**Compiled by**


**Prof. Rabindra Kumar**
**Department of Geology**
**Patna Science College**
**Patna University**
**Mob:9431492334**
**Emai: rabindra.hydrogeologist@gmail.com**


# Topic: Introduction to Hydrogeology

## Introduction to Hydrogeology

**Water** is a precious natural resource. Without water there would be no life on Earth. Two-thirds of our body is composed of water by weight.

In regard to water, our everyday lives depend on the following (Hiscock, 2005):

- the availability of inexpensive water,
- the availability of clean water,
- and safe ways to dispose of water after use.

**Water supplies** are also essential in supporting food production and industrial activity. The most important factor that determine the density and distribution of vegetation is the amount of the precipitation (Fetter, 2001).

**Agriculture** can flourish in some deserts, but only with water either pumped from the ground or imported from other areas (Fetter, 2001).

**Civilizations** have flourished with the development of reliable water supplies, and then collapsed as their water supplies failed (Fetter, 2001).

**A person** requires 3 liters (L) of potable water per day to maintain the essential fluids of the body (Fetter, 2001).

**Primitive people** in arid lands existed with little more than this amount as their total daily consumption

### Definition and Scope of Hydrogeology

**Hydrogeology** is the science which mainly deals with the groundwater.

In the broadest sense, hydrology addresses:

- occurrence,
- distribution,
- movement,
- and chemistry of all waters of the earth.

**Hydrogeology** is an interdisciplinary subject and also encompasses aspects of hydrology.

**Hydrology** is the study of water.

**A *detailed definition* of hydrogeology may be given as follows:**

**Hydrogeology** is the science that studies

**Occurrence-**

- distribution,
- movement,
- physical and chemical properties,
- interactions with the environment,
- field investigation,
- consumption,
- conservation
- and development

of the water in the rocks of the earth crust.

***Hydrogeology*** is both a descriptive and an analytic science (Fetter, 2001).

The *development* and *management* of water resources are important parts of hydrogeology as well.

**Field hydrogeology** encompasses:

- the methods performed in the field to understand groundwater systems and their connection to surface water sources and sinks.

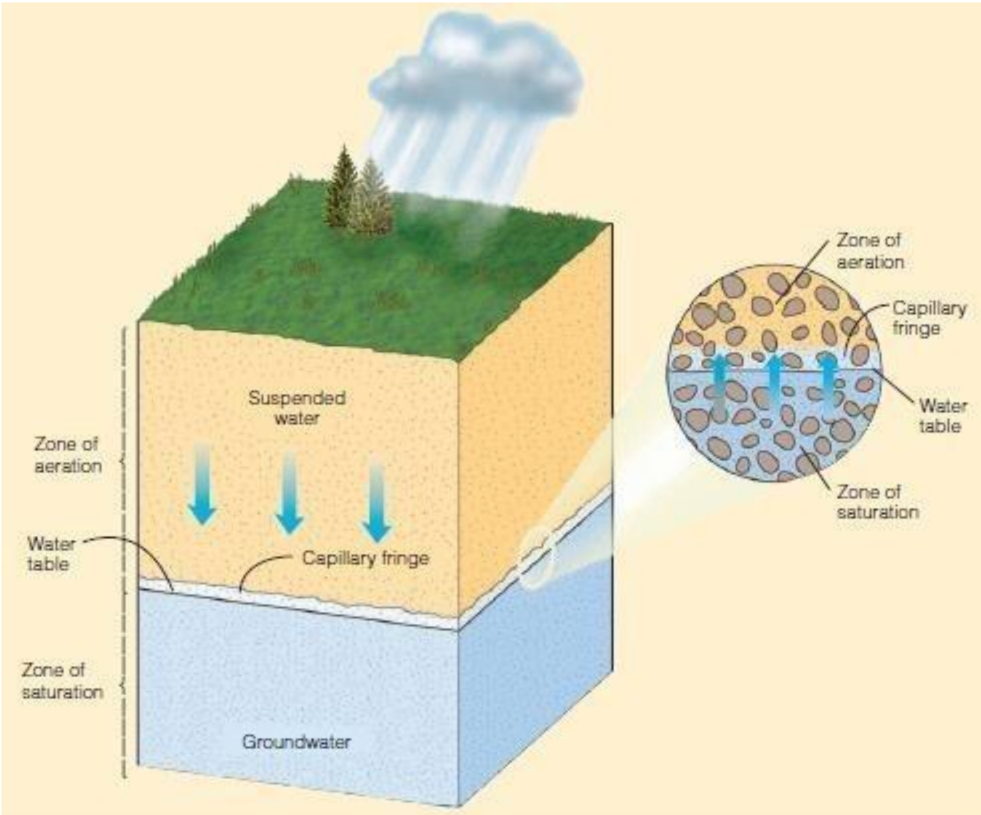
*Hydrogeological investigation* is carried out to understand groundwater system in the field.

**Hydrogeological investigation** can be defined as:

**Studies -**

- mapping,
- measurement,
- analysis,
- drilling,
- and pumping activities aiming at determination of
- occurrence,
- reserve,
- quality,
- consumption,
- conservation,
- and development

of the groundwater resources.




What is "***groundwater***"?

**Groundwater** is defined by water engineers to mean "subsurface water below the water table".

The top of the **zone of saturation** is called the **water table.**

**Subsurface water** is the sum of **soil moisture** (above the water table) and **groundwater** (below the water table).

*Who specializes* in studying groundwater and surface waters?

*Groundwater* tends to be the specialist province of the **"hydrogeologist**," while *surface waters* are the particular domain of the "**hydrologist**" (Younger,2007).

Often, the *groundwater specialists (**hydrogeologists**)* have Bachelor's degrees in *geology or geological engineering*, while the *surface water specialists **(hydrologist)*** hold degrees in *civil engineering* or *physical geography*.

**Hydrogeology and Human Affairs**

Many of the most important *advances in hydrogeology* today have been stimulated by studies designed to solve problems of great economic importance (Davis and DeWiest, 1966).This *trend* will probably continue as the *demand for water* will undoubtedly *increase* with growing population and industrialization.*Water is used* by human in various areas such as *municipal, industrial, agricultural, and recreational* purposes.*An individual* in an industrialized urban area may use approximately from four million to twenty million liters of water *during his lifetime* (Davis and DeWiest, 1966). *Water* can be used *to transport* most industrial and domestic wastes at a cost of a few cents per ton.

Unlike most other commodities, *water:*

- can be *stored economically* in amounts of billions of cubic meters
- and *retained in storage* for many months or even years.

Rapid *increase in groundwater used for irrigation* is largely due to a post-World War II expansion of irrigated lands.

*Groundwater is more desirable than surface water* for at least seven reasons (Davis and DeWiest, 1966):

1. it is commonly free of pathogenic organisms and needs no purification for domestic or industrial uses;
2. the temperature is nearly constant which is great advantage if the water is used for heat exchange;
3. turbidity and color are generally absent;
4. chemical composition is commonly constant;
5. groundwater storage is generally greater than surface water storage;
6. radiochemical and biochemical contamination of most groundwater is difficult;
7. groundwater is available in many areas which do not have dependable surface water supplies

**History of Hydrogeology**

*Water* has vital importance for mankind. For this reason the construction of hydraulic structures goes back to very early times. The date of construction of the first hydraulic structure is not known (Usul, 2001).

The *oldest water works* known are (Usul, 2001):

- Irrigation systems built in Mesopotamia, Egypt, Middle Asia, and China around the famous large rivers of these regions,
    - Arabian wells,
    - Persian kanats,
    - Roman aqueducts,

*Kanats* were used to collect water from alluvial fan deposits and soft sedimentary rock. These structures were probably used first more than 2500 years ago in Iran. The technique of construction spread rapidly eastward to Afghanistan and westward to Egypt.*The foundation of the hydrogeology* began in 17th century (Davis and DeWiest, 1966).Pierre Perrault (1608-1680) measured rainfall in the Seine River basin between the years 1668 and 1670. He then estimated runoff from the basin. Edme Mariotte (1620-1684) studied evaporation, infiltration and capillary rise. Edmond Halley (1656-1742) studied evaporation from the Mediterrenean Sea.

***Henri Darcy*** (1803-1858) was the first person to state clearly the mathematical law which governs the flow of groundwater (Davis and DeWiest, 1966).

His formula is known as "***Darcy's Law***".

The development of his formula was the result of experiments with filter sands and was presented in 1856. Darcy's Law (formula) was presented in a report on the municipal water supply of the city Dijon.

*In 19th century*

J. Boussinesq, J. Dupuit, P. Forcheimer and A. Theim made important contributions to hydrogeology (Todd and Mays, 2005).Their studies were on the groundwater hydraulics.Improvement of hydrogeolgy also continued*in 20th century*.Many scientists have contributed to the development of the hydrogeolgy.Some of these scientists are;

R. Dachler, J. Kozeny, H. Schoeller, and G. Theim.

*By the end of 19th century* the scientists in USA played important roles in the development of the hydrogeology.

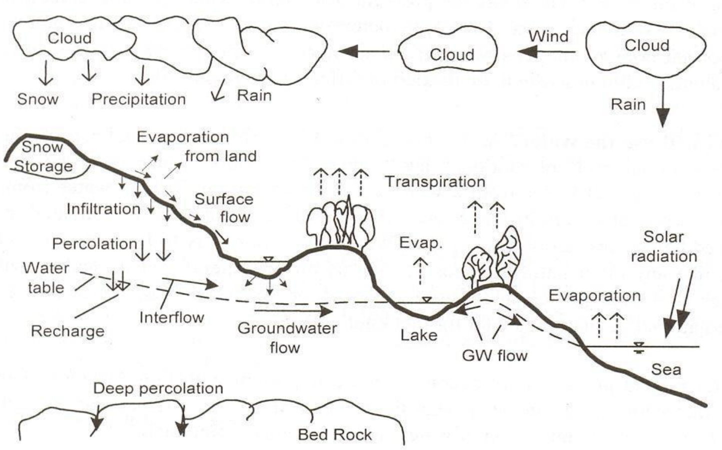
The most important of these are:

A. Hazen, F.H. King, O.E. Meinzer, C.V. Theis, M.K. Hubbert, M.S. Hantush, C.E. Jacob, and R.W. Stallman.

A.M. Piper, H.A. Jr. Stiff, M.D. Foster, I.I. Chebotarev, J.D. Hem, and W. Back are the researchers whose studies have made significant contribution to the progress in *chemical hydrogeology*.

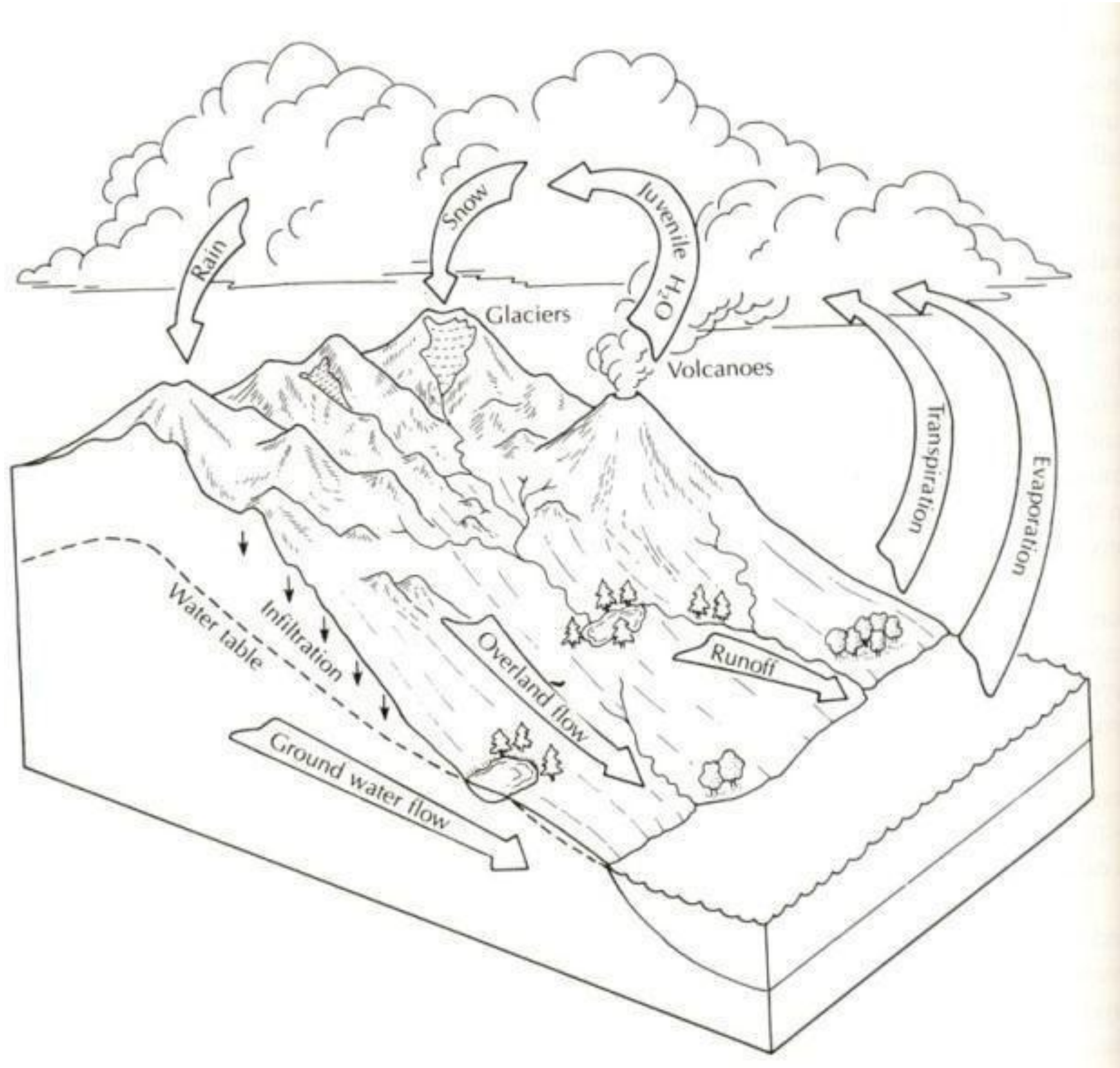
**Hydrologic Cycle -**

The water on our planet Earth is found in three phases, as solid, liquid and gas.




Hydrologic cycle (after Usul, 2001)

The water continuously moves between different parts (atmosphere, hydrosphere, and lithosphere) of the earth which is known as “**Hydrologic Cycle**”




The hydrologic cycle (after Fetter, 2001)
Above the surface of the Earth, the water is in the *atmosphere*.

***Surface water*** occurs as:

- stream,
- lake,
- wetland,
- sea (ocean)
- snow and ice.

The water below the surface of the Earth primarily is ***groundwater***,but it also includes ***soil water***.

**During the hydrologic cycle (Usul, 2001)**:

***The water***

1. proceeds to the atmosphere: from the sea, lake, and land surface by *evaporation*, and from vegetation by *transpiration*,
2. falls as *precipitation* (rain, snow, etc.),
3. flows on the earth surface,
4. *infiltrates* into ground,
5. then runs back to the sea and lake through either streams or groundwater flow.

***Evaporation*** of the water from the surface waters (sea, lake, and river) and land surface and ***transpiration*** from vegetation *produces* ***clouds***.

When suitable meteorological conditions arises, ***precipitation*** occurs as rain, snow, etc., and falls on land or surface water bodies.

A portion of the precipitation falling on the vegetation covered land may be retained by plants. This portion is called ***interception***.

This portion generally evaporates back to the atmosphere.

A very small amount of the water retained on the plants falls on the ground from the leaves. This portion is named as ***through fall.***

*Precipitation that falls on the land surface* enters various pathways of the hydrologic cycle.

The part of the precipitation reaching the ground surface first wets the soil and rocks.

Some *water* may be temporarily *stored on the land surface* as ice and snow or water in puddles. This is known as ***depression storage***.

Some of the rain or melting snow drains across the land to a stream channel, lake, or sea. This is termed ***overland flow*** or ***surface flow***.

If the surface soil or rock is porous, some rain or melting snow will seep into the ground. This process is called ***infiltration***.

A portion of the infiltrated water is stored in the ***vadose zone*** (or ***zone of aeration***).

The soil and rock pores in the vadose zone contain both water and air.

The water in the vadose zone is called ***vadose water.***

At the top of the vadose zone is the belt of ***soil water***.

Some parts of the *waters* stored in depressions, vadose zone, and flowing as overland flow *evaporates*.

The plants use the soil water, and then transpire as vapour to the atmosphere by a process called ***transpiration***.

Evaporation form the land surface, water bodies, and transpiration by plants are lumped together as ***evapotranspiration***.

The water entering the soil or rock may move laterally in the vadose zone above the ***groundwater table*** towards lower elevations.

This water is called ***interflow*** or ***subsurface flow***.

Part of the infiltrated water; may reach the groundwater table by ***percolation***, recharge of groundwater storage.

Then the water moves there horizontally becoming *groundwater flow* (or *base flow*).

*Surface, subsurface and groundwater flows* eventually reach *sea lake, and stream* and from there evaporate back to the atmosphere.

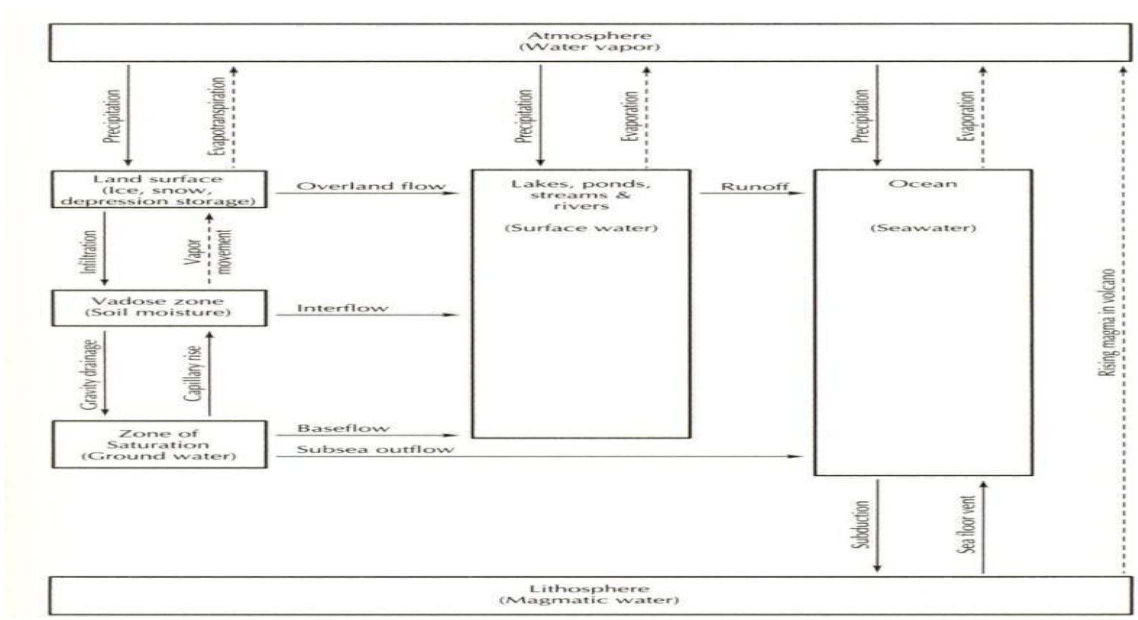
At some depth, the pores of the soil or rock are saturated with water.

The top of the ***zone of saturation*** is called the ***water table*** (or ***groundwater table***).

Water stored in the zone of the saturation is known as *groundwater*.

*Groundwater moves* as *groundwater flow* through the rock and soil layers of the earth.

*Groundwater* discharges as a ***spring*** or as ***seepage*** into a pond, lake, stream, river, sea, or ocean.



Schematic drawing of the hydrologic cycle (after Fetter, 2001).

The figure shows the major reservoirs and the pathways by which water can move from one reservoir to others.

*Magmatic water* is contained within magmas deep in the crust.

If the magma reaches the surface of the earth or the ocean floor, the magmatic water is added to the water in the hydrologic cycle (Fetter, 2001).

Hydrologic processes rarely operate completely uninfluenced by human activities; in other words human activities cause changes in these processes.

The main *activities that result in modifications* in the hydrologic processes are;

- artificial precipitation,
- modifications in the vegetative cover (afforestation, deforestation, change in vegetation type),
- urbanization,
- construction of dams on the rivers,
- irrigation,
- drainage,
- abstraction of groundwater and surface water.

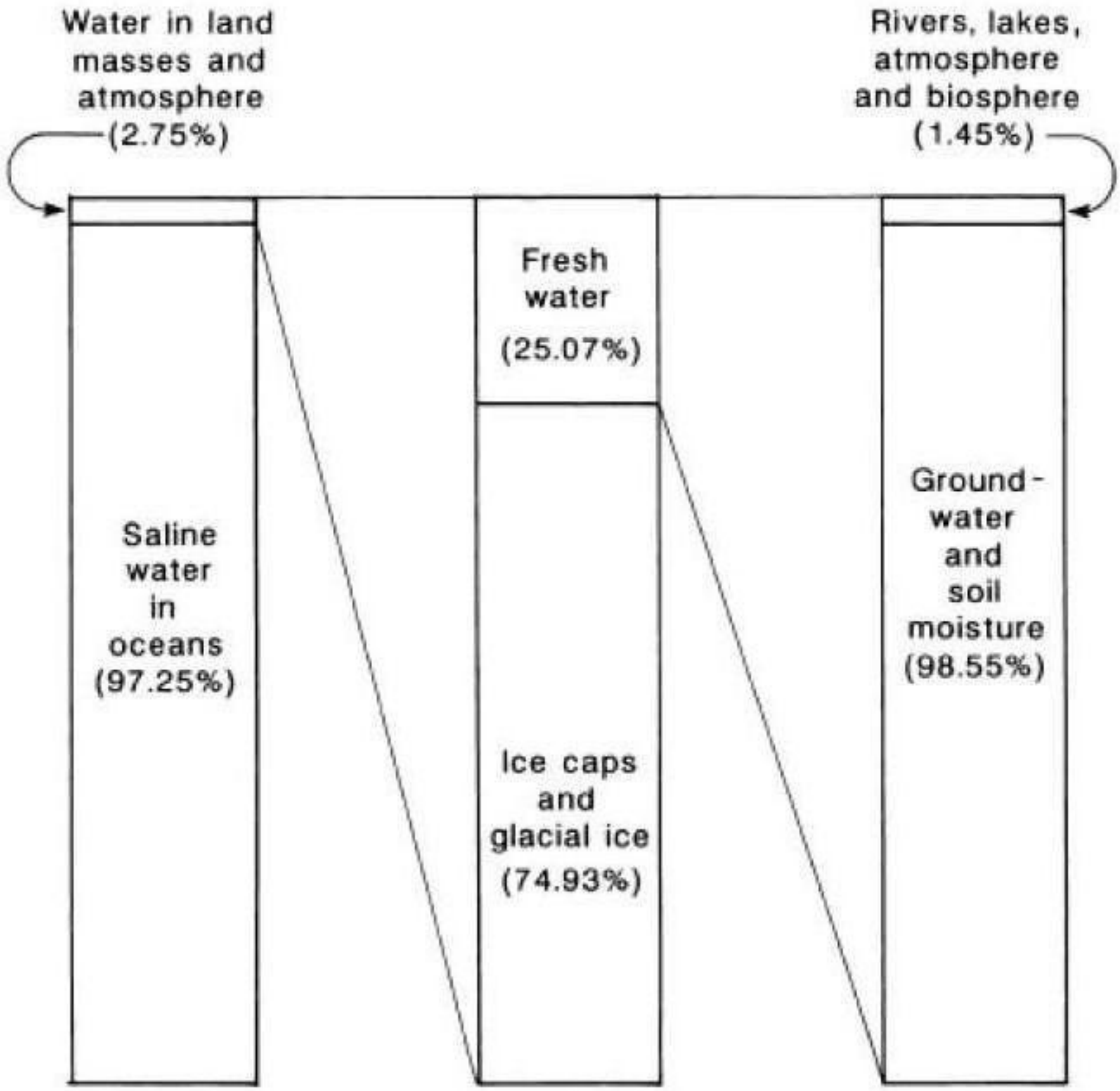
**Global Distribution of the Water**

The water in the whole Earth is *in equilibrium*.*Saline water* in the oceans

**Table 1.1** Inventory of water at or near the Earth's surface. (After Berner and Berner, 1987: Hiscock, 2005).

| Reservoir | Volume ($x10^6$ $km^3$) | % of total |
|---|---|---|
| Oceans | 1370 | 97.25 |
| Ice caps and glaciers | 29 | 2.05 |
| Deep groundwater (750-4000 m) | 5.3 | 0.38 |
| Shallow groundwater (<750 m) | 4.2 | 0.30 |
| Lakes | 0.125 | 0.01 |
| Soil moisture | 0.065 | 0.005 |
| Atmosphere | 0.013 | 0.001 |
| Rivers | 0.0017 | 0.0001 |
| Biosphere | 0.0006 | 0.00004 |
| Total | 1408.7 | 100 |

accounts for 97.25%.*Land masses and the atmosphere* therefore contain 2.75%.*Ice caps and glaciers* hold 2.05%*Groundwater* to a depth of 4 km accounts for 0.68%,*Freshwater lakes* 0.01%,*Soil moisture* 0.005%, *Rivers* 0.0001%, and *biosphere* 0.00004%




About *75%* of the water in land areas is locked in *glacial ice* or is *saline*.

The remaining quarter of water in land areas, around *98%* is *stored underground.*

Only *a very small amount of freshwater available to humans and other biota.*

Taking the constant volume of water in a given reservoir and dividing by the rate of addition (or loss) of water to (from) it enables the calculation of a *residence time* for that reservoir.

The time that a water molecule spends in the *ocean and sea* more than 4 000 years.

**Table 1.2.** Residence times of the waters on the Earth. (After Freeze and Cherry, 1979; Newson, 1994)

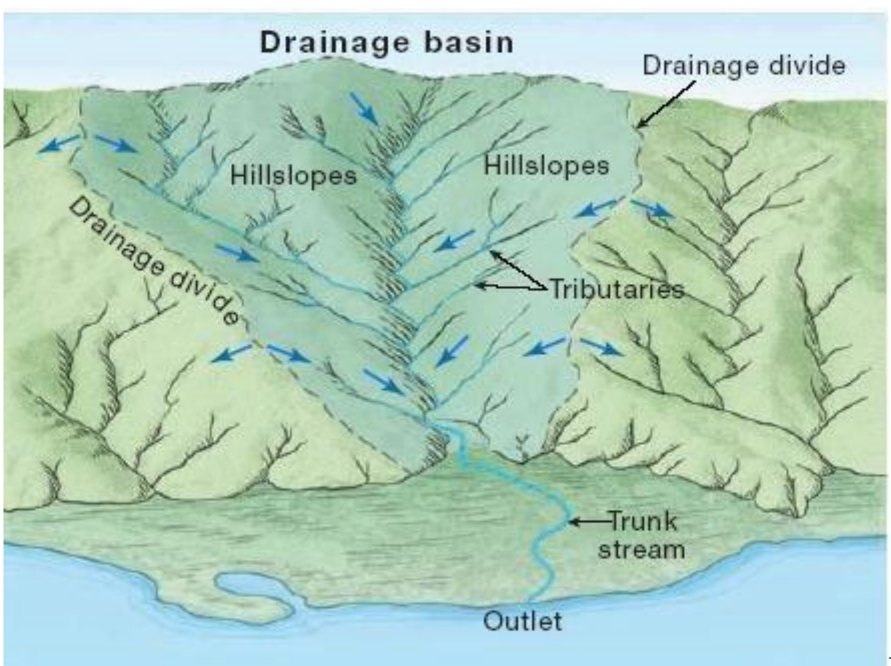
| Water resource | Residence time |
|---|---|
| Atmosphere | 8-10 days |
| Oceans and seas | 4000 years + |
| Lakes and reservoirs | 2 weeks-10 years |
| Rivers | 2 weeks |
| Wetlands | 1-10 years |
| Biological water | 1 week |
| Soil water | 2 weeks-1 year |
| Groundwater | 1-2 days -10 000 years |
| Ice | 10-1000 years |

*Lakes, rivers, glaciers and shallow groundwater* have residence times ranging between days and thousands of years.

*Groundwater* residence times vary from about 2 weeks to 10 000 years, and longer.

A similar estimation for *rivers* provides a value of about 2 weeks.

Basin Properties




Drainage basin

For any cross section on a river, the area above that section which gives all its surface water to this river is called the ***drainage basin*** or simply ***basin*** for that particular section (Usul, 2001). This area is also named as **catchment** or **watershed**

As the control point moves downstream, the basin becomes larger and larger.

It has largest or full area when the section is at the point where river reaches a sea or a lake.

This means that the basin for any cross section along the river is different and therefore each branch of the river has its own ***subbasin***

Basin is a *dynamic and very complex system*, which has mainly *two types of characteristics* (Usul, 2001):

***Geomorphologic characteristics*** of the basin are;

- area,
- shape,
- and slope.

These characteristics can be assumed to be constant, since they change in a very long time.

***Hydrologic characteristics*** are:

- stream shape,
- infiltration capacity,
- soil conditions,
- and vegetal cover

This characteristics change with time.

The line that seperates adjacent basins, passing through the highest points between them and leaving all branches (tributaries) of different rivers at opposite sides, is called the ***water divide*** or ***boundary*** of the basin.

A suitable scaled topographic (contour) map of the area is used for this purpose.

The area in this boundary is the ***drainage area*** (or ***catchment area***, ***watershed area***).

In some areas surface and subsurface basin devides may differ depending on the geological features of the area.

***In karst terranes*** the boundaries of the surface drainage area and underground watershed in general do not coincide.

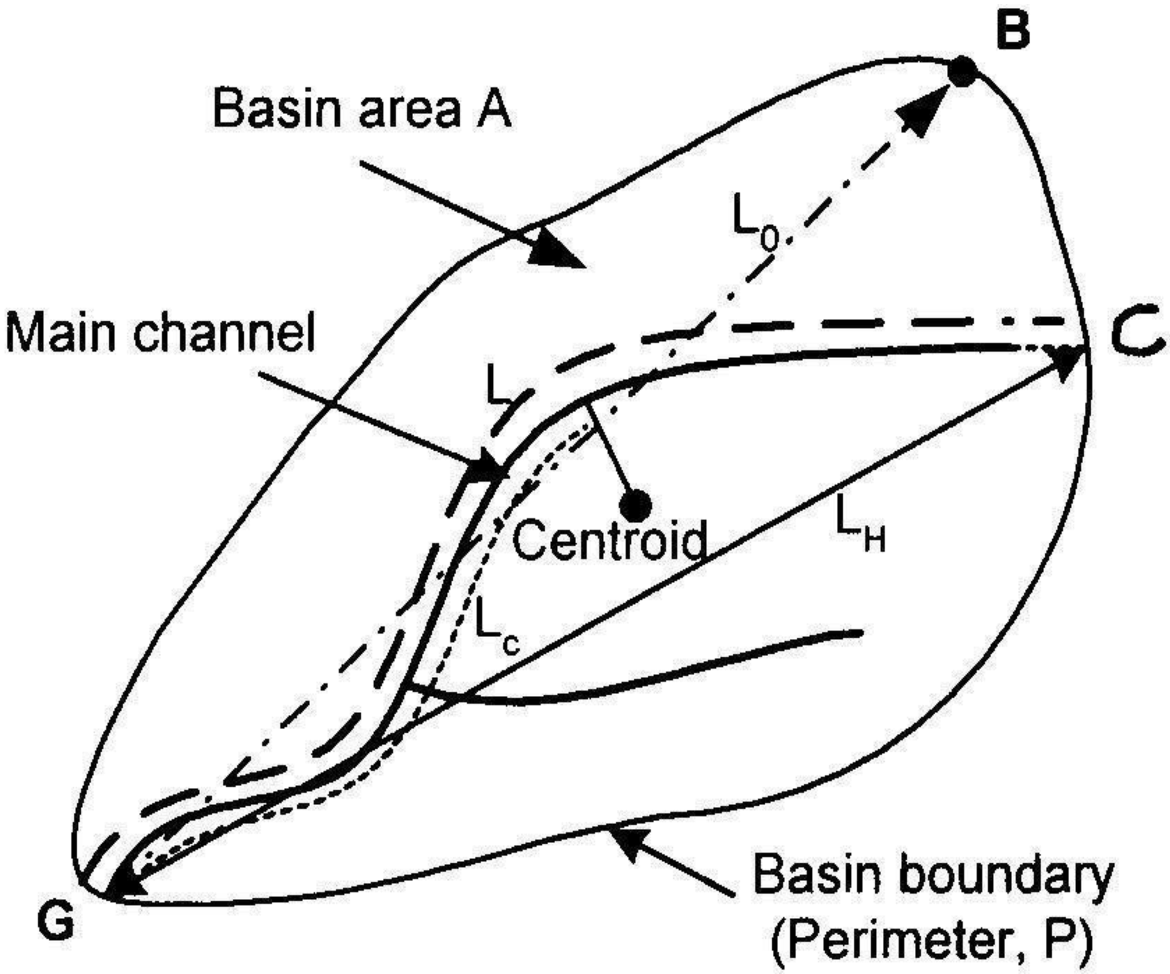
The definition of the boundaries and extention of the watershed area in karst is a difficult and complex task.

In order to precisely define it, it is necessary to conduct detailled geological and hydrogeological investigations .

Basin properties (after Usul, 2001).

The longest branch of the river is called the ***main branch*** and its length gives the ***main channel length*** (L).

When this branch is continued till the boundary, point C in Figure, the birds eye view distance between this point and basin outlet is called ***basin length*** (LH).




Basin properties (after Usul, 2001).

***Basin width*** (WH) is ratio of the area to the basin length (WH = A / LH).

The length from the mouth (G) to the centroid, measured on the main channel is denoted as LC.

The ***longest basin diameter*** (LO) is the distance between the outlet (G) and the most distant point (B) on the basin perimeter

The ***drainage density*** is the total length of the drainage network per unit area of the basin:

Dd= ∑ Lu / A

where Dd is the drainage density

[km/km2]

,

Lu is the total length of the streams of all orders [km],

and A is the area of the basin [km2].

The ***drainage frequency*** (*hydrographic density*) is the number of flow channels per unit area of the basin:

$Df = \sum Nu / A$

where Df is the drainage frequency [km-2], Nu is the number of streams,

and A is the area of the basin [km2].

## REFERENCES


Prof.Dr. FİKRET KAÇAROĞLU, Lecture Note, Muğla Sıtkı Koçman University

Domenico, P.A., Schwartz, F.W., 1990. Physical and Chemical Hydrogeology. John Wileyand Sons, USA, 824 p.

Fetter, C.W., 2001. Applied Hydrogeology (Fourth Ed.). Prentice Hall, USA, 598 p.

Hiscock, K., 2005, Hydrogeology. Blackwell Publishing, 389p.

Younger, P.L., 2007, Groundwater in the Environment. Blackwell Publishing, 318 p.

Usul, N., Engineering Hydrology. METU Press, Ankara, 404 p.

Newson, M., 1994. Hydrology and The River Environment. Oxford Univ. Pres, UK, 221 p.