TRAINING COURSE

ON

BASIC COMPUTER SKILLS

(UNDER WORLD BANK AIDED HYDROLOGY PROJECT)

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MODULE - 1

BASIC HYDROLOGY

by

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BASIC HYDROLOGY

1.0 INTRODUCTION

The break-up of the word hydrology is: "hydro" and "logy". "Hydro" means water and "logy" means science.

Hydrology is concerned with the circulation of water and its constituents through the hydrologic cycle. It deals with precipitation, evaporation, infiltration, groundwater flow, runoff, streamflow and the transport of substances dissolved or suspended in flowing water. Hydrology is primarily concerned with water on or near the land surface; ocean waters are the domain of oceanography and the marine sciences.

1.1 Definition

Hydrology is the science that treats the waters of the Earth, their occurrance, circulation and distribution, their chemical and biological properties and their reaction with their environment, including their relation to living things. The domain of hydrology embraces the full life history of water on the Earth.

Hydrology is closely related to other natural sciences. Understanding precipitation and evaporation requires knowledge of climatology and meteorology; similarly, infiltration is concerned to soil science, groundwater flow to geology, surface runoff to geomorphology, streamflow to fluid mechanics. Besides the flow of water, understanding the transport of constituents calls for knowledge drawn from chemistry and physics etc.

Engineering hydrology, however, includes those segments of hydrology that are important for the design and operation of engineering projects responsible for the control and use of water.

1.2. Hydrological Cycle

The hydrologic cycle is a concept which considers the processes of motion, loss and recharge of the earth's water. This continuum of the water cycle can be visualized as shown in Fig.1. As indicated in this figure, the cycle may be divided into three principal phases. (a) precipitation (b) evaporation and (c) runoff-surface and ground water. Further, it is interesting to note that at some point in each phase there usually occurs: (a) transportation of water (b) temporary storage and (c) change of state. For example, in the precipitation (atmospheric) phase there occurs vapour flow, vapour storage in the atmosphere and condensation or formation of precipitation created by a change from vapour to either the liquid or solid state. The quantities of water going through individual sequences of the hydrologic cycle can be evaluated by the so called hydrologic equation, which is simple continuity or water budget equation defining the process. That is :

$$I - Q = \Delta S \qquad (1)$$

where, I = inflow of water to a given area during any given time period

Q = outflow of water from the area during the selected time period, and

ΔS = Change in storage of the volume of water in or on the given area during the time period.

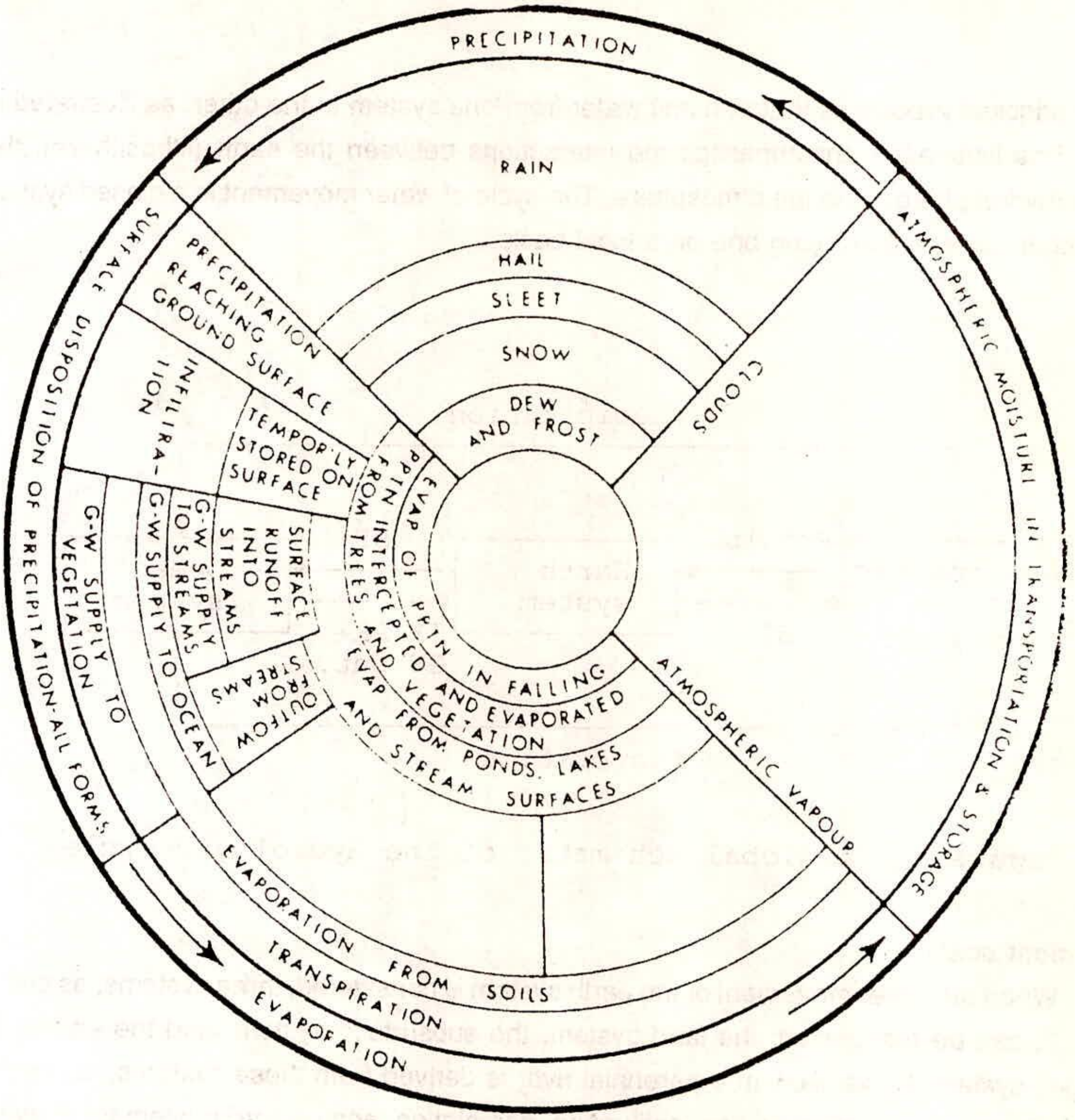

Figure 1 : The Hydrologic Cycle - A Qualitative Representation

Global scale

From a global perspective, the hydrologic cycle can be considered to be comprised of three major systems; the oceans as the major source of water, the atmosphere as the deliverer of water and the land as the user of water. In this cycle, there is no water gained or lost, but the amount of water available to the user may fluctuate because of variations at the source, or, more usually, in the delivering system. Clearly, precipitation, runoff and evaporation are the principal processes that transmit water from one system to the other, as illustrated in Fig. 2. This illustration encompasses the interactions between the earth (lithosphere), the oceans (hydrosphere), and the atmosphere. The cycle of water movement is a closed system on a global basis, but an open one on a local basis.

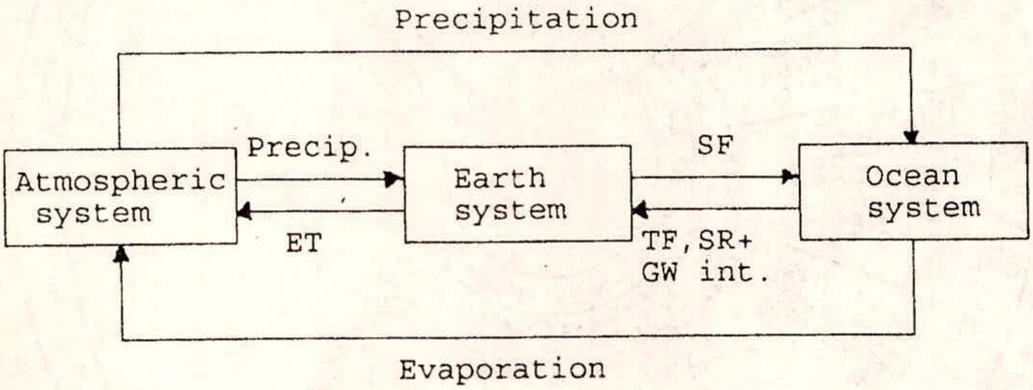

Figure 2 : A Global Schematic of the Hydrologic Cycle

Catchment scale

When the water movement of the earth system is considered, three systems, as shown in Fig. 3, can be recognized: the land system, the subsurface system, and the aquifer (or geologic) system. Streamflow in a perennial river is derived from these systems, connected through the processes of infiltration, exfiltration, percolation, and upward movement of water. If we focus our attention on the hydrologic cycle of the land system, then precipitation, surface runoff, infiltration and evapotranspiration are the dominant processes transmitting water. The land system itself can be comprised of three subsystems: vegetation subsystem, structural subsystem and soil subsystem. These subsystems subtract water through interception, depression and detention storage, whereby water is either lost to the atmospheric system or subsurface system.

It should be recognized that the hydrologic cycle has neither a beginning nor an end, as water evaporates from the land, oceans and other water surfaces to become part of the atmosphere. The moisture evaporated is lifted, carried and temporarily stored in the atmosphere until it finally precipitates and returns to the earth either on land or oceans. The precipitated water may be intercepted or transpired by plants, may runoff over the land surface to streams (surface runoff) or may infiltrate the ground. Much of the intercepted water and surface runoff is returned to the atmosphere by evaporation. The infiltrated water may be temporarily stored as soil moisture and evapotranspired, or percolate to deeper zones to be stored as ground water which may be used by plants, or flow out as springs, or seep into streams as runoff; and finally evaporate into the atmosphere to complete the cycle. A schematic sketch of the runoff phase is given in Fig. 4.

From the above discussions about the hydrologic cycle, it is obvious that the hydrologic cycle is subject to the various complicated processes of precipitation, evaporation, transpiration, interception, infiltration, percolation, storage and runoff.

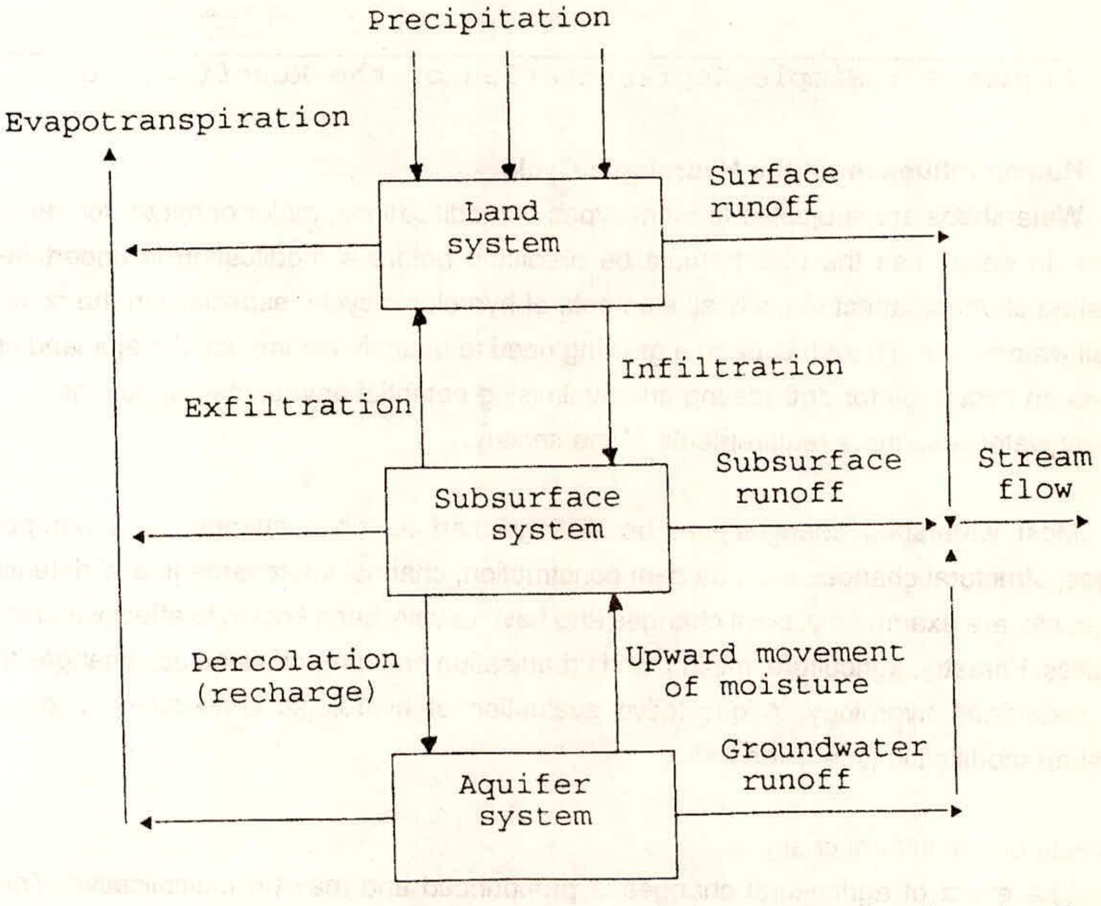

Figure 3 : A Schematic of the Hydrologic Cycle in the Earth System

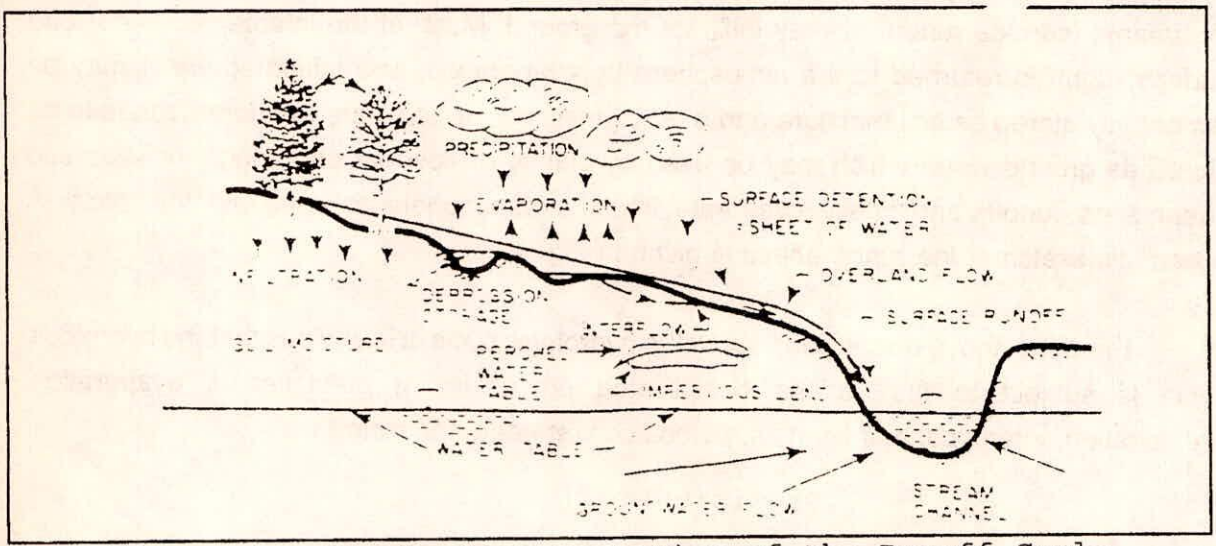

Figure 4 : Simple Representation of the Runoff Cycle

1.3 Human Influence on the Hydrologic Cycle

Watersheds are subjected to many types of modifications, major or minor, for various reasons. In each case the effects must be predicted before a modifcation is undertaken. Watershed changes affect virtually all elements of hydrologic cycle, especially in the context of small watersheds. There has been a growing need to quantify the impact of major land use changes on hydrology for anticipating and minimising potential environmental detriment and to satisfy water resources requirements of the society.

Most watershed changes can be distinguished as point changes and non-point changes, structural changes such as dam construction, channel improvement, and detention storage, etc. are examples of point changes and have usually been known to affect watershed hydraulics. Forestry, agriculture, mining, and urbanisation are non-point land use changes that affect watershed hydrology. A qualitative evaluation of hydrologic consequences due to watershed modifications is given below:

(a) Effects of agricultural changes

The effect of agricultural changes is pronounced and may be multiplicative. These changes after vegetal cover and land surface, which in turn affect evapotranspiration, overland flow, channel flow, infiltration, and recharge to ground water. Fertilizers affect water quality and may indirectly reduce direct runoff by increasing vegetation.

(b) Effects of urbanisation

Urban development usually increases the volume and peak of direct runoff for a given rainfall event. Since removal of storm water is accelerated, its time of travel is reduced resulting in lower lag time and lower times of concentration. However, it is entirely possible to reverse these effects. By increasing the storage capacity of the area and delaying the flow of water, the peak of direct runoff can be decreased and its time increased. This can be accomplished by providing detention storage or changing the landscape and sizing the storm drains. In brief the hydrologic effects of urbanisation are:

(i) increased water demand, often exceeding the available natural resources;
(ii) increased peak flow;
(iii) reduced infiltration,
(iv) increased waste water, burdening rivers and lakes and endangering the ecology,
(v) increased use of ground water, adversely affecting agriculture and forestry, deminishing the base flow of streams, and aggravating the pollution problem,
(vi) changes in local micro-climate, and
(vii) increasing wastes of all kinds from urbanisation and decreasing space for their disposal, thus complicating the water quality program.

(c) Effects of forest activities

The immediate effect of forest activities is changes in vegetal cover. When forested area is deforested and forest litter removed, the interception of precipitation is virtually eliminated. Litter removal changes infiltration capacity of soil and has a pronounced effect on raindrop impact and the resulting soil erosion. With the loss of forest mulch, the infiltration capacity is reduced and the erosion increased. With the loss of vegetation, evapotranspiration is generally decreased. These changes amount to increased production of direct runoff, reduced surface roughness, and decreased recharge to ground water for the same rainfall event. The hydrograph of direct runoff rises more quickly because of reduced time to peak.

(d) Effects of highway development

The impact of highway development on soil erosion and water quality is usually significant. Because highways and roads occupy a relatively small portion of watershed area, they have little effect on the volume of direct runoff. Channel straightening and narrowing, culvert sizing, drainage, and so forth, occurring in highway construction, may affect the runoff timing significantly. During floods, road embankments may form a reservoir, and a culvert or bridge may act as a spillway. Thus highway development may temporarily retard flow and in turn reduce peak flow.

(e) Effects of mining

Surface mining is often conducted in a harsh environment and may involve major changes in topography. Usually hydrologic data are lacking in mine areas, as well as data involving rearrangement of over burden and land cover.

(f) Effects of structural changes

A reservoir is constructed for many purposes. Regardless of its intended function, it does affect the hydrology of the stream on which it is built. For example, a flood control reservoir reduces peak flow and delays its time of occurrence.

In contrast with reservoirs, channel improvements have an opposite effect. For example, decreasing channel roughness increases flow velocity and hence peak discharge for the same channel size. Removal of vegetation, lining the channel, and proper maintenance can greatly reduce roughness. Likewise other alterations such as straightening the channel, maintenance of bands, or increasing slope significantly affect travel time and flow velocity. Depending upon the bed material, infiltration through the bed and banks also modifies flow characteristics. If a channel is closed, it can also act as a temporary low volume flow retarding structure.

1.4 Space-Time Scales in Hydrology

The scope of hydrology is best defined by the hydrologic cycle. Depending on the hydrologic problem under consideration, the hydrologic cycle or its components can be treated at different scales of time and space. As a consequence, different hydrologic problems may have different space-time scales. The global sclae is the largest spatial scale and the watershed, or drainage basin, the smallest spatial scale. A drainage basin, or watershed, is the area that diverts all runoff to the same drainage outlet. In between these two scales lie such scales as continental, regional and other space scales convenient for hydrologic analysis. Clearly, the watershed, or drainage-basin, scale is the most basic of all; and all other scales can be constructed by building on the drainage basin scale. Most hydrologic problems deal with a drainage basin. It should be clearly understood that the watershed scale does not usually or necessarily coincide with territorial or jurisdictional boundaries that might be determined by political or economic considerations. A drainage basin can be of almost any size. It might be as small as a small parking lot or as large as Ganga River basin. Large watersheds are usually broken down into smaller drainage basins to suit the requirements of a particular problem and to assist in orderly quantitative analysis.

Time scales used in hydrologic studies range from a fraction of an hour to a year or perhaps many years. The time scale used in a hydrologic study depends on the purpose of the study and the problem involved. Hourly, daily, weekly, ten daily, monthly, seasonal and annual time scales are common. Sometimes the time interval for the collection of data determines the time scale for hydrologic analysis. Hydrologic time scales often do not coincide with those used in fluid mechanics or in hydraulics and likewise do not coincide with political, environmental or economic time scales.

1.5 Hydrologic Budget

The hydrologic budget of a drainage basin is a mathematical statement of its hydrologic cycle. It is expressed by equating the difference between inflow, I, and outflow, Q, of a drainage basin to the rate of change of storage within the basin, ΔS, for a specified period of time, Δt. When the basin is considered as a black-box system, as shown in Fig. 5, or as a reservoir, as shown in Fig.6,

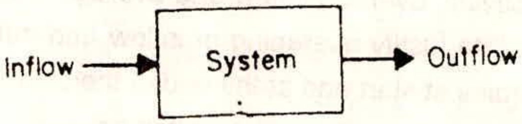

Fig.-5 : The drainage basin as a simple black box system.

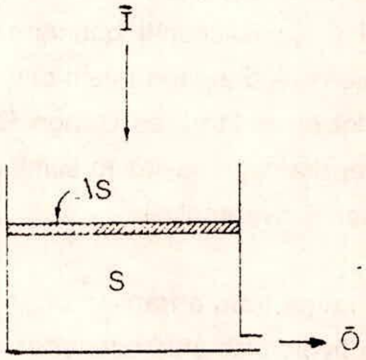

Fig-6 : The drainage basin as a reservoir receiving average inflow and discharging average out flow

its hydrologic budget can be expressed as:

$$\frac{\Delta S}{\Delta t} = \bar{I} - \bar{Q} \qquad (2a)$$

$$\frac{S_2 - S_1}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{Q_1 + Q_2}{2} \qquad (2b)$$

$$\frac{ds}{dt} = I(t) - Q(t) \qquad (3)$$

where $\bar{I}$ *and* $\bar{Q}$ are, respectively, average inflow and average outflow for time interval Δt, which is assumed to be small to justify averaging of inflow and outflow. Subscript 1 and 2 correspond to values of variables at start and at the end of the time interval $\Delta t = t_2 - t_1$. If I and Q vary continuously with time t, then eq. (2) can be written as: In eq. (2) or eq. (3) it is implied that I, Q and S do not vary in space. It means these are spatially lumped. Eq. (3) is also referred to as the spatially lumped continuity equation, or sometimes as the water budget. Eq.

(2) or (3) form the basis of the system approach in hydrology.

All hydrologic analyses of drainage basins must satisfy eq. (3) or else the analysis is incomplete and is, therefore, not reasonable. The appearance of this equation is deceiving in its simplicity. For most of the hydrologic problems, more than one variable is unknown, therefore, eq. (3) cannot be solved without additional information. For example, both Q(t) and S(t) are unknown when a rainfall-runoff relation is desired. Without an extra relation between S(t) and Q(t) with or without I(t), Q(t) cannot be evaluated. Furthermore, I and Q are not known as continuous explicit functions of time.

In eq. (3), I and Q are expressed as rates having the dimensions of L^3/T. This budget equation can also be written in volumetric unit by integrating eq. (3) i.e.

$$S(t) - S(0) = V_I(t) - V_Q(t) \quad (4)$$

where, S(0) is the initial storage or storage at t = 0, $V_I(t)$ and $V_Q(t)$ are volumes of inflow and outflow at time t having the dimensions of L^3. Eq. (3) or its variant in eq. (2b) or (4) is the fundamental governing equation for hydrologic analysis.

For a drainage basin, the inflow may be comprised of rainfall, snowfall, hail and other forms of precipitation. Surface runoff, subsurface runoff, ground water runoff, evaporation, transpiration and infiltration may constitute the outflow.

The components of storage may include surface storage (over the ground, including storage in channels and reservoirs, depression and detention storage), sub-surface storage (within the root zone), ground water storage (within the aquifers) and interception (over vegetation, buildings etc.). All these components may be included in eq. (4) and the resulting water budget equation is known as the hydrologic water balance equation. It is dealt in detail under section 1.5.1 of this lecture.

2.0 WATER RESOURCES

Water is the most essential natural resource for life next to air and is likely to become a critical scarce resource in many regions of the world. The availability of global water resources and water resources of India is briefly described hereunder.

2.1 Global Water Resources

The relative quantities of the earth's water contained in each of the phases of the hydrologic cycle are presented in Table 1. The oceans contain 96.5 percent of the earth's water, and of the 3.5 percent on land, approximately 1 percent is contained in deep, saline groundwaters or in saline lakes, leaving only 2.5 percent of the earth's water as fresh water. Of this fresh water, 68.6 percent is frozen into the polar ice caps and a further 30.1 percent is contained in shallow groundwater aquifers, leaving only 1.3 percent of the earth's fresh water mobile in the surface and atmospheric phases of the hydrologic cycle. The proportions of this water in the atmosphere, soil moisture and in lakes are similar, while that in rivers is less and that in snow and glacier ice is greater. A small amount of biological water remains fixed in the living tissues of plants and animals. All the data on the earth's waters cited here are taken from a comprehensive study of world water balance conducted in the Soviet Union during the International Hydrological Decade. These values are estimates, and future studies made with more comprehensive data will lead to refinement of these values. It is remarkable that the atmosphere, the driving force of the hydrologic cycle, contains only 12,900 cubic kilometers of water, which is less than 1 part in 100,000 of all the waters of the earth. Atmospheric water would form a layer only 25 mm (1 in) deep if precipitated uniformly onto the earth's surface (Maidment, 1992).

Table 1 : Quantities of Water in the Phases of the Hydrologic Cycle

Sl. No.	Item	Area 10^6 km^2	Volume Km^3	Percent of total water	Percent of fresh water
1.	Oceans	361.3	1,338,000,000	96.5	-
2.	Groundwater:		10,530,000		
	Fresh	134.8	12,870,000	0.76	30.1
	Saline	134.8		0.93	-
3.	Soil moisture	82.0	16,500	0.0012	0.05
4.	Polar ice	16.0	24,023,500	1.7	68.6
5.	Other ice and snow	0.3	340,600	0.025	1.0
6.	Lakes:	1.2	91,000	0.007	
	Fresh	0.8	85,400	0.006	0.26
	Saline				-
7.	Marshes	2.7	11,470	0.0008	0.03
8.	Rivers	148.8	2,120	0.0002	0.006

9.	Biological water	510.0	1,120	0.0001	0.003
10.	Atmospheric water	510.0	12,900	0.001	0.04
11.	Total water	510.0	1,385,984,610	100	-
12.	Fresh water	148.8	35,029,210	2.5	100

Table adapted from World Water Balance and Water Resources of the Earth, UNESCO, 1978.

2.2 Water Resources of India

(a) Surface water resources

India with a geographical area of 3.29 million square kilometers receives the annual precipitation of about 4000 cubic kilometers, including snowfall. Out of this seasonal rainfall is of the order of 3000 cubic kilometers. Rainfall in India is dependent in differing degrees on the South-West and North-East monsoons, on shallow cyclonic depressions and disturbances and on violent local storms which form in regions where cool humid winds from the sea meet hot dry winds from the land and occasionally reach cyclonic dimension. Most of the rainfall in India takes place under the influence of South-West monsoon between June to September except in Tamil Nadu where it is under the influence of North-East monsoon during October and November. The rainfall in India shows great variations unequal seasonal distribution, still more unequal geographical distribution and the frequent departures from the normal.

As per the estimates made by Dr. A.N. Khosla, the founder Chairman of Central Water and Power Commission, the total average annual flow of all the river systems of India is found to be 1673 cubic kilometers. In this approach runoff was considered as a function of rainfall and temperature.

Central Water and Power Commission during 1952 to 1956 estimated the surface water resources of the country as 1881 cubic kilometers. These estimates are based on the statistical analysis of of the available flows of rivers and suitable rainfall runoff relationships in case of meagre observed data.

Dr. K.L. Rao in his book "<u>India's Water Wealth</u>" (1973) has stated the country's available annual surface runoff as 1645 cubic kilometers. Thus, the estimates of surface water resources of the country vary from 1645 to 1881 cubic kilometers. Most of surface flow of the rivers occurs during the monsoon season of 4 to 5 months and particularly as flood flows. The basinwise average annual flow in Indian river systems is summarized in Table 2.

Utilisable Surface Water Resources

Within the limitations of physiographic conditions and socio-political environment, legal and constitutional constraints and the technology of development available at present, utlisable quantities of water from the surface flow have been assessed by different authorities differently. These are indicated below:

i) Irrigation Commission of India, 1972, places the country's utilisable quantity at 666 cubic kilometers or 38 percent of the surface water resources of the country.

ii) Dr. K.L. Rao put the utilisable quantity much more and has suggested that the quantum should be about 50% of the country's available annual surface water resources.

iii) The National Commission on Agriculture, 1976 have estimated the utilisable quantity as 700 cubic kilometers . This amount constitutes about 38% of the annual average flow of the river, the estimate being almost the same as that by the Irrigation Commission of India, 1972.

iv) Indian Council of Agricultural Research estimates the usable annual surface flow at 920 cubic kilometers.

v) In the Sixth Five Year Plan document, the total availability of water including the ground water has been assessed as 1050 cubic kilometers out of which 700 cubic kilometers consist of surface flow and 350 cubic kilometers as ground water.

vi) As per the recent estimates made by the Central Water Commission the utilisable annual surface runoff is about 684 cubic kilometers.

The availability of water shows a great deal of variability from place to place. Due to the topographic, hydrological and other constraints, it is assessed that only about 700 cubic kilometers of surface water may beneficialy utilized by the conventional methods of development.

Table 2 : Average Annual Flow in the Indian River Systems (CWC, 1987)

(In cubic kilometers)

Sl. No.	Basin	Average annual flow	Utilisable flow
1.	Indus (upto border)	73.305	46.000
2.	(a) Ganga (upto border)	501.643	250.000
	(b) Brahmaputra (upto border)	499.914	24.000
	(c) Barak etc.	90.800	
3.	Godavari	118.982	76.300
4.	Krishna	67.790	58.000
5.	Cauvery	20.695	19.000
6.	Pennar	6.858	6.858
7.	East flowing Rivers between Krishna and Pennar and between Mahanadi and Godavari	16.948	13.110
8.	East flowing rivers between Pennar and Kanyakumari	17.725	16.732
9.	Mahanadi	66.879	49.990
10.	Brahmani & Baitarani	36.227	18.297
11.	Subarnarekha	10.756	6.813
12.	Sabarmati	2.883	1.925
13.	Mahi	11.829	3.095
14.	West flowing rivers of Kutch Kathiawar including Luni	15.098	14.980
15.	Narmada	42.966	34.500
16.	Tapi	16.967	14.500
17.	West flowing Rivers from Tapi to Tadri	110.877	15.068
18.	West flowing Rivers from Tadri to Kanyakumari	71.981	14.932
Total		1801.123	684.100

(b) Ground water resources

Ground water development has gained an increased importance during the recent years and extensive exploration work has been done. A rough assessment of ground water resources has been made by the Central Ground Water Board. The annual utilizable ground water resources of the country have been assessed as 422.860 cubic kilometers, and the present utilization is about 100 cubic kilometers per year which is about 24% of the total utilizable resources. The annual replenishable resources of ground water are assessed to be about 600 cubic kilometers. Ground water resource potential of the country is given in Table3.

Table 3 : Groundwater resources potential in the States and Union Territories of India (as on 1982)

(in Cubic kilometers per year)

Sl. No.	State/UnionTerritories	Utilizable Resource	Draft	Potential available for future development	Stage of Groundwater development in %
1.	Andhra Pradesh	36.60	7.40	29.20	20
2.	Arunachal Pradesh	1.13	N.A.	1.13	1
3.	Assam	16.50	0.20	16.30	1
4.	Bihar	28.60	5.90	22.70	21
5.	Gujarat	20.30	6.90	13.40	34
6.	Haryana	8.80	6.10	2.70	70
7.	Himachal Pradesh	0.67	0.16	0.51	24
8.	Jammu & Kashmir	1.89	0.10	1.79	5
9.	Karnataka	13.00	1.80	11.20	15
10.	Kerala	6.90	0.90	6.00	13
11.	Madhya Pradesh	59.50	4.90	54.60	8
12.	Maharashtra	34.50	6.60	27.90	12
13.	Manipur	0.08	N.A.	0.08	1
14.	Meghalaya	0.28	0.01	0.27	3

15.	Mizoram	N.A.	N.A.	N.A.	N.A.
16.	Nagaland	0.03	N.A.	0.03	1
17.	Orissa	21.50	0.90	20.60	4
18.	Punjab	13.10	9.50	3.60	73
19.	Rajasthan	18.30	4.60	13.70	25
20.	Tamil Nadu	26.90	9.90	17.00	37
21.	Tripura	0.59	0.01	0.58	1
22.	Uttar Pradesh	92.70	26.80	65.90	29
23.	West Bengal	16.40	4.90	11.50	30
24.	Sikkim	N.A.	N.A.	N.A.	N.A.
Sub-Total-I		418.27	97.58	320.69	23.3
1.	Andaman & Nicobar	N.A.	N.A.	N.A.	N.A.
2.	Chandigarh	0.03	0.035	N.A.	116
3.	Dadra, Nagar Haveli	0.03	0.01	0.02	33
4.	Delhi	2.68	2.37	0.31	88
5.	Goa	1.85	0.17	1.68	9
6.	Lakshadweep	N.A.	N.A.	N.A.	N.A.
7.	Pondicherry	N.A.	N.A.	N.A.	N.A.
Sub-Total-II		4.59	2.585	2.01	56.8
Grand Total (I+II)		422.86	100.165	322.70	23.7

3.0 WATER RESOURCES REQUIREMENT

The availability of water resources in our country shows a great deal of spatial and temporal variability. The growth process, the increase in population and the expansion of economic activities inevitably, lead to increasing demands for water use for the diverse purposes. Hence, overall national planning and resource management in respect of water with emphasis on allocation of priorities among the diverse uses is necessary.

3.1 Existing Scenario of Water Use

Consumptive uses of water are (a) rural and municipal water supply, (b) industrial water supply and (c) Irrigated agriculture. The principal consumptive use of water is for irrigation. The Planning Commission recognised the crucial importance of developing irrigation to increase agricultural production and accordingly, assigned a very high priority to it in the plans. Giant schemes like the Bhakra Nangal, Hirakud, Damodar Valley, Nagajunasagar, Rajasthan Canal project etc. were taken up to increase the irrigation potential and thereby contribute to maximising the agricultural production.

The ultimate irrigation potential from major, medium and minor irrigation schemes is estimated at 113 m ha. of which 58 m ha. is from major and medium schemes and 55 m ha. from minor irrigation schemes.

The irrigated area in the country was only 22.6 m.ha. in 1950-51. As compared to this the potential that has been created upto 1989-90 (i.e. the end of VIIth Five Year Plan) is about 78 m.ha. comprising 42 m.ha. by surface water and 36 m.ha. by ground water. The actual area irrigated is 38.4 m.ha. from surface water and 32.5 m.ha. from ground water. The quantum of water used for irrigating these areas is of the order of 300 cubic kilometers of surface water and 128 cubic kilometers of ground water.

Quantum of water being utilised for other consumptive uses is far less than that used for irrigated agriculture. The water for community water supply, is the most important requirement. The water use for community water supply is about 5% of the total water use. While rural areas may be able to live with the ground water urban areas have to depend heavily on the surface waters.

It is roughly estimated that about 7 cubic kilometers of surface water and 18 cubic kilometers of ground water are being used for community water supply in urban as well as rural areas. However, organised water supply and sanitation programmes are yet to cover the entire country. Under the International Drinking Water Supply and Sanitation Decade Programme launched in 1981 it has been aimed at providing adequate drinking water facilities to 90% of the urban population and 85% of rural population, and sanitation facilities to 50% of urban population and 5% of rural population.

Water use by industries has not so far been precisely estimated. Paper, petrochemicals, mining, fertilizer, chemical and steel industries are some of the highly water intensive industries. Rough estimates based indicate that the present water use in the industrial sector is of the order of 15 cubic kilometers, both from surface and ground water sources.

The water use by thermal and nuclear power plant with installed capacities of 40000 MW and 1465 MW respectively has at present been estimated to be about 4 cubic kilometers. This supply is mostly from surface water sources.

As far as hydropower generation is concerned, against the total assessed potential of 85,550 MW, only 20% is being tapped by the existing and ongoing schemes put together. Hydropower generation is a non consumptive use, but requires water supply. The water is released in the stream after hydropower generation and is available again for consumption and water uses. The water for releases for hydropower generation to the extent these are not available for consumptive use needs, constitutes water demand for it.

The actual utilisation upto Seventh Plan (1989-90) under various uses is as per details given hereunder:

Sl. No.	Description	Quantity
1.	Irrigation using surface water	31.12 m ha m
2.	Irrigation using surface water	12.80 m ha m
3.	Community water supply (urban and rural area)	2.50 m ha m
4.	Industrial use	1.50 m ha m
5.	Energy	0.45 m ha m
	Total	48.37 m ha m Say 50 m ha m

3.2 Projected Water Needs

The population in the country is steadily growing and is expected to approach 100 crores by the turn of the century and 150 crores by 2025. The per capital food availability is at present low and needs to be increased. The food grain production should increase to 240 million tons by the year 2000 from the present level of 170 million tons. This rate of growth in foodgrain production can be achieved through extension of irrigated areas and by increasing the grain yield per unit area assuming that there may not be any significant increase in net sown area. It has been established that productivity of irrigated areas is atleast double, if not more than, that of unirrigated areas in respect of wheat and rice crops. Therefore, Irrigation will be the prime input for increasing the foodgrain output.

The Eighth Five Year Plan envisages creating additional irrigation potential of 10 m.ha. from surface water and another 10 m.ha. from ground water. This would mean that at the end of Eighth Plan, 97 m.ha. of irrigation potential would have been created. Of this 52 m.ha. would be from surface sources and 45 m.ha. would be using ground water.

Rough estimates indicate that by the year 2000, the water use for irrigation will increase to 630 cubic kilometers (420 cubic kilometers of surfacr water and 210 cubic kilometers of ground water). By 2025, it may reach a level of 770 cubic kilometers (510 cubic kilometers of surface water and 260 cubic kilometers of ground water). In the domestic water supply sector, even after achievement of the targets set by the International Drinking Water Supply and sanitation Decade Programme ending 1990-91, 10% of irban population and 15% of rulal population would be still left without drinking water facilities.

It has been roughly estimated that by the year 2000, community water supply requirement may go upto 30 cubic kilometers from the present use of 25 cubic kilometers, while the industrial demand may go upto 30 cubic kilometers from present use of 15 cubic kilometers. Consumptive requirements for thermal power may be about 6 cubic kilometers. By 2025, the demand for community water supply may be around 53 cubic kilometers and that for industrial supply 120 cubic kilometers. The power plants may demand 15 cubic kilometers of water. The toal storage required for hydropower will be about 375 cubic kilometers. The total requirement of water by the year 2025 is thus estimated to be around 1050 cubic kilometers. The annual requirement of fresh water upto the year 2025 for various uses is given in Table 4.

Table 4 : Annual requirement of fresh water (In cubic kilometers)

Sl. No.	Water Use	1985		2000		2025	
		Surface Water	Ground Water	Surface Water	Ground Water	Surface Water	Ground Water
1.	Irrigation	320	150	420	210	510	260
2.	Other uses	40	30	80	40	190	90
i.	Domestic & Live Stock	16.70		28.70		40.00	
ii.	Industrial	10.00		30.00		120.00	
iii.	Thermal Power	2.70		3.30		4.00	
iv.	Miscellaneous	40.60		58.00		116.00	
v.	Total	540.00		750.00		1050.00	

4.0 WATER RESOURCES ASSESSMENT

In water resources assessment current knowledge of hydrology, meteorology, geology, biology and chemistry are combined to provide a quantitative picture of the physical characteristics and possible range in extremes of this natural resource. Such an assessment considers the total catchment and its meteorologic inputs. Various phases must be considered with the catchment. These have been classified as the phases of :

(i) Land surfaces;
(ii) River channel networks;
(iii) Reservoirs; and
(iv) Sub-surface

Landphase:

It considers the water of the land surface, which either enters the soil or flows from the surface as land surface runoff, otherwise called overland flow or sheet flow i.e. the land surface runoff is not characterised in terms of rills, gulley or channel flow. Here the processes of sediment erosion and yield, surface or sub-surface division of water and the entrainment of chemical and biological material by the surface runoff are represented. Each of these aspects will be affected by the land surface characteristics such as vegetation, rainfall, topography, land use and so on.

River phase:

It is representative of all processes relating to river channels and their tributaries. Here the stream channel scour, sediment transport and deposition processes; the flow of water through the river channel system and the variability of the physical, chemical and biological processes within the river are considered.

Reservoir phase:

It is defined as the natural or artificial storage of water on the catchment surface and includes lakes, reservoirs and storage tanks. Processes to be considered include sediment deposition; the inflow, outflow, circulation and change in storage of water; thermal stratification and density currents and the changes in the chemical quality and the biologic process of the impounded water.

Sub-surface phase:

It is representative of all processes relating to water moving or stored below the land surface. These processes include the inflow and outflow of water to the sub-surface zone, the flow processes within the zone and the natural and artificial contamination or purification of the water quality within the sub-surface zone.

Each of these phases interact. The land phase divides water between the river phase and the ground water phase. The ground water phase (or sub-surface phase) allows water to return to the river phase by interflow and groundwater flow. The river phase provides inflow to the reservoir phase and receives discharge and releases in turn from this phase. Loss of moisture to the atmosphere takes place from all the phases in the form of evaporation or transpiration. In the analysis of the total catchment it is possible to estimate the quantity of water available for use and the magnitude and possible frequency of extreme processes such as floods, low flow or water pollution.

Physically based hydrological models are used to represent the various land phase components of the hydrologic cycle and their interactions. Such models can be applied to assess the spatial and temporal variation of surface water and ground water considering the various factors including those due to land use changes.

4.1 Surface Water Assessment

One of the most important aspects in planning of a water resources development project is to assess the availability of water and its time distribution. Water availability is the life line of any water resources project. The estimation of total quantity of available water and its variability on long term as well as short term basis are the major factors contributing to success of any water resources scheme. Therefore, accurate estimation of water availability is very much essential both for planning as well as operation of a water resources development scheme. This requires collection of data and analysis thereof by suitable methods to work out the same. Application of the hydrological models also provides a runoff series for selected time scales at the project site.

In order to ensure the success of a project, it is necessary to plan it such that desired quantity of water is available on most of the time. Of course some shortage may be permitted in order to make the project cost effective and to have optimum utilization of the scarce water resources. Necessary analyses are to be carried out for identifying the characteristics of the flows which are essentially required in decision making process. In India, the normal practice is to plan an irrigation project with 75% dependable flows. On the other hand, the hydropower and drinking water supply schemes are planned for 90% and 100% dependable flows , respectively.

The data requirements for water availability studies are summarized below:

(a) Runoff data of the desired specific duration (daily, 10-daily, or monthly, annual etc.) at the proposed site for atleast 40 to 50 years; or

(b) Rainfall data of specific duration for atleast 40 to 50 years for raingauge stations influencing the catchment of the proposed site as well as runoff data of specific duration at the proposed site for the last 5 to 10 years; or

(c) Rainfall data of specific duration of the catchment of the proposed site for the last 40 to 50 years and runoff data of the specific duration and concurrent rainfall data of the existing work upstream or downstream of the proposed site for the last 5 to 10 years or more; or

(d) Rainfall data of specific duration of the catchment for the last 40 to 50 years for the proposed site and runoff data and concurrent rainfall data of specific duration at existing works on a near by river for 5 to 10 years or more, provided orographic conditions of the catchment at the works are similar to that of the proposed site.

Further, the catchment characteristics are also utilised for estimating the dependable flows in case of ungauged catchments. In case the runoff data are not virgin because of construction of water resources structures upstream of the gauging site, the information about reservoir regulation such as outflows from spillway, releases for various uses etc. is required. If the runoff data series consists of the records for the period prior as well as after the construction of the structure, the runoff series is considered to be nonhomogeneous. Necessary modifications have to be made to the records belonging to the period prior to the introduction of the structure. So that all available runoff records become homogeneous. Water availability studies are also carried out modifying the runoff records for virgin condition of the catchment.

Water availability analysis

In carrying out water availability studies, it is always desirable to use the observed runoff data. If long term (say 40 to 50 years) runoff data are not available, the runoff series can be generated by using the rainfall runoff relationships, which may be for daily, weekly, 10-day, monthly, seasonal and/or annual period. In case rainfall data are not available, but sufficient observed runoff data are available, the same can be used for generation of long term runoff series. using a suitable stochastic model. The stochastic model usually requires atleast 10 to 15 years of record to generate the runoff within the acceptable accuracy. In case very scanty observed or no data are available, then one has to carry out the special analysis using empirical approaches for generation of necessary data.

For estimation of dependable flow using the runoff series, the runoff series is arranged in descending order. The synthetic year for a particular dependability is calculated from (N+1) years, when N is the number of years for which runoff data are available.

Say, runoff data are available for N = 39 years

Hence, 75% dependable item number is = $\frac{(N+1) * 75}{100} = \frac{(39+1) * 75}{100} = 30$

Thus, the runoff corresponding to 30th observation from top in the descending annual flow series will be 75% dependable runoff in this case. In the same way 90%, 100% other dependable flows may be computed.

Flow duration curves

It is a popular method of studying the streamflow variability . A flow duration curve of a stream is a plot of discharge against the per cent of time the flow was equaled or exceeded. This curve is also known as discharge-frequency curve. For drawing flow duration curve.

The streamflow data is arranged in the descending order of discharges, using class intervals. The data used can be daily, weekly, ten daily or monthly values. If N number of data points are used in this listing, the plotting position of any discharge (or class value) Q is:

$P = m/(N+1) * 100\%$ (5)

where, m is the order number of the discharge (or class value), P is percentage probability of the flow magnitude being equaled or exceeded. The flow duration curve represents the cumulative frequency distribution and can be considered to represent the streamflow variation of an average year. The ordinate Q_p at any percentage probability P represents the flow magnitude in an average year that can be expected to be equalled or exceeded P per cent of time and is termed as P% dependable flow. In a perennial river Q_{100} = 100% dependable flow is a finite value. On the other hand in an intermittent or ephemeral river the streamflow is zero for a finite part of an year and as such Q is equal to zero.

Some important characteristics of a flow duration curve are :

(a) The slope of a flow duration curve depends upon the interval of data selected. For example a daily streamflow data gives a steeper curve than a curve based on monthly data for the same stream. This is due to the smoothening of small peaks in monthly data.

(b) The presence of a reservoir stream considerably modifies the virgin-flow duration curve depending on the nature of flow regulation.

Uses of flow duration curves are:

(i) In evaluating various dependable flows in the planning or water resources engineering projects,
(ii) In evaluating the characteristics of the hydropower potential of a river,
(iii) In the design of drainage systems,
(iv) In flood-control studies,
(v) In computing the sediment load and dissolved solids load of a stream, and
(vi) In comparing the adjacent catchments with a view to extend the stream flow data.

4.2 Ground Water Resources Assessment

For quantifying the ground water resource available, two different concepts based on the existing hydrogeological situations are used:

1. Quantity concept - for unconfined (water table) aquifers
2. Rate concept - for confined aquifers.

(a) Unconfined (water table) aquifers

Ground water resources can be classified as static and dynamic. The static resource can be defined as the amount of ground water available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic resource can be defined as the amount of ground water available in the zone of water level fluctuation. The useable ground water resource is essentially a dynamic resource which is recharged annually or periodically by rainfall, irrigation return flows, canal seepage, influent seepage, etc. The most important component of recharge to the aquifer is the direct infiltration of rain water, which varies according to the climate, topography, soil and subsurface geological characteristics. A part of applied irrigation water both from ground water and surface water resources, reach ground water depending on the efficiency of irrigation system and soil characteristics. Influent streams also recharge the ground water body depending on the drainage density, width of streams and on the texture of river bed material. Other sources of recharge are percolation from canal systems, reservoirs, tanks, etc.

(b) Confined aquifers

For the confined aquifers which are hydrogeologically separate from shallow water table aquifers, the ground water assessment is done by rate concept. The ground water available in a confined aquifer equals the rate of flow of ground water through this aquifer. The rate of ground water flow available for development in a confined aquifer in the area can be estimated by using Darcy's law.

Unconfined aquifers respond to ground water withdrawals differently than confined aquifers. Confined aquifers yield water to wells by the mechanisms of fluid volume expansion and compaction of pore volume. By definition, a confined aquifer remains saturated. In addition to their elastic storage properties, unconfined aquifers yield water by desaturation of the pore space as the water table declines. Water released from storage in an unconfined aquifer greatly exceeds that of a confined aquifer for equal water level declines.

5.0 WATER BALANCE

The water balance equation can be used to calculate the reservoir inflow either as a long average value or as a critical period value. Water balance is nothing but the 'book keeping' of water of a basin or region in relation to the components of the entire hydrologic cycle or part thereof, carried over a specified period of time.

Study Need:

The purpose of water balance study are: (1) to evaluate the net available water resources, both on the surface and subsurface; and (2) to assess the existing water utilisation pattern and practices. This information will help in planning the optimal and sufficient management of water resources.

Components of Study:

The three studies included in water balance are the hydrologic water balance, ground water balance, and water use balance. The study thus encompasses the consideration of the following equations: (1) hydrological water balance equation, (2) ground water balance equation, and (3) irrigation water use equation.

5.1 Hydrological Water Balance

The equation is based on the concept of continuity as follows:

Input to the system - Outflow from the system
= Change in storage in the system

The various components of the above continuity equation can be represented in equation form as:

$$P + \text{Input} = Q + E_T + \text{Export} + S_m + S_g + S_d + L \quad (6)$$

$$P + (I_c + I_g) = Q + E_T + (O_c + O_g) + S_m + S_g + S_d + L \quad (7)$$

where, P = precipitation
I_c = surface supplies through rivers, canals and drainage from outside the basin
I_g = inflow to the groundwater from other basins
Q = runoff
E_T = evaporation and evapotranspiration
O_c = surface supplies going out to other basins
O_g = ground water outflow from the basin to other basins
S_m = change in soil moisture
S_g = change in ground water storage
S_d = change in depression storage
L = loss through deep percolation

5.2 Ground Water Balance

Considering the various sources of recharge and charge to the ground water reservoir and change in storage in the ground water, the basic equation of ground water balance based on the concept of continuity can be written as:

$$R_r + R_c + R_l + I_g + I_s = T_p + O_g + E_T + E_s + S_g + L \quad (8)$$

where, R_r = natural recharge from precipitation
R_c = recharge due to seepage from rivers, canals, water courses, ponds, reservoirs, etc.
R_l = recharge from irrigation and other activities
I_s = influent seepage

T_p = withdrawal from groundwater storage

E_T = evaporation and evapotranspiration from ground water

E_s = effluent seepage

5.3 Water Use Balance

Water use for the growth of crops and other vegetation comes from their root zone. Considering the various sources of supply to and losses from the root zone of crops and vegetation and the change in the soil moisture of the root zone, the water use balance equation can be written for irrigated areas, unirrigated areas and for water bodies as follows:

$$E' = C_c + T'_p + I_T + P_E + M_g - L_c - L_l \quad (9)$$

where, E' = evaporation from irrigated crops

C_c = canal supplies

T'_p = supply from groundwater storage for irrigation

I_T = irrigation supplies from drains and tanks

M_g = contribution from groundwater irrigated fields

L_c = losses from canals and water courses

L_T = losses from irrigation fields

For unirrigated crops:

$$E'' = P'_E + M'_g + E'_T \quad (10)$$

where E'' = evapotranspiration from vegetation, unirrigated crops and natural land

P'_E = effective precipitation for vegetation and unirrigated fields

M_g = contribution from ground water for forests, trees and unirrigated fields

For water bodies:

$$E = E_r + E_c + E_w \quad (11)$$

where, E = evaporation from water surface

E_r = evaporation from surfaces in rivers, drains, etc.

E_c = evaporation from canals, water courses, etc.
E_w = evaporation from other water bodies

It may be noted that in Eq. (7),

$$E_r = E' + E'' + E$$

6.0 HYDROLOGICAL PROBLEMS

Hydrologists face different types of problems which are required to be solved for economic, social, environmental or many other reasons. Hydrologists apply the current knowledge of the technology for analysing the available data and information and provide the solutions for those problems. In this section of the lecture some of the general problems of applied hydrology and specific problems of peninsular India have been listed.

6.1 General Problems of Applied Hydrology

Some of the important problems of applied hydrology, hydrologists come across are:

(i) Data management
  - Hydrologic instrumentation & measurements
  - Data collection network
  - Data storage and retrieval
  - Data processing
  - Data generation

(ii) Hydrologic Design
(iii) Hydrologic System Operation
(iv) Flood and its management
(v) Drought and its management
(vi) Waterlogging and drainage
(vii) Urban drainage
(viii) Water quality and environment
(ix) Conjunctive uses of surface and ground water
(x) Salinity
(xi) Salt water intrusion
(xii) Coastal drainage

- (xiii) Over exploitation of ground water (Ground water management)
- (xiv) Soil Erosion
- (xv) Reservoir Sedimentation
- (xvi) Global Warming and Climate Change
- (xvii) Glacier, snow and ice melt
- (xviii) Crop water requirements & Irrigation Scheduling
- (xix) Impacts of watershed developments & land use changes
- (xx) Hydrological problems of Lakes and Tanks
- (xxi) Water Resources Assessment

6.2 Specific Problems of Peninsular India

Some of the specific hydrological problems of peninsular India are:

- (i) Data management
- (ii) Hydrologic design
- (iii) Hydrologic system operation (Reservoir operation)
- (iv) Flood & its management
- (v) Drought & its management
- (vi) Conjunctive use of surface and ground water
- (vii) Ground water management particularly in hard rock region
- (viii) Salt water intrusion in coastal areas
- (ix) Coastal drainage
- (x) Reservoir sedimentation
- (xi) Crop water requirements and irrigation scheduling
- (xii) Hydrological problems of tanks
- (xiii) Water resources assessment
- (xiv) Water quality & environmental impact assessment
- (xv) Urban drainage
- (xvi) Watershed development and landuse changes

7.0 APPLICATION OF HYDROLOGY

Hydrology touches every human life in some manner. Modern applications of hydrology are often concerned with floods and flooding alongwith flood plain management. Changing land use patterns such as urbanisation, deforestation etc. have aggravated flooding, and as a result, flooding is higher and more spread in some areas than before. Drought is other extreme of the hydrologic cycle. To those people who depend on water for crops and livestock, this is most important role of hydrology. Increasing populationand the accompanying increase in industry have provided tremendous sources of pollution for our water resources. Hydrologists are deeply involved in attempting to alleviate this serious problem.

There are many other applications than those mentioned previously. Industry throughout the world has an important concern with hydrology. Agriculture is dependent on irrigation for the production of food and fibre. The irrigated food production is so important that the present world could not be fed without this hydrologic application of water. Highways, rail roads and other commercial entities require bridges to span streams and rivers. Navigation of streams, harbours and seas have always been a basis for commerce. Water sports are an important part of life of many people. Fortunately, other hydrologic applications such as dams for power and irrigation provide added opportunity for the recreational use of water. The fishing industry and recreational fisherman have a vital interest in providing water compatible with fishing. More and more, modern society demands that the appearance of water development and use be maintained in a manner that is pleasing to view. These and other demands by people, government and industry provide unlimited opportunities for application of hydrology. In this section some specific applications of hydrology are discussed.

7.1 Flood Control

A flood occurs when a lake, reservoir or channel is unable to contain the amount of water it receives. It also occurs when an area has inadequate drainage to dran excess precipitation. The result is an inundation of what is usually a dry land. Floods are sometimes caused by the failure of hydraulic structures such as dams, levees and dykes. Natural floods are, however, more common. The problem of flooding is defined by its areal exten, duration, intensity and damage. The projects designed to mitigate flooding and flood damage may be structural (e.g. dams, levees, dykes, diversions, flood walls and channels), non structural (e.g. flood forecasting, flood plain zoning, flood plain management and relocation) or a combination of both. The hydrologic input needed to design such projects includes : (i) peak discharge and its frequency of occurrence, (ii) duration and volume of flood hydrograph and their probabilities of occurrence and (iii) the arrival of the next flooding.

7.2 Drought Mitigation

A drought occurs when there is a shortage of water by comparison with the demand for it. There may not be enough water in lakes, reservoirs or streams or precipitation may be deficient. Agricultural, hydrological and meteorological droughts are usually distinguished. These three types are significantly interrelated, although in the extreme, these may be independent of one another. Analogous to flooding, the problem of flooding is defined by its areal extent, duration, severity and the onset of the next drought. From a hydrological perspective, low discharge (defined over a period) and its frequency of occurrence, duration of this low discharge and volume of low flow, as well as their frequencies, and the probability of occurrence of the next drought are useful to design drought mitigation projects. A similar type of information is needed for rainfall in case of meteorological drought and for soil moisture in case of agricultural drought. Construction of water impoundmants, groundwater pumpage, interbasin transfer, water conservation and even augmentation of atmospheric precipitation through cloud seeding are some of the ways to mitigate droughts.

7.3 Water Supply

A water supply scheme must provide sufficient water of acceptable quality to serve its intended purpose, be it urrban, agricultural or industrial. The disruption in water supply should be minimum. Hydrology determines the volume of water to be stored to achieve the desired objective and the probability with which this volume of water will not be available. Hydrology also specifies the arrival of the next shortage of water and the frequency of its occurrence. In coastal areas, ground water aquifers are threatened by salt water intrusion. This problem is further exacerbated by an excessive pumping of ground water. Hydrological techniques are used to determine a safe yield without encroachment of salt water.

7.4 Pollution Control

Water is an efficient and economical carrier of undesirable materials. It dilutes the waste and to a certain extent, by natural processes, disposes of that waste. However, there is a limit to the amount of waste that can be absorbed by any water course, including rivers, lakes, reservoirs and seas. This limitation is too often forgotten in the rush of disposing of waste resulting from growing population and expanding industry. Our polluted water bodies are an ample evidence to attest to this attitude. This, however, is not to suggest prohibition of all water products from watercourses, but to plea for wise water management, economically and socially viable. Hydrology is a key to achieve an acceptable, economic balance that takes into account the many and various services rendered by water bodeis. Specially, it provides information for disposition of water in time and space, both in terms of quantity and quality, in water bodies.

7.5 Urban Development

Urban planning and development involve construction of houses or sub-divisions, schools, sports and recreation facilities, shopping centres, roads, culverts, bridges, drainage systems, parks, water supply schemes, waste disposal facilities etc. Hydrology gives the design discharge and its probability of occurrence needed for design of hydraulic works. It specifies the extent and severity of flooding needed to ensure building of houses on safe ground, out of flood plains. It also quantifies, on the other hand, hydrologic consequences upstream and downstream of urban development. For example, hydrology determines if flooding will increase or decrease as a result of urban development.

7.6 Industrial Development

For industrial development to take place, two basic problems have to be resolved : (i) water supply and (ii) disposition of waste. Hydrology assists with addressing these problems. However, industrial development also involves roads, land use change etc. and hydrology determines consequences of these changes.

7.7 Design of Hydraulic Works

Dams, culverts, spillways, bridge crossing, dykes, levees, diversions, channel improvement works, drainage works etc. are typical hydraulic works required for water resources development and management. Design of these works requires an estimate of peak discharge of given frequency. Hydrology produces this estimate. The environmental consequences of these works are also estimated using hdyrology.

7.8 Agricultural Production

Crop production involves moisture forecasting, supply of water to farms, management of irrigation water, application of chemical and fertilizers, drainage of excess water, soil conservation etc. Hydrology is used to determine the time history of soil moisture needed for irrigation scheduling and to dispose of excess waters during flooding. It also is needed to determine soil erosion and sediment transport, migration of chemicals and fertilizers and their impacts on water quality. Hydrology may be used to design a network of wells for a famr, or plan a system of dams, canals and ditches based on soil properties, land slope, location of the water table, climate and other factors. Hydrology also assists for identifying the areas prone to water logging and salinity problems so that the remedial measures could be planned in those areas.

7.9 Energy Resources Development

Thermal, nuclear and hydropower plants constitute the principal sources of electrical power generation. Hydrology is applied to design these plants safely to avoid flooding and minimise consequent risk of failure. Thermal and nuclear power plants generate waste that needs to be disposed of. Hydrology is applied to determine the water supply needed for cooling purposes and for safe disposition of plant generated waste. Geothermal energy appears as steam from deep beneath the earth's surface. Hydrology is used to help locate areas where use of geothermal energy may be feasible and then locate and help design well fields to extract the heated water. Hydrology plays a crucial role in mining and oil exploration. The landscape disturbed, as a result of these activities, should be restored to its original form. Hydrology is applied to design such a landscape.

7.10 Land Conservation

Careless farming methods can speed up the runoff of rainfall, resulting in erosion of soil. This increases the danger of flooding downstream and causes streams to become more turbid because of increased concentration of sediments in the stream. Loss of fertile lands due to erosion and of coastal areas has been of growing concern. Not only does hydrology determine the space-time history of erosion, but is also used to develope scenarios for prevention of erosion through, for example, soil conservation, appropriate farm practices, vegetation management, water diversion, afforestation, reduced flooding and controlled land use.

7.11 Environmental-Impact Assessment

Sediment transport, fertilisers, pesticides and feedlot wastes, disposal of urban and industrial waste, chemical spills etc. have major impact on the quality of environment and ecology. With increasing industrialisation and urbanisation, larger and larger amounts of waste are generated and their disposition, without detrimental effects, is of growing concern. Sediment from eroded fields may choke streams and silt reservoirs. Fertilisers, pesticides and feedlot waste and disposal of hazardous waste through landfill may leach into ground water or wash into streams, poisoning plants, fish and wildlife. Hydrology determine migration of these wastes and their effect on water quality, thereby developing standards for safe and economic disposal of waste through water bodies.

7.12 Land Use Change

Land use change can be point or non-point. Agricultural practices, afforestation and deforestation, urbanisation, highway development, channel improvement and so on are examples of non-point change. Dams, culverts, bridges, industrial plants, land fill sites etc. represent point changes. Hydrologic consequences of these changes are to be determined before a land use change can be justified. These changes can have significant effect on environment, the quality of life, fish and wild life, plants and vegetation etc.

7.13 Forest and Wildlife Management

Application of pesticides and chemicals, forest clearing and cutting, forest fires, plantation, logging, road construction, etc. are typical forest management practices. Preservation of wild life, animal grazing, animal husbandry etc. are within the purview of wild life management. Hydrology determines the consequences of these activities on water quantity and quality. Forest and vegetation cover certainly slow down the rate at which surface water flows to the main channels and spreads runoff over a larger period and reduces peak flow at the same time. This effect is significant in the case of small streams and small floods and may not be so for large watersheds and large floods. Great floods overcome the retarding effects of vegetation and the nature of the land surface becomes of little importance in slowing runoff.

7.14 Military Operations

Hydrology plays a crucial role in the planning and conduct of military operations. Military camps are to be located on safe grounds. When the ground is trafficable is of vital importance for movement of military vehicles. A knowledge of river flow ahead of time is required to determine if river crossing would be safe. Dam breaching and the resulting damage are important in planning tactical offences against enemies as well as adequate defence. Downstream flooding can be an effective combat multiplier. In addition to damaging structures, the resulting flood wave may create a significant barrier in troop and vehicular movement. Military camping is done at awkward places and locating water supply quickly is crucial. Hydrology is used to address all of these problems of military action environment.

7.15 Rural Development

Hydrology is needed to properly plan development of activities constituting rural development, such as water-supply schemes, housing, schools and hospitals, roads and drainage systems, sanitary systems, ponds and fisheries development, communication, energy resources, afforestation and recreation.

7.16 Navigation

In order to maintain navigability, a minimum depth of flow has to be maintained in the river. A system of locks and dams is built on the river, which monitors the river traffic. Hydrology is employed to provide peak discharge and its probability of occurrence for designing these dams. The volume of water that will be available for river flow is estimated using hydrology. Because of siltation, navigable rivers may have to be dredged. The bulk of the sediment received by the river is generated in the upland areas. The upland erosion and supply of this sediment to the river are determined using hydrology. The study of sedimentation processes is needed to determine the location of jetties and levees so as to minimize future silting problems.

7.17 Recreation

Nowadays, recreational requirements are an important consideration in the development of water use projects. Design and operation of these facilities require adequate availability of water, which is estimated using hydrology. Moreover, measures for protection of the facilities from vagaries of weather and other extremes depend on hydrologic analysis. Many rivers and lakes close to urban population centres are highly polluted to the extent of being useless for recreational purposes. Hydrology determines the effect of waste disposal on water quality and level of pollution may be controlled keeping in mind the recreational requirements.

7.18 Fisheries

Commercial and sport fishing are receiving important consideration in the preliminary planning and design of water use projects. Hydrology is used to determine how much, and of what quality, water will be available in streams, ponds, reservoirs, etc., for a specific time period. Thus hydrolgy, plays a critical role in development of fisheries resources.

8.0 REGIONALISATION IN HYDROLOGY

8.1 Need

In engineering hydrology, regional analysis encompasses the study of hydrologic phenomena with the aim of developing mathematical relations to be used in a regional context. Generally, mathematical relations are developed so that information from gauged or long-record catchments can be readily transferred to neighbouring ungauged or short record catchments of similar hydrologic characteristics.

The transfer of hydrological data, parameters or relationships obtained from one basin to others or their estimation for ungauged basins is of considerable practical importance. Usually, the small projects and even some large hydroprojects are located at ungauged sites or their location does not permit pre-project data acquisition at the site. For such cases, the transfer of hydrological information, especially runoff characteristics, by using conventional methods, e.g. regression analysis, rainfall runoff analysis, etc. is not appropriate. The method of regionalization has been found to be appropriate for such spatial transfer of information. This involves use of basin's physiographic, landcover and climatic characteristics. The regionalisation in hydrology also involves quantification of the components of the hydrologic cycle at a regional scale as opposed to a plot or catchment scale. It enables construction of models at the basin scale from knowledge and data which have been accummulated from smaller scale units. One of the important inputs available for this purpose is use of remote sensing techniques for the analysis of factors characterizing spatial variability that influence the hydrologic processes in a drainage basin.

8.2 Spatial and Temporal Homogeneity

For developing the regional relationships for prediction of the various hydrological variables it is essential that these relationships are developed for the hydrologically homogeneous region i.e. the region exhibits spatial and temporal hydrological homogeneity. Spatial homogeneity refers to the homogeneity at various locations in a region; whereas, temporal homogeneity means that the data collected for the hydrological variables under consideration do not show non-homogeneity with period of time.

Spatial non-homogeneity may be attributed to the climatic, physiographic and other factors affecting the surface and sub-surface components of hydrologic cycle. The data collected at a site may exhibit temporal non-homogeneity, if the catchment above that site undergoes developmental activities such as construction of dams, landuse changes, urbanization etc. and a part of the data collected prior to the developmental activities are considered alongwith the data collected after the developmental activities. In such a situation, these factors should be utilized for developing the regional relationships. The factors which do not change from one catchment to other should not be considered for developing the regional relationships, however, these factors should be considered for tested the regional homogeneity. For example, if the mean annual rainfall over the different catchments of the regional is more or less the same, then this rainfall variable should not be considered for developing the regional relationships.

8.3 General Procedure for Regionalisation

Whenever adequate data are available for a site/catchment the hydrological variables such as peak flood, water availability, floods of desired return period, low flows etc. may be predicted by analysing the observed data. However, the required data are not available for most of the small catchments, which are generally ungauged, and many water resources projects are planned in these catchments. Therefore, it becomes necessary to have estimates of hydrological variables in these catchments also. The main purpose of regionalisation is to estimate the hydrological variables for ungauged or inadequate data situations. The procedure involved in regionalization is based on development of regional relationships between criterion variable and one or more predictor variables. The variable for which values are available is called a predictor variable. The variable for which values must be estimated is called the criterion variable. The regression analysis is used to relate criterion variable to predictor variable(s). Correlation provides a measure of the goodness of fit of the regression. Therefore, while regression provides the parameters of the prediction equation, correlation describes its quality.

Regionalisation involves two steps : first is the testing of regionhal homogeneity and second is developing the regional relationship for hydrological variables. There are various criteria for testing the regional homogeneity. Some of these criteria are based on statistics of the hydrological variables observed for a number of catchments in the region. Other criteria are based on the considerations of the catchments exhibiting similar hydrological and hydrometeorological characteristics. Based on this criteria, India has been divided into 26 hydrometeorological subzones. Various regionalization studies such as flood estimation by regional unit hydrograph approach and regional flood frequency studies have been carried out for these subzones, using the data of small catchments in these subzones.

The identification of the hydrometeorologically homogeneous regions can also be achieved on the basis of the physical characteristics of the basin, which control the hydrological processes. The type and rate of hydrological processes which occur within a drainage basin are ultimately determined by its physical properties. If the relationships between these properties and the hydrological response could be defined, the hydrological behaviour of basins could be predicted without the need for direct process measurement. However, it would not be practical, or possible, to consider all the physical characteristics of a basin which can be identified as influential. Apart from these, there are numerous indices of climate, soil type and landuse. Nevertheless, the dominant controlling factors can be indexed by a small number of variables. Basin area in particular displays a stron correlation with many flood indices. Other variables such as slope, length of main channel, channel slope, stream density, soil type, landuse etc. and climatological characteristics e.g. rainfall etc. may be used for identifying the hydrologically homogeneous regions.

In order to identify groups of basins with similar hydrologically homogeneous behaviour, a classification technique is required. Cluster analysis provides an analytical methodology which to this multivariate problem. Many clustering algorithms are available but the choice depends on the type and structure of data to be classified.

8.4 Hydrological Parameters to be Regionalized

For hydrological analysis the various hydrological parameters need to be regionalized. Such as in case of streamflow, peak floods, dependable flows, low flows, unit hydrograph parameters etc. are required to be regionalised.

The earliest approach to regionalization of hydrologic properties was to assume that peak flow is related to catchment area and perform a regression to determine the parameters. The equation expressing the above relationship is of the following form:

$$Q = CA^b$$

where, Q is peak flow; A is catchment area; and C and b are regression parameters. In nature, as catchment area increases, the spatially averaged rainfall intensity decreases, and consequently peak flow does not increase as fast as catchment area. Therefore, the exponent b in the above equation is always less than 1, usually in the range of 0.4 to 0.9. In most of the regional flood formulae of the above form such as Dicken's formula, Ryve's formula were quite commonly used in our country. In such formulae, the exponent b was assigned a fixed value and for coefficient C, certain range of values for different regions of the country was specified.

Regional unit hydrograph analysis

In the regional unit hydrograph analysis the representative unit hydrograph parameters and pertinent physical characteristics of the gauged catchments of a hydrologically homogeneous region are evaluated. Then multiple linear regression is performed, considering one of the unit hydrograph parameters at a time as dependent variable (criterion variable) and various catchment characteristics as independent variables (predictor variables), in order to develop the regional relationships for unit hydrograph derivation. Further, after evaluating the catchment characteristics for an ungauged catchment in the homogeneous region from toposheet, the unit hydrograph for the ungauged catchment can be derived using the relationship developed for the region. Central Water Commission, India Meteorological Department and Railway Designs and Standards Organisation have developed regional unit hydrograph relationships for the various 26 hydrometeorologically homogeneous subzones of India. Regional unit hydrograph studies have also been carried out using the conceptual models such as Nash and Clark models. Attempts have been made to regionalize parameters of these models also.

Regional flood frequency analysis

Flood magnitudes and their frequencies are often needed for planning and design of various hydraulic structures, flood plain zoning etc. Flood frequency analysis procedures provide such information from the available limited historical records of annual maximum peak floods. The peak flood data used for flood frequency analysis should be of good quality, random and homogeneous.

The flood frequency analysis methods may be categorized into three groups: (a) at site flood frequency analysis, (ii) at site and regional flood frequency analysis, and (iii) regional flood frequency analysis.

When annual maximum peak flood records for a site are available for quite a long period say 30 years or more, then at site flood frequency analysis may be carried out. If the peak flood records for a site are available for a short length of period, and peak flood records are also available for the various sites in a hydrologically homogeneous region, then at site and regional flood frequency analysis is used, and if no information about peak floods is available for a site, then the relationship between mean annual peak floods and catchment as well as climatological characteristics is used for estimation of mean annual peak flood for the ungauged catchment, together with regional parameters of the flood frequency distribution for estimation of floods of desired return periods.

The other stream flow variables such as dependable flows can also be regionalised following the similar type of approach. Attempts have been made to regionalise the other hydrological variables such as precipitation, evapotranspiration, etc.; however, effort made for regionalisation of the sub-surface hydrological variables in India are rather limited. There is need to evolve methodologies for regionalisation of the various hydrological variables for prediction of response of variables representing the surface and sub-surface components of the hydrological cycle. Such regional regional relationships would be very much useful for predicting the respective hydrological variables for limited data situations.

9.0 TOOLS FOR HYDROLOGICAL STUDIES

Theory of hydrology is presented in two forms: descriptive and quantitative. Descriptive hydrology presents the subjects in a written or subjective manner, by defining the basic concepts and processes which combine and interact to form the subject as a whole. These concepts and processes are defined by observation, logic and thought.

Quantitative hydrology is the means by which the descriptive theory is expressed in terms of numbers, whether by measurement or calculation. Mathematics is the science of magnitude and numbers and all their relations. Mathematical hydrology is the functional relationship between numbers which are quantitative representation of the descriptive concepts and processes in hydrology. In this context, the method whereby processes are modelled by representing them mathematically has led to the expression "<u>mathematical model</u>".

Mathematics and computers are important tools for the quantitative hydrological analysis. The basic mathematics, statistics, optimisation techniques and computers are widely applied for providing the solutions of many hydrological problems. In this section, some of the important applications of these tools in quantitative hydrology are briefly described :

9.1 Basic Mathematics

Basic mathematics include matrix operation, differentiation, integration, solutions of differential equations, solutions of linear and non-linear simultaneous equations etc. These techniques of basic mathematics are widely applied in hydrology. For example, in simple regression and multiple linear regression analysis of hydrologic variables, the matrix operation plays a very important role. Physics of the overland flow and channel flow is represented by the differential equations known as Saint Venant Equations, which are equations of continuity and momentum. These equations are solved for a simple case of kinematic wave approximation to the complex case of dynamic wave solution using various explicit and implicit finite difference schemes for given initial and boundary conditions. The governing differential equations for sub-surface flow and ground water flow are Richard's equation and Boussineq equation respectively. These differential equations are also solved using the techniques of finite difference schemes. Analytical solution of these differential equations are also attempted for some simplified scenerios. Now a days finite element methods are also becoming popular particularly in the area of ground water modelling. The numerical integration techniques are applied to compute the volume of the flow hydrograph or area under any other curve which is function of one or more hydrologic variables.

9.2 Statistics

The concepts and techniques of statistics are applied to predict the hydrologic variables. Frequency analysis is used to predict the flood of desired frequency. Such estimates are needed for design of hydraulic structures such as embankments, barrages, weirs, bridges, culverts and dam etc. Frequency analysis is also used to compute the low flow frequency and extreme rainfall values. Generally, frequency analysis approach is applied for modelling all those hydrologic variables whose observations are random and independent. This approach also generates the random sequences of the hydrologic variables. The generated data may be used to study the characteristics of the respective hydrologic variable. The generated sequences of flow are considered as synthetic inflows to the reservoir. It forms one of the important inputs for the reservoir simulation studies.

Stochastic models or time series models are applied to model the time dependent hydrologic variables. In this approach the stochastic models are fitted with the historical data and the parameters are estimated. A best fit model, which preserve the basic statistics of the historical data, is considered to be a suitable model. The selected stochastic model is applied to generate the synthetic data of the time dependent hydrologic variables. For example, daily, ten daily, monthly, seasonal or annual flow series are generated using the time series models such as AR, ARMA and ARIMA etc. These generated flow series are utilised to compute the dependable flows. These flow series are also considered as synthetic inflows to the reservoir for the reservoir operation studies.

9.3 Optimisation Techniques

In operation research various optimisation techniques are used. Some of the commonly used techniques of optimisation which have been widely applied in hydrology and water resources are broadly categorised in four groups: (i) linear programming, (ii) non-linear programming, (iii) dynamic programming and (iv) geometric programming. Linear programming has been applied in case the objective function as well as constraints are linear. Non-linear programming techniques are used to solve the non-linear optimisation problem wherein either objective function or constraints or both are non-linear. Dynamic programming is used to determine the most optimum path out of the various available paths considering the constraints associated with each path. Geometric programming techniques are applied if the objective functions can be represented as the product of variables or their combinations.

Non-linear programming techniques such as Newton Raphson method, Univariate Search method, Rosen brock optimisation method, Quasi Newton method and Marquardt algorithm etc. are used for the calibration of the conceptual hydrologic models. Linear programming and dynamic programming are generally applied in the area of water resources system in order to decide the optimum policy for the reservoir operation. Linear programming approach is also applied to estimate the unit hydrograph of specific duration analysing the available rainfall-runoff records for the different storm events.

9.4 Computer Programming

Recent developments in computers and analysis techniques have led to significant developments in their application in hydrology. Personal/micro-computers and microprocessors have an important collection of data through automatic recording devices and compilation of data in computer compatible from after proper introduction of different sizes and types of computers in the country.

Hydrological Instrumentation:

With the fast technological developments, automated instrumentation has gained the momentum. many hydrological instruments have been developed using microprocessors. These equipment can be used to collect the data automatically and the data can also be transmitted to the central station at a desired distance.

Automatic data acqusition system:

The need for collection of reliable hydrological and meteorological data is obvious in flood and weather forecasting, and efficient water management. With conventional manual observation system, there is often inadequate information, especially from remote areas and where observers are not readily available. With the use of automated data collection systems, most of the hydro-meteorological parameters can be measured reliabily and continually. Moreover, the automation of data collection systems may reduce or eliminate the human observational errors. These systems are capable of collecting and storing data for a long time period and are highly reliable in both laboratory and field environments.

Telemetry for networking applications:

If the spatial coverage and volume of data is involved then data is retrived through telemetry. With this technology, the data loggers can be accessed by radio telemetry which requires no physical conncetion from the computer to data logger, thereby reducing the number of regular visits to remote suite.

Data base management system:

Now-a-days computer based database management techniques are being applied for efficient handling of hydrological data. It consists of creating a database, updating it frequently as and when new data are available and retrieving the data from the database when desired after carrying out validation checks on database. IMD has been storing climatological data of various stations for last four decades. This data is available on magnetic tapes and/or on floppy disks.

Remote Sensing and GIS:

In hydrological analysis, geographic information system (GIS) and remote sensing have important place, since both deal with spatial and non-spatial data. Remote sensing technique produces synoptic, repetitive spatial data which can be handled to produce data and maps with the help of computer and software which are useful in many hydrologic applications.

Project hydrology:

For meeting the increasing requirements of water for our growing population, it is necessary that intensive and extensive investigations and studies are carried out in a systematic manner on various aspects of hydrology of water resources projects. The use of personal/micro-computers and interactive computer programmes for this purpose would provide wide spread use of various techniques leading to proper scientific management of hydrological activities for water resources development projects starting right from data collection.

Flood Studies:

Flood studies dealing with flood plain zoning and economic analysis for assessing the actual flood damages are useful for the planners and government agencies invilved in flood relief and flood protection activities. Now-a-days various dam break models are available by which impact of dam break and sensitivity analyses can be performed and adequate measures can be adopted. Also almost states and CWC, during monsoon period establish flood cells where information about rainfall and dam level is being monitored and supplied to higher authorities. This information is analysed on computers and if necessary further actions are taken.

Hydrologic modelling:

The development and application of mathematical and conceptual models in hydrology have increased tremendously during the last three decades particularly with the rapid developments within computer technology. For complicated problems, particularly those involving natural and man made changes in land use such as effects of urbanisation, forest clearence, forest fire and impact of climate change distributed modelling approach becomes necessary which can be solved only with the help of computers.

Hydrology Project:

One of the main objective of the project is to improve facilities for measurement, collection, analysis, transfer and dissemination of hydrological and hydrometeorological data at central level as well as at state levels. For This it is proposed to establish data banks at both the levels. Computer facilities will be provided for analysis of data and with the help of NICNET, facility of National Informatic Centre, the data transfer will take place. Project also support the improvement of technical capability particularly with regard to water allocation and planning and management of water resources development at national, state, basin and indivudal project levels.

9.5 GIS and Remote Sensing

Remote sensing can often acquire data that are otherwise not available. It is being increasingly used in engineering discipline. In hydrology work has been carried out using remotely sensed data in i) mapping, ii) snow and glacier hydrology, iii) flood hydrology, iv) water quality monitoring, v) land use mapping and vi) assessment of water logging and salinity.

Continuing development of new remote sensing systems and improvements in the spatial, sepctral, radiometric and temporal measurement capabilities would considerably enhance the use of remote sensing for water resources development and management as well as hydrologic studies. It seems safe to predict that as a result of more pressure being placed on our finite water resources, the remote sensing technology would be increasingly sought for with the passage of time and eventually become as integral part of operational procedures. Based on remote sensing and other collateral parameters effective GIS may be developed and judiciously exploited for basin wise water resources management as macro and micro levels.

10.0 REMARKS

In the expanding modern economy, exploitation of the natural resources is of primary importance. Extensive efforts are being made in every country to harness the water potential for the benefit of the people. For economic and optimum utilization, planning, design and operating of water resources, determination of the extent and availability of surface and ground water is the first requisite. As the hydrological processes are continuous and quite complex, therefore, an accurate assessment of quantities of water simultaneously passing through all these phases becomes quite a difficult task. With the improvement in hydrological data base and availability of better computational facilities, the application of mathematical models to simulate the various components of hydrological cycle as well as their interactions are becoming popular. The advanced hydrological models are being developed, which consider the point and non-point changes in the catchment and predict the effects of these changes on the components of the landphase of the hydrological cycle. Such types of hydrological models have a good potential for the assessment of surface as well as ground water resources in space and time. Efforts should be made to develop such mathematical models to simulate the hydrological processes for better estimation, optimal planning and utilization of water resources of the country.

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