Hydrology

Contents

- Ch 1 Introduction
- Ch 2 Precipitation
- Ch 3 Abstractions from Precipitation
- Ch 4 Streamflow Measurement
- Ch 5 Runoff
- Ch 6 Hydrographs
- Ch 7 Floods
- Ch 8 Flood Routing
- Ch 9 Groundwater
- Ch 10 Erosion and Reservoir Sedimentation

Chapter 1

- 1.1 Introduction
- 1.2 Hydrologic Cycle
- 1.3 Water Budget Equation
- 1.4 World Water Balance
- 1.5 History of Hydrology
- 1.6 Applications in Engineering
- 1.7 Sources of Data

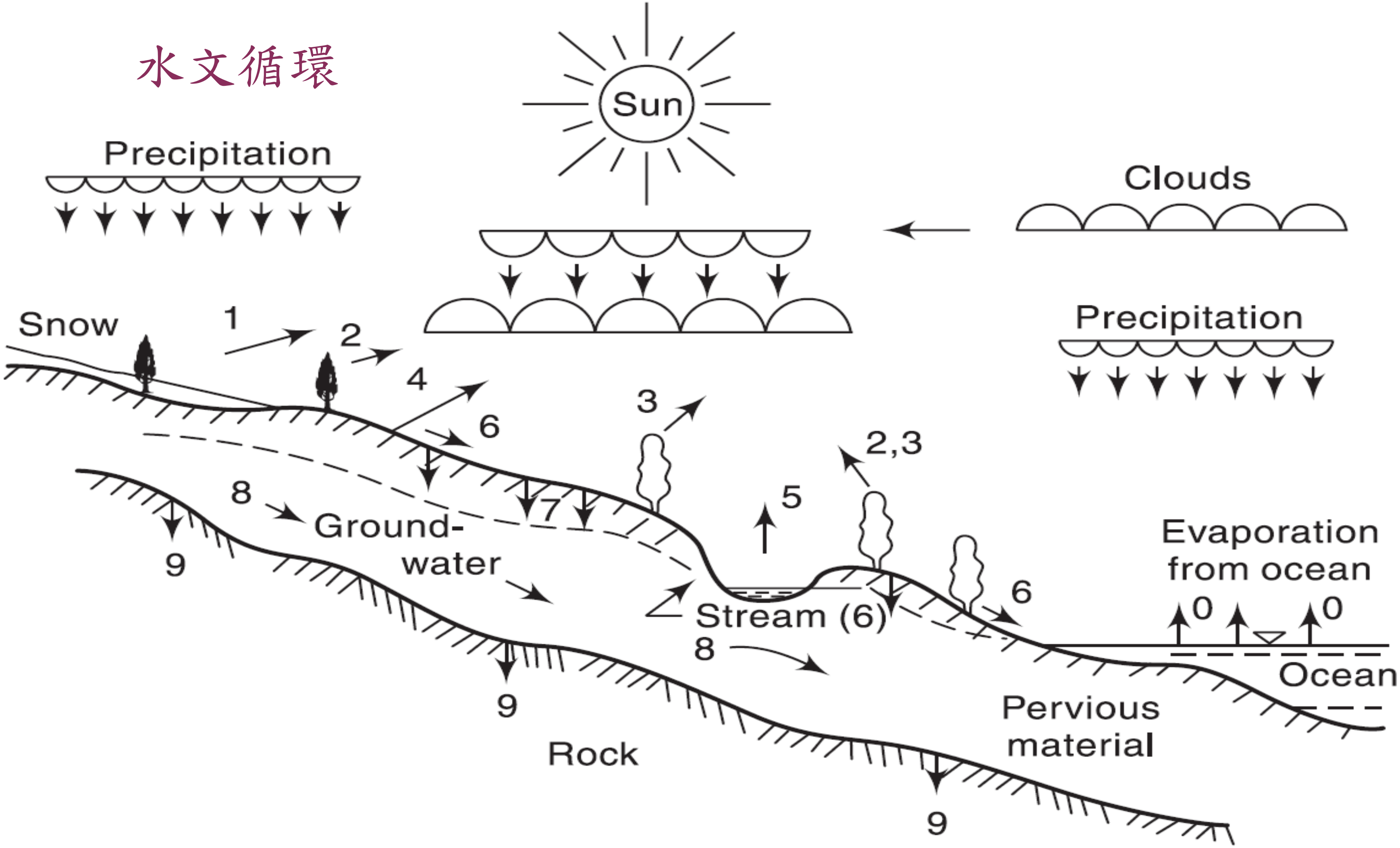
1.1 Introduction

- Hydrology means the science of water. It is the science that deals with the occurrence, circulation and distribution of water of the earth and earth's atmosphere.

- Inter-disciplinary nature

1. estimation of water resources
2. the study of process such as precipitation, runoff, evapotranspiration and their interaction
3. the study of problems such as floods and droughts, and the strategies to combat them.

水文循環



0 = Evaporation from ocean
1 = Raindrop evaporation
2 = Interception
3 = Transpiration
4 = Evaporation from land
5 = Evaporation from water bodies
6 = Surface runoff
7 = Infiltration
8 = Groundwater
9 = Deep percolation

Fig. 1.1 The Hydrologic Cycle

- Precipitation
- Evaporation
- Transpiration
- Interception
- Surface runoff
- Groundwater
- Percolation

1.2 Hydrologic Cycle

Transportation components	Storage components
Precipitation	Storage on the land surface (Depression storage, Ponds, Lakes, Reservoirs, etc)
Evaporation	Soil moisture storage
Transpiration	Groundwater storage
Infiltration	
Runoff	

1.2 Hydrologic Cycle

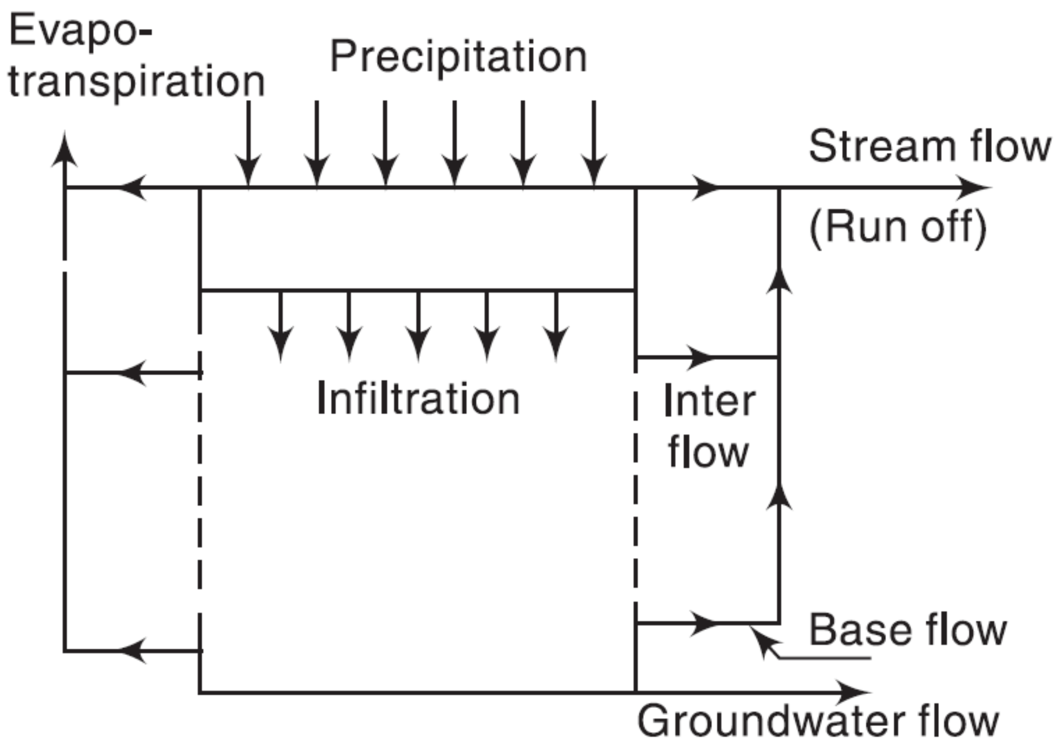


Fig. 1.2 Transportation Components of the Hydrologic Cycle

1.2 Hydrologic Cycle

- The quantities of water going through various individual paths of the hydrological cycle can be described by the continuity principle known as ***water budget equation*** or ***hydrologic equation***.

- It is important to note that the total water resources of the earth are **constant** and the **sun** is the source of energy for the hydrologic cycle.

- Agriculture, forestry, economics, sociology, water power, costal works, etc.

1.3 Water Budget Equation

- **Catchment Area**

  : The area of landing draining into a stream or a water course at a given location is known as catchment area.

Drainage area, drainage basin, watershed

It is normal to assume the groundwater divide to coincide with the surface divide.

1.3 Water Budget Equation

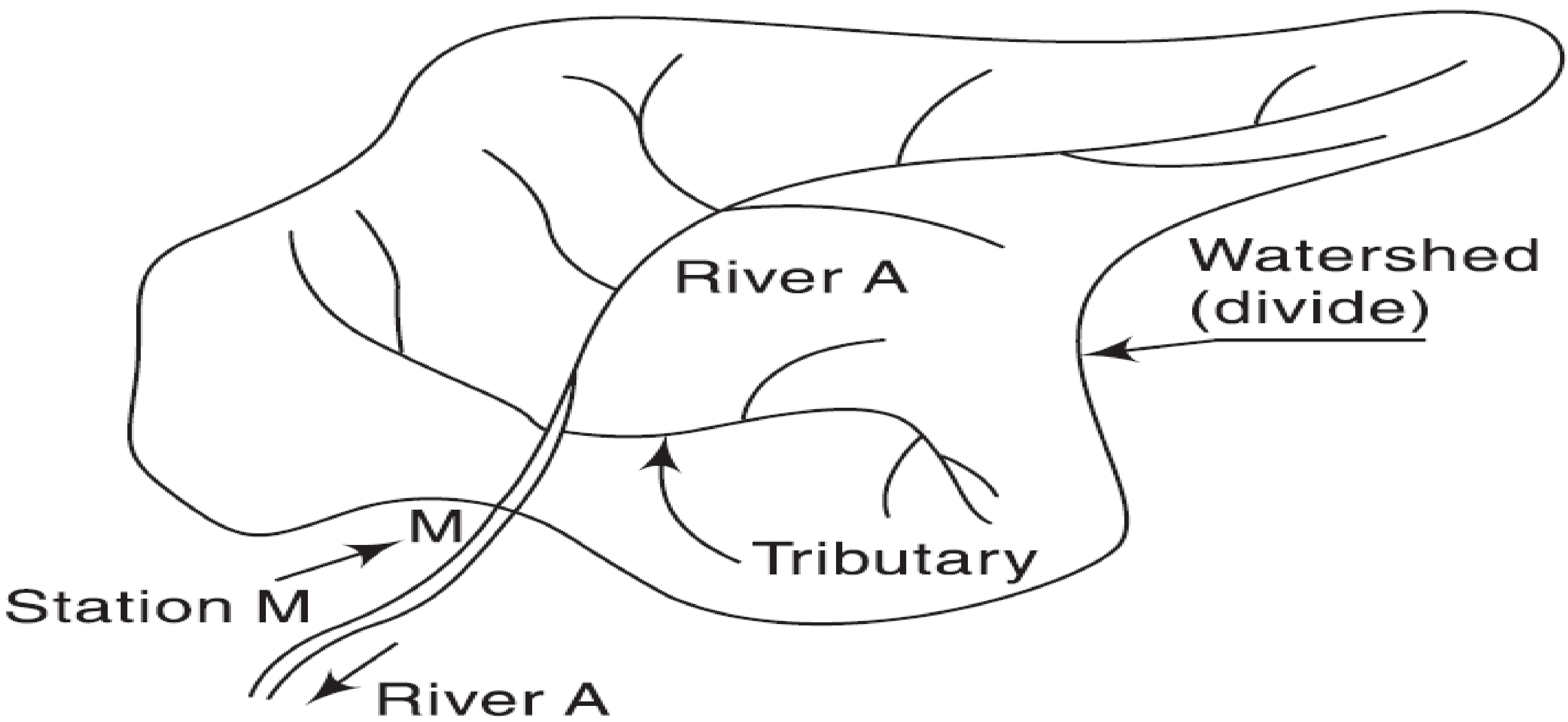


Fig. 1.3 Schematic Sketch of Catchment of River A at Station M

1.3 Water Budget Equation

- **Water Budget Equation**

mass inflow – mass outflow

= change mass storage

$$V_i - V_o = \Delta S$$

$$P - R - G - E - T = \Delta S$$

P: precipitation, R: surface runoff, G: net groundwater flow out of the catchment, E: evaporation, T: transpiration, ΔS: change in storage

Example 1.1

EXAMPLE 1.1 *A lake had a water surface elevation of 103.200 m above datum at the beginning of a certain month. In that month the lake received an average inflow of 6.0 m^3/s from surface runoff sources. In the same period the outflow from the lake had an average value of 6.5 m^3/s. Further, in that month, the lake received a rainfall of 145 mm and the evaporation from the lake surface was estimated as 6.10 cm. Write the water budget equation for the lake and calculate the water surface elevation of the lake at the end of the month. The average lake surface area can be taken as 5000 ha. Assume that there is no contribution to or from the groundwater storage.*

ha = hectare = 10,000

SOLUTION: In a time interval Δt the water budget for the lake can be written as

Input volume – output volume = change in storage of the lake

$$(\bar{I}\Delta t + PA) - (\bar{Q}\Delta t + EA) = \Delta S$$

where $\bar{I}$ = average rate of inflow of water into the lake, $\bar{Q}$ = average rate of outflow from the lake, P = precipitation, E = evaporation, A = average surface area of the lake and ΔS = change in storage volume of the lake.

Here $\Delta t = 1 \text{ month} = 30 \times 24 \times 60 \times 60 = 2.592 \times 10^6 \text{ s} = 2.592 \text{ Ms}$

In one month:

$$\text{Inflow volume} = \bar{I}\Delta t = 6.0 \times 2.592 = 15.552 \text{ M m}^3$$

$$\text{Outflow volume} = \bar{Q}\Delta t = 6.5 \times 2.592 = 16.848 \text{ M m}^3$$

$$\text{Input due to precipitation} = PA = \frac{14.5 \times 5000 \times 100 \times 100}{100 \times 10^6} \text{ M m}^3 = 7.25 \text{ M m}^3$$

$$\text{Outflow due to evaporation} = EA = \frac{6.10}{100} \times \frac{5000 \times 100 \times 100}{10^6} = 3.05 \text{ M m}^3$$

Hence $\Delta S = 15.552 + 7.25 - 16.848 - 3.05 = 2.904 \text{ M m}^3$

Change in elevation $\Delta z = \dfrac{\Delta S}{A} = \dfrac{2.904 \times 10^6}{5000 \times 100 \times 100} = 0.058 \text{ m}$

New water surface elevation at the end of the month = 103.200 + 0.058

= 103.258 m above the datum.

Example 1.2

EXAMPLE 1.2 *A small catchment of area 150 ha received a rainfall of 10.5 cm in 90 minutes due to a storm. At the outlet of the catchment, the stream draining the catchment was dry before the storm and experienced a runoff lasting for 10 hours with an average discharge of 1.5 m^3/s. The stream was again dry after the runoff event. (a) What is the amount of water which was not available to runoff due to combined effect of infiltration, evaporation and transpiration? What is the ratio of runoff to precipitation?*

ha = hectare = 10,000

Example 1.2

SOLUTION: The water budget equation for the catchment in a time Δt is

$$R = P - L \qquad (1.2\text{-b})$$

where L = Losses = water not available to runoff due to infiltration (causing addition to soil moisture and groundwater storage), evaporation, transpiration and surface storage. In the present case Δt = duration of the runoff = 10 hours.

Note that the rainfall occurred in the first 90 minutes and the rest 8.5 hours the precipitation was zero.

(a) P = Input due to precipitation in 10 hours

$= 150 \times 100 \times 100 \times (10.5/100) = 157{,}500 \text{ m}^3$

R = runoff volume = outflow volume at the catchment outlet in 10 hours

$= 1.5 \times 10 \times 60 \times 60 = 54{,}000 \text{ m}^3$

Hence losses $L = 157{,}500 - 54{,}000 = 103{,}500 \text{ m}^3$

(b) Runoff/rainfall = 54,000/157,500 = 0.343

(This ratio is known as *runoff coefficient* and is discussed in Chapter 5)

1.4 World Water Balance

Table 1.1 Estimated World Water Quantities

Item	Area ($M\ km^2$)	Volume ($M\ km^3$)	Percent total water	Percent fresh water
1. Oceans	361.3	1338.0	96.5	—
2. Groundwater				
(a) fresh	134.8	10.530	0.76	30.1
(b) saline	134.8	12.870	0.93	—
3. Soil moisture	82.0	0.0165	0.0012	0.05
4. Polar ice	16.0	24.0235	1.7	68.6
5. Other ice and snow	0.3	0.3406	0.025	1.0
6. Lakes				
(a) fresh	1.2	0.0910	0.007	0.26
(b) saline	0.8	0.0854	0.006	—
7. Marshes	2.7	0.01147	0.0008	0.03
8. Rivers	148.8	0.00212	0.0002	0.006
9. Biological water	510.0	0.00112	0.0001	0.003
10. Atmospheric water	510.0	0.01290	0.001	0.04
Total: (a) All kinds of water	510.0	1386.0	100.0	
(b) Fresh water	148.8	35.0	2.5	100.0

Table from WORLD WATER BALANCE AND WATER RESOURCES OF THE EARTH, © UNESCO, 1975. Reproduced by the permission of UNESCO.

1.4 World Water Balance

Table 1.2 Global Annual Water Balance

Item	Ocean	Land
1. Area (M km^2)	361.30	148.8
2. Precipitation (km^3/year)	458,000	119,000
(mm/year)	1270	800
3. Evaporation (km^3/year)	505,000	72,000
(mm/year)	1400	484
4. Runoff to ocean		
(i) Rivers (km^3/year)		44,700
(ii) Groundwater (km^3/year)		2,200
Total Runoff (km^3/year)		47,000
(mm/year)		316

Table from WORLD WATER BALANCE AND WATER RESOURCES OF THE EARTH, © UNESCO, 1975. Reproduced by the permission of UNESCO.

1.4 World Water Balance

Table 1.3(a) Water Balance of Continents[2] mm/year

Continent	Area ($M\ km^2$)	Precipitation	Total runoff	Runoff as % of precipitation	Evaporation
Africa	30.3	686	139	20	547
Asia	45.0	726	293	40	433
Australia	8.7	736	226	30	510
Europe	9.8	734	319	43	415
N. America	20.7	670	287	43	383
S. America	17.8	1648	583	35	1065

1.4 World Water Balance

Table 1.3(b) Water Balance of Oceans[2] mm/year

Ocean	Area (M km^2)	Precipitation	Inflow from adjacent continents	Evaporation	Water exchange with other oceans
Atlantic	107	780	200	1040	–60
Arctic	12	240	230	120	350
Indian	75	1010	70	1380	–300
Pacific	167	1210	60	1140	130

1.5 History of Hydrology

- The knowledge of the hydrologic cycle came to Europe around AD 1500.

Chow[1] classifies the history of hydrology into eight periods as:

1. Period of speculation—prior to AD 1400
2. Period of observation—1400–1600
3. Period of measurement—1600–1700
4. Period of experimentation—1700–1800
5. Period of modernization—1800–1900
6. Period of empiricism—1900–1930
7. Period of rationalization—1930–1950
8. Period of theorization—1950–to–date

- Most of the present-day science of hydrology has been developed since 1930, thus giving hydrology the status of a young science.

1.6 Applications in Engineering

1. The capacity of storage structures such as reservoirs.
2. The magnitude of flood flows to enable safe disposal of the excess flow.
3. The minimum flow and quantity of flow available at various seasons.
4. The interaction if the flood wave and hydraulic structures, such as levees, reservoirs and bridges.

1.7 Sources of Data

- Weather records
- Precipitation data
- Stream flow records
- Evaporation and evapotranspiration data
- Infiltration characteristics of the study area
- Soils of the area
- Land use and land cover
- Groundwater characteristics
- Physical and geological characteristics of the area
- Water quality data ….

Problems

1.2 / 1.4 / 1.5

1.2 A catchment area of 140 km² received 120 cm of rainfall in a year. At the outlet of the catchment the flow in the stream draining the catchment was found to have an average rate of 2.0 m^3/s for 3 months, 3.0 m^3/s for 6 months and 5.0 m^3/s for 3 months. (i) What is the runoff coefficient of the catchment? (ii) If the afforestation of the catchment reduces the runoff coefficient to 0.50, what is the increase in the abstraction from precipitation due to infiltration, evaporation and transpiration, for the same annual rainfall of 120 cm?

1.4 A river reach had a flood wave passing through it. At a given instant the storage of water in the reach was estimated as 15.5 ha.m. What would be the storage in the reach after an interval of 3 hours if the average inflow and outflow during the time period are 14.2 m^3/s and 10.6 m^3/s respectively?

Problems

1.5 A catchment has four sub-areas. The annual precipitation and evaporation from each of the sub-areas are given below.
Assume that there is no change in the groundwater storage on an annual basis and calculate for the whole catchment the values of annual average (i) precipitation, and (ii) evaporation. What are the annual runoff coefficients for the sub-areas and for the total catchment taken as a whole?

Sub-area	Area Mm^2	Annual precipitation mm	Annual evaporation mm
A	10.7	1030	530
B	3.0	830	438
C	8.2	900	430
D	17.0	1300	600