Module 1

HYDROLOGIC CYCLE

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1.1 Introduction

Water can occur in three physical phases: solid, liquid, and gas and is found in nature in all these phases in large quantities. Depending upon the environment of the place of occurrence, water can quickly change its phase.

A number of cycles are operating in nature, such as the carbon cycle, the nitrogen cycle, and several biogeochemical cycles. The *Hydrologic Cycle,* also known as the water cycle, is one such cycle which forms the fundamental concept in hydrology. Hydrologic cycle was defined by the National Research Council (NRC, 1982) the as “the pathway of water as it moves in its various phases to the atmosphere, to the earth, over and through the land, to the ocean and back to the atmosphere”. This cycle has no beginning or end and water is present in all the three states (solid, liquid, and gas). A pictorial view of the hydrological cycle is given in Fig. 1.1. The science of hydrology primarily deals with the land portion of the hydrologic cycle; interactions with the oceans and atmosphere are also studied. NRC (1991) called the hydrologic cycle as the integrating process for the fluxes of water, energy, and the chemical elements.

The hydrologic cycle can be visualized as a series of storages and a set of activities that move water among these storages. Among these, oceans are the largest reservoirs, holding about 97% of the earth’s water. Of the remaining 3% freshwater, about 78% is stored in ice in Antarctica and Greenland. About 21% of freshwater on the earth is groundwater, stored in sediments and rocks below the surface of the earth. Rivers, streams, and lakes together contain less than 1% of the freshwater on the earth and less than 0.1% of all the water on the earth.

Hydrologic cycle considers the motion, loss, and recharge of the earth's waters. It connects the atmosphere and two storages of the earth system: the oceans, and the land sphere (lithosphere and pedosphere). The water evaporated from the earth and the oceans enters the atmosphere. Water leaves the atmosphere through precipitation. The oceans receive water from the atmosphere by means of precipitation and from the land through rivers and ground water flow. Water goes out of oceans only through evaporation. The water leaves land through evapotranspiration, streamflow, and ground water flow. Evaporation and precipitation processes take place in the vertical plane while streamflow and ground water flow occur mostly in the horizontal plane.

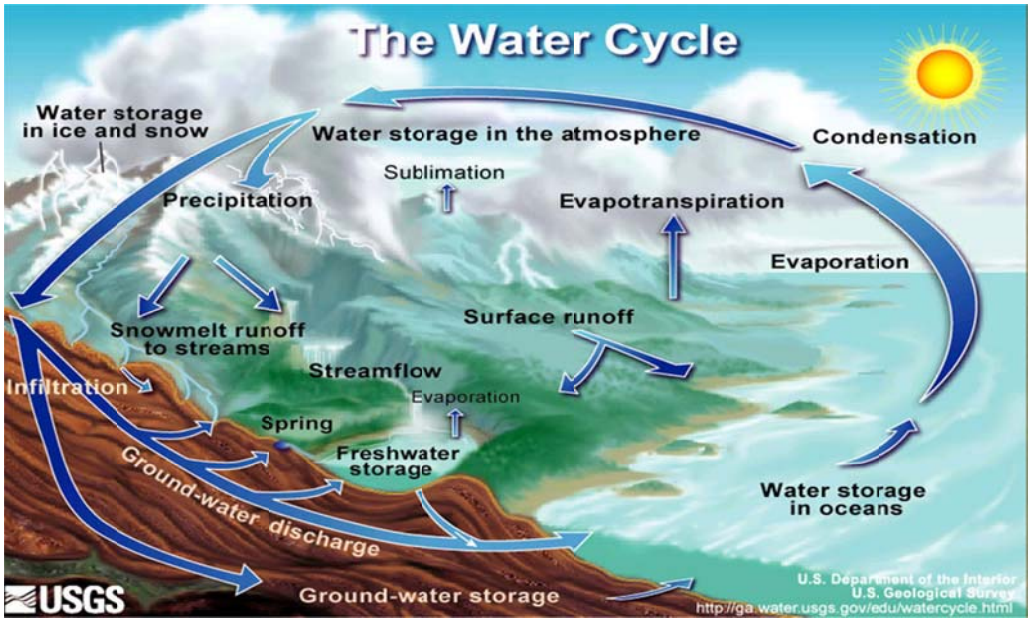

Fig. 1.1 Pictorial view of the hydrological cycle. (Source: Wikipedia, www. http://en.wikipedia.org/wiki/Water_cycle).

The exchange of water among the oceans, land, and the atmosphere was termed as 'the turnover' by Shikhlomanov (1999). This turnover affects the global patterns of the movement of ocean waters and gases in the atmosphere, thereby greatly influencing climate. Since water is a very good solvent, chemistry is an integral part of the hydrologic cycle. Usually, rain and snow are considered as the purest form of water although these may also be mixed with pollutants that are present in the atmosphere. During the journey on earth, many chemical compounds are mixed with water and consequently the water quality undergoes a change. One can also visualize the hydrologic cycle as a perpetual distillation and pumping system in which the glaciers and snow packs are replenished and rivers get water of good quality.

We need to study the hydrologic cycle since water is essential for survival of life and is an important input in many economic activities. From the use point of view, the land phase of the hydrologic cycle is the most important.

In view of the complexities and extensive coverage, the study of the complete hydrologic cycle is truly interdisciplinary. For instance, the atmospheric part is studied by meteorologists, the pedospheric part by soil scientists, the lithosphere part by geologists, and the part pertaining to oceans falls in the domain of oceanographers. A host of other professionals study hydrologic cycle: agricultural engineers, energy managers, ecologists and environmentalists, public health officers, industrialists, chemists, and inland navigation managers.

1.2 Components of Hydrologic Cycle

The hydrologic cycle can be subdivided into three major systems: The oceans being the major reservoir and source of water, the atmosphere functioning as the carrier and deliverer of water and the land as the user of water. The amount of water available at a particular place changes with time because of changes in the supply and delivery. On a global basis, the water movement is a closed system but on a local basis it is an open system.

The major components of the hydrologic cycle are precipitation (rainfall, snowfall, hale, sleet, fog, dew, drizzle, etc.), interception, depression storage, evaporation, transpiration, infiltration, percolation, moisture storage in the unsaturated zone, and runoff (surface runoff, interflow, and baseflow).

Evaporation of water takes place from the oceans and the land surface mainly due to solar energy. The moisture moves in the atmosphere in the form of water vapour which precipitates on land surface or oceans in the form of rain, snow, hail, sleet, etc. A part of this precipitation is intercepted by vegetation or buildings. Of the amount reaching the land surface, a part infiltrates into the soil and the remaining water runs off the land surface to join streams. These streams finally discharge into the ocean. Some of the infiltrated water percolates deep to join groundwater and some comes back to the streams or appears on the surface as springs.

This immense movement of water is mainly driven by solar energy: the excess of incoming radiation over the outgoing radiation. Therefore, sun is the prime mover of the hydrologic cycle. The energy for evaporation of water from streams, lakes, ponds and oceans and other open water bodies comes from sun. A substantial quantity of moisture is added to the atmosphere by transpiration of water from vegetation. Living beings also supply water vapor to the atmosphere through perspiration. Gravity has an important role in the movement of water on the earth's surface and anthroprogenic activities also have an increasingly important influence on the water movement.

An interesting feature of the hydrologic cycle is that at some point in each phase, there usually occur: (a) transportation of water, (b) temporary storage, and (c) change of state. For example, in the atmospheric phase, there occurs vapor flow, vapor storage in the atmosphere and condensation or formation of precipitation created by a change from vapor to either the liquid or solid state. Moreover, in the atmosphere, water is present in the vapor form while it is mostly (saline) liquid in the oceans.

1.3 Scales for study of hydrologic cycle

From the point of view of hydrologic studies, two scales are readily distinct. These are the global scale and the catchment scale.

Global scale

From a global perspective, the hydrologic cycle can be considered to be comprised of three major systems; the oceans, the atmosphere, and the landsphere. Precipitation, runoff and evaporation are the principal processes that transmit water from one system to the other. This illustration depicts a global geophysical view of the hydrologic cycle and shows the interactions between the earth (lithosphere), the oceans (hydrosphere), and the atmosphere. The study at the global scale is necessary to understand the global fluxes and global circulation patterns. The results of these studies form important inputs to water resources planning for a national, regional water resources assessment, weather forecasting, and study of climate changes. These results may also form the boundary conditions of small-scale models/applications.

Catchment Scale

While studying the hydrologic cycle on a catchment scale, the spatial coverage can range from a few square km to thousands of square km. The time scale could be a storm lasting for a few hours to a study spanning many years. When the water movement of the earth system is considered, three systems can be recognized: the land (surface) system, the subsurface system, and the aquifer (or geologic) system. When the attention is focused on the hydrologic cycle of the land system, the dominant processes are precipitation, evapotranspiration, infiltration, and surface runoff. The land system itself comprises of three subsystems: vegetation subsystem, structural subsystem and soil subsystem. These subsystems subtract water from precipitation through interception, depression and detention storage. This water is either lost to the atmospheric system or enters subsurface system. The exchange of water among these subsystems takes place through the processes of infiltration, exfiltration, percolation, and capillary rise.

Fig. 1.2 shows the schematic of the hydrologic cycle at global scale, in the earth system, and micro-scale view of the cycle in the land system. Fig. 1.3 gives a schematic presentation of the hydrologic cycle of the earth system. Detailed schematic of the hydrologic cycle in the land system is shown in Fig. 1.4.

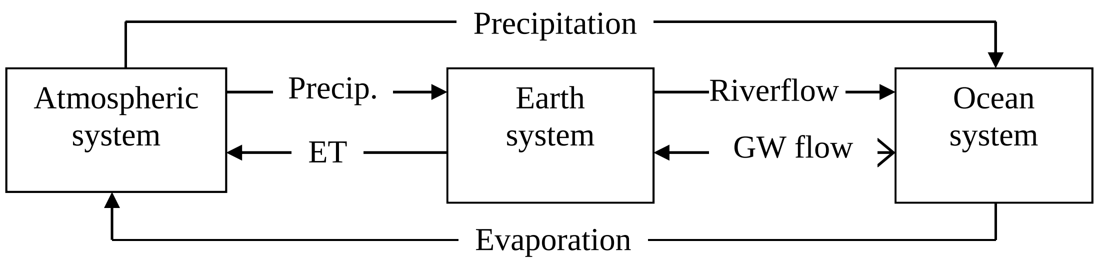

Fig. 1.2 A global schematic of the hydrologic cycle.

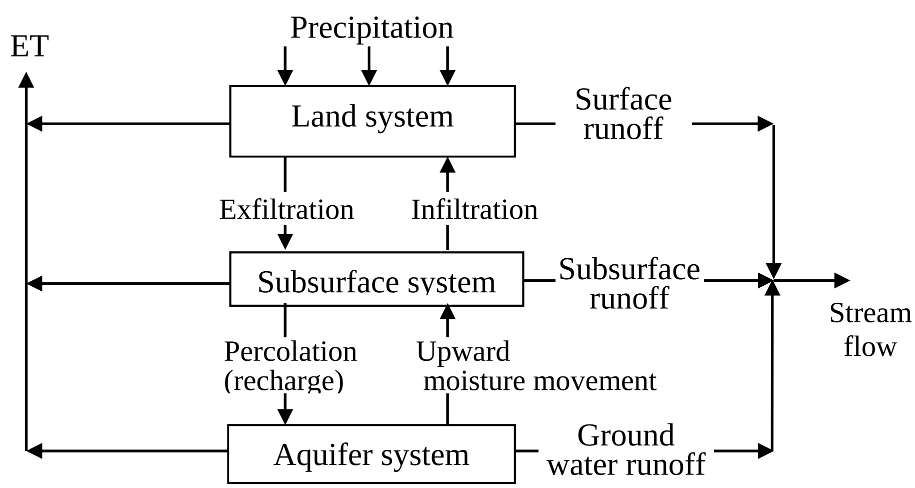

Fig. 1.3 A schematic of the hydrologic cycle of the earth system.

Time scales in hydrologic cycle

The time required for the movement of water through various components of the hydrologic cycle varies considerably. The velocity of streamflow is much higher compared to the velocity of ground water. The time-step size for an analysis depends upon the purpose of study, the availability of data, and how detailed the study is. The estimated periods of renewal of water resources in water bodies on the earth is given in Table 1.1. The time step should be sufficiently small so that the variations in the processes can be captured in sufficient detail but at the same time, it should not put undue burden on data collection and computational efforts.

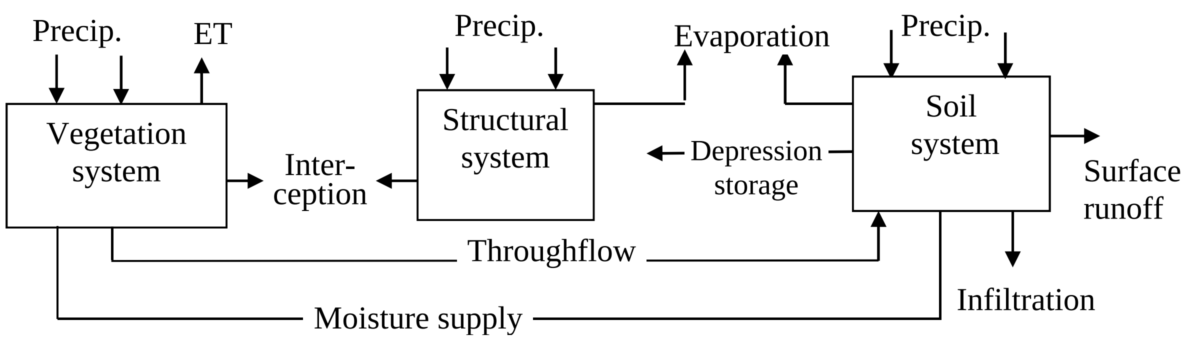

Fig. 1.4 A detailed schematic of the hydrologic cycle in the land system.

Table 1.1 Periods of water resources renewal on the Earth

Water of hydrosphere	**Period of renewal**
World Ocean	2500 years
Ground water	1400 years
Polar ice	9700 years
Mountain glaciers	1600 years
Ground ice of the permafrost zone	10000 years
Lakes	17 years
Bogs	5 years
Soil moisture	1 year
Channel network	16 days
Atmospheric moisture	8 days
Biological water	Several hours

Source: Shiklomanov (1999).

The range of spatial and temporal dimensions of many processes related to the hydrologic cycle is shown in Fig. 1.5.