CHAPTER

1

Hydrology and Water Resources

1.1 INTRODUCTION

The objective of this chapter is to give an easily comprehensible introduction to hydrology and water balance calculations for engineering students and practitioners. The text has been compiled in order to give a holistic view of the water environment, i.e., hydrology seen as the water carrier in nature with human influence. The main hydrological components are treated with simple calculation methods to quantify water balances and mass transport.

Water is a chemical union between hydrogen and oxygen. Water is unique in the sense that it can exist in three phases at almost the same temperature: solid state (ice), liquid, and gas (water vapour). On Earth, about 2/3 of the surface is covered by water and about 1/3 by land. Water is a prerequisite for all known forms of life. A biological cell is usually made up of at least 70% water. Humans contain 55–60% water by weight (men about 60% and women about 55%).

1.1.1 Importance of Water

Water is a basic, natural resource for agriculture and industry. Water has always been intimately linked with human development, and its role is considered crucial for the transition of men from hunters to farmers. The earliest known human civilizations were developed at places having stable and regular access to water, e.g., the Nile valley, the Euphrates and Tigris, and the Indus valley. The river water provided water supply, food, fertile sediments, and easy transportation. Later, the water became a prerequisite for industrial development through the production of hydropower (mills, steam engines, etc.) and transportation routes. Consequently, for both agriculture as well as industry, water has become a key component as a natural resource, energy producer, solvent, and transporter. In many developed countries, people have constant access to water of good quality, and water is an indispensable component of clean outdoor environment. Water has, however, many other societal functions, and in many *arid* (dry) and semi-arid countries, lack of water is a limiting factor for economic and social development.

Water is a prerequisite for life, but it also creates many problems. Water-borne diseases (malaria, bilharzia, etc.), floods, as well as droughts cause innumerable casualties in excess of those due to all other disasters. About 1.2 billion people have to drink unhygienic water. This results in 5 million deaths every year. Proper management of water is, therefore, related not only to drinking water and a clean outdoor environment, but also to developments in public health, and social and economic development. Thus, the study of water is strongly interdisciplinary because all major societal areas and scientific disciplines are related to utilization of water resources.

1.1.2 Human Influence

Hydrology is associated with the circulation of water in nature and the human influence on this system. The water transport can be conceptualized as a combination of the natural circulation in an exterior system and an inner man-made system where humans tap water from the outer system and return it back after shorter or longer use, unfortunately quite polluted. In the natural water system, changes occur slowly (except in cases of natural disaster). The human influence, however, is now so large that even the exterior system is being affected significantly. Acidification of water resources and global warming are glaring examples of the damaging effect of human influence on nature. The entire water and energy system, with its exterior natural part and inner human-regulated part, is extremely complex and difficult to analyze. Figure 1.1 shows the two components and the transport of water from the natural system to and within a typical human community (after Anderberg, 1994). To supply the community's residents with water, a *water supply source* is connected to a *water treatment plant*. Consequently, water is taken from the natural system to the man-made water system. The water supply sources are open water reservoirs such as a large river or a lake.

1.1.3 Civic Use

However, the water supply can also come from *groundwater*, through a drilled or dug well. To secure a continuous supply, a *reservoir* is built that helps to even out seasonal differences in water availability, e.g., long dry periods during summer and snow melt and high flows during spring. A reservoir can be built by damming up a river in a suitable location so that an artificial lake is created.

From the reservoir, water is taken to the *treatment plant* where it is properly treated in order to make the water drinkable. After treatment, the water is sent through pipes to households and consumers. However, problems may arise because the use of water is extremely variable during the day. The quantity of

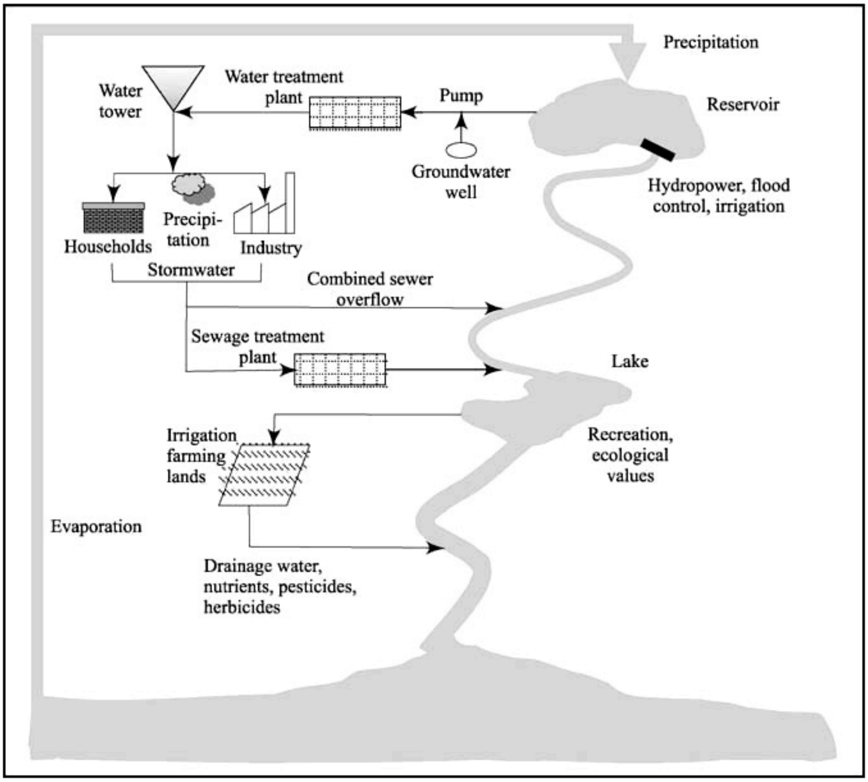

Fig. 1.1 *Circulation of water through an exterior natural and an inner man-modified system (after Anderberg, 1994)*

water used in households and industry during the night-time is relatively low; but water usage peaks, especially during morning and evening hours. To cope with such large daily variations, a short-term reservoir, usually a *water tower*, is built somewhere in between the consumer household and the treatment plant. The objective of the water tower is to keep as much water stored as is needed to cope with temporary consumption peaks without changing the production rate of the treatment plant. From the water tower, water is then distributed to consumers. Because the water is under constant pressure (from the water stored in the tower), continuous flow is provided to the water taps. The quantity of water consumed for drinking and cooking is considerably less in comparison to the quantity used for washing (rinsing soap, detergents, and washing powder), and flushing waste from the kitchen, toilet, and bathroom.

Water used in the kitchen, toilet, and bathroom is discharged from the buildings through common pipes. If the polluted water is discharged directly to the *recipient* (such as lakes and rivers) without treatment, it usually leads to serious deterioration of the ecological life in the water body. At the same time, the water becomes more or less unusable for downstream residents. Nowadays, the polluted water is usually treated in a *sewage treatment plant* before it is lead to the recipient. However, along with the sewage water from households and industry, *storm-water* (rain water from impermeable areas such parking lots, roofs, etc) also goes to the treatment plant in *combined sewer pipes* (which have sewage and storm-water in the same pipes). This is especially the case for the older central areas of cities built before the 1960s. Cities that are built after 1960s sometimes have *separated sewer pipes* (sewage water and storm-water in different pipes) instead, which direct the sewage water to the treatment plant and storm-water directly to the recipient without any treatment. Manholes and drains, which collect storm-water and lead it to recipients in order to avoid flooding problems after heavy rainfall, can be seen along the paved streets in some cities. However, storm-water, which has flushed off roofs, parking lots, and streets, can often carry quite a large pollution load from petrol, oil, heavy metals, sediments, etc. If a heavy rainfall occurs during a period of heavy water consumption in households and industry, the *combined sewer system* (sewage and storm-water in the same pipes) can be flooded and the polluted water may have to be discharged directly to the recipient without treatment (*combined sewer overflow*) in order to avoid serious flooding.

1.1.4 Environmental Fallout

Water is also used for other purposes. A major water consumer is agriculture. About 80% of the global water consumption is used in agriculture and *irrigation* of crops. To feed the human population, cereals and vegetables must be produced; and *fertilizers, pesticides, and herbicides* are to be used to keep the insects from destroying the crops. Heavy rainfall and irrigation water can then flush the soil and transport the fertilizers and pollutants such as *nitrogen* (N) and *phosphorous* (P) to nearby streams and lakes. Eventually, these will be transported to the sea, resulting in *eutrophication*, algae, and pollutant problems.

Evaporation occurs from water surface (and even from land surface). *Precipitation* closes the *hydrological cycle*. The evaporation mainly transports pure water, so substances in *runoff* accumulate in the sea, either as sediments in the sea bottom or as *dissolved matter* in the sea water. Precipitation forms runoff, and we are back to where we, began in the water supply and reservoir. The reservoir is a simple construction where the water is dammed by concrete obstruction in the water course itself (*dam building*). The water level upstream from the dam can then be regulated by releasing more or less water through gates or over a variable dam crest level. The difference in height between the upstream and the downstream water level can also be used to generate electricity in a *hydropower plant*. Reservoirs can be exclusively built for hydropower production, or they can combine this function with the control of water supply, irrigation, and/or flood protection.

As mentioned above, the total water system is very complex. If the objective is to improve the water environment, this cannot be achieved by improving the situation only in a part of the total system. The continuous circulation of water means that all parts are connected in one way or another. The water quality is affected by all the components related with the system. Problems in hydrologic engineering therefore cannot be solved without regarding the entire system.

The hydrological circulation and transportation of water as depicted in Fig. 1.1 also helps to envisage how a pollutant may be transported. Water itself is the most important transporter of chemical substances as well as biological organisms. Thus, knowledge about the hydrological circulation and transportation of water will empower us to stop potential pollutants from contaminating the system. With suitable assumptions, it is also possible to make predictions about the future of a pollutant. This may be a frequently done task for the hydrologic engineer.

1.2 HYDROLOGICAL CYCLE

The *hydrological cycle* is the most important carrier of water, energy, and matter (chemicals, biological material, sediments, etc), locally and globally (Fig. 1.2). The hydrological cycle acts like an enormous global pump that is driven mainly by two forces; *solar energy* and *gravitation pull*. Humans have ingeniously utilized this global and free pump to get irrigation water and to draw power from the enormous amount of energy that this cycle represents.

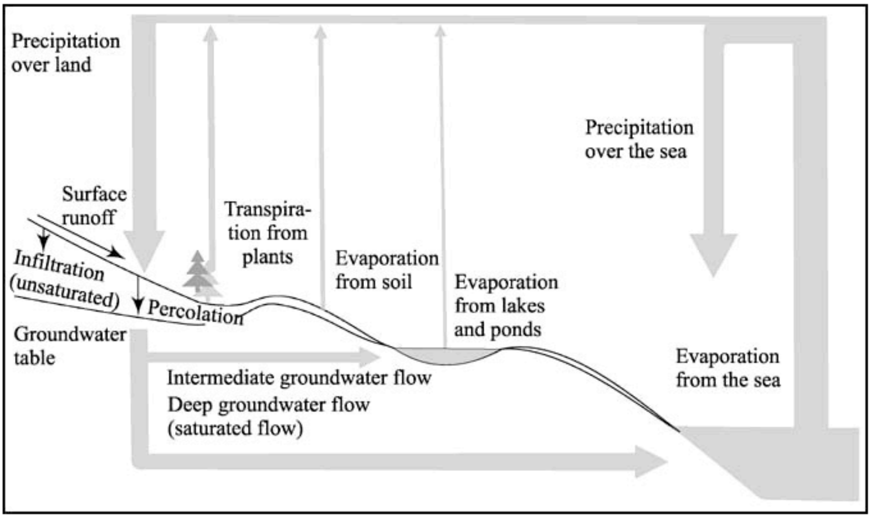

Fig. 1.2 *The hydrological cycle (after Bonnier World Map, 1975)*

The incoming solar energy forces water to evaporate from both land and sea. Much of this vapour condensates and falls directly over the sea surface again (globally about 7/8 of the rainwater falls over the oceans). The remainder of the rainwater falls over land (globally about 1/8), and it falls as *precipitation* (rainfall, snow, and/or hail). This forms *runoff* as creeks, rivers, and lakes on the soil surface. A major part, however, *infiltrates* through the soil surface and forms *soil water* (water in the upper soil layers above the *groundwater table*, also called the *unsaturated zone*) that may later *percolate* (deeper infiltration) down to the groundwater (groundwater zone also called the *saturated zone*) level.

In the ground, water can also be taken up by plant roots, and evaporate into the atmosphere through *transpiration* (evaporation through the plant leaves by plant respiration) or by direct *evaporation* from the soil. The total evaporation from both soil and plants is called *evapotranspiration*.

1.2.1 Carrier for Pollutants

The global cycle of water transports different types of chemical, biological, and sediment matter. Finally, these may be deposited in the sea because this is the lowest point in the system. If the release point for these constituents is known, it is often possible to predict the transport path by studying the local hydrology in the area. This is due to the fact that the pollutant often follows the same path as the water. However, chemical and/or biological transformation may also affect the pollutant.

Humans influence and change the general hydrological cycle to a great extent. Activities in the landscape directly affect the different components of the hydrological cycle. The chemical content of different hydrological parts is also increasingly affected by various activities such as industry, agriculture, and city life. Yet, the total amount of water on earth is constant. Water is neither created nor is disappearing from earth. However, the content of various biological and chemical elements can fluctuate, depending on the location of the hydrological cycle (Fig. 1.3).

1.2.2 Turnover Time

Only a fraction of the total water volume is fresh water (about 2.7%). And, a major part (2/3) of this fresh water is located around the poles as ice and glaciers. The total amount of fresh water resources is consequently limited, and desalination of seawater is still an expensive process. The water contained in different components (shown in Fig. 1.3) is continuously exchanged due to the constant movement of water.

The theoretical turnover time indicates the average time that it takes for the water volume to be exchanged once. For some components, e.g., water in rivers and atmosphere, the turnover time is very short, about one week (Table 1.1). This also indicates the theoretical transport time for pollutants released in various parts of the water cycle. A pollutant that accumulates on the glacial ice would theoretically surface again after about 8000 years (Table 1.1). A pollutant released in the atmosphere or a river would be flushed out after about a week. However, the average turnover is theoretical, and assumes that the pollutants are not adsorbed or transformed by biological and geological media through which they are transported. In any case, the turnover time can give a rough estimation in order to understand transport velocities in different parts of the hydrological cycle.

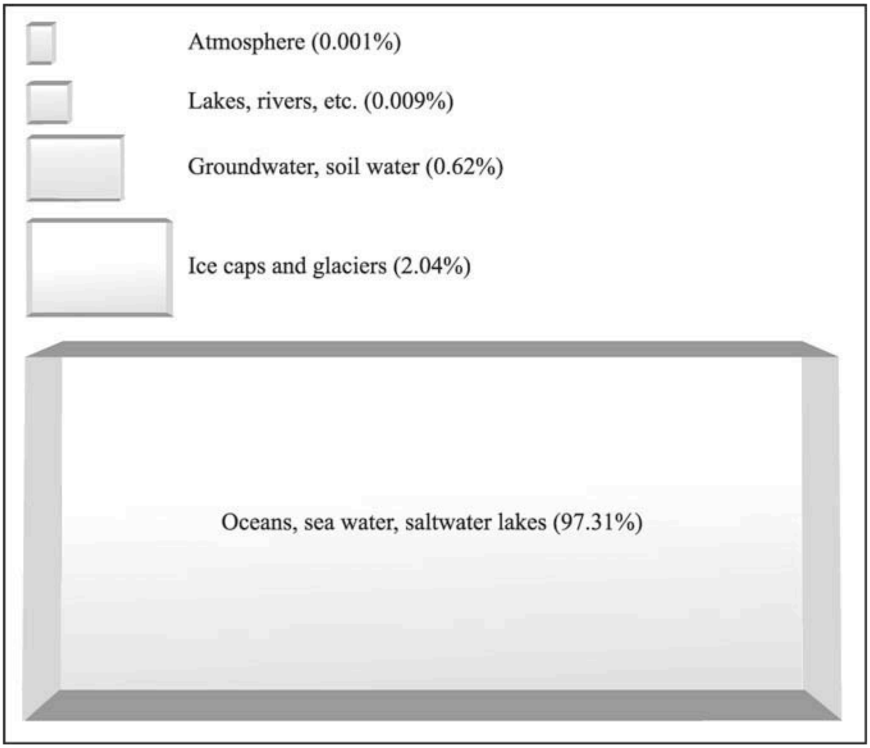

Fig. 1.3 *The global distribution of water in different hydrological parts (after Bonnier World Map, 1975)*

Table 1.1 Average turnover time for water in different hydrological parts

Hydrological part	*Volume (10^6 km^3)*	*%*	*Turnover time (year)*
Oceans	1370	94.2	3000
Groundwater	60	4.1	5000
Ice caps and glaciers	24	1.7	8000
Lakes	0.3	0.02	10
Soil water	0.1	0.006	1
Atmosphere	0.01	0.001	1 week
Surface water	0.001	0.0001	1 week

Consequently, the turnover time may give a rough but general idea of how quickly a water particle may travel through a water body. This can be compared to a more detailed picture as seen in Table 1.2. The table shows typical velocities by which a water molecule or a pollutant travelling with the same speed as water may travel. Note that these values are based on approximation. Large variations may be expected, depending on the hydrological situation, the hydraulic conductivity of the geologic medium, etc.

Table 1.2 Typical average velocity for a water molecule

Water body	*Soil type*	*Water molecule velocity*
Soil water (vertical)	—	1–3 m/year
Groundwater	Moraine close to soil surface	1–10 m/day
	1 m depth	0.1 m/day
	Deep	0.01 m/day
	Cracked bed rock	0–10 m/day
Creek	—	0.1 m/s ≈ 10 km/day
River	—	1 m/s ≈ 100 km/day

Humans interact with the natural hydrological system by diverting water for different activities. A major part of this water, about 80% on a global scale, is used for irrigation and production of agricultural products. The remaining 20% is used for industrial needs and domestic water supply. Figure 1.4 shows, in a schematic way, how water is used in households. It is seen that for a rich and developed country, a very small part (about 3%) is used for direct consumption (drinking water and cooking).The remaining part is used for sanitation purpose. For a poor country in the developing world, average per capita water consumption may be only 20 liters a day. The UN recommends that people need a minimum of 50 liters of water a day for drinking, washing, cooking, and sanitation.

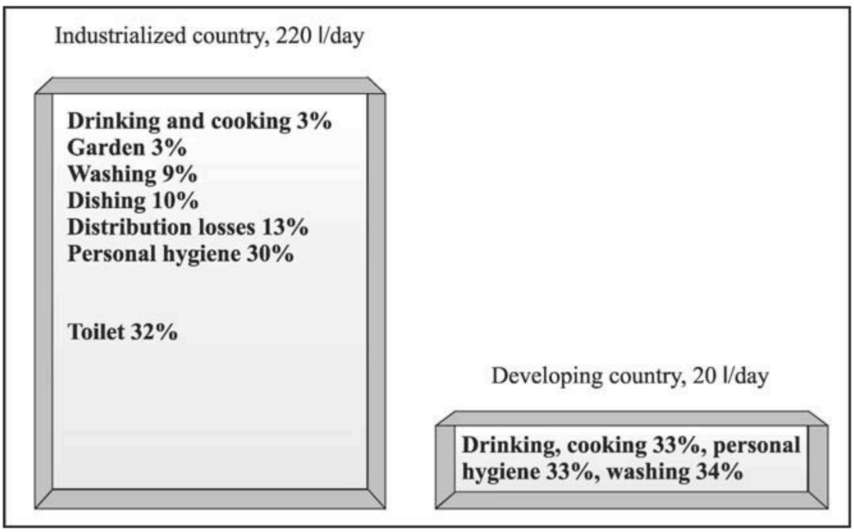

Fig. 1.4 *Domestic water consumption (after Bonnier World Map, 1975)*

1.3 CLIMATE AND WATER AVAILABILITY

As mentioned earlier, the global influx of solar energy is the main driving force of the hydrological cycle. The greater the influx of solar energy, the more water can evaporate over a specific area. And greater the evaporation, greater will be the water available for precipitation. The great effect of the *solar influx* is modified by the general atmospheric circulation. Winds from ocean bring moist air to land where precipitation occurs. Evaporation also occurs from land. The major influx of solar energy occurs along the equator (Fig. 1.5). The solar influx falls perpendicular to the soil surface at the equator. At higher latitudes, the solar influx falls at an oblique angle to the soil surface and over a larger area and thus brings less energy.

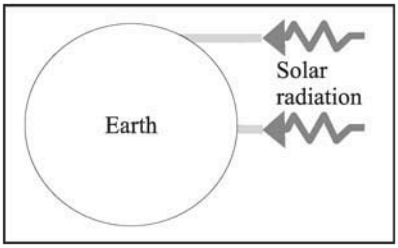

Fig. 1.5 *Solar influx (radiation)*

The moist air at the equator is warmed up by the solar influx, and due to density differences, a strong vertical uplift of the air occurs. This phenomenon is called *convection*. Convection is the result of the rising of expanding warm air of less density as compared to the surrounding cooler and denser air. The rising air parcels induce the flow of fresh air from the sides replacing the rising air. This gives rise to a general global atmospheric flow that, to a great extent, distributes air and precipitation over the entire globe.

Due to the rotation of earth, this general global atmospheric pattern is split up into six smaller atmospheric cell systems (Fig. 1.6). The whole system is, however, driven by the equatorial solar influx of energy. The friction between the cells (the cells are moving approximately as six inter-connected cogwheels) drives the circulation from the equator to the polar areas.

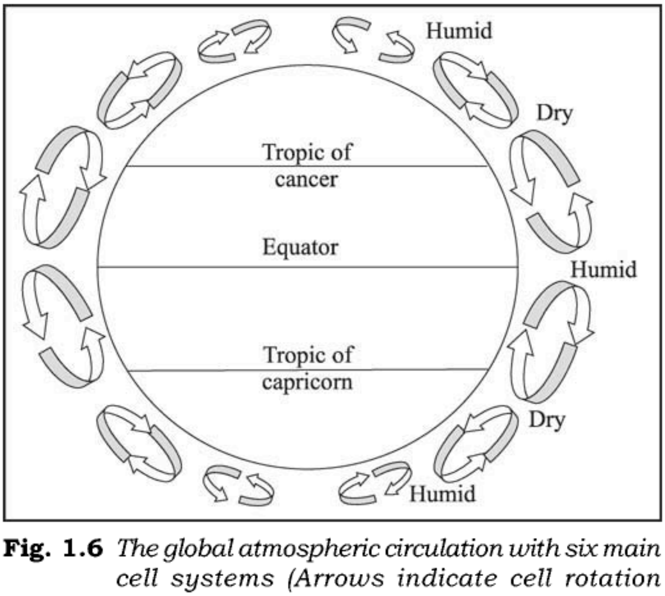

Fig. 1.6 *The global atmospheric circulation with six main cell systems (Arrows indicate cell rotation direction) (after Whipple, 1984)*

The atmospheric flow moving over ground surface can potentially take up moisture. When moisture in the air is driven up in to the upper part of the cells, the air is cooled off and precipitation may occur. Cooler air can hold less moisture as compared to warm air. The air in the upper part of the cell is then driven down again to the lower part of the cell. This air, however, does not contain any moisture. In turn, these down-turning cell areas with no moisture can explain much of the dry areas of the globe. The equator area as well as the tropics of Cancer and Capricorn have a large excess of precipitation. Areas where the dry cell air is descending to the ground contain the great deserts of the world: the *Sahara* and *Taklamakan* in the northern hemisphere and the deserts of Australia in the southern hemisphere. Further up towards the poles, the cells again bring rising moist air that precipitates over the *temperate areas* (e.g., northern Europe, North America, and southern South America). These areas have an excess of precipitation. However, this general precipitation pattern, is modified by local precipitation mechanisms.

The precipitation and therefore the availability of water also vary for different time scales. In general, precipitation and temperature may vary in the same manner. Higher the temperature, higher would be the evaporation (provided that there is water to evaporate). The precipitation at a single location is, however, difficult to predict because it depends on local conditions and local wind systems that modify the general large-scale atmospheric circulation. This also makes it very difficult to predict how precipitation will look after a hundred years from now. Figure 1.7 shows an example of how the monthly precipitation

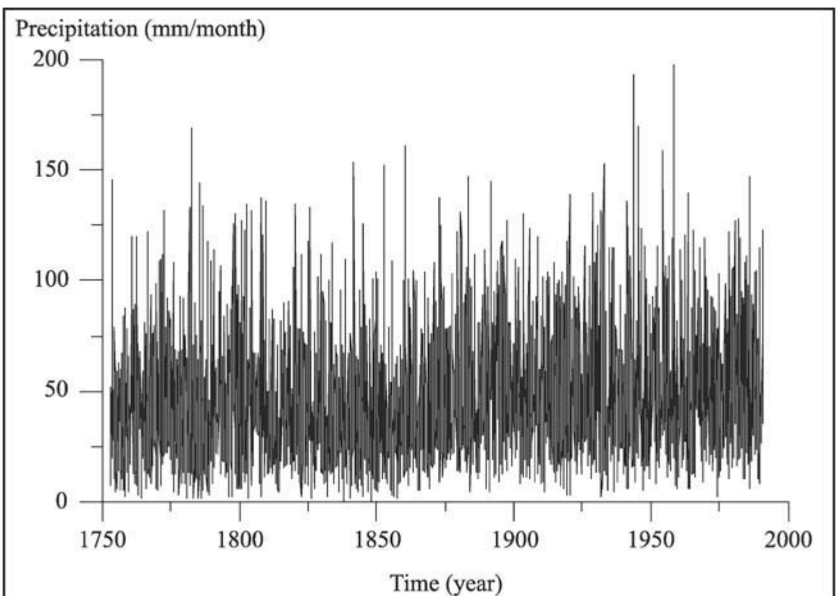

Fig. 1.7 *Monthly precipitation in Lund, Sweden, between 1750 and 2000*

has looked in Lund, Sweden, for the last 250 years. It is rather evident that the monthly precipitation can vary widely between 0 to 200 mm per month. At the same time, it is difficult to see if there is any long-term trend (general increase or decrease with time).

In general, the temperature and also the precipitation pattern are governed by both atmospheric and oceanic circulation. In short, the total *energy balance* over a specific area decides the general climate.

1.4 WATER BALANCES

The basis for availability and general transportation of water and pollutants for a specific area is called the *water balance* or *mass balance equation* or *continuity equation*. The water balance equation, in general, stipulates that all inflow minus all outflow to an area during a certain time period must be equal to the storage changes.

$$I - O = dS/dt \tag{1.1}$$

where, I is all inflow, O is all outflow, and dS is storage changes that occurred during time period dt. For a specific area and a specific time period, the water balance equation can be written as:

$$P - Q - E = \Delta S \tag{1.2}$$

where,

P = precipitation

Q = runoff

E = evaporation

ΔS = change in storage

Usually, the unit for water balance is mm/time (e.g., mm/month or mm/year). But, it can also be expressed in volume (for a specific period) or volume per time. The change in water storage (ΔS) will modify the total water storage (S) of the area. All the water that enters or leaves an area can be represented by these terms.

The precipitation (P) is the amount of water that falls as rain, snow, and/or hail. The runoff or discharge (Q) is the water that appears as surface water such as water in creeks, rivers, and/or lakes. The evaporation (E) can usually not be seen, but after condensation of the water vapour, we see the water as cloud drops. The total evaporation includes both evaporation from soil and water surfaces as well as transpiration from plants. The change in storage (ΔS) can be many things. It may be water that does not go directly as runoff. This may be snow and/or ice. It can also be infiltrating water that will appear as delayed runoff, and/or water that will percolate to the groundwater table, and/or water that will evaporate a little later.

1.4.1 Role of Water Balance Equation

The water balance equation is used for many basic analyses of water availability in an area, e.g., to find out how much water is available that can be used for drinking purpose or irrigation. This part is usually constituted by Q, i.e., runoff. The components of the water balance equation look different for different climatic conditions. It is logical that the total evaporation in warm areas is much larger as compared to cooler areas. Figure 1.8 shows, in a schematic way, an example of water balances for three different types of climatic conditions.

As seen in Fig. 1.8, the storage term (ΔS) is missing. This is due to the fact that for average values over longer time periods (e.g., several years) or over periods corresponding to multiples of a year, the storage is more or less likely to be constant. Thus, storage changes will be close to zero. We can, therefore, write the water balance equation as:

$$P - Q - E = 0 \tag{1.3}$$

This simplifies the calculations because there is one term less to determine when, for example, estimating available water (Q) for an area. The reason why the storage term can be assumed zero for longer periods is examplified in Fig. 1.9. When looking at the storage term of the water balance for a typical area over several years, it is usually noticed that it behaves in a periodic manner with a frequency equal to one year. That is, the typical period is one year and it is seen over many one-year periods that the change in storage is approximately

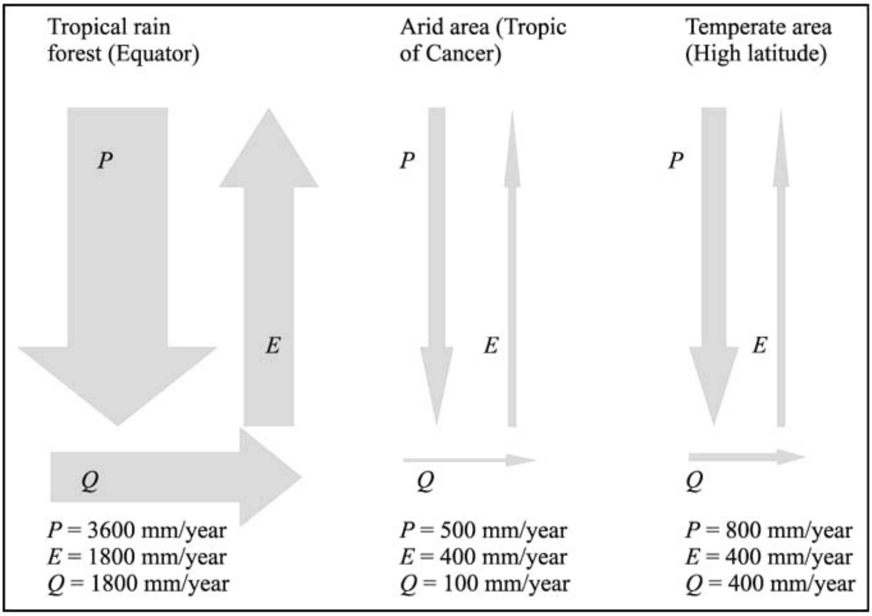

Fig. 1.8 *Example of water balances for three different types of climatic conditions*

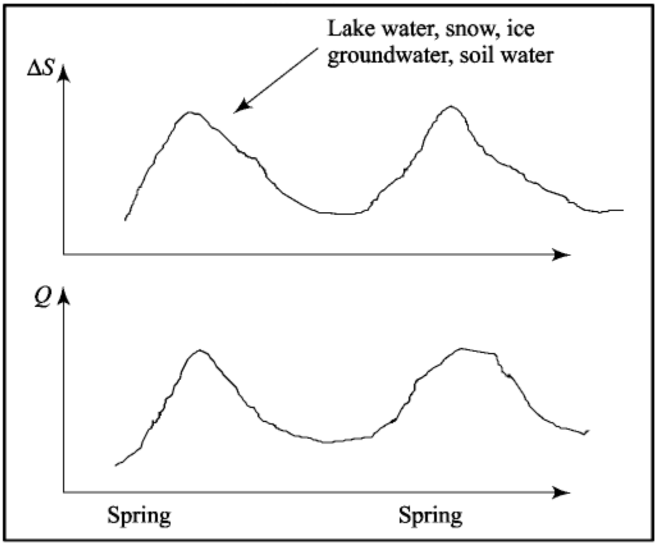

Fig. 1.9 *The storage term (ΔS) co-varies with precipitation and runoff in a cyclical manner over the year*

zero. This means that in water balance calculations involving a minimum of a one-year period, the storage term can be assumed to be zero ($\Delta S = 0$).

1.4.2 Catchment Area

Water balances are usually calculated for a specific area, which is called the *catchment area* (also called as *drainage basin*, *discharge area*, *precipitation area*, and *watershed*). A catchment is defined as the area upstream from a certain point in the water course that contributes to flow when precipitation falls. The size of the catchment depends on where this point is located in the stream and its topography or altitude situation.

In general, water flows from upper-lying areas to lower-lying areas in the catchment due to gravity. The area of the catchment is determined by the *water divide* (Fig. 1.10). The water divide is constituted by hills and peaks in the landscape over which the water cannot flow. Consequently, the catchment is completely surrounded by the water divide on all sides. All precipitation that falls within the catchment border (water divide) will tend to flow towards the lowest-lying point of the area which is the outflow point for the entire catchment. Some water, however, will infiltrate into the ground and become soil water or groundwater and be transported very slowly to the outflow point. Some water will never reach the outflow point because of evaporation. But, water reaching the outflow point must have come from the area within the catchment border. Consequently, other material and constituents transported by water, such as pollutants and nutrients that could come in contact with the water, will also reach the outflow point.

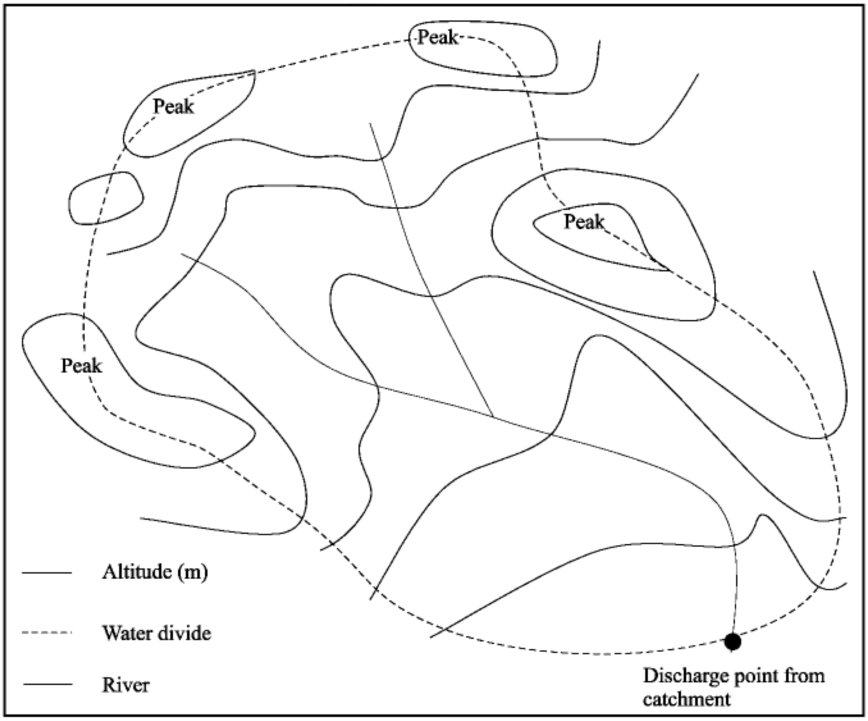

Fig. 1.10 *The water divide surrounds the catchment area and is defined by the topographical pattern*

From a topographical map (map with altitude levels) as in Fig. 1.10, the catchment area for a certain point in a stream can be determined. By following the altitude levels on the map, i.e., the highest points in the landscape (e.g., hills or mountain ridges) upstream from the point, one will eventually come back to the starting point, but on the other side of the water course. The water divide will always run perpendicular to the altitude levels on the map over the high peaks and ridges.

Usually, an outflow point is chosen so that it coincides with a location where water level or discharge measurement is performed. Once the catchment area is defined, it is possible to determine water balances for the area upstream from the discharge point. It is usually assumed that the water divide for the surface water coincides with the groundwater divide. This is usually the case; however, for some geological situations, (Fig. 1.11), the underground material's *hydraulic conductivity* (*rate of permeability*) can result in some discrepancies. For hydrologic engineering calculations it is often assumed in a relevant way that both surface water and groundwater follow the same water divide.

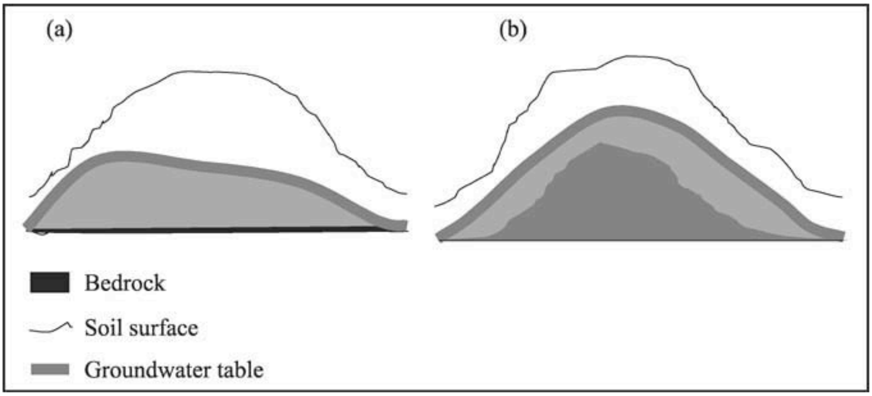

Fig. 1.11 *Example of a geological situation when the surface water divide does not coincide with the groundwater divide, (a) shows the case when the surface water and groundwater divide coincide, and (b) shows the case when the surface water and groundwater divide do not coincide (the underlying bedrock determines the groundwater divide instead) (Source: Grip and Rodhe 1991)*

The world's largest catchment is the Amazonas in South America (Table 1.3). Every 5th second, 1 Mm^3 of water is discharged into the Atlantic from this gigantic river. This represents 20% of all the world´s freshwater discharge from land areas. The largest river in India is the Brahmaputra with an average discharge of almost 20,000 m^3/s.

Table 1.3 The largest rivers in the world with catchment areas

River	*Catchment area (km^2)*	*Annual average discharge (m^3/s)*
Amazon	7,180,000	220,000
Kongo	4,014,500	39,600
Yangtze	1,942,500	22,000
Brahmaputra	935,000	19,800
Ganges	1,059,300	18,700
Jenisej	2,590,000	17,400
Mississippi	3,221,400	17,300
Orinoco	880,600	17,000
Lena	2,424,200	15,500
Parana	2,305,100	14,900
St. Lawrence	1,289,800	14,200
Irrawaddy	429,900	13,600
Ob	2,483,800	12,500
Mekong	802,900	11,000

1.4.3 Hydrological Data

To do a more detailed hydrological and environmental study, it is usually necessary to divide larger catchments into *sub-catchments* (smaller runoff catchments within the larger ones). This is done in the same way as above by defining smaller areas delimited by smaller water divides. In doing so, a more detailed picture can be obtained about water and environment problems of specific areas. Hydrological information can usually be found in national weather, hydrological, geological, and environmental surveys. Also, regional centers for water supply, hydropower, and/or irrigation usually keep hydrological data records. However, hydrological data can often be found at research centers, universities, river basin organizations, and various kinds of NGOs as well. Using this information, it is possible to find catchment discharge and use it, for example, to estimate the available water resources or pollutant transport.

Table 1.4 shows an example of a typical discharge statistics from a catchment. This type of information is typically necessary in order to estimate availability of water resources, the size of reservoirs, flood estimation, pollutant transport, etc. From the table, it is seen that the discharge is given both as dm^3/s and in $dm^3/(s\ km^2)$, i.e., runoff per unit area (km^2) within the catchment. It is also possible to see the *duration* of a specific flow (i.e., how many days per year), expressed in % of the total time that a certain runoff value is exceeded. This information is needed in order to decide the size of a reservoir to prevent flooding. Different minimum and maximum values (for different years and different months) for runoff are also given in the same table. This type of information is useful to determine if a certain organism with specific flow requirements would be able to survive in the water course (e.g., during dry summer months).

Table 1.4(a) Example of discharge statistics that can be used to solve water resources problems

Catchment Blue River *Water course: Blue River; Drainage area 52 km², Lake percentage 11.5%* *Characteristic values of discharge*												
	Maximum		*Mean*			*Minimum*		*Duration*				
	max	*mean*	*max*	*mean*	*min*	*mean*	*min*	*1%*	*50%*	*75%*	*95%*
dm^3/s	3208	1573	477	287	159	23	8.0	1612	119	46	21
$dm^3/s\ km^2$	62	30	9.2	5.5	3.1	0.45	0.15	31	2.3	0.88	0.40

Table 1.4(b) Mean duration of runoff 1965–1990

$dm^3/s\ km^2$	0.5	1	2	3	4	5	6	8	10	15	20	25	50	75	100	150	200
days/year	334	252	195	165	149	136	119	87	66	38	14	6	0	—	—	—	—

Table 1.4(c) Monthly and annual values of discharge and max and min values for the year in dm^3/s

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Year*	*Max*	*Min*
1965	411	311	175	222	369	166	77	37	72	36	66	604	212	1182	8
1966	465	622	851	1181	883	370	125	106	139	118	130	745	477	2028	72
1967	850	903	790	689	38	217	92	54	62	98	106	454	390	1706	21
1968	1135	889	659	457	213	53	78	32	28	80	252	230	341	2256	21
1969	316	472	238	279	463	199	76	54	46	23	118	35	191	736	21
1970	34	26	599	2146	715	211	29	43	69	68	261	724	411	3208	20
1971	302	668	452	488	119	119	75	33	21	24	43	85	199	1518	21
1972	57	124	372	533	283	238	100	58	35	16	44	57	159	1034	8
1973	70	302	500	409	263	96	46	45	32	30	25	295	175	848	8
1974	713	743	354	95	45	34	35	22	37	106	508	1012	307	1512	21
1975	1076	750	453	632	286	110	50	47	48	54	55	52	299	1274	34
Mean	494	528	495	648	367	165	71	48	54	59	146	390	287	3208	8

Hydrologic information can also be published as maps of water balances for each month or average values as *isolines* (line joining points of equal values), e.g., *isohyets* (line joining points of equal precipitation on a map) for precipitation as exemplified in Fig. 1.12. The figure shows average precipitation in India. From maps like these, it is possible to get a quick overview of the water balance on an average for different areas in the country.

1.4.4 Role of Hydrological Engineer

Typical tasks of a hydrological engineer may be to estimate how much water or quantity of a specific pollutant is at hand at a specific location and time. This is an unusually concrete and specific question. More commonly, the contractor may provide the hydrological engineer with information on how to improve the flood situation or water environment in an area. To do this, the hydrological engineer has to create a logical map of what is governing the water environment of that particular area. Probably, first of all, the hydrological data and the land use information of the area have to be gathered. How much is the quantity of water and pollutants that enters and leaves the area? The hydrological engineer must find an answer to this question.

To solve this task, there is a set of commonly used calculation methods and techniques. These are mainly *empirical methods*, i.e., methods based on observations of water and material flows at various locations (usually not the specific location, one is interested in) during shorter or longer periods. These observations can be used to estimate the specific water and material balances for the area in question under given assumptions. The calculation methods are thus more or less based on physical quantities (conceptually imitating reality) and therefore be interpreted with great care. Most calculation techniques are

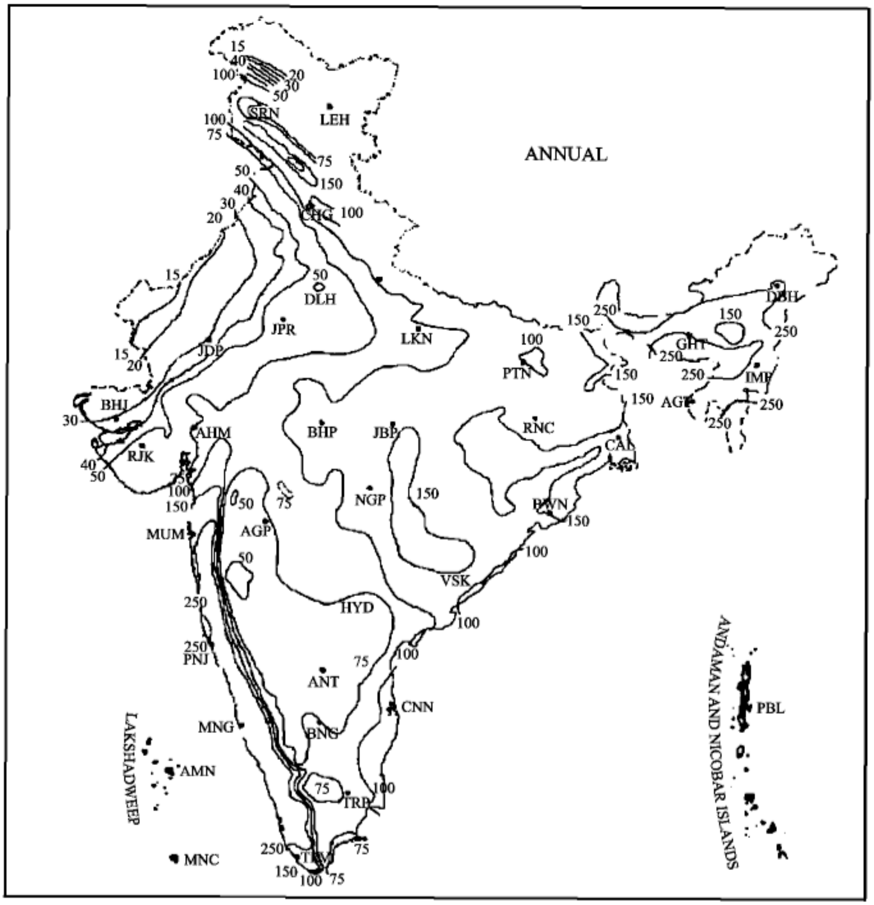

Fig. 1.12 *Precipitation isohyets in mm/year in India (Source: Indian Meteorological Department 2007)*

built upon simplifications of natural processes. It is, therefore, not evident that more or less general calculation techniques are valid for the specific area in question.

The most important task for the hydrological engineer is not to calculate some numbers for the above area but to *interpret* these numbers for the contractor. The interpretation is dependent upon what assumptions were made before the calculations, the degree of simplification, and the amount of background information acquired for the specific location.

Hydrological engineering can be said to be a typically *empirical* (based on observations in nature) science and not an exact science. This is obvious when numbers have to be estimated for water volumes entering an area under study. At the same time, typical questions from a contractor regarding hydrological problems are: (i) amount of pollutants, (ii) duration of flooding, (iii) frequency of flood, etc. Due to this, it is almost impossible to give any exact answers.

It is more important to try to give a reasonable interval for the answer to the questions. Primarily, *all hydrological calculations should be seen as a method to find a reasonable order of magnitude and/or interval and not a single number to falsely represent an absolute correct answer because this does not exist.*

The calculation methods in this text book are commonly used techniques that a hydrological engineer may use to solve practical problems. None of these methods give correct and definitive answer. Instead, every calculation must be complemented by assumptions made in the calculations.

Studying hydrology as an engineering subject means the emphasis is put on solving practical engineering problems involving different hydrological and environmental issues. The problem-solving also involves other aspects as listed below.

- Engineers often have to solve problems that are not well-defined by the contractor. Thus, more often than not, the engineer has to help himself or herself to formulate the correct questions. This involves finding the correct information or data which are required to solve the problem. For this reason, several assumptions and clarifications have to be made before the actual problem-solving can start. Each problem is therefore dependent on the starting assumptions that were made from the beginning, and these have to be clearly stated for every solution of a problem. The same problem may have several solutions depending on what assumptions were made.

- All engineering calculations and especially those involving hydrology, include uncertainties and errors. For this reason, all solutions to a problem should be given with an uncertainty interval. Especially, it is necessary to point out what factors can affect the final results. Calculations in hydrological and environmental problem-solving must not be given with unnecessary high (or low) numerical accuracy.

The components of the water balance are often given in different units depending on what part of the balance is in question. For example, precipitation is given in mm/day, mm/month, or mm/year; while runoff is usually given in l/s, dm^3/s, $dm^3/(s\ km^2)$, m^3/s, $m^3/month$, $m^3/year$, etc. When working with the water balance equation of a specific area, it is important to use the same unit in the equation. Some examples on how to use the water balance to solve some typical basic problems are discussed below.

SUMMARY

In this chapter, the basics of hydrology and the water balance and its components have been discussed. The water balance equation is the mass balance of water for a particular catchment. It states that all inflows of water to the catchment area minus all outflows from the catchment area during a certain time period must be equal to storage changes inside the catchment. For average values over longer periods, the storage change term may be set to zero.

The catchment is defined by the *water divide* and the area upstream from a certain point in the water course that contributes to flow when precipitation falls. The water divide may not always be the same for surface water and groundwater. In such cases, an error may be introduced in the water balance estimation. Hydrological information may be obtained from national and regional hydrological, meteorological, geological, and environmental surveys and agencies. Also, research institutes, universities, and NGOs may be able to provide useful hydrological information and data.