1 INTRODUCTION

1.1 Definition of Hydrology and Hydrometry

Hydrology is a multidisciplinary subject that deals with the ***occurrence, circulation*** and ***distribution*** of the waters of the Earth. In other words, hydrology is the study of the ***location*** and ***movement*** of inland water, both frozen and liquid, above and below ground. The domain of hydrology embraces the physical, chemical, and biological reaction of water in natural and manmade environment (Chow et al, 1988).

Hydrometry means literally water measurement. In the past hydrometric engineers were particularly involved in streamflow measurements. Today many aspects of water measurements are included.Hydrometry is defined in this course as the measurement of flow in open watercourses, supported or complemented by the measurements of water levels, bed levels and sediment transport.About hydrometry will be indicussed in detail in the last chapter.

Hydrology is applied to major water and civil engineering projects such as irrigation schemes, dams and hydroelectric power, and in planning water supply projects. Hydrological information is essential in:

(1) Estimating reservoir storage capacity that is needed to ensure adequate water supplies for municipal, irrigation and hydropower needs.
(2) Planning water resources projects the peak discharge and its volume of flood that have to be adopted in design of irrigation, hydropower, and flood control projects. If the selected flood is too high, it results in a conservative and unnecessary costly structures while adoption of a low design flood can result in the loss of the structure itself and devastating damage to downstream residence and properties.
(3) Estimating the impact of watershed management on the quantity and quality of the surface and the groundwater resources.
(4) Planning an integrated water resources development master plan for a basin.
(5) Trans-boundary river water allocation problems, and
(6) Delineation of a probable flood levels to plan a protection of settlements and projects from flooding or to promote better zoning.

1.2 Development of Hydrology

From the very beginning mankind attempted to utilize the precious water resources of the Earth in a thoughtful way. History tells us that Samaritans and Egyptians along the Nile Delta, Chinese along the banks of the Hwang - Ho and Aztecs in South America applied detailed methods for their water resources management (Shaw, 1994).

The Greek philosophers were the first students of hydrology, with Aristotle proposing the conversion of moist air into water deep inside mountains as the source of springs and streams. Homer suggested the idea of an underground sea as the source of all surface waters.

During the Renaissance, a gradual change occurred from purely philosophical concepts of hydrology toward observational science. Leonardo da Vinci (1452-1519) made the first systematic studies of velocity distribution in streams using a weighted rod held afloat by an inflated bladder. The rod would be released at a point in the stream, and Leonardo would walk along the bank marking its progress with an odometer and judging the difference between the surface and the bottom velocities by the inclination of the rod. Later the Frenchman, Pierre Perrault (1608-1680), measured surface runoff and found it to be only a fraction of rainfall.

The year 1850 might be regarded as marking the beginning of the development of methods in current use in hydrological practice. In 1851, Mulvaney first described the concept of time of concentration that now forms the backbone of the rational method of runoff computation, and he also designed primitive form of rain-gauge that would record time-varying rainfall intensity during a storm. Five years later Darcy established the basic law of groundwater motion.

During the following decades, knowledge gradually accumulated: in 1871 Saint Venant derived the equations of one-dimensional surface water flow, in 1891 Manning developed his equation for open channel velocity, in 1908 the first watershed level measurement of the hydrologic effects of the land-use change was done, in 1911 Green and Ampt produced their infiltration model, and in 1925 Streeter and Philps developed the dissolved oxygen sag curve for rivers.

The period from 1930 to 1950 produced a significant step forward in the field of hydrology as government agencies especially in USA began to develop their own programs of hydrologic research. Sherman's 1933 unit hydrograph, Horton's 1933 infiltration theory, and Theis's 1935 nonequilibrium equation in well hydraulics advanced the state of art significantly. Gumbel 1958 proposed the use of extreme value distribution for frequency analysis of hydrological data laying a ground for modern statistical hydrology (Maidement 1993).

1.3 Hydrological Cycle

Water on earth exists in a space called the hydrosphere that extends about 15 km up into the atmosphere and about 1 km down into the lithosphere, the crust of the earth. Water circulation in the hydrosphere through numerous paths forms the hydrological cycle. It can be said that the hydrological cycle has no beginning or end and its main processes occur continuously.

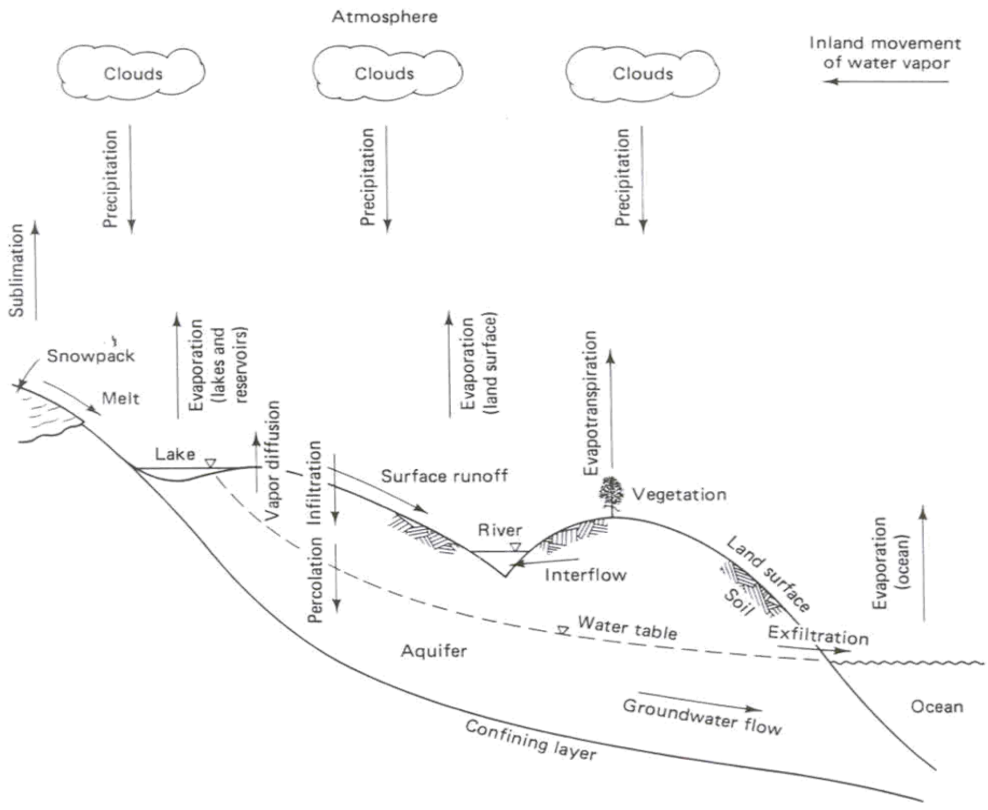
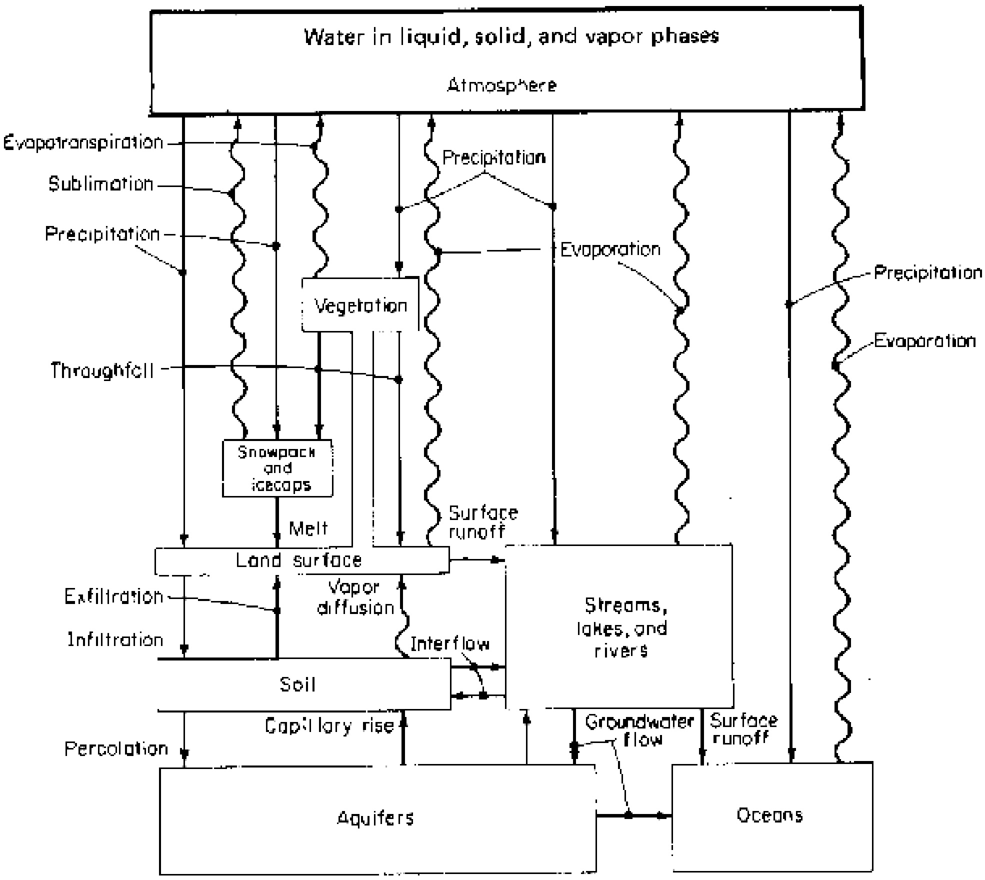


Figure 1-1a: The hydrological cycle with major components (Ponce, 1989)



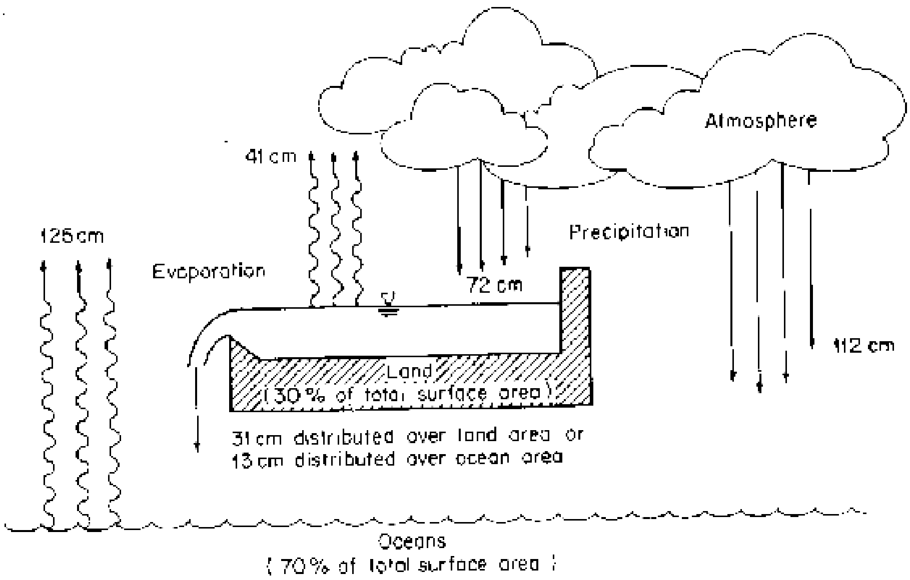


Figure 1.1b. **The hydrological cycle with major components (another perspective)**

Table 1.1: Estimate of the world's water (Maidement, 1993).

	Volume (10^6 km^3)	Percentage of total water
Ocean	1370.00	96.50
Groundwater		
Fresh	10.53	0.76
Saline	12.87	0.93
Ice sheet and glaciers	24.00	1.65
Lakes:		
Fresh	0.0910	0.0070
Saline	0.0850	0.0060
Soil moisture	0.0160	0.0015
Biological water	0.0012	0.0001
Rivers	0.0021	0.0002
Marshes	0.0110	0.0008
Atmospheric vapor	0.0130	0.0010

Table 1.1 gives the relative quantities of the earth's water contained in each of the phases of the hydrological cycle. The oceans contain 96.5 % of the earth's water, and of the 3.5 % on land, approximately 1% is contained in deep, saline groundwater or in saline lakes, leaving only 2.5 % of the earth's water as fresh water that is 35 million cubic kilometer. Of this fresh water, 68.6% is frozen into the polar ice caps and a further 30.1 % is contained in shallow aquifers, leaving only 1.3% of the of the earth's fresh water mobile in the surface and atmospheric phases of the hydrological cycle.

The driving force of the circulation is derived from the radiant energy received from the Sun. The largest atmospheric moisture sources of the earth are Pacific, Atlantic and Indian oceans. Heating of ocean surface causes **evaporation**, the transfer of water from the liquid to the gaseous state, to form part of the atmosphere, then the water vapor changes back to the liquid again through the process of **condensation** to form clouds and, with favorable atmospheric conditions, **precipitation (rain or hail)** is produced either to return directly to the ocean storage or to the land surface. Snow may accumulate in polar regions or on high mountains and consolidate into ice.

In more temperate lands, rainfall may be **intercepted** by vegetation from which the intercepted water may return at once to the air by evaporation. Remaining rainfall reaching the ground may collect to form **surface runoff** or it may **infiltrate** into the ground. The liquid water in the soil then **percolates** through the unsaturated layers to reach the **water table** where the ground soil stratum becomes saturated, or it is taken up by vegetation from which it may be transpired back into the atmosphere. The surface runoff and base flow forming stream-flow or river-flow flows into lakes, swamps, or seas, or oceans.

An example of marco-hydrological cycle of the Ethiopian part of the Nile basin is described as follows. Part of rainfall collected over western Ethiopia is destined to the Mediterranean sea through the Baro, Akobo, Blue Nile and Atbara rivers. Mediterranean sea is connected to the Atlantic Ocean and to the Indian Ocean via the Red Sea. Clouds formed from the moisture evaporated form the Atlantic and Indian Ocean will come back as rainfall over Ethiopian highlands to complete a micro hydrological cycle.

It appears that the concept of hydrologic cycle is simple, but the phenomenon is enormously complex and intricate. It is not just one large cycle but rather is composed of many interrelated cycles of continental, regional, and local extent. Moreover, although the total volume of water in the global hydrologic cycle remains essentially constant, the distribution of this continually changing on continents, in regions, and within local drainage basins.

Under certain well-defined conditions, the response of a watershed to rainfall, infiltration and evaporation can be estimated if simple assumptions are made. A watershed is defined as an area of land that drains to a single outlet and is separated from other watershed by a watershed divide. A water budget equation connects the elements of the hydrological cycle. For example, for a given watershed a water budget equation for time step of *t* is given by

$$P_t - SR_t - G_t - E_t - T_t = \Delta S_t \qquad (1.1)$$

Where P_t = rainfall (mm)
SR_t = Surface runoff (mm)
G_t = groundwater flow (mm)

E_t = Evaporation (mm)
T_t = Transpiration (mm)
ΔS_t = Change in storage (mm)

Note that if t is a year, it may be assumed for preliminary analysis that what is infiltrated will be shown up in the groundwater flow, and thus the infiltration term may not be considered in Eq. (1.1) and the change in storage term may be zero.

Example 1.1 In a given year, a watershed with a drainage area of 215 km^2 received 900 mm of rainfall. The average flow rate measured at the outlet of the watershed was 3.1 m^3/s. Estimate the amount of water lost due to the combined effects of evaporation and transpiration. Assume the annual change in storage is zero.

Solution:

The equivalent runoff depth in mm over the watershed is calculated by dividing the annual volume of runoff by the watershed area.

Runoff depth = (3.1 * 86400 s/day * 365 d/year * 1000mm/m) / (215 km^2 * 10^6 m^2/km^2)

Then using Eq.(1.1): $P_t - (R_t + G_t) - E_t - T_t = \Delta S_t$, *we estimate* $(E_t + T_t)$

$$900 \text{ mm} - (3.1 * 86400 \text{ s/day} * 365 \text{ d/year} * 1000\text{mm/m}) / (215 \text{ km}^2 * 10^6 \text{ m}^2/\text{km}^2) - (E_t + T_t) = 0.$$

$$(E_t + T_t) = 900 - 454.7 = 445.3 \text{ mm}$$

445.3 mm of rainfall is consumed annually by evaporation and transpiration over the whole watershed.

1.4 Practice problems

1.1. The following yearly data were collected from a 2000 km^2 catchment. Total precipitation is 620 mm, total combined loss due to evaporation and evapotranspiration is 350 mm, estimated groundwater outflow is 100 mm, and mean surface runoff is 150 mm. What is the change in volume of water (m^3) remaining in storage in the catchment at the end of the elapsed year.

1.2. The average annual discharge of the Nile river having basin area of $2.96x10^6$ km^2 is 100 $x10^9$ m^3. Calculate the discharge per unit area in $m^3/s/100\text{-}km^2$.

1.3. A watershed with a drainage area of 450 km^2 received 700 mm of rainfall in a given rainy three months. The average flow rate measured at the outlet of the watershed over these three months was 15 m^3/s. Estimate the amount of water lost due to the combined effects of evaporation and transpiration, and groundwater storage.

1.4. What is a hydrological cycle? How does it keep a balance between the water of the earth and the moisture in the atmosphere?

1.5. List the major water resources projects in your area. What specific hydrological problems did each project involve?

1.6. A lake has a surface area of 708,000 m2.In May a stream flows into the lake at an average rate of 1.5 m3/s. A small river flows out of the lake at an average rate 1.25m3/s. The evaporation rate was measured as 14.0 cm/month. A total of 22.5 cm of precipitation fell in May. Seepage, interception and infiltration losses are negligible. The average depth in the lake on May 1 was 19 m. What was the average depth on May 30th? (Hint: please look the figure below for inflows and outflows and use the hydrological equation to solve the problem)