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HYDROLOGIC DATA COLLECTION, PROCESSING & ANALYSIS

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PREFACE

Collection, processing and analysis of the hydrological data forms a very important aspect in the hydrological modelling studies. This report deals with the existing system of the data measurement/estimation including rainfall, snow, evaporation, infiltration, streamflow, sedimentation and soil moisture etc. The organisations/universities and private agencies which are involved in hydrologic data collection have been mentioned. The processing of hydrological data including compilation, estimation of accuracy, filling in gaps, adjustment of missing data for precipitation and streamflow are considered. A brief description about the hydrologic models is also given in this report.

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ABSTRACT

Hydrological and related meteorological data are needed for proper planning in development, management and optimal utilization of water resources of the country and its water related environment. Advances in hydrology are dependent on good, reliable and continuous measurements of the hydrological variables. The data collected by various agencies in our country is generally in raw form. The first important task in the whole gambit of hydrologic analysis is the collection true, accurate and regular data. This needs a through understanding of methods of measurement, on the part of the people responsible to collect such data. The conventional and responsible to collect such data. The conventional and modern methods need to be imbibed into, not only observers, technicians but also in water resources engineer & managers. The second concern is the processing of such raw data. Data processing classified as preliminary and secondary data processing is essential before putting the data for further use in analysis. Processing of hydrological data has two major objectives : One to evaluate the data for its accuracy and the other to prepare the data in a form most valuable to the users. The measurements of hydrological data are recorded and processed by a wide range of methods, from the manual writing down and processing to the invisible marking and processing of electronic impulses on a magnetic

tape. Automated data processing using high speed computers has immense potential for handling large volume of hydrologic data in a quick and economic way. The third step in this link is the analysis of hydrologic data by existing methods and use of new and modern methods like hydrologic modelling etc.

In the study reported herein various aspects of hydrologic data collection, processing and analysis have been dealt in detail. In the present study an attempt has been made to cover in depth one of the most important, crucial and need of the day i.e. collection, processing and analysis of hydrologic data. The report opens with a basic discussion on data processing including important definitions and concepts after this a section has been devoted to hydrologic data collection/estimation, existing system of data collection in India and the various organisations involved in these activities. Though more stress has been focused on precipitation and discharge data however, other data like ground water, water quality, sediment, and other meteorological data have also been covered. The next part of the report deals with the processing of various hydrological parameters. The stress has been made on the use of computers and electronic data processing. This is followed by the recent developments in hydrology i.e. mathematical modelling. The chapter cover the basic definition, classes of mathematical models and provides a brief review of available hydrologic models. Finally the conclusions brings out the importance of data processing and usefulness of automated data processing in present context. It has also been concluded from the study that the automated data processing and persons trained in this field are needed to maintain the pace with the development in hydrological data analysis and modelling.

1.0 INTRODUCTION

Water has to cater needs of various sectors. To meet these varying types of uses which are even on the increase with the development of irrigation, industries, hydro power, navigation etc., it is necessary to measure rainfall, runoff and other hydrological and related meteorological data in each major and medium river catchment. Further-more the data thus collected have to be organised and analysed to determine water availability at various times of the year. In fact, in planning and designing water resources projects (e.g. irrigation, hydropower, flood control etc.), the peak and magnitude of flood are of great importance to an engineer. In practice it is rare an engineer may find all the necessary records (e.g. stream flow) at the proper site in question. It is generally necessary either to use the records obtained at a more or less distant point or to extend the records to cover a long period, needing thereby the long term data and a study between the complicated relationships of hydrological components through the hydrologic cycle.

Adequate hydrologic data are essential for planning engineering projects. In our country various organisations are involved in collection of hydrologic and other related data. Data collected on hydrologic process are generally raw data and can not be used directly in most hydrologic analysis work. Therefore, processing of such data is essential to make them usable for various studies.

Advancement in computer technology has opened a new path for speedy and more accurate data processing. The manual data processing which require lot of labour and time is now slowly becoming obsolete. Most of the developed countries are using high speed computers for such works.

1.1 Data Processing

The term "data processing" is of relatively recent origin, the activity itself is not new. On the contrary, there is evidence that the need to process data originate as back as the beginning of recorded history, when peoples activity first exceeded their ability to remember the details of their actions. The purpose of data processing is to collect and record facts, and figures relating to events and present them as a meaningful information in a concise form.

The term data processing refers to the recording and handling of data that are necessary to convert it into more refined or useful form of information. The volume of data has grown to such proportions that data processing has become a major activity attracting a great deal of interest. The data processed should not be taken as an end in itself. It is rather the beginning step of achieving objectives which can vary as the nature of data. The objectives of data processing now extend for beyond the routine handling of transaction documents and records of other types, providing timely information to facilitate greater control and improved decisions.

1.2 Data and Information

The term "data" refers to the raw facts and figures that are generated by and could record an event or an activity or a situation. Sources of data may be personal, business, trading, technical, scientific and legislative. Sources may be internal as well as external to the organization. Such data when procured provide different classes namely operating data, reference data, control data and management data. These are isolated facts and figures which may not mean anything in particular but may be transferred into meaningful information.

Data is defined as "things known" and information as "items of knowledge". Data is the raw material used to produce information. Information consists of selected data. Data is selected and organized with respect to user, problem, time, place, and the function. The conversion of data to information is the primary function of data processing.

1.3 Data Processing Cycle

The data processing activities which come in cyclic way is called data processing cycle. In the data processing cycle we first gather information for our data processing work. This is known as origination and collection. The collected data is made as input for the processing. It is stored for further processing and retrieval. The result and information obtained as the product of data processing is subject for feed back which can be either negative or positive. Depending upon the type of feed back, corrections or modification are incorporated to get the new system. The obtained new system may be run for the subsequent operations. The data processing life cycle activities are illustrated in Figure 1.1.

1.4 Data Processing Operations

In data processing cycle, various activities are carried out in different situations. These activities are called data processing operations. The various data processing operations are :

i. Recording
ii. Coding
iii. Classifying
iv. Conversion
v. Copying and duplicating
vi. Verifying/validating
vii. Manipulation of data
viii. Sorting
ix. Collating and merging
x. Comparing and analysing
xi. Calculating

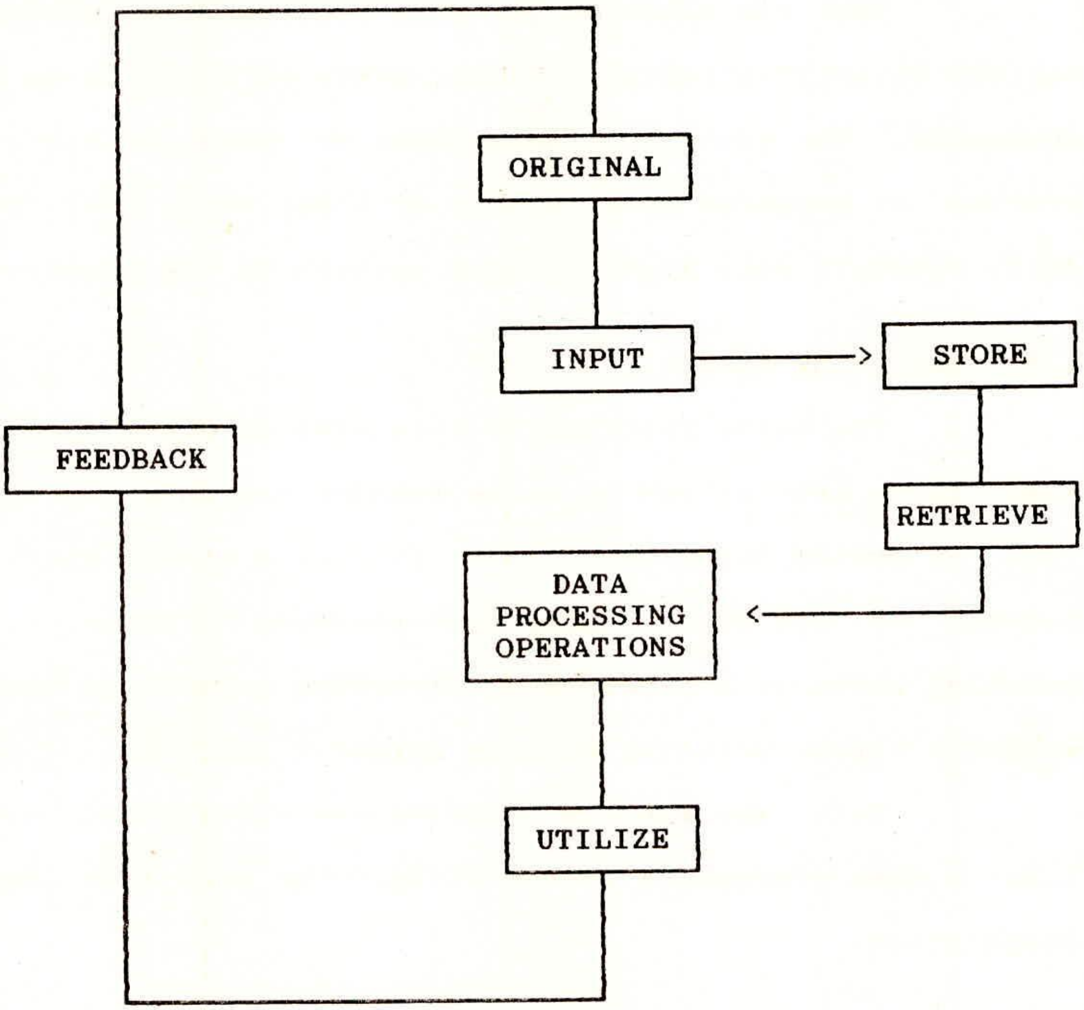

FIG.1.1 AN ILLUSTRATION OF DATA PROCESSING LIFE CYCLE ACTIVITIES

xii. Summarizing

xiii. Report preparations.

1.5 Data Origination

The raw material for data processing originated on various scientific/business forms, often referred to as source documents. The original data might be hand written, type written or prepared in a variety of other ways. For example daily rainfall data might be hand written by the observer.

1.5.1 Recording data

The basic function of this step is recording data in some form that allows it to be handled conveniently in any type of system being used. This involves a manual entry in a journal or register of some type-punching holes in a card, punching holes in a paper tape, recording magnetized spots on magnetic tapes, printing data in magnetic ink.

Data may also be recorded and transmitted directly into a data processing system without the need for document preparation.

1.5.2 Coding

As a means of further reducing the amount of data to be recorded and processed, abbreviated codes are often used to condense data. The technique of converting data to symbolic form has been used in many fields as a means of saving time, effort and space and as a device for identifying data. The most familiar codes are the "alphabetic" which used both numbers or characters or both.

1.5.3 Classification

Classification is an initial step that precedes the actual sorting of data. It is the process of identifying one or more common characteristic to be used as a means of systematically grouping data into classes. Classifying may occur as a separate step. Since the need is usually anticipate at the time data is recorded, classifications are generally determined and entered as a part of the recording process.

1.5.4 Conversion

Conversion is a means of transforming data from one form to another. For example, data recorded in punched cards may be converted to magnetic tape. Conversion facilitates easy processing of data.

1.5.5 Copying and duplicating

These are processes by which fascimiles of data can be prepared for distribution to more than one user or for use in different steps. It is also helpful in retrieval of the original data in case of its accidental loss from storage medium in which it has been recorded earlier.

1.5.6 Verification

The essential function assures that all parts of the recording process have been accomplished without error and that accurate data is entered into the processing system. Validating the data obtained before it is being processed also forms the part of verification of data.

1.5.7 Manipulation of data

The original form of data is not suitable for all purpose at the time of origination. In order to obtain the real objective, data should be converted to more useful form. The conversion is generally carried out by sorting, collating, merging, comparing, analysing etc.

1.5.8 Sorting

Sorting is the process of arranging or selecting data according to order/rank or common characteristics.

Sorting according to order or rank known as sorting in a sequence takes place when data is arranged in numeric or alphabetic sequence.

Sorting according to common characteristic known as sorting by classification takes place when data is arranged in similar groups.

1.5.9 Collating or Merging

In this operation two files of cards already in sequence can be combined into one file. As cards from the two files are fed simultaneously, the card at the primary reading station is compared with the card at the secondary reading station and the one with the smaller number is dropped, pocket. As a card advances to replace the one that has dropped, it is compared with the card remaining from the previous operation and the process is repeated.

1.5.10 Comparing and analyzing

The process with which factors such as the nature, type, proportion, relationship, order, similarity or relative value of data is compared with existing one.

1.5.11 Calculating

Calculating refers to the arithmetic process like addition, subtraction, multiplication and division which are necessary to convert data into more significant form.

1.5.12 Summarizing

Summarizing is the process of condensing data so that the main points are emphasized. Summarizing generally involves listing, tabulating, and totaling of each list. Sorting of data is also carried out during summarization.

1.5.13 Report preparation

The processed information that results from the data processing cycle is known as output. Report preparation is the processed information in any kind of output medium.

1.6 Analysis

Like most of the basic sciences, hydrology requires "Analysis" to use the fundamental concepts in the solution of engineering problems. Because of the complexity of most hydrologic engineering problems, the fundamental elements of hydrologic science can not be used directly. Instead, it is necessary to take measurements of the response of a hydrologic process and analyse the measurement in an attempt to understand how the process functions. Quite frequently, a model is formulated on the basis of the physical concepts the underline the process and the fitting of the model with the measurements provides the basis for understanding how the physical process various as the input to the process varies. That is, the analysis leads to a set of systematic rules that explain how the underlying hydrologic process will function in the future.

It should be emphasized that almost every hydrologic design (or synthesis) was preceded by hydrologic analysis. Most often, one hydrologic analysis is used as the basis for many, many hydrologic designs. But the important point is that the designer most understand the basis for the analysis that underlies any design method; otherwise, the designer may not apply the design procedure in a way that is compatible with underlying analysis. This not to say that a design method can not be applied without knowing the underlying analysis, only that it is best when the design engineer fully understands the analysis that let to development of the design rules. Anyone can substitute the values of input variables into a design method. But when a design is used under circumstances that it was not intended to be used for, inaccurate designs can be the result.

Most decisions regarding the management of water resources are based, in part at least, on estimates of the quantity of water to be managed or the rate of flow to be regulated. Hydrology is therefore basic to the planning of water resources projects and to the subsequent operation of these projects. The projects does not have to be a physical structure-it may be only management plan.

Traditionally, hydrology has been considered tool which could provide the design parameters of a project - reservoir capacity, spillway capacity, design flood, etc. The designer needs only a single value for each parameter. In contrast, the planner requires data in probabilistic form in order to make meaningful socioeconomic evaluations and an effective choice among the possible alternatives.

With minor exceptions there are no "standard" methods in hydrology. This situation is in part justified by the fact that differing climatic and physical characteristics, varying levels of data availability and reliability, and differing end purposes do require differences in the details of analysis. On the other hand different countries tend to use their own methods, and within the United States each government agency concerned with hydrology has its own manual of procedures. Hydrology is highly data-dependent, and the steps required to prepare data for analysis are an important part of every study. There is, however, no way that the hydrologist can be relieved of the necessity of using judgment in the selection and application of procedures. The many simple empirical procedures which abound in the literature of hydrology cannot be recommended, since the scanty tests available show them to be highly unreliable.

2.0 HYDROLOGIC DATA AND DATA MEASUREMENT/ESTIMATION

2.1 Hydrologic data Requirement

The complex features of the natural processes involved in hydrologic phenomenon make it difficult to treat many hydrologic process by rigorous deductive reasoning. Moreover, most of the factors governing hydrologic phenomena are not controllable and capable of experimentation. One cannot always start with a basic physical law and determine the expected hydrologic result because of the random nature of the factors controlling the hydrologic phenomena. Rather, it is necessary to start with a mass of observed data, analyse these facts statistically to establish the systematic natural law that governs these events and thereby give the results needed in decision-making. Thus without adequate historical data for the particular problem, the hydrologist is in a difficult position. The solution to all hydrologic problems is based on the collection and systematic compilation of data, and the intelligent analysis and correct interpretation of data. However, a proper balance between these two phases is to be made keeping in mind that too much of data is a waste of time and effort while the most detailed analysis and interpretation of limited data can lead to dangerously erroneous conclusions.

2.2 Uses of Hydrologic Data

Because water enters into so many facets of economy and society, the types of hydrological information required by government for their own use and for use by others may span many areas. Hydrological information is needed over a wide front but particularly for the activities shown in Table 2.1

Table 2.1 Water related activities where hydrological information is needed

Water resources
Water supply
Sewerage and sewage disposal
Water pollution control
Fisheries
Land drainage
Flood warning and protection
Irrigation
Navigation
Power production
Recreation
Mining control
River conservancy
Forestry management
Soil conservation

Within these areas the uses of hydrological information are many but they can be categorized in the manner shown in Table 2.2. This table shows how the uses change so as to meet central, regional and local needs. Probably the density of the information required increases towards the local end of the scale : conversely, the degree of digestion increases towards the national end of the scale.

Proper analysis and design of any hydrologic project depends on adequacy of data and length of records. A

Table 2.2 Uses of hydrological information

National
policy
planning
environmental monitoring
standards
international commitments
research
public health and safety
public relations
Regional
policy
forecasting
planning
environmental monitoring
design operations
research
public health and safety
public relations
Local
maintenance
control
emergencies
construction
revenue collection
operations
design and construction
public health and safety
public relations

hydrologist is often posed with lack of adequate data. The basic hydrological data required are :

(i) climatological data

(ii) hydro-meteorological data like temperature, wind velocity, humidity, etc.

(iii) precipitation records

(iv) stream-flow records

(v) seasonal fluctuation of ground water table or piezometric heads

(vi) evaporation data

(Vii) soil moisture data

(viii) cropping pattern, crops and their consumptive use

(ix) water quality data of surface streams and ground water

(x) geomorphologic studies of the basin like area, shape and slope of the basin, mean and median elevation, mean temperature (as well as highest and lowest temperature recorded) and other physiographic characteristics of the basin; stream density and drainage density; tanks and reservoirs.

2.3 Areas and Reaches from Hydrologic Point of View and Specific Information Required

The various areas and reaches of interest from the hydrologic point of view considering different development possibilities and specific information required for different reaches and areas have been presented in Table 2.3 (derived from Mutreja,1990)

Table 2.3 Specific Information Required for Different Areas and Reaches

Areas and Reaches	Specific Information Required
Drainage basins up to control points i.e. sites of hydraulic structures, hydrometric sites, flood-damage points, conflu-ences with large rivers, etc.	1. Index map for infiltration and soil erodibility characteristics. 2. Table of drainage areas at all control points. Also give notes where natural or man-made diversions divert a part of the flow from or into the

Areas and Reaches	Specific Information Required
	drinage area. For the drainage area computation, use a sufficiently large map, preferably 1:200,000, although presentation can be in much smaller size 3. Area-altitude curve for orographic regions having sizable areas above 100-m elevation 4. Water quality data
Potential irrigation area	1. Tables of charts presenting monthly rainfall normal and the monthly coefficient of variation for a few stations in the irrigation areas Monthly evaporation normals for few stations in or near irrigation area 2. Information about Infiltration 3. Information about groundwater regime in the area and data of monthly average and extreme groundwater levels
Potential flood damage area, Potential drainage congestion area, River reach through the area of potential flood damage or potential drainage damage	1. River profile showing flood level and river cross-section 2. Information of past floods and past events of drainage congestion giving levels, discharge, flooded areas and depth and durations of submergence 3. Notes and index plan about flood protection and drainage works already executed/sanctioned and their performance 4. Notes about problems of bank erosion, aggradation, degradation and meandering of rivers 5. Plan showing existing flood-control works and protected areas

Areas and Reaches	Specific Information Required
River system reach within and slightly upstream of a reservoir, River system reach from a hydraulic structure to a downstream point which is a control point	1. Observed river profile and river cross-sections and information about roughness coefficients
Potential ground water recharge area	1. Information on infiltration characteristics 2. Detailed notes about ground-water regime of area and data about monthly groundwater levels (normals and extreme observed)
Reservoir submergence area	1. Monthly average pan-evaporation data for station in or near the area 2. Elevation - area - capacity curves. Note on surveys from which curves are obtained, indicating method and distances between ranges, contour intervals, formulas used for volume computation
River reach in which industrial or domestic water supply is contemplated and where the quantity and quality of water is to be monitored	1. Water quality data regarding both chemical and biological quality. Information may be given for both high flows and low flows
River reach in which navigation is to be sustained by monitoring low flows	1. River profile with cross-sections 2. Low flow (discharges and depth) data 3. Notes about historical changes in levels and cross-sections 4. Notes about problems of bank erosion, aggradation, degradation and meandering or river 5. Notes about river-training works executed or sanctioned and their performance

Areas and Reaches	Specific Information Required
River reach in which water quality and salinity of low flows are to be monitored for fish and wild life sustenance for recreation	1. Water temperature and water salinity and other water quality parameters and changes in them from season to season.

2.4 Type of Data

To investigate properties of hydrologic variables relating to distribution of water quantity and water quality in time and space, four types of data are available.

(1) The first type is historic or chronological data or observation of processes in time. If not observed initially, this information is lost. A majority of present-day hydrologic data belong to this type. For example, river discharge, rainfall depths, etc.

(2) The second type is field-data observations along lines or surveys of hydrologic phenomena across or in space like the determination of depths of groundwater, determination of sediment characteristic along a river bed and similar surveys. This data can be resurveyed when necessary; the economic factor is usually the limiting condition. A substantial part of hydrologic data can be of this type.

(3) The third type is laboratory and field experimental data related to hydrology acquired by methods similar to data obtained in hydraulic experiments. This type of data is

mainly used in basic and applied research.

(4) The fourth type is the simultaneous measurement of two or more hydrologic variables in order to establish a relationship among these variables mainly for the purpose of transferring statistical information among variables.

2.5 Existing System of Data Measurement/Estimation

The assessment, development and management of water resources of the country is primarily based on the hydrologic and water resources data. The existing system of water resources and hydrologic data measurement/ estimation/ generation is presented in this section. As the purpose of this report is not only to deal with data measurement/estimation, therefore, various measurement/ estimation techniques of hydrological parameters are given in brief. A detailed information of such techniques is given in literature.(Chow,1964,Varshney,1986,Todd,1959,Mutreja,1990).

2.5.1 Rainfall

Since amount of rainfall varies from place to place, it is necessary to install measuring devices at various key points. It is assumed that the amount of rainfall collected in the gauge is representative of a certain area around the point where the measurement is made. It is the rainfall at single station. The rainfall data of various stations is used to estimate areal rainfall (Raghunath,1986).

(a) Point Measurement : Point or station rainfall is measured in depth (generally in mm) and it can be listed as daily, monthly or yearly depending on need. Two kinds of raingauges are generally used. First is the 'non recording type' raingauge, and the second is the recording type raingauge.

i. **Non-recording rain-gauge** : Non recording raingauges are most widely used in India. They do not record the rain but only collect the rain. Symons gauge, which is a non-recording raingauge, gives only the total depth of rainfall for the previous 24 hours and not the intensity and duration of rainfall during different time intervals of the day (IS:5225-1969).

ii. **Recording Raingauges** : These are also called self-recording, automatic or integrating raingauges. These raingauges give us a permanent automatic record in the form of continuous plot of rainfall against time and are superior to non-recording type.

There are three types of recording raingauges (IS:5235-1969) :

- **Tipping bucket type** : This is electrically operated and ideally suited for digitalising of the output signal.
- **Weighing bucket type** : This type of raingauge can give mass curve of rainfall for as long as one week and believed to give more accurate than can be obtained by

tipping bucket type gauge.

- **Natural syphon or float type** : This type of raingauges is adopted as the standard recording type raingauge in India.

(b) <u>Areal Estimates</u> : Where a gauging network has been established or records are available for a given watershed, the following methods are applicable for determining the average depth of rainfall over an area.

i. **Arithmetic average method** : It is obtained by simply averaging arithmetically the amounts of rainfall at the individual raingauge stations in that area. It yields good estimates in flat regions if the gauges are uniformly distributed and the rainfall at various stations do not vary widely from the mean.

ii. **Thiessen-polygon method** : This method attempt to allow for non-uniform distribution of gauges by providing a weighting factor for each gauge. It is more accurate than Arithmetic average method but suffers from a serious limitation in its flexibility since a new Thiessen diagram is required every time there is a change in the gauge network.(Thiessen,A.H.,1911)

iii. **Grid point method** : It has advantage over Thiessen polygon method, but is practical only with the aid of a computer.

iv. **Isohyetal method** : In this method the average rainfall between the successive isohyets taken as the average of the two isohyetal values are weighted with the area between the isohyets, added up and divided by the total area which gives the total average depth of rainfall over the entire basin. It is a most accurate method when the stations are large in number and is used by an experienced analyst (Chow,1964, Varshney,1986).

2.5.2 Snow

For the measurement/estimation of snow cover areal extent, snow quantity, snow depth, snow water equivalent, snow profile characteristics and snow melt runoff, various techniques are available (Toebes & Ouryvaev,1970).

(a) **Snow cover areal extent** : It can be measured by following methods.

i. **Visual observation** : It is quick practical method but requires thorough familiarity of the area.

ii. **Photo graphical method** : This method gives a permanent record for checking, but it is expensive and time consuming.

(b) **Snow quality** : It is measured by calorimetric process.

- **Calorimetric process** : In this method the quality, is presented as the ratio or weight of the ice content to the total weight.

(c) **Snow depth** :

i. **Raingauge measuring stick** : It is used where snow accumulation is not large.

ii. **Permanent snow stakes** : It is used where the snow accumulations are the rule.

iii. **Aerial markers** : It is adopted in remote areas for visual reading from air-craft.

(d) <u>Snow water equivalent</u> :

i. **Sampling with snow** : Along an established snow course these measurements should be made. This method tend to overmeasure the snow water equivalent.

ii. **Pressure pillows** : In this method there in no error due to wind but is has instrumental problems.

iii. **Raingauges with weighing scales/heating system** : In this method snow collection is weighed or melted for the determination of water equivalent.

iv. **Nuclear radiation snow gauges** : It is based on attenuation of the radiation beam by the snow.

v. **Radio active snow gauges** : These type of gauges are used for studying temporal variations of the internal structure of the snowpack.

(e) <u>Snow profile characteristics</u> :

i. **Open pits** : This is a direct and practical, but time consuming technique.

ii. **Thermistors** : It is a quick, inexpensive way to obtain snow profile temperature.

iii. **Isotope profiling techniques** : In this technique excellent detailed profile data rapidly available but expensive and requires sophisticated technical support.

(f) <u>Snow melt runoff</u> :

i. **Heat budget method** : This method is based on melt due to heat supplied by solar radiation, or vapour or condensation or air convection or rainfall or the earth (if not frozen).

ii. **Degree-day method** : In this method snow melt is related to the daily average of the temperature above 0°C (Varshney,1986).

2.5.3 Evaporation

(a) <u>Evaporimeter</u> : In this method, a pan of certain standards is taken the amount of water evaporated from this pan is measured, from which the rate of evaporation is calculated. The rate of evaporation so obtained is multiplied by a suitable pan coefficient, so as to obtain the evaporation rate from the given surface water.

i. **US Weather Bureau Class A Land Pan** : It is most commonly used & average pan coefficient is generally taken as 0.70 (0.60 in summer to 0.82 in winter). Gives reasonably accurate figures of evaporation (Shaw,1989).

ii. **The Sunken Screened Pan** : Annual pan coefficient is practically 1.0 (Monthly coefficient in winter is <1.0, in summer>1.0) (Varshney,1986).

iii. **The U.S. Bureau of Plant Industry Pan** : Evaporation obtained by it is normally 5 % more than reservoir evaporation (Varshney,1986).

iv. **The U.S.Geological Survey Floating Pan** : This pan is used to simulate the characteristics of large water body. Reservoir evaporation is obtained at a pan coefficient of 0.80 while the range is 0.70-0.82.

v. **The Colorado Sunken Pan** : It has radiation and aerodynamic characteristics similar to lake. The pan coefficient generally adopted for computing reservoir evaporation is 0.78 and the range of variation is 0.75-0.86 (Varshney,1986).

vi. **ISI Standard Pan** : Average value of pan coefficient for lake evaporation is generally 0.80 while the range is 0.65-1.10 (IS:5973-1970).

vii. **Piche evaporimeter** : It consists of a disc of filter paper kept constantely saturated with water from a graduated glass tube (Raghunath,1986). It is quite in use in India.

(b) **Atmometers** : These áre the devices that can give direct measurement of evaporation. They are used to measure evaporation from plant surfaces (Shaw,1989).

i. **Living stone atmometer**

ii. **Piche atmometer** : When the Piche atometer is exposed in a standard temperature screen, the annual values have been found to be approximately equivalent to the open water evaporation from a US class A pan. This type of instrument is used widely in the developing countries at Africa and the Near East.

(c) <u>Analytical methods (for estimating reservoir evaporation)</u> :

i. **Water budget method** : It is simplest, but least reliable method (Varshney,1986).

ii. **Energy budget approach** : This method is not of much practical importance it is found to give satisfactory results with errors of the order of 5 % for periods less than a week (Varshney,1986).

iii. **Mass-transfer method** : Application of the method based on mass transfer principles requires measurements of wind velocity and humidity at two or more elevations and is seldom practical (Varshney,1986).

(d) **Empirical equation** : Various numerical formulae are available based on Dalton's law of evaporationr involving function of atmospheric elements parallel to mass transfer approach in some respects (Varshney,1986).

i. **Meyer's formula** : It is a commonly used formula.

ii. **Rohwer's formula** : It is also a commonly used formula.

iii. **Lake Hefner's formulae**

iv. **US Geological Survey and USBR's Formula** :

v. **Bigelow's formula**

vii. **Utah formula (revised)**

(e) **Penman's equation** : It uses weather data for evaporation estimation.

2.5.4. **Transpiration** : Transpiration is the process by which the water vapour escapes from the living plants leaves and enters the atomospere. Various methods devised to measure transpiration are :

(a) **Phytometer** : It consists of a closed water tight tank with sufficient soil for plant growth with only the plant exposed; water is applied artificially till the plant growth is complete. The results of phytometer experiments are mostly of academic interest to the hydrologist as it is virtually impossible to simulate natural conditions (Raghunath,1986).

(b) **Ceramic and Piche atmometers** :It is widely used and useful for estimating temporal and spatial variations in potential transpiration.

(c) **Potometer** : A potometer is a vessel containing water into which cut end of the plant or claf is inserted. It is used to measure transpiration from parts of plants.

2.5.5. **Evapo-transpiration (ET) or consumptive use :**

(a) **Water budget determination (Inflow-outflow method)** : For determining mean ET over large basins for long periods this method is used. Reliability hinges on the time increments considered.

(b) **Tank (Lysimeter) experiments** : Lysimeter studies involves the growing of crops in large containers (lysimeter) and measuring their water loss and gains. This experiments are time consuming and expensive. Reliability of measurements is dependent on the nearness of reproduction of natural conditions (Toebes & Ouryvaev,1970).

(c) **Field experimental plots** : This method is more dependable than lysimeters provided there is no percolation of water or presence of ground water table near the root zone of the crop. This method, though satisfactory for computing seasonal water requirements, does not provide information on intermediate soil moisture condition, short term use, profile use, deep percolation losses and peak use rate of the crop.

(d) **Soil moisture depletion studies** : These studies are suitable for areas where the soil is fairly uniform and the ground water table sufficiently lower so as to cause no influence on the root zone soil moisture.

(e) **Evaporation pan method** : A close relationship exists between the consumptive use by crop and the rate of evaporation from an evaporation pan located in the crop environment. The relation between evapotranspiration and pan evaporation is given by crop factor ranges from 0.6-1.2 for commonly cultivated crops in India.

(f) **Methods for estimating ET from climatological data**: Owing to difficulty in obtaining accurate direct measurement of pan evaporation under field conditions, ET is often predicted based on climatological data. It should be used with caution in areas different from those for which they were derived (Michael,1981).

i. **Blaney-Criddle method** : This method assumes that the consumptive use is related only to temperature and duration of sunshine hours which is not fully true. It has generally given sufficienty accurate estimates of seasonal consumptive use. This method is largely used by irrigation engineers to calculate the water requirements of crops.

ii. **Blaney-Morin Equation** : It is similar to Balney-criddle method but with additional correction for humidity.

iii. **Thornthwaite Formula** : This formula use only the mean monthly temperature together with an adjustment for day-lengths. The formula was originally developed for the purpose of a rational classification of the broad climatic patterns of the world. The formula gives a reasonable estimate of potential evapotranspiration (PET) in the temperate, continental climate of North America but it is less successful in other parts of the world.

iv. **Penman Formula** : Penman formula is based on sound theoretical reasoning on a combination of the energy-balance and mass-transfer approach. The formula estimates mainly evaporation from a free water surface, so the results be modified to provide potential evapotranspiration (PET). It is widely used in India and found to be satisfactory in both humid and arid regions. It involves many meteorological parameters and tedious computation.

v. **Modified Penman Formula (Doorenbos and Pruitt, 1975) :** This formula gives satisfactory estimates of crop ET and it is less tedious than Penman formula (1948).

vi. **Christiansen Method :** The equations for the determination of coefficients given by christiansen may not yield desirable results when the mean values of the climatic factors of a place differ much from the standard values used in the formula. For reliable estimates, therefore, the standard values of the climatic, factors need to be worked out for the local data to derive equations for the coefficients of those factors.

2.5.6. **Infiltration :**

(a) **<u>Flooding type infiltrometers</u>** : These are the infiltrometers in which the rate of infiltration is determined directly as the rate at which water must be applied to maintain constant depth within the infiltrometer. The disadvantage of these infiltrometers are raindrop-impact effect is not simulated; soil structure gets disturbed during installation of rings and results depend to some extent on their size with large meters giving less rates than the smaller ones due to boarder effect (Mutreja,1990).

i. **Simple or tube infiltrometer** : The data base has high degree of variability mainly due to the uncontrolled lateral movement of water from the cylinder after the wetting front reaches the bottom of the cylinder. It is no longer recommended.

ii. **Concentric or double ring infiltrometer** : The latteral movement of water is minimized here by using two concentric rings.

(b) **Rainfall simulator or a sprinkling type of infiltrometer**: It gives lower values of infiltration than flooding type infiltrometers due to the effect of rainfall impact and turbidity of the surface water. It uses water budget equation for computing infiltration.

(c) **Gravimetric method** : This method involves soil sampling for moisture determination before and after irrigation. Though accurate it is time consuming as it involves sampling at many locations.

(d) **Inflow-outflow method** : This method is mainly used in furrow irrigation.

(e) **Observation in infiltration pits and ponds**

(f) **Lysimeters** : It can be used either by applying an artificial supply with constant head or by using the data collected during natural storm rainfalls.

(g) <u>**Hydrograph analysis**</u> : The results obtained by hydrograph analysis are approximatiôns but are of considerable practical value in the estimation of flood flows.

2.5.7. **Streamflow** :

(a) <u>**Measurement of stage**</u> : Stage or gauge hight is the level of the water surface above the zero of a gauge. Discharge is estimated by using the previously established stage discharge relationship. Generally it is used for small rivers where sufficient head is available and where constriction in the river is acceptable (Raghunath,1986).

i. **Staff gauge** : It is simplest stage measurement.

ii. **Wire gauge** : It is used to measure water-surface elevation from above the surface such as bridge.

iii. **Crest-stage gauge** : It is used to provide low-cost supplementary records of crest stages at locations where recorders are not justified and where manually read staff gauges are inadequate.

iv. **Automatic stage recorders:**

- **Float gauge recorder** : Most common type in use and the advent of units for the conversion of chart information directly to computer tape. It has reduced the advantage of punched tape recorder.
- **Bubble gauge** : It has certain advantages over float type.

- **Punched-tape recorder** : A absance of these records in the absance of visual record of stage, calling for an elaborate system for defecting and restoring periods of either missing or incorrect records.
- **Servo-manometer** : This is specially for use where the installation of standard stilling wells is difficult or impossible because of unstable terrain, swamp and/or slumping river banks. The advantages are its portability while the disadvantages are the initial expense and the possibility of temperamental behaviour.

(b) <u>Measurement of depth</u>

Direct methods

i. **Sounding rods or sounding weights** : It is used with current meters to measure depth at various locations in flowing water.

ii. **Echo-depth recorder** : It is an electroacoustic instrument for quick and accurate depth measurement especially when the stream depth is large. It is also advantageous in high velocity streams and streams with soft or mobile beds.

iii. **Wading (or) suspension rod** : It is used for smaller depths and velocities of the order 1 m sec^{-1}.

iv. **Lead (log) lines** : It is used for depths greater than 6 m provided the current is slow.

v. **Real line and cranes** : Where the depths are great and velocities are high to permit the use of log line; a cable line lowered by a crane measures the depth.

Indirect methods : Indirect method uses theodolite or a level fitted with stadia wires and a leavling staff.

i. **Pivot point method**

ii. **Linear Measurement method**

iii. **Angular measurement method**

iv. **Stadia method**

(c) <u>**Velocity measurements**</u>

i. **Current meters** : These are most commonly used for accurate determination of flow velocity. They measure mean velocity in a strip of cross-section by one point method (0.6d) or by two points method (mean of 0.2d and 0.8d)

ii. **Float method** : It measures stream surface velocity. Coefficients are used to convert the surface velocity to the mean velocity.

iii. **Velocity rods** : It is used to measure mean velocity.

(d) <u>**Streamflow measurement**</u> :

Direct determination method (Raghunath,1986,Toebes & Ouryvaev, 1970, Mutreja,1990, Shaw,1989)

i. **Area velocity method** : Gauging site must be in a straight and stable reach to assure that stage-discharge curve is reasonably constant for over a long period of about a few years. This method is costly and tedious for large rivers. It is called standard current meter method.

ii. **Moving boat method** : This method useful when the river is in spate making impossible to use the standard current meter technique due to the difficulty of keeping the boat stationary on the fast moving stream for observation purposes. It provides a single measurement of discharge and an accuracy of ±5% is claimed at the 95% confidence level.

iii. **Chemical or Dilution method** : By this method discharge is estimated directly. It is an attractive method for small turbulent streams and can be used for checking the calibration, stage-discharge curves etc. obtained by other methods.

- **Colour velocity (or) dyeing method** : This method is used for approximate determination of the high velocity and flow velocity observed and is open to question as to whether it is the mean velocity or surface velocity. But it can be detected at very low levels (~1 in 10^{11}) and hence is required in very small amounts for injection.
- **Salt velocity method** : This method is best adapted to small streams of constant cross-section. Common salt can be detected with an error ±1% upto a concentration of 10 ppm. This method is expensive as it requires special equipment and special observation crew.
- **Radiotracer method** : It is a very quick and accurate method, but requires experienced crew and sophisticated instruments. Detectable upto 1 in 10^{14} and hence permit

large scale dilutions.

iv. **Hydraulic model method** : The hydraulic model method permits development of hydraulic model of a stream and its calibration checked is against stream stage data. Where the gauge data are available for long periods (but not the measured discharges) this method is useful.

v. **Electromagnetic method** : It is based on Faraday's principle. This method is useful for situations where cross-sectional properties changes with time (as in mountaineous streams) and where the flow changes rapidly both in magnitude and direction and the measurement can be made upto an accuracy of ±3%. Electromagnetic method involves sophisticated and expensive instrumentation.

vi. **Ultrasonic method** : It measures velicity using ultrasonic signals. It is a rapid and highly accurate method and suitable for automatic recording of data. It measures reverse flow and can handle rapid changes in the magnitude and direction of flow in a tidal rivers.

Indirect methods : Indirect method make use of the relationship between the flow discharge and the depths at specified locations. Their use in field conditions is limited by the ranges of head, debris or sediment load of the stream and the back-water effects produced by the installations.

i. **Flow measuring devices**

- **Notches** : The notches may be rectangular, traingular or trapezoidal notches. These are made of metal sheets and used for measuring small discharges. 90° V-notch is commonly used.

- **Weirs** : Weirs are to measure for large discharge values. They are made of concrete or masonry and classified as sharp, broad crested and cippoletti weirs. They are not accurate unless proper conditions for their measurements are maintained.
- **Flumes** : Flumes are made of concrete, masonry or metal sheets, depending on their use and location. Depend primarily on the width constriction to produce a control section. Parshall and Cutthroat are the two flumes mainly used.
- **Orifices** : In open channels orifices usually have circular or rectangular openings in a vertical bulkhead through which water flows. Orifices may operate under free flow or submerged conditions. They are made of sheet iron, steel or aluminimum plates that accurately machnined opening.
- **Meter Gates** : It is basically a modified submerged orifice so arranged that the orifice is adjustable in area. These gates are used by canal irrigation agencies in USA and some other countries at canal outlets where irrigation water in charged on volumetric basis.

ii. **Slope-area method** : Slope area method is particularly useful in estimating the flood discharge in a river by past records of stages at different sections. Manning's formula is used is this method.

2.5.8. **Runoff** (Chow,1964, Mutreja,1990, Schwab,at.al,1981)

i. **Rational method** : Application of rational method is normally limited to watersheds of area less than 13 sq km. The method is considered sufficiently accurate for runoff estimation in the design of relatively inexpensive sturctures where the consequences of failure are limited.

ii. **Rainfall runoff correlation** : Rainfall runoff correlation is used to generate synthetic runoff data from rainfall data. It may be adequate for preliminary studies. For accurate results sophisticated methods are adopted for synthetic generation of runoff data.

iii. **Empirical formulae** : These formulae are applicable to the region in which they were developed. They are essentially rainfall-runoff relations with third or fourth parameters to account for climatic or catchment characteristics.

- **Binnie's Percentages** : Binnie's percentages are based on observations in M.P.and Vidarbha in Maharashtra. Runoff coefficient depends on the catchment type and nature of monsoon rainfall
- **Barlow's Tables** : These tables are developed for use in U.P. It takes into account the catchment, the monsoon and the nature of the season.
- **Strange's Tables** : These tables are based on data in Maharashtra. Runoff coefficient in strange's tables depends on the amount of rainfall and the state of the

ground.

- **Inglis and Desouza's formulae** : These formulae are based on studies on catchments in western ghats and plains of Maharastra.
- **Lacey's formula** : Lacey's formula is based on catchment and monsoon duration factors.

iv. **Estimating losses**

- **A.N. Khosla's formula** : Indirectly based on the water-balance concept and the mean monthly catchment teperature is taken as a measure of losses due to evapotranspiration, sunshine and wind velocity. This formula was tested on various catchments in India and is found to give fairly good results for the annual yeild for use in preliminary studies.

v. **Infiltration method** : It takes into account the maximum rainfall intensity rate for the area. Due to limitations, there is less rigorous application of infiltration theory in estimating runoff.

vi. **Watershed simulation** : Hydrologic water budget equation is used for runoff estimation. Use of computer is required to facilitate the calculations.

vii. **Watershed simulation** : Hydrologic water budget equation is used for runoff estimation. Use of computer is required to facilitate the calculations.

viii. **Curve number technique** : This technique is based on land use/cover conservation practice, hydrologic condition, hydrological soil groups and antecedent soil moisture conditions.

2.5.9 Flood, flood inundation and damage : (Raghunath,1986, Chow,1964, Varshney,1986)

(a) <u>Flood</u> :

i. **Rational method** : This is the same method discussed under Runoff estimation.

ii. **Slope-area method** : Limitation of this method is the uncertainty involved in the selection of the factor of safety and the values in Manning's formula through user judgement. There is no indication available regarding the probable frequency of the maximum recorded flood.

iii. **Empirical formulae** : These formulae must be used with great prodence and must never be used unless their orgin has been invistigated. Some of these important formulae are given below.

Formula involving drainage area only

- **Dicken's formula** : Used for moderate size basins in the central and northern India.
- **Ryve's formula** : Originally developed for Tamil Nadu and is in use in Tamil Nadu and parts of Karnataka and Andhra Pradesh.
- **Inglis formula** : Derived on the basis of flood data of catchments in western ghats in Maharashtra. Used in Maharashtra for designs in small catchments.

- **Nawab Jung Bahadur formula** : It has been drived for hyderabad deccan catchment.
- **W.P. Creager's formula** : This formula was evolved by Creager from the study of flood peaks in USA.
- **Jarvis formula** :
- **Modified Myer's formula** : Formula involving drainage area and its shape.
- **Dredge or Burge formula** : It is based on Indian records formula involving rainfall and drainage are variables.
- **Pettis formula** : It was originated for Northern United states, Ohio to connecticut by Pettis.

Formula involving total runoff and drainage area

- **Boston Society of Civil Engineers Formula** : This formula is based on the New England flood of November 1927. The formula was evolved by assuming flood hydrograph as a traingle.

iv. **Envelope curves** : Kanwar and Karpov collected the data on Indian rivers and have drawn two envelope curves one for basins of South Indian and the other for basins of North and Central India. They can be used for preliminary guidance for determining peak flood discharges, and are better than empirical formulae in the sense that here the selection of co-efficients on the basis of judgement is eliminated. The order of frequency of floods derived from the curve would be somewhat greater than the longest period of record. They are used to develop a relationship between the maximum flood flow and drainage for regions of similar climatological characterics if the available flood data are meagre. As more data are available the curves need to be redrawn.

v. **Unit hydrograph** : Unit hydrographs are useful for the development of flood hydrographs for extreme rainfall magnitudes for use in the desing of hydraulic structures. This is also useful for extension of flood flow records and for developing flood forecasting and warnining systems. Application is limited to 2-5000 km^2 and very accurate reproduction of results should not be expected.

vi. **Flood frequency** : It involve statistical method of frequency analysis of the available flood data. Results depend upon length of the data. Generally a minimum of 30 years of data is considered as essential. Frequency analysis should not be adopted if the length of the records is less than 30 years. Most reliable for regions of uniform climates from year to year.

- **Gumble's method**
- **Log Pearson Type-III distribution**
- **Weibull distrubution**
- **Log normal distribution**
- **Hazen's method**
- **Ven te chow method**

(b) <u>Flood inundation and damage assement</u> :

Aerial and field surveys : Field surveys are difficult, tedious and time consuming while aerial surveys and costly.

2.5.10 Soil Moisture Measurement (Michael,1981)

i. **Gravimetric method** : Moisture measurements are made on soil samples of known weight or volume. It is essential for water budget studies and crop husbandry. The method, though accurate, is used mainly for experimental work.

ii. **Tensiometers** : Tensiometers provide direct measure of the tenacity (matric or capillary potential) with which water is held by soils. Tension measurements are limited to matric suction values of below 1 atmosphere, and are best suited to use in sandy soils. Tensiometer do not measure the entire range of available moisture in all soil types.

iii. **Pressure Membrance and Pressure plate technique** : Laboratory measurement of soil moisture potential are mostly made with this method. The appratus is useful for soil moisture measurements upto 15 bars.

iv. **Vapour pressure psychrometers** : It is used to measure the osmotic pressure of soil solution which is extracted from soil samples, Measurement of osmatic potential is essential in heavily fertilised and salt-affected soils.

v. **Electrical resistance devices (or) Bouyoucos moisture meters** : The dependance of electrical conductivity of porous solid on the amount of soil moisture forms the basis of the method. The devices function most effectively for wide range of tensions (1-51 àtm). Readings are susceptible to error in case of accumulation of salts and fertilisers in the soil

vi. **Feel and apperance method** : This is a simplest method of estimating the soil moisture. It require practical experience and correct judgement.

vii. **Neutron moisture meter** : The neutron scattering method is a rapid means of making in-situ measurement of soil moisture. The working of neurton moisture meter is based on the measurement of number of hydrologen nuclei that are present in a unit volume of soil which is directly prportional to water molecules in that volume. The equipment should be carefully handled to avoid danger from exposure to radiation

2.5.11 **Sedimentation** (Toebes & Ouryvaev,1970, Michael,1981)

(a) **Bed load estimation** : Bed load is not amenable to theoretical treatment

i. **Stream sampling** : In stream sampling bed load is generally taken as a certain percentage (3-25) of suspended load which is amenable to sufficiently accurate measurement. A percentage of 10 is the commonly accepted figure.

- **Box type sampler**
- **Slot type sampler**

ii. **Analytical methods** : It is based on tractive force theory and flume studies in laboratories

- **Du Bolys equation** : It is the simplest one and omits direct consideration of the mechanism of turbulent flow.

- **Shields formula**
- **Meyer Peter's formula**
- **Einstein formula** : It differs from earlier formulae. It involves the probability concept of particle commencing to move equted to flow and material parameters as well as forces of flow
- **Borland and Maddock's percentages** : These percentages are based on U.S.B.R. experience on estimation of bed load in streams.

(b) **Suspended load** :

Periodic sampling : For the measurement of suspended sediment concentration periodic samples from the rivers are taken at various discharges. A sediment rating curve which is a plot of sediment concentration vs discharge is prepared and used for approximate estimation of suspended load.

2.5.12 **Reservoir sedimentation (silt load into reservoir)** :

The sediment load into the reservoir is measured by capacity survey and is converted to weight after finding out the density of the deposited sediment all over the reservoir. Buoys and boats are used for sampling.

(a) **Sedimentation distrubution** :

i. **Trigonometric method** : It is a graphical method used for small reservoirs upto 300 Mm^3 capacity

ii. **Pool elevation-duration method** : This method is developed by U.S.Army Corps of Engineers. Takes into account the effect of reservoir operation, sediment size, reservoir size and shape

iii. **Area increment method** : This method is recommended where expected quantity of sediment to be deposited in 100 years does not exceed 15% of the original capacity

iv. **Empirical area reduction method** : It is more reliable than area increment method. In this method reservoirs are clssified on the basis of ratio of reservoir capacity to its depth plot on a log-log scale into (i) gorge; (ii) hill; (iii) flood plain foot hill and (iv) lake

v. **Observed pattern of distribution method** : Based on the long term available data on sedimentation resurvey of reservoirs in India and U.S.A a relationship is suggested for different types of reservoirs

2.5.13. **Water quality** : Water quality can be completely defined and estimated by studying its physical characteristics, chemical characteristics and bacterial characteristics (Shaw,1989).

i. **Physical characteristics:** It comprise include colour, Teste and ordour , turbidity, temperature and specific conductance of water.

ii. **Chemical characteristics** : It include hardness, pH value, hydrologen ion concentration, inorganic nutrients, suspended solids, dissolved and colloidal solids, dissolved gases and organic matter.

iii. **Bacteriological microscopic characteristics** : It involve detection and elimination of pathogenic organisms.

2.5.14 Water resources assessment

(a) <u>Surface water</u> :

i. **Adequate gauge-discharge data** : The available gauge discharge data of 30-40 years is scrutinished for consistency and reliability in gauge discharge relationship from a comparison of gauge and discharges - hydrographs at a particular discharge site. The data should be consistent with gauge discharge sites above and below. The reliability of the data is ascertained from the methods and equipment used for discharge observation

ii. **Limited gauge-discharge data** : A 35 years runoff cycle (as adopted in India) is obtained from the limited available gauge-discharge data say 10-15 years, the runoff data for balance period of 20-25 years by extrapolating statistically established rainfall-runoff correlation. The relationship which gives runoff closer to observed ones is adopted for extrapolation of runoff series

iii. **Empirical formulae** : For ungauged river basins with no discharge records the water resources are assessed either from the runoff records of an adjacent river basin of similar characteristics or by empirical formulae. The long term runoff series for 35 years is obtained using the rainfall-runoff curve after working out the rainfall for the past years. The percentage dependabilities of the runoff values are determined based on the estimated runoff series.

(b) <u>Ground water</u> :

i. Strata Logs : It is necessary to ascertain the specific yield of the substrata. For the estimation of the ground water. The procedure involves the classification of well logs data in various classes of materials. Percentage of each class of materials is assigned specific yield values and average specific yield percentage based on the experimental results obtained in U.S.A.

ii. From rainfall : Where rainfall is the predominant source for the recharge, the ground water estimate would be the available potential less by losses through evapotranspiration and subsurface drainage, which may be estimated or assumed. Rainfall-recharge relationship can be worked out for the are taking into consideration physical characteristics of the soil, slope rainfall intensity, initial moisture content etc.

iii. From rainfall and seepage : Adopted in the case of canal command areas. The amount of deep percolation due to seepage from canals reaching the ground water is added to the rainfall recharge to arrive at overall available ground water potential.

2.5.15 Climatological data

Meteorological observatories : Data on temperature, wind, humidity and solar radiation are obtained using proper instruments in meteorological observatories.

2.5.16. Ground water level

Depth gauges, water level recorders : They are installed/used in observation wells

2.5.17. Drought

Ground surveys : Generation and compilation of information on drought conditions at different level of bureaucracy and confirmity visits by inspecting teams.

2.5.18. Drainage and river channel characteristics

Ground surveys : They are tedious and time-consuming.

2.5.19. Watershed geology

Ground surveys,aerial photographs : Ground surveys are tedious and time-consuming.

2.5.20. Soil characteristics

Ground surveys, aerial photographs : Ground surveys are tedious and time-consuming.

2.5.21. Soil and land degradation

Ground surveys : They are tedious and time-consuming.

2.5.22. Watershed characteristics

Ground surveys : They are tedious and time-consuming.

2.5.23. **Irrigation command area pattern activities**

Ground surveys : They are tedious and time consuming. Absence of agreement in the statistics of Depts. of Agriculture & Irrigation and CADA is very common.

2.5.24. **Surface water or tank inventory**

Ground surveys : They are tedious and time-consuming.

2.5.25. Land use details

- **Temporarily settled states field surveys** : There are field to field village based enumeration of land use by the village official of State Revenue and Land Records Department. This primary land use data is complied for a group of villages (circles), blocks, tahsils/taluks, districts and state and national level.
- **Permanently settled states sample surveys** : There is no regular village agency for collection of data. A scheme establishment of an agency for reporting agricultural statistics (EARAS) exits.
- **North Eastern Counciladhoc or eye estimates** : There is no cadastral survey or requisite revenue agency.

3.0 DATA AVAILABILITY AND ORGANISATIONS INVOLVED IN DATA PROCESSING IN INDIA

3.1 Water, Soil and Land Resources Data Availability in India

Planning and management of water resources projects calls for accurate assessment of the water resources potential and the current utilisation of resource for various purposes. Observation of not only the rate of flow but also other relevant information such as sediment load carried by the river, water quality etc. is important for the integrated development of a river basin. Apart from the assessment or surface waters, it is essential to assess the ground waters too in order to plan for the conjunctive use of surface and ground waters. In our country, the various hydrologic data and water resources information including data on soil and land resources are not being collected and maintained at one place or available with one organisation. A number of various Central and State Government agencies is involved in it and these organisations collect and maintain the records to cater to the needs of water resource activities. Meteorological data like temperature, vapour pressure, relative humidity, wind velocity and rainfall are collected by India Meteorological Department (IMD) and by some State Government Organisations such as Department of Agriculture and Irrigation Department. Data on evaporation, transpiration, infiltration and other soil properties are available with the aforesaid and other state agencies. Flow data of major rivers are monitored by Central Water Commission (CWC) while stream flow data of various rivers are usually available with the State Irrigation Departments. Data on ground water is collected by Central Ground Water Board (CGWB), Geological Survey of India (GSI) and State Ground Water Boards or agencies. The principal types of hydrologic data and Water resource information and the various agencies concerned with them are listed in Table 3.1.

Soil and agricultural land use data are usually available with State Departments of Agriculture. State Land Use Boards and Revenue Departments collect information on general land use in the states. Soils and land degradation data can be obtained from State Departments of Agriculture and Agricultural Engineering/Soil Conservation. Soil conservation data at central level are available with the Department of Agriculture and Co-operation. Indian Council of Agricultural Research (ICAR) and its research stations existing all over the country collect data on rainfall, evaporation, evapotranspiration, infiltration, soils, etc. Agricultural Universities with their research stations spread over in the states also gather such data similar to ICAR.

3.3 Organisations Involved in Hydrologic Data collection in India

In our country various state and central government organisations are engaged in hydrological data collection. Activities and other detailsthem of some of the major data

Table 3.1 Hydrologic Data for Water Resources

Particulars	Data				
	IMD	CWC	CGWB	GSI	State Govt.Deptts.
Storms	✓		✓	✓	✓
Precipitation	✓	✓		✓	✓
Snowfall	✓	✓		✓	✓
Ice	✓				✓
Air temperature	✓	✓			✓
Soil temperature	✓				✓
Water temperature	✓	✓			✓
Evaporation	✓	✓			
Solar radiation	✓				
Wind	✓	✓			
Humidity	✓	✓			
Snowflow					✓
(i) Gauge		✓			✓
(ii)C & D		✓			✓
River,lake,reservoir stage		✓			✓
Sedimentation		✓			✓
Suspended load		✓			✓
Reservoir sedimentation		✓			✓
Chemical quality of water		✓	✓		✓
Soil moisture					✓
Density currents					✓
Tides					✓
Floods		✓			✓
Drought		✓			✓
Water use and waste disposal					✓
Drainage					✓
Sewage and waste disposal					✓
Industrial use			✓		✓
Infiltration					✓
Interception			✓	✓	✓
Ground water			✓	✓	✓

(Source: Report of the Task Force on Water Resources, 1985) collection organisations primarily responsible for collecting hydrologic and related data, are given below :

3.3.1 Indian Meteorological Department

Indian Meteorological Department (IMD), a central government organisation is engaged in collection of various meteorological data through a large number of observation stations spreading all over the country. This agency is the model agency in the country to collect such data. Their observation stations are considered to be standerized stations and serve as model example for other agencies. The total number of rain-gauges having published normals and the number of reporting rain-gauges for which rainfall data are received or arranged to be received at the India Meteorological Department's (IMD) Office at Pune are 2488 and 4473 respectively. The IMD collects data from 531 hydrometeorological and arometeorological surface observatories of all classes. There are 62 pilot balloon, 32 radio wind and 32 radio sonde observatories which take temperature, relative humidity observation for the upper atmosphere (Report of the Task Force on Water Resources, 1985).

Indian Meteorological Department has been storing the meteorological data for the last 40 years of period on punch cards. In 1964 IMD went in for machine processing of rainfall data using Holeritu machine which can sort out, make tables and give printouts in the desired format. The IMD, Pune is equipped with Tape drives and key to tape punch units with the acquisition of computer system. A program DAILY is developed in IMD to read the daily rainfall data (after identifying the card format and checking the leap year) and writes it into a 12x31 matrix. It also produces long term series of ten daily, monthly, seasonal and annual totals. Another program HOURLY reads the hourly rainfall data and stores the data in a 31x24/ 28x14/ 29x24/ 30x24/ matrix as the case may be. The total of 24 hr. is computed from the hourly data for each day & the maximum hourly rainfall is determined. The computer program RAIN has been developed to distribute the rainfall recorded at the totaling gauges during an observational day (8.30 hr. to 8.30 hr.) into hourly using an average pattern hyetograph derived from a set of representative recording raingauges in the vicinity of the totaling gauges as per a given set of weights. The hourly rainfall pattern thus obtained at each of the totaling gauges is then used alongwith those observed at the recording gauges to determine the average hourly rainfall which eventually could be used as input to the rainfall-runoff models (Jha, 1992).

The IMD complies the data tables of the State governments and issues the "Daily Rainfall of India" and the "Monthly Rainfall of India". The daily observations from a selected list of stations in the country are published in the

"Indian Daily Weather Report". However, summary of observations of all the stations is published in annual reports.

The Indaian Meteorological Department also publishes summary of reports of snow fall the Himalayas, based on records of snowfall observations made at the observatories and reports collected by local officers from local residents, headmen of villages or from travelers who have passed through the region and transmitted them to the meteorological office. A few meteorological observatories are maintained by IMD in the Himalayas where snow-gauges or snow poles have been installed to measure the quantity of snowfall. At present there are a few IMD stations distributed over the Himalayas from where snowfall observations in some form or other are collected.

In addition, Indian Meteorological Department also publishes records of temperature, wind velocity, sunshine, evaporation, humidity etc.

3.3.2 Central Water Commission (CWC)

Central Water Commission is the premier organisation under the ministry of water resources, which primarily responsible for collection of hydrologic data in the major and medium rivers of the country. It is also the nodal agency responsible for water resources development in the country.

In order to conduct systematic hydrological observations on scientific lines, the Central Water Commission has set up a large number of key observation stations. River data directorate and statistics directorate in the headquarters of Central Water Commission are primarily responsible for establishing a data bank for collection, processing storage and analysis of hydrological data in a systematic manner. Majority of these stations are meant for collection of basic data for the assessment of surface flows and other purposes. Sediment load and water quality are also observed at most of these stations. In addition the Central Water Commission has also established some hydrological observation stations for the specific purpose of investigation of the feasibility of projects. These stations are operated mostly for short durations of 10 years or so and then closed down (Water REsources of India, 1988).

In the Central Water Commission, for the purpose of establishment and operation of hydrological observation stations the country has been divided into three zones viz. North, East and South. In all there are about 540 observation stations presently under operation by the Central Water Commission basinwise details of which are presented in Table 3.2.

The CWC is engaged in computerized storage & retrieval of hydrological data for quite sometime. Data on computer is initially processed mechanically with the objectives of storing of hydrological data on magnetic tape

Table 3.2 Statement Showing Basinwise Hydrological and Sediment Observation Stations of Central Water Commission

Sl.No.	River Basin	No. of Stations G&D	GDS/WQ	Total
1.	Indus	8	10	18
2. (a)	Ganga	113	114	227
(b)	Brahamputra & Meghna	11	20	31
(c)	Barak	9	10	19
3.	Godavari	29	20	49
4.	Krishna	23	25	48
5.	Cauvery	3	19	22
6.	Pennar	-	4	4
7.	East flowing rivers	8	10	18
8.	Mahanadi	4	13	17
9.	Brahmani & Baitarani	-	7	7
10.	Subarnarekha	-	3	3
11.	Sabarmati	1	-	1
12.	Mahi	-	5	5
13.	West flowing rivers of Kutch Saurashtra Incl. Luni	4	10	14
14.	Narmada	7	12	19
15.	Tapi	4	12	16
16.	West flowing rivers from Tapi to Tadri	-	3	3
17.	West flowing rivers from Tadri to Kanya Kumari	-	21	21
	Total	224	318	542

G&D : Gauge & Discharge Observations

GDS/WQ : Gauge Discharge Sediment/Water Quality Observations

(Source : Water Resources of India, CWC Publication No. 30/88 Central Water Commission, New Delhi, April 1988) and processing of data on computer for various hydrological computations. One of these software package processes the gauge & discharge data of the various rivers flowing in the country and produces the reports usually known as "Water year book". The daily gauge and discharge data for all the month for particular site on a river is printed in a tabular format. In case of missing data, the computed discharge is substituted. The maximum & minimum water level/discharge & its data of water level and discharge is further carried out in a stratified spectrum such as monsoon season, non-monsoon season and annual basis. Flow duration of the discharge is further analyzed to depict the flowing water data received from the field units and transferred to magnetic tapes.

3.3.3 Central Ground Water Board

The Geological Survey of India (GSI) set up for the first time in 1969, a basis net work of 410 Ground Water Stations in various hydrogeological settings. The Central Ground Water Board (CGWB) was constituted as a national apex organisation in 1972 by the merger of Ground Water Wing of Geological Survey of India with the erstwhile Exploratory Tubewells Organization(ETO). The Central Ground Board has since increased this number to about 8000 (Water Resources of India, 1988); water levels are monitored five times a year and water samples are collected twice a year once before and once after the monsoon, for analysis of the chemical quality. The

Central Ground Water Board keeps the account of replenishable ground water recharge and utilisable water resources on an annual basis. Most of the States have also set up Ground Water Departments and they have their own network of monitoring Stations.

3.3.4 State Government Irrigation Departments

The State Government departments are collecting the hydrological data through their gauging station located in the vicinity of various river systems in the state. At present most of the hydrological data collection activity is based on manual observations. A perceptible beginning is yet to be made for computation & analysis of available data in the State Government Departments. For the network of tstate organisation a reference can be made to National Hydrology Project (1987).

3.3.5 Survey of India

The topomaps being prepared by Survey of India, the national mapping agency and available on various scales including 1:50,000 on a periodicity of 5-6 years, contain some useful information in respect of the water resources e.g. perennial and non-perennial streams, lakes, glaciers, swamps, marshy areas and other physical data of watershed. For selected areas, depending on the specific demands of the various users, large scale maps are also produced by Survey of India. These topomaps are prepared and updated using aerial remote sensing methods (aerial photography).

3.3.6 Geological Survey of India

The Directorate of Engineering Geology of the Geological Survey of India provide data required in water resources development projects such as suitability of dam foundations and flanks, reservoir area stability, surface and subsurface features along water conductors, stability of slopes and general suitability of ground for other hydraulic structures that are required in water resources development projects. These data are obtained during planning, pre-project and subsequent construction stages.

3.3.7 Universities

In India academic institutions including five IIT's and various agricultural universities are carrying out both fundamental and applied researches in the field of water resources for this purpose most of these institutions have their own observatories to collect various hydro-meteorological data.

3.3.8 Research Organisations

The central government has setup research institutes such as Central Water and Power Research Station (CWPRS), National Institute of Hydrology (NIH), Water Technology Centre (WTC), Central Arid Zone Research Institute (CAZRI), National Remote Sensing Agency (NRSA) etc. and similarly the states have their own research stations. These research organisations has setup hydro-meteorological observatories and also conducting infiltration tests in various parts of the country.

3.3.9 Private Agencies

In India, various tea gardens and other private companies require hydro-meteorological information of specific sites for crop water requirement or various related purposes. For the collection of such information they have setup their own observatories. Through these observatories they are collecting precipitation data, wind velocity, relative humidity, maximum and minimum temperature. Some of them are also conducting infiltration tests to get the rate of infiltration of the soils.

3.4 Processed Hydrological Data

The data collected by Indian Meteorological Department are generally published in the form of various reports and records of relevance such as "Daily Rainfall of India" and "Monthly Rainfall of India".

The data collected by Central Water Commission are published as "Annual Water Year" and "Annual Sediment Year' books. Of late some of the States have also begun to publish such records. For major river basins an attempt has been made to publish an inventory of basic hydrological information. An attempt has also been made to collect and publish certain

Irrigation and Agricultural Statistics.

The Central Ground Water Board has been publishing hydrogeological, hydro-chemical and related maps as also reports on the findings of areas surveyed and explored. The actual data processing depends on specific requirements.

4.0 HYDROLOGICAL DATA PROCESSING

4.1 General Considrations

Rainfall is the most important meteorological parameter which determines the quantity of run-off in streams directly as overland flow and indirectly as sub-surface flow and ground water (base flow). The other important hydrological parameter is stream flow which is required for the efficient day today management and regulation of a river system. The stream flow data are also required for design, planning and modeling purposes. The stream flow data and rainfall data collected from the field have to be processed or reduced in a manner to suit it for an analysis. Similarly, other climatic observational data like snow, pressure, air temperature, are input to various hydrological models. The amount, intensity and areal distribution of rainfall and other climatic data are essential in any hydrological study. Thus, the processing of the hydrological and meteorological data is essential before it is put to further use in analysis.

Data processing is the manipulation of data into a more useful form. Data processing includes not only numerical calculations but also operations such as the classification of data and transmission of data from one place to another.

Basically the data processing has three steps : input, processing and output. These three steps related as illustrated in fig. 4.1 constitute the data processing cycle.

INPUT ——> PROCESSING ——> OUTPUT

FIGURE 4.1 DATA PROCESSING CYCLE

Input : Here the initial data, or input data are prepared in some convenient form for processing machine. The input data could be recorded on any one of several types of input medium such as cards, tapes and so on if electronic computers are used.

Processing: In processing the input data are changed, and usually combined with other information to produce data in a more useful form. The processing step usually involves a sequence of certain basic processing operations.

Output : In output the results of the preceding processing step are collected. The particular form of the output data depends on the use of the data. The output media may be cards, disk, tape and so on. The output data, thus obtained, may be stored for further processing at a later date.

4.2 Hydrological Data Requirements :

The type and extent of Hydrological inputs required depend on the proposed plan(s) of development. The type and form of Hydrological inputs for simulation (working tables) and other studies depend upon the type of structures (which can be classified based on the element of storage) and on the contemplated use of water and storage space.

Table 4.1 Alternate Plans Based on Water Storage and Water Use

Alternate Plans Based on	
Water Storage	**Water Use**
Classification by storage behind the structure	Classification by use of project
Diversion projects without pondage	Irrigation
Diversion projects with pondage	Hydropower
Within the year storage projects	Water supply and industrial use
'Over the year' storage projects	Navigation
Complex system involving combinations of mentioned above	Salinity control
	Water quality control
	Recreation, fish and wild life
	Flood control
	Drainage
	Surface to ground water recharge
	Multipurpose

(Source: derived from Mutreja,1990)

4.3 Inputs

Type of inputs :

The nature of inputs required for simulation studies and studies other than simulation are given below under two different groups respectively :

Table 4.2 Inputs Required for Simulation and other Studies

Inputs Required for	
Simulation	**Other Studies**
Water inflows	Design floods for the safety of structures
Lake Evaporation	Design floods and flood levels for flood control works
Potential evapotranspiration and rainfall	Design floods for design of drainage works
Sediment inflows	Design floods for planning construction and diversion arrangements
Flood inputs	Studies for determination of levels for locating structures on river banks or for location of out-lets
Water quality inputs	Tail water rating curves
Low flow inputs	
Surface to ground water recharge	

(Source: derived from Mutreja,1990)

4.4 Compilation and Processing of Basic Hydrological Data :

Hydrological investigations specially carried out for proposed project keeping in view the guidelines. The details of the specific data collected for the purpose shall be furnished.

All the basic/processed hydrological data available from the various sources as relevant to the project shall be collected, compiled and discussed. The source of such data collected shall be indicated at the appropriate place. Where processed data is available need or otherwise of further processing of the data shall be indicated.

4.4.1 Preliminary processing and scrutiny:

Preliminary processing and scrutiny of the data are essential before the observed data is stored on computer. The preliminary processing includes : verification, valid status, reasonable report, quality of data, filling up of short data gaps, consistency of data, quality control procedures, adjustment of records,

4.4.2 Secondary data processing :

Specific tasks in secondary data processing include: calculation of the averages, preparation of regular time series and miscellaneous graphs showing variations with time and preparation of chronological tables with elementary statistical parameters.

4.4.3 Homogeneity tests

Before subjecting hydrological data to rigorous analysis, they should be checked for temporal and spatial homogeneity, Traditional subjective methods can be used for this as well as objective methods based on statistical techniques.

The best known technique for testing homogeneity in time series is the double mass curve analysis. The spatial homogeneity analysis is very simple but it needs sound practical experience to apply correctly.

4.4.3.1 Double mass analysis

The technique of double mass analysis is well known Briefly it involves plotting the accumulating total of one time series variable against that of another. One of the series is assumed homogeneous; if the plot is an acceptably straight line, the other series is assumed homogeneous too.

4.4.3.2 Analysis of rating curve stability

The purpose of the study to examine the history of rating curve assessments at the site to see if the suspected discontinuity in the flow series have a rational explanation.

4.4.3.3 Residual analysis

The detection of inhomogeneities of hydrological time series is a classical task for hydrologists. In the purely graphical double mass analysis, inhomogenety can be identified with confidence only if it shows as discrete break on the plot. Even the apparently clear changes of slope in appear obvious after a straight line has been fitted to the early part of the record. The main drawback of this method, therefore, is the absence of a statistical test that can quantify the significance of the change. The problem is to distinguish between natural variations and systematic inhomogeneities: the variability of hydrological variables is an a rule very large, which naturally makes it difficult to detect the latter. The problem of setting up confidence limits for a test of non-homogeneities in hydrological time series has been treated by Bernier (1977) and by Gottschalk (1982).

4.4.3.4 Spatial homogeneity analysis

It is equally relevant to test the validity of a data series by examining, for example, its mean value in conjunction with means derived from a number of other series in the region.

4.4.3.5 Statistical tests on means and variances

This section provides the basic theory for testing whether two data samples should or should not be regarded as having come from the same parent population.

Objective homogeneity tests of hydrological data series are most usefully carried out by someone who also understands the physical processes at work. If the basic observational data demonstrates non-homogeneity, it is as important to understand the reasons as to quantify the certainty with which it can be inferred.

Whenever a quantitative estimate of data homogeneity is needed one should apply statistical tests for mean and variance making due allowance for correlation within and between the data series.

Homogeneity testing begins with estimation of the homogeneity of the sampling variance; Fisher's ratio test is used for this. Homogeneity testing of the sample mean is carried out using Student's t-test.

4.4.4. Estimation of accuracy

A prerequisite for any study using hydrological data is that the investigator should be aware of their quality (i.e. reliability, accuracy). Before data are used, therefore, they should be reviewed from a qualitative point of view. The methods of determining data accuracy give an estimate to random errors in the data but do not reveal anything about systematic errors.

4.4.5 Filling in gaps

Historic hydrological series are often too short or include too many gaps for solving major problems. The techniques exemplified in this chapter are based on relations between such short or incomplete series and those from neighbouring sites which may be complete and/or longer. There are basically two approaches, multiple station correlation and rainfall-runoff relations.

4.4.5.1 Multiple station correlation

In the case of inadequate hydrometric data, the adjustment, by linear regression, of the estimated parameters of the distributions of hydrological characteristics to a longer period can be carried out. There are several ways of estimating the parameters of the distribution of the hydrological characteristic of the short-term station. Some of them are: graphical method, grapho-analytical method, use of other data series etc.

4.4.5.2 Rainfall-runoff relations

In this case, the systematic records of runoff were not sufficiently long to perform a frequency analysis. In order to extend the record the conventional approach of regression analysis to establish the rainfall-runoff relation was carried out. However, there is an alternative, namely the application of a deterministic rainfall-runoff model. This has several important advantages; for example, it allows consideration of man's activity within the basin.

4.4.6 Recovery of natural streamflow

Many historical streamflow records reflect upstream regulations and/or abstractions. For a variety of hydrological analyses the observed flow must be corrected in order to re-establish the natural flow (Sokolov et at, 1982). In some cases the correlation method can be very simple, namely eliminating the effect of man-made structures such as dams. The recovery of natural streamflow with variations larger than the accuracy of its determination may be done by of three methods : correlation method, runoff analogy method and water balance method (Shiclomanov, I.A., 1979).

4.4.7 Analysis of processed data :

Various analyses normally performed with the processed data are : time series analysis, correlation and regression analysis, frequency analysis and computation of frequency curves and forcasting etc.

4.5 Processing of Rainfall data

4.5.1 Preliminary processing and scrutiny

It is necessary to carry out preliminary checks, inquires and manual scrutiny of the data before storing the precipitation data on computer compatible device for machine processing by computer.

The preliminary processing ensures the completeness of data for the period under consideration in respect of relevant details like station identification, data, time and other visible errors. The reasonableness of the report is checked by using appropriate verification and validation techniques.

There are several types of errors occuse while measuring and registering the hydrological data. On a first inspection, same of these may be indentified and corrected at once, same noted and marked and other may remain undetected. There can be generalised as :

a. Instrumental error

b. Misreading, misplaced decimal points, copying errors and airthmetic mistakes.

c. Accumulated readings over several days entered as if a one-day total.

d. Correct reading entered on wrong days, persistently or only occasionally.

e. Occasional errors due to temporary disturbance of the gauge or its exposure.

f. Systematic errors caused by gradual alteration of exposure over a long period (years) or a leaking gauge with increasing losses.

The automate basic or synoptic network stations supply the zero precipitation which is an acceptable report. Therefore, care has to be taken so that the zero report are not caused by instrumental mal-function.

Positive but likely reports are the most difficult to detect. These reports could be in error because of transpose digits in the report, misreading by observer and spurious pulses occuring in recording and transmitting in the case of automate gauges.

4.5.1.1 Verification

It is very important to verify the reports received from manually observed stations by telephone or other communication channels like wireless verified by a repeat back system. In case of data received from telemetering raingauges (Tipping bucket type) or automated weather stations, the parity check or some other checking process has to be devised and carried out.

4.5.1.2 Valid status

Before using or storing rainfall records, the validity of the station should be checked. The worth of rainfall data depends primarily on the instrument, its installation, its site characteristics and its operation by a responsible observer. Therefore, the station should be equipped with standard instrument with proper identification with respect to its location, latitude, longitude, elevation, district and state to which it belongs etc and it should be part of a recognised network. It is essential for a hydrologist using tl data to have direct knowledge of raingauge station, and it is recommended to keep the history of each raingauge station.

4.5.1.3 Reasonable report

Copying or registering error of rainfall data includes entering against wrong date and time, misplaced decimal points and alteration of figures etc. Transmitting errors occur while sending the data either through telegram, wireless by observer or Telemetering by automatic raingauges. The reasonableness of the data received from automatic raingauges by judging the report based on the history of raingauge and other precipitation statistics for the region to which the reporting station belongs.

Before carring out other tests are the internal consistency of the record is to checked. By considering the possible physical, meteorological and climatological constraints, limits of precipitation for the region of interest could be set and the values of precipitation checked against these limits. Any data falling outside these limits is suspect and should be screened more carefully after flagging. The precipitation limits which could be used for checking are

i. Regional parameters like probable maximum precipitation or return period (25,50 or 100 yr) values and
ii. Other locally determined record precipitation values.

The WMO/ World Weather Watch Report (1968) listed some of the values which could be used as checking standards :

i. Forecast value for the actual period.
ii. Polynomial of second or third degree.
iii. Local statistical parameters such as mean or mean some multiple of standard deviation.

Other kinds of test which could be applied include

i. A test to see that the hourly report of precipitation is within the reported maximum and minimum values of the daily record.

ii. A check for occurrence or non-occurrence of precipitation based on the weather reports.

The precipitation values could be checked by examining dew point, cloud amount, type of cloud etc. Particularly in places where data of other meteorological parameters are also observed,

In case of precipitation data reported for shorter durations, the totals of such short period amounts could be compared with the equivaalent long period total precipitation reported.

4.5.2 Estimation of missing data

Some times, it becomes necessary to ascertain time trends in the precipitation data, which may be due to change in the gauge location, changes in the immediate surroundings and changes in the observation techniques. Precipitation for the missing data period is estimated from the data available at the stations surrounding the station under question. If the normal annual precipitation at each of the index stations is within 10 % of that for the station with missing record, a simple arithmetic average of the precipitation at the neighbouring stations provides the estimated precipitation for the missing period(s).

In case, however, the normal annual precipitation at any of the neighbouring stations differs from that at the stations in question by more than 10 %, the weighted interpolation methods are used. The simple well known and In this method the amounts at the index stations are weighted by ratios of normal precipitation value.

4.5.3 Adjustment of missing data

Adjustment of data is necessary to obtain homogeneity among and with measurement of precipitation. It has two principal objectives : first is to make the record homogeneous with a given environment and the second is to eliminate or reduce extraneous influences by correcting for change in gauge location or exposure.

The historical inconsistencies are noticed when the archived data is used for climatological analysis such as ten daily rainfall totals, rainfall series for water availability studies etc.

When data are arranged in long arrays, examination of usual expected trends can enable a trained eye to detect

i. reading entered on worng days or against a wrong station and

ii. wrong entries of amounts due to inadvertence or misprint. The consistency of records at the stations in question is tested by a double mass curve by plotting the comulative annual rainfall at that station against the concurrent cumulative values of mean annual rainfall for a group of surrounding stations, for the number of years of records.

4.5.4 Editing

In case of manually recorded and pre-processed precipitation data there is no need of editing Even if the data are punched on cards, they may be appropriately sorted using a sorting machine for a given precipitation code and fed to the computer. However, necessary editing is to be carried out in case of data recorded on magnetic tapes or data logged in by microprocessors from automatic weather stations and satellite transmitted data from data collection platforms.

4.5.5 Data conversion

Precipitation of shorter duration is often required for hydrological analysis. The network of recording raingauges being small in comparison to that of the non recording raingauges. Therefore, it is necessary to convert of the rainfall recorded at totaling gauges into shorter period (usually hourly) intervals either manually or by using appropriate computer subroutines. The data so converted is generally stored on computer disc files, magnetic files or other such devices.

4.5.6 Areal estimates

The average annual rainfall calculated from the rainfall measured at a rain gauges station is a most important hydrological stastic and is used as input is number of hydrological models. It is, therefore, necessary that areal estimates of precipitation be available in a processed form for use directly as input in the hydrological models. Mean areal precipitation is estimated from the data (observed or converted) of precipitation at a number of locations by means of suitable methods.

4.6 Processing of Snow Data

The objectives of routine data processing of snow observations are as follow :

1. To determine the mean water equivalent of snow, ice and free (snowmelt) water under the snow pack for an entire basin and individual parts of a basin.
2. To calculate the percentage of the coverage of a basin and its individual parts with snow, ice crust and water.
3. To determine an integral curve of the distribution of the water equivalent snow on the surface of a basin.

4.6.1 Errors in snow data

The measurements at regular intervals with no change in site, sampling points, equipment, or technique of observation result an ideally consistent snow-survey record. All too frequently, however, changes have been made without adequate documentation. Therefore, it should not be directly assumed that snow records are homogeneous and all records should be treated as though biased by some undocumented change along the course.

Physical changes at a snow course site may take place due to natural or man's activities. Natural changes consist mainly of increases in tree canopy or growth of brush which changes the interception of snow and modifies the movement of wind. Man-made changes include and construction and logging.

Errors in snow data may be introduced by a failure to re-establish the course on the same site on successive surveys or to change the number of sampling points or by observational inaccuracy.

4.6.2 Tests for consistency

The consistency of snow data is generally tested by standard statistical methods or the double mass curve technique. Another method is to plot historical records of all surveys at each sampling point of a snow course. This may reveal a pattern characteristic of that course. From such a plots or missed samples may usually be estimated. Experience has shown that at any given time the densities of individual samples along a snow course do not vary more than a regular percentage; therefore, a comparision of densities may yield a clue to an inconsistent sample.

Where resurveys are not possible, some questionable snow-course surveys may be adjusted by direct correlation with records from other courses surveyed at the same time. Very high correlation may occur between adjacent snow courses.

4.7 Processing of Evaporation Data

Processing observational data on the evaporation from soil (obtained by evaporimeters) includes the calculation of evapotranspiration, evaporation from soil under the vegetative cover and transpiration; depth of precipitation, the layer of water percolated through soil monoliths into the evaporation pans; soil moisture and water equivalent in soil monoliths; data on the evolution stages and state of the vegetation.

4.8 Processing of Other Climatic Observations, Including Energy Balance

Processing of observational data on pressure, air temperature, humidity, wind velocity, cloudiness, soil temperature, depth of soil frost and thaw is generally carried out by standard methods. Temporal variations of individual climatological elements are checked by comparing various elements. In particular, an evaluation of the reliability of observations of the depth of soil frost and thaw is made by means of comparing temporal variations of these characteristics and temporal variations of air temperature and snow depth.

Major climatological observations may be tabulated as daily, weekly, ten-day, monthly and annual mean values. As a rule, the climatological data measured at the main climatological station may be assumed to be applicable to the entire basin. In some case auxiliary observations are required. Data processing for energy-balance calculations depends on the purpose; for example, the estimation of evapotranspiration from an experimental basin during the most intensive snowmelt period, etc. Note that climatic observations are often made at a fixed time of the day. When correlating, such observations should agree with hydrological data which is frequently based on a day. A standard day should be decided upon (e.g. 00.00 to 24.00 hrs) and all climatic variables adjusted if possible.

4.8.1 Wind

Wind velocity can be recorded manually or automatically. In either case it is the practice to express values in metres per second (daily, monthly and yearly).

4.8.2 Temperature

Temperature data can be recorded manually or automatically. In either case data is to be recorded in degree Celsius to the nearest whole degree. The daily mean temperature can be calculated approximately as the mean of the daily maximum and minimum temperatures.

Other important characteristics are the monthly mean temperature, which is the mean of all the daily mean values for one month, and the annual mean temperature, which is the mean of all the daily mean values for one year.

For some types of climate the following definitions are useful; the monthly mean maximum temperature is the mean of the daily maximum temperature for one month, and the monthly mean minimum temperature is the mean of the daily minimum temperature for one month.

4.8.3 Humidity

Humidity is recorded with an hygrometer or wet-and dry-bulb thermometer. Daily monthly and annual values of relative humidity are recorded as for temperature.

The relative humidity can be read directly from the hygrograph chart. Where only dry-and wet-bulb readings are available, the temperature of the dew point is obtained from the dry-bulb reading and the temperature difference between wet-and dry-bulb readings. The latter is termed depression of wet bulb. Standard psycrometric tables are used to convert wet-and dry bulb readings to values of relative humidity, expressed as a percentage.

Of the methods for expressing humidity the vapour pressure one is probably the most useful. Vapour pressure can be obtained, together with dew point, from wet-and dry-bulb readings using standard psycrometric tables.

4.8.4 Radiation

Solar radiation data is tabulated in langleys (1 small calorie per square centimeter of surface per minute) for daily, monthly and annual values.

Sunshine duration records are tabulated as hours of sunshine.

4.8.5 Energy balance

Energy aspects of a number of hydrological processes and, in particular, energy losses by evapotranspiration from a basin, are evaluated by energy-balance calculations. It is particularly desirable to make such calculations on experimental basins where detailed research in all aspects of the hydrological cycle is carried out.

4.9 Processing and Analysis of Stream Flow Data

Stream flow data collected from the field as such can not be utilised in hydrological studies and the processing of the raw data is extremely essential. Processing and analysis of stream flow data includes :

4.9.1 Preliminary processing and scrutiny:

Preliminary processing and scrutiny of the data are essential before the observed data is stored on computer. The preliminary processing includes :

4.9.1.1 Verification

The reports received from manually observed stations by telephone or other communication channels like wireless need to be checked by repeat back system .

4.9.1.2 Valid status

The station reporting should form part of a standard network accompanied by proper identification with respect to its location i.e. latitude, longitude, district and state to which it belongs.

4.9.1.3 Reasonable report

Improper registering of data includes entering against wrong time and dates alteration of figures etc. Also transmission errors occur while sending the data either through telegram or wireless.

4.9.1.4 Quality of data

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.

4.9.1.5 Filling up of short data gaps

The following are some of the techniques which can be used for gap filling :

i. Random choice from values observed for that period.

ii. Inter-polation from adjoining values by plotting a smooth hydrograph (for run-off alone)

iii. Normal ratio method (for rainfall alone)

iv. Distance power method (for rainfall alone)

v. Double mass curve techniques.

vi. Correlation with adjoining station either of the same hydrologic element or of different hydrologic element.

vii. Auto correlation with earlier period at the same station.

4.9.1.6 Consistency of data

i. Internal consistency check

The study of consistency of the observed data at specific control points and correction 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 cyclic variation of the climate.
- To observe the modification of catchment physiography especially through human activity.

ii. 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.

It may be noted here that the consistency can be checked by :

- Comparing monthly and annual rainfall with corresponding run-off.
- Comparing average annual specific flow expressed in depth unit with corresponding figures at other sites of the same river or adjacent basins.
- By comparing the hydrograph of daily discharge at the control point with adjacent sites etc.
- By use of double mass curve techniques.
- Trend analysis.

4.9.1.7 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. The estimates may be based on regression equations. By transforming the data it is possible to increase the weight on high or low values. By plotting the estimates possible errors are easily identified.
- Comparing the observed data with estimates based on a precipitation-run-off.

- Checking for negative values during the computation of inflow to a reservoir when the stage-storage relationship and the outflow are known.
- Comparing the run-off at a station with run-off 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 comparison of monthly and annual stream flow deficits.

4.9.1.8 Adjustment of records

The adjustment of flows to natural and virgin conditions for historical uses in the upper reaches and the manner in which this has been done should be discussed duly supported by the withdrawal data, reservoir operation data and irrigation statistics. Where adjustments due to upstream storage are made, such storage changes and evaporation losses are to be properly accounted for. Apart from addition upstream withdrawals return flows have to be subtracted.

1. The adjustment of the observed flows data may not be necessary if :

   - The utilisation by upstream projects has been same throughout the period of observation of flows.
   - If the pattern and quantum of usage has not changed appreciably for with a definite trend.

2. Adjustment with flow records in required in those case where appreciably changes in land use have taken place.

3. Adjustment of floods and low flows to remove the effect to upstream regulation may be required where this is appreciable.

4.9.2 Secondary Data Processing :

Specific tasks in secondary data processing include :

- Calculation of the average areal rainfall over river basins.

- Calculation of mean velocity and discharge based on stream gaugings.
- 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 values (means, totals, extremes or frequencies of occurrence) with elementary statistical parameters, discharges classified into ranges and probability envelope curves (tables and graphs), and characteristic discharges and probability envelope curves etc.

4.9.3 Analysis of processed data

The following analyses are normally performed with the processed data :

- Computation of flow- duration curves.
- Computations of summation and Regulation curves.
- Computation of the inflow to a reservoir.
- Routing of flood through reservoirs or River channels.
- Flood forecasting.
- Computation of flow-frequency curves.
- Flood frequency analysis.
- Low flow frequency analysis.
- Analysis of flood or low water volumes.

- Multiple regression analysis.
- Time series analysis.

4.10 Processing of Soil Moisture

Soil moisture data reject the moisture status of the zone of greatest hydrological activity. The soil-moisture status reflecting the condition of the soil immediately prior to the occurrence of precipitation of snowmelt is important for snowmelt or precipitation-runoff relationship. Soil moisture data are also essential in hydrological model and water balance studies.

Data processing of soil moisture may include :

i. estimation of soil moisture content of differnt soil horizons;

ii. determination of water content of the zone of greatest soil-moisture change for soil moisture profile at every observation point or at master sites only;

iii. determination of the soil moisture profile at every observation point or at master sites only

iv. estimation of the variations of the basin soil moisture between observational dates.

To defect sampling errors it is useful to compare soil moisture data observed at similar depths with adjacent observation points. Missing records may often be replaced by correlation techniques. A further check of soil-moisture variations with precipitation will indicate approximately the validity of increase in soil moisture.

4.11 Processing of Sediment Data

Sediment transport depends on the physical properties of the sediment, as well as on the hydraulic characteristics of flow. Many of the cross section plotting techniques for the gauging are directly relevant to the validation of suspended sediment data. The two sets of data may be validated together if both sediment and velocity observations were made. The relation of suspended-sediment load to discharge in often called a sediment rating curve and is usually shown as a plot, on logarithmic paper, of suspended sediment in units of weight per unit of time against discharge of sediment water mixture.

It sediment yield are calculated from the average concentration of sediment in a series of sample, a substantial error may result unless the data cover wide ranges in discharge and in concentration. Errors of this kind are minimized if discharge-concentration or sediment rating curves are applied to instantaneous discharge similar to daily mean discharge calculations.

When sufficient quantities of data exists, the mass balance calculations may be performed. A useful check where catchment reservoir is to test that rivers sediment loads within a reasonable distance downstream of the reservoir are less than those upstream. The departure of the sampled value from curve may be estimated for statistical significance and/of plotting for manual sorting if a sediment rating curve exists for section sampled.

4.12 Processing of Groundwater Data

In designing a groundwater data collection programme in a basin and processing them, many considerations are involved. The concepts that are probably the most important are given below :

i. Groundwater is not an isolated resource because, except in special cases, precipitation and surface water of an area are part of the boundary conditions for the groundwater body, they are part of the input output of a complex system. Groundwater basin geology, basin precipitation, surface streams are either inherent properties or boundary conditions of the groundwater body. As such, these data may have equal or greater rank than data derived from water level measurements.

ii. Groundwater data are usually not directly transferable from one basin to another. Streamflow data can be transferred in the sense that the sequence of flows in different streams can be correlated with meteorologic phenomena that affect, to some extent, all the streams in a region.

iii. A data collection program is meaningful only within a problem solving context. In other words, the design of a data collection program must be in response to an overall plan established to achieve a well specified and feasible objective such as developing and testing an appropriate model of a groundwater system. The need for groundwater data is related directly to the stresses imposed on the system natural or an made, because the response to a particular stress may occur at a distant point long after the event. In other words, a properly designed system for the collection of groundwater data must be organised around solving problems and only on the basis of solving existing or potential problems specific to individual groundwater basin.

iv. A very general objective of all groundwater data collection programme is to produce useful facts for the present and /or future control and management of aquifers.

v. The groundwater problems are characterized by relatively small time variability and pronounced spatial or areal variability. because of pronounced areal variability of the groundwater system, the hydrologic data collection programme places major emphasis on the appraisal of areal units.

4.12.1 Observation network & requirement of ground water for analysis (ground water balance)

Aquifer calibration require reliable water level contour maps. Water level gradient are commonly in the range 0.1 % - 1.0%. Observation points spaced at 2 km distance from each other will enable the drawing of contour lines at 2- 10m intervals and this is approximately work. Much closer spacing is often required atleast in certain parts of the area.

For administrative purpose wider spacing is acceptable. It can often be shown by statistical correlations that water levels in a certain area are represented fairly well by observations in one borehole. However, this conclusion remains valid only as long as the pattern of groundwater abstraction does not appreciably change.

Records obtained by monthly water level measurements are sufficiently detailed for most purposes. Recording instruments are indispensable for specialized researches that require the continuous monitoring of water levels, but their installation for the purpose of routine observations does not always prove to be advantageous.

Monitoring of water quality is almost always carried out by water samples taken from exploited wells. Yearly or twice yearly measurements of electrical conductivity are required for the purpose of general supervision. Closely spaced observations and more detailed analyses are necessary where significant changes of water quality are anticipated.

The following data are required for water balance study and groundwater modeling.

1. Topographical map of the basin
2. Maps showing layout of existing main canals, branch canals and their distributories in the study area

3. Geological and Hydrogeological maps of the area
4. Maps showing locations of raingauge stations and meteorological observatories
5. Daily rainfall data at raingauge stations lying within and around the study area for a period of atleast 10 years
6. Daily pan evaporation values for the above duration
7. Daily minimum and maximum temperature, minimum and maximum relative humidity, average wind speed, sunshine hours for the above duration
8. Cross sections of canals and their distributories
9. Monthwise discharge in main and branch canals and their running days
10. Depth of water in the main and branch canals
11. Data on seepage from canals
12. Monthly stage and discharge data of river
13. Soil types and hydrological soil properties e.g. infiltration capacity, hydraulic conductivity and field capacity
14. Litholog of tubewells with locations
15. Pumping test data to evaluate transmissivity and specific yield
16. Monthly water table data observed at observation wells in the study area
17. Groundwater withdrawal data : location of existing state tubewells, private tubewells, pumping sets, open wells fitted with mechanical device or otherwise, sample survey

of drafts and running hours

18. Land use data : Forests, orchards, tall vegetations, urban area, water logged areas, cultivated areas, canal irrigated area, well irrigated area and unirrigated area

19 Existing cropping pattern

20. Existing irrigation practices

4.13 Processing of Water Quality Data

Observed chemical water-quality data should be processed by calculating the difference between the total milligramme-equivalents and the estimated concentration of anions and cations. The ionic run-off is determined by plotting discharge in 1/sec on the ordinate against inoic concentration in mg/1 on the abscissa. A curve is drawn through the mean of the points. Applying this curve to the discharge hydrograph, the daily mean ionic concentration may be derived. By multiplying the daily mean inoïc concentration (mg/1) by the mean daily run-off (in litres), the daily inoic run-off (in mg) can be calculated.

Adding these values for corresponding periods, the total values of inoic run-off for month, season and year may be derived; these are usually expressed in tons/km^2 of a respresentative or experimental basin area. With the accumulation of new data the graphs should be brought up to data.

The result of chemical quality observations may be tabulated. Such a table would contain water sampling and analysed data, individual ionic concentrations of samples, etc.

4.14 Automated Processing of Data

It is desirable to process the basic observational data in the form most valuable to the users, before or immediately after publication. Depend on the needs of the most important and most numerous users of the data in any country, the types of processing is selected.

The publication of data subjected to data processing does not necessarily supersede publication of the basic observational data. However, rapid storage and retrieval of data by means of computerized techniques may eventually rusult in no need, or at least much less need, for publication of data.

4.14.1 Automated process

4.14.1.1 Digital recorder

Digital recorders are being used more extensively (especially for recording river stage) because the data from such recorders are usable for computation and analysis by computer. The digital recorder now in use in several countries is a battery-operated, slow-speed, paper-tape punch that records four-digit number on a sixteen-channel paper tape at preslected time intervals. The paper tape format requires rearrangement before input to any of the presently available high-speed digital computers. For greater detail on the digital tecorder and its application, refer to the literature. Once the data have been translated into machine-usable form, they may be processed by a computer through a wide variety of spacial programmes.

4.14.1.2 Pencil follower

A new development is the pencil follower which is a device for transferring either manually or semi-automatically a chart record into machine-usable form (punchards,paper tape of magnetic tape). One type, developed in the United Kingdon (D.Mac Pencil Follower) is suitable for all types of chart, including circular ones. The operation is either manual or semi-automatic and an average chart record can be converted into digital form in about five minutes. Another type, developed by the CSIRO, Austrilia, is particularly suited for continuous charts.

4.14.1.3 Punchcard system

Observed hydrological data are frequently transferred to punchcards for data processing and analysis.

Samples of soil are often collected during sampling operations for hydrological studies. These samples are chosen to be representative of the depths and soils of particular interest to the soil-moisture study. The hydrological and physical properties of these samples are obtained by suitable analyses in the laboratory.

The data are recorded on special summary forms by a suitable system of numerial and alphabetical codes. These coded data are transferred directly from the summary forms to punchcards by the key-punch operator. The punchcards are used for automated print-out of tables of data, for data computations and statistical analysis, and for other data processing by computer techniques.

4.14.1.4 Computer programmes

A wide variety of computer programmes is available for continuous processing of routine field data, as well as for processing specialized data for a variety of research purpose (Toebs & Ouryvaev, 1970).

5.0 MODEL CLASSIFICATION AND HYDROLOGICAL MODELS

Hydrological models require various hydrologic, meteorologic and related data as input. Processing of the these data is essential before putting the data as input for such models. It is fact that the hydrological modelling and data processing are inter-related. This section describes the basic definition of hydrologic modelling, classes of mathematical models and provide a brief review of available hydrologic models.

5.1 Hydrological Modelling

Models, regardless of their purpose, are simply representations of how some part of the real-world operates. Models often essential for the solution of complex problems, but models do not have to be complex to be successful. In fact, models can vary in structure from simple, logical statements, to network diagrams, to sets of detailed mathematical equations. With the availability of present-day electronic computer systems, the development and application of models in the management water resources has progressed very rapidly.

Models can be deterministic or statistical in development. A deterministic model illustrates relationships among variables without consideration of randomization among variables in terms of probability distributions. Both types of models are useful and have a role in studying the consequences of alternative courses of action in the management of water resources.

Simulation techniques are employed to reproduce the behavior of a system in the form of a model that, hopefully, represents real-life. Through simulation, appropriate models are operated to generate alternative solutions to management problems. Simulation techniques do not necessarily produce optimal solutions. Instead, they predict impact of alternative actions, allowing a user to make decisions on the levels of inputs that are best for a specified purpose.

Simulation exercises frequently are carried out on digital computer systems, since these exercises typically require many kinds of calculations. However, the concept of simulation is not dependent upon the use of electronic computers. In fact, simpler simulation exercise can be completed without them.

5.2 Classes of Mathematical Models

So many classifications of mathematical models are given in the literature that it is not possible to include all these classifications. The classification of any model depends upon its uses. A pairwise comparison of models is given. (Bhatia, 1988)

5.2.1 Research models and management models

It is very difficult to distinguish the two from the point of view of usefulness. Management models are mostly used as management tools whereas research models are used as research tools. For example eutrophication models have been widely used as research tools in addition to its use for management. Similarly CO_2 climate model is at present more useful to make further research rather than as a predictive model.

5.2.2 Deterministic and stochastic models

In case of deterministic models the values are computed exactly whereas in the stochastic model the predicted values depend upon probability distribution. Mostly the models used in water quality and sediment routing are deterministic. It can be concluded from the literature that our experience in this field is not advanced enough to allow the use of stochastic modelling, although some attempts have been made.

5.2.3 Compartment models and matrix models

In the case at compartment models, the variables defining the system are quantified by means of time dependent differential equations whereas in case of matrix models matrices are used in the mathematical formulations. Mostly the models used in water quality are sedimentation field are compartment type but some biodemorgraphic ecological models and using matrix models.

5.2.4 Reductionistic models and holistic models

The difference between these two types is that the holistic models use general principles whereas the reductionistic models include as many relevant details are as possible. In this field limited attempts have been made to use holistic models.

5.2.5 Steady state models and dynamic model

In case of steady state models the variables defining the system are not dependent on time (or space), whereas in the case of dynamic models the variables defining the system are functions of time. Normally in water quality and sedimentation field steady state models do not find much use as they did not predict the time varying phenomena. Though there are some models which are steady state.

5.2.6 Distributed models and lumped models

In case of distributed models the parameters are considered function of time and space and in the case of limped models the parameters are within certain prescribed spatial locations and time, and are considered constants. Distributed models are used normally when large ecosystems are to be modelled. For the purpose of our studies lumped models are sufficient.

5.2.7 Linear models and nonlinear models

In the case of linear models first order equations are consecutively used whereas in non-linear models one or more of the equations are not of the first order. In principle there is no difference between linear and non-linear models, only thing is that linear type has a simpler form than the non-linear type. Most of the environmental systems models contain non-linear expression such as hyperbolic or exponential expressions. With the advent of modern computer techniques there seem to be reason to force such models into linearity for the sake of saving some milliseconds of computer time.

5.2.8 Casual models and black box models

In case of casual models inputs, state variable and output are interrelated, whereas in the other case the input disturbances affect only the output responses. In case of environmental modelling, an understanding of the system is required and hence casual modelling is normally used. The black box models do not certain any understanding of the system constituents & their relationship.

Table 5.1 A List of Notable Hydrological Models

Sl. No.	Name of Country	Name of Model	Name of Model Developer	Purpose of Forecast	Number of parameters
1.	Austrilia	Commonwealth bureau of meteorology model(CBM)	Commonwealth Bureau of Meteorology, P.O. Box 1289K,Melbourne, Vic.3001, Australia	short term forecast of flood heights	9
2.	Australia	Rainfall-Runoff Routing (RORB) Model	Laurenson and Mein (1983)	Flood estimation, design of spillway and detention	
3.	Australia	Runoff routing model		Floods from ungauged catchments	2
4.	Australia	Watershed Bounded Network Model (WBNM)	Boyd et al. (1979a, 1979b)	In general similar to RORB model	
5.	Australia	Australian Representative Basin Model (ARBM)	Chapman (1968)	discharge	12
6.	Canada	Guelph Agricultural Watershed Storm Event Runoff (GAWSER) model	Ghate & Whiteley (1977,1982)	estimates the surface & subserface runoff to assess pollution from land use activities and the effect of land use change	
7.	Canada	UBC		Flow forecasting with snowsmelt	
8.	China	XinanJiang Model (XJM)	Zhao et al. (1980)	To estimat effective rainfall	9
9.	Denmark	Susa Catchment Model (SCM)	Refsgard (1981)	stimulates the total annual streamflow and low flow	
10.	France	Girard I	Orstrom, 19 rue E. Carriere, 75018-Paris, France	various	12
11.	France	BILIK		General forecasting	
12.	France	CREC		Forecasting discharge	

Sl. No.	Name of Country	Name of Model	Name of Model Developer	Purpose of Forecast	Number of parameters
13.	Israel	Mero		Cyprus water planning	
14.	ITALY	Constrained linear system (CLS)	IBM Scientific Centre, Via S.Marie 67, Pisa, Italy & Hydraulic Inst. of Pavia University, Piazza Leonardo da Vinci, Pavia Italy	Flood forecasting	Several est.as those necessary spacify the IUH for a given time
15.	Japan	Storage type model (Tank I)	National Research Central for Diasaster Prevention, 1-Ginza Higasi 6, Chuo-Ku, Tokyo, Japan	Discharge forecasting for water management	12-24
16.	Japan	Kizugawa Model (Tank 2)	--do--	Discharge forecasting for water management	3
17.	Romania	The flood fore-casting model (IMH2 - SSVP)	Institute of Meteo-rology and Hydro-logy,SOS,Bucaaresti-Ploiesti 97,Bucarest, Romania	Rain floods	13
18.	South Africa	HYRBUN		Flood hydrograph simulation	
19.	UK	Nash Model	J.E.Nesh (1957)	Surface runoff forecasting	2
20.	UK	River catchment flood model		Runoff for gaged and ungauged catchments	
21.	UK,France	System Hydrologi-European		Precp. rate ET loss model Overland channel flow model unsaturated flow saturated flow	4 2 3 3 2 2
22.	USA	Streamflow Synthesis and reservoir operation regulation (SSARR)	Corps of Engineers, Portland,Oregon, USA	Flood and low water warning for reservoir	Several establish-ed by trial & error error

Sl. No.	Name of Country	Name of Model	Name of Model Developer	Purpose of Forecast	Number of parameters
23.	USA	National water service hydrologic model (NWSH)	National Weather Service, Silver Spring, Mary Land, USA	Flood & low flow forecasting for water resources	18
24.	USA	Sacramento river forecast centre hydrologic model(SRFCH)	National Weather Service, River Forecast Centre Sacramento, California, USA	Flood and low flow forecasting for water management	11
25.	USA	TR-20 Storm water	Soil Conservation Service (1973)	evaluation of flood events	7
26.	USA	(SWMM)	Metcalf and Eddy, Inc. et al.(1971)	stormwater runoff and combined sewer overflow	
27.	USA	Stanford Water Model IV (SWM)	Carwford & Linseley (1966)	Synthesizing hourly or daily streamflow at a watershed outlet	
28.	USA	USGS	Dawdy et al. (1972)	Parametric rainfall-runoff simulation model	
		HYMO	Williams & Hann (1973)	Planning flood precention projects & forecasting floods.	2
29.	USA	Huggins-Monke (HM) Model	Huggins & Monke (1968)	distributed streamflow simulation model for both gauged & ungauged watersheds	
30.	USA	Massachusetts Institute of Technology (MIT)	Maddaus & Eagleson (1969)	Flood hydrograph using linear storage & linear channels	2
31.	USA	Kansas Model	Smith & Lumb (1966)	simulates stream flow	

Sl. No.	Name of Country	Name of Model	Name of Model Developer	Purpose of Forecast	Number of parameters
32.	USA	USDA Model	Holtan et al. (1969)	stream flow predection, simulate soil erosion, transport of chemical & environmental impact assessment	
		Systeme Hydrologique Europeen (SHE) Model	Abbott et al. (1986)	modelling the impact of people on land use change & water quality & other commercial uses	18
33.	USA	Ohio State University Model (OSUM)	Ricca(1972)	modified version of SWM	
34.	USA	HEC	Hydrologic Engineering Centre (1981,1982)	Flood and low flow forecasting	
35.	USSR	Rainfall-runoff model of the hydrometeorological centre of the USSR (HMC)	Hydrometeorological Centre of the USSR, Bolsevists Kaja-13, Moscow-123376, USSR	short term forecast of rain floods	11

Table 5.2 Commonly Used Receiving Water Quality Models (Whitehead, 1984)

Sl.No.	Mode Name	Commonly Used Acronym	Originator
1	2	3	4
CHEMICAL REACTION MODELS			
Analytically Integrated			
1.	Streeter-Phelps Dissolved Oxygen Equation	-	Indian State Board Bloomington, Indiana
2.	Laumped Parameter Nutrient Budget Model	-	Centre for Inland Waters, CAnadian Fisheries Research Board, Barlington, Ontario.
3.	Long Term phosphorus Balance Model	-	Battelle Pacific North-west labs, Richland, Washington.
4.	Steady- State Stream Network Model	SNSIM	Us Environment Protection Agency-Region-II, New Yark.
5.	Simplified Stream Model	SSM	Hydrosciences, Inc. Westwood new Jersey
Numerically Integrated			
6.	Dissolved Oxygen Sag Model	DOSAG-1	Texas Water-Development Austin, Texas
7.	Dissolved Oxygen Sag Model (revised version)	DOSAG-3	Water Resources Engineers Austin, Texas
8.	SOL, DOSAG Modification	DOSCI	Stream Control Inc., Palo Alto California
9.	Automatic Quality Model	AUTO-QUAL	U.S.Environmental Protection
10.	Receiving Water Model Module of SWMM	RECEIV	Water Resources Engineers Walnut Creek, California

1	2	3	4
11.	Receiving Water Model (modification)	RIVSCI	Systems Control, Inc., palo Alto-California
12.	Receiving Water Model (modification)	WRECEV	Water Resources Engineers,Austin, Texas
13.	Deep Reservoir Model	DRM	Water Resources Engineers, Walnut Creek, California
14.	Lake Ecologic Model	LAKSCI	System Control, Inc., Palo Alto, California
15.	Reservoir Water Quality Model	EPARES	Water Resources Engineers Austin, Texas
16.	Hydrocomp Hydrologic Simulation Programme	HSP	Hydrocomp, Inc., Palo Alto California
17.	Water Quality Feedback ($HARO_3$ modification)	FEDBAKO-3	U.S.Environmental Protection Agency Region-II New York
18.	Two Dimensional Stream Model	-	Water Resources Division, US Geological Survey, Washington, D.C.
19.	Outfall Flume Model	PLUME	US Environmental Protection Agency, Pacific Northwest Laboratory, Corvallis Oregon
20.	Willametee River Model	WIRQAS	Water Resources Division, US Geological Survey, Washington D.C.
Ecologic Models (All Numerically Integrated)			
21.	River Quality Model (QUAL-I modification)	QUAL-II	Water Resources Engineers Walnut Creek, California

1	2	3	4
22.	Lake Ecologic Model (DRM modification)	LAKE	Water Resources Engineers Walnut Creek, California
23.	Lake phytoplankton Model	LAKE-1	Department of Civil Engineering, Manhsttan College, New York
24.	Eutrophic Lake Quality Model	-	Battelle Pacific Northwest Labs, Richland, Washington
25.	Lake Ecology Model	CLEAN ClEANER	International Biological Program, Rensselaer Polytechnic Institute New York
26.	Water Quality in River	WQRR HEC 5	Us Army Corps of Engineers Hydrologic Engineering Center, Davis, California
Surface Runoff Models			
27.	Field runoff	CREAMS	US Deptt. of Agriculture Research Service.
28.	Storm Water Runoff	STORM	Environmental Protection Agency

6.0 CONCLUSIONS

The advent in scientific and engineering hydrology has necessitated the development of hydrological network and data processing systems. Systematic hydrological data processing is desirable to bring data in the form most valuable to the users. In any country the types of processing performed depend on the needs of the most important and most numerous users of the data. A sufficiently good number of countries have well established and expanded hydrological networks, producing correspondingly increasing quantity of data. However, because of the shortage of suitable trained personnel and inevitable pressure to perform urgent work at the expense of routine data processing, much of the collected data remains unprocessed. The manual processing technique become totally impractical, except for limited individual studies, due to increasing volume of unprocessed data. The automated data storage and processing using computer memories, magnetic tapes, microfilms etc. is now become essential in such situations. Modern computers can work at very high speeds and at the same time are very reliable. These computers can handle voluminous hydrological data in a more efficient manner. It is well known that a computer may not do anything that could not be done manually, given enough personnel and enough time. However, it will do repetitive computations with such speed and accuracy that man can now afford to process many more hydrological data than ever before and can try new methods which could never be processed earlier.

In the present report an attempt has been made to systematically put together data processing operations, data analysis, hydrologic data and data measurement/estimation, data availability and organisations involved in the field of data collection in India, hydrological data processing and hydrological modelling.

From a careful study of the present status of data processing and analysis it can be concluded that status of hydrological data processing studies, in Indian context has improved marginally in recent times, hence there is an urgent and crucial need to take up extensive studies. As we can observe that India has a long history of collection of hydrologic and meteorologic data. The record/data rooms of various organisations are full of good, long and precious data which can be very valuable if it is processed. If immediate steps are not taken such data may be lost for ever. Hence the strategy for processing the data would have to be two pronged firstly processing of all past data in a usable form and secondly storing and processing.

Therefore, keeping in view the necessity and importance of various aspects of the hydrological data processing discussed in the report, following points are concluded :

1. With the advent in engineering hydrology it is proved that the manual data processing is totally impractical for the increasing volume of various hydrological data.

2. Automated data processing using computer can help in repetitive computation with such speed and accuracy that man can now afford to process many more data and can try for new methods for research purpose.

3. With the help of specialized trained persons in the field of hydrological data collection and processing a significant improvement can be made in hydrological data collection, quality control, storage, retrieval and analysis. Hence there is an urgent need for training persons in data processing and data analysis. It would also be necessary that such trained people continue work in this area for sufficient time.

4. In India large volume of hydrological data collected by various central and state government organisations is stored in registers and a major part of it is raw or unprocessed.

5. An immediate step is required to process the large volume precious past data available with various organisations.

6. It is also necessary to adopt/develop a continuous data processing technique for storing and processing of current data.

7. A wide variety of computer programmes are available for continuous processing of routine field data, as well as for processing of specialized data for a variety of research purposes. It would be necessary that users manuals of these models are prepared in simple language, relating to Indian situations and availability in Indian context.

8. Collection, quality control, storage, accessibility, and analysis of hydrological data can be improved significantly with specialized trained persons working in field.

In the light of afore-mentioned points, the problems selected for the project, thus, include :

1. Selection of a computer software on the basis of its importance and input requirements.

2. Use of available software with data from a typical Indian basin or development and use of PC based softwares for hydrological data processing and analysis and testing their applicability (or making them applicable).

Hydrological data processing and analysis study to be carried out would be presented in the form of a Report of National Institute of Hydrology, Roorkee, India. The copy of the report can be made available to various central and state government organisation working in the country whenever required. Once the report for hydrologic analysis of a typical basin, using present day data processing and analysis methods is available, it will provide an appropriate model example for studying the hydrology of other basins by various central, state & research agencies.

APPENDIX I

LIST OF INDIAN STANDARDS OF METEOROLOGICAL INSRUMENTS

IS : 4849-1969	Specification for rain measures
IS : 5225-1969	Specification for raingauge, non-recording
IS : 5235-1969	Specification for raingauge, recording
IS : 5793-1970	Specification for aneroid barometers
IS : 5799-1970	Specification for mercury barometers
IS : 5799-1970	Specification for windvane
IS : 5900-1970	Specification for hair hygrograph
IS : 5901-1970	Specification for thermograph, bimetallic
IS : 5912-1970	Specification for anemometer, cup counter
IS : 5924-1970	Specification for clock mechanisms and drums for meteorological instruments
IS : 5945-1970	Specification for barograph, aneroid
IS : 5948-1970	Specification for thermometer screens
IS : 5973-1970	Specification for pan evaporometer
IS : 6805-1973	Specification for assamann phychrometer
IS : 6806-1973	Specification for snowgauge
IS : 6871-1973	Specification for distant indicating wind equipment
IS : 7243-1974	Specification for sunshine recorder
IS : 7244-1974	Specification for thermometer for mercury barometer
IS : 8754-1978	Specification for electrical anemograph
IS : 9085-1979	Specification for correction slide for mercury barometers
IS : 10473-1983	Specification for cloud serchlight
IS : 11876-1986	Specification for airmeter

APPENDIX II

LIST OF INDIAN STANDARDS ON STREAM GAUGING EQUIPMENT

IS : 3910-1966	Specification for current meters (cup type) for water flow measurement
IS : 3911-1966	Specification for surface floats
IS : 3912-1966	Specification for sounding rods
IS : 3913-1966	Specification for suspended sediment load samplers
IS : 3917-1966	Specification for type bed material samplers
IS : 4073-1967	Specification for fish weights
IS : 4080-1967	Specification for vertical staff gauges
IS : 4858-1968	Specification for velocity rods
IS : 6064-1971	Specification for sounding and suspension equipment
IS : 9116-1979	Specification for water stage recorder (float type)

APPENDIX III

LIST OF INDIAN STANDARDS ON METHODS OF MEASUREMENT OF FLOW IN OPEN CHANNELS

IS : 1192-1981	Specification for velocity-area methods for measurement of flow of water in open channels (first revision)
IS : 2913-1964	Recommendation for determination of flow in tidal channels
IS : 2914-1964	Recommendations for estimation of discharge by establishing stage-discharge relation in open channels
IS : 4477-(Part 1)-1977	Method of measurement of fluid flow by means of venturimeters Part 1 liquids
IS : 4477(Part 2)-1975	Method of measurement of fluid flow by means of venturimeters Part 2 Compressible fluids
IS : 4890-1968	Methods for measurement of suspended sediment in open channels
IS : 6059-1971	Recommendation for fluid flow measurement in open channels by wiers and flumes-weirs of finite crest width for free discharge
IS : 6062-1971	Method of measurement of flow of water in open channels using standing wave flume-fall
IS : 6063-1971	Method of measurement of flow of water in open channels using standing wave flume
IS : 6330-1971	Recommendations for liquid flow measurement in open channels by weirs and flumes-end depth method for estimation of flow in rectangular channels with a free overfall (approximate method)
IS : 6339-1971	Methods of analysis of concentration, particle size distribution and specific gravity of sediment in streams and canals
IS : 9108-1979	Specification for liquid flow measurement in open channels using thin plate weirs
IS : 9117-1979	Recommendation for liquid flow measurement in open channels by weirs and flumes-end depth method for estimation of flow in non-rectangular channels with a free overfall (Approximate method)
IS : 9119-1979	Method of flow estimation jet characteristics (Approximate method)
IS : 9163 (Part 1)-1979)	Specification for dilution methods for measurement of steady flow Part 1 Constant rate injection method
IS : 9922-1981	Guide for selection of method of measuring flow in open channels

APPENDIX IV

LIST OF INTERNATIONAL STANDARDS PREPARED BY ISO/TC 113 - MEASUREMENT OF LIQUID FLOW IN OPEN CHANNELS

ISO 555/I-73	Dilution methods for measurement of steady flow Part I : Constant-rate injection method
ISO 555/II-87	Dilution methods for measurement of steady flow-Part II : Integration (sudden injection) method
ISO 555/III-82	Dilution methods for measurement of steady flow Part III : Constant rate injection methods and integration method using radioactive tracers
ISO 748-79	Velocity area methods
ISO 772-78	Vocabulary and symbols
ISO 1070-73	Slope area method
ISO 1088-85	Velocity are methods-Collection of data for determination of errors in measurement
ISO 1100/I-81	Establishment and operation of a gauging relation
ISO 1100/II-82	Determination of stage discharge relation
ISO 1438-75	Thin-plate weirs and venturi flumes
ISO 1438/I-80	Thin-plate weirs
ISO 2425-75 (with Amdt I)	Measurement of flow in tidal channels
ISO 2537-85	Cup-type and propeller type current meters
ISO 3454-83	Direct depth sounding and suspension equipment (first revision)
ISO 3455-76	Calibration of rotating-element current meters in straight open tanks
ISO 3716-77	Functional requirements and characteristics of suspended sediment load samplers
ISO 3846-77	Free overfall weirs of finite crest width
ISO 3847-77	End depth method for estimation of flow in rectangular channels with a free overfall
ISO 4359-83	Rectangular, trapezoidal and U-shaped flumes
ISO 4360-84	Triangular profile weirs (first revision)
ISO 4363-77	Methods for measurement of suspended sediment
ISO 4364-77	Bed material sampling
ISO 4365-85	Sediment in streams and canals-determination of concentration, particle size distribution and relative density
ISO 4366-79	Echo sounders for water depth measurements
ISO 4369-79	Moving boat method

ISO	4371-84	End depth method for estimation of flow in non rectangular channels with a free overfall (approximate method)
ISO	4373-79	Water level measuring devices
ISO	4374-82	Round nose horizontal crest weirs
ISO	4375-79	Cableway system
ISO	4375-79	Flat 'V'- Weirs
ISO	6416-85	Measurement of discharge by the ultrasonic (acoustic) method
ISO	6419/I-84	Hydrometric data transmission systems-Part I: General
ISO	6420-84	Position fixing equipment
ISO	8333-85	'V' shaped broad-crested weirs
ISO	8363-86	General guidelines for the selection of methods
ISO	8368-85	Guidelines for the selection of flow gauging structures
ISO	TR 7178-83	Velocity area methods-Investigation of total error

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