# PRACTICING HYDROLOGY-AN OVERVIEW

Er. R. D. Singh
Director, NIH, Roorkee

**Training Course on**
**HYDROLOGICAL INVESTIGATION TECHNIQUES FOR WATER RESOURCES DEVELOPMENT & MANAGEMENT**
**(26-28 August 2012)**

# PRACTICING HYDROLOGY-AN OVERVIEW

**Er. R.D. Singh**
Director
National Institute of Hydrology,Roorkee
Email: rds@nih.ernet.in

## 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.

### 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.

### 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:

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

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

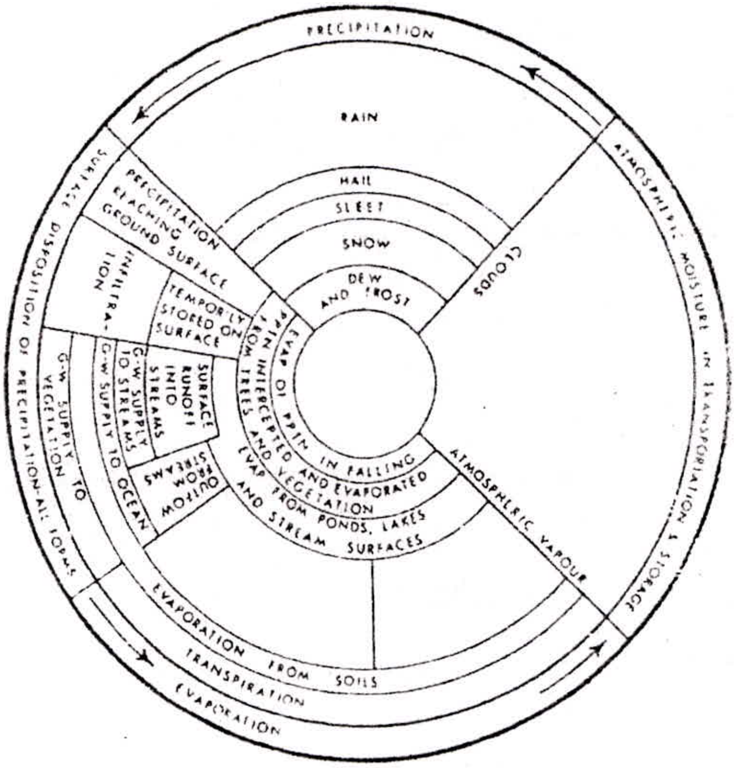


Figure 1. The Hydrologic Cycle – A Qualitative Representation

## 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.

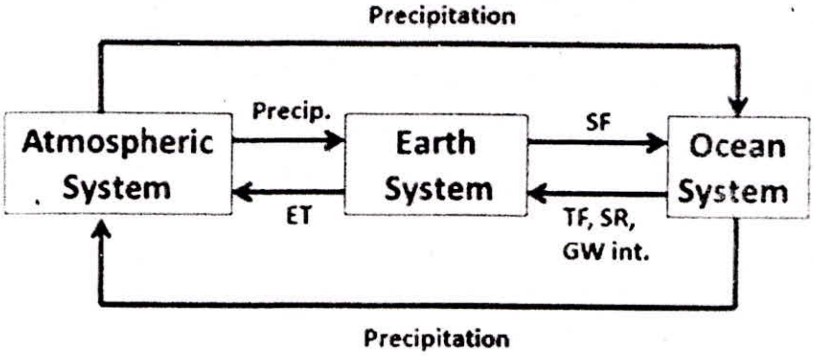


Figure 2. A Global Schematic of the Hydrologic Cycle

## 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.

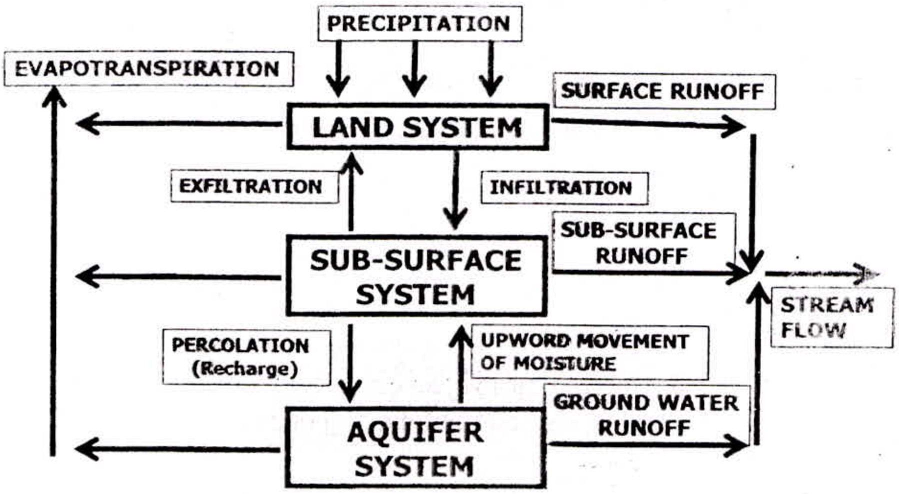


Figure 3. A Schematic of the Hydrologic Cycle in the Earth System

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.

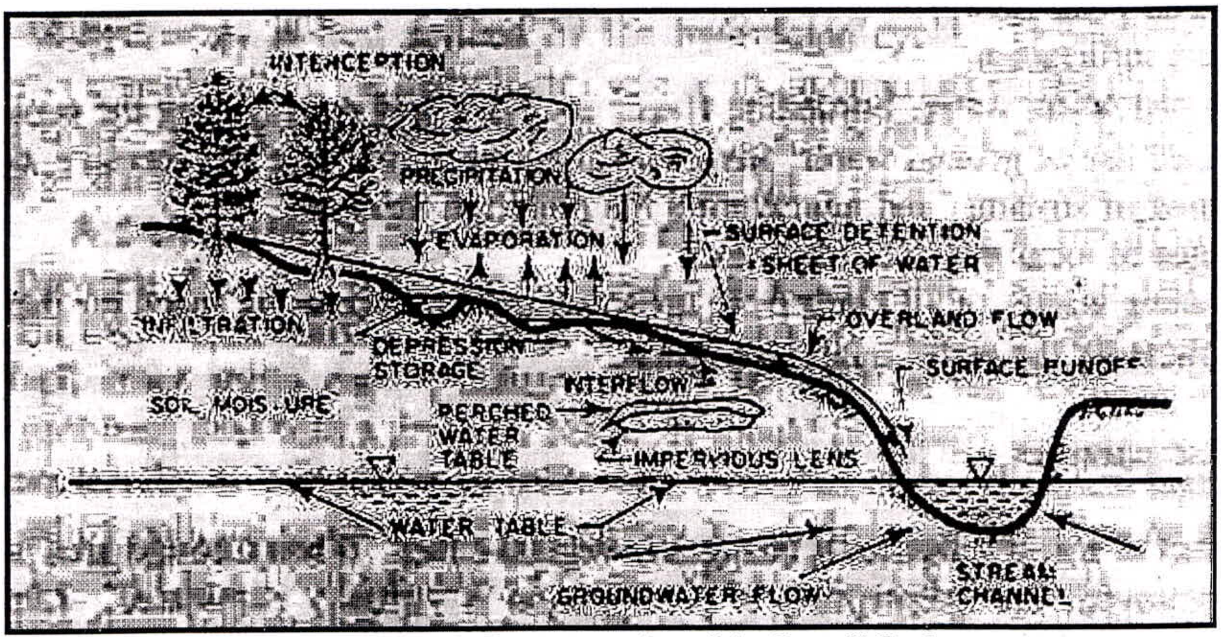


Figure 4. Simple Representation of the Runoff Cycle

## 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.

## 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 GangaRiver 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.

## 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, □S, for a specified period of time, □t. When the basin is considered as a black-box system, as shown in Fig. 5, or as a reservoir, as shown in Fig.6,

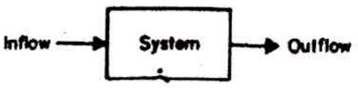


Fig. 5 : The drainage basin as a simple black box system.

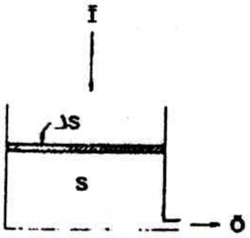


Fig.: 6 : The drainage basin as a reservoir receiving average inflow and discharging average outflow

its hydrologic budget can be expressed as:

$$\frac{\Delta S}{\Delta t}=\bar{I}-\bar{Q}\,(1)$$

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

where $\bar{I}$ *and* $\bar{Q}$ are, respectively, average inflow and average outflow for time interval □t, 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 □t = $t_2$-$t_1$. If I and Q vary continuously with time t, then eq. (2) can be written as:

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

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.

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

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.

## 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.

### 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: | | | | |
| | Fresh | 134.8 | 10,530,000 | 0.76 | 30.1 |
| | Saline | 134.8 | 12,870,000 | 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: | | | | |
| | Fresh | 1.2 | 91,000 | 0.007 | 0.26 |
| | Saline | 0.8 | 85,400 | 0.006 | - |
| 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.

## Water Resources of India

## Availability of Surface and Ground Water Resources

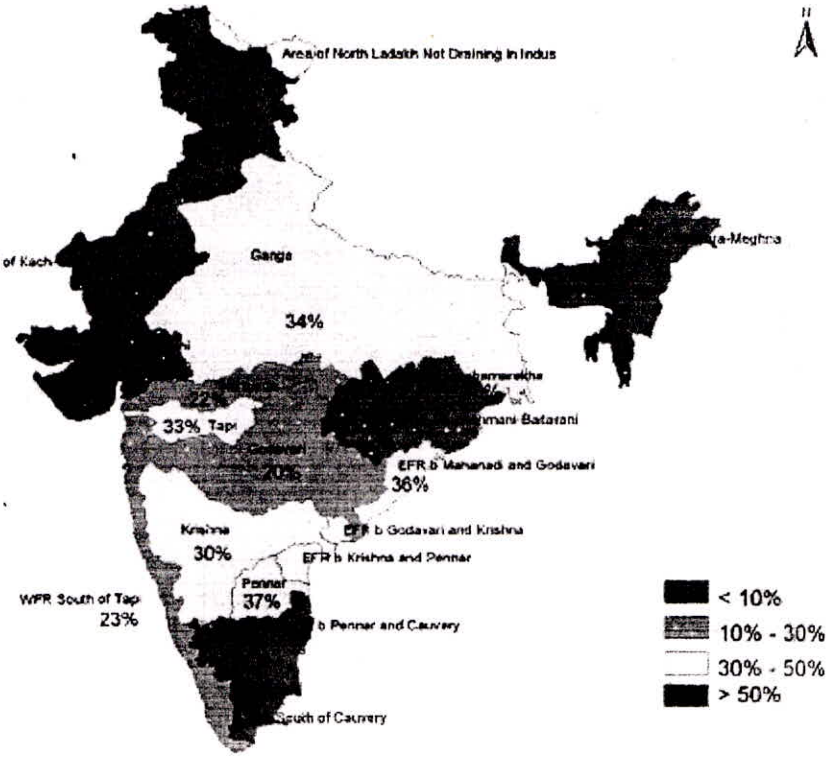


Figure 7. Level of ground water development basin

Although, India occupies only 3,287,590 km$^2$ geographical area, which forms 2.45% of the world's land area, it supports over 15% of the world's population. The population of India as on 1st March 2001 stood at 1,027,015,247 persons. Thus, India supports about 1/6th of world population, 1/50th of world's land and 1/25th of world's water resources (Water Management Forum, 2003). India also has a livestock population of 500 million, which is about 20% of the world's total livestock population. More than half of these are cattle, forming the backbone of Indian agriculture. A brief description of availability of surface and groundwater water resources of India is given as follow.

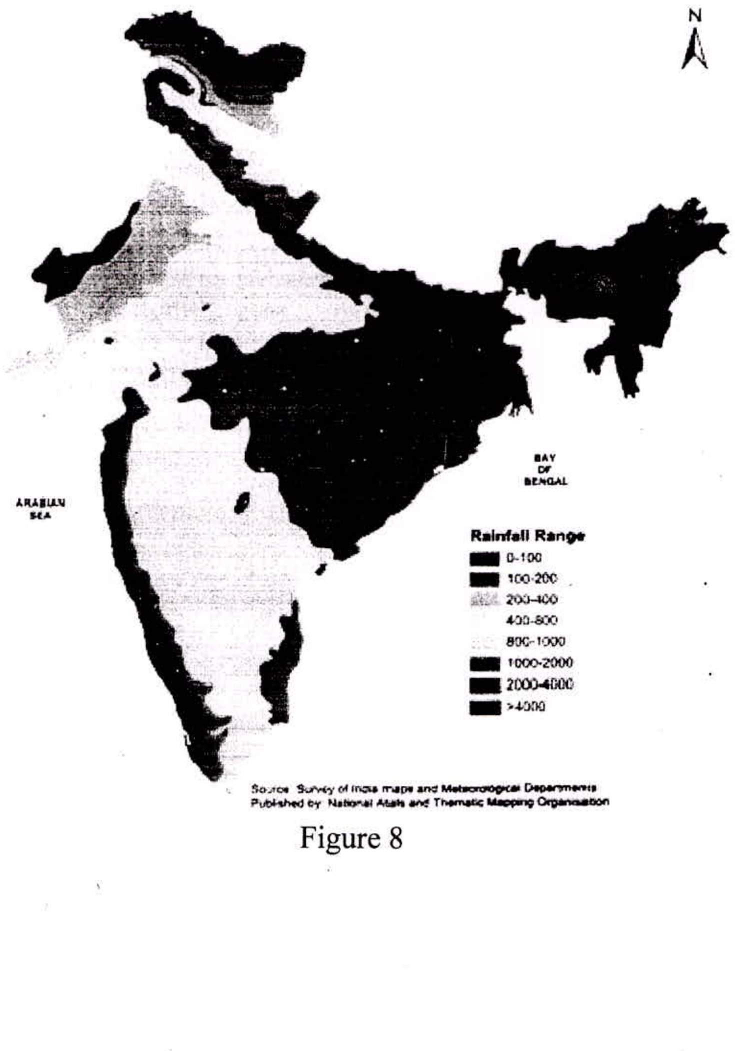
### *Surface Water Resources*

In the past, several organizations and individuals have estimated water availability for the nation within the limitations of physiographic conditions and socio-political environment, legal and constitutional constraints and the technology of development available differently. Utilizable water resource is the quantum of withdrawable water from its place of natural occurrence. Recently, the National Commission for Integrated Water Resources Development (NCIWRD, 1999) estimated the basin-wise average annual flow in Indian river systems as 1953 km$^3$ and the utilizable annual surface water of the country is 690 km$^3$. Figure 9 shows location map of river basins of India and the details of available and utilizable surface water resources in India are given in Table 4

### *Ground Water Resources*

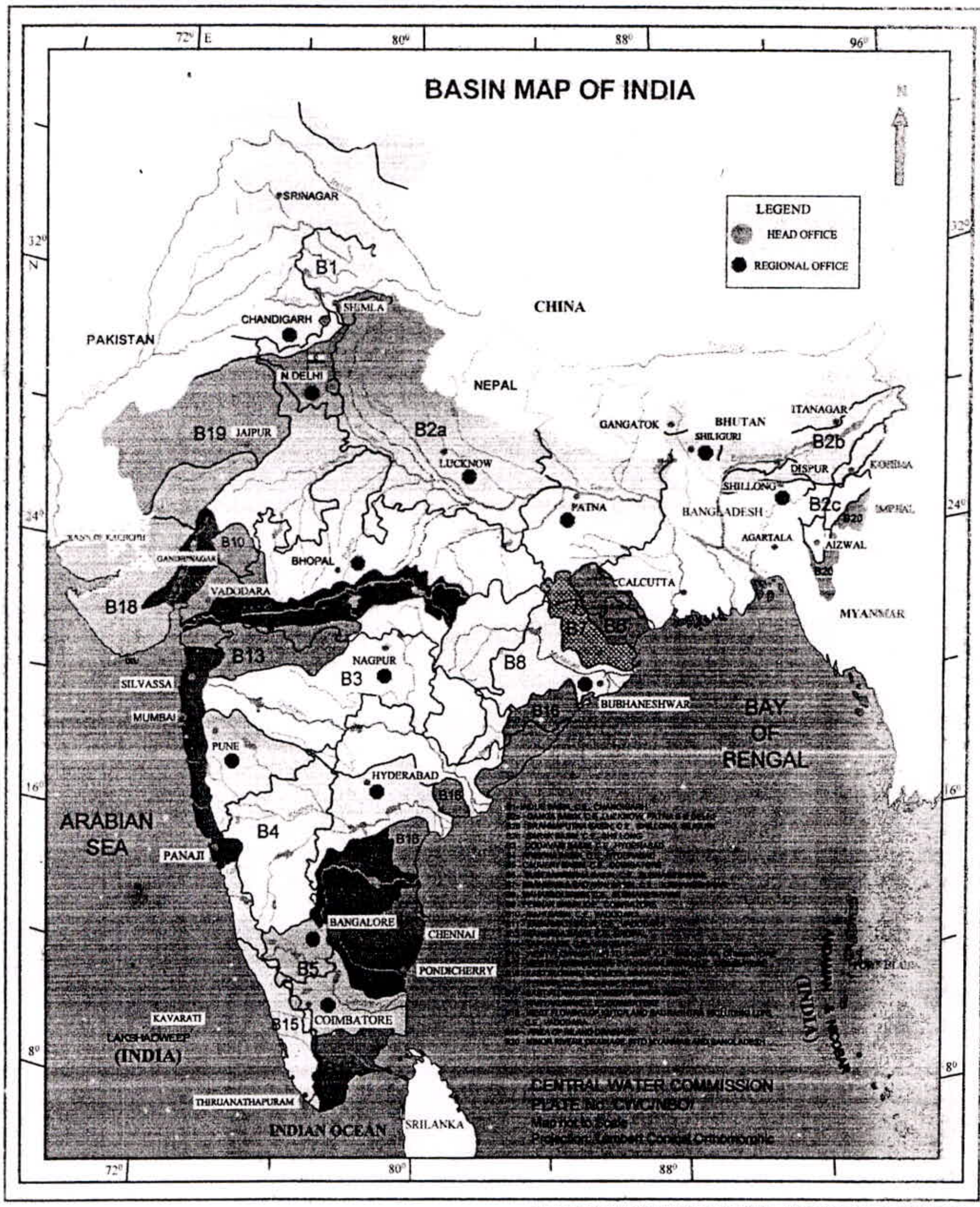
The annual potential natural ground water recharge from rainfall in India is about 342.43 km$^3$, which is 8.56% of total annual rainfall of the country. The annual potential ground water recharge augmentation from canal irrigation system is about 89.46 km$^3$. Thus, total replenishable groundwater resource of the country is assessed as 431.89 km$^3$. After allotting15% of this quantity for drinking, and 6 km$^3$ for industrial purposes, the remaining can be utilized for irrigation purposes. Thus, the available ground water resource for irrigation is 361 km$^3$ of which utilizable quantity (90%) is 325 km$^3$. The basin wise per capita water availability varies between 13,393 m$^3$ per annum for Brahmaputra-Barak basin to about 300 m$^3$ per annum for Sabarmati basin. The basin-wise ground water potential of the country is given in Table 3 (IWRS, 1998).

RAINFALL MAP OF INDIA



Source Survey of India maps and Meteorological Departments
Published by National Atlas and Thematic Mapping Organisation

Figure 8



For international / State boundaries and Coast - Line refer to Survey of India maps.

**Figure 9. Location map of river basins of India.**

**Table 2. Basinwise average flow and utilizable water (in $km^3$/year) (NCIWRD, 1999)**

| S. No. | River Basin | Average Annual Flow | Utilizable Flow |
|---|---|---|---|
| 1. | Indus | 73.31 | 46 |
| 2. | Ganga-Brahmaputra-MeghnaBasin | | |
| | 2a Ganga | 525.02 | 250 |
| | 2b Brahmaputra sub-basin | 629.05 | 24 |
| | 2c Meghna (Barak) sub-basin | 48.36 | |
| 3. | Subarnarekha | 12.37 | 6.81 |
| 4. | Brahmni-Baitarani | 28.48 | 18.3 |
| 5. | Mahanadi | 66.88 | 49.99 |
| 6. | Godavari | 110.54 | 76.3 |
| 7. | Krishna | 69.81 | 58 |
| 8. | Pennar | 6.32 | 6.86 |
| 9. | Cauvery | 21.36 | 19 |
| 10. | Tapi | 14.88 | 14.5 |
| 11. | Narmada | 45.64 | 34.5 |
| 12 | Mahi | 11.02 | 3.1 |
| 13. | Sabarmati | 3.81 | 1.93 |
| 14. | West flowing rivers of Kachchh and Saurashtra including Luni | 15.1 | 14.98 |
| 15. | West flowing rivers south of Tapi | 200.94 | 36.21 |
| 16. | East flowing rivers between Mahanadi and Godavari | 17.08 | |
| 17. | East flowing rivers Between Godavari and Krishna | 1.81 | 13.11 |
| 18. | East flowing rivers Between Krishna and Pennar | 3.63 | |
| 19. | East flowing rivers Between Pennar and Cauvery | 9.98 | 16.73 |
| 20. | East flowing rivers south of Cauvery | 6.48 | |
| 21. | Area of North Ladakh not draining into Indus | 0 | NA |
| 22. | Rivers draining into Bangladesh | 8.57 | NA |
| 23. | Rivers draining into Myanmar | 22.43 | NA |
| 24. | Drainage areas of Andman, Nicobar and LakshadweepIslands | 0 | NA |
| | Total (Rounded) | 1953 | 690 |

*Water Requirements*

Traditionally, India has been an agriculture-based economy. Hence, development of irrigation to increase agricultural production for making the country self-sustained and for poverty alleviation has been of crucial importance for the planners. Accordingly, irrigation sector was assigned a very high priority in the 5-year plans. Giant schemes like the Bhakra Nangal,Hirakud, DamodarValley, Nagarjunasagar, RajasthanCanal project etc. were taken up to increase irrigation potential and maximize agricultural production. Long-term planning has to account for the growth of population (Jain et al., 2004). According to National Water Policy

(2002) the production of food grains has increased from around 50 million tonnes in the fifties to about 203 million tonnes in the year 1999-2000. A number of individuals and agencies have estimated likely population of India by the year 2025 and 2050. According to the estimates adopted by NCIWRD (1999), by the year 2025, the population is expected to be 1333 million in high growth scenario and 1286 million in low growth scenario. For the year 2050, high rate of population growth is likely to result in about 1581 million people while the low growth projections place the number at nearly 1346 million. The projected food-grain and feed demand for 2025 would be 320 million tonnes (high demand scenario) and 308 million tonnes (low demand scenario). The requirement of food grains for the year 2050 would be 494 million tonnes (high demand scenario) and 420 million tonnes (low demand scenario). Table 4 provides details of the population of India and per capita water availability as well as utilizable surface water for some of the years from 1951 to 2050 (projected).

**Table 3. Ground water potential in river basins of India (Pro rata basis) (in km$^3$/year) (IWRS, 1998)**

| S. No. | Name of the basin | Total replenis-able ground water resources | Provision for domestic, industrial and other uses | Available ground water for irrigation | Net draft | Balance ground water potential | Level of ground water develop-ment (%) |
|---|---|---|---|---|---|---|---|
| 1. | Brahmani with Baitarni | 4.05 | 0.61 | 3.44 | 0.29 | 3.16 | 8.45 |
| 2. | Brahmaputra | 26.55 | 3.98 | 22.56 | 0.76 | 21.80 | 3.37 |
| 3. | Chambal Composite | 7.19 | 1.08 | 6.11 | 2.45 | 3.66 | 40.09 |
| 4. | Cauvery | 12.30 | 1.84 | 10.45 | 5.78 | 4.67 | 55.33 |
| 5. | Ganga | 170.99 | 26.03 | 144.96 | 48.59 | 96.37 | 33.52 |
| 6. | Godavari | 40.65 | 9.66 | 30.99 | 6.05 | 24.94 | 19.53 |
| 7. | Indus | 26.49 | 3.05 | 23.43 | 18.21 | 5.22 | 77.71 |
| 8. | Krishna | 26.41 | 5.58 | 20.83 | 6.33 | 14.50 | 30.39 |
| 9. | Kutch& Saurashtra Composite | 11.23 | 1.74 | 9.49 | 4.85 | 4.64 | 51.14 |
| 10. | Madras and South Tamil Nadu | 18.22 | 2.73 | 15.48 | 8.93 | 6.55 | 57.68 |
| 11. | Mahanadi | 16.46 | 2.47 | 13.99 | 0.97 | 13.02 | 6.95 |
| 12. | Meghna | 8.52 | 1.28 | 7.24 | 0.29 | 6.95 | 3.94 |
| 13. | Narmada | 10.83 | 1.65 | 9.17 | 1.99 | 7.18 | 21.74 |
| 14. | Northeast Composite | 18.84 | 2.83 | 16.02 | 2.76 | 13.26 | 17.20 |
| 15. | Pennar | 4.93 | 0.74 | 4.19 | 1.53 | 2.66 | 36.60 |
| 16. | Subarnarekha | 1.82 | 0.27 | 1.55 | 0.15 | 1.40 | 9.57 |
| 17. | Tapi | 8.27 | 2.34 | 5.93 | 1.96 | 3.97 | 33.05 |
| 18. | Western Ghat | 17.69 | 3.19 | 14.50 | 3.32 | 11.18 | 22.88 |
|  | Total | 431.43 | 71.08 | 360.35 | 115.21 | 245.13 | 31.97 |

**Table 4. Per capita per year availability and utilizable surface water in India (in $m^3$)**

| S. N. | Year | Population (in million) | Per-capita surface water availability | Per-capita utilizable surface water |
|---|---|---|---|---|
| 1 | 1951 | 361 | 5410 | 1911 |
| 2 | 1955 | 395 | 4944 | 1746 |
| 3 | 1991 | 846 | 2309 | 816 |
| 4 | 2001 | 1027 | 1902 | 672 |
| 5 | 2025 (Projected) | a. 1286 (Low growth)<br>b. 1333 (High growth) | 1519<br>1465 | 495 |
| 6 | 2050 (Projected) | a. 1346 (Low growth)<br>b. 1581 (High growth) | 1451<br>1235 | 421 |

***Domestic use water requirement.*** Community water supply is the most important requirement and it is about 5% of the total water use. About 7 $km^3$ of surface water and 18 $km^3$ of ground water are being used for community water supply in urban and rural areas. Along with the increase in population, another important change from the point of view of water supply is higher rate of urbanization. As per the projections, the higher is the economic growth, the higher would be urbanization. It is expected that nearly 61% of the population will be living in urban areas by the year 2050 in high growth scenario, as against 48% in low growth scenario. Different organizations and individuals have given different norms for water supply in cities and rural areas. The figure adopted by the NCIWRD(1999) was 220 litres per capita per day (lpcd) for class I cities. For the cities other than class I, the norms are 165 for year 2025 and 220 lpcd for the year 2050. For rural areas, 70 lpcd and 150 lpcd have been recommended for the year 2025 and 2050. Based on these norms and projection of population, it is estimated that by the year 2050, water requirements per year for domestic use will be 90 $km^3$ for low demand scenario and 111 $km^3$ for high demand scenario. It is expected that about 70% of urban water requirement and 30% percent of rural water requirement will be met by surface water sources and the remaining from ground water.

***Irrigation water requirement.***Irrigated area in the country was only 22.6 million hectare (M-ha) in 1950-51. Since food production was much below the requirement of the country, due attention was paid for expansion of irrigation. The ultimate irrigation potential of India has been estimated as 140 M-ha. Out of this, 76 M-ha would come from surface water and 64 M-ha from ground water sources. The quantum of water used for irrigation by the last century was of the order of 300 $km^3$ of surface water and 128 $km^3$ of ground water, total 428 $km^3$. The estimates indicate that by the year 2025, water requirement for irrigation would be 561 $km^3$ for low demand scenario and 611 $km^3$ for high demand scenario. These requirements are likely to further increase to 628 $km^3$ for low demand scenario and 807 $km^3$ for high demand scenario by the year 2050.

***Hydroelectric power water requirement.***The hydropower potential of India has been estimated at 84,044 MW at 60% load factor. At the time of independence (1947), the installed capacity of hydropower projects was 508 MW. By the end of 1998, the installed hydropower capacity was about 22,000 MW. The status of hydropower development in major basins is highly uneven. According to an estimate, India has plans to develop 60,000 MW, additional hydropower by the twelfth five year plan. It includes 14,393 MW during tenth five year plan (2002-2007); 20,000

MW during eleventh (2007-2012) and 26,000 MW during twelfth (2012-2017) five year plans. A potential of the order of 10,000 MW is available for development of small hydropower projects in the Himalayan and sub-Himalayan regions of the country. Therefore, it is not only desirable but also a pressing need of time to draw a master plan for development of small, medium and large hydro-schemes for power generation.

***Industrial water requirement.***Rough estimates indicate that the present water use in the industrial sector is of the order of 15 km$^3$. The water use by thermal and nuclear power plants with installed capacities of 40000 MW and 1500 MW (1990 figures) respectively, is estimated to be about 19 km$^3$. In view of shortage of water, the industries are expected to switch over to water efficient technologies. If the present rate of water use continues, the water requirement for industries in the year 2050 would be 103 km$^3$; this is likely to be nearly 81 km$^3$ if water saving technologies are adopted on a large scale.

***Total water requirements.*** Total annual requirement of water for various sectors has been estimated and its break up is given Table 5.

**Table 5.** Annual water requirement for different uses (in km$^3$) (NCIWRD, 1999)

| **Uses** | **Year 1997-98** | **Year 2010** | | | **Year 2025** | | | **Year 2050** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **Low** | **High** | **%** | **Low** | **High** | **%** | **Low** | **High** | **%** |
| **Surface Water** | | | | | | | | | | |
| Irrigation | 318 | 330 | 339 | 48 | 325 | 366 | 43 | 375 | 463 | 39 |
| Domestic | 17 | 23 | 24 | 3 | 30 | 36 | 5 | 48 | 65 | 6 |
| Industries | 21 | 26 | 26 | 4 | 47 | 47 | 6 | 57 | 57 | 5 |
| Power | 7 | 14 | 15 | 2 | 25 | 26 | 3 | 50 | 56 | 5 |
| Inland Navigation | | 7 | 7 | 1 | 10 | 10 | 1 | 15 | 15 | 1 |
| Environment – Ecology | | 5 | 5 | 1 | 10 | 10 | 1 | 20 | 20 | 2 |
| Evaporation Losses | 36 | 42 | 42 | 6 | 50 | 50 | 6 | 76 | 76 | 6 |
| Total | 399 | 447 | 458 | 65 | 497 | 545 | 65 | 641 | 752 | 64 |
| **Ground Water** | | | | | | | | | | |
| Irrigation | 206 | 213 | 218 | 31 | 236 | 245 | 29 | 253 | 344 | 29 |
| Domestic | 13 | 19 | 19 | 2 | 25 | 26 | 3 | 42 | 46 | 4 |
| Industries | 9 | 11 | 11 | 1 | 20 | 20 | 2 | 24 | 24 | 2 |
| Power | 2 | 4 | 4 | 1 | 6 | 7 | 1 | 13 | 14 | 1 |
| Total | 230 | 247 | 252 | 35 | 287 | 298 | 35 | 332 | 428 | 36 |
| Grand total | 629 | 694 | 710 | 100 | 784 | 843 | 100 | 973 | 1180 | 100 |
| **Total Water Use** | | | | | | | | | | |
| Irrigation | 524 | 543 | 557 | 78 | 561 | 611 | 72 | 628 | 807 | 68 |
| Domestic | 30 | 42 | 43 | 6 | 55 | 62 | 7 | 90 | 111 | 9 |
| Industries | 30 | 37 | 37 | 5 | 67 | 67 | 8 | 81 | 81 | 7 |
| Power | 9 | 18 | 19 | 3 | 31 | 33 | 4 | 63 | 70 | 6 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Inland Navigation | 0 | 7 | 7 | 1 | 10 | 10 | 1 | 15 | 15 | 1 |
| Environment – Ecology | 0 | 5 | 5 | 1 | 10 | 10 | 1 | 20 | 20 | 2 |
| Evaporation Losses | 36 | 42 | 42 | 6 | 50 | 50 | 6 | 76 | 76 | 7 |
| **Total** | **629** | **694** | **710** | **100** | **784** | **843** | **100** | **973** | **1180** | **100** |

With the increasing population as well as all round development in the country, the utilization of water has also been increasing at a fast pace. In 1951, the actual utilization of surface water was about 20% and 10% in the case of ground water. The utilizable water in river basins is highly uneven. For example in the Brahmaputra basin, which contributes 629 billion $m^3$ of surface water of the country's total flow, only 24 billion $m^3$ is utilizable.
ha respectively (Jeyaseelan, 2005).

## CURRENT TRENDS, CHALLENGES AND ISSUES IN WATER RESOURCES SECTOR OF INDIA

India faces an increasingly urgent situation: its finite and fragile water resources are stressed and depleting while various sectoral demands are growing rapidly. The historical situation in which relatively plentiful water resources have been used primarily for irrigated agriculture, with demands in other sectors insignificant relative to resource availability, is changing rapidly and will continue to do so in the foreseeable future. Population is expected to grow by about 40 to 50 per cent before eventual stabilization, and will be combined with major changes in the composition of demand resulting from rising incomes, urbanization and rapid industrialisation. Industrial needs will be a high economic priority; agriculture - with two-thirds of production dependent on irrigation and accounting for 83 per cent of consumptive water use - continues to remain crucially dependent on water; and rural and urban drinking water requirements, being a fundamental societal need, must be met without fail. Conflict between sectoral uses - domestic needs in rural and urban areas, agriculture, industry, energy, ecological, flood control, navigation, fisheries, recreation, ceremonial, religious, and other uses - is already a serious problem. In view of the above, World Bank has prepared a report on: *India Water Resources Management Sector Review - Initiating and Sustaining Water Sector Reforms*, wherein the current trends, challenges and issues in the water resources sector of India has been brought.

Summing up the various sectoral projections reveals a total annual demand for water increasing from 552 billion cubic meters (BCM) in 1997 to 1050 BCM by 2025. This would represent virtually the entire utilizable water resources of the country, casting some doubt on the realism of the projections, particularly that for irrigation. What is clear, however, is the rapid increase in non-irrigation demands. Consumption for industry and domestic purposes is expected to realise about a three-fold increase and its share in overall water consumption to increase from 8 to 25 per cent.

### Current Trends and Developments

Alterations in the water requirements and relative claims by the various sectors over time are partly a reflection of their changing significance in the economy and India's process of development. Although industrial development was quite slow in the years following independence, industrial growth rates have accelerated in recent years, exceeding agricultural growth and peaking at 11.6 per cent in 1995-96. This trend is resulting in a role reversal between the industrial and agricultural sectors as regards their relative contributions to the economy. Although agriculture remains the major employer in India's economy - with about 67 per cent of the Indian labour force, compared with 13 per cent for industry - the industrial sector now exceeds the agricultural sector (in rupee value) as regards its contribution to India's economy. Industrial growth will be the main contributor to future economic growth and employment generation. This trend notwithstanding, agriculture will maintain an important role in society and the economy, particularly in overall employment, poverty alleviation and in meeting the growing and increasingly diverse food needs (through productivity improvements and diversification of crop production). As the principal engine of growth for the agricultural sector, irrigation will thus remain crucial, though it will need to evolve into an efficient farmer-oriented service in order to serve agriculture effectively into the future. If India's aspirations for continued economic growth and improved social and environmental conditions are to be met, fundamental changes in how water is allocated, planned and managed - intersectorally and within sectors - must occur today in view of the already present water availability and quality problems.

The development of water constraints in India has been incremental, but the cumulative impact on present and future water availability is nevertheless dramatic. At Independence, population was less than 400 million and per capita water availability over 5000 cubic metres per year ($m^3$/yr). Today, fifty years later, population has grown to 945 million and water availability as fallen to about 2000 $m^3$/yr per capita. By year 2025, per capita availability is projected at only 1500 $m^3$/yr or thirty per cent of availability levels at Independence. Such aggregate indicators, which do not reflect local conditions or seasonal variability, only partly illustrate the development or water constraints in India. While resources may be plentiful in such areas as Eastern and North-eastern India, in other areas rainfall is unreliable and/or acutely short. At basin and local levels, the water availability situation is already critical - six of India's 20 major river basins have less than 1000 $m^3$/yr per capita, and localized shortages are endemic in all basins. By the year 2025, five more basins will become water scarce, and by 2050, according to one estimate, only the Brahmaputra, Barak, and west-flowing rivers from Tadri to Kanyakumari would be water sufficient. Exacerbating the inequalities in water resources endowments between basins and regions are the concentrated nature of human settlement and economic growth. Rapidly developing water requirements do not necessarily coincide with the natural distribution of water resources.

The water availability index includes surface water only, yet groundwater is an important component of water availability that factors significantly in the Indian economy. Groundwater is an important source of drinking water and food security for India's 950 million inhabitants, supplying about 80 per cent of water for domestic use in rural areas and perhaps 50 per cent of water for urban and industrial uses. Over the last three decades, the rapid expansion in use of ground water primarily for irrigation, has contributed significantly to India's agricultural and overall economic development. Groundwater irrigated area, the number of wells, and the number of energized pump sets have grown exponentially since the early 1950s. With more than 17 million energized wells nationwide, groundwater now supplies more than 50 per cent of the irrigated area and, due to higher yields under groundwater irrigation, is central to a significantly higher proportion of total agricultural output. In addition, in drought years, groundwater is often the most reliable source of irrigation.

This rapid development of groundwater has had a price. In many arid and hard-rock zones, increases in overdraft areas are emerging. Blocks classified as 'dark' or critical increased at a continuous rate of 5.5 per cent over the period 1984-85 to 1992-93. At this pace, and without regulatory or recharge measures, over 35 per cent of all blocks will become over-exploited within 20 years.

Water availability of both surface and ground water is further reduced by problems of pollution and inappropriate waste disposal practices on water quality. There are now few states or river basins in India where water quality issues are not present. Environmental problems include water quality degradation from agro-chemicals, industrial and domestic pollution, groundwater depletion, waterlogging, soil salinization, siltation, degradation or wetlands, ecosystem impacts, and various health-related problems. Environmental and health related issues are less evident than the more visible quantity-related problems, but are critically important to social welfare and resource sustainability.

There is a unique mix of water constraints in each locality. Four broad regions in India may be classified - the Northwest, South, East and Central, and Northeast - according to the following set of common distinguishing characteristics: (i) rainfall and water availability - surface and groundwater, (ii) development and use of water resources, (iii) water quality problems emanating from development and use of water, and (iv) other quality problems. This tremendous diversity implies that while a broad array of general actions will be required for addressing current water problems throughout India, specific strategies for improving water management must be tailored to the unique needs of each region and state and, more specifically, to the basin or sub-basin concerned.

Though India is facing serious water constrains today, India is not on the whole a water scare country. The present per capita availability of water in India of approximately 2200 $m^3$ per annum, actually compares quite favourably with a number of other countries. The per capita availability in many countries throughout the world is far less than in India. Yet, quite a number of these countries have by and large managed to harness their water resources more effectively to support intensive agriculture, to fulfil drinking water and sanitation needs of both rural and urban populations, and to satisfy the needs of industry. The handling of environmental issues, in addition, has often also been managed more successfully in other countries.

Current water resource constraints in India, in terms of both quality and quantity, can be expected to manifest themselves even more rapidly in the coming years. In the past, with lower population and development levels, there was still substantial room for each sector to satisfy its water needs and concerns independently. Now, as the gap between the availability of water resources and the demands on such resources narrows, the past approach to water management pursued in India is no longer tenable. Competition for water between urban and agricultural sectors will be a major challenge in the forthcoming century. Further, expansion in irrigation, industry, and domestic water demands will have serious implications for competing non-consumptive uses, such as hydropower and navigation. Provision for environmental and ecological concerns will have to be made. The weaknesses and inefficiencies in the existing institutional and operational mechanisms for allocating, reusing and reallocating water between sectors, as well as for distributing water to end users within sectors will need be rectified.

## The Cost of Inaction

It is increasingly realised in India that the current approach to the country's water resources is unable to cope effectively with the existing and emerging problems. Substantial cost to the nation and to individuals, in economic, social and environmental terms, is already evident and will magnify over time. Water has tended to be developed rather than managed in India, with much less emphasis on efficient and sustainable use. While some positive examples of comprehensive approaches to water development and allocation exist in India, in most instances water decisions are still fragmentary. Comprehensive management - on a river basin basis, multi-sectoraly, conjunctively for both surface and groundwater, incorporating both quality and quantity aspects of water, and fully incorporating long-term demand trends or environmental concerns - is largely lacking. Cooperation between states sharing river basins has been limited, and allocations of inter-state rivers between riparians have in some cases been highly contentious. Management of water has been through a top-down approach, and a supply-oriented approach - of exploiting additional water resources - has been used almost exclusively.

Some of the deleterious implications of the current approach include:

1. Large foregone mutual benefits to various sectors;
2. High fiscal cost without achieving the objectives;
3. Exorbitant costs of future provision;
4. Closure of various income-generating water uses and activities;
5. Continued high incidence of many severe water-borne diseases.

Estimates of these costs of inaction, even though partial and definitely a lower bound, are already staggering and will likely to increase with each year of delay in implementing water sector reforms.

## The Critical Challenges

The two critical challenges for India today are the need to:

(i) Improve resource allocation and management of water, including attention to environmental considerations and integrated treatment of water on a river basin basis, to enable mutually-beneficial resolutions of competing demands, whether inter-sectoral or inter-state; and

(ii) Improve service delivery in the water sub-sectors (i.e. irrigation, urban water and sanitation, and rural water supply and sanitation) to enable efficient, equitable and client-oriented provision of reliable and safe water at affordable prices to users and viable costs to providers.

An enhanced management and demand-oriented focus is required. To meet both these challenges, India will have to implement a shift from development (i.e., additional extraction activities) to management of water resources, or from supply-oriented to demand-oriented approaches. The combination of challenges now emerging necessitates a broad-based approach to water management, which needs to focus on the inter-linked hydrologic and use systems as a whole rather than primarily on supply-side aspects. To date, most responses to water scarcity or intersectoral competition have generated supply-side solutions such as rationing or reallocation of water by expropriation. Management responses to groundwater overdraft, for instance, have focused on groundwater recharge and attempts to regulate extraction. Although recharge activities are important and should be enhanced, they represent an extremely limited aspect in a much broader array of potential interventions. On the supply side, conjunctive 'management' or augmentation approaches involving the operation of surface systems can improve the availability of both ground and surface water.

Enhanced management focus and additional development needs should be balanced. Improvements in irrigation efficiency, encouragement of municipal and industrial water conservation, efficiency improvements and reuse, and introduction of value-based allocation and reallocation mechanisms between sectors and states, need to be central objectives of the new approach. the emphasis on management needs does not, however, imply that surface and groundwater resources in India are fully developed. Additional development and extraction in certain regions or locations, could still be supported. However, even in these localities, the inclusion of significant development activities must now be balanced by enhanced management mechanisms to establish a sustainable utilization of surface and groundwater resources.

Water should be treated as both a social and economic good. In addition to enhanced management focus, there will also have to be a shift from viewing water as a fully social resource to accepting it as an economic good. There will thus need to be greater use of market mechanisms and participation of private sector actors, in order to achieve a more efficient and effective allocation, use and management of water. The nature of water as both a public as well as private good, however, precludes the exclusive application of market-based mechanisms to the development, use and management of water.

There is a need to clarify appropriate roles for the public and private sectors. Activities in the sector will need to be divided between the public and private sectors. While the private sector should increasingly take over many of the responsibilities or activities currently handled by the government, the government will need to retain responsibility for certain activities to ensure that social and environmental considerations are properly incorporated in sector investments, operations, transactions and management. The presence of certain characteristics interrelate to determine whether a water sector activity should appropriately be transferred to the private sector or retained by government. The private sector will be discouraged from participating, if the investment or initial costs of doing so are high, or if transaction costs (such as the costs of collecting water bills from individual households) are high. In such cases the government would need to step in. In situations in which significant spillover advantages or disadvantages exist from engaging in an activity, or in which the activity is critical for livelihoods or other social objectives, the private sector will not be as effective as the public sector in addressing these concerns.

In general, provision of network facilities (especially primary level networks), investment planning, and monitoring and regulatory activities, are largely public goods and hence should be handled by the government. Other activities such as generation and maintenance of services from the networks can be subject to a degree of competitive market forces by inclusion of the private sector thorough investment or management contracts.

Decentralization of operations will be critical. Achieving sustainable use and management of water in India will further require a shift from the traditional top-down, centralised approach towards a more decentralized and participatory approach. While government has an important role to play, it is only one among many stakeholders involved. These stakeholders include every household in India as a consumer of water, all of India's farms, commercial entities and industries, and larger community aggregates such as water users associations, villages, associations of industries, etc. Even within the government, the state or central level institutions are only at the apex of an array of more local institutions: panchayats, block and district administrations, municipalities, etc. The more central government agencies, both at state and central levels, are not the directly concerned stakeholders. They are not directly accountable, are too far from the action to be effective at grass-roots levels, and do not have the staff or financial capacity to be deeply involved at micro levels.

Sector stakeholders will need to be fully engaged in sector activities. All stakeholders, including local level administrations, water user groups, and grass-roots organisations should be involved maximally in decision-making and implementation. Government has, to day, held almost exclusive responsibility for all decision-making, investment and management in the water sector. As a result, civil society institutions in the water sector are weakly developed or non-existent. Local government administrations, such as the relatively recently activated panchayat (village level) institutions, are also still fragile and require progressive strengthening. Fostering such formal or informal institutions is a matter of urgency and will require energetic actions by government, including capacity building, transparency of information and public awareness.

## 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.

### 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, DamodarValley, Nagajunasagar, RajasthanCanal 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:

**Table 6** actual utilization upto Seventh Plan

| 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<br>Say 50 m ha m |

## 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 7.

**Table 7 : 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 |
| 3. | Domestic & Live Stock | 16.70 | | 28.70 | | 40.00 | |
| 4. | Industrial | 10.00 | | 30.00 | | 120.00 | |
| 5. | Thermal Power | 2.70 | | 3.30 | | 4.00 | |
| 6. | Miscellaneous | 40.60 | | 58.00 | | 116.00 | |
| | **Total** | **540.00** | | **750.00** | | **1050.00** | |

## 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.

**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 $= \dfrac{(N+1)*75}{100} = \dfrac{(39+1)*75}{100} = 30$

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:

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

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.

## 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.

## 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.

### 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:

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

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

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

**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:

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

where, $R_r$ = natural recharge from precipitation
$R_c$ = recharge due to seepage from rivers, canals, water courses, ponds, reservoirs, etc.
$R_I$ = 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

**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:

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

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:

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

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, $E$ = evaluation 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),

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

## 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.

### 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

**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

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## 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.

## EDUCATION AND TRAINING IN HYDROLOGY AND WATER RESOURCES

The main motivation for the study of hydrology in the past was to improve technologies for the development of water resources. It has tended to follow problem solving approach of engineering profession mostly based on imperical relationship, without the application of established principles natural sciences. The major inadequacies of present day hydrology may include: (a) methodologies defficiencies, (b) slowness and unevenness of the advance of scientific knowledge of hydrology through research and (c) the slow diffusion of knowledge from research to practice.

The International Hydrological Decade (1965-75) was launched by the General Conference of UNESCO at its thirteenth session to promote international cooperation in the field of hydrological research and education as ameans for achieving a fuller assessment of the world's water resources and their more rational use. In 1972, the General Conference decided to continue and develop the basic objectives of the Decade within the frame work of a long term International Hydrological Programme which started in 1975. This provided a strong impetus for growth of hydrological education and a number of postgraduate courses in hydrology and in water resources development were instituted at a number of universities throughout the world, with the support and sponsorship of UNESCO and WMO.

In India there is very less or no education at primary level in the area of hydrology. Also at graduate level it is being taught as a part of irrigation subject in the final year of civil engineering. Thus, when a young engineer, who joined the department, is asked to do a design, the lack of proper knowledge many times comes in his way. Likewise, observers and technicians posted at various sites for hydrological data collection and measurement are also untrained. At postgraduate level also there are less facilities existed to impart training in the field of hydrology. To improve the status of hydrology in the country different levels of education and training can be broadly categorised as follows:

(i) Basic hydrology training
(ii) Hydrological technicians and observers training
(iii) Professional hydrologist training and
(iv) Research hydrologist training

There is a urgent need to introduce an introductory chapter on hydrology at primary levels at the school level. Chapter may include in simple language different aspects of hydrologic cycle. Also it has been recommended by various experts that at least one to one and half unit course on hydrology must be included at under graduate level at all the engineering colleges.

In India post graduate training course in hydrology is being organised by Department of Hydrology, IIT, Roorkee and Water Resources Engineering, Anna University, Madras. Also WRDTC at IIT, Roorkee is providing masters degree in water resources. Other institutions like IIT, Kharagpur, Madras, Bombay and Delhi, AndhraUniversity, Waltair, Bihar College of Engineering, Patna, M R Engineering College, Jaipur and a number of engineering colleges and Agriculture universities also provide facilities for post graduate programmes with the subjects dealing with the areas of water resources and water management and hydrology.

For accurate data collection and measurement it is important that a person who is collecting the data must be well aware of the importance of this data and must know the correct way of its measurement and handling. Under IHP (IV) programme of UNESCO some training coureses for technicians and observers were organised. Some state governments and WALMIs are also providing training to these personnels.

Professional hydrologists or field engineers are responsible for carrying out planning, design, construction and operation of water resource projects. They must be well aware of most common modern techniques prevelent in the area of hydrology. Some training workshops for field engineers covering different topics are being organised by National Institute of Hydrology and Central Water Commission. Also NWDA, CWPRS and state water resources department have also organised some training courses.

The role of research hydrologist is to develop new techniques of observation, analysis and design as well as to undertake basic studies of a scientific nature. Full facilites and suitable data base is necessary for carrying out research studies. Apart from it, an interaction between research hydrologists and field engineers is a must for use of developed technology in the field.

In order to meet the needs of short term and long term plans for water resources development in the country, creation of suitable mechanism for education and training of hydrologists is not only necessary at degree and post-graduate level but also at junior levels, i.e. overseer, technician, obserevr etc. Adequate trained manpower is necessary to improve the capabilities of operational organisations in the centre and in the states in regard to observation as well as primary and secondary processing of hydrological data. With a few exceptions, hydrological and hydrometric units are staffed with generalists who are not given specific training in the subject. Since there are few specilists, standards expected from supporting staff, such as technicians and obserevrs, tend to be low and "on the job" training is generally ineffective.

To overcome above deficiency Hydrology Project with the assistance of World Bank has come up with training as one of the major component. The aim of the project is to strengthen the training and research programmes which may include the following:

(i) Basic course for Observers
(ii) Training for supervisors
(iii) Advanced level/refresher courses for senior staff
(iv) Basic computer and data entry training
(v) Advanced computer course for databas supervisiors
(vi) Study tours within India
(vii) Postgraduate training in India
(viii) Overseas study tours/training

## ORGANISATIONS DEALING WITH HYDROLOGY AND WATER RESOURCES

State Remote Sensing Centre
State Irrigation Departments
State Pollution Control Boards
Engineering Colleges
Indian Institute of Technologies
Agriculture Universities
State WALMIs
State CDOs
Jawaharlal Nehru Technological University, Hyderabad
India Meteorological Department, New Delhi
Central Ground Water Board, Faradibad

Central Water Commission, New Delhi
National Water Development Agency, New Delhi
Narmada Control Authority, New Delhi
Bharamputra Board, New Delhi
National Informatic Centre, New Delhi
Water Technology Centre, IARI, New Delhi
World Bank, New Delhi
UNESCO, New Delhi
CSMRS, New Delhi
WAPCOS, New Delhi

Ministry of Agriculture, New Delhi
Ministry of Urban Development, New Delhi
Ministry of Transport, New Delhi
Ministry of Railways, New Delhi
Ministry of Water Rsources, New Delhi
Ministry of Power, New Delhi
Indira Gandhi National Open University, New Delhi

Nuclear Research Laboratory, New Delhi
Central Pollution Control Board, New Delhi
Tata Energy Research Institute, New Delhi
Ganga Flood Control Commission, New Delhi
WALAMTARI, Hyderabad
Indian Institute of Tropical Meteorology, Pune
North-Eastern Research Institute for Water & Land Management, Tezpur

Andhra Pradesh Engineering Research Laboratory, Hyderabad
National Remote Sensing Agency, Hyderabad
National Geographical Research Institute, Hyderabad
Central Water & Power Research Station, Pune
Central Training Unit (CWC), Pune
Maharashtra Engineering Research Institute, Nasik
Bhabha Atomic Research Centre, Bombay
Bureau of Indian Standards, New Delhi
National Environmental Engineering Research Institute, Nagpur
Indian Institute of Science, Banglore
All India Soil and Land Use Survey, Nagpur

National Institute of Hydrology, Roorkee
Irrigation Research Institute, Roorkee
Indian Institute of Remote Sensing, Dehradun
Birla Institute of technology and Science, Pilani
NVDA, Bhopal
Space Application Centre, Ahmedabad
Indian Space Research Organisation, Bangalore
Physical Rearch Laboratory, Ahmedabad

Gujarat Engineering Research Institute, Vadodara
Institute for Water Studies, Madras
Institute of Hydraulics and Hydrology, Poondi, Madras
Anna University, Madras
Jawaharlal Nehru University, New Delhi
Centre for Water Resources Development & Management, Kozhikode (Kerala)
Water Technology Centre (ICAR), Bhubneshwar
Damodar Valley Corporation, Maithon
Bhakara Beas Management Board, Chandigarh
Central Soil Salinity Research Institute, Karnal

Indian Association of Hydrologists, Roorkee
Indian Water Resources Society, Roorkee
Institution of Engineers, Calcutta
Bhagirath (CWC) New delhi
INCOH (NIH), Roorkee
ARCCOH (NIH), Roorkee
MAUSAM (IMD), New Delhi

## 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.

The uneven spatial and temporal distribution of the precipitation in India, results in highly uneven distribution of available water resources and leads to floods and drought affecting vast areas of the country. In addition to focusing on the agricultural needs of water, equal emphasis is to be laid on management of floods and droughts. Mitigation of floods and special needs of drought prone areas will continue to require due attention in future and development plans will need to address these issues. Suitable models are needed for forecasting the monsoon rainfall accurately, which may be utilized by the decision makers and farmers for adopting appropriate strategies for management of droughts and floods. For increasing the availability of water resources, there is a need for better management of existing storages and creation of additional storages by constructing small, medium and large sized dams considering the economical, environmental and social aspects. The availability of water resources may be further enhanced by watershed management, improving efficiency of irrigation, rejuvenation of dying lakes, ponds and tanks and increasing the artificial means of ground water recharge. Integrated and coordinated development of surface water and ground water resources and their conjunctive use should be envisaged right from the project planning stage and should form an integral part of the project implementation. Some of the important measures which may be taken up for sustainable development of groundwater resources include improving public water supply, use of energy pricing and supply to manage agricultural groundwater draft, increasing rain-water harvesting and ground water recharge, transfer of surface water in lieu of groundwater pumping, increasing the economic growth and reduction in dependence on agriculture and formalizing the water sector. In addition to these measures, inter-basin transfer of water provides one of the options for mitigating the problems of the surplus and deficit basins. However, for inter-basin transfer of water the scientific studies need to be carried out for establishing its technical and economic feasibility considering the environmental, social and echo-hydrological aspects.

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.

The available information and data collected so far by different operational and field organizations, scientific groups and engineering community are inadequate for planning, development and management of the vast water resources in the country. Thus, a comprehensive, reliable and easily accessible Information System for water resources data is a pre-requisite. The efforts made in the World Bank aided Hydrology Project – I, are important steps in this direction. The DSS and design aids are required to be developed for planning, development and management of the water resources projects. For predicting the future climatological variables on micro, meso and macro watershed scales, a comprehensive general circulation model coupled with the physically based hydrological model is required to be developed for India. The movement of pollutants in the rivers, lakes and ground water aquifers needs to be regulated. A regular water quality monitoring programme has to be launched for identifying the areas likely to be affected because of the water quality problems. For maintaining the quality of freshwater, water quality management strategies are required to be evolved and implemented. Minimum flow should be maintained in the rivers for meeting the criteria of EFR. The eco-hydrological approach based on the concepts of blue and green waters may be considered as an integral part of the water resources management practices. Also, the concept of virtual water transfer requires to be introduced at policy level for food trade, water management and agriculture. There is a need for greater inter-state cooperation for integrated development of water resources. Water resource will have to be planned, developed and managed with an integrated approach keeping national perspective in view, which calls for a more effective and proactive role to be played by the central and state governments. The capacity building and awareness programmes should be organised for the users and public for encouraging their effective participation in water management practices and developing ethical concepts for making efficient use of water resources.

## BIBLIOGRAPHY

C.W.C., 1987. *Water Resources of India*. New Delhi.

Maidment, D.R., 1993. *Handbook of Hydrology*. McGraw Hill, Inc., New York.

Mutreja, K.N., 1986. *Applied Hydrology*. Tata McGraw-Hill Publishing Company Limited, New Delhi.

N.I.H., 1989. *Flood Estimation by Unit Hydrograph Techniques*. Workshop Course Material.

Ponce, V.M., 1989. *Engineering Hydrology - Principles and Practices*. Prentice Hall, Englewood Cliffs, New Jersey 07632.

Rodda, J.C., 1976. *Facets of Hydrology*. John Wiley & Sons Ltd., London.

Singh, V.P., 1992. *Elementary Hydrology*. Prentice Hall, Englewood Cliffs, NJ 07632.

World Bank, 1998. India Water Resources Management Sector Review Initiating and Sustaining Water Sector Reforms. Report No 18356-IN, Sept.

Bose, D. and Saxena, N. (2001) Monsoon, Employment News, XXVI, No. 8.

Central Ground Water Board (CGWB) (1995) Ground Water Resources of India, Central Ground Water Board, Govt. of India, New Delhi.

Chandra, S. (1987) Planning for integrated water resources development project with special reference to conjunctive use of surface & groundwater resources, Central Ground Water Board, New Delhi.

Chowdhary, H., Jain, S. K. & Ogink H. J. M. (2002) Upgrading a Conventional Hydrological Information System – An Indian Example. *FRIEND 2002—Regional Hydrology: Bridging the Gap between Research and Practice* (Proceedings of the Fourth International FRIEND Conference held at Cape Town, South Africa, March 2002). IAHS Publ. No. 274, pp. 35–42.

Dawoud, M.A. & Allam, A.R. (2004) Effect of new Nag Hammadi Barrage on groundwater and drainage conditions and suggestion of mitigation measures, *Wat. Resour. Manage.*, 18(4), 321-337.

Gates, T.K., Burkhalter, J.P., Labadie, J.W., Valliant, J.C. & Broner, I. (2002) Monitoring and modeling flow and salt transport in a salinity threatened irrigated valley, *J. Irrig. Drain. Engng. ASCE*, 128(2), 87-99.

Gupta, S.K., & Deshpande, R.D. (2004) Water for India 2050: First Order Assessment of Available Options. Current Science, 86(9), 1216-1224.

International FRIEND Conference held at Cape Town, South Africa, (2002). IAHS Publ. No. 274, pp. 35–42.

Intergovernmental Panel for Climate Change (IPCC) (2001) Climate Change, The science of climate change, Assessment Report of IPCC Working Group I [Houghton, J.T. et al. (eds.) and WMP/UNEP, Cambridge University Press, Cambridge.

Intergovernmental Panel for Climate Change (IPCC) (1998) The regional impacts of climate change: an assessment of vulnerability. A special report of IPCC Working Group II, [Watson, R.T. Zinyowera, M.C. & Moss, R.H. (eds)]. Cambridge, University Press, UK, pp. 517.

Indian Water Resources Society (IWRS) (1996) Theme paper on Inter Basin Transfers of Water for National Development - Problems and Prospects. Indian Water Resources Society, Roorkee.

Indian Water Resources Society (IWRS) (1998) Theme Paper Five Decades of Water Resources Development in India. Indian Water Resources Society, Roorkee.

Indian Water Resources Society (IWRS) (2001) Theme paper on Management of floods and droughts, Indian Water Resources Society, Roorkee, India, pp. 4-12.

Jain, S.K., Sharma, A. & Kumar, R.(2004)Freshwater and its management in India. International Journal of River Basin Management, U.K., Vol. 2, No.3, pp. 1-12.

Jeyaseelan, R. (2005) Water resources management problems of India. International Symposium on Recent Advances in Water Resources Development and Management. Dept. of Water Resources Development and Management, IIT, Roorkee, Nov. 23-25.

Kumar, Singh, & Sharma, K.D. Sharma (2005) Water resources of India. Current Science Journal, Vol. 89, No. 5, September.

Lal, M., (2001) Climate Change – Implications for India's Water Resources. J. of India Water Resources Society, 21, 3, July, pp. 101-119.

Lazaroff, C., Hidden (2000) Ground water Pollution Problem Runs Deep, Environment News Service, Worldwatch Institute, Washington, DC.

Nagaraj, N., Marshall Frasier, W., & Sampath, R. K. (1999) A Comparative Study of Groundwater Institutions in the Western United States and Peninsular India for Sustainable and Equitable Resource Use. Department of Agricultural and Resource Economics, Colorado State University, Fort Collins, Colorado, USA.

National Water Policy (2002), Ministry of Water Resources, Government of India.

National Council for Integrated Water Resources Development (NCIWRD) (1999) Integrated Water Resources Development – A Plan for Action. Report of The National Commission for Integrated Water Resources Development. Govt. of India, Ministry of Water Resources, New Delhi.

National Natural Resources Management System (NNRMS) (2002) Flood risk zoning using satellite based remote sensing, Ministry of Water Resources, Govt. of India.

Padma T. V. (2004) India unveils new monsoon forecast model. Source: Sci. Dev. Net, http://www.clivar.org/recent/monsoon_forec2.htm.

Pant, G.B. & Kumar, K.R. (1997) Climates of South Asia, John Wiley & Sons Ltd., West Sussex, UK., 320 pp.

Raghuvanshi, C.S., M. Chandra & Raghuvanshi, T.K. (1990) Socio-economic impact of waterlogging – A critique of mismanagement of surface irrigation. Proceedings of All India Seminar on Waterlogging and Drainage, Roorkee.

Rao, K L. (1973) India's Water Wealth. Orient Longman Limited, New Delhi.

Rashtriya Barh Ayog (1980) Report Vol. 1. Ministry of Energy and Irrigation, Govt. of India.

Renault D. (2002) Value of virtual water in food: Principles and Virtues. Paper presented at UNESCO-IHE, Workshop on Virtual Water Trade, Dec. 12-13, Delft, the Netherlands.

Rosegrant, M. & Ringler, C. (1999) Impact of food security and rural development of reallocating water from agriculture. IFPRL. Washington DC.

Scot, C.A., Shah, T. & Beuchler, S.J. (2003) Lessons from Maxicon agriculture. Anand, India, IWMI-TATA, Water Policy Research Highlight 3.

Seth, S.M. (2000) Integrated water resources management – role of research and development in hydrology. Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, New Delhi. Organized by National Institute of Hydrology, Roorkee.

Shah, T. (2005) Groundwater and human development: Challenges and opportunities in livelihoods creation and environment. Lecture delivered during the Workshop on Creating Synergy between Groundwater Research and Management in South Asia, National Institute of Hydrology, Roorkee, India, 7-9 February.

Water Management Forum (WMF) (2003) Inter-basin transfer of water in India – Prospects and Problems. New Delhi, February, Water Management Forum. The Institution of Engineers (India).