**Lecture 1 Introduction to Groundwater**

1.1What is Groundwater?

Groundwater is broadly defined as the water present in the zone of saturation below the ground. A precise and practical definition of groundwater is given in Lesson 2. The zone of saturation is technically called ‘aquifer’. Aquifers are significantly porous and permeable to supply water to wells and springs. On the other hand, water stored in ponds, lakes, rivers, streams, seas/oceans and other surface reservoirs is called surface water.

The term Hydrogeology or Subsurface Hydrology (popularly known as Groundwater Hydrology) is defined as the study of the occurrence, distribution, movement, and geological interaction of water in the earth’s crust, especially groundwater. A similar term ‘Geohydrology’ is sometimes used as a synonym for hydrogeology, although it more properly describes an engineering field dealing with subsurface fluid hydrology.

A ‘groundwater basin’ is defined as a hydrogeologic 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.

**1.2 Groundwater and the Water Cycle**

Water perpetually circulates on the earth from the oceans to the atmosphere to land and back to the oceans; this is called water cycle or hydrologic cycle. Note that the term ‘hydrologic cycle’ literally means “Water-Science Cycle”, and hence the correct term to describe this cyclic movement of water in nature is water cycle, which should be used instead of widely-used term ‘hydrologic cycle’. The major pathways in the water cycle are schematically shown in Fig. 1.1. Thus, the water cycle describes how water moves into and out of various domains viz., atmosphere, land surface, subsurface (underground) and oceans. The main components of water cycle are precipitation, evaporation, transpiration, infiltration, surface runoff (overland flow and streamflow), and subsurface runoff (interflow, vadose-water flow and groundwater flow).

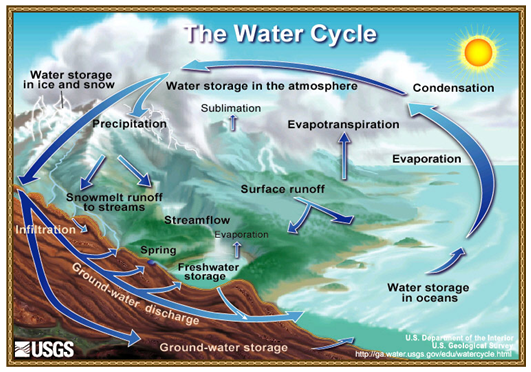


Fig. 1.1. Schematic diagram of the water cycle.

 (Source: http://ga.water.usgs.gov)

Of the water falling on the land, a proportion quickly evaporates, some flows into streams or lakes as overland flow, and some infiltrates into the subsurface. Of the water entering the subsurface, some is transpired back into the atmosphere by plants, some is retained in the vadose zone, some reaches saturated zone (aquifer) as groundwater recharge, and the remaining water follows a subsurface pathway back to the land surface and oceans (Fig. 1.1). Note that water moving in the water cycle is neither gained nor lost, i.e., it is conserved (Input – Output = Change in Storage). Thus, the water cycle follows the principle of continuity.

Groundwater is found in aquifers (water-bearing geologic formations), which act as conduits for water transmission and as underground reservoirs for water storage. Practically, all groundwater originates as surface water. Water enters aquifers from the land surface or from surface water bodies through the vadose zone, and then it travels slowly within the aquifer for varying distances until it finally returns to the land surface by natural flow, plants, or humans (Fig. 1.2). The residence time of groundwater in the subsurface can vary from days to thousands of years (centuries or millennia) depending on the length of the flow path and the transmissivity of porous media.

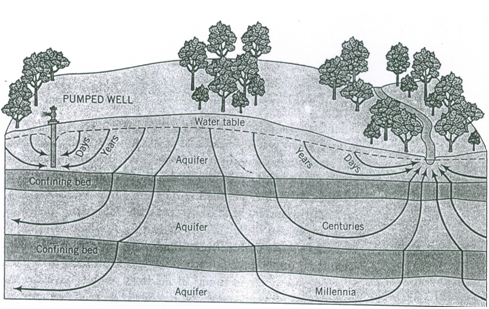


Fig. 1.2. Schematic of groundwater flow paths and residence time in multi-layered aquifer systems. (Source: Winter et al., 1998)

Principal sources of natural groundwater recharge are precipitation, streamflow, lakes and reservoirs, while the artificial sources of recharge are seepage from canals, return flow from irrigation, recharge from storage and percolation tanks, recharge due to check dams, and the water purposely applied to augment groundwater. The discharge of groundwater occurs when water emerges from underground (subsurface) as flow into streams, lakes or oceans (called ‘baseflow’), or as springs. Very shallow groundwater may return directly to the atmosphere by evapotranspiration. Pumping of wells constitutes the major artificial discharge of groundwater.

**1.3 Importance of Groundwater**

The study of groundwater is essential because of several reasons. Of the freshwater readily available for human use (approximately 1% of the liquid freshwater available on the earth), about 98% is groundwater and the remaining is surface water. Hence, groundwater serves as a major source of water supply to life (humans, animals and ecosystems) throughout the world. Because of its physical and chemical quality, groundwater provides a reliable source of water supply in both humid and arid/semi-arid regions of the world and during emergencies (e.g., droughts, earthquakes, etc.) as well as it sustains flow in rivers/streams and lakes during dry periods. Thus, groundwater is one of the most valuable natural resources of the earth, which supports human health, human livelihoods, socio-economic development, and ecological diversity.

Besides the above-mentioned vital roles, groundwater also influences the design and construction of engineering facilities such as dams, open-pit mines, tunnels, deep foundations, and geologic storage of nuclear wastes or carbon sequestration. Groundwater is also important due to its geologic role by supporting various geological processes such as the formation of soils and their alternation, the development of landslides, rock falls, channel networks and karst landscapes, oil formation and valuable mineral deposits. Thus, groundwater plays a variety of roles on a global scale, which make this resource so vital for human beings. However, the water resource and engineering aspects of groundwater hydrology are the major focus of practice, though the groundwater hydrology field has a rich relationship with other earth sciences.

**1.4 Groundwater Scenario: Global and Indian Perspectives**

Of the 37 Mkm3 of freshwater estimated to be present on the earth, about 22% exists as groundwater (Foster, 1998). Although groundwater is the largest available source of freshwater lying beneath the ground, its replenishment is finite and slow, and its quality can be degraded by anthropogenic activities. Historically, groundwater has been a reliable, clean and virtually unlimited water supply for much of the world population. However, with the improvement in the knowledge of hydrogeology and advances in well-drilling and pump technologies, massive groundwater withdrawal started from the 1950s in developed countries and from the 1970s in developing countries. During the past 25-30 years, more than 300 million wells have been drilled for water withdrawal in the world, and about one million wells are drilled annually in the USA alone (Zektser, 2000). Consequently, the worldwide groundwater overdraft or aquifer depletion, declining well yields, drying up of springs, streamflow depletion, and land subsidence due to over-exploitation of groundwater as well as the growing degradation of groundwater quality by natural and/or anthropogenic pollutants and by saltwater intrusion are threatening our ecosystems and even the life of our future generations (e.g., Brown, 2000; Zektser, 2000; Biswas et al., 2009). Excessive groundwater depletion currently affects major regions of North Africa, the Middle East, South and Central Asia, North China, North America, and Australia as well as localized areas throughout the world (Konikow and Kendy, 2005). The key concern is how to maintain a long-term sustainable yield from aquifers (Alley et al., 1999; Sophocleous, 2005). Global climate change and socio-economic changes are expected to complicate the use of groundwater and enhance stress on aquifer systems.

As to the groundwater scenario in India, firstly let’s have a look on the rainfall characteristics of India, which has far-reaching implications for groundwater. The mean annual rainfall in India is estimated at 1,143 mm, which ranges from 11,489 mm at Mawsynram, a village in Meghalaya (wettest place on the earth) to 217 mm at Jaisalmer, a district in the Thar Desert of Rajasthan (Asawa, 1993). India is endowed with water resources only in very high rainfall regions like the eastern Gangetic plains and the Konkan-Malabar coastal strip down below the Western Ghat Mountains. Elsewhere, India's water bounty is far from plentiful (Dhawan, 1989). Such a spatial variation in the water resources is inevitable for a country of continental dimensions. What is truly striking is the temporal variation in water availability within the year as well as from one year to another!

Out of the annual precipitation of about 4000 km3 in India, the accessible water is 1869 km3. However, hardly 690 km3 water is currently used, and the remaining 1179 km3 of water directly drains into the sea –– much of it in 100 days that define the India’s wet season (Aiyar, 2003). India’s water problem basically stems from significant spatial and temporal variations of precipitation, mismanagement, and the fact that while nearly 70% of precipitation occurs in 100 days, the water requirement is spread over 365 days. In a number of regions, water tables have been falling at an average rate of 2 to 3 m per year due to the growing number of irrigation wells (Postel, 1993). Overuse of groundwater is reported from different parts of the country such as Tamil Nadu, Gujarat, Rajasthan, Punjab, Haryana, Orissa and West Bengal, among several other states (CGWB, 2006). A recent study based on the analysis of GRACE satellite data revealed that the groundwater resources in the states of Rajasthan, Punjab and Haryana are being depleted at a rate of 17.7 ± 4.5 km3/year (Rodell et al., 2009). It indicated that between August 2002 to December 2008, these north-western states of India lost 109 km3 of groundwater which is double the capacity of India’s largest reservoir ‘Wainganga’ and almost three times the capacity of USA’s largest artificial reservoir ‘Lake Mead’. In addition, the growing pollution of freshwater (both surface water and groundwater) from point and nonpoint sources and seawater intrusion into coastal aquifers of the country are posing a serious problem of human health and hygiene. Thus, increasing water scarcity and unabated water pollution threaten the sustainability of water supply and environment in India (Aiyar, 2003; Garg and Hassan, 2007). Even water is rationed in megacities such as Chennai, Bangalore, Mumbai and Delhi. Water tankers during dry periods are the burning evidence of India’s severe water scarcity! Consequently, India’s water security and food security are under a serious threat and the lives and livelihoods of millions are at risk.

The population of India is expected to stabilize around 1640 million by the year 2050 (UN, 1995). As a result, the gross per capita water availability will decline from about 1820 m3/year in 2001 to as low as 1140 m3/year in 2050. The total annual water requirement for different sectors in India was about 634 km3 (BCM) in 2000, which will increase to 1093 km3 (BCM) in 2025 and 1447 km3 (BCM) in 2050 (Table 1.1). By 2050, the annual water demand in all the sectors would be more than two times the water demand in 2000. In the industry and energy sectors, the increase in water demand would be about 8 and 65 folds, respectively (Table 1.1) due to rapid growth in industrial activities and increased power demand. The water demand of 2050 is appreciably more than the current estimate of utilizable water resources potential of 1122 km3/year (surface water = 690 km3/year and groundwater = 432 km3/year) through conventional development strategies (MOWR, 1999). Based on the popular Falkenmark water scarcity indicator, India is under ‘water stress’ conditions (freshwater availability less than 1700 m3/person/year) today and will face ‘chronic water scarcity’ freshwater availability less than 1000 m3/person/year) by 2025. Thus, water is a critical factor in determining the limits of socio-economic development of various regions and in sustaining the health of diverse ecosystems in India.

Table 1.1. Trend of annual water requirements in India (CWC, 2000)

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| Sl. No. | Particulars | Annual Water Requirement (km3) | | |
| 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 |

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. 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. Water conflicts, ‘water lords’, and water markets are gradually increasing (Jha et al., 2001). 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).

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