Water Balance Analysis

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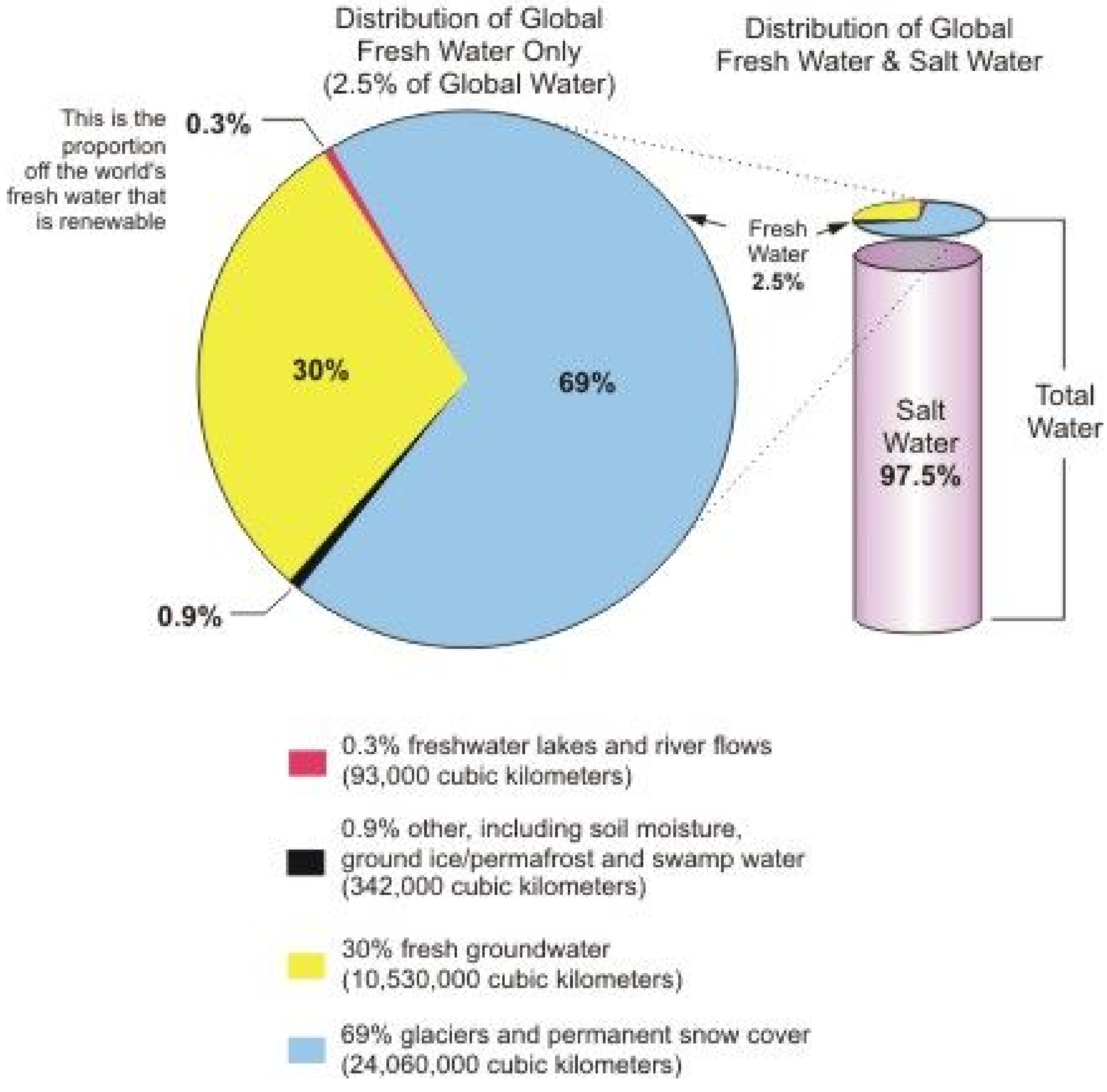
Presentation Overview

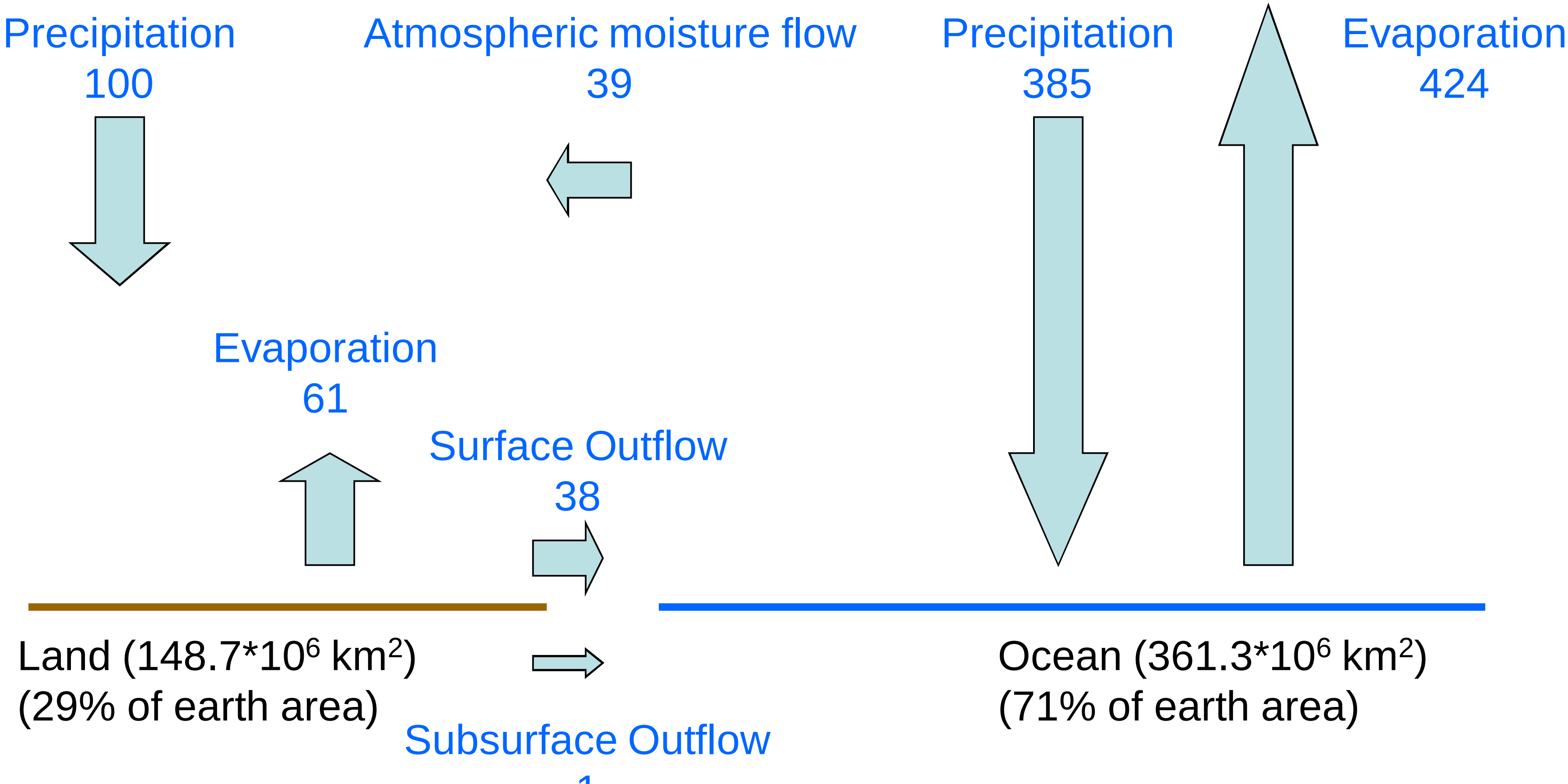
- Introduction
- Hydrologic Cycle
- Basic Concept of Water Balance
- Water Balance of Unsaturated Zone
- Water Balance at Land Surface
- Groundwater Balance
- Integrated Water Balances

Introduction

THE WORLD'S WATER

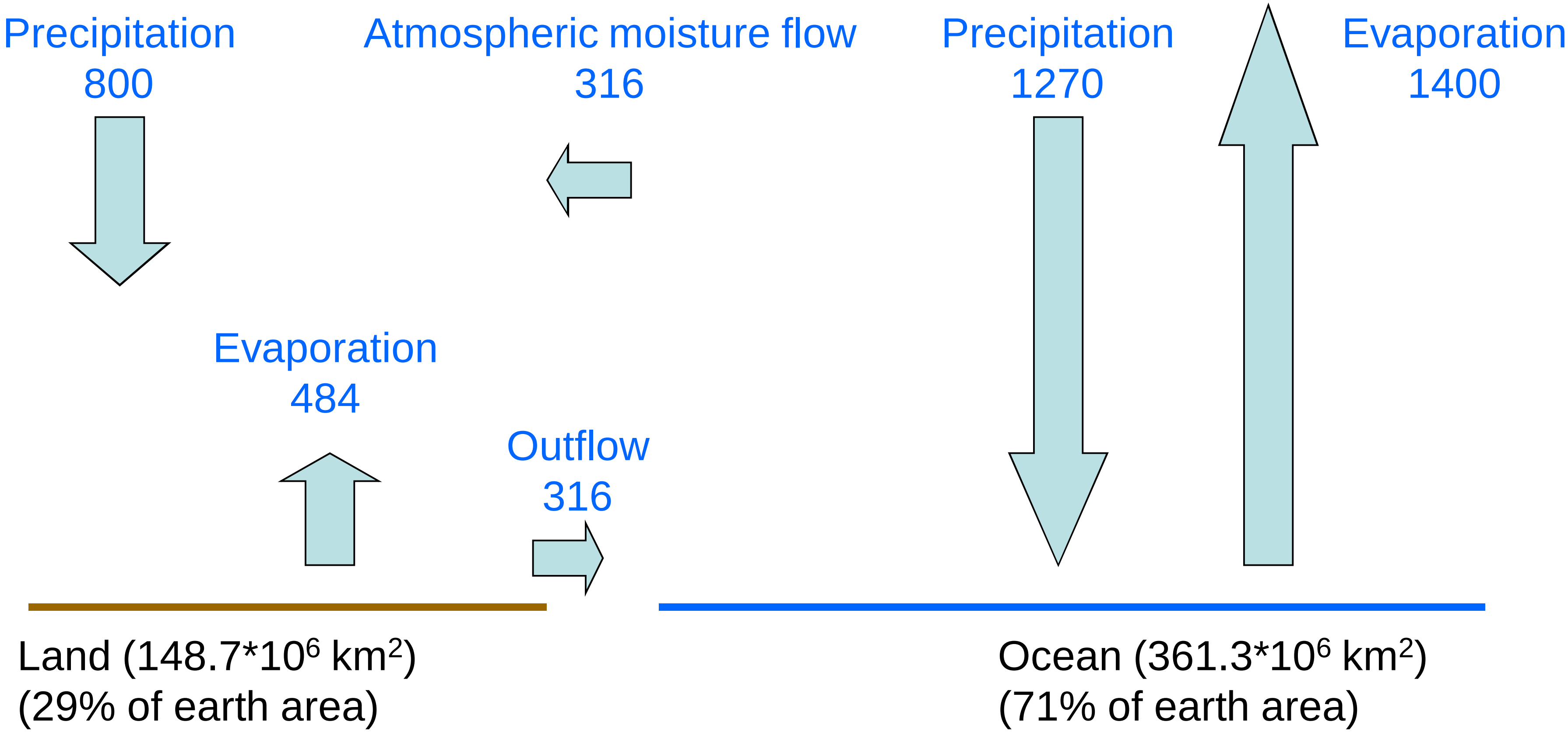


Global Water Balance (Volumetric)



Units are in volume per year relative to precipitation on land (119,000 km^3/yr) which is 100 units

Global Water Balance (mm/yr)



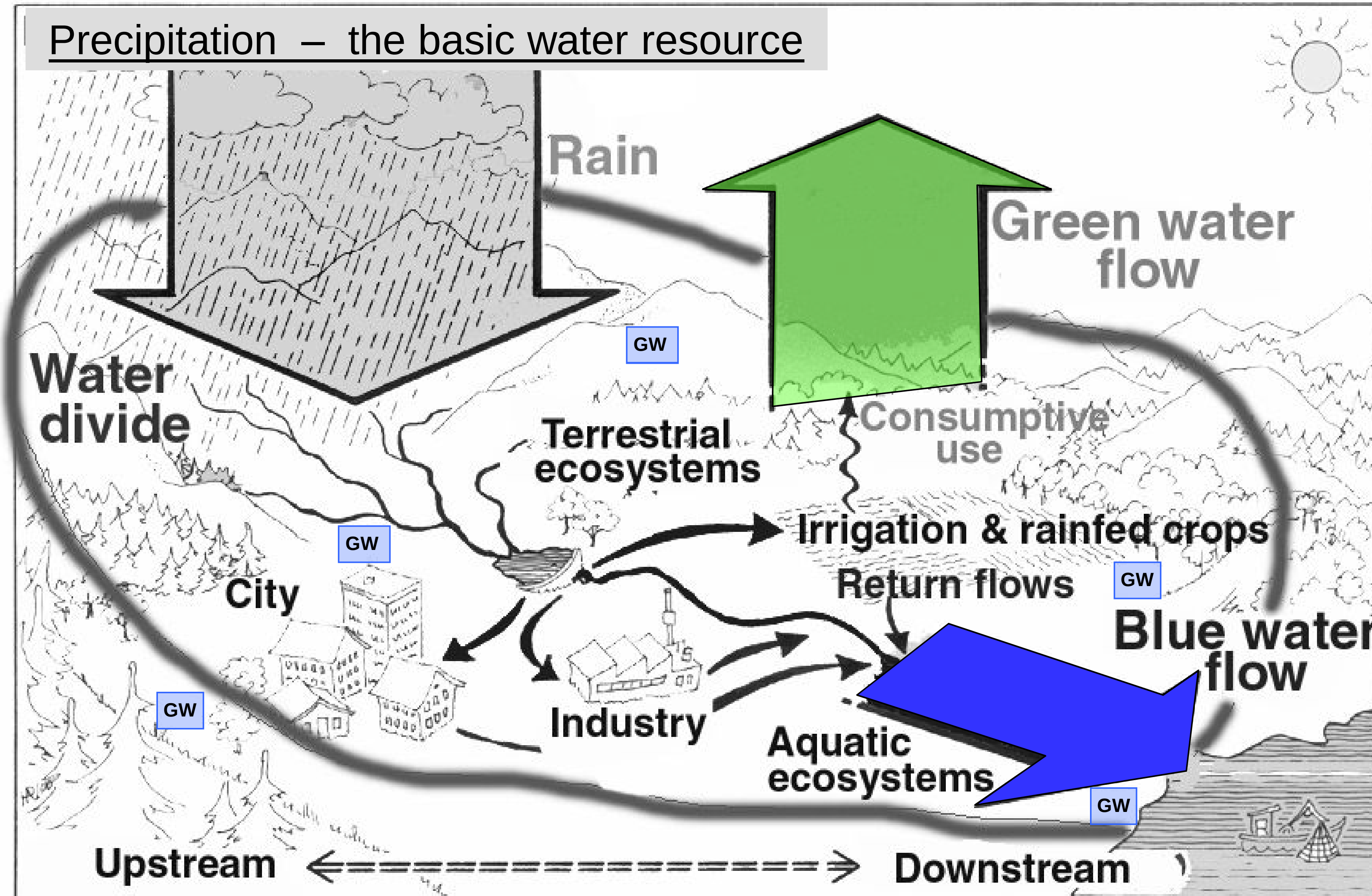
Green Water -

Water that is stored in the soil and is taken up by plants and lost by evapotranspiration.

Blue Water -

Water that is found in rivers and lakes as well as groundwater that is used for agriculture, industrial and domestic purposes.

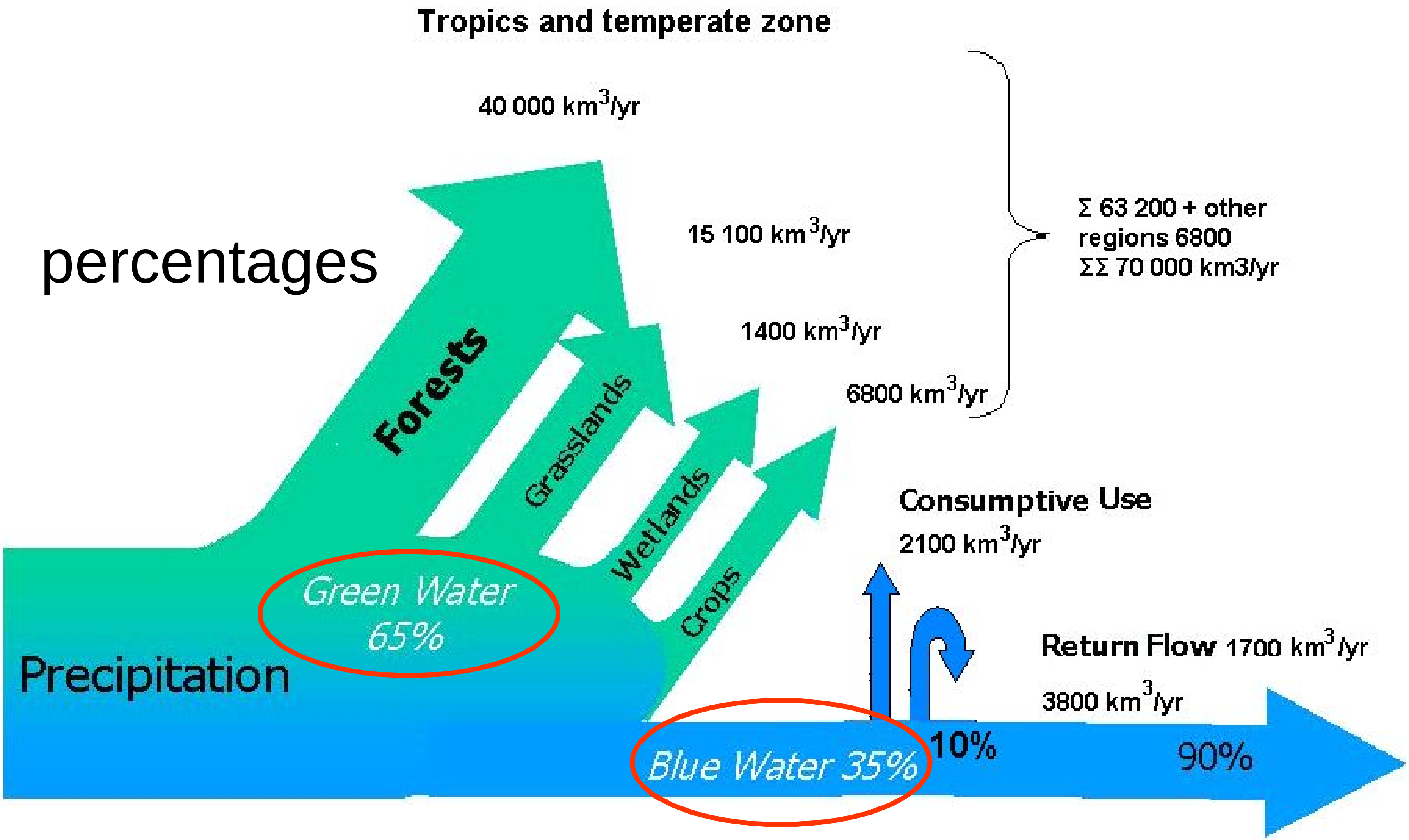
Blue & Green Water - Perspective



Adapted from: GWP (M. Falkenmark), 2003, Water Management and Ecosystems: Living with Change

Blue & Green Water – Pathways

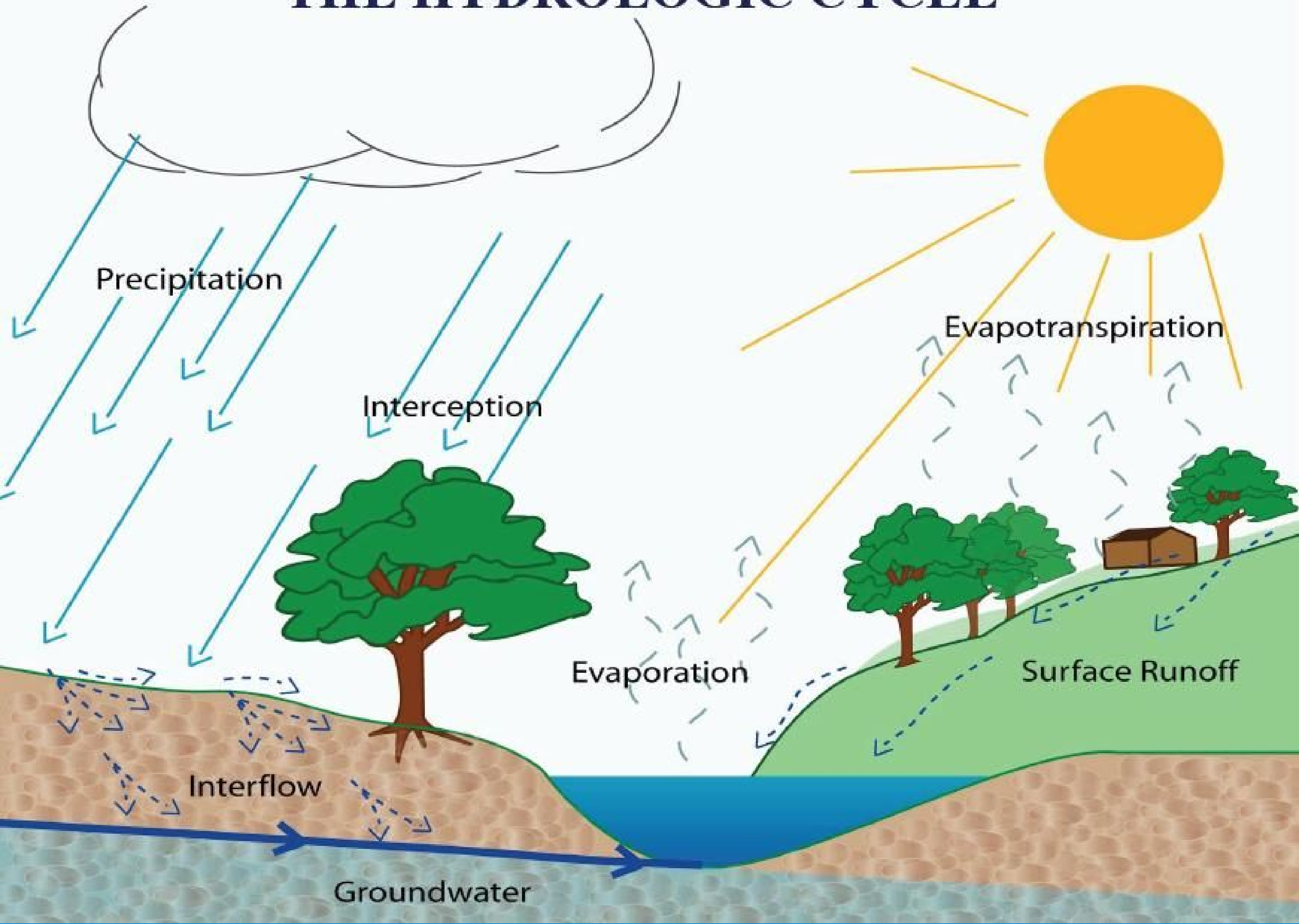
percentages



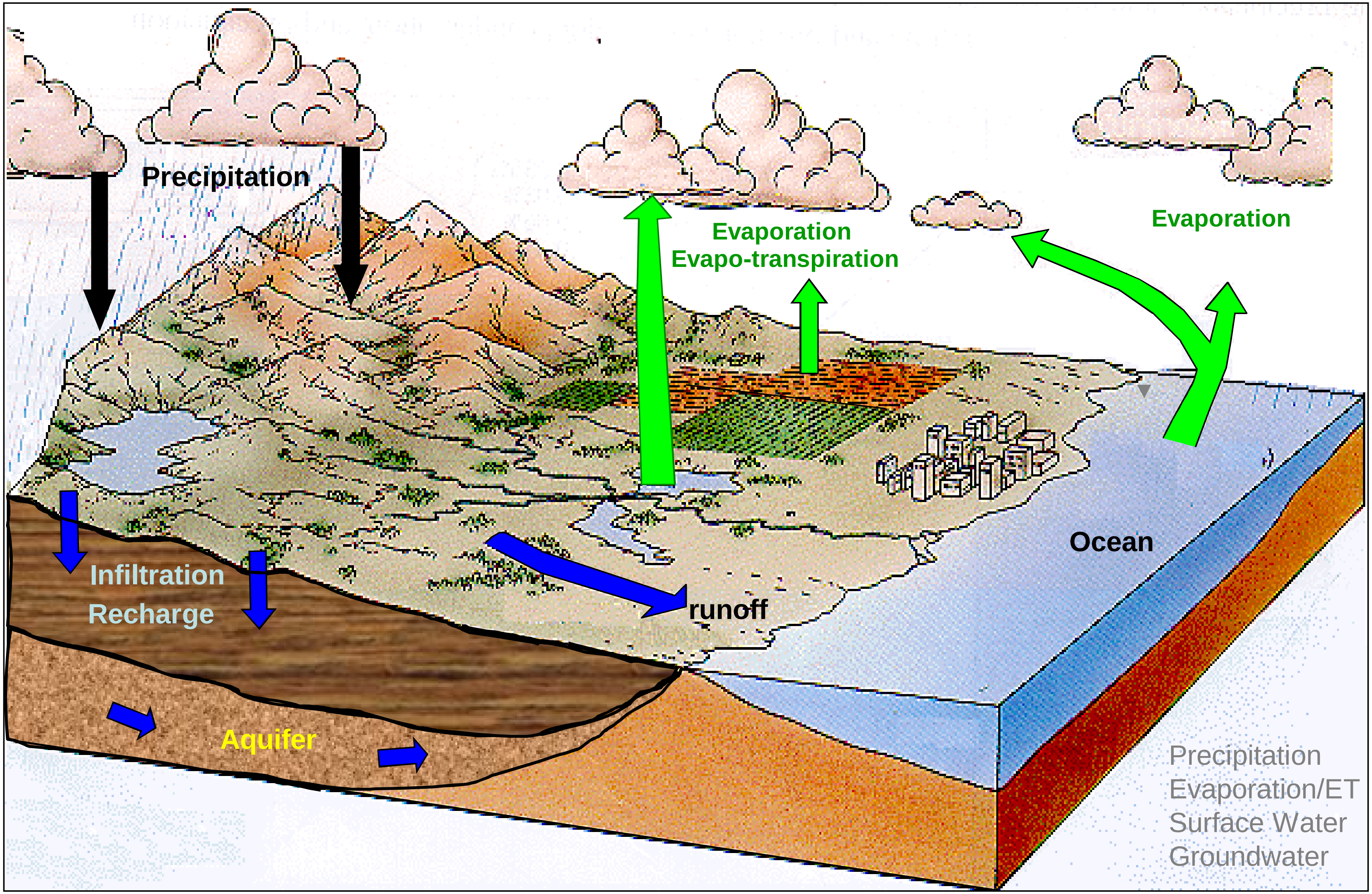
Consumptive water use by terrestrial ecosystems as seen in a global perspective. (Falkenmark in SIWI Seminar 2001).

Hydrologic Cycle

THE HYDROLOGIC CYCLE

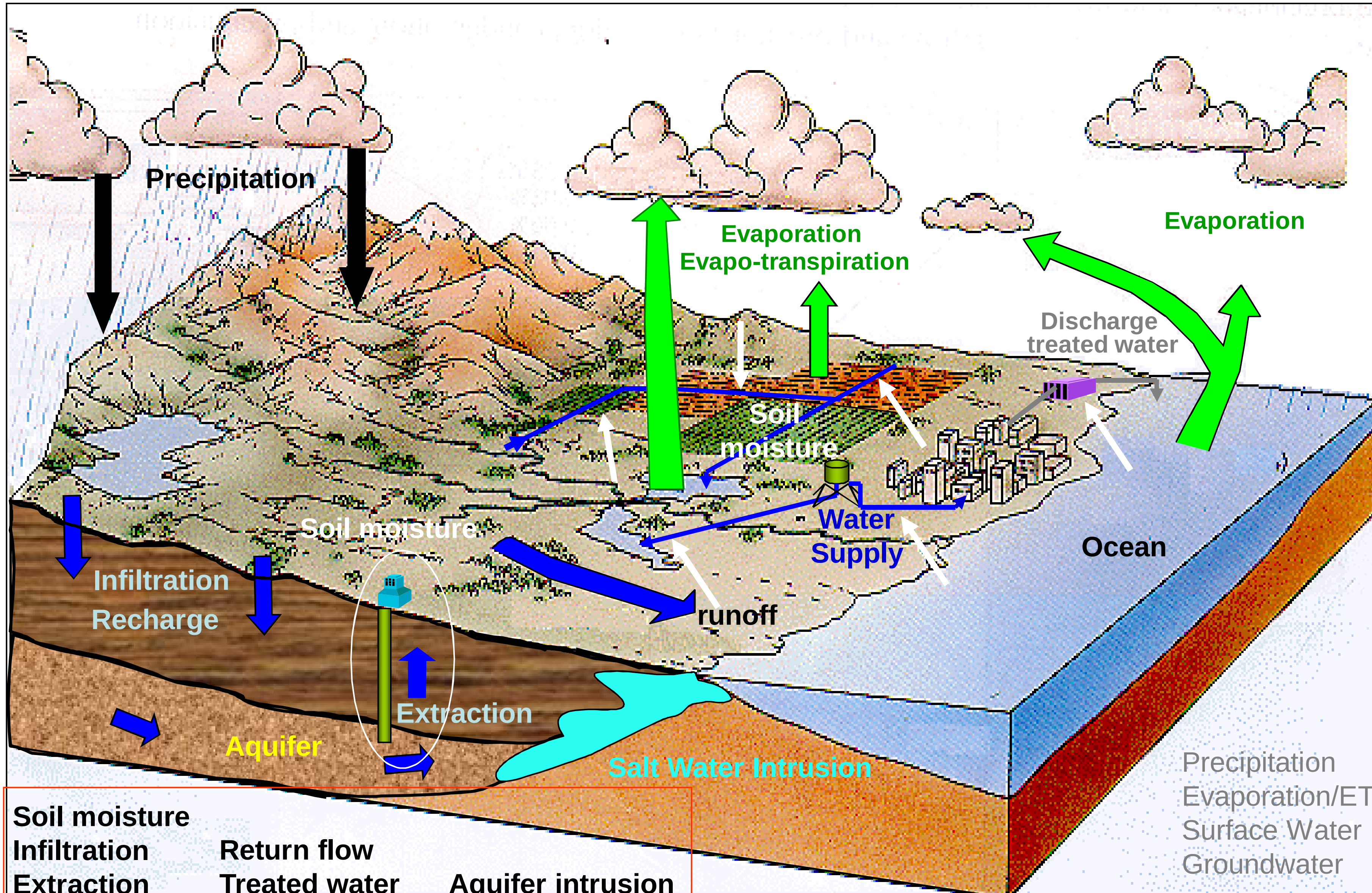


Hydrologic Cycle

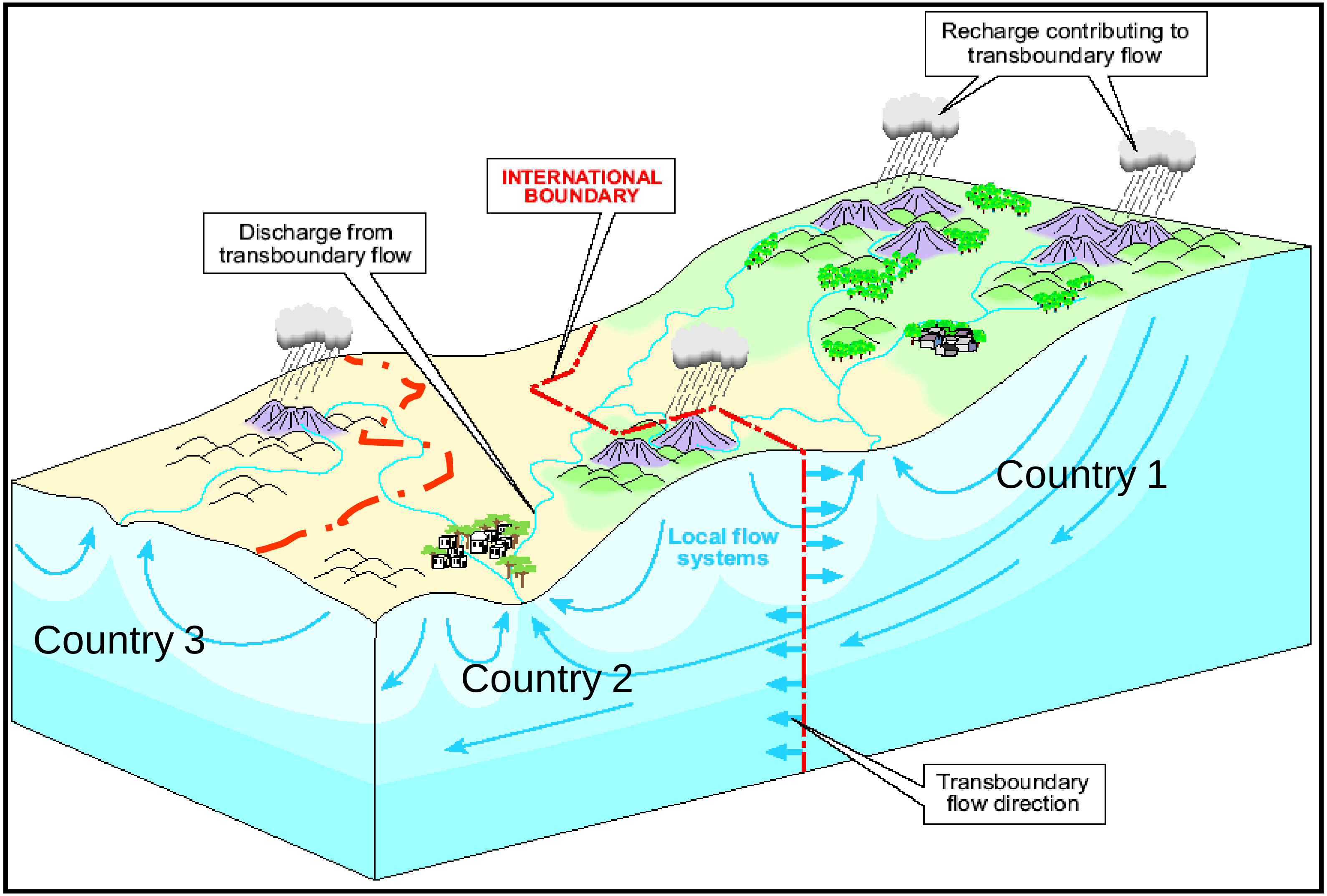


Precipitation
Evaporation/ET
Surface Water
Groundwater

Hydrologic Cycle (detailed)



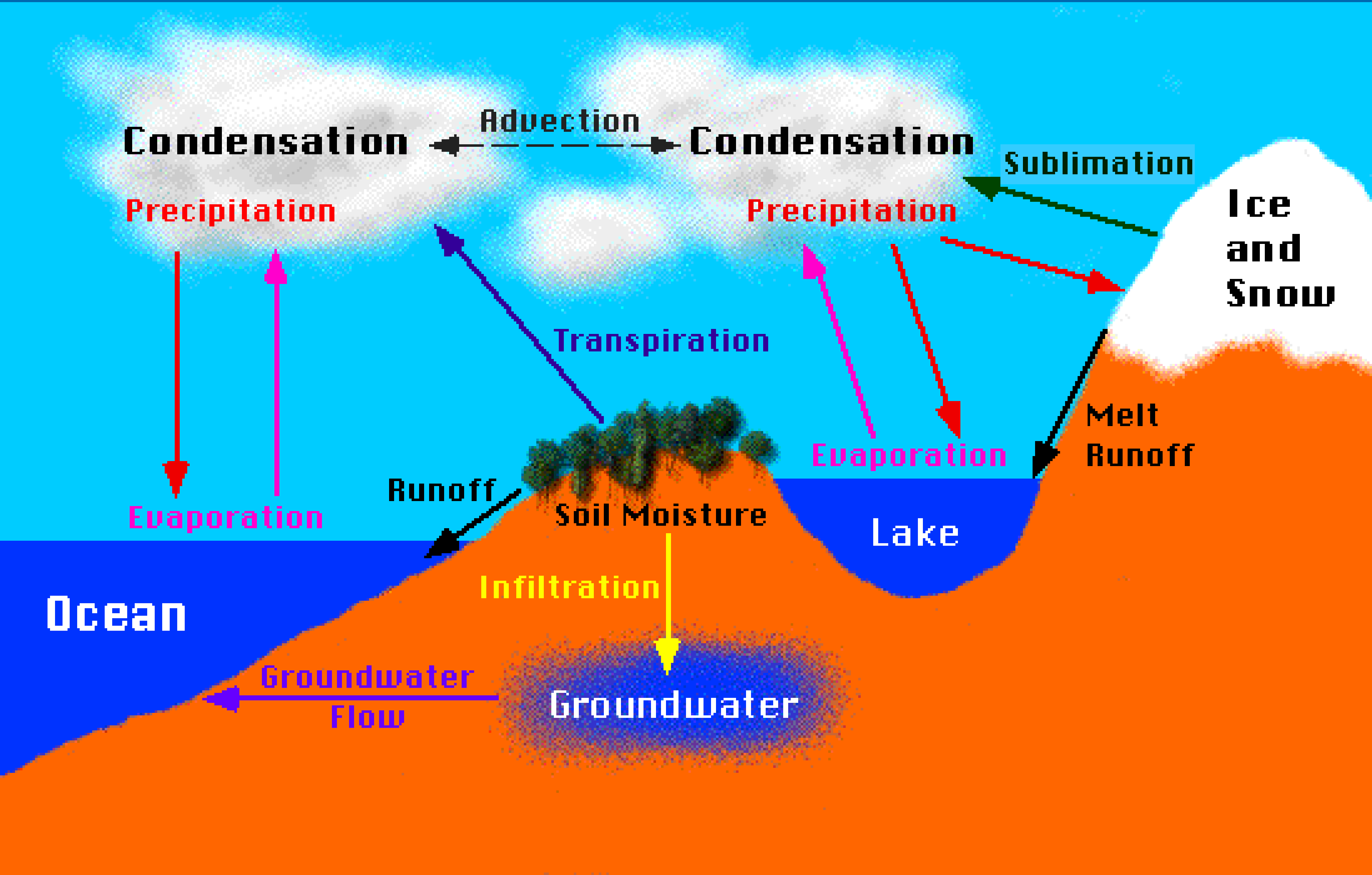
Watersheds – Boundaries and Divides ?



What is the Hydrologic Cycle?

The hydrologic cycle is the system which describes the distribution and movement of water between the earth and its atmosphere. The model involves the continual circulation of water between the oceans, the atmosphere, vegetation and land.

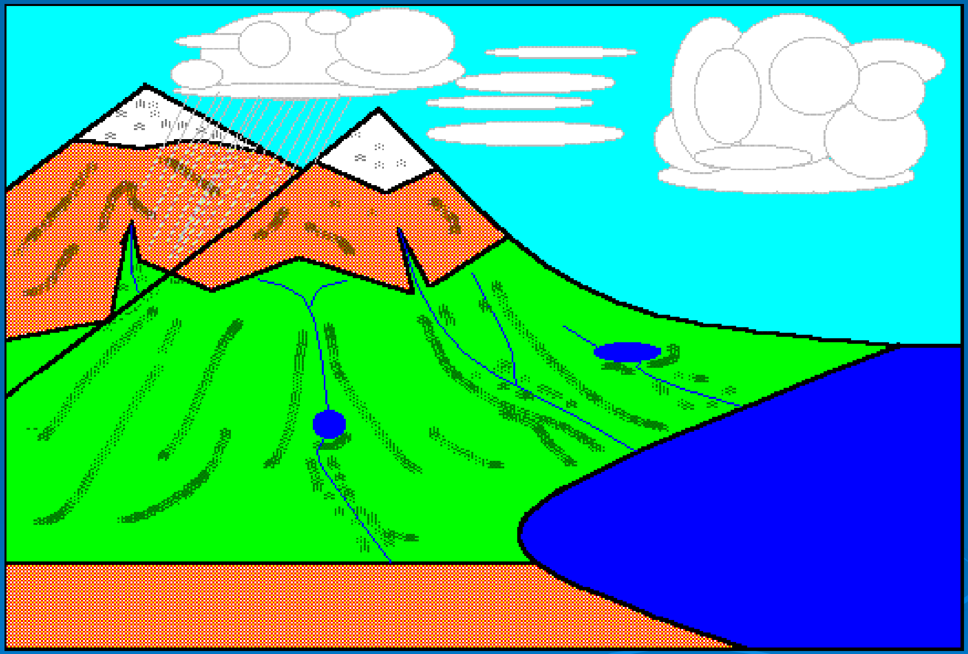
Hydrologic Cycle



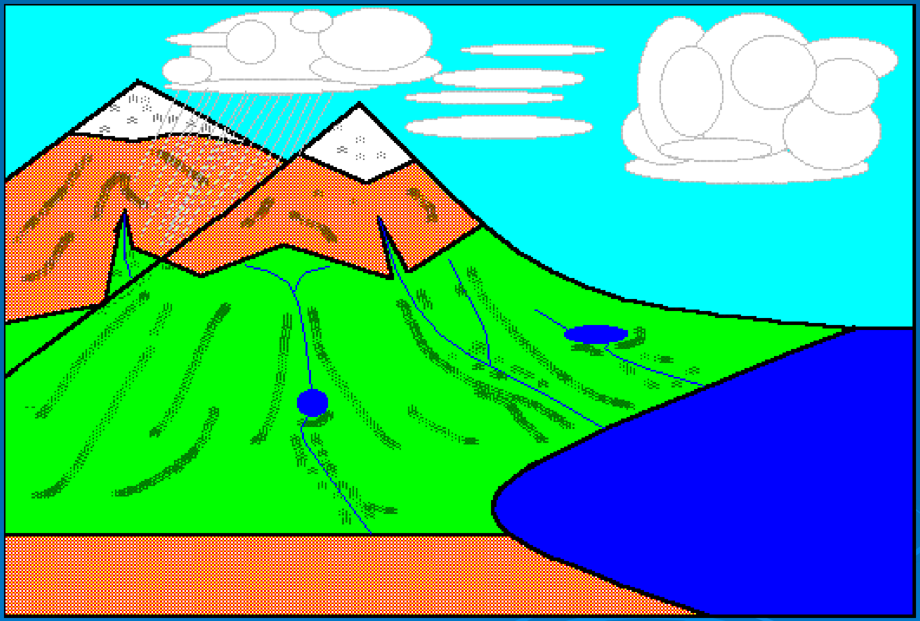
Describing the Cycle

- <u>Evaporation</u>

  Solar energy powers the cycle. Heat energy from the sun causes evaporation from water surfaces (rivers, lakes and oceans) and....

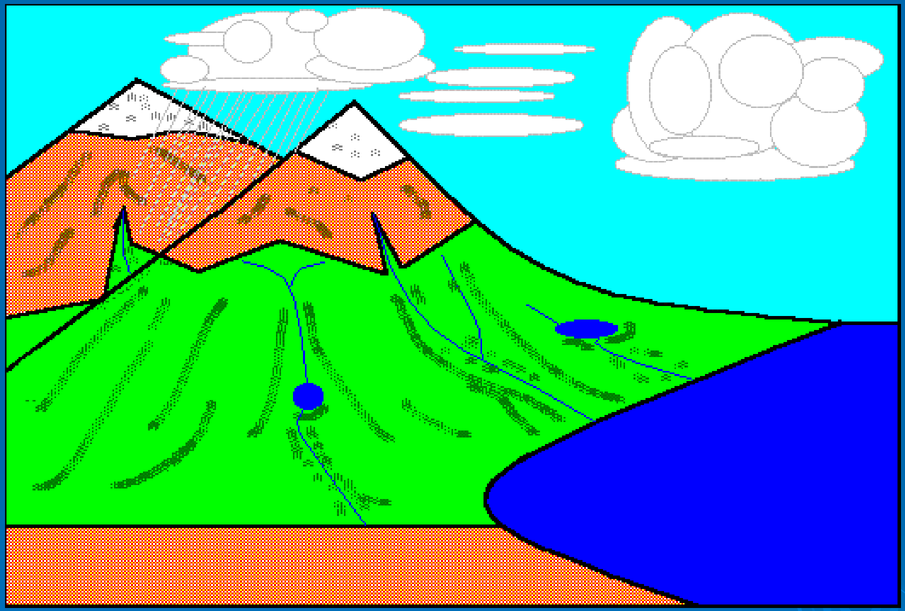


- … transpiration from plants.
- Evapotranspiration – water loss to the atmosphere from plants and water surfaces.



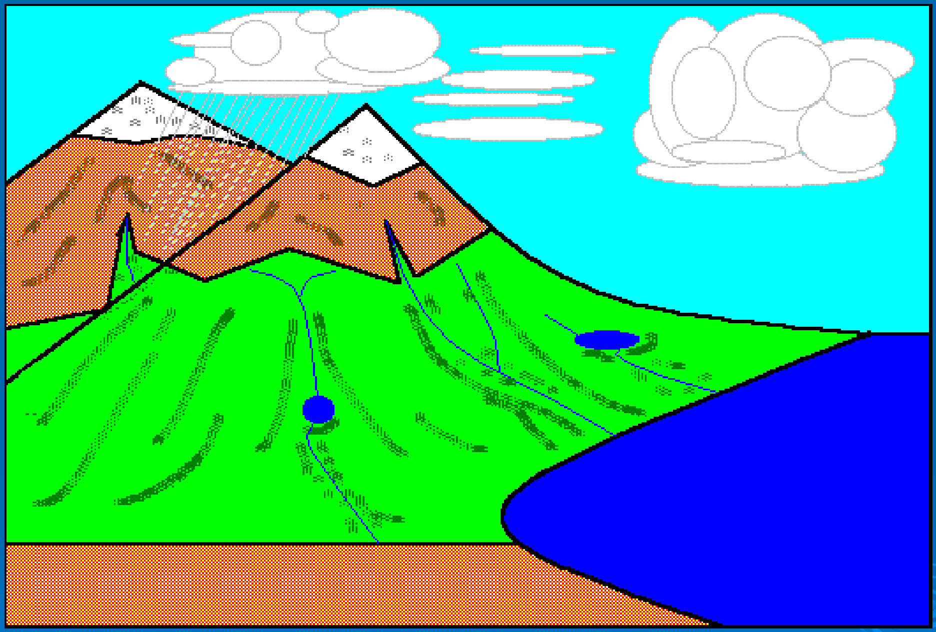
Condensation

- The warm, moist air (containing water vapour) rises and, as it cools, condensation takes place to form clouds.



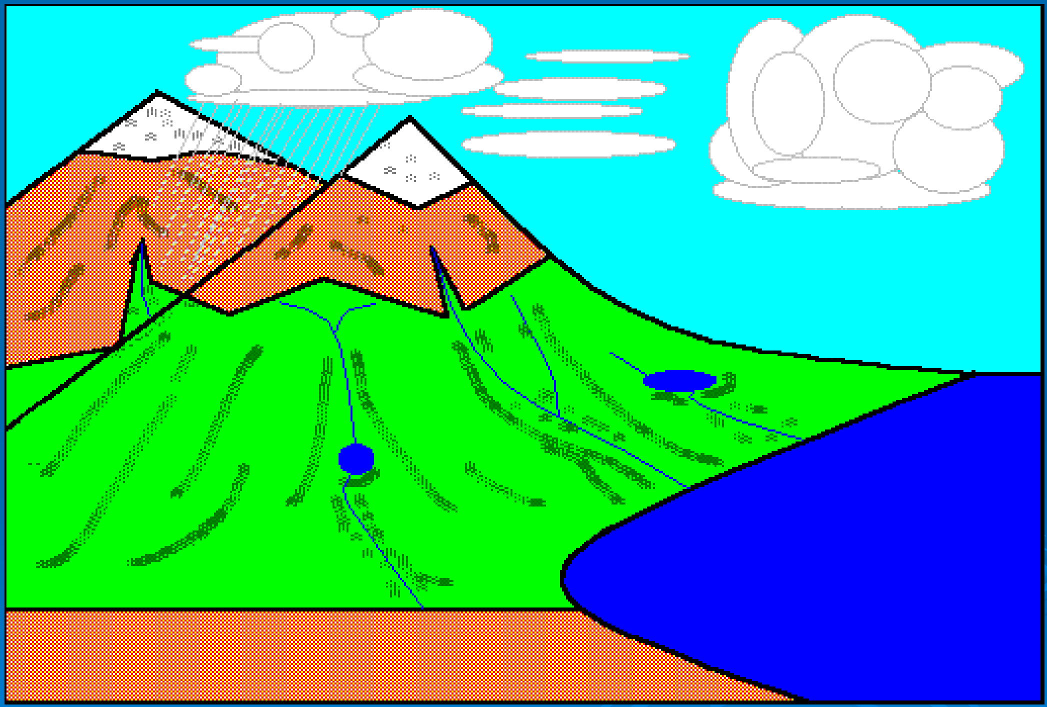
Advection

- Wind energy may move clouds over land surfaces where …



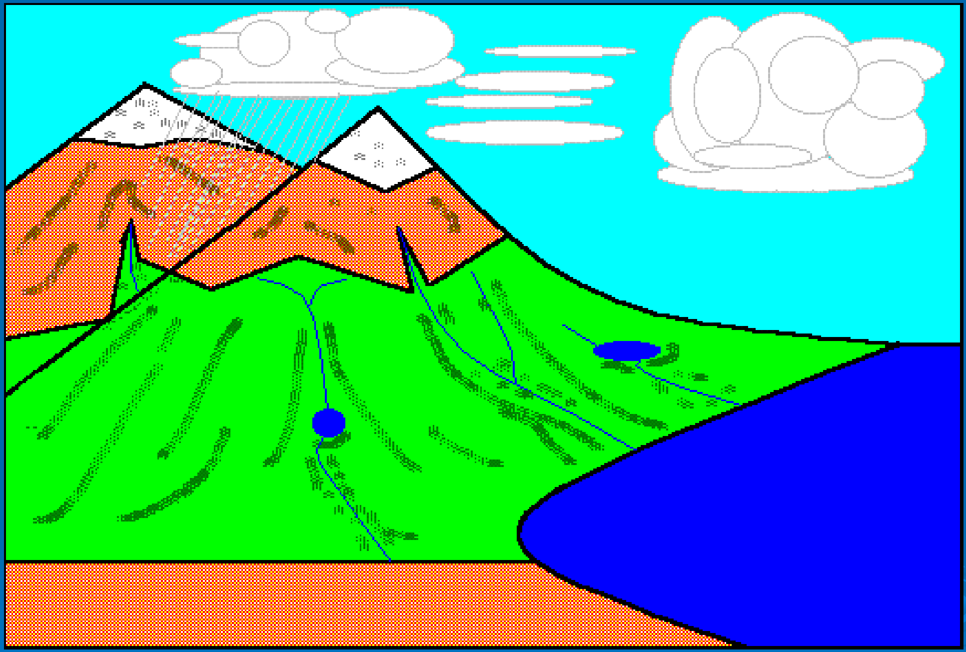
Precipitation

- …precipitation occurs, either as rain or snow depending on altitude.



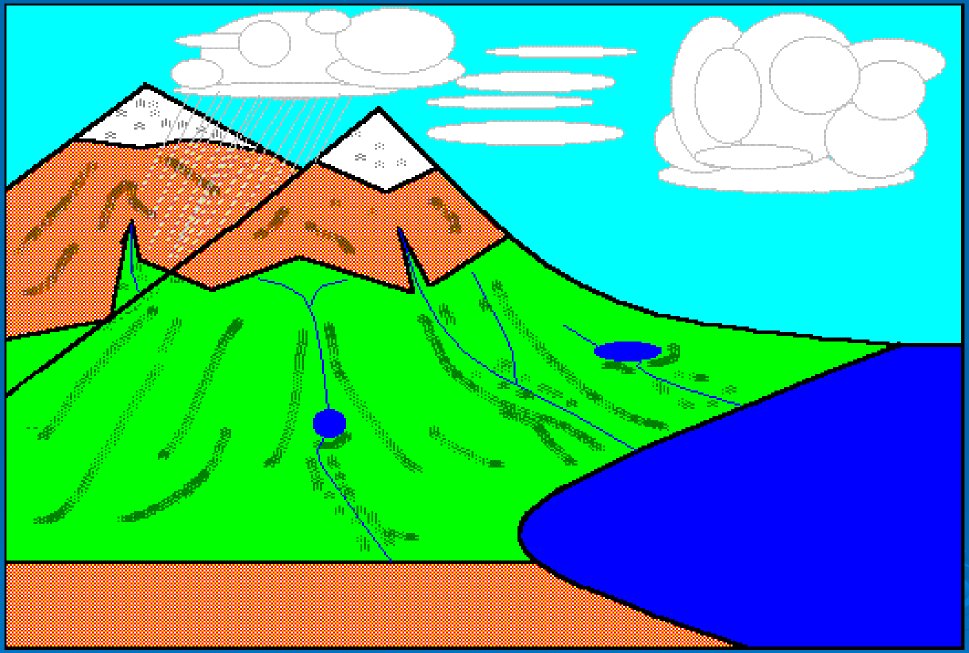
Runoff / Surface Flow

- The rainwater flows, either over the ground (run off / surface flow) into rivers and back to the ocean, or…

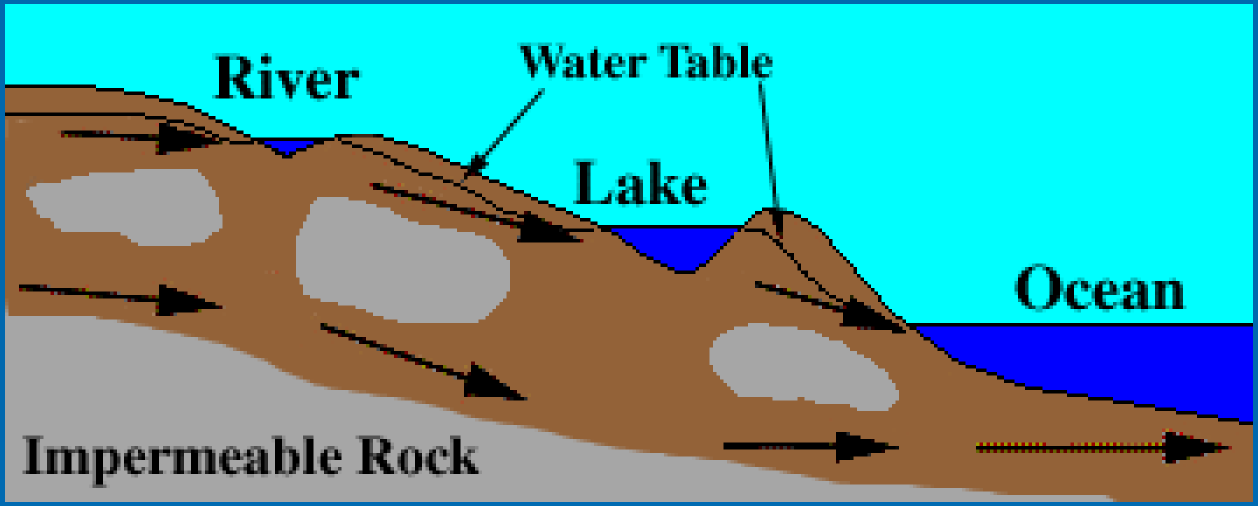


Groundwater Flow

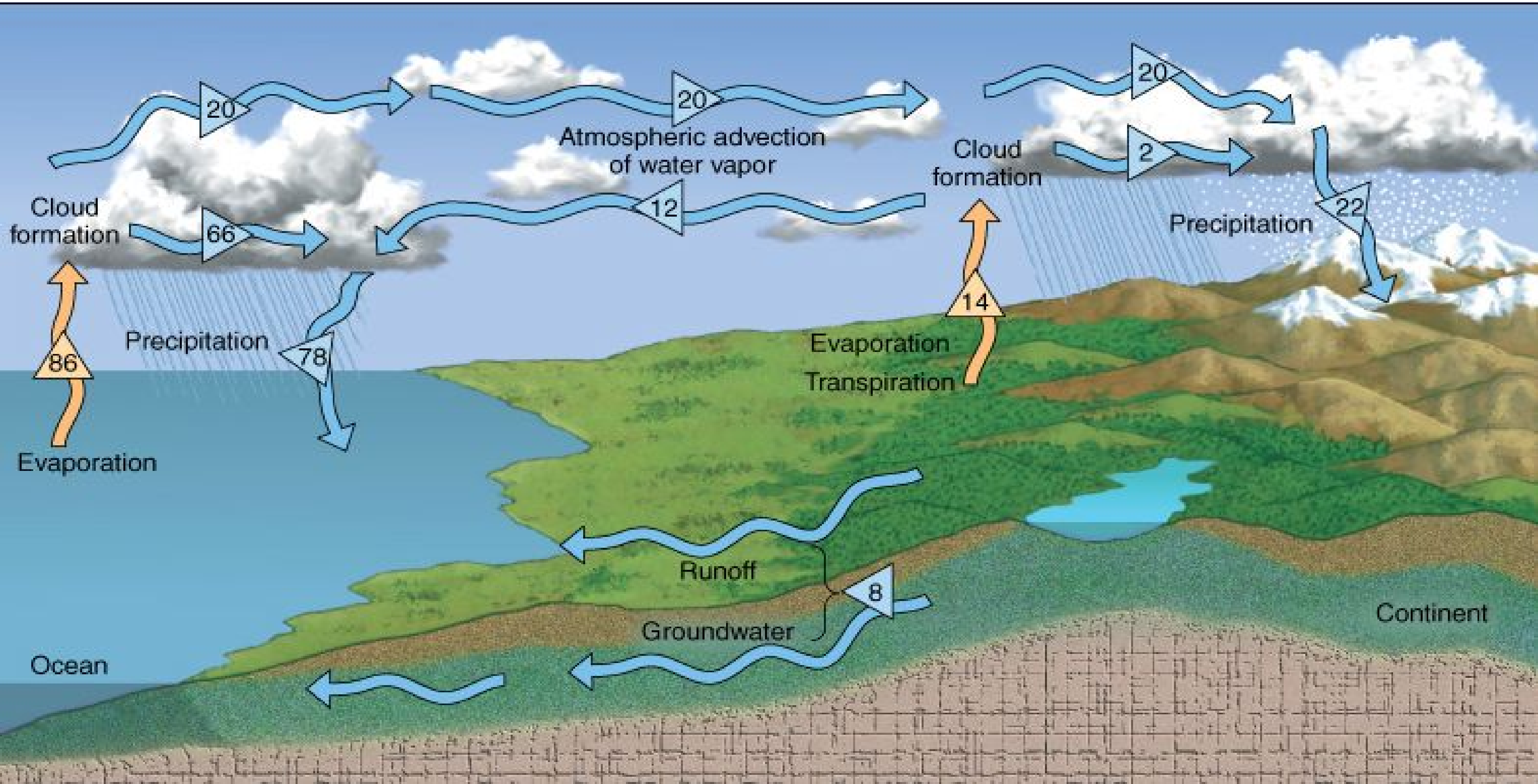
- … infiltrates downwards through the soil and rocks where it is returned to the oceans through groundwater flow.



Groundwater Flow



Hydrologic Cycle Model: The model shows how water travels endlessly through the hydrosphere, atmosphere, lithosphere, and biosphere. The triangles show global average values as percentages. Note that all evaporation equals all precipitation when all of the Earth is considered. Regionally, various parts of the cycle will vary, creating imbalances and, depending on climate, surpluses in one region and shortages in another.



- If we assume that mean annual global evaporation equals 100 units, we can trace 86 of them to the ocean. The other 14 units come from the land, including water moving from the soil into plant roots and passing through their leaves.
- Of the ocean's evaporated 86 units, 66 combine with 12 advected (transported) from the land to produce the 78 units of precipitation that fall back into the ocean.
- The remaining 20 units of moisture evaporated from the ocean, plus 2 units of land-derived moisture, produce the 22 units of precipitation that fall over land. Clearly, the bulk of continental precipitation derives from the oceanic portion of the cycle.

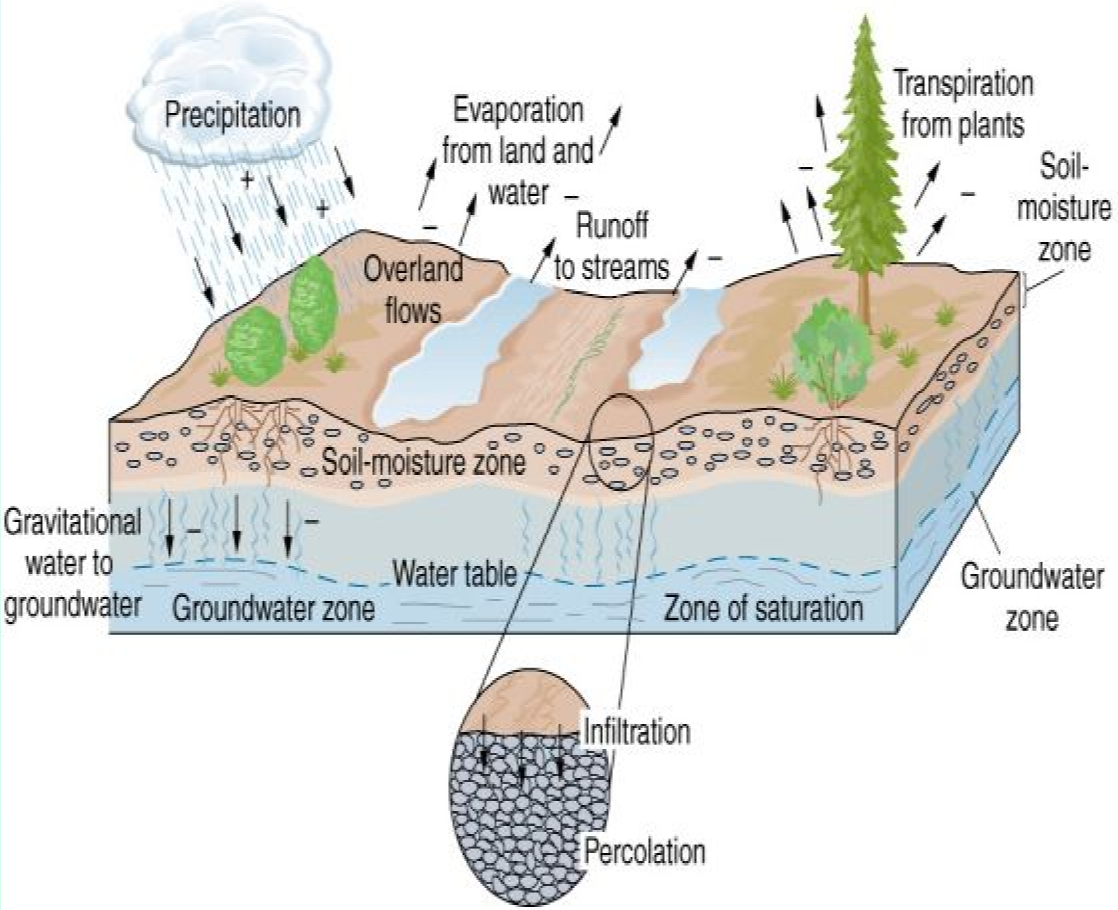
Possible routes that raindrops may take on their way to and into the soil surface

- Precipitation that reaches Earth's surface follows a variety of pathways.
- The process of precipitation striking vegetation or other groundcover is called **interception**.
- Intercepted precipitation may be redistributed as throughfall and stemflow. Precipitation that falls directly to the ground, is coupled with drips onto the ground from vegetation (**throughfall**).
- Intercepted water that drains across plant leaves and down plant stems is termed **stem flow**.
- Water reaches the subsurface through **infiltration**, or penetration of the soil surface. It then permeates soil or rock through vertical movement called **percolation**.

Groundwater Resources

- Groundwater is the part of the hydrologic cycle that lies beneath the ground and is therefore tied to surface supplies.
- Groundwater is the largest potential source of freshwater in the hydrologic cycle – larger than all surface reservoirs, lakes, rivers, and streams combined.
- Between Earth's surface and a depth of 3 km (10,000 ft) worldwide, some 8,340,000 km^3 (2,000,000 mi^3) of water resides.

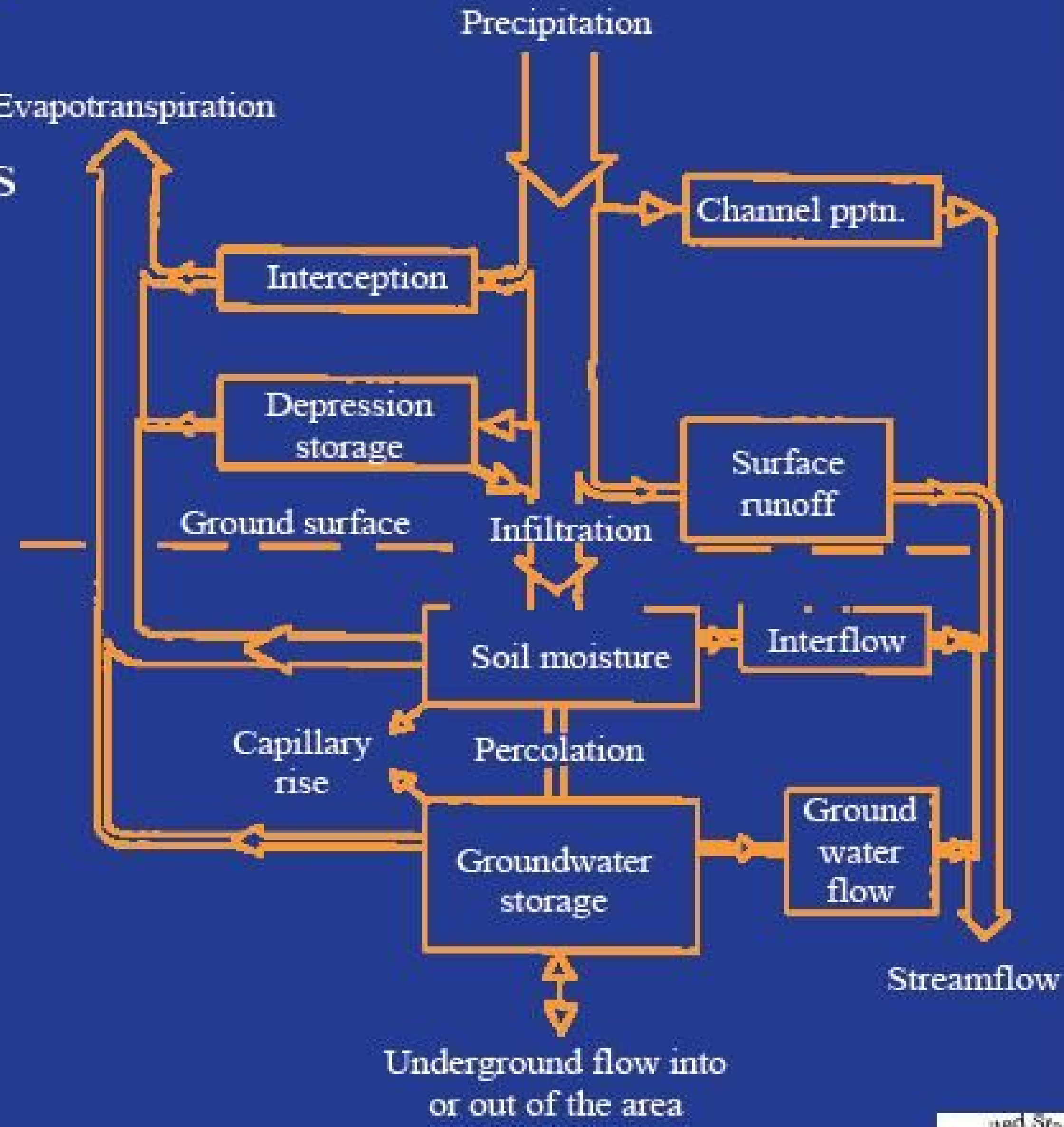
The soil-moisture environment: Precipitation supplies the soil-moisture environment. The principal pathways for water include interception by plants; throughfall to the ground; collection on the surface, forming overland flow to streams; transpiration (water moving from the soil into plant roots and passing through their leaves) and evaporation from plant; evaporation from land and water; and gravitational water moving to subsurface groundwater. Water moves from the surface into the soil by infiltration and percolation.



HYDROLOGY - HYDROLOGIC COMPONENTS

Hydrologic Components

- Rainfall or Snow
- Interception
- Depression storage
- Evapotranspiration
- Infiltration
- Surface storage
- Runoff
- Interflow
- Groundwater flow



The Water Cycle Balance

- Usually the water cycle is in balance, and the amount of precipitation falling will slowly soak into the ground and eventually reach the rivers.

- However, if rain falls for a long period of time or if the ground is already soaked or saturated with water, then the chance of flooding is increased.

A Closed System

- The hydrologic cycle is a good example of a closed system: the total amount of water is the same, with virtually no water added to or lost from the cycle.
- Water just moves from one storage type to another.
- Water evaporating from the oceans is balanced by water being returned through precipitation and surface run off.

Human Inputs to the Cycle

- Although this is a closed system, there is a natural balance maintained between the exchange of water within the system.
- Human activities have the potential to lead to changes in this balance which will have knock on impacts.
- For example, as the earth warms due to global warming, the rate of exchange in the cycle (between land and sea and atmosphere) is expected to increase.

Human Inputs

- Some aspects of the hydrologic cycle can be utilized by humans for a direct economic benefit.

- Example: generation of electricity (hydroelectric power stations and reservoirs)

- These are huge artificial lakes which may disrupt river hydrology (amount of water in a river).

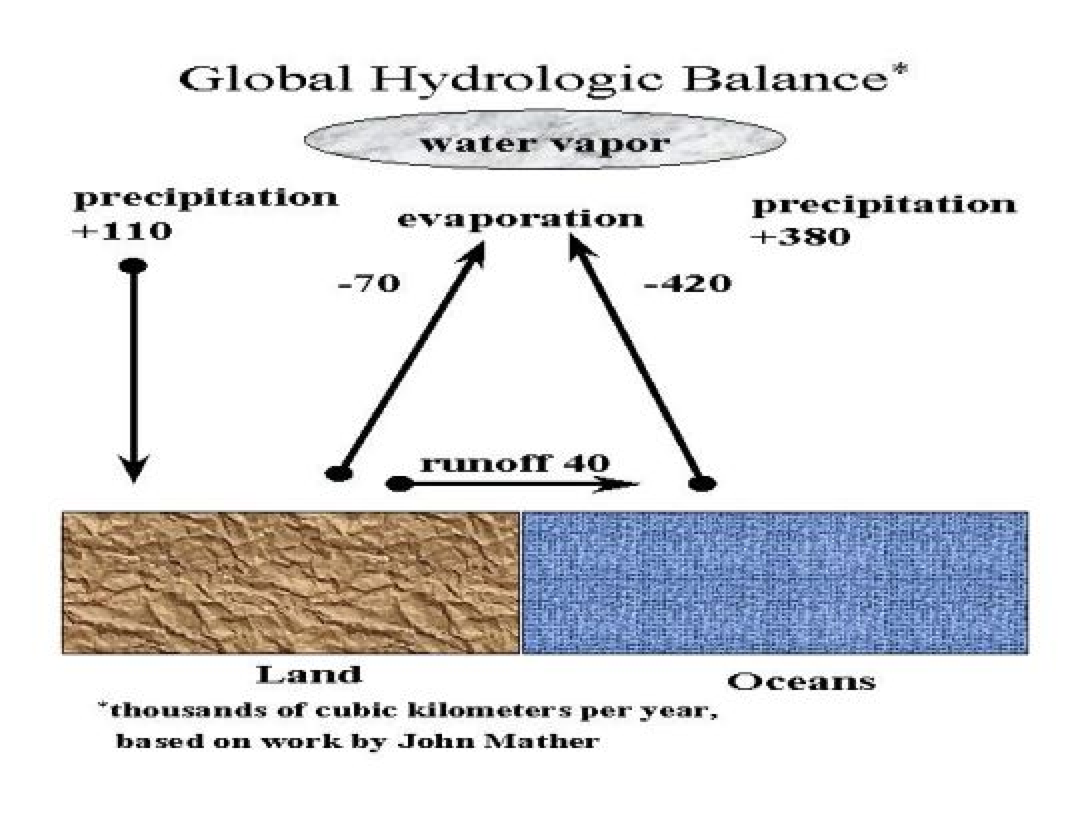
Basic Concept of Water Balance

Water Balance

- A water balance can be established for any area of earth's surface by calculating the total precipitation input and the total of various outputs.
- The water-balance approach allows an examination of the hydrologic cycle for any period of time.
- The purpose of the water balance is to describe the various ways in which the water supply is expended.
- The water balance is a method by which we can account for the hydrologic cycle of a specific area, with emphasis on plants and soil moisture.

- ☞ Water input and output is in balance globally.

$$P = R + ET$$



Hydrologic Water Balance

- Water input and output is not always in balance locally

$$P \neq R + ET$$

- Something is missing ?

$$P = R + ET + \Delta S$$

- ΔS is the change in water storage

Hydrologic Water Balance

- Measuring the amount of water coming in and going out to assess availability

- The water balance is defined by the general hydrologic equation, which is basically a statement of the law of conservation of mass as applied to the hydrologic cycle. In its simplest form, this equation reads

Inflow = Outflow + Change in Storage

- Water balance equations can be assessed for any area and for any period of time.

- The process of 'making an overall water balance for a certain area' thus implies that an evaluation is necessary of all inflow, outflow, and water storage components of the flow domain - as bounded by the land surface, by the impermeable base of the underlying groundwater reservoir, and by the imaginary vertical planes of the area's boundaries.

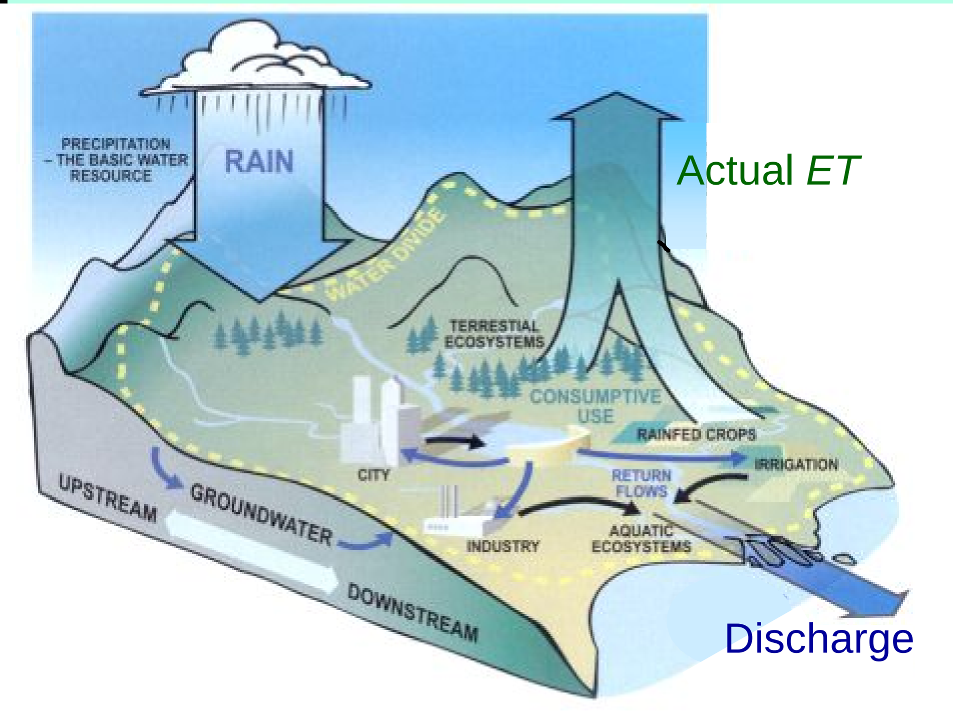
The water balance method has four characteristic features.

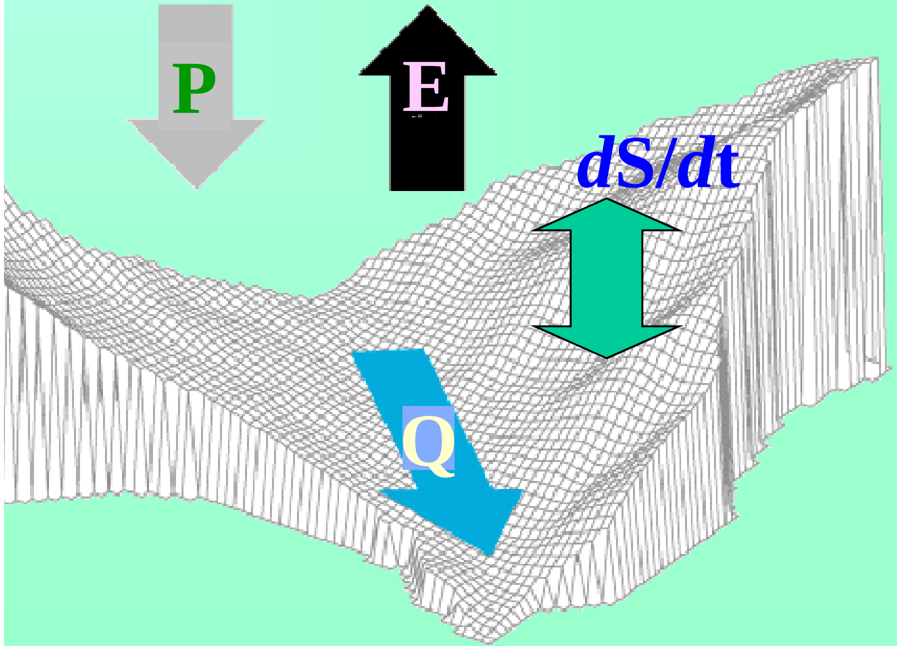
- A water balance can be assessed for any subsystem of the hydrologic cycle, for any size of area, and for any period of time;
- A water balance can serve to check whether all flow and storage components involved have been considered quantitatively;
- A water balance can serve to calculate one unknown of the balance equation, provided that the other components are known with sufficient accuracy;
- A water balance can be regarded as a model of the complete hydrologic process under study, which means it can be used to predict what effect the changes imposed on certain components will have on the other components of the system or subsystem.

Water Balance Equation

$$P = Q + E + dS/dt$$

P	:	Precipitation [mm a^{-1}]
Q	:	Discharge [mm a^{-1}]
E	:	Evaporation [mm a^{-1}]
dS/dt	:	Storage changes per time step [mm a^{-1}]





- Without an accurate water balance, it is not possible to manage water resources of a country. When working on the water balance, it is inevitable to face the fact that appearance of water within a country is highly dynamic and variable process, both spatially and temporarily. Therefore, methodology, which is directly dependent on a time unit and is a function of measured hydrometeorological and hydrological data quality and data availability, is the most significant element.
- Due to the human influence, change of the water needs and climatic variations and/or changes, water balance of an area cannot be taken as final. The process must constantly be monitored, controlled and updated. Major role of each water balance is long term sustainable management of water resources for a given area.

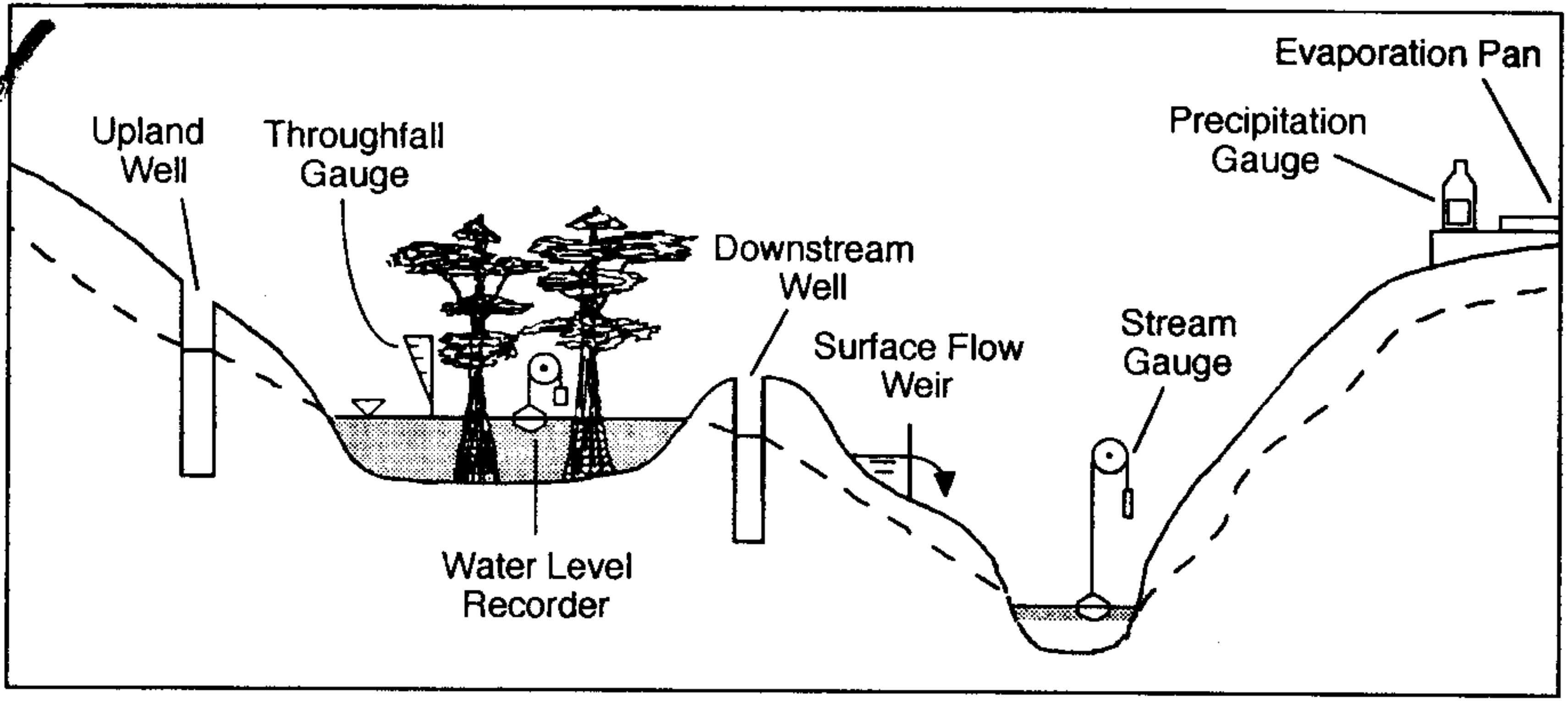
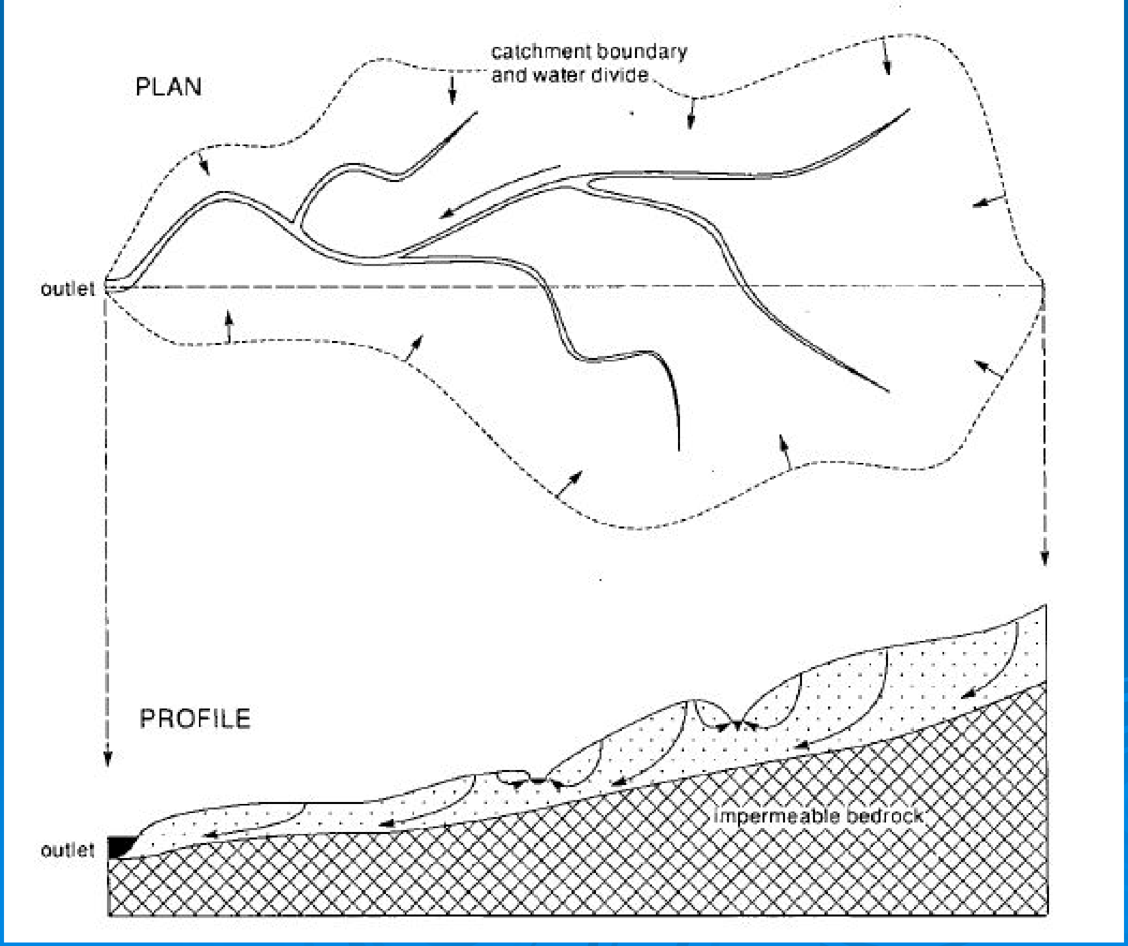


Figure 4–19. Placement of typical measuring equipment for monitoring a water budget of an alluvial wetland.

Catchment Water Balance

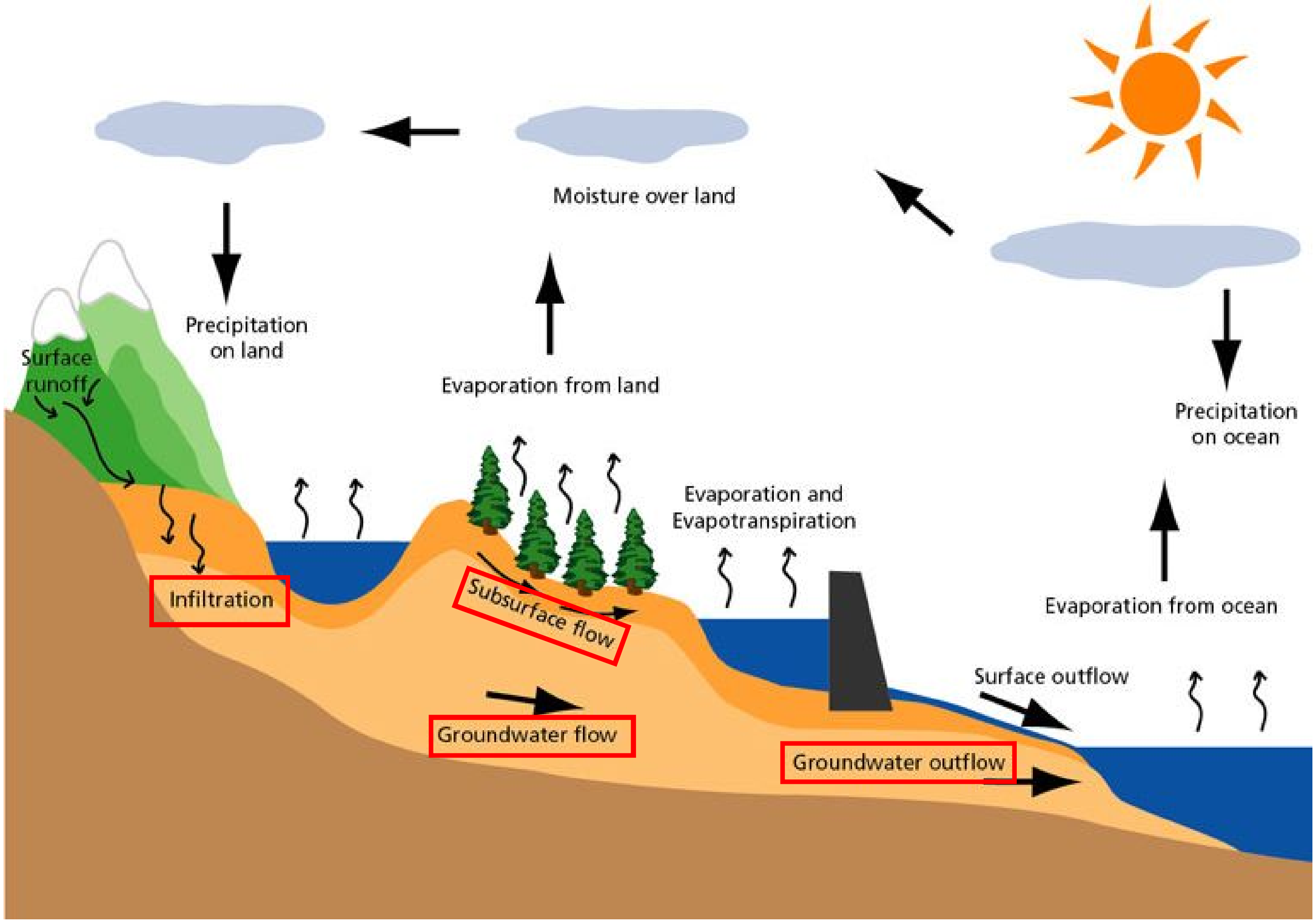
Rainfall - River Outflow = Evapotranspiration

From this equation, we can solve the unknown evapotranspiration.



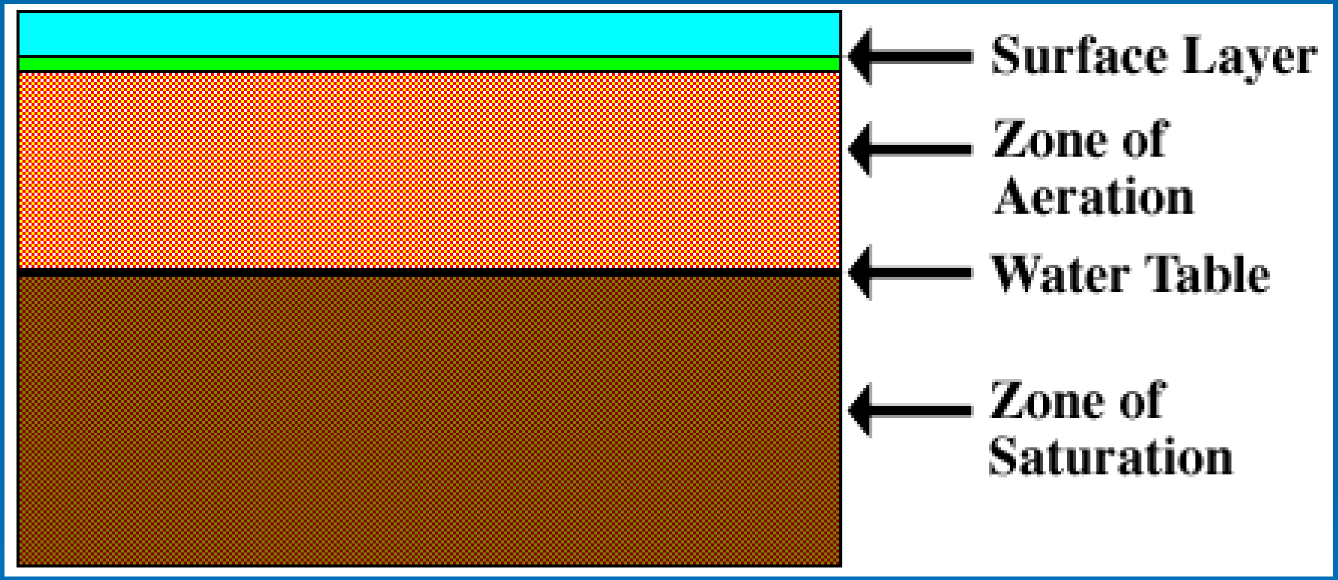
Water Balance of Unsaturated Zone

Subsurface Water

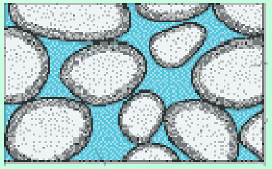


- Infiltration
- Soil moisture
- Subsurface flow
- Groundwater flow

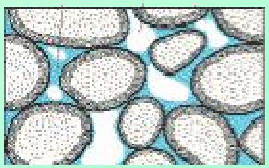
Under the Ground



Porous Medium Flow



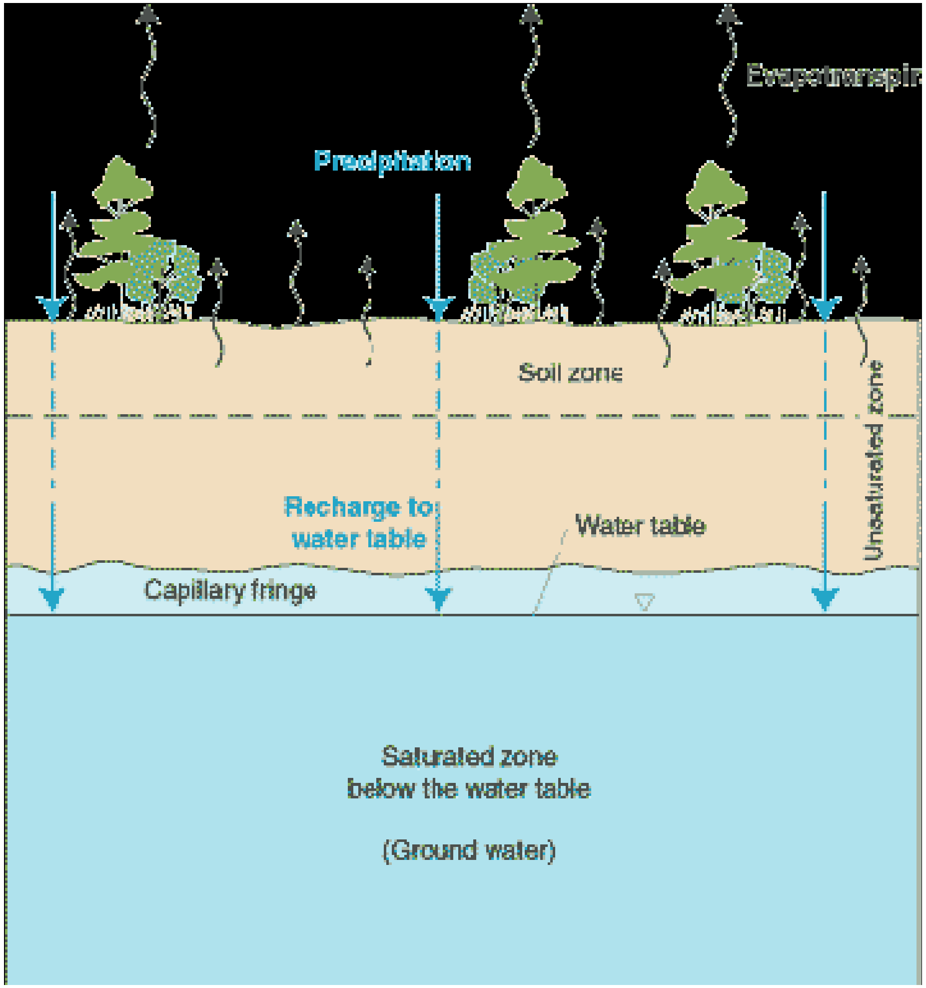
- Subsurface water
  - All waters found beneath the ground surface
  - Occupies pores (void space not occupied by solid matter)
- Porous media



  - Numerous pores of small size
  - Pores contain fluids (e.g., water) and air
  - Pores act as conduits for flow of fluids
- The storage and flow through porous media is affected by
  - Type of rocks in a formation
  - Number, size, and arrangement of pores
- Pores are generally irregular in shape because of
  - differences in the minerals making up the rocks
  - geologic processes experienced by them

Zones of Saturation

- **Unsaturated zone**
  - Zone between the land surface and water table
  - Pores contain water and air
  - Also called as vadose zone or the zone of aeration
- **Saturated zone**
  - Pores are completely filled with water
  - Contains water at greater than atmospheric pressure
  - Also called phreatic zone
- **Water table**
  - Surface where the pore water pressure is atmospheric
  - Divide between saturated and unsaturated zone
- **Capillary fringe**
  - Zone immediately above the water table that gets saturated by capillary forces



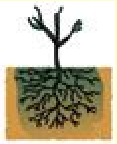
Soil Water

Three categories -

1. **Hygroscopic water**

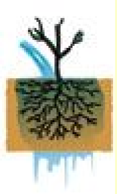
   – Microscopic film of water surrounding soil particles
   – Strong molecular attraction; water cannot be removed by natural forces
   – Adhesive forces (>31 bars and upto 10,000 bars!)

2. **Capillary water**



   – Water held by cohesive forces between films of hygroscopic water
   – Can be removed by air drying or plant absorption
   – Plants extract capillary water until the soil capillary force is equal to the extractive force
      • Wilting point: soil capillary force > plant extractive force

3. **Gravity water**



   – Water that moves through the soil by the force of gravity

- Field capacity
  – Amount of water held in the soil after excess water has drained is called the field capacity of the soil.

Soil Moisture Storage

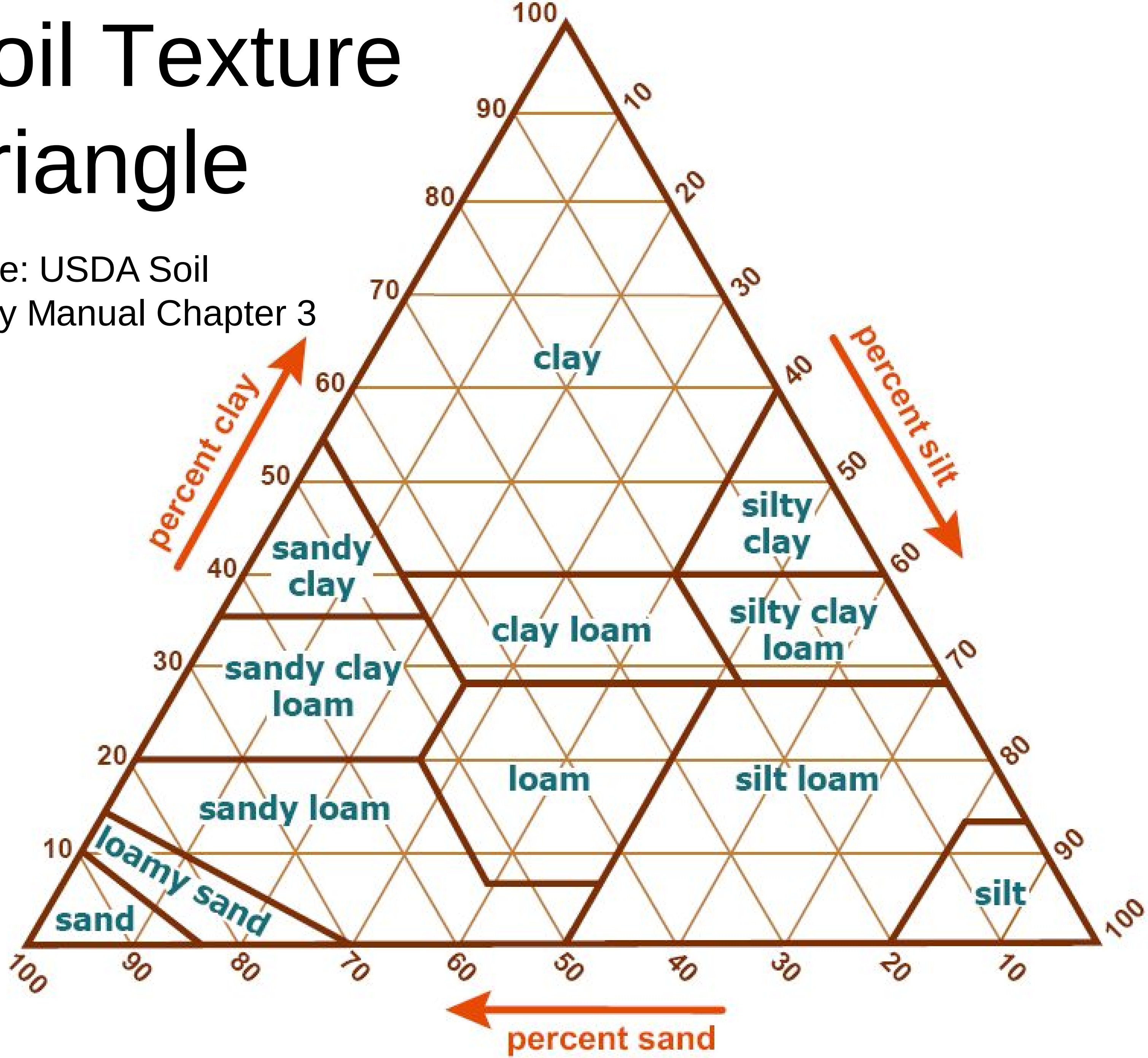
- Soil moisture storage refers to the amount of water that is stored in the soil and is accessible to plant roots, or the effective rooting depth of plants in a specific soil. This water is held in the soil against the pull of gravity. Soil is said to be at the wilting point when plant roots are unable to extract water; in other words, plants will wilt and eventually die after prolonged moisture deficit stress.

- The soil moisture that is generally accessible to plant roots is capillary water, held in the soil by surface tension and cohesive forces between the water and the soil. Almost all capillary water is available water in soil moisture storage and is removable for PET demands through the action of plant roots and surface evaporation; some capillary water remains adhered to soil particles along with hygroscopic water. When capillary water is full in a particular soil, that soil is said to be at field capacity.

- When soil moisture is at field capacity, plant roots are able to obtain water with less effort, and water is thus rapidly available to them.
- As the soil water is reduced by soil moisture utilization, the plants must exert greater effort to extract the same amount of moisture.
- Whether naturally occurring or artificially applied, water infiltrates soil and replenishes available water content, a process known as soil moisture recharge.

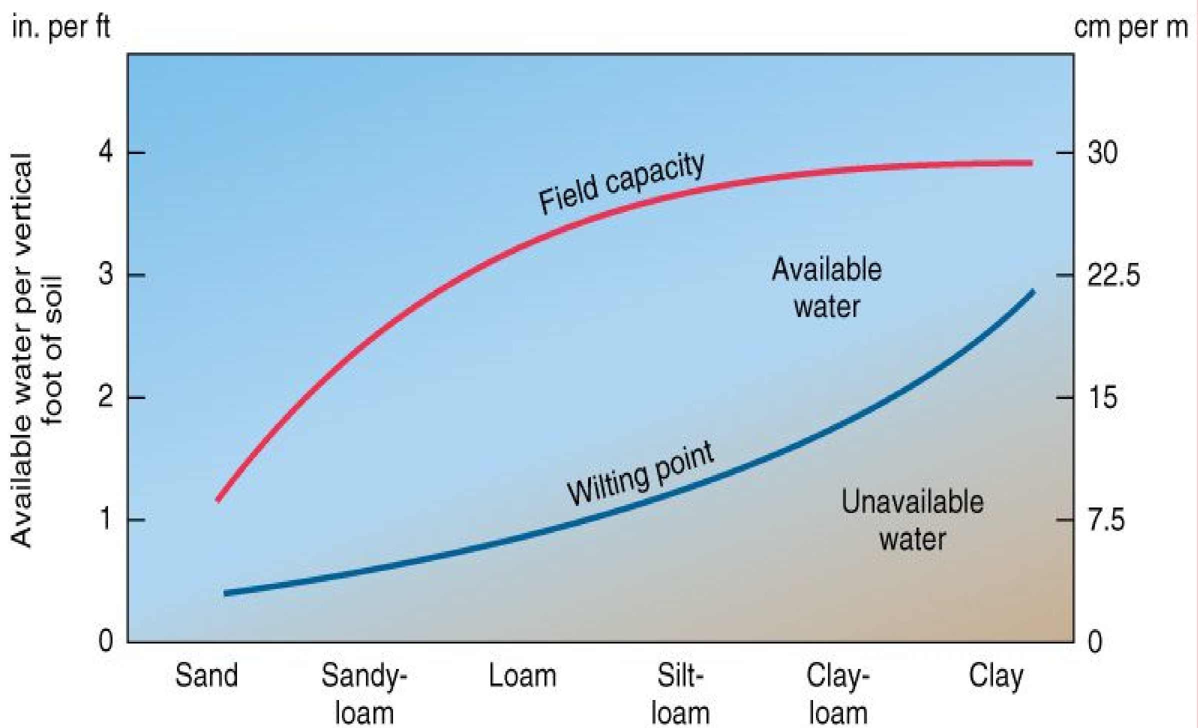
Soil Texture Triangle

Source: USDA Soil Survey Manual Chapter 3



Available Soil Moisture

The lower line on the graph plots the wilting point; the upper line plots field capacity. The space between the two lines represents the amount of water available to plants given varying soil textures. Different plant types growing in various types of soil send roots to different depths and therefore are exposed to varying amounts of soil moisture. For example, shallow-rooted crops such as spinach, beans, and carrots send roots down 65 cm (25 in.) in a silt loam, whereas deep-rooted crops such as alfalfa and shrubs exceed a depth of 125 cm (50 in.) in such a soil. A soil blend that maximizes available water is best for supplying plant water needs.



Darcy's Law

- K = hydraulic conductivity
- q = specific discharge
- $V = q/n$ = average velocity through the area

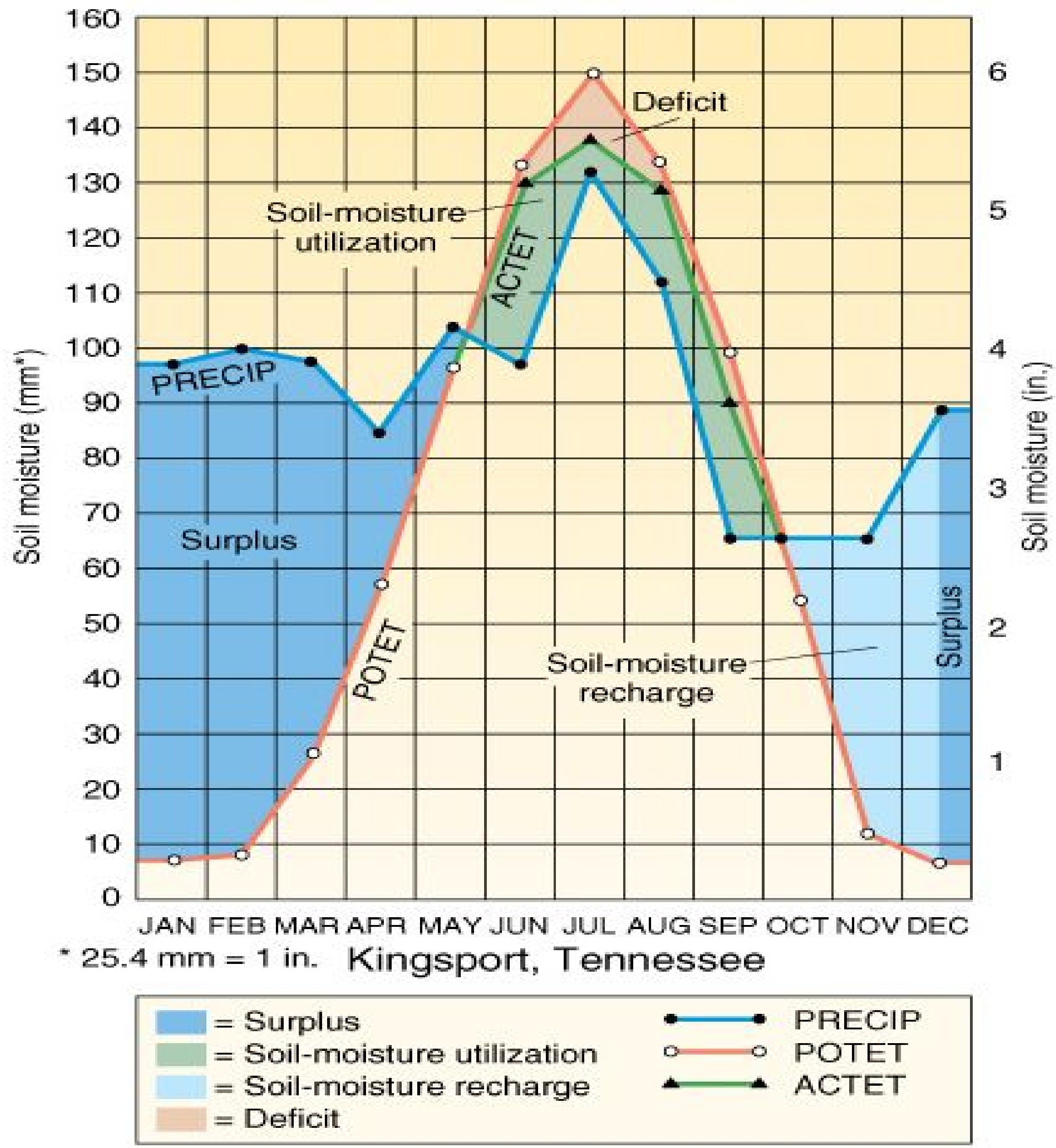
$$\boxed{Q = -KA\frac{\Delta h}{L}}$$

$$q = \frac{Q}{A} = -K\frac{h_{down} - h_{up}}{L}$$

$$q_z = -K\frac{\partial h}{\partial z}$$

- A soil-moisture budget can be established for any area of earth's surface by measuring the precipitation input and its distribution to satisfy the "demands" of plants, evaporation, and soil moisture storage in the area considered.
- A budget can be constructed for any time frame, from minutes to years.

- **Sample Water Budget**: Annual average water-balance components. The comparison of plots for precipitation inputs (PERCIP), and potential evapotranspiration outputs (POTET) determines the condition of the soil-moisture environment. A typical pattern of spring surplus, summer soil-moisture utilization, a small summer deficit, autumn soil-moisture recharge, and ending surplus highlights the year.



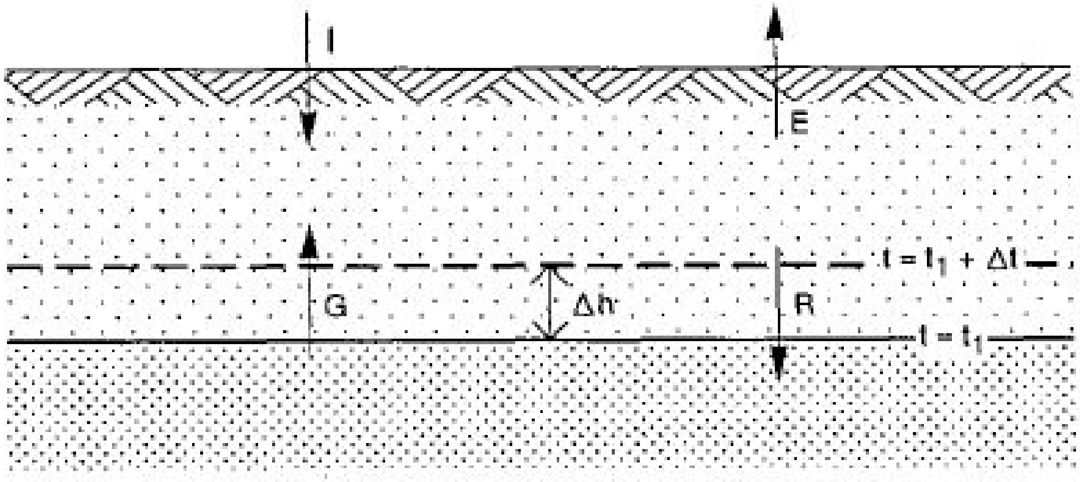
Water Balance Data Inputs

- Field Measured data
  - Soil types and area
  - K_{sat} in least permeable horizon within 2 metres
  - Runoff

The water balance of the unsaturated zone reads -

$$I - E + G - R = \frac{\Delta W_u}{\Delta t}$$

I	= rate of infiltration into the unsaturated zone (mm/d)
E	= rate of evapotranspiration from the unsaturated zone (mm/d)
G	= rate of capillary rise from the saturated zone (mm/d)
R	= rate of percolation to the saturated zone (mm/d)
ΔW_u	= change in soil water storage in the unsaturated zone (mm)
Δt	= computation interval of time (d)



- A rise in the water table Δh (due to downward flow from, say, infiltrating rainwater) is depicted during the time interval Δt.
- Conversely, during a period of drought, we can expect a decline in the water table due to evapotranspiration by the crops and natural vegetation.
- In areas with deep water tables, the component G will disappear from the water balance equation of the unsaturated zone.

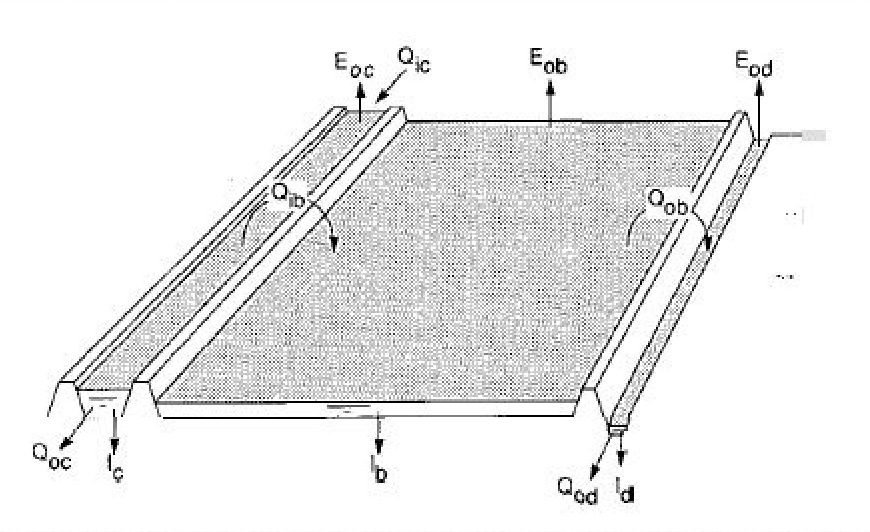
Water Balance at Land Surface

Water balance at the land surface can be expressed by the following equation -

$$I = P - E_0 + 1000\frac{Q_{si} - Q_{so}}{A} - \frac{\Delta W_s}{\Delta t}$$

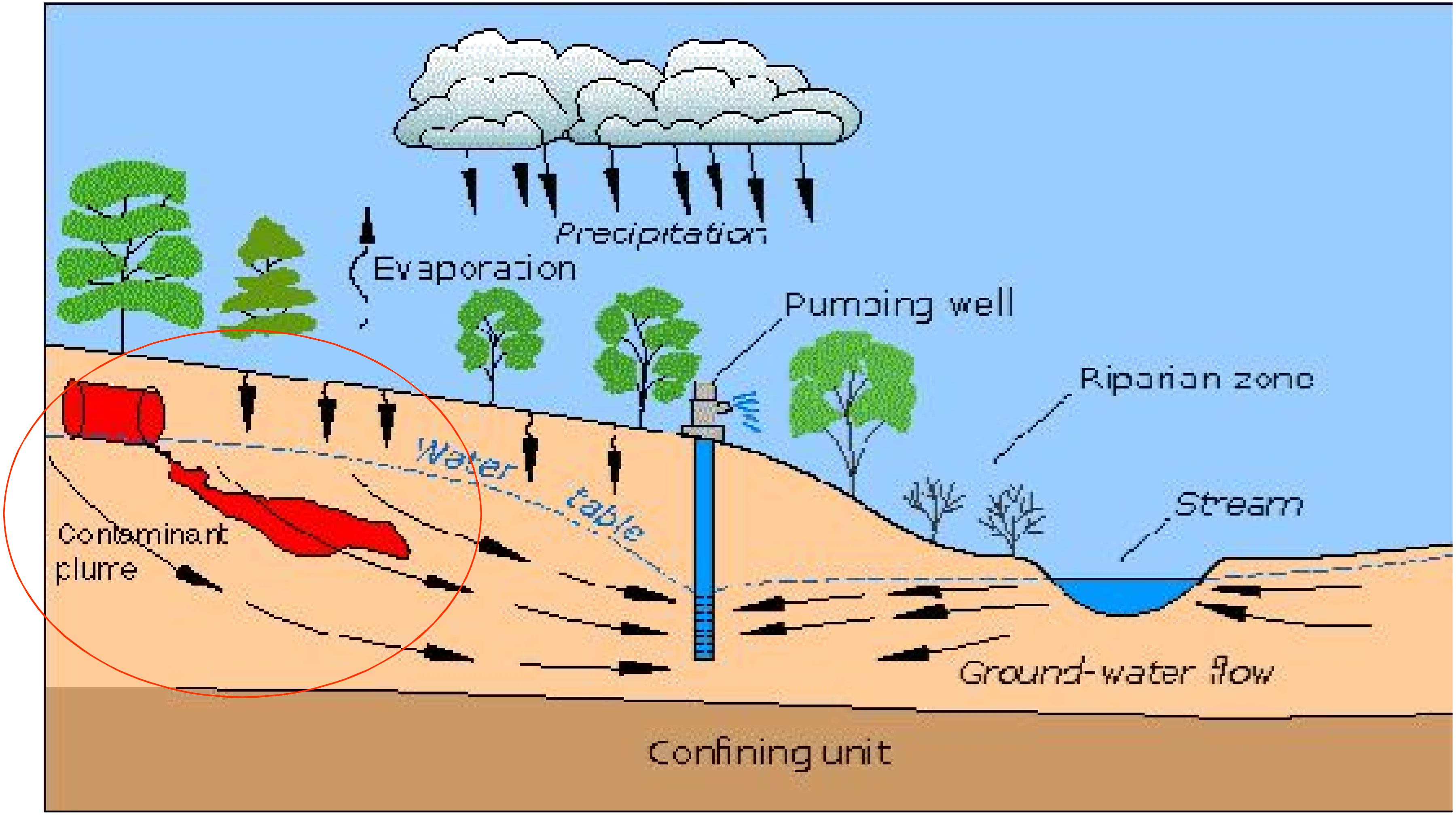
I	= infiltration in the unsaturated zone (mm/d)
P	= precipitation for the time interval Δt (mm)
E_0	= evaporation from the land surface (mm/d)
Q_{si}	= lateral inflow of surface water into the water balance area (A) (m^3/d)
Q_{so}	= lateral outflow of surface water from the water balance area (A) (m^3/d)
A	= water balance area (m^2)
ΔW_s	= change in surface water storage during the time interval Δt (mm)

Surface Water Balance Components for a Basin-Irrigated Area



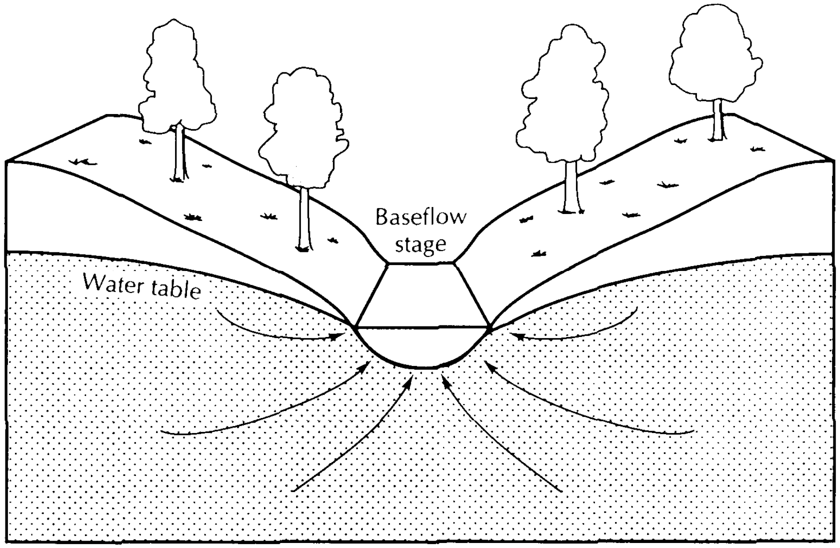
On the left, an irrigation canal delivers surface water to an irrigation basin (Q_{ib}). A portion of this water is lost through evaporation to the atmosphere (E_{ob}). Another portion infiltrates at the surface of the basin (I_b), increasing the soil-water content in the unsaturated zone. Any surface water that is not lost through either evaporation or infiltration is discharged downslope by a surface drain (Q_{ob}). Both the irrigation canals and the surface drains lose water through evaporation ($E_{oc} + E_{od}$) to the atmosphere and through seepage to the zone of aeration ($I_c + I_d$).

Groundwater Balance

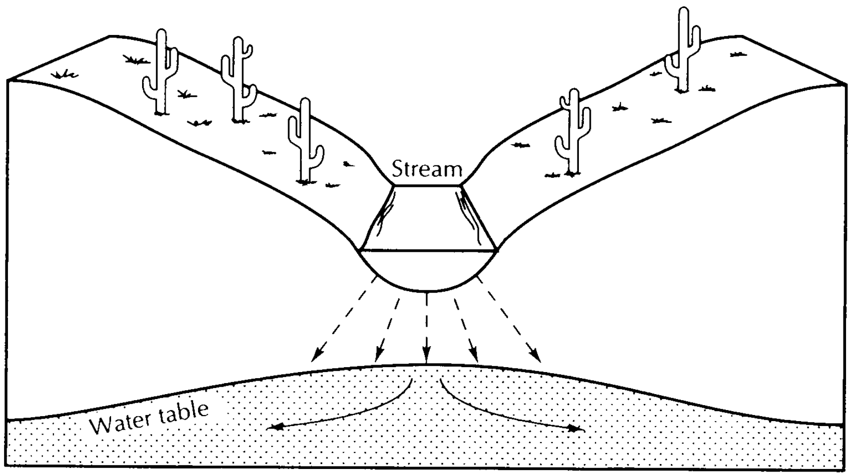


- Groundwater
  - Contamination Issues

SW/GW Relations - Humid vs Arid Zones

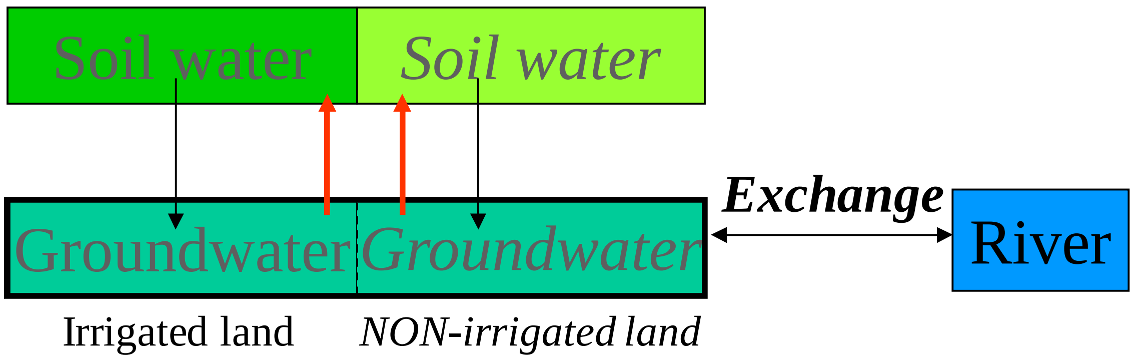


A. Cross section of a gaining stream, which is typical of humid regions,
where groundwater recharges streams

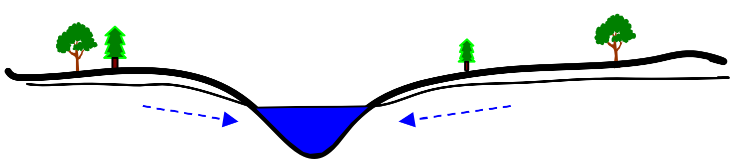


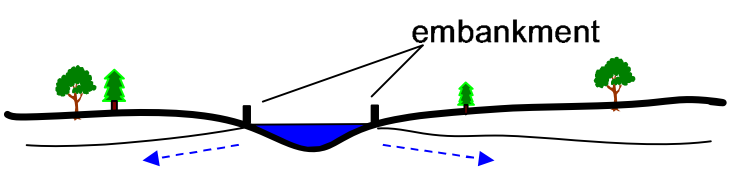
B. Cross section of a losing stream, which is typical of arid regions, where streams can recharge groundwater

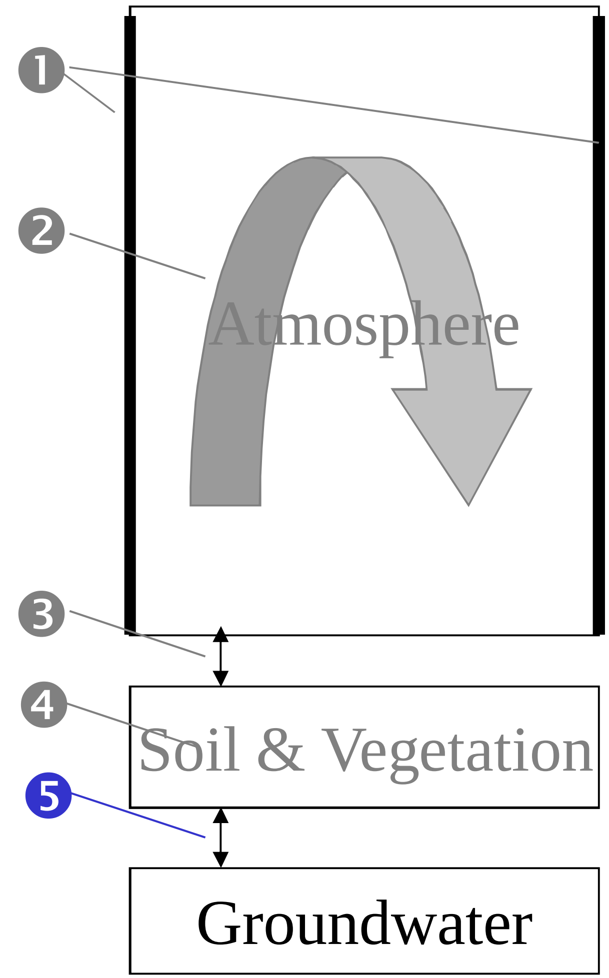
❺ Groundwater Balance



Exchange =*f(water level,water table)*







The water balance for the saturated zone, also called the groundwater balance, can generally be expressed as follows -

$$R - G + 1000\frac{Q_{gi} - Q_{go}}{A} = \mu\frac{\Delta h}{\Delta t}$$

Q_{gi} = Q_{gih} + Q_{giv} = total rate of groundwater inflow into the shallow unconfined aquifer (m^3/d)

Q_{go} = Q_{goh}+ Q_{gov} = total rate of groundwater outflow from the shallow unconfined aquifer (m^3/d)

Q_{gih} = rate of horizontal groundwater inflow into the shallow unconfined aquifer (m^3/d)

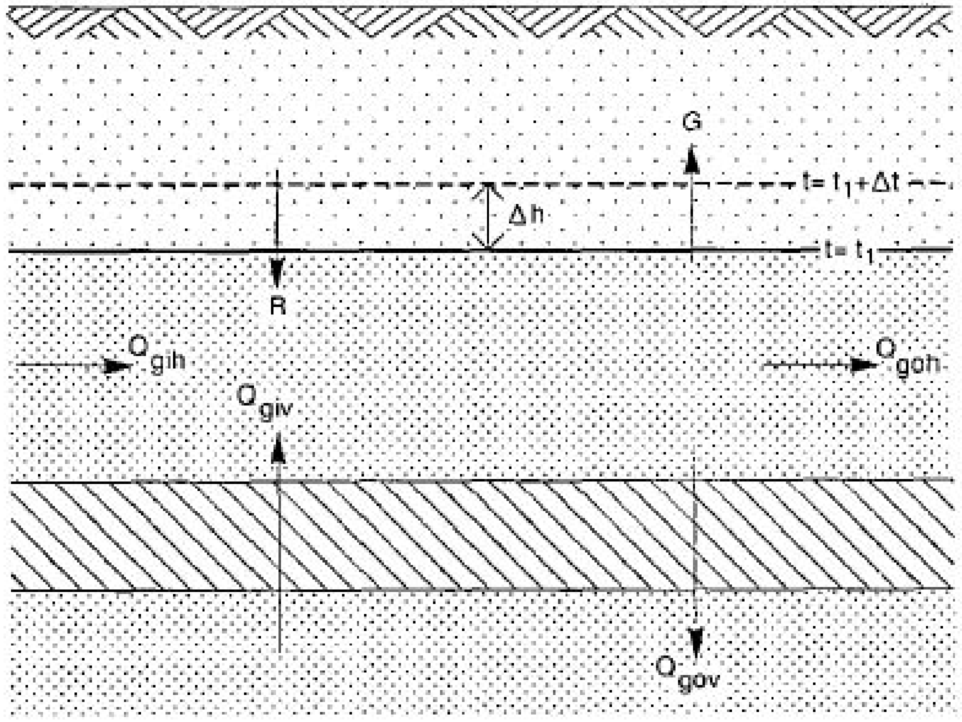
Q_{goh} = rate of horizontal groundwater outflow from the shallow unconfined aquifer (m^3/d)

Q_{giv} = rate of vertical groundwater inflow from the deep confined aquifer into the shallow unconfined aquifer (m^3/d)

Q_{gov} = rate of vertical groundwater outflow from the shallow unconfined aquifer into the deep confined aquifer (m^3/d)

μ = specific yield, as a fraction of the volume of soil (-)

Δh = rise or fall of the water table during the computation interval (mm)



To get the data necessary for direct calculations of horizontal and vertical groundwater flow, and of the actual amount of water going into or out of storage, we must install deep and shallow piezometers and conduct aquifer tests.

Detailed Groundwater Balance Equation

Considering the various inflow and outflow components in a given study area, the groundwater balance equation can be written as:

$$R_r + R_c + R_i + R_t + S_i + I_g = E_t + T_p + S_e + O_g + \Delta S$$

where,

R_r = recharge from rainfall;
R_c = recharge from canal seepage;
R_i = recharge from field irrigation;
R_t = recharge from tanks;
S_i = influent seepage from rivers;
I_g = inflow from other basins;
E_t = evapotranspiration from groundwater;
T_p = draft from groundwater;
S_e = effluent seepage to rivers;
O_g = outflow to other basins; and
ΔS = change in groundwater storage.

- Preferably, all elements of the groundwater balance equation should be computed using independent methods.

- Computations of various components usually involve errors, due to shortcomings in the estimation techniques. The groundwater balance equation therefore generally does not balance, even if all its components are computed by independent methods.

- The resultant discrepancy in groundwater balance is defined as a residual term in the balance equation, which includes errors in the quantitative determination of various components as well as values of the components which have not been accounted in the equation.

- The water balance may be computed for any time interval. The complexity of the computation of the water balance tends to increase with increase in area. This is due to a related increase in the technical difficulty of accurately computing the numerous important water balance components.

For carrying out a groundwater balance study, following data may be required over a given time period:

Rainfall data: Monthly rainfall data of sufficient number of rainguage stations lying within or around the study area, along with their locations, should be available.

Land use data and cropping patterns: Land use data are required for estimating the evapotranspiration losses from the water table through forested area. Cropping pattern data are necessary for estimating the spatial and temporal distributions of groundwater withdrawals, if required. Monthly pan evaporation rates should also be available at few locations for estimation of consumptive use requirements of different crops.

River data: Monthly river stage and discharge data along with river cross-sections are required at few locations for estimating the river-aquifer interflows.

Canal data: Monthwise water releases into the canal and its distributaries along with running days during each month are required. To account for the seepage losses through the canal system, the seepage loss test data are required in different canal reaches and distributaries.

Tank data: Monthly tank gauges and water releases should be available. In addition, depth vs. area and depth vs. capacity curves should also be available for computing the evaporation and seepage losses from tanks. Field test data are required for computing infiltration capacity to be used to evaluate the recharge from depression storage.

Water table data: Monthly water table data (or at least pre-monsoon and post-monsoon data) from sufficient number of well-distributed observation wells along with their locations are required. The available data should comprise reduced level (R.L.) of water table and depth to water table.

Groundwater draft: For estimating groundwater withdrawals, the number of each type of wells operating in the area, their corresponding running hours each month and discharge are required. If a complete inventory of wells is not available, then this can be obtained by carrying out sample surveys.

Aquifer parameters: Data regarding the storage coefficient and transmissivity are required at sufficient number of locations in the study area.

Groundwater balance study is a convenient way of establishing the rainfall recharge coefficient, as well as to cross check the accuracy of the various prevalent methods for the estimation of groundwater losses and recharge from other sources. The steps to be followed are:

1. Divide the year into monsoon and non-monsoon periods.

2. Estimate all the components of the water balance equation other than rainfall recharge for monsoon period using the available hydrological and meteorological information and employing the prevalent methods for estimation.

3. Substitute these estimates in the water balance equation and thus calculate the rainfall recharge and hence recharge coefficient (recharge/rainfall ratio). Compare this estimate with those given by various empirical relations valid for the area of study.

4. For non-monsoon season, estimate all the components of water balance equation including the rainfall recharge which is calculated using recharge coefficient value obtained through the water balance of monsoon period. The rainfall recharge (R_r) will be of very small order in this case. A close balance between the left and right sides of the equation will indicate that the net recharge from all the sources of recharge and discharge has been quantified with a good degree of accuracy.

- By quantifying all the inflow/outflow components of a groundwater system, one can determine which particular component has the most significant effect on the groundwater flow regime.

- Alternatively, a groundwater balance study may be used to compute one unknown component (e.g. the rainfall recharge) of the groundwater balance equation, when all other components are known.

Groundwater Balance Study - An Example

Sl.No.	COMPONENT	1978–79		1979–80		1980–81	
		Monsoon	Non-monsoon	Monsoon	Non-monsoon	Monsoon	Non-monsoon
1.	Draft from Ground Water(Tp)	259.87	1326.33	275.75	1356.85	284.26	1398.74
2.	Evapotranspiration Losses(E_t)						
	(a) Forested Areas	235.07	235.50	224.98	225.39	220.50	220.90
	(b) Water Logged Areas	427.61	394.99	377.75	327.31	505.26	444.35
3.	Net Effluent Seepage ($S_e - S_i$)	595.41	864.93	504.76	564.96	434.90	624.23
4.	Net Inflow from other Areas (Ig–Og)	27.20	45.65	32.42	44.05	31.77	45.91
5.	Seepage Losses (R_c)						
	(a) Main and Branch Canals	236.22	1156.41	872.47	1130.76	817.03	1183.70
	(b) Distributories and Minors	72.10	217.81	184.55	154.51	153.06	190.51
	(c) Field channels	111.87	367.35	290.88	237.14	234.34	307.90
6.	Recharge from Field Irrigation (R_r)	106.27	348.98	276.33	225.28	222.62	292.51
7.	Change in Ground Water Storage (ΔS)	1678.75	-740.69	547.75	-783.46	1258.36	-735.60
8.	$O = T_p + E_t + (S_e - S_i)$	1517.96	2821.75	1383.24	2474.51	1444.92	2688.22
9.	$I1 = (I_g - O_g) + R_c + R_r$	553.66	2136.20	1656.65	1791.74	1458.82	2020.53
10.	Recharge from Rainfall, $R_i = \Delta S + O - I1$ (monsoon)	2643.05	0	274.34	0	1244.46	0
11.	Rainfall (P)	14187.64	1414.76	4612.04	604.18	8382.24	1418.51
12.	Recharge Coefficient (Monsoon) = (R_i /P)	0.1863	-	0.0595	-	0.1485	-
13.	Unaccounted Water (Non-monsoon) = $(I1 + R_i) - O - \Delta S$	-	+55.14	-	+100.69	-	+67.91

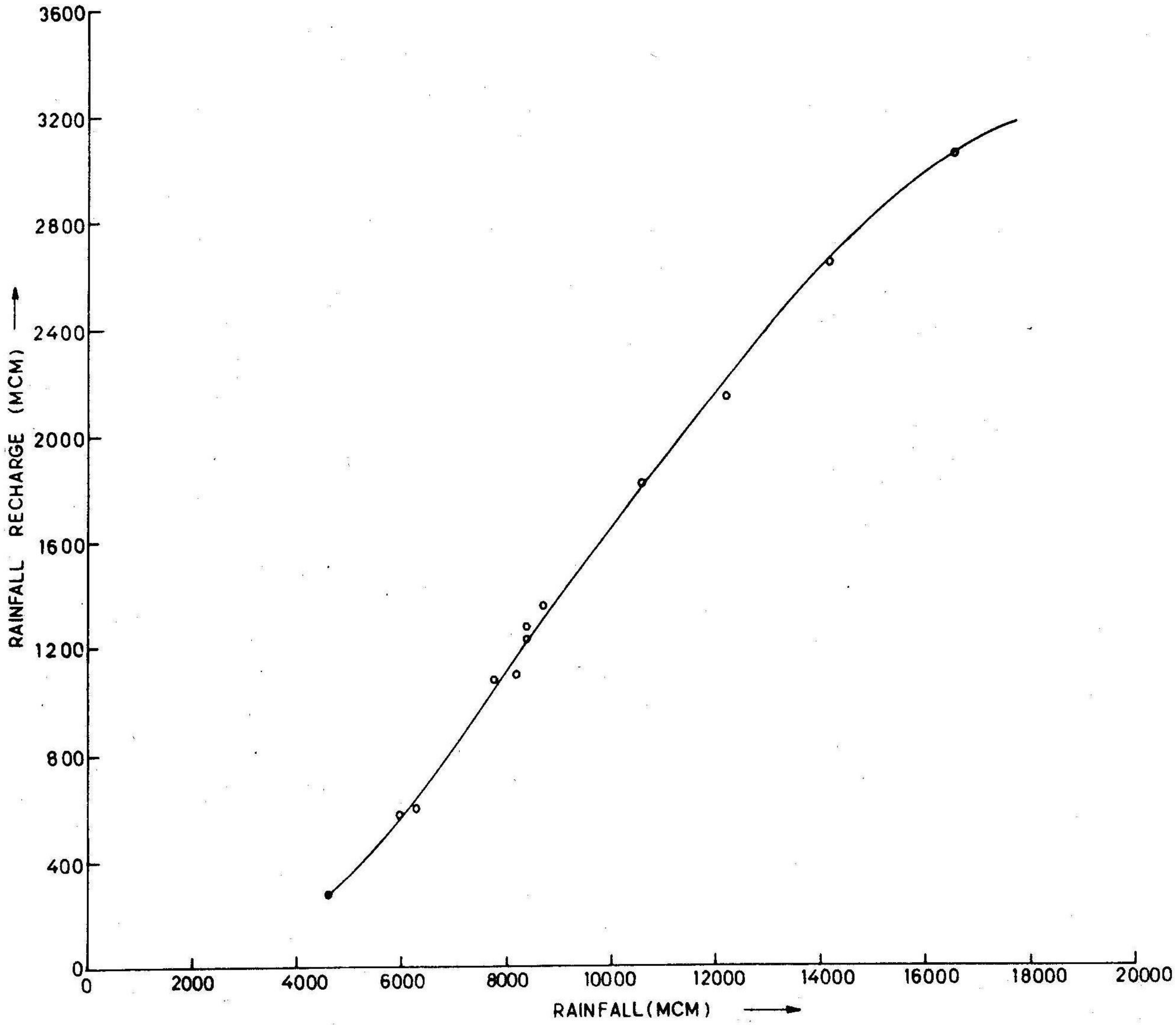


FIGURE 4-VARIATION OF RAINFALL RECHARGE WITH RAINFALL

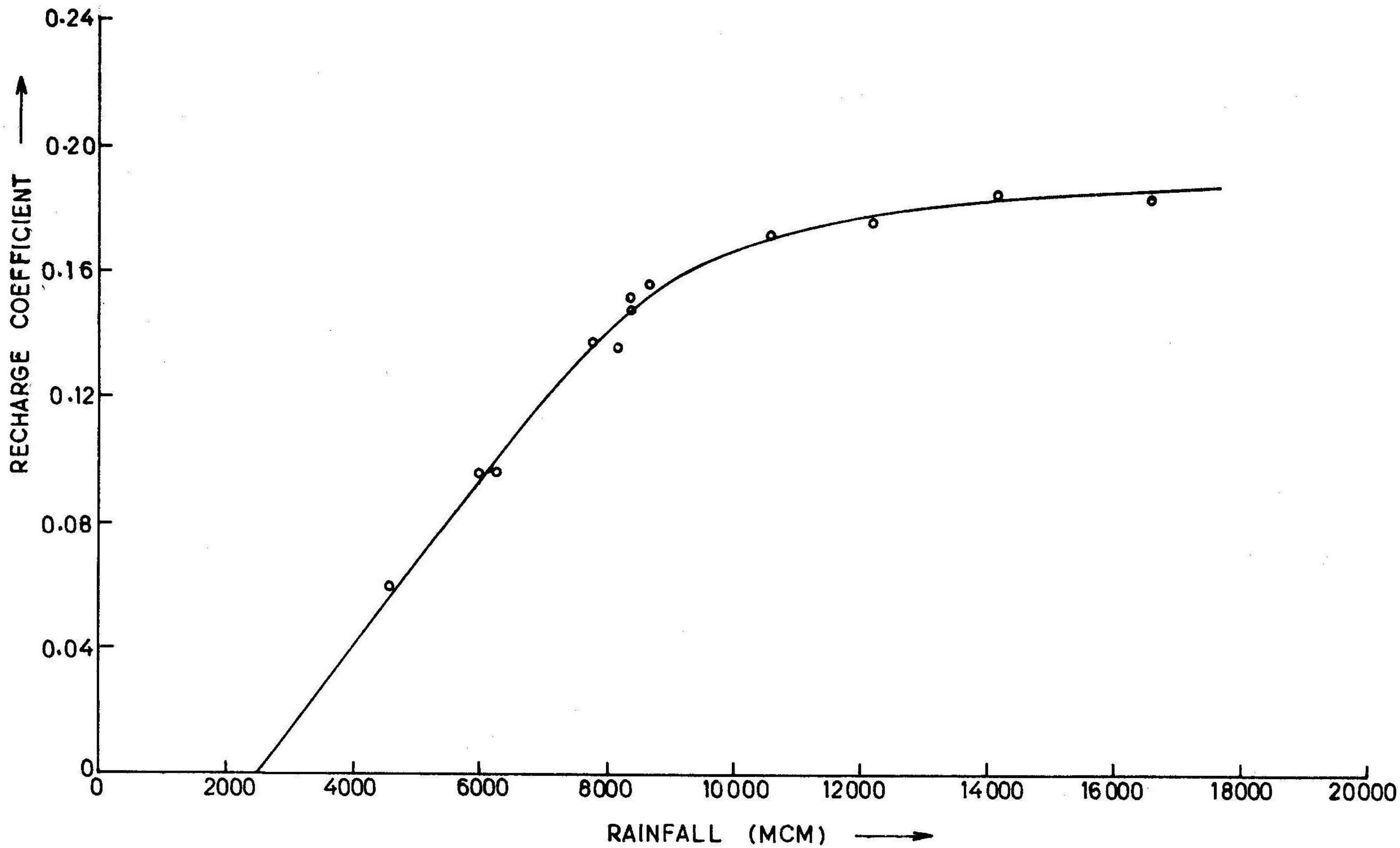


FIGURE 5-VARIATION OF RECHARGE COEFFICIENT WITH RAINFALL

Integrated Water Balances

By combining water balance equations for land surface and unsaturated zone, we get water balance of the topsoil -

$$P - E_0 - E + G - R + 1000\frac{Q_{si} - Q_{so}}{A} = \frac{\Delta W_s + \Delta W_u}{\Delta t}$$

To assess the net percolation $R^* = R - G$, we can use above equation. We can also assess this value from the groundwater balance equation. And, if sufficient data are available, we can use both of these methods and then compare the net percolation values obtained. If the values do not agree, the degree of discrepancy can indicate how unreliable the obtained data are and whether or not there is a need for further observation and verification.

Another possibility is to integrate the water balance of the unsaturated zone with that of the saturated zone. Combining the two equations, we get the water balance of the aquifer system -

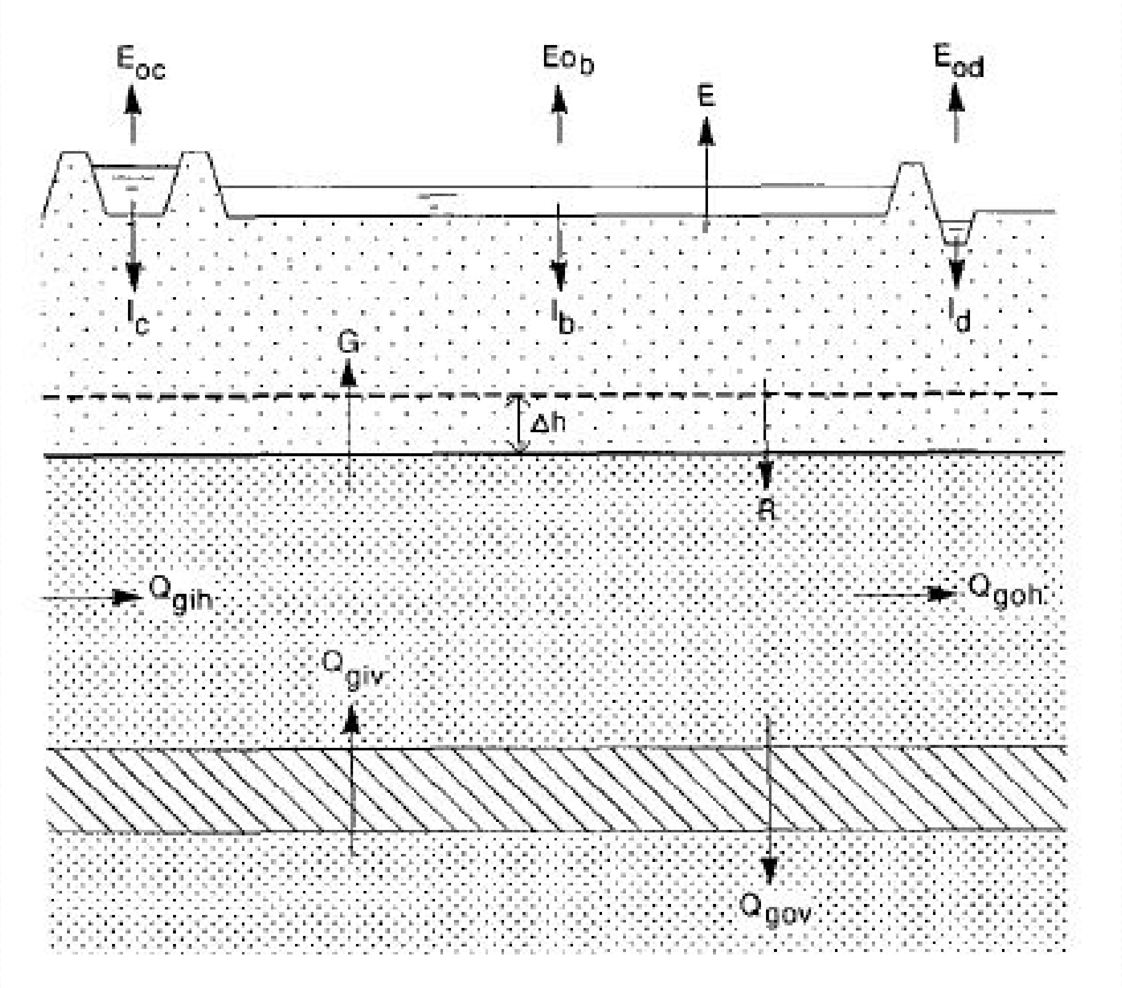
$$I - E + 1000\frac{Q_{gi} - Q_{go}}{A} = \frac{\Delta W_u}{\Delta t} + \mu\frac{\Delta h}{\Delta t}$$

We can assess the infiltration from above equation, provided we can calculate the total groundwater inflow and outflow, the change in storage, and the actual evapotranspiration rate of the crops. We can also assess the infiltration from the surface water balance equation, if sufficient data are available. If the values do not agree, the degree of discrepancy can indicate how unreliable the obtained data are and whether or not there is a need for further observation and verification.

Integrating all three of the water balances (land surface, unsaturated zone, groundwater), the overall water balance reads -

$$P - E_0 - E + 1000\frac{Q_{si} - Q_{so}}{A} + 1000\frac{Q_{gi} - Q_{go}}{A} = \frac{\Delta W_u}{\Delta t} + \frac{\Delta W_s}{\Delta t} + \mu\frac{\Delta h}{\Delta t}$$

Equation shows that the vertical flows I, R, and G (all important linking factors between the partial water balances) disappear in the overall water balance.



When water balances are assessed for a hydrologic year, changes in storage in the various partial water balances can often be ignored or reduced to zero if the partial balances are based on long-term average conditions.

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dcshyfhy@iitr.ernet.in
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Dear all, Can you share the brochure giing deatils of India Water week,2012? Thanks, Dr D.C.Singhal Prof. (Hydrology) Deptt. of Hydrology Indian Instt. of

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Information about indus river

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Hello, I am looking to develop a proposal on fluvial geomorphology of Indus river especially about the headwaters. If you have any background information to

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Comment on Draft National Water Policy (2012)

Himanshu Thakkar
cwaterp@vsnl.com
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See for our response at: http://sandrp.in/wtrsect/NWP_2012_SANDRP_PR.pdf Himanshu Thakkar South Asia Network on Dams, Rivers & People, c/o 86-D, AD block,

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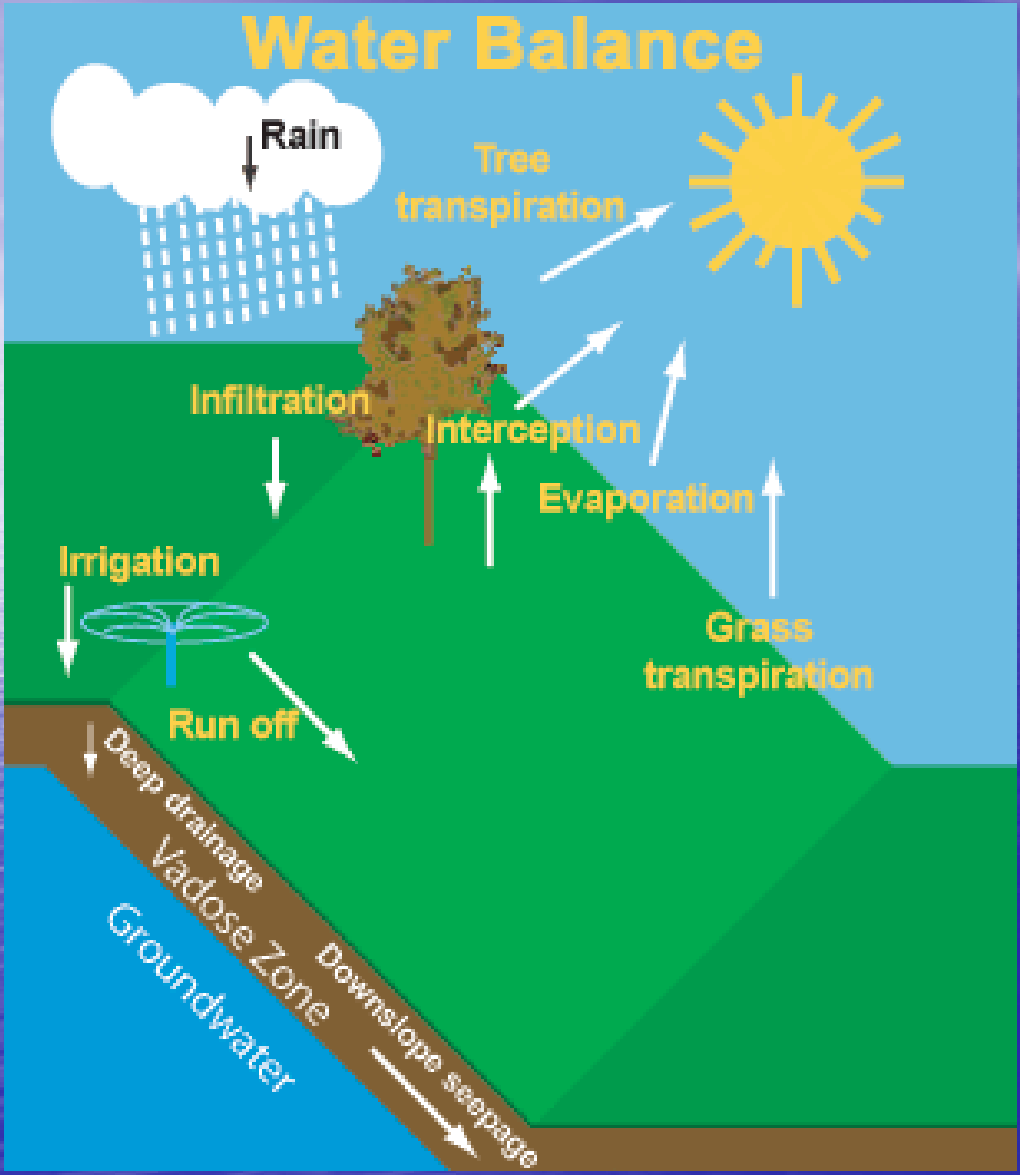

Thank you for your kind attention!