation of precipitation.

Weighing-Type Gauge



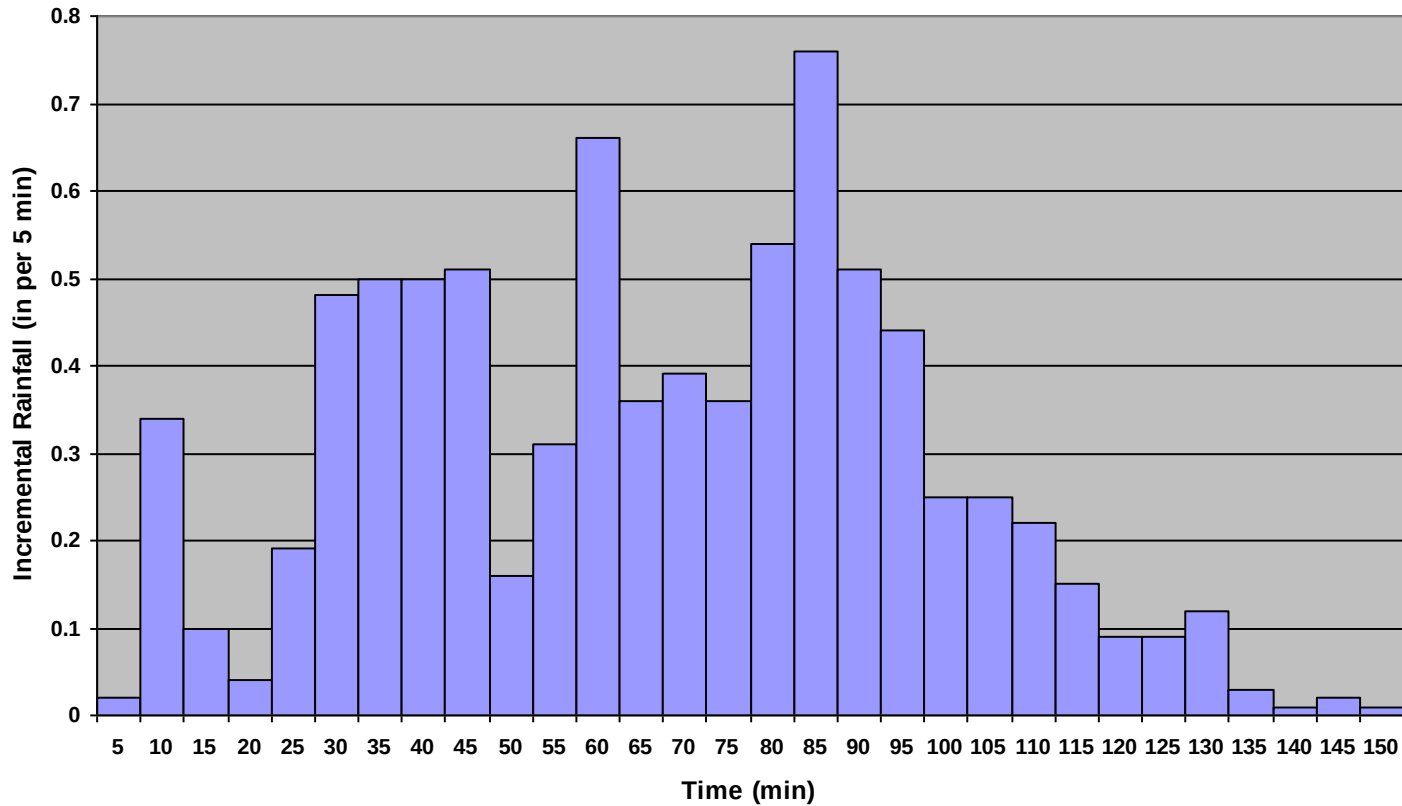
Temporal Representation

- **Rainfall hyetograph** – plot of rainfall depth or intensity as a function of time
- **Cumulative rainfall hyetograph or rainfall mass curve** – plot of summation of rainfall increments as a function of time
- **Rainfall intensity** – depth of rainfall per unit time

Rainfall Depth and Intensity

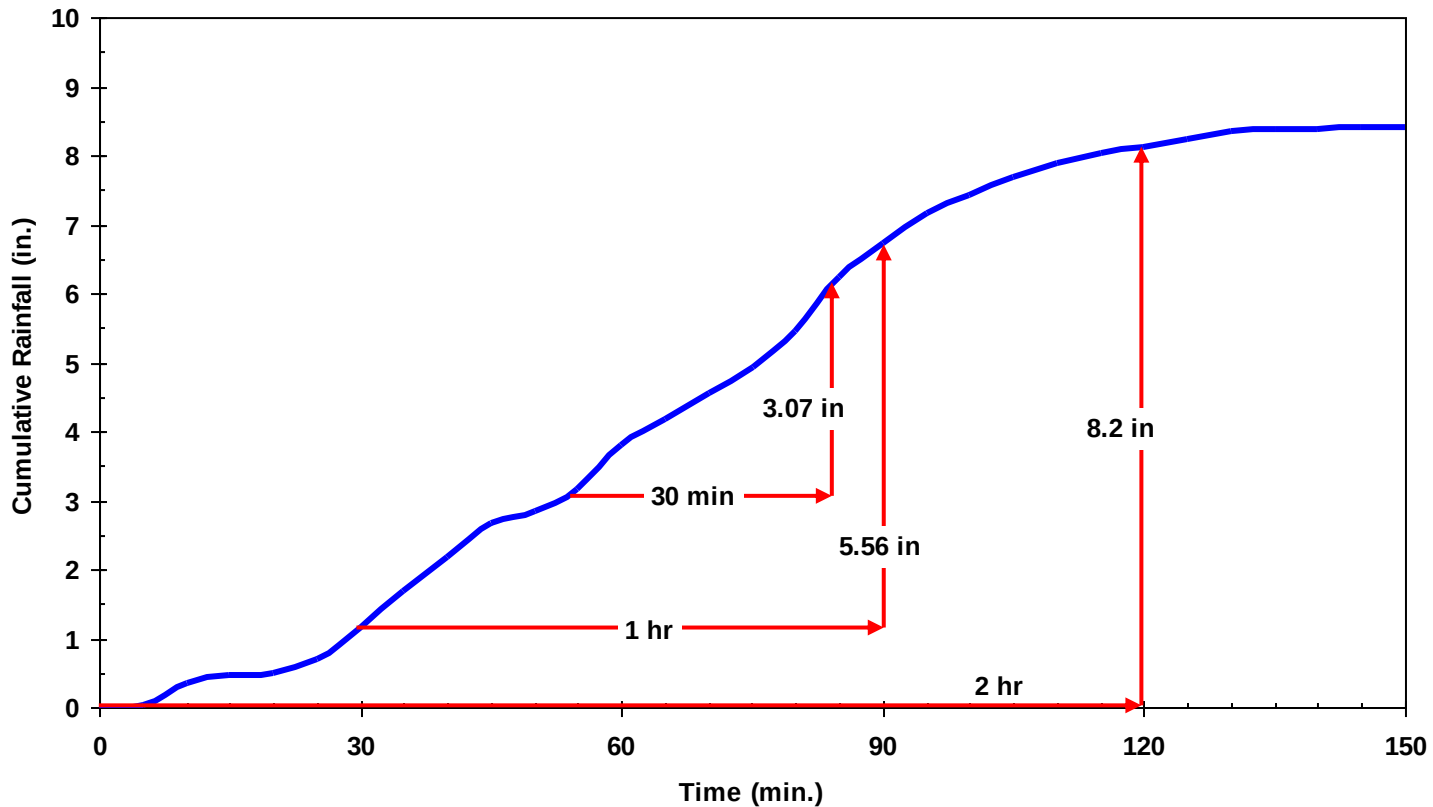
Time (min)	Rainfall (in)	Cumulative Rainfall (in)	Running Totals		
			30 min	1 h	2 h
0		0			
5	0.02	0.02			
10	0.34	0.36			
15	0.1	0.46			
20	0.04	0.5			
25	0.19	0.69			
30	0.48	1.17	1.17		
35	0.5	1.67	1.65		
40	0.5	2.17	1.81		
45	0.51	2.68	2.22		
50	0.16	2.84	2.34		
55	0.31	3.15	2.46		
60	0.66	3.81	2.64	3.81	
65	0.36	4.17	2.5	4.15	
70	0.39	4.56	2.39	4.2	
75	0.36	4.92	2.24	4.46	
80	0.54	5.46	2.62	4.96	
85	0.76	6.22	3.07	5.53	
90	0.51	6.73	2.92	5.56	
95	0.44	7.17	3	5.5	
100	0.25	7.42	2.86	5.25	
105	0.25	7.67	2.75	4.99	
110	0.22	7.89	2.43	5.05	
115	0.15	8.04	1.82	4.89	
120	0.09	8.13	1.4	4.32	8.13
125	0.09	8.22	1.05	4.05	8.2
130	0.12	8.34	0.92	3.78	7.98
135	0.03	8.37	0.7	3.45	7.91
140	0.01	8.38	0.49	2.92	7.88
145	0.02	8.4	0.36	2.18	7.71
150	0.01	8.41	0.28	1.68	7.24
Max. Depth	0.76		3.07	5.56	8.2
Max. Intensity	9.12364946		6.14	5.56	4.1

Incremental Rainfall



Rainfall Hyetograph

Cumulative Rainfall



Rainfall Mass Curve

AVERAGE PRECIPITATION OVER AN AREA

- The depth of precipitation over a specified area, either on a storm, seasonal or annual basis is required in many types of hydrologic problems. There are three major methods:
 - Arithmetic Mean
 - Thiessen Polygon Method
 - Isohyetal Method

Arithmetic Mean Method

- Simplest method for determining areal average

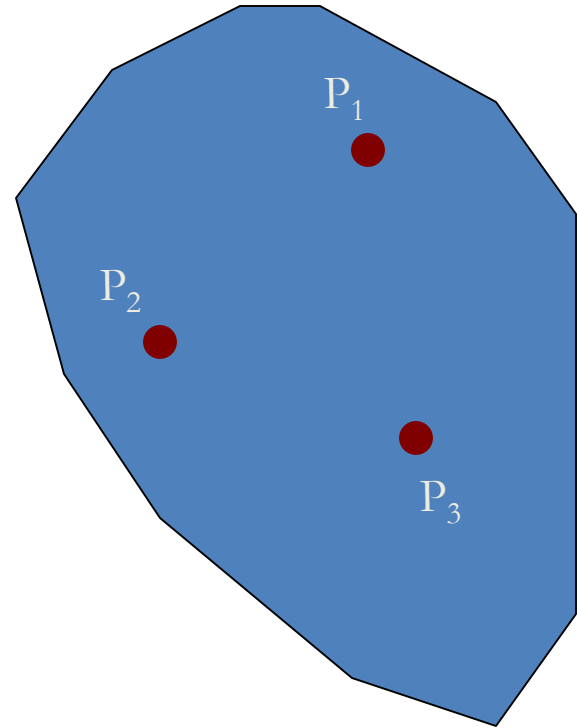
$$P_1 = 10 \text{ mm}$$

$$P_2 = 20 \text{ mm}$$

$$P_3 = 30 \text{ mm}$$

$$\bar{P} = \frac{1}{N} \sum_{i=1}^N P_i$$

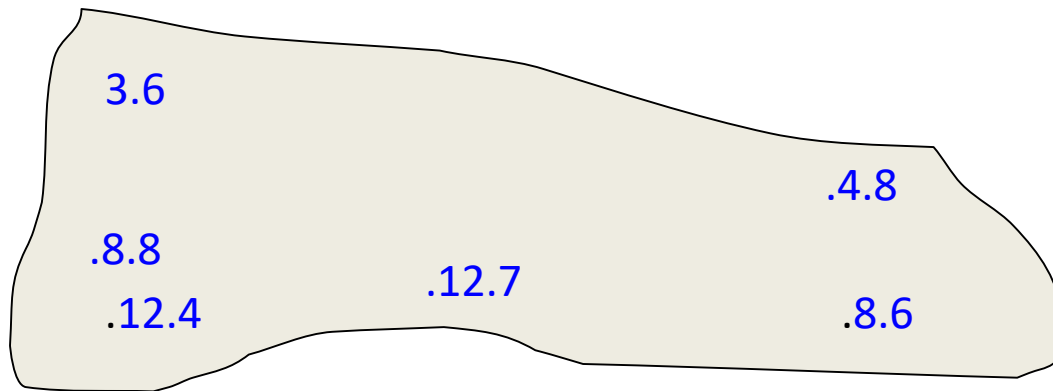
$$\bar{P} = \frac{10 + 20 + 30}{3} = 20 \text{ mm}$$



- Gages must be uniformly distributed
- Gage measurements should not vary greatly about the mean. The method yields good estimates in flat country, if the gauges are uniformly distributed and the individual gauge catches do not vary widely from the mean.

Arithmetic Mean

- This is the simplest method.



- The method yields good estimates in flat country, if the gauges are uniformly distributed and the individual gauge catches do not vary widely from the mean.

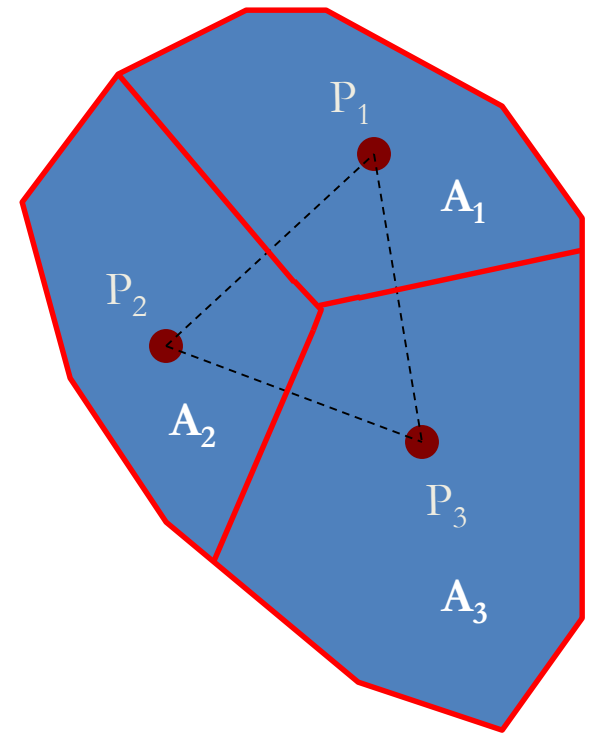
Thiessen Method:

- The method allows for non-uniform distribution of gauges by providing a weighting factor for each gauge.
- The stations are plotted on a map and connecting lines are drawn.
- Perpendicular bisectors of these lines form polygons around each station.
- The sides of each polygon are the boundaries of the effective area assumed for the station.

Thiessen polygon method

- Any point in the watershed receives the same amount of rainfall as that at the nearest gage
- Rainfall recorded at a gage can be applied to any point at a distance halfway to the next station in any direction
- Steps in Thiessen polygon method
 1. Draw lines joining adjacent gages
 2. Draw perpendicular bisectors to the lines created in step 1
 3. Extend the lines created in step 2 in both directions to form representative areas for gages
 4. Compute representative area for each gage
 5. Compute the areal average using the following formula

$$\bar{P} = \frac{1}{A} \sum_{i=1}^N A_i P_i \quad \bar{P} = \frac{12 \times 10 + 15 \times 20 + 20 \times 30}{47} = 20.7 \text{ mm}$$



$$P_1 = 10 \text{ mm}, A_1 = 12 \text{ Km}^2$$

$$P_2 = 20 \text{ mm}, A_2 = 15 \text{ Km}^2$$

$$P_3 = 30 \text{ mm}, A_3 = 20 \text{ km}^2$$

Isohyetal Method

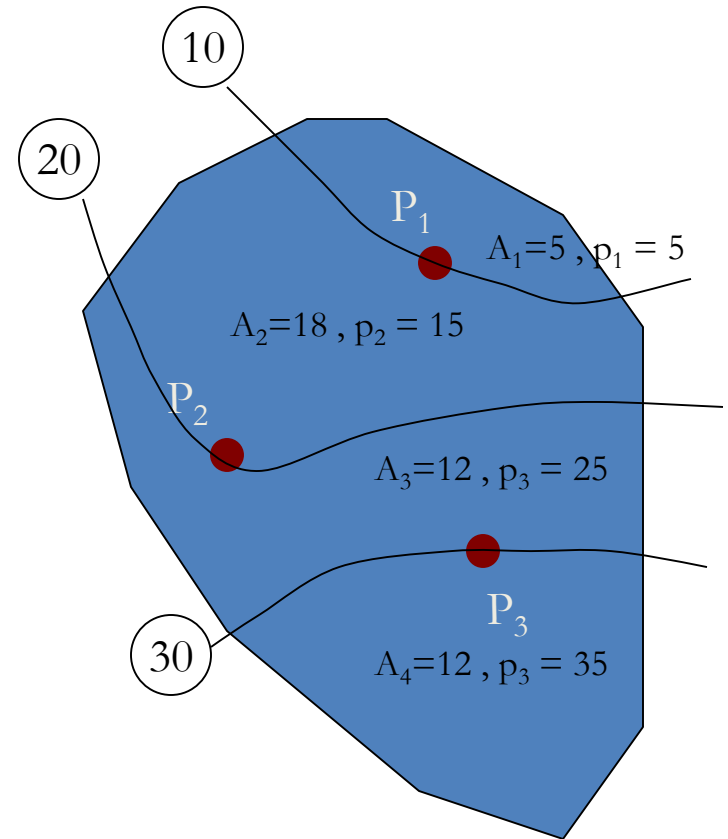
- The most accurate method of averaging precipitation over an area is the isohyetal method.
- Station locations and amounts are plotted on a suitable map and contours of equal precipitation (isohyets) are then drawn.
- Multiply the areas enclosed by the isohyetal lines by the average of their two rainfall values.
- Do the same to all the areas, and then sum the whole product and divide by the total area.

Isohyetal method

- Steps
 - Construct isohyets (rainfall contours)
 - Compute area between each pair of adjacent isohyets (A_i)
 - Compute average precipitation for each pair of adjacent isohyets (p_i)
 - Compute areal average using the following formula

$$\bar{P} = \frac{1}{A} \sum_{i=1}^N A_i P_i$$

$$\bar{P} = \frac{5 \times 5 + 18 \times 15 + 12 \times 25 + 12 \times 35}{47} = 21.6 \text{ mm}$$



Estimating missing precipitation data

- Many precipitation stations have short breaks in their records because of absence of the observer or because of instrument failure. It is often necessary to estimate this missing record. If the normal annual precipitation at each of the index stations is within 10 percent of that for the station with the missing record, a simple arithmetic average of the precipitation at the index stations provides the estimated amount.

- Otherwise, the amounts at the index stations are weighted by the ratios of the normal annual precipitation values. That is precipitation P_x at station X is,
- In which N is the normal annual precipitation.
- i.e., N_A = Normal annual precipitation at station A
- P_A = Precipitation at station A of duration concerned.

$$P_x = \frac{1}{3} \left[\frac{N_x}{N_A} \cdot P_A + \frac{N_x}{N_B} \cdot P_B + \frac{N_x}{N_C} \cdot P_C \right]$$

Activity

- Precipitation station X was inoperative for part of a month during which a storm occurred. The respective storm totals at three surrounding stations A, B and C were 107, 89 and 122 mm.
The normal annual precipitation amount at station X, A, B and C are, respectively 978, 1120, 935 and 1200 mm. Estimate the storm precipitation for station X.

Appropriate Number of Rain Gauges

- One simple method used is to arbitrarily use a few (2 or 3) gauges, spread them across the catchment and observe the rainfall readings in them. If they are approximately same then this number or even lesser may be sufficient. However if they vary a lot, then this number would not be sufficient.
- Therefore since lot depends on the variation of rainfall within the allocated gauges the following statistical technique is used to calculate the appropriate number of rain gauges.

$$\text{Appropriate number (NR)} = \frac{(\text{Coefficient of variation of observed rainfall})^2}{(\text{Allowable percentage error of mean rainfall})^2}$$

- (Cv) Coefficient of variation =
(Standard deviation/ mean) x 100
- (Sd) Standard deviation = $(\sum (x_i - X)^2 / n)^{1/2}$

X: Mean value of observed rain gauge values

-

Activity

- **Example**
- If three rain gauges were initially used to measure the rainfall and if the readings were 30, 40 and 50mm respectively. Calculate and show whether this number is sufficient to obtain the mean rainfall of this catchment and if it is insufficient, find out the appropriate number of gauges required. The allowable error of mean rainfall is 11%.

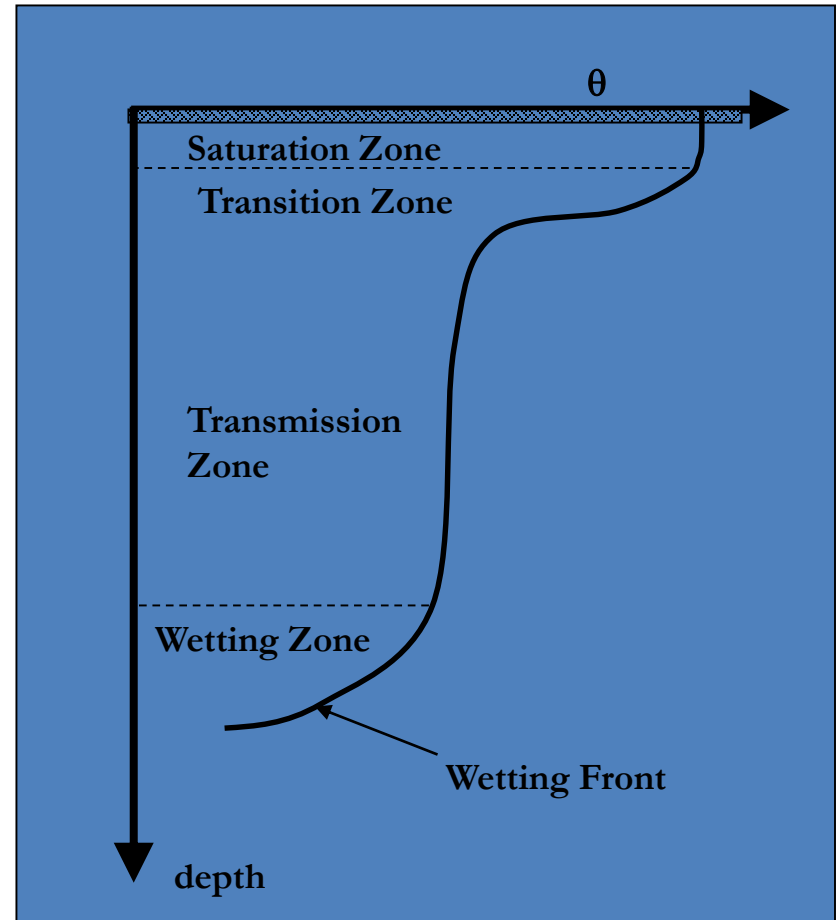
- $X = (30+40+50)/3 = 40 \text{ mm}$
- $S_d = \{[(30-40)^2 + (40-40)^2 + (50-40)^2] / 3\}^{1/2}$
- $= 8.16$
- $C_v = (8.16/40) \times 100$
- $= 20.4$
-
- $NR = [(20.4/11)]^2 = 3.44$
- Therefore the present number of gauges are insufficient and the appropriate number is 4 gauges.

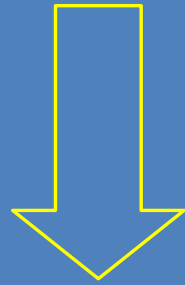
Infiltration

- Infiltration
 - Process of water entry into the soil through the soil surface
- Infiltration Capacity
 - Maximum rate water is absorbed by the soil
- Infiltration Rate
 - Infiltration occurring at less than capacity

Infiltration

- General
 - Process of water penetrating from ground into soil
 - Factors affecting
 - Condition of soil surface, vegetative cover, soil properties, hydraulic conductivity, antecedent soil moisture
 - Four zones
 - Saturated, transmission, wetting, and wetting front

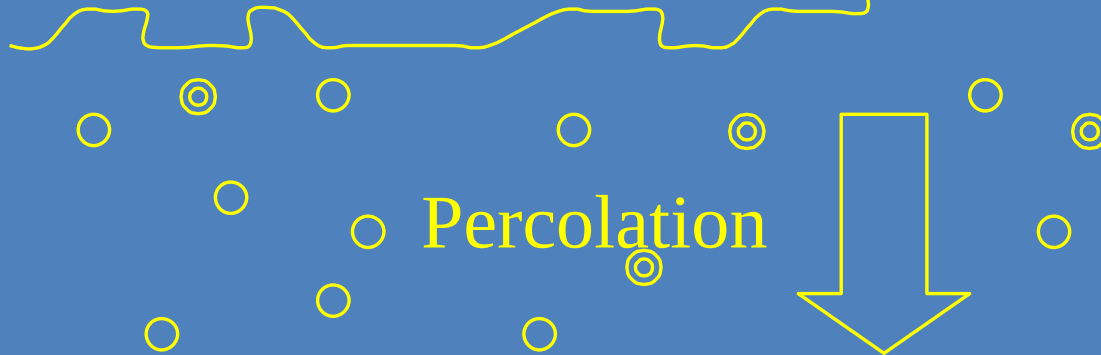




Rainfall

Infiltration

Soil
surface



Percolation

Factors Affecting Infiltration Capacity

- Rainfall
- Soil Compaction
- Depth of surface detention
- Slope
- Cracks
- Cultivation
- Vegetation
- Litter
- Trampling
- Soil Moisture
- Temperature
- Soil Porosity
- Crusting
- Soil Type
- Urban Areas

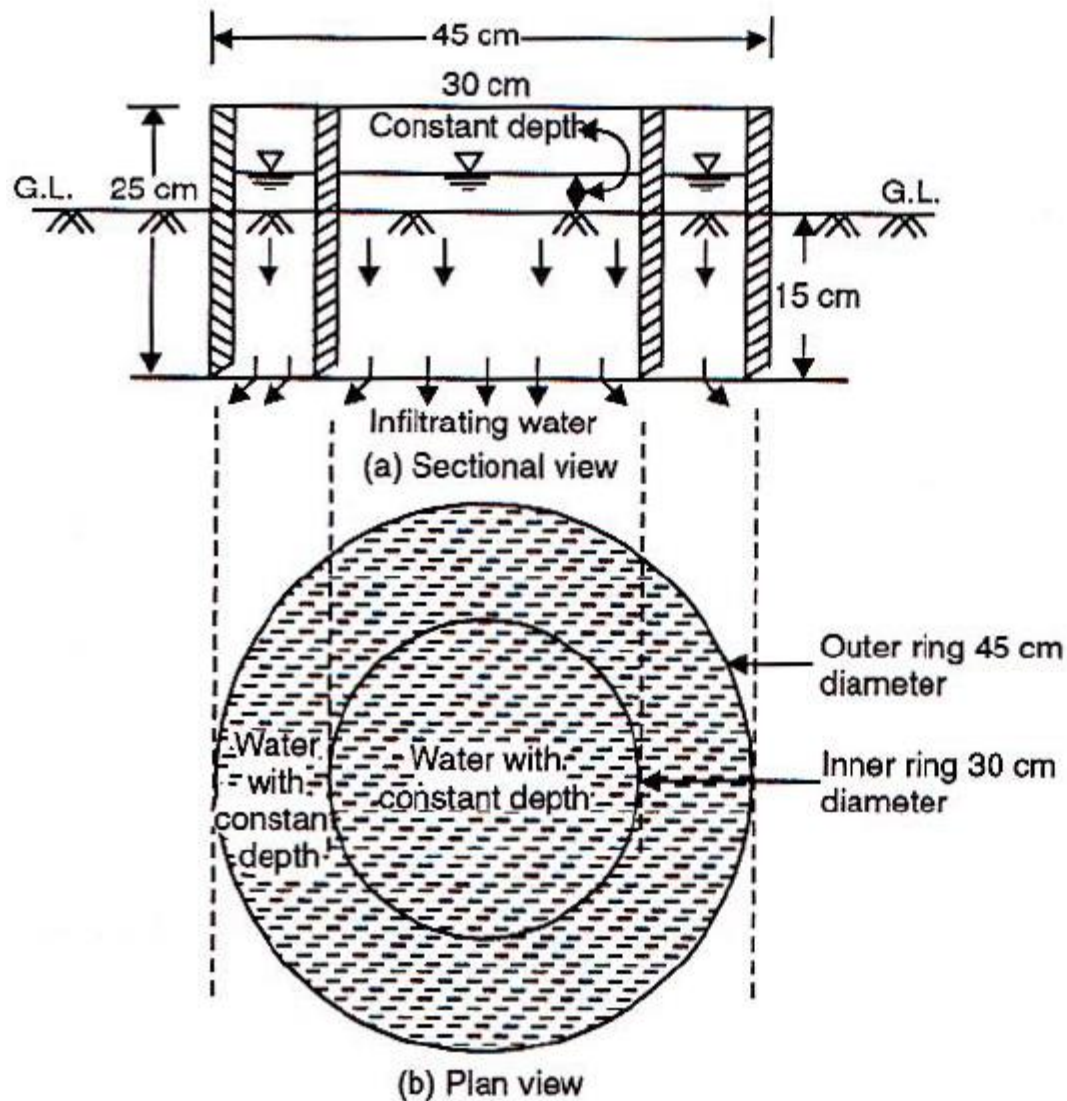
Double Ring



- Clean the surface vegetation without disturbing soil surface
- Rings driven into 15 cm
- Put a plastic / polythene sheet to inner ring and fill water on that for a particular depth
- Water poured into outer ring and allow it to infiltrate
- Remove the plastic sheet from the inner ring and start recording depth with time



- Double ring infiltrometer



Soil Surface

- Can impose upper limit to infiltration
- Infiltration capacity reduced by:
 - surface compaction
 - fines blocking pores
 - frost action
- Infiltration capacity increased by:
 - cracks and fissures
 - slope

Vegetation

- Complex effect on infiltration
- Reduces raindrop impact
- Improves soil structure
- Retards surface water movement
- Ground litter

Infiltration

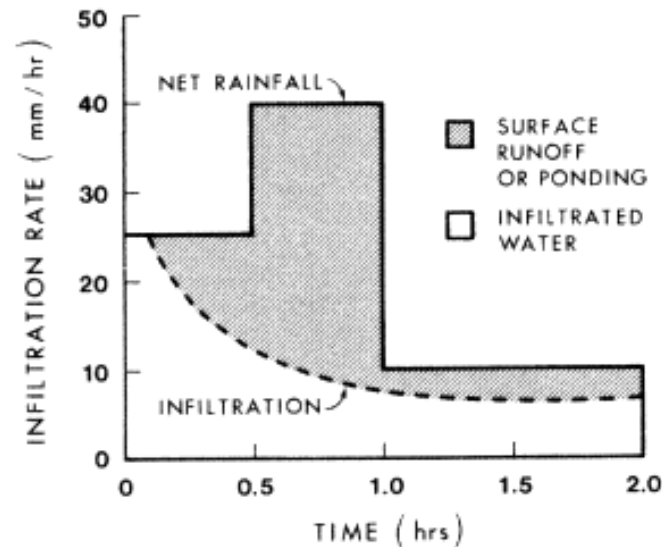
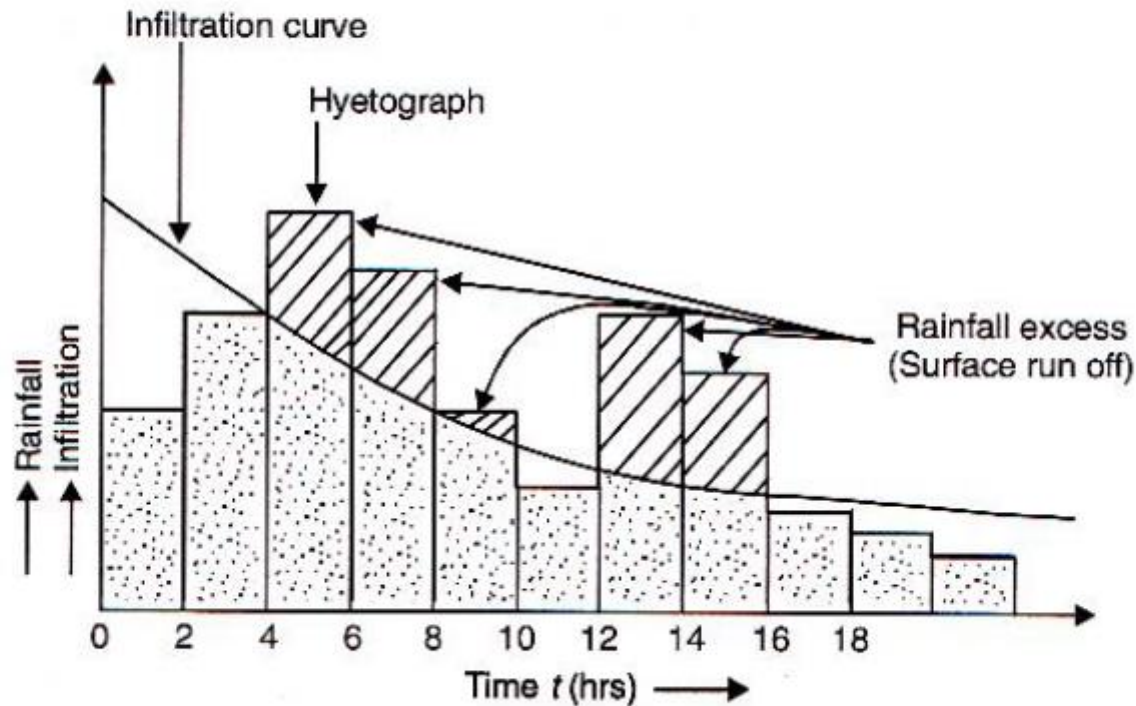


Figure 4.2.
Relationship between rainfall rate and infiltration rate
resulting in surface runoff or ponding.

- Infiltration is the actual rate at which water is entering the soil at any given time(SCSA, 1976).
- Infiltration capacity: Maximum rate (LT^{-1}).

Infiltration indices

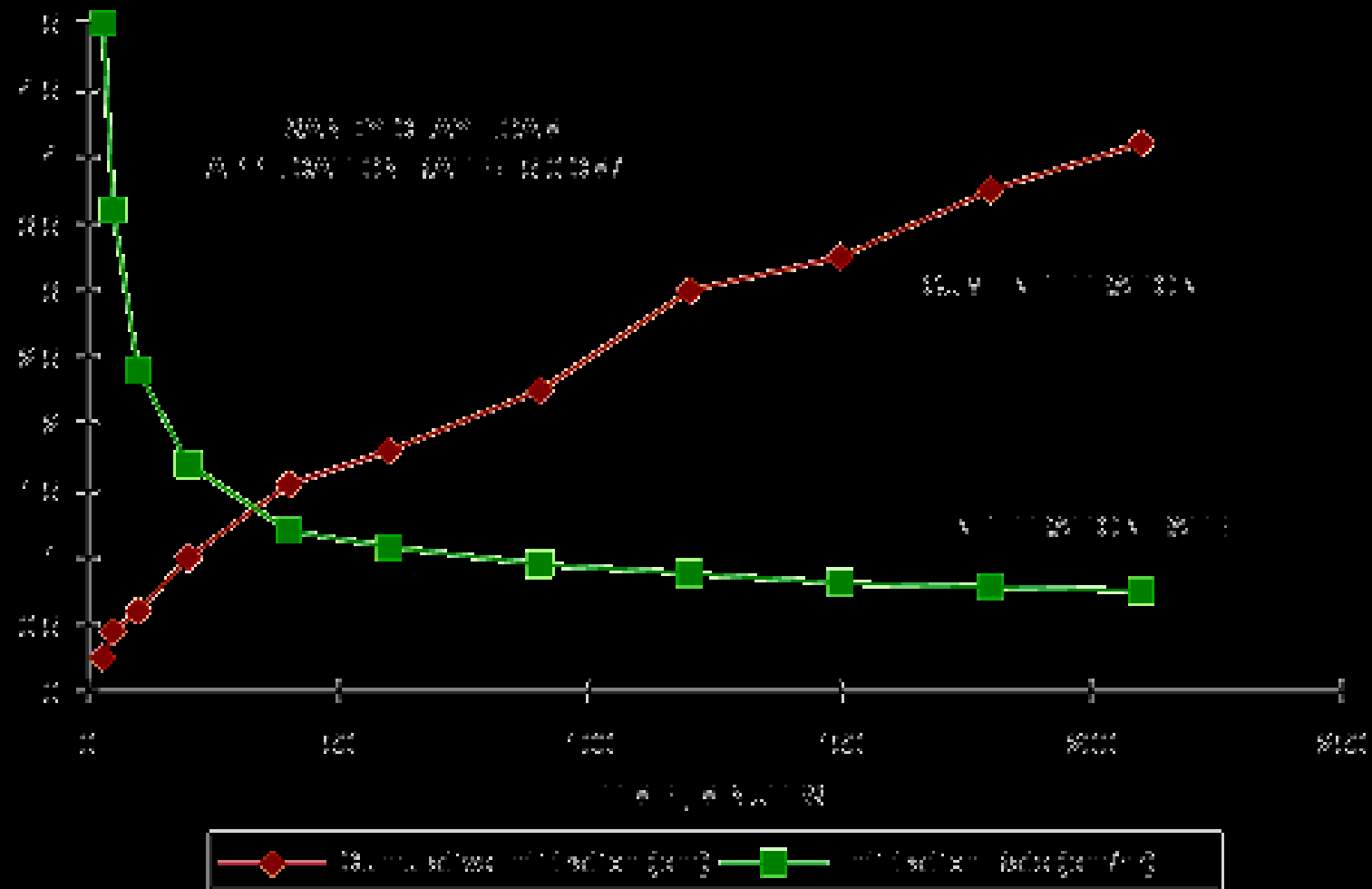
- Constant infiltration rate is know infiltration index



Relationship between infiltration, rainfall and runoff.

- Area above the infiltration curve is runoff
- In order to simplify the infiltration rate, infiltration indices with constant infiltration rate is used
- infiltration rate is assumed to be constant throughout the rain
- Φ -index – average rainfall intensity above which rainfall volume is equal to runoff volume ($\Phi = \text{Phi}$)

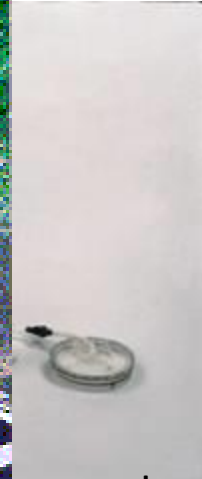
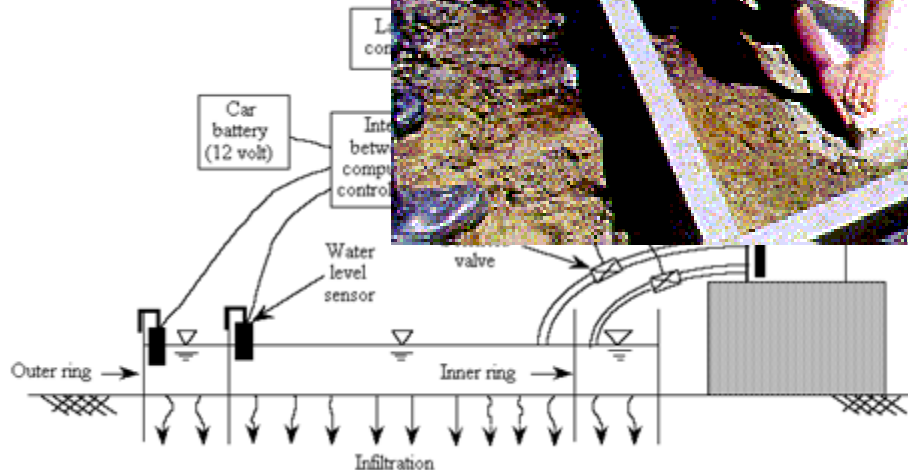
24 6 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24



Measuring infiltration

Double ring infiltrometer

Tension infiltrometer



neameter



Xiaodong, 2002

Infiltration Characteristics

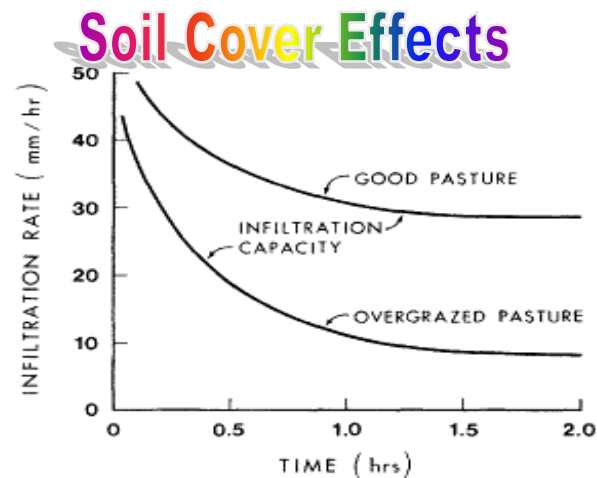
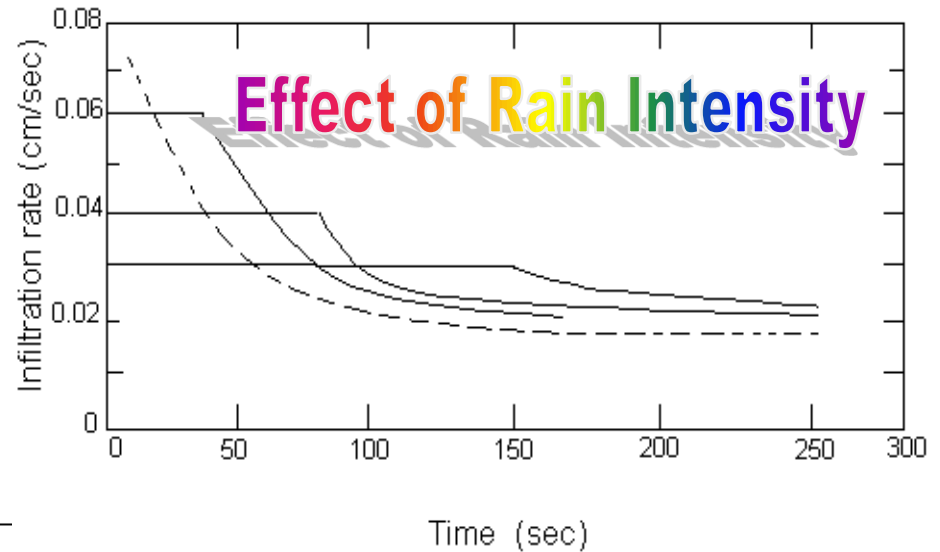
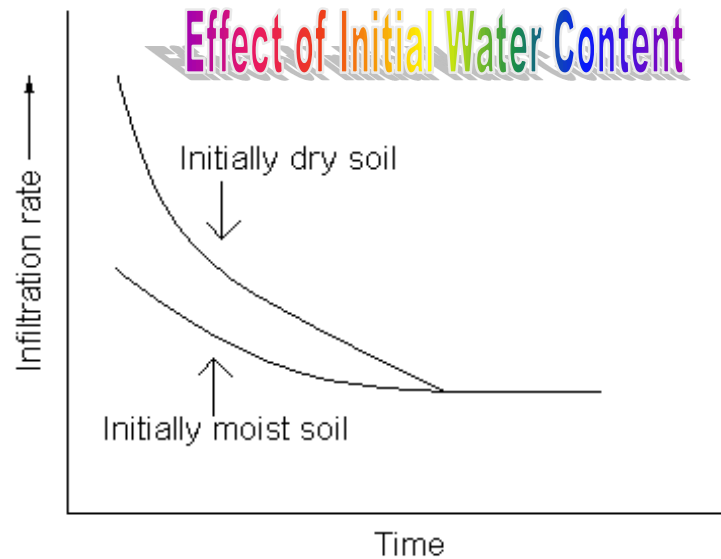
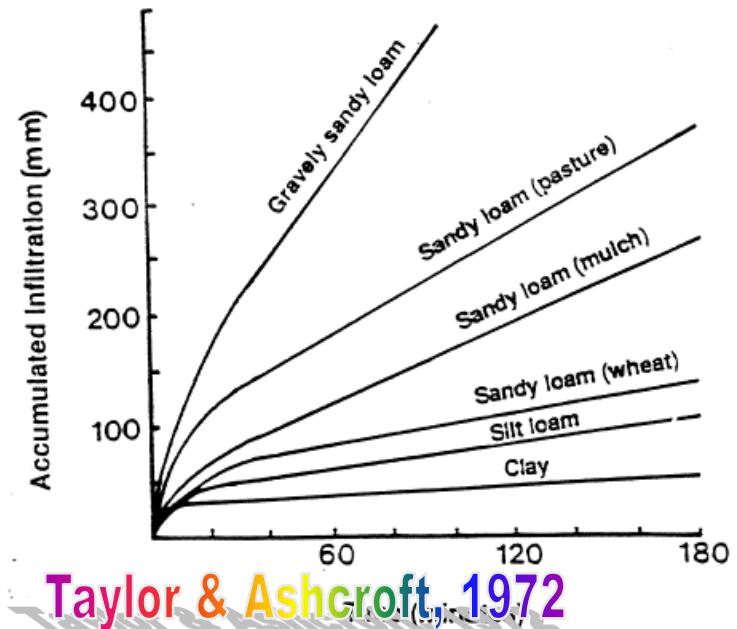
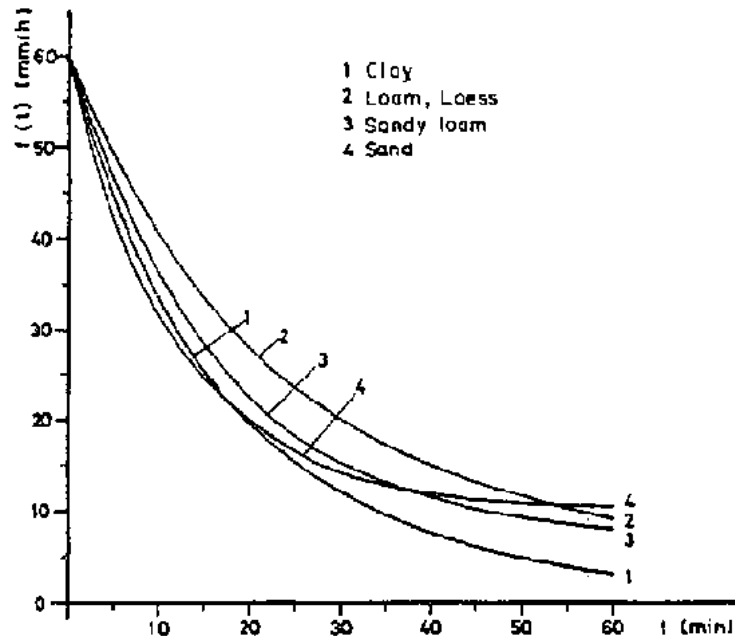


Figure 4.1.
Infiltration capacity curves for soils subjected to different levels of grazing.

Soil Type Effects on Infiltration

- Sand soils have the highest infiltration rates
- Clay soils have the lowest infiltration rates.
- High organic matter improves infiltration rates.

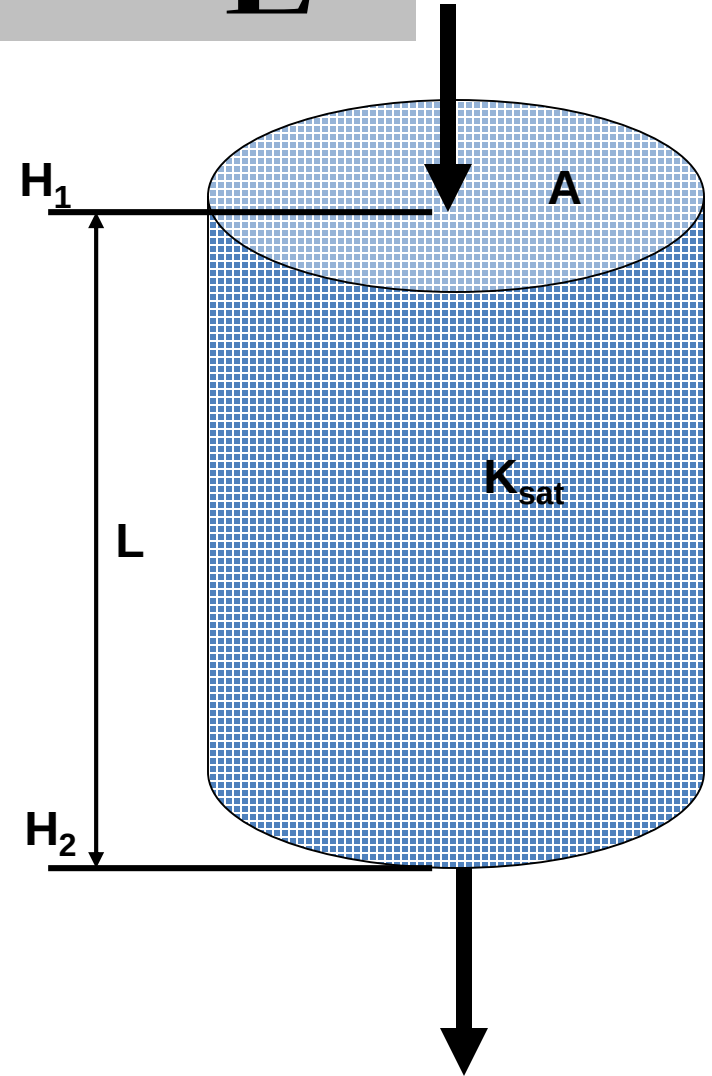


Taylor & Ashcroft, 1972

Water Flow in Soil

$$q = \frac{Q}{A} = K \frac{\Delta H}{L}$$

- The flux density, q , is the rate of water movement through a medium.
- q is a function of ΔH and the hydraulic conductivity of the medium.
- $\Delta H = H_1 - H_2$ is the difference between total water potential inlet and outlet.
- H = Pressure head + Gravitational head



Infiltration equations

- Kostiakov's equation

$$I = k t^n$$

I = Cumulative depth of infiltration

t = time

k and n are constants

$$i = \frac{dI}{dt} = n k t^{n-1}$$

i = infiltration rate

Horton's Equation

- Assumes K & constants (no dependence on f)
- Solve the equation for the rate of moisture diffusion at soil surface $f(t) = f_c + (f_0 - f_c) e^{-kt}$
- k = Decay constant $\sim T^{-1}$

Assume that the time evolution of the infiltration capacity for a given soil is governed by Horton's equation (Note that this equation assumes an infinite water supply at the surface, that is, it assumes saturation conditions at the soil surface).

$$f_p(t) = f_c + (f_o - f_c)e^{-kt} \quad (1)$$

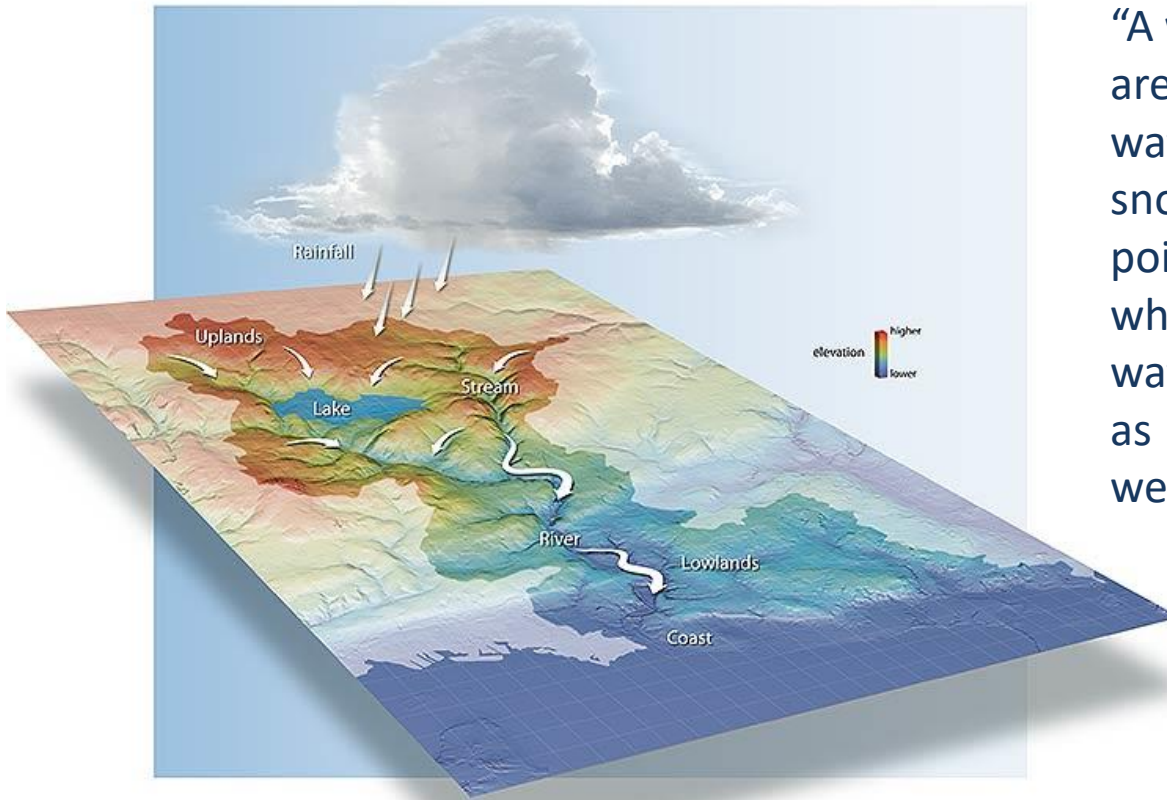
For this soil, the asymptotic or final equilibrium infiltration capacity is $f_c = 1.25 \text{ cm/h}$; and the initial infiltration capacity is $f_o = 8 \text{ cm/h}$. The rate of decay of infiltration capacity parameter is $k = 3 \text{ h}^{-1}$. For the precipitation hyetograph tabulated below, carry out a complete infiltration analysis, including evaluation of cumulative infiltration and rate of production of precipitation excess, $\sigma + v$.

Time (<i>min</i>)	Precipitation (<i>cm/h</i>)		Time (<i>min</i>)	Precipitation (<i>cm/h</i>)
0 - 10	1.5		40 - 50	4.0
10 - 20	3.0		50 - 60	3.0
20 - 30	8.0		60 - 70	0.8
30 - 40	5.0			

1. Compute accumulated precipitation volume as a function of time. The incremental volume over each time period of 10 minutes is:

$$\Delta P = i \Delta t$$

HYDROLOGY | watershed | definition



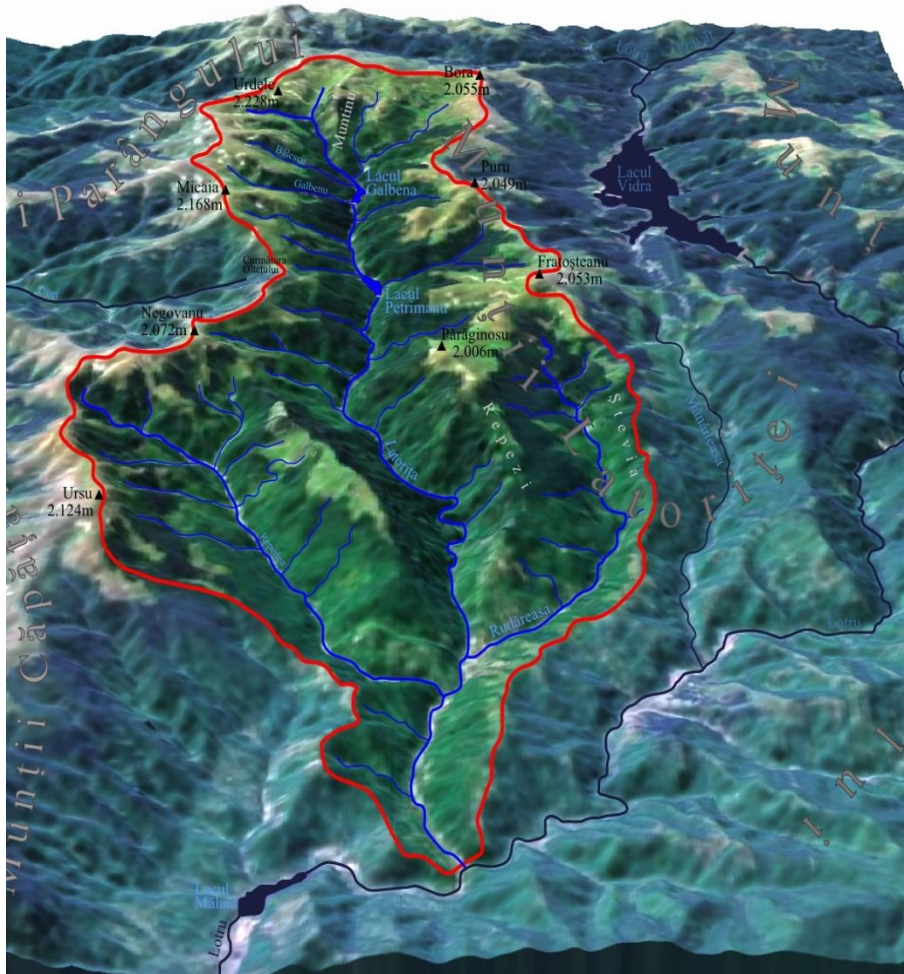
“A **watershed** is an extent or an area of land here surface water from rain and melting snow or ice converges to a single point, usually the exit of the basin, where the waters join another water body, such as river, lake, reservoir, wetland, sea, or ocean”

Also known as:

- Catchment
- Catchment area
- Catchment basin
- Drainage area
- River basin
- Water basin



HYDROLOGY | watershed | characteristic factors



Topography

Topography determines the **speed** with which the runoff will reach a river. Clearly rain that falls in **steep** mountainous areas will **reach the river faster** than flat or gently sloping areas.

Shape

Shape will contribute to the **speed** with which the runoff reaches a river. A **long thin catchment** will take **longer** to drain than a circular catchment.

Size

Size will help determine the **amount** of water reaching the river, as the **larger the catchment the greater** the potential for **flooding**.

Soil type

Soil type will help determine **how much** water reaches the river.

Sandy soils are very **free draining** and **rainfall** on sandy soil is likely to be **absorbed** by the ground.

Clayey soils can be almost **impermeable** and therefore rainfall on clay soils will **runoff** and contribute to flood volumes.

Land use

Land use can contribute to the **volume** of water reaching the river, in a similar way to clay soils. For example, rainfall on roofs, pavements and roads will be collected by rivers with almost no absorption into the groundwater.



Assignment.

5-10 pagers

Define and explain , with diagrams where appropriate, all of the following

Solar radiation, Albedo, radiation, vapour pressure, saturation vapour pressure, dew point, Humidity, relative humidity

Format of the front page

**Department of Environmental Technology (20)- Calibri
University of Colombo (22)**

**Topic of the Assignment (22)
Hydrology- (Course code) (22)**

Index no (24)

Colombo (20)