HYDROLOGICAL CYCLE, DATA COLLECTION AND PROCESSING

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1.0 HYDROLOGY

The term Hydrology refers to the Science of water. In a broad sense, the Hydrology can be defined as an Applied Science, which links Atmosphere, Hydrosphere, Lithosphere and Biosphere. The Science of Hydrology includes the scientific examination and appraisal of the whole continuum of a hydrologic, or water cycle. To define hydrology as a science as distinguished from the application of Science-in-general to problems of water resources assessment and management, Ad Hoc panel on Hydrology of the Federal Council for Science and Technology (established by the President of the United States in 1959) recommended the following definition: "Hydrology is the Science that treats of the waters of the Earth, their occurrence, circulation, and distribution, their physical and chemical 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".

1.1 Hydrologic Cycle

Hydrologic cycle is the descriptive term applied to the general circulation of water from the sea to atmosphere, to the ground, and back to the seas again. It has no beginning or end, as water evaporates from the oceans and the land and becomes a part of the atmosphere. The evaporated moisture is lifted and carried in the atmosphere until it finally precipitates to the earth. The precipitated water may be intercepted or transpired by plants, may run over the ground surface and into streams or may infiltrate into the ground. The intercepted and transpired water and the surface runoff return to the air, through evaporation. The infiltrated water may percolate to deeper zones to be stored as groundwater, which may later flow out as springs or seep into streams as runoff (base flow) and finally evaporates into the atmosphere to complete the hydrologic cycle. Thus, the hydrologic cycle undergoes various complicated processes of evaporation, precipitation, interception, transpiration, infiltration, percolation, storage, and runoff.

The hydrologic cycle is driven by the energy of the sun and the gravity of the earth, and proceeds endlessly with or without human intervention. Also referred to as the "water cycle", the hydrologic cycle is actually made up of a series of complex processes and storages.

Processes refer to how we describe the movement of water between the various storage components:

- Surface runoff
- Infiltration, groundwater recharge
- Discharge
- Groundwater flow

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It can involve a change in phase:

- Precipitation (vapor to liquid or solid)
- Evaporation and transpiration (liquid to vapor)
- Condensation (vapor to liquid)

Schematic presentation of the hydrologic cycle often lump the ocean, atmosphere, and land areas into single component. Yet another presentation of the cycle is one that portrays the various moisture inputs and outputs as a basin scale, as shown below.

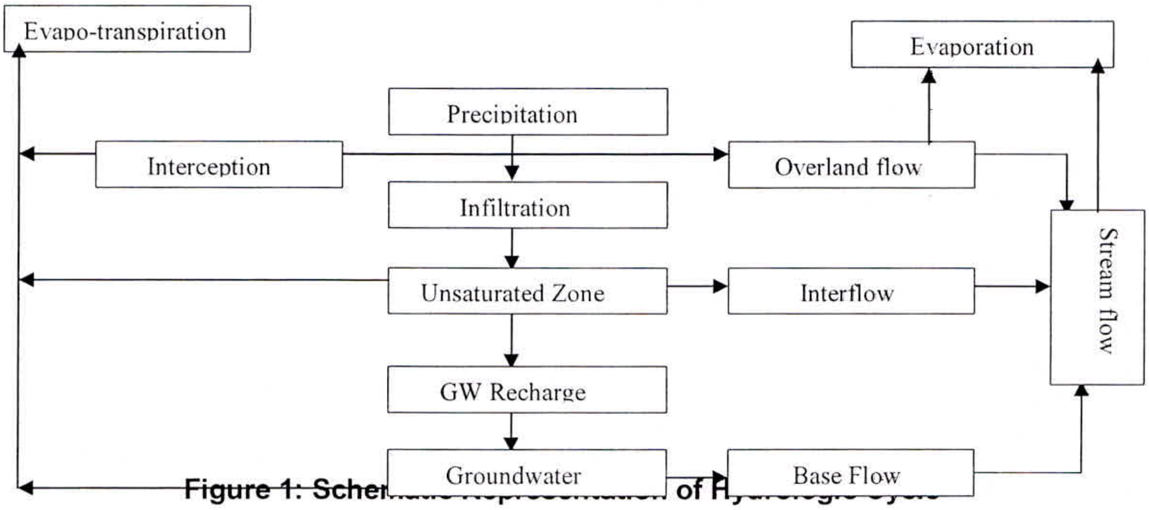
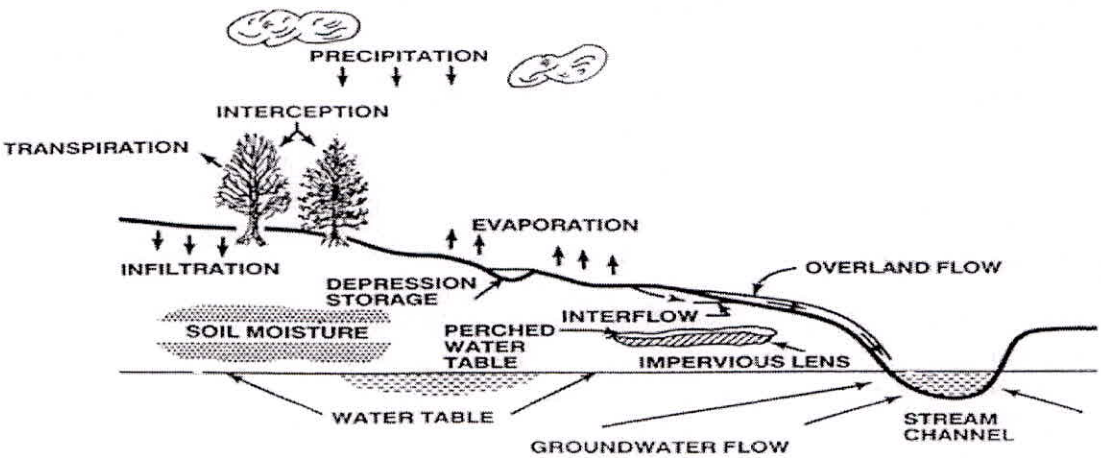


Figure 1: Schematic Representation of Hydrologic Cycle



Major pathways of precipitation and the runoff phase of the hydrologic cycle.

1.2 Major Components Of Hydrologic Cycle

1.2.1 Precipitation

It is the primary source of fresh water supply and its records are the basis of all water resources development and management projects. Precipitation from the atmosphere to the earth's surface will only occur under certain conditions. The conditions necessary are:

- cooling of the incoming air until it is supersaturated with water vapour,
- condensation (conversion of water vapour to liquid water in the form of cloud droplets), which requires the presence of tiny nuclei, and
- coalescence of water droplets to form particles which are large enough to fall to the ground as rain or snow.

Cooling of moist air to a sufficient extent to produce condensation in appreciable amounts occurs when the air is lifted. Rainfall can be classified according to the lifting mechanism into;

- Orographic rain, where the lifting is due to flow over a mountain barrier,
- Frontal rain (Cyclonic storms, movement is from high to low pressure area), where the lifting is due to the relative movement of two large air masses (warm air over cold air), and
- Convective rain (thunderstorms), where the lifting is due to local heating of the ground and violent uplift of air over a localized area.

Drizzle, rain, glaze, sleet, snow, hail, etc. are some of the forms of precipitation.

The aerial or spatial distribution of precipitation is related to meteorological and topographical factors. Rainfall is recorded using a network of rain gauges and is usually recorded on a daily basis and in certain cases in an hourly basis. Rainfall is measured as the vertical depth of water that would accumulates on a flat level surface, if all the precipitation remained where it had fallen. Rainfall can be measured using an ordinary raingauage, automatic recording raingauge, radars, remote sensing, etc. Rainfall data can be defined in terms of depth, intensity, duration, time distribution rainfall (hyetograph), and return period.

Average rainfall over a specified area (river basin, taluk, district, state, etc.) can be computed from the point rainfall observations by, arithmetic average method, Theissen polygon method, isohyetal method, etc.

1.2.2 Infiltration

Infiltration is the movement of water into the soil through the surface of the ground. When rain falls after a long dry spell, infiltration occurs initially at a high rate. But, as the rain continues, the rate of infiltration decreases and ultimately reaches a constant value. Infiltration is one of the important components of the hydrologic cycle, since it divides the rainfall into runoff and groundwater.

Infiltration depends largely on the properties and state of the soil, ground cover, topography, intensity and duration of precipitation, etc.

It is one of the most difficult elements of the hydrological cycle to quantify. It can be measured in the field using infiltrometers, permeameters, or rain simulators.

A curve denoting infiltration rate or cumulative depth of water infiltrated against time is called an infiltration curve. Horton (1933) established an exponential relation between the rate of infiltration and time, the infiltration rate being maximum f_0 to start with, falling off to a constant rate f_c. The infiltration capacity curve satisfies the equation

$$f_t = f_c + (f_0 - f_c)e^{-kt}$$

f_t = infiltration rate at time t
f_0 = initial infiltration rate at time 0
f_c = final infiltration rate
k = constant, depending on soil and vegetation

1.2.3 Percolation

Part of the infiltrated water flows laterally (subsurface flow or interflow) through the unsaturated soil zone and reaches shallow streams or other storages. Percolation denotes the movement of water to the deeper saturated zone through unsaturated zone, where it reaches the groundwater. Percolation depends on the characteristics of unsaturated zone such as porosity, permeability (hydraulic conductivity), moisture condition, etc.

Unsaturated (Vadose) zone is the link between surface and underground hydrologic processes. It also controls the amount of precipitation that enters the soil or remains on the surface. The water in this zone can remain in storage, move downwards by gravity to the groundwater, or move upwards through evaporation or transpiration. In the vadose zone, some pores contain water, some are partially filled, and some are empty. The space not occupied by water is filled by air. This zone acts as a reservoir containing water for vegetation growth, and as a conduit for water moving down to recharge groundwater.

A complete evaluation of water in soil requires knowledge of the energy status of water in soil. The energy status of water is expressed through soil-water potential. The total-soil water potential is formally defined as the mechanical work required to transfer water from soil to a standard reference state, where the total soil-water potential is zero by definition. In soil science and hydrology, soil-water potential is mostly expressed in energy/volume (J/m^3; bar) or energy/ weight (head, cm or m).

There is a relationship between the amount of water held in soil and its energy status. This relationship is unique for each soil and is called as the soil-water characteristic curve or soil-water retention curve. Two points on the water retention curve are of special interest. They are Field Capacity (FC) and Permanent Wilting Point (PWP). When the soil moisture content of a layer reaches the point at which the force of gravity acting on the water equals the surface tension, gravity drainage ceases. The soil moisture content is the field capacity of the soil. It is the maximum amount of water that the unsaturated soil can hold against gravity. In other literature, field capacity is often defined as the water held at 333 cm (0.3 bar) tension. If the soil moisture drops too low, the remaining moisture is too tightly bound to the soil particles for the plant roots to withdraw it. The permanent wilting point is the soil-water condition at which movement of soil water to plant root is too slow to keep up with transpiration losses, and plants do not recover upon wilting. The permanent wilting point is different for different soils and is generally taken around 15,000 cm (15 bar). The wilting-point moisture content is greater for fine textured soils owing to their greater surface area.

Soil moisture status of the vadose zone can be determined by gravimetric method, using tensiometers, neutron probes, etc. The soil water retention curve for different soils can be estimated in the laboratory using a pressure plate apparatus.

1.2.4 Runoff

This is the most important component of the hydrological cycle, which forms the major part of the water resources available for the use, apart from the under ground water resources. When the rate of rainfall exceeds the interception and infiltration rates, water starts accumulating on the ground and then to move down the slope as overland flow. Depending on the soil conditions and topography, overland flow changes into flow through small rills and gullies and joins together to form small streams. Runoff depends on the physical characteristics of drainage basin (such as area, shape, elevation, slope, drainage network, soil, land use, etc.)

Total runoff can be roughly estimated by subtracting the losses (infiltration and evaporation) from the amount of rainfall. Total runoff through a stream can be divided into surface runoff and base flow.

Continuous river gauge-discharge monitoring has to be performed to get an idea of the total discharge flowing past a river cross section. This can be done in a daily basis or continuously using an automatic recorder. Time distribution of discharge is called a hydrograph.

Discharge can be estimated using empirical formulae developed by various investigators for different regions/river basins. Many mathematical models are presently available, which predicts runoff from the rainfall records and catchment characteristics. Unit hydrograph, synthetic hydrograph, etc. are the runoff estimation methods using hydrograph approach.

1.2.5 Evaporation

Evaporation is the process by which a liquid is changed to vapour. Evaporation takes place from a water surface when the atmosphere above it has a relative humidity less than 100 %. The prime energy source for evaporation from water is solar radiation. It depends on the wind speed, degree of turbulence in the air, as well as the vapour pressure difference between the water surface and air.

Transpiration is the process by means of which water passes through a living plant into the atmosphere as water vapour. A plant transpires during the growing season and it is an important component in the hydrologic cycle in vegetated areas.

The term evapo-transpiration is often used to indicate the combined effect of water evaporated from the soil surface and transpired from the soil moisture storage through plants.

Apart from mathematical expressions to compute evaporation (by knowing the temperature, vapour pressure, solar radiation, wind speed, etc), field measurement of evaporation is done as the evaporation from pans of standard size. Evapo-transpiration can be measured using Lysimeters.

1.2.6 Groundwater Flow

It is the water contained in the saturated zone of soil. Water bearing formations of the earth's crust act as conduits for transmission and as reservoirs for storage of groundwater. It results from water that infiltrates from the ground surface and percolates to the underlying saturated strata. The geologic formations control the occurrence, movement, quality and availability of groundwater.

The water existing in the soil is called subsurface water and is of two kinds: soil water and groundwater. The zone in which soil water occurs is called the unsaturated zone or vadose zone or zone of aeration, and the zone in which groundwater occurs is the saturated zone. The water table (phreatic surface) separates the saturated and unsaturated zones. The pressure at the water table is atmospheric. The water table level will fluctuate and may be directly related to precipitation. Porosity and permeability of the underlying strata is the controlling factor for the storage and movement of groundwater.

The zone of saturation consists of rocks with different water bearing and water yielding properties. Aquifers are geological formations, which are sufficiently porous to store large quantities of water and permeable enough to transmit it in quantities that can be economically exploited. Aquicludes are low permeability formations which contains water, but incapable to transmit significant quantities. Aquitard is a low permeability geologic formation, which contains water and can transmit it slowly from one aquifer to another. Aquifuge is an impermeable unit, which can neither contain nor transmit water.

An aquifer may be roughly divided into two major categories: unconfined aquifers and confined aquifers. Unconfined aquifers, also known as phreatic or water table aquifers, are characterised by an upper unsaturated zone and a lower saturated zone. When a well is drilled or dug into the saturated zone of an unconfined aquifer, water will flow into it and settle at a level, which marks the boundary between saturated and unsaturated zones, which is called water table.

A confined aquifer, also called an artesian or pressure aquifer consists of saturated porous materials, such as sands and gravel, which are sandwiched between two formations of low permeability. They usually occur at a depth, and tend to be relatively well protected from contamination. An example would be sand and gravel aquifers, sandwiched between two impermeable clay strata. Water in a well penetrating such an aquifer will rise above the base of the upper confining formations; it may or it may not reach the ground surface. The water levels in a number of wells or piezometers, penetrating a confined aquifer are the hydrostatic-pressure levels of the water in the aquifer at the well sites. These water levels define an imaginary surface called the piezometric or potentiometric surface. If the piezometric surface is above ground level, the confined aquifer will yield a flowing well.

The hydrologic equation based on the law of conservation of matter, as applied to the hydrologic cycle, defines the total water balance. Groundwater balance deals with aspects of balancing various components of groundwater recharge and discharge, with storage changes in the groundwater basin. It states that all water entering a system during any period of time should either go into storage within its boundaries or leave the system during the same period, and a balance is obtained.

Many of the streams and lakes are fed by groundwater during lean periods. This can be extracted to augment surface water resources. The study of hydrologic cycle would not be complete without an understanding of the exchanges of water between ground and surface supplies.

1.3 Water Availability

According to the estimates made by various authors, 97 per cent of all the water in the world exists in the oceans. If the world were a uniform sphere, this quantity would be sufficient to cover it to a depth of 800 ft. Total amount of fresh water is distributed roughly as follows. 75 per cent in polar ice and glaciers; 14 per cent in ground water between depths of 2,500 and 12,500 ft; 11 per cent in ground water at depths less than 2,500 ft; 0.3 per cent in lakes; 0.06 per cent as soil moisture; 0.035 per cent in atmosphere; and 0.03 per cent in rivers. These are, however, stationary estimates of distribution. While the water content of the atmosphere is relatively small at any given moment, immense quantities of water pass through it annually. The annual precipitation on land surfaces alone is 7.7 times as great as the moisture contained in the entire atmosphere at any one time, which is about 30 times as great as the moisture in the air over the land. The mean annual precipitation for the entire earth is about 86 cm/year, which under stationary conditions is balanced by an equally large evaporation amount. Thus, the average evaporation for the whole earth amount to 2.37mm of water per day. The availability of global water resources and water resources of India is briefly described here under. The relative quantities of the earth's water contained in each of the phases of the hydrologic cycle are presented in Table 1.

Table 1.Quantities of Water in the Phases of the Hydrologic Cycle (UNESCO, 1978)

Sl. No.	Item	Volume cu. Km	Percent of total water	Percent of fresh water
1.	Oceans	1,338,000,000	96.5	
2.	Groundwater Fresh Saline	 10,530,000 12,870,000	 0.76 0.93	 30.1 -

3.	Soil moisture	16,500	0.0012	0.005
4.	Polar ice	24,023,500	1.7	68.6
5.	Other ice and snow	340,600	0.025	1.0
6.	Lakes Fresh Saline	 91,000 85,400	 0.007 0.006	 0.26 -
7.	Marshes	11,470	0.0008	0.03
8.	Rivers	2,120	0.0002	0.006
9.	Biological water	1,120	0.0001	0.003
10.	Atmosphere water	12,900	0.001	0.04
11.	Total water	1,385,984,610	100	-
12.	Fresh water	35,029,210	2.5	100

Table 2: Major Hydrologic Cycle Components – Continental break-up (Lvovich, 1973)

Regions	Area (10^6 sq. km)	Precipitation (mm)	Runoff (mm)	Evaporation (mm)
Europe	9.8	734	319	415
Asia	45.0	726	293	433
Africa	30.3	686	139	547
N. America	20.7	670	287	383
S. America	17.8	1648	583	1065
Australlia	8.7	736	226	510

The amounts of evaporation, precipitation, runoff, and other hydrologic quantities are not evenly distributed on the earth. About 70 to 75 per cent of the precipitation is returned to the atmosphere by evapotranspiration and direct evaporation, while the remaining 30 per cent becomes runoff. About one-fourth of the runoff is diverted. About two-thirds of that diverted is fed back into the stream and eventually goes to oceans for storage and evaporation, and the remaining one-third is consumed and returns to the atmosphere directly.

1.4 Water Resources of India

India with a geographical area of 3.29 million square kilometers receives annual precipitation of about 4000 cubic kilometers, including snowfall (average annual rainfall of about 114 cm). Out of this, seasonal rainfall is of the order of 3000 cubic kilometers. Rainfall in India is dependent in differing degrees on south-west and northeast monsoon, on shallow cyclonic depressions and disturbances and on violent local storms which form in regions where cool humid winds from the sea meet hot dry winds from the land and occasionally reach cyclonic dimension. Most of the rainfall in India takes place under the influence of south-west monsoon between June to September except in Tamil Nadu, where it is under the influence of north-east monsoon during October and November. The long-term average annual rainfall for the country is 1160 mm, which is the highest anywhere in the world for a country of comparable size. However, it shows great variations, unequal seasonal distribution, still more unequal geographical distribution and frequent departures from the normal.

Recently, the National Commission for Integrated Water Resources Development (NCIWRD) has estimated the basin-wise average annual flow in Indian river systems as 1953 km^3 and the utilizable annual surface water of the country as 690 km^3. These estimates are based on the statistical analysis of the available flows of rivers and suitable rainfall-runoff relationships in case of meager observed data.

The annual potential natural groundwater recharge from rainfall in India is about 344.43 km^3, which is 8.56 % of total annual rainfall of the country. The annual potential groundwater recharge augmentation from canal irrigation system is about 89.46 km^3.

Traditionally, India has been an agriculture-based economy. Hence, development of irrigation to increase agricultural production for making the country self-sustained has been of crucial importance for the planners. The water demand for other uses such as domestic water supply, industrial, power generation, etc are also to be fulfilled from the available water. The National Commission for Integrated Water Resources Development (NCIWRD) has estimated the annual water requirement for different uses. At the current rate of water use, about 399 km^3 of the demand is met by the surface water and 230 km^3 is met by the groundwater resources. With the increasing population as well as other developments in the country, the utilization of the water also will be increasing at a faster pace. Therefore, various conservation and management strategies have to be formulated for optimum use of available water resources to maximize the benefits.

1.5 Space -Time Scale 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 scale 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. 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 hydraulics and likewise do not coincide with political, environmental or economic time scales.

1.6 Hydrologic Budget

Water balance techniques are a way of solving important theoretical and practical hydrological problems. By using the water balance approach, it is possible to make a quantitative evaluation of water resources and to assess any changes that might occur through the influence of man's activities. Water balance studies can also provide an indirect evaluation of any unknown water balance components by providing the difference between known components.

The quantities of water going through any phases of the hydrologic cycle can be evaluated usually by the so-called hydrologic equation, which simply states as;

$$I - O = \Delta S$$

where, I is the inflow during a given period to a problem area including, for instance, the total inflow to the area above the ground surface and of the groundwater across the boundaries of the area plus the total precipitation over the area during the period; O is the outflow during the given period to the area including, for instance, total evaporation, transpiration, and outflow of surface runoff and the overflow of groundwater across the boundaries of the area; and ΔS is the change in storage in various forms of retention depression, and interception. The above equation is essentially a form of continuity equation.

For a drainage basin, the inflow may be comprised of rainfall, snowfall, hail and other forms of precipitation. Surface runoff, subsurface runoff, deep percolation, 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 the equation and the resulting water budget equation is known as the hydrologic water balance equation.

1.7 Water Quality

Water is a multiple use resource. With the advent of industrialization and increasing population, the range of requirements of water has increased, together with greater demands for higher quality of water. The term water quality is a widely used expression, which has an extremely broad spectrum of meanings. From the user's point of view, the term water quality is defined as "those physical, chemical or biological characteristics of water by which the user evaluates the acceptability of water".

A scientific rationale, on which decision or judgment on the suitability of water quality to support a designated use is based, is called water quality criteria. Water quality criteria specify concentrations of water constituents which, if not exceeded, are expected to be suitable for the designated use. Such criteria are derived from scientific facts obtained from experimental or in situ observations that depict organism responses to a defined stimulus or material under identifiable or regulated environmental conditions for a specified time period.

1.8 Water Resources Management and Conservation

In view of the existing status of water resources and increasing demands of water for meeting the requirements of the rapidly growing population of the country as well as the problems that are likely to arise in future, a holistic well planned and long term strategy is needed for sustainable water resources management. Also, knowledge sharing, people's participation, mass communication and capacity building are essential for effective water resources management.

Water conservation implies improving the availability of water through augmentation by means of storage of water in surface reservoirs, tanks, soil and as groundwater. It emphasizes the need to modify the space and time availability of water to meet the demands. The concept also highlights the need for judicious use of water.

Implementation of water pollution prevention strategies and restoration of ecological systems are integral components of all development plans. To preserve our water resources and environment, we need to make systematic changes in the way we grow our food, manufacture the goods and dispose off the waste. Efforts should be made to restore landscapes and ecosystems to more efficiently protect water quality, aquatic and wildlife.

Water is one of the most essential natural resources for sustaining life and it is likely to become critically scarce in coming decades, due to continuous increase in its demands, rapid increase in population and expanding economy of our country. 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 droughts affecting vast areas of the country. For an efficient water resources conservation and management programme, some of the measures to be adopted are listed below:

- Development of efficient monsoon forecasting models for adopting appropriate strategies for management of floods and droughts.
- Increasing the availability of water resources by proper management of existing storages and creating additional storages by considering economical, environmental and social aspects.
- Enhancing the availability of water resources by watershed management, improving irrigation efficiency, rejuvenation of dying lakes, ponds and tanks and increasing means of artificial groundwater recharge.
- Inter-basin transfer of water for mitigating the problems of the surplus and deficit river basins.
- Integrated and coordinated development of surface water and groundwater resources and their conjunctive use.
- Regulation of movement of pollutants in the rivers, lakes and groundwater aquifers.
- Developing and implementing proper water quality management strategies.
- Maintaining minimum flow in rivers to meet the criteria of Environmental Flow Requirement (EFR).

- Organising capacity building and awareness programmes for the water users and public for encouraging their effective participation in water management practices and for developing ethical concepts for making efficient use of water resources.

2.0. Data Processing

2.1 Rainfall Data Processing

It is common experience that the precipitation data in its raw form would contain many gaps and
inconsistent values. As such preliminary processing of precipitation data is essential before it is put to further use in analysis. Processing of the data has two major objectives. One is to evaluate the data for its accuracy and the other is to prepare the data in a form appropriate for subsequent
analysis. Manual scrutiny for the carrying out processing has obvious limitations. Computerised
processing and analysis has several advantages over the manual scrutiny and analysis.

Rainfall

Rainfall in India in any year is controlled not only by local factors but also a large number of global factors far from India. While some of the factors like orography and distance from sea are fixed, others like prevailing temperature and pressure conditions over the main land, Himalayas and Tibet, southern oscillation and El Nino intensity vary from year to year and influence the amount and distribution of rainfall over the country.

Annual normal rainfall of India is about 1170 mm which is more than the global average of 1000
mm. But it has very much temporal and spatial variation over the country. About three-fourth of
rain is concentrated in one-third of the year (June-Sept.). Spatially it ranges from more than 11000 mm in parts of Meghalaya to about 100mm in extreme western parts of Rajasthan and north India
The rainfall in India is principally contributed by the following weather systems.
1. Local severe storms
2. Monsoon rains
3. Tropical cyclones
4. Western disturbances

DATA PROCESSING SYSTEM

The processing system consists of a series of steps and procedures. The efficiency, economy and speed of the system would depend upon the type of storage devices, the quality of machines and software (computer programmes). The methodology for executing the various steps involved in the processing system are briefly described. Ramasastri et al. (2005) has briefed about computerized processing of the data.

Preliminary Scrutiny

Before the precipitation data is stored on computer compatible devices for computer processing, it becomes necessary to carry out preliminary checks, manual scrutiny etc. The reports received from manually observed stations by telephone or other communication channels are checked by a repeat back system.

Improper registering of data includes entering data against wrong time and date, alteration of figures etc. The official at receiving station could check the reasonableness of report by judging the report based on past experience and statistics of the station and region to which the station belongs.

Some of the climatological parameters used for checking the values of normal rainfall, highest observed rainfall or value of rainfall, corresponding to 25, 50 or 100yr. return period.

Checking reasonableness of a daily reported precipitation

For example, daily precipitation reported from a station is 360.6 mm and its precipitation statistics of the reporting station are :

(i) Normal monthly rainfall of the corresponding month : 350.0 mm
(ii) Mean maximum 1 day rainfall ((x)) : 210.6 mm
(iii) Standard deviation (σ) of maximum 1 day rainfall : 50.0 mm
(iv) Highest observed 1 day rainfall : 285.3 mm
(v) 100-year return period value of 1 day maximum rainfall : 300.0 mm
(vi) Probable maximum precipitation value of 1 day rainfall : 370.8 mm

The reported daily rainfall value of 360.6 mm is more than the normal monthly rainfall of the corresponding month and is, therefore, doubtful but not reasonable. The reasonableness is checked with other statistics. The value is compared with the mean 1 day maximum rainfall and the highest observed value. The reported value is more than the mean 1 day maximum and the corresponding to ($x + \sigma$) and ($x + 2\sigma$) are computed. They are 260.6 mm and 310.6 mm, respectively.

The reported daily value is compared with the 1 day Probable maximum precipitation (PMP) value, which is 370.8 mm. The value is less than the PMP and is, therefore, reasonable and is further checked by spatial consistency.

Quality Control

Quality control is a pre-requisite before the precipitation data are used either in an operational system for flood forecasting or achieved for climatological purposes. The basic objective of the

quality control procedure is to detect and if possible correct errors in observational data at the
earliest stage possible in the flow of data from local data source to the centralized database.

Source and types of data errors

Measurement errors have been classified by WMO (1982) into various groups.

(a) Errors built into instruments
(b) Errors involved in regarding instruments and transmitting or recording data
(c) Errors due to improper instrument exposure or to the lack of representativeness of the
instrument site to the area for which it is to be used as an index
(d) Errors occurring during the processing of the data.

Most of the errors described above could be further sub classified as

(i) Systematic errors, and
(ii) Random errors

(i) Systematic errors

Systematic errors are essentially due to malfunctioning of instrument, wrong exposure conditions and/or lack of knowledge of observer. WMO (1982) listed the following errors for which adjustment needs to be made to get a near accurate estimate of precipitation from a measured
precipitation report.

(a) error due to the systematic wind field deformation above the gauge orifice
(b) error due to the wetting loss on the internal walls of the collector
(c) error due to evaporation from the container (generally in hot climates)
(d) error due to the wetting loss in the container when it is emptied
(e) error due to blowing and drifting snow
(f) error due to splashing in and out of water, and
(g) random observational and instrumental errors.

(ii) Random errors

Some of the random errors could arise due to spilling of the water when transferring it to the
measuring jar, leakage into or out of the receiver, observational error etc. The others which could
be due to observer are

(i) misreading and transposing digits,
(ii) misrecording because of faulty memory,
(iii) recording the data at the wrong place on the recording sheet,

(iv) misplacing the decimal point,
(v) making readings at improper interval,
(vi) incorrect dating of the report,
(vii) making an estimate of the precipitation in some case because of non- availability or other problems with the gauge,
(viii) incorrectly reading or communicating the data to a reporting centre etc.

ESTIMATION OF MISSING DATA

While retrieving data for climatological purpose or inputting data in real time, one often comes across missing data situations. Since blank in a data set is read as zero by computer, necessary software for identifying the blanks and marking them appropriately need to be developed. Data for the period of missing rainfall data could be filled using estimation technique. The length of period up to which the data could be filled is dependent on individual judgment. Generally, rainfall for the missing period is estimated either by using the normal ratio method or the distance power method.

ESTIMATION OF MEAN AREAL PRECIPITATION

Precipitation observations from gauges are point measurements and is characteristic of the precipitation process, exhibits appreciable spatial variation over relatively short distance. An accurate assessment of mean areal precipitation is a pre-requisite and basic input in the hydrological analysis.

Numerous methods of computing areal rainfall from point raingauge measurements have been proposed. Some of the well known methods are described in text books of Hydrology (Chow, 1964; Linsley et al., 1958) and in Manual of Hydrometeorology of IMD etc. The most commonly used methods are\

(a) Arithmetic average
(b) Thiessen polygon method, and
(c) Isohyetal method

The choice of the method is dependent on the quality and nature of data, importance of use and
required precision, availability of time and computer.

2.2. PROCESSING AND ANALYSIS OF STREAM FLOW DATA

The stream flow data is important to determine the extent and pattern of available water supply and used in determining the reliable water supplies for various purposes, which include domestic water supply, commercial and industrial use; irrigation, hydropower and transport channels etc. These records are therefore very useful in planning and designing and later for operating and managing the surface water related projects. Apart from water resources projects the stream flow records are also utilized in designing the bridges, culverts, flood plain delineation and flood warming systems.

Stream flow records are primarily continuous records of flow passing through a particular section on the stream. These sections of interest where the flow is measured are called the stream gauging stations. A network of stream-gauging stations is established to get the information about the surface water resources of the region. However the measurement made at the gauging site may subject to various random, systemic and spurious errors. Therefore data processing is required to transform the raw data into their most usable forms through a variety of quality checks at appropriate stages to ensure data quality and reliability.

Processing of stream flow data is not a single step process. Several processing steps are required to produce reliable stream flow data. The first deals with flow measurements data, second incorporates the gauges flows into rating curves and third deals with the computation of flows from stage data and the final step outlines some standard analyses performed that use the flow estimates.

PROCESSING OF STREAMFLOW DATA

Preliminary Processing and Scrutiny

Preliminary Processing and scrutiny of the data are essential before the observed data is stored on
computer. The preliminary processing is involved with comparisons within a single data series and is concerned with making comparisons between observations and pre-set limlis and/or statistical range of a variable or with the expected hydrological behaviour of a hydrological phenomenon. Preliminary data processing highlights those data, which are not within the expected range or are not hydrologically consistent. To sure data quality following information should also be furnished:

i. Methods of measurement/observation of hydrological data, standards followed, instruments used, frequency of observation etc. shall be discussed item wise.

ii. Details of history of station, shift in the location, shift in the rating curves should be identified. Sample calculation for discharge should be furnished. Mention shall be made as to whether discharge data is observed or estimated from the rating curve. Indicate the methods of estimation.

iii. Discuss development of stage discharge curves at discharge site bringing out the extrapolations shall be verified by other methods such as hydraulic calculations etc.

Filling up of short Data gaps: The following techniques can be used for data gap filling:

i. Random choice from values observed for that period.
ii. Interpolation from adjoining values by plotting a smooth hydrograph (for runoff alone).
iii. Double mass curve techniques.
iv. Correlation with adjoining station either of the same hydrologic element or different hydrologic elements.
v. Auto correlation with earlier period at the same station.

Consistency of data: The consistency of the data should also be checked to ensure

Internal consistency check: The study of consistency of the observed data at specific control points and corrections if any made shall be checked and discussed. The check can be done by study of stage discharge relationship for different periods. Large variations if any should be investigated, corrected and explained suitably if required. Trend analysis should be performed

• To detect a slow continuous variation of meteorological conditions or a long periodic variation of the climate.
• To observe the modification of catchment physiography especially through human activity.

External consistency check: The consistency of the observed stream flow data should be discussed with reference to the rainfall in the project catchment and observed data in adjacent locations/basins

The consistency can be checked by:

• Comparing monthly and annual rainfall with corresponding runoff.
• Comparing average annual specific flow expressed in depth unit with corresponding figures at other sites of the same river or adjacent basins.
• Comparing the hydrograph or daily discharge at the control point with adjacent sites etc.

Quality control procedures: Some of the methods for quality control are

• Testing the stage or discharge of a given day within a year against the highest and lowest value
of the same date in all the previous years.
• Apply the same test on the difference between the value on the day and the day before.
• Comparing observed data with estimates based on data from adjacent stations.
• Comparing the observed data with estimates based on a precipitation runoff.
• Checking for negative values during the computation of inflow to a reservoir when the stage
storage relationship and the outflow are known.
• Comparing the runoff at a station with runoff at upstream stations.
• Applying double mass curve analysis to identify shift in control.
• Applying time series analysis to detect changes in the homogeneity in time series. This is a
valuable supplement to double mass analysis.
• Plotting a graph of the points at which measurements are made and comparison with the
original cross section.
• Plotting the graph of the annual regime of specific discharges and regional comparison.
• Regional comparisons of monthly and annual streamflow deficits.

Secondary Processing

Specific tasks in secondary data processing include :

• Calculation of mean velocity and discharge based on stream gauging.
• Analytical fitting of stage-discharge relations
• Conversion of stages to discharges.
• Preparation of regular time series containing monthly tables of hourly values with means and extremes, annual tables of daily values with means and extremes and miscellaneous graphs showing variations with time.
• Preparation of chronological tables with elementary statistical parameters, daily data tables for spatial comparison, multi-annual summary tables of monthly and annual value (means, totals, extremes or frequencies of occurrence) with elementary statistical parameters, discharge classified into ranges and probability envelope curves (table and graphs).

Analysis of Processed Data

The following analysis are normally performed with the processed data:

• Computation of flow duration curves
• Computation of summation and regulation curves
• Computation of natural runoff from a regulated reservoir
• Computation of the inflow to a reservoir
• Routing of flood through reservoir or river channels
• Unit hydrograph analysis
• Flood forecasting
• Computation of flow-frequency curves
• Flood frequency analysis
• Low flow frequency analysis
• Analysis of flood or low water volumes
• Multiple linear regression analysis
• Time series analysis