Bharathidasan University

Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. **M.Tech. Geological Technology and Geoinformatics**

***Course code :* MTIGT0604**

GEOINFORMATICS IN WATER RESOURCES MANAGEMENT

Unit-1 : Surface Water Resources

Dr. K. Palanivel
Professor, Department of Remote Sensing

Course Objectives

- ❖ To know the potential sources, origin, occurrences of water resources
- ❖ To understand the concepts of water resources prospecting, water quality mapping and conservation
- ❖ To learn the capabilities of Geoinformatics and its applications for water resources targeting, quantification, budgeting and management
- ❖ To learn the Geological Technology and Geoinformatics in understanding the functions of aquifers and groundwater movement
- ❖ To learn the basics and applications of hydrogeological models.

MTIGT0604: GEOINFORMATICS IN WATER RESOURCES MANAGEMENT

--- 4 Credits

1. Surface Water Resources: Hydrological Cycle - Global Distribution of Surface water Bodies – Drainage Morphometry – Sources of Surface water – Snow, Rainfall and groundwater table. Modelling assumptions - choice of equation - phenomena and model geometry - choice of variables and parameters - data and knowledge acquisition - model building – calibration and verification, results presentation. **12Hrs.**

2. Geoinformatics in Surface Water Resources: Satellite data based Surface water budgeting and Quantification – Automated drainage Mapping Using DEM – Spectral Response Pattern of Water – Water quality mapping and monitoring using Remote Sensing – Infra Red data based Water Quantity Forecasting – Water quality Mapping and Monitoring using satellite data. **12 Hrs.**

3. Groundwater Resources: Groundwater Origin & Occurrence: Sources of Groundwater – Classification of Groundwater. Aquifer Types**:** Crystalline Aquifer, Sedimentary aquifer, Unconsolidated Sedimentary Aquifer, Geomorphic aquifer. Darcy's Law in homogeneous and heterogeneous media, Groundwater quality, Application of H and O isotopes in groundwater studies; Targeting: General Investigations - Geological mapping- Geological Cross sections - Well inventory – Geophysical Methods – Drilling and Exploration - Pump tests **-** Groundwater Assessment and Budgeting - Issues and conservation Strategies**.** **16 Hrs.**

4. Geoinformatics in Groundwater Resources: Geoinformatics and evaluation of lithologically controlled, Structurally controlled and Geomorphologically controlled aquifers – Concept of Hydro geomorphic mapping. Natural and Artificial recharge site selection - detection of site specific mechanisms – Quantification of allowable recharge. **12 Hrs.**

5. Hydrological Models: Surface Water Hydrological Models: Snow melt Runoff modeling – GIS based Runoff modeling – Various hydrological models using Geoinformatics. Models for Inter watershed water transfer. Groundwater models: Stochastic – MOD Flow- Linear – Finite Element Modeling. **12 Hrs.**

6. Current Contours: (Not for Final Exam, only for Discussion): Hydrogeological Information System; Hydrological models in GIS, Use of Digital Image Processing methods for surface water prospecting; Use of high resolution DEM for surface water quantification; Use of tracers to understand the aquifer characters, recharge behaviors and contaminant transport through groundwater.

Text Books:

1. David Keith Todd, Groundwater Hydrology, Wiley Student Edition.
2. Raghunath H.M., Ground Water, New Age International (P) Limited Publishers, 1987.
3. Ramakrishnan. S. Groundwater, 1998.

References:

1. Chang, H.H. Fluvial processes in river engineering, John Wiley and Sons, New York. 1988.
2. Bedient, P.B, Hydrology and flood Plain analysis, Addision westery publishing company. 1988.
3. Driscoll, F.S. Groundwater & Wells, 2nd Edition, Scientific Publishers, Joclpur, 1986.
4. Karanth K.R., Groundwater Assessment Development and Management, Tata McGraw Hill Publishing Company Limited, New Delhi, 1987.
5. Clorer. R.C., Groundwater Management.
6. Scalf M.R., Manual of SW Quality Sampling procedure
7. Mutreja, K.N Applied Hydrology, Tata McGraw Hill Publishing Company Limited, New Delhi, 1986.
8. Thomann R.V, Principles of Surface Water Quality Modeling and Control, HIE, Harper & Row, Publishers, New York, 1987.
9. Mohammed Ali, George E Radosevich, Water Resource Policy for Asia, A. A. Balkema/Rotterdam/Boston, 1987.

10. Mc Donald AT, Water Resources: Issues and Strategies, Longman Scientific & Technical, 1988.
11. Pillai, K.M., Water Management and Planning, Himalaya Publishing House, 1987.
12. Gower. A.M., Water Quality in Catchment Ecosystem, John Willey & Sons, 1980.
13. Ramesam. V. Trends in Groundwater Research, The Geological Society of India, Bangalore, 1987.
14. Trivedi, R.N., Shatrunjay Kumar Sing, Water Resources and Quality Management, Commonwealth Publishers, New Delhi, 1990.
15. Fetter C.W. Applied Hydrology, CBS Publishers & Distributors, 1988.
16. Gautam Mahajan. Groundwater Surveys and investigations, Ashish Publishing House, New Delhi, 1995.
17. Chow V.T., maidment, D.R., and Mays, L.W. applied Hydrology, McGraw Hill, New York, pp.530 to 537. 1988.
18. Deman, MCJ. Smith G.S and H.T.Verstappen (eds), Remote Sensing for resources development and environmental management, A.A. Ballkema Publishers, Totterdam, Netherlands. 1986.

Course outcomes

After the successful completion of this course, the students are able to:

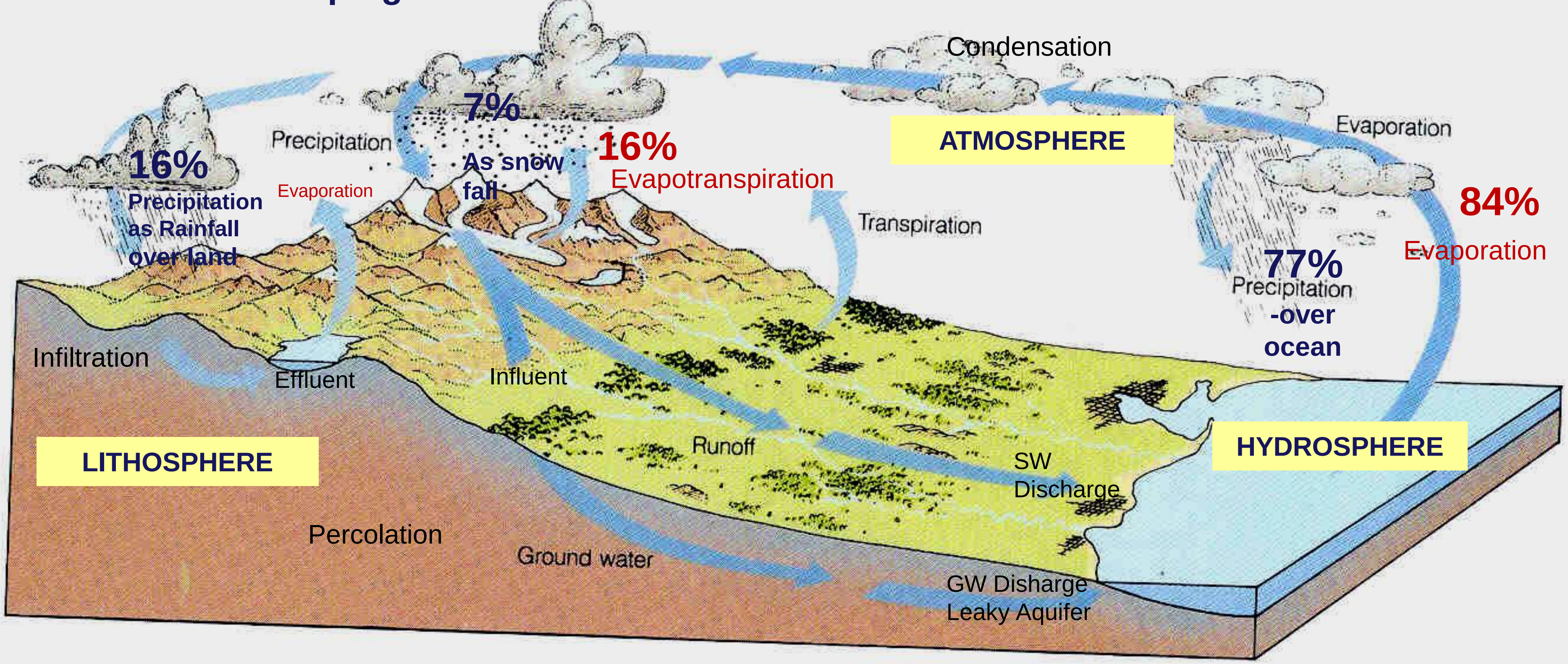
- ✓ Understand the availability, sources and importance of the water resources prospect for both surface and groundwater resources using Geoinformatics technology
- ✓ Determine the types of aquifers, their characteristics and their recuperation ability
- ✓ Delineate suitable sites and mechanisms for natural and artificial recharge
- ✓ Understand the application of Geoinformatics technology for surface and groundwater resources exploration, targeting, quantification, budgeting, conservation and management
- ✓ Learn the application of Geological technology and Geoinformatics tools in developing various hydrological models.

UNIT-1 **Surface Water Resources:**

- Hydrological Cycle – Global distribution of surface water bodies – Drainage morphometry – Sources of surface water – Snow, rainfall, groundwater table. Modelling assumptions – choice of equation – phenomena and model geometry – choice of variables and parameters – data and knowledge acquisition – model building – calibration and verification, results presentation.

The circulation of water in the 3 spheres of the hydrologic system

Keeping the Mean Annual Global Rainfall of 85.7 cm as 100%



What governs the movement of water in a cyclic manner?
How does work the Hydrological Cycle?

The energy from both **Solar & Earth energy systems,** such as

- **Solar Heat, Earth's internal heat & Gravity and the ongoing**
- **Lithological, Structural & Geomorphological processes (ESP)** of the Earth.

How many such possible hydrological cycles of local and regional kind? (4+2…)

Hydrological cycle, Water cycle, or **H_2O cycle**

- It is a continuous movement or gigantic circulation of water between 3 spheres of the Earth such as Hydrosphere, Atmosphere and Lithosphere, in 3 different states/forms, i.e., liquid, vapour & solid, and through the physical processes of Emanation, Condensation, Precipitation, Runoff, Evaporation, Transpiration (in total it is Evapotranspiration), Infiltration, Percolation Subsurface Groundwater flow and surface water and groundwater Discharges.

What makes the Mother Earth to possess water in it in all three forms which is not possible in other planets or meteorites?

Cold Trap …..a layer of atmosphere at a height of above 20km from the Earth's surface with very low temperature upto -70ºC.

The natural Earth System Processes (ESP) responsible to condense the water vapour into droplets and traps the condensed droplets without escaping from the Earth's atmosphere are:

- **Gravitational attraction &**
- **Lapse rate.**

Ocean is the major source of water

Solar energy converts water in to vapour and forms clouds in the atmosphere

Condensation leads to precipitation on land surface

Part forms surface run off flow and part gets recharged into the sub surface

Finally drains into the ocean.

Water on the land can be classified into two categories:

- **SURFACE WATER:**
  River, Stream, Lakes, Ponds, Ice etc., and

- **SUBSURFACE WATER:**
  Beneath the ground; i.e., Groundwater.

Earth: The Water Planet

- **74% of the Earth's surface is water** – The overall distribution of this water on the Earth surface is as follows:

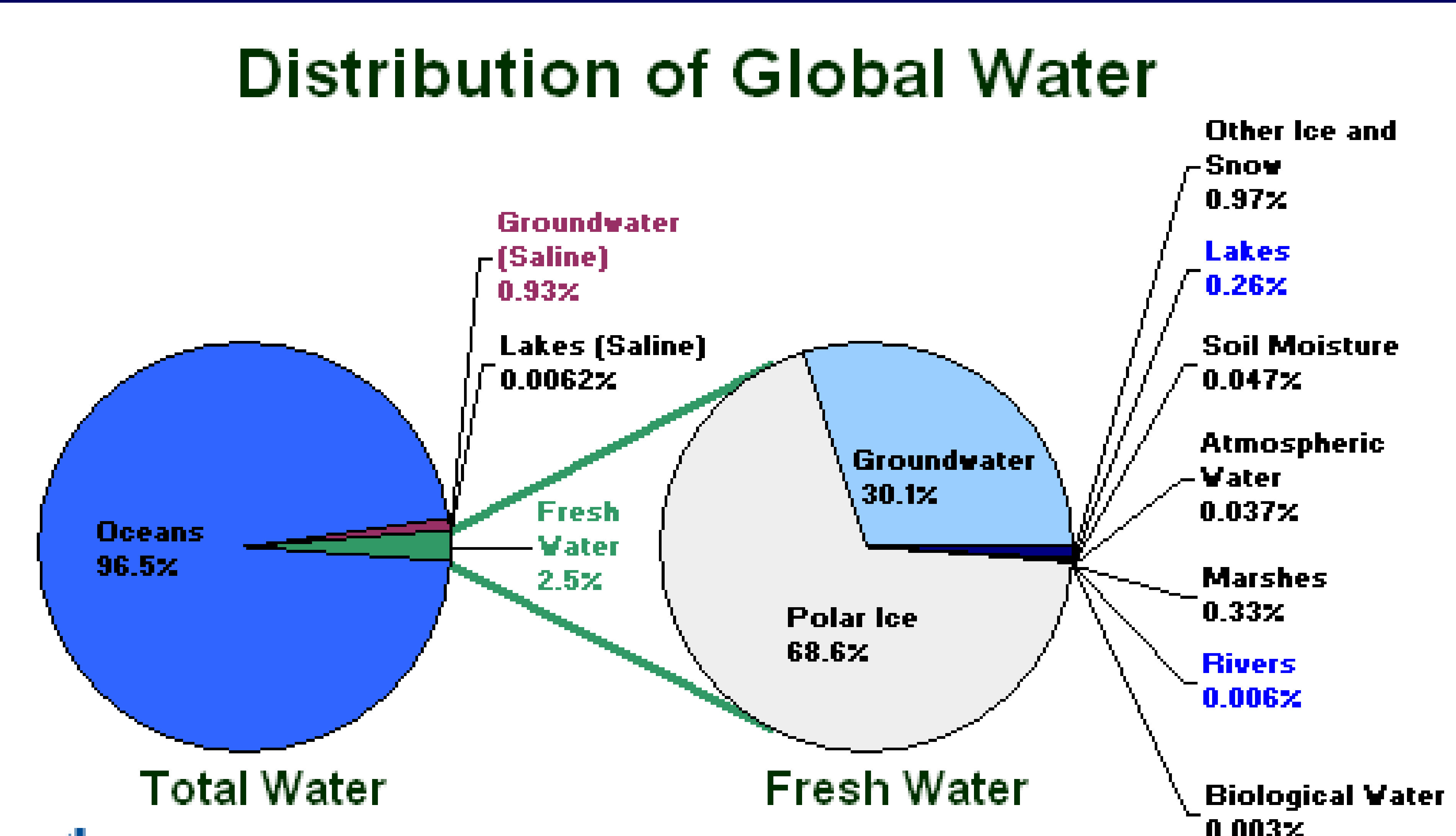
- 97% of the Earth's volume of water is in the saline oceans
- 2.2% is in the permanent icecap
- Only 0.02% is in freshwater streams, rivers, lakes, reservoirs
- Remaining water is in:
  - underground aquifers (0.6%) and in
  - atmosphere, in the form of water vapor (0.001%)

SOURCES OF WATER

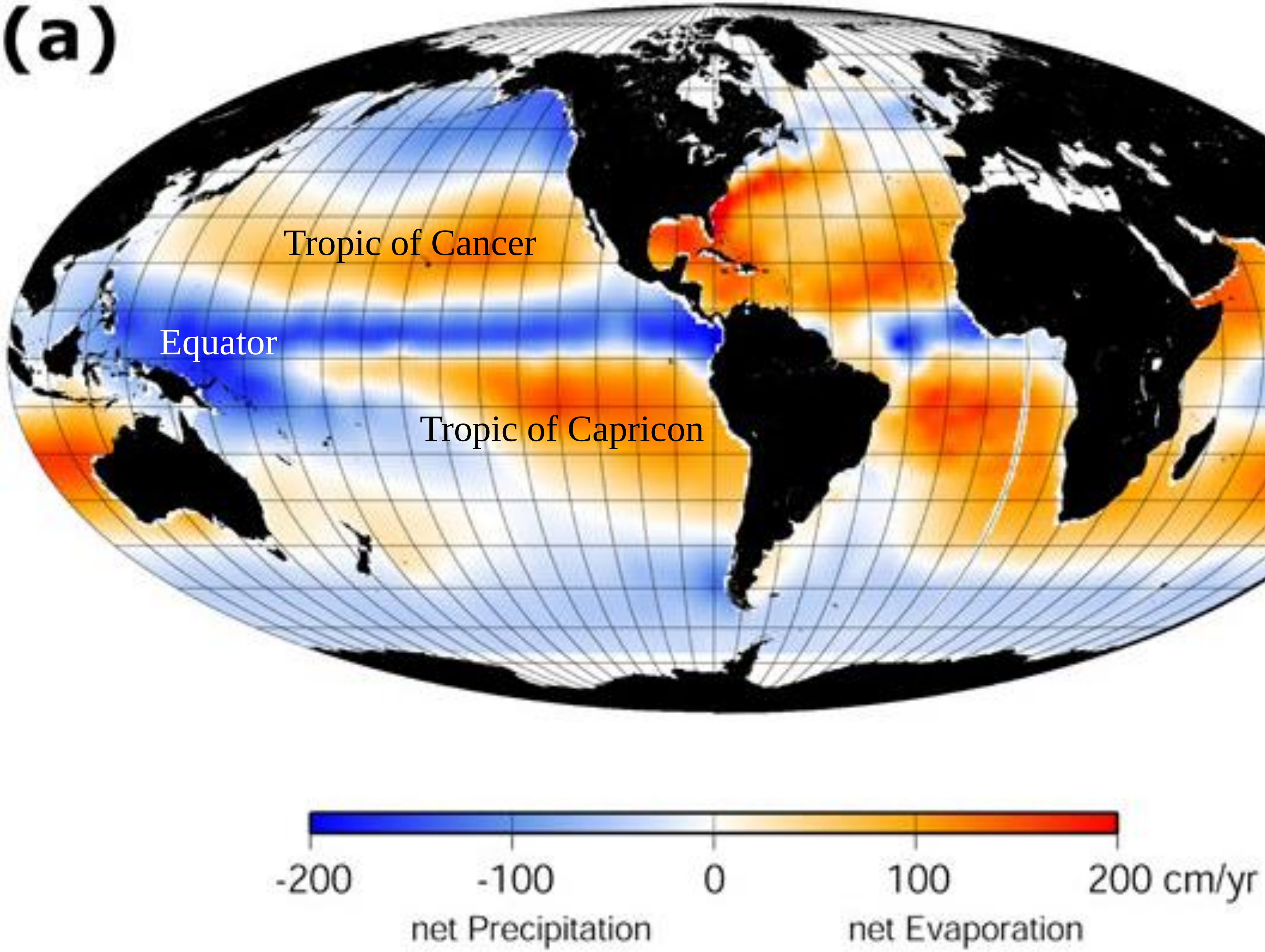
Meteoric Water: Meteoric water derived from precipitation (rainfall)

Juvenile (Magmatic water) water: Juvenile water formed in the cracks (or) pores of rocks due to condensation of stream emanating from magmas.
Eg. Hot springs or Geysers

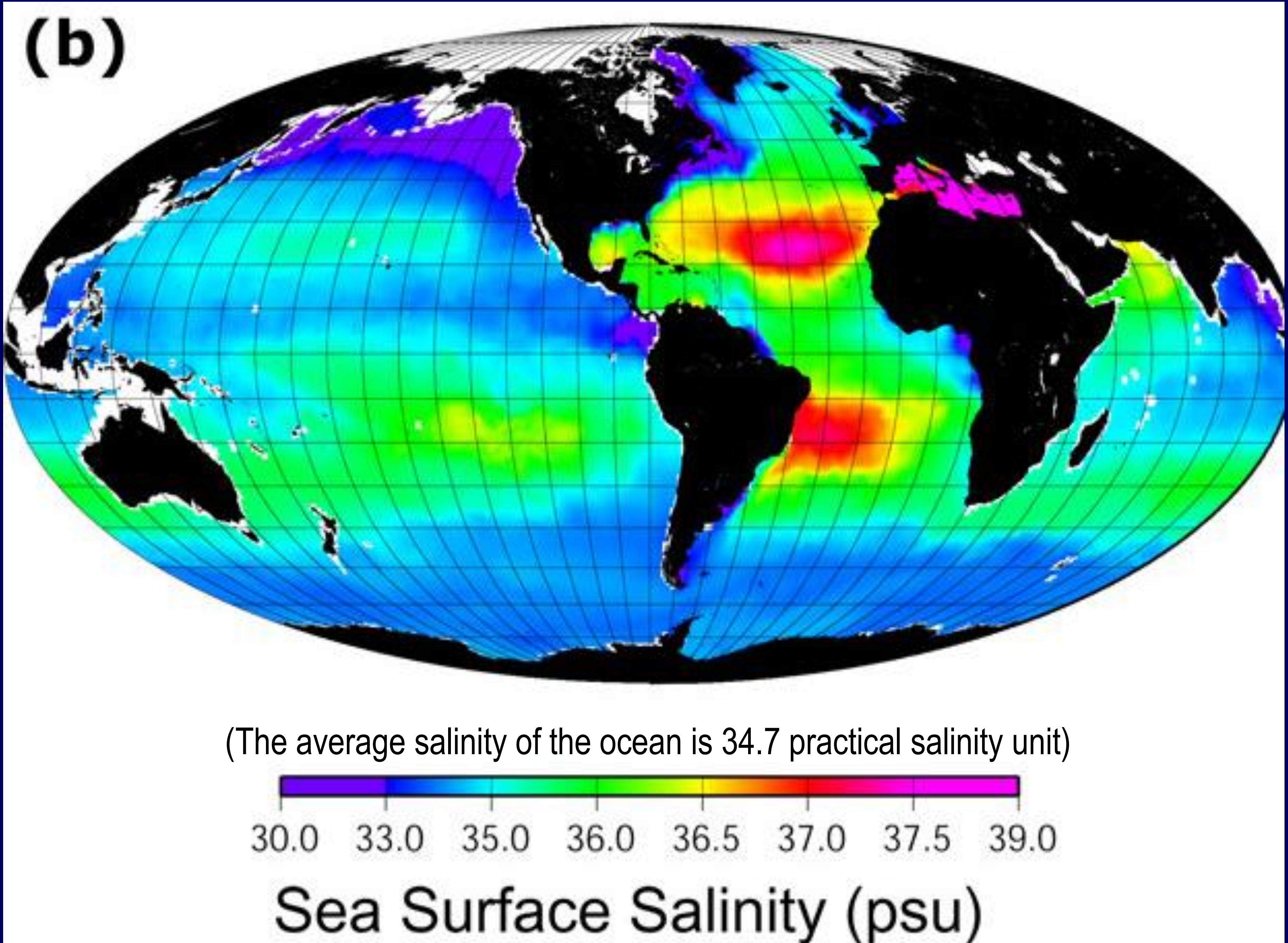
Connate water: The water is entrapped in the rocks during their formations due to sedimentation in an aqueous environment, also known as fossil water.



Distribution of Global Water
Groundwater (Saline) 0.93%
Lakes (Saline) 0.0062%
Oceans 96.5%
Fresh Water 2.5%
Total Water
Groundwater 30.1%
Polar Ice 68.6%
Fresh Water
Other Ice and Snow 0.97%
Lakes 0.26%
Soil Moisture 0.047%
Atmospheric Water 0.037%
Marshes 0.33%
Rivers 0.006%
Biological Water 0.003%



Evaporation minus Precipitation (E-P)

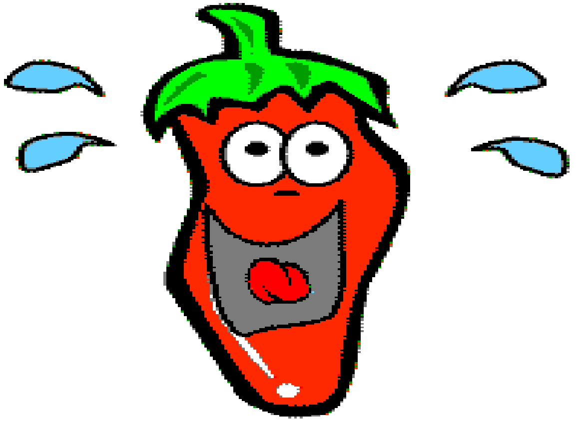

(b)
(The average salinity of the ocean is 34.7 practical salinity unit)
30.0
33.0
35.0
36.0
36.5
37.0
37.5
39.0
Sea Surface Salinity (psu)

EVAPORATION

Evaporation is when the sun heats up water in rivers or lakes or the ocean and turns it into vapour or steam which rises in to the air.

TRANSPIRATION

Do plants sweat? Kind of. Transpiration is the process by which plants lose water from their leaves. The water rises in to the air.



CONDENSATION

Water vapour in the air gets cold and changes back into liquid, forming clouds. This is called condensation.

PRECIPITATION

Precipitation occurs when so much water has condensed that the air cannot hold it anymore. Water falls to the earth in the form of rain, hail, sleet or snow.

The major energy sources of Hydrological Cycle are:

- The influence of
  - Solar heat – **evaporation, transpiration**
  - Temperature and pressure difference in atmosphere – displacement, accumulation, condensation, **precipitation**
  - Gravity – rainfall, flowing of water – as running water/surface water flow/**runoff** and **groundwater movement/flow**
- Thus, it is an intricate combination of evaporation, transpiration, precipitation, runoff and groundwater flow.

- This Circulation Continues for ever and there by a **BALANCE** is maintained between the **precipitation** and **evaporation** process.
- But ocean receives all salts into it continuously, resulting into more concentrations of salts.
- In one stage, at the Destructional Margin, the dried up oceanic plate contains salt + marine resources will get recycled – taken into very deep – melted with magma by tectonic activities and regenerated as fresh plates in constructional margins.
- **Most part** of the precipitation falls directly on the **seas** and **a portion** falls on the **land surfaces;**
- In different forms such as snow, fog, rainfall, etc.

The falling water is **temporarily retained** in the form of **glaciers**, some amount by **soil, surface depressions, [** (puddle, mere, pool, pond, tank, lake, lagoon, reservoir, basin, tarn, sea, ocean, (marine, naval), **running waters,** e.g.

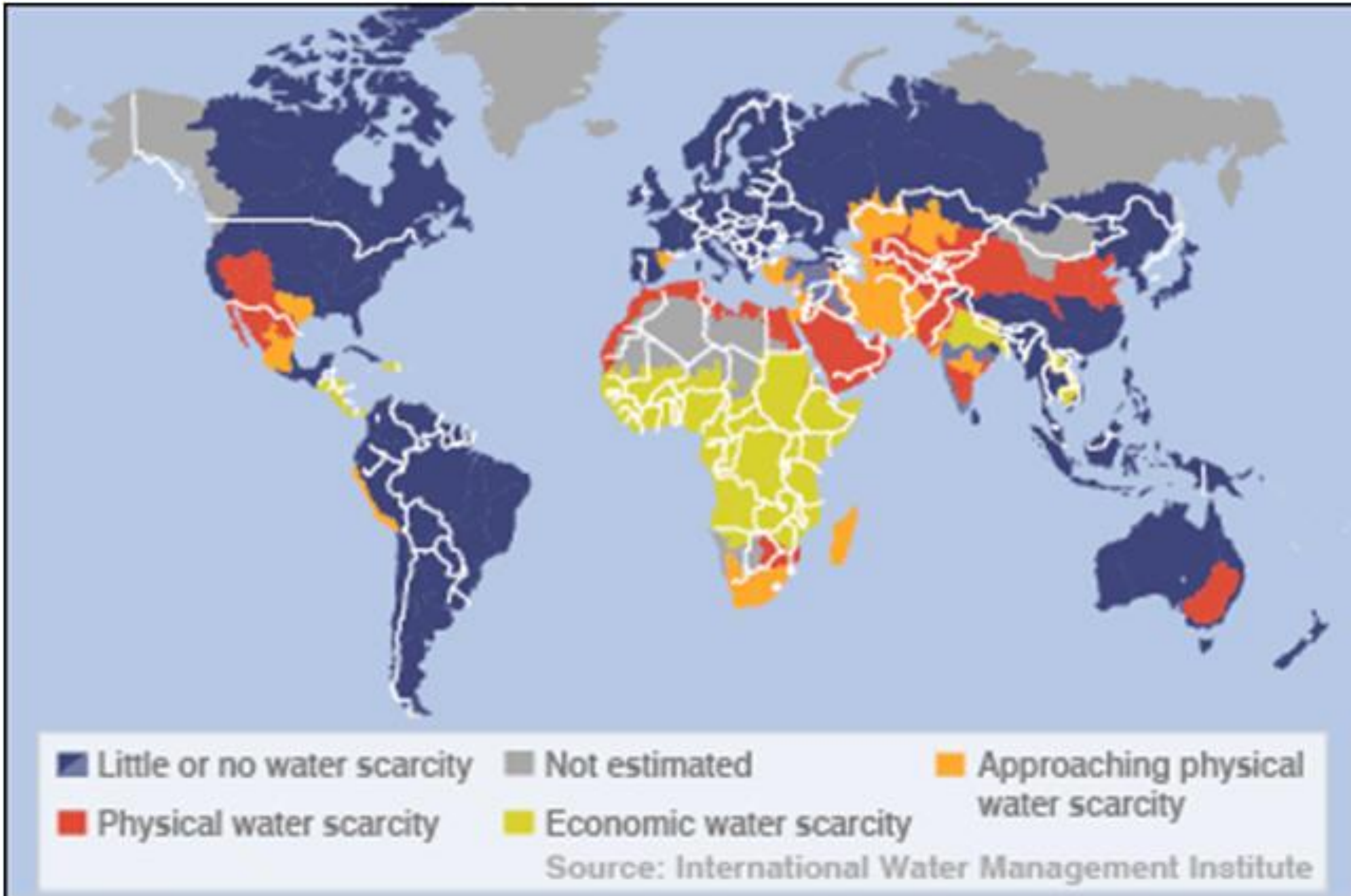
- Stream
- Spring
- River,
- Rivulets,
- Brook,
- Creek,
- Gully,
- Torrent,
- Watercourse,
- Tributary,
- Branch
- Distributary,
- Flow,
- Channel
- Drain,
- Drainage
- Waterway,
- Canal,
- Ditch
- Flood …**],**

vegetation, other living beings and objects until it is returned to the atmosphere by evaporation and transpiration.

- The **remainder** is moving in underground channels as groundwater
- Finally these surface and ground water are reaching sea - subject to evaporation and transpiration throughout their travel.
- The volume of moisture involved in this earth phase cycle is relatively constant
- Mean annual global precipitation is 85.7 cm, we keep it as 100 units.
- Then, from oceans 84 units of water gets evaporated and lifted to the atmosphere – evaporation.
- At the same time, 16 units of water over the continents are lifted to the atmosphere – evapo-transpiration.
- From the above said 84 units, 77 units of water vapour is condensed and falling as rainfall over the oceans itself
- Remaining 7 units of water vapour is advancing towards landside.
- So, totally 7+16 = 23 units of water vapour is condensed and falling over the continental regions.
- This way the water balance is maintained throughout the year continuous without any interruption.
- This cycle has slowed-down, when
  - Plants and animals use water for cell building
  - Ice caps and snow fields detain it in solid form
  - Chemical action incorporates it in other compounds
  - groundwater is trapped
  - Cloud seeding / artificial nucleation is done (using silver iodide crystals, dry ice, portland cement)

3	a) SATURATION	1) Movement of water in to the soil from the surface
10	b) EVAPORATION	2) Water stored in rocks
8	c) TRANSPIRATION	3) When the soil is full of moisture/water
6	d) HYDROLOGY	4) Most water returns to the sea by running overland.
9	e) PERCOLATION	5) Water vapour changes back to water and forms as water droplets which are visible as clouds.
2	f) GROUNDWATER	6) The study of water
1	g) INFILTRATION	7) Moisture falls to the earth (as rain, snow, hail)
7	h) PRECIPITATION	8) The transfer of water from plants to the air as gas.
4	i) SURFACE RUN OFF	9) Movement of water into underlying rocks.
5	j) CONDENSATION	10) Transfer of water from the sea to the air

Global water scarcity



-atmosphere holds only very small percentage of Earth's water supply at any given time

World Water Supply

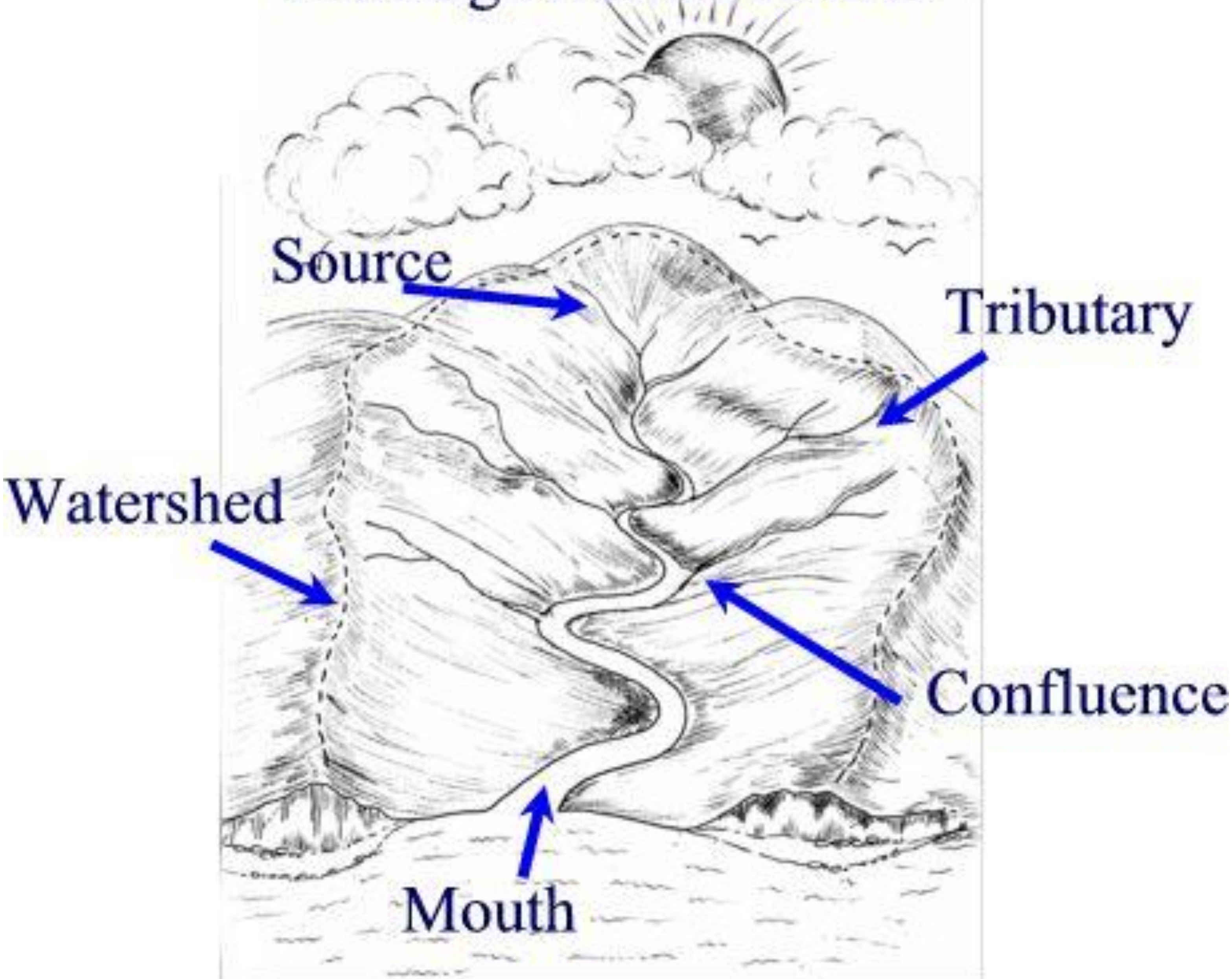
Source	% of Supply
Oceans	97.08
Ice Sheets and Glaciers	1.99
Ground Water	0.62
Atmosphere	0.29
Lakes (Fresh)	0.01
Inland Seas / Salt Water Lakes	0.005
Soil Moisture	0.004
Rivers	0.001

-rapid recycling of water must occur between earth's surface and atmosphere

Drainage

- Fundamentally the earth's surface is organized into watersheds.
- Watershed managers and planners are interested in different types of environmental conditions within distinct segments of watersheds (e.g., hill slopes, terraces, floodplains, etc...), while hydrologists and geomorpho-logists are interested in the spatial variability in processes throughout a watershed.
- The **fundamental unit** of virtually all watershed and fluvial investigations is the **drainage basin**
- A **drainage basin** or **catchment** or **watershed** is a finite area whose runoff is channelled through a single outlet.
- In its simplest form, a **drainage basin** is an area that funnels all runoff to the mouth of a stream.

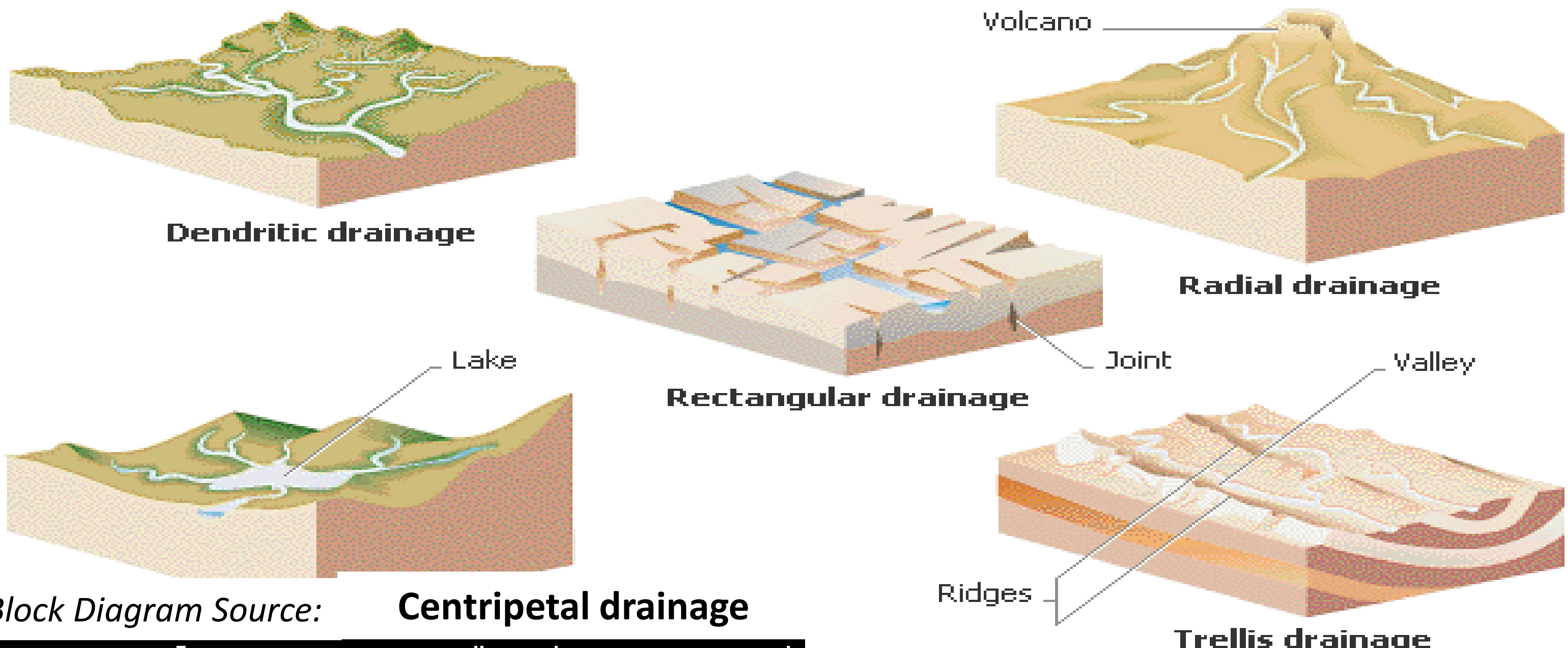
Drainage Basin Features



- So simply, a drainage basin is defined as an area defined by a topographic boundary that diverts all runoff to a single outlet.
- Drainage basins may be delineated on a topographic map by tracing their perimeters or **drainage divides**.
- A drainage divide is simply a line on either side of which water flows to different streams, i.e., the topographic boundary that separates runoff between two basins is the drainage divide.
- Locally, the most famous drainage divide is the Continental Divide.
- Each drainage basin is entirely enclosed by a drainage divide.
- The drainages in the basins are developed in various patterns according to the geology and topography.

Drainage Patterns

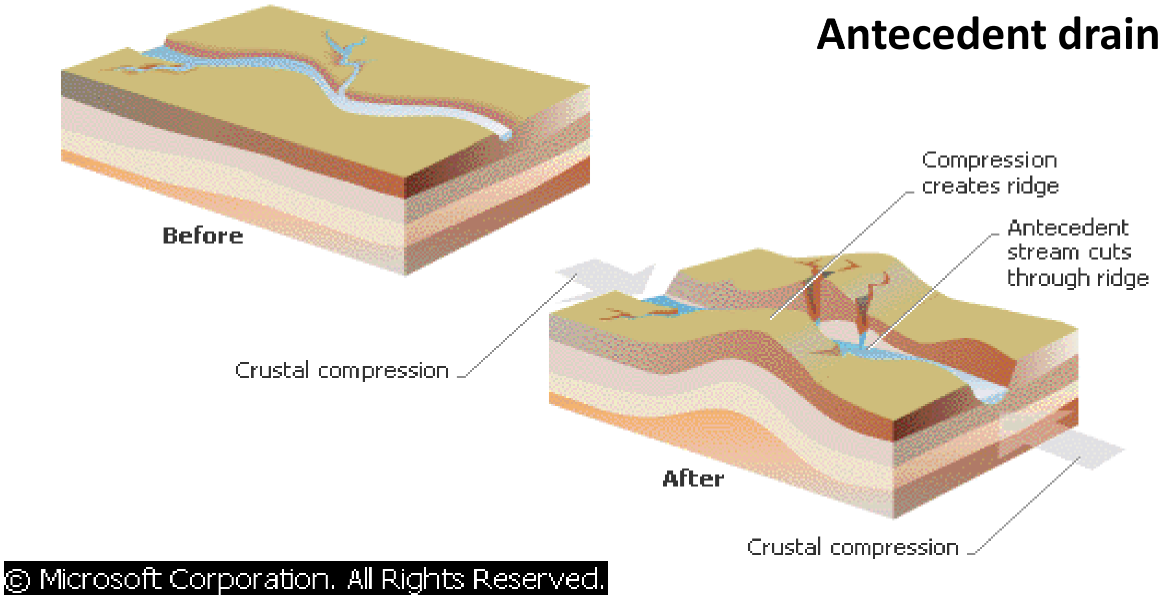
- Consequent / Concordant drainages
- Obsequent / Discordant drainages
- Subsequent drainages
- Resequent drainages
- Dendritic drainages
- Radial drainages
- Rectangular drainages
- Trellis drainages
- Centripetal drainages
- Antecedent drainages
- Stream Capture …



Block Diagram Source:

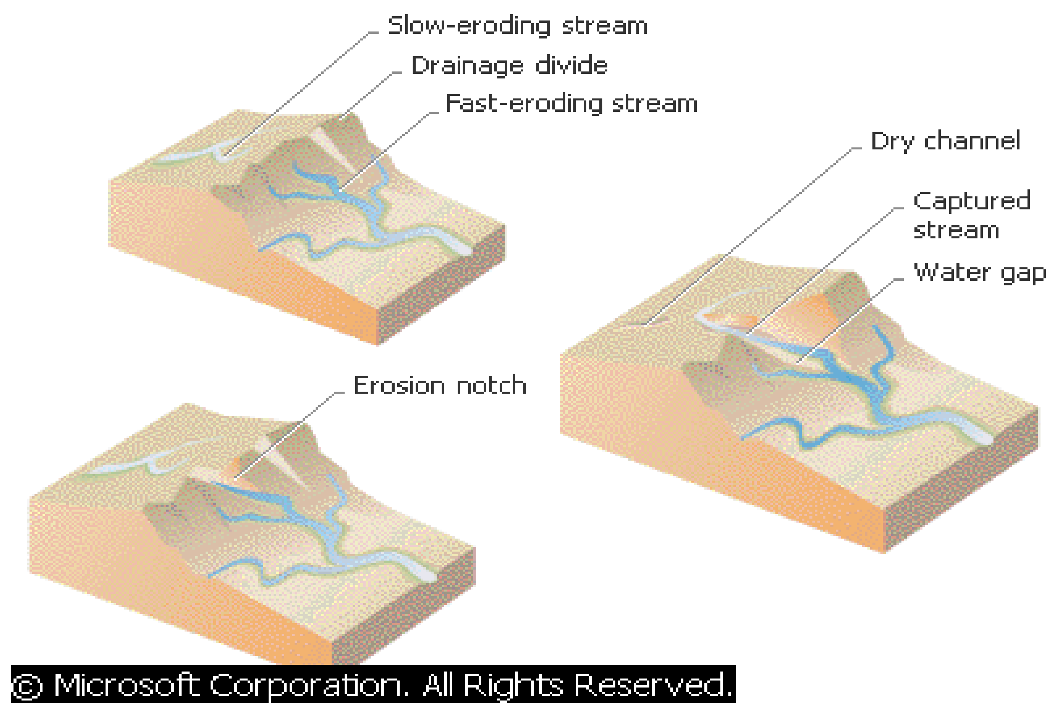
Antecedent drainage

- established before the land beneath it was uplifted through geologic processes such as crustal compression.
- An antecedent stream will maintain its course in spite of crustal compression, and the stream will continue to erode the land at almost the same rate as the crustal compression uplifts it.



Stream Capture

Over time, a stream on the steep side of a mountain slope will erode the slope faster than a stream on the less steep slope, and may erode the drainage divide that separates them.
When the fast-eroding stream erodes a notch in the drainage divide, it eventually takes over the headwaters of the slow-eroding stream on the other side and captures it.



- Drainage basins are commonly treated as physical entities.
- Because drainage basins are discrete landforms suitable for statistical, comparative, and analytical analyses, innumerable means of numerically and qualitatively describing them have been proposed.
- Watershed managers, Hydrologists, Geomorphologists, planners… are interested in such spatial variables of watersheds.
- Obtaining this information requires delineation of the drainage system, which includes the stream channel network and smaller catchments within the basin.

- In addition, every watershed can be characterized by geometric properties related to its linear, areal and relief properties.
- These properties are related to the position of a stream within the watershed, and can be used to compare watersheds.
- Spatial parameters prove valuable, however, in determining whether basin`s are sufficiently similar for direct comparison.
- For example, to study the effects of fire, one might compare a vegetated watershed with a burnt / barren watershed.
- For this comparison to isolate the effects of fire, other spatial factors (drainage area, relief, etc.) should remain relatively constant between drainage basins.
- In addition, spatial variables are used to calculate a wide variety of more sophisticated parameters.

Drainage Morphometry

- The measurement of drainage density provides a hydrologist or geomorphologist with a useful numerical measure of landscape dissection and runoff potential.
- On a highly permeable landscape, with small potential for runoff, drainage densities are sometimes less than 1 kilometer per square kilometer(1 km/1sqkm).
- On highly dissected surfaces, densities of over 500 kilometers of drainages per square kilometer (500km/1sqkm) are often reported.
- Closer investigations of the processes responsible for drainage density variation has been discovered that a number of factors collectively influences the stream density.
- The major factors include, **(a) Geology, (b) Climate, (c) Topography / slope, (d) Soil infiltration capacity**, and **(e) Vegetation / Landuse / land cover.**
- Linking of Lithological and Geomorphological parameters with Aquifer characteristics of basin provides a simple way to understand the hydrogeologic behavior of different basins.
- The geomorphological properties which are important from hydrogeological studies point of view includes **linear**, **aerial** and **relief** aspect of watersheds.
- GIS modules made the computation of parameters required for drainage morphometric analyses easier & less time consuming than manual method like Area measurement, Length measurement & Density, Bifurcation ratio and other calculations.

This quantitative analysis of drainage networks was developed to enable,

- Comparisons to be made between different drainage basins,
- Establishing relationships between different aspects of drainage pattern of same basin, and
- Certainly, a channel with perennial flow is a stream. But, toward the end of the drainage network stream flow is typically ephemeral; flow occurs only after precipitation or snow melt. Channels may be well defined, but we will assume that all channels are streams.
- Deriving certain useful properties of drainage basins in numerical terms, such as,

Linear Areal & Relief Aspects:

1. **Stream Order**
2. **Stream Length**
3. **Stream Length Ratio / Law of Stream Lengths**
4. **Bifurcation Ratio / Law of stream numbers**
5. **Perimeter**
6. **Basin length**
7. **Basin width**
8. **Length of overland flow**
9. **Area / Basin Area**
10. **Law of drainage areas**
11. **Basin Shape (or) Form Factor**
12. **Drainage Density**
13. **Stream frequency**
14. **Drainage texture (or) Infiltration Number**
15. **Texture Ratio**
16. **Circularity ratio**
17. **Elongation ratio**
18. **Ruggedness Number**
19. **Relief / Height (H) / Basin Height**
20. **Relief Ratio**
21. **Constant of channel maintenance**
22. **Compactness coefficient**
23. **Hypsometric Curves…**

A. LINEAR ASPECTS:

1. Stream Order / Stream Number

An important quantifiable characteristic of stream networks is related to the hierarchical arrangement of stream channels.

- The most commonly used is the method proposed by the famous hydrologist **Robert Horton.**
- According to this system, a stream segment with no tributaries is designated as a first-order stream.
- When two first-order segment join, they form a second-order stream; two second-order segments join to form a third-order segment, and so forth.
- When a lower order segment joins a higher order segment, there is no change in river order.

Comparison of two principal methods of defining stream orders - **Strahler Order system** and **Shreve Magnitude system**

Orders increase in the **Strahler stream order system** where two streams of equal order meet. Mostly, the 1st orders are located along outer most upper part of the basin. Study of drainage orders reflects **morphological, hydrographical characters, fluvial** and **earth system processes** of the catchment.

Shreve Magnitude system designates streams that lack a tributary as magnitude 1.

Where streams join, their magnitudes are added together.

Therefore unlike the Strahler system, magnitudes increase at **all** junctions in the Shreve system.

For instance, where a magnitude 2 stream joins a magnitude 3 stream, the magnitudes are added to form a magnitude 5 stream. Note that in such a case there is *no* magnitude 4 stream.

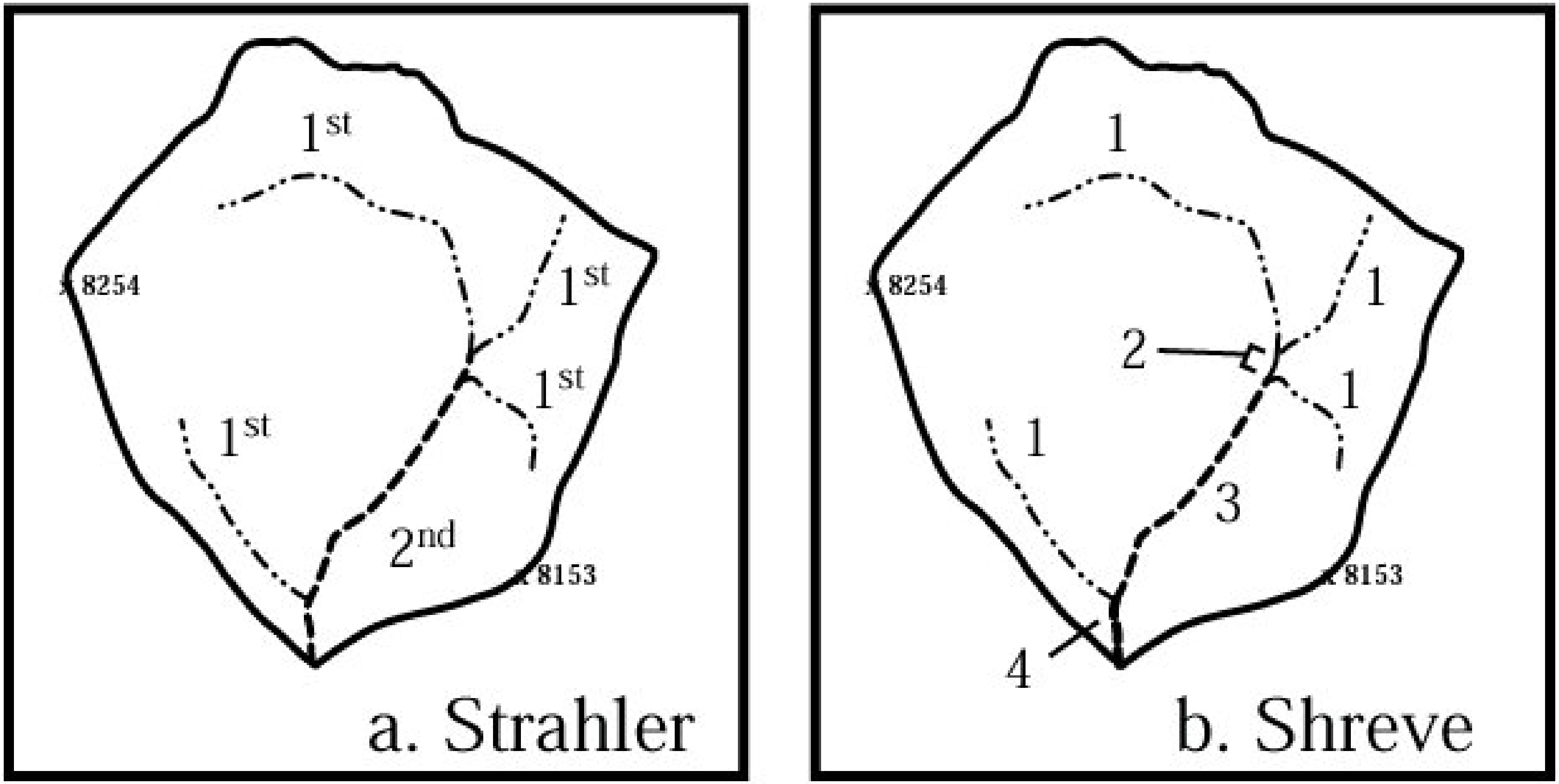


Figure : Stream order

In the **Shreve magnitude system**, magnitudes increase through addition at all stream junctions.
Using the Shreve system, the number of magnitude-1 streams in a basin is equal to the basin's / stream’s magnitude.

Shreave magnitude of streams offers **hydrodynamics** such as the number of drainage sources in each catchment above a stream gauge or outflow, and correlates roughly to the **discharge volumes** and **pollution levels**.

The number of 1st order streams in a basin of a given size is dependent upon a variety of climatic, geologic, and hydrologic factors.

For instance, holding all other variables constant, we would expect that a drainage basin in an arid climate would have *more* 1st order streams than a watershed in a more humid climate.

Similarly, increasing relief is associated with increasing stream densities.

2. Stream Length : Stream length, or more appropriately channel length, is an important morphological variable.

3. Stream Length Ratio : The **law of stream lengths** suggests that the length of streams in successive stream orders increases following a geometric relationship.

Similarly, the number of streams within each order decreases with order in a linear fashion.

4. Law of Stream Numbers or **Bifurcation Ratio (Rb) :**
Not only are the numbers and lengths of particular stream orders important, but their ratios are quite instructive as well.

Consider a dendritic drainage pattern versus trellis. In an ideal **dendritic drainage** pattern, the number of 1^{st} order tributaries would be exactly twice the number of 2^{nd} order streams.

Thus, the number of 1^{st} order streams will be exactly twice that of 2^{nd} order streams.

In a **trellis network**, long main stem streams are fed by many low order streams. As a result, 1^{st} order streams typically outnumber the 2^{nd} order streams by 3 to 5 times.

Bifurcation Ratio is the relation between no. of streams of one order and of next higher order.

i.e., The relationship between the number of streams in successive stream orders is called the **Bifurcation ratio (R_b)**.

This is obtained by dividing no. of streams in one order by the no. of the stream in next highest order for all the orders of the stream. These calculations were also based on **Strahler method**.

“The ratio between the number of streams of a given order to the number in the next order, has been found to vary around the value from 3 to 5 in basins where Geology is reasonably homogeneous”.

$$R_b = \frac{S_{o-1}}{S_o}$$

Where, $\mathbf{S_o}$ is the number of streams in any given order and $\mathbf{S_{o-1}}$ is the number of streams in the next lowest order.
For e.g., if, the No. of streams in 1st order = 75 & in 2nd order = 30;
Then, R_b of ½ = 75 / 30 = 2.5; or the R_b is 2.5 : 1
Average of such 1/2, 2/3, 3/4, …..orders can be considered for a watershed / sub-watershed / mini watershed / micro watershed / nano watershed.

5. Perimeter Length (P): Perimeter length is the linear length of a drainage basin perimeter. One can measure this length with a string, map wheel / Rotometer, or digitizer.

Using a map wheel or digitizer/ rotometer, a pen-like device with a small wheel at the tip and large dial on top, perimeter can be calculated, by moving the wheel along a line, an arm on the dial is moved.

The length of the line, typically measured in inches, is read directly from the position of the arm on the dial.

Converting the dial units into ground distance is a simple matter.

For instance, if the wheel transcribed a distance of 2.5 inches on a 1:24000 scale map, we can readily calculate that 2.5 inches multiplied by 2000 feet equals 5000 feet (12 inches = 1 foot, thus, 24000/12=2000feet; i.e., 60,000/12=5,000ft).

Hence, the line we measured represents a distance of 5000 feet on the ground.
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6. Basin Length (L) : It is a measure of the linear distance (L) between the mouth of the basin and the point most distant from the mouth.

7. Basin Width (W) : It is a measure of the linear distance (W) across the basin perpendicular to the length.

8. Length of Overland flow (Lo): It is the length of water over the ground before it gets concentrated into definite stream channels. This factor relating inversely to the average shape of the channel is quite synonymous with the length of sheet flow to a large degree.

B. AREAL ASPECTS:

The **areal** aspects of drainage morphometric parameters of the sub-watersheds are: **Area** (A), **Perimeter** (P), **Form factor** (R_f), **Circularity ratio** (R_c) and **Elongation ratio** (R_e) …..

9. Area / Basin Area : The total Area of the basin calculated either using a rotometer or digitization in GIS.

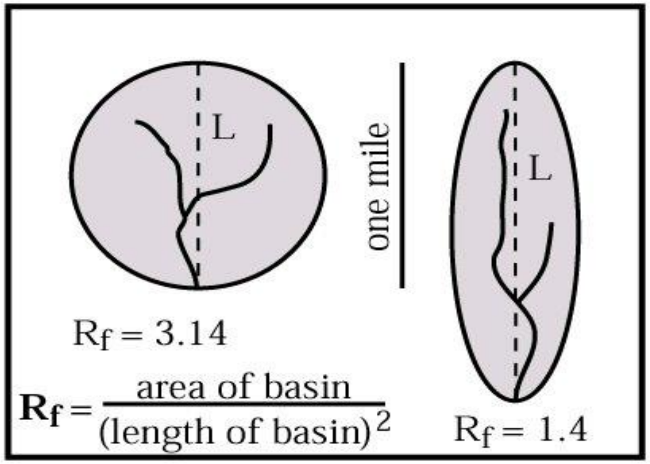
10. Law of drainage areas : The **law of drainage areas** states that the area of the basin is related to stream order in a geometric series.

11. Basin Shape (R_f) or **Form Factor:** A measure of the elongation of a basin.

As elongation increases for a given area, R_f decreases. For a given area, as basin length increases the value R_f decreases. The value Rf should be comparable among basins of very different size.
To calculate R_f, simply measure the linear distance (L) between the mouth of the basin and the point most distant from the mouth and use the formula:

$$R_f = \frac{A_b}{L^2}$$

Where,
Ab = Area of basin
L = Length of basin



For instance, a **circular basin** with an area of 3.14 mi^2 would have an R_f value of 3.14.

Whereas an **elliptical basin** 1.5 miles long, but with an area of 3.14 mi^2 would have an R_f value of 1.4.

12. Drainage Density (Dd):

The one important areal measurement is drainage density, which is simply defined as the total length of drainages per unit area.

This is a useful measure of frequency and spacing of streams with in drainage basin.

Drainage density (Dd) is expressed in **km** Channel length **per sq.km or a unit area** of the basin.

Drainage density is an important index to geomorphologists and hydrologists because it provides a quantitative index of how dissected a drainage basin is.

The controls on drainage density are climate (which supplies precipitation for runoff and stream incision) and geology (resistance to erosion and as a control on runoff through infiltration).

13. Stream frequency : It is the ratio of total no. of streams of any/all orders & the area of the basin in which its lies. i.e.

$$\mathbf{F = Nu / Au}$$

where, F – Stream frequency of any order 1- 4
Nu – No. of streams of any order 1-4 and
Au – Area of basin where stream lies.

14. Drainage Texture (or) Infiltration Number : Total number of stream segments of all orders per perimeter of the area.

15. Texture ratio: It is the ratio of total no. stream of any order, & perimeter of the area which it lays.

16. Circularity Ratio (Rc): Ratio of the area of a basin to the area of a circle having the same circumference as the perimeter of the basin. It is influenced by the length and frequency of streams, geological structures, land use / land cover, climate and slope of the basin.

17. Elongation Ratio (Re): The elongation ratio is defined as the **ratio** of diameter of a circle of the same area as the basin to the maximum basin length. The values generally vary from 0.6 to 1.0 and can be grouped into three categories, i.e, circular (>0.9), oval (0.9 – 0.8) and less elongated (<0.7).

C. RELIEF ASPECTS:

18. Ruggedness number (R): A combined measure of relief and stream density. As topography becomes more convoluted, the ruggedness number increases.

To calculate R, multiply the drainage density (D) by basin relief (H). Be sure to use the same unit of length as used in calculating drainage density (typically kilometers), R = DH

19. Relief / Height (H) / Basin Height : Relief is calculated by determining the difference between any two elevations.

Relative to a drainage basin, relief is measured by subtracting the elevation of the mouth of the basin from the highest point within the basin.

Some workers refer to this parameter as basin height.

$$R_h = \frac{H}{L}$$

20. Relief Ratio (R_h): A unitless measure of the overall gradient acr

Calculated by dividing the relief (H) of a basin by its length (L).

Be sure to use values with equal units. It is an indicator of the intensity of erosion processes operating on the slopes of the basin.

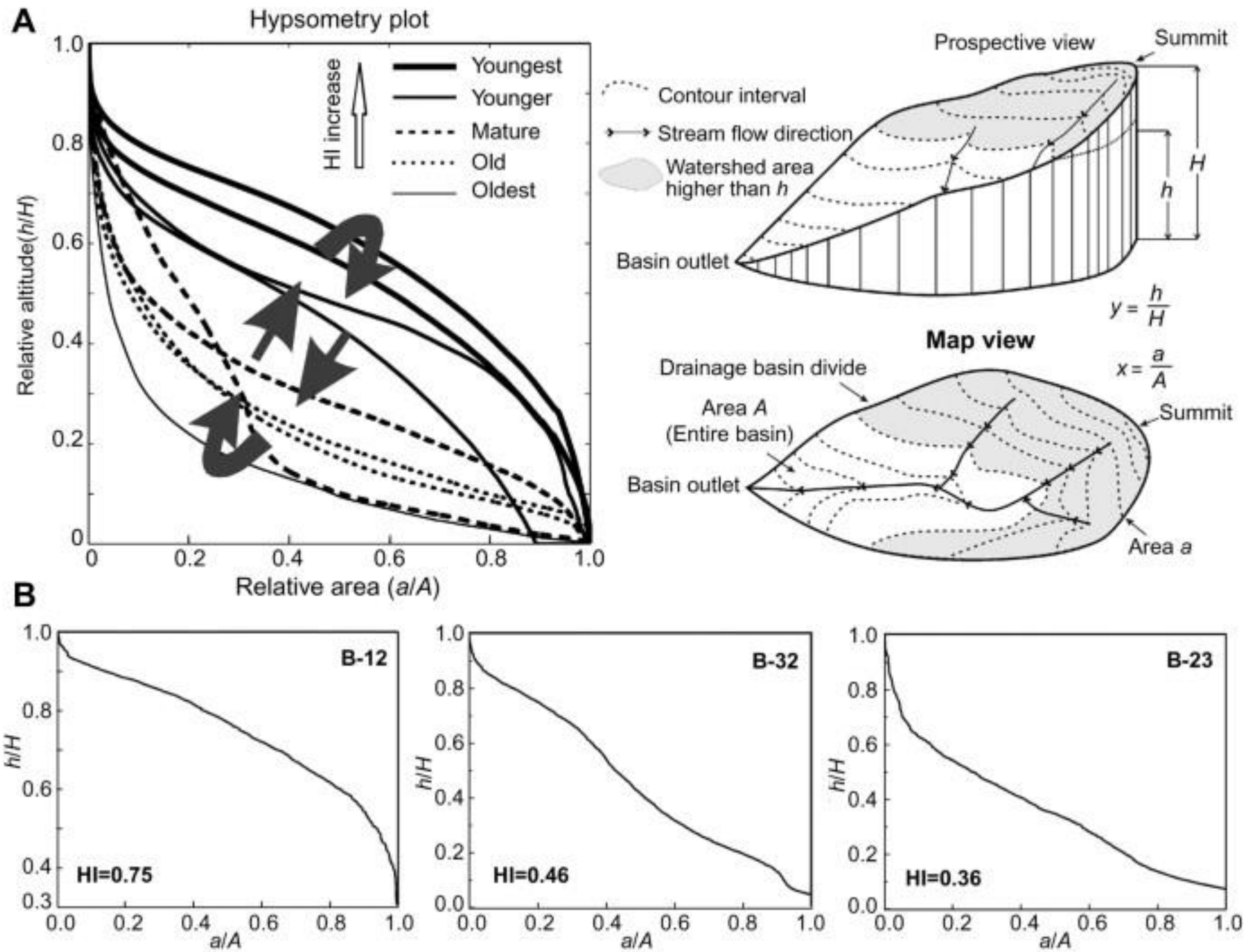
21. Constant of Channel Maintenance : the ratio between the area of the drainage basin and total length of all the **channels**.

$$D = \frac{\sum L_i}{A_b}$$

Where,
D = Sum of stream lengths / Basin Area
Li denotes stream lengths and Ab is drainage basin area

22. Compactness coefficient (Cc): It is used to express the relationship of a hydrologic basin with that of a circular basin having the same area as the hydrologic basin. A circular basin is the most hazardous from a drainage stand point because it will yield the shortest time of concentration before peak flow occurs in the basin.

23. Hypsometric Curves: Empirical cumulative distribution function of elevations in a catchment. The hypsometric curve may also be shown as a continuous function and graphically displayed as an x-y plot with elevation on the vertical. The curve can also be shown in non-dimensional or standardized form by scaling elevation and area by the maximum values.



This curve provides hydrologist with a way to assess the similarity of watersheds. Differences in **hypsometric curves** between landscapes arise because the geomorphic processes that shape the landscape may be different.

Sources/Types of surface water

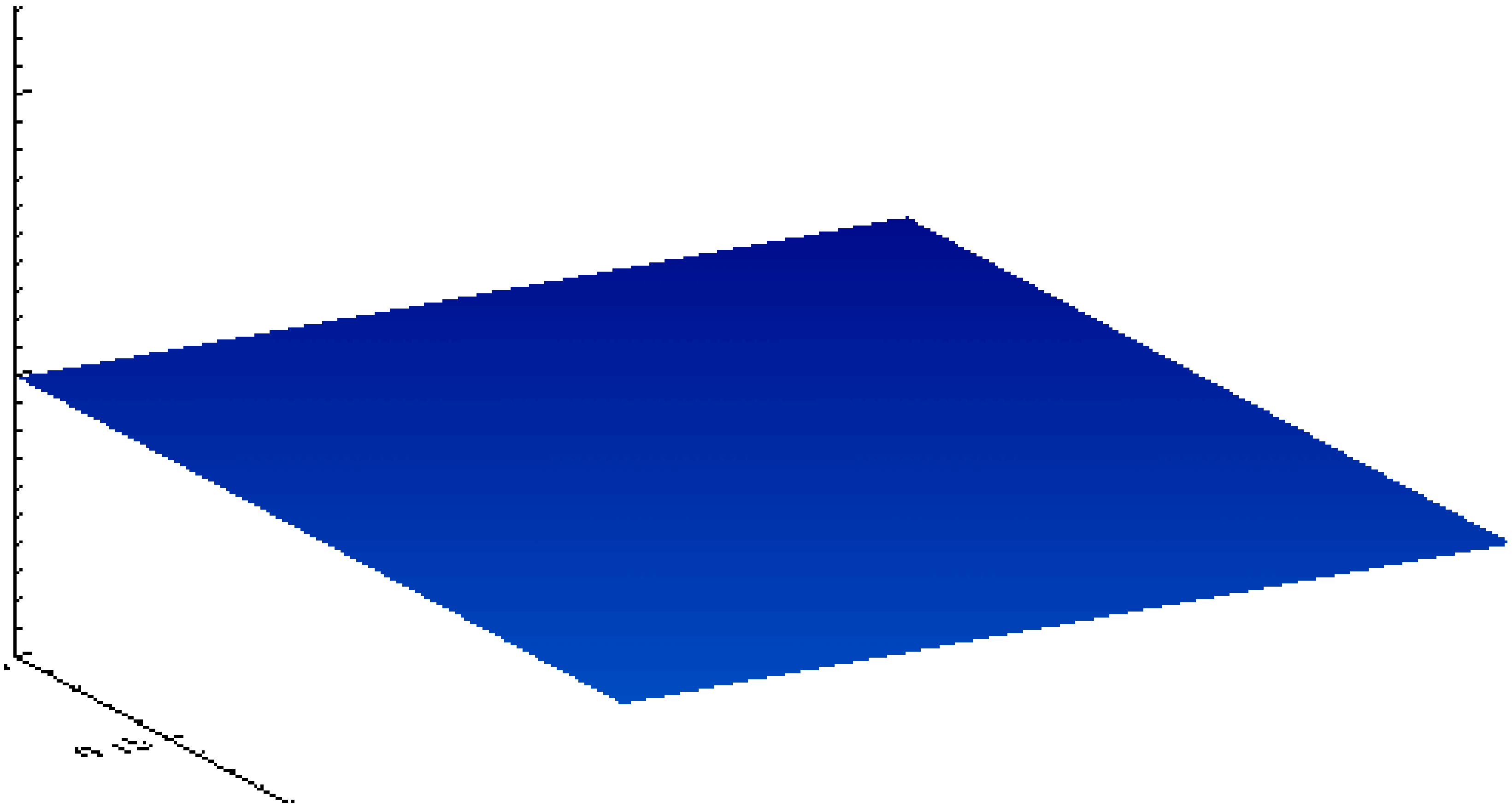
- Meteoric water - Rain water
  - Derived from precipitation /rainfall
- Juvenile - Magmatic water
  - Formed in cracks / pore spaces of rocks due to condensation of steam emanating from magma
- Connate water - Fossil water
  - Entrapped in the rocks during their formations due to sedimentation in an aqueous environment

Sources of surface water – contd…

- Snow –
  - **Sleet** (rain combined with hail or snow),
  - **Glaze** (glassy coating of ice, typically caused by rain freezing on impact),
  - **Hail** (pellets of frozen rain falling in showers from cumulonimbus clouds),
  - **Snow** (atmospheric water vapour frozen into ice crystals and falling in light white flakes or lying on the ground as a white layer),
  - **Mist** (a cloud of tiny water droplets in the atmosphere, at or near the earth's surface, limiting the visibility to a lesser extent than fog)
  - **Fog** (a thick cloud of tiny water droplets suspended in the atmosphere at or near the earth's surface which obscures or restricts visibility)
- Rainfall –
  - **Drizzle -** light rain falling in very fine drops,
  - **Raindrops** – Sparse / Medium / Dense, Heavy downpour, and
  - **Cyclonic rainstorm** – Heavy rainfall with cyclonic wind
- Groundwater table –
  - Influent stream - through Springs and Ooze-outs.
- Geysers & Hot-springs.

Modelling assumptions

- Assumption for developing a model includes **several independent** and **a dependent** parameters / variables and with some **constants-** as **Phenomena.**
- For e.g., Size of drop, Speed of it's fall over a calm surface water body, area, boundaries, etc.



Output from a shallow water equation model of water in a bathtub. The water experiences five splashes which generate surface gravity waves that propagate away from the splash locations and reflect off the bathtub walls

Choice of equation

- Phenomena and model geometry
- Choice of variables and parameters
- Data and knowledge acquisition
- Model building
- Calibration and verification
- Results presentation

Example-1,

– Darcy's Law of surface water flow

– User defined Equations – Quantification of surface Runoff

Example-2

- Volume of water against water spread area of tanks in a study area

Example-3

- Land management models for improving Natural Recharge of Hard rock terrain
  - Regression Model – Establishing the relationship between different terrain controlling parameters quantitatively

Phenomena and Model Geometry

- The world real phenomena / geo-system processes need to be determined
- Based on the inducing / controlling / functional parameters, and their influence, model geometry, i.e., frame of the model need to be build, using statistical analyses such as,
- Factor Analysis,
- Multiple Regression Analysis, etc.

Choice of Variables and Parameters

- According to the influence of each functional parameters and variables, the model can be build involving them
- Based on Climate / environmental impacts
- Status of water resources exploitation, aquifer functions, water requirement, etc.
- Accuracy of the outcome from a model, some parameters, scale of maps can be decided.

Data and Knowledge Acquisition

- Data Collection - field survey / secondary
- Data Preprocessing – Detection and Removal of anomalies, Conversion of dataset to unitless / under similar unit by Linear stretching algorithm (((X-Xmin / Xmax-Xmin)*99)+1)
- Understanding of data and information derivation – knowledge acquisition

Model Building

- Use of Statistics in status depiction / prediction / prevention, actual, qualitative / quantitative / time series models can be developed
- GIS helps us in visualizing the data of a particular terrain and the current processes that are involved and the results derived by spatial / statistical analyses and also to plan for future.

Calibration and Verification

- Model Calibration can be done by inputting a user defined value – may be density sliced values from an existing data or
- By inserting expected value ranges
- Verification can be done by conducting ground truth / field surveys or with existing secondary data

Thank you