1. GROUNDWATER RESOURCES

Water is a precious natural resource, a basic human need and a prime national asset. The extent to which water is plentiful or scare, clean or polluted, beneficial or destructive, profoundly influence the extent and quality of human life. In India, the growth of population is about 2 % per year. It is essential that food production should increase about 2.5 % per year to provide a better food intake. The competing demands for water are for irrigation, industrial production, domestic water supply, hydro-power generation and environmental management. Requirement of water for transport, recreation and fresh water fisheries also require adequate provision for water. Irrigation is the application of water of soil to assist in the production of crops.

The pressure for survival and need for additional food supplies are causing the rapid expansion of irrigation throughout the world. Nine countries-China, India, the United States of America, Pakistan, Indonesia, Mexico, Iran, Thailand and Uzbekistan-have the largest irrigated areas, amounting to almost 70 % of the world total irrigated area i. e. 248 Mha.

The oceans occupy about 70.8 % of the earth's surface and only 29.2 % is land. About 97.3 % of the world water resource is in the oceans and is saline. Of the remaining 2.7 % of the global fresh water resource, about 75.2 % is in ice-caps and glaciers and is not available for the requirement of mankind. A major part of the balance amount of water (22.6 %) occurs as groundwater, of which about 56 % of the volume lies in water bearing formations deeper than 800 m below ground surface and is not ordinarily available for economical development. The amount of water available for development by men is mainly the water in the streams, rivers, lakes, and about 44 % of the quantity of groundwater which occurs at depths less than 800 m from ground surface.

INDIA'S WATER BUDGET

Water resource of India is limited. The average annual rainfall of India is about 119.4 cm. This rain amounts to 392 Mha-m of water. These may round off the 400 Mha-m including snowfall. After allowing for evaporation losses and interception, the country's estimated water potential from surface flow is 180 Mha-m. It is estimated that only about 70 Mha-m of surface water can be put to beneficial use by conventional methods of development. The ultimate irrigation potential of India has been estimated at 139.5 Mha (58.5 Mha from major and medium schemes, 15 Mha from minor irrigation schemes and 66 Mha from groundwater exploitation). India has acquired an irrigation potential of about 84.9 Mha against the ultimate irrigation potential. Our water resources are insufficient to meet long term requirement of agriculture, industry and other user, unless its judicious and economic utilization are ensured. The available resources are ill-distributed, resulting in seasonal abundance and devastating floods in some areas while large tracts in other regions are drought affected.

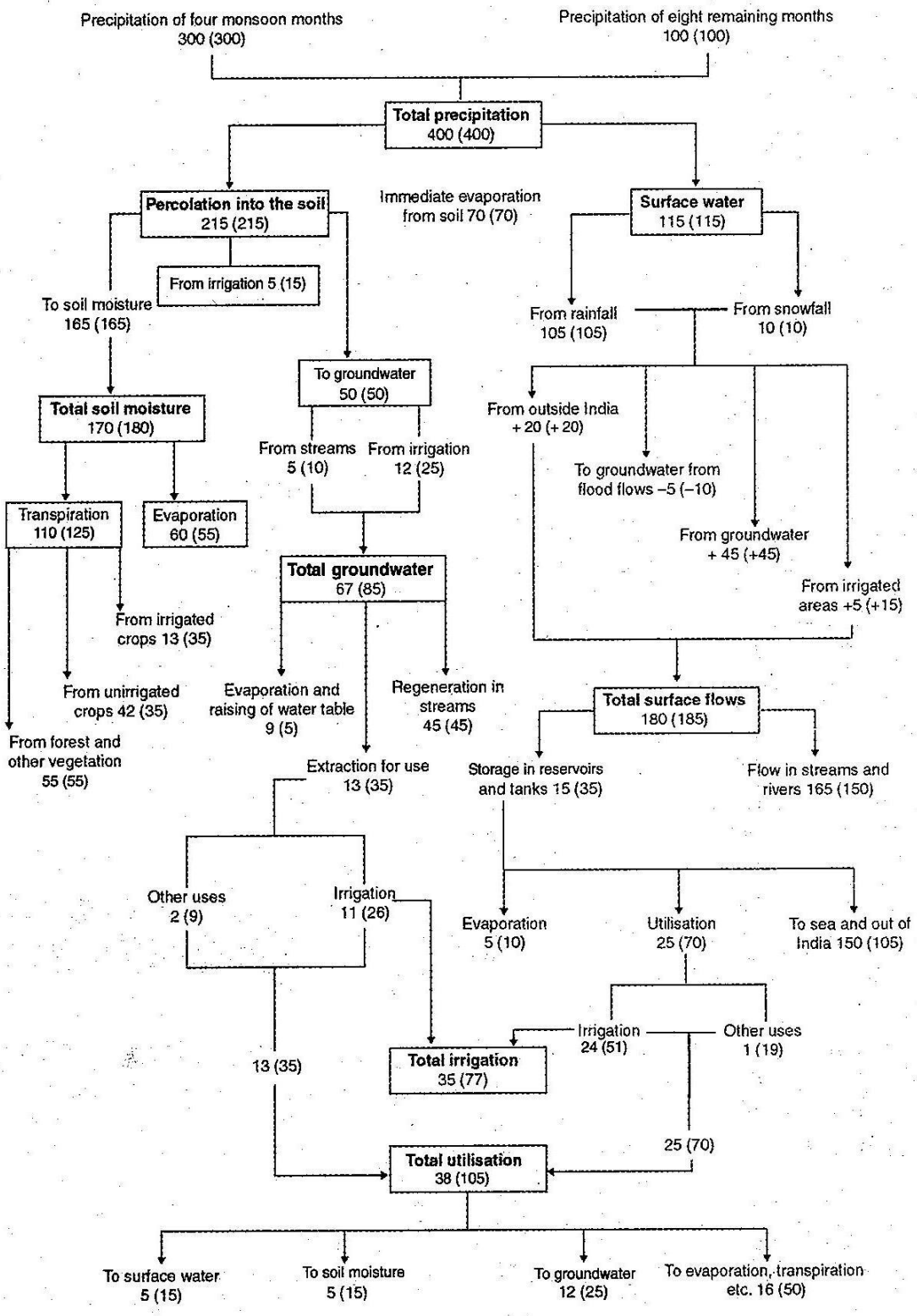
Sl. No.	Particulars	Annual Water Requirement (km^3)		
		2000	2025	2050
1	Domestic Sector	42	73	102
2	Irrigation Sector	541	910	1072
3	Industrial Sector	8	23	63
4	Energy Sector	2	15	130
5	Other Uses	41	72	80
	Total	634	1093	1447

Trend of annual water requirements in India (CWC, 2000)

Human use of water has increased more than 35 times over the past 3 centuries. Globally 3240 Km^3 of fresh water is withdrawn and used annually. Of this, 69 % for agriculture, 23 % for industry and 8 % for domestic use. Recent research shows that groundwater irrigation has overtaken surface-water irrigation as the main supplier of water for India's crops. Groundwater presently sustains almost 60% of the country's irrigated area (IWMI, 2001) and the use of groundwater for irrigation has increased tremendously in the recent past. India also has the highest annual groundwater extraction in the world. Unfortunately, well-defined policies for the sustainable use of groundwater are lacking in India. Heavy energy subsidies and even free electricity to farmers are promoting the unsustainable withdrawal of groundwater. Therefore, the policy makers and water managers must rise to the challenge of finding ways to sustainably manage vital groundwater resources. It is, after all, the most 'democratic' source of water available for improving livelihoods and household food security, and reducing poverty in the country's rural areas (IWMI, 2001).

Distribution of average water resources of India 1974 and (2025) AD

(All figures in million hectare-metre)



(***Source:*** **Based on estimates for 1974 and projections for 2025 of (in brackets), National Commission on Agriculture (1976), Part I, Chapter 15. *Irrigation*. Ministry of Agriculture, Govt. of India.)**

HYDROLOGICAL CYCLE / WATER CYCLE / MOISTURE CYCLE

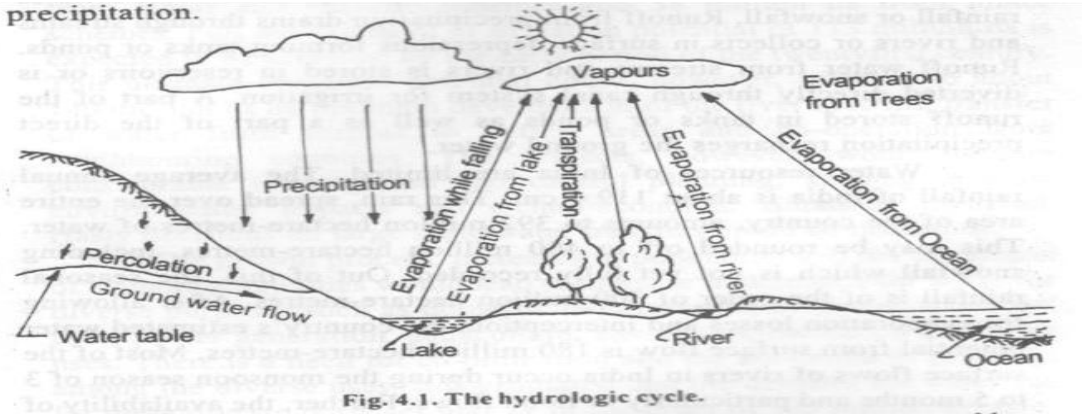


Fig. 4.1. The hydrologic cycle.

The various aspects of water related to the earth can be explained in term of a cycle is called hydrological cycle. It is earth's un-ending moisture cycle. It is the circulation of water from the ocean, sea, lake, river, reservoir, surface detention, underground water and vapour in the atmosphere. The process involves cloud formation and its movement, condensation, precipitation, interception by vegetation and land surfaces, infiltration, soil moisture storage, percolation, ground water storage, subsurface flow, runoff, evaporation and transpiration. It is general circulation of water from the sea to the atmosphere, to the land surface and back to the sea again.

The total amount of water contained in planet earth is constant i. e. 1.36 x 10^8 M ha-m and can neither be increased nor decreased. However the availability of water for the use of men is dependent on the hydrological cycle.

HYDROLOGY

1) It is a science that deals with the occurrence and movement of water on the earth or below the land surface and in atmosphere in all its three state.
2) Hydrology is the science which describes the behaviour of water in the atmosphere, above and below surface of the earth.

Water occurs on the earth in all its three states i. e. solid, liquid and gas. It is concerned with the physical, chemical and hydrological reactions of water with the rest of the earth and its relation to the life on earth.

Agro-Hydrology

Def.: It is the study of movement of water in unsaturated and saturated zone of the soil under the influence of rainfall, evaporation, irrigation and drainage. The study includes the effects of these processes (rainfall, evaporation, irrigation and drainage) on the crop growth.

Ground Water Hydrology / Hydrogeology /Subsurface Hydrology

Def.: It is the science of occurrence, distribution and movement of water below the surface of earth.

The main source of groundwater is precipitation. Water bearing formations of the earth's crust act as conduits for transmission and as reservoirs of storage of groundwater.

Ground Water Basin

Def.: It is defined as a hydro geologic unit comprising one large aquifer or several connected and interrelated aquifers.

It may or may not coincide with a physiographic unit. As we know that watershed/catchment or drainage basin is the basic hydrologic unit for managing surface water resources. Similarly, 'groundwater basin' is the basic unit for groundwater management. The modern concept of water management emphasizes that surface water and groundwater should be treated as a single resource and unlike traditional approach, both surface water and groundwater should be managed in an integrated manner at a basin or sub-basin scale.

GROUNDWATER RESOURCES

The outer part of the earth's crust is usually porous to varying depths at different places. The pores in this part of the lithosphere may be partially or completely filled with water. The occurrence of water below the land surface may be divided into two zones, the zone of saturation and the zone of aeration. In the zone of saturation, all the pores are completely filled with water. The saturated zone is bound at the bottom by impervious strata. The upper surface of the zone of saturation is known as the water table. Water occurring in the zone of saturation is commonly referred to as groundwater.

The zone of aeration occurring above the zone of saturation consists of pores occupied partially by water and partially by air. This zone may be subdivided into three belts such as the belt of soil water, the intermediate belt and the capillary fringe. The soil water zone is immediately below the surface and extends through the root zone of crops. It is the region from which plants extracts the necessary moisture from their growth.

Types of Subsurface Formations

In subsurface hydrology, the material present below the ground is normally called subsurface formation or subsurface deposit. Subsurface formations can be divided into two broad groups: *(a) soil, and (b) geologic formations*. As we know that the soil is formed by weathering of rocks. However, geologic formations can be consolidated, semi-consolidated and unconsolidated formations.

1) Consolidated geologic formations are the rocks formed by cementation, compaction and re-crystallisation, and their grains are tightly held together. They are also known as 'hard rocks'. Examples of consolidated geologic formations are igneous and metamorphic rocks such as granite, basalt, and indurate sedimentary rocks such as sandstone, shale and limestone.

2) Semi-consolidated geologic formations are sedimentary rocks wherein the induration process is incomplete.

3) Unconsolidated geologic formations are comprised of non-indurated colluvial, alluvial, aeolian (wind-borne sediments), lacustrine, marine (coastal) and glacial deposits. These formations/deposits consist of sand, silt, clay, gravel and pebbles.

A study of occurrence and movement of groundwater is needed for the location of wells, their design and in overall management of groundwater resources.

AQUIFER / WATER BEARING FORMATION / GROUNDWATER RESERVOIR

Defination :

1) The formations or strata within the saturated zone below the ground surface, from which groundwater can be obtained for beneficial use is called aquifer.

2) The geological formations which will yield significant quantity of water are defined as aquifers.

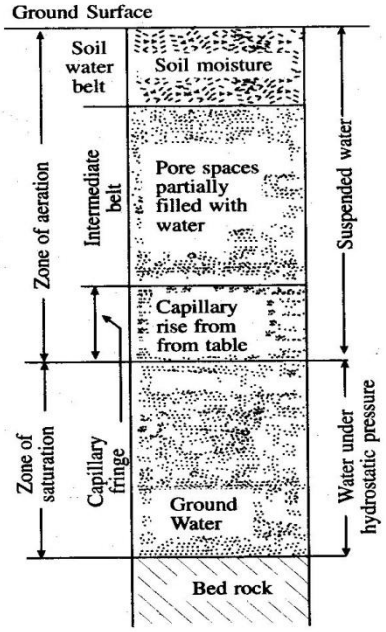
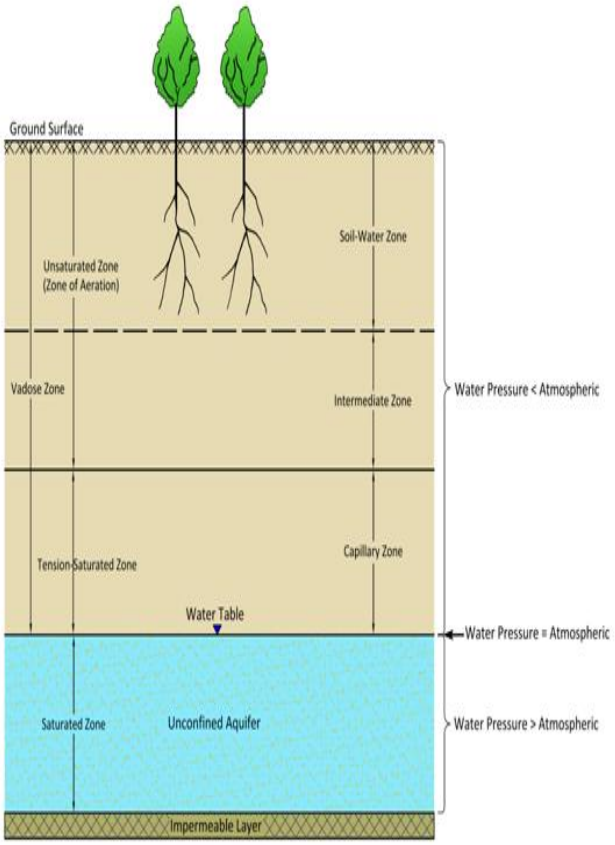


Fig. 2.1 Diagram illustrating soil-moisture relationship and groundwater in an underground strata.



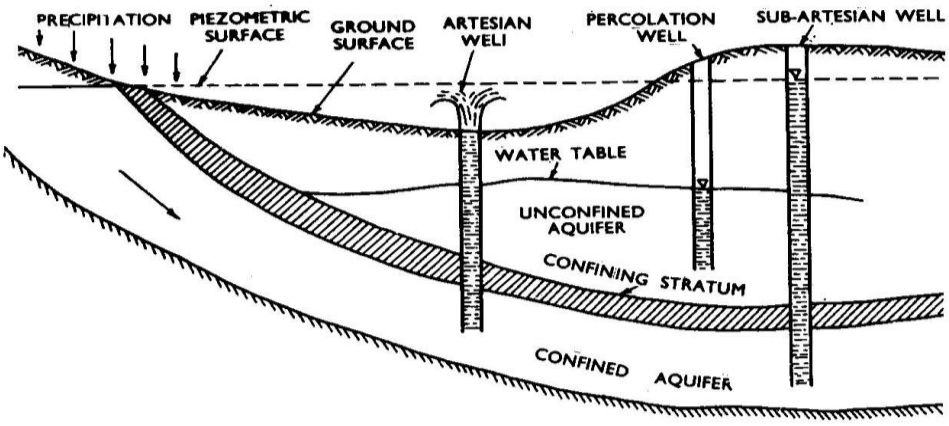


Fig. 5.1. Diagram illustrating unconfined and confined aquifers, recharge areas, percolation wells, sub-artesian wells and artesian wells.

Aquifers are permeable geological formations that permit appreciable amount of water to move through them. For an aquifer to be good in water yield, the aquifer material must be sufficiently porous and permeable i. e. the openings must be interconnected to permit the travel of water through them. Among all kind of rocks, the best aquifers are deposits of gravel.

Aquitard: It is a formation through which only seepage is possible and thus yield is insignificant as compare to an aquifer. It is partially permeable. A sandy clay unit is an example of aquitard.

Aquiclude: Acuiclude are the impermeable formations which contain water but not capable of transmitting and supplying a significant quantity.

Aquifuge: It is a geological formation which is neither porous nor permeable. There are no interconnected openings and hence it cannot transmit water. Massive compact rock without any fractures is an aquifuge.

Assignment 2: Groundwater Regions of India

About two thirds of the total land area in India comprises consolidated formations. The remaining one third of the total land area comprises semi-consolidated and unconsolidated formations like alluvial tracts.

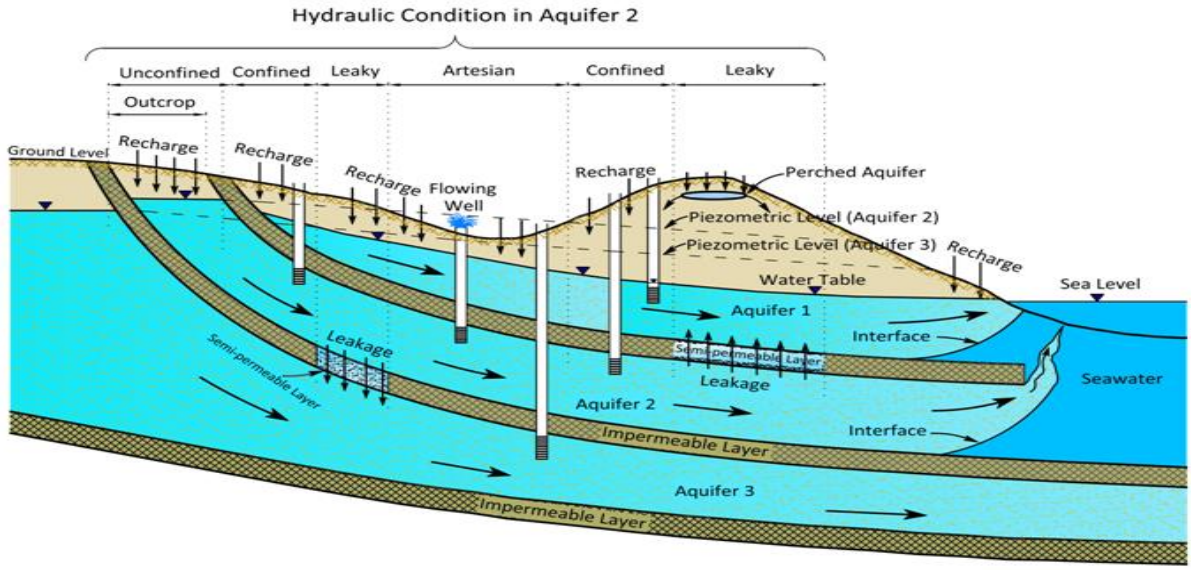
Groundwater Classification

Groundwater aquifers may be classified as unconfined, confined and semi-confined aquifers.

1) **Un-confined Aquifer/ Watertable Aquifer / Phreatic Aquifer**

It is the aquifer whose upper boundary is formed by a free water surface and lower boundary is formed by a relatively impervious layer. Water in this aquifer is at atmospheric pressure. The upper surface of the un-confined aquifer is known as the watertable. At the water table, water is at the atmospheric pressure, and hence unconfined aquifers are also called 'water-table aquifers' or 'phreatic aquifers'.

When a well is constructed in this aquifer, the level of watertable is the level of water in the well. Water will not rise from its level after being opened in atmosphere. Unconfined aquifers receive recharge directly from the overlying surface through rainfall infiltration or percolation from surface water bodies.



2) **Confined Aquifer/ Artesian Aquifer / Pressure Aquifer**

An aquifer found between two impermeable (impervious) layer is known as confined aquifer. Because of the upper confining (imperious) layer, the pores are not open to atmospheric pressure. Water in this aquifer is under pressure above atmospheric pressure.

Since the water present in a confined aquifer is at a pressure greater than the atmospheric pressure, the water level in a bore well penetrating a confined aquifer will always rise above the top confining layer of the aquifer. The term 'piezometric level' is used to denote this water level. Thus, 'Piezometric level' is an imaginary position to which the water level

will rise in a bore well tapping a confined aquifer. The imaginary surface to which water will rise in a well constructed in artesian aquifer is known as piezometric surface.

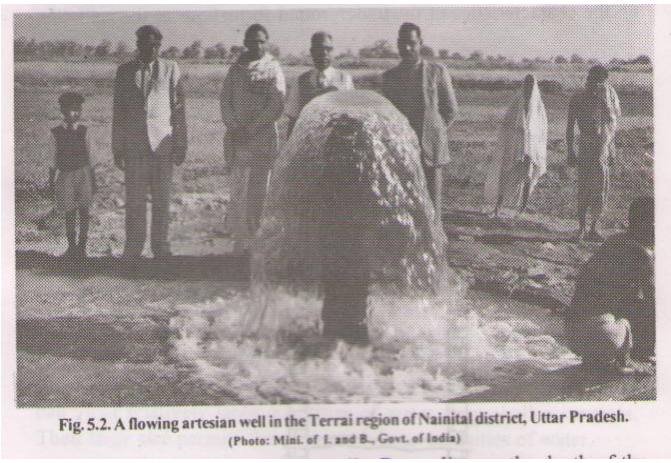


Fig. 5.2. A flowing artesian well in the Terrai region of Nainital district, Uttar Pradesh.
(Photo: Mini. of I. and B., Govt. of India)

The groundwater within a confined aquifer is under a pressure equal to the sum of the weight of the atmosphere and the overburden. The groundwater level in a well penetrating a confined aquifer is usually above the upper boundary of the confined aquifer. However, there may be cases where the piezometric level of a confined aquifer is above the ground surface. The well tapping such a confined aquifer yields water like a spring, and hence it is called a 'flowing well' and such a confined aquifer is known as an 'artesian aquifer'.

Unlike unconfined aquifers, confined aquifers don't receive significant amounts of recharge from the overlying surface. They receive significant recharge through the outcrop by direct rainfall infiltration into this unconfined portion. Confined aquifers also receive recharge through their upper and lower leaky confining layers under natural conditions or when pressure changes are artificially induced by pumping or injection.

3) **Semi-confined Aquifer/ Leaky Aquifer**

If an aquifer (confined aquifer or unconfined aquifer) loses or gains water through adjacent semi-permeable layers, it is called a 'leaky aquifer' (Fig. 3.1). Therefore, the terms 'leaky confined aquifer' and 'leaky unconfined aquifer' are widely used depending on whether the leaky aquifer is confined or unconfined. It is the aquifer whose upper boundary is formed by a semi-pervious layer and lower boundary is formed by an impervious or semi-pervious layer.

4) Perched Water Table

A special case of a localized water body in an unconfined aquifer is the perched water table. It is a body of water which has been retarded in its downward movement by a layer of earth materials at some distance above the water table. Perched aquifer always exists in the vadose zone above an unconfined aquifer when a low-permeability layer impedes the downward movement of water above it. The upper surface of the ground water in such a water body is called a perched water table. Perched aquifers have generally very limited areal extent