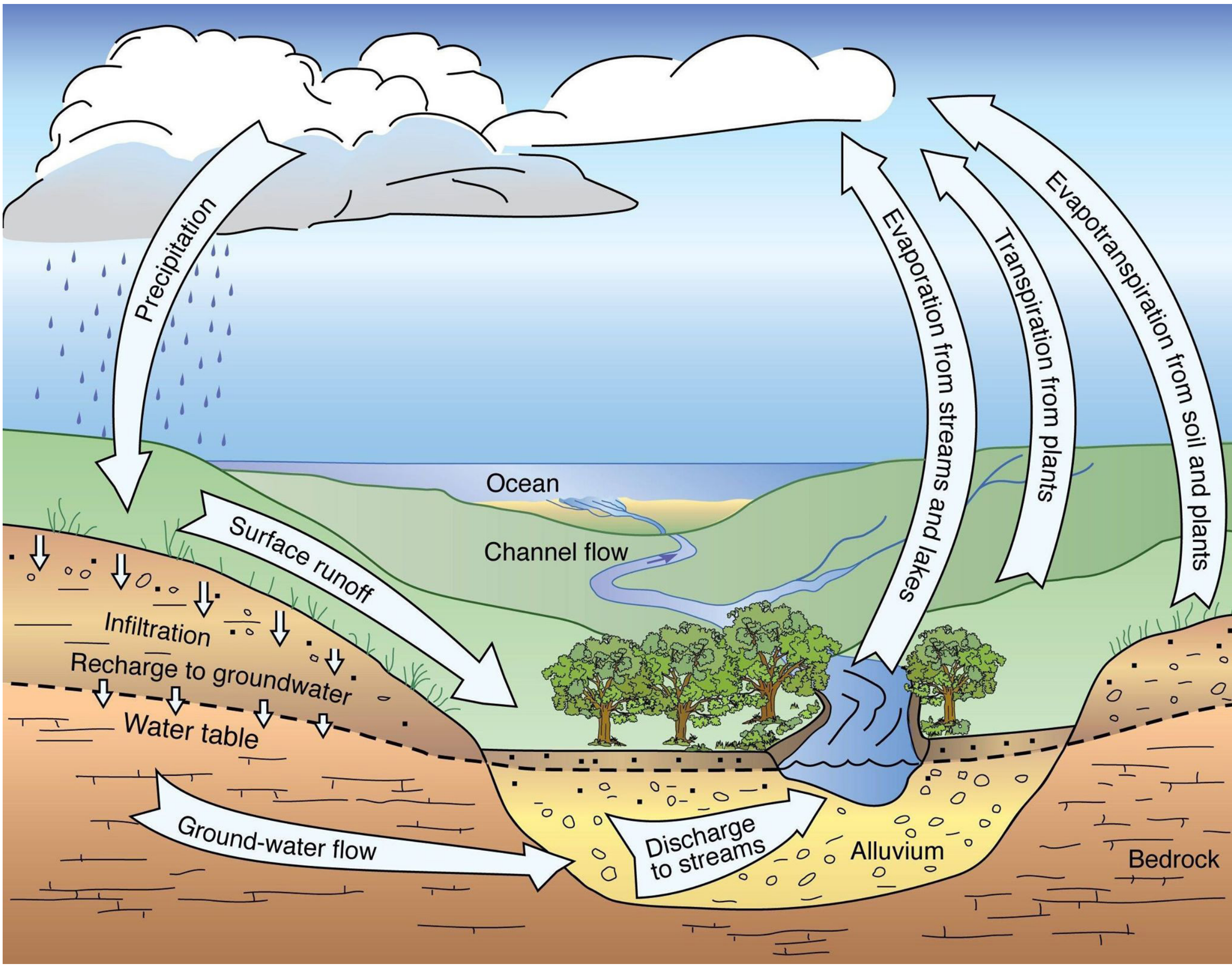
# Hydrology



Precipitation
Surface runoff
Infiltration
Recharge to groundwater
Water table
Ground-water flow
Ocean
Channel flow
Discharge to streams
Alluvium
Bedrock
Evaporation from streams and lakes
Transpiration from plants
Evapotranspiration from soil and plants

Judit Pál-Schreiner

# Hydrology

Pécs

2019

The Hydrology course material was developed under the project EFOP 3.4.3-16-2016-00005 "Innovative university in a modern city: open-minded, value-driven and inclusive approach in a 21st century higher education model".

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Pécs

2019

A Hydrology tananyag az EFOP-3.4.3-16-2016-00005 azonosító számú, „Korszerű egyetem a modern városban: Értékközpontúság, nyitottság és befogadó szemlélet egy 21. századi felsőoktatási modellben” című projekt keretében valósul meg.

# 1. The Water Cycle

## Content

Major Components of the Water Cycle
The Global Atmospheric Water Cycle
Where is Earth’s water?
Questions for Discussion

# The Water Cycle

- The water cycle also called Hydrologic Cycle.
- It is a continuous circulation of water from water reservoir (seas, lakes, rivers etc.) to the atmosphere to the land and back again to the sea.

Major components are:

- Evaporation
- Precipitation
- Runoff
- Infiltration

# Major Components of the Water Cycle

Evaporation (Transpiration) is the process by which water changes from a liquid to a gas or vapor.

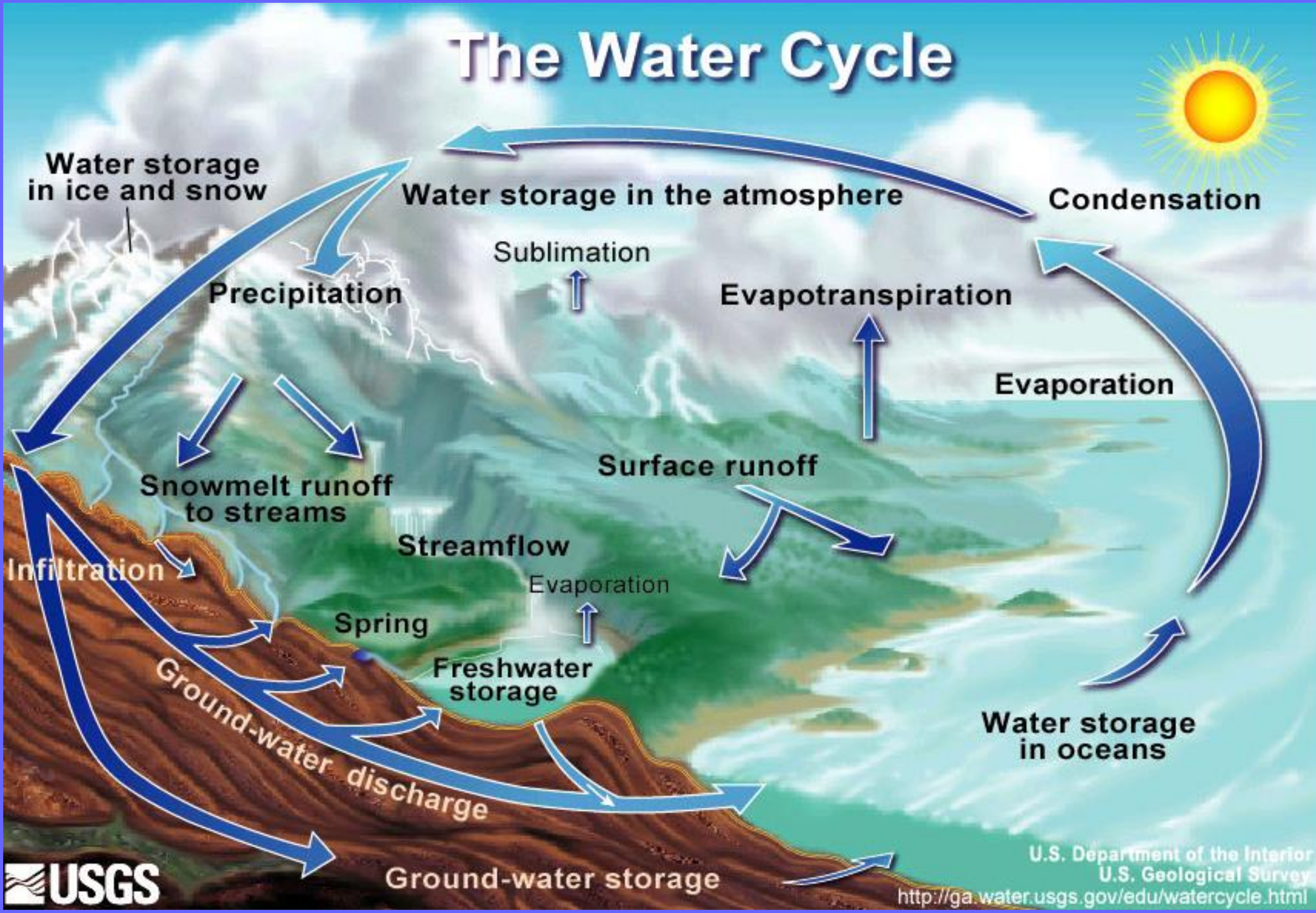
Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail.

Runoff is surface water that flows downhill due to gravity.

Infiltration is the process by which water on the ground surface enters the soil.

# The Hydrologic Cycle (film)

http://svs.gsfc.nasa.gov/vis/a010000/a010500/a010501/water_cycle_ipod_640x480.m4v

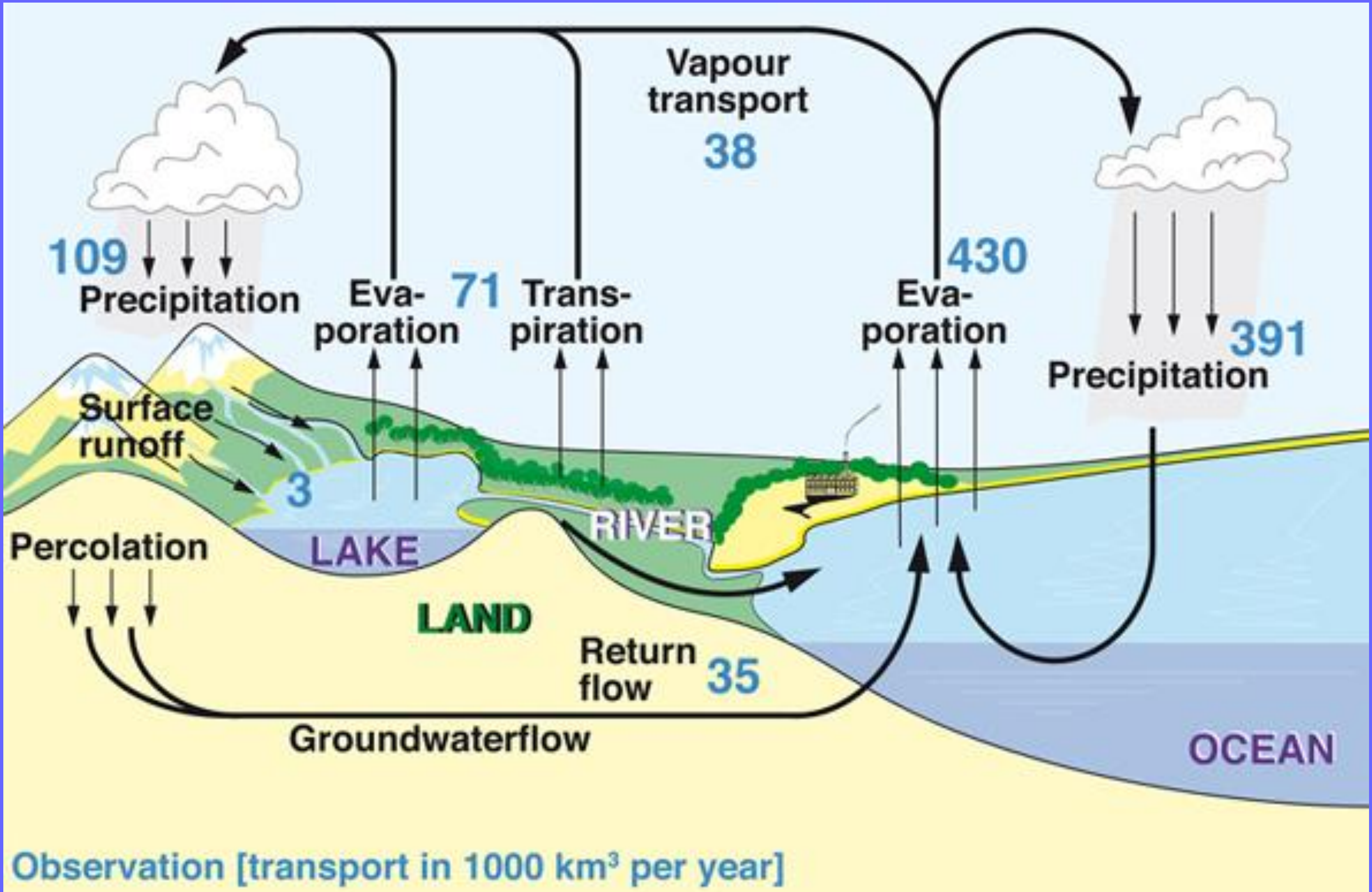



https://www.google.hu/search?q=the+hydrologic+cycle&espv=2&biw=1517&bih=692&source=lnms&tbm=isch&sa=X&ved=0ahUKEwimzIDaoIfPAhWHiCwKHTSBCI0Q_AUIBigB&dpr=0.9#tbm=isch&q=the+hydrologic+cycle+steps&imgrc=13jhHN7D-b4QGM%3A

The hydrologic cycle is driven by:

- (1) solar energy from Sun,
- (2) global wind streams (caused by Earth’s rotation) and
- (3) gravitational forces.

# The Global Atmospheric Water Cycle

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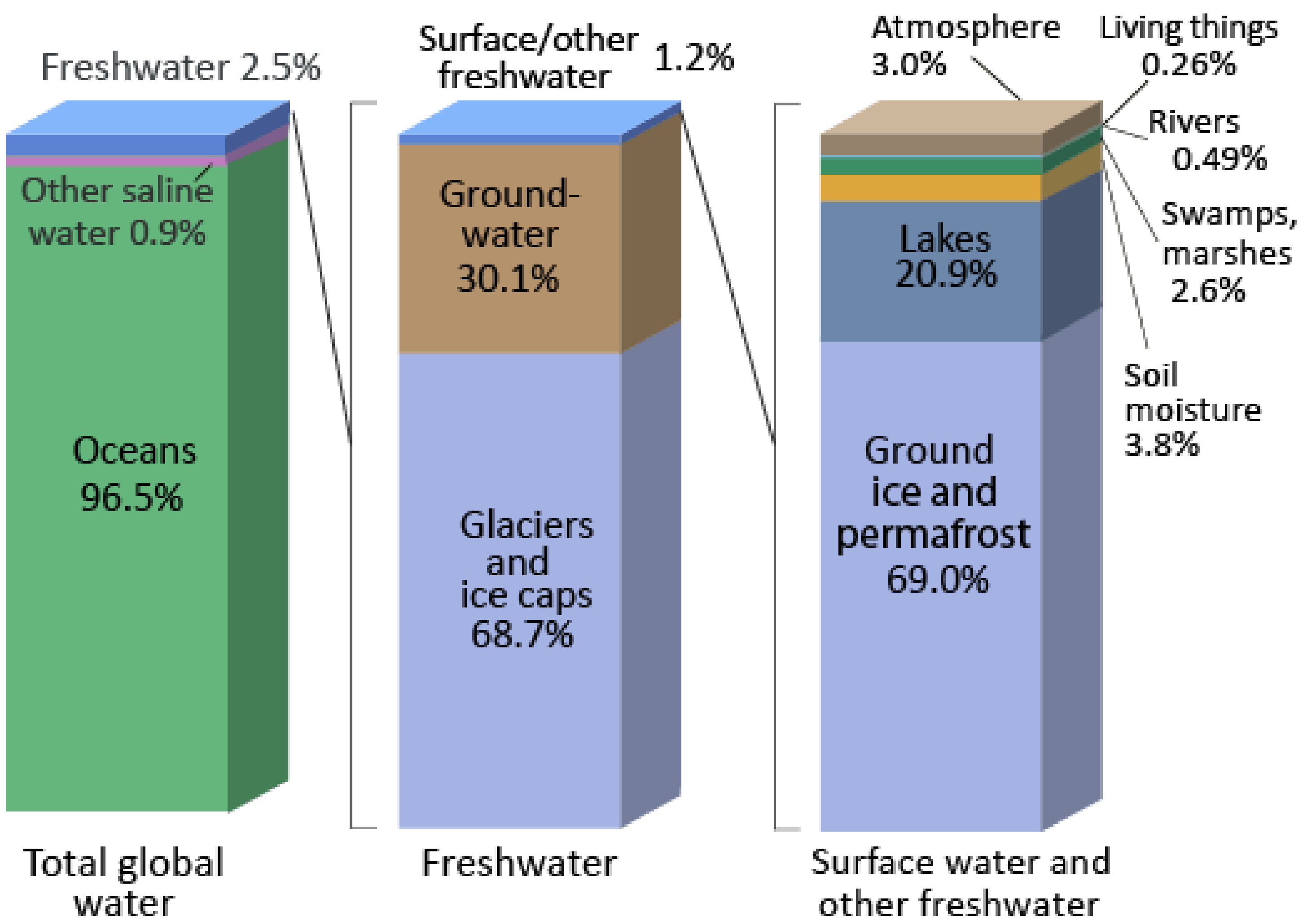
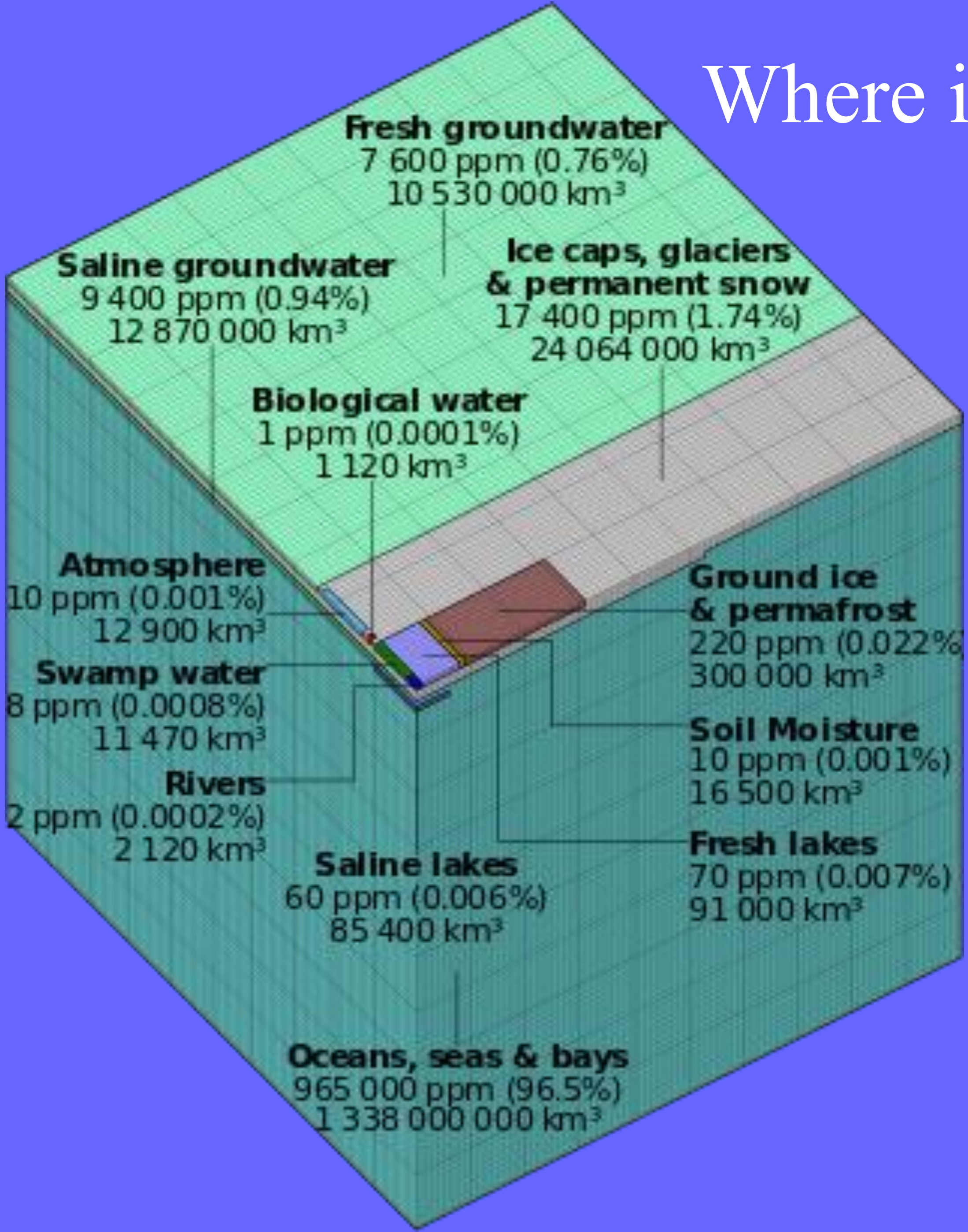
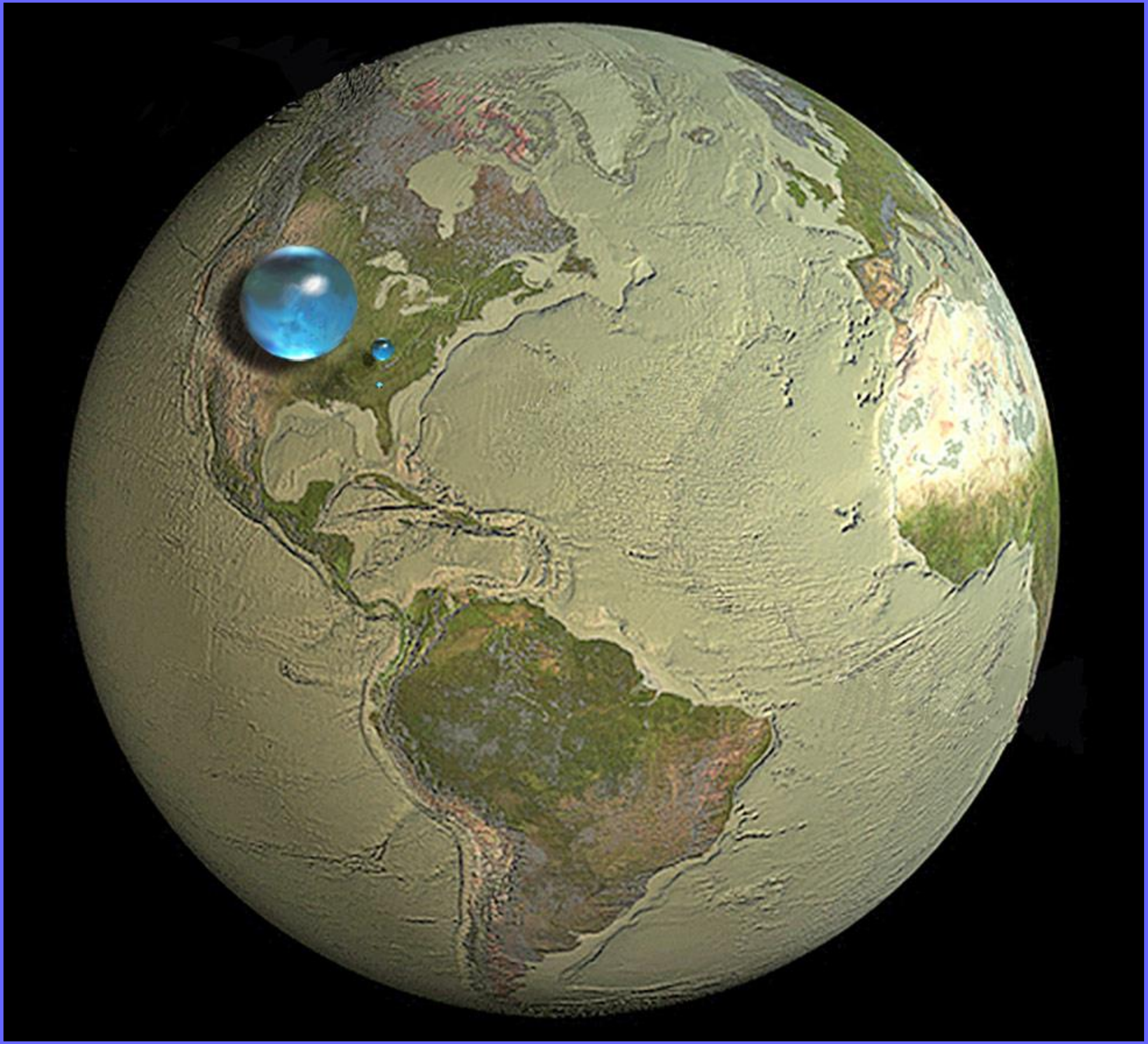
# Where is Earth's water? (1)




Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.
NOTE: Numbers are rounded, so percent summations may not add to 100.

# Where is Earth's water? (2)





- Earth water
- Total fresh water
- Fresh water in all the lakes and rivers

# Questions for Discussion

- The major components of the water cycle
- What are the differences between climate and weather?
- What are the main driving factors of the hydrologic cycle?

# 2 The Evaporation

## Content

Vaporization, Boiling, Evaporation

Evapotranspiration (ET)

Potential evapotranspiration (PET)

Humidity

Saturation Curve – Dewpoint – RH – Condensation

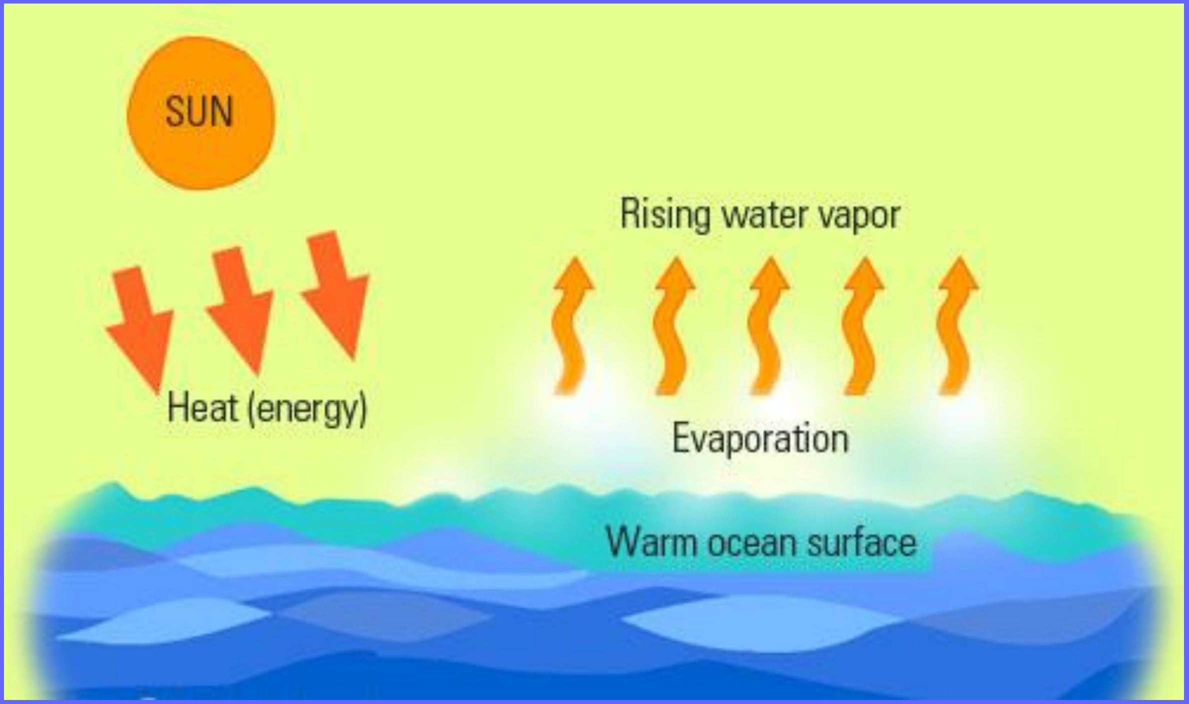
Questions for discussion

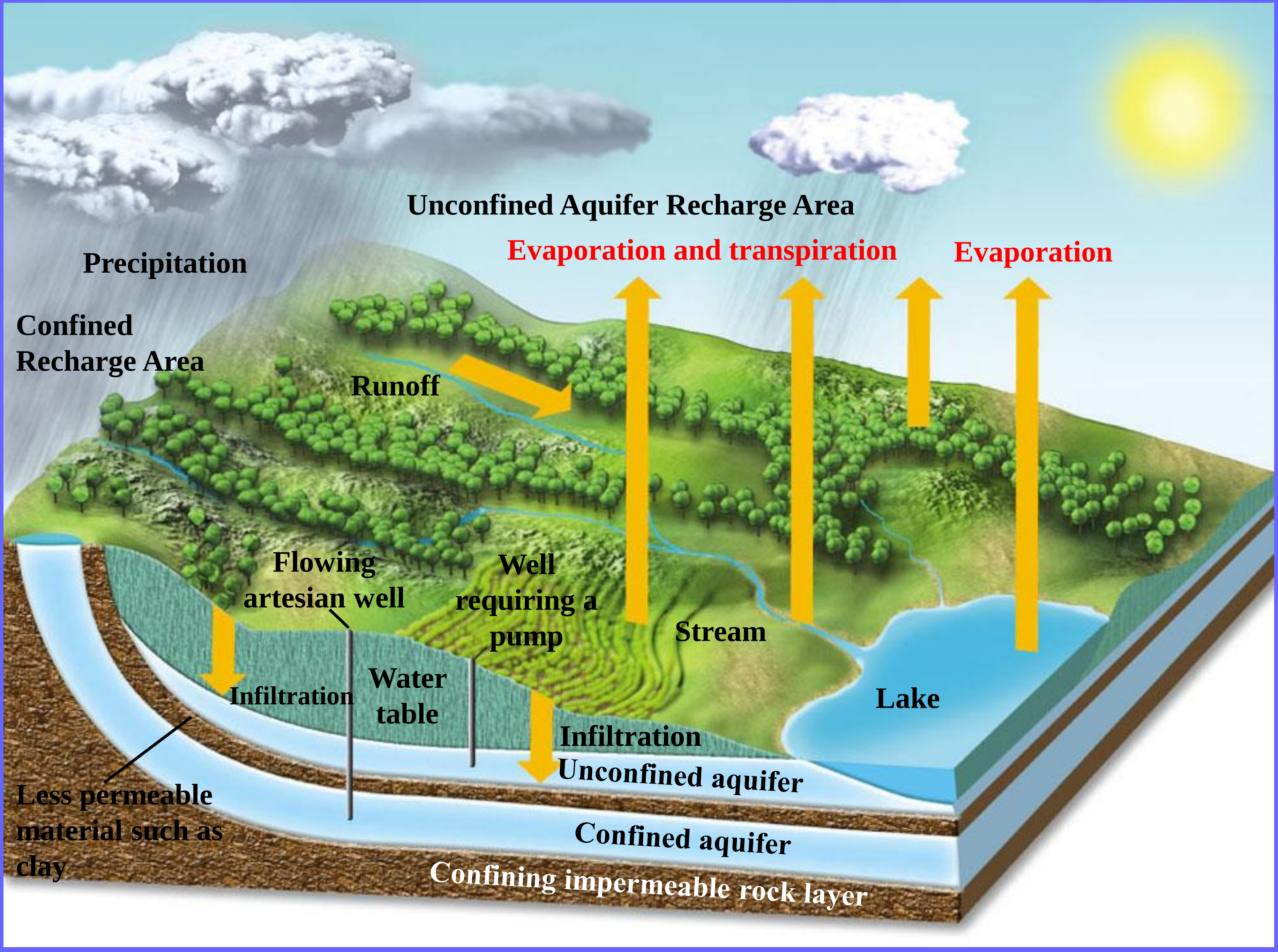
# Define of Vaporization

Vaporization is the process by which a liquid is turned into a gas. The two types of vaporization are evaporation and boiling. Evaporation refers to the surface of a body of liquid turning into gas, such as a drop of water on the concrete turning into a gas on a hot day. Boiling refers to heating up a liquid until it releases vapor, such as heating water on a stove until steam forms

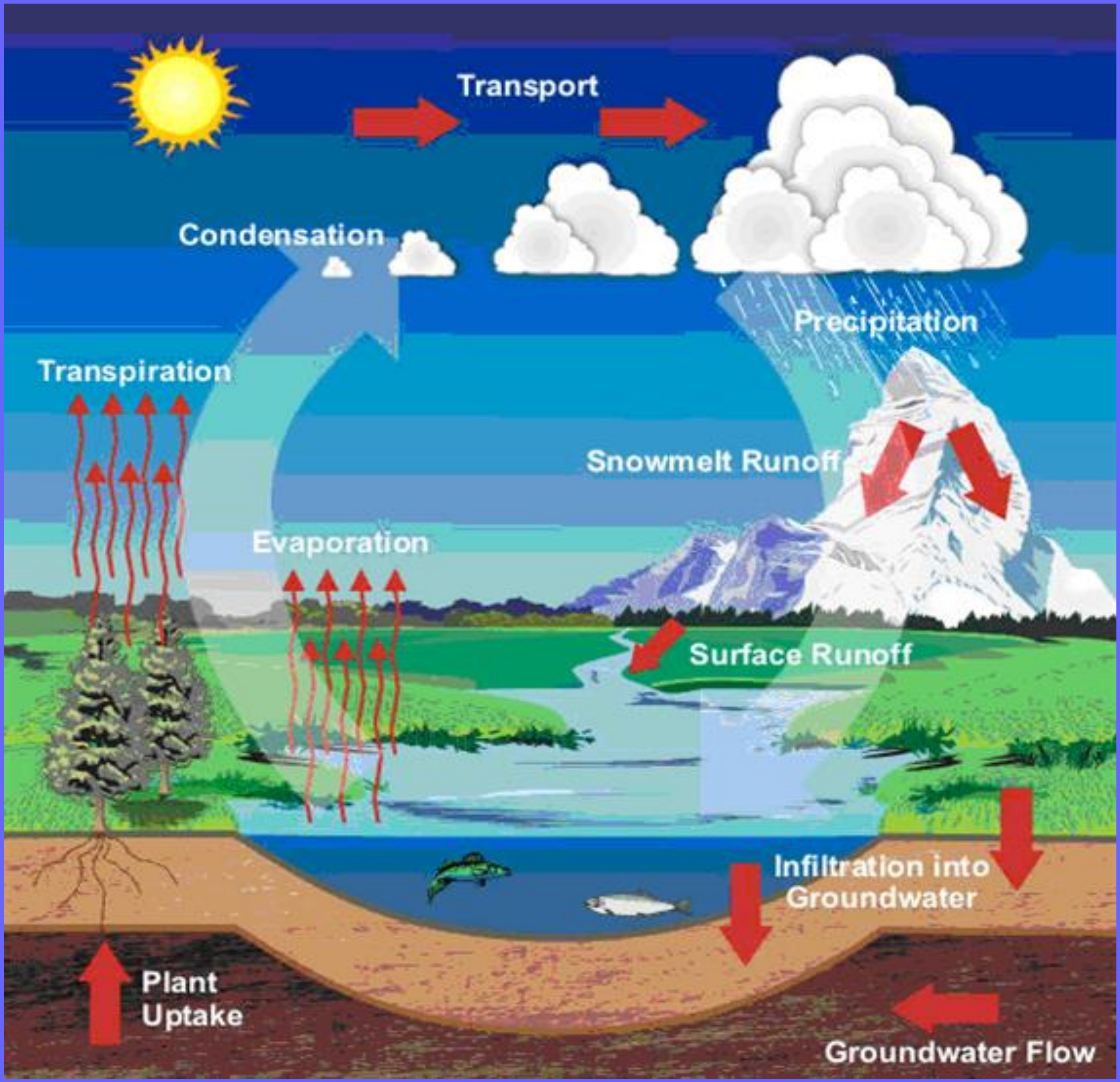
Boiling is the rapid vaporization of a liquid, which occurs when a liquid is heated to its boiling point. A substance begins to boil, and molecules within the material assume a gaseous state. Every liquid has a different boiling point temperature.

Evaporation occurs on the surface level of a liquid, in which a heat source activates molecules with kinetic energy. The heat source causes the molecules to break bonds with one another and turn into a gas. For example, the sun may cause a lake to evaporate by heating the molecules on the lake's surface. When these molecules are heated, they rise into the air as steam.





Unconfined Aquifer Recharge Area
Evaporation and transpiration
Evaporation
Precipitation
Confined
Recharge Area
Runoff
Flowing
artesian well
Well
requiring a
pump
Stream
Water
table
Infiltration
Infiltration
Lake
Unconfined aquifer
Less permeable
material such as
clay
Confined aquifer
Confining impermeable rock layer


Transport
Condensation
Precipitation
Transpiration
Snowmelt Runoff
Evaporation
Surface Runoff
Infiltration into
Groundwater
Plant
Uptake
Groundwater Flow

# Evapotranspiration (ET)

- Evaporation – loss of liquid water from land and water surfaces as it is converted to a gas (water vapor)
- Transpiration – liquid water moving from soil through a plant and evaporating from the leaves
- Evapotranspiration (ET) – combination of evaporation and transpiration

# Potential Evapotranspiration (PET)

The rate of evaporation depends on:

- the temperature and
- the humidity of the air.

PET is the water loss that would occur if there is an unlimited supply of water available for transpiration and evaporation.

If the amount of water available is less than the potential, then the actual evapotranspiration will be lower than the potential.

# Humidity

Humidity refers to the amount of moisture in the air, more specifically:

Absolute humidity

Saturation humidity

Saturation deficit

Dewpoint

Relativ humidity

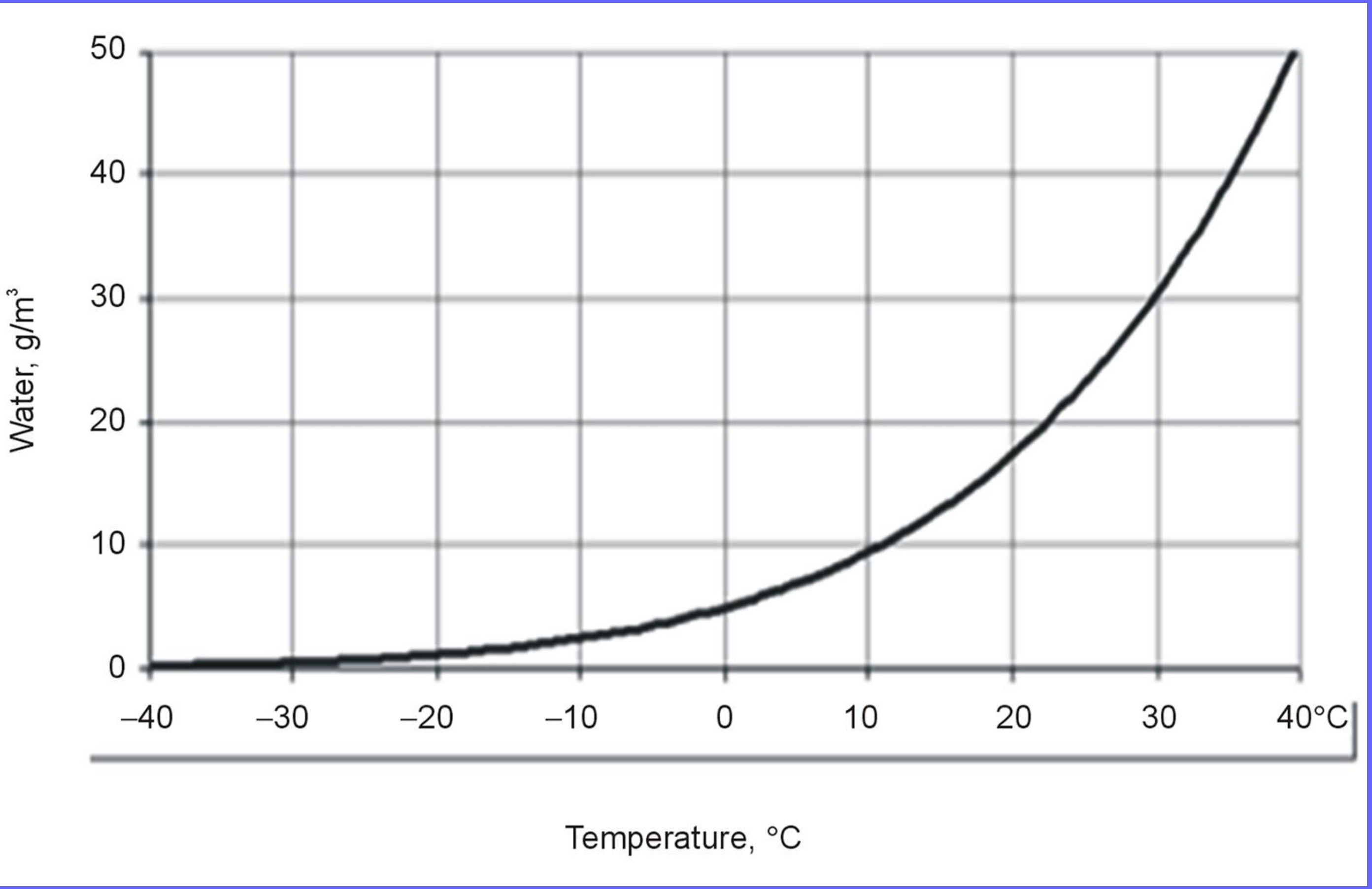
Absolute humidity ($e_d$) is the mass of water vapor per unit volume of air at a given temperature. It is the water vapor density. The unit is usually grams of water per cubic meter of air.

$$e_d = \frac{mass\ of\ water\ vapour\ (g)}{volume\ of\ air\ (m^3)} = \frac{m_w}{V}\left(\frac{g}{m^3}\right)$$

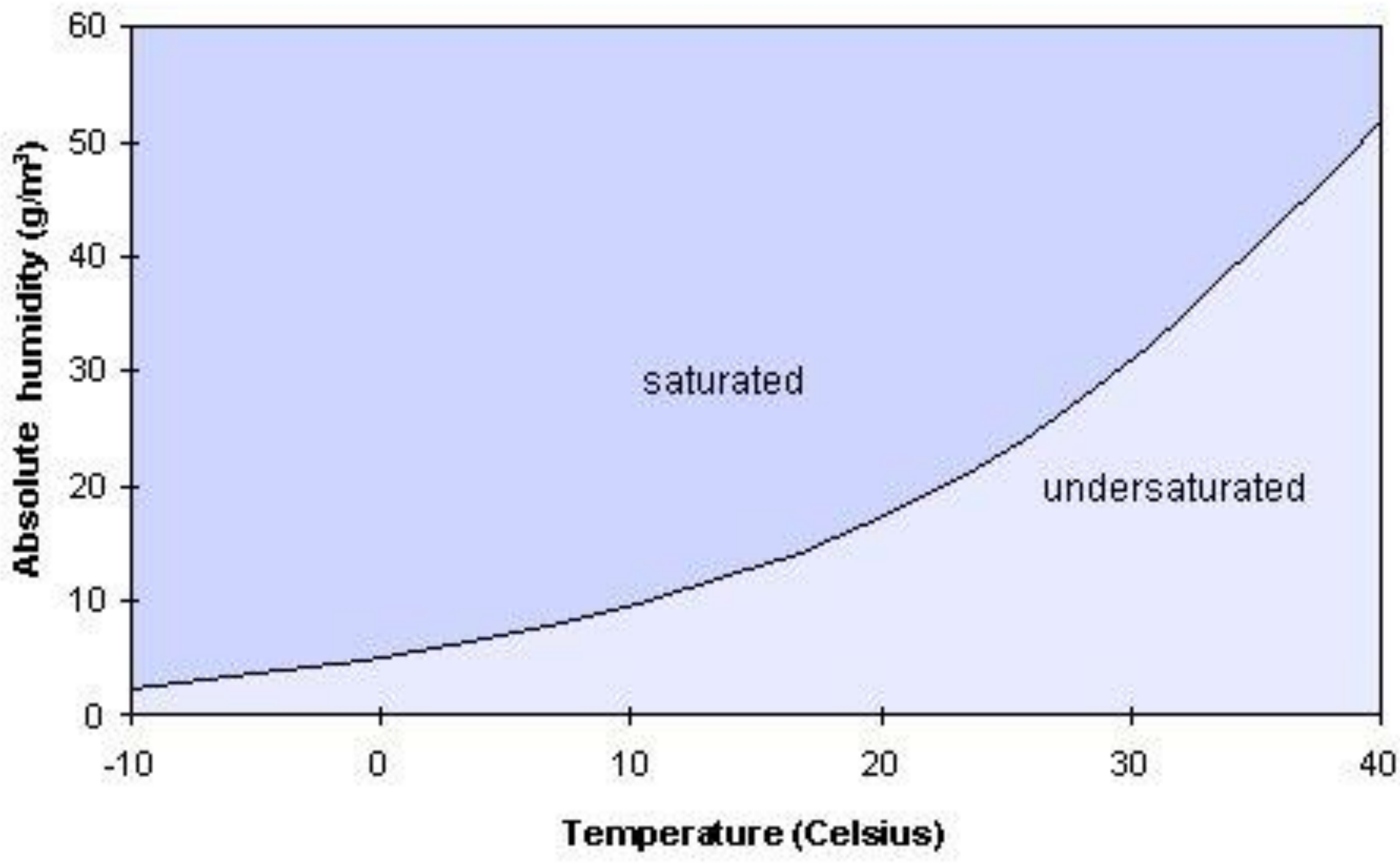
Saturation humidity ($e_a$) is the maximum amount of moisture that can remain in a vaporous state in the air at a given temperature. On the next slide, the saturation curve shows the connection between the saturation humidity and the temperature. The unit is usually grams of water per cubic meter of air.

# Saturation Curve (1)

The water vapor capacity of the air is the maximum amount of moisture that can remain in a vaporous state in the air at a given temperature.



# Saturation Curve (2)



Saturation deficit (SD) is a further amount of water vapor that the air can hold at a given temperature before becoming saturated. Saturation humidity subtracts absolute humidity at a given temperature is equal to saturation deficit usually, in-unit grams water per cubic meter of air.

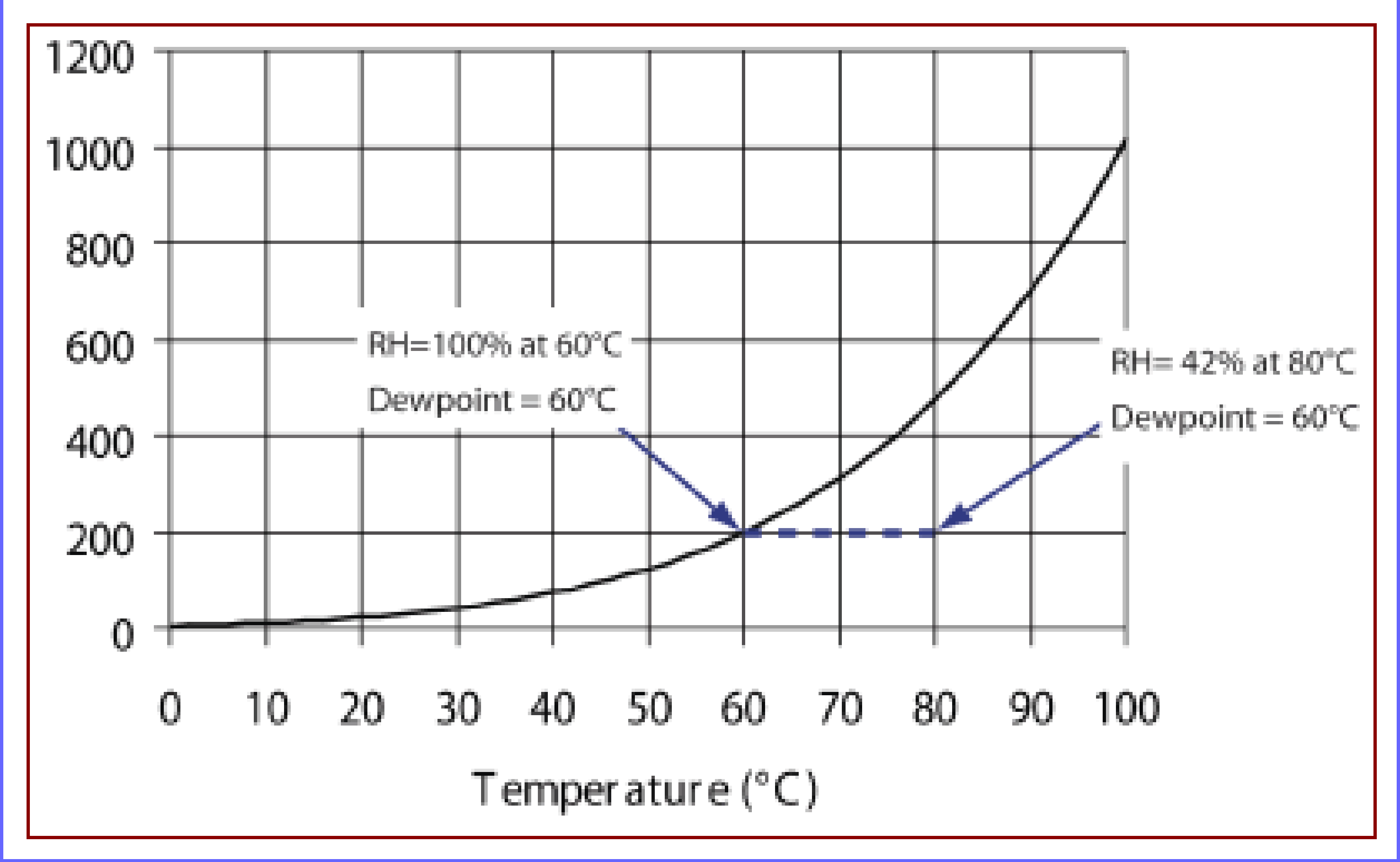
$$SD\left(\frac{g}{m^3}\right) = e_a\left(\frac{g}{m^3}\right) - e_d\left(\frac{g}{m^3}\right)$$

Dewpoint (Td) - is the highest temperature at which airborne water vapor will condense to form liquid dew. At dew point, the saturation deficit is zero (SD=0).

Relative humidity (RH) – the absolute humidity over the saturation humidity (i.e., the percent ratio of the amount of moisture in the air to the total amount it could hold).

$$RH(\%) = \frac{e_d\left(\frac{g}{m^3}\right)}{e_a\left(\frac{g}{m^3}\right)}$$

# Saturation Curve – Dewpoint – RH - Condensation




Condensation is when the water vapor (the gaseous form of water) changes into liquid water. It starts at dewpoint.

Examples from the saturation curve:

(1) $t=80\ ^0C$ $e_d=200\ g/m^3$ $e_a=476\ g/m^3$

$Td=e_a-e_d=276\ g/m^3$

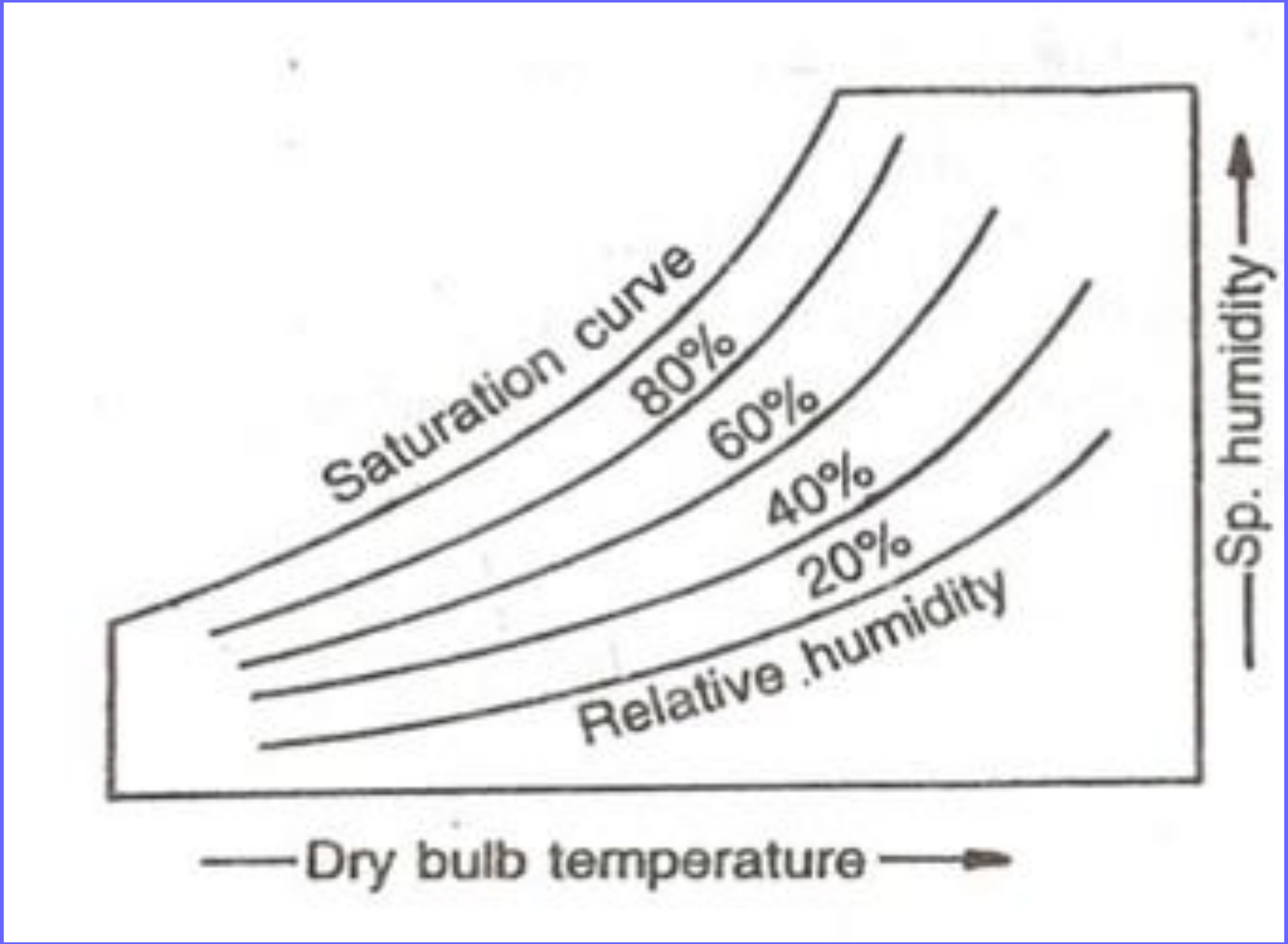
$RH= e_d/e_a *100= 42\%$

(2) $t=60\ ^0C$ $e_d=200\ g/m^3$ $e_a=200\ g/m^3$

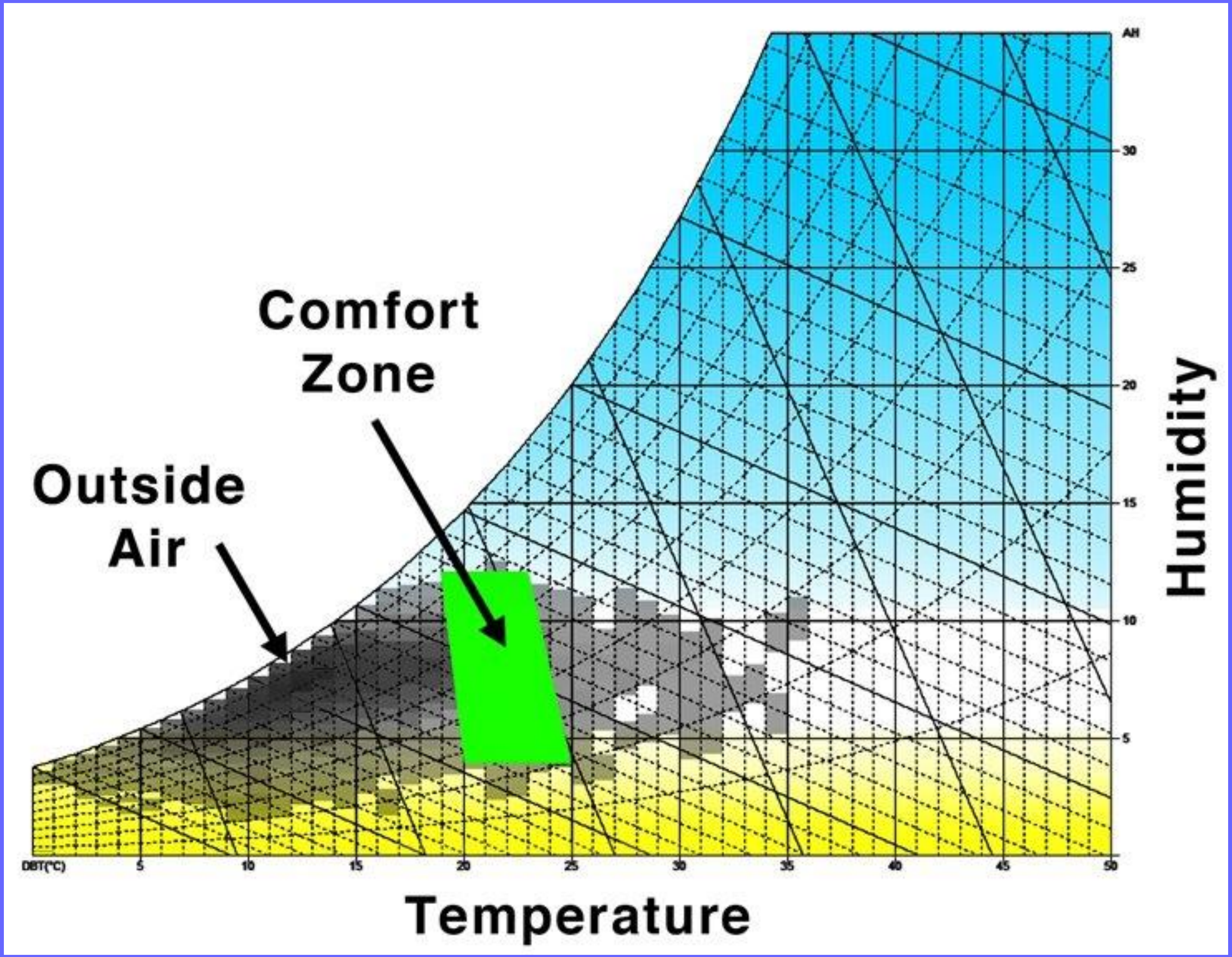
$Td=0\ g/m^3$

RH= 100%

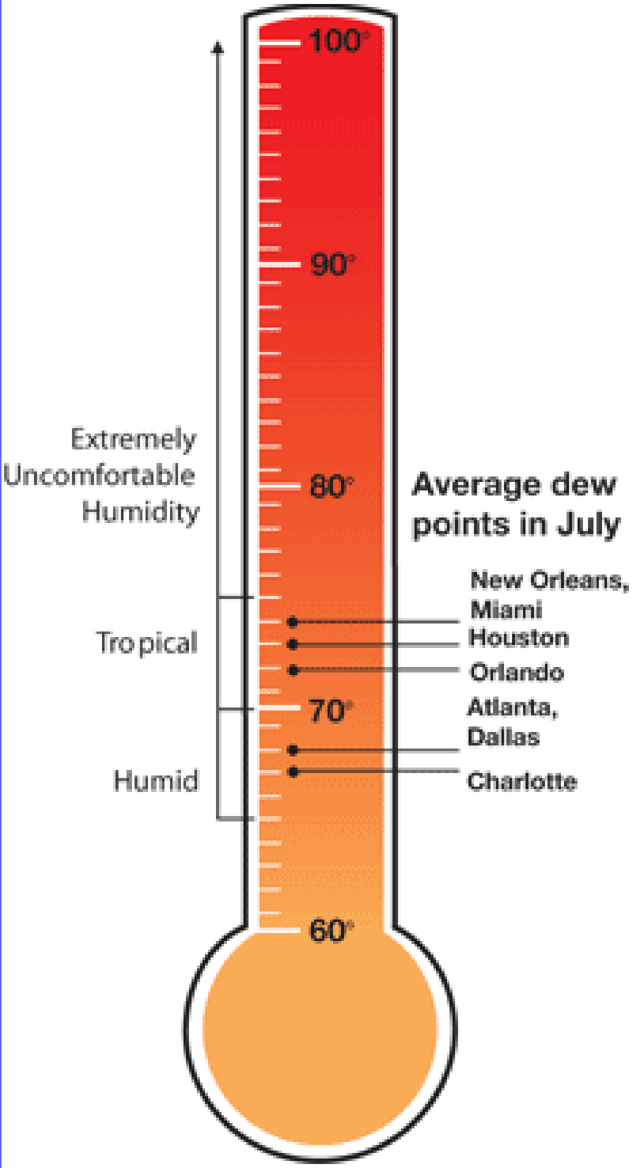
# Saturation Curve - RH



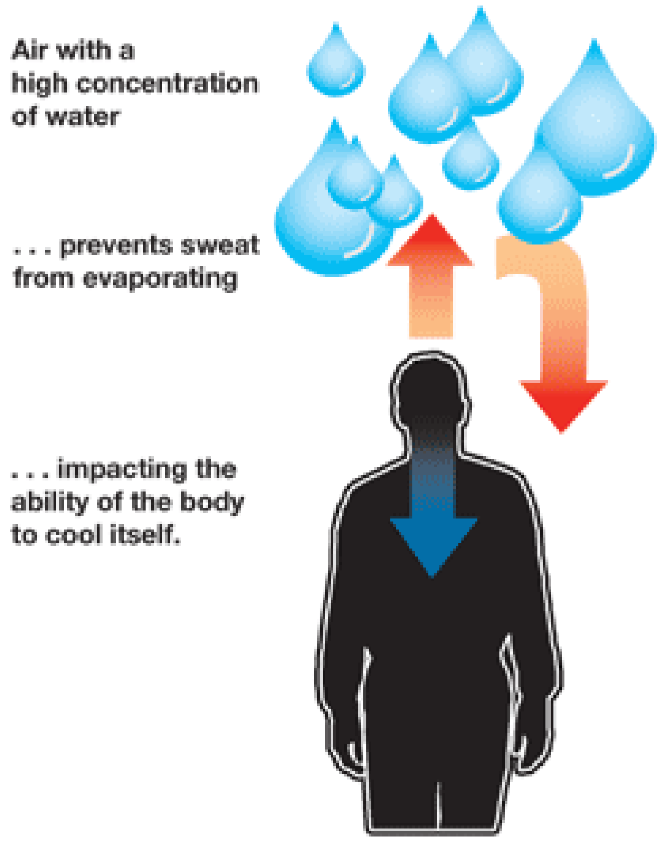
# Where is our comfort zone? (1)



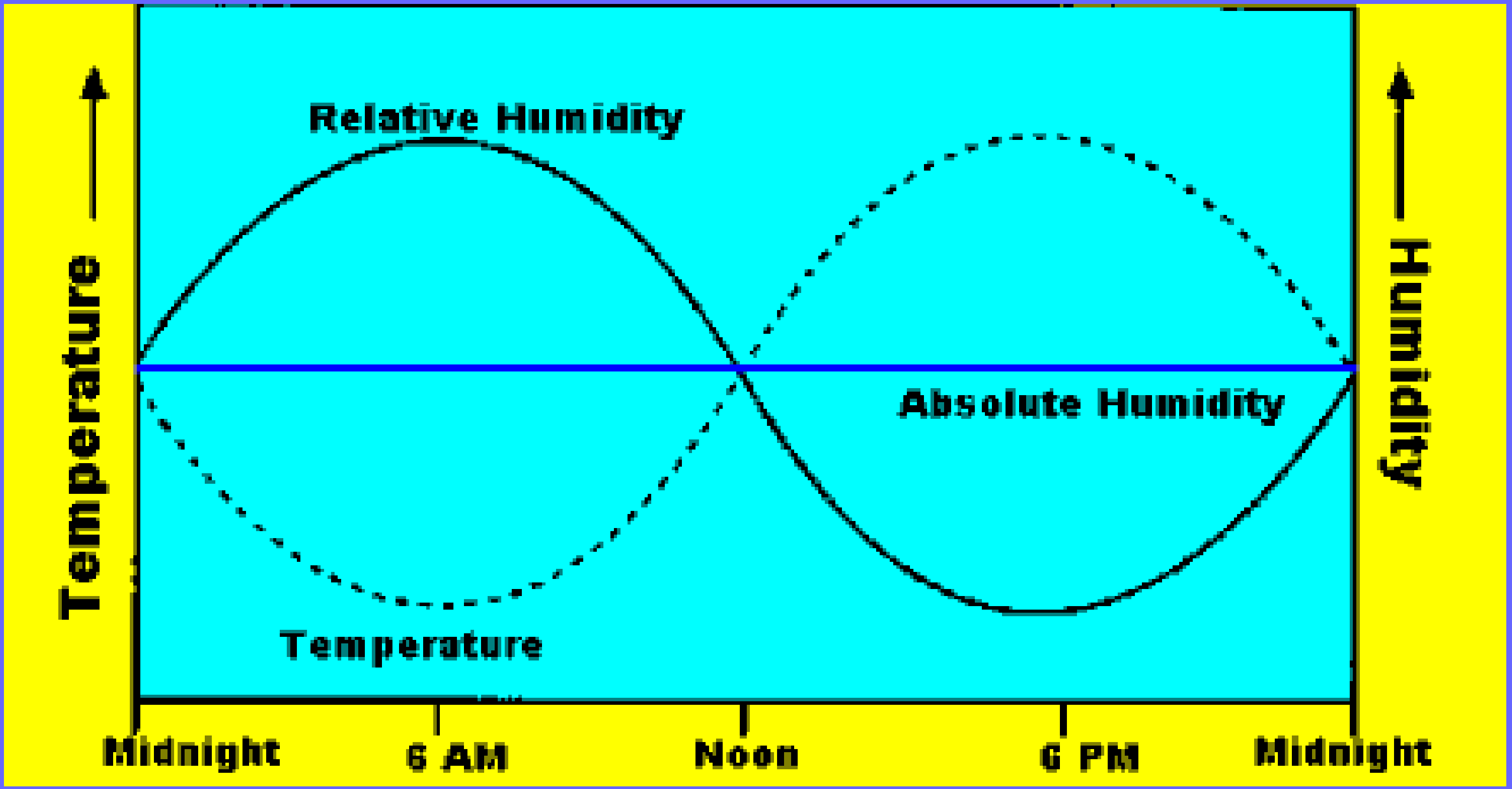
# Where is our comfort zone? (2)



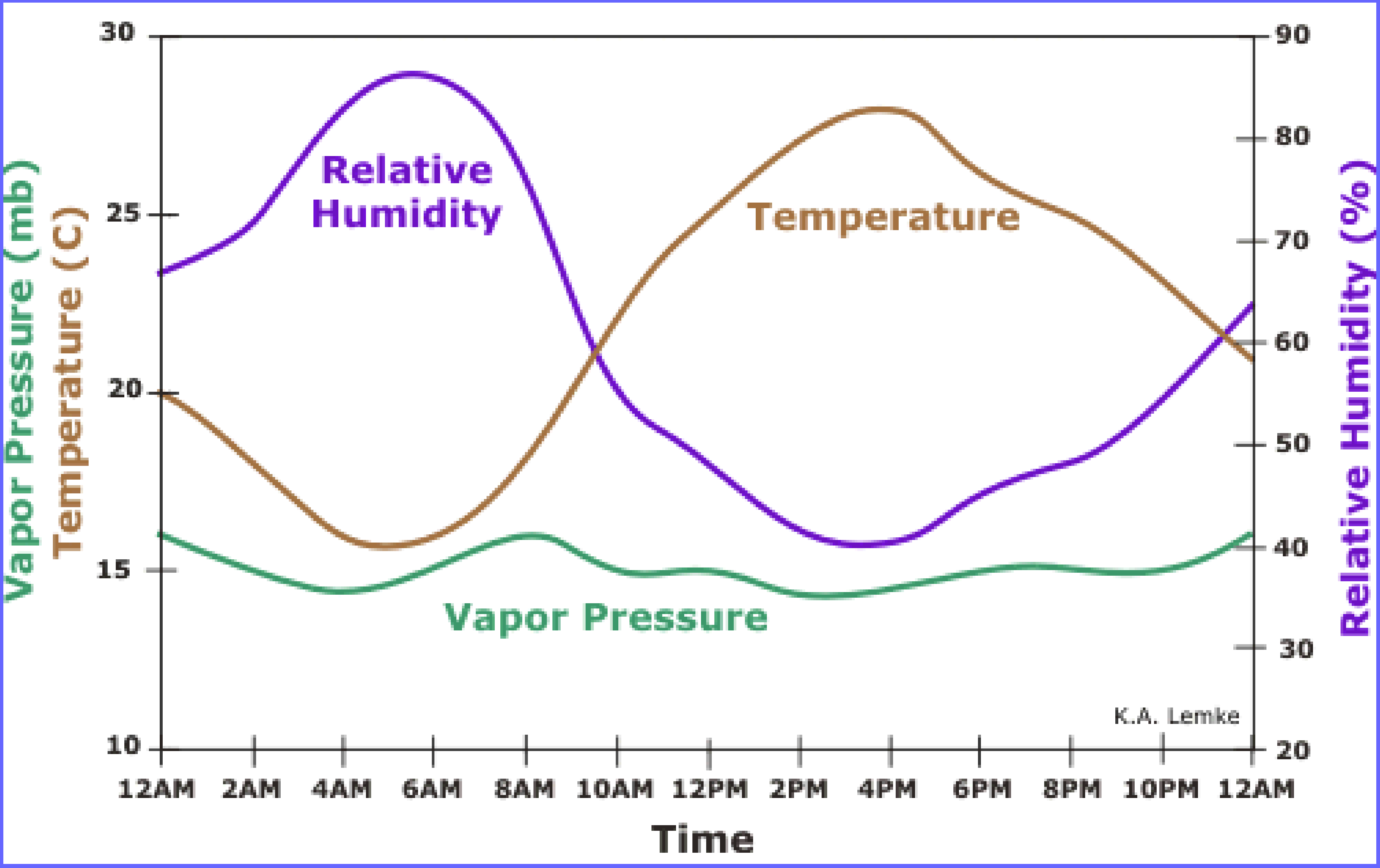

Dew points and relative humidity (Rh) affect the way your body senses heat. Higher humidity levels can cause teh atmosphere to feel much hotter than the actual temperature. By taking the humidity out of the air, the homeowner can turn their thermostat up and may feel cooler at a higher temperature. Energy Star estimates homeowners can save up to 6 % on cooling costs for every degree the termostat is turned up.

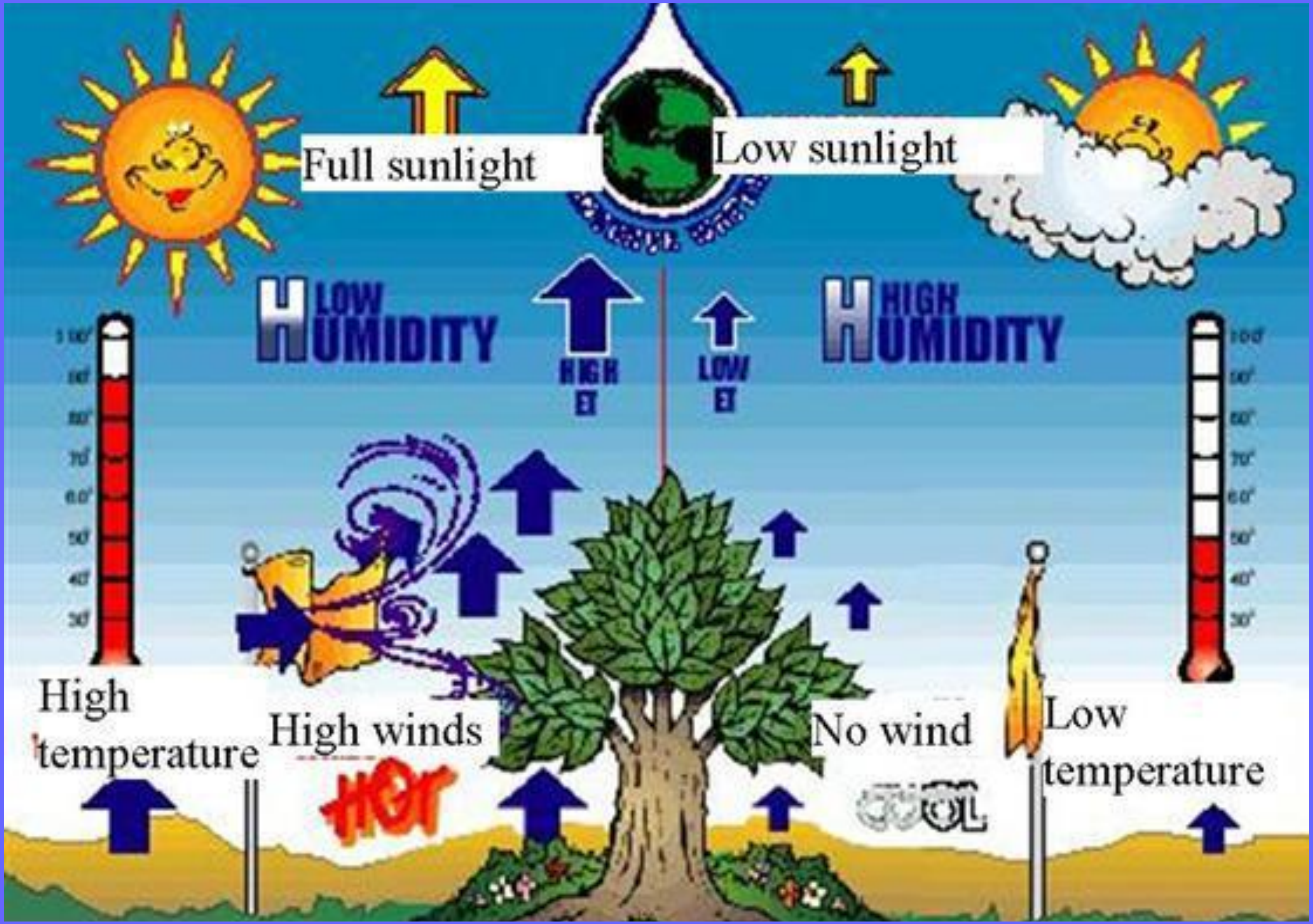


# Idealized Daily Trend of Humidity and Temperature



# Diurnal Relative Humidity Patterns






The relationship between precipitation and potential/actual ET in an area with a warm, dry summer and a cold, wet fall/winter/spring.

# Questions for Discussion

Define evaporation, transpiration and evapotranspiration.
What is condensation?
How can we calculate humidity (AH, SH, RH, DP)?
What is the saturation curve, explain how can we use it?
Discribe the relationship between the saturaton curve, the dewpoint, the RH and the condensation.
Factors affecting evaporation.

# 3 The Precipitation

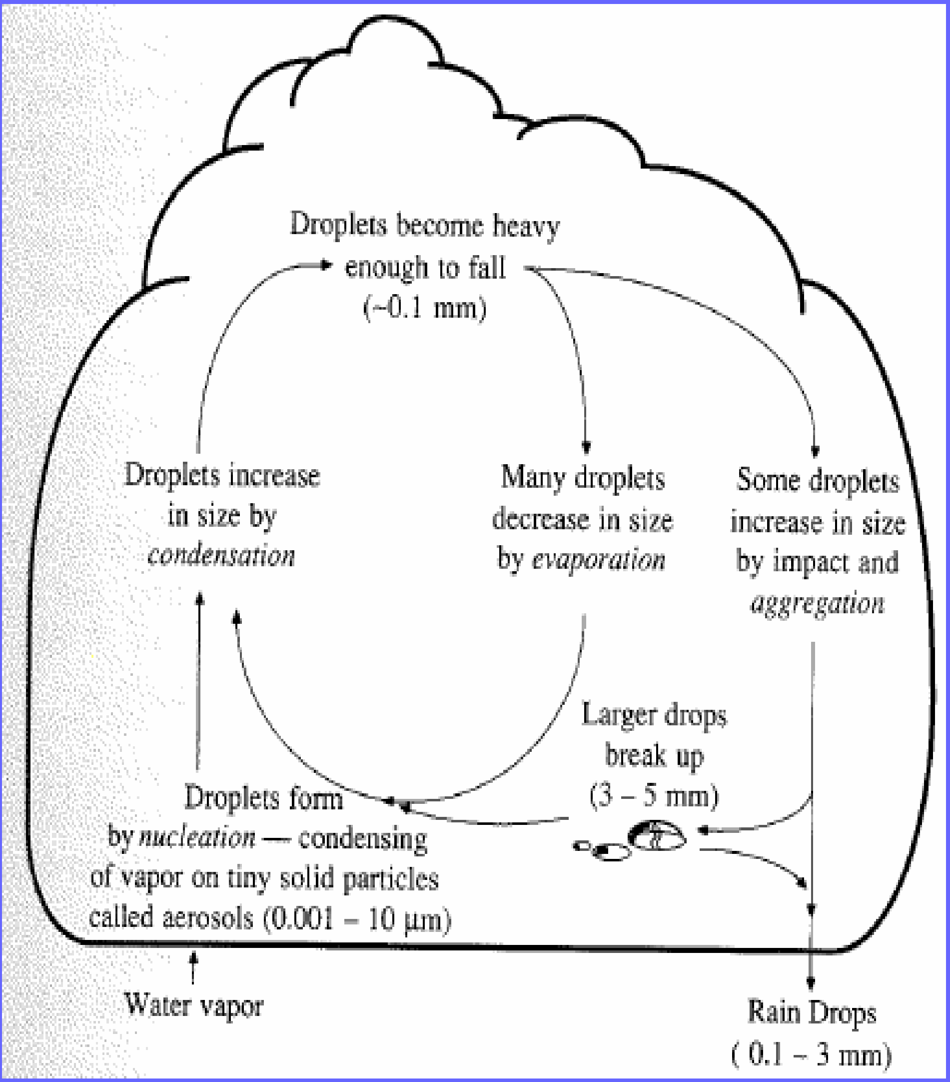
## Content

Define Precipitation
Mechanism of Precipitation
Main Forms of Precipitation
Primary Types of Clouds
Mechanism of Air Lifting
Measurement of Precipitation
Data for Precipitation
Examples
Questions for discussion

# Define Precipitation

- All types of moisture reaching the surface of the earth from the atmosphere.
- Precipitation is the primary input to the hydrology.
- Precipitation is water released from clouds in the form of rain, freezing rain, sleet, snow, or hail.
- Precipitation occurs when atmospheric moisture becomes too great to remain suspended in clouds.

# Mechanism of Precipitation



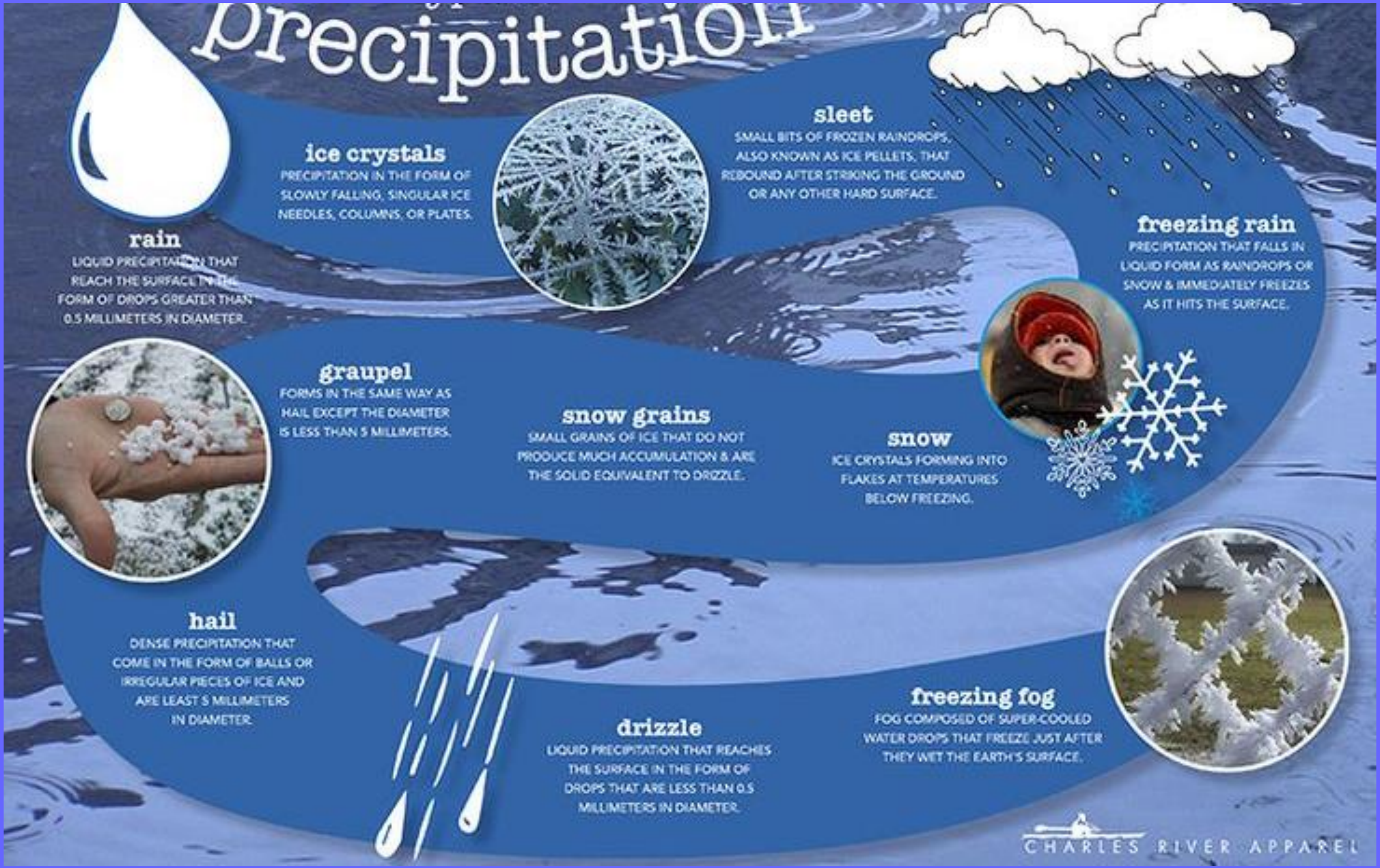

Three steps:

1. Lifting cool air masses so moisture condenses

2. Droplet formation around nuclei
    - aerosols
    - water molecules attach

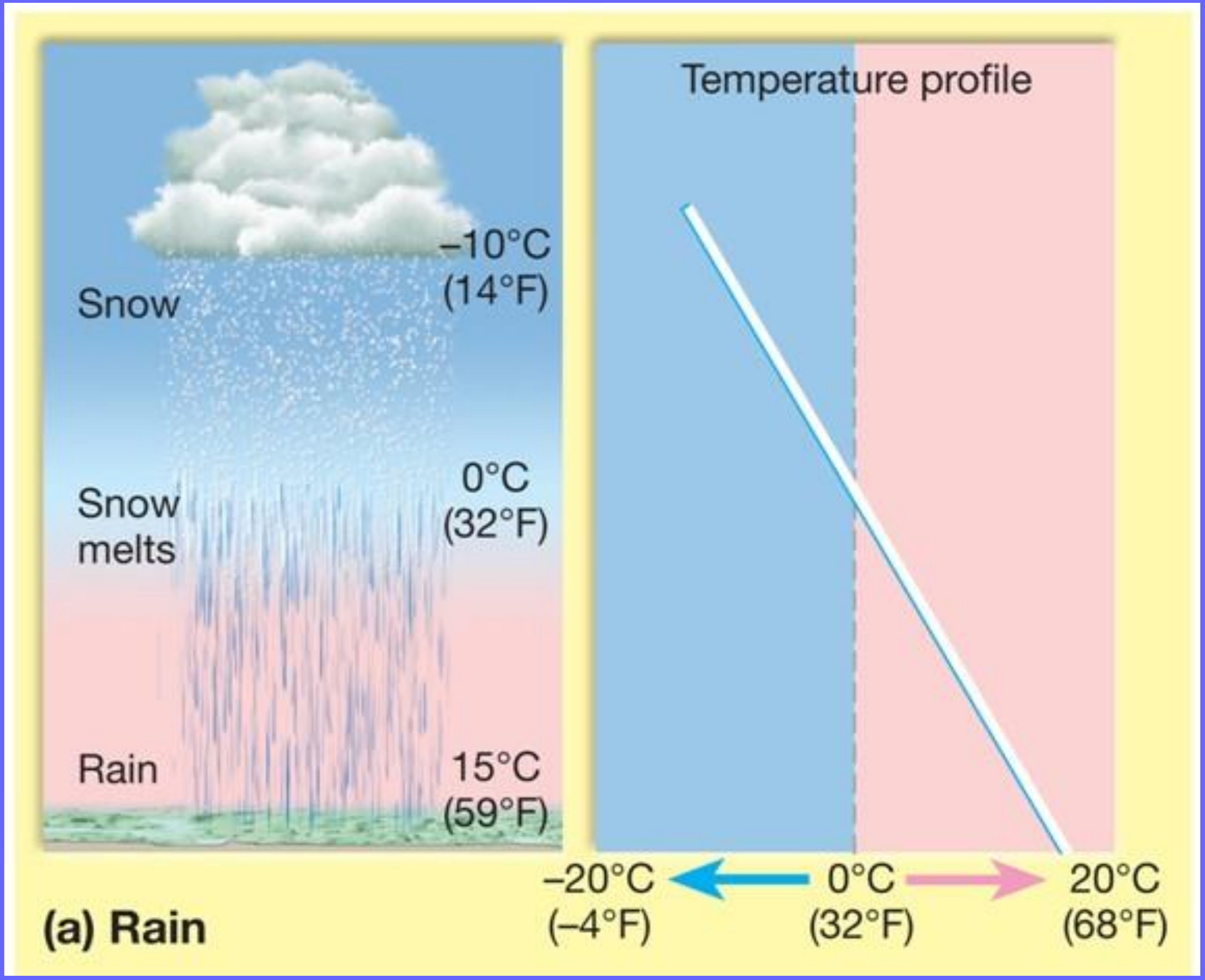
3. Rising and growing
    - Air current speed 0.5 cm/s sufficient to carry 10µm droplet
    - critical size (~0.1 mm)
    - gravity overcomes and drops fall

# Main Forms of Precipitation




https://www.google.hu/search?q=precipitation+forms&espv=2&biw=1366&bih=667&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjahNKw05PPAhXjYJoKHfpJB6AQ_AUIBigB&dpr=1#tbm=isch&q=types+of+precipitation&imgrc=vsqJBnLv6TmtGM%3A

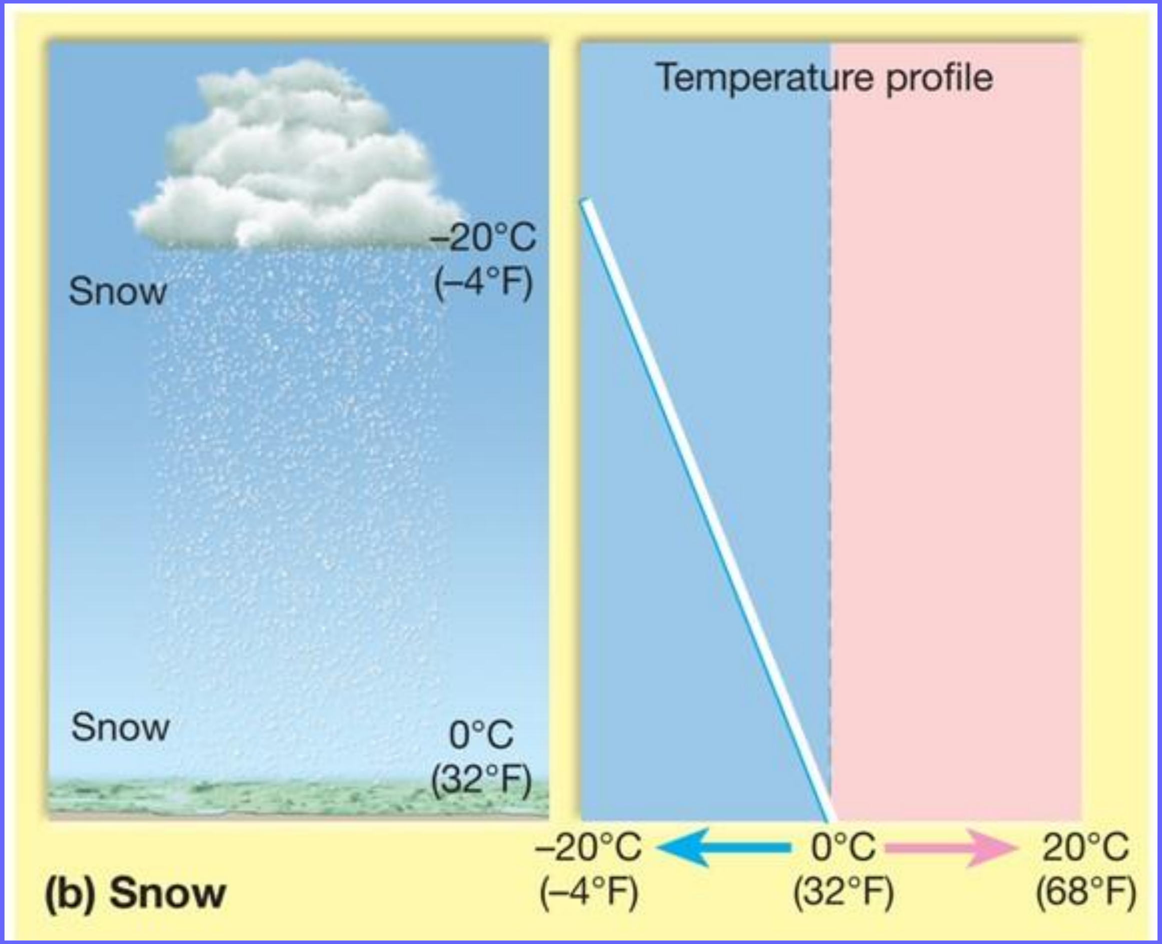
# Form of Precipitation (1)

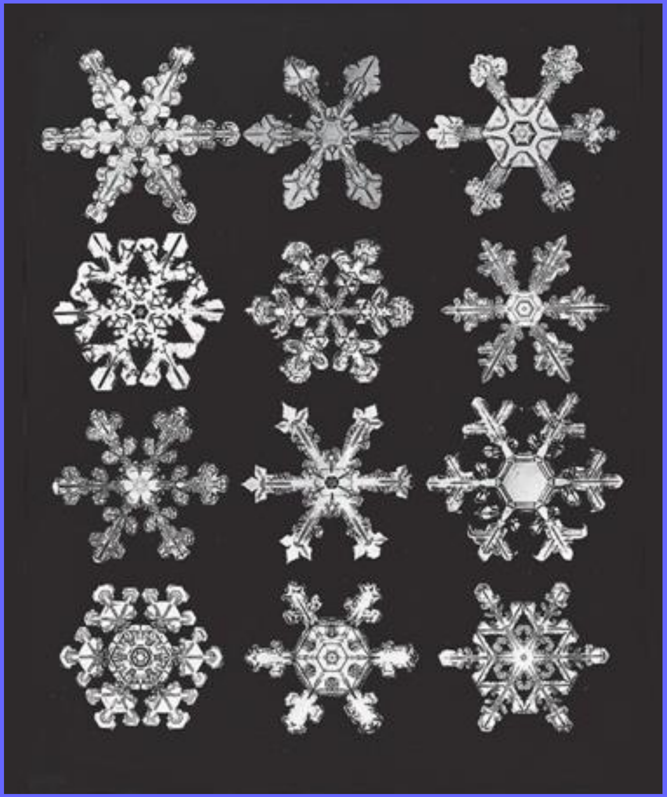



http://slideplayer.com/slide/8974698/

**Rain:** the condensed water vapor of the atmosphere falling in drops (0.5 mm-6 mm) from the clouds

# Form of Precipitation (2)

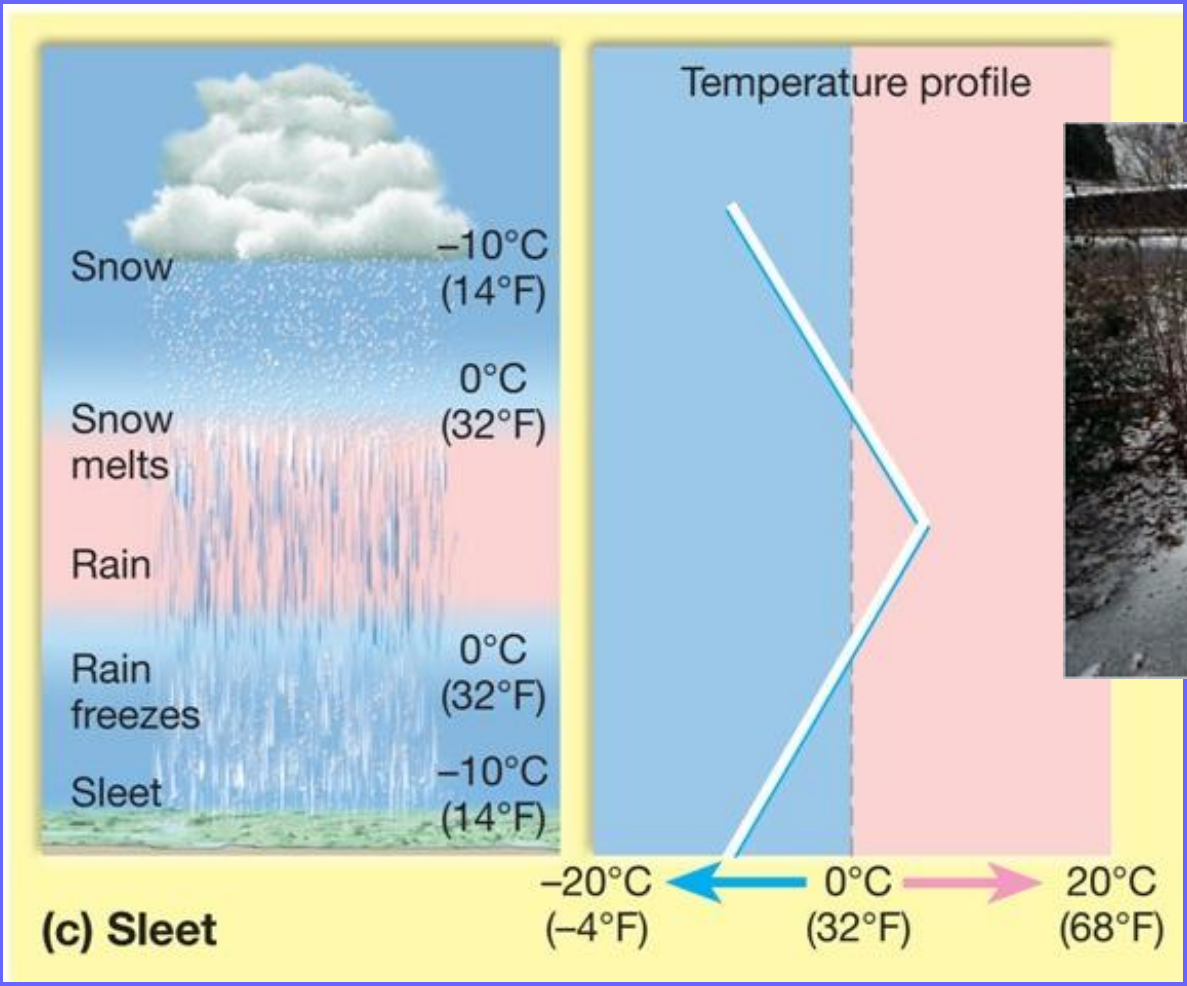


**Snow** — ice crystals resulting from sublimation (i.e., water vapor condenses to ice)

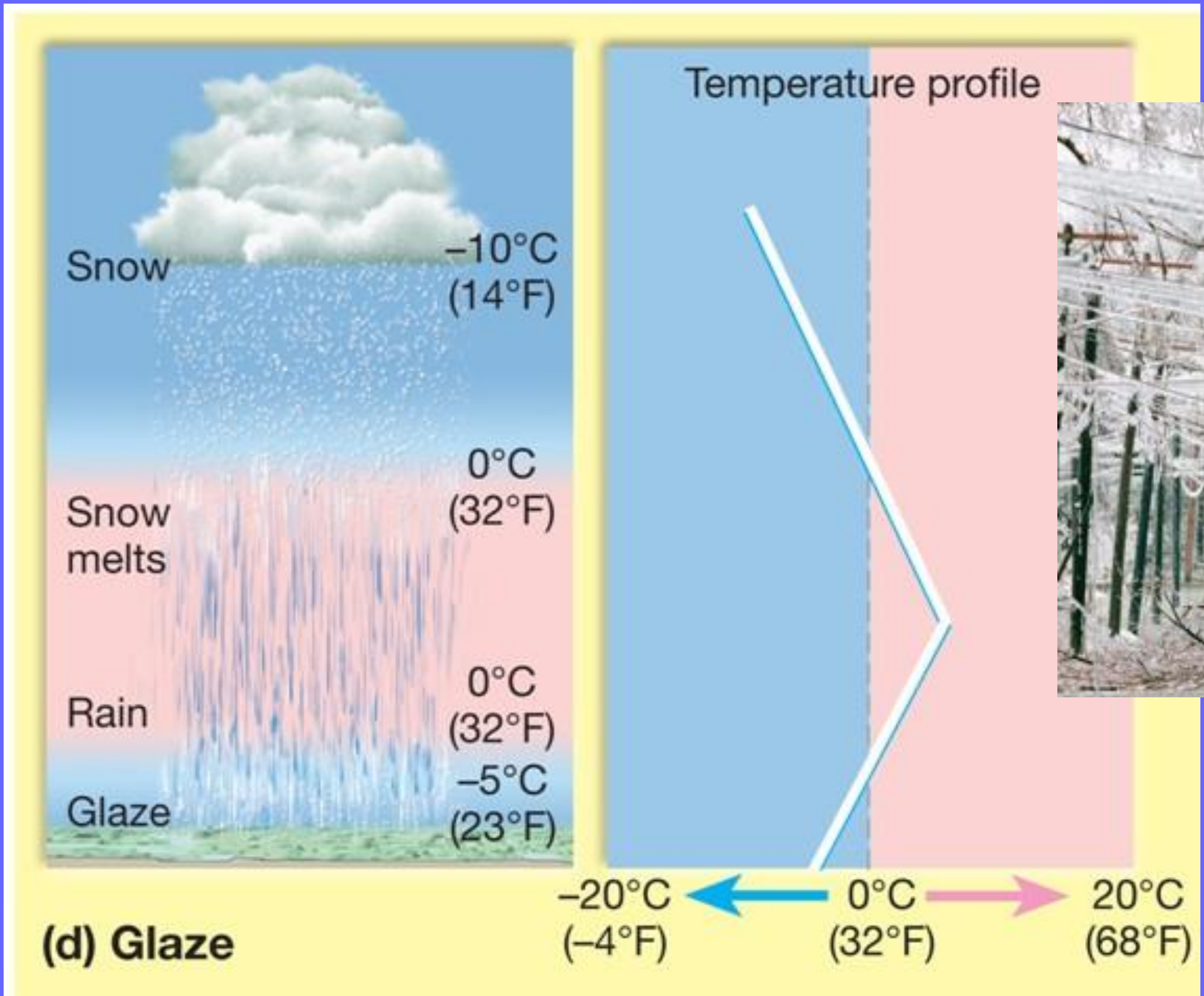
**Snowflakes** — ice crystals fused together

# Form of Precipitation (3)




**Sleet:** frozen rain drops while falling through air at subfreezing temperature

# Form of Precipitation (4)



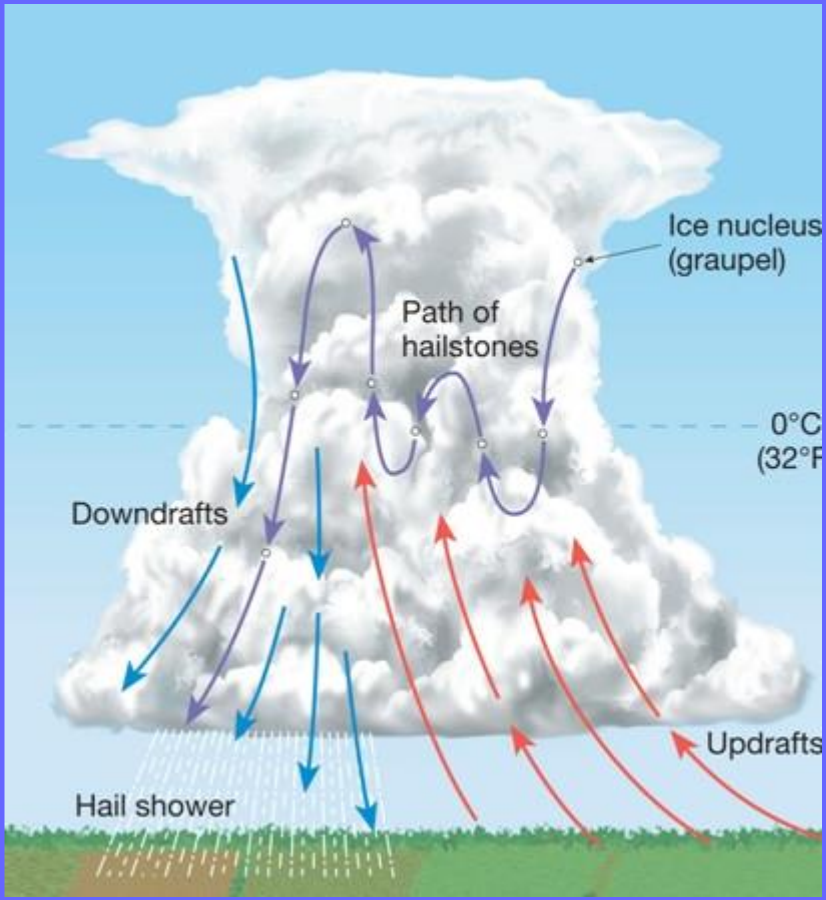


**Glaze**: freezing of drizzle or rain when they come in contact with cold objects

# Form of Precipitation (5)

**Frost**: a feathery deposit of ice formed on the ground or on the surface of exposed objects by dew or water vapor that has frozen

# Form of Precipitation (6)




**Hail:** small lumps of ice (>5 mm in diameter) formed by alternate freezing and melting, when they are carried up and down in highly turbulent air currents

# Form of Precipitation (7)

**Virga**: rain evaporates before reaching the ground in the desert region, „rain curtain”

# Form of Precipitation (8)

**Drizzle**: a light steady rain in fine drops (0.5 mm) and intensity <1 mm/hr

**Fog**: a thin cloud of varying size formed at the surface of the earth by condensation of atmospheric vapor (interfering with visibility)

**Mist**: a very thin fog

**Dew**: moisture condensed from the atmosphere in small drops upon cool surfaces

| | Intensity (mm/hour) | Median diameter of drop (millimeters) | Velocity of fall (meters/second) | Drops per second per (square meter) |
|---|---|---|---|---|
| **Fog** | 0.13 | 0.01 | 0.003 | 67,425,000 |
| **Mist** | 0.05 | 0.10 | 0.210 | 27,000 |
| **Drizzle** | 0.25 | 0.96 | 4.100 | 151 |
| **Light rain** | 1.00 | 1.24 | 4.800 | 280 |
| **Moderate rain** | 3.80 | 1.60 | 5.700 | 495 |
| **Heavy rain** | 15.20 | 2.05 | 6.700 | 495 |
| **Excessive rain** | 40.60 | 2.40 | 7.300 | 818 |
| **Cloudburst** | 102.00 | 2.85 | 7.900 | 1,220 |

Source: Lull, H.W., 1959, Soil Compaction on Forest and Range Lands, U.S. Dept. of Agriculture, Forestry Service, Misc. Publication No.768

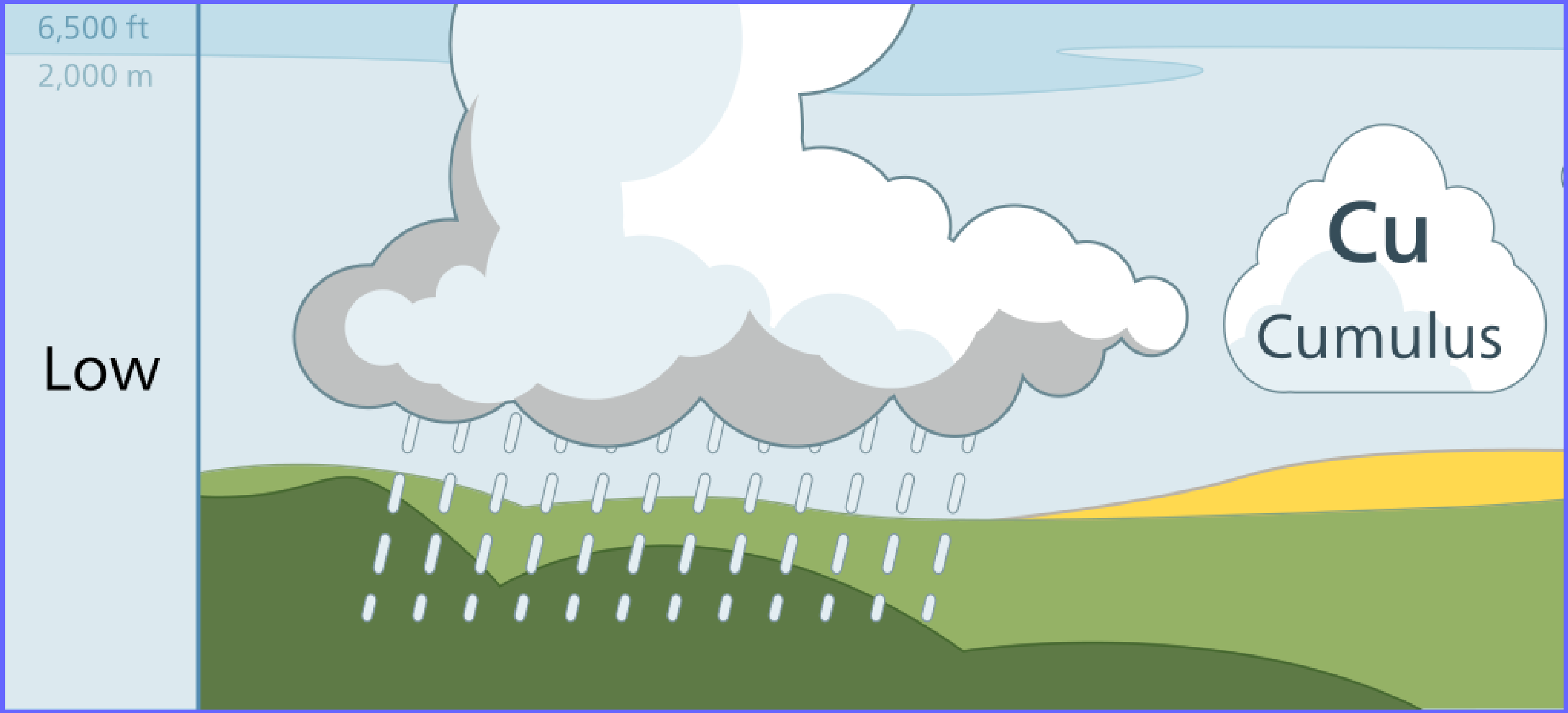
# Primary Types of Clouds

Clouds are classified on the basis of

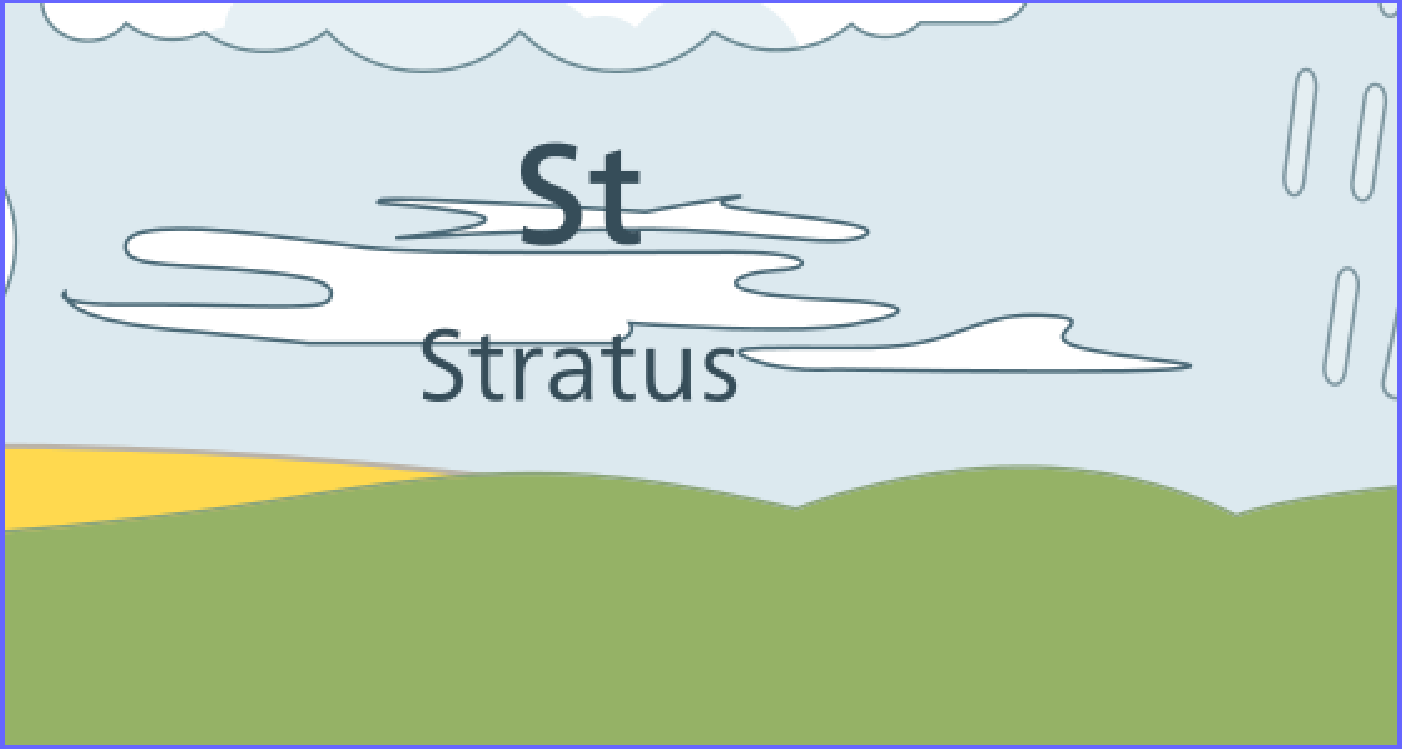
- shape,
- appearance and
- height.

Cumulus
Stratus
Cirrus
Nimbus

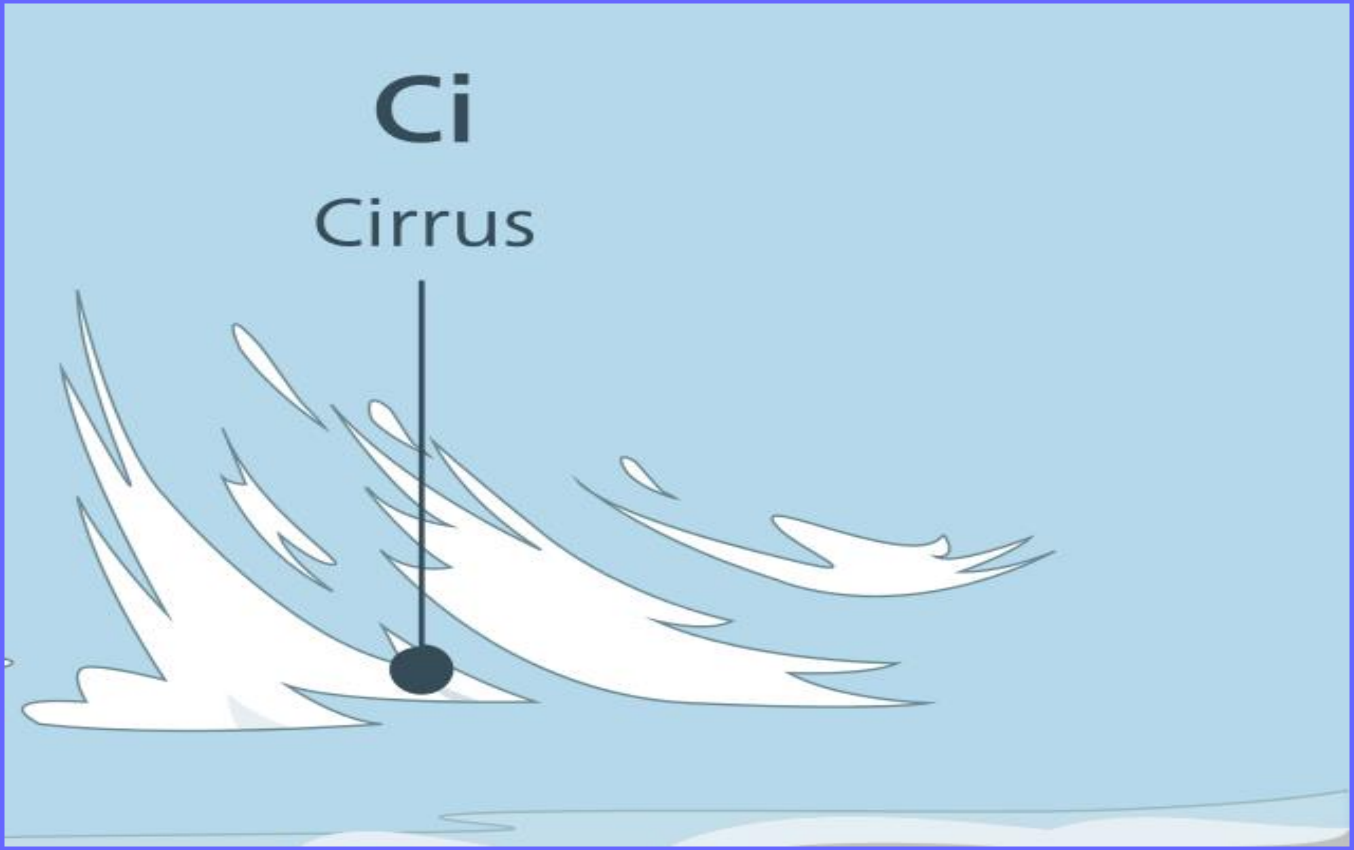
**Cumulus**: puffy individual clouds, where the flat base marks the condensation level, found in mid-atmosphere



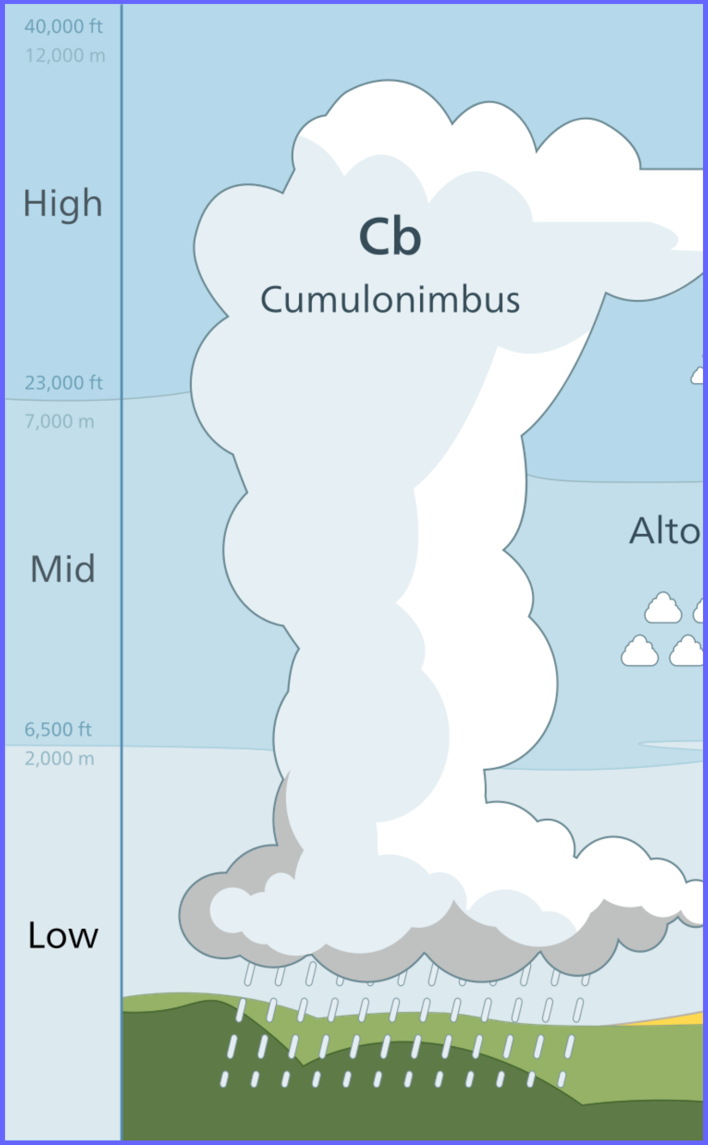
**Stratus**: sheets of cloud cover spread laterally rather than vertically, found in the low atmosphere



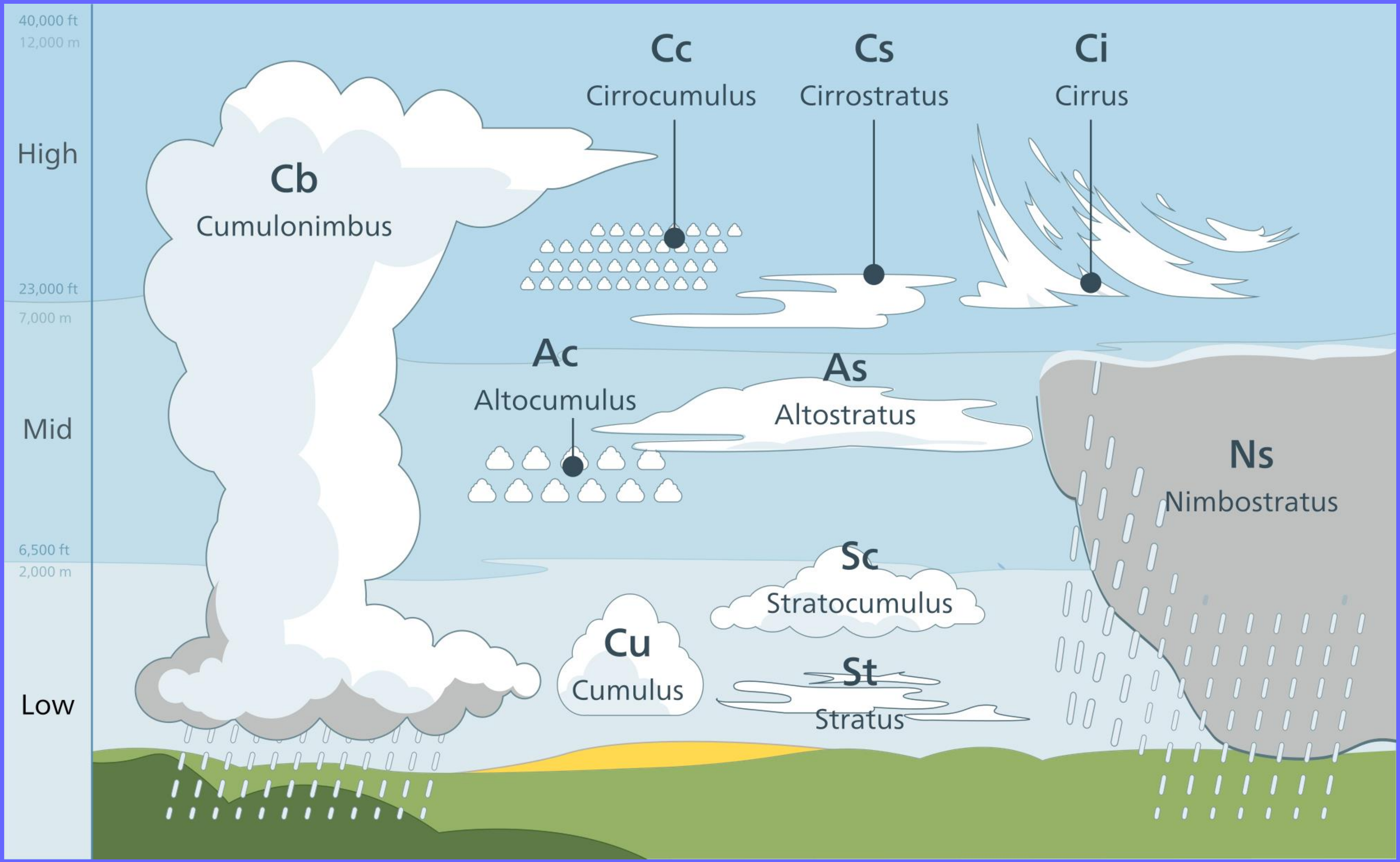
**Cirrus:** highest of the clouds, wispy feathers composed of ice crystals



# **Nimbus**: rain –(as in cumulonimbus), storm clouds



# Types of Clouds (1)

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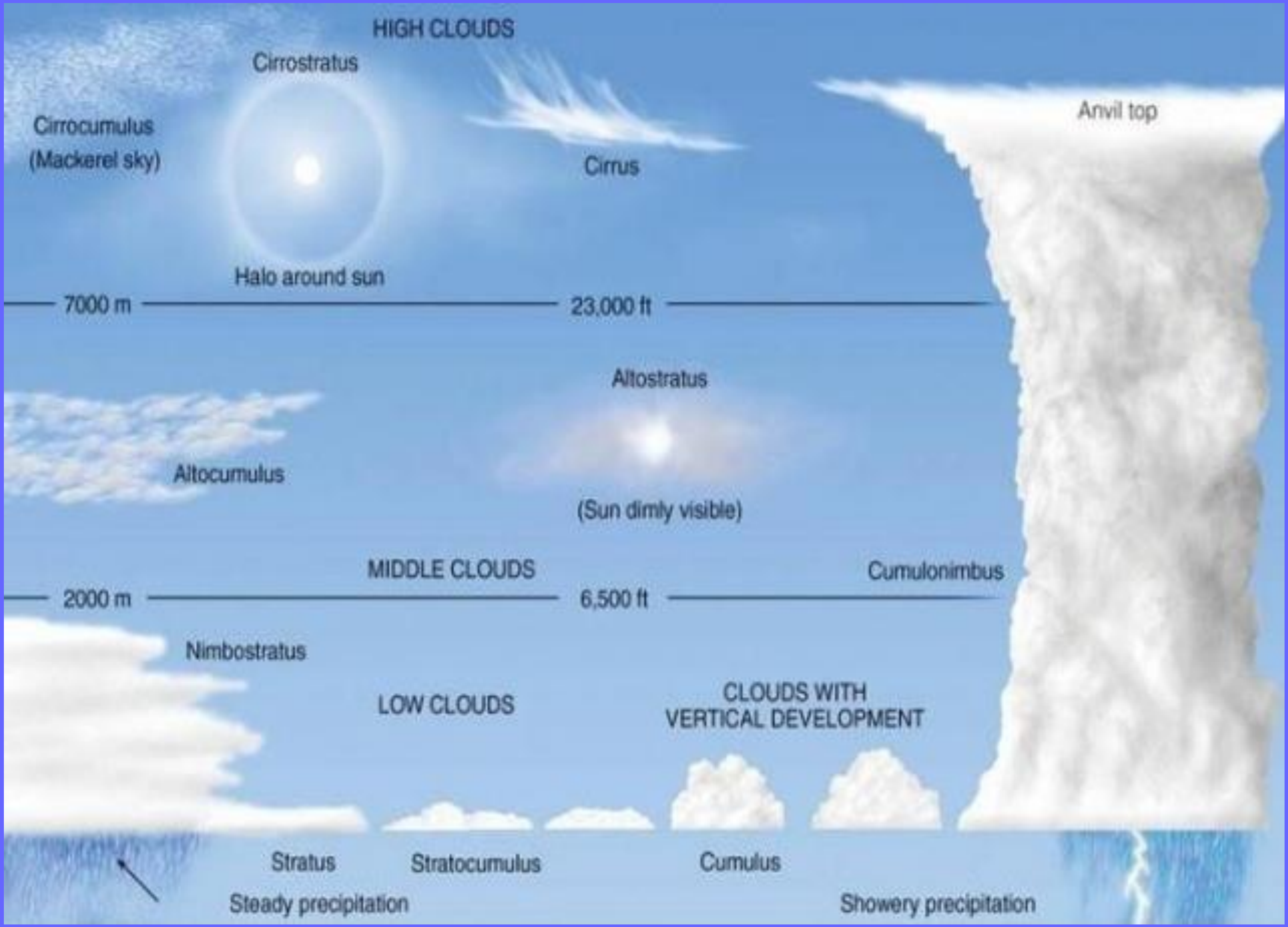
# Types of Clouds (2)

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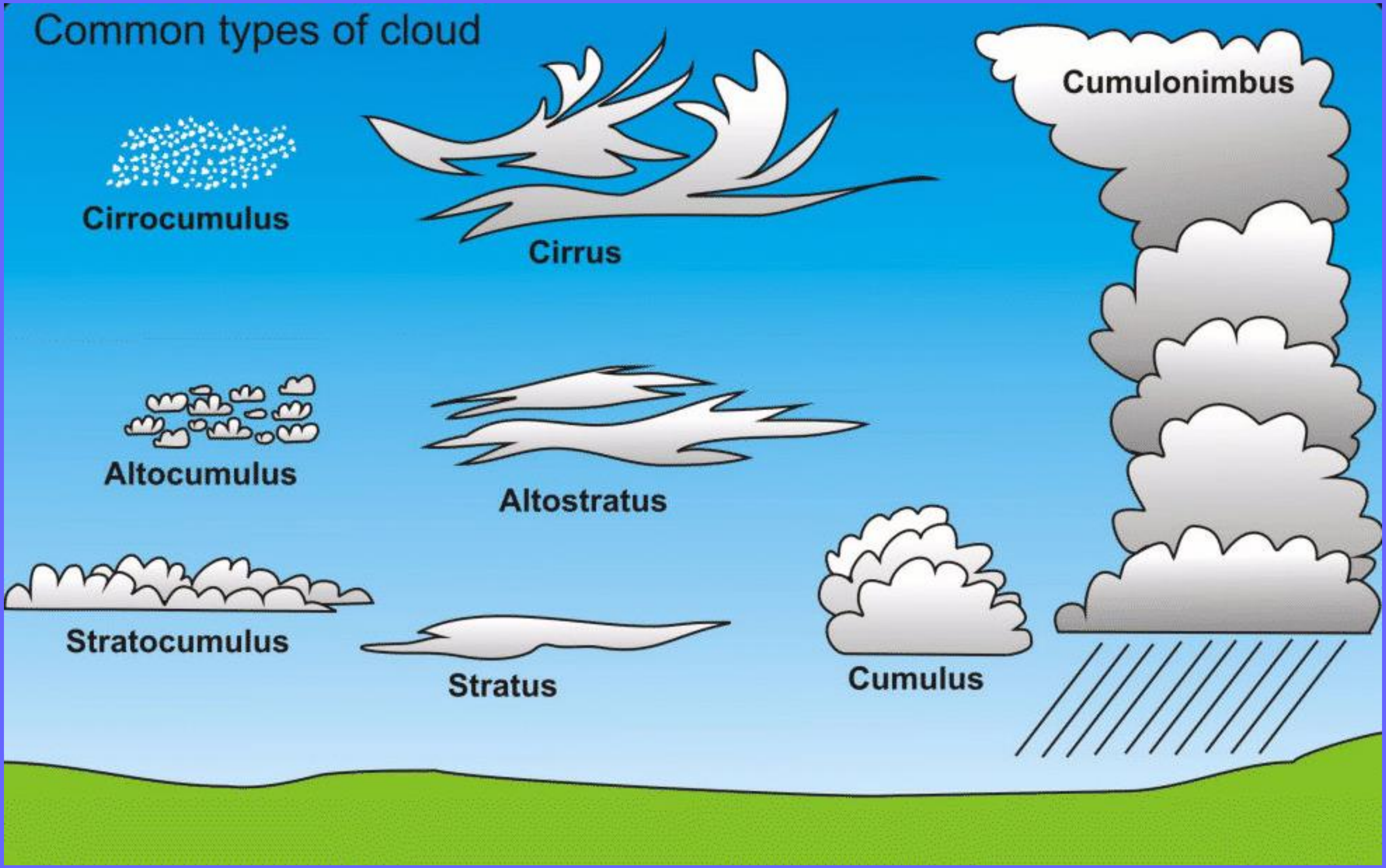
# Types of Clouds (3)




http://silvergrovescience.angelfire.com/IntegratedScience/Earthscience/Earthsatmosphere.htm

| Cloud Type | Description | What kind of weather? | Picture |
| --- | --- | --- | --- |
| Cirrus | High-level clouds. Thin, feathery, ice crystals | Just before snowfall or rainfall |  |
| Stratus | Low sheets or layers | Little precipitation to heavy rains or snowfall |  |
| Cumulus | Thick, puffy masses, "cotton balls" | Fair weather, maybe leading to abrupt storms |  |
| Nimbus | Thick, grey masses | Rain, snow and thunderstorms |  |

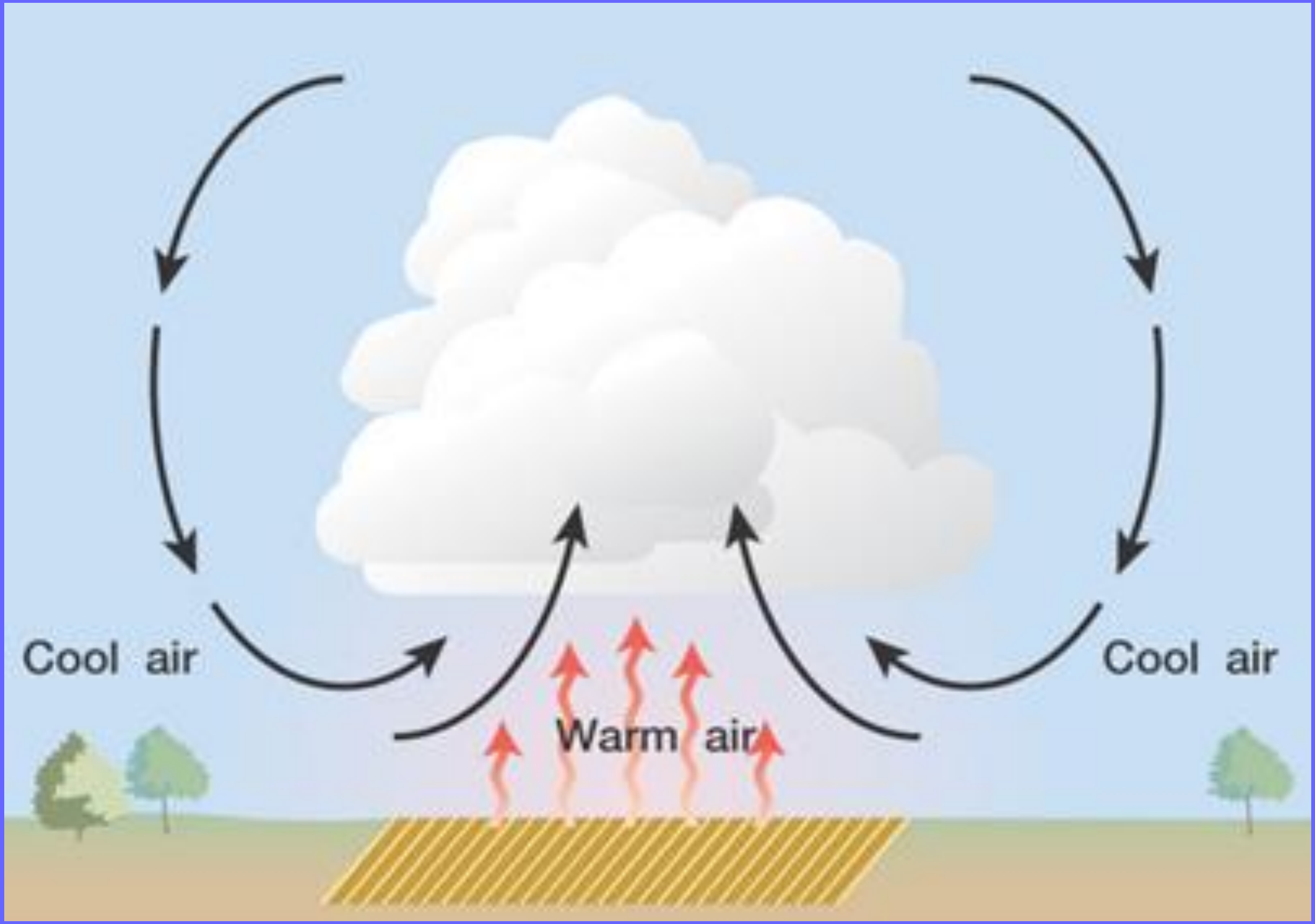
https://www.google.hu/search?q=basic+form+of+cloud&espv=2&biw=1366&bih=662&source=lnms&tbm=isch&sa=X&ved=0ahUKEwiO6f7qt5jPAhXCApoKHXl8DJkQ_AUIBigB&dpr=1#tbm=isch&q=Precipitation+%E2%80%93+Cloud+Type&imgrc=kGvo02B87_z2OM%3A

# The Three Types of Rainfall
## Mechanism of Air Lifting

Causes of precipitation are classified into the following types based upon the lifting mechanism:

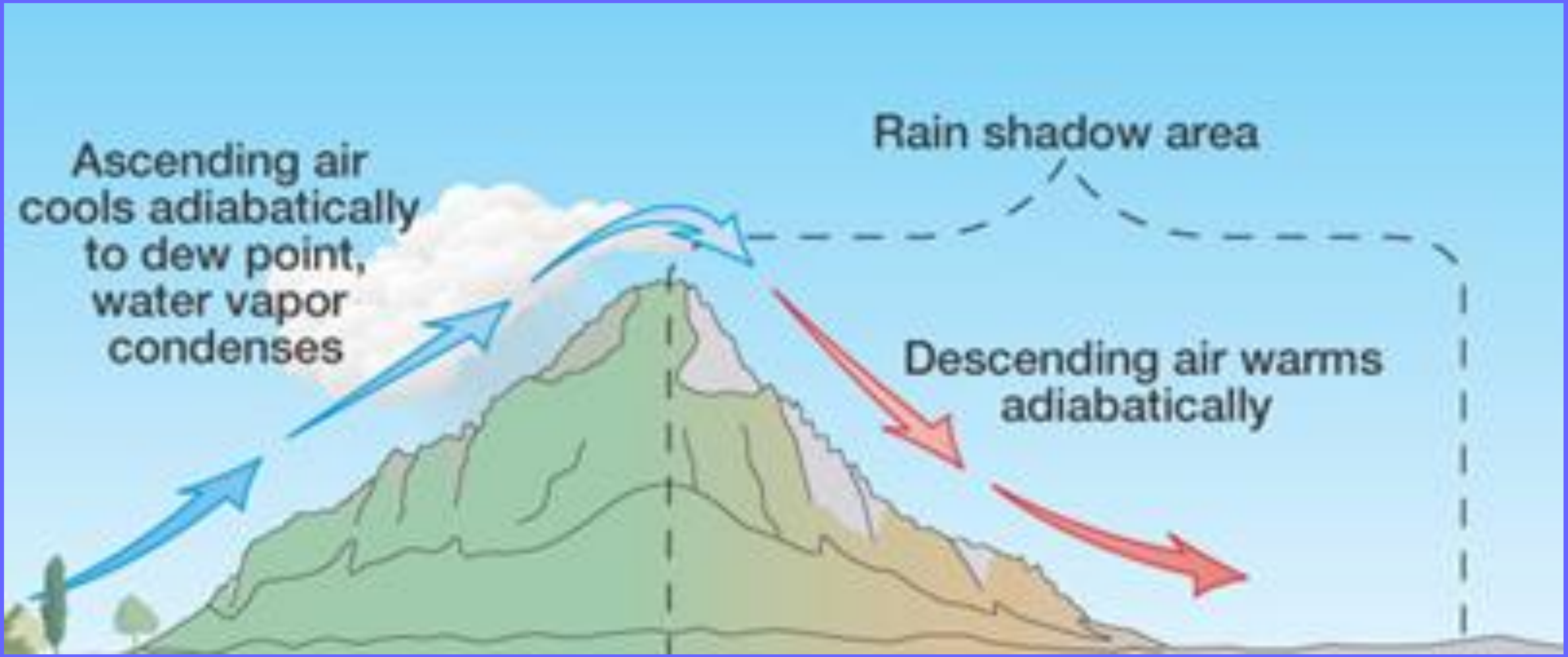
Convective lifting
Orographic  lifting
Frontal lifting

Convective lifting: the air near the ground is heated by the earth’s warm surface. This warm, low-density air rises cools down and creates precipitation.




https://www.google.hu/search?q=precipitation+forms&espv=2&biw=1366&bih=667&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjahNKw05PPAhXjYJoKHfpJB6AQ_AUIBigB&dpr=1#tbm=isch&q=convergence+lifting+mechanism&imgrc=N17h39V_CxQJ6M%3A

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

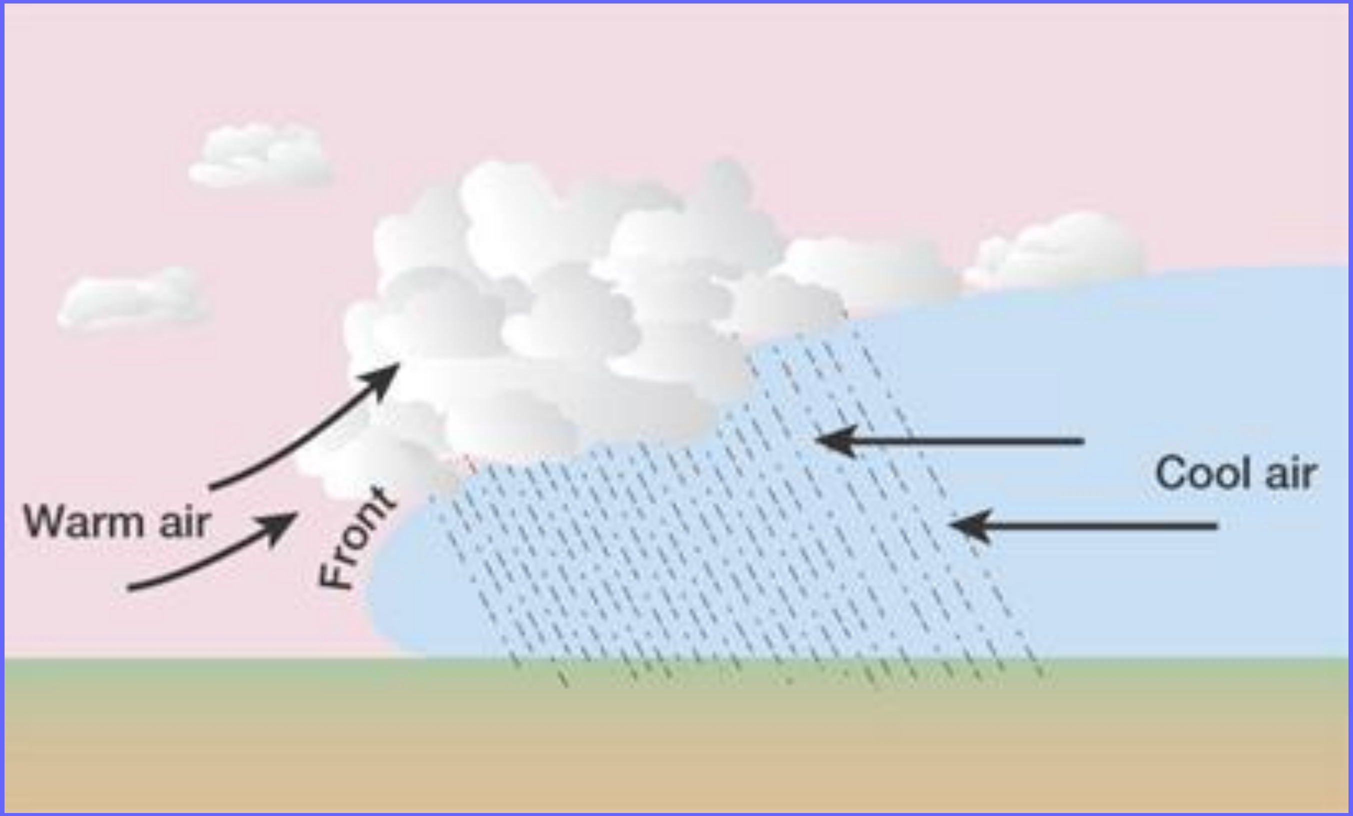



https://www.google.hu/search?q=precipitation+forms&espv=2&biw=1366&bih=667&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjahNKw05PPAhXjYJoKHfpJB6AQ_AUIBigB&dpr=1#tbm=isch&q=convergence+lifting+mechanism&imgrc=N17h39V_CxQJ6M%3A

Cyclonic precipitation:

Two flowing air masses of different density meet, one forcing the other up.

Cyclonic precipitation may be either frontal or non-frontal cyclonic precipitation.

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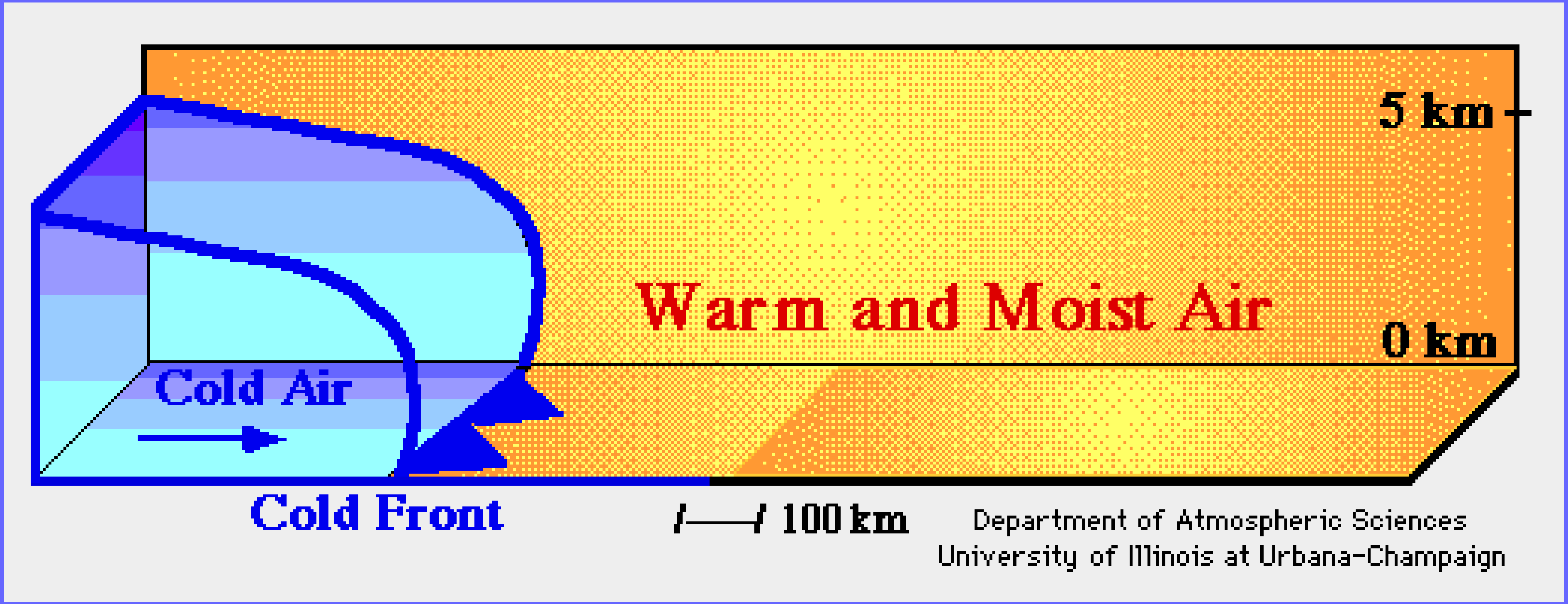
# Frontal Precipitation

The boundary between air masses with different properties is called a front.

It results from the lifting of warm and moist air on one side of a frontal surface over colder, denser air on the other side.

A front may be a warm front or cold front depending upon whether there is an active or passive accent of warm air mass over cold air mass.

# Cold Front (1)

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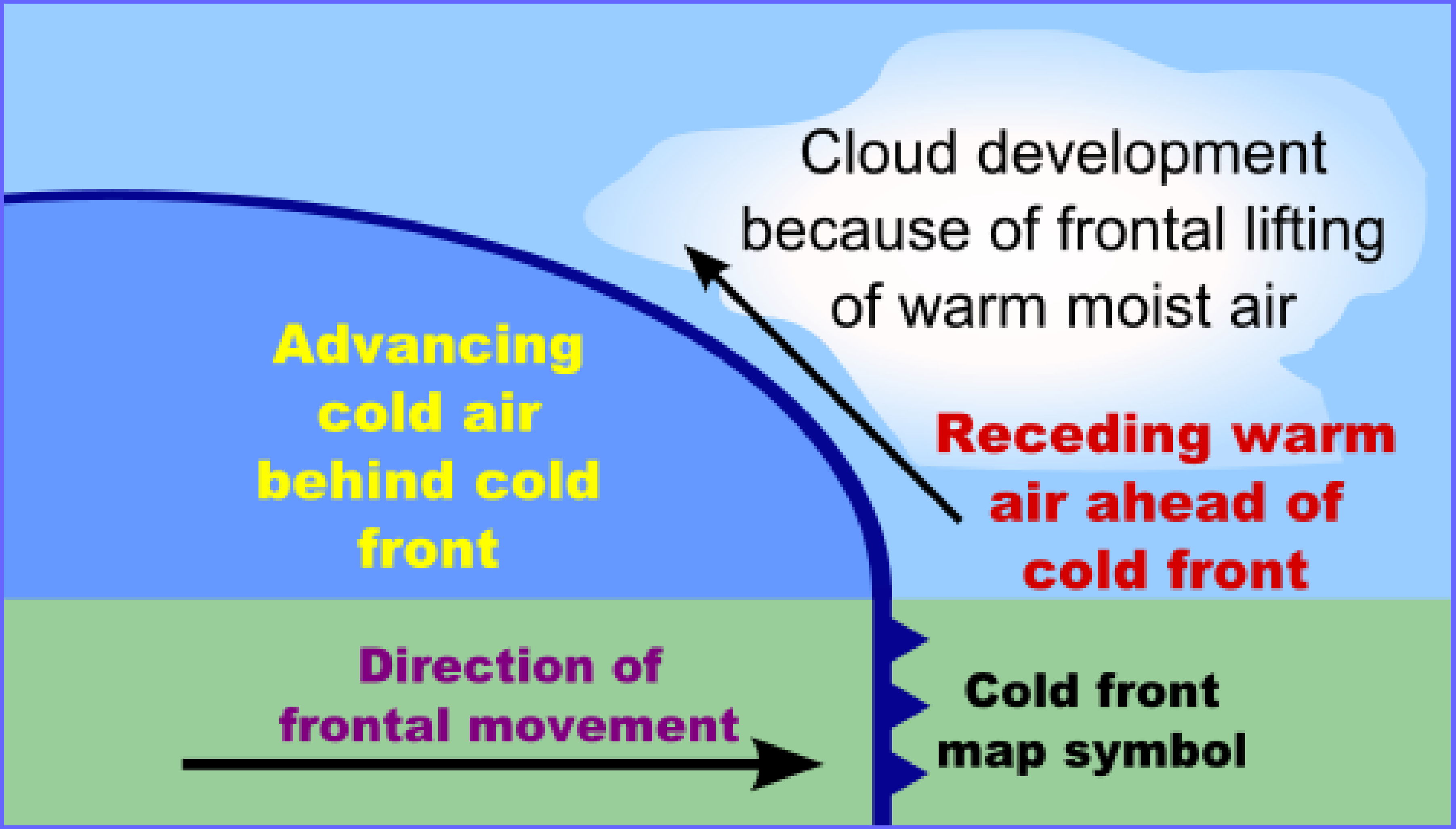
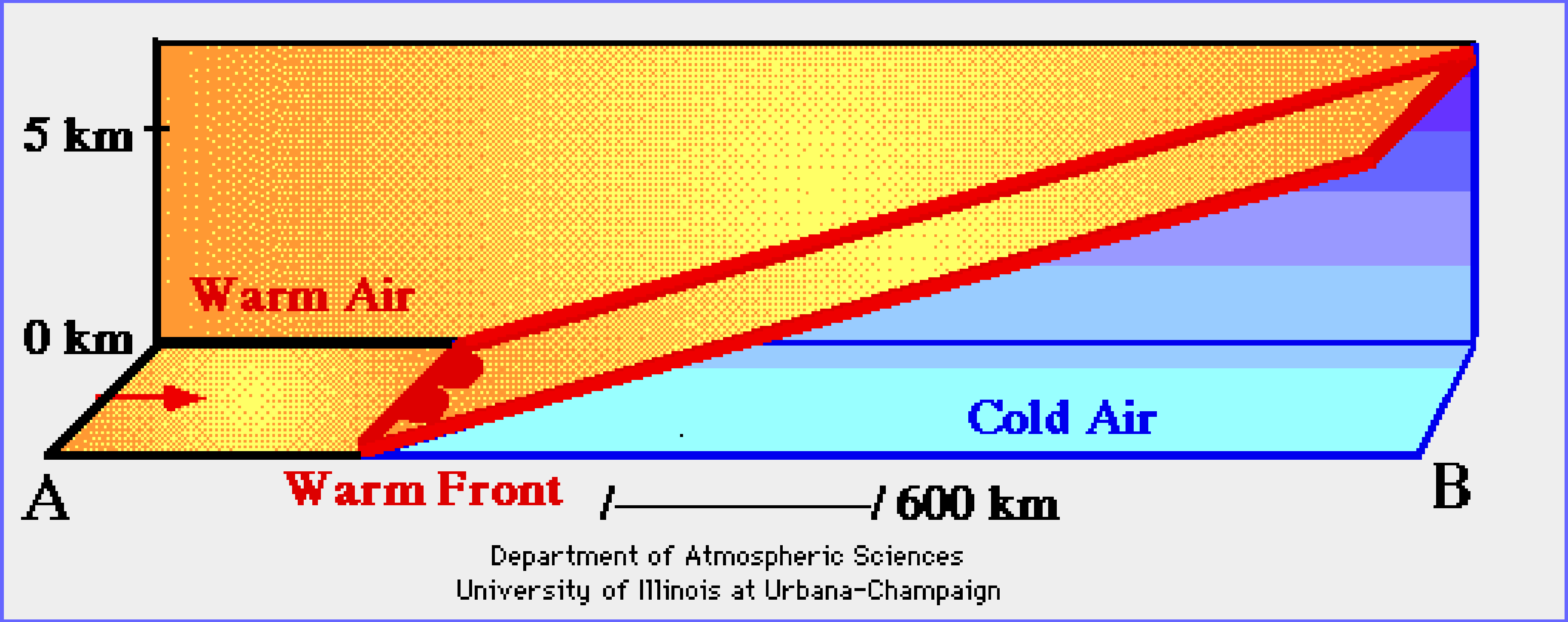
Cold, dense air displaces warm air and forces the warm air up along a steep front

Forceful rising motion is often produced, leading to the development of showers and thunderstorms.

# Cold Front (2)


Cloud development because of frontal lifting of warm moist air
Advancing cold air behind cold front
Receding warm air ahead of cold front
Direction of frontal movement
Cold front map symbol

# Warm Front (1)

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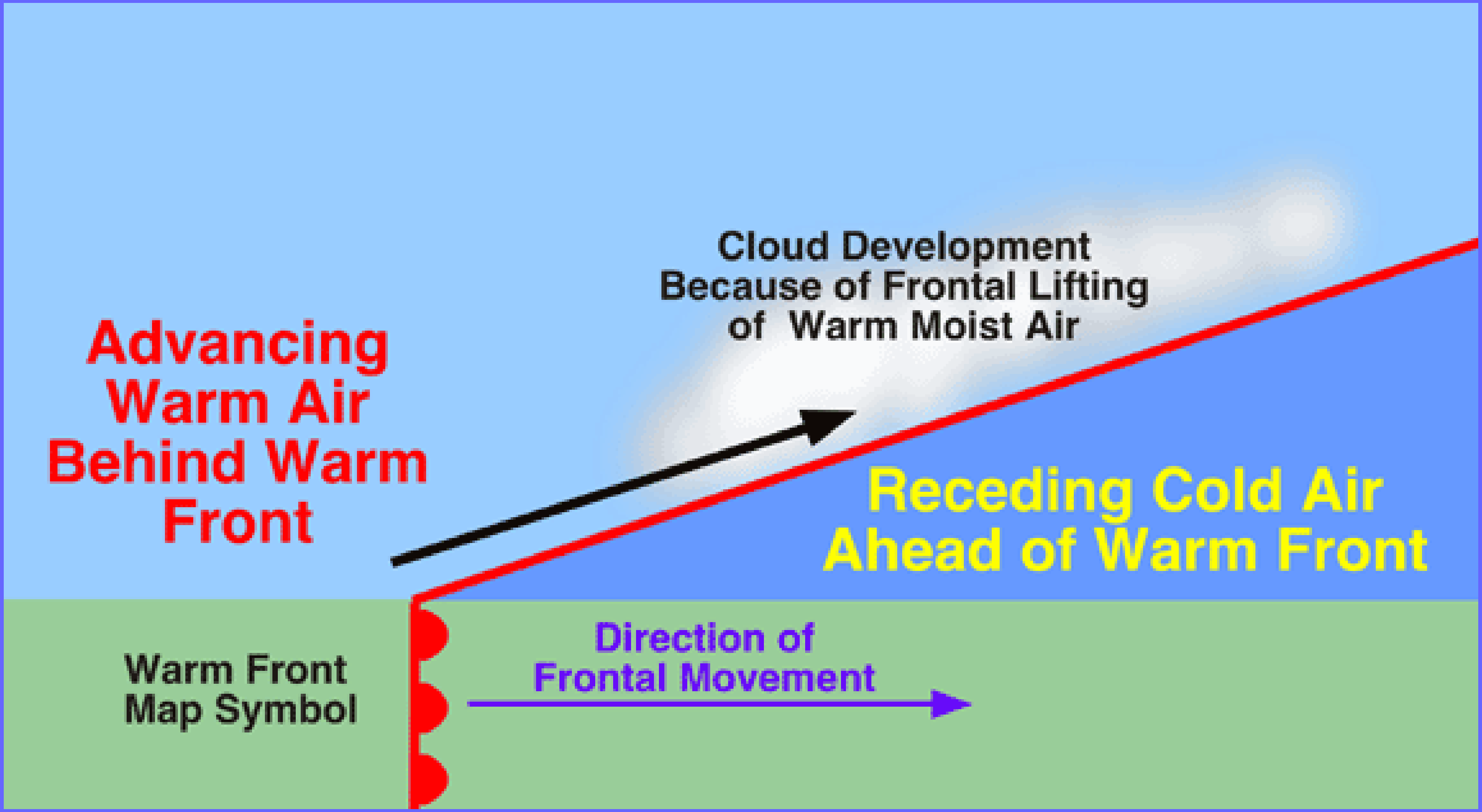
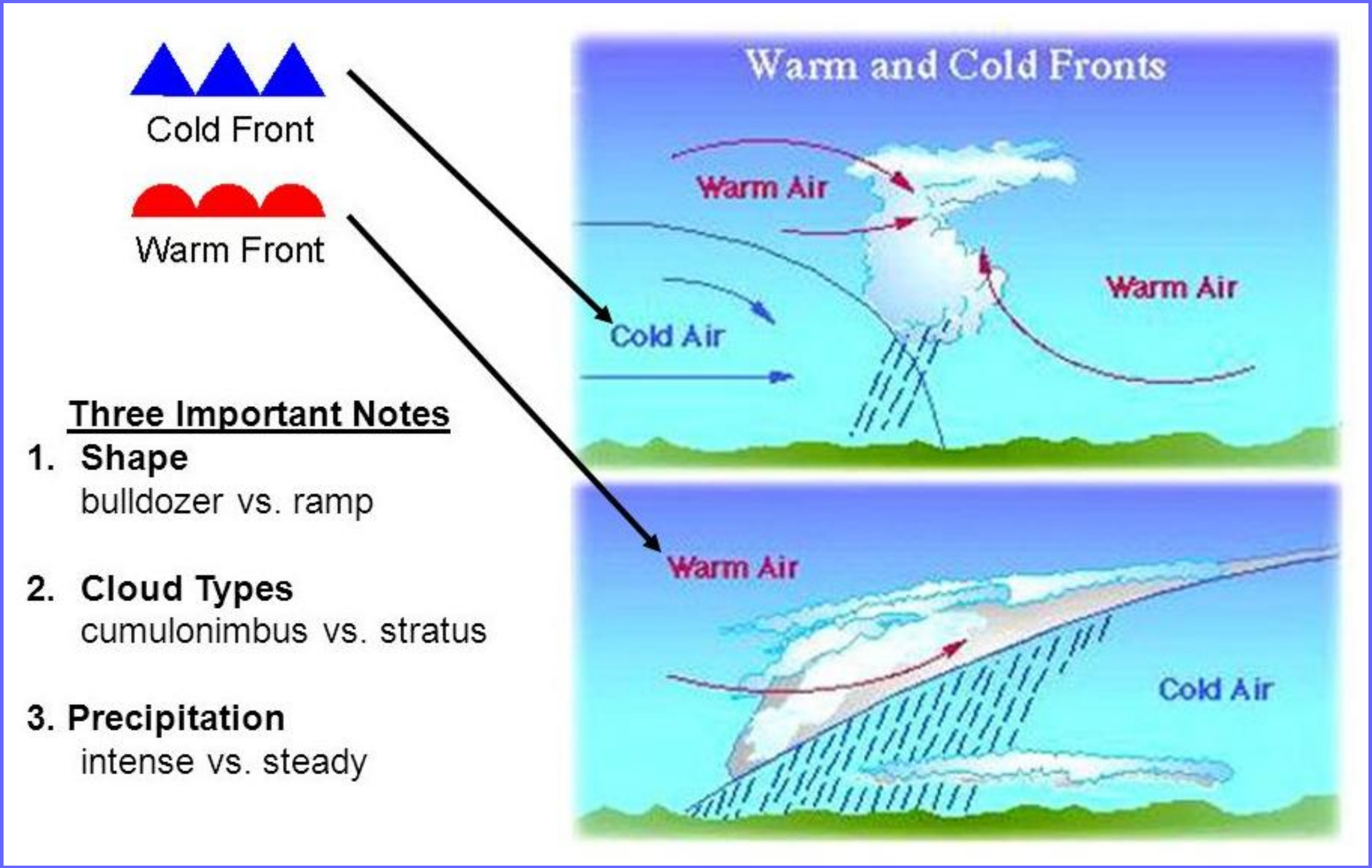
The warm air moves over the cold air because it is less dense. Has a gentle slope and moves slower than cold front. Precipitation is typically steady, widespread and generally light to moderate, in winter brings snow.

# Warm Front (2)


Cloud Development
Because of Frontal Lifting
of Warm Moist Air
Advancing
Warm Air
Behind Warm
Front
Receding Cold Air
Ahead of Warm Front
Warm Front
Map Symbol
Direction of
Frontal Movement

# Cold Front vs. Warm Front



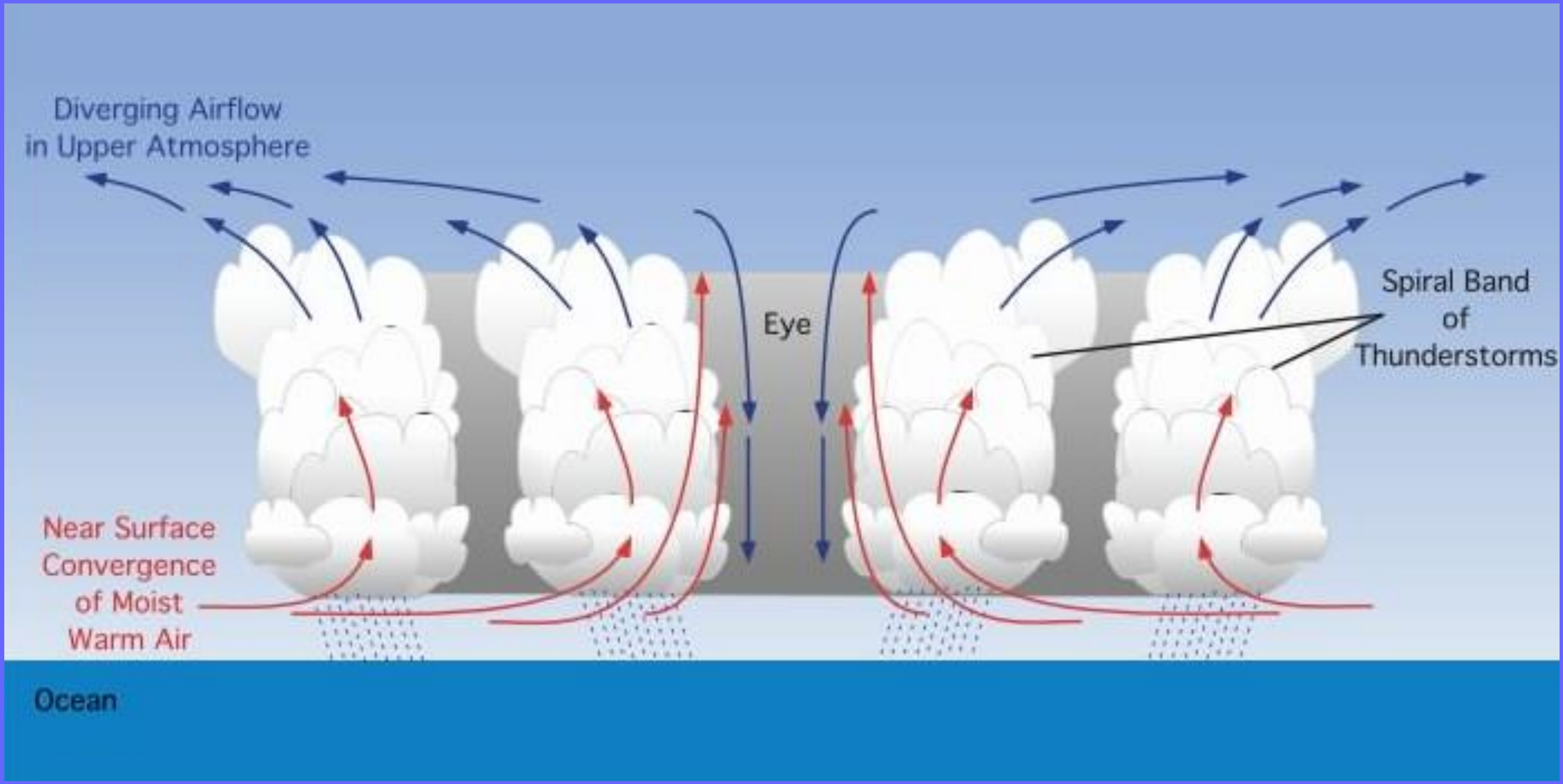

https://www.google.hu/search?q=non+frontal+cyclonic+precipitation&espv=2&biw=1366&bih=623&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwid8YqOzZjPAhWjPZoKHewlBJcQsAQIKw#tbm=isch&q=cold+front+vs+warm+front&imgrc=VOloGe7rjm9ddM%3A

# Non-frontal Precipitation

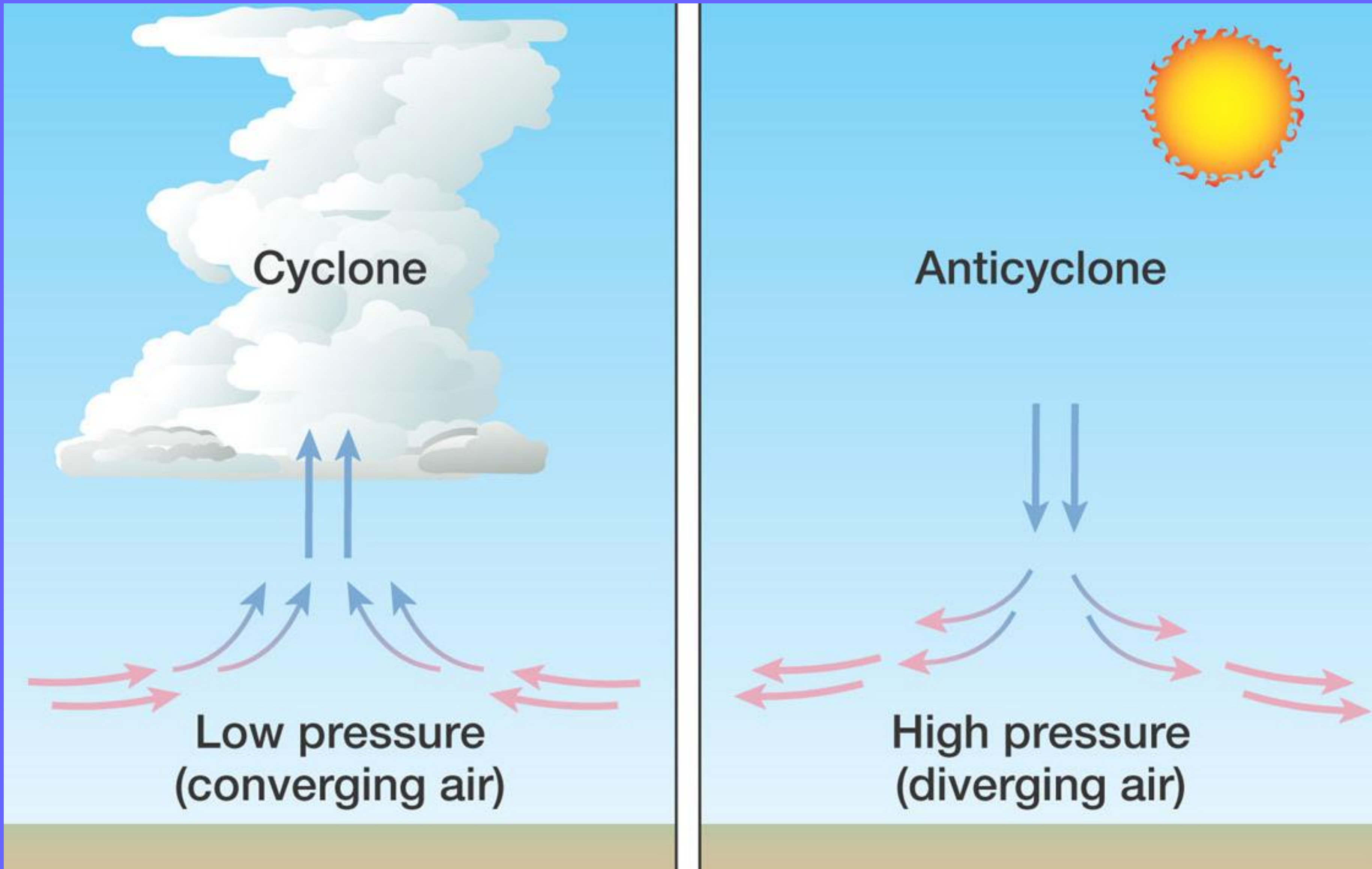
If low pressure occurs in an area (called cyclone), air will flow horizontally from the surrounding area (high pressure), causing the air in the low-pressure area to lift.

When the lifted warm-air cools down at a higher altitude, non-frontal cyclonic precipitation will occur.

# Cyclone




https://www.google.hu/search?q=non+frontal+cyclonic+precipitation&espv=2&biw=1366&bih=623&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwid8YqOzZjPAhWjPZoKHewlBJcQsAQIKw#tbm=isch&tbs=rimg%3ACVY1nUqrFbHyIjjTE72k9uPh2FgDD_1YRNPgI7pnTe-RsqAFcHoxMYF0oIo9Ap3gL5xW3HCzeXH12vR1Wb_1pM26u-WioSCdMTvaT24-HYEXeRIqKhCgQ7KhIJWAMP9hE0-AgRF4HJTzE3eD0qEgnumdN75GyoARHcwgWzxd4pqSoSCVwejExgXSgiEUDl-3ZS9kgfKhIJj0CneAvnFbcRWd1O3gnDxc0qEgkcLN5cfXa9HRE8_1aE-7P4g0SoSCVZv-kzbq75aEZC2F4_1qlBMj&q=causes%20of%20cyclones&imgrc=VwGQAYl93uSRmM%3A




https://www.google.hu/search?q=precipitation+forms&espv=2&biw=1366&bih=667&source=lnms&tbm=isch&sa=X&ved=0ahUKEwjahNKw05PPAhXjYJoKHfpJB6AQ_AUIBigB&dpr=1#tbm=isch&q=convergence+lifting+mechanism&imgdii=N17h39V_CxQJ6M%3A%3BN17h39V_CxQJ6M%3A%3B0pKuPFAFj6GiCM%3A&imgrc=N17h39V_CxQJ6M%3A

# Why do we need to measure rainfall?

Agriculture: what to plant in certain areas, where and when to plant, when to harvest

Horticulture/viticulture: how and when to irrigate

Engineering: to design structures for runoff control i.e., storm-water channel, -drains, bridges, etc.

Science: hydrological modeling of catchments

# Measurement of Precipitation

Often have a funnel opening into a cylinder gauge.

Come in a variety of shapes and sizes.

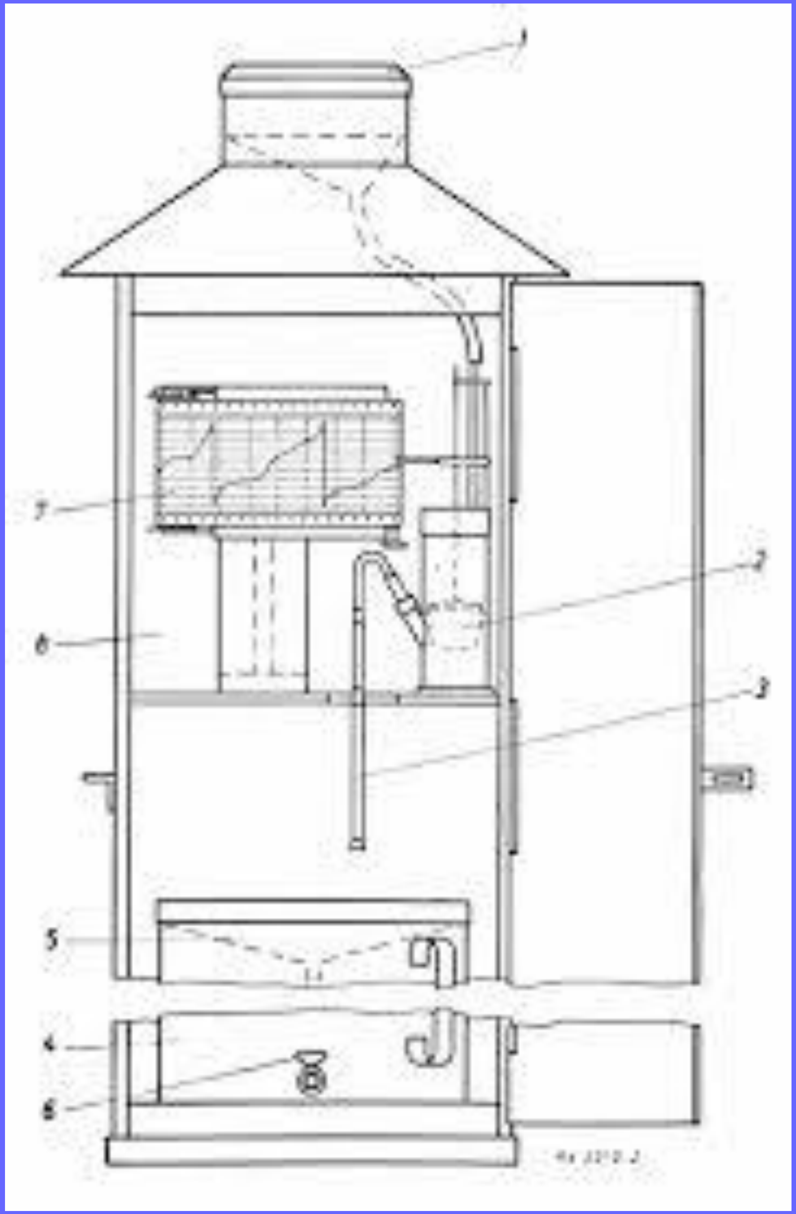
Calculate the rainfall (in mm) by dividing the volume of water collected by the area of the opening of the cup.

# Hellmann precipitation gauge

The area covered by this gauge is 200 $cm^2$, and the collection vessel's capacity is 1.2 liters to 1.4 liters.

The gauge is normally placed at the height of 1 meter above the ground surface.


# **Hellmann type with chart recorders** (1)

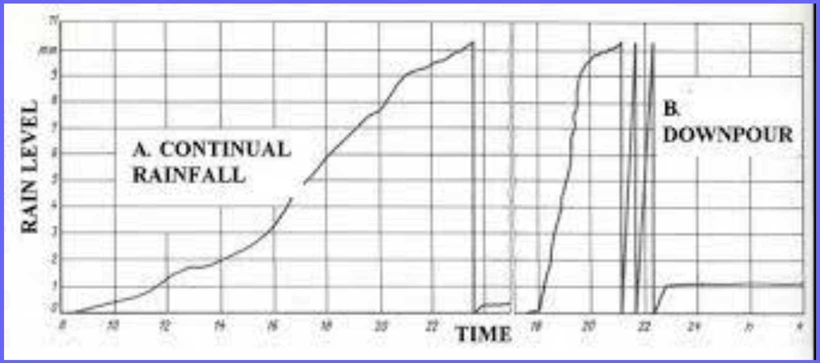


The working principle is based on a float.

Precipitation water flows from the collection vessel into a metal cylinder containing the floating object.

The float is fitted with a spindle to which a recording pen is attached, which records the water height onto a registration drum.

# Hellmann type with chart recorders (2)




When the height of water corresponding to the precipitation height of 10mm is achieved, the metal cylinder is emptied by means of a siphon system, and the precipitation water is drained into the collection vessel Hellmann precipitation gauge and recorder.

# Data for Precipitation

Rainfall Depth

Rainfall Time

Rainfall Intensity

Rainfall Volume

Rainfall Yield

Hyetograph

Rainfall Mass Curve

**Rainfall Depth** is the measure of the total depth of rainfall in one day (or hour).

Symbol: P

Unit: mm (at rainfall), cm (at snow)

**Rainfall Time** is the duration of rainfall

Symbol: T

Unit: h, min, sec

**Rainfall intensity** is defined as the ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period. It is expressed in depth units per unit time.

Symbol: i

Formula: $i = \frac{P}{T}$

Unit: $\frac{mm}{hr}, \frac{mm}{min}, \frac{cm}{hr}$

**Rainfall volume:** the amount of precipitation can be converted into a total volume of water. A rainfall of 1 mm depth supplies 0.001 $m^3$, or 1 litre of water to each square metre of the catchment area.

Symbol: V

Formula: $V = A \cdot P = A \cdot i \cdot T$

(A is the catchment area in $m^2$ or in ha)

Unit: $dm^3$ ($1\ dm^3 = 1$ liter), $m^3$

**Rainfall yield:**

Symbol: Y

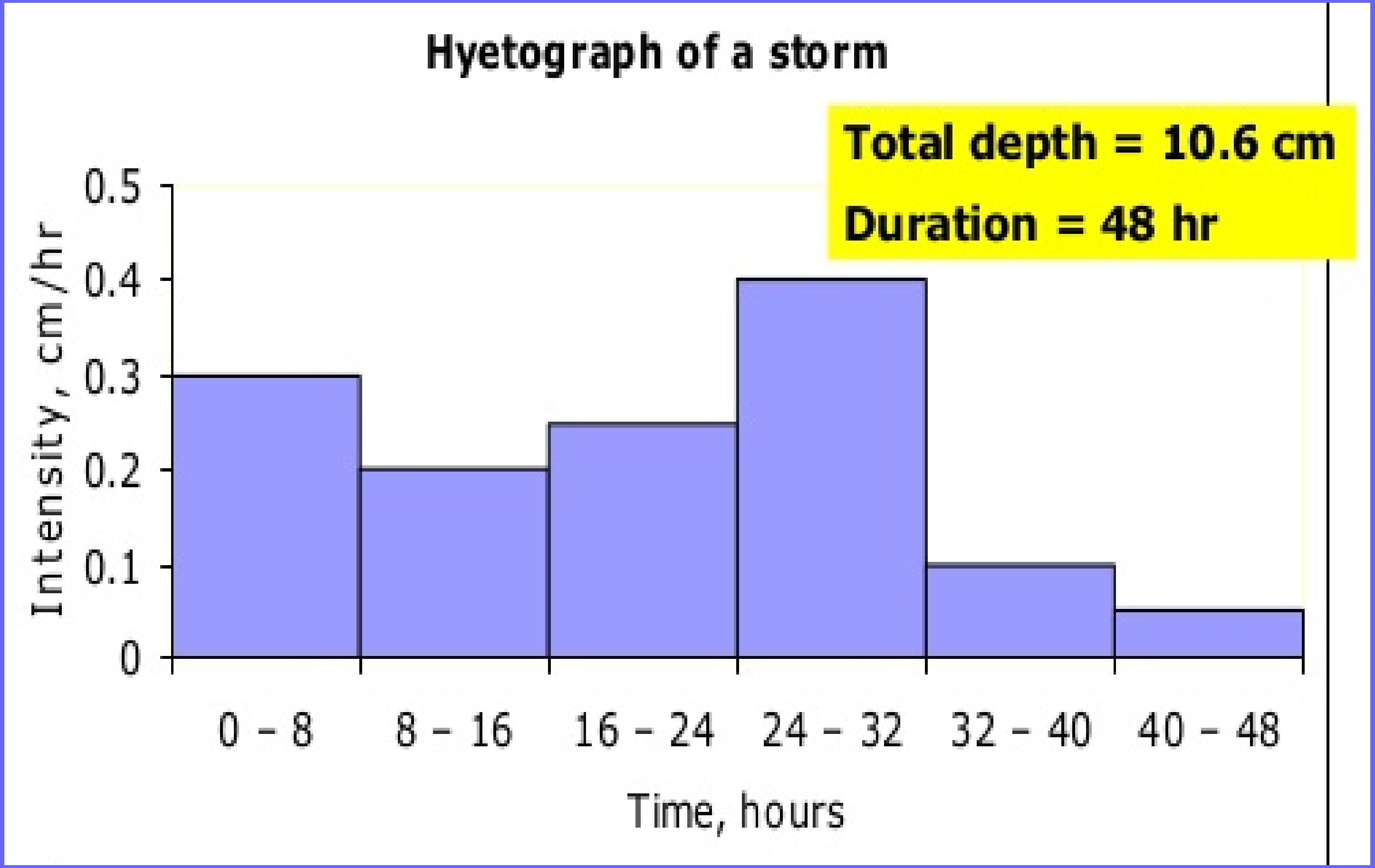
Formula: $Y = \frac{V}{T} = \frac{P \cdot A}{T} = \frac{i \cdot A \cdot T}{T} = \mathrm{i} \cdot A$

Unit: $\frac{m^3}{hr}$ , $\frac{m^3}{sec}$, $\frac{liter}{sec}$

**Hyetograph** is a bar graph showing the intensity of rainfall with respect to time.

Symbol: i(t)

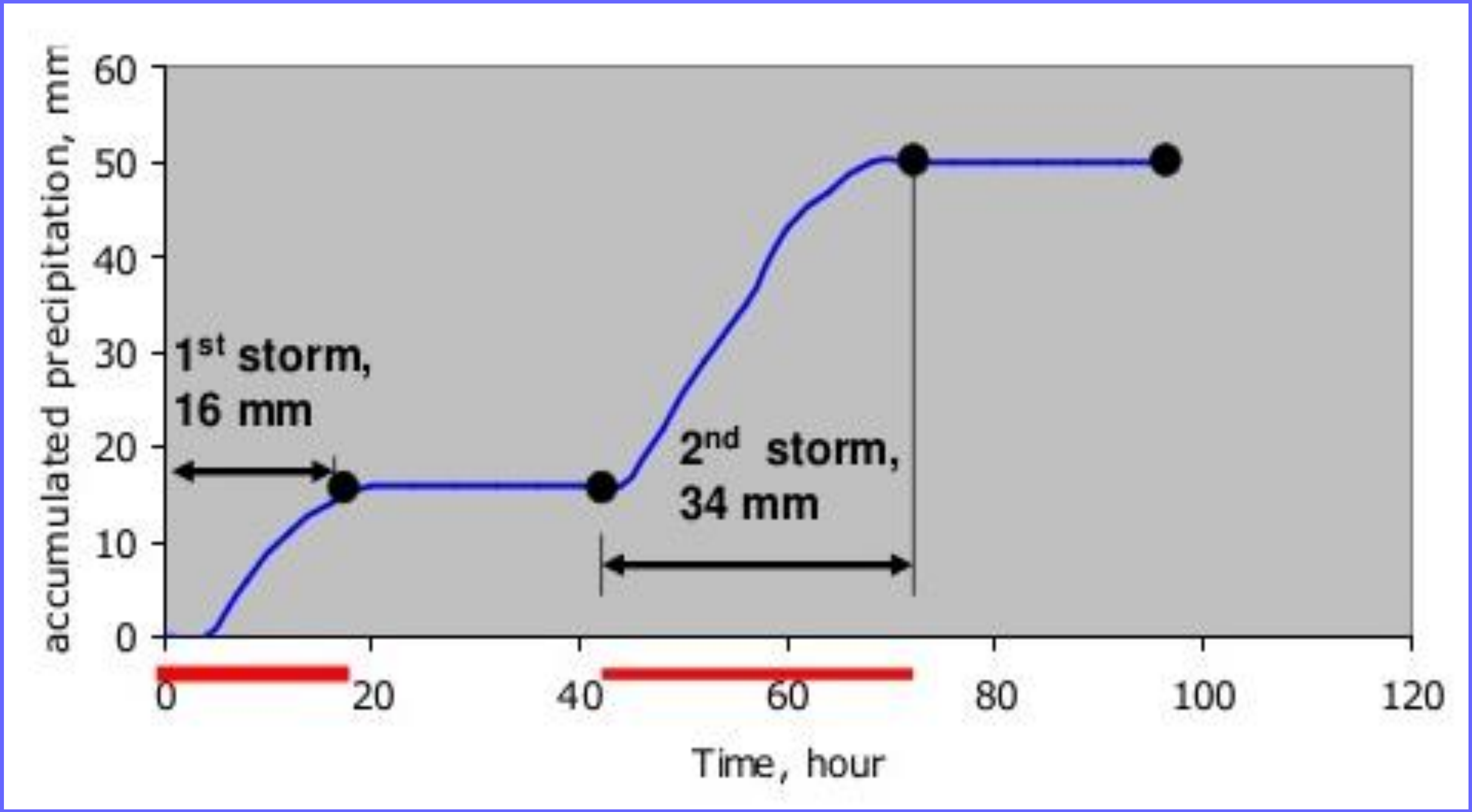
Formula: $i(t) = \frac{dP}{dt}$



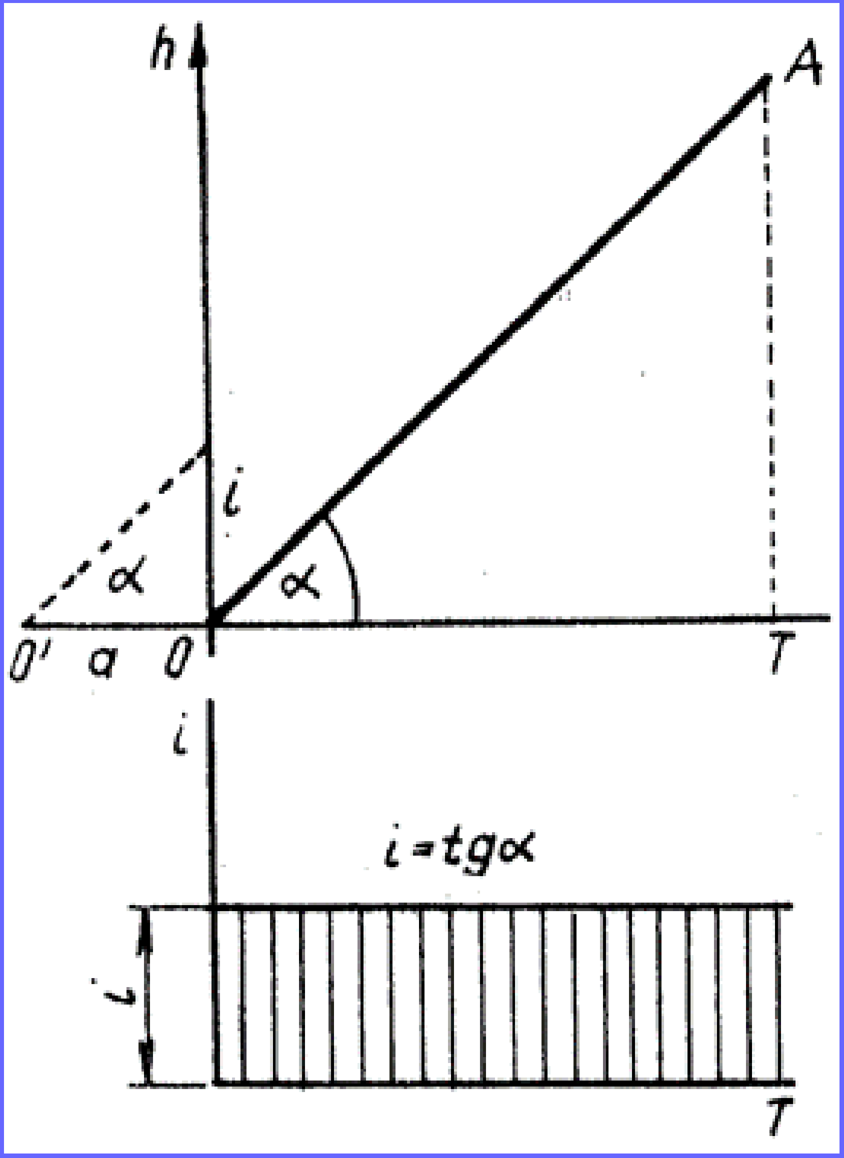
**Rainfall Mass Curve** is a plot of the cumulative depth of rainfall against time.

Symbol: P(t)

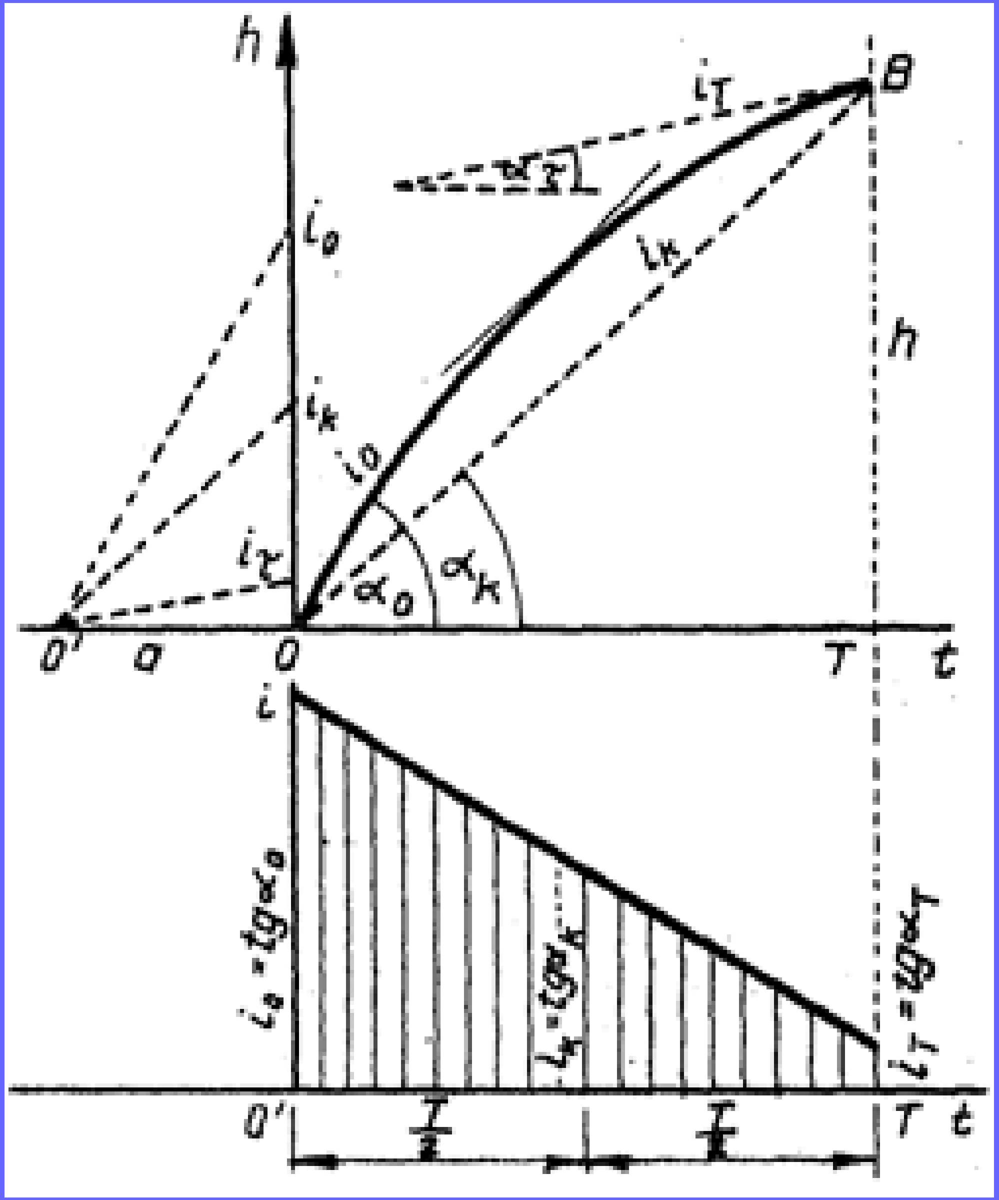
Formula: $P(t) = \int_0^t i \, dt$



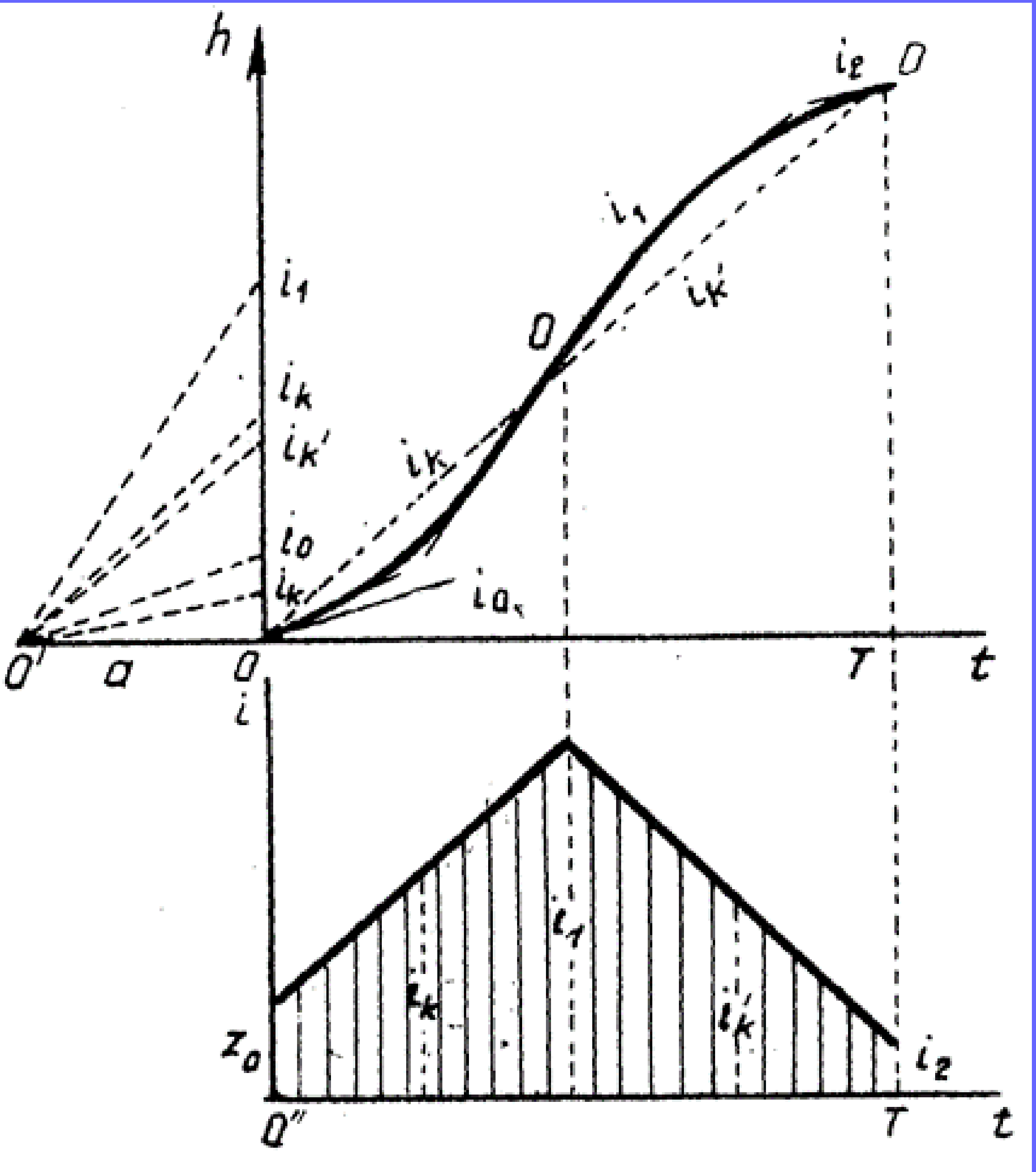
# Hyetograph - Rainfall Mass Curve connection (1)



# Hyetograph - Rainfall Mass Curve connection(2)



# Hyetograph - Rainfall Mass Curve connection (3)



E1:

There was a rainfall. The total rainfall depth was $P=20$ mm, the duration of the rainfall was $T=4$ hours. The catchment area is $A=15$ hectares.

Calculate

(a) the intensity (i);

(b) the volume (V);

(c) the yield (Y),

construct

(d) the hyetograph (i(t)) and

(e) the rainfall mass curve (P(t)).

E2:

The catchment area is A=200 hectares. The duration of the rainfall was T=4 hours, the average intensity was $i_{avg}$= 0.05 mm/min .

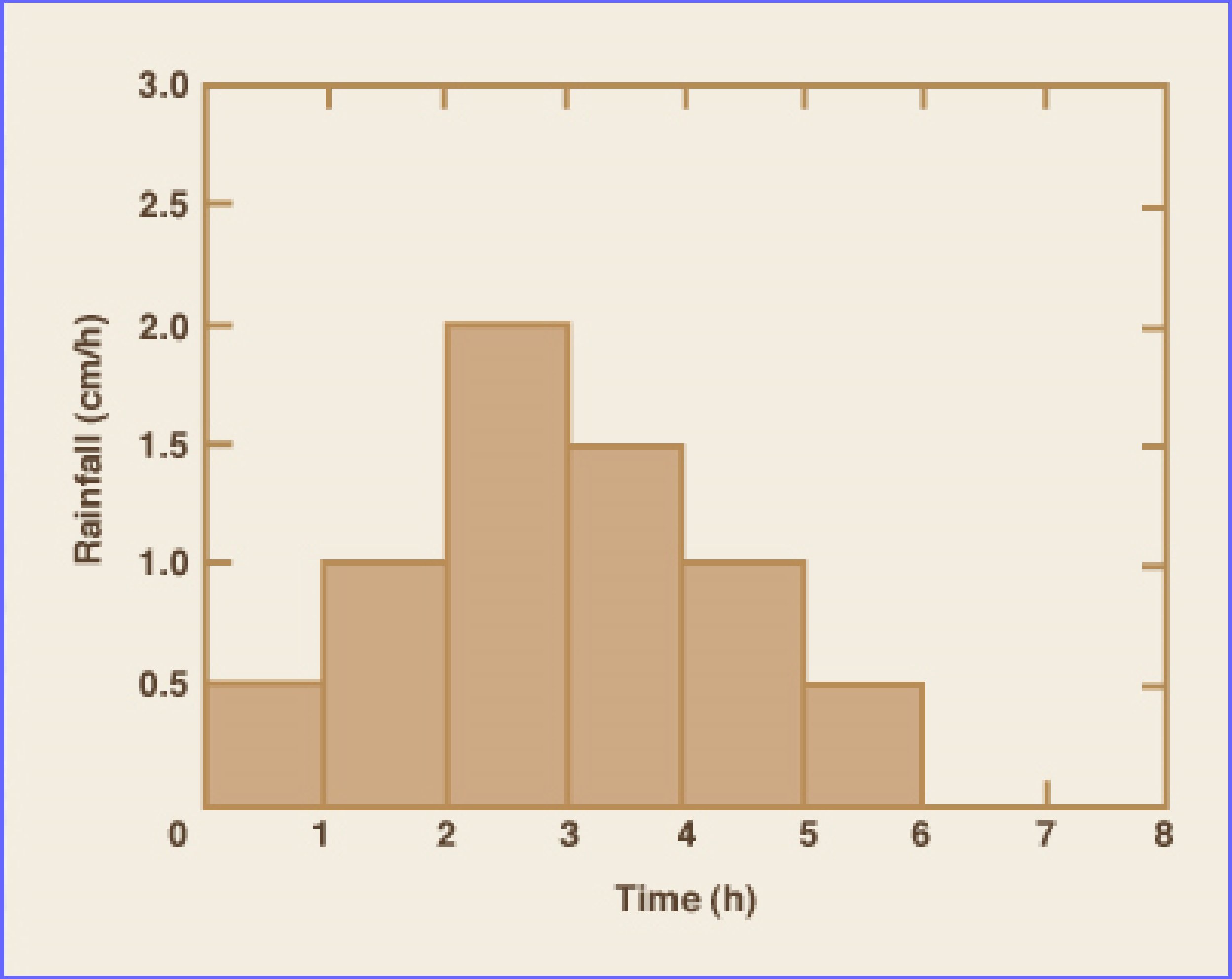
Calculate

(a) the volume (V);

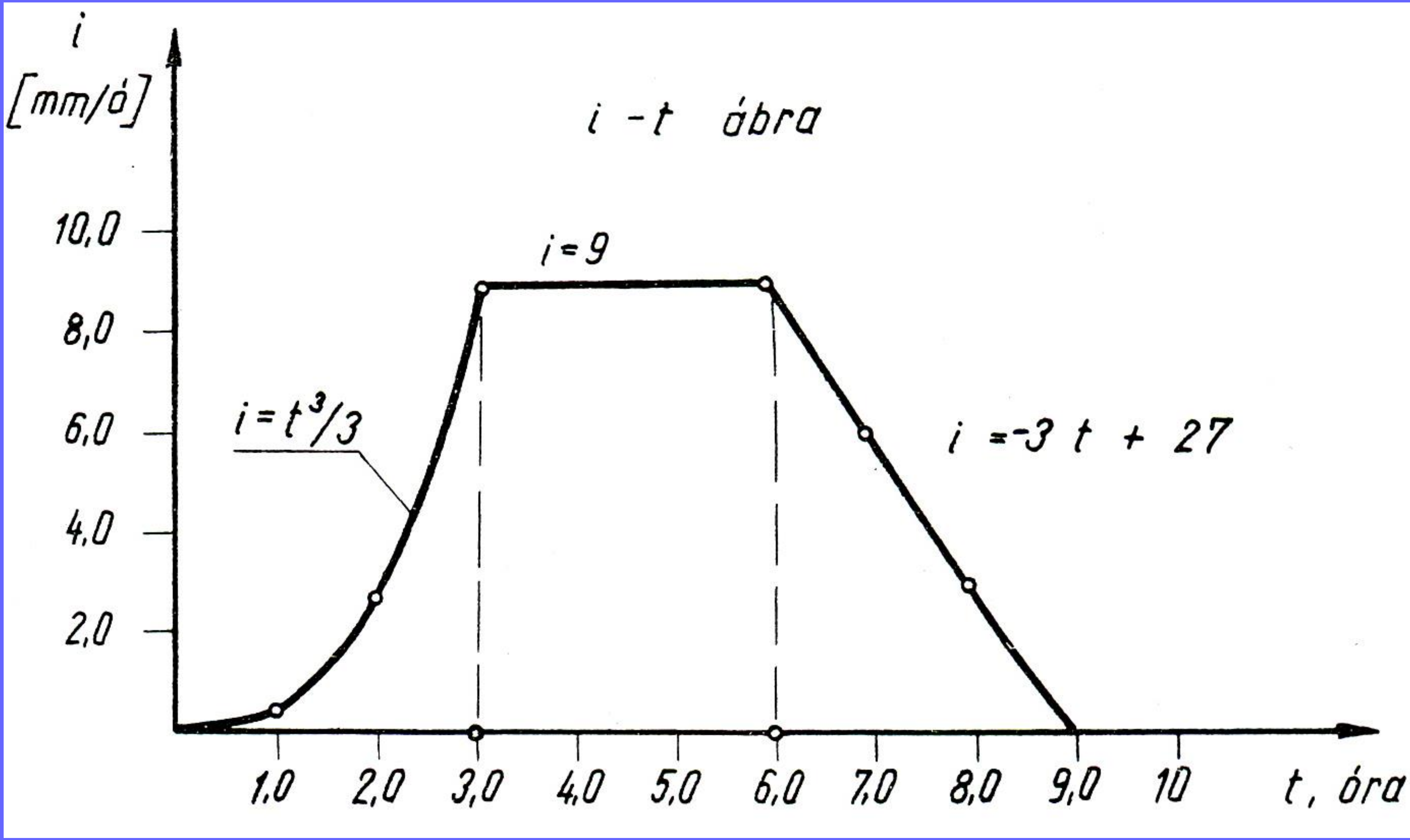
(b) the yield (Y) and

(c) the average intensity in unit liter/sec ha.

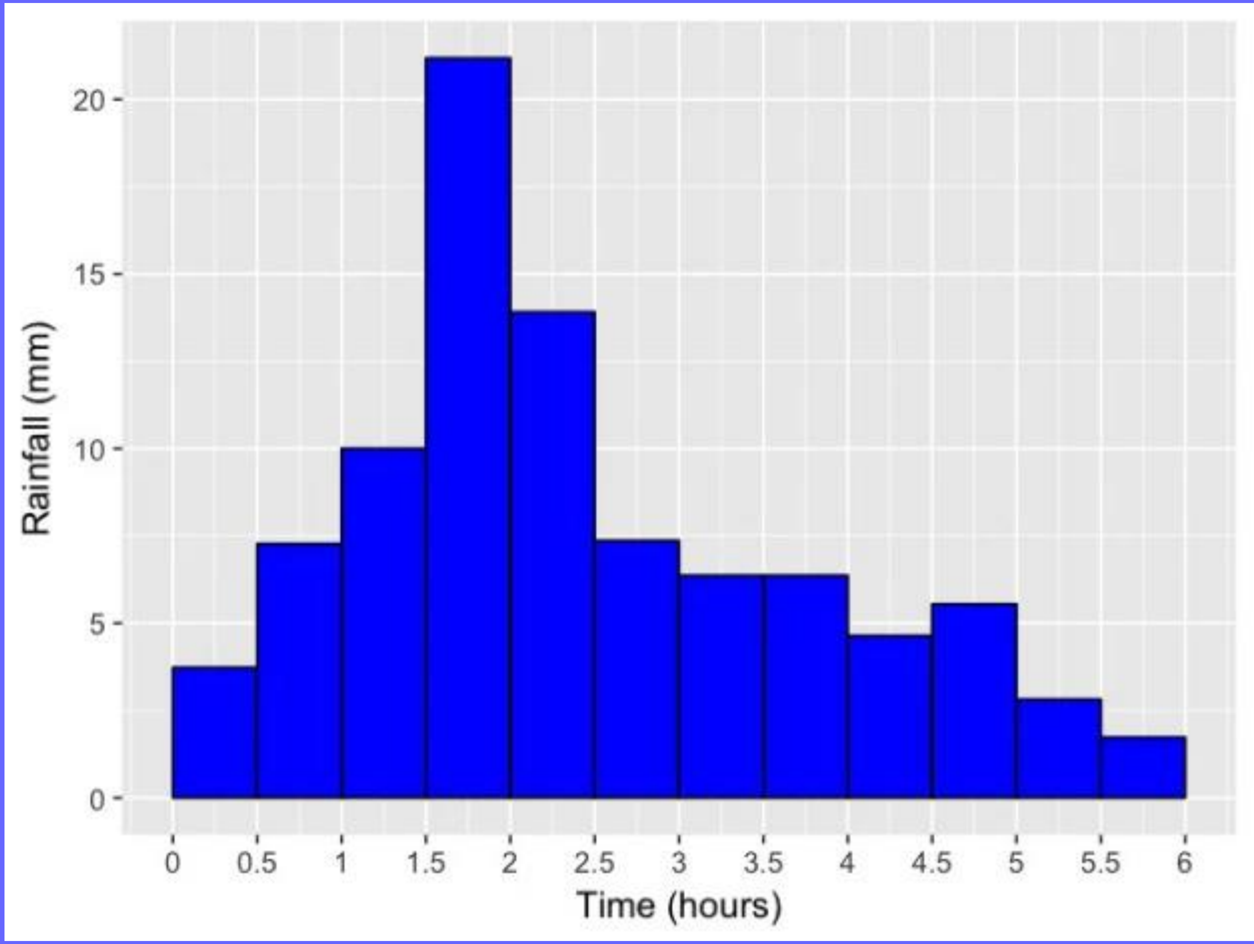
E3: The Hyetograph of the rainfall is known (below).
Calculate (a) total rainfall depth, (b) average intensity
Construct (c) rainfall mass curve



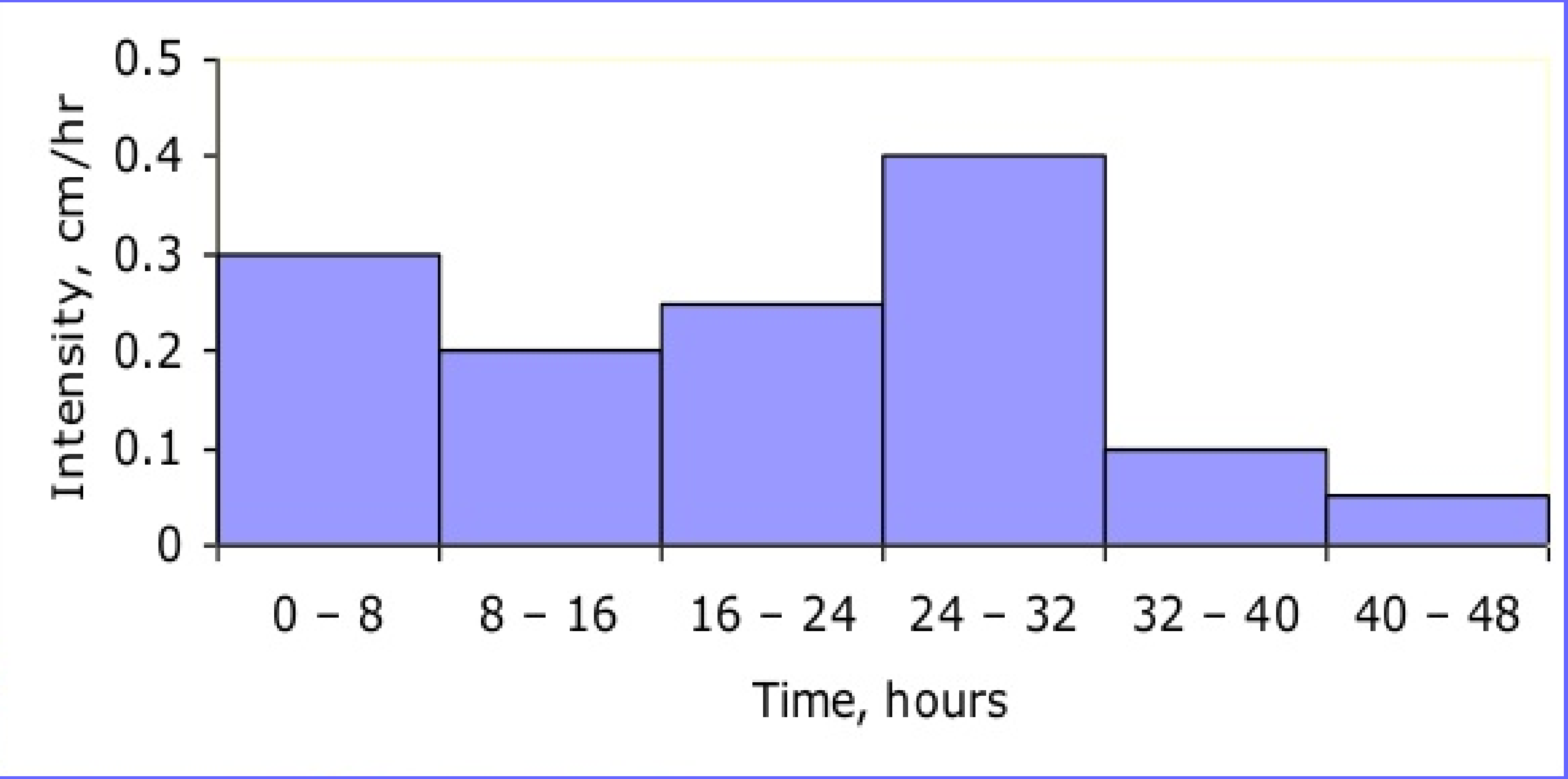
E4: The Hyetograph of the rainfall is known (below). Construct the rainfall mass curve



E5: Calculate (a) total rainfall depth, (b) average intensity; construct (c) rainfall mass curve



E6: Calculate (a) total rainfall depth, (b) average intensity; construct (c) rainfall mass curve



E7:

The hyetograph of the rainfall is known.

Calculate

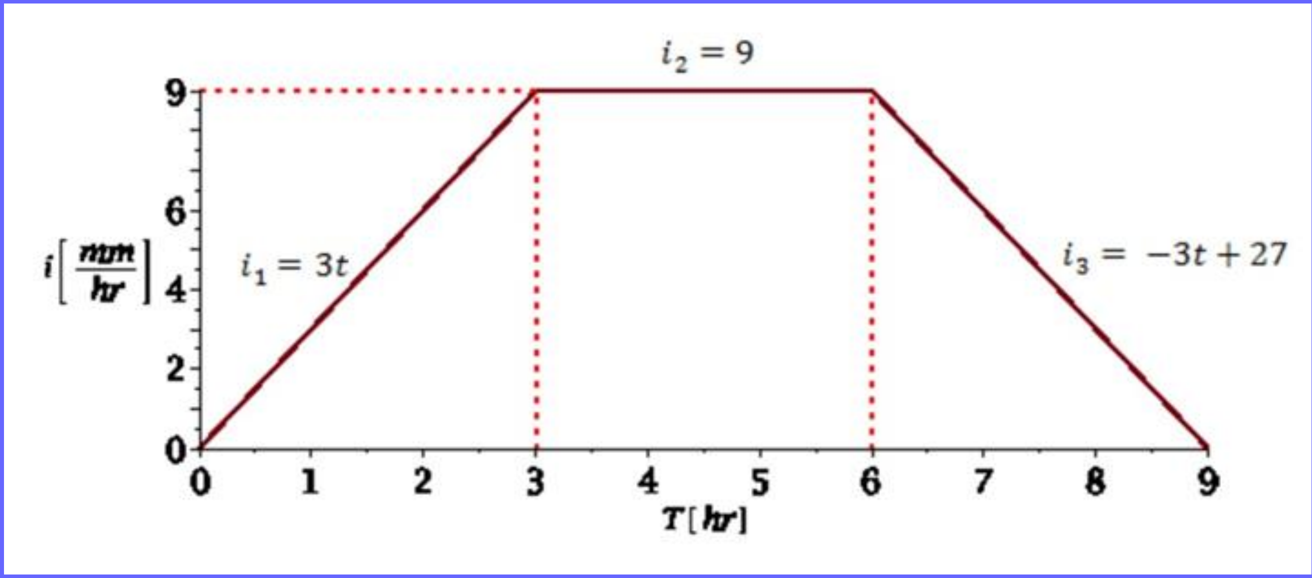
(a) the total rainfall depth (P),

(b) the average intensity ($i_{avg}$) and

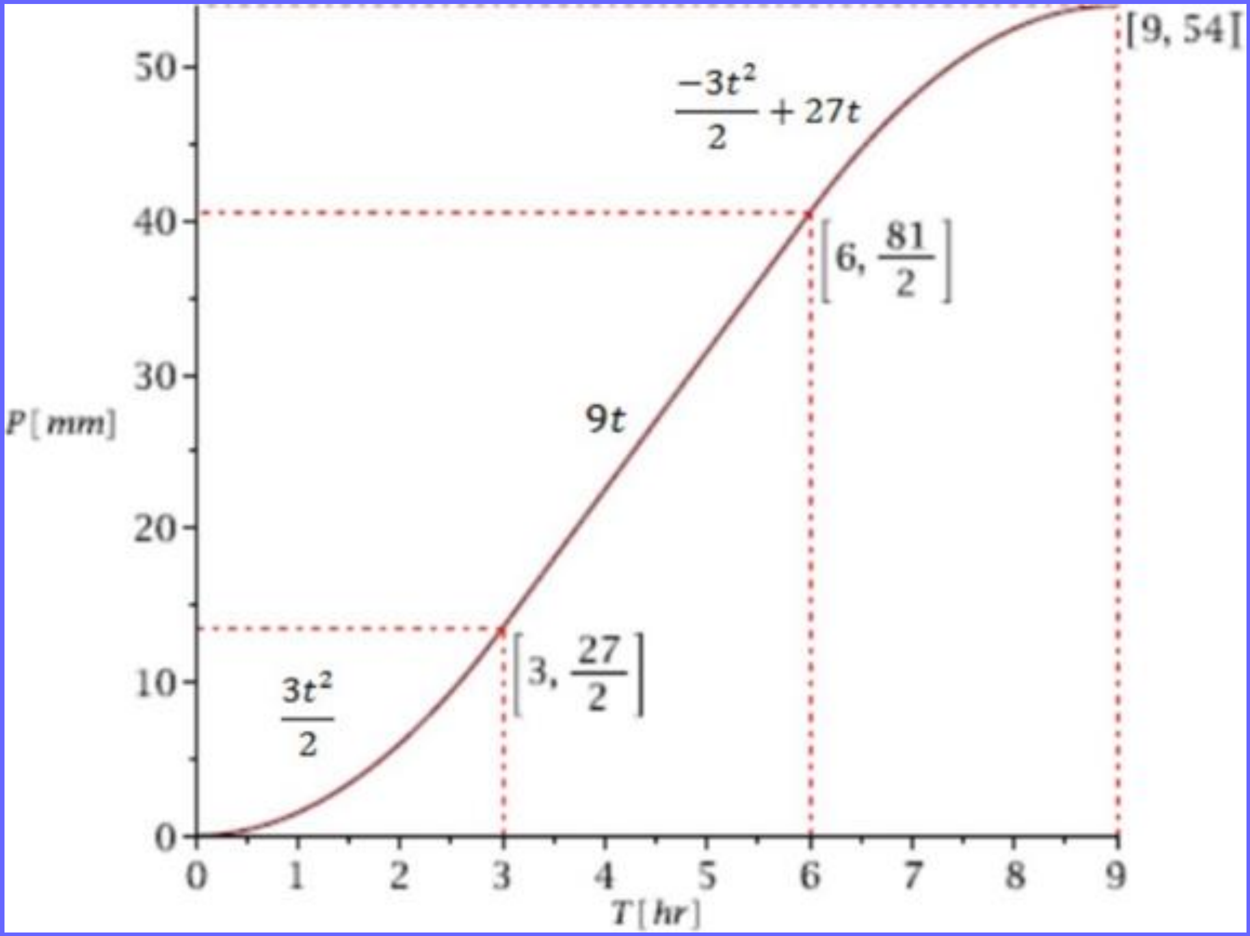
construct

(c) the rainfall mass curve (P(t)).

The hyetograph is:



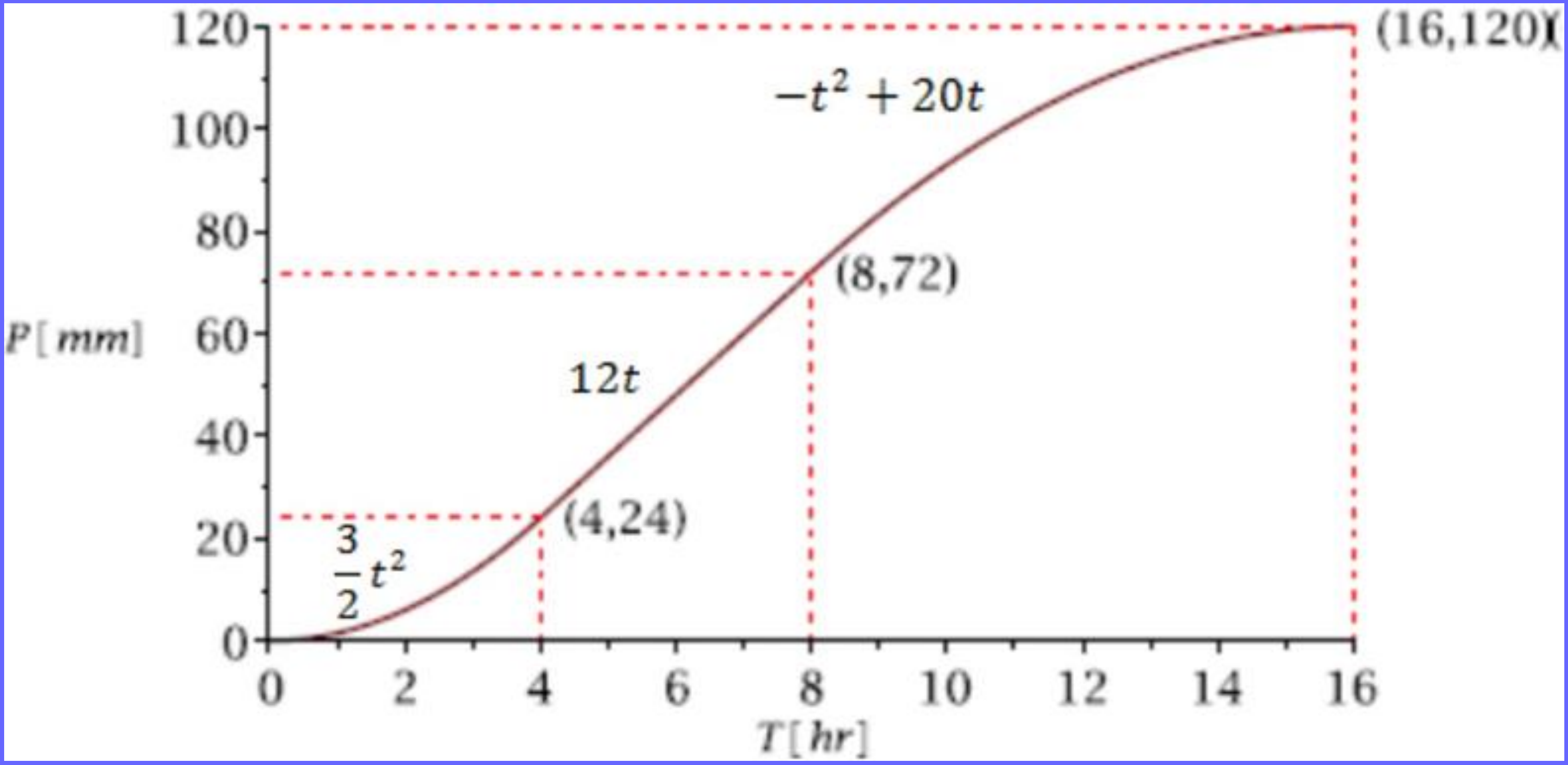
# E7: result (c)



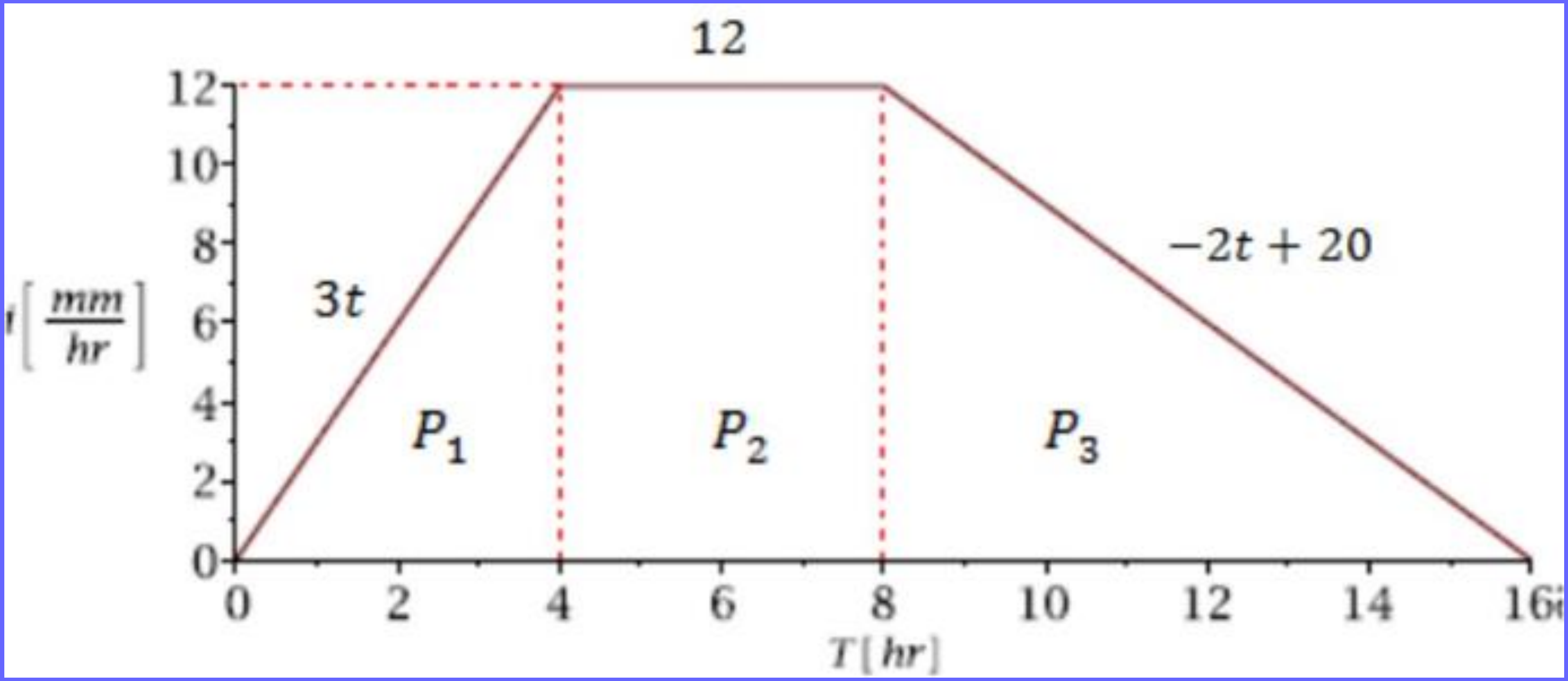
P [ mm ]
T [ hr ]
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
$\frac{3t^2}{2}$
9t
$\frac{-3t^2}{2} + 27t$
$[3, \frac{27}{2}]$
$[6, \frac{81}{2}]$
[9, 54]

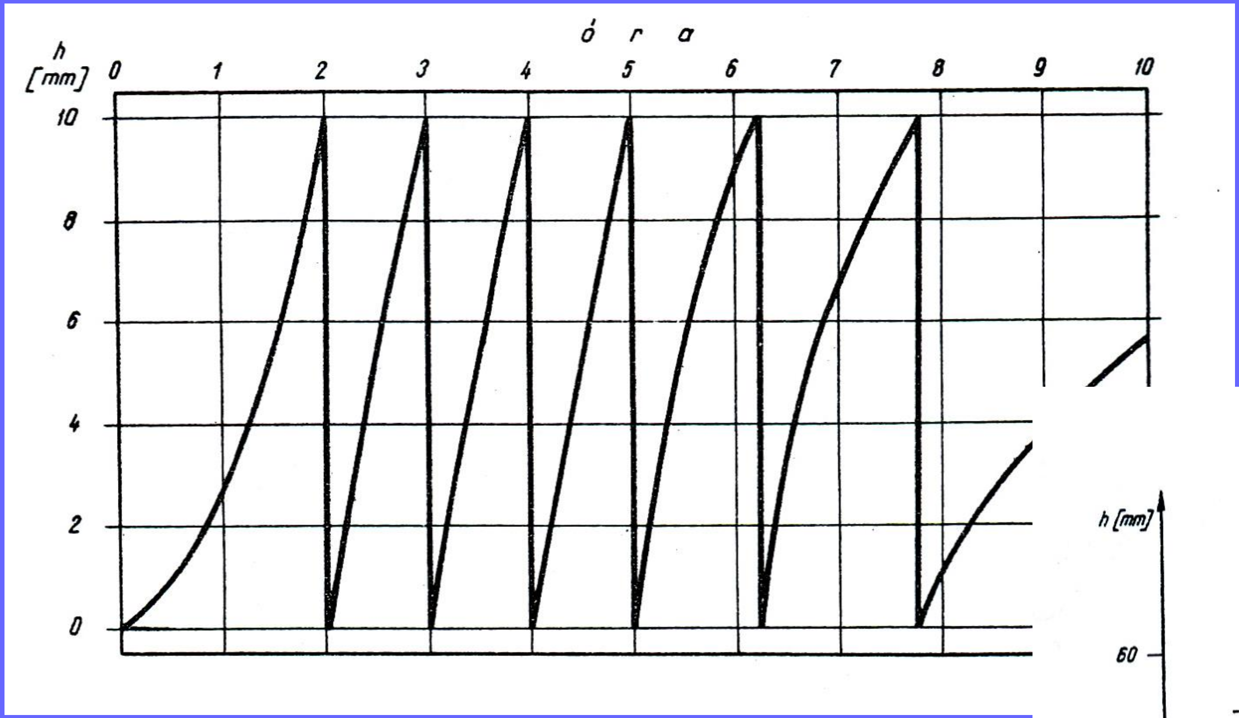
E8: The rainfall mass curve is known from a Hellmann rain recorder (from a registration drum paper). Construct (a) the hyetograph (i(t)) and calculate (b) the total rainfall depth (P), (c) the average intensity ($i_{avg}$).

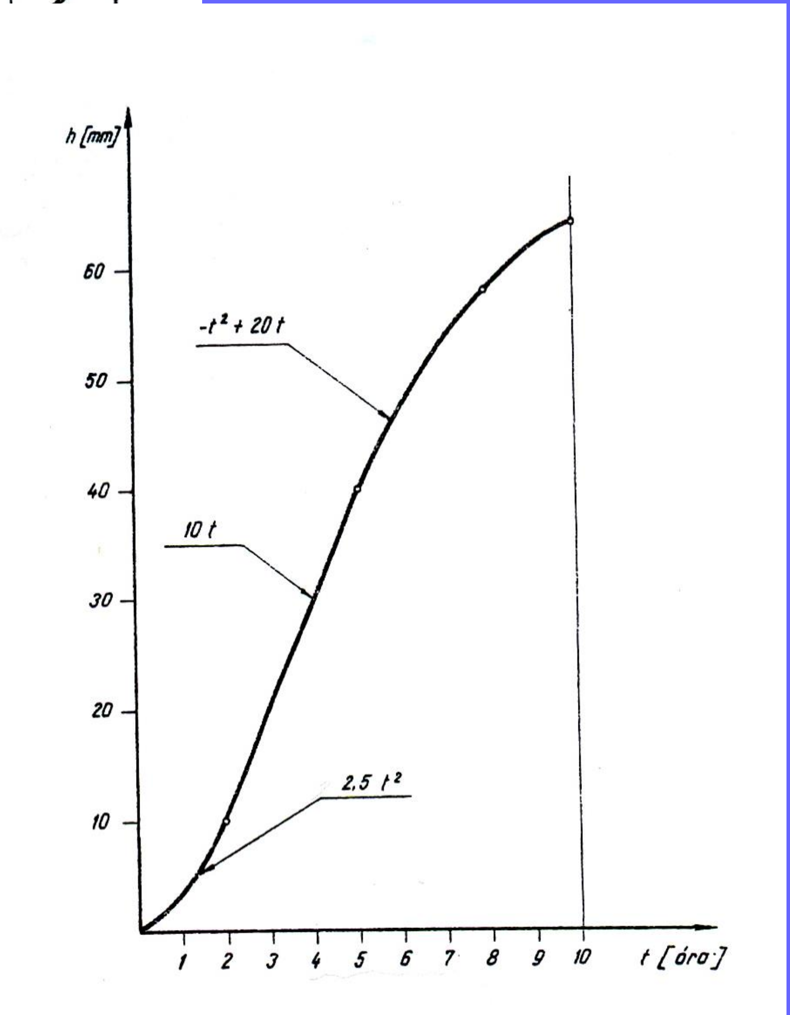
The rainfall mass curve from a Hellmann rain recorder is:



# E8: result (a)



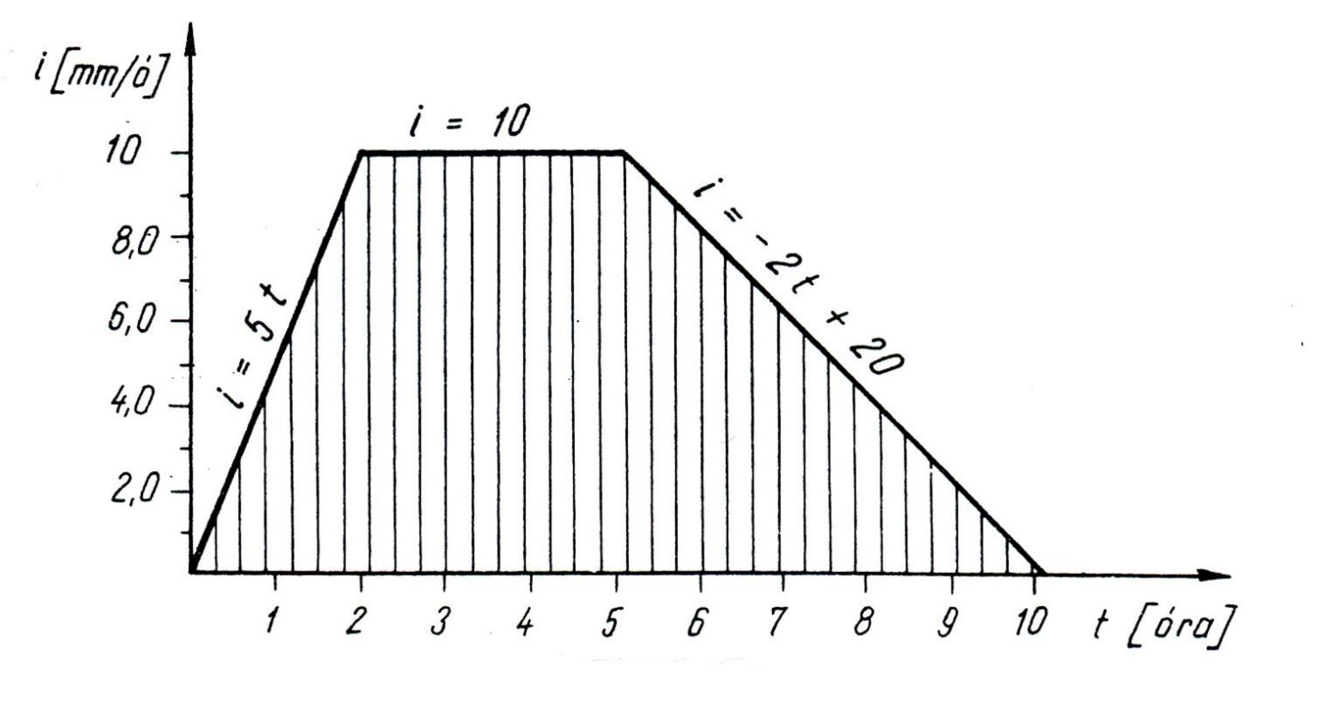


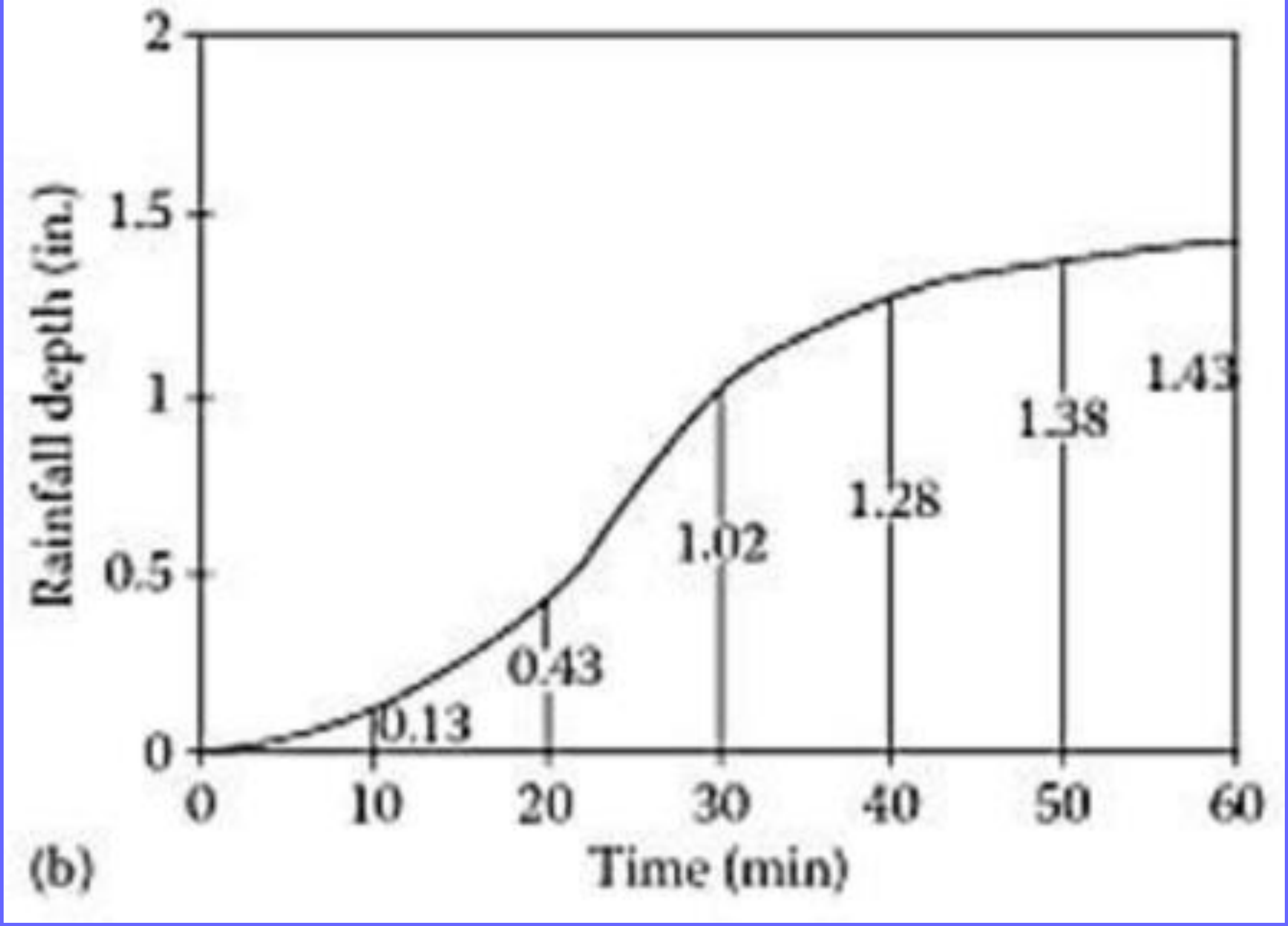

# E9:

Contruct the Hyetograph from the rainfall mass curve

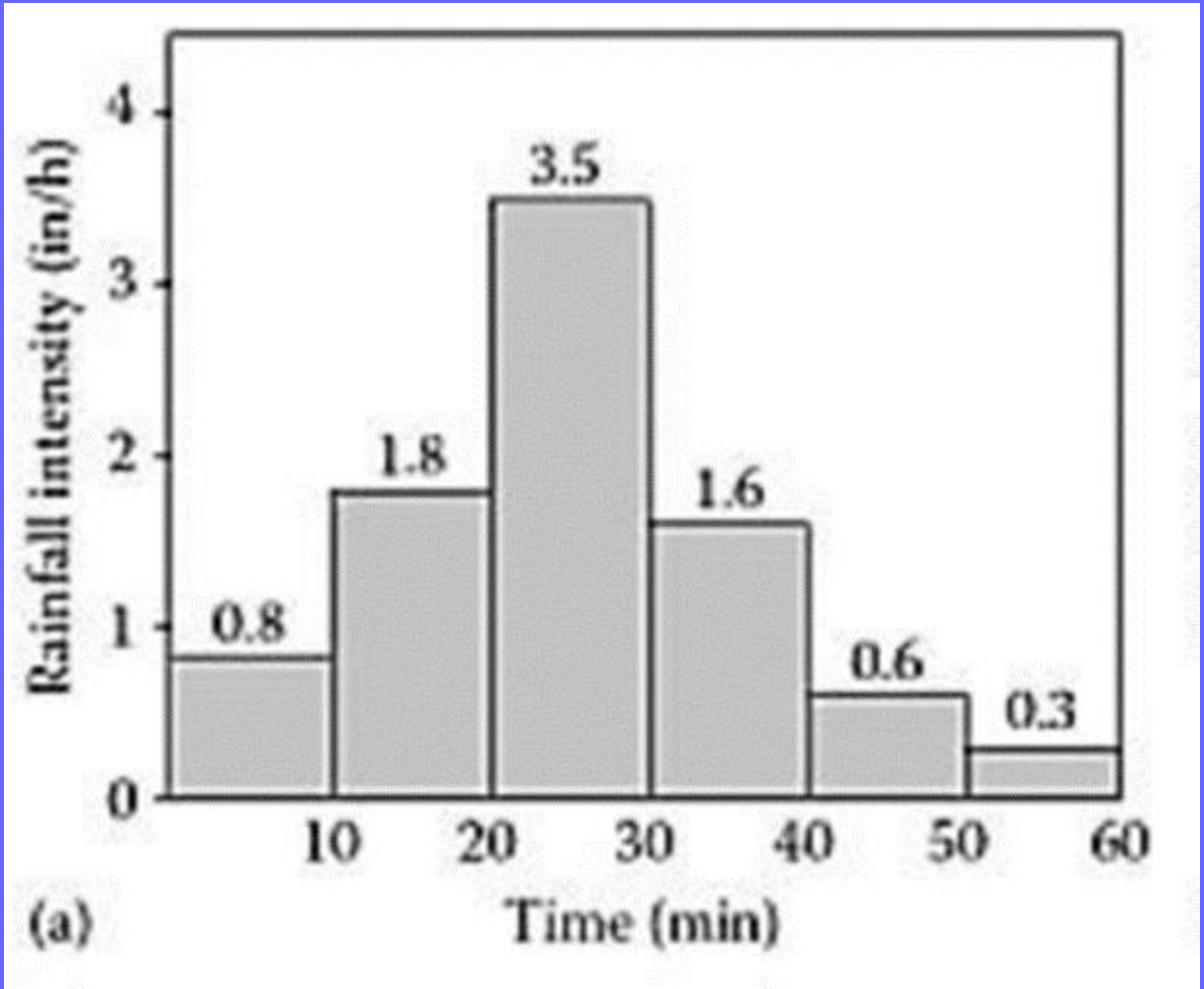
# E9: result



# E10: Contruct the Hyetograph from this rainfall mass curve



# E10: result



Rainfall intensity (in/h)
0
1
2
3
4
0.8
1.8
3.5
1.6
0.6
0.3
10
20
30
40
50
60
(a)
Time (min)

# Questions for discussion

The mechanism of precipitation
The primary types of clouds (should draw)
Five optional forms of precipitation (name, key features)
The three types of precipitation
How can we measure the precipitation (should draw)
Compare the cold front and warm front (should draw)

# 4 The Runoff and The Surface Water Hydrology

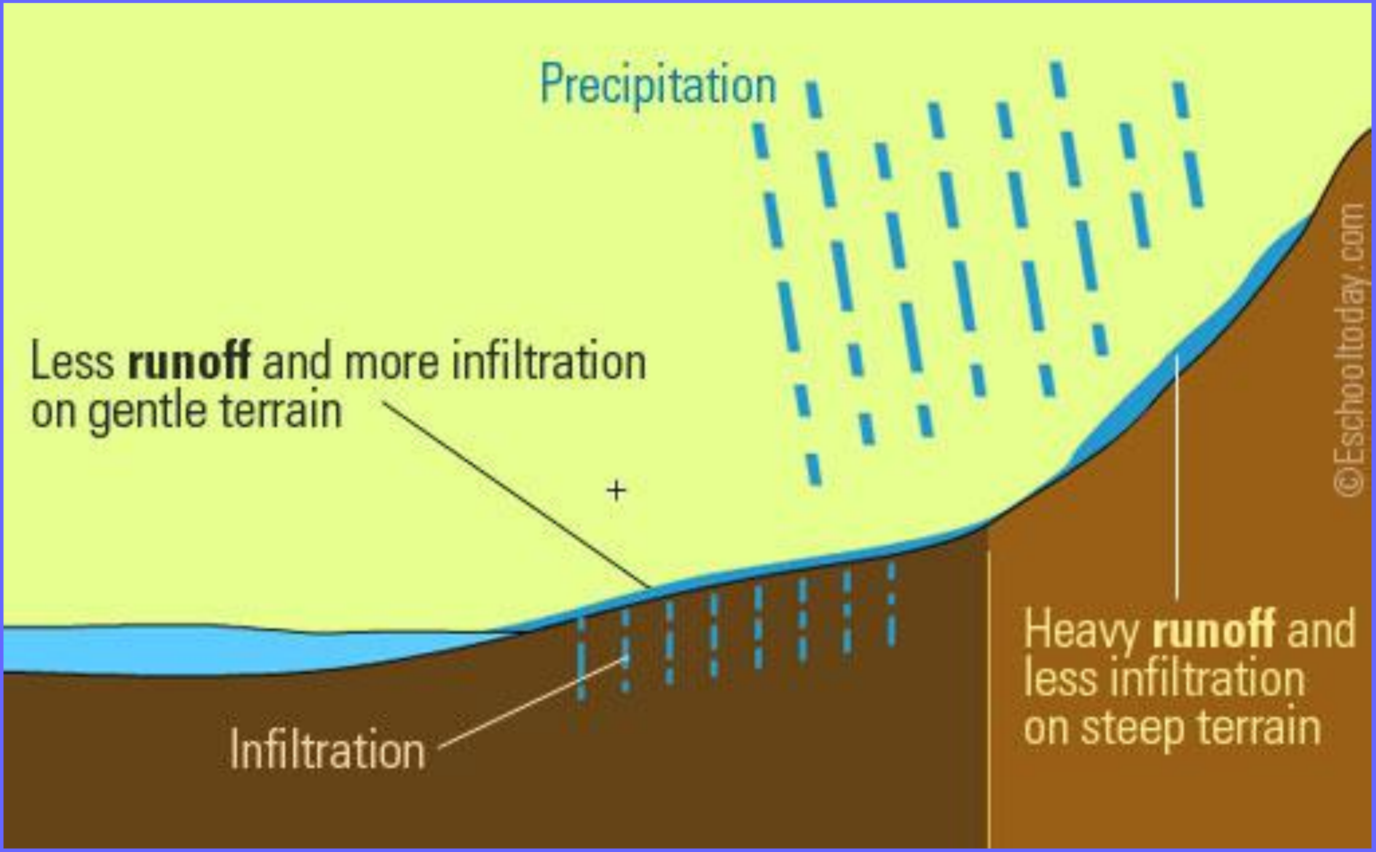
## Content

The Amount of Runoff
The Runoff Process
The Formation of Runoff
Interaction of Ground Water and Streams
Surface Water Hydrology
Three Stages of River Development, River Morphology
Lakes, Seasonal Layering
Surface Routing Models
Examples
Questions for Discussion

# Definition

Runoff is precipitation that did not infiltrate into the soil or did not evaporate, and therefore, made its way from the ground surface into places that water collect.

Runoff causes erosion.



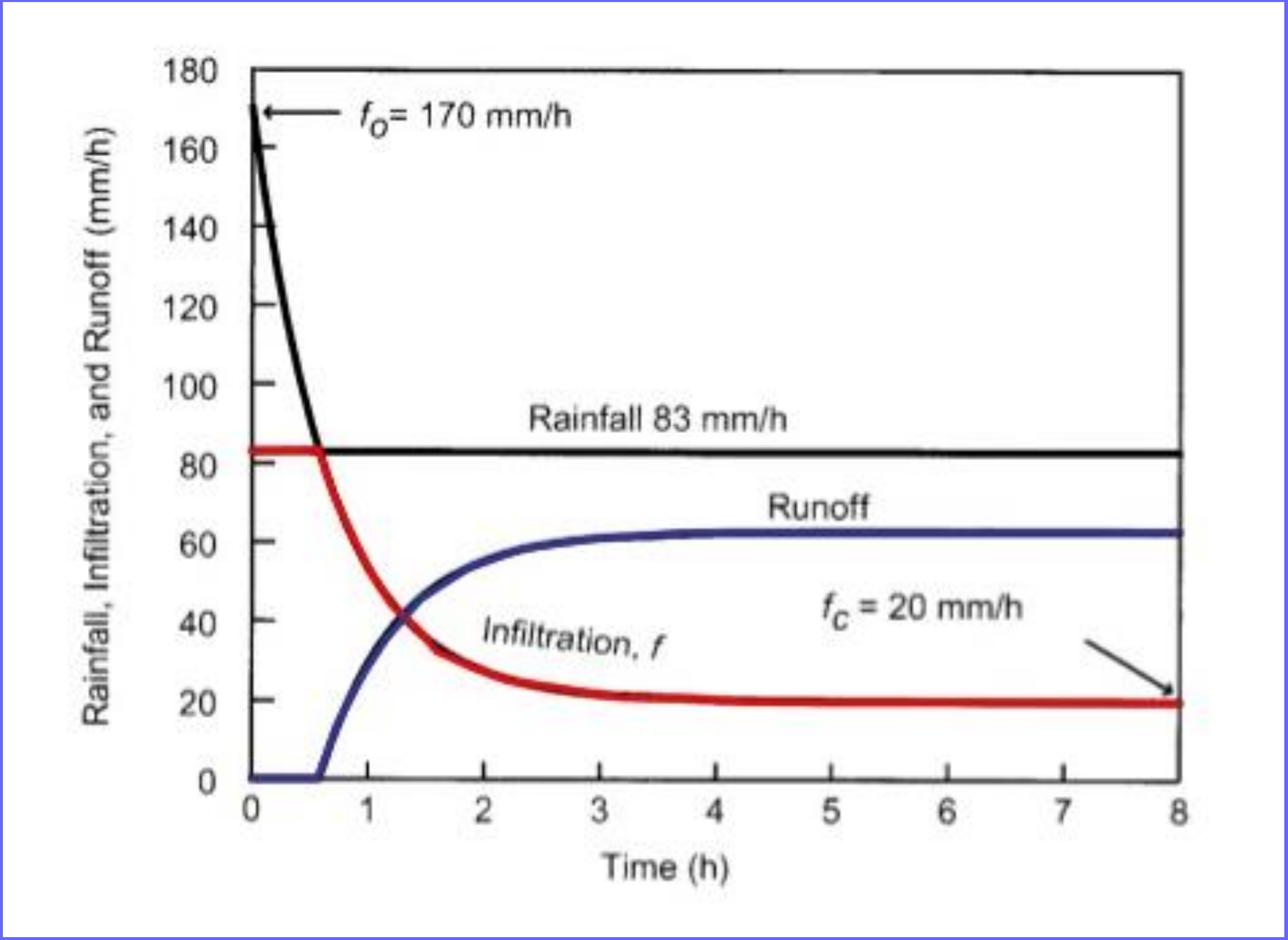
# The Amount of Runoff Depends on

**The topography of the land:** in areas with lots of hills, the water tends to have little time to be absorbed into the soil, it quickly runs down. If an area is very plain, the water has nowhere to flow.

**The nature of the soil or ground:** areas with soft, porous soils absorb more water than areas with rocky non-porous surfaces.

**The amount of precipitation:** when precipitation occurs in mild showers over long periods, the ground is not saturated, and the water is easily absorbed into the soil. In case of very heavy rain when the water is so much that it floods the area and water will find its level.

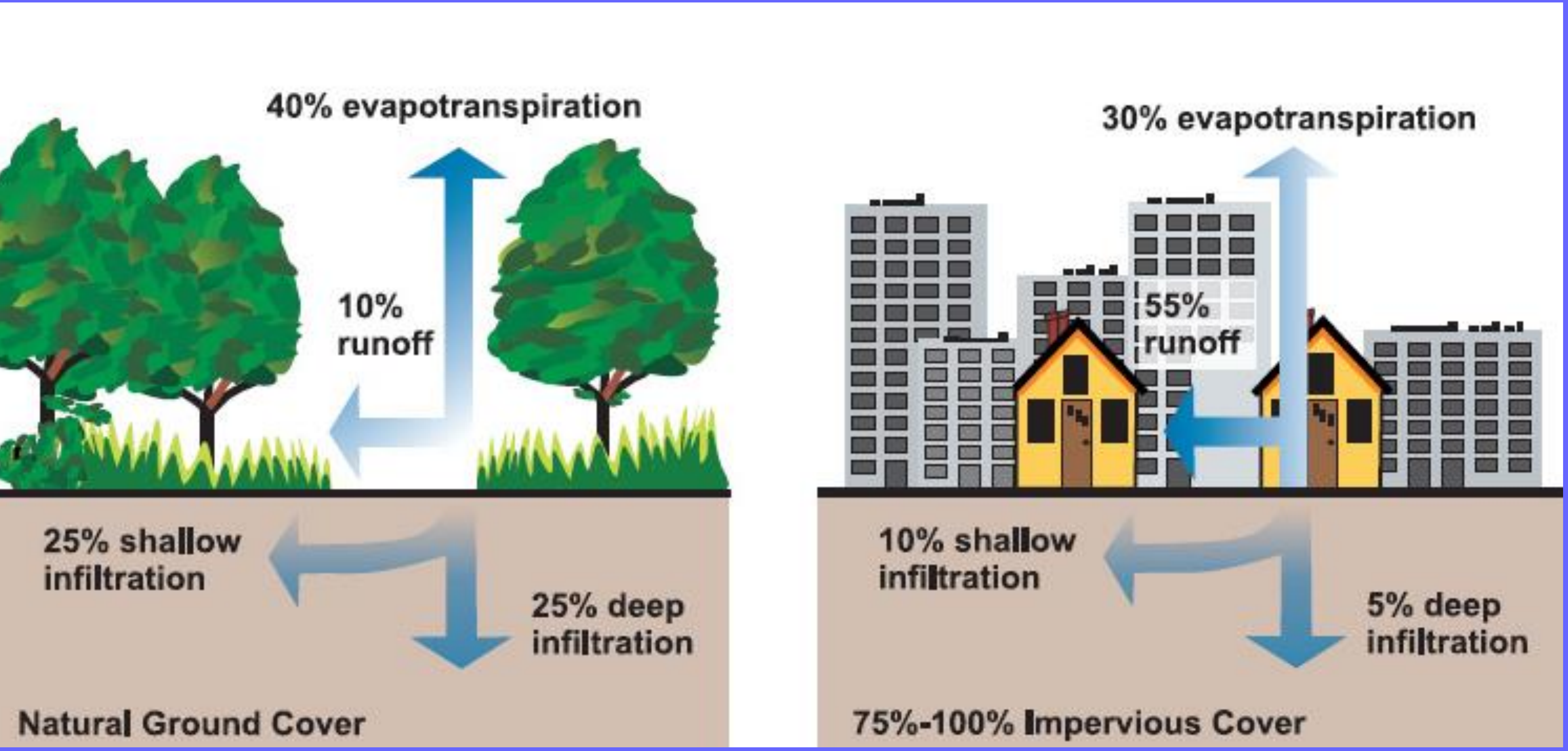
# The Runoff Process



# The Runoff Cycle (Process)

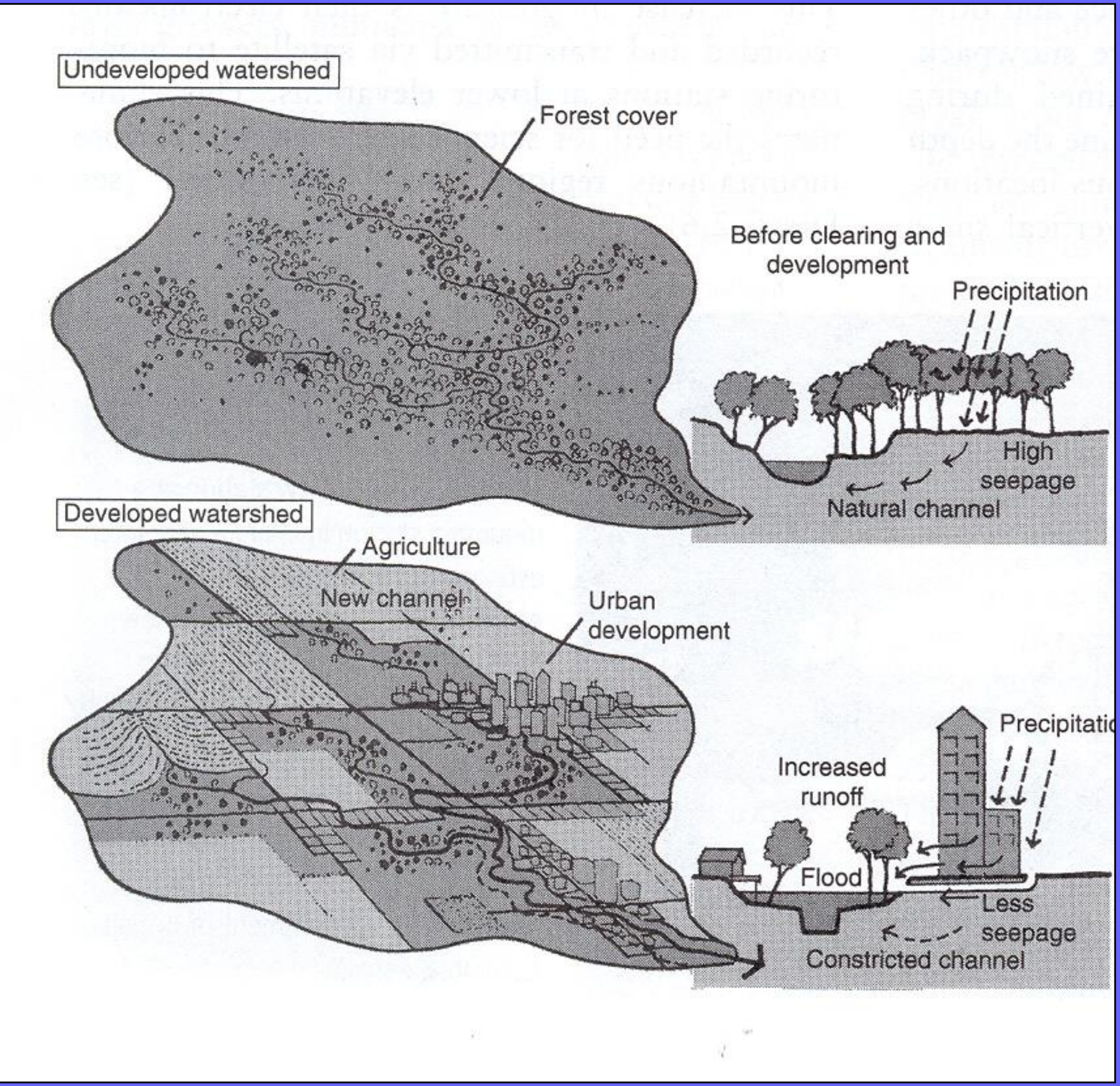
1. Rain is drown into the soil by infiltration and evaporate into the atmosphere
2. Continuous rain is producing runoff from overland and interflow
3. Rain moves along the land surface as runoff during and after a storm event.

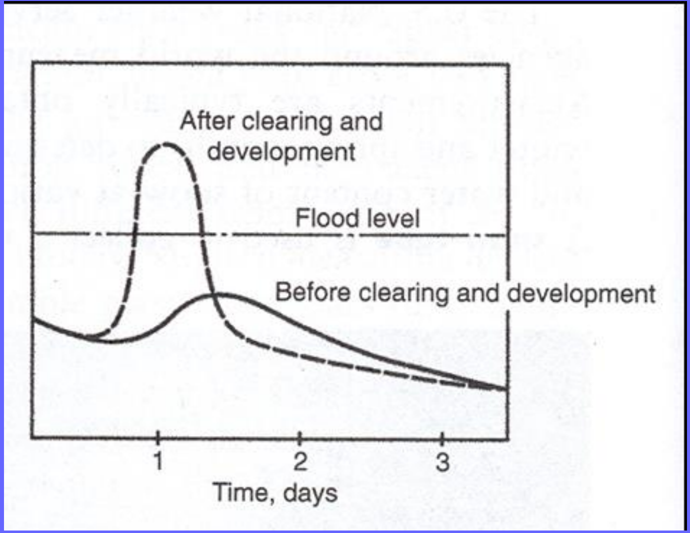
# Amount of Runoff (1)




https://upload.wikimedia.org/wikipedia/commons/4/46/Natural_%26_impervious_cover_diagrams_EPA.jpg

# Amount of Runoff (2)



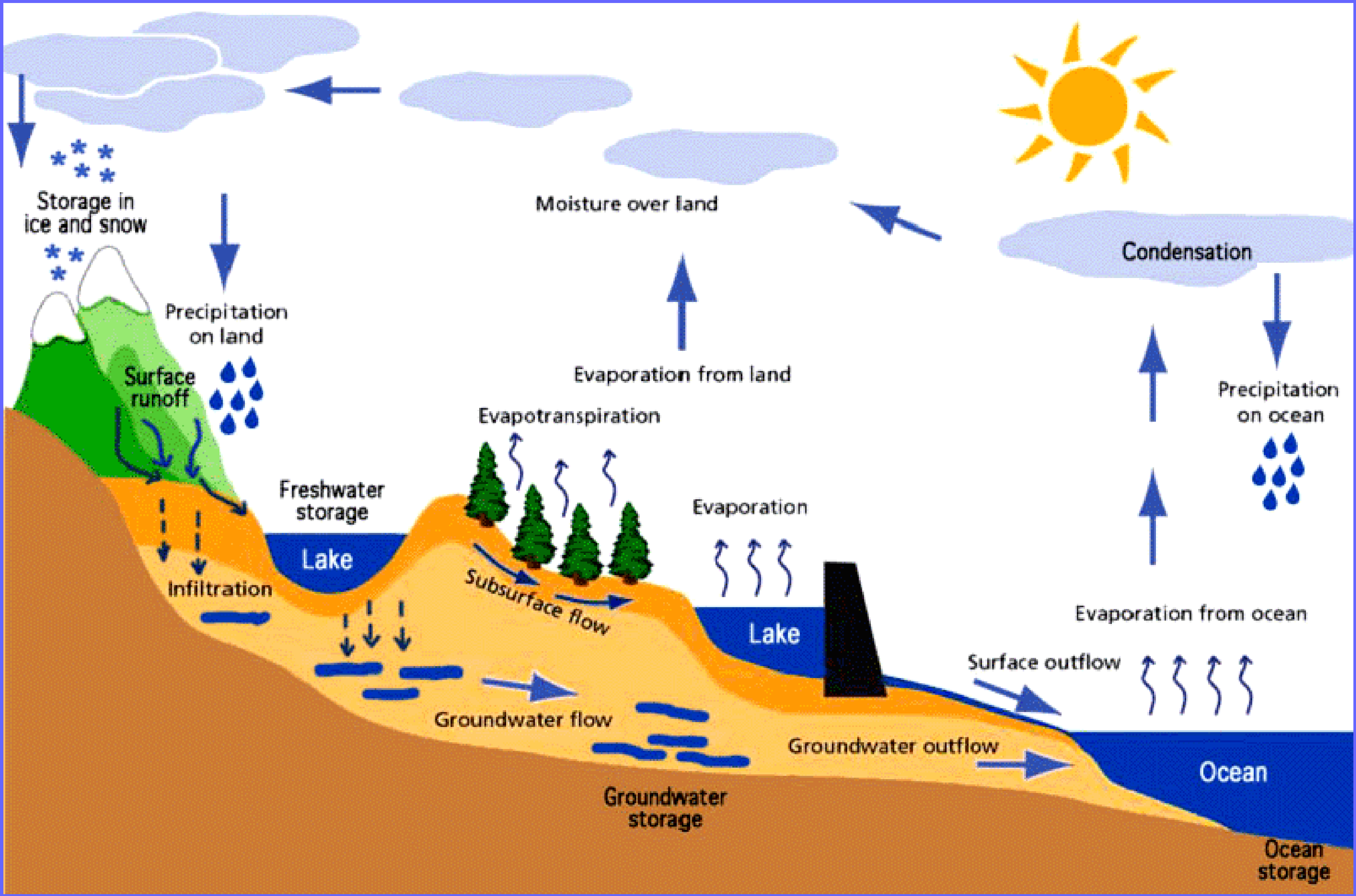
# The Formation of Runoff (1)

1. **Overland flow (surface runoff)**: flow above the soil.

2. **Interflow (subsurface flow)**: a part of the precipitation that infiltrates and flows laterally through upper crusts of the soil and returns to the surface at some location away from the point of entry.

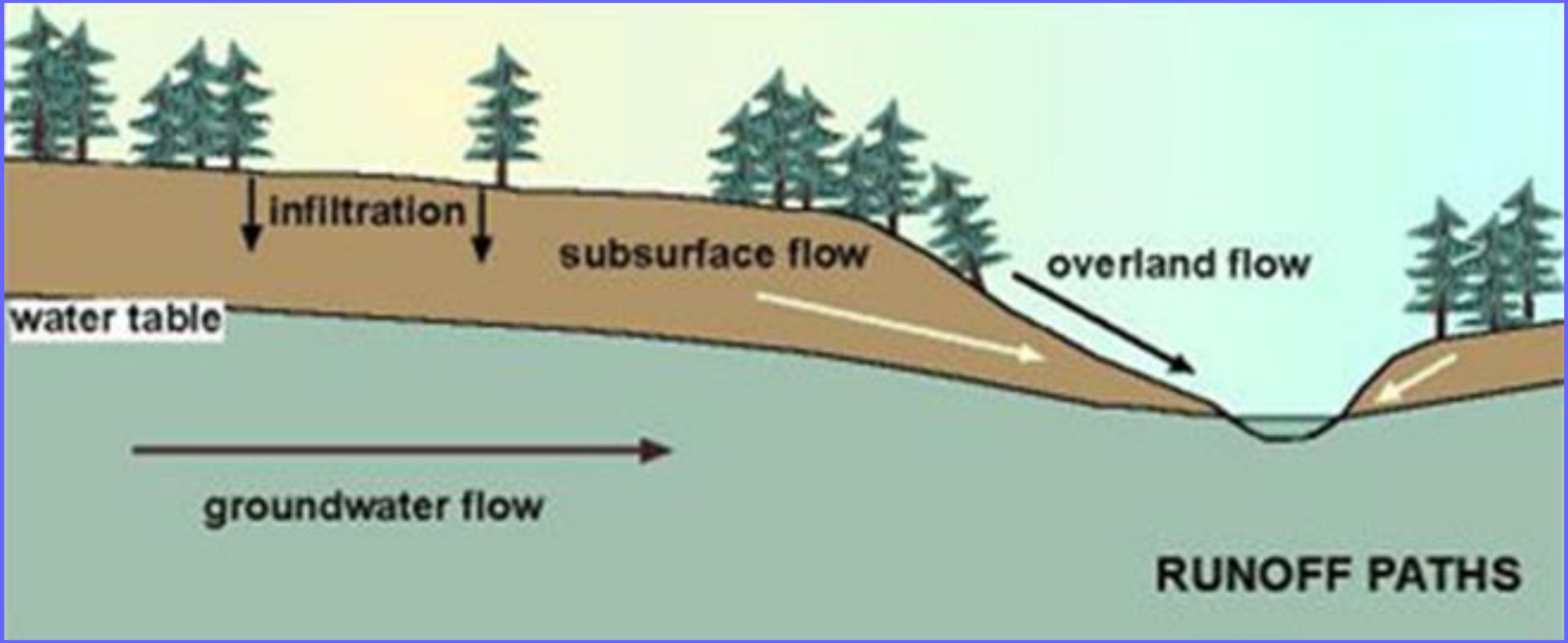
3. **Groundwater flow (groundwater runoff)** flow deeply below the soil over a long period time and ultimately reaches the surface.

# The Formation of Runoff (2)




https://www.google.hu/search?q=runoff&espv=2&biw=1366&bih=662&source=lnms&tbm=isch&sa=X&ved=0ahUKEwivo7LSz6LPAhXMC8AKHfFnA9QQ_AUIBigB#tbm=isch&q=surface+water+hydrology+pdf&imgrc=xsiWTaGie8iL7M%3A

# The Formation of Runoff (3)




https://www.google.hu/search?q=runoff&espv=2&biw=1366&bih=662&source=lnms&tbm=isch&sa=X&ved=0ahUKEwivo7LSz6LPAhXMC8AKHfFnA9QQ_AUIBigB#imgdii=69EChehqZ3JnTM%3A%3B69EChehqZ3JnTM%3A%3B9VkR6JRyYD4R_M%3A&imgrc=69EChehqZ3JnTM%3A

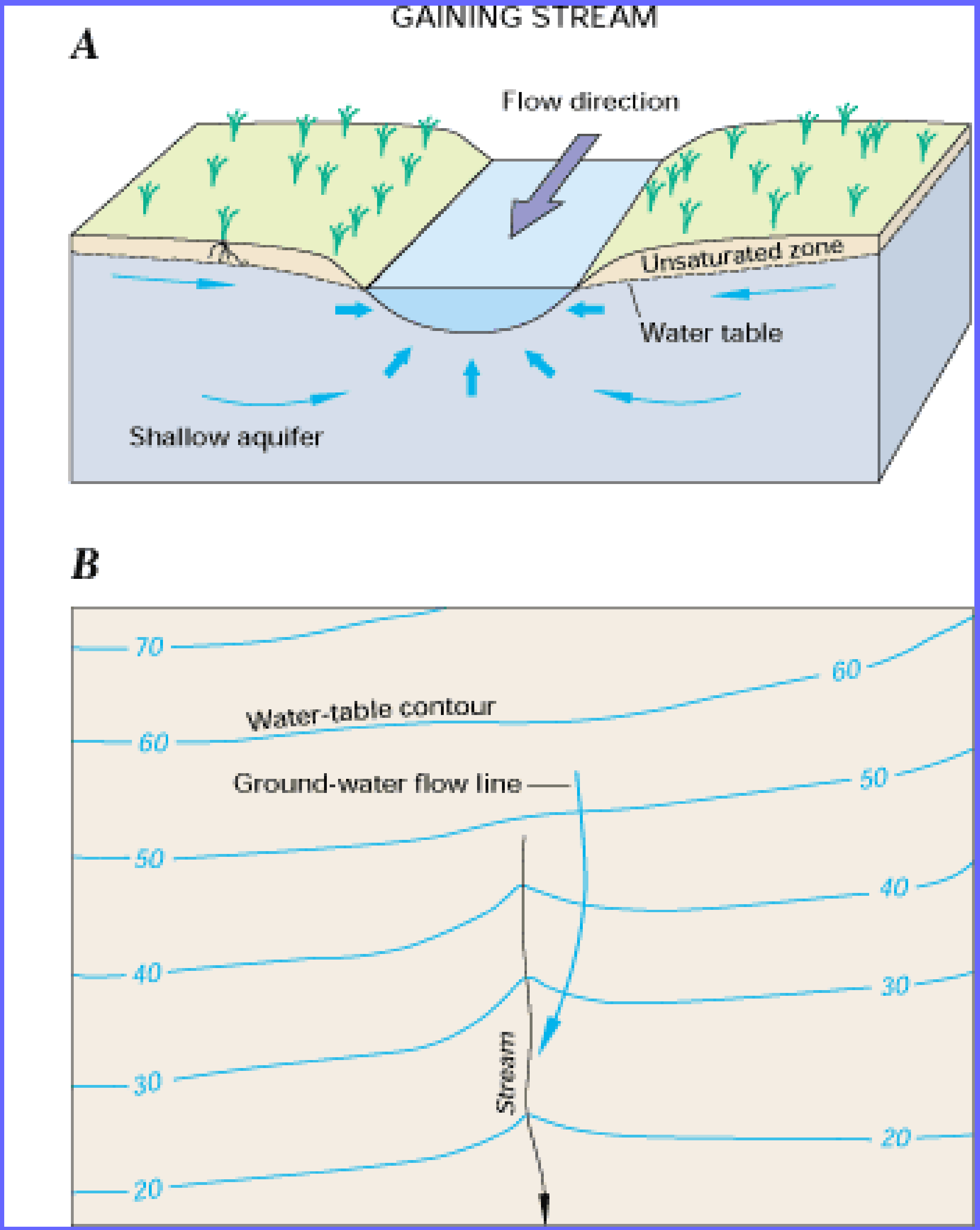
# Interaction of Groundwater and Streams

Streams interact with groundwater in three basic ways:

- Gaining stream: streams gain water from the inflow of groundwater through the streambed
- Losing Stream: they lose water to groundwater by outflow through the streambed
- Both, gaining in some reaches and losing in other reaches.

# Gaining Streams

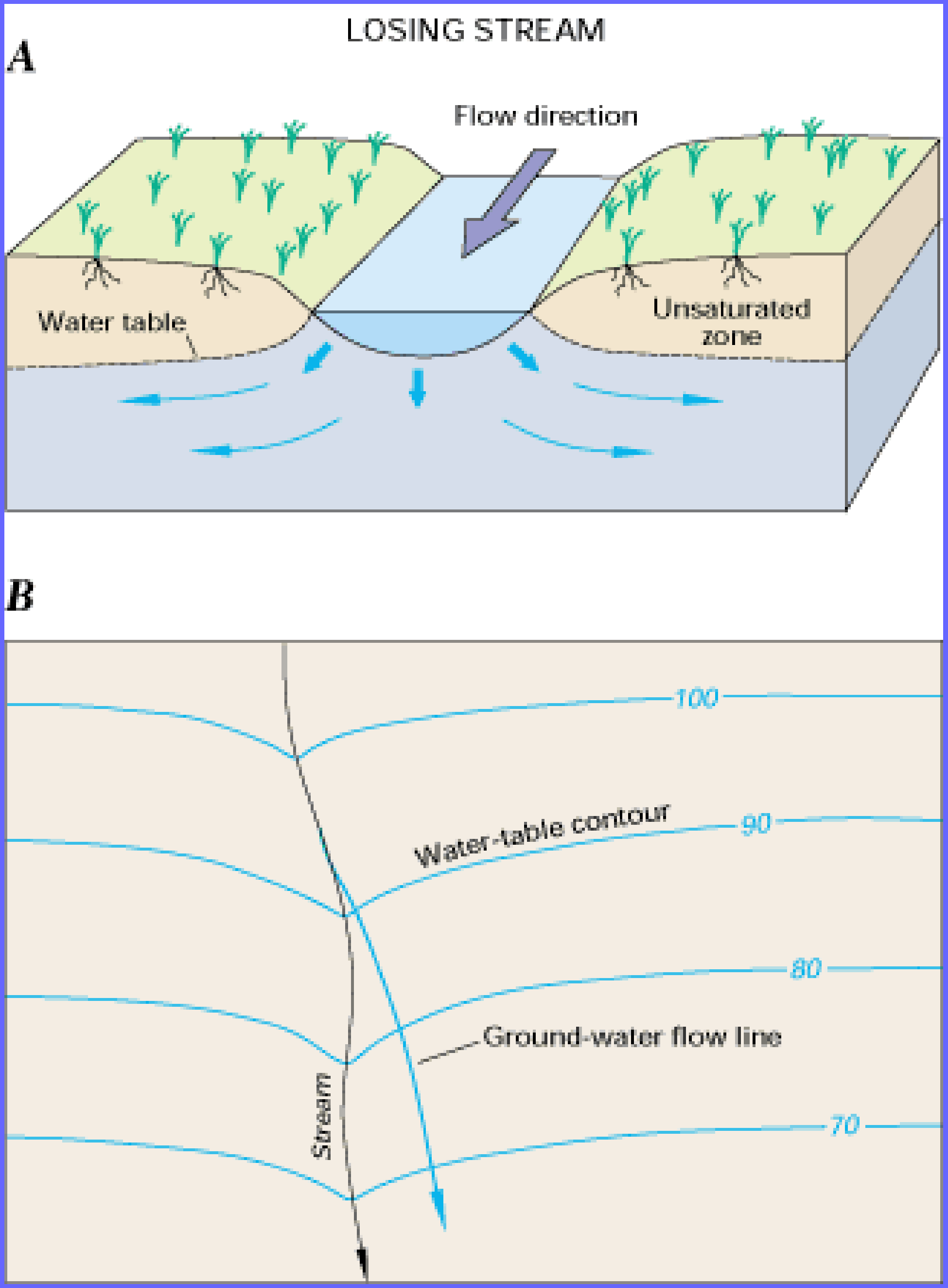
Gaining streams receive water from the ground-water system (A).
This can be determined from water-table contour maps because the contour lines point in the upstream direction where they cross the stream (B)



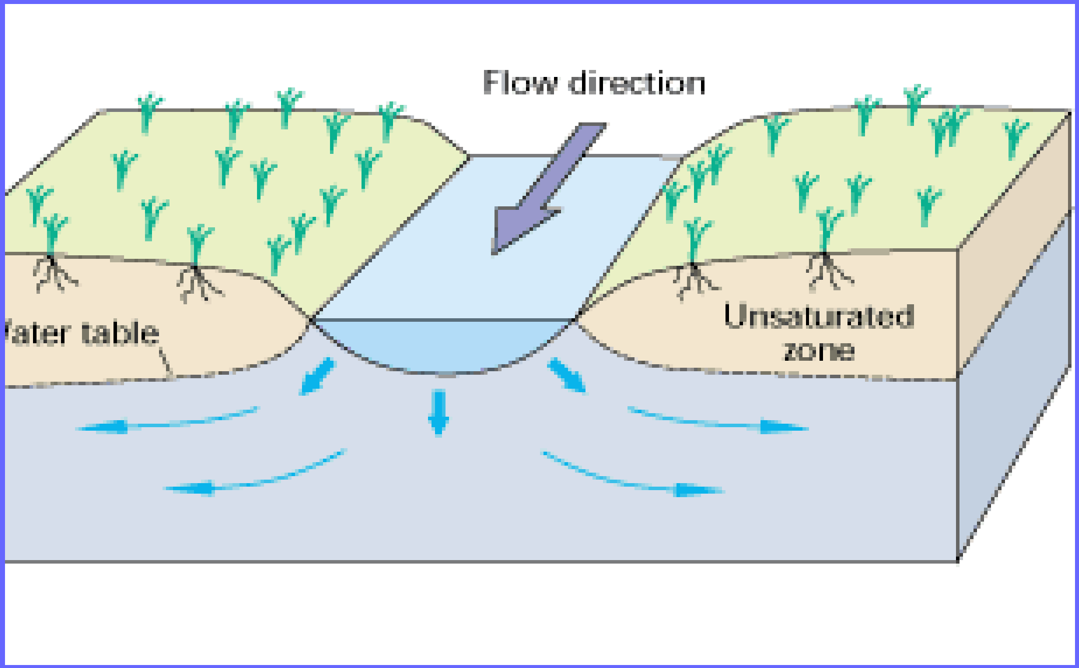

http://pubs.usgs.gov/circ/circ1139/htdocs/natural_processes_of_ground.htm

# Losing Streams(1)

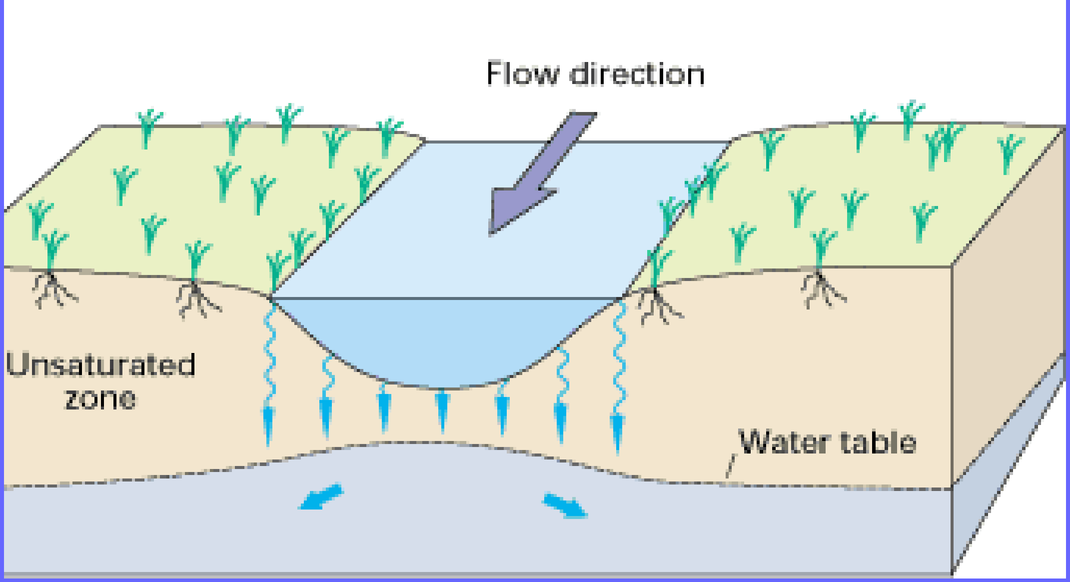
Losing streams lose water to the ground-water system (A). This can be determined from water-table contour maps because the contour lines point in the downstream direction where they cross the stream (B).



# Losing Streams(2)

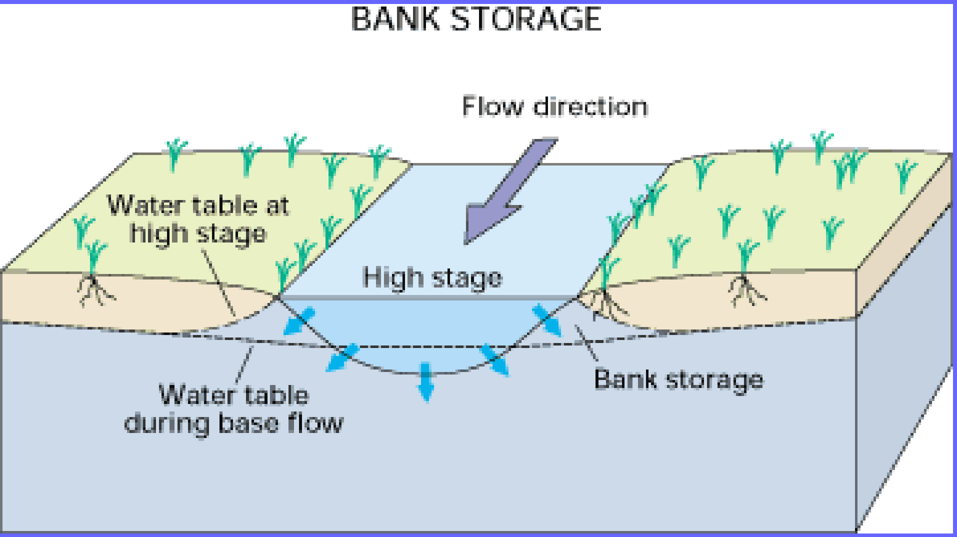


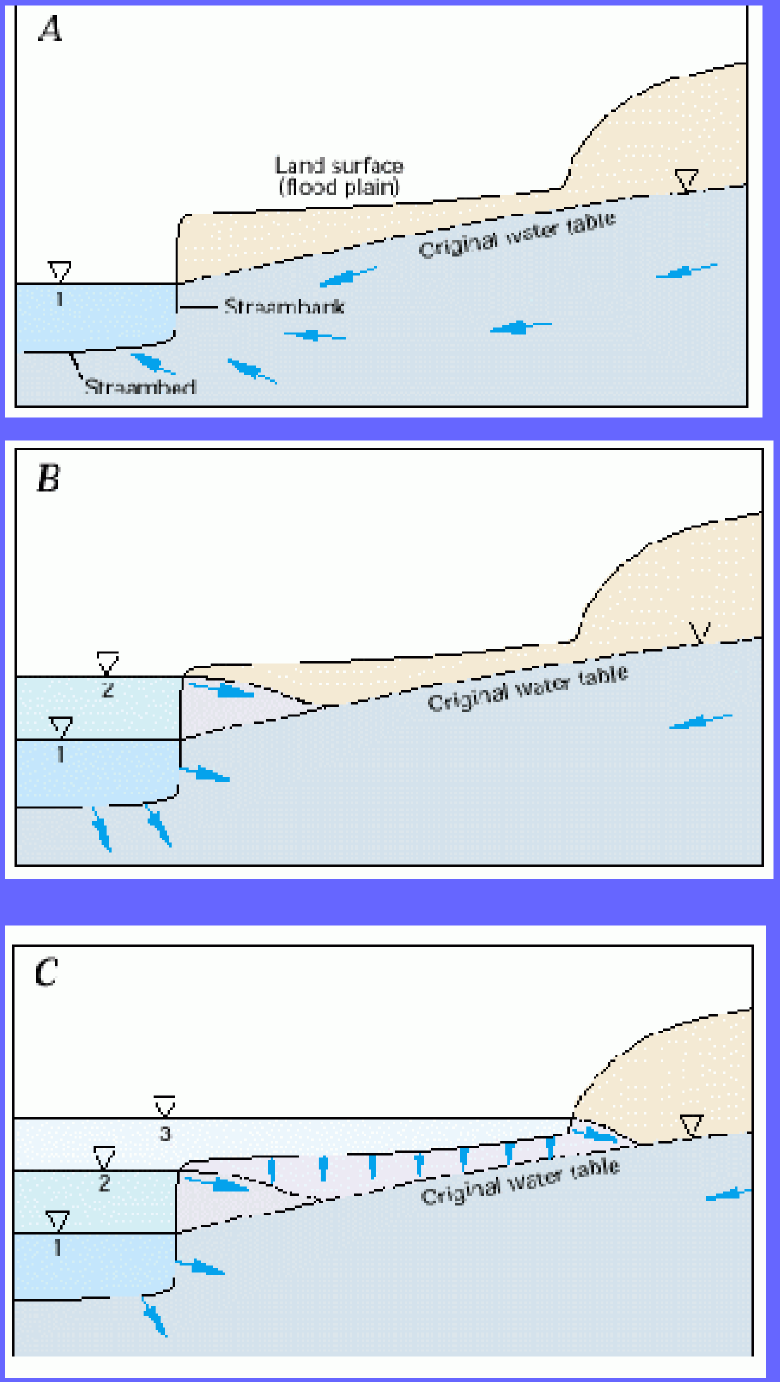

Can be connected to the groundwater system or




can be disconnected from the groundwater system.

# Both
## Gaining- and Losing Streams




When stream levels rise higher than ground-water levels, stream water moves into the streambanks as bank storage.

# Surface Water Hydrology

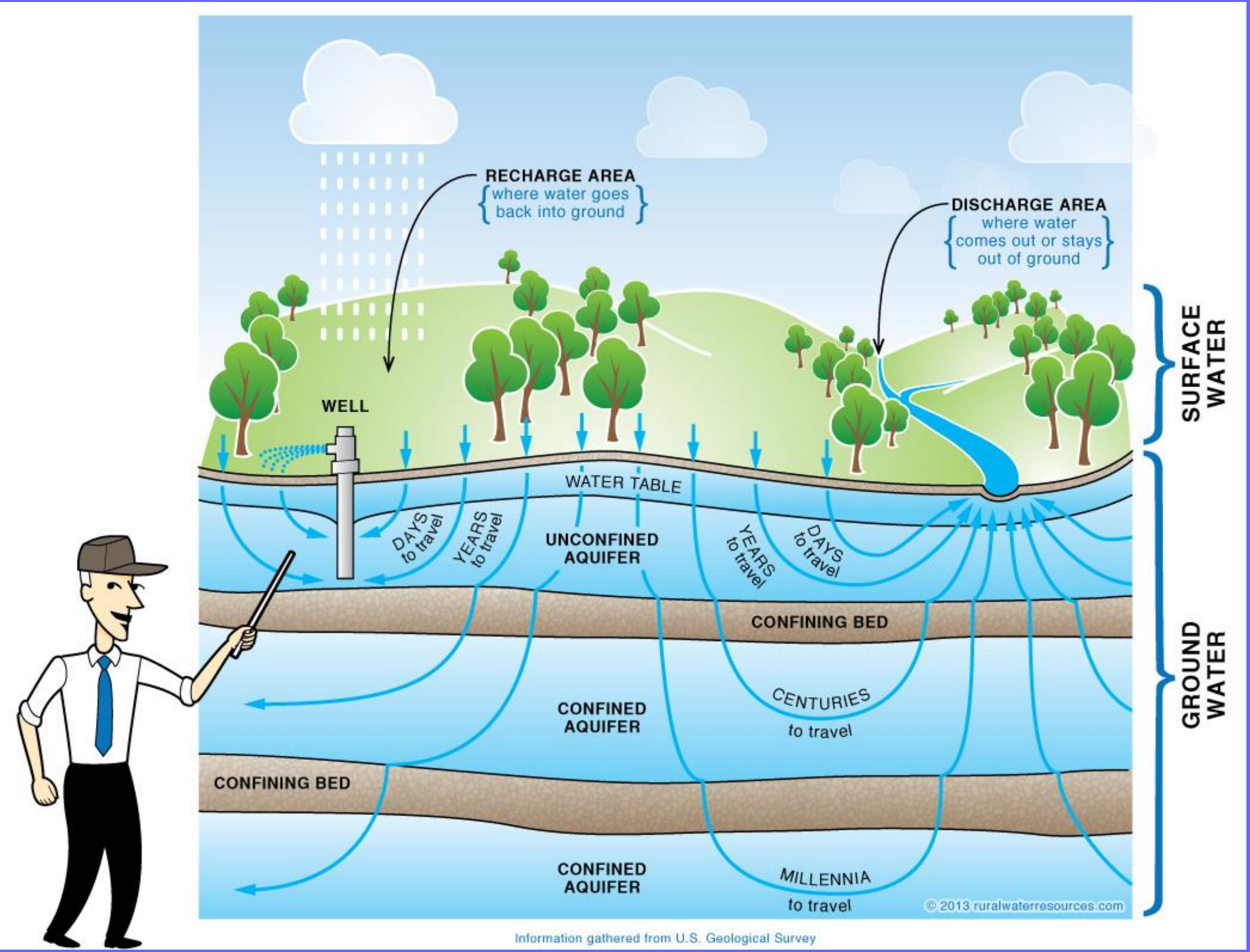
The study of moving water found in

- rivers, stream, creek, brook
- open channels,
- lakes, and
- runoff across the open land surface.

Important for:

- transportation,
- irrigation,
- water supply,
- hydropower.

# Groundwater vs. Surface Water



# Watersheds (1)

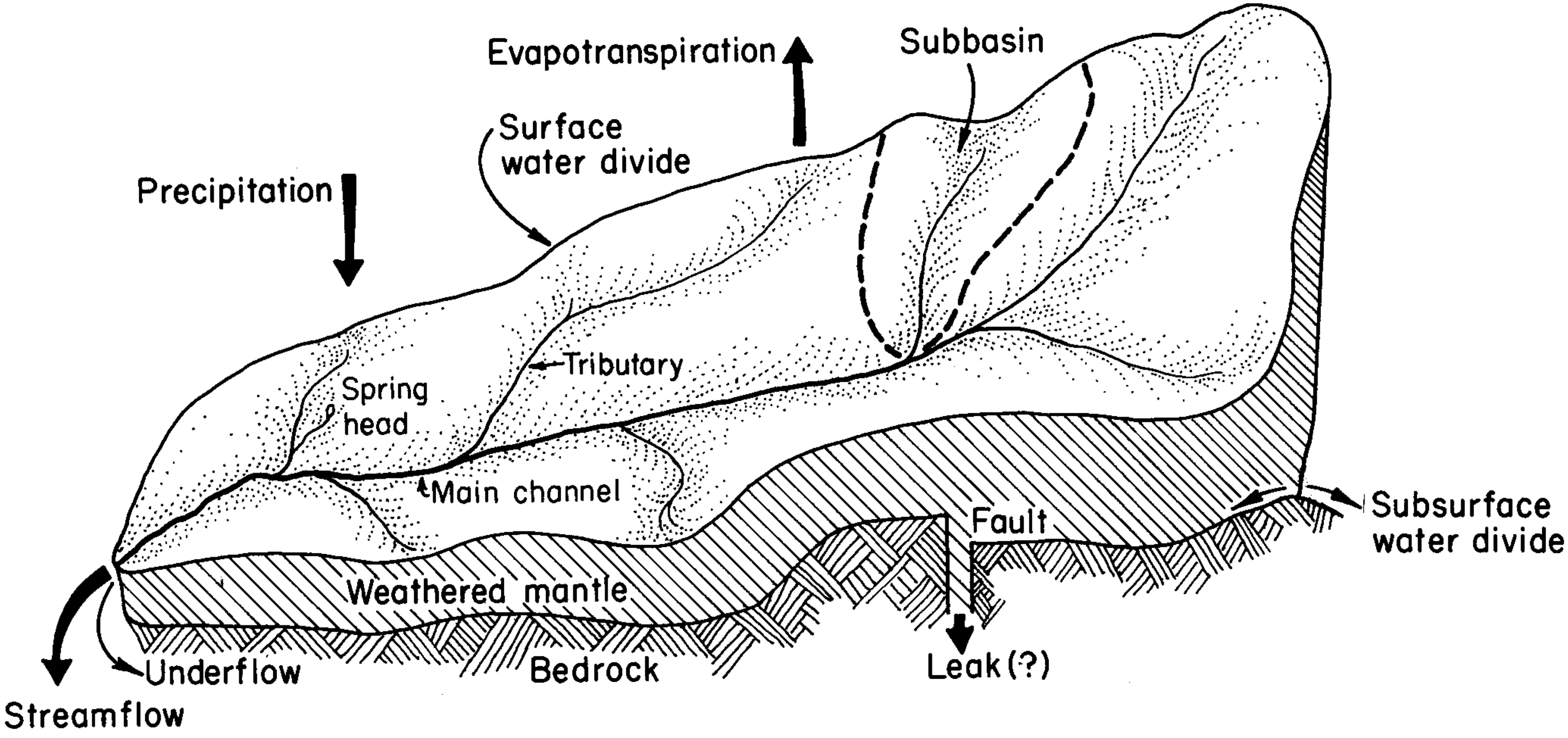
The total land area drains to a common point.

Also called:

- river basin,
- drainage basin, or
- catchment.

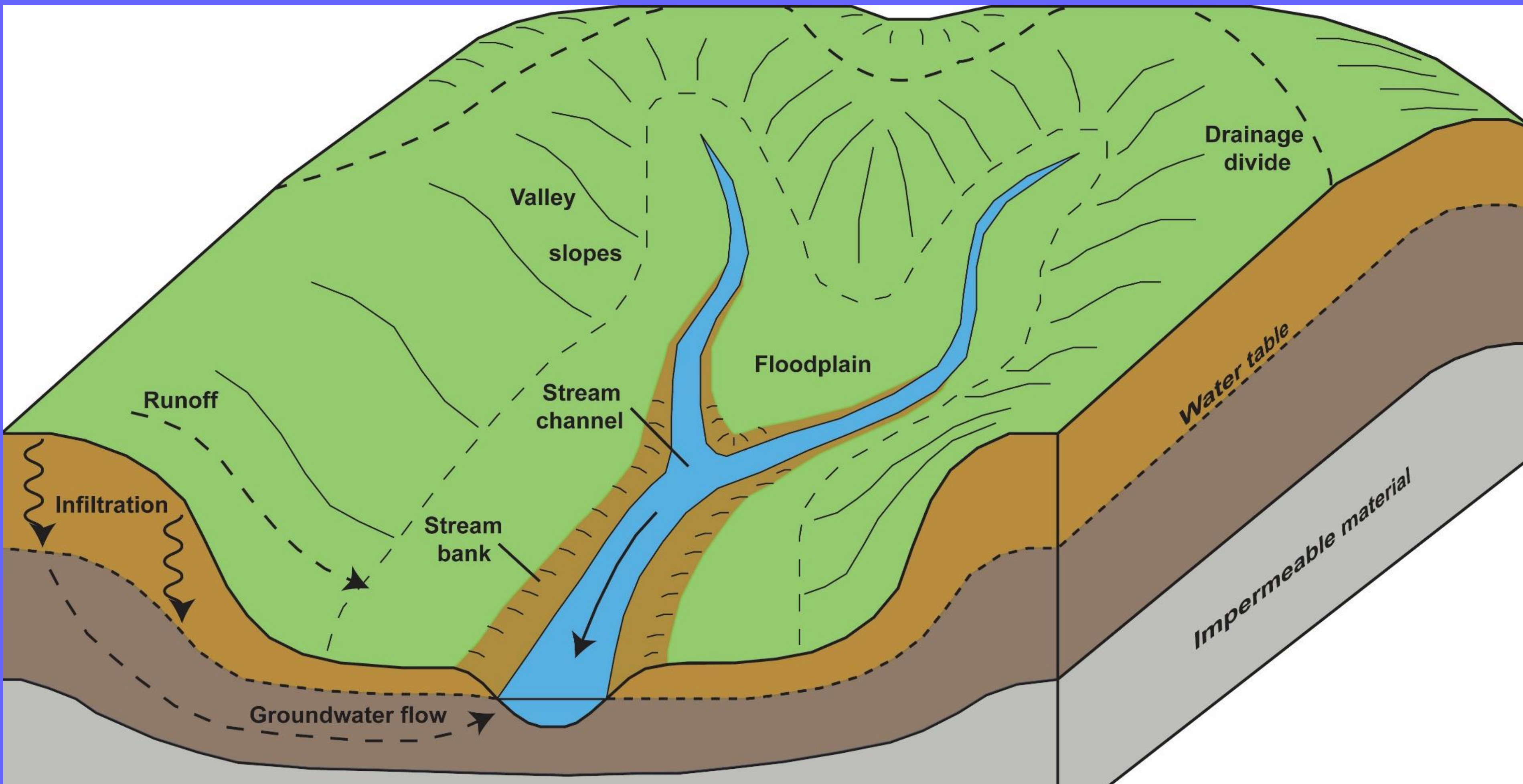

https://www.google.hu/search?q=runoff&espv=2&biw=1366&bih=662&source=lnms&tbm=isch&sa=X&ved=0ahUKEwivo7LSz6LPAhXMC8AKHfFnA9QQ_AUIBigB#imgdii=_8ObToYAxIonBM%3A%3B_8ObToYAxIonBM%3A%3By1wBfTcDLSDRAM%3A&imgrc=_8ObToYAxIonBM%3A

# Watersheds (2)

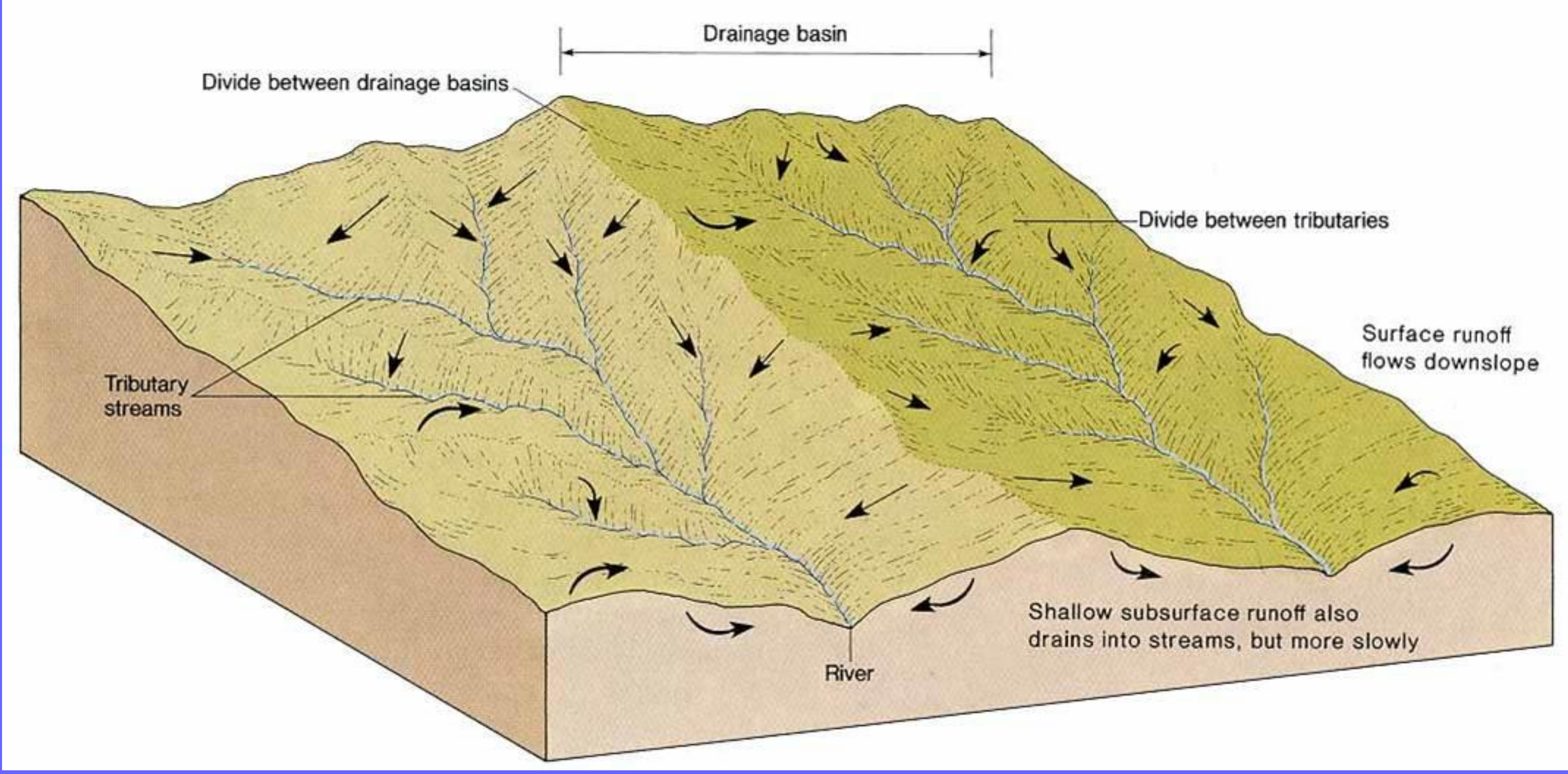



The watershed is delineated by finding the watershed divide that separates the watershed from its neighbors.

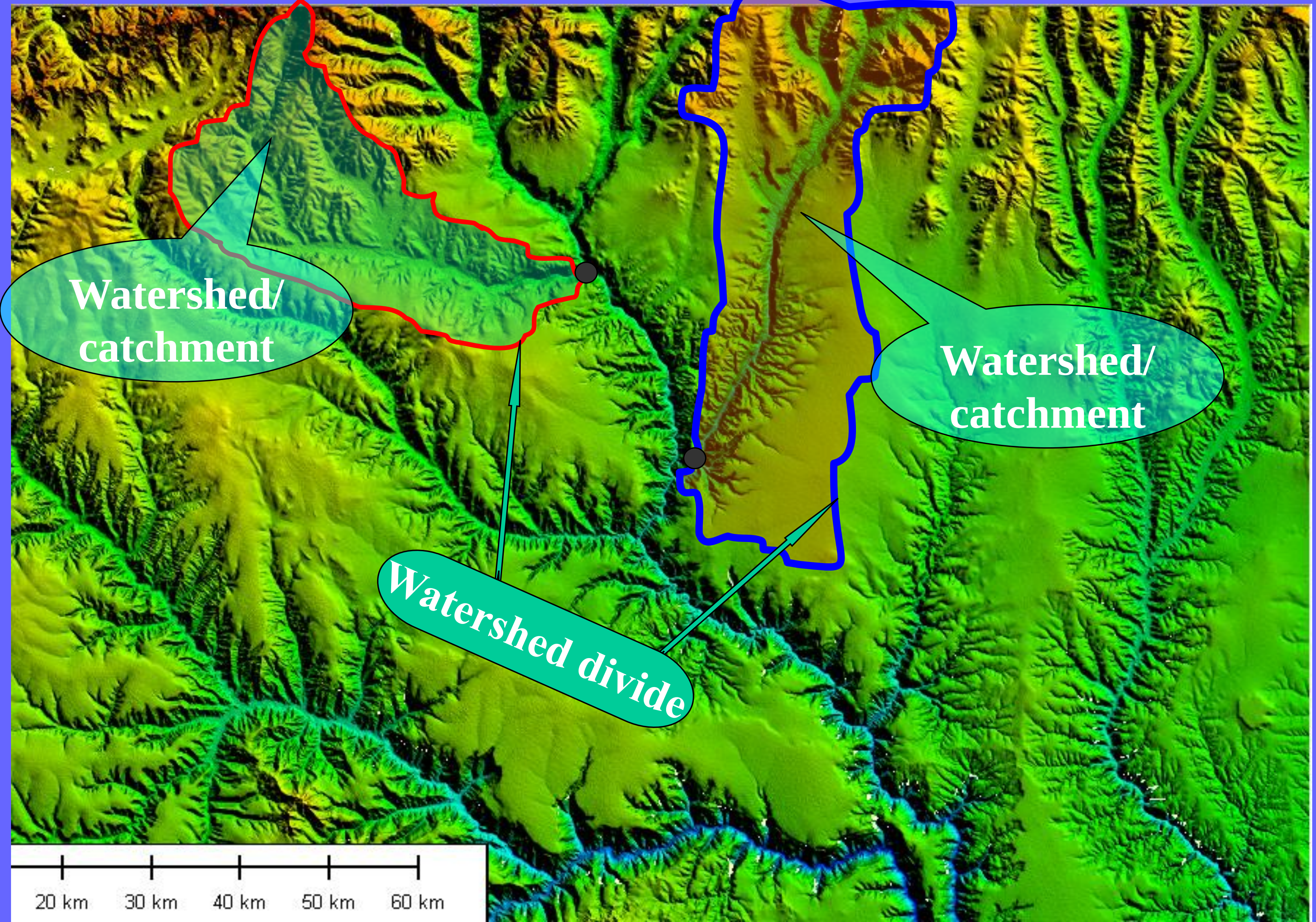
# Watersheds (3)



# Watersheds (4)



# Watershed and Watershed Divide



# Parts of a River System

Headwaters: the source of the river

Tributaries: smaller streams that combine at a confluence

Thalweg: main part of river channel, the thread of fastest flowing water

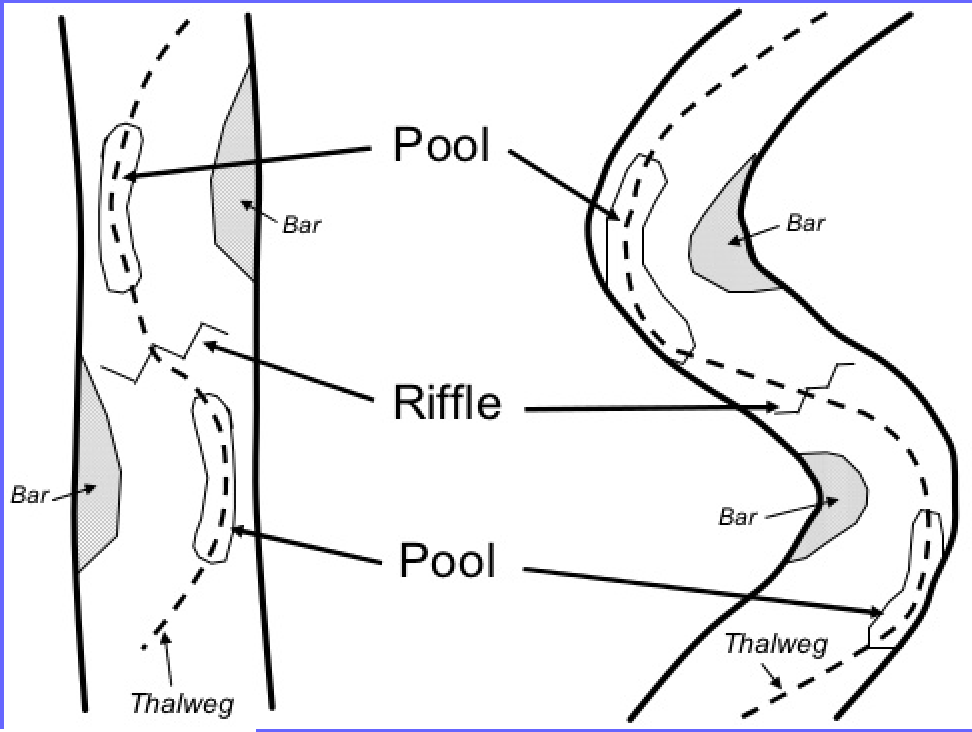
Mouth: is where a river or stream enters a larger body water

Hyporheic Zone: shallow ground-water flow below the river bed

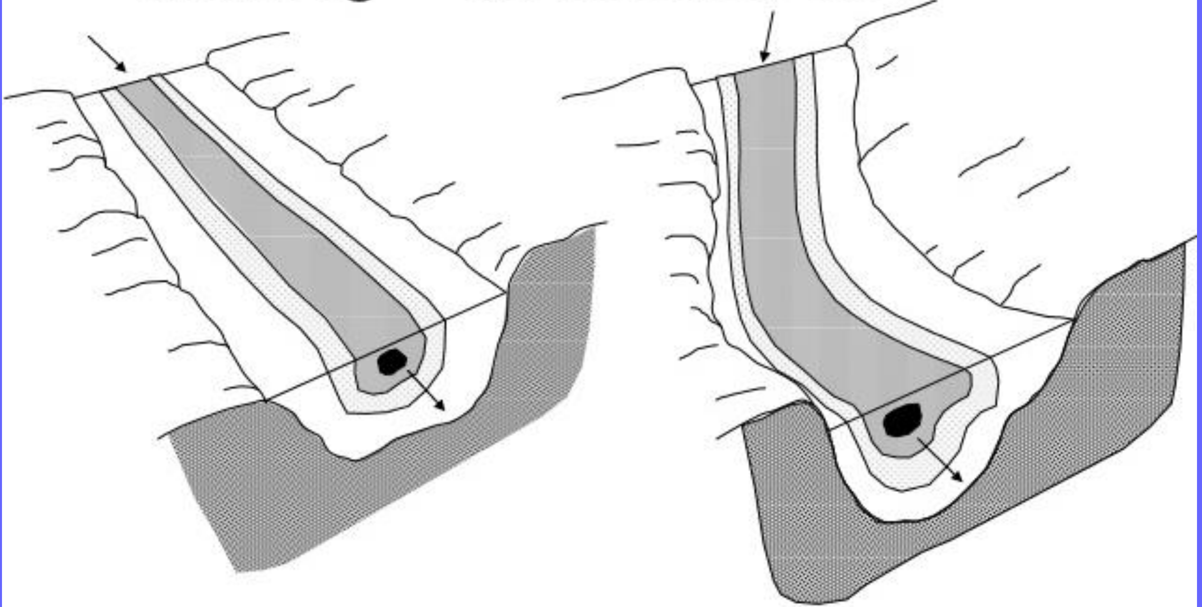
# Hyporheic Zone

# Thalweg

The line that connects the lowest points in a valley or river channel, and thus the line of fastest flow along a river's course.



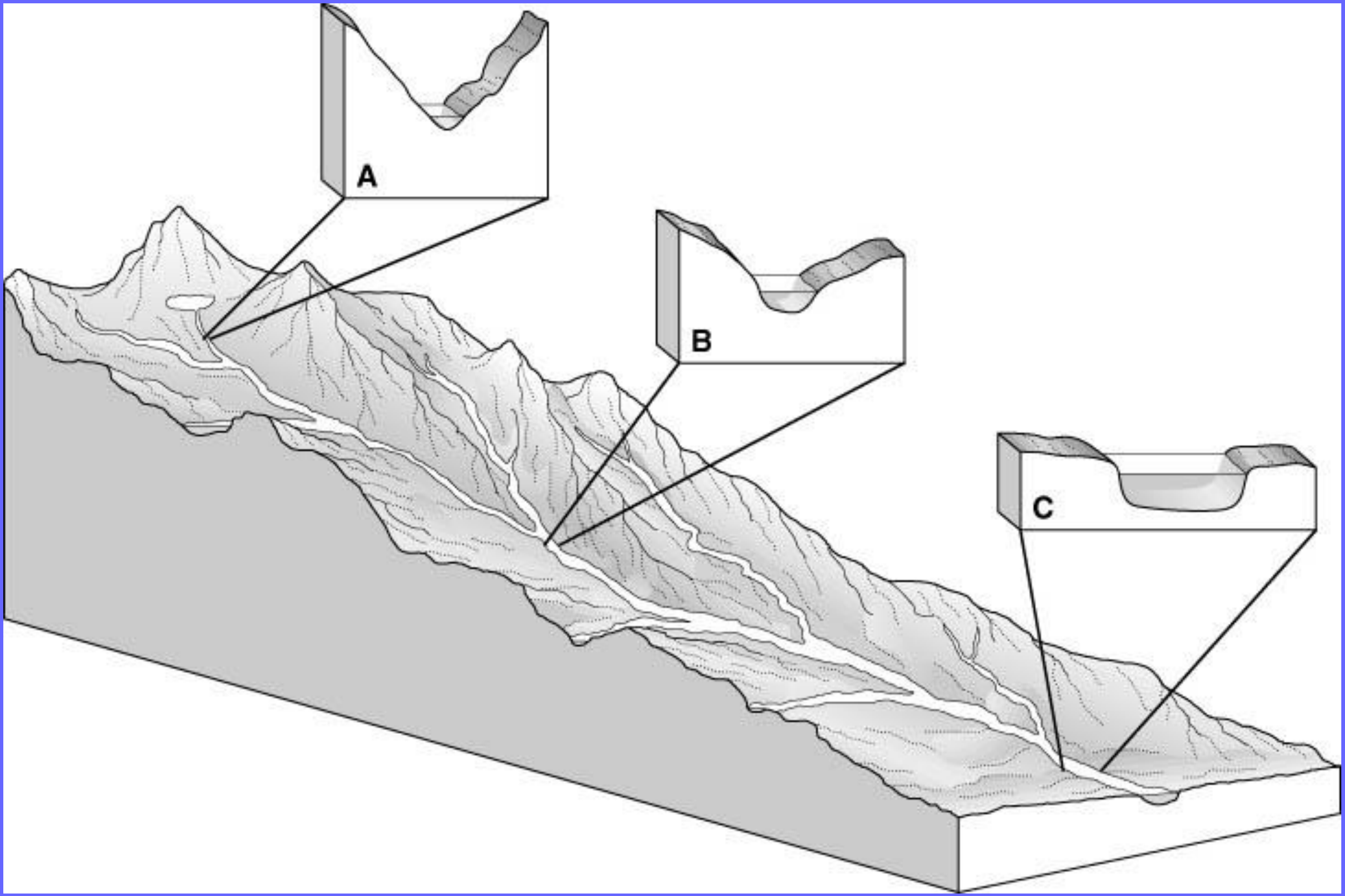

- **Thalweg** – *"the fast-flow tube"*



# Three Stages of River Development (1)

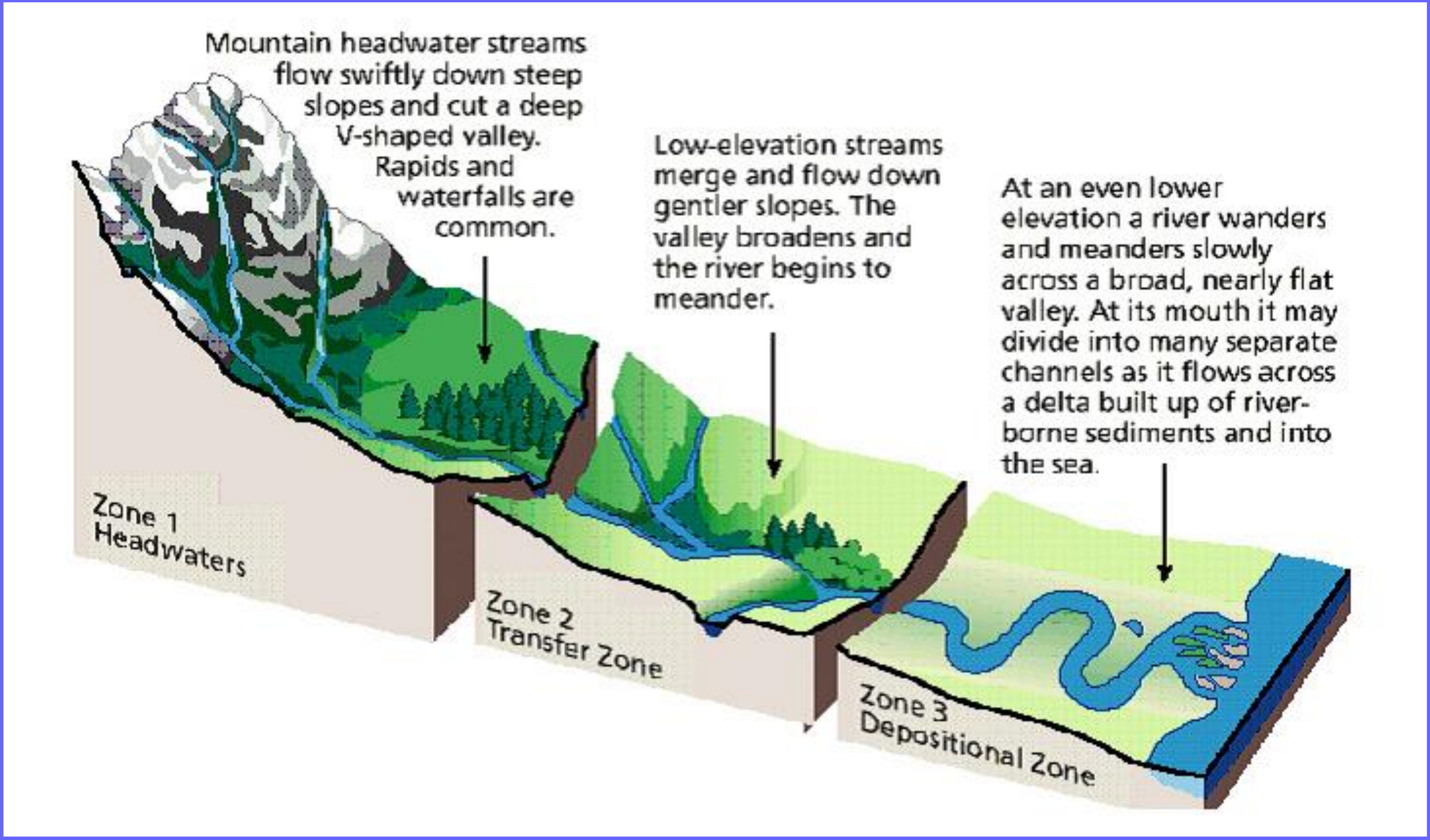
- Young "V" shaped valleys
- Mature "U" shaped valleys
- Old meandering channels with oxbow lakes

# Three Stages of River Development (2)

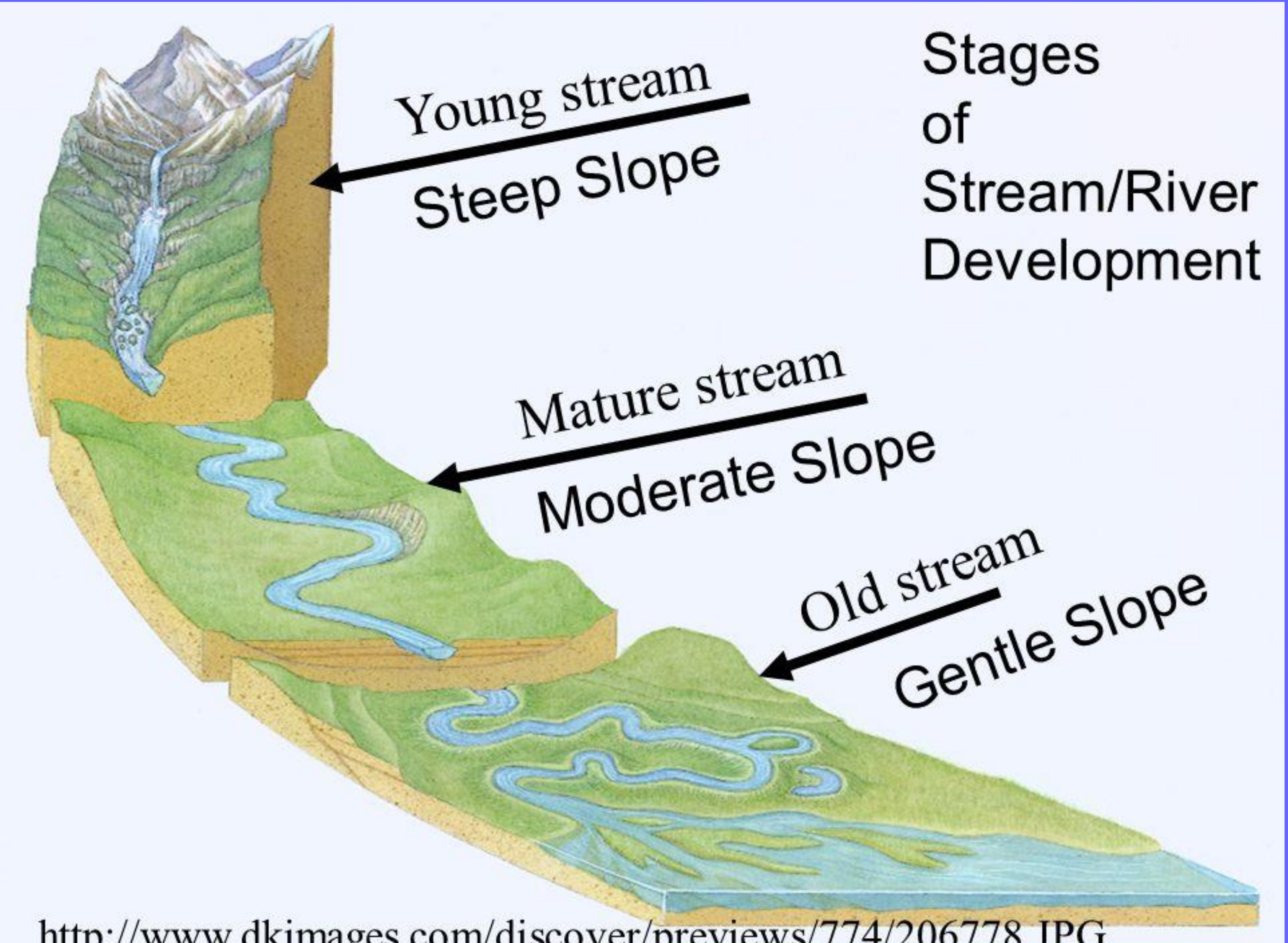



Changes in stream properties along a watershed

# Three Stages of River Development (3)

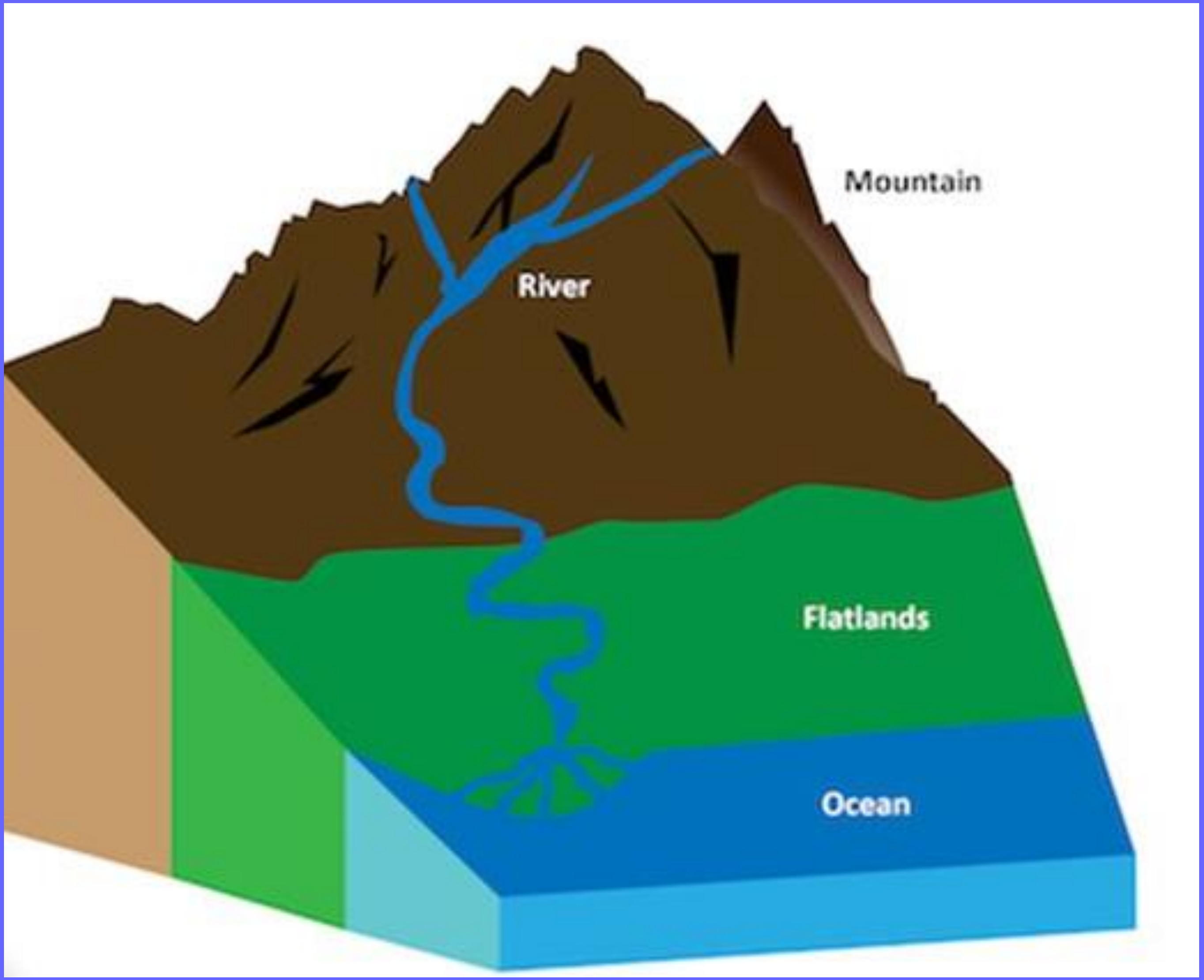


# Three Stages of River Development (4)



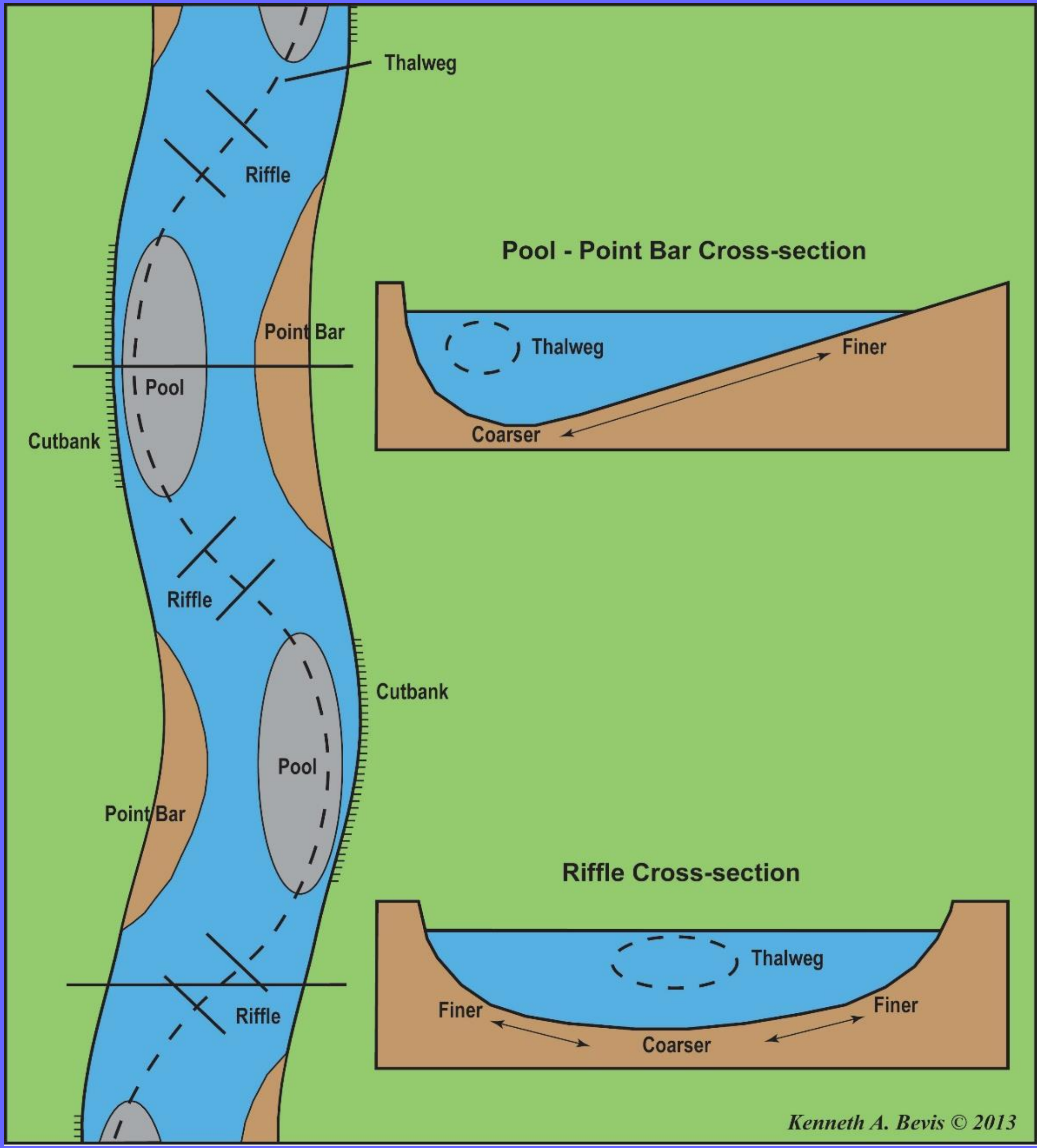

http://www.dkimages.com/discover/previews/774/206778.JPG

# Three Stages of River Development (5)

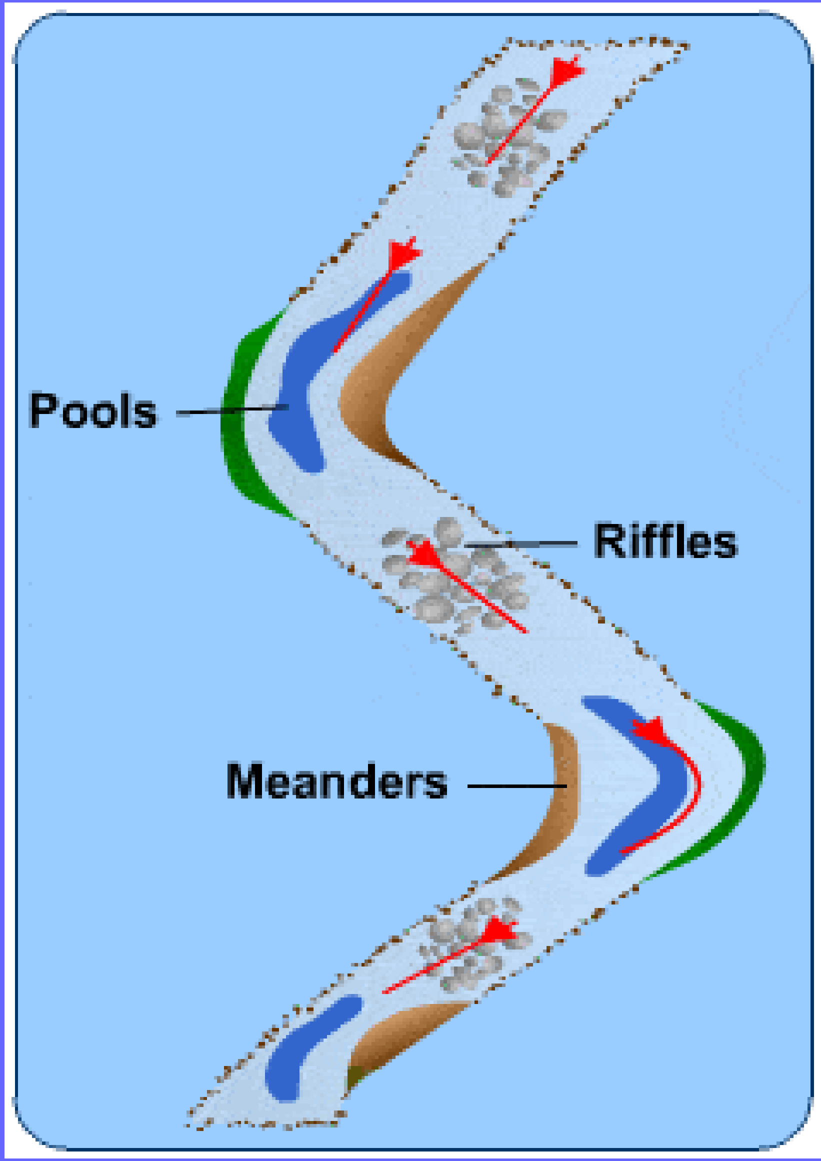


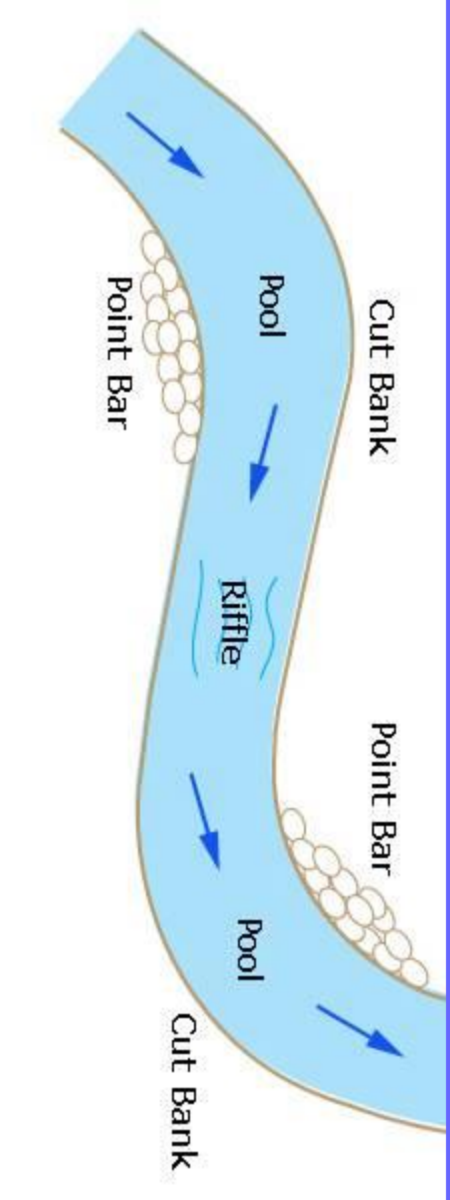
# River Morphology (1)

A typical straight channel pattern formed on steep gradient streams.



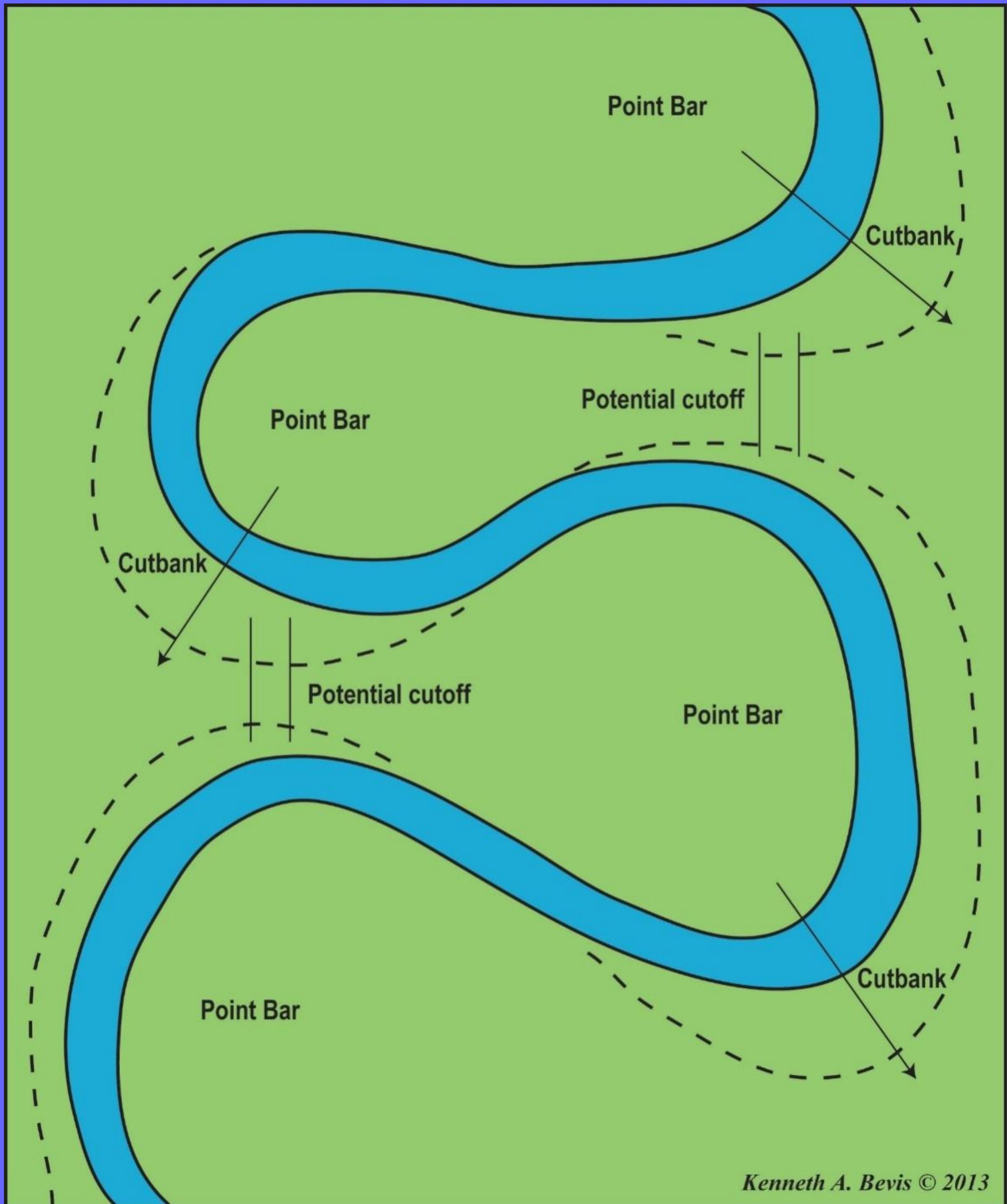
# River Morphology (2)



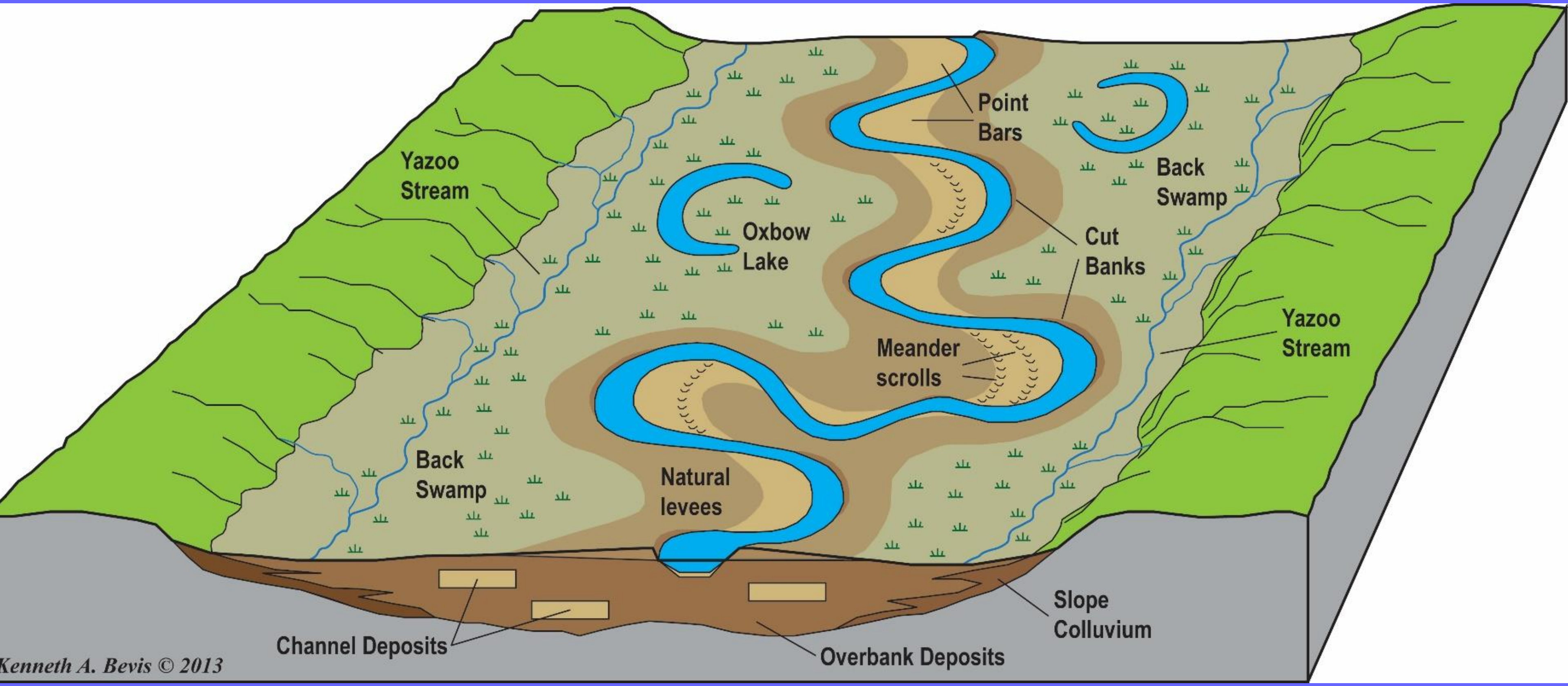



# River Morphology (3)

- A typical meandering channel pattern formed on a gentle gradient stream.
- Meander loops tend to migrate laterally and down-gradient within the valley and eventually, adjacent loops may migrate into one another creating cut-offs.

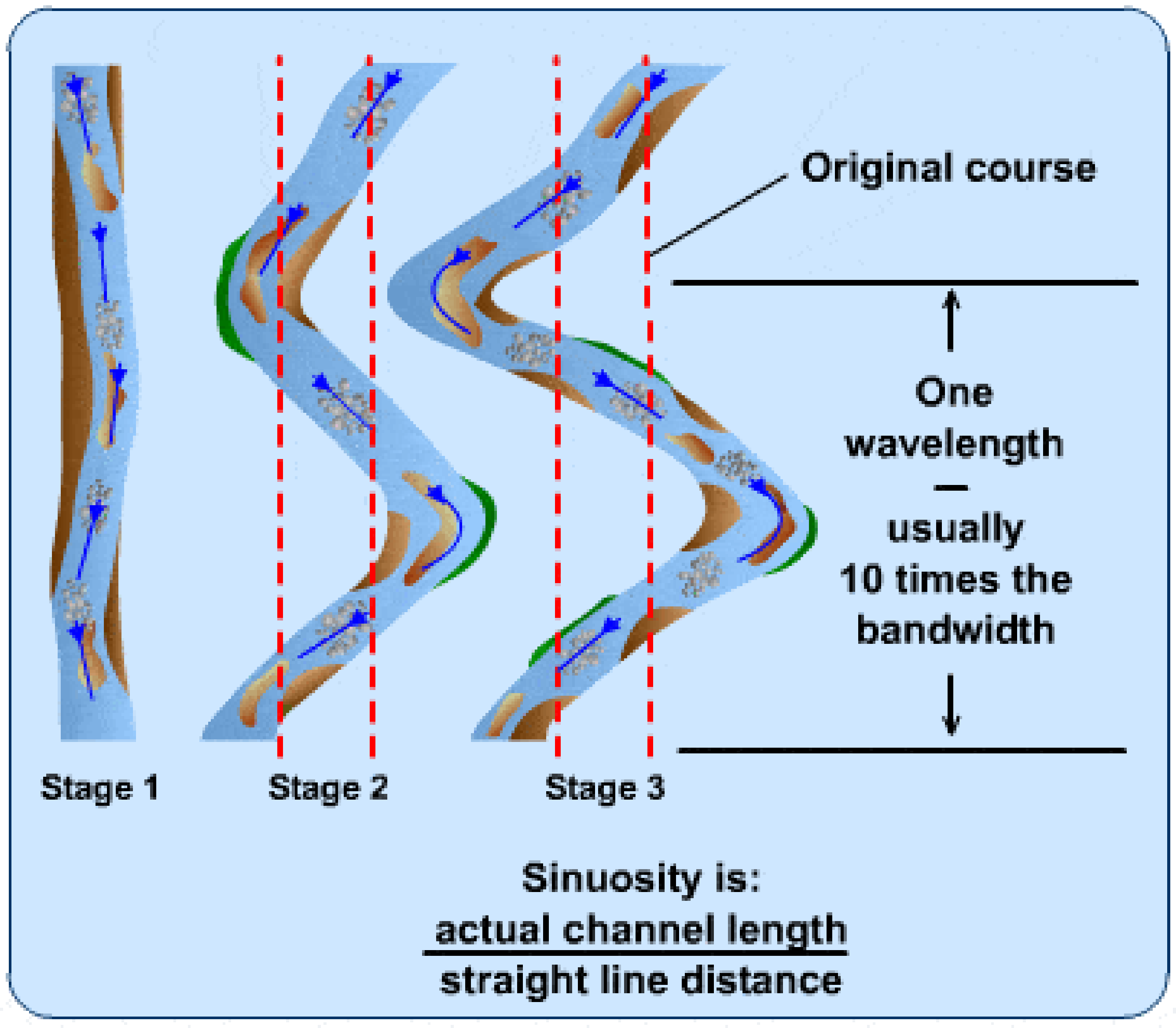


# River Morphology (4)

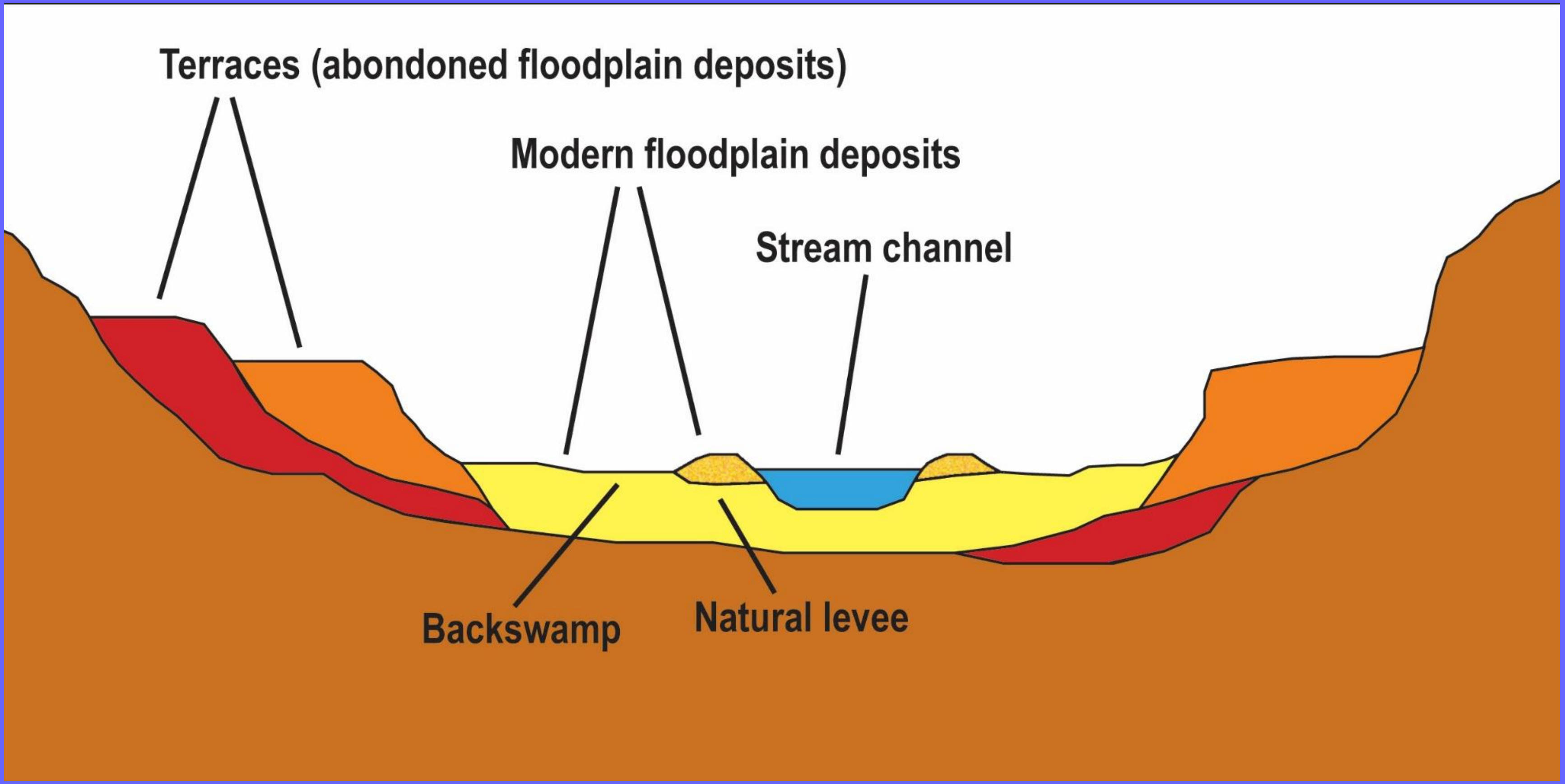



A model of a meandering stream system's floodplain and valley sedimentary fill.

# River Morphology (5)



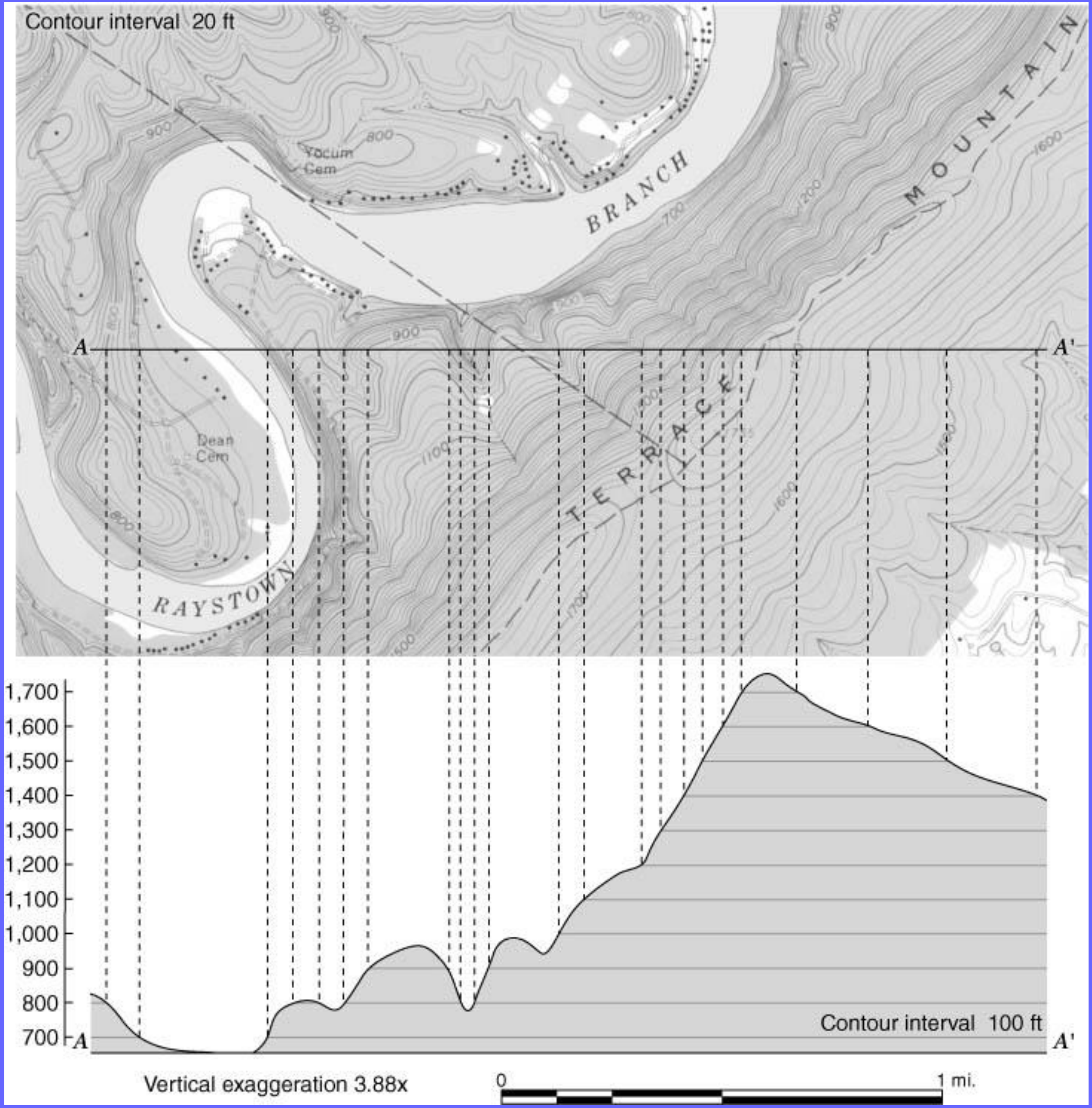
# River Morphology (6)




A typical low-gradient stream valley displaying the active channel and adjacent flood plain with successively older, bench-like stream terraces perched on the valley slopes.

# Topographic Maps (1)

Hills, valleys, and slopes of a topographic map.



# Topographic Maps (2)

used to show slope, elevation, distance, and physical features

- Scale: used to relate the distance on the map to the true distance. 1 map cm = 12,000 true cm = 120 truemeter (M=1:12,000)
- Contour Line: used to show points of similar elevation. 1000 meter contour line is a constant elevation above sea level
- Contour Interval: the distance between contour lines
- Slope: the steepness of the ground. An 1% slope is where the surface drops 1 meter every 100 meter
- Aspect: the direction that the slope faces, North, South, East, West

# Lakes

Anybody of water (other than an ocean) that is of reasonable size impounds water and moves very slowly

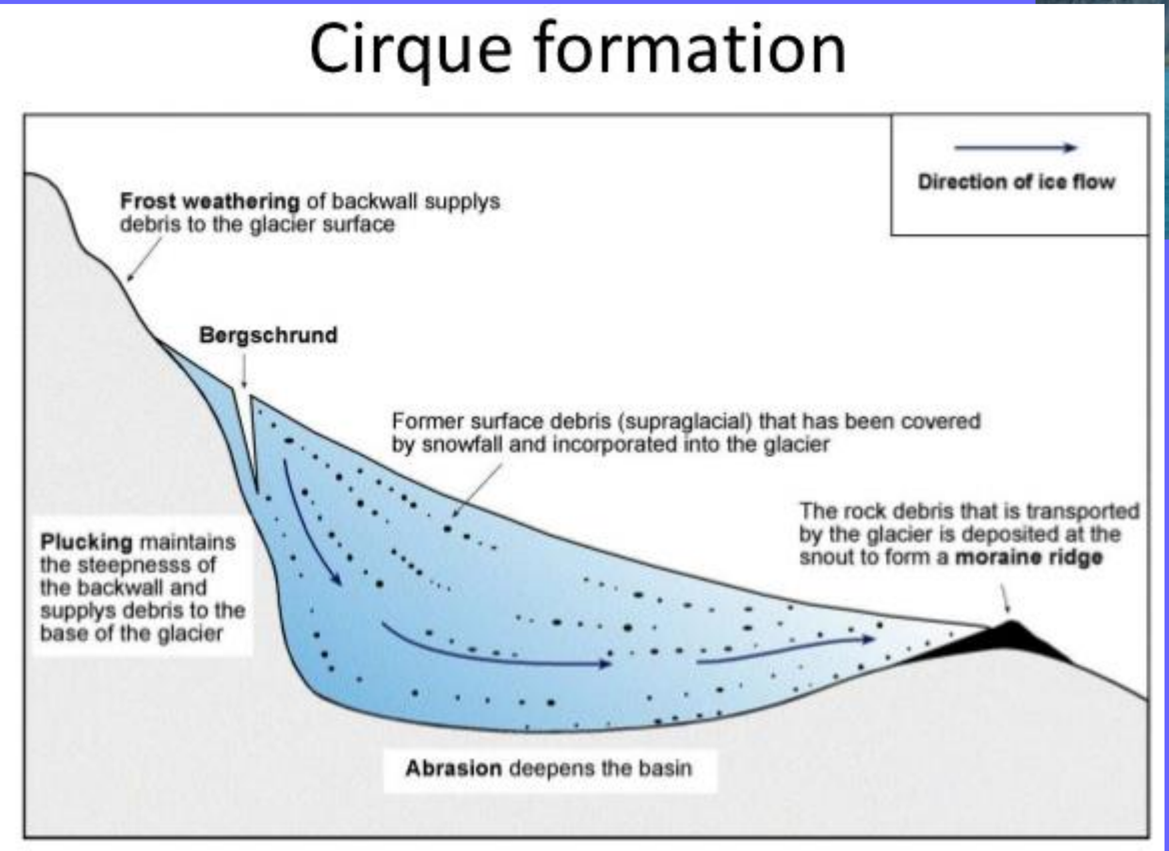
Shape of lakes:

- cirques: formed in mountains by glaciers
- pluvial: formed in deserts
- kettles: formed by buried glacial ice that melted

Lake productivity

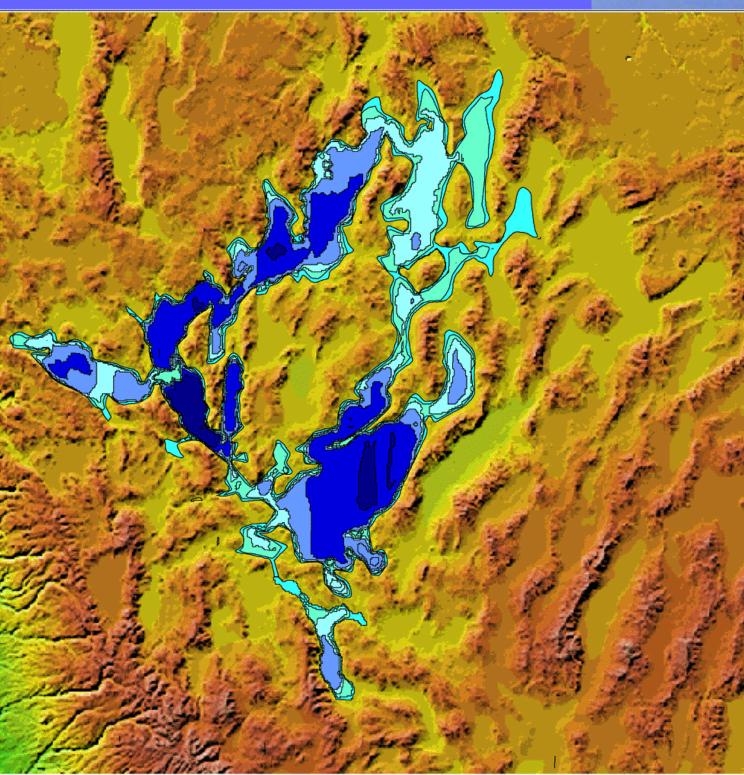
- oligotrophic: very low productivity, clear
- eutrophic: very high productivity, green

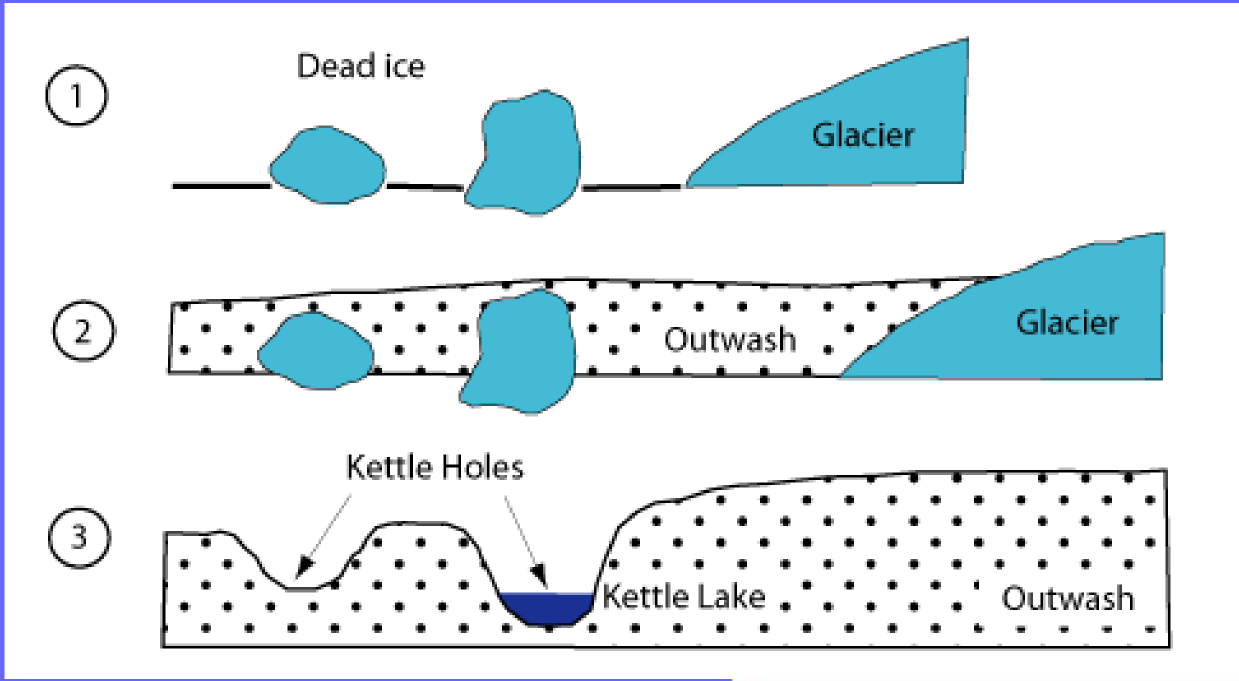
# Cirque Lake



Cirque formation
Direction of ice flow
Frost weathering of backwall supplys debris to the glacier surface
Bergschrund
Former surface debris (supraglacial) that has been covered by snowfall and incorporated into the glacier
The rock debris that is transported by the glacier is deposited at the snout to form a moraine ridge
Plucking maintains the steepnesss of the backwall and supplys debris to the base of the glacier
Abrasion deepens the basin

# Pluvial Lakes





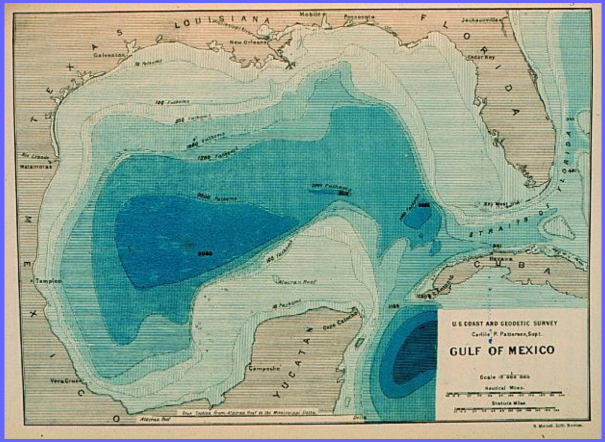
1
Dead ice
Glacier
2
Outwash
Glacier
3
Kettle Holes
Kettle Lake
Outwash

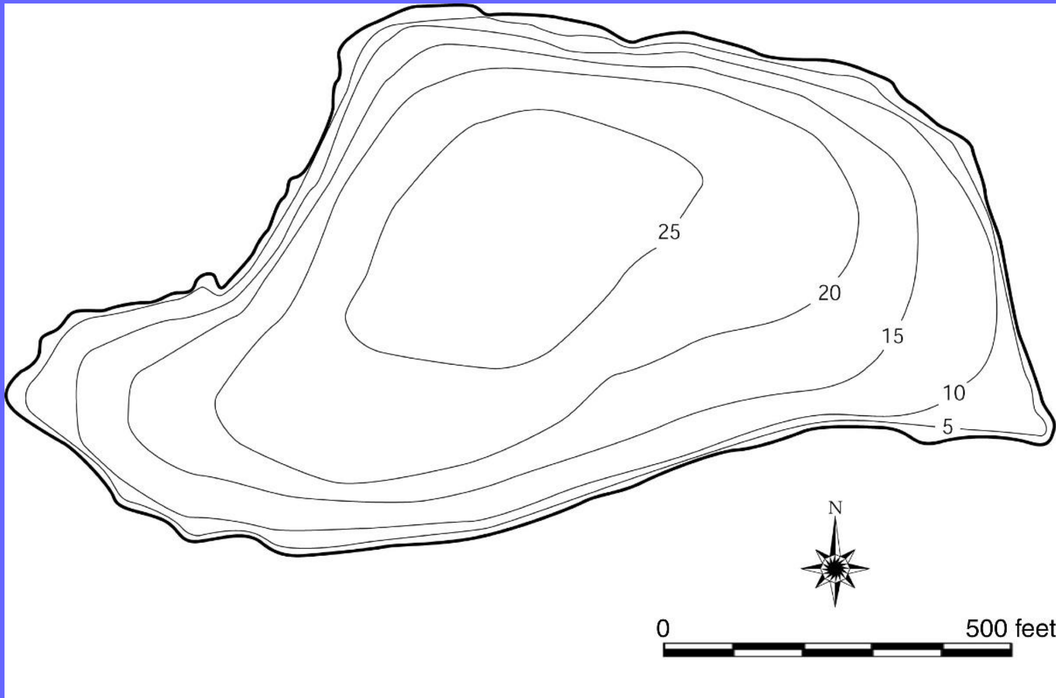

# Kettle Lake

# Bathymetric Map

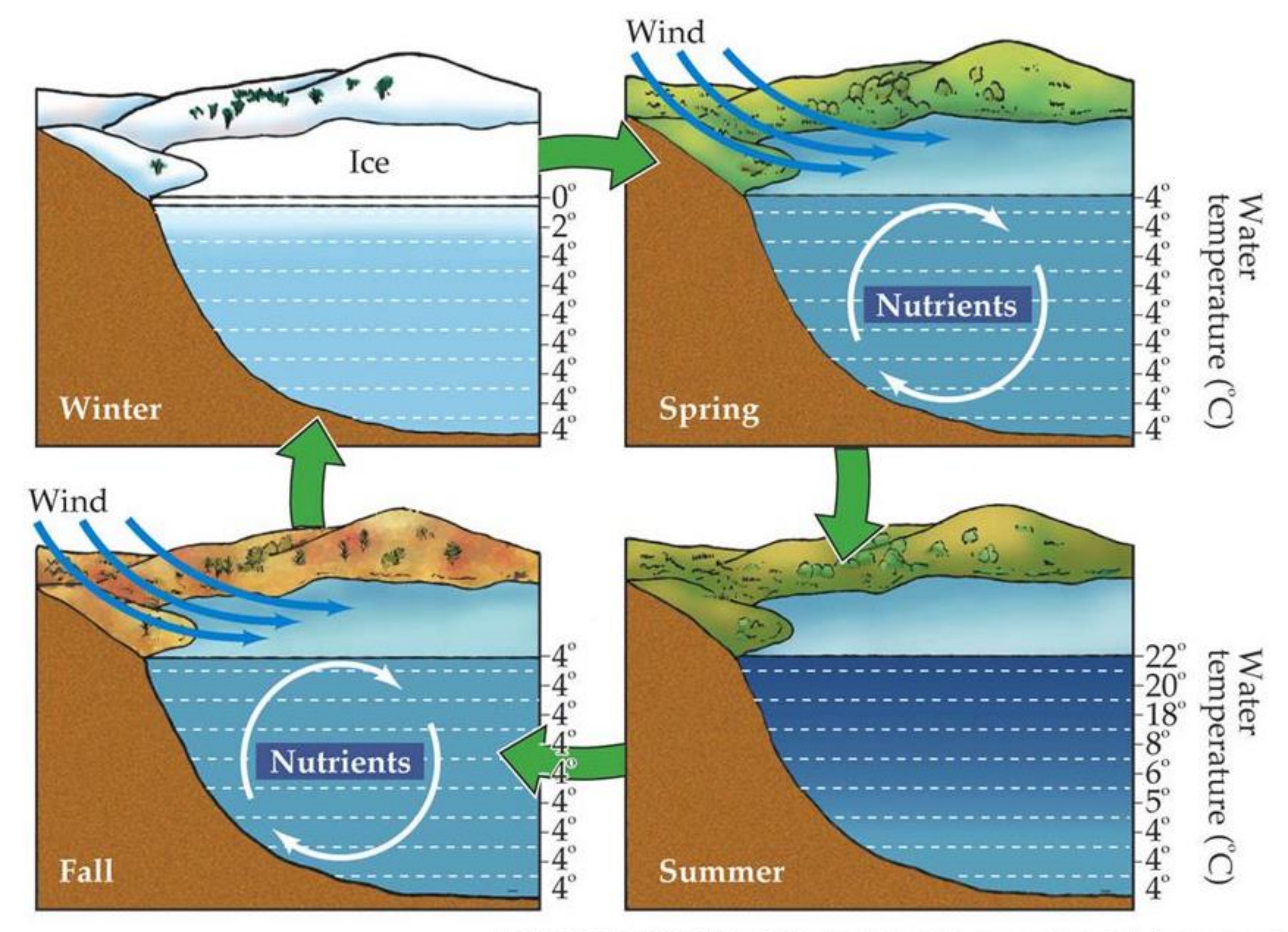
## Great source of lake morphometry information

- Lake area ($A_0$)
- Maximum depth($Z_{max}$)
- Mean depth ($\bar{z}$)
- Deep hole
- Shorelines Lenght (L)
- Shallow areas
- VolumeV=$A_0$ * $\bar{z}$



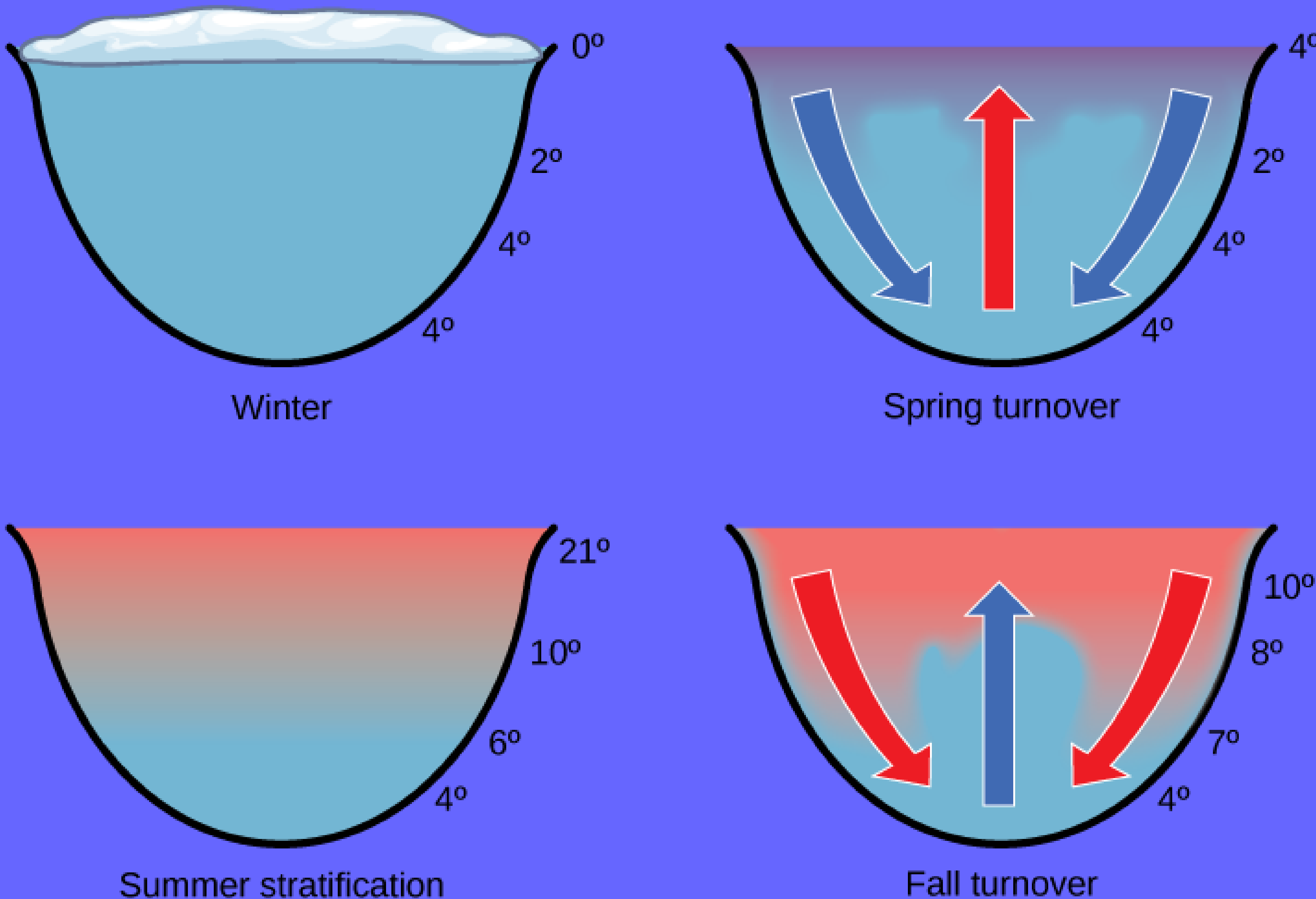



# Seasonal Layering, Lake Turnover (1)

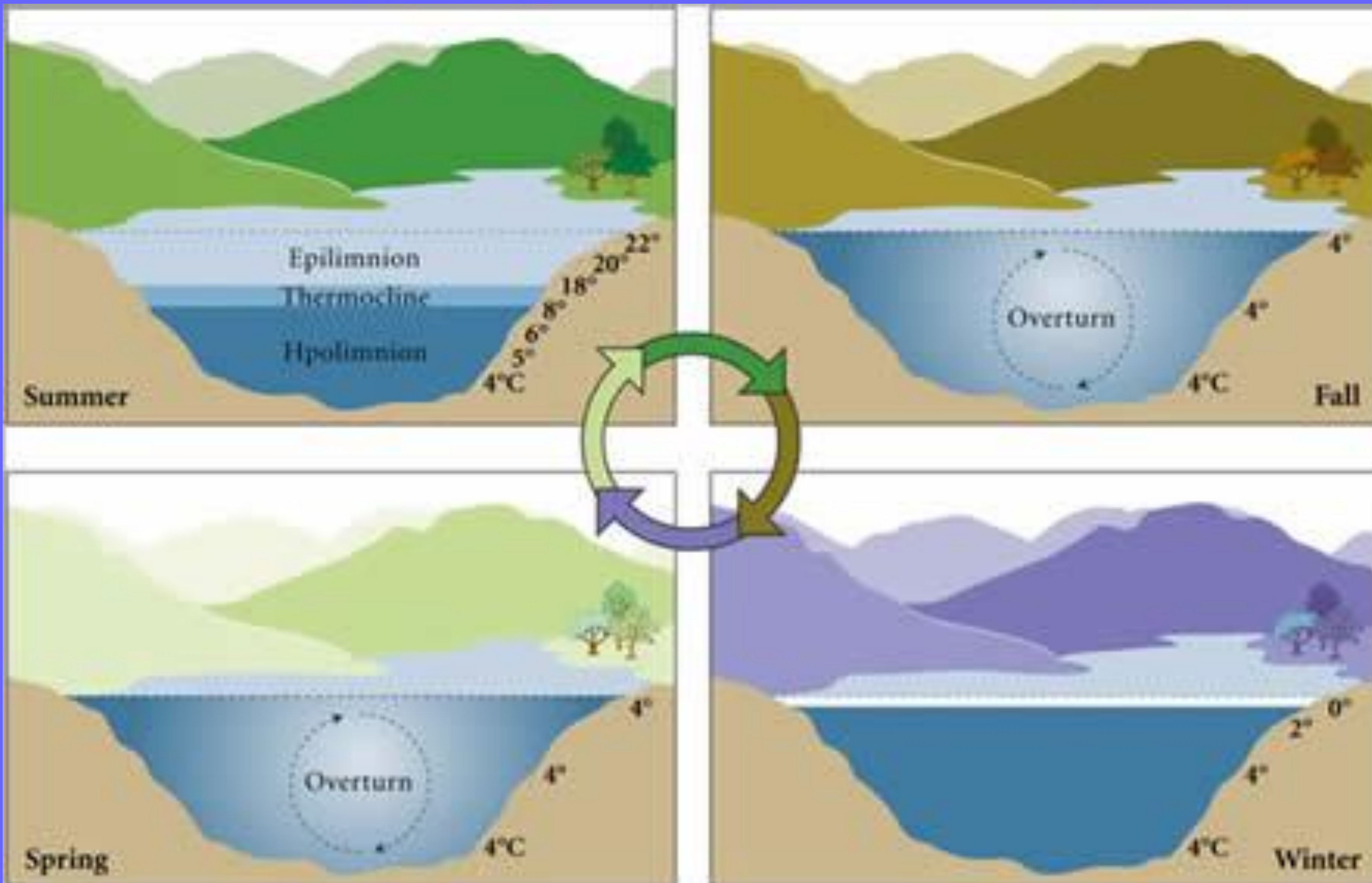



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 58.3 Annual Temperature and Oxygen Cycles in a Temperate Lake

# Seasonal Layering, Lake Turnover (2)



# Seasonal Layering, Lake Turnover (3)



# Water Measurement (Surface Routing Models)

Rational Method Equation

Unit Hydrograph Method

# Rational Method Equation

This is the simplest method to determine peak discharge from drainage basin runoff. It is the most common method used for sizing sewer systems.

The formula to give the peak runoff rate (flow) is:

$$Q\left(\frac{m^3}{s}\right) = \bar{C} \cdot \bar{i}\left(\frac{mm}{hr}\right) \cdot A\left(km^2\right)$$

where $\bar{C}$ is the average runoff coefficient

# Runoff Coefficient

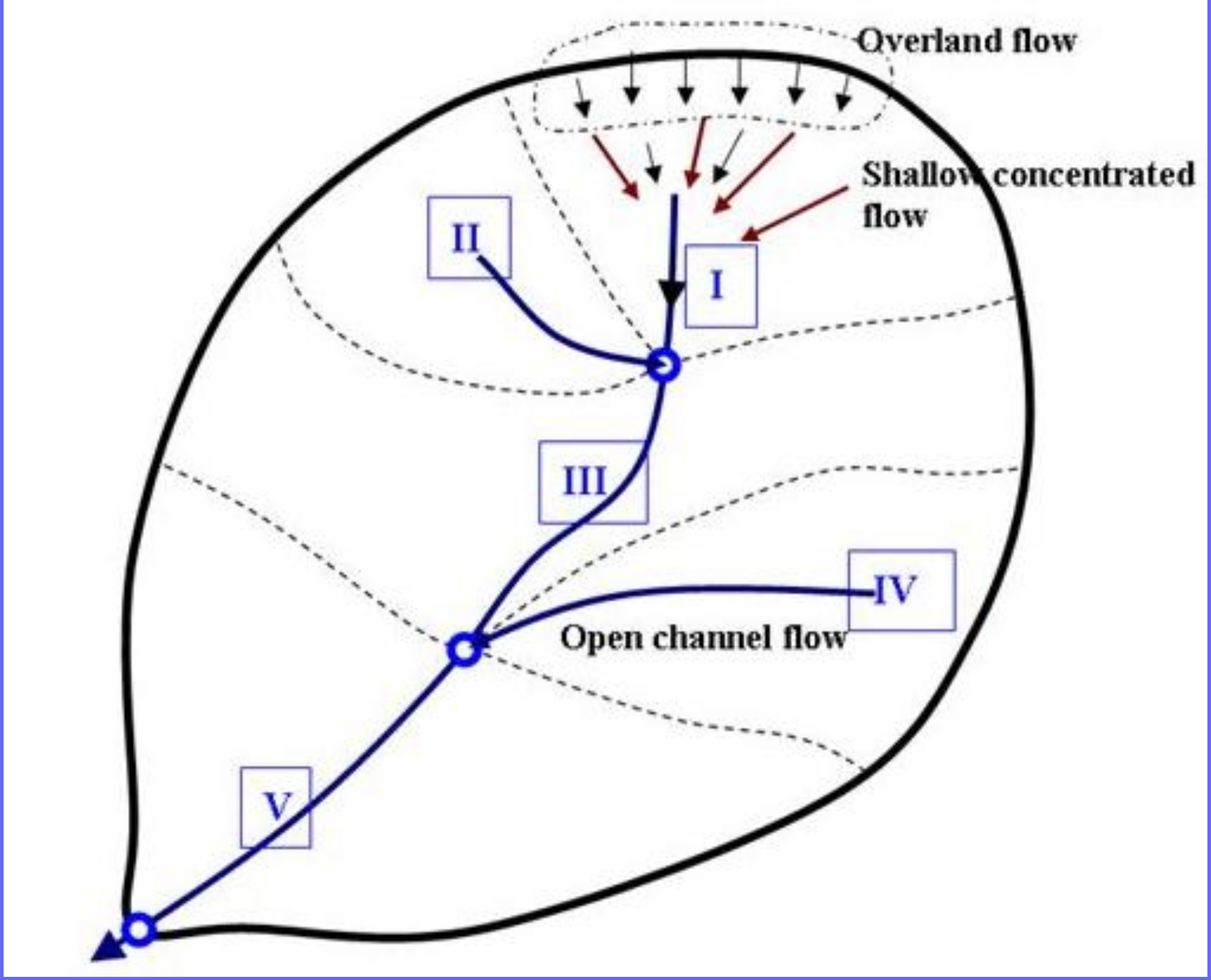
Is a function of the soil type and drainage basin slope.

$$C = \frac{Runoff\,(mm)}{Rainfall\,(mm)}$$

$$\bar{C} = \frac{\sum_{i=1}^{n} A_i \cdot C_i}{\sum_{i=1}^{n} A_i}$$

| Ground Cover | Runoff Coefficient, c |
|---|---|
| Lawns | 0.05 - 0.35 |
| Forest | 0.05 - 0.25 |
| Cultivated land | 0.08-0.41 |
| Meadow | 0.1 - 0.5 |
| Parks, cemeteries | 0.1 - 0.25 |
| Unimproved areas | 0.1 - 0.3 |
| Pasture | 0.12 - 0.62 |
| Residential areas | 0.3 - 0.75 |
| Business areas | 0.5 - 0.95 |
| Industrial areas | 0.5 - 0.9 |
| Asphalt streets | 0.7 - 0.95 |
| Brick streets | 0.7 - 0.85 |
| Roofs | 0.75 - 0.95 |
| Concrete streets | 0.7 - 0.95 |

# Formation Process of Surface Runoff



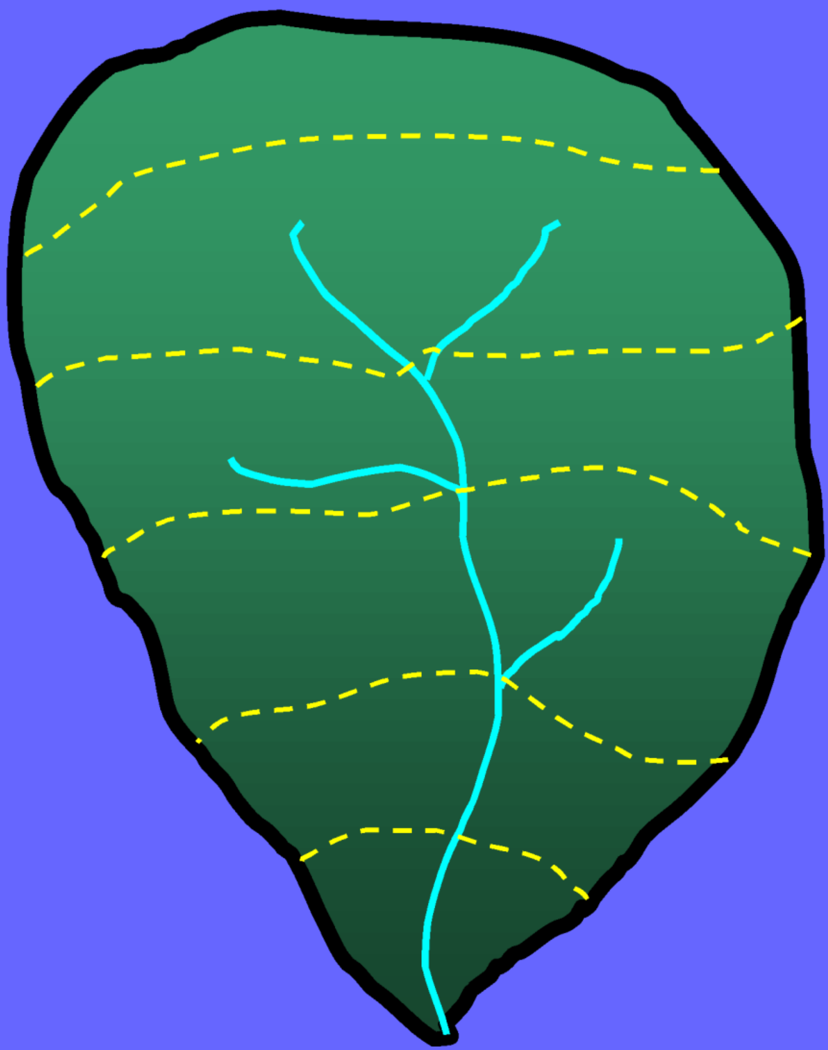
# Isochrones

A relationship between the travel time and a portion of a basin that may contribute runoff during that travel time.

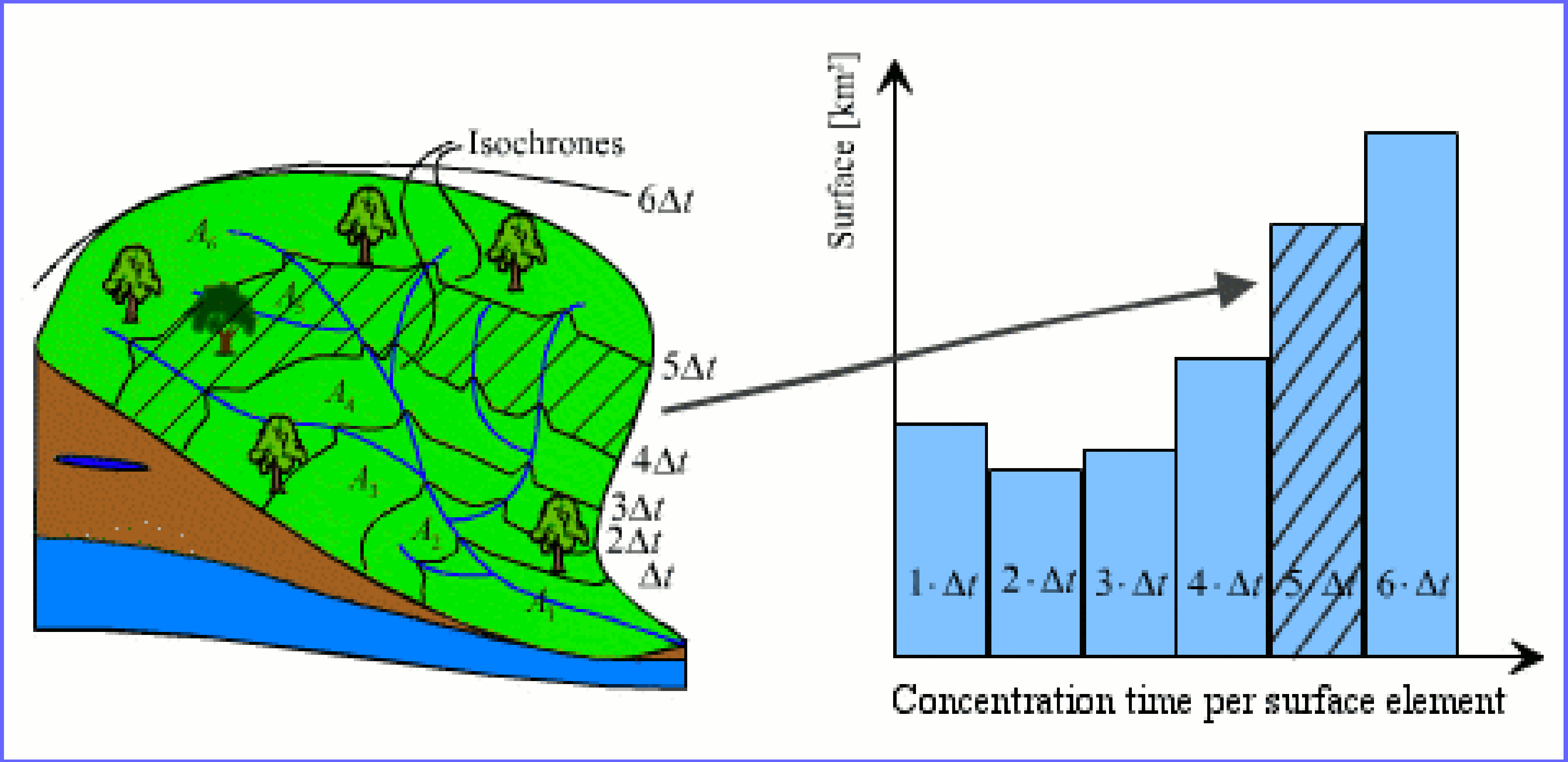
In a time-area method, the watershed is traditionally broken into areas of travel time.

These lines of equal travel time are known as isochrones.

Watershed divided into six areas of approximately equal travel time to the outlet.



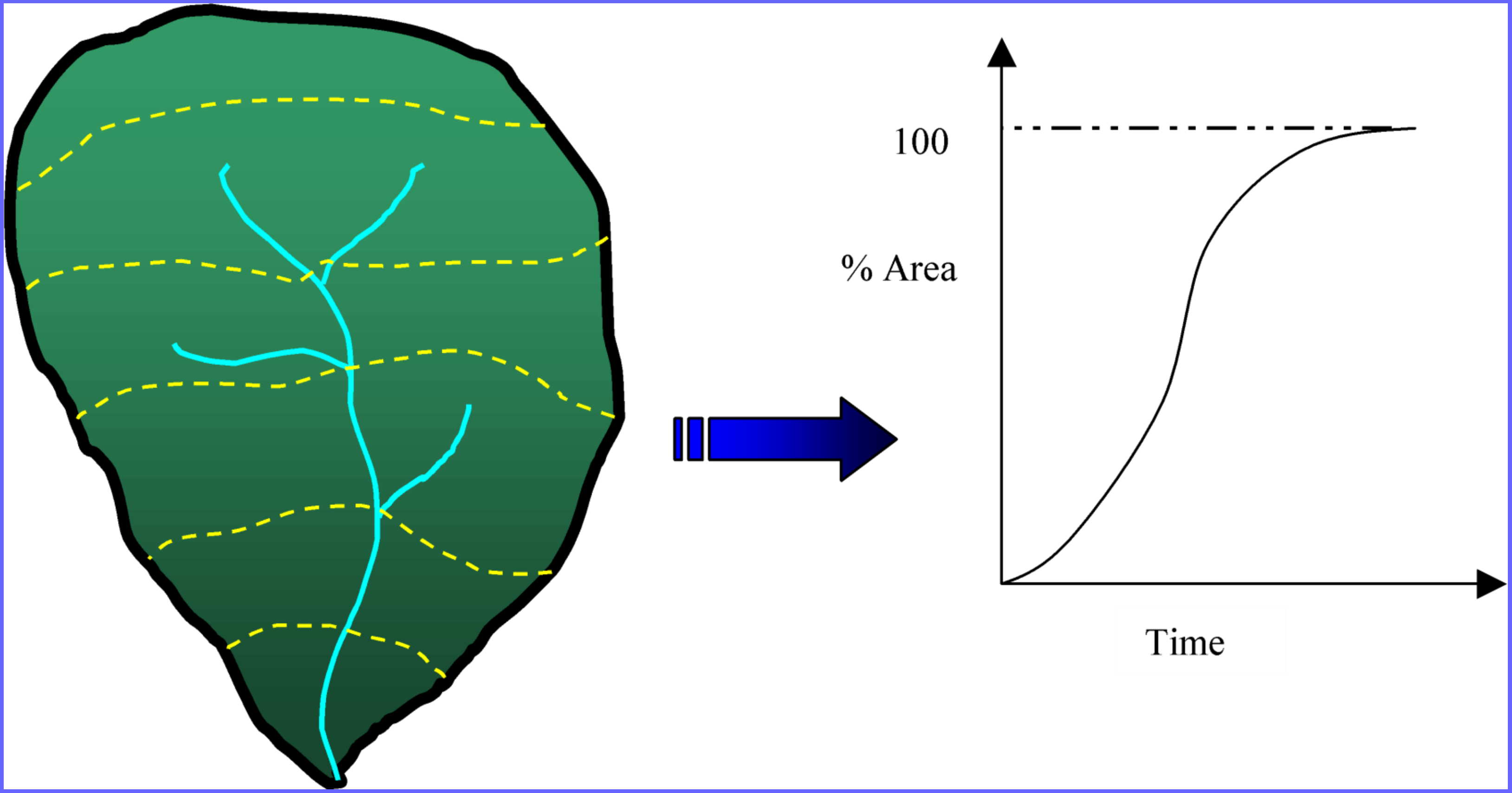
# Isochrones-Watershed Area




The isochrone is a contour joining points of equal concentration time of the water in a watershed.

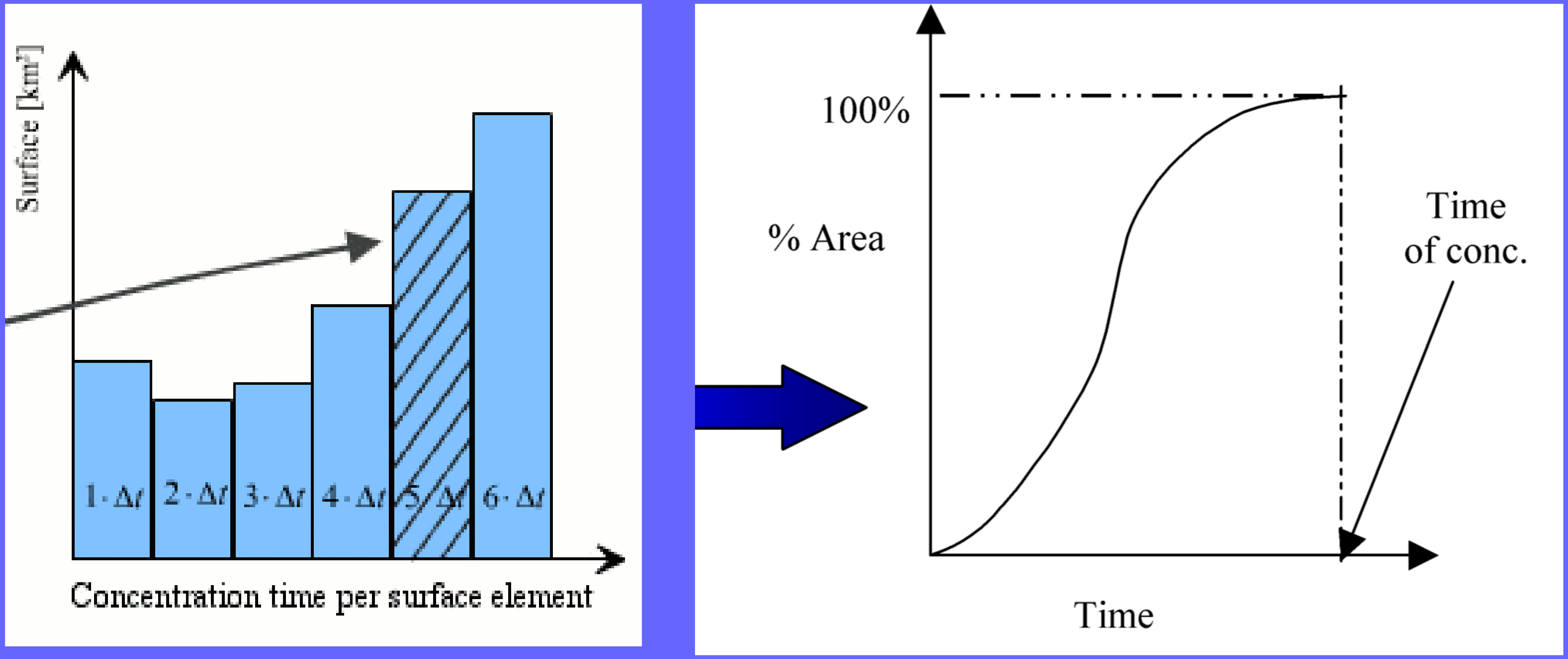
The farthest isochrones from the outlet section represent the time passed for which the whole watershed surface contributes to the flow towards the outlet section after a uniform rainfall.

# Watershed Characteristics(1)



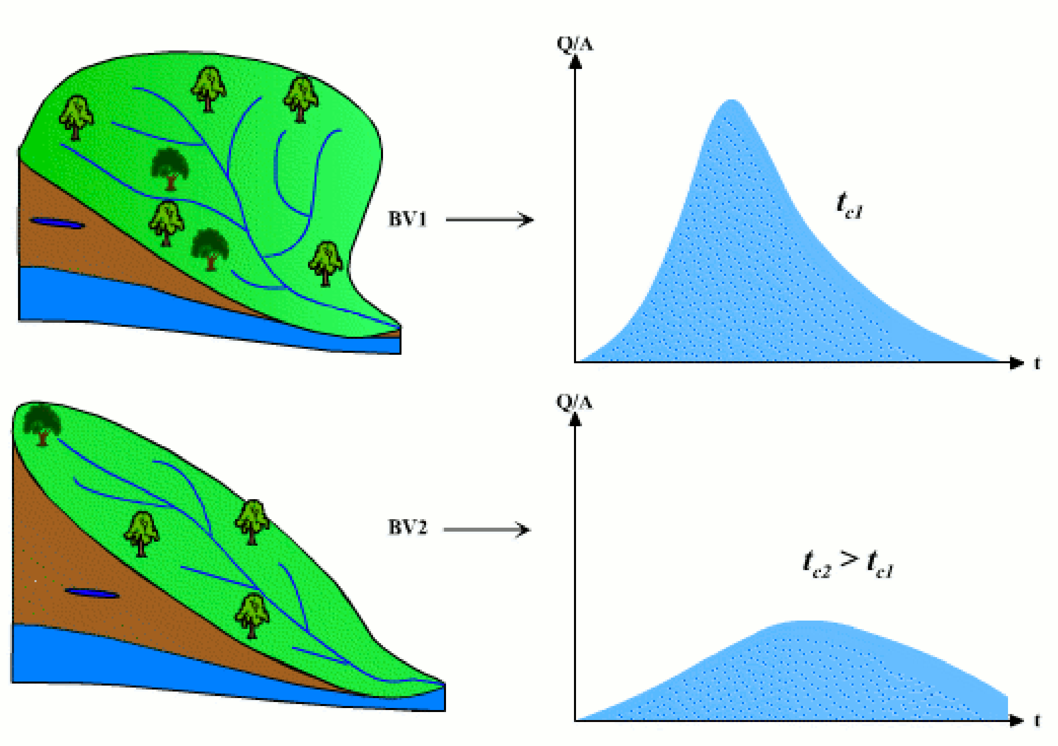

Watershed divided into six areas of equal travel time to the outlet. Accumulative time-area curve is also illustrated.

# Watershed Characteristics (2)




Time-area histogram and associated cumulative time-area diagram.

# Watershed Shape

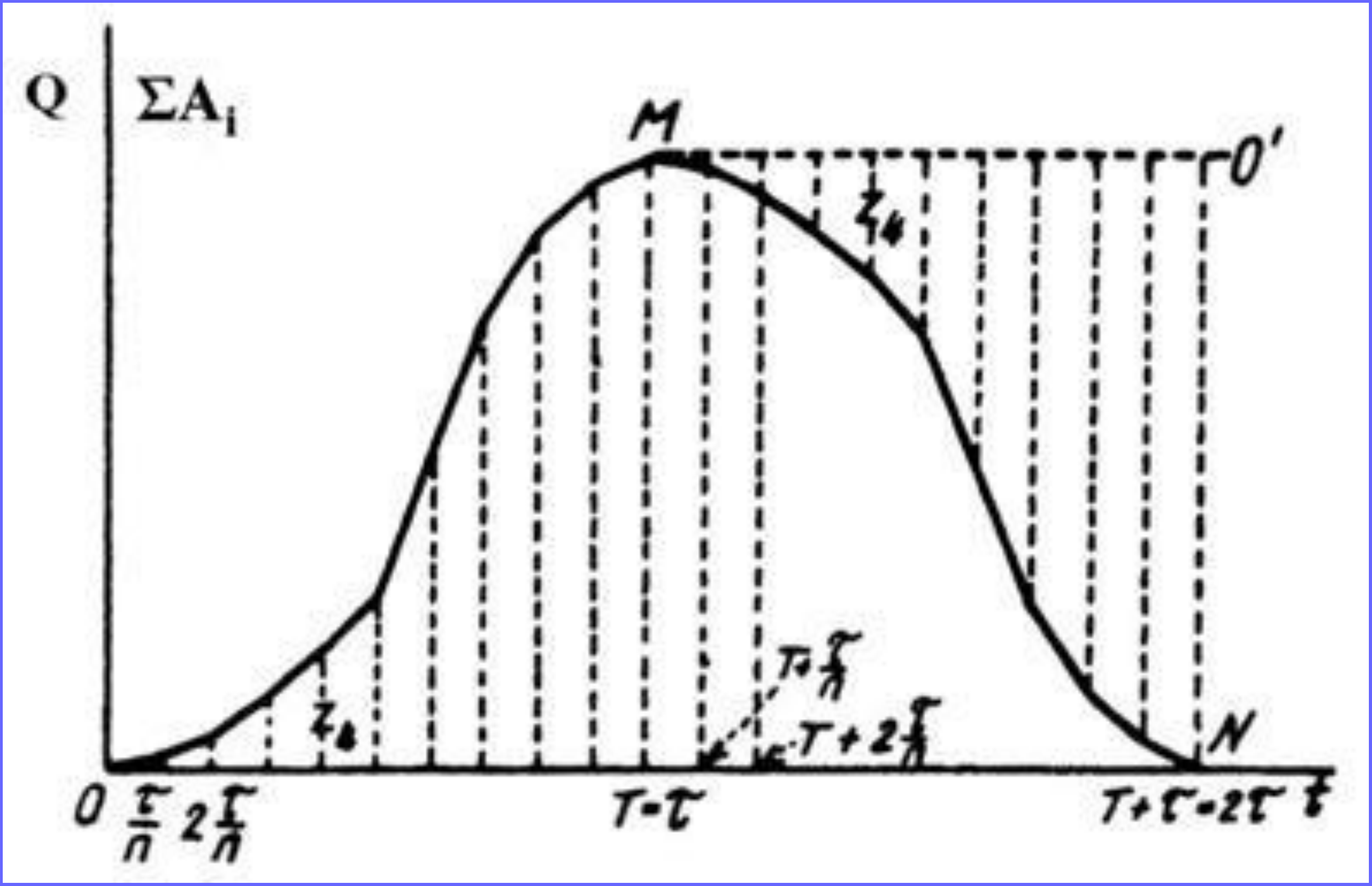



The shape of a watershed influences the shape of its characteristic hydrograph.

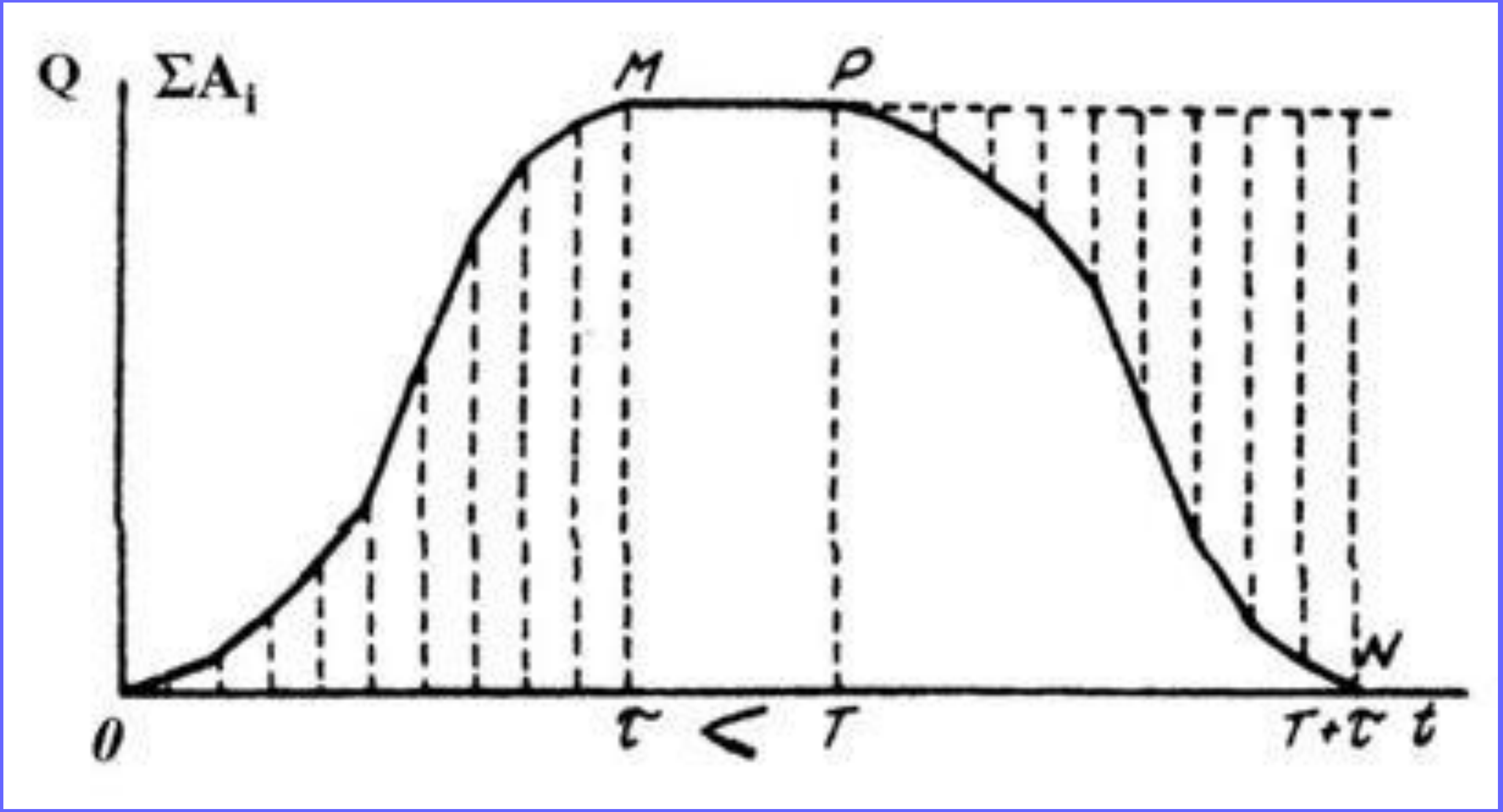
A long shape watershed generates, for the same rainfall, a lower outlet flow, as the concentration-time is higher.

A watershed having a fan-shape presents a lower concentration time, and it generates higher flow.

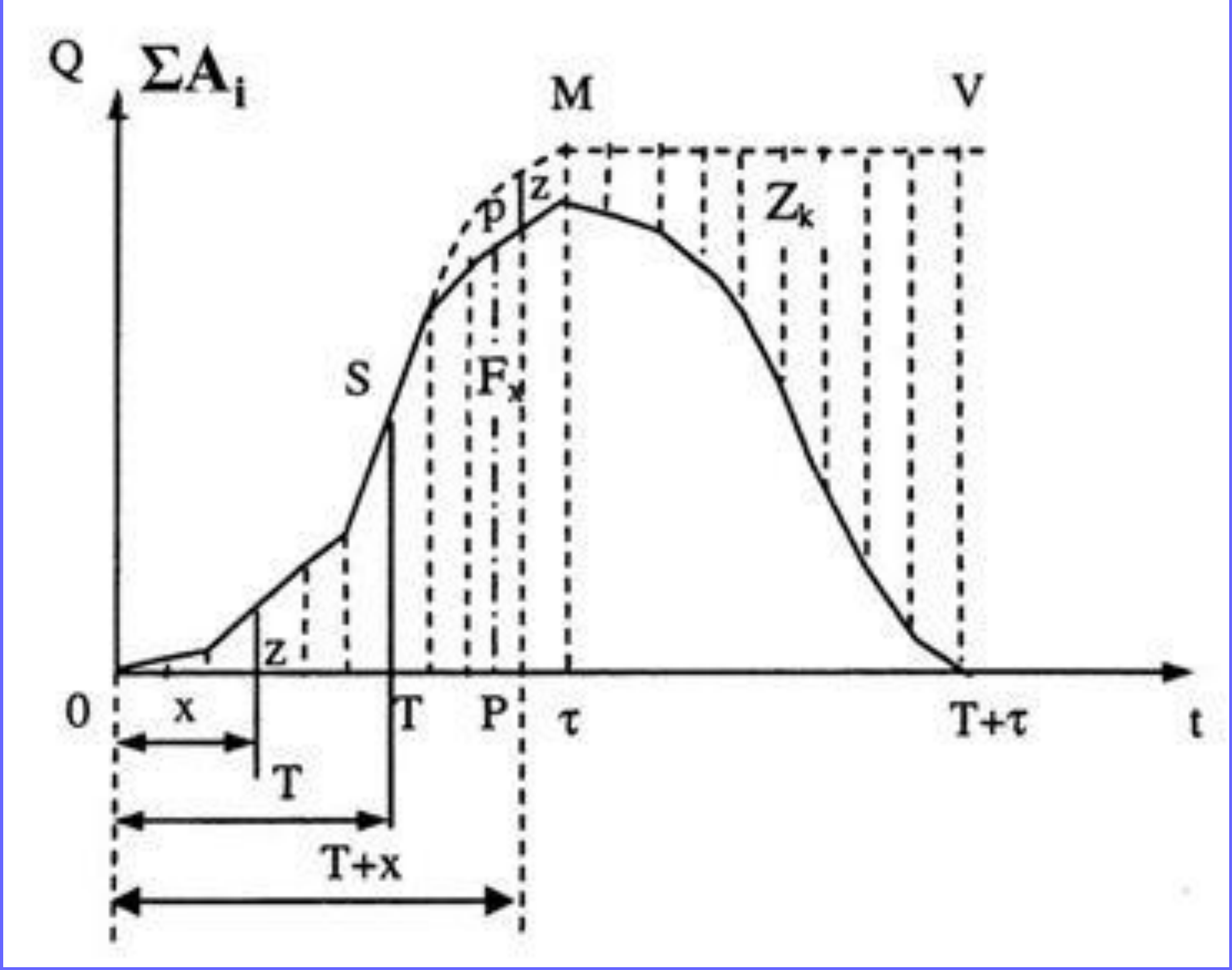
# (a) T=τ



# (b) T>τ



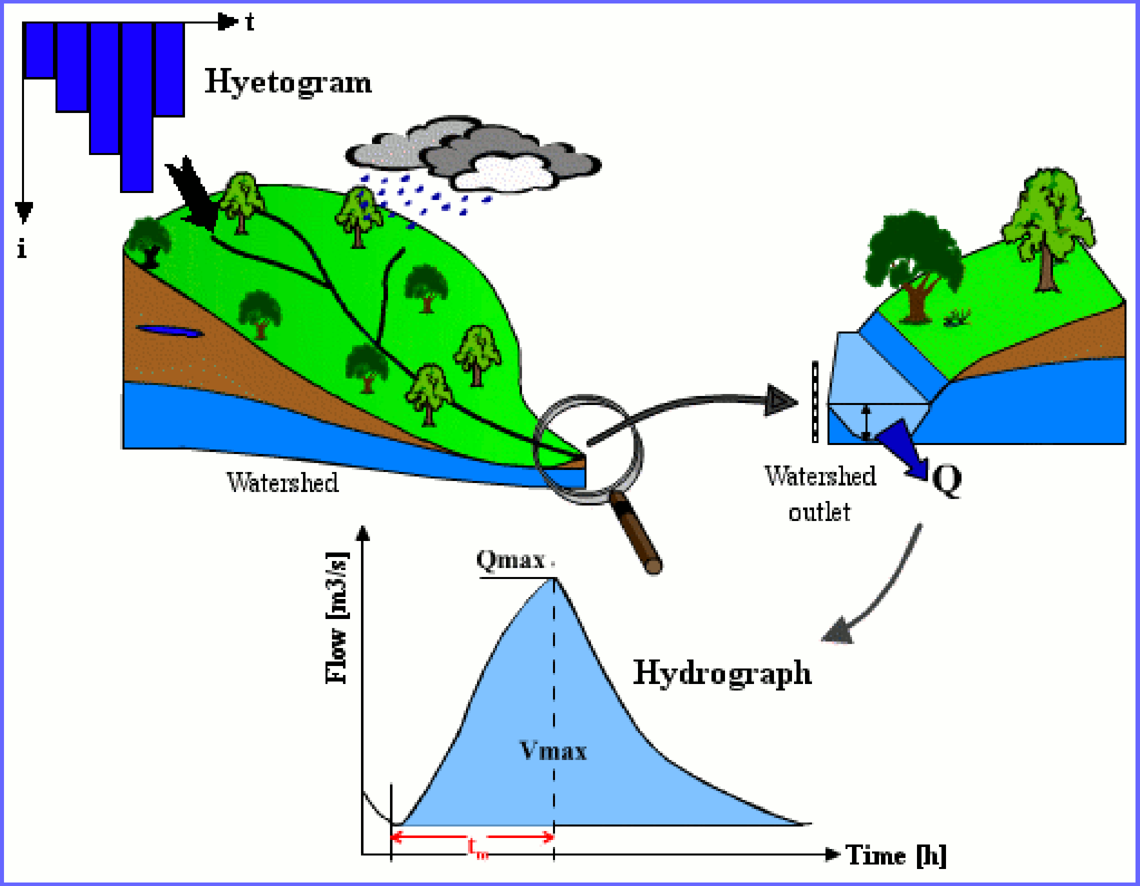
# (c) T<τ



# Unit Hydrograph Method

A hydrograph is a graph showing the rate of flow (discharge) versus time past a specific point in a river.

The rate of flow is typically expressed in cubic meters per second.




Hydrological response of a catchment [Musy, 2001]

# Unit Hydrograph

A unit hydrograph is the hydrograph of surface runoff resulting from rain that falls in a unit of time (1 hour or one day) and produced uniformly in space and time over the total catchment area.

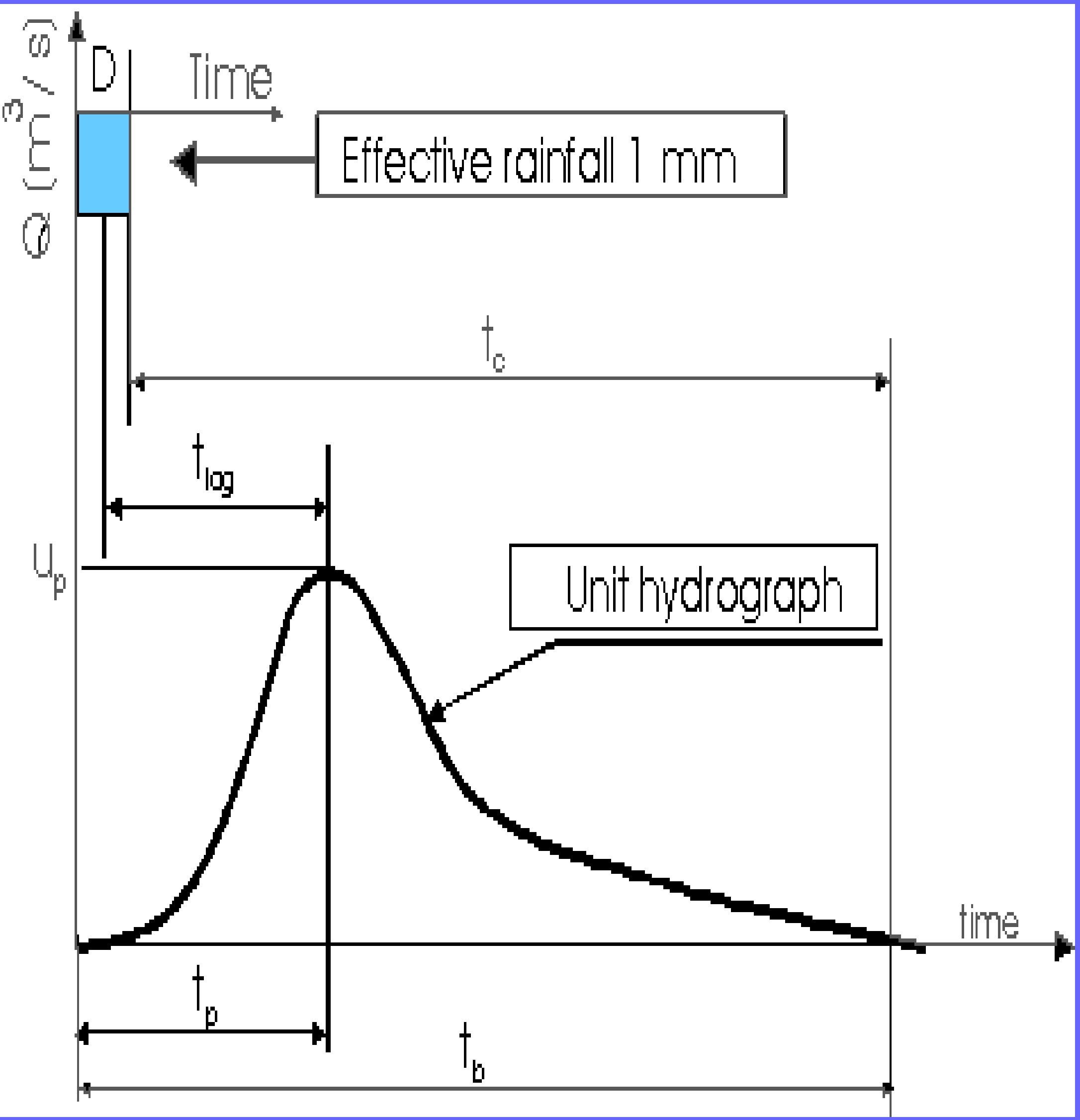
In practice, a *t* hours unit hydrograph is defined as resulting from a unit depth of effective rainfall falling in *t* h over the catchment.

The chosen magnitude for *t* depends on the size of the catchment and the response time to major rainfall events.

The standard depth of effective rainfall was chosen by Sherman to be 1mm or 10mm.

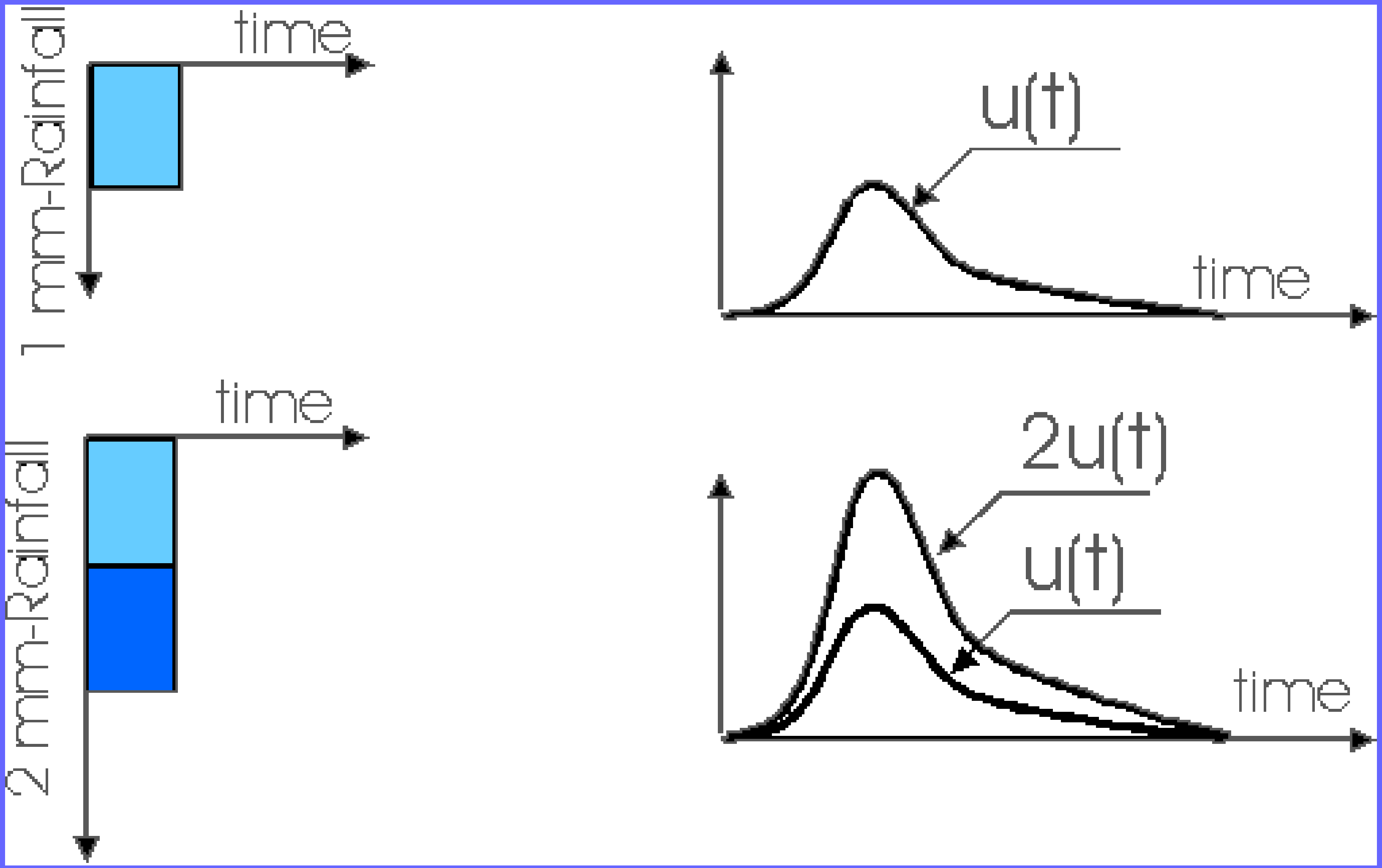
# The Theory of Unit Hydrograph

1. The net rainfall is of uniform intensity within its duration (i.e., unit period).
2. The net rainfall uniformly occurs over the entire area of the drainage basin.
3. For a given drainage basin, the base period of the hydrographs of direct runoff corresponding to net rains of different intensities but the same unit duration is constant.
4. The ordinates of direct runoff hydrographs due to net rains of different intensities (but same unit duration) are proportional.
5. A unit hydrograph reflects all the physical characteristics of the basin.

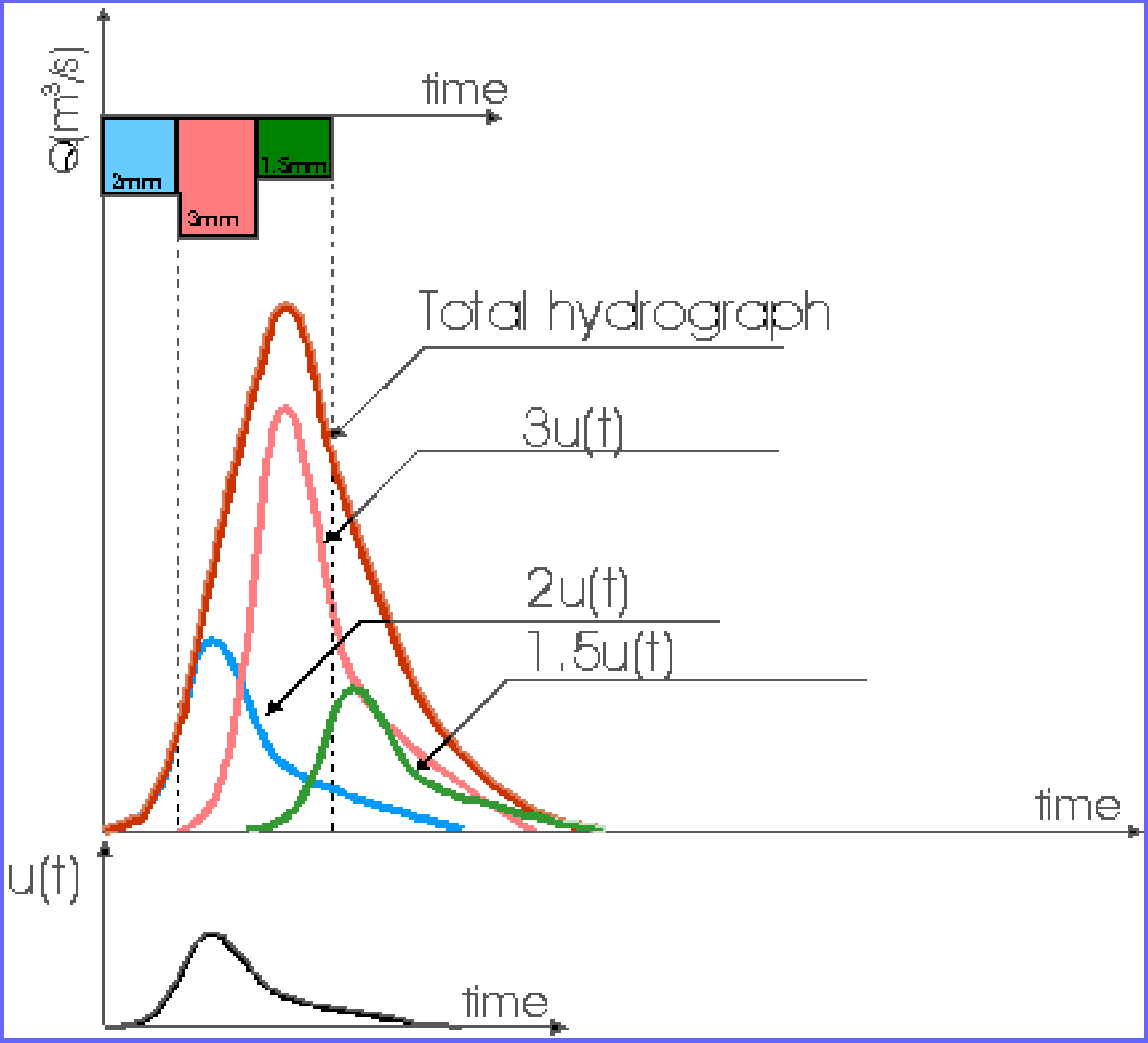



- Peak discharge of the unit hydrograph, $u_p$;
- Base time $t_b$ is the total duration of the unit hydrograph;
- Increase time or time to peak $t_p$ is the time between the start point of the hydrograph and the peak;
- Concentration time $t_c$ is the time between the end of rainfall and the end of the hydrograph;
- Lag time $t_{lag}$ is the time between the gravity center of rainfall and the peak of the hydrograph

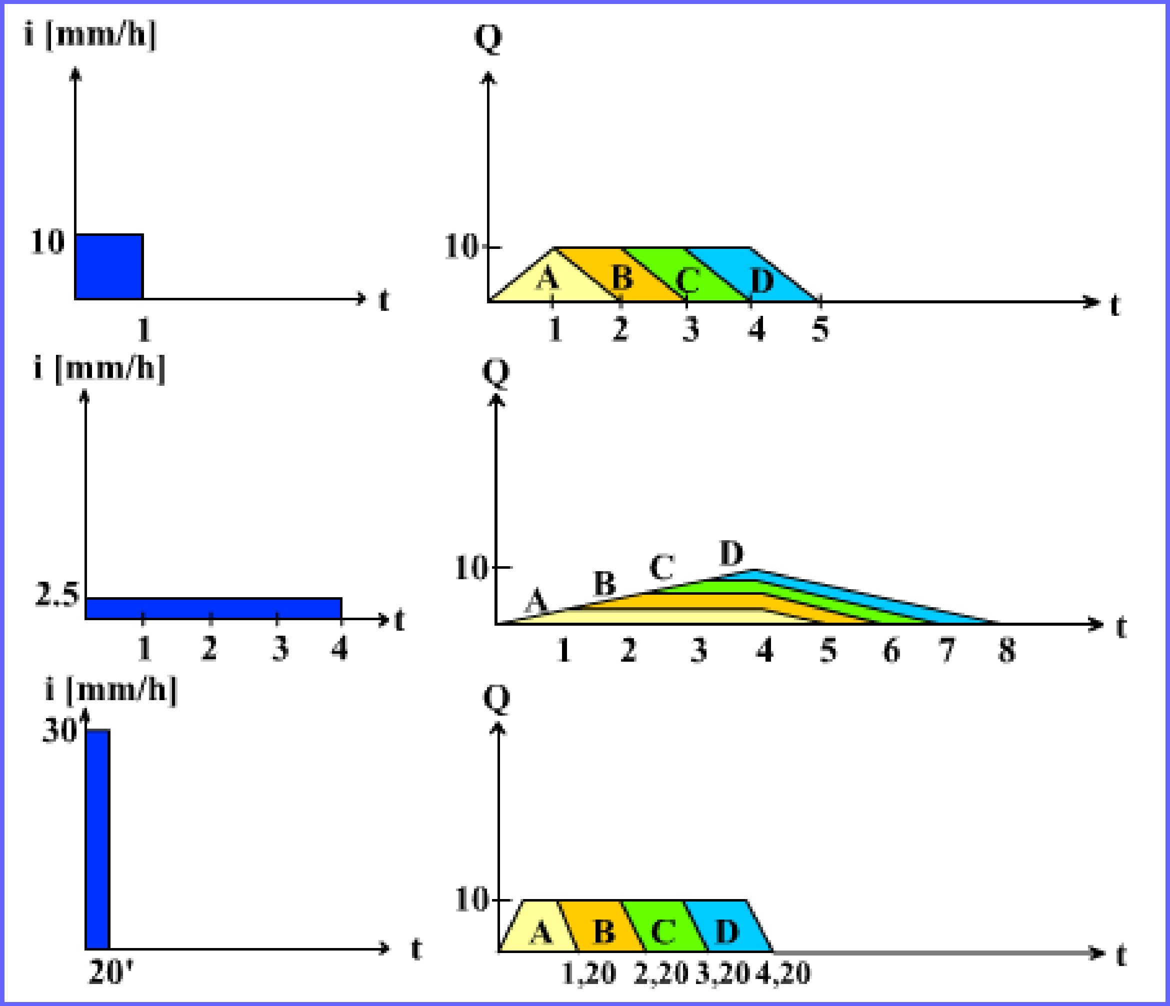
# Linearity hypothesis of the unit hydrograph

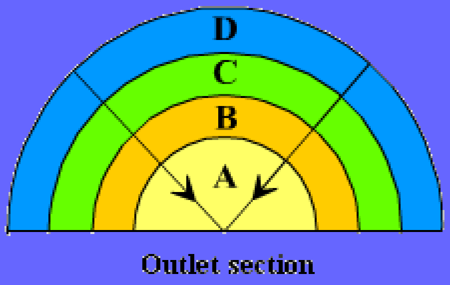


# Principle of superposition



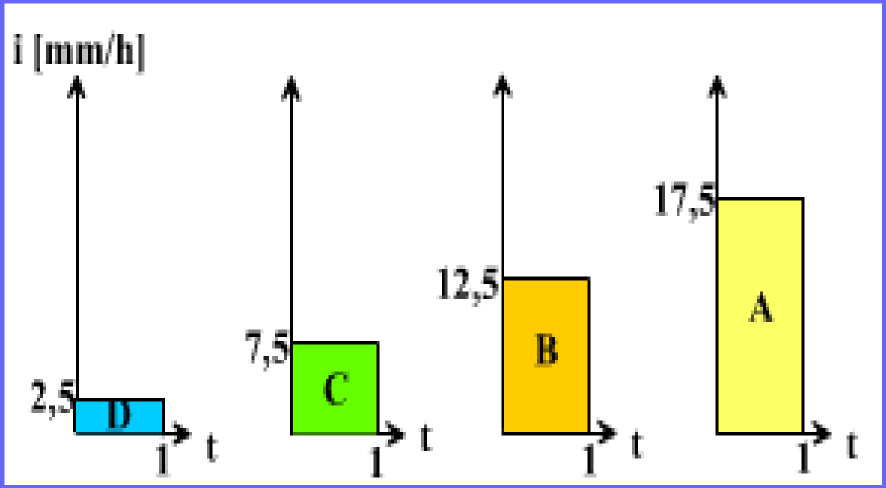
# Catchment representation

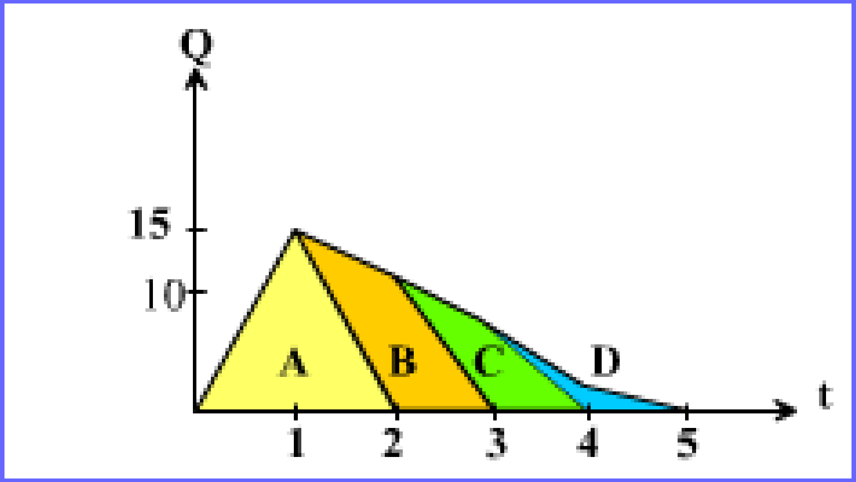


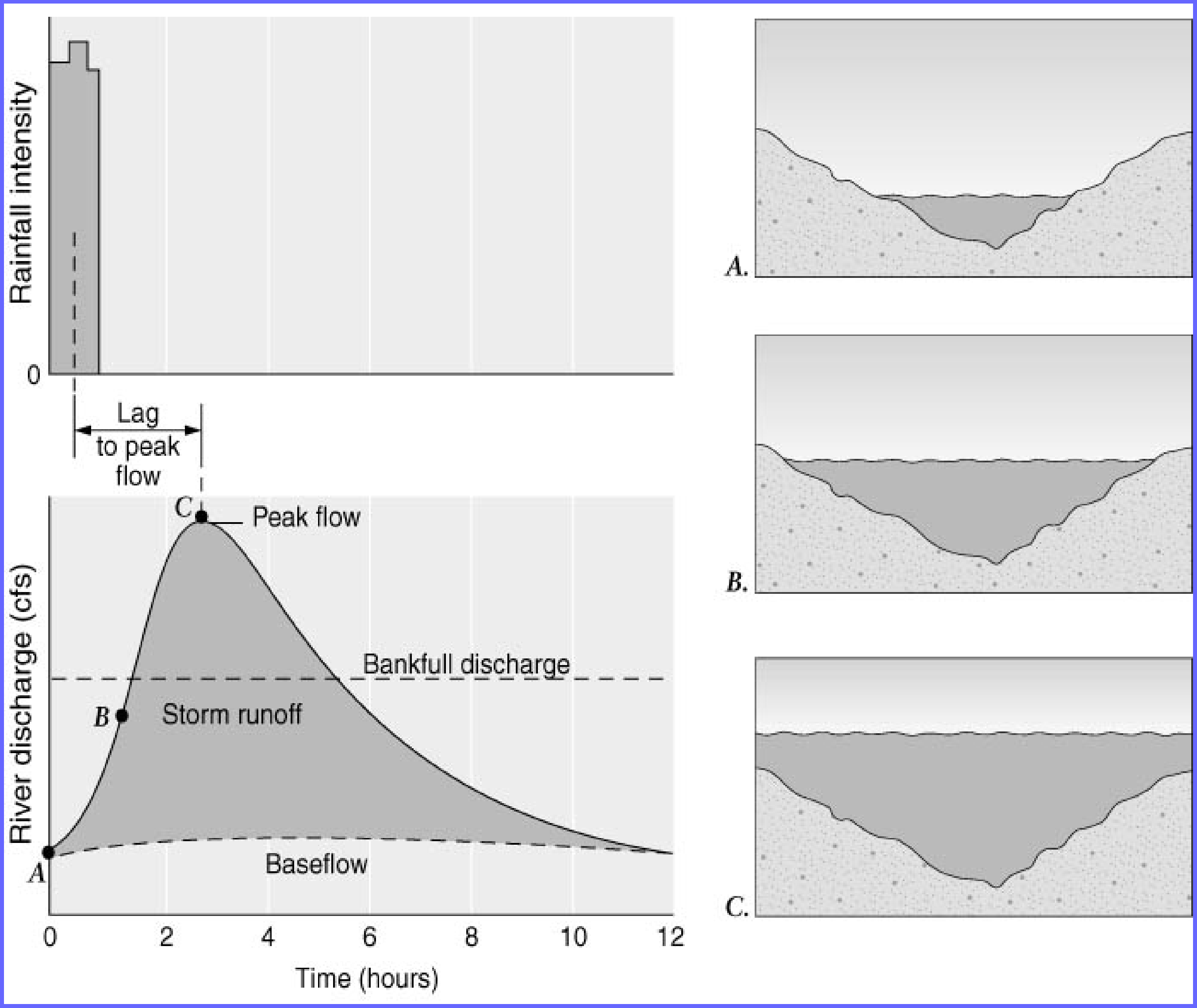

The rainfall influence in time, on the hydrological response of a catchment. Hyetograms are represented on the left side, and hydrographs on the right side.

# The influence of rainfall spatial distribution on the hydrological response of a catchment

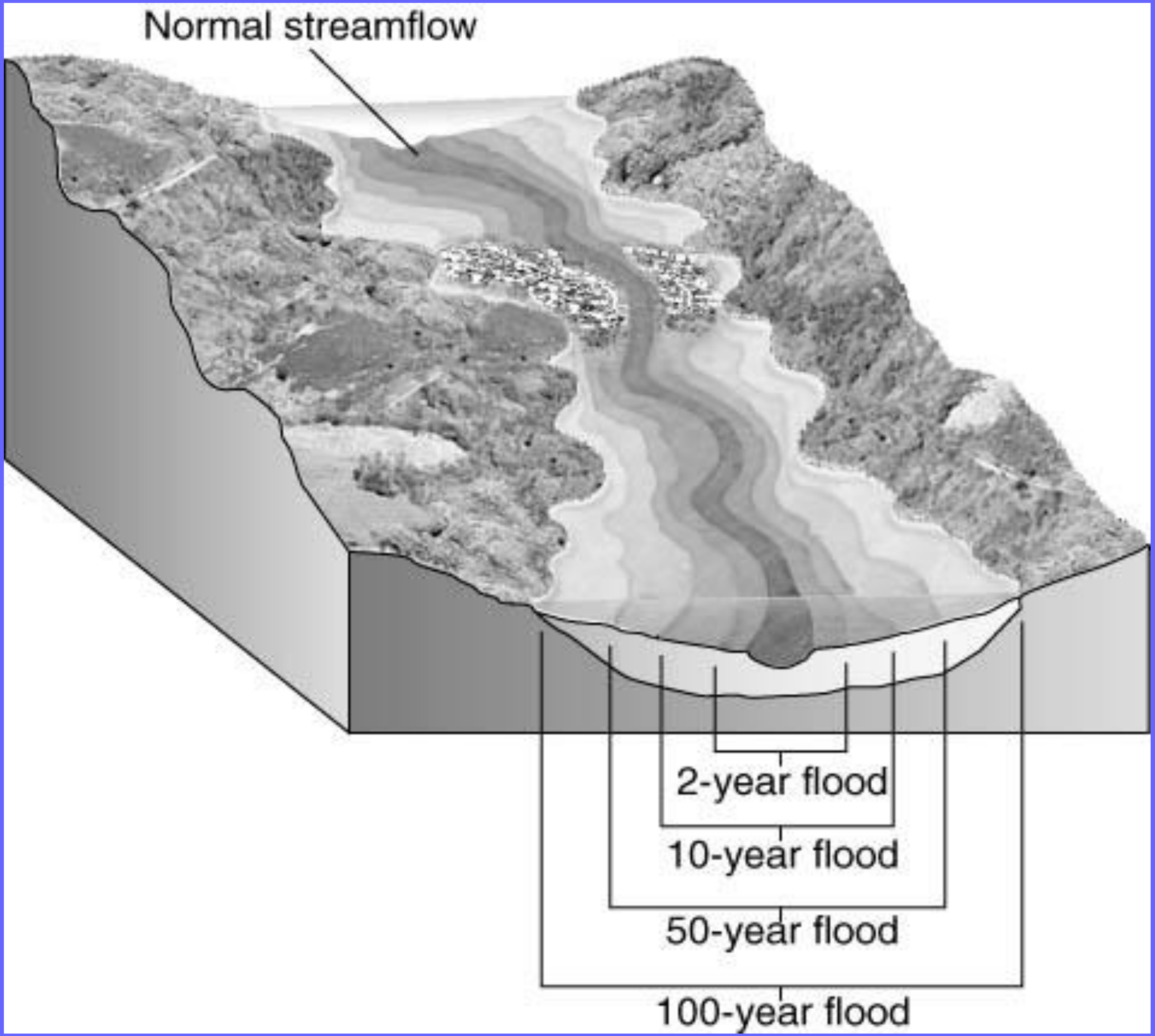


The hydrograph of a river can look similar to this example after a brief but intense rainfall event.



Flood damage can be predicted based on the intensity of a storm and the topography of a region.



# Flood Events

**Flood frequency**: the likelihood that a large flood will happen

**100-year flood**: flood that is exceeded - on average - once every 100 years, the probability in 1 year is 1/100 = 1 %

**10-year flood:** probability = 10 %

**Mean annual flood:**exceeded once every two years, probability = 50%

# Extreme Events

**Probable Maximum Precipitation (PMP)**

- The most extreme rainfall possible
- Used for estimating the effects of extreme weather

**Probable Maximum Flood (PMF)**

- The most extreme flood possible
- Used for estimating maximum extent of flooding

## Example 1

The area of a catchment (watershed) is 8 hectars. The 15% of the watershed is covered by parks, the 25% is by forests, the 40% is by roofs and the 20% is by asphalt streets. The runoff coefficients are at parks 0.15, at forests 0.05, at roofs 0.75, and at asphalt streets 0.85. Calculate the values of the average runoff coefficient.

# Solution 1

Parks

$$A_1 = 0.15 \cdot \sum A = 0.15 \cdot 8\ ha = 1.2\ ha$$

$$C_1 = 0.15$$

Forests

$$A_2 = 0.25 \cdot \sum A = 0.25 \cdot 8\ ha = 2\ ha$$

$$C_2 = 0.05$$

Roofs

$$A_3 = 0.4 \cdot \sum A = 0.4 \cdot 8\ ha = 3.2\ ha$$

$$C_3 = 0.75$$

Asphalt streets

$$A_4 = 0.2 \cdot \sum A = 0.2 \cdot 8ha = 1.6\ ha$$

$$C_4 = 0.85$$

$$c_{avg} = \frac{\sum_{i=1}^{n} A_i \cdot C_i}{\sum A} = \frac{A_1 \cdot C_1 + A_2 \cdot C_2 + A_3 \cdot C_3 + A_4 \cdot C_4}{\sum A} = \frac{1.2ha \cdot 0.15 + 2ha \cdot 0.05 + 3.2ha \cdot 0.75 + 1.6ha \cdot 0.85}{8ha} = 0.505$$

## Example 2

The area of a catchment is 100 hectars. The intensity of the rainfall was $i = 150 \frac{l}{sec,ha}$ , the values of the average runoff coefficient is $C_{avg} = 0.1$. The first isochrone's catchment area is 5 hectars, the second is 10 hectars, the third is 10 hectars, the fourth is 15 hetctars, the fifth is 15 hectars, the sixth is 15 hectars, the seventh is 10 hectars, the eight is 10 hectars, the ninth is 5 hectars and the tenth is 5 hectars. Constract the watershed characteristics and calculate the peak runoff rate (Q) when (a) the duration of the waterfall is T=10 hours, (b) T=11 hours, (c) T=7 hours.

# Solution 2

(a)

$$T = \tau$$

$$Q_{max} = C_{avg} \cdot i \cdot A = 0.1 \cdot 150 \frac{l}{sec, ha} \cdot 100ha = 1500 \frac{l}{sec} = 1.5 \frac{m^3}{sec}$$

(b)

$$T > \tau$$

$$Q = Q_{max} = C_{avg} \cdot i \cdot A = 0.1 \cdot 150 \frac{l}{sec, ha} \cdot 100ha = 1500 \frac{l}{sec} = 1.5 \frac{m^3}{sec}$$

(c)

$$T < \tau$$

$$Q_{red} = C_{avg} \cdot i \cdot A_{red} = 0.1 \cdot 150 \frac{l}{sec, ha} \cdot 85ha = 1275 \frac{l}{sec} = 1.275 \frac{m^3}{sec}$$

## Example 3

On a catchment, area is 120 km$^2$, was a 6 hours long waterfall with intensity $i = 4\frac{mm}{hr}$. On the watershed the values of the average runoff coefficient is 0.1. The stream witch flow in the middle of the catchment is 14.4 km long, with 0.5 $\frac{m}{\text{sec}}$ main velocity. The isochrone's catchment areas connect linear. Calculate (a) the travel time of the runoff $(\tau)$, constract (b) the watershed characteristics and calculate (c) the peak runoff rate (Q).

## Solution 3

(a)

$$\tau = \frac{L}{v_{main}} = \frac{14.4\ km}{0.5\frac{m}{sec}} = \frac{14.4 \cdot 10^3 m}{0.5\frac{m}{sec}} = 28800 sec = 8\ hr$$

(c)

$$T = 6\ hr$$

$$\tau = 8 hr$$

$$T < \tau$$

$$Q = Q_{red} = C_{avg} \cdot i \cdot A_{red} = 0.1 \cdot 4\frac{mm}{hr} \cdot 90 km^2 = 0.1 \cdot 4 \cdot 10^{-3}\frac{m}{hr} \cdot 90 \cdot 10^6 m^2$$
$$= 3.6 \cdot 10^4\ \frac{m^3}{hr} = 10\frac{m^3}{sec}$$

## Example 4

A watershed first isochrone's catchment area is 3 km$^2$, the second is 4 km$^2$, the third is 5 km$^2$, the fourth is 6 km$^2$, the fifth is 7 km$^2$, the sixth is 8 km$^2$, the seventh is 4 km$^2$, the eigth is 3 km$^2$. The peak runoff rate on the watershed is $4.7\,\frac{m^3}{sec}$, the intensity of the rainfall was $i = 8 \cdot T^{-0.5}\ \frac{mm}{hr}$ . The relation between the duration of the rainfall (T) and the travel time of the runoff (τ) is T= 0.5 τ. Calculate (a) the average runoff coefficient, (b) the reduce catchment area and (c) the reduce runoff rate.

# Solution 4

(a)

$$Q_{max} = C_{avg} \cdot i \cdot A \rightarrow T = \tau = 8\ hr$$

$$i_{max} = 8 \cdot T^{-0.5}\ \frac{mm}{hr} = 8 \cdot 8^{-0.5}\ \frac{mm}{hr} = \frac{8}{\sqrt{8}} \cdot \frac{mm}{hr} = 2.82\ \frac{mm}{hr}$$

$$C_{avg} = \frac{Q_{max}}{i \cdot A} = \frac{4.7\ \frac{m^3}{sec}}{2.82\frac{mm}{hr} \cdot 40km^2} = \frac{4.7\ \frac{m^3}{sec}}{\frac{2.82 \cdot 10^{-3}m}{3600\ sec} \cdot 40 \cdot 10^6 m^2} = 0.15$$

(b)

$$A_{red} = 26km^2$$

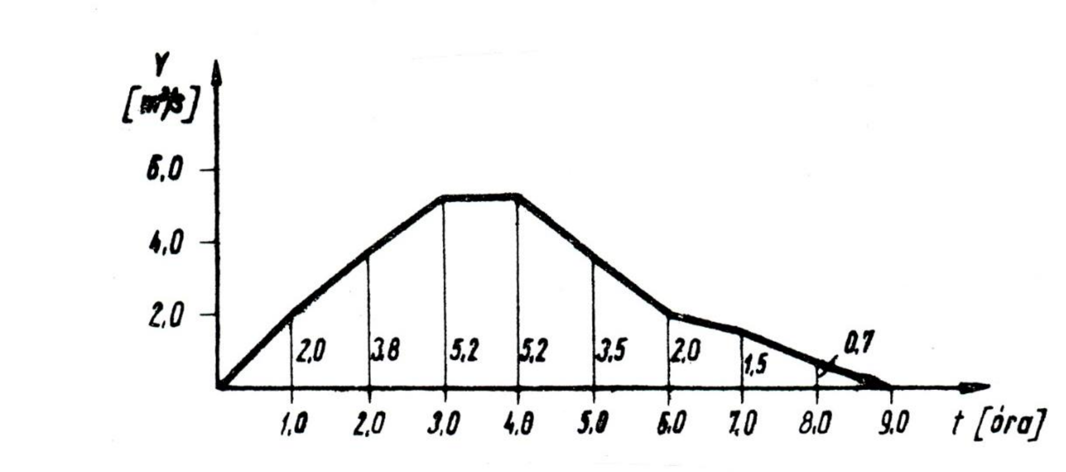
(c)

$$i_{red} = 4\ \frac{mm}{hr}$$

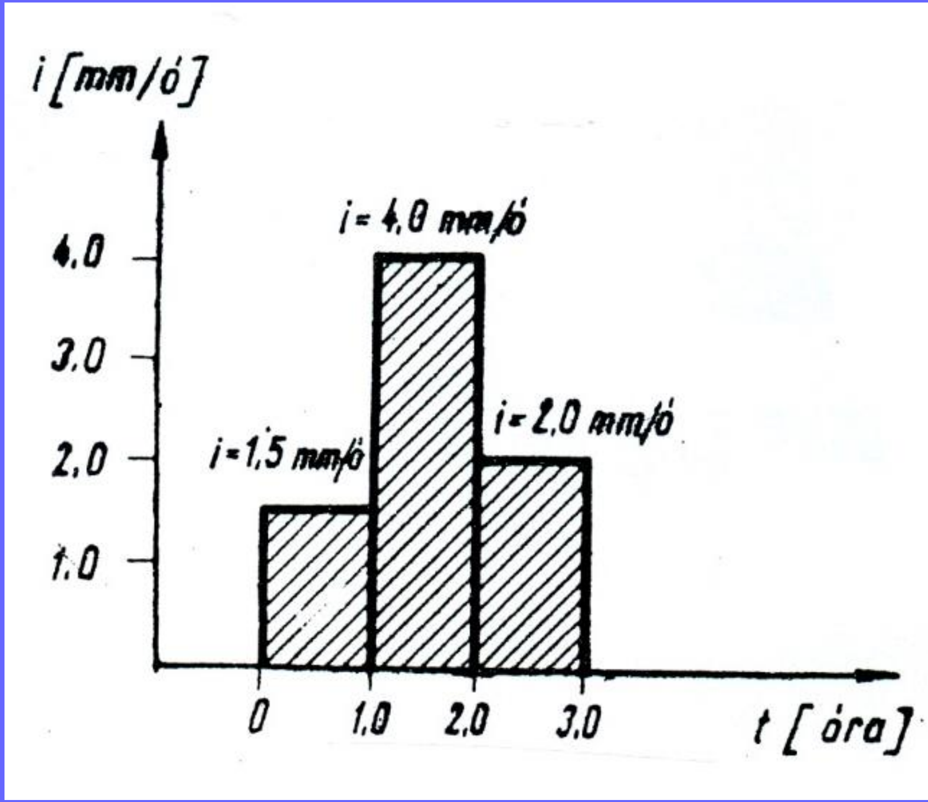
$$Q_{red} = 4.33\ \frac{m^3}{sec}$$

# Example5

Unit hydrograph




Intensity of rainfall



# Example6

Precipitation:

0 – 1 hr: $P_1 = 3,1$ mm

1 – 2 hr: $P_2 = 0,5$ mm

| t [óra] | 0 – 1 | 1 – 2 | 2 – 3 | 3 – 4 | 4 – 5 | 5 – 6 | 6 – 7 | 7 – 8 |
|---|---|---|---|---|---|---|---|---|
| Q[$m^3$/s] | 0,2 | 0,6 | 2,1 | 1,6 | 0,8 | 0,3 | 0,1 | 0 |

U(t)=? Constract the unit hydrograph

# Questions for discussion

Explain the runoff cycle (graph)
The three formation of runoff (should draw)
Parts of a river system (should draw)
The three basic interactions of groundwater and river (stream) (should draw)
Three stages of river development
River Morphology (should draw)
Seasonal layering, lake turnover (should draw)

# 5 The Infiltration and Groundwater Hydrology

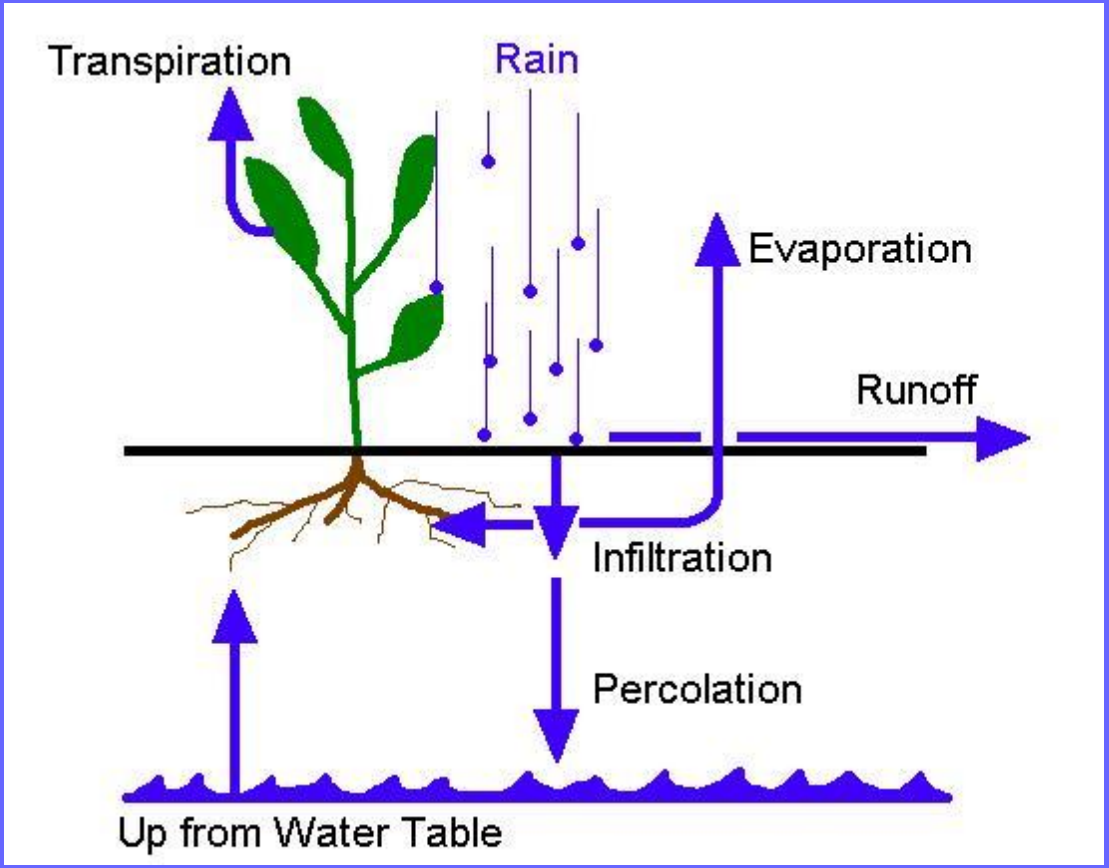
## Content

- The Infiltration Process
- Groundwater Hydrology
- Groundwater Recharge
- Aquifer Types
- Wells Problems
- Questions for Discussion

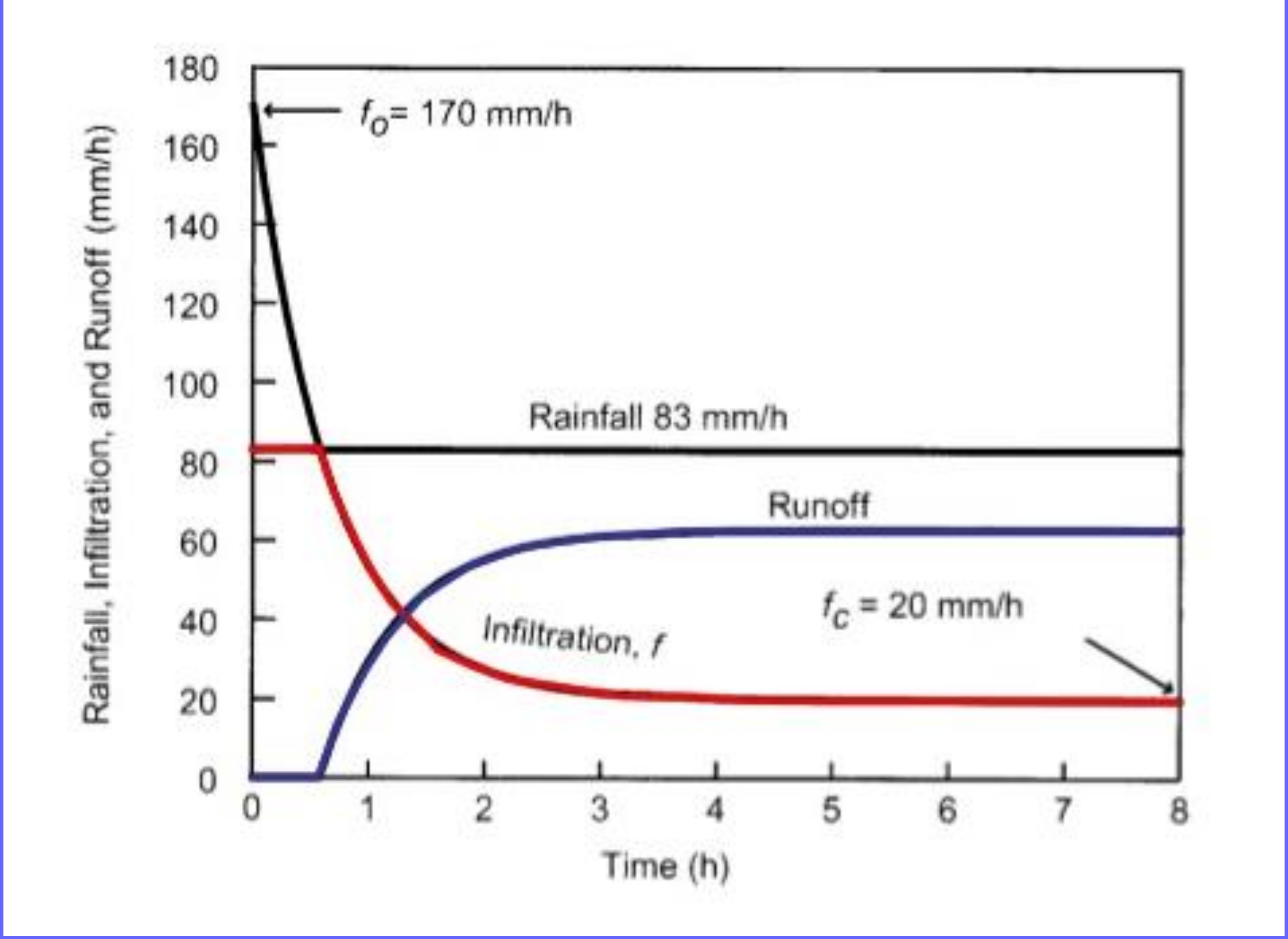
# Definitions

Infiltration is the passage of water though the ground surface.

Percolation of water is the movement of water down through the soil profile until it reaches the upper level of saturation or the water table.



# The Infiltration Process



# What factors are needed for infiltration?

Water - rainwater, snow melt, glacier water, river water, lake water etc

Soil porosity

# Soil Porosity

Porosity: the fraction of the total volume of a rock or soil that is pore space.

Symbol: n - volume of pores (voids) per total volume of aquifer ($n = V_v / T_t$)

Unit: [%]

## Example Porosity Calculation

- Take a 1000 ml beaker (1 liter) and fill it with sand to the top
- Measure how much water it takes to fill the beaker to the top (say 300 ml)
- The porosity = (300 ml) / (1000 ml) = 30%

# Specific Yield

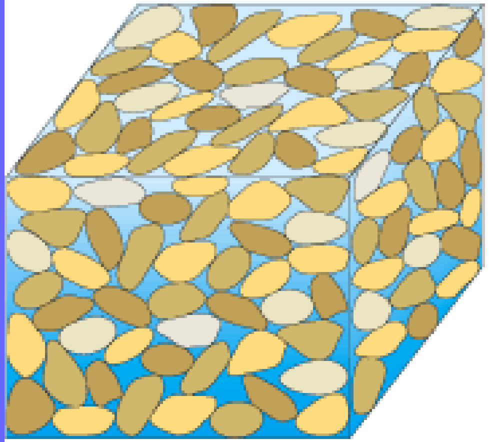
The volume of water that can be removed per unit volume of aquifer - less than the porosity, hard to get the last drop!

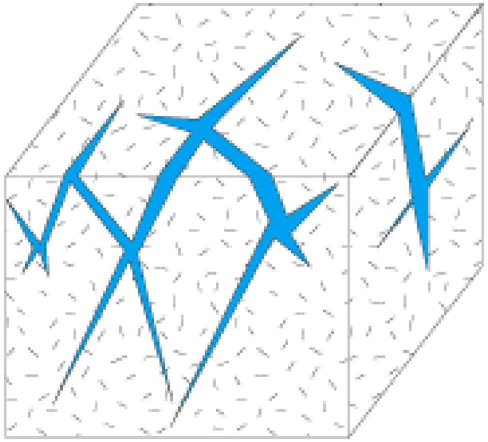
| Material | Maximum % | Minimum % | Average % |
|---|---|---|---|
| Clay | 5 | 0 | 2 |
| Sandy clay | 12 | 3 | 7 |
| Silt | 19 | 3 | 18 |
| Fine sand | 28 | 10 | 21 |
| Medium sand | 32 | 15 | 26 |
| Coarse sand | 35 | 20 | 27 |
| Gravelly sand | 35 | 20 | 25 |
| Fine gravel | 35 | 21 | 25 |
| Medium gravel | 26 | 13 | 23 |
| Coarse gravel | 26 | 12 | 22 |

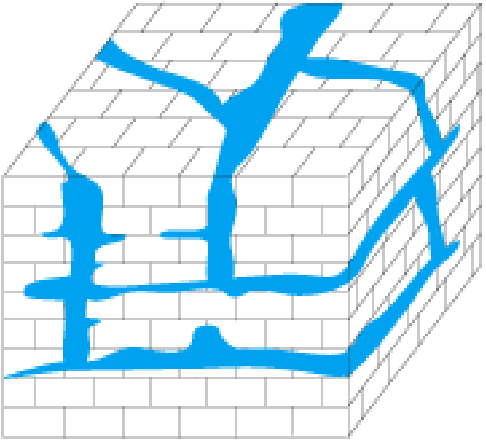
*Source:* A. I. Johnson, "Specific Yield—Compilation of Specific Yields for Various Materials," U.S. Geological Survey Water-Supply Paper 1662-D, Washington, DC, 1967.

# Grain-Size Classification

| Material | Size (inches) | Size (mm) | Example |
|---|---|---|---|
| Boulder | >12 | >300 | Basketball |
| Cobbles | 3–12 | 75–300 | Grapefruit |
| Coarse gravel | 0.7–3 | 18–75 | Grape |
| Fine gravel | 0.2–0.7 | 5–18 | Pea |
| Coarse sand | 0.08–0.2 | 2–5 | Water softener salt |
| Medium sand | 0.02–0.08 | 0.5–2 | Table salt |
| Fine sand | 0.003–0.02 | 0.075–0.5 | Powdered sugar |
| Fines | <0.003 | <0.075 | Talcum powder |


A. Well-sorted sand


B. Fractures in granite


C. Caverns in limestone

# Examples of Rock Interstices

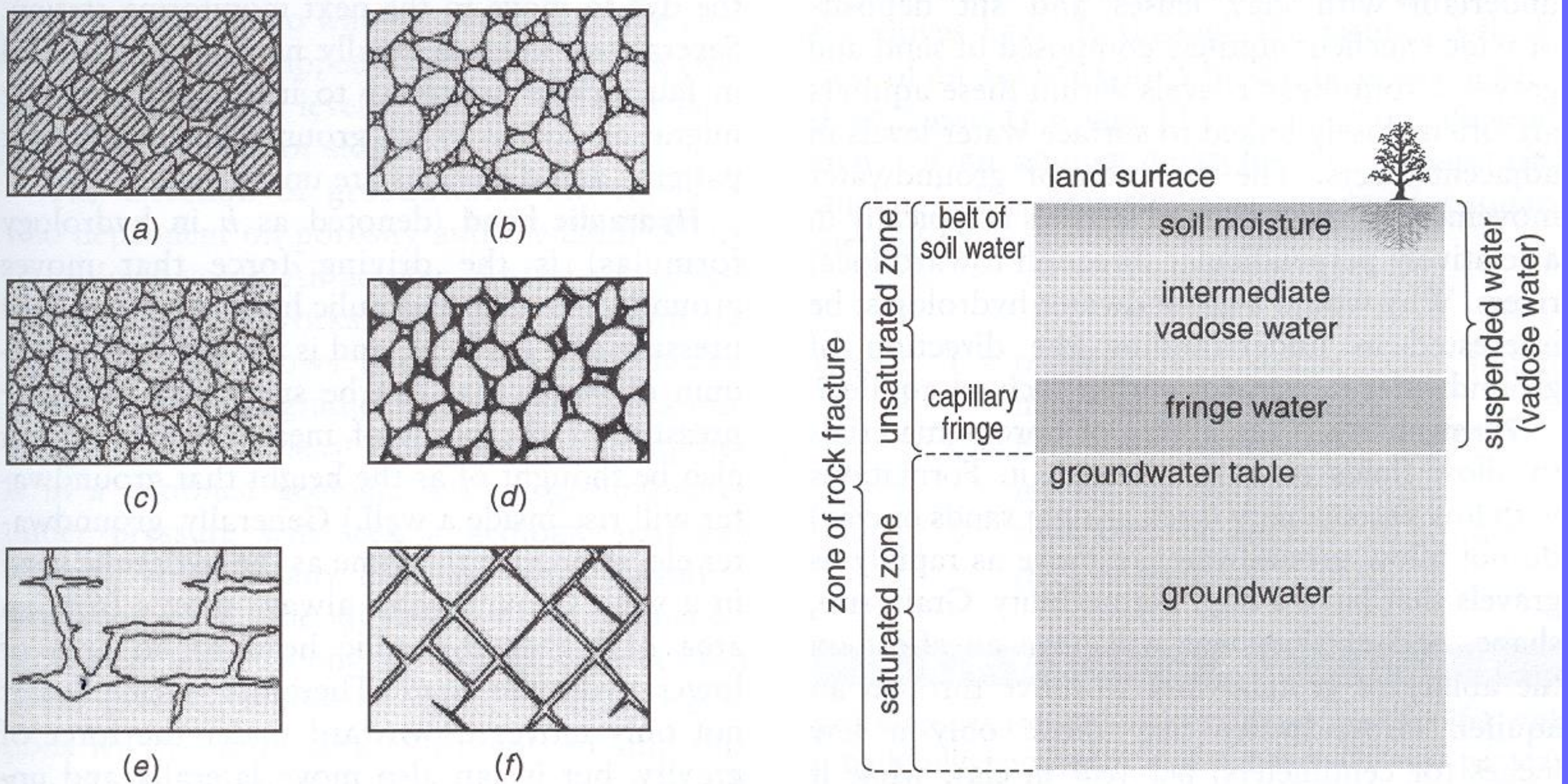



**FIG. 4.11.** Examples of rock interstices. *(a)* Well-sorted sedimentary deposits with a high porosity. *(b)* Poorly sorted sedimentary deposits with a much lower porosity. *(c)* Well-sorted material containing porous pebbles. *(d)* Well-sorted material that has a low porosity due to nonporous sediments found between pore spaces. *(e)* Porous rock due to solution. *(f)* Porous rock due to fracturing. These types of rock interstices form the zone of rock fracture illustrated to the right.

# What is Groundwater?

- Found in the subsurface, inside pores within soil and rock
- Spelled either as two words Ground Water or as one Groundwater
- Groundwater is the largest source of fresh water on earth and was little used until recently.
- With electricity and the modern pump, groundwater has become very important to agriculture, cities, and industries.
- It is usually much cleaner than surface water.

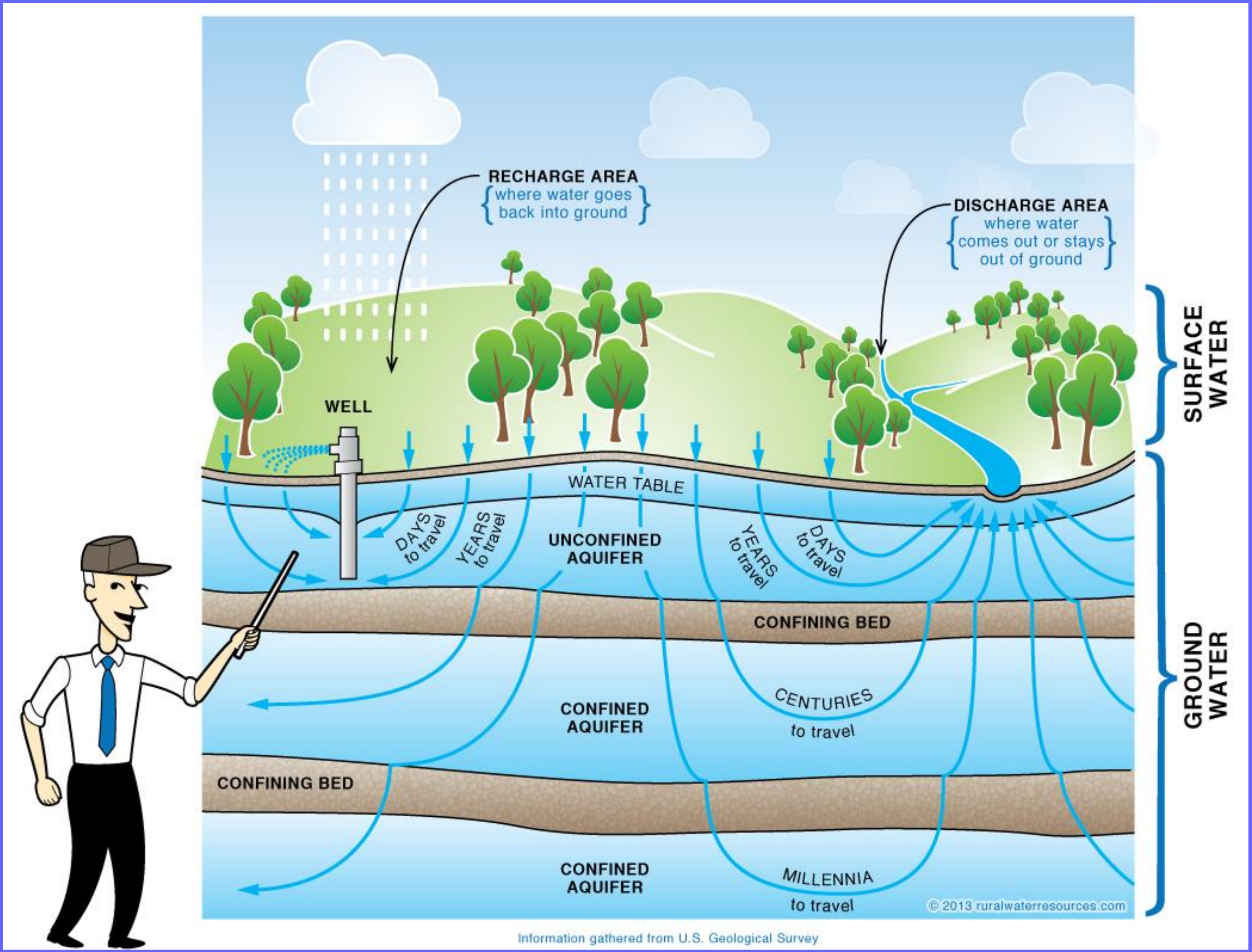
# What is Groundwater Hydrology?

It is the study of the characteristics, movement, and occurrence of water found below the surface.

Groundwater and aquifers are like surface water and watersheds

- An aquifer is a geologic unit that transmits water.
- Piezometric surfaces are used to map water levels, similar to topographic lines on maps.
- Each aquifer has its piezometric surface.
- The water level elevation in wells is used to create the piezometric surface.

# Groundwater vs. Surface Water



# Age of Water

| Water Type | Residence Time |
|---|---|
| Oceans and seas | 4000 years (approx.) |
| Lakes and reservoirs | 10 years (approx.) |
| Swamps | 1–10 years (approx.) |
| Rivers | 2 weeks |
| Soil moisture | 2 weeks–1 year |
| Groundwater | 2 weeks–10,000 years |
| Icecaps and glaciers | 10–1000 years |
| Atmospheric water | 10 days |

*Source:* Adapted from R. Allen Freeze and John A. Cherry, *Groundwater* (Englewood Cliffs, NJ: Prentice-Hall, 1979), 5.

# Age of Groundwater

- Time it takes for water to move through the subsurface
- Maybe 1 to 25 years in aquifers
- Up to 10,000 years for water down on the coast

# Groundwater Recharge (1)

- Usually from surface water or precipitation that infiltrates, and then percolates through the vadose zone
- Recharge happens when percolating water finally reaches the water table, which is the top of the saturated zone.
- Above the water table is the unsaturated zone where capillary forces hold water.
- The root zone may capture some water that infiltrates and lift it back to the atmosphere.

# Groundwater Recharge (2)

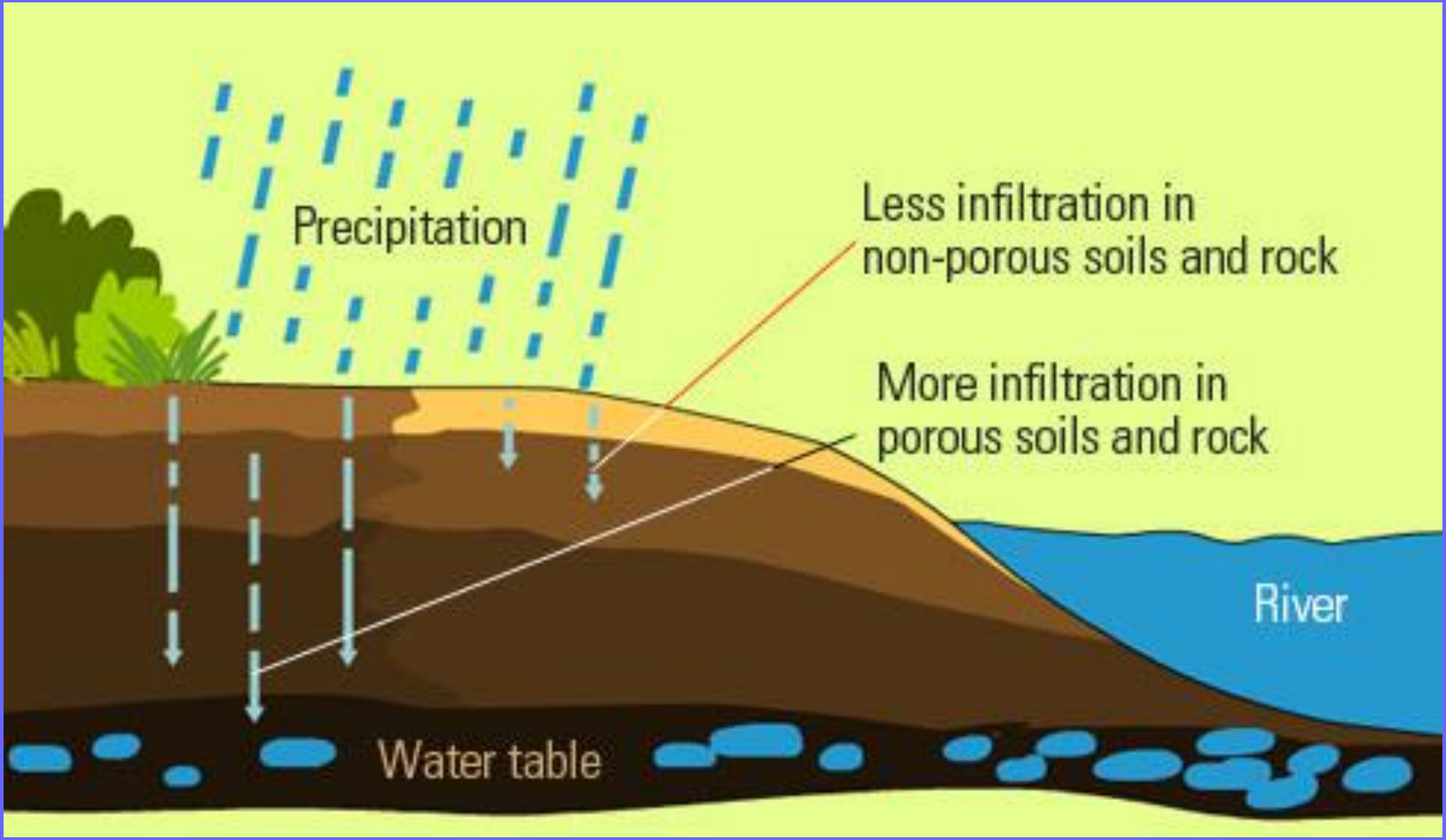
Two important factors required for the recharge of groundwaters and their aquifers:

Water - rainwater, snowmelt, glacier water, river water, lake water, etc

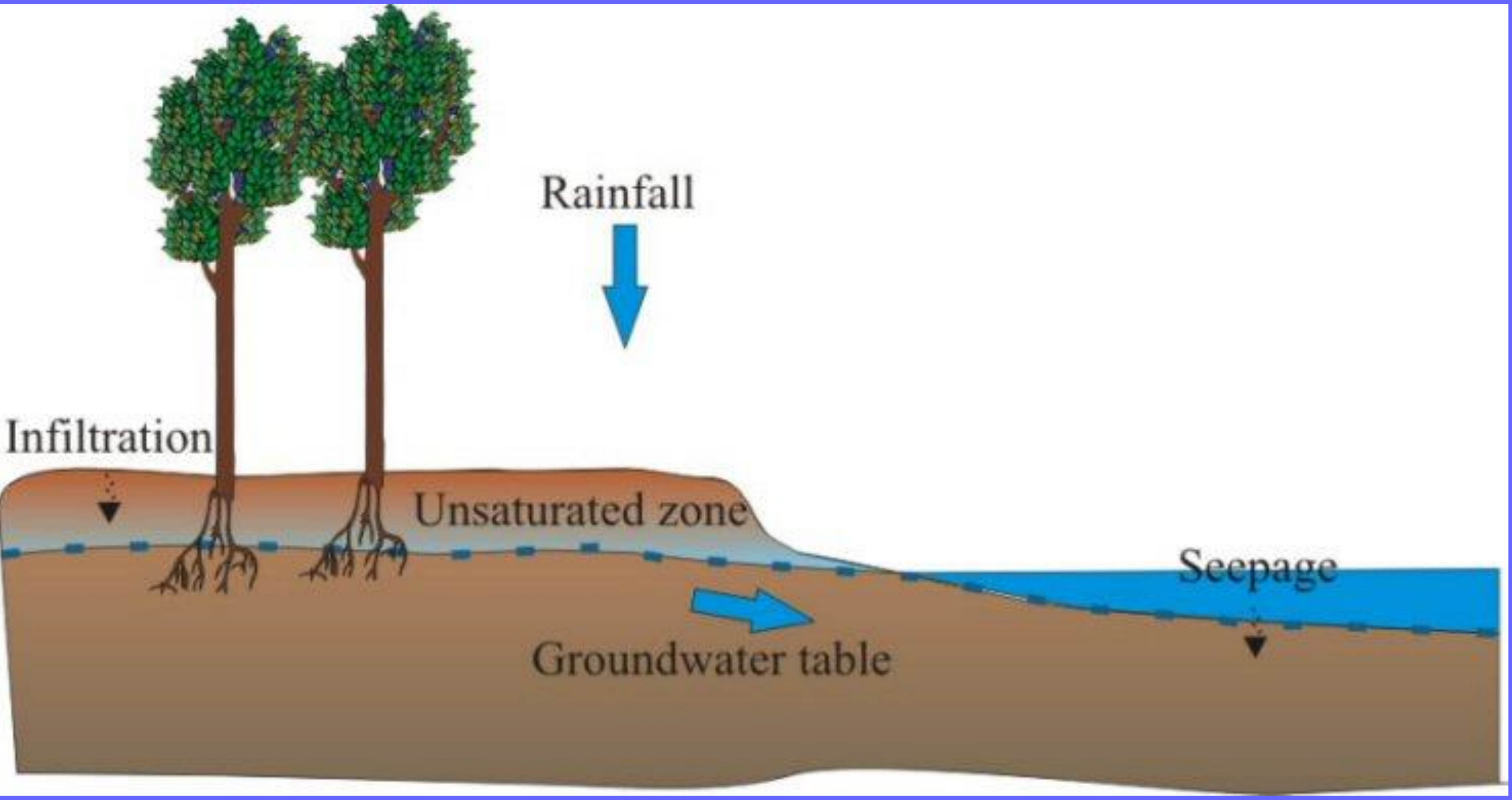
Granular soil - which is both porous- and permeable surface materials.

Porous: have lots of void spaces and connections between grains
Permeable: the entire void spaces are connected each other, thereby ensuring the free movement of water inward the soil

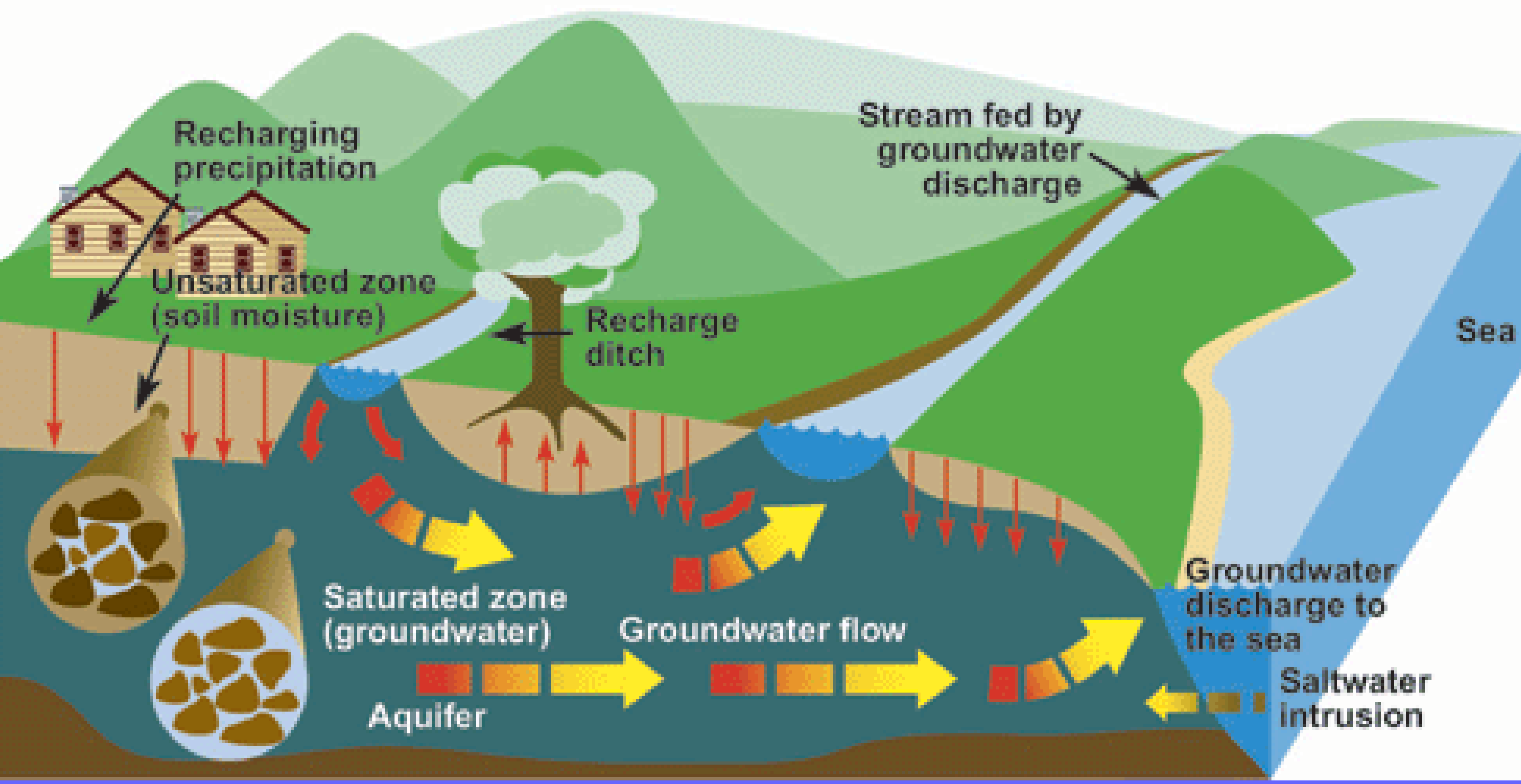
# Groundwater Recharge (3)



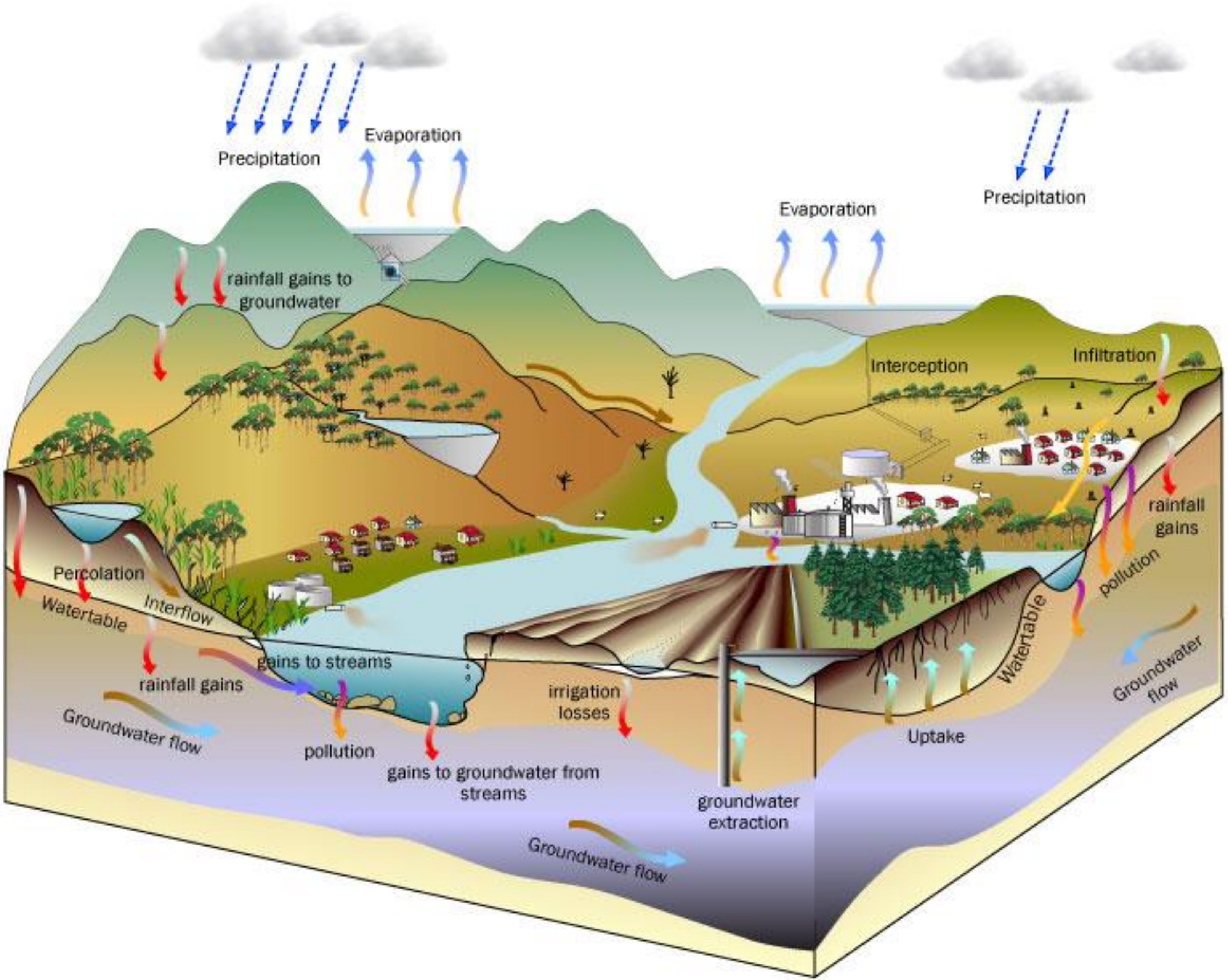
# Groundwater Recharge (4)



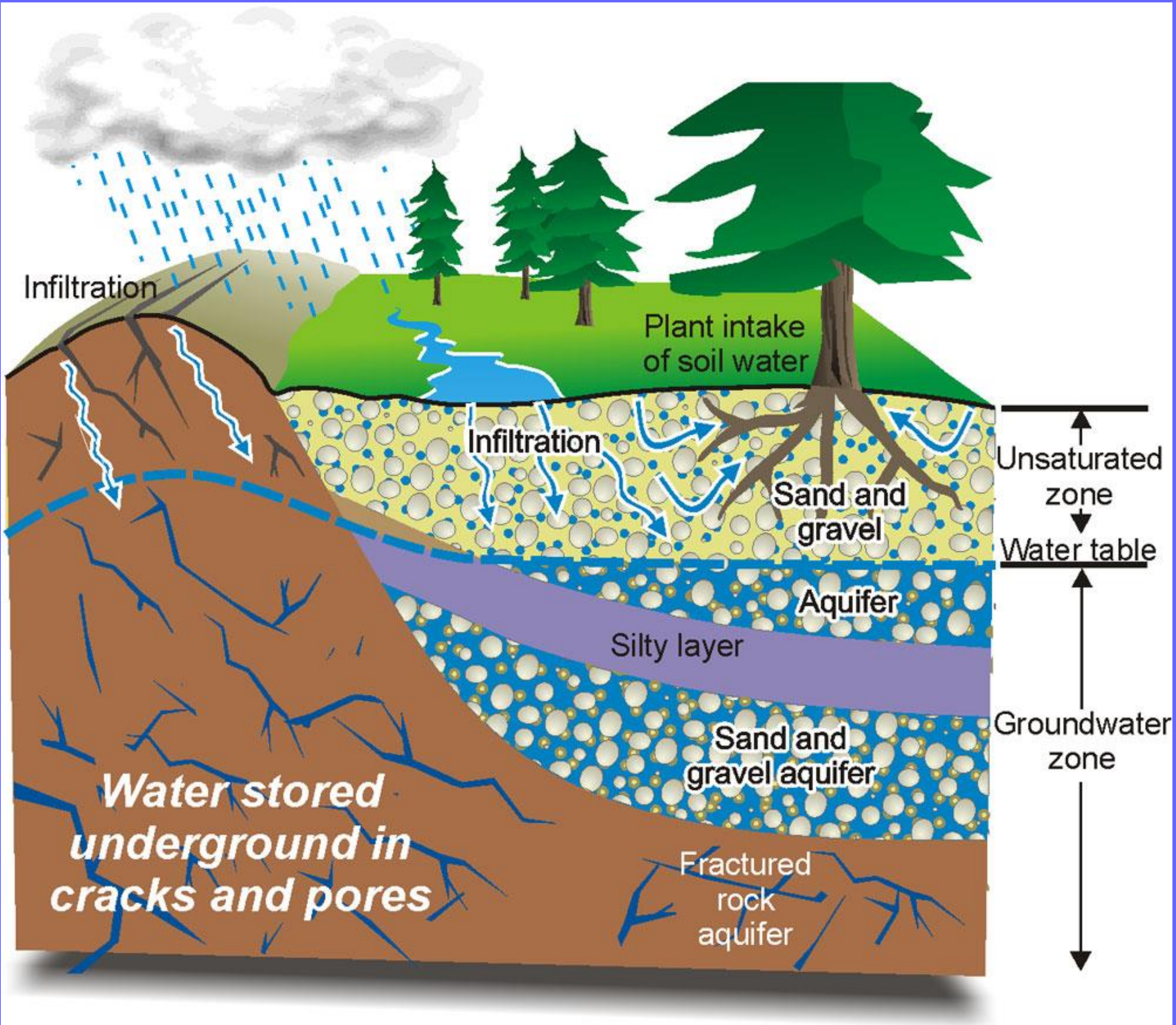
# Groundwater Recharge (5)



# Groundwater Recharge (6)



# Groundwater Recharge (7)



# Aquifers

Def1:Water-bearing geologic formation that can store and yield useful amounts of water.

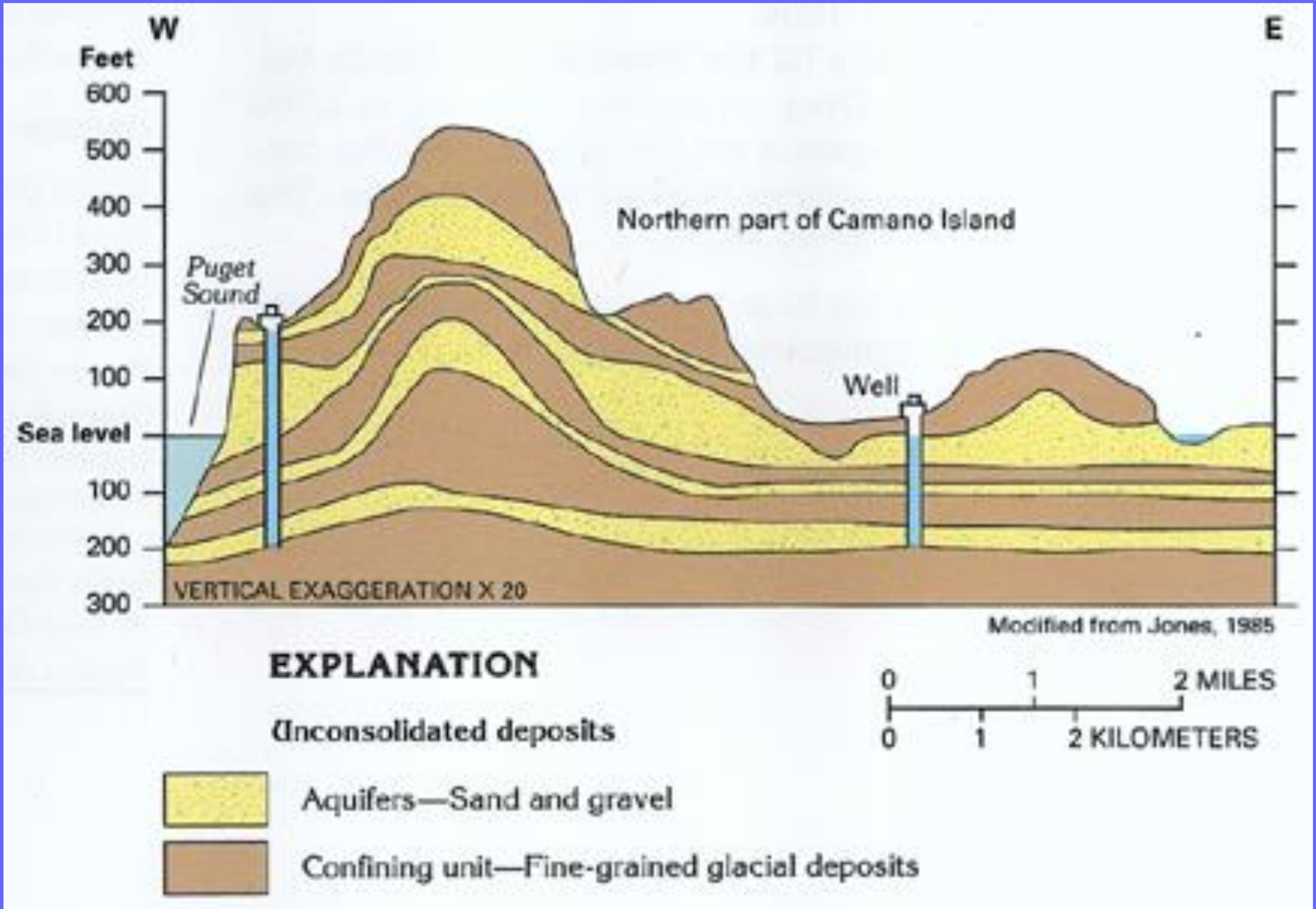
Def2: It is a geologic unit that can accumulate and transmit a sufficient quantity of water to provide a well.

The factors that determine if a geologic layer is an aquifer the next:

- permeability – must be high enough that flow can be continued
- aquifer dimensions – there must be a significant saturated width to supply water to the well

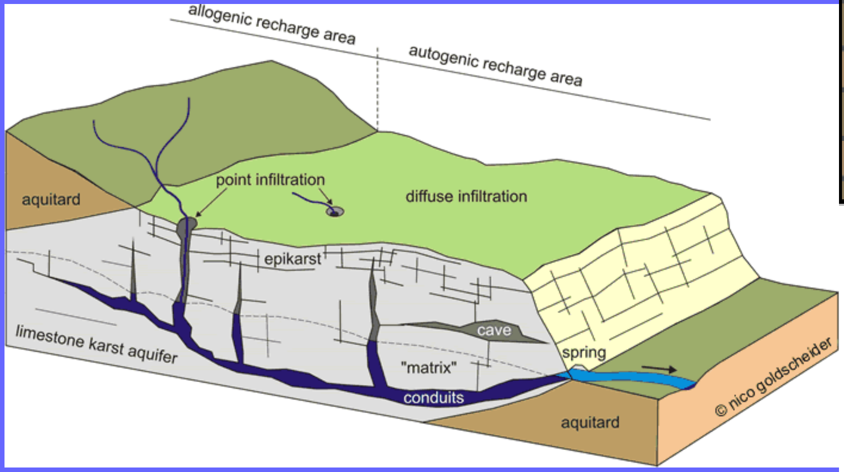
# Aquifer types (1): unconsolidated

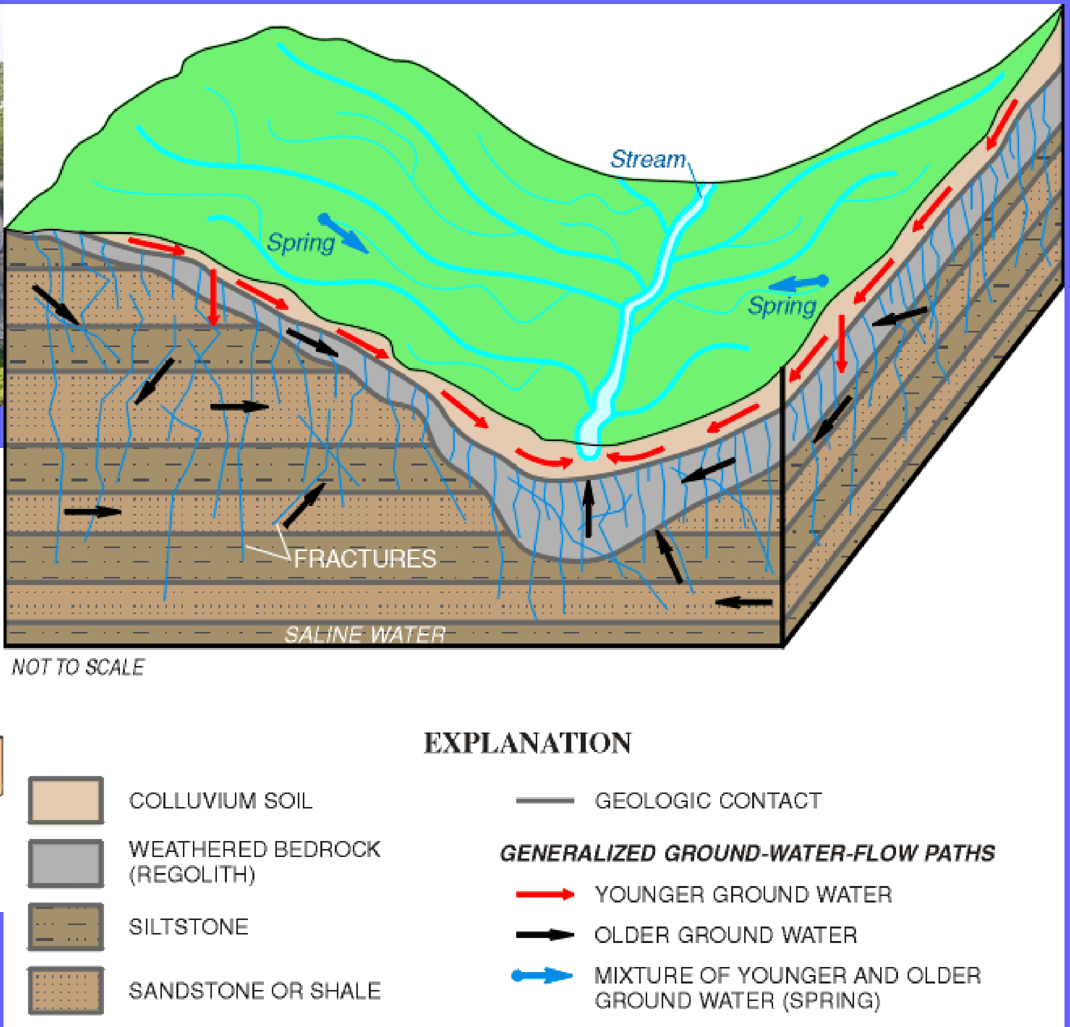
Unconsolidated sediment has sufficient permeability to allow water to flow through it. River terrace deposits are a typical example of an unconsolidated aquifer.



# Aquifer types (2): fractured

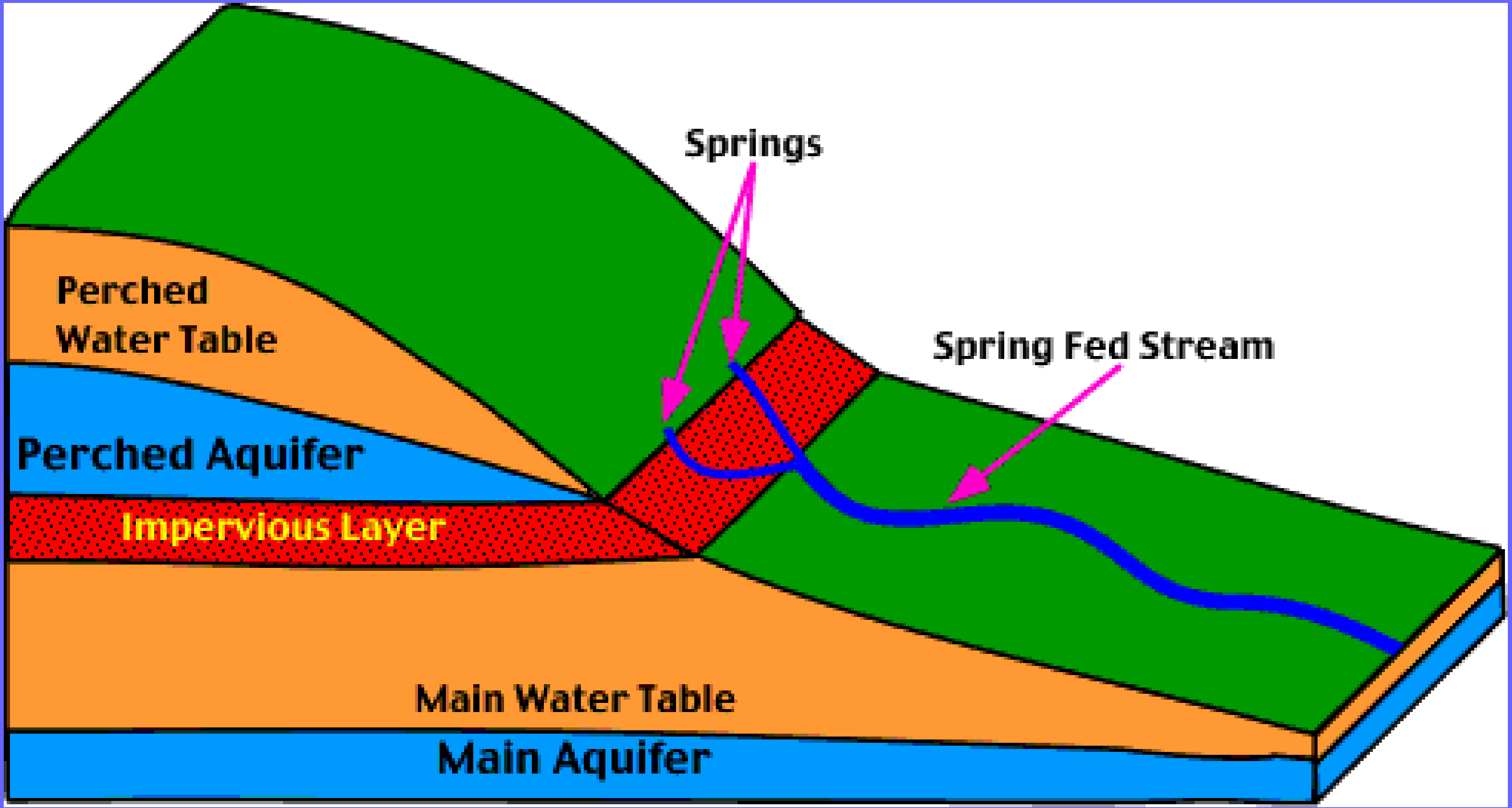
A fractured aquifer is defined as a formation that contains sufficient fissures, fractures, cracks, joints, and faults that yield economic quantities of water to boreholes and springs.



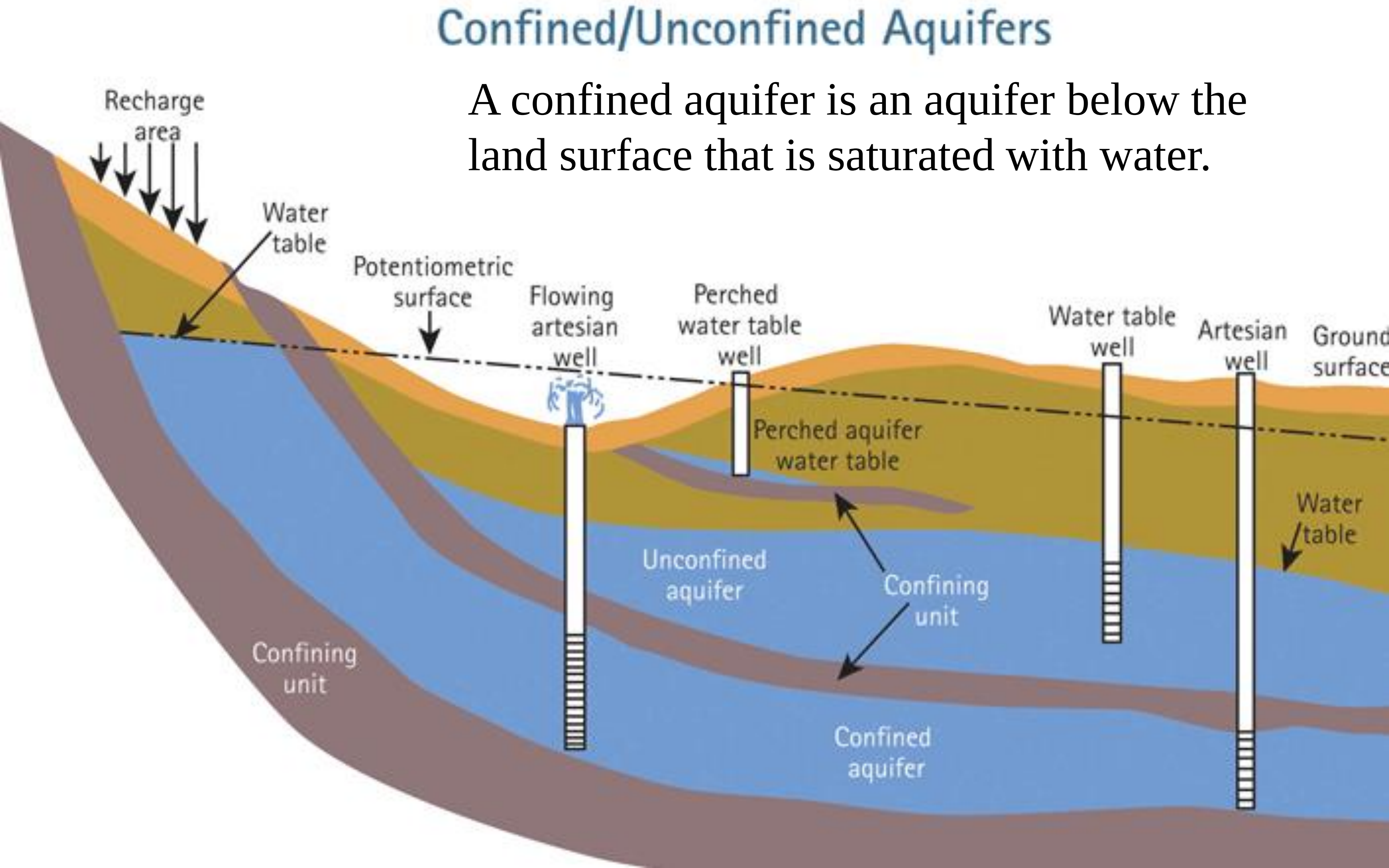



# Aquifer types (3): perched

A perched water table (or perched aquifer) is an aquifer that occurs above the regional water table in the vadose zone.

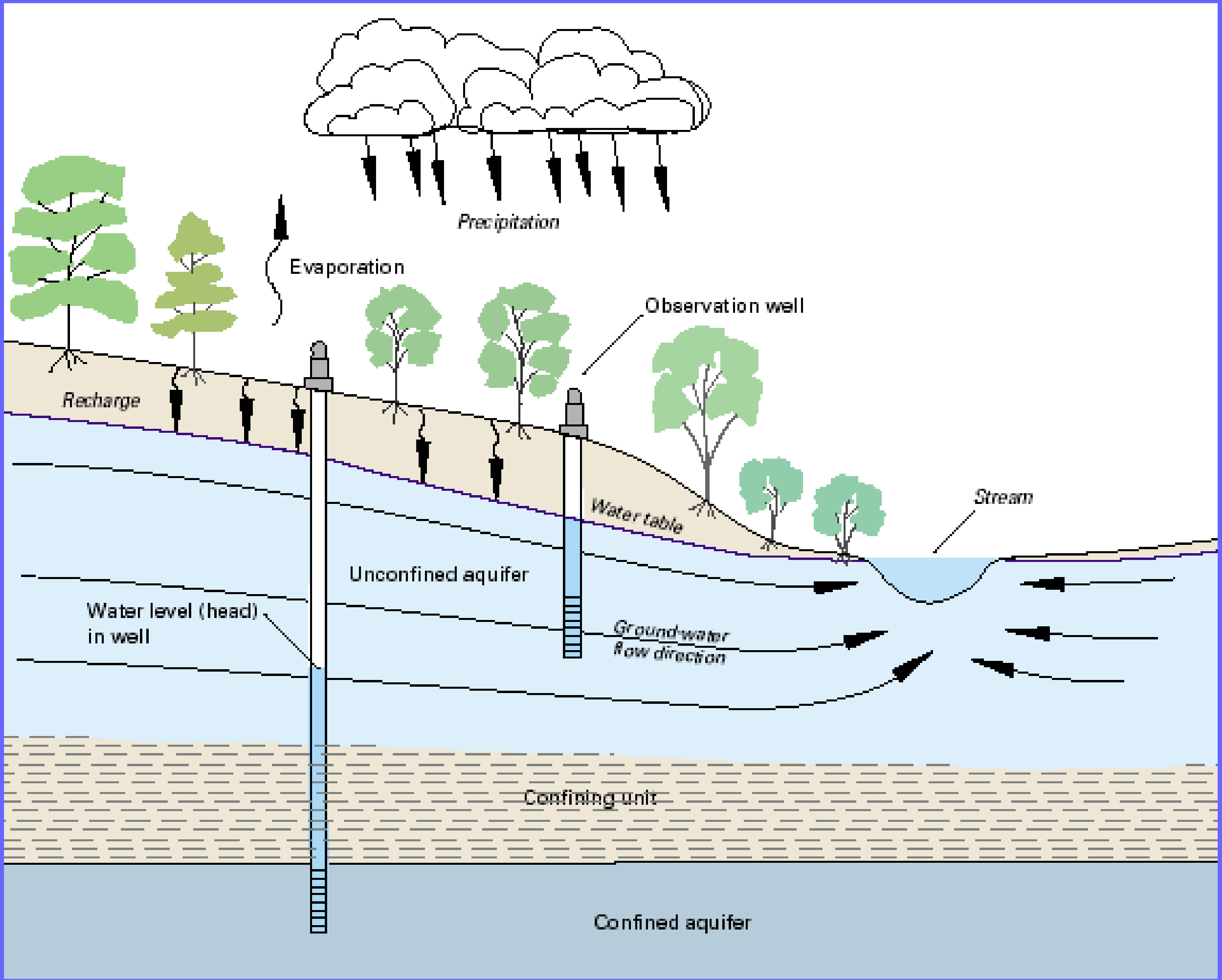


# Aquifer types (4): unconfined, confined



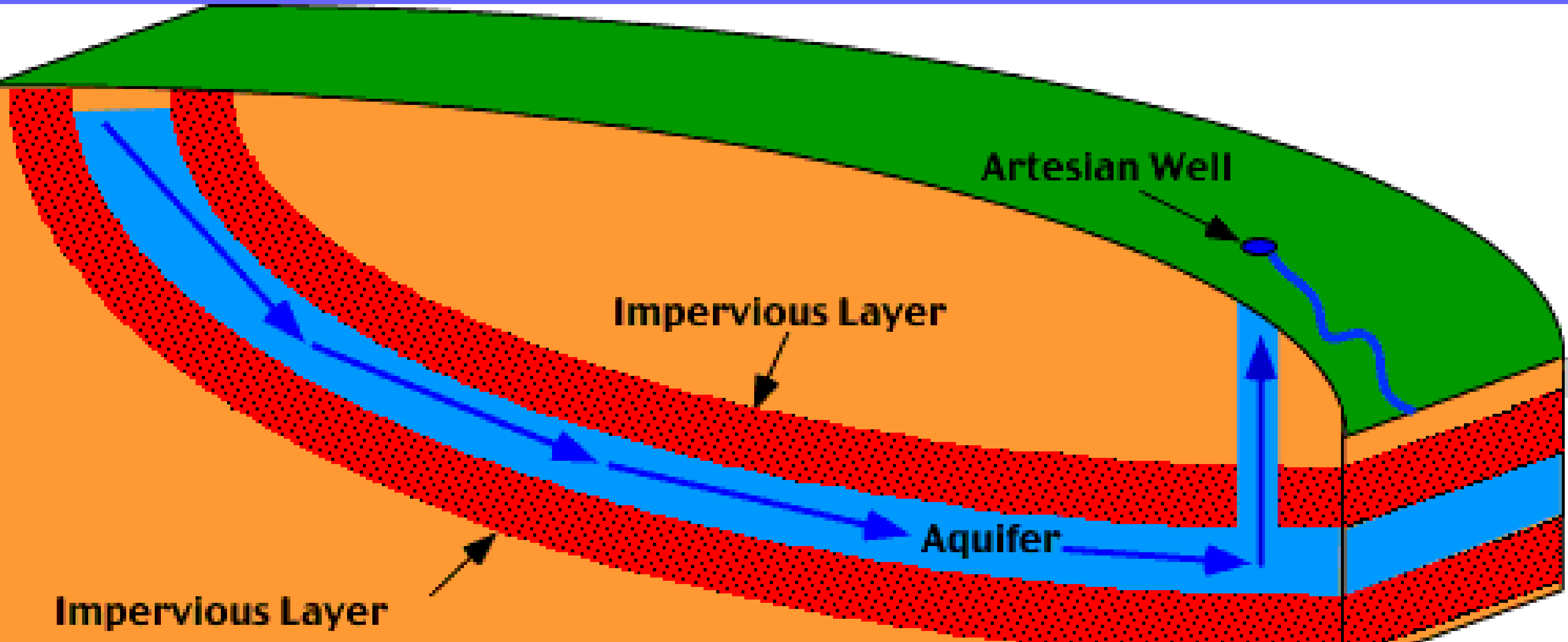

A confined aquifer is an aquifer below the land surface that is saturated with water.

# Aquifer types (5): unconfined, confined



# Aquifer types (6): artesian

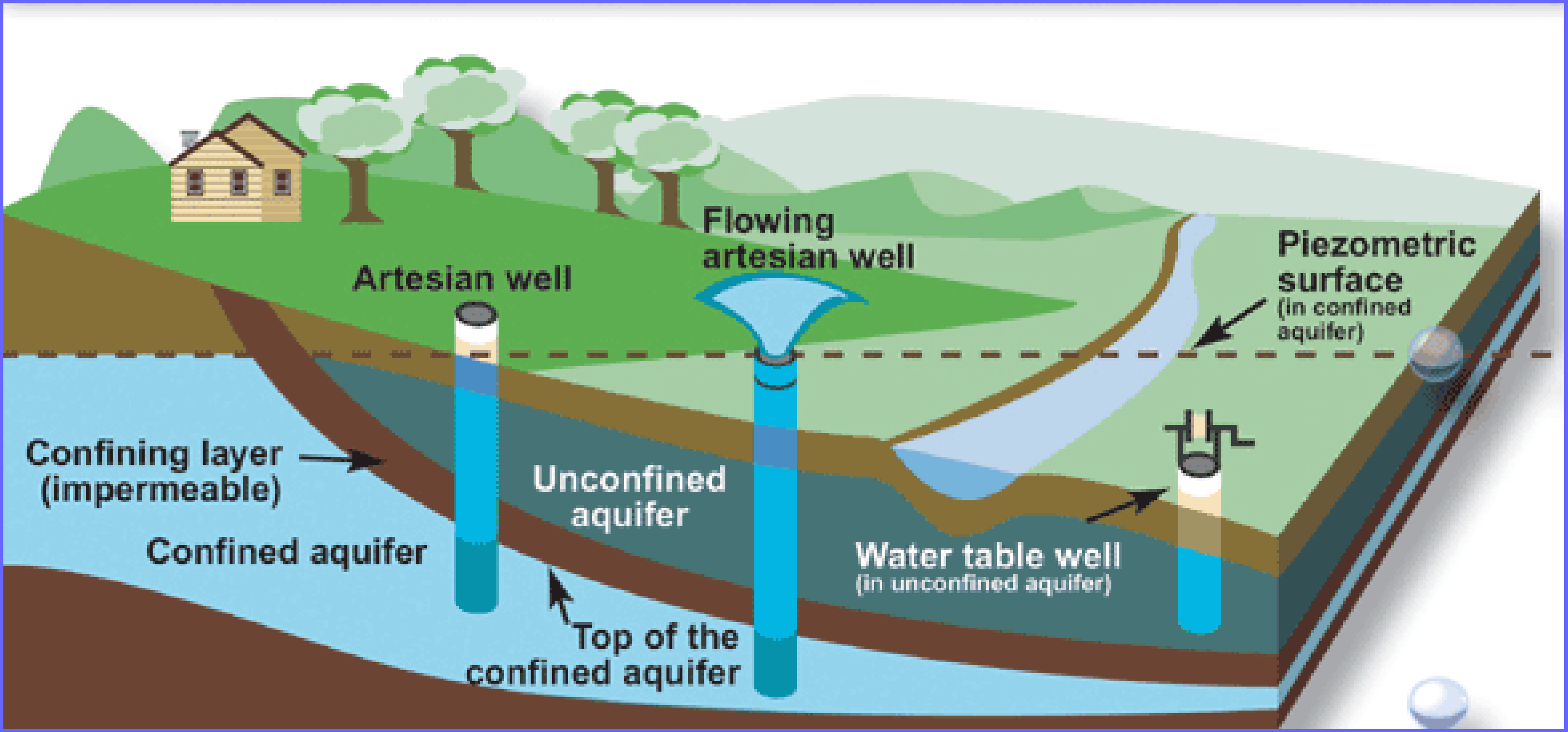
An artesian aquifer is a confined aquifer containing groundwater under positive pressure.



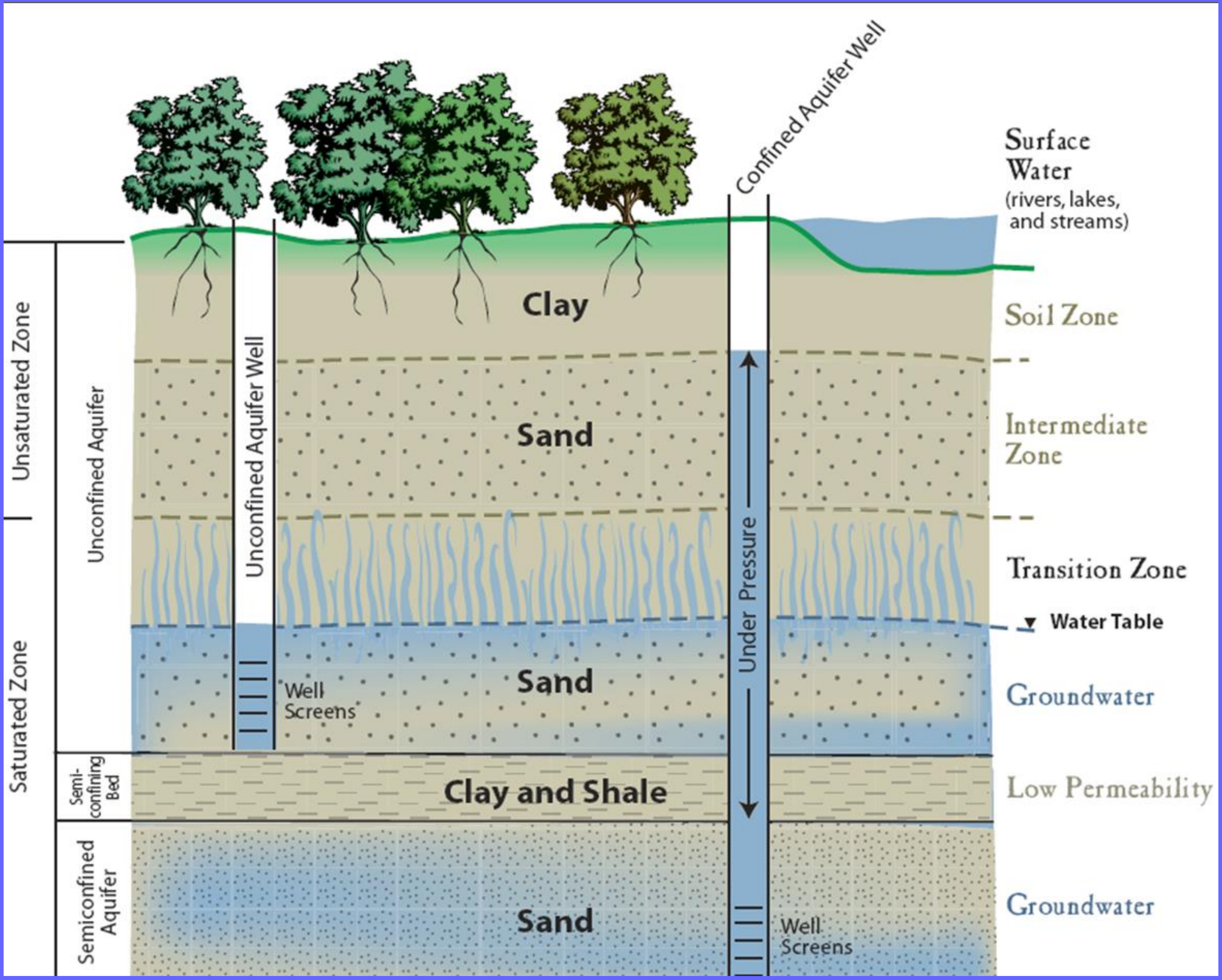
# Aquifer types (7): thermal springs

Thermal springs are a natural phenomenon that occurs where hot water from great depths in the Earth rises to the surface.

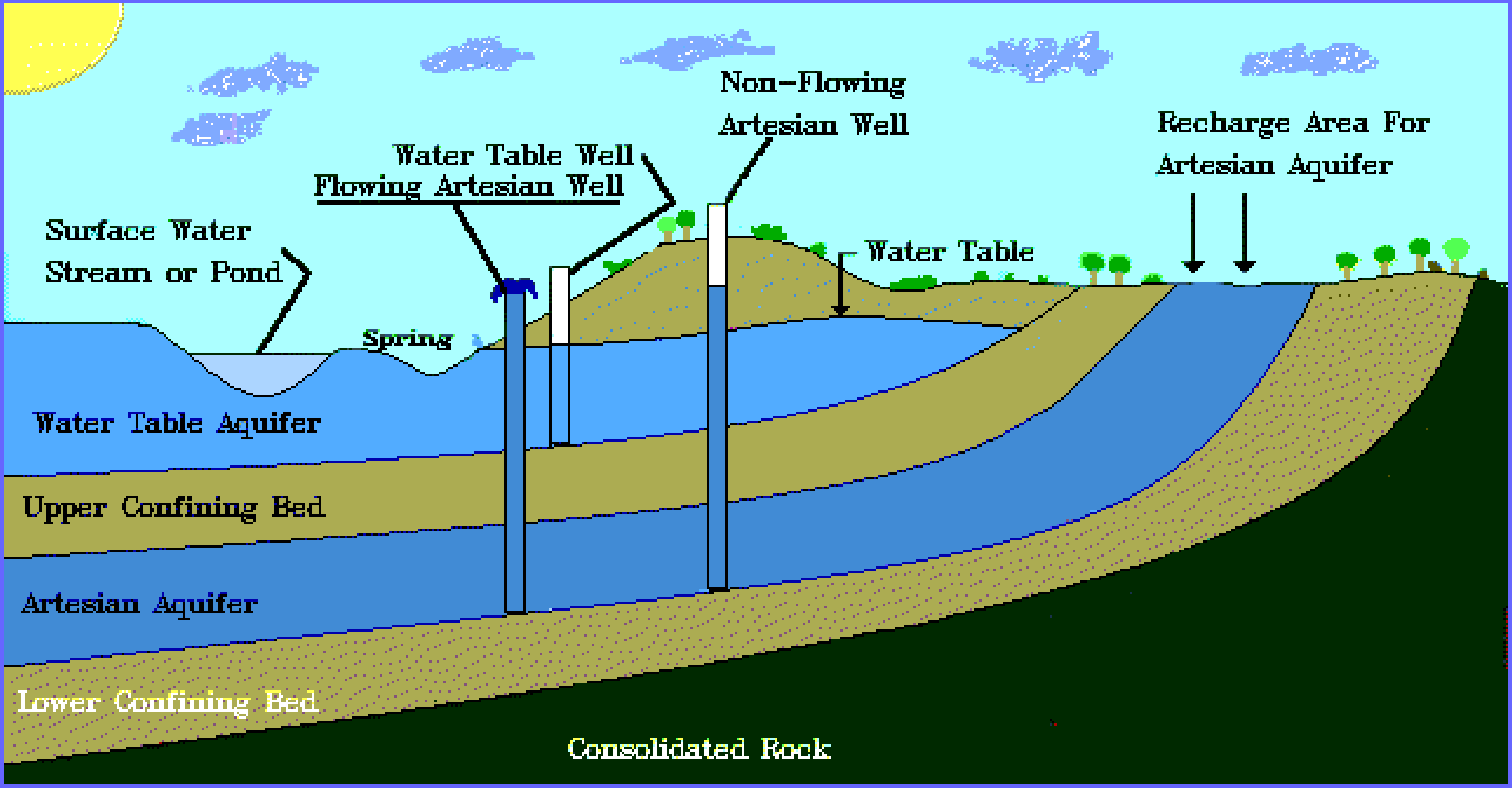
# Aquifers and Well Types



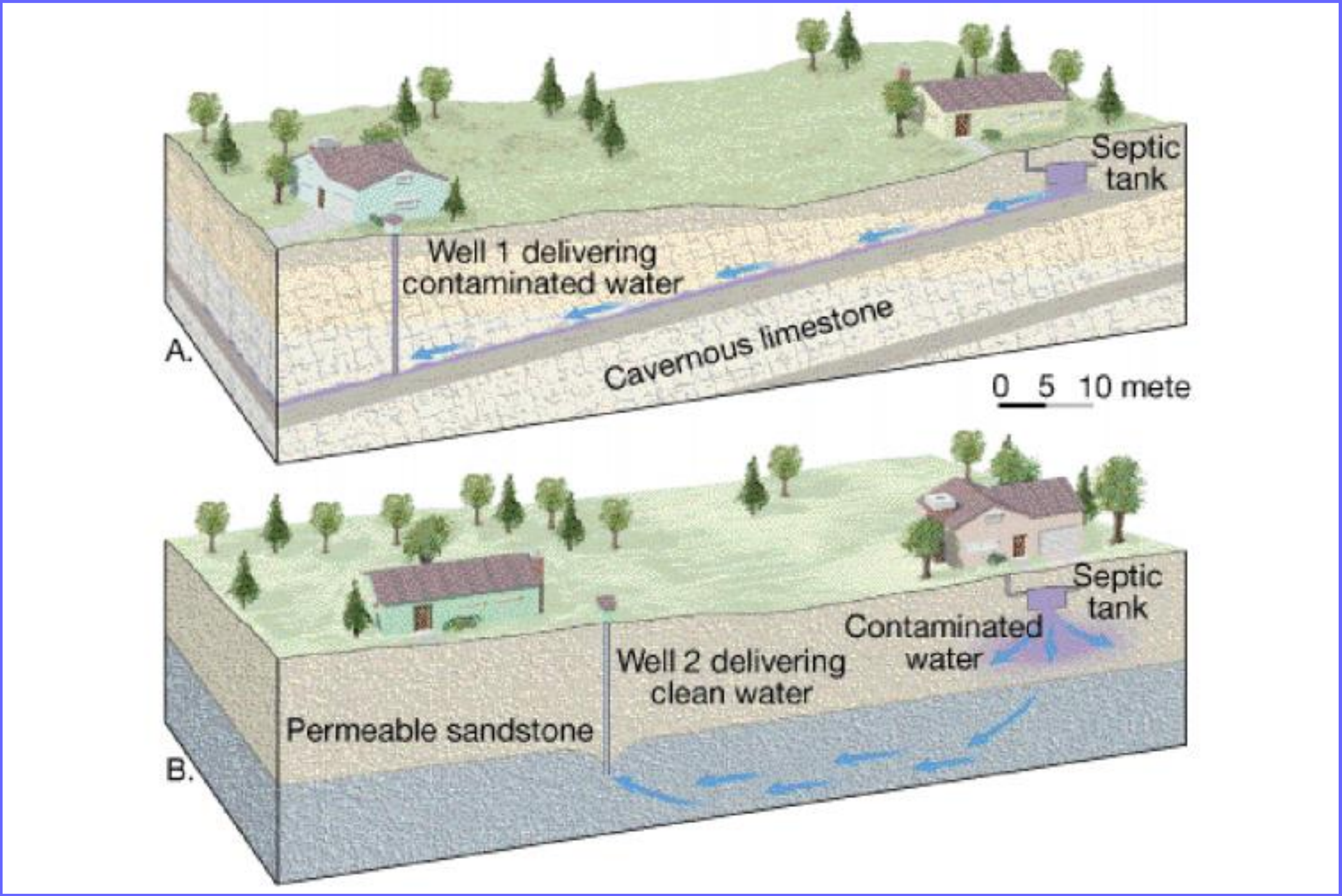
# Unconfined- and Confined Well



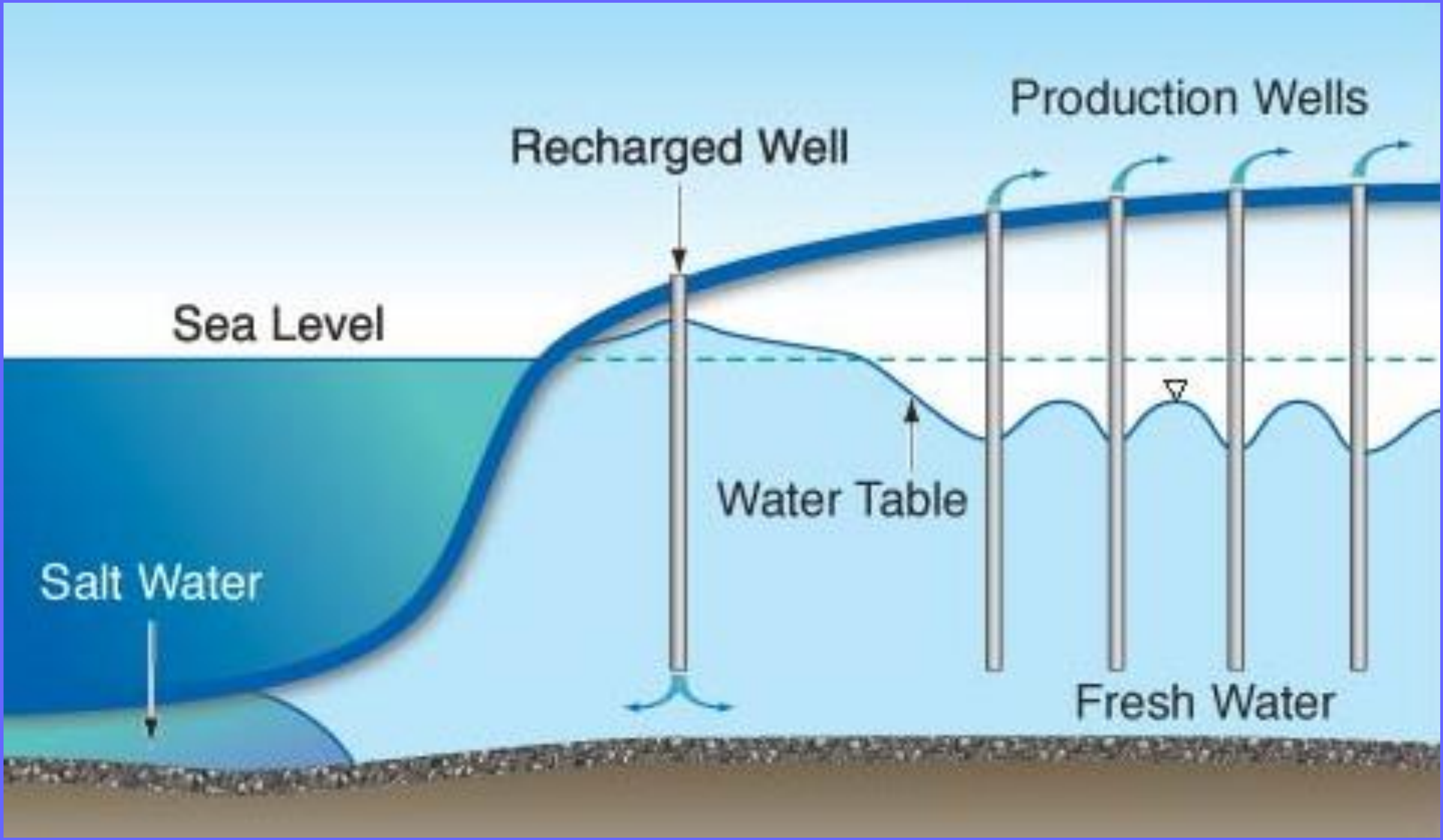
# Water Table Well and Flowing- and Non-Flowing Artesian Wells



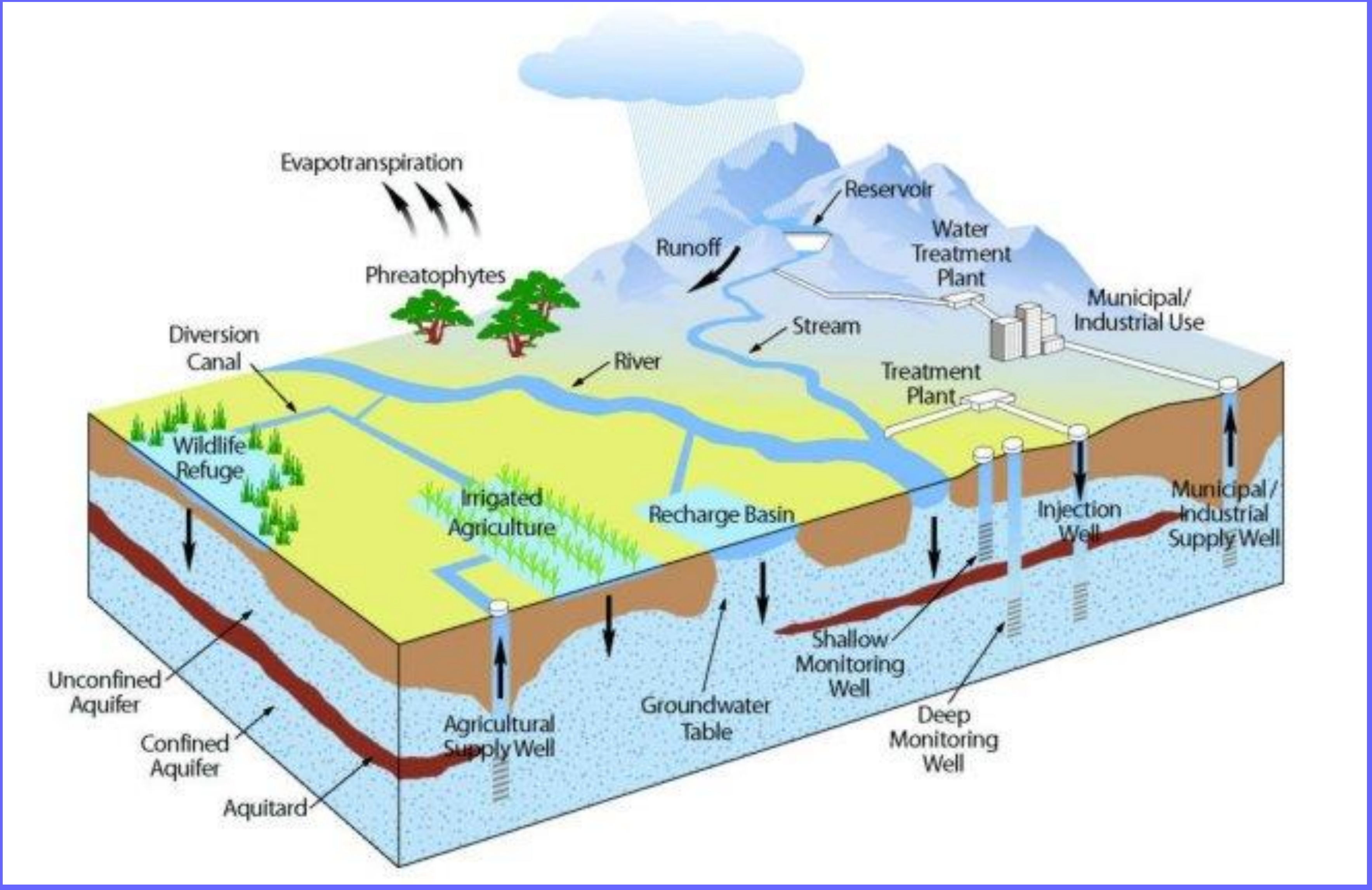
# Wells Problems (1)



# Wells Problems (2)



# Wells Problems (3)



# Locating and Mapping Groundwater

- The first step is to generate a piezometric surface.
- Wells are plotted on a map, and water levels in the wells are indicated.
- Lines of constant water level elevations are plotted (called equipotentials).
- Flowlines (also call streamlines) are drawn so that they are perpendicular to the equipotential lines.
- Local rivers, lakes, and other surface water features are plotted on the map.

# Questions for Discussion

Explain the infiltration process (graph)
What is groundwater?
What is groundwater hydrology?
Groundwater recharge (should draw)
What is aquifer (def) and what types of aquifer do you know?
Wells Problems (should draw)