Meteoric water :-

→ It is the water which is derived from precipitation, i.e snow & rain.

→ It includes water in lakes, river & ice melts, which have fallen from precipitation indirectly.

→ It orginates in the atmosphere by evapoaration which falls as rain & becomes groundwater by the process of infiltration.

→ The infiltrated water goes downward & becomes groundwater.

Connate water :-

→ It is the water which includes in the rock itself, at the time of rock formation when water gets trapped in rock strata.

→ Rock containing connate water is typically formed from ocean sediments.

→ Generally connate water are those liquid molecules which got trapped in the pores of sedimentary rocks.

Juvenile water :-

→ It is also known as magmatic water.

→ The juvenile water orginates in the earth's interior & associates with the magmatic activities.

→ Magmatic water rises from great depth with volcanic eruption, so as its name.

Ground water :-

The water present below the zone of saturation is called as groundwater.

Hydrological Cycle

It is chain of events or continous process i.e, neither a beginning nor an end in broad sence water exist on earth in 3 forms gaseous, liquid & solid.

The gaseous water is the part of the atmosphere

liquid ocean, sea & river.

solid water occurs in the extensive ice body or glacier

It is the part of H.C the liquid water evaporates from the surface water bodies & it is lost from the vegetation by transpiration & becomes the part of the atmosphere

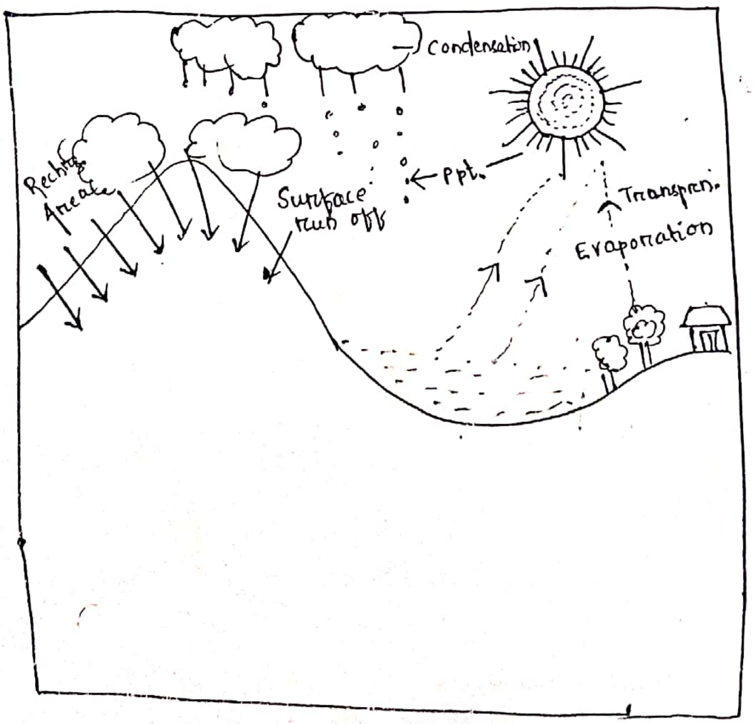
Under suitable condn the water vapours condensed into clouds & subsequently get ppt.ed in the form of rain, snow & hail etc.

- After that the percolated water goes through the aeration zone to the saturation zone forms ground water
- During the movement, very large portion moves as streams & river. & some portion of water from the stream may directly descharge to the ground water & conversely ground water into the stream
- In this way H.W repeats, through 4 phases
  - (a) ppt
  - (b) Evapotranspiration
  - (c) Surface run off
  - (d) Ground water

Then we can calculate the amount of ground water mathematically,

$$G = P - (E + S)$$

G = Amount of ground water
P = ppt
E = Evapotranspiration.
S = Surface run off



$\frac{Q}{A} = KAI$

ARTIFICIAL RECHARGE OF GROUNDWATER

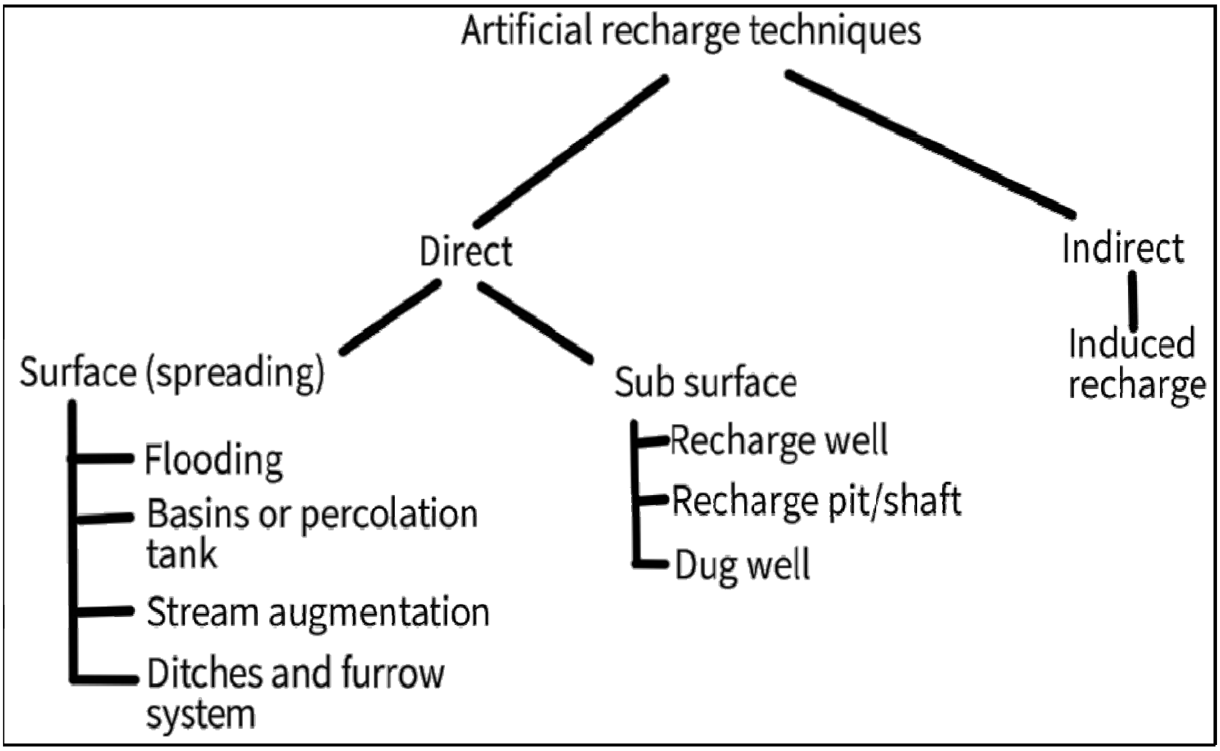
- Artificial recharge is the process by which the ground water is augmented at a rate much higher than those under natural condition of percolation.
- In most low rainfall areas of the country the availability of utilizable surface water is so low that people have to depend largely on ground water for agriculture and domestic use.
- So in order to improve the ground water situation it is necessary to artificially recharge the depleted ground water aquifers.

Areas of recharge:

- Where groundwater levels are declining due to over-exploitation.
- Where substantial part of the aquifer has already been desaturated i.e regeneration of water in wells and hand pumps is slow after some water has been drawn.
- Where availability of water from wells and hand pumps is inadequate during the lean months.
- Where ground water quality is poor and there is no alternative source of water.

Methods of Artificial Recharge

The techniques of artificial recharge can be broadly categorized as follows.



Surface Method

- These methods are suitable where large area of basin is available and aquifers are unconfined without impervious layer above it.
- The rate of infiltration depend on nature of top soil if soil is sandy the infiltration will be higher than those of silty soil.
- The presence of solid suspension in water used for recharge clogs the soil pores leading to reduction in infiltration rate that is recharge rate.
- Water quality also affect the rate of infiltration. The various spreading methods are as below;

Flooding:

- This method is suitable for relatively flat topography.
- The water is spread as a thin sheet.
- It requires a system of distribution channel for the supply of water for flooding.
- Higher rate of vertical infiltration is obtained on areas with undisturbed vegetation and sandy soil covering.

Basin and percolation tank method:

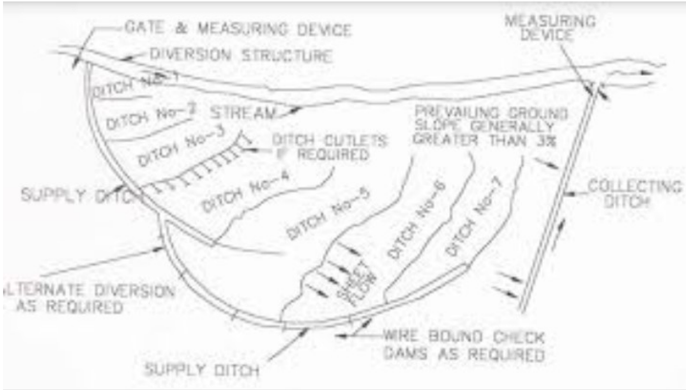
- This is the most common method for artificial recharge.
- In this method, water is impounded in series of basin or percolation tank.
- The size of basin may depend upon the topography area, in flatter area will have large basin.
- This method is applicable in alluvial area as well as hard rock formation.
- The efficiency and feasibility of this method is more in hard rock formation where the rocks are highly fractured and weathered.

Stream augmentation:

- Seepage from natural streams and river is one of the most important source of recharge of the ground water reservoir.
- When total water supply available in a stream/river exceeds the rate of infiltration, the excess is lost as run-off.
- These run-off can be arrested through check bands or widening the stream beds, thus larger area is available to spread the river water increasing the infiltration.
- The site selected for check dams should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time.
- The water stored in this structure is mostly confined to stream course and height is normally 2m.

Ditch and Furrow system:

- In areas with irregular topography ditches and furrows provide maximum water contact area for recharge.
- This techniques consist of a system of shallow flat bottomed closely spaced ditches/furrows which are used to carry water from source like stream/canals and provide more percolation opportunity.
- This required less soil preparation and is less sensitive to silting.



Sub-surface method:

- In this method the structure lies below the surface and recharges ground water directly.
- The important structure commonly use are recharge wells, recharge shaft, dug wells etc.

Recharge well:

It can be of two types;

a. Injection well, where water is pumped in for recharge.
b. Recharge well, where water flows under gravity.

Injection well:

- The injection wells are similar to a tube well.
- This technique is suitable for augmenting the groundwater storage of deeper aquifer by pumping in treated surface water.
- These wells can be used as pumping well during summer.
- The method is suitable to recharge single/multiple aquifer.
- The recharge through this technique is comparatively costlier and required specialized techniques.

Recharge well:

- The recharge well for shallow water table aquifer up to 50m are cost effective because recharge cam take place under gravity flow only.
- These wells could be of 2 types. One is dry and another is wet.
- The dry types of well have bottom of screen above the water table in such ways excessive clogging is reported due to release of dissolved gases as water leaves the well.

- The wet type of wells are the wells in which screen is kept below water table. These wet types of wells have been found more successful.

Pits and shafts

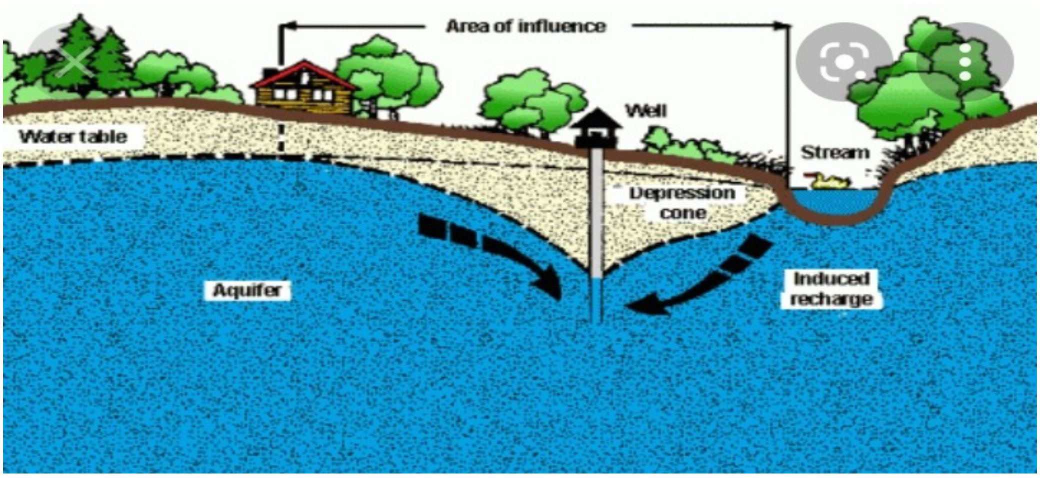
- In areas where impervious layer is encountered at shallow depth the pits and shaft are suitable structure for artificial recharge.
- These structures are cost effective to recharge the aquifer directly.
- The advantage of shaft or pit structure is that they do not require large piece of land like percolation tank and other spreading methods.
- There is no loss of water in form of soil moisture and evaporation like methods of spreading.

Dug wells

- In alluvial as well as hard rock areas there are thousands of dug wells have either gone dried due to considerable decline of water level.
- These dug wells can be used as recharge structure water and surplus water from canal etc. can be diverted into this structure to directly recharge the dried aquifer.
- The water for recharge should be guided through a pipe to the bottom of well to avoid entrapment of bubbles in the aquifer.

Induced recharge

- It is an indirect method of artificial recharge involving pumping from aquifer hydraulically connected with surface water such as perennial streams, unlined canal or lakes.
- The heavy pumping lowers the ground water level and cone of depression of depression is created. Lowering of water levels induces the surface water to replenish the groundwater.
- This method is effective where stream bed is connect to aquifer by permeable formation.



Advantages of groundwater recharge

- To enhance the groundwater yield in depleted in aquifer due to urbanization.
- Conservation and storage of excess surface water for future requirements.
- To enhance the quality of existing groundwater through dilution.
- To remove the bacteriological and other impurities from sewage and waste water by natural filtration, so that water is suitable for re-use.

Conclusion

Thus it can be concluded that artificial recharge give the reduction of runoff, increased availability of ground water especially in summer month, increase in irrigation, revival of springs, improvement in ground water quality, yet even with full development of artificial recharge, ground availability would remain limited. Though ground water recharge scheme either naturally or artificially may not be the final answer, but they do call for the community effort and create the spirit of cooperation needed to subsequently manage sustainably ground water as a community resource.

Engineering Properties of Rocks

Objectives :
The aim of this lesson is to understand the important physical properties of rocks and their determination, geological characteristics, general characteristics, modulus properties of rocks, building stones and their occurrences. The role of a geotechnical engineer is also highlighted**.**

1.0 Introduction :
Engineering properties of rocks is a collective nomenclature which includes all such properties of rocks that are relevant to engineering application after their extraction from natural beds or without extraction i.e. *insitu* conditions.The first set include all those properties for which a rock must be tested for selection as a material for construction such as a building stone, road stone or aggregate for concrete making.The second set of the properties include the qualities of a natural bed rock as and where it exists. That would determine its suitability or otherwise as a construction site for aproposed engineering project.

Obviously, in both cases, the economy and safety of an engineering project are greatly dependent upon the proper understanding and determination of theengineering properties of rocks.Engineering properties of rock are controlled by the discontinuities within the rock mass and theinherent properties of the intact rock. Therefore, engineering properties must account for the properties of the intact rock and for the properties of the rock mass as a whole.

A combination of laboratory testing of small samples, empirical analysis, and field observations should be employed to determine the requisite engineering properties. Rock properties can be divided into two categories: intact rock properties and rock mass properties. Intact rock properties are determined from laboratory tests on small samples typically obtained from coring, outcrops or exposures along existing cuts. Common engineering properties typically obtained from laboratory tests include specific gravity, point load strength, compressive strength, tensile strength, shear strength, modulus, and durability.

Rock mass properties are determined by visual examination and description of discontinuities within the rock mass. It should follow the suggested methodology of the International Society of Rock Mechanics (ISRM 1978), and how these discontinuities will affect the behavior of the rock mass when subjected to the proposed construction.

2.0 Physical properties of rocks:

In most of the engineering applications, rocks are used as building stones. A building stone may be defined as a rock that can be safely used as a rough unit or as a properly cut and shaped (dressed) block or slab or column or sheet in different situation in an engineering construction.The following physical properties are considered to be important for a rock to be used as a building material.

2.1 Crushing Strength

It is also termed as compressive strength of a stone. It may be defined as maximum force expressed per unit area which a stone can withstand. Any force beyond the compression strength will cause a failure of the stone. Mathematically, compressive strength is expressed by simpler method as follows

Where Compressive strength, *P*= Load at failure, *A* = Area of cross section of stone under *P*

The determination of compressive strength of a building stone involves making standard test specimens (which are either cubes of 5cm side or cylinders of length: diameter ratio of 2 or 2.5). These specimens are then loaded gradually one at a time after placing on the base plate of a universal testing machine, till the first crack appears in the specimen. Any further loading will crush the specimen.The compressive strength determined in this way using the above relationship is called “unconfined or universal compressive strength”. Because the test specimen has no lateral support or restraint.

When the compressive strength is tested by a method providing a lateral support , as by keeping the specimen in a special cell filled with a liquid under pressure. The value obtained, then it is called as confined or triaxial compressive strength.

The crushing strength of a rock depends on a number of factors, such as its

i. Mode of formation

ii. Composition

iii. Texture and structure

iv. Moisture content and

v .extent of weathering it has already suffered

Igneous rocksare crystalline rocks. They are compact and characterized by interlocking in texture and uniform in structure. These rocks possess very high crushing strengths compared to sedimentary and metamorphic rocks. In the sedimentary and metamorphic rocks, the presence of planes of weakness along bedding planes, foliation and schistosity and cleavage, greatly affects the compressive strength, both in direction and magnitude.

The sand stone may show a very low crushing strength when loaded parallel to bedding planes than when loaded perpendicular to the same structure.Except for sandstone, quartzite and most other sedimentary and metamorphic rocks are composed of clays, calcareous and hydrated silicate minerals which are inherently weak is strength.

Crushing strengths of common types of building stones are generally higher than the loads that they are supposed to withstand, in ordinary type of building constructions. The compressive strengths of some rocks and their range are as follows. They are expressed in Kg/cm2. Dolerite=1500-3500, Basalt= 1500-3500, Quartzite=1500-300, Granite= 1000-2500, Marbles=700-2000, Gneisses=500-2500, Sand Stone= 200-2500, Limestone= 200-2000.

During the last few years thousands of tests have been made to classify the rocks on the basis of uniaxial compressive strength in to grades. The following classification proposed by Deere and Miller has been found usefull.

Class Description Uniaxial compressive strength(Kg/cm2

A Very high strength More than 2240

B High strength 1120—2240

C Medium strength 500—1120

D Low strength 200—500

E Very low strength less than 200

2.2 Transverse strength:

It is defined as the capacity of the stones to withstand bending loads. Such loads are only rarely involved in situations where stones are commonly used. But when a stone is intended for use as a beam or a lintel, its transverse strength is determined as modulus of rupture using the following relationship.

R = Modulus of rupture; W = weight at which sample breaks; *l*= length of the specimen; *b* = width of specimen; *d* = thickness of the specimen.

This property is determined practically by loading transversely a bar shaped test specimen generallyof 20cmsx8cmx8cm dimension and is supported at ends from below.
It has been found that in stone, the transverse strength is generally 1/20th to 1/10th of their compressive strengths.

2.3 Shear Strength :

Shear strength is the resistance offered by a stone to shear stresses, which tends to move one part of a specimen with respect to the other. It is obtained by using the relationship. Shear strength of a stone is also not commonly determined except when the stone is to be used as a column
Where P = load at failure; A = area of cross section of the specimen.
It has been observed that shear strength of most common building stones ranges from 70 to 140 kg/cm2.
In laboratory testing, a bar shaped specimen is held with grip andis supported at ends below, is loaded from above. Rupture occurs when the shear strength is exceeded.

2.4 Tensile Strength:

Tensile strength of a rock is related to its ability to withstand breakage. It happens after some level. That level is its strength.It may be determined directly or indirectly. The tensile (pulling) strength that has to be applied to a material to break it. It is measured as a force per unit area.The direct method would require elaborate means to avoid bending while applying tensile forces by gripping the specimens at the ends. Since tensile stresses are seldom required accurately, an indirect method is commonly applied.
The indirect method is calledthe Brazilian test. It consists of loading a test cylinder diametrically in such a way that the applied loads would develop tensile rupturing along the diametrical plane of the specimen.
Loads are gradually increased till the cylinder fractures. The load *P*, at rupture being thus known. Transverse strength Ts is calculated by using the formula
D = diameter of the specimen; L = length of the specimen

2.5 Porosity :

The shape, size and nature of packing of the grains of a rock give rise to the property of porosity or development of pore spaces within a rock. Numerically it is expressed as the ratio between the total volume of pore spaces and the total volume of the rock sample. Porosity is commonly given in percentage terms. Presence of interlocking crystals, angular grains of various sizes and abundant cementing materials are responsible for low porosity of stones. Conversely the rock will be highly porous it composed of spherical or rounded grains, (sandstone) or if the cementing material is distributed unevenly or is of poor character.
Porosity is an important engineering property of rocks. It accounts for the fluid absorption value of the stones in most cases and also that a higher porosity signifies a lesser density which generally means a lesser compressive strength.
Porosity values for a few common building stones. Granite-0.1 to 0.5%, Basalt- 0.1 to 1%, Sandstone- 5 to 25%, Limestone- 5 to 20%, Marble- 0.5 to 2%, Quartzite- 0.1 to 0.5%,

2.6 Absorption Value:

It defines the capacity of a stone to absorb moisture when immersed in water for 72 hours or till it gets full saturation.It is generally expressed in percentage terms of original dry weight of the mass. . It maybe obtained from the relationship
Where Ws = weight at saturation; W0 = dry weight of the sample used.

2.7 Permeability:

It is the capacity of a rock to transmit water. Sand stones and limestones may show high values for absorption or 10% or even more. Selection of such highly porous verities of these stones for use in building construction, especially in most situations, would be greatly objectionable.
Presence of water within the pores not only decreases the strength of the rock but also makes the stones very vulnerable to frost action, in cold and humid climatic conditions.

2.8 Density :
It is defined as weight per unit volume of a substance.But in the case of rock it is not only the solid mineral matter which wholly accounts for the total volume of a given specimen.A part of the rock may comprise of pores or open spaces, which may be empty, partly filled or wholly filled with water. Accordingly, three types of density may be distinguished in rocks. They are a)Dry density, b) bulk density and c) saturated density.
1.**Dry density**: It is the weight per unit volume of an absolutely dried rock specimen, it includes the volume of the pore spaces present in the rock.
2.**Bulk density**: It is the weight per unit volume of a rock sample with natural moisture content where pores are only partially filled with water.
3.**Saturated density**: It is the density of the saturated rocks or weight per unit volume of a rock in which all the pores are completely filled with water.
The fourth type is also recognized as true density. Itis the weight per unit volume of the mineral matter(without pores and water) of which a rock s made up. The most engineering calculations, it is the bulk density which is used frequently.
Bulk density values in gram/cubic cm for some common building stones are granite-2.7, basalt-2.9, sandstone-2.6, and limestone-2.2 to 2.6.
2.9 Abrasive Resistance :
It is more a qualitative than a quantitative property. It may be broadly defined are the resistance which a stone offers to rubbing action of one kind or another.Determination of this is of considerable significance when stones are intended for use in situations where rubbing by natural or artificial causes is involved as a routine.Example a) stones used in paving along roads, b) Facing stones in buildings of arid region where strong sand laden winds are blown.These type of situations demand stones that have not only high abrasive resistance but also of essentially uniform, composition. So that thewear is as uniform as possible.
Stones composed of more than one mineral like granite may look quite appealing. In such cases, when freshly used, but within short time, they may get pitted or disfigured because of unequal wear of the different mineral components.
2.10 Frost and fire resistance
Many building stones show quick disintegration of building stones or rocks when used in situations involving frost formation (excessive cold) or heating. Frost causes disintegration by expansion of water on breezing within the rock pores.
In the case of fire, the unequal expansion in different mineral components and also at different depths from surface inwards may cause disintegration. This effect becomes more pronounced when the rock is first heated and then suddenly cooled by water by water. Heavy stones including granites crumble to piecesunder such a treatment. It is easy to understand that rocks which are found porous and weak in strength are easily deteriorated in cold humid climates by frost action. Limestone and sandstones fall in this category. They show very poor frost resistance.

Fire resistance is especially determined when the stone is intended for use around stoves, heating places and in the wall of furnaces. Only compact and massive sandstones and quartzites suite reasonably well in fire and heating places.

3.0 Methods of Determining and Rock Properties :

Subsurface rock properties are generally determined using one or more of the following methods:

- In-situ testing during the field exploration programme;
- Laboratory testing, and
- Back-analysis based on site performance data

3.0 In-Situ Field Testing :

The Geotechnical Engineers are expected to determine various soil and rock parameters under natural in-place conditions. This type of testing is useful for projects, where obtaining representative samples suitable for laboratory testing is difficult, such as those involving soft clays, loose sands and/or soils below the water table.

Common in situ tests are performed in conventional drilled borings, whereas specialized tests require a separate borehole or different insertion equipment. Field in situ borehole tests can be grouped into three categories:

a)Correlation Tests

- Standard Penetration Test (SPT)
- Dynamic Penetration Test (DPT)

b)Strength and Deformation Tests

- Penetrometers, such as Cone Penetrometer Test (CPT) and Piezocone
- Penetrometer Test (PQS)
- Pressure meters (PMT), such as Menard, Self-Boring, and Dilatometer
- stress or Shear Devices, such as Vane Shear and Borehole Shear Tests

c)Permeability Tests

- Pump Tests and Slug Tests
- Water Pressure Tests
- Hydraulic Conductivity Tests
- Percolation Tests

3.2 Laboratory Testing of Rock :

Rock strength is measured by laboratory testing. Strengths are very different depending on the stress field applied to the rock. All rocks and soils are very much stronger inpossessing compression strength than in tensile strength.

The two common laboratory tests to determine the compressive strength of rock are:

a)Uni-axial Unconfined Compression Test –In this method a cylindrical rock core is loaded axially until it fails.
b)Tri-axial Confined Compression Test – In this method a cylindrical rock core is placed in a cell, subjected to all around (confining) pressure by hydraulic oil acting through a thin impermeable membrane, and loaded axially to failure.

There are a variety of testsused to determine the tensile strength of rock:

- Direct Pull Test - A cylindrical rock core sample is anchored at both ends and stretched.
- Brazilian Test - A relatively thin disk is load across the diameter until it splits.
- Beam Flexure Test - A thin slab of rock is loaded vertically when supported at three or four points along its length.

3.3 Back-analysis based on site performance data:

Back-analysis is a quantitative approach to adjust soil or rock properties to match measureable site performance. Back-analysis is a method used to determine engineering properties of soil or rock. It is often used with geotechnical failures. When failures occur, back analysis can be used to model the conditions, and loads which resulted in failure. Back-analysis can also be used in some situations where failure has not occurred but the geotechnical performance can be quantified (e.g., deformations). Back-analysis is a quantitative approach to adjust soil or rock properties to match measureable site performance.

Most back-analyses in geotechnical engineering are based on methods that utilize field displacement monitoring data. Following are the methods of back analysis.

- Back-Analysis of Slopes
- Back-Analysis of Soil Settlement Resulting from Changes in Loading
- Back-Analysis of Foundations
- Use of Numerical Modeling for Back-Analysis

4.0 Geological characteristics of rocks

4.1 Mineralogical composition :

Rocks are made up of smaller units of the minerals. Their properties depend upon the nature and composition of these minerals. It has been observed that rocks composed chiefly of silica (SiO2) especially in free form, are the strongest in all respects Quartzites are the strongest in all respects.Fresh Quartzite, Sand Stone and granite are some of the examples.

Carbonate rocks show a wide variation in their properties. A particular deposit of these rocks has to be tested by taking random representative samples before the stone is recommended for use in engineering construction of any importance. Presence of some minerals even in small quantites is to be viewed with caution while using in building stones. These minerals are mica, gypsum, sulphides, tremolite, flint and chert and clays. These destroy the inherent strength of the rock.

4.2 Texture and Structure:
Texture defines the size, shape and mutual relationship of the mineral compounds in a rock. Whereas structure determines the development of large scale features in the rock mass as a whole. Rocks may be coarse grained, medium grained or fine grained.
The fine grained equigranular textured rocks are better building stones compared to coarse grained and inequigranular rocks. In the later cases different compounds often tend to behave as separate units under the imposed loads and thereby reaction offered is of a complexes and certainly weaker character.
Structurally speaking features like bedding planes, foliations, cleavage, joints and flow structures which might not be fully represented in small sized test specimens, but which may be present in rock masses on a large scale, have to be given due considerations.
4.3 Resistance to weathering (Durability):
It is essentially a geological character of a stone that is commonly determined by its composition, texture and structure on the one hand and the climate environment where the stone is ultimately used on the other hand.
A stone may remain almost fresh and untarnished for 500 years or more when used in the interior of a building. But the same stone used on the exterior might get pitted and weathered badly within 100 years.Good example is granite. Similarly, limestone used in building construction, in industrial townships may weather badly and quickly due to reaction with sulphorous acid polluted air. Whereas the same rock used only a little amount in temples and forts and historical buildings may last for centuries. An engineer and especially a town planner has to bear in mind this fact that rocks also live and sensitive to the environment in which they are placed.
Durability of a stone can be experimentally determined by subjecting the stone sample to disintegrating action of Sodium sulphate. Test specimens generally of 5cm side cubes, are dried perfectly and weighed. They are suspended in 14% solution of Sodium sulphate for 4 hours at 27 degree Celsius and then air dried and oven dried at 105degree Celsius. The stone samples are subjected to 30 such cycles and lots of weight determined which gives a measure of the durability of the rock. Greater the loss in weight after these cycles, poorer is the durability of the stone.
5.0 **General characteristics of rocks**: In addition to these engineering and geological properties of rocks, there are certain other characteristics that may add value or otherwise to them. They are a) cost, b) colour.

5.1Cost: It is an important consideration similar to engineering properties or geological character.A stone may be quite suitable for use in building construction on first two considerations, but still it may not find use for the simple reason that it is uneconomical.Cost of a building stone depends upon its availability, accessibility and workability. Good quality building stones are not available elsewhere.
Their transport from one place to another might be a very costly affair.The workability of a stone is understood the ease in effort and economy with which it can be extracted from its place of occurrence

and dressed to the desired dimensions and shapes. Harder and stronger rocks become costlieron these accounts.

5.2 Color: Color is the property of appears and gets involved only where the stone is used in construction exposed to public view.For stones to be used in foundations is dams or in situations where they are ultimately to be given covering, color of a rock has no relevance in its selection.

In the case of residential or official building, it becomes a property of major importance. The color of a rock is a geological character depending upon the type of rock and more precisely upon the composition of rock. Eg. Granites are light coloured, Basalt are dark, and Sandstone are lighter shades.

6.0 Modulus properties or Flexible strength or Elastic properties of rocks

The elasticity of rocks indicates their deformation under loads. The deformation is recovered when loads are removed. It is determined in accordance with Hook's law which states that in elastic substances stress is directly proportional to strain.

It is expressed by the relationship

Q/E=E

Where Q= stress, E= Strain, E= Modulus of elasticity, It is also termed as young's modulus.

It is tested for rocks by loading test specimens usually a cylinder of L/D ratio 2, Under uniaxial compression and sometimes tension.

The axial deformation i.e. change in parallel to stress direction is determined at the application of each increment of load using strain gauges. This process of loading and determining the strain is continued till the specimen actually breaks.

That is the ultimate limit up to which the specimen could be deformed. The limit up to which it remains elastic i.e. recovers the original shape when the load is removed is reached slightly earlier.

Rocks arehighlyanisotropic so far as their elastic constants are concerned. They show all varieties ranging from perfectly elastic to practically inelastic. This depends on their composition, texture and structures.It is possible to broadly group the rocks into three categories, based on their Modulus of elasticity.

6.1 Quasi elastic:

These are rocks in which the stress-strain relationship is expresses by almost a straight-line till the point of failure. Such rocks include massive, denselypacked uniformly structured verities of igneous sedimentary and metamorphic groups such as Syenites, Diorites,Dolerites, gabbros, basalts and quartzites.Quasi elastic rocks show E values ranging from 6x10 to the power of 5 to 11x 10 to the power of 5 kg/cm2.

6.2 Semi elastic Rocks:

Are coarse, grained slightly open packed with some porosity and very minor in any structure discontinuities. The semi elastic rock show E value range between 4x10 to the power of 5 to 6x10 to the power of 5 kg/cm2.

Coarse grained igneous rocks like granites, some massive compact sediments like Sandstones and dolomite may often show semi elastic properties. In this group the curve indicating the modulus of elasticity. Such a characteristic that is slope tends to decrease with increasing loads.

6.3 Non elastic Rocks :

Are those in which stress strain relationship tends to break in two zones.A initial zone of steep slope followed by a curve of least slope. These are open textured coarse grained and rich in structural discontinuities.Values of E obtained with such rocks are commonly of the order of less than 4x10 to the power of 5 kg/cm2.

7.0 Important Building stones

Any type of rock that satisfies the above considerations may be used as a building stone. Granites, Sand stones,Limestones, Marbles and Quartzites and others like Dolerites,Syenites, Basalts and Gneisses etc. are some of them are not available , because they do not possess all the requisite properties.

Let us see one by one…

7.1 Granites: These are the most commonly used building stones of all the igneous rocks.They generally possess all the essential qualities of a good building stone showing very high crushing strength, low absorption values, least porosity, interlocking texture, variety of appealing colors, and susceptibility to perfect polish.

Indian occurrence: India has got good reserves of granite and granitic rocks. The archean group of rocks of peninsular India are comprised chiefly of Gneisses and Granites

7.2 Sandstone: Massive sandstones consisting of closely interlocking and angular grains and free from structural defects find extensive use of building stones. Ferruginous and calcareous varieties should not be used for exterior work, especially in industrial towns. Argillaceous sandstones are generally weak in character. Massive varieties with siliceous cement possess sufficient strength and are easily workable.

Indian occurrence: India has got immense reserves of Sandstones fit for construction purposes. The most important supplies come from two important stratigraphical systems, namely the Vindhyan and Gondwana systems. Vindhyan sandstones are fine grained in texture and available in abundance in a variety of colours like white, cream and deep red and grey etc. They are easily quarried and economically workable.

These stones are available in a large area of the country for over 350,000 sq.kms extending from Bihar to Aravallis. Many buildings of Delhi, and Agra are built of these stones. No other rock formation of India posseses such as assemblages of characters rendering it so eminently suitable for building or architectural work.

The gondawana formations of India have also yielded very good quality of sandstones. The fine grained sandstones of Cuttack(known as Athgarh sandstones) have been used most widely and famous temples of Jaganathpuri are built of them. **7.3 Lime stones**: These sedimentary rocks are veryextensively used as building stones. It is not due to their physical properties. It is due to the crushing strength. They may be weak showing values much below 300 kg/cm2 or as strong as 1500 kg/cm2 or even more.A similar variation in other property like absorption, specific gravity and porosity may be observed.

The use of limestones as facing stones even if they are sufficiently hard should be avoided in situations where

a. The air is polluted with industrial gases

b. The air from sea can approach them easily.

The reason for first precaution is that sulphuric acid vapours contained in the industrial gases react with calcium carbonate of limestone producing gypsum (calcium sulphate) crystals. This change involves an increase in the volume and results in disintegration of the surface layer of the rock.Salt crystals, may be formed from moist air from sea and cause dampness and disintegration of the stone.

Indian occurrence: Lime stones occur in many geological formations of this country. i. The cuddapah system outcropping in Andhra, Chennai, Delhi and Chattisgarh, ii) The Bijawar, Kondalite and Aravalli groups iii) TheVindhyan system of Madhya Pradesh, vi)The hill limestone, exposed at many places in northern India.

7.4 Marbles: These are metamorphic rocks that are used for ordinary structural work as well as for decorative purposes.

Marbles are varying intheir texture, color and composition. Their absorption value is generally below 1% and normally they possess sufficient crushing strength.

They have been extensively used as decorative stones and this is because of their susceptibility to brilliant polish and beautiful colors.

Indian occurrence: Most important source of commercial marbles in the crystalline formations of Rajasthan. i) Makrana in Jodhpur-white and pink, ii) Kharva in Ajmer – green and yellow, iii) Kishengarh and Jaipur are famous for black and dense marbles.

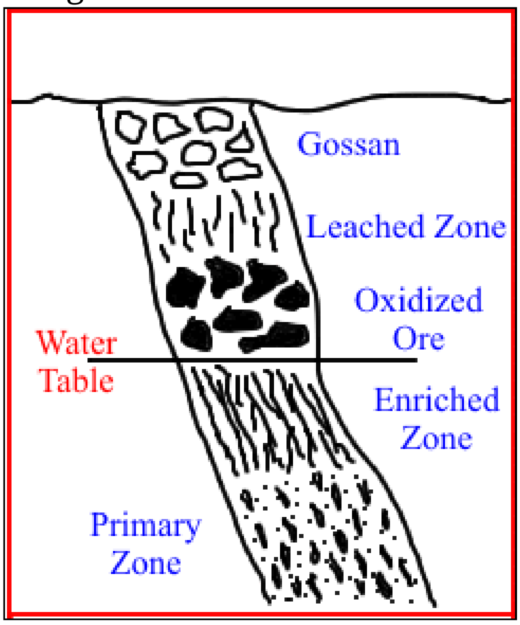
7.5 Slate: It is another metamorphic rock, characterized by a perfect cleavage and because of this property it does not find any use in building stones except for paving roofing purposes.

8.0 Conclusion :

- It is a well-known fact that rocks play a vital role in constructing the structures which are destined to be strong, appealing and economical.
- All the factors which have been considered so far give a clear guideline for an engineer to choose the right type of naturally occurring rocks or stones to be used to build such structures.
- By choosing all the properties judiciously in conjunction with one another, it is possible to adhere to the safety regulations prescribed in building standards. A combination of laboratory testing of small samples, empirical analysis and field observations should be employed to determine the requisite engineering properties.
- Engineering properties of rocks are very essential properties to be determined in every project of civil engineering, construction engineering and structural engineering.

Ore Deposits Formed by Oxidation and Supergene Enrichment

- When ore deposits are exposed to the oxidation zone they are weathered and altered with the country rocks.
- The surface waters oxidize many ore minerals and yield solvents that dissolve other minerals.
- An orebody thus becomes oxidized and generally leached of many of its valuable materials down to the groundwater table, or to depth where oxidation cannot take place.
- The effects oxidation may, however, extend far below the one of oxidation.
- As the cold, dilute, leaching solutions trickle downwards, they may lose a part or all of their metallic content within the zone of oxidation to give rise to oxidized ore deposits.
- The oxidized or near-surface part of an orebody is made colorful due to the oxidation of sulfides to oxides and sulfates.
- As the down trickling solutions penetrate the water table, their metallic content may be precipitated in the form of secondary sulfides to give rise to a zone of secondary or supergene sulfide enrichment.
- The lower, unaffected part of the orebody is called the hypogene zone.
- In some places the supergene zone is absent and in rare cases the oxidized zone may be shallow or lacking (as in some glaciated areas undergoing rapid erosion).



- Special conditions of time, climate, physiographic development and amenable ores are necessary for the process of oxidation and supergene enrichment to be effective.
- Such ores occur in most of the non-glaciated land areas of the world.

Secondary enrichment

An especially important class of residual deposit is formed by both the removal of

valueless material in solution and the solution and redeposition of valuable ore minerals. Because solution and redeposition can produce highly enriched deposits, the process is known as a secondary enrichment.
Secondary enrichment can affect most classes of ore deposit, but it is notably important in three circumstances:

1. The first circumstance arises when gold-bearing rocks--even rocks containing only traces of gold--are subjected to lateritic weathering. Under such circumstances, the gold can be secondarily enriched into nuggets near the base of the laterite. The importance of secondary enrichment of gold in lateritic regions was realized only during the gold boom of the 1980s, especially in Australia.
2. The second circumstance involves mineral deposits containing sulfide minerals, especially copper sulfides, that are subjected to weathering under desert conditions. Sulfide minerals are oxidized at the surface and produce sulfuric acid, and acidified rainwater then carries the copper, as copper sulfate, down to the water table. Below the water table, where sulfide minerals remain unoxidized, any iron sulfide grains present will react with the copper sulfate solution, putting iron into solution and precipitating a copper mineral. The net result is that copper is transferred from the oxidizing upper portion of the deposit to that portion at and just below the water table. Secondary enrichment of porphyry copper deposits in the southwestern United States, Mexico, Peru, and Chile is an important factor in making those deposits ores. Lead, zinc, and silver deposits are also subject to secondary enrichment under conditions of desert weathering.
3. The third circumstance in which secondary enrichment is important involves Banded Iron Formations and sedimentary manganese deposits. A primary BIF may contain only 25 to 30 percent iron by weight, but, when subjected to intense weathering and secondary enrichment, portions of the deposit can be enriched to as high as 65 percent iron. Some primary BIFs are now mined and beneficiated under the name taconite, but in essentially all of these deposits mining actually commenced in the high-grade secondary-enrichment zone. Sedimentary manganese deposits, especially those formed as a result of submarine volcanism, must also be secondarily enriched before they become ores.

Effects of Oxidation & Supergene Enrichment:

- Effects of oxidation on mineral deposits are profound - the minerals are altered and the structure is obliterated.
- The metallic substances are leached or altered to new compounds which require different metallurgical treatment for their extraction unlike that employed for the extraction for the unoxidized ore.
- The texture and type of deposits are obscured. Compact ores are rendered cavernous, ubiquitous limonite obscures everything and imparts to the gossan the familiar rusty color. The effects are therefore:

1) To render barren the upper parts of many ore deposits.

2) To change minerals into more usable or less usable form or to make rich bonanzas.
3) Supergene enrichment may add much where there was little.
4) Leaner parts of the vein may be made rich.
5) Unworkable protore may be enriched to the ore grade. E.g. many of the copper districts would not have come into existence except for the process of enrichment.

- Water with dissolved and entangled oxygen is the most powerful oxidizing agent, but carbon dioxide also plays n important role.
- Locally chlorides, bromides and iodides also play an important role.
- These substances react with certain minerals to yield strong solvents, such as ferric sulfate and sulfuric acid.
- Sulfuric acid, in turn, reacting with sodium chloride yields hydrochloric acid, with which iron yields the strongly oxidizing ferric chloride.
- Bacteria also promote oxidation, they oxidize ferrous iron to ferric iron at low pH.

Oxidation & Solution in the Zone of Oxidation:

- Supergene oxidation and reduction enrichment go hand in hand. Without oxidation there can be no supply of solvents from which minerals may later be precipitated in the two zones.
- The process operates in three stages:

1) Oxidation & solution in the zone of oxidation
2) Deposition in the zone of oxidation
3) Supergene sulfide deposition

Chemical Changes:

- There are two main chemical changes within the zone of oxidation:
    a) Oxidation, solution and removal of the valuable material.
    b) Transformation, in situ, of metallic minerals into oxidized compounds.

- Most metallic minerals contain pyrite, which rapidly yields sulfur to form iron sulfate and sulfuric acid:

$$FeS_2 + 7O + H_2O \rightarrow FeSO_4 + H_2SO_4$$

$$2FeSO_4 + H_2SO_4 + O \rightarrow Fe_2(SO_4)_3 + H_2O$$

- The ferrous sulfate readily oxidizes to ferric sulfate and ferric hydroxide:

$$6FeSO_4 + 3O + 3H_2O \rightarrow Fe_2(SO_4)_3 + 2Fe(OH)_3$$

- The ferric sulfate hydrolizes to ferric hydroxide and sulfuric acid:

$$Fe_2(SO_4)_3 + 6H2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4$$

- Ferric sulfate is also a strong oxidizing agent and attacks pyrite and other sulfides to yield more ferrous sulfate:

$$Fe_2(SO_4)_3 + FeS_2 \rightarrow 3FeSO_4 + 2S$$

- The ferric hydroxide changes over to hematite and goethite and forms the ever present "limonite" that characterizes all oxidized zones;
- The part played by ferric sulfate as a solvent can be seen by the following reactions:

Pyrite	$FeS_2 + Fe_2(SO_4)_3 \rightarrow 3FeSO_4 + 2S$
Chalcopyrite	$CuFeS_2 + 2Fe_2(SO_4)_3 \rightarrow CuSO_4 + 5FeSO_4 + 2S$
Chalcocite	$Cu_2S + Fe_2(SO_4)_3 \rightarrow CuSO_4 + 2FeSO_4 + CuS$
Covellite	$CuS + Fe_2(SO_4)_3 \rightarrow 2FeSO_4 + S$
Sphalerite	$ZnS + 4Fe_2(SO_4)_3 + H_2O \rightarrow ZnSO_4 + 8FeSO_4 + 4H_2SO_4$
Galena	$PbS + Fe_2(SO_4)_3 + H_2O + 3O \rightarrow PbSO_4 + 2FeSO_4 + H_2SO_4$
Silver	$2Ag + Fe_2(SO_4)_3 \rightarrow Ag_2SO_4 + 2FeSO_4$

- Most of the sulfates formed are readily soluble, and these cold dilute solutions slowly trickle downwards through the deposit till the proper Eh-pH conditions are met to cause deposition of their metallic content.
- If pyrite is absent in deposits undergoing oxidation, only minor mounts of solvents are formed, and the effects are mild. This is illustrated in the New Cornelia Mine, Ajo, Arizona.
- A country rock of limestone tends to inhibit migration of some sulfate solutions.

Deposits in the zone of oxidation: When the oxidised zone is well developed and the secondary minerals sufficiently concentrated, it is a highly profitable zone to mine as the processing is much cheaper and easier and the metals more concentrated. However, most oxidised zones have been mined because they formed outcrops of easily identifiable gossans. The most common minerals found in oxidised zones are:

Copper: malachite, azurite, chrysocolla
Gangue minerals: quartz (usually cryptocrystalline), baryte, calcite, aragonite
Iron: goethite, hematite
Lead: anglesite, cerussite
Manganese: pyrolusite, romanechite, rhodochrosite
Nickel: gaspeite, garnierite
Silver: native silver, chlorargyrite
Zinc: smithsonite

Deposits in the zone of supergene enrichment: In the supergene zone metals are concntrated in a narrow band just below the water table. This is the richest part of an ore deposit but in many instances, is either only very thin or not developed at all. The most common minerals found in supergene zones are:

Copper: chalcocite, bornite
Lead: supergene galena

Nickel: violarite
Silver: acanthite, native silver
Zinc: supergene sphalerite, wurtzite

Mechanical Concentration

Mechanical concentration is a process by which heavy minerals are separated from light ones by moving water or air and concentrated in the form of placer deposits. It, thus, includes two steps

a) *separation of heavy and stable minerals from mother rock by the process of weathering, and*

b) *their accumulation at suitable site.*

The source materials of the placer deposits may be lode deposits including veins and stringers, disseminated ore minerals, rock forming minerals and earlier placer deposits such as buried placers or bench stream gravels. A continuous supply of placer minerals is essential for mechanical concentration. The placer minerals have high specific gravity, and are durable and resistant to weathering.

Process

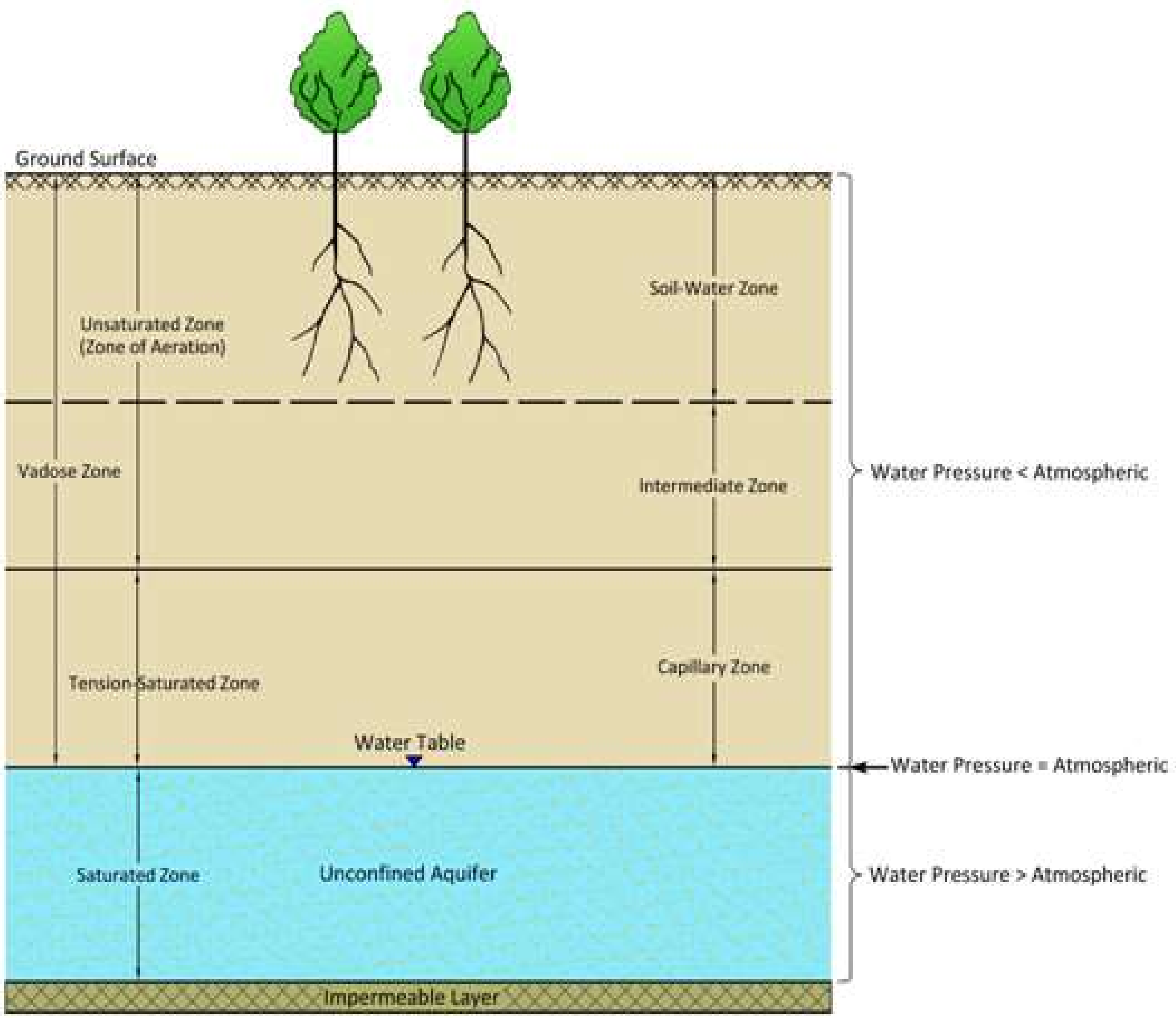
The placer minerals after release from the source materials by weathering are washed downslope to the nearest stream or to the seashore. The moving stream water takes away the lighter matrix to the farthest distance, while the heavies sink to the bottom and lag in their travel.

The short currents and waves also separate heavy minerals from light ones. The heavies, thus, concentrate in the stream or beach gravels in sufficient amounts to form placer deposits. The process of concentration is dependent upon the difference in specific gravity, size and shape of particles. A heavier mineral sinks more rapidly than a lighter one of the same size. The shape and size of particles determine their specific surfaces which decide the rate of settling in water. Lesser specific surface means lesser friction and causes rapid settling, the weights of particles remaining the same. For example, a spherical body having less specific surface compared to a thin platy disc of the same weight, sinks more quickly. Velocity of moving water is the added factor which affects mechanical concentration. With the increase in velocity of water, the transporting power is increased and the material is carried away to a great distance. With its decrease, much of the transported load is dropped. In case the water velocity is too low, the lighter materials will not be removed from the heavier; and if it is too high, the placer minerals will be swept away and lost. Hence, water velocity must be favourable to cause concentration of placer minerals.

Resulting Placers

The placers are known as eluvial in case of their concentration on hill slope, stream or alluvial if concentrated in stream and beach when on beaches. They are known as colian placers in case of their concentration by wind action. Obviously eolian placers occur in arid regions, e. g. eolian gold placers of Australian deserts. Eluvial placers of tin-ore (cassiterite) are reported in the foot hills of some hillocks of Tongpal-Leda-Kudripal area, Bastar district, M. P. Corundum though in small amounts, occurs as eluvial placers in Bastar and Morena districts of Madhya Pradesh. Stream or alluvial placers are known to have been worked for gold in Sona, Subarnrekha and South Koel basins of Bihar and at numerous places in the country. The beach placers of Quilon district, Kerala; Kanyakumari district, Tamil Nadu and Ganjam district, Orissa are being worked for monazite, zircon, ilmenite and rutile.

Vertical distribution of ground water



- In order to understand the occurrence of groundwater and its vertical distribution, let's first consider the hydrological zones present below the ground.
- The zone between the ground surface and the top of capillary fringe is called unsaturated zone (or, zone of aeration) which

consists of voids (pores or interstices) partially filled with water and partially with air.

- Water is held at a pressure less than the atmospheric pressure in the unsaturated zone.
- The zone between bottom of the unsaturated zone and top of the water table is called capillary zone, wherein most voids are filled with water but the water is held at a pressure less than the atmospheric pressure.
- Finally, the zone extending from the water table to an impermeable layer is called saturated zone (or, zone of saturation), wherein all voids are completely filled with water.
- In this zone, water is held at a pressure greater than the atmospheric pressure, and hence it moves in a direction based on the contiguous hydraulic situation.
- The unsaturated zone can be further sub-divided into 'soil-water zone' and 'intermediate zone' (Todd, 1980). The zone between the ground surface and the top of water table is known as the vadose zone.
- Thus, the vadose zone consists of unsaturated zone and capillary zone (also known as 'capillary fringe'). The water present in the vadose zone is called vadose water which is held at a pressure less than the atmospheric pressure.
- Hence, while this water is still able to move within the vadose zone due to matric potential and gravity, it cannot move out of the zone into wells, pits, or other water collection systems that are exposed to the atmospheric pressure.
- Note that the term vadose zone is technically more appropriate than the conventional term unsaturated zone. This is because

portions of the vadose zone may actually be saturated, even though the pressure of water is below the atmospheric pressure.

- Hence, the term vadose zone has become popular and is widely used these days in the fields of groundwater hydrology and soil physics.
- Broadly speaking, the water stored in the zone of saturation is called groundwater.
- Not all underground water is groundwater, rather only free water or gravitational water, the water that moves freely under the force of gravity into wells, constitutes the groundwater.

HYDROGEOLOGY

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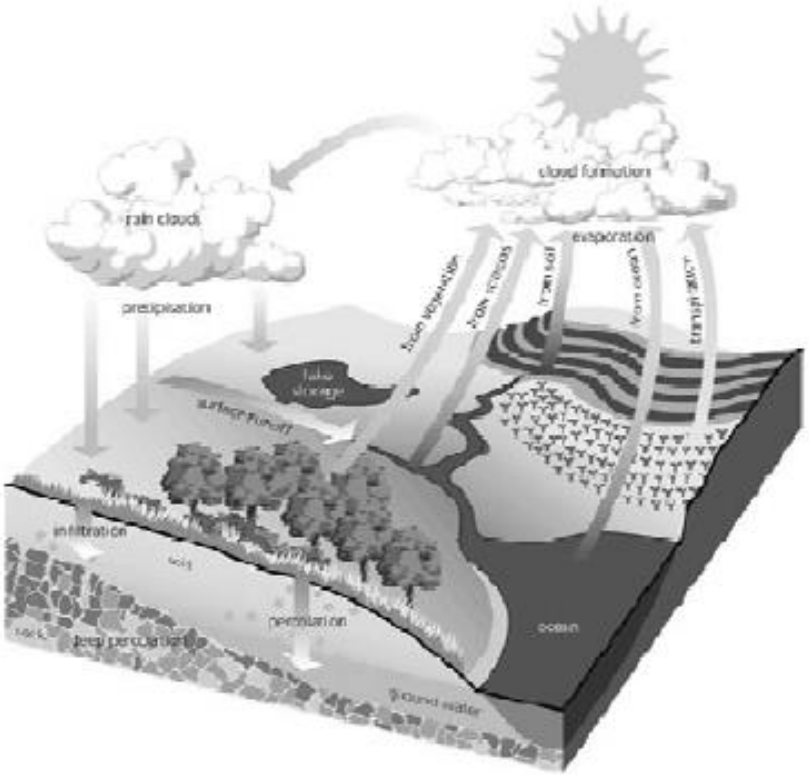
Reference text:
Hydrogeology
Groundwater - Freeze, R.A and Cherry, J.A,
Groundwater Hydrology – David Keith Todd
Groundwater -- H.M. Raghunath

- **Hydrology and Hydrogeology**
- **Hydrology**
- Science of occurrence, movement and transport of water
- **Hydrogeology**
- Hydrogeology deals with the occurrence, distribution, movement of water and its constituents (quality of water) beneath the Earth's surface
- that is groundwater

- Hydrogeology is an interdisciplinary subject
- ►**Involving**
- ▯ ▯ Geology
- ▯ ▯ Hydrology
- ▯ ▯ Chemistry
- ▯ ▯ Mathematics
- ▯ ▯ Physics
- ▯ ▯ Computing
- ▯ ▯ Engineering
- ▯ ▯ Agriculture
- ▯ ▯ Etc.
- Scope of Hydrogeology
- ► Important resource
- **Agriculture**
- **Industry**
- **Domestic**
- **Global Distribution of Water**
- Oceans
- **Ocean water: 97.2%**
- **Fresh water: 2 8%**

Hydrologic Cycle



The cyclic movement of water through atmosphere, Hydrosphere,Bio sphere and Lithosphere

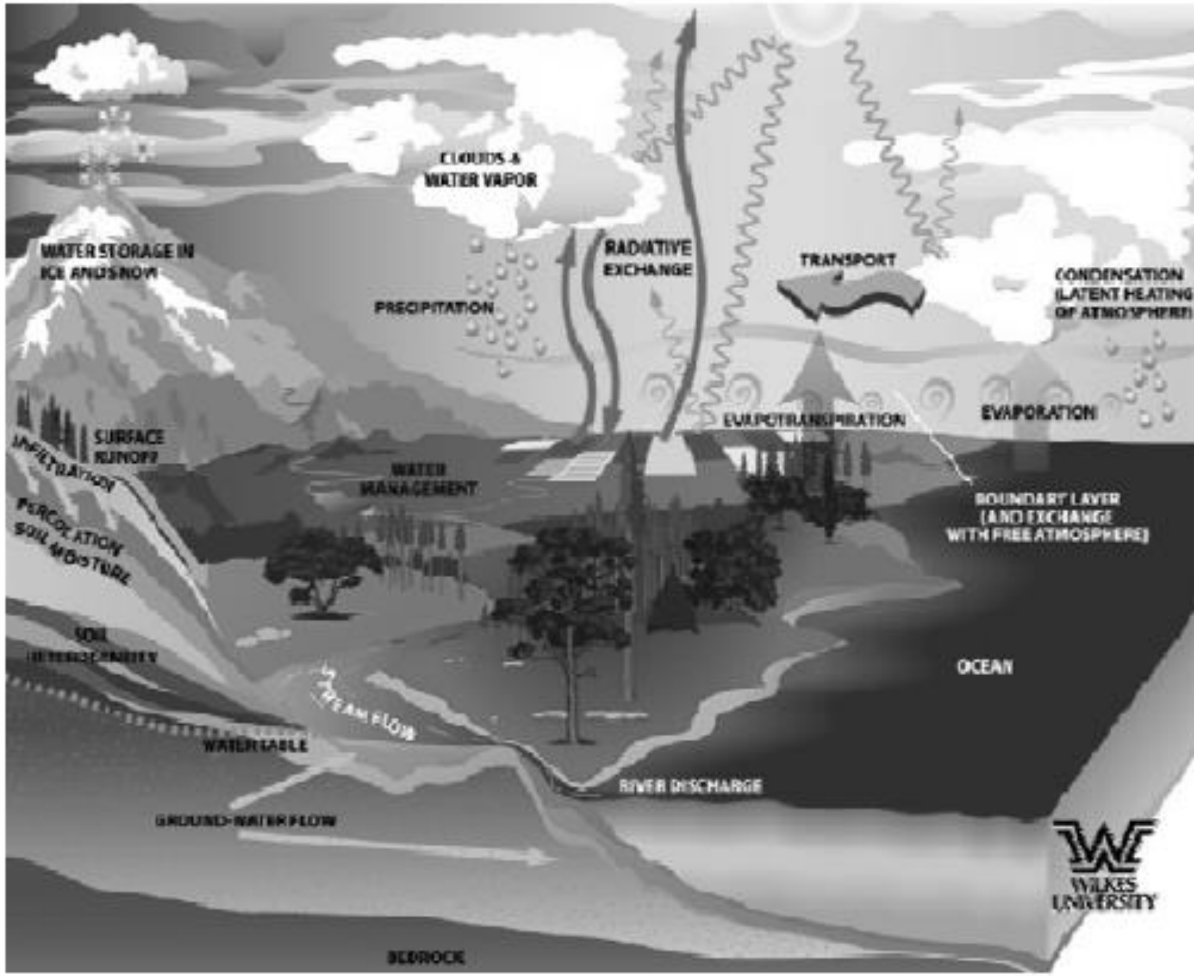
Components of the Water Cycle

Ins

Solar Energy Input
Precipitation
Condensation
Well Injection
Irrigation

Outs

Evaporation
Transpiration
Infiltration
Percolation
Runoff
Groundwater Flow
Surfacewater Flow
Well Pumping



Powered by the Sun- Solar Power

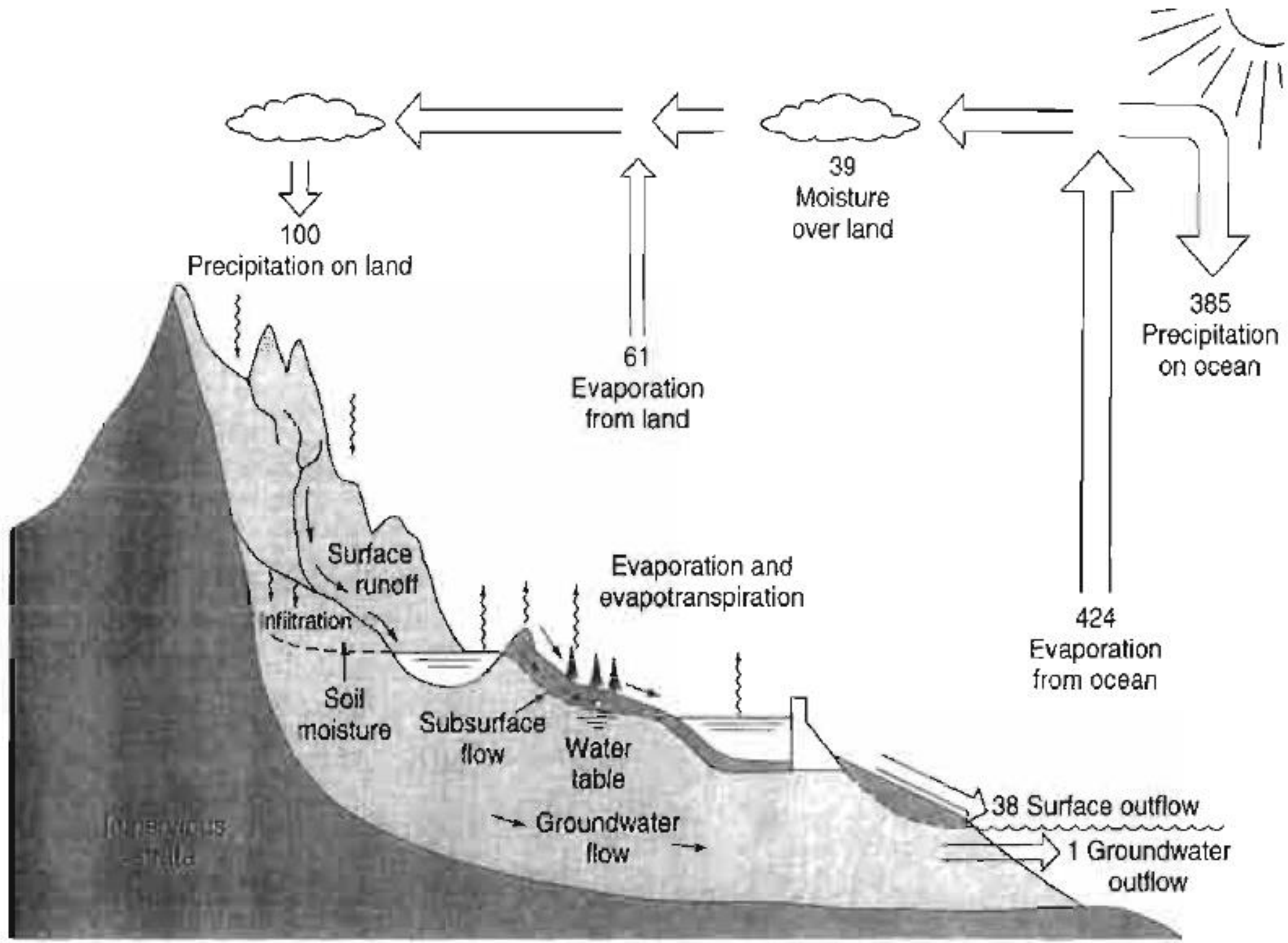


Figure 1.5.1. Hydrologic cycle with global annual average water balance given in units relative to a value of 100 for the rate of precipitation on land.[22]

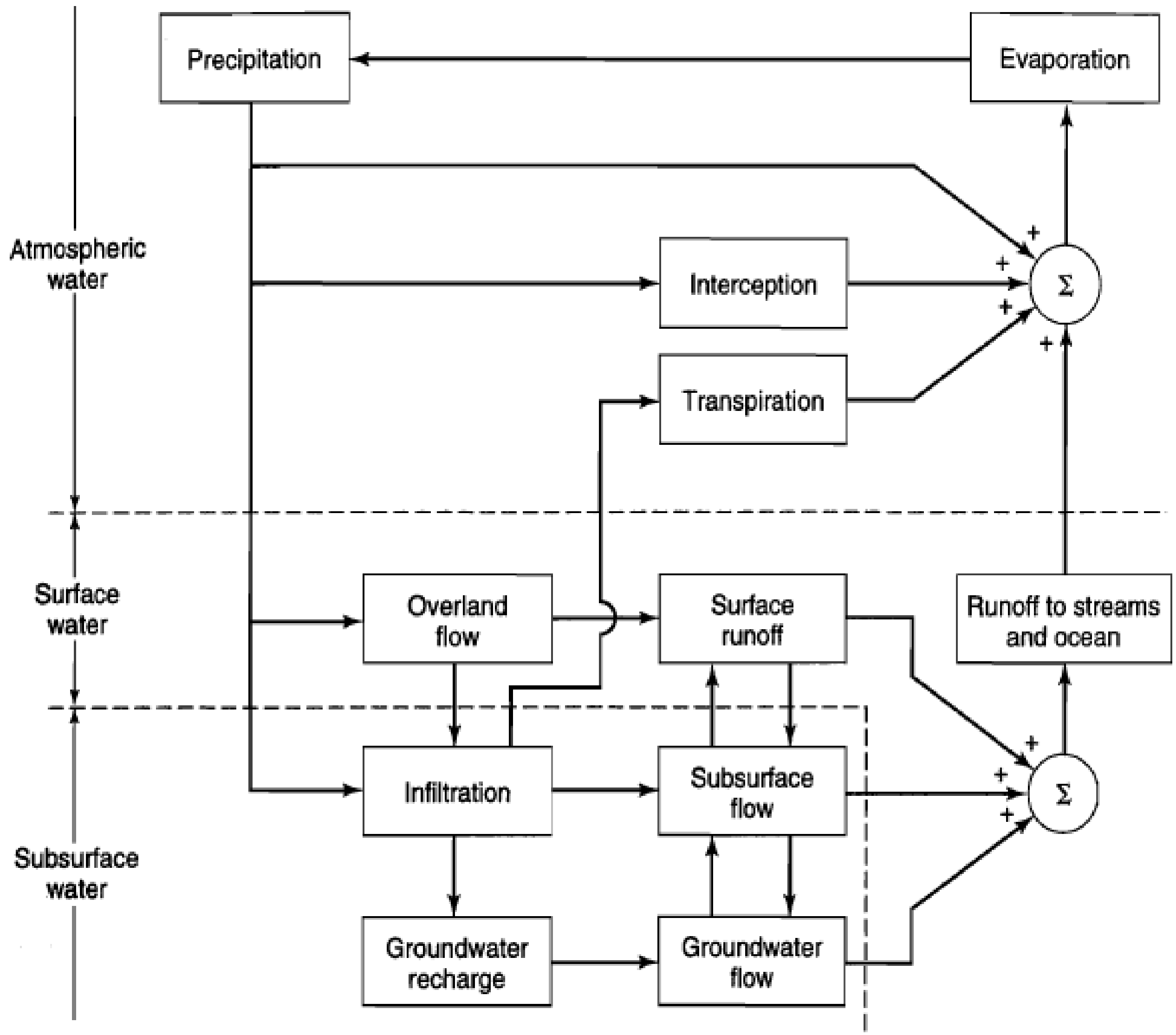


Figure 1.5.2. Block-diagram representation of the global hydrologic system.[22]

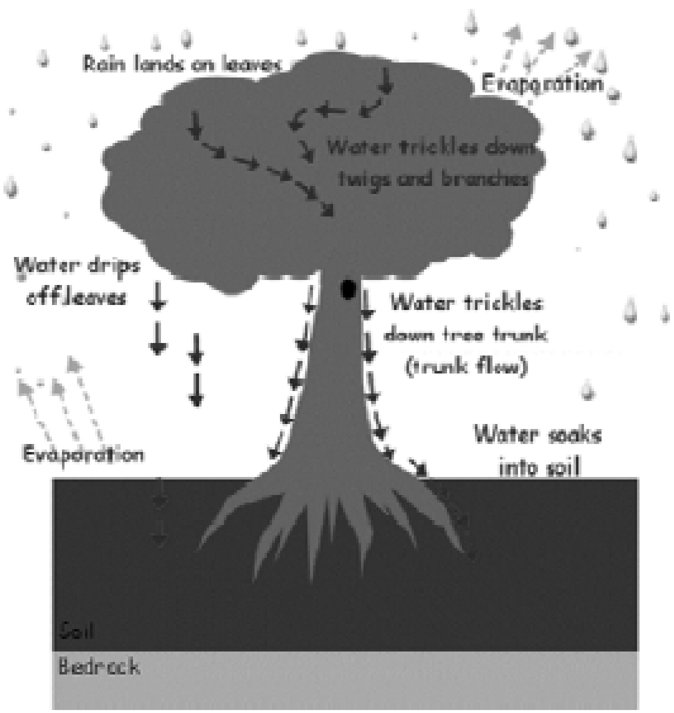
Precipitation

Types of Precipitation

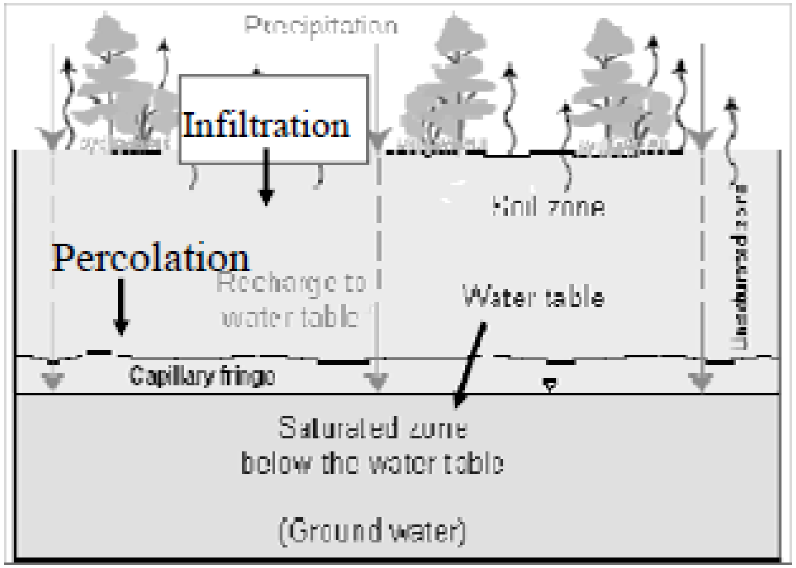
Natural
Rain
Snow
Ice
Hail
Condensation/ Dew

Man-Made
Irrigation
Wastewater Applications

Interception
Infiltration / Percolation



Canopy Interception

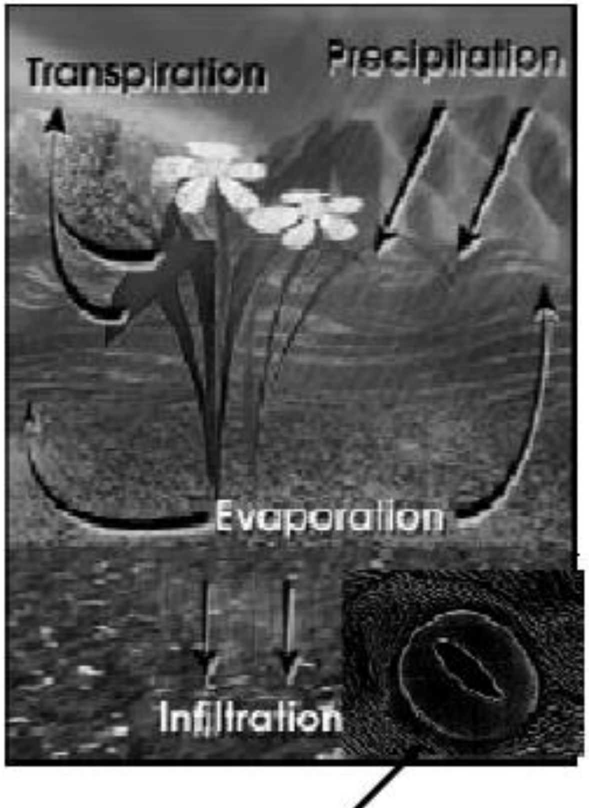


Infiltration- Movement Water Into Soil

Percolation - Water Movement Through the Soil

Evaporation / Transpiration
Evapotranspiration

Evaporation- Driven by Thermal Gradient and Moisture Difference



Stomata

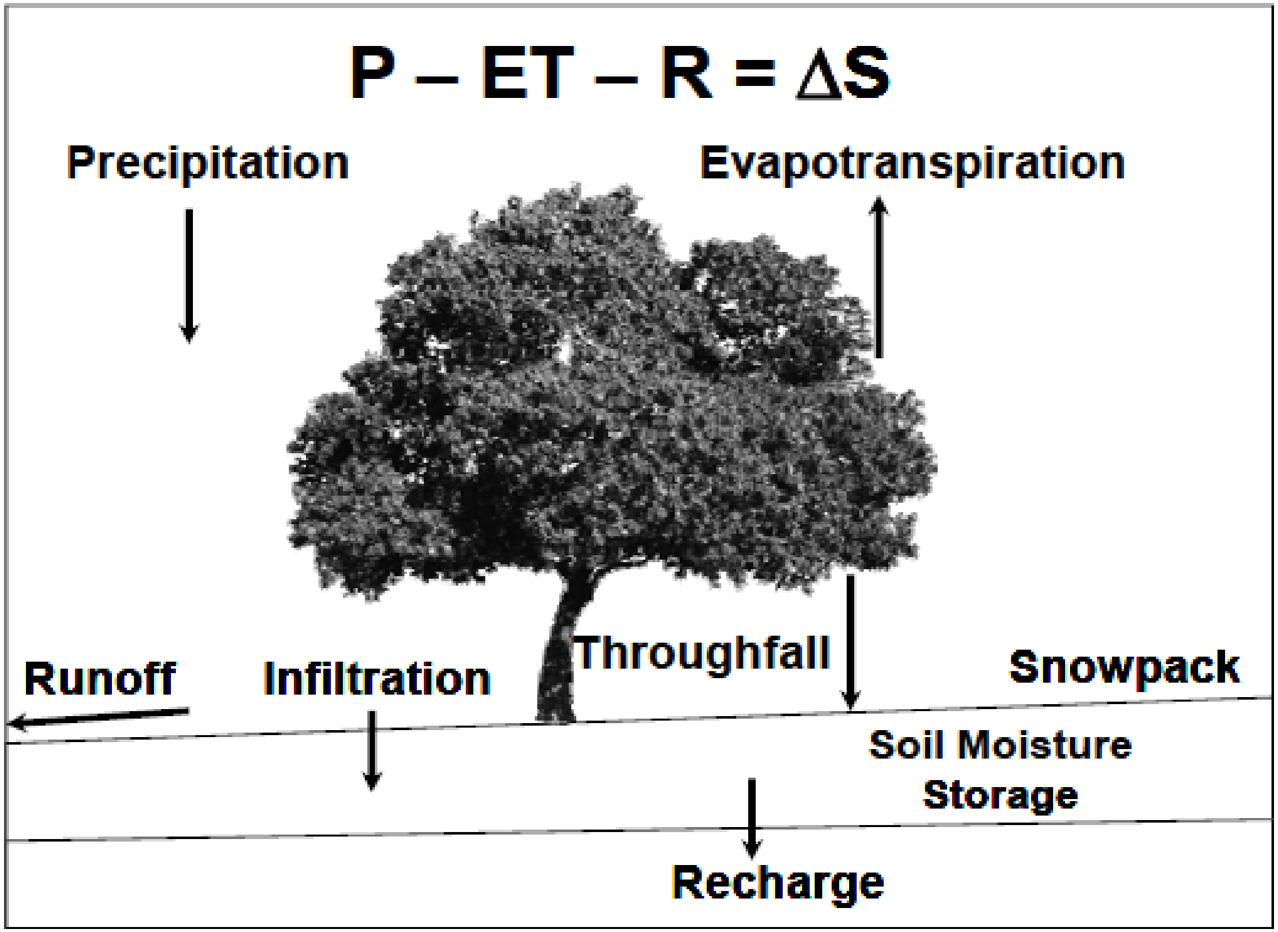
Runoff / Overland Flow

Uncontrolled Runoff
Causes Erosion

Low Infiltration
Causes - Overland Flow- Loss
Organic Material

When Rainfall Rate Exceeds Infiltration Runoff is Generated

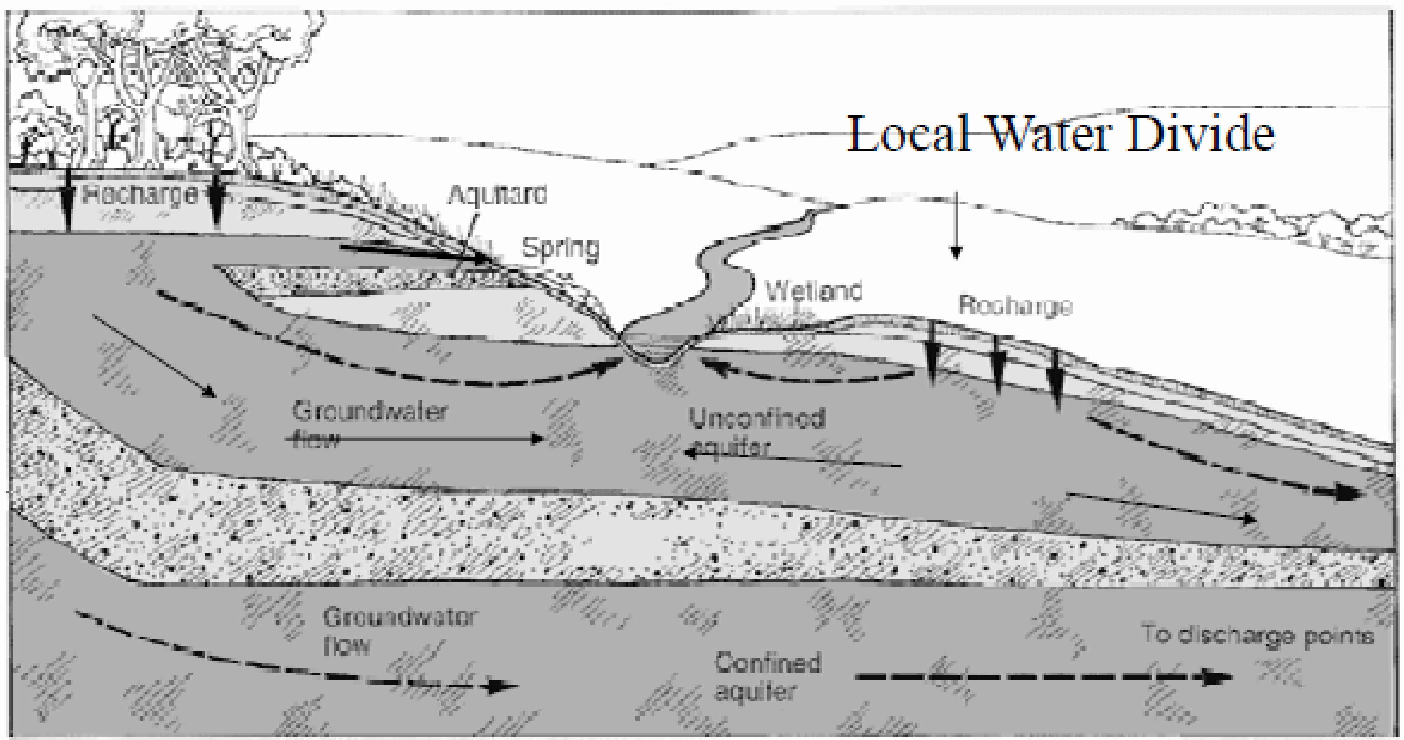
The Water Budget: Law of Mass Conservation



Input – Output = Change in Storage

Importance of spatial and temporal variability

Surface Water & Groundwater are Related and Connected !



2.1 ORIGIN AND AGE OF GROUNDWATER

Almost all groundwater can be thought of as a part of the hydrologic cycle, including surface and atmospheric (meteoric) waters. Relatively minor amounts of groundwater may enter this cycle from other origins.

Water that has been out of contact with the atmosphere for at least an appreciable part of a geologic period is termed *connate water;* essentially, it consists of fossil interstitial water that has migrated from its original burial location.[62] This water may have been derived from oceanic or freshwater sources and, typically, is highly mineralized.[20] *Magmatic water* is water derived from magma; where the separation is deep, the term *plutonic water* is applied, while *volcanic water* designates water from relatively shallow depths (perhaps 3 to 5 km).[61] New water of magmatic or cosmic origin that has not previously been a part of the hydrosphere is referred to as *juvenile water.* And finally, *metamorphic water* is water that is or has been associated with rocks during their metamorphism. The diagram in Figure 2.1.1 illustrates the interrelations of these genetic types of groundwater.

The residence time of water underground has always been a topic of considerable speculation. But with the advent of radioisotopes, determinations of the age of groundwater have become possible. Hydrogen-3 (tritium) and carbon-14 are the two isotopes that have proved most useful. Tritium with a half-life of 12.33 years is produced in the upper atmosphere by cosmic radiation; carried to earth by rainfall and hence underground, this natural level of tritium begins to decay as a function of time, such that

$$A = A_o e^{-\lambda t} \tag{2.1.1}$$

where A is the observed radioactivity, A_o is the activity at the time the water entered the aquifer, λ is the decay constant, and t is the age of the water. Carbon-14 has a half-life of 5,730 years and is also produced at an established constant level in the atmosphere. This isotope is present in groundwater as dissolved bicarbonate originating from the biologically active layers of the

Sources of Groundwater

- Meteoric water- derived from rainfall
- Connate water- fossil interstitial water
- Magmatic water or Juvenile water- from hot molten magma
- Plutonic water- very deeper condition (>5km)
- Volcanic water- shallow depths (<5km)
- Metamorphic water- during metamorphism

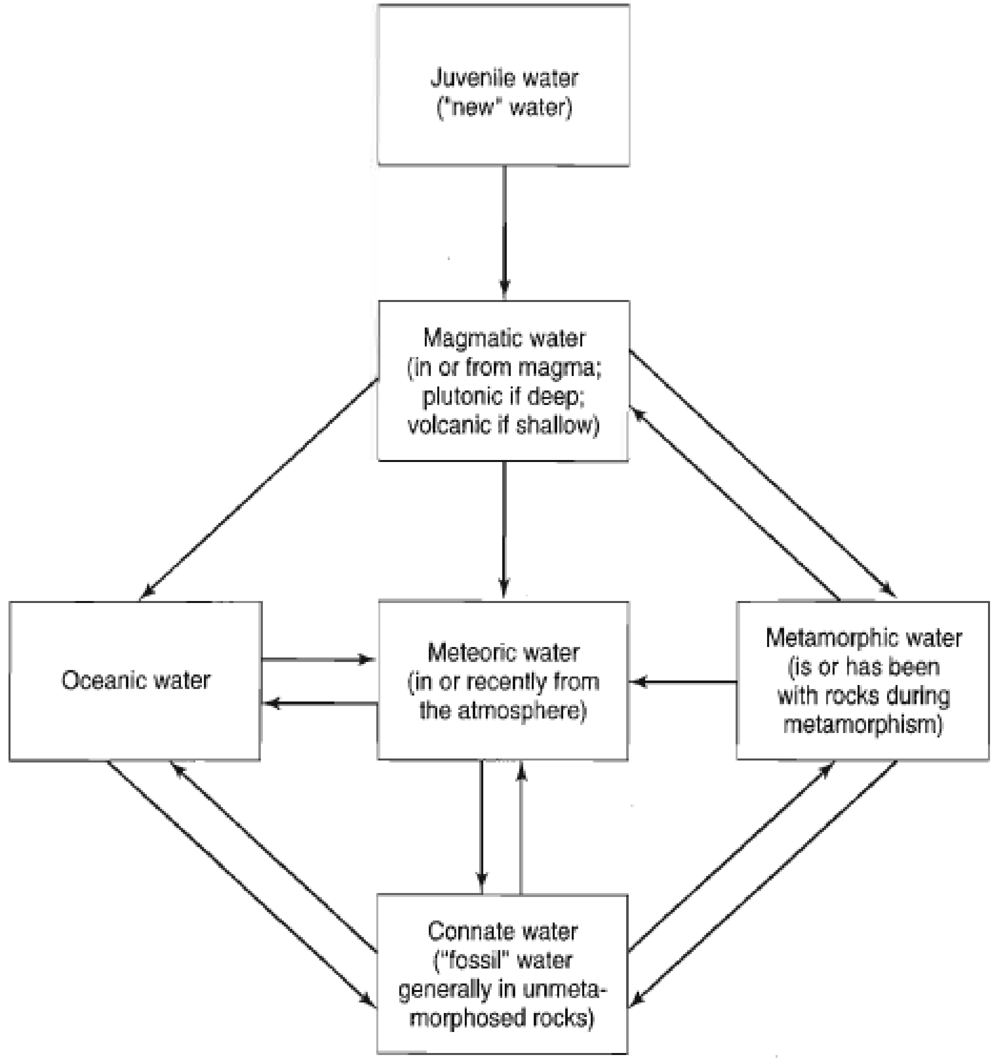
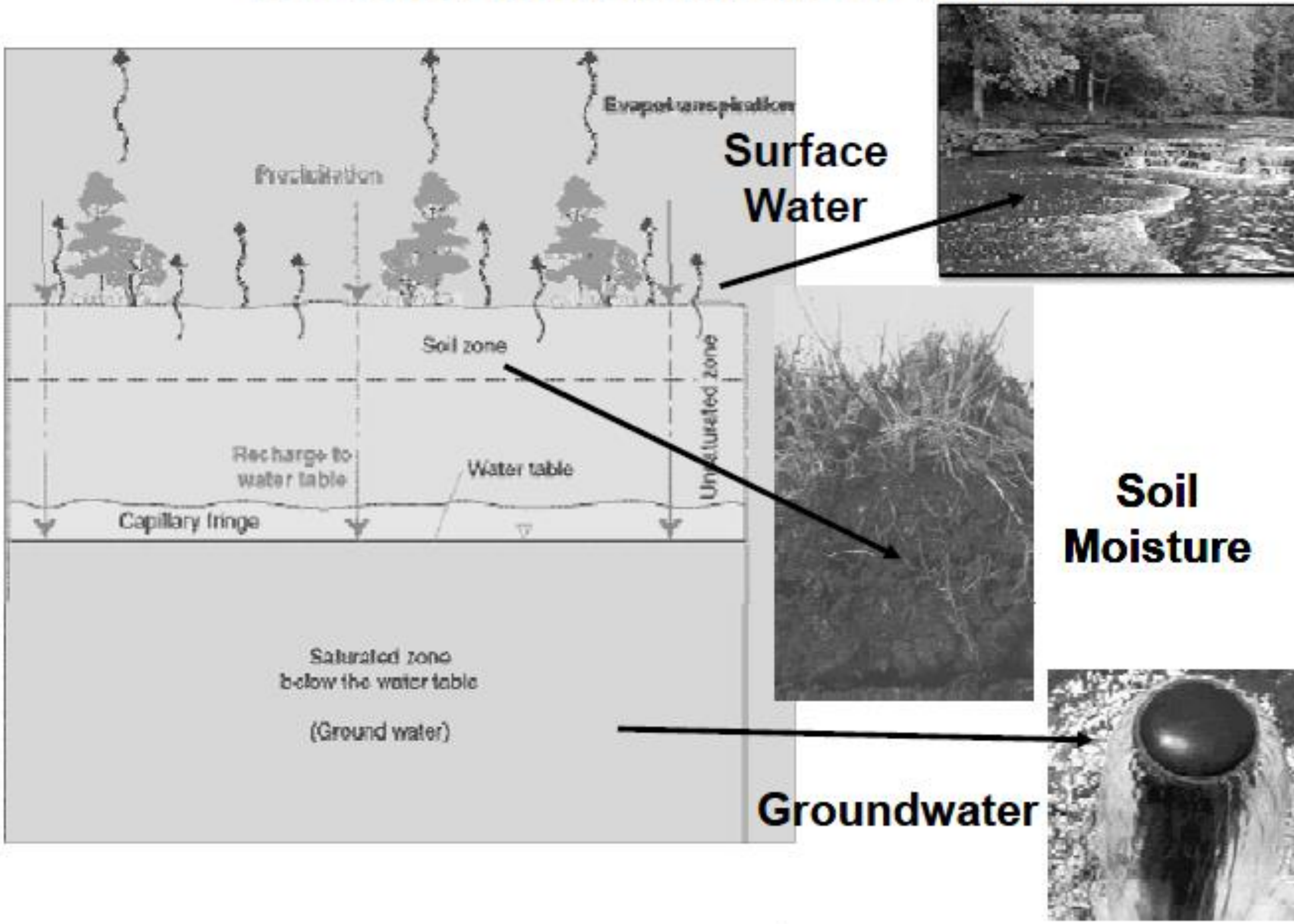


Figure 2.1.1. Diagram illustrating relationships of genetic types of water[62] (courtesy The Geological Society of America, 1957).

Vertical distribution of Water



VERTICAL DISTRIBUTION OF GROUNDWATER

The subsurface occurrence of groundwater may be divided into zones of aeration and saturation. The *zone of aeration* consists of interstices occupied partially by water and partially by air. In the *zone of saturation*, all interstices are filled with water under hydrostatic pressure. On most of the land masses of the earth, a single zone of aeration overlies a single zone of saturation and extends upward to the ground surface, as shown in Figure 2.3.1.

In the zone of aeration, *vadose water** occurs. This general zone may be further subdivided into the *soil water zone*, the *intermediate vadose zone*, and the *capillary zone* (Figure 2.3.1).[14]

The saturated zone extends from the upper surface of saturation down to underlying impermeable rock. In the absence of overlying impermeable strata, the *water table,* or *phreatic surface,*† forms the upper surface of the zone of saturation. This is defined as the surface of atmospheric pressure and appears as the level at which water stands in a well penetrating the aquifer. Actually, saturation extends slightly above the water table due to capillary attraction; however, water is held there at less than atmospheric pressure. Water occurring in the zone of saturation is commonly referred to simply as *groundwater,* but the term *phreatic water* is also employed.

**Vadose* is derived from the Latin *vadosus* ("shallow").

†*Phreatic* is derived from the Greek *phrear*, *-atos* ("a well").

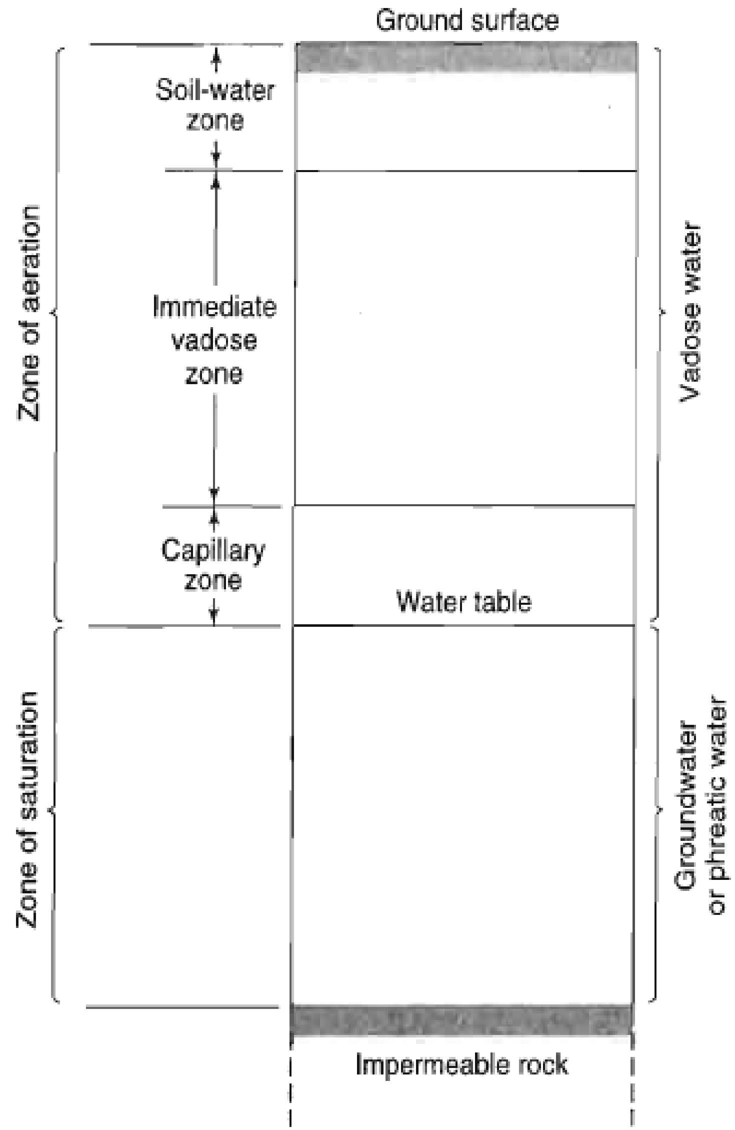
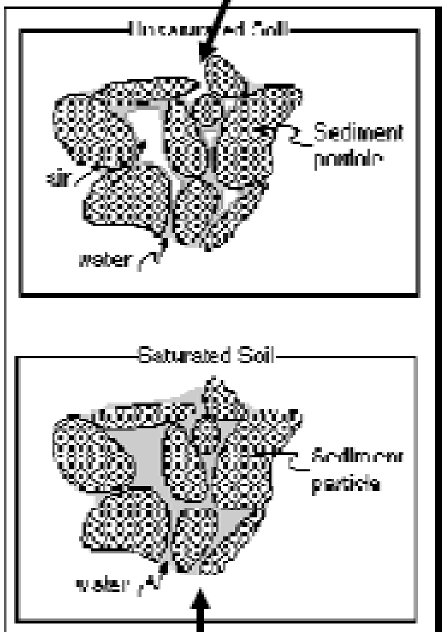
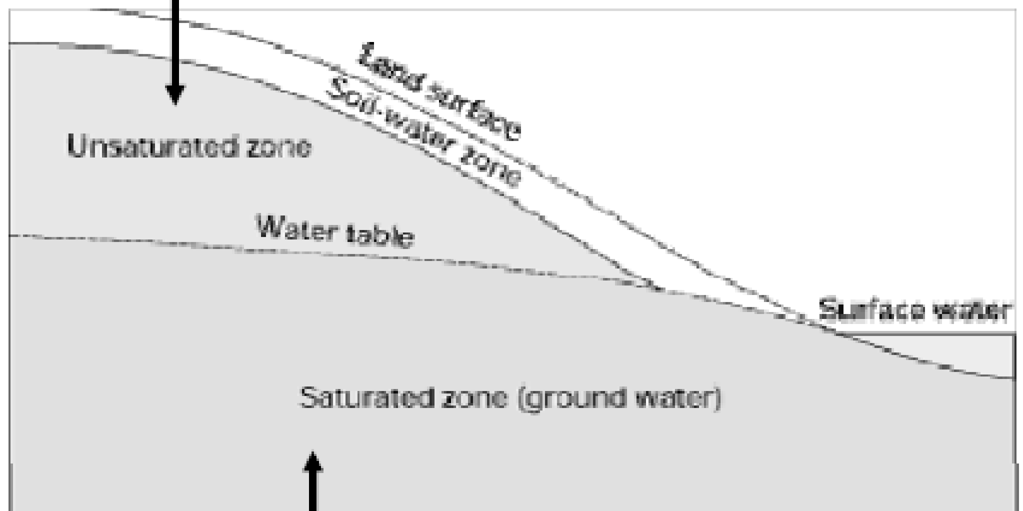


Figure 2.3.1. Divisions of subsurface water.

Pores Full of Combination of Air and Water

Unsaturated Zone – Zone of Aeration





Zone of Saturation

Pores Full Completely with Water

Soil and Groundwater Zones

Unsaturated Zone:

Water in pendular saturation

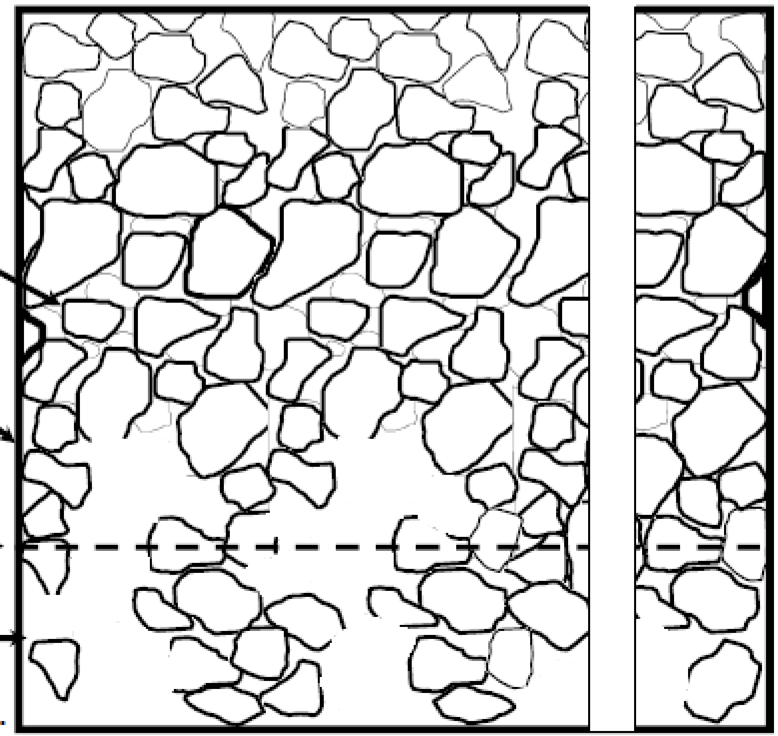
Caplillary Fringe:

Water is pulled above the water table by capilary suction

Water Table: where fluid pressure is equal to atmospheric pressure

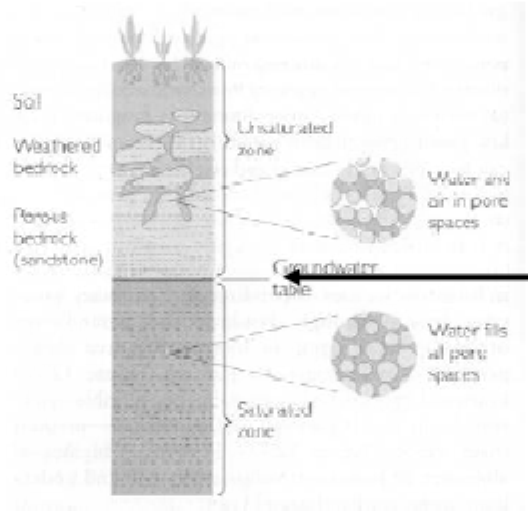
Saturated Zone:

Where all pores are completely filled with water.

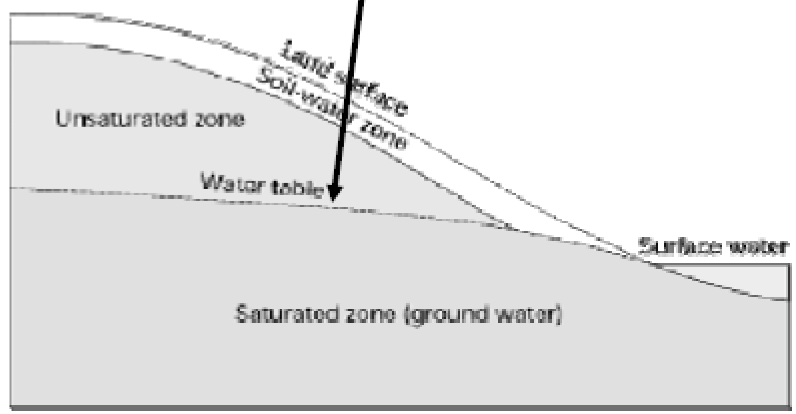


Phreatic Zone: Saturated zone below the water table

The Water Table

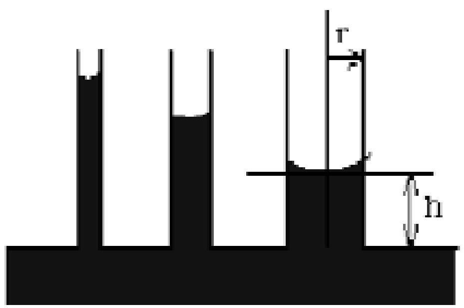


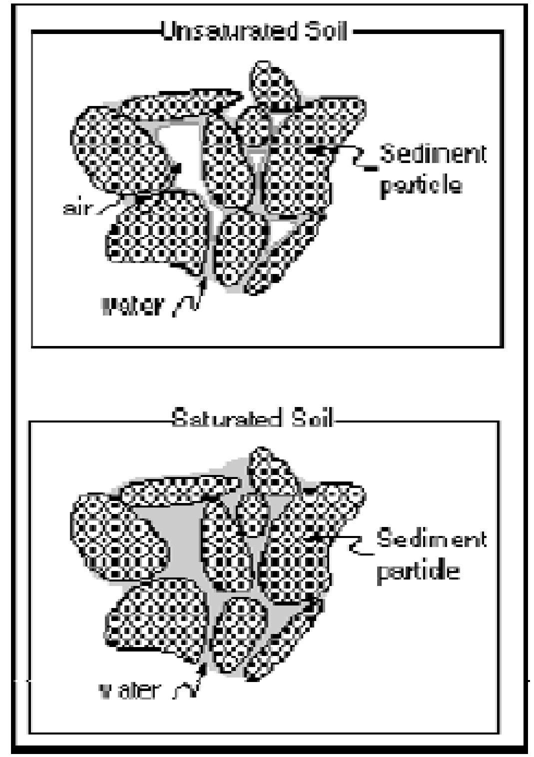
Lies *Roughly* at the Interface Between the Unsaturated Zone and the Saturated Zone



But How Do We Define the Water Table?

Capillary Fringe





Surface tension – sediments retain water

Depends on Surface area:
smaller grains – higher surface area – higher surface tension

Capillary Fringe

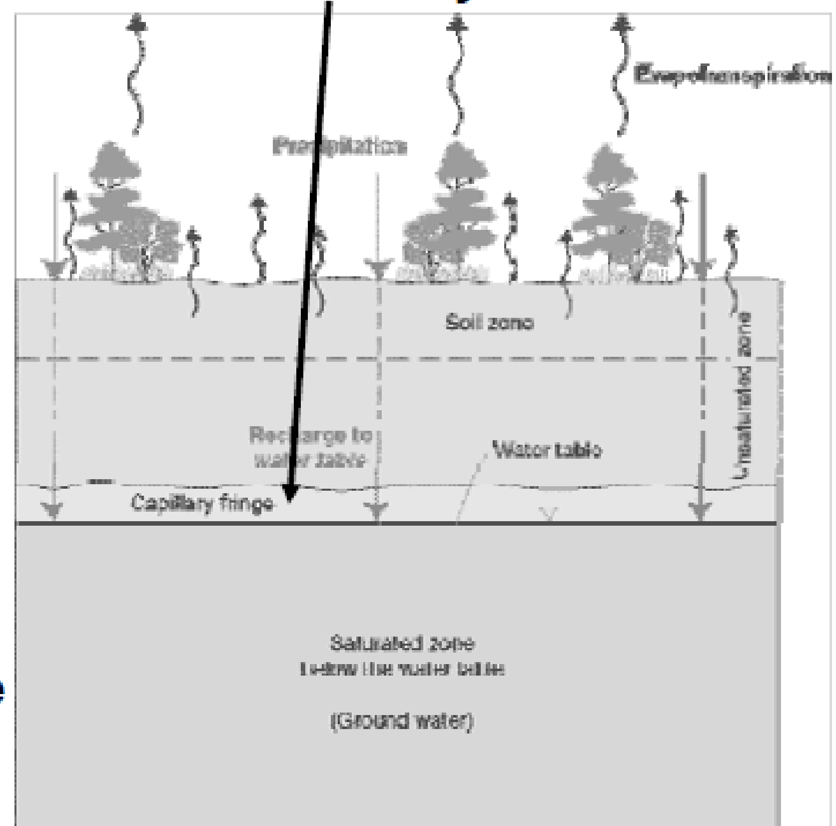
Water Held by Tension

Zone above water table that is effectively saturated

Capillarity Due to Adhesion of Water to a Surface

Capillary Rise Related to Size of Pores

Smaller the Pore, The Larger the Capillary Rise

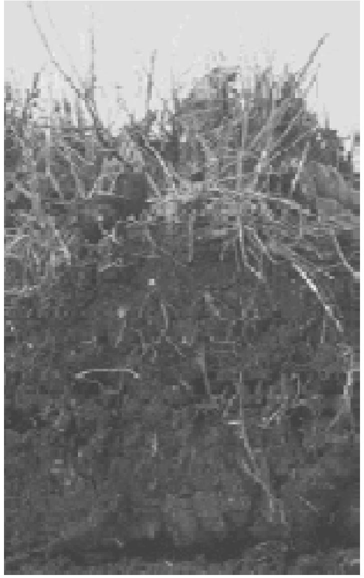


Soil water

Depth up to which the root zone extends

Depth up to which the atmospheric conditions has an influence

Intermediate/Gravitational water – zone between soil water and capillary fringe



AQUIFERS

- Aquifer is derived from the Latin term meaning water bearer.
- Lithologic unit or collection of units capable of yielding water to wells

- An aquifer is <u>not</u>:
  - A geological formation,
  - A permeable geologic unit,
  - A porous medium, or
  - A petroleum reservoir

Aquifers

Groundwater occurs in many types of geologic formations; those known as aquifers are of most importance. An *aquifer* may be defined as a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.[35] This implies an ability to store and to transmit water; unconsolidated sands and gravels are a typical example. Furthermore, it is generally understood that an aquifer includes the unsaturated portion of the permeable unit. Synonyms frequently employed include *groundwater reservoir* and *water-bearing formation*. Aquifers are generally areally extensive and may be overlain or underlain

*The fallout of bomb tritium and C-14 in precipitation since the advent of nuclear weapon testing in 1952 has greatly complicated much of the dating of groundwater because recent levels greatly exceed the prebomb level.

by a *confining bed*, which may be defined as a relatively impermeable material stratigraphically adjacent to one or more aquifers. Clearly, there are various types of confining beds; the following types are well established in the literature:

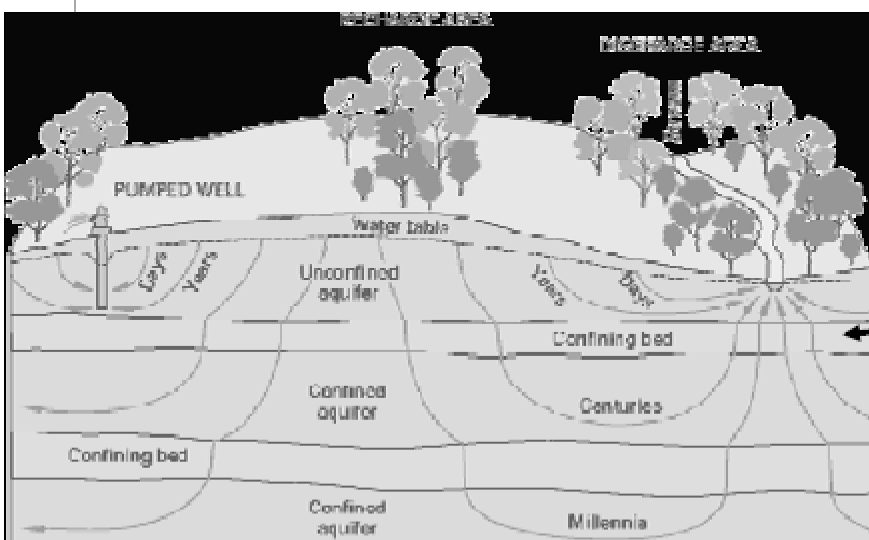
1. *Aquiclude*—A saturated but relatively impermeable material that does not yield appreciable quantities of water to wells; clay is an example.
2. *Aquifuge*—A relatively impermeable formation neither containing nor transmitting water; solid granite belongs in this category.
3. *Aquitard*—A saturated but poorly permeable stratum that impedes groundwater movement and does not yield water freely to wells, that may transmit appreciable water to or from adjacent aquifers and, where sufficiently thick, may constitute an important groundwater storage zone; sandy clay is an example.[45*]

Other geological formations!

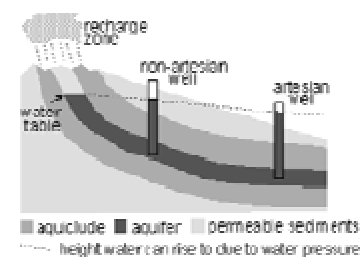
- Aquitard (flow through the layer is signifcant on a regional scale or over very long (e.g., geologic) time scales) sandy clay
- Aquifuge (no K and no n) massive rock
- Aquiclude (no/very less K) clay

AQUIFER Types

- <u>confined</u> (or <u>artesian</u>) - an aquifer that is immediately overlain by a low-permeability unit (confining layer). A confined aquifer does not have a water table.

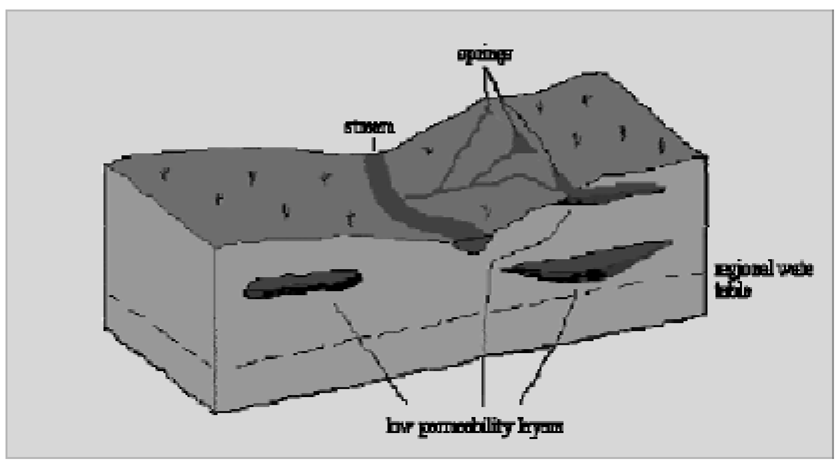


overlain by confining layer



AQUIFER Types

- perched - a local, unconfined aquifer at a higher elevation than the regional unconfined aquifer. An unsaturated zone is present between the two unconfined aquifers.



AQUIFER Types

- Leaky or semi confined- an aquifer that receives recharge via cross-formational flow through confining layers.
- Leaky confining unit (K is too low to be an aquifer, but great enough to permit significant flow through the layer)

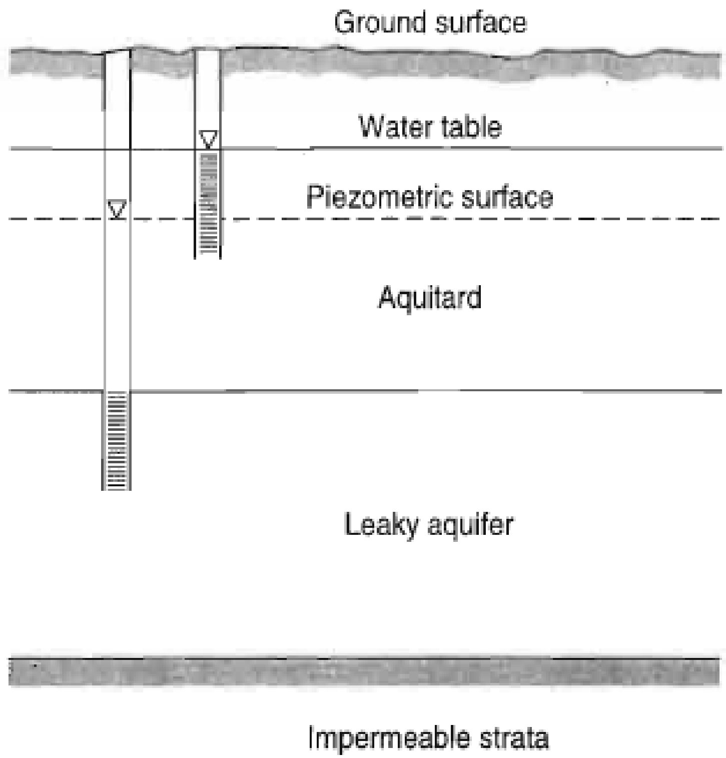
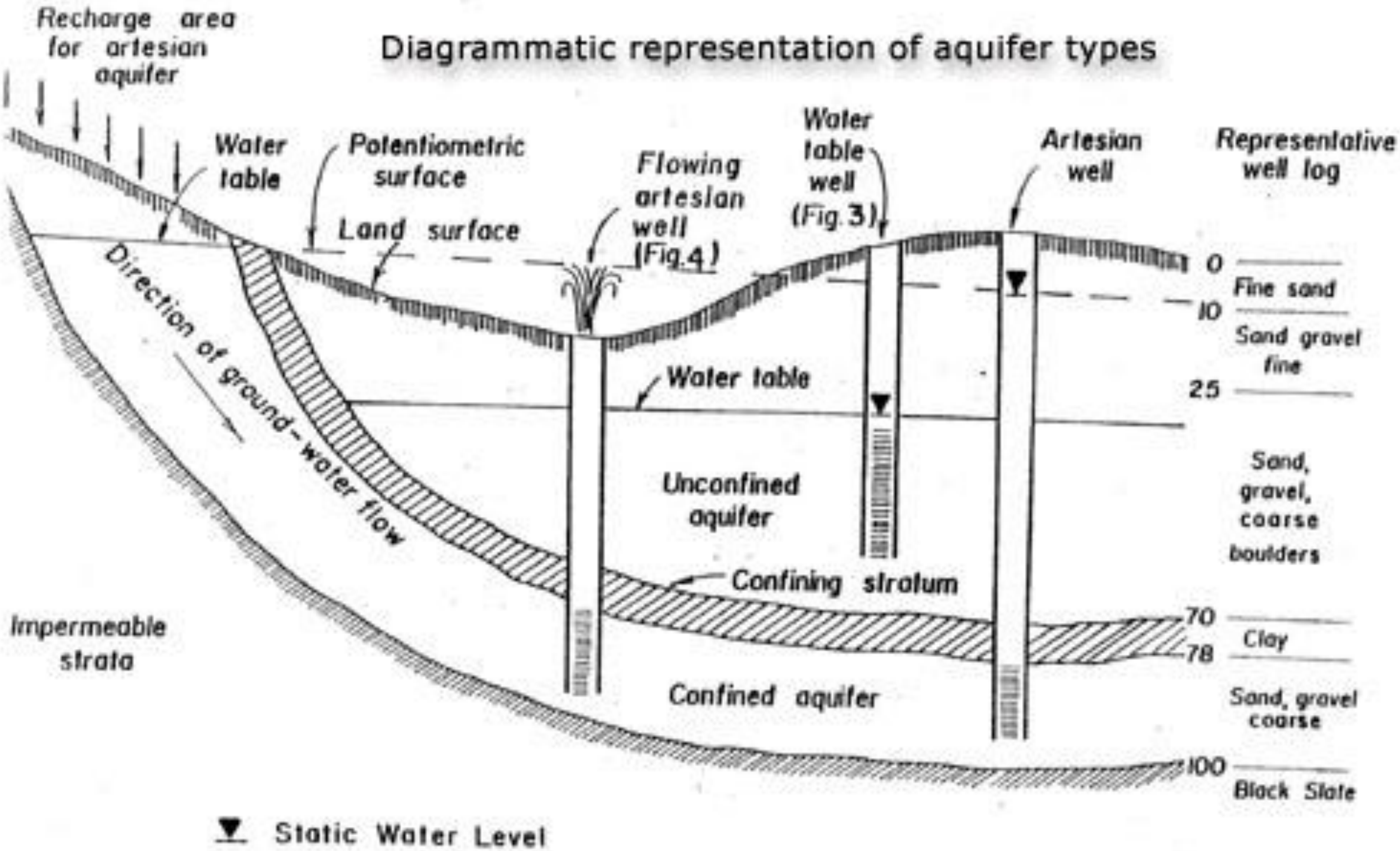


Figure 2.7.3. Sketch of a leaky, or semiconfined, aquifer.

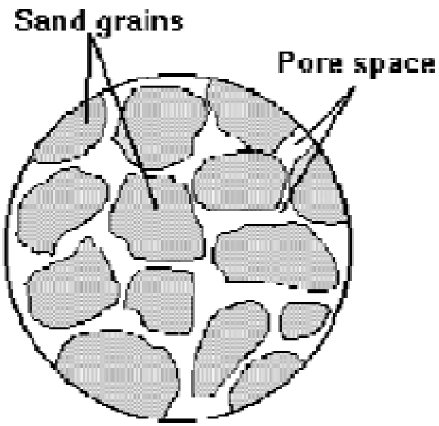
Diagrammatic representation of aquifer types



How water occurs in beneath ground surface?

- Spaces between solid grains – Pores
- Fractures
- Measure of pore volume - Porosity
- Measure of water yield – Specific Yield
- Measure of water retention –
  Specific Retention

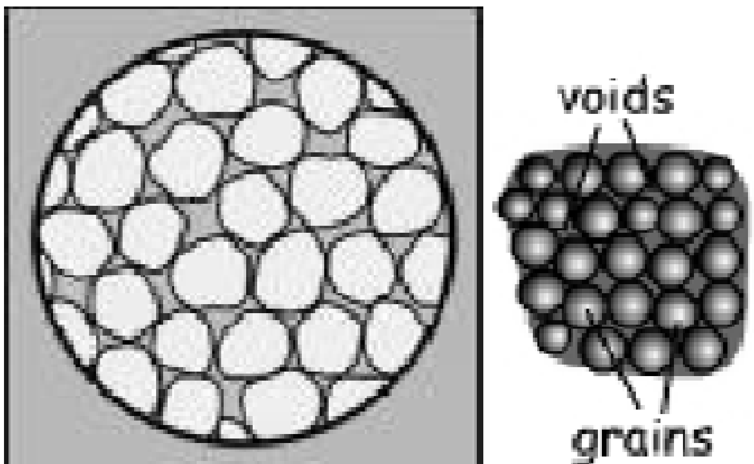
Porosity

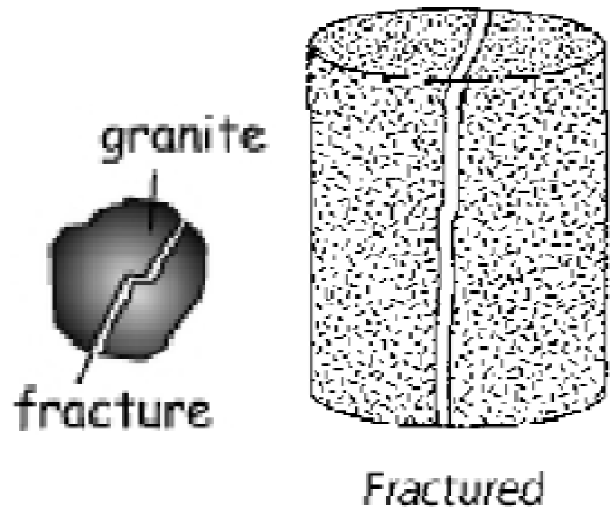


$$n\% = \frac{V_V}{V_T} \times 100\%$$

$n\%$ = porosity (expressed as a percentage)
V_V = volume of the void space
V_T = total volume of the material (void + rock)

Primary and secondary porosity





Primary Porosity

Sediments
Sedimentary Rocks

Secondary Porosity

Igneous Rocks
Metamorphic Rocks

Igneous / Metamorphic Rocks

Low Primary Porosity
Can Have High Secondary Porosity

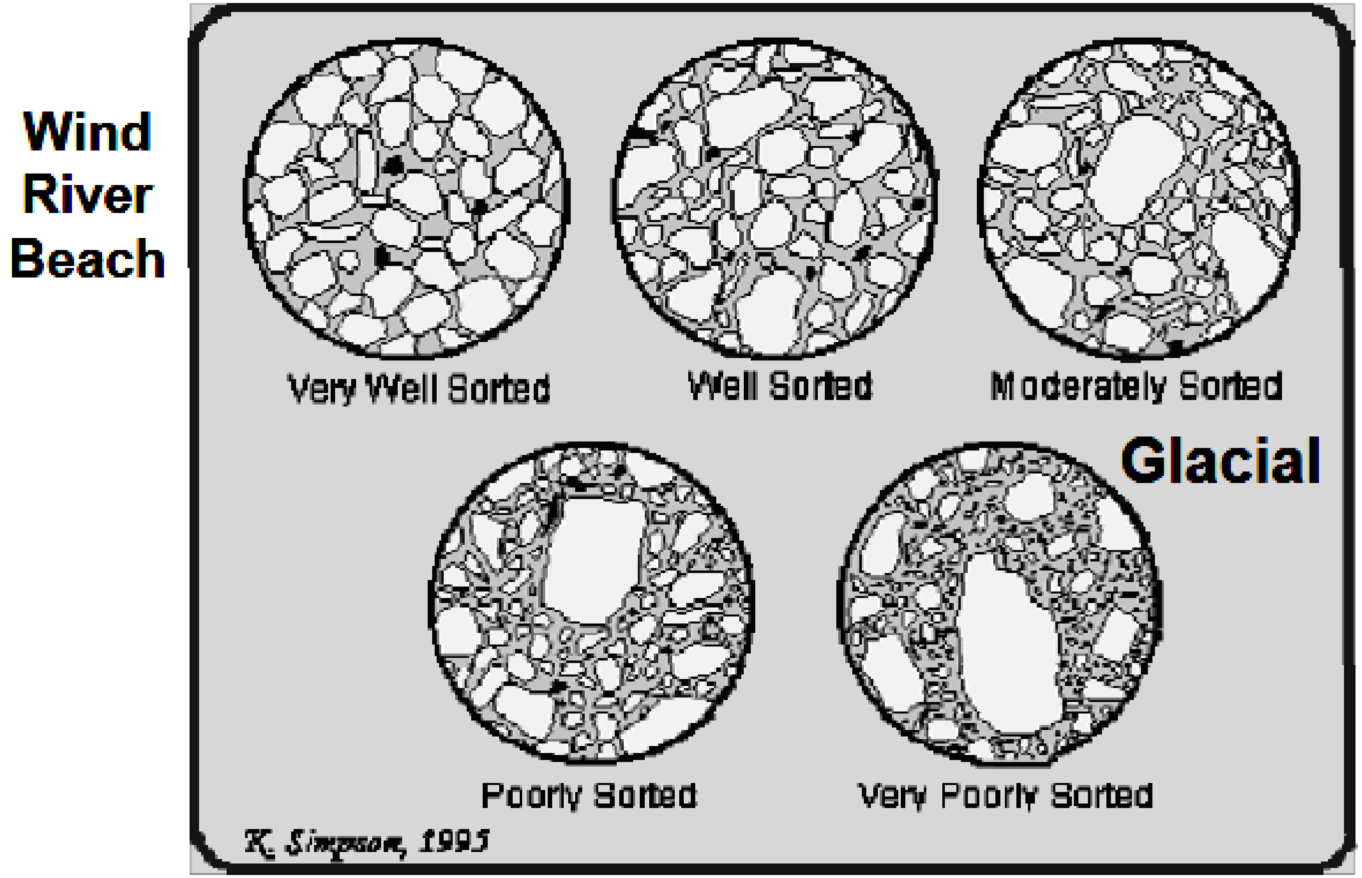
Porosity Ranges for Sediments

Well Sorted Gravel:	25 – 50%
Sand and Gravel Mix:	20 – 35%
Glacial Till:	10 – 20%
Silt:	35 – 50%
Clay:	33 – 60%

Factors controlling porosity

- Grain size
- Grain shape
- Mode of arrangement
- Sorting
- Cementing
- Compaction
- Solution activity

Sorting



Better Sorting = Higher Porosity

2.5.1 Specific Retention

The *specific retention* S_r of a soil or rock is the ratio of the volume of water it will retain after saturation against the force of gravity to its own volume. Thus,

$$S_r = \frac{w_r}{V_t} \tag{2.5.1}$$

where w_r is the volume occupied by retained water* and V_t is the bulk volume of the soil or rock.

2.5.2 Specific Yield

The *specific yield* S_y of a soil or rock is the ratio of the volume of water that, after saturation, can be drained by gravity to its own volume.[17] Therefore,

$$S_y = \frac{w_y}{V_t} \tag{2.5.2}$$

where w_y is the volume of water drained. Values of S_r and S_y can also be expressed as percentages. Because w_r and w_u constitute the total water volume in a saturated material, it is apparent that

$$V_v = w_r + w_y \tag{2.5.3}$$

or

$$\alpha = S_r + S_y \tag{2.5.4}$$

where all pores are interconnecting.

Values of specific yield depend on grain size, shape and distribution of pores, compaction of the stratum, and time of drainage.[40] Representative specific yields for various geologic materials are listed in Table 2.5.1; individual values for a soil or rock can vary considerably from these values. It should be noted that fine-grained materials yield little water, whereas coarse-grained materials permit a substantial release of water and hence serve as aquifers. In

	Specific Yield (%)		
Material	**Maximum**	**Minimum**	**Average**
coarse gravel	26	12	22
medium gravel	26	13	23
fine gravel	35	21	25
gravelly sand	35	20	25
coarse sand	35	20	27
medium sand	32	15	26
fine sand	28	10	21
silt	19	3	18
sandy clay	12	3	7
clay	5	0	2
(Johnson (1967) as quoted by C.W. Fetter(2000))			

Safe Yield

- Management of groundwater systems requires some kind of yield analysis to determine how much groundwater is available.
- The term “safe yield”, coined by Lee(1915), is used to denote the sustainable maximum rate at which water can be withdrawn without dangerous depletion of storage.

overdraft

- **Groundwater overdraft** occurs when **groundwater**use exceeds the amount of recharge into an aquifer, which leads to a decline in **groundwater** level.
- **Overdrafting** is the process of extracting groundwater beyond the *safe yield* or equilibrium yield of the aquifer.