Chapter II

CHAPTER II

DATA FOR HYDROLOGICAL ANALYSIS

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DATA REQUIREMENT FOR PLANNING DEVELOPMENT AND OPERATION OF WATER RESOURCES PROJECTS

INTRODUCTION

In the expanding modern economy, exploitation of natural resources if of primary importance. As water is one of the main natrual resource, extensive efforts are being made in every country to harness the water potential for the benefit of the people. For economic and optimum utilisation, planning, design and development of water resources, determination of the extent and availability of surface and groundwater is the first requisite and this in turn requires readily accessible, reliable and adequate observation data on the elements of hydrological cycle and related factors. Long term hydrological and meteorological data and information about physical characteristics of watersheds provide the basis for all hydrological studies as well as development and management of water resources. Further, variations in climatic characteristics both in space and time lead to uneven distribution of precipitation in our country. This uneven distribution causes highly uneven distribution of available water, which leads to floods and droughts. As the hydrological processes are continuous and quite complex, therefore, an accurate assessment of quantities of water simultaneously passisng through all these phases becomes quite a difficult task.

The planning, development and operation of water resources projects is solely dependent upon the hydrological data. The length of data required depends upon the type of storage,type of development and variability of inputs.The present lecture deals with data requirement and related considerations pertaining to some of the thrust areas of planning development and operation of water resources.

WATER AVAILABILITY STUDIES

Water availability studies are carried out to estimate percentage dependable flows depending upon the purpose of the project.

Data Requirement for Water Availability Study

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

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

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

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

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

DATA REQUIREMENT AND OTHER CONSIDERATIONS FOR MULTIPURPOSE PROJECT PLANNING AND OPERATION

Modern water resources projects are planned for more than one purposes because multiple-purpose projects usually have a greatly improved economic and social advantages to offer. Chow (1964) defined an multiple-purpose project as one that can be operated on an assumed basis to provide more than one purpose and whose design is such that its method of operation can be altered from time to time, if desirable, to change the emphasis of its services so that it can always contribute most beneficially, whether it is to serve as a single - development project or as a productive element in a larger system of dams, rendering usereither circumstance the optimum of economic benefits that are desired with each service at a cost that is warranted.

The author gives following condensed outline, which is stated to be primarily as an illustrative example and also as a checklist of major factors to be considered in an area investigation for the project planning and development.

Physical and Related Items

PROJECT AREA

a. Physical geography: location and size; physiography; climate; soils
b. Settlement: histroy: population; cultural background both rural and urban
c. Development: industry; transportation; communication commerce; power; landuse; water uses; minerals; undeveloped resources
d. Economic conditions general: relief problems; community needs, national needs
e. Investigations and reports: previous investigations; history; scope

HYDROLOGIC DATA

a. Hydrologic records and networks: gauging and observation stations; data collecting agencies
b. Hydrometeorological data: precipitation; evaporation and evapotranspiration
c. Surface weater: low flows; normal flows; maximum floods; "design food", drought ; quality
d. Groundwater: aquifers; recharge; quality

SUPPLY OF WATER

a. Sources of supply: surface-water;groundwater supply; reservoirs
b. Variation of supply: variability; consumptive use; regulation; diversion requirements; return flow; evapotranspiration losses, seepage losses or gains.
c. Quality of water: physical, chemical, biological, and radioactive qualities; quality requirements; pollution
d. Legal rights: water rights; development of project rights; operation rights

GENERAL CONSIDERATIONS FOR DESIGN AND PLANNING

a. Geology: explorations; geological formations; foundation problems
b. Design problems: design criteria; methods of analysis; project operation and maintenance.
c. Construction problems: acessibility to project site; rights of way and relocation;construction materials; construction period;flow diversion; manpower; equipment; accessibility
d. Alternative plans: comparison of alternative plans; supplementary plans, possible alternative plans; relationships to area to be served

e. Estimates of costs
f. Intrastate, interstate, and international problems
g. Organisations involved; public and/or private; technical, social, and political

FLOOD CONTROL

a. Flood characteristics of the project area: historical floods; flood magnitude and frequency
b. Design criteria: project design storms and floods; degree of protection
c. Damage: survey of flooding areas and things affected by floods, nearby or quite a distance away, including commerce, good will, dates of delivery of goods, etc
d. Measure of control: reduction of peak flows by reservoirs;confinement of flow by levees,floodwalls, or a closed conduit ; reduction of peak stage by channel improvement;' diversion of floodwater through bypasses or floodways ; floodplain zoning and evacuation; floodproofing and flood insurance of specific propertie s, reduction of flood runoff by warershed management.
e. Existing remedial works

AGRICULTUTAL USE OF WATER

a. Factors for land classificaltion: soil texture; depth to sand, gravel, shale, raw soil, or penetrable lime zone; alkalinity; salinity; slopes; surface cover and profile, drainage, waterlogging.
b. Present and anticipated development: crops; livestock; financial resources; improvements; organisations; development period
c. Water requirements, if any: total crop requirement, irrigation water demand; farm delivery losses; diversion amounts
d. Available water: sources; quality; quantity; distribution
e. Irrigation methods: flooding furrow irrigation; sprinkling; subirrigation; supplemental irrigation
f. Structural works: storage reservoirs; dams; spillways; diversion works; canals and distribution systems;

HYDROELECTRIC POWER

a. Development: sources; present potential and future capacities
b. Alternative sources of power: stream; oil;gas;nuclear power,.interties;
c. Types of power plants: run-of-river; storage; pumped

storage

d. Structural components: dams, canals, tunnels; penstock; forebay; power-house tailrace
e. Power problems: load demand and distribution; interties (interconnections with other power transmission systems)
f. Markets; revenues; costs

NAVIGATION

a. Water traffic: present and future needs and savings in shipping costs, if any on the basis of which the justifications are primarily judged at the present time
b. Alternative means of transportation: air; land
c. Navigation requirements: depth, width, and alignment of channels, locking time; current velocity; terminal facilities.
d. Methods of improving navigation: channel improvement by reservoir regulation; contraction works; bank stabilisation, straightening, and snag removal; lock and dam construction; canalisation; dredging.

DOMESTIC AND INDUSTRIAL WATER SUPPLY

a. Sources of supply: surface and/or groundwater, location and capacity; desalinisation
b. Water demand; climate; population characteristics; industry and commerce; water rates and metering size of project area; fluctuation
c. Water requirements: quantity; pressure; quality (tastes, odors, color, turbidity, bacteria content, chemicals, temperature, etc)
d. Methods of purification: plain sedimentation; chemical sedimentation or coagulation; filtration; disinfectionl; aeration;water softening
e. Treatment plant: location; design; purpose or purposes
f. Distribution systems: reservoirs; pumping stations; elevated storage; layout and size of pipe systems; location of fire hydrants
g. Waterworks organisations: maintenance and operation of supply, distribution, and treatment facilities

RECREATIONAL USE OF WATER

a. Population tributary (population near enough to the project area to use it for recreational purposes)
b. Facilities: boating; fishing, swimming etc
c. Water requirements: Depth of water; area of water surface sanitation

FISH AND WILDLIFE

a. Biological data: species; habits
b. Facilities: reservoirs; fish ladders
c. Water requirements: temperature; current velocity; biological qualities

DRAINAGE

a. Existing projects
b. Drainage conditions: rainfall excess, soil condition; topography; disposal of water
c. Drainage system: urban. farmaland

WATER QUALITY CONTROL

a. Problems involved: sources, nature and degree of pollution, sediment; salinity; temperature; oxygen content; radioactive contamination
b. Hydrologic information and measurement
c. Methods of control

Economic Aspects of Project Formulation

1. Benefits and damages: identification and evaluation
2. Costs: identificatiokn and estimation
3. Financial feasibility
4. Allocation of costs
5. Reimbursement requirements and sharing of allocated costs
6. Methods and costs of financing the plroject, whether Federal, state, or local, bringing all benefits and all costs to an annual basis and recognising interest on the investment not only during construction, but throughout the entire proposed "life of the project"
7. Benefit-cost-ratio analysis: alternative plans.

Data Requirement for Reservoir Operation

The following data are needed for operation of a reservoir;

i) Reservoir elevation-area-capacity curve
ii) Carrying capacity of downstream channel
iii) Evaporation rates from reservoir
iv) Inflows to the reservoir
v) Demand of water for various uses viz. irrigation, power generation, drinking and industrial water supply, navigation recreation and lowflows.

DESIGN FLOOD ESTIMATION

The engineers and scientists involved in the design of water resources structures such as storm sewers, spillways, diversion works, bridges, culverts amd other flood control works often require the design flood at a certain location in order to estimate the size and cost of these structures.In the design of water resources structure, it is not practical, from economic considerations to provide for the safety of the structure and the system at the maximum possible flood in the catchment. Small structures such as culverts and storm drainages can be designed for less severe floods as the consequences of higher than the design flood may not be very serious. It may cause temporary inconvenience like the disruption of traffic and sometimes property damage and loss of life.On the other .hand, storage structures such as dams demand greater attention for their design flood estimation. The failure of these structures leads to large loss of life and great property damage in down stream region of the structure.

From the above,it is evident that the type and importance of the structure and economic development of the surrounding area +dictate the design criteria for choosing the flood magnitude. From this, it is apparent that the data used for development,planning and operation of any structure depends upon the importance and size of the water resources project.In the following text some the terms used in desined flood estimation and data requirements for some of the important methods of design flood estimation are discussed.

Design Flood

Flood adopted for design of a structure

Probable Maximum Flood (PMF)

It is the flood discharge that may be expected from the most severe combination of critical meteorological and hydrological conditions that the reasonably possible in the region. The probable maximum flood is used in the design of projects, for example dams - where virtually complete security from potential floods is sought.

Standard Project Flood (SPF)

It is the flood discharge that may be expected from the most severe combination of meteorological and hydrological conditions that is considered reasonably characteristics of the geographic area in which the study drainage basin is located,extremely rare combinations of those conditions are not considered. The peak discharge for a standard project flood is generally about 40 to 60 percent of that for the probable maximum flood for the same basin. The standard project flood is often used where failure of structure would have somewhat less disastrous effect. For example, it is used in the design of flood control facilities whose failure might be disastrous.

Guidelines for Salecting Design Floods

A summary of the guideliness adopted by CWC (1969) to select design floods in India is as follows.

Methods of Flood Estimation

The following methods are generally used for flood estimation:

A) Empirical methods
B) Flood frequency analysis
C) Unit hydrograph techniques and
D) Watershed models

Summary of guidelines adopted by C.W.C.(1969)

S.No.	Structure	Recommended Design Flood
1.	Spillways for major and medium projects with storage more than 60 M cub.m.	a) PMF determined by unit hydrograph and probable maximum precipitation (PMP) b) If (a) is not applicable or possible, flood frequency method with T=1000 years
2.	Permanent barrage and minor dams with capacity less than 60 M cub.m.	a) SPF determined by unit hydrograph and standard project storm (SPS) which is usually the largest recorded storm in the region b) Flood with a return period of 100 years. (a) or (b) whichever gives higher value
3.	Pickup Weirs	Flood with a return period of 100 or 50 years depending upon the importance of the project
4.	Aqueducts	
	a) Waterway	Flood with T=50 years
	b) Foundations and free board	Flood with T=100 years
5.	Project with very scanty or inadequate data.	Empirical formulae

EMPIRICAL METHODS

Empirical methods and flood frequency methods are generally used for estimating the magnitude of flood peak. However, the unit hydrograph technique and watershed models can be used to estimate the design flood hydrograph in addition to the magnitude of design flood peak. The data used and suitability of a particular method depends upon a) the desired objective b) the available data and c) the importance of the project.

The rational formula is only applicable to small size (50 km) catchments. The empirical formulae are essentially the regional formulae based on statistical correlation of the observed peak and important catchment properties. These formulae are only applicable in the region for which they were developed within the range of flood peaks used. If these formulae are applied to other areas they can at the best give approximate values. These formulae generally require information about rainfall and catchment characteristics.

FLOOD FREQUENCY ANALYSIS

The flood frequency analysis is the approach based on statistical methods to predict the flood peak of specified return period. Most of the flood frequency studies are concerned with peak flows and the data comprise of selected observed peaks. Usually, two types of data series are used in flood frequency studies.

a) Annual peak series

b) Partial duration series

a) Annual Series

Annual series of data includes largest or smallest values with each value selected from one water year.

b) Partial duration series

Partial duration series comprises of data which are so selected that their magnitude is greater than a certain base value.

The data must deal with the problem. Most of the flood studies are concerned with peak flows and data series will consist of selected observed peaks. If the problem is of duration of flooding e.g. for what period of time a highway adjacent to a stream is likely to be flooded, the data series should represent the duration of flows in excess of some critical value. If the problem is of interior drainage of levelled area, the data required must consist of those flood volumes occuring when the main river is too high to permit gravity drainage.

Frequency analysis of hydrologic data begins with the treatment of raw hydrologic data and finally determines the frequency or probability of a hydrologic design value.

Data Requirement for Flood Frequency Analysis

a) For frequency analysis it is required that samples are purely random. In other words they should be unbised, independent and homogeneous.

b) Annual peak flow series or the flow values which are adequate to form partial duration series, if required,

c) In case annual peak series data are not available, then hourly stage values alongwith the rating curve at the gauging site are required to convert hourly stage values in hourly discharge and find peak flood for each year,

d) When the sufficient length of peak flood record is not available then the regional flood frequency may be adopted to estimate design flood. This requires information about catchment characteristics. Such information may be derived from toposheets and other maps of the basin

Roudkivi (1979) states that frequency analysis of flood flow records is, in principle, a good method. Unfortunately, records, if availabladequate definition of extreme floods. An extrapolation of a 25 year record to a 500-year return flood yields a very unsatisfactory answer of low confidence value. The author further mentions that if, for example, the Gumbel distribution is assumed then the theoretical 68% confidence limits of the 50,100 and 500-year return period floods, in terms of years, are according to Bell (1969) as follows:

25 years of record: $12 \leq 50 \leq 200$, $15 \leq 100 \leq 400$, $16 \leq 500 \leq 2200$

100 Years of record: $25 \leq 50 \leq 100$, $40 \leq 100 \leq 250$, $60 \leq 500 \leq 1500$

The author further mentions that the problem may arise with longer discharge records from the fact that catchment conditions may get changed over the period of record.

If the sample is too small the probabilities derived cannot be expected to be reliable. Some estimates in this regard derived from data synthetic data (Linsley et al., 1975) are given below:

Length of record in years required to estimate floods of various probablities with 95% confidence

Design Probability	Return Period	Acceptable Error 10%	25%
0.1	10	90	18
0.02	50	110	39
0.01	100	115	40

From the above, it is clear that extrapolation of frequency estimates beyond probability of 0.01 is extremely risky with data series generally available (30-40 years).

Ott (1971) stated that with 20 years of record the probability is 80 percent that the design flood will be over estimated and that 45 percent of over estimates will exceed 30 percent, so it thus appears that records shorter than 20 years should not be used for frequency analysis; 40-50 years data series have been found to define event magnitude upto 50 years appreciably well.

Unit Hydrograph Analysis

Unit hydrograph analysis is a simple and versatile technique which is widely used for determination and prediction of flood peaks. Unit hydrographs can be derived from analysis of rainfall and runoff records for those catchments where such records are available.

Unit hydrograph techniques are applicable to small catchment viz. having area less than 5000 sq.km. However, these techniques alongwith routing can be used to estimate the design flood for larger size basins by dividing the basin in sub-basins.

Data Requirement for Design Flood Estimation Using Unit Hydrograph Analysis

1. Drainage basin map showing the contours and river network
2. Network of ordinary and self-recording raingauge stations
3. Observed rainfall data for ordinary and self recording raingauge stations for major historical flood events. (Atleast the data for 4 to 5 flood events are needed for gauged catchments).
4. Daily gauge and discharge data at the gauging site
5. Rating curve for the gauging site
6. Hourly gauge (or hourly discharge, if available) values for the corresponding 4to 5 flood events.
   Daily gauge and discharge data are usually required to develop the stage-discharge relationship (rating curve). In case the rating curve is available, the above data may be utilised to verify its accuracy.
7. Design storm (probable maximum precipitation or standard project precipitation values for different durations viz. 1 day, 2 days etc are required depending upon the type of structure for which the design flood is to be estimated).
8. Time distribution for PMP or SPS (A time distribute the PMP or SPS values at shorter time interval viz 1 hr, 3 hrs etc.)
9. Design loss parameters - For computing the excess design rainfall uniform loss rate for design condition is required It represents a part of precipitation which does not contri-

bute to the direct surface runoff. This amount of precipitation is lost in the form of infiltration, evaporation etc.

10. Design Base Flow- The discharge hydrograph consists of two components i) direct surface runoff resulting due to excess rainfall and ii) baseflow, which is contribution from groundwater reservoirs to the stream. The application of unit hydrograph technique provides an estimate for design direct surface runoff. In order to obtain the design dishcarge hydrograph the design baseflow should be added to the direct surface runoff hydrograph.

A study by CWC (1973) on rainfall runoff correlation envisages the following relationships for the estimation of uniform loss rate (ϕ - index) for flood producing storms and soil conditions prevalent in India.

$$R = \alpha \, I^{1.2}$$

and $$\phi = \frac{I - R}{24}$$

where,

R= runoff in cm from a 24 h rainfall of intensity I cm/day and

α = a coefficient which depends upon the soil type as given below

S.No.	Type of soil	Coefficient (α)
1.	Sandy soils and sandy loam	0.17 - 0.24
2.	Coastal alluvium and silty loam	0.25 - 0.34
3.	Red soils,clay loam,grey and brown alluvium	0.42
4.	Black cotton and clayey soils	0.41 - 0.46
5.	Hilly soils	0.46 - 0.50

U.S.Army Corps of Engineers has recommended to use an infiltration Φ-index of 1.0 mm/hour for the first 12 hours, 0.8 mm/hour for the subsequent 12 hours and 0.5 mm/hour thereafter. An alternative practice being used in India recommended by CWC as the use of constant loss rate of 1.0 mm/hour throughout the storm. The rates adopted for a particular project are primarily influenced by the nature of soil type and vegetal cover of thebasin and the purpose of the estimate.

A study (CWC, 1973) conducted for baseflow for small catchment revealed that the baseflow during flood season varies from 0.05 cumec/sq.km. to 0.44 cumec/sq.km. depending upon the meteorological zones in which the basin are located. The values given below were considered reasonable.

S.No.	Region	Baseflow (Cumec/sq.km.)
1.	For Luni, Chambal,Sore,Punjab plains, Gangetic plains, Upper Narmada Tapi basins, Upper Godavari, Krishna,Cauveri, Jammu and Kashmir and Kumaon hills	0.05
2.	Betwa, Mahi, Sabarmati, Lower Narmada, and Tapi, Lower Godavari Indrawati basin, east cost	0.11
3.	Mahanadi basin and west cost	0.22
4.	Brahmputra basin	0.44

Watershed Models

Since the hydrological processes are continuous and quite complex, therefore an accurate assessment of quantities of water simultaneously passing through the various processes becomes quite a difficult task. The problem becomes even more complex, when the natural hydrological cycle gets disturbed by the man's activities, such as landuse changes, agricultural practices and construction of water resources structures etc. A number of watershed models such as USGS model, NWSRFS Model, USDAHL Model, HBV Model, CREAMS Model, HEC-1 Model and NAM Model.

Due to a large number of parameters involved in the application of the watershed models the scope of such models for the estimation of design flood is limited.However,event based watershed models requiring limited number of parameters viz.Hec-1 model have been successfully applied for design flood estimation.

PHYSICALLY BASED-DISTRIBUTED MODELS

With the advancement in computer technology, the hydrologists are currently making efforts to develop physically based distributed models.

THE SHE Model (Systeme Hydrologique European - European Hydrological Systems)is one of the physically based, distributed models, jointly developed by three European organisations (Abbott et al,1986). The data requirements for the physically based, distributed models are quite exhaustive. The data requirements for an application of the SHE Model have been given below:

Data Requirements for SHE Model

The physically based, distributed modelling system SHE in principle does not require long term hydrometeorological data for its calibration but it requires the evaluation of a large number of parameters defining the physical characteristics of the catchment on a spatial distributed basis. It should of course be emphasized, that different hydrological regimes being considered may call for various degrees of accuracy in the estimation of the individual basin parameters, and the evaluatiokn of some parameter values may simply be based on experience. The data availability, however, will in any case determine the degree of reliability, which can be put into the simulation results. Abott et al. (1986) mention that in principle the parameters and their spatial distributions can be measured in the field but the expense of such a survery applied to all the parameters would prohibit practical implementation of such a model. Hence, it is necessary to reduce the number of direct measurements and to employ more indirect evaluations. Bathurst (1986a) states a typical approach which involves a few measurements at representative sites in the catchment, providing information on soil properties and channel flow resistance especially. These parameters are likely to have the most influence on simulations of runoff response. These measurements are then assumed, on the basis of their physical nature,to apply to other areas of the catchment. In this manner it is possible to evaluate parameters on the basis of vegetation or soil type within a catchment and also to transfer information from studies carried out elsewhere.

The information about parameters like hydrualic conductivity of soil, soil moisture retention curve, leaf area index, root zone depth required for the model can be obtained from measurements reported in the literature for other field or laboratory studies. Some of the data such as landuse and soil types can be provided by remote sensing techniques. Even after procurement of available data there remains the problem of sampling and evaluating the parameters in such a way as to be representative of the grid scale adopted in the model. Many hydrological measurements, for example, are made at the point scale, of the order of a metre, and may or may not be representative of conditions at grid scale of a kilometre or more. It important, therefore, that techniques of measurements used should as far as possible, correspond to the structure and scale of the model . Remote sensing technique may play an important role, by providing average parameter values on a grid basis in such cases. In the same way, tracers can be used to provide information on the integrated characteristics of overland and channel flow over given reaches. In the following a brief introduction to the required data is listed. This comprises of;

Catchment geomentry

- Topography (from toposheets on e.g. 1:50,000 scale)
- Soil depths (distance to impervious layer)
- River geometry (cross sections, the river network and information about structures)

Land use and soil parametric data

- The spatial distribution of soil and vegetation types (from e.g. 1,250,000 maps).

For each vegetation type:

- Temporal variation of either 1) root depth and leaf area index or 2) canopy drainage parameters, soil shading indices and canopy and aerodynamic resistances.

For each soil type

- Soil moisture characteristics $\theta - \psi$ relationship
- Hydraulic conductivity function K $- \theta$ relationship
- Horizontal hydraulic conductivity

Surface Parameteric Data

These data are required for each grid square, and include:

- Strickler roughness coefficient for overland flow and rive flow
- Soil cracking coefficients
- Depth to drains and subsurface drainage coefficients

Snowmelt Prametric Data

- Rainfall and meteorological station network, and records of data obtained at these stations (possibly including potential evapotranspiration data).
- Streamflow data
- Other relevant data which can be utilised in the model calibration and validation,e.g. water table, soil moisture data etc.
- Boundary and initial conditions

As mentioned previous, some of these data may not be generally available. For example, a complete information of θ- ψ relationship is seldom available. However other application studies already have gained some knowledge about the possible form of this relationship, and information available in current literature may be utilised for the evaluation of this relationship.

FLOOD PLAIN ZONIING

One of the thrust areas of water resources engineering is flood plain zoning, which is a non-structural measure for flood managemenT.The following data are required for flood plain zoing.

Data Requirement for Flood Plain Zoning

i) Information about reservoirs and major water resources structures.
ii) Contour map preferably at a shorter contour interval
iii) Location of the raingauge stations and stream gauging sites
iv) Index plan showing details of meandering river
v) Map providing geological details about the basin
vi) Map giving details of landuse of the basin
vii) Cross- sections and longitudinal sections of the river at different locations
viii) Rating curves at different gauging sites
ix) Annual flood peak series and hydrographs of the corresponding flood peaks at the confluence
x) 100, 200, 500 and 1000 years return period floods and other typical floods observed at the confluence
xi) Roughness characteristics for flood plain and channel from velocity measurements or sediment size of river bed at various sites.

DAM BREAK STUDIES

Dam failures are often caused by over topping of the dam due to inadequate spillway capacity during large inflow to the reservoir from heavy precipitation runoff. Dam failures may also be caused by seepage or piping or piping, slope embankments slides, earthquate etc. The protection of public from the consequences of dam failures has taken on increasing importance as population have concentrated in areas vunerable to dam break disasters. This has created general interest in the dam safety analysis in recent years. The organisations which are responsible for the safety of dams should plan in such a way, so that in the eventuality of dam failure the disaster does not struck the lives of public livign downstream of the dam. There are a number of modlels available now for dam break analysis. The present section describes data requirement for one of such models viz DAMBRK model developed by National Weather Services, USA.

Data requirements for Dam Break Studies

The DAMBRK model was developed so as to require data that was accessible to the forecaster. The input data requirement are flexible in so far as much of the data may be ignored (left blank on the input data cards or omitted altogether) when a detailed analysis of a dam break flood inundation event is not feasible due to lack of data or insufficient data preparationtime.

Nontheless the resulting approximate analysis is more acurate and convenient to obtain than that which could be computed by other techniques. The input data can be categorised into two groups.

The first data group pertains to the dam (the breach spillways, and reservoir storage volume). The breach data consists of the following parameters: (failure time of breach, in hours), b (final bottom width of breach), Z (side slope of breach), h_{bm} (final elevation of breach bottom), h_o (initial elevation of water in reservoir), h_f (elevation of water when breach begins to form), and h_d (elevation of dam). The spillway data consists of the following: h_s (elevation of uncontrolled spillway crest), C (coefficient of discharge of uncontrolled spillway), h_g (elevation of center of submerged gated spillway, C_g (coefficient of discharge of gated spillway), C_d coefficient of discharge of crest of dam), Q (constant head independent discharge from dam). The storage parameters consist of the following : a table of surface area (A) in acres or volume in acre ft. anmd the corresponding elevations within the reservoir. The forecaster must estimate the values of r ,b,Z, h_{bm}, and h_f. The remaining values are obtained from the physical description of the dam, spillways, and reservoir. In some cases h_s , C , h_g and C_g and C_d may be ignored and Q used in their place.

The second group pertains to the routing of the outflow hydrograph through the downstream valaley. This consists of a description of the cross-sections, hydraulic resistance cocefficients, and expansion coefficients. The cross sections are specified by location milage, and tables of top width (active and inactive) and corresponding elevations. The active top widths may be total widths as for a composite section, or they may be left floodplain, right flood plain, and channel widths. The channel widths are usually not as significant for an accurate analysis as the overbank widths. The number of cross sections used to describe the downstream valley dlepends on the variability of the valley widths. They also depend on the availability of cross-section measurements. However, a minimum of two must be used. Additional cross-sections are created by the model via linear interpolation between adjacent cross-sections specified by the forecaster. This feature enables only a minimum of cross-sectional data to be input by the forecaster according to such criteria as data availability, variation, preparation time tc. The number of interpolated cross-sections created by the model is controlled by the parameter DXM which is input for each reach between specified cross-sections. The expansion-contraction coefficients (FKC) are specified as non-zero values at sections where significant expansion or contractions occur. But they may be left blank in most analyses.

REMARKS

In a developing country like India it is observed that adequate and reliable data are not available for most of the studies related to water resources. Many a time the required data are not available for desired locations or for desired length of period. In case of basins having insufficient data or having no data, the inputs have to be prepared using data transfer and data extension techniques. Further, in order to obtain adequate data, there is a great need that the optimal number of strem gauging stations and other related observation stations are established in various basins of the country. Though desirable level of information regarding optimal network design level of informationis not available in the literature but WMO (1974) gives norms for minimum density of hydrometric network as given in following table.In addition to this some of the points which need special consideration in this regard have been highlighted by Hiranandani and Chitale (1964).

Minimum Density of Hydrometric Network

Type of region	Range of norms for minimum network. Area (Km^2) per stn.	Range of provisional norms tolerated in difficult conditions. Area (Km^2) per station
a) Flat regions of temperate, Mediterrancan and tropical zones	1,000-2,5000	3,000-10,000
b) i) Mountainous regions of temperate, mediterranean and tropical zones	300-1,000	1,000-5,000[4]
ii) Small mountainous islands with very irregular precipitations, very dense stream network	140-300	
c) Arid and polar zones[2]	5,000-10,000[3]	

1. Last figure of the range should be tolerated only for exceptionally difficult conditions.
2. Great deserts are not included.
3. Depending on feasibility
4. Under very difficult conditions this may extended to 10000 km.

Further it can be emphasised that there is a great need of hydrological and related data for planning, development and management of water resources projects and efforts should be made by the concerned people so that adequate and reliable data are available for efficient planning and management of water resources projects.

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OBSERVATION OF HYDROMETEOROLOGICAL PARAMETERS

INTRODUCTION

Almost all hydrological studies require measurements of precipitation amounts. The amount, intensity and areal distribution of precipitation are essential in any hydrological study more so for design purposes. Observations of other meteorological parameters such as temperature, humidity, wind speed and direction, evaporation and sunshine are also essential. For studies relating to water management and watershed development.

For systematic collection of this scientific data, the station have to be established to conform to international and national standards and observation of data must also be accurate and scientific. Even the compilation of the data has to be systematic. It will also be desirable to have standard proforma for collection of data.

This lecture has been prepared to highlight certain points on the method of installation, maintenance and compilation of data.

LAYOUT OF THE HYDROMETEOROLOGICAL OBSERVATION STATION

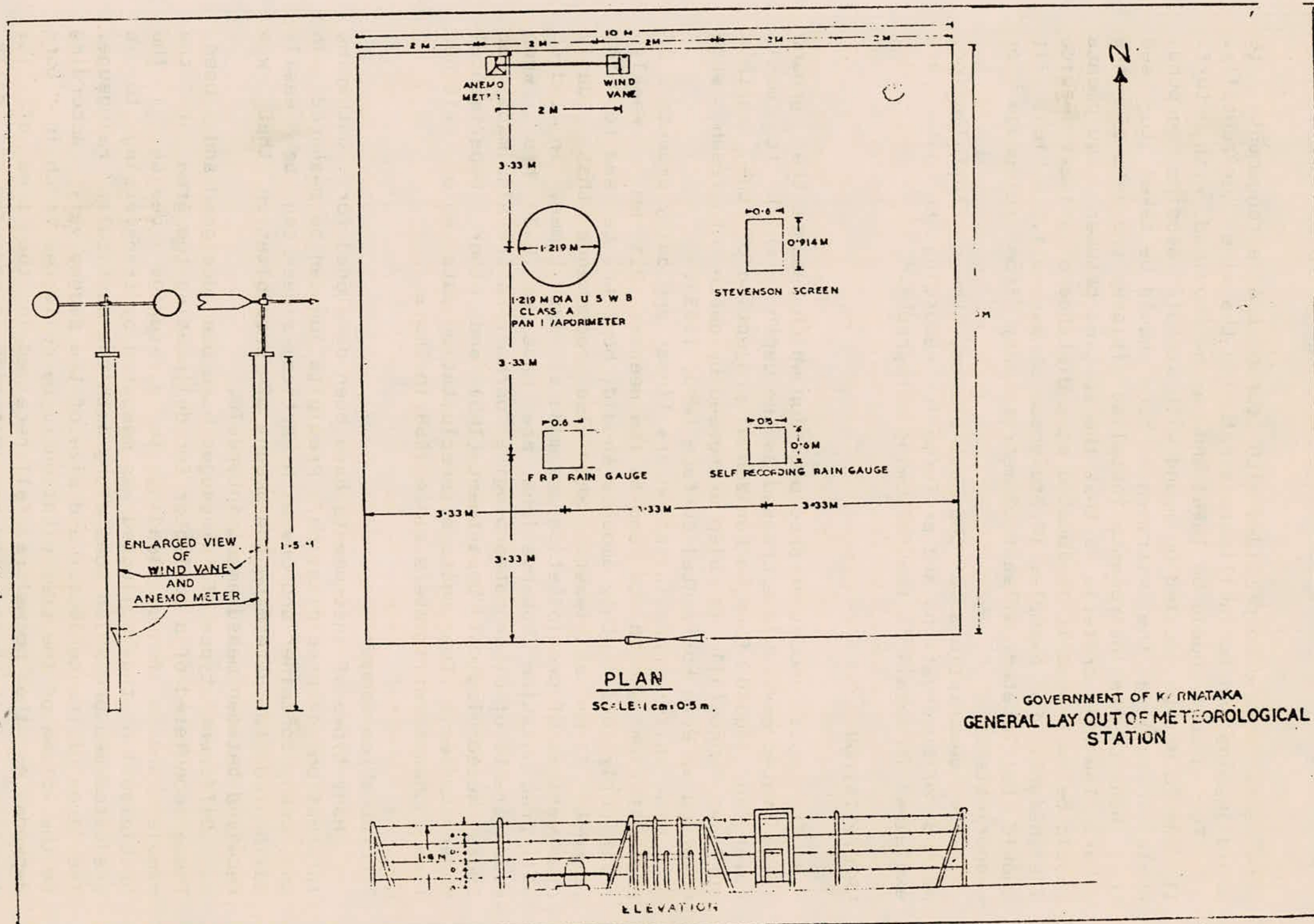
The hydrometeorological station generally consists of the following equipments.

1) Ordinary raingauge,
2) Self-recording raingauge,
3) Stevenson screen in which wet and dry bulb, Maximum and minimum thermometers are kept,
4) U.S.W.B. Class 'A' pan,
5) Anemometer and
6) Wind direction indicator.

The minimum dimension for the site should be 30' x 30', preferably 35' x 40'.

The general layout plan showing location and orientation of various equipments is shown in figure 1.

As a general principle, the site chosen for a meteorological station should be an open one so that there is free flow of air over the plot of ground on which out door instruments are installed. The site needs to be fenced to keep out animals and unauthorised persons. The fencing should be of angle iron and barbed wire, care should be taken to see that end corners and doors side poles are given struts to avoid bending of angle iron poles when the barbed wires are pulled under tension. The barbed



10 M
2 M
2 M
2 M
2 M
2 M
ANEMO METER
WIND VANE
3·33 M
1·219 M
1·219 M DIA U S W B CLASS A PAN EVAPORIMETER
0·6
0·914 M
STEVENSON SCREEN
0·6
F R P RAIN GAUGE
0·5
0·6 M
SELF RECORDING RAIN GAUGE
3·33 M
ENLARGED VIEW OF WIND VANE AND ANEMO METER
1·5 M
PLAN
SCALE: 1 cm : 0·5 m.
GOVERNMENT OF KARNATAKA
GENERAL LAY OUT OF METEOROLOGICAL STATION
1·8 M
ELEVATION
N

wire ends should be provided with turnbuckle arrangements to avoid sagging and to facilitate stretching the wire horizontally.

The ground should be level and may be provided with turf. It should not be located on mound with steeply sloping ground. While installing the instruments, care should be taken to see that none of the instruments installed vitiates the data of the other. The main criteria is that the spacing between equipments should be such that it is located at a distance of atleast twice its height. For example, if Stevenson screen is 1.5 m high, it should be located atleast 3 metres away from raingauge or evaporimeter.

The descriptions of the equipments, their installation, method of observations and proforma for recording the data are explained in detail in the following paragraphs.

PRECIPITATION

The total amount of precipitation which reaches the ground in a stated period is expressed as the depth to which it would cover in liquid form, a horizontal projection of the earth's surface. Snowfall is also expressed by depth of fresh snow covering an even horizontal surface (WMO, 1983).

The units of precipitation are linear and daily amounts of precipitation should be read to the nearest 0.1 mm. Weekly, fortnightly and monthly amounts should, however, be read to the nearest 1 mm at least. WMO also recommends that daily observations of precipitation are made at fixed times. In India, all precipitation observations are made at 0830 hrs when measurements of other meteorological parameters are also made at India Meteorological Department (IMD) and other Departmental Observatories. The units of precipitation data were switched from inches to millimeters since 1958 in India.

Precipitation Gauges

Many types of instruments have been developed for gathering information on precipitation. Precipitation can be measured in any open container and one with vertical sides can be easily calibrated to determine the amount of precipitation that was received between measurement intervals.

Different types of raingauges have been designed and used. These consisted of a collector for delineating the area of the sample and a funnel leading to a storage device. The precipitation thus collected was measured by transferring to a graduated measure which goes along with the particular raingauge. The area of the collector and size of the gauges vary according to the volume of the precipitation to be collected which in turn depends on the normal rainfall received in the area of its location and on whether the precipitation is measured at daily, weekly or monthly intervals. Special instruments were developed for determine snowfall.

Since the size, shape and exposure affect the precipitation caught by a raingauge, it is desirable to develop a standard gauge so that observations from different gauges could be comparable. Most countries have selected one particular type of gauge to be the national 'Standard' gauge which makes up the bulk of the country wide network. In India, the Symon's raingauge has been adopted as the standard rain measure since the British days. For the recording gauge float and syphon type was being used.

NON - RECORDING TYPE RAIN GAUGES

The Symon's raingauge consists of the funnel, which has an accurately turned and bevelled gunmetal rim 127 mm in diameter, a cylindrical body, a receiver with a narrow neck and a splayed base which is fixed in the ground. (Fig.2).

These gauges are now being replaced by Fibre Glass Reinforced Plastic (FRP) raingauges having same dimensions. The collector area of the FRP gauge is 200 cm2. In heavy precipitation areas a gauge with a smaller orifice area is preferred to allow collection of less volume of water.

Exposure of Raingauge

The precipitation collected, as is well known, depends on the exposure of the raingauge. The following points, therefore, need special attention while installing the gauge (ISI-4986:1983).

i) The gauge shall be placed on level ground and not upon a slope or terrace and never on a wall or roof.
ii) On no account the raingauge shall be placed on a slope such that the ground falls away steeply on the side of the prevailing wind.
iii) The distance between the raingauge and the nearest object should generally be four times the height of the object, but shall never be less than twice the height of the object.
iv) Great care shall be taken at mountain and coastal stations such that the gauges are not unduly exposed to the sweep of the wind. A belt of trees or a wall on the side of the prevailing wind at a distance, preferably, four times its own height but exceeding at least twice its height, shall form an efficient shelter.
v) In the hills where it is difficult to find a level space space, the site for the gauge shall be chosen with a minimum level area of 6m x 6m where it is best shielded from high winds and where the wind does not cause eddies.

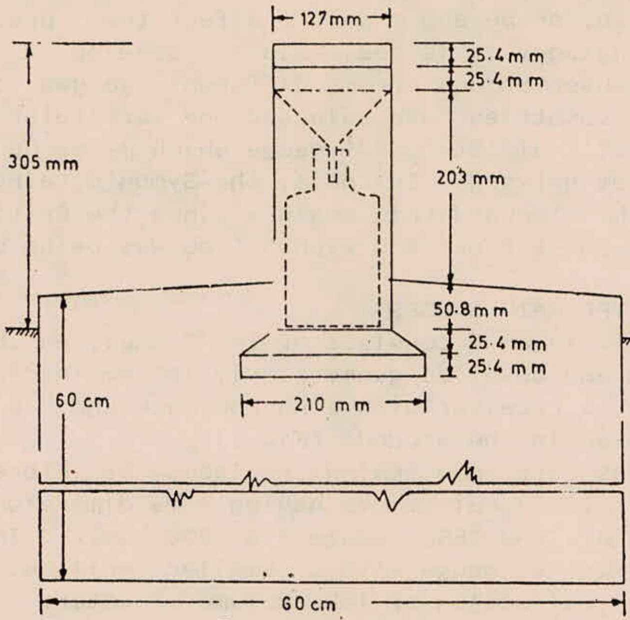


Fig. 2 Non-recording raingauge

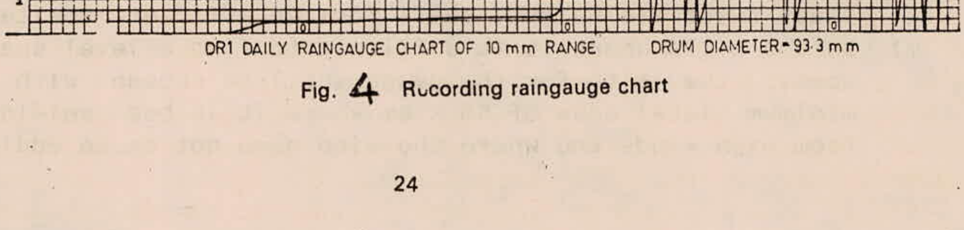


Fig. 4 Rucording raingauge chart

Installation of Raingauge

The raingauge shall be fixed on a masonry concrete foundation 600 x 600 x 600 cub.mm sunk into the ground as shown in fig. 2 The gauge should be cemented into the platform in such a way that the rim of the gauge is 300 mm above ground level. This height is necessary to prevent the splashing of water into the gauge. A height of more than 300 mm would result in wind eddies set up by the gauge. Where the gauge is likely to be flooded, the gauge should be kept such that the rim is 300 mm above the maximum expected flood level. It should also be ensured that the rim of the gauge is perfectly levelled. The gauge should be protected by a fence keeping the height-distance considerations in view.

Measurement of Rainfall

To measure the rainfall, the water in the bottle should be poured into the glass measuring cylinder which should be placed on a level surface. The glass cylinder is graduated to 0.2 mm of accuracy. It could, however, be read upto 0.1 mm accuracy if the water meniscus rests between two divisions. Care should be taken to avoid spilling and parallax error while reading.

If there is more water in the bottle than the measuring glass could hold, the glass is filled upto the 20 mm mark and the water thrown away after noting. The procedure is repeated until all the water in the bottle is measured. The total rainfall will be, naturally, the sum of readings.

All observations of rain are taken in India at 0830 IST (0300 GMT) to ensure standardization and intercomparison of rainfall from different raingauge stations. If at the time of observation heavy rainfall happens to occur, a spare bottle could be placed beneath the funnel to avoid loss of catch. The contents of the spare bottle are subsequently transferred to the original bottle.

A sample form for the record of precipitation is given at Table 1.

Measurement of Snow and Frozen Rain

In India, at high altitude stations precipitation during winter occurs mainly in the form of snow. It is always advisable to install a snow gauge in these areas. India Meteorological Department and other state agencies in the northern states do maintain snow gauges. The snow gauge is, generally, provided with a wind shield.

When there was only light wind during the period since the previous observations, the liquid water equivalent may be measured by one of the following methods.

i) a cloth dipped in hot water is applied to the outside in the funnel and receiver to melt the snow or ice and the melted contents measured the usual way.

ii) Some warm water measured accurately with the appropriate rain measure is poured in the raingauge. Only as much water as is necessary to melt the snow or ice is used. The total water content is then measured using the measure glass. The amount of water added is subtracted from the total to determine the water equivalent of precipitation which occurred. This method is preferable for F R P raingauges.

When the snowfall is heavy, the reading of the raingauge might become unreliable in the event of the gauge being entirely buried under snow or in the event of the snow being blown away by wind. Under such conditions separate methods of measurement as indicated below are to be followed.

The amount of water (rain and melted snow) already in the receiver should be measured first. Then all the snow accumulated over the collector shall be pressed into the funnel. This snow shall be melted and its equivalent water obtained as described earlier. The sum of two measurements gives the total amount of precipitation.

For other details regarding maintenance and inspection of gauges, ISI standard 4986-1983 may be referred to.

RECORDING TYPE RAIN GAUGES

Three types of precipitation recorders are in general use. The float type, the tilting or tipping bucket type and the weighing type. In India, the float and syphon type recording gauge is widely used.

FLOAT AND SYPHON RECORDING RAIN GAUGES

The natural syphon recording raingauge (Fig. 3) is an instrument designed to give a continuous record of rainfall. The instrument can record :

i) the total amount of rainfall which has fallen since the record was started;and

ii) the times of onset and cessation of rain and therefore the duration of rain.

From the record, the rate of rainfall could be estimated. The recording raingauge is generally used in conjunction with an ordinary raingauge exposed close-by for use as standard, by means of which the readings of the recording raingauge can be checked.

The natural syphon recording raingauge consists of a collector and rainfall recording mechanism mounted on a base. The recording mechanism consists of a float chamber and a syphon chamber. The pen is mounted on the stem of the float and as the water level rises in the receiver, the float rises and the pen records on a chart placed on a clock drum, the amount of water in

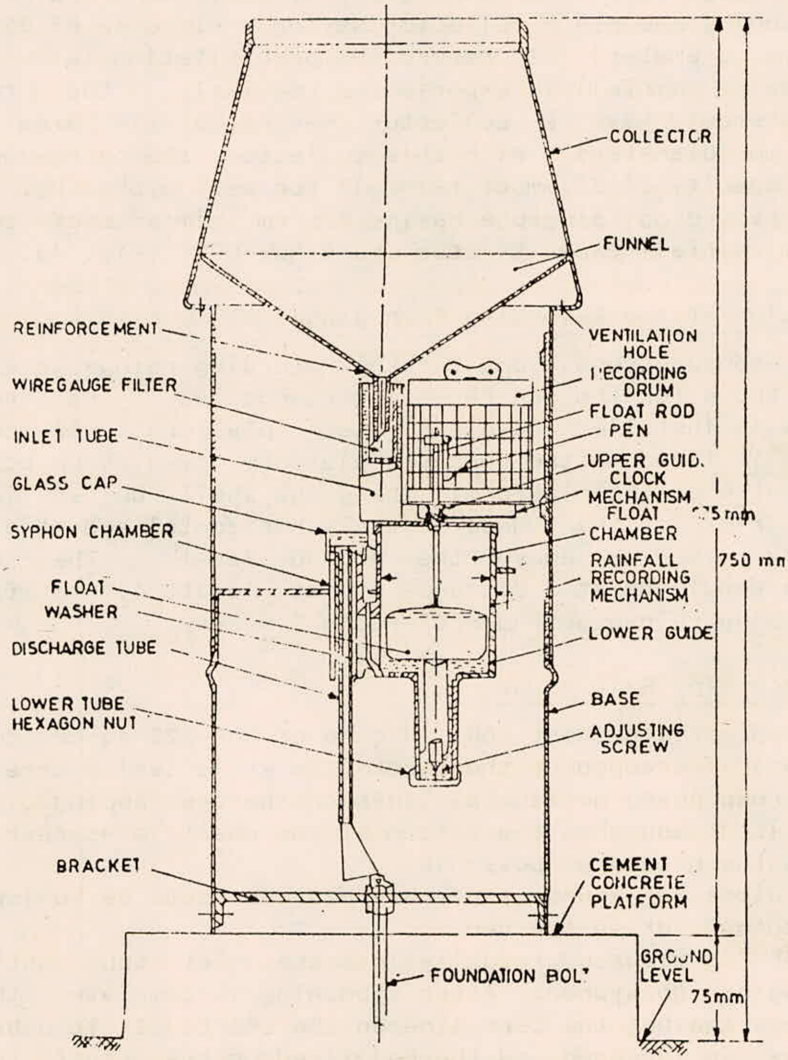


Fig. 3 Float and Syphon type recording raingauge

the receiver at any instant. The clock drum revolves once in 24 hours or 7 days as the case may be, so that a continuous record of the movement of the pen is made on the chart. Syphoning occurs automatically when the pen reaches the top of the chart and as the rain continues, the pen rises again from the zero line of the chart. If there is no rain, the pen traces a horizontal line from where it leaves off rising.

The gauge generally has a capacity of 10 mm of rainfall for each syphoning and has a collector having a rim area of 325 sq cm (203.4 mm diameter). To record the precipitation at stations where heavy rainfall is experienced regularly, the recording raingauge should have a collector having a rim area 130 sq cm(128.6 mm diameter). With this collector, the raingauge would have a capacity of 25 mm of rainfall for each syphoning.

The recording raingauge having 325 cm rim area of collector and 10 mm rainfall capacity uses chart No. DR 1 (Fig. 4).

Installation of the Recording Rain gauge

The exposure conditions for the recording raingauge are the same as those for the non recording raingauges. The recording raingauge is installed on a concrete platform 60 cub. cm. the gauge is fixed to the concrete platform by a 15 cm bolt fixed in the centre of the platform. The gauge shall be so installed that the rim of the funnel is truly horizontal and at a height of exactly 750 mm above the ground level. The recording raingauge should be at a distance of at least 1.5 m from the non-recording raingauge and preferably 3 m away.

Use of Recording Rain gauge

An appropriate chart (DR1 in case of the 325 sq cm collector raingauge) is wrapped on the clock drum while taking care to see that corresponding horizontal lines on the overlapping portions are coincident and that the bottom of the chart is as near to the flange at the bottom as possible.

The clock is wound and the pen is set as follows after putting enough ink in the pen.

Water is poured gradually into the inlet tube until the water begins to syphon. After syphoning is complete, the pen should rest against the zero line on the chart. If it does not, the screw is loosened and the pen fixed on the float rod and moved until it rests exactly on zero line and the screw tightened.

The chart is changed at the same time each day, usually between 0830 and 0900 IST. For details regarding the installation, maintenance and inspection of the gauge ISI code 8389-1983 may be referred to.

Determination of the rate of Rainfall

The rate of rainfall can be determined from the record by noting the amount of rain which has fallen in a short time centered about a given time. Thus the slope of the rain at any point of time gives the intensity of rain at the instant.

To obtain the average intensity for a given time interval t, the total rainfall Δp may be divided by Δt. Thus if

p_t = 0.5 mm $p_{t+\Delta t}$ = 8.5 , and Δt = 2 hrs.

Then the average intensity is $\frac{8.5 - 0.5}{2}$ = 4.0 mm/hr

Tabulation of Hourly Values

The charts removed from the instrument every day are analysed and the hourly rainfall is tabulated in a form given in Table 2.

Besides entering details in respect of station, standard time, type of instruments, month and year, units etc. the hourly rainfall is entered correct upto 0.1 mm. Care should be exercised to see that the entries refer to the date of their recording. It also need to be noted that for completing the record for 1 day, the charts for two days would be required as each charts begins from 0800 hr ends at 0800 hrs of next day. The rainfall during 0 to 1 hr should be entered against 1 hr, 1 to 2 hr should be entered against 2 hr and so on.

The sum of the 24 hourly values for the hours 1 to 24 should be entered in column 'Row Total' S. The entry in the column S divided by 24 gives the daily mean and should be entered in column 'Mean S/24'.

The maximum rainfall among all the hours of a day together with the hour in which it has occured should be entered in the column 'Maximum Reading' and ' Hour and Time' respectively. The next column is meant for the total duration of rainfall in hours and minutes.For example if the total duration of rainfall in a 24 hour period is 5 hours and 25 minutes it is entered as such under hours and minutes columns.

INSTRUMENTS FOR MEASUREMENT OF OTHER HYDROMETEOROLOGICAL PARAMETERS

Stevenson Screen

Stevenson screen consists of a louvered wooden box through which air can pass freely. It has double roof and a bottom. It is mounted on legs sunk into ground which are fixed in concrete firmly such that the bulbs of the two vertically hung thermometers are at a height of 1.3 m (4 ft.) above ground level. The Stevenson screen houses thermometers, thermograph etc. In double Stevenson screen both recording and non-recording type can be housed and in single Stevenson screen only maximum and minimum thermometers and wet and dry bulb thermometers are kept (all non-recording types).

The screen is oriented so that the door opens towards the north in the northern hemisphere and towards the south in the
southern hemisphere. This is to minimise the risk of sunshine falling on the thermometers when the door is opened to read them.

The following are the descriptions of various instruments housed in Stevenson screen.

MAXIMUM AND MINIMUM THERMOMETERS

1. For estimating runoff from precipitation the daily mean or monthly mean temperature data are to be collected. This can be obtained with the help of maximum and minimum thermometers. The average of daily maximum and daily minimum gives daily mean temperature.
2. The monthly mean temperature is obtained by totaling the daily mean values and dividing it by number of days of the month.
3. The maximum and minimum thermometers are mounted on a single board and they may be of the U shaped tube type or individual ones. The maximum temperature of the day is measured through rise in the day temperature as indicated by rise of mercury column and the minimum by fall in the column of mercury/alcohol.
4. Index is provided in the thermometer which stop at maximum and minimum temperature levels. The reading at the bottom of the Index indicates the maximum and minimum temperatures.
5. The Indices are required to be brought to touch the mercury column every day at 8.30 a.m. by using a magnet which is provided with the instruments in case of U shaped thermometers.

DRY AND WET BULB THERMOMETERS

1. The humidity data is obtained by using the values of dry and wet bulb thermometers. The dry bulb gives the air temperature. The wet bulb is exactly similar to dry bulb except that its bulb is covered with muslin which is kept continuously moistured with water. The evaporation of water through muslin cloth produces a cooling effect, so that wet bulb reads lower than dry bulb unless air is completely saturated with water vapour. In such a case there will be no cooling effect.
2. Tables 3 and 4 give values of relative humidity at 1000

mb and 900 mb levels for different values of dry and wet bulb thermometer values.

3. These thermometers along with maximum and minimum can either be installed vertically or horizontally with slight slope.

THERMOHYGROGRAPH

The thermo-hygrograph records on one chart the change in both temperature and humidity. The thermometric element is a bimetallic spiral coil, and the pen records on the upper part of the chart. The hygrometric record is obtained from the action of human hairs and is on the lower part of the chart. The total height of the chart is 7". The pen arm and movements, situated well away from the case, are protected by a perforated metal guard.

Care

Keep the instrument clean and treat with reasonable care. Where the atmosphere is acid-laden the outside of the case should be wiped over with oil damped cloth. Ink drops should be wiped off immediately to prevent spreadings as they will not dry. Wind the clock regularly once every week.

Adjustments

Zero adjustment (temperature). Place the bulb of a high grade thermometer with scale divided on glass stem close to, but not in contact with the bimetal coil. Allow ample setting time, compare readings and correct error, if any, by means of the zero adjustment screw adjustment to the bimetal coil.

Zero adjustment (Humidity). Tests should be conducted with steady humidity/temperature conditions preferably within the region of normal use, the observer standing so that the air flows past the instrument prior to himself.

EVAPORIMETERS

Modified Class 'A' Pan Evaporimeter

1. This is modification of Class 'A' pan and is as per I.S. 6939-1973. The pan is made out of 1 mm copper sheet tinned inside and painted with white paint outside or from fibre glass reinforced polyester. It is 1225 mm in diameter and 255 mm high.
2. Measuring cylinder is used to measure the depth of evaporation. The diameter of the measuring cylinder will be 1/10 that of the pan and the area of the cylinder is Kept 1/100 of that of pan such that the

depth of measurement by measuring cylinder is magnified 100 times. The cylinder (made of brass) is graduated from 0 to 200 mm. The 200 mm corresponds to 2 mm of depth of water in the pan (ratio of cylinder to pan is 100). Also each one cm in the cylinder corresponds to 0.1 mm of water in pan.

Exposure and Maintenance of Evaporimeter

Pan should be installed by the side of the raingauge.

Installation

1. It is covered with hexagonal wire mesh (0.70 mm) to avoid birds etc., drinking the water in the pan.
2. It is mounted on a wooden platform (100 mm high) to allow for air circulation below the pan.
3. No concrete or masonry platforms should be constructed below the pan as they induce radiation effects.
4. The reference point should be at a height of 30 cm (12 inches) above ground level.

Measurement

1. If the rainfall for the day is more than evaporation, there will be accumulation of water. Otherwise, there will be depletion in the water level.
2. To measure the accumulation or depletion of water level in the pan, water is either taken out or added by means of a measuring cylinder.
3. The temperature of water has also to be observed to assist in computing evaporation from meteorological factors and for purposes of estimating the missing pan data.
4. The thermometer is clamped to the side of the pan such that the bulb is below water levels. Care should be taken to read the thermometer when the thermometer is touching the water. It should not be taken out and read.
5. The pan must be cleaned atleast once in 15 days.
6. Pan should be painted annually. The pan should be checked for leakages, if any.

Observation of Data

As per I.M.D. standards, the evaporation is to be measured daily at 8.30 and 17.30 hours. The following example illustrate the computation of evaporation.

1. If on the day of no rain, suppose 62 cm of water has to be added to bring water to the reference point it means

that the evaporation is 6.2 mm (62 cm/100=6.2 mm).

2. If on the other hand, on the day it has rained and the water level is above the reference point, water has to be actually removed. Let us suppose that 5 mm of rain has fallen during the previous 24 hours and that on the day of measurement, an amount of 35 cm or 350 mm of water had to be removed from the pan to bring the water level to reference (5 - 1/100 x 350) = 1.5 mm.
3. Let us take a case of light rainfall when water level does not rise above reference point. Let the rainfall recorded be only 1.5 mm and the water to be added to the pan to bring it to reference point level be 40 cm. The quantity of water added is 4 mm and the depth of rainfall is 1.5 mm, thus the total evaporation will be 5.5 mm.

WIND SPEED

1. Anemometer is an instrument used to measure the wind speed or velocity. In India cup type anemometer is approved by I.M.D. The data is useful in estimating the wave height in reservoirs and for estimation of evaporation from meteorological factors and for estimation of consumptive use of crops.
2. The requirement of an engineer is therefore different from that of the meteorologist whose aim is to study the wind gradient at different heights. For our purpose, we require wind speed at practically ground level (reservoir level) and at crop height level. The suitable height from our point of view would be from 1 ft. to 5 ft. from the ground level. Table 5 gives approximately the values of wind speed at 1 ft. from ground level for values obtained (measured) at different heights.

Installation

1. The anemometer should be fixed in the corner of the observatory as shown in the approved layout.
2. It should never be fixed on the sloping roofs or just above buildings, where eddies created vitiate the readings.
3. The anemometer should be fixed to 20 mm galvanised iron pipe embedded in concrete block.
4. By the side of the anemometer, the wind vane that is the direction indicator should also be fixed.

OBSERVATION OF WIND DIRECTION

The wind direction is specified relative to the true North at the place of observation, and is normally expressed as a bearing in degrees from true North (in a clock wise direction). The direction of wind is of great importance in meteorology, Transport, Aviation, Shipping, Industry, General engineering and various other areas of human activity. The instrument is generally as per IS-5799.

Wind Vane

The wind vane consists of a horizontal arm which carries a flat tail fin at one end and a counter weight at the other end. The horizontal arm is mounted on a vertical spindle mounted on bearings. A cap nut is provided on the top end of the spindle to hold the horizontal arm. The support table has at its bottom a mounting ring for fixing direction arms. Four direction arms are provided which carry the letters, North, East, South & West, which shall point towards the corresponding true directions. Lock nuts are provided for tightening the direction arms to the mounting ring.

Setting Up

The wind vane shall be mounted on a main mast with the direction arms indicating the true direction, which shall be set with a good magnetic compass. The mast shall be about 30 feet tail and shall be away from tail buildings, trees and other obstructions. The position of the counter weight with respect to the direction arms indicates the wind direction and may be easily determined by interpolation to a reasonable accuracy.

Maintenance

The bearing assembly of the instrument shall be oiled at intervals to have a smooth movement of horizontal arm.

SUNSHINE RECORDER

1. Once the instrument has been set up and properly adjusted it requires no attention except changing the cards each day. The cards should normally be changed after sunset each day.In rainy season it is advisable to insert the fresh card early in the morning, before sunrise. If for any reasons it is quite impracticable to change the cards after sunset, any other hour may be chosen provided it is always strictly adhered to. There is a risk of having overlapping burns on the card, if varying times of changing are employed. If the sun is shining when inserting the card, the sphere should be shaded so that a false scorch is not made. If the cards are not changed after sunset, the actual time of insertion and withdrawal should be noted on the card. When inserting the cards care must be taken to

ensure that the noon line on the card coincides exactly with the mark on the bowl. If after rain, a card cannot be withdrawn without tearing, it should be cut out by carefully drawing a sharp knife along the edge of one of the flanges which holds it in place. A fresh card should be inserted every day even if no sunshine has been recorded and all cards should be properly dated on the back.

2. The long curved summer cards should be used from April 12 to September 2 inclusive. They are inserted with their convex edge uppermost. The short curved winter cards should be used from October 15 to February 28 (or 29 in a leap year) inclusive. The straight cards are for use during the remainder of the year (about the equinoxes). When inserting the equinoctial card care should be taken to ensure that the hour figures are erect, otherwise the morning sunshine will be recorded on the portion of the card intended to receive the afternoon record and vice versa. Before bringing a new set of cards into use, it is advisable to clean away any dirt which may have accumulated in the flanges.

3. The glass sphere should be cleaned as required with a chamois leather. It should not be cleaned with rough cloth that would abrade the surface and excessive vigour in polishing should be avoided. If snow or hoar frost settle on the instrument, it should be removed as soon as possible.The recorder should be examined each morning and any deposit such as snow, frost, dew, bird-droppings, should be immediately removed. The whole instrument must be periodically cleaned first by brushing off the dust and then wiping with a soft cloth. Provided the support for the instrument is firm and does not warp. Little is needed in the way of maintenance apart from keeping the base and bowl clean.

TABLE - 1

DISTRICT : -------------------- STATION : --------------------

NATIONAL INSTITUTE OF HYDROLOGY

DAILY RAINFALL

Lat: 29 51 Elev. 274 m Year State: Uttar Pradesh
Long: 77 53 Time: 0830-0830

Date	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
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30												
31												

TOTAL RAINFALL :

TOTAL RAINY DAYS : ANNUAL

TABLE - 2

PROFORMA FOR RECORDING HOURLY RAINFALL

Station :

Year

Standard of Time : Instrument Element : Unit : Month :

Zero of Tabulation :

Day	Hous																								S, that is Raw Total 1+2+3+...+24	Mean S/24	Maximum Reading in an Hour & Time		Duration of Rainfall	
	1	2	3	4	5	6	7	8	9	10	11	12	13	15	14	16	17	18	19	20	21	22	23	24			Reading	Time	Hour	Minutes
1																														
2																														
3																														
4																														
5																														
6																														
7																														
8																														
9																														
10																														
11																														
12																														
13																														
14																														
15																														
16																														
17																														
18																														
19																														
20																														
21																														

Table - 3

Hygrometric Tables for computing relative humidity % (1000 mb) (Elevation up to 1500ft) Wet blub °C

Dry bulb C	5	6	7	8	9	10	11	12	13	14	15	16	17	18	91	20	21	21	23	24	25	26....	27	28	29	30
10	39	50	62	74	37	100																				
11	30	41	52	65	75	88	100																			
12	23	33	43	54	65	76	88	100																		
13	16	25	35	45	55	66	77	88	100																	
14	10	19	28	37	47	57	67	78	89	100																
15	5	13	21	30	39	48	58	68	78	89	100															
16		8	16	24	32	41	50	59	69	79	89	100														
17		3	11	18	25	34	43	52	61	70	80	90	100													
18			6	13	21	29	36	45	53	62	71	80	90	100												
19			2	9	16	23	31	38	46	54	63	72	81	91	100											
20				5	11	18	25	33	40	48	56	64	72	61	91	100										
21				1	8	14	21	27	34	42	49	57	65	73	82	91	100									
22					4	10	16	23	29	36	43	50	58	66	74	82	91	100								
23						7	13	18	25	31	38	45	52	59	67	75	83	91	100							
24						4	9	15	21	27	33	39	46	53	60	67	75	83	91	100						
25						1	6	11	17	23	28	34	40	47	54	61	68	76	84	92 ..	100					
26							3	8	13	20	24	30	36	42	48	55	62	69	76	84	92	100				
27							1	6	10	15	21	26	32	47	43	50	56	63	70	77	84	92	100			
28								3	8	12	17	22	28	33	39	45	51	57	63	70	77	85	92	100		
29								1	5	10	14	19	23	29	35	40	46	52	58	64	71	78	85	92	100	
30									3	7	12	16	21	26	31	36	41	47	53	59	65	71	78	85	92	100
31									1	5	9	13	18	23	27	32	37	42	48	54	60	66	72	79	85	93
32										3	7	11	15	20	24	29	33	38	44	49	55	60	66	73	79	86
33										1	5	9	13	17	21	25	30	35	40	45	50	55	61	67	73	79
34											3	7	11	14	18	23	27	31	36	41	46	51	56	62	67	73
35											2	5	9	12	16	20	24	28	33	37	42	47	52	57	62	68
36												3	7	10	14	17	21	25	29	34	38	43	47	53	58	63
37												2	5	8	12	15	19	23	27	31	35	39	44	48	53	58
38												1	4	7	10	13	17	20	24	28	32	36	40	45	49	54
39													2	5	8	11	15	18	21	25	29	33	37	41	45	50
40													1	4	7	10	13	16	19	23	26	30	34	38	42	46
41														3	5	8	11	14	17	20	24	27	31	35	39	43
42														1	4	7	9	12	15	18	22	25	28	32	36	40
43															3	5	8	11	14	17	20	23	26	29	33	37
44															2	4	7	9	12	15	18	21	24	27	30	34
45															1	3	5	8	11	13	16	19	22	25	28	31

Extract from IMD Hygrometric Tables (1000 mb), Rota Print, Poona-5 - December 1970.(reprinted)

Table - 4

Hygrometric Tables for computing relative humidity % (900 mb) (Elevation 1500ft & above) Wet blub °C

Dry bulb C	5	6	7	8	9	10	11	12	13	14,	15	16	17	18	91	20	21	22	23	24 ..	25	26	27	28	29	30	
10	42	53	64	76	88	100																					
11	34	44	55	65	77	88	100																				
12	27	36	46	56	66	77	88	100																			
13	20	29	38	48	57	68	78	89	100																		
14	14	23	31	40	49	59	69	79	89	100																	
15	9	17	25	33	4	51	60	70	80	90	100																
16	5	12	20	27	35	44	52	61	70	80	90	100															
17	1	8	15	22	30	37	45	54	62	71	80	90	100														
18		4	10	17	24	32	39	47	55	63	72	71	80	90	100												
19			6	13	20	26	33	41	48	56	64	73	82	91	100												
20			3	9	15	22	28	35	42	50	57	65	73	82	91	100											
21				6	11	17	24	30	37	44	51	58	66	74	82	91	100										
22				3	8	14	20	26	32	39	45	52	59	67	75	83	91	100									
23					5	10	16	22	28	34	40	47	53	60	68	75	83	91	100								
24					2	7	13	18	23	29	35	41	48	54	61	69	76	84	92	100							
25						5	10	15	20	25	31	37	43	49	56	62	69	76	84	92	100						
26						2	7	12	17	22	27	32	38	44	50	56	63	70	77	84	92	100					
27							4	9	14	18	23	29	34	39	45	51	57	64	71	77	85	92	100				
28							2	7	11	15	20	25	30	35	41	46	52	58	65	71	78	85	93	100			
29								4	8	13	17	22	27	31	37	42	47	53	59	65	72	78	85	93	100		
30								2	6	10	14	19	23	28	33	38	43	48	54	60	66	72	79	86	93	100	
31								1	4	8	12	16	20	25	29	34	39	44	49	55	61	67	73	79	86	93	100
32									3	6	10	14	18	22	26	31	35	40	45	50	56	61	67	73	80	86	93
33									1	4	8	12	15	19	23	28	32	36	41	46	51	57	62	68	74	80	86
34										3	6	10	13	17	2	25	29	33	38	42	47	52	57	63	68	74	80
35										1	4	8	11	15	18	22	26	30	34	39	43	48	53	50	63	68	74
36											3	6	9	13	16	20	23	27	31	35	40	44	49	54	59	64	
37											2	5	8	11	14	17	21	25	28	32	36	41	45	50	54	59	
38											1	3	6	9	12	15	19	22	26	29	33	37	41	46	50	55	
39												2	5	8	10	14	17	20	23	27	31	34	38	42	47	51	
40												1	4	6	9	12	15	18	21	24	28	32	35	39	43	47	
41													2	5	8	10	13	16	19	22	26	29	32	36	40	44	
42														1	4	6	9	12	14	17	20	23	27	30	33	37	41
43															3	5	8	10	13	15	18	21	24	28	31	34	38
44															2	4	6	9	11	14	17	19	22	25	28	32	35
45															1	3	5	8	10	12	15	18	20	23	26	29	33

Extract from IMD Hygrometric Tables (900 mb), Rota Print, Poona-5 - December 1975.

TABLE 5

GROUND WIND VELOCITIES FOR WIND MEASUREMENTS AT DIFFERENT HEIGHTS ABOVE THE GROUND
(Miles per hour)

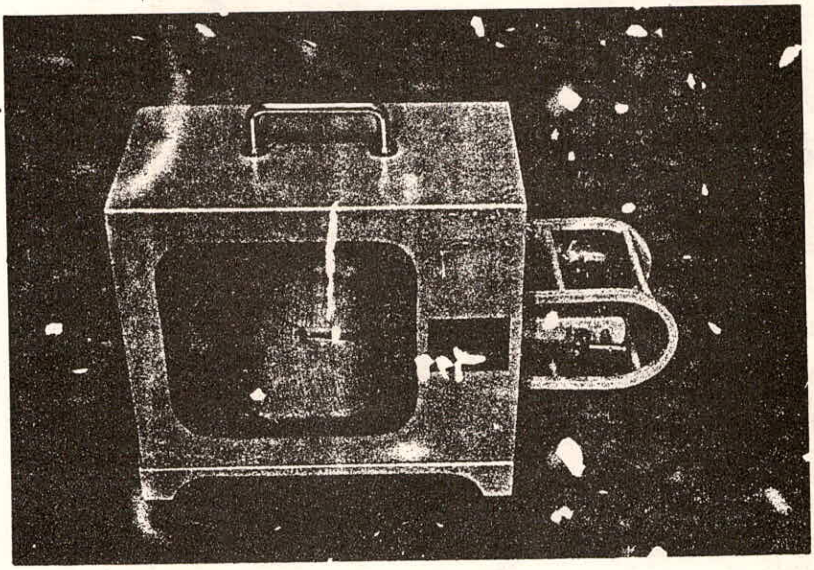
Equivalent velocities 1 ft. above ground level when height of anemometers are

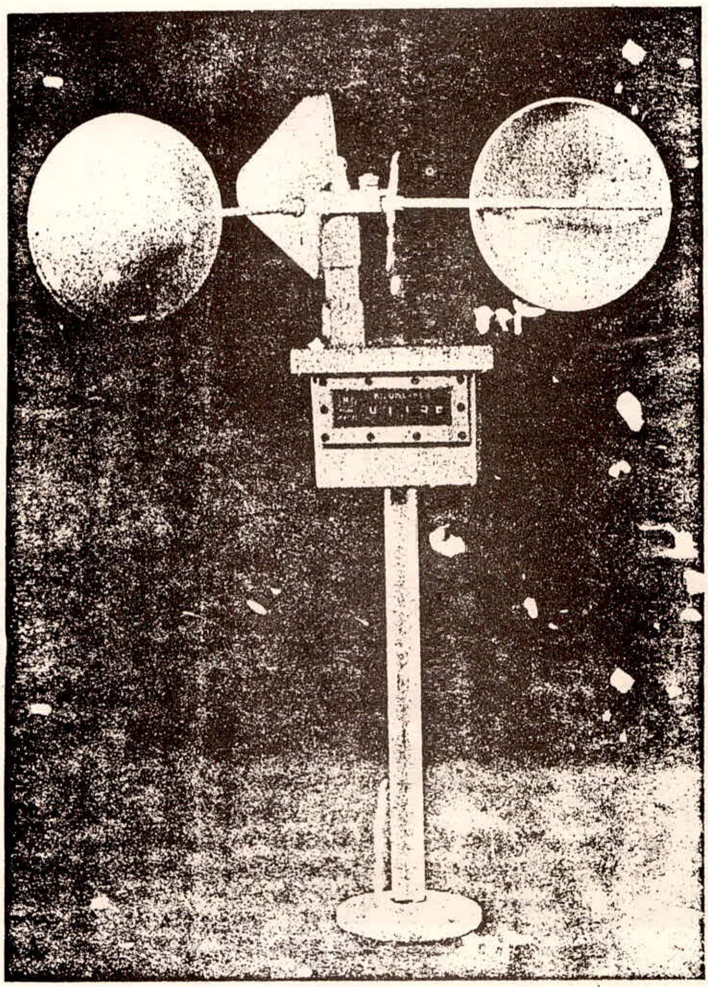
Measured wind velocity	10 ft.	20 ft.	30 ft.	40 ft.	50 ft.	75 ft.	100 ft.	150 ft.	200 ft.
2.	1.85	1.73	1.62	1.58	1.53	1.44	1.37	1.28	1.22
3.	2.68	2.48	2.32	2.23	2.18	2.05	1.90	1.78	1.68
4.	3.48	3.18	2.97	2.88	2.75	2.55	2.38	2.22	2.08
5.	4.25	3.84	3.58	3.45	3.30	3.05	2.84	2.65	2.48
6.	5.00	4.50	4.18	4.00	3.80	3.54	3.28	3.04	2.83
7.	5.86	5.08	4.75	4.52	4.30	4.00	3.68	3.42	3.18
8.	6.42	5.75	5.30	5.05	4.78	4.42	4.06	3.78	3.50
9.	7.10	6.35	5.82	5.55	5.30	4.82	4.45	4.10	3.82
10.	7.75	6.90	6.38	6.05	5.70	5.28	4.85	4.45	4.12
12.	9.08	8.00	7.35	6.95	6.60	6.02	5.55	5.10	4.70
14.	10.30	9.00	8.30	7.90	7.40	6.75	6.25	5.70	5.30
16.	11.60	10.00	9.20	8.75	8.20	7.50	6.85	6.30	5.85
18.	12.80	10.90	10.05	9.55	8.95	8.10	7.50	6.85	6.35
20.	13.90	11.80	10.85	10.40	9.70	8.80	8.10	7.35	6.80
25.	16.60	14.25	13.00	12.40	11.45	10.40	9.55	8.65	7.95
30.	19.30	16.35	15.00	14.20	13.20	11.85	10.85	9.90	9.10

Source: Extract from PP. 252 of "Irrigation Engineering - Volume I Agricultural & Hydrological Phase by Ivan E.Houk.

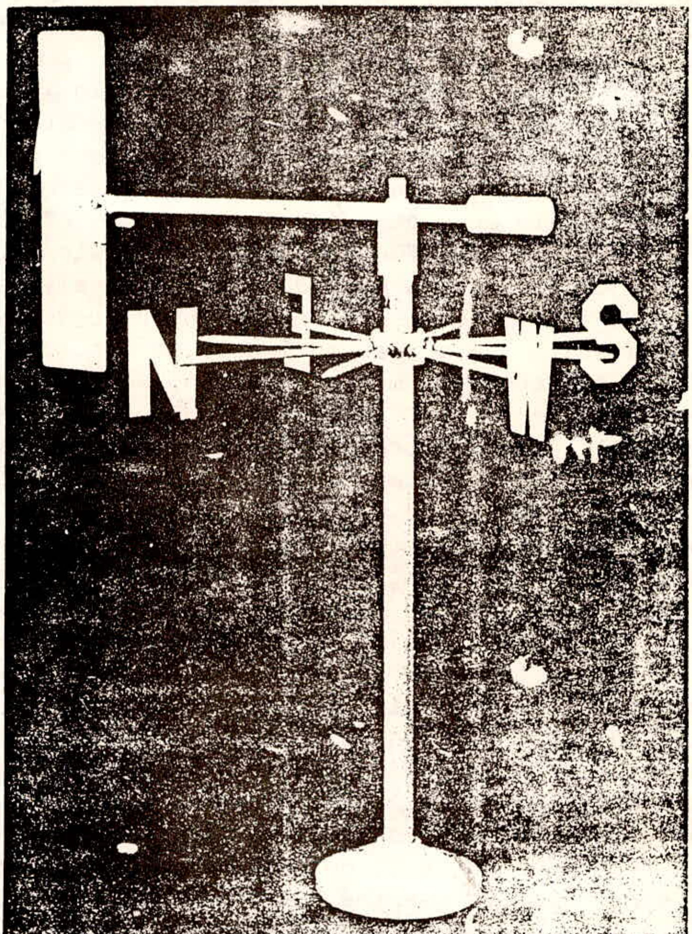
THERMOGRAPH Bimetallic

AS PER -.IS : 5901 - 1970





I.M.D. CUP COUNTER ANEMOMETER, M II



I.M.D. WINDVANE, Mk II

PROCESSING OF RAINFALL DATA

INTRODUCTION

In water resources planning and management it is imperative to know how much water is available and how best to use this water and the related land resources. Long and continuous historical records are required for system planning. Where the length of record of stream flow data is limited, the series are made up either by synthetic data generation technique or establishing rainfall-runoff relationships for extending the runoff series.

Hydrometeorological analysis forms an important and integral part of hydrological research. The hydrometeorological analysis comprises of a wide range of studies for providing input for water resources estimation and feasibility studies for developmental projects and estimation of design storm for determining design flood for hydraulic structures. One of the important parameters needed in these analysis is the rainfall which in itself forms part of the hydrologic cycle.

Rainfall data is collected at a number of locations in India. In earlier times, processing was generally done manually. The need for use of faster methods of processing the data has been felt with increase in the number of data records for processing and this led to the use of computers and data handling by punched cards. Primary processing of rainfall data is essential before further use can be made of this data in other analysis such as estimation of probable maximum precipitation using statistical and physical methods, mean aerial precipitation estimation etc. Besides observational and instrumental errors, during the transfer of data from manuscript to punched cards, errors can occur at the stage of recording and punching. Detailed quality control of large volumes of data by visual inspection is quite impracticable. However, the use of digital computers has made the task simpler and all the data can be subjected to desired quality control checks. The transfer of data from punched cards on to magnetic tapes has made it possible to conveniently use the hydrometeorological data particularly rainfall for research and enquiry purposes.

OBJECTIVES

Rainfall data in its raw form would contain many gaps and inconsistent values. Preliminary processing of data is, therefore, essential before the data are subjected to further analysis. Processing of the data has two objectives. One is to evaluate the data for its accuracy and the other is to prepare the data in a form appropriate for subsequent analysis. Manual processing has obvious limitations. Computerised processing has several advantages over the manual processing.

In this lecture, the methods of processing and analysis of rainfall data are described with a view to make the user self sufficient and self dependent in the processing and analysis of rainfall data.

The methods of processing rainfall data described are simple to adopt and easy to use with microcomputers. The methodology is explained with examples and illustrations where necessary.

METHODOLOGY

Storage of Rainfall Data

In India the rainfall data collected by State organisations is generally stored only in the form of printed records. The data are, however, transferred on to magnetic tapes by the office of the Additional Director General of Meteorology, IMD, Poona.

FORMAT OF DAILY RAINFALL DATA

The daily rainfall data were punched in a 31 card format as shown in figure 1(a) until 1970 and was switched over to a 24 card format as shown in figure 1(b) since 1971.

In the 31 card format, the data of 12 months for each day are punched on each card together with station related information, year and date. In the 24 card format, each month's rainfall data are punched on 2 cards, 16 days data on the first card and 15 days data and monthly total on the second card.

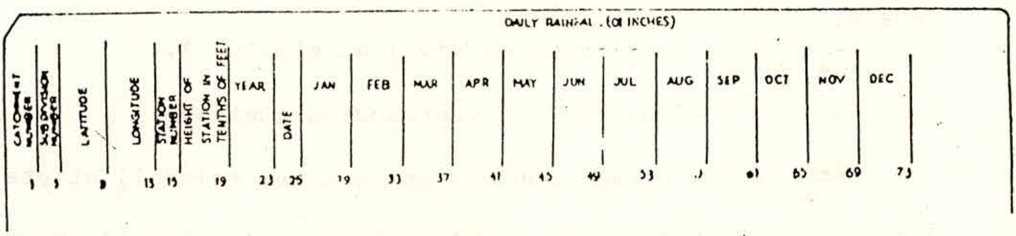


Figure 1(a)- 31 Card Daily Rainfall Data Format

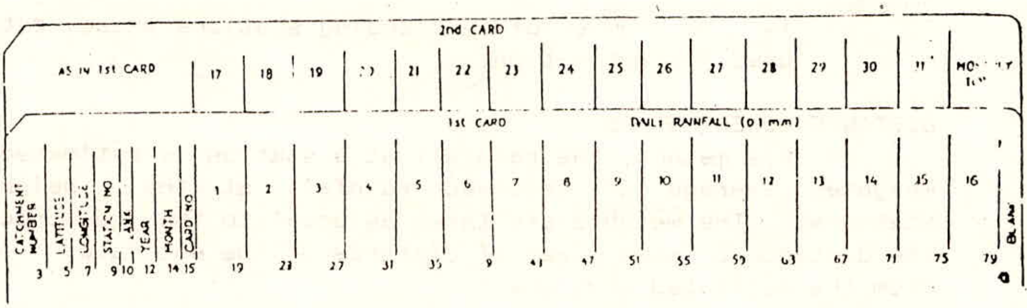


Figure 1(b)-24 card Daily Rainfall Data Format

Identification of Missing Rainfall Data

While retrieving the data for climatological purposes or inputting the data in real time, one often comes across missing data situations. Since blank in a data set is read as zero, necessary software for identifying the blanks and marking them appropriately has been developed. The programme reads the daily rainfall data of different stations from the input disk file of rainfall data supplied by IMD on magnetic tapes. The blank spaces in the data are read and replaced by -999 while rewriting the whole data onto another disk file.

Estimation of Missing Rainfall Data

Data for the period of missing rainfall data could be filled using estimation technique. The length of period upto which the data could be filled is dependent on individual judgment. Rainfall for the missing period is estimated either by using the normal ratio method or the distance power method.

NORMAL RATIO METHOD

In the normal ratio method, the rainfall R_A at station A is estimated as a function of the normal monthly or annual rainfall of the station under question and those of neighbouring stations using actual rainfall data recorded at neighbouring stations for the period of missing data at the station under question.

$$R_A = \frac{\sum_{i=1}^{n} \frac{NR_A}{NR_i} \times R_i}{n} \quad \ldots\ldots (1)$$

where,

R_A is the estimated rainfall at station A,

R_i is the rainfall at surrounding stations,

NR_A is the normal monthly or seasonal rainfall at station A,

NR_i is the normal monthly or seasonal rainfall at station i,

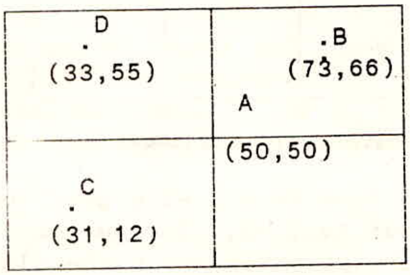
n is the number of surrounding stations whose data are used for estimation.

DISTANCE POWER METHOD

In this method, the rainfall at a station is estimated as a weighted average of observed rainfall at the neighbouring stations. The weights are taken as equal to the reciprocal of the distance or some power of distance of the estimator stations from the estimated stations.

$$R_A = \frac{\sum_{i=1}^{n} \frac{R_A}{D_i^2} \times R_i}{\sum_{i=1}^{n} \frac{1}{D_i^2}} \quad \text{..........} \quad (2)$$

where, R_A and R_i has the same notation as in equation (1) and D is the distance of estimator station from the estimated station. The procedure for estimating rainfall data by this technique is indicated.



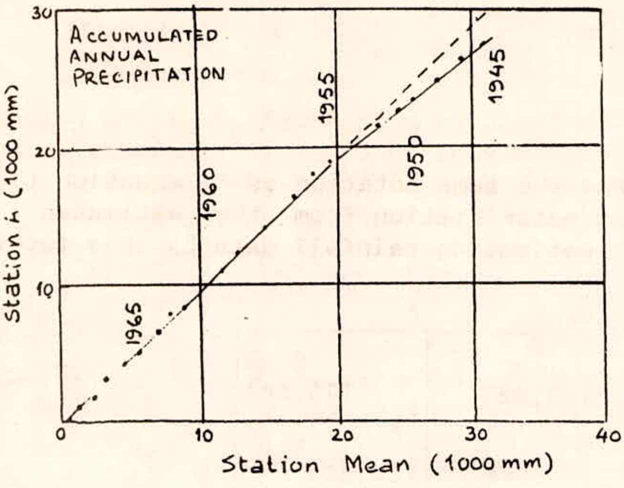
If, A, B, C and D are the locations of stations, the distance of each estimator station (B,C and D) from the station (A) whose data is to be estimated is computed with the help of the coordinates using the formula

$$D_i = [(x-x_i)^2 + (y-y_i)^2]^{1/2} \quad \text{.........} \quad (3)$$

where x and y are the coordinates of the station whose data is estimated and x_i and y_i are the coordinates of the estimator stations. The weights $1/D_i^2$ are computed for each station and the rainfall at station A is estimated using the equation (2).

Adjustment of Data

To obtain homogeneity among and within measurements of rainfall data, adjustment of the data becomes necessary. The 'Double Mass Curve' is used to check the consistency of the rainfall data of a particular period. Double mass analysis is a graphical method for identifying and adjusting inconsistencies. This is carried out by comparing the data of the station with the general trend of the reference stations in the neighbourhood. As the name implies the double mass curve's both axis are accumulated rainfall. Cumulated rainfall data of the station whose data is to be checked is plotted against the average cumulated rainfall data at a number of nearby stations. Usually the accumulated seasonal or annual rainfall values of reference station or stations is taken as abscissa and those of the station under question as ordinate.



Divergence of the line from a straight line indicates an error at the gauge under testing. The period of the error is known by identifying the point at which the slope of the line changes.

Distribution of Daily Rainfall Data into Hourly Rainfall

For hydrological analysis, rainfall data of shorter duration is required. The network of recording raingauges in India being small in comparison to that of daily (non-recording) raingauge, it becomes necessary to convert the daily rainfall into shorter period intervals either manually or by using appropriate computer routines. The information of short interval rainfall is used together with information of daily rainfall from nearby non-recording (daily) gauges.

Mass curve is a graphical display of accumulated rainfall Vs time. Mass curves of accumulated rainfall at (non-recording) daily stations and recording stations are prepared by plotting the accumulated rainfall values against time for the storm duration under analysis.

A comparison of the mass curves of the recording raingauge stations with those of the non-recording stations would help in deciding which recording raingauges or group of gauges could be considered as representative of which of the non-recording raingauge for the purpose of distributing daily rainfall into hourly rainfall.

The procedure for distribution of daily rainfall at non-recording raingauge stations into hourly rainfall is dealt in detail in the tutorial on the subject.

STREAMFLOW MEASUREMENT

INTRODUCTION

The importance of accurate observation of the discharge of a river need not be emphasized. In view of considerable variations in the river discharge , both on long term as well as short term basis as also because of large spatial variations, it is necessary to have a properly designed network of the gauging stations.

GAUGING STATION NETWORK

The discharge observation stations are of following types:

a) Principal Hydrologic Stations;
b) Secondary Hydrologic Stations; and
c) Special Stations.

The principal hydrologic stations are operated permanently and are established with a view to determine the basic stream flow characteristics of the region.

The secondary hydrologic stations are intended to be operated only long enough to establish the flow characteristics of their watersheds , relative to those of a watershed gauged by a principal hydrologic station.

The special stations are intended to be established to provide specific information at a site for various purposes such as fulfillment of a legal requirement, management and operation of an existing project or design of a potential or proposed project etc.

SELECTION OF A SITE

The objective of the selection of a proper site is to make accurate observations with ease and economically. Some of the points which are to be given due consideration in selection of a discharge observation site are as follows :

i) The general course of the river should be reasonably straight.
ii) The total flow should be confined to one channel at all stages and no flow should bypass the site as sub surface flow.
iii) Banks should be permanent and high enough to contain floods.
iv) The stream bed should not be subjected to scour and fill and should be free from weeds

v) The site should be away from the confluence with another stream and should be preferably on the upstream.

vi) Site subjected to tidal effect or local disturbances should be avoided.

vii) the cross sections of the site should be fairly uniform for the straight reach.

viii) The site should be easily accessible.

ix) The site should not be unduly exposed to the winds.

x) The site should be preferably away from bridges , water intakes or other manmade structures.

xi) The installations at site should be free from tree and other vision obstructions.

xii) The stage discharge relations at site should be stable.

xiii) The site should be free from aquatic growth.

xiv) Sites with tendency for the formation of vortices, return flow or local disturbances should be avoided.

xv) The site should be selected in such a way that the installations are not likely to be disturbed for a considerable period of time.

xvi) Availability of facilities for transport of construction materials , equipment and personnel should not be lost sight of at the time of selection of the site.

An ideal site is rarely found and very often , all the sites have one or more shortcomings. However,every effort should be made to select the most appropriate site under the given conditions.

Discharge observation is generally time consuming process and involves considerable cost. Therefore it is necessary to have a water recorder at the discharge sites as the gauge observations can be made at a very close interval and also on continuous basis with the help of an automatic recorder.

WATER LEVEL OBSERVATIONS

Water level observations are carried out with the help of gauges . There are various types of gauges in use and the most commonly used are :

a) Non-recording type or manually operated gauges.
   - i) staff gauges;
   - ii) sloping gauge or stepped gauges;
   - iii) cantilever gauges; and
   - iv) gauge wells provided in major hydraulic structures.

b) Continuous river stage recorders or automatic water level recorder.

i) float type; and

ii) pneumatic type.

The various types of gauges are briefly described as under.

Non-recording Type or Manually Operated Gauges

STAFF GAUGE

Non-recording graduated staff gauges are generally used for the measurement of river stages. These gauges are commonly made of seasoned wooden posts of size of 0.15m x 0.10m x 3.00m and founded vertically in concrete block (mix 1:2:4) of size 0.60m x 0.60m x 0.75m, leaving about 2.15m length of the gauge above the block. They are installed in steps with an overlapping of about 0.15m and in sufficient numbers to enable the measurement of entire range of flow from the minimum water level to the maximum water level expected at the site. To avoid error in measurement due to afflux , the upstream face is streamlined in a cut water shape. The upstream graduations of the gauge are generally engraved in 0.01 m alternatively, the decimeter and full meter markings covering a greater width than the rest. Using synthetic enamel water proof paint, the gauge post is first painted in white and the engraved graduations are then repainted in black , except that the whole marks may be painted in red . The numbers to indicate the decimeter marks are painted in black and those to read the meter marks in red.

The gauge is read upto the third place of decimal. The gauge observation is done thrice daily at 08.00,13.00 and 18.00 hours in lean season and hourly during flood season.

The detailed specifications for the vertical staff gauges are given in IS:4080-1967.

SLOPING GAUGE OR STEPPED GAUGE

Sloping or stepped gauges are provided when the banks are quite stable . This is generally made of concrete blocks fixed along the slope of the banks and provided with steps for reading the gauges, painting them etc.The marking of the slope gauge is to be made with precise levelling . These gauges are to be checked every year before floods for possible disturbances. The water levels can be read with greater degree of accuracy because of enlarged scale.

CANTILEVER GAUGE

Cantilever gauges are generally provided at hill streams where it is not possible to approach the river bed on account of high and steep banks, and it is difficult to install a vertical or inclined staff gauge . In the case of a cantilever gauge, the scale is attached to a beam which cantilevers out over the stream from inshore. A weight is lowered to the water surface with a chain which runs over a pulley at the outer end of the cantilever . The position of a marker on the chain is read on the scale.

GAUGE WELLS

The gauge wells are generally provided in hydraulic structure for recording the upstream and the downstream water levels. The gauging wells are for the purpose of dampening the disturbances of the water caused in hydraulic structures. Gauges are generally painted on the inside of the well.

Automatic Water Level Recorder

FLOAT TYPE GAUGES

Float operated gauges require a stilling facility, i.e. a well or a G.I.pipe of suitable diameter , in which the float operates. It senses the fluctuations in the water level and conveys to the recording mechanism through pulley and counterweight. The strip chart in the recorder is moved by a clock at a speed required for the proper definition of the graphic record. The well is connected to the water outside in the river through an intake pipe. It is preferable to fix two or more intakes at different levels. The intake pipes need to be flushed after every flood, especially where the river carries sufficiently high silt load. If a hydraulic structure like a barrage or a bridge is in the vicinity, a suitable G.I.pipe can be anchored to its pier or abutment for installation of a float operated gauge. The cost of installation and maintenance in this case is relatively less.

PNEUMATIC GAUGE

Pneumatic gauge recorder does not need a stilling well or pipe. Shifting of the equipment of the pneumatic gauge and pipe and its installations from station to station is easier and cheaper. In this type of gauge , the gauge the gauge height element is actuated by the static pressure of the head of water above the orifice. It usually has three components i.e. gas purge system; manometer assembly; and servo control and amplifier units.

A bubble tube connects the instruments installed inside a shelter on the high bank of a river to the orifice tube in the water. When the nitrogen gas bubbles enter freely into the water through the orifice , a back pressure is created inside the tube which is proportional to the water level and the corresponding difference in hydrostatic pressure is sensed by a mercury manometer or a piston manometer.

When water depth changes , the resulting pressure variation causes the mercury to move from one cup to another , unbalancing the system in the case of the mercury manometer. This action is detected by a sensitive float switch which closes a set of contacts. The servo control unit amplifies the position change signal and supplies to the servo drive motor. The motor is geared to a movable carriage upon which the pressure reservoir is mounted. When the carriage reaches a point where the mercury column in the two cups is brought into a balance, the float switch opens and stops the motor. The servo motor is also geared to a digital counter and the stylus of the recorder. Errors, due to variation in the density of water with temperature and with chemical and salt content can be compensated by adjustment of the inclination of the manometer provided they are directly proportional to be pressure.

In the case of a piston manometer, the movement of the piston on account of difference of pressure disbalances the balance bean. This causes electrical contacts and the servo motor is actuated through the servo amplifier and the balance weight shifted till the beam is balanced when the motor stops.

MEASUREMENT OF RIVER DISCHARGE

The methods for the measurement of discharge of a river are as follows.

a) Direct Method
   - i) Area velocity method
      - a) By wading
      - b) By boat or jet boat or catamaran or motor launch
      - c) From bridge
      - d) From a cable way
      - e) By moving boat method
   - ii) Tracer method
   - iii) Other methods such as ultrasonic method, electromagnetic method etc.

b) Indirect Method
   - i) Slope area method
   - ii) Assessment by using stage discharge curve
   - iii) Assessment of flow passing through hydraulic structures

The choice of a specific method of discharge observation depends on many factors including site conditions, the flow characteristics, the availability of skilled manpower and the facilities for navigation. However, the velocity area method is the most commonly used method, particularly in India. The indirect methods of discharge estimation are also used in many areas.

Velocity Area Method

The detailed procedure for the measurement of flow of water in open channel is described in IS:1192-1959. The velocity area method consists of the measurement of stream velocity, depth of flow and the distance across the channel between observation verticals. The velocity is measured at one or more points in each vertical by current-meter and an average velocity determined in each vertical. The discharge is derived from the sum of the discharges passing through different segments.

$$Q = \sum_{i=1}^{m} b_i \, d_i \, v_i$$

where,
- Q = calculated discharge;
- b = width of the i^{th} segment;
- d = depth of the i^{th} segment;
- v = mean velocity in the i^{th} segment; and
- m = number of verticals in a cross section

In practice, the river section is divided into a number of compartments depending upon the width of the channel and the required degree of accuracy. The recommendations of the Bureau of Indian Standards are given below.

Description of Channel	Number of Observation Verticals	Maximum Width of Segments(m)
< 15m	15	1.5
15m to 90m	15	3.0 to 6.0
90m to 180m	15	6.0 to 15.0
> 180m	25	-

The depth of the stream is measured by sounding rod; log line or echo-sounder. The location of the vertical is usually determined by geometrical layout on the bank usually called pivot point method. In the case of moving boat method the distance, the velocity, the direction of flow, and the depth etc. are recorded automatically.

The velocity is generally measured by means of a cup type or propeller type current-meter by lowering at 0.6 D where D is the water depth of the section. An average of two readings i.e. at 0.20 and 0.80 are also adopted with good result. However, it is better to find out the exact point of mean velocity by actual experiment.

The segmentation is also made in such a way that more than 10% of the total discharge does not pass through any segment and the variation in discharges passing through two adjacent segment is not more than 4% .

In case, the velocity measurement can not be done with current-meter due to floating debris or current-meter being out of working order etc. the same can be done with the help of floats. In such a case the total discharge is multiplied by a conversion factor to determine the mean discharge of the river. Generally, the surface velocity obtained by the float is multiplied by 0.89 to estimate the average velocity. However, the conversion factor varies from 0.85 to 0.95.

DISCHARGE MEASUREMENT BY MOVING BOAT METHOD

The discharge measurement by moving boat method is essentially based on the principles of the velocity area method. The data such as depth, velocity and distance of segment is automatically observed & recorded while the boat crosses the river. The equipment required are:

a) Vane and angle indicator
b) water current-meter
c) Rate meter
d) Echo sounder

First, a path for the boat to travel is selected which is as nearly perpendicular to the flow direction as is possible. Then two clearly visible range markers are placed on each bank in line with this path. Anchored floats are placed in the stream at about 15m from either bank from the selected path. Finally, the width of the stream is measured by triangulation or other methods and the exact locations of the floats are determined,

During a moving boat discharge measurement the current-meter is set at a pre-determined, fixed depth or 1 to 1.25 m. below the surface; thus this technique uses the sub surface method of measuring the velocity. Observed velocities should ideally be multiplied by a coefficient to adjust it to the mean velocity for the vertical. However, it is observed that in larger streams where the moving boat techniques would be applicable, these coefficient would be fairly uniform across a section, thus permitting the use of an average cross section coefficients to be applied to the total discharge. Information obtained from several vertical velocity curves well distributed across the measuring site, would be needed to determine a representative coefficient for the total cross section.

The depth sounder records a continuous graph of the stream bed during the traverse. At 30 to 40 points along the cross section, a vertical mark is made on depth sounder chart to serve as observation points. It is recommended that at least six such individual runs should be made and the results should be averaged to obtain the discharge in uniform flow.

Indirect Measurement of River Discharge

SLOPE AREA METHOD

This method employs the principle of energy loss to estimate the velocity. These require measurement of the water surface slope along the stream from which an estimate of the energy gradient can be made. The energy gradient can then be used in the Manning's method.

$$v = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$

where, v = velocity in m/sec

R = hydraulic radius ; and

S = slope

The cross sectional area is determined by surveying usually after the passage of the flood.

∴ Discharge of the river is obtained by multiplying the cross sectional area with the mean velocity computed as above.

DISCHARGE ESTIMATION BY STAGE DISCHARGE CURVE

As discussed earlier, the observations for gauges are taken simultaneously with discharge observations.

The stage and discharge values measured over a large range of discharge are plotted on a graph and a Rating Curve is drawn. If the site for the stream gauging station is properly selected with a stable controls, a well defined curve can be fitted. The curve so drawn is generally known as Rating Curve or Stage Discharge Curve. A suitable mathematical equation can also be developed. The most commonly used equation is as follows:

$$Q = K\ (\text{Stage} - a)^{b}$$

where,

Q = discharge in cubic meters per second;

Stage = water surface elevation in meters;

K,b = constants to be determined; and

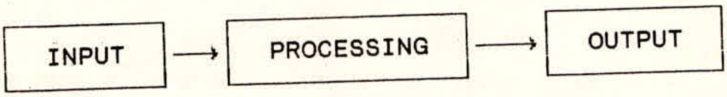
a = the elevation corresponding to the zero discharge

The stage discharge relationship can be very conveniently used to estimate the discharge of a large flood where only high marks or other information is available regarding the stage. The stage discharge relationship may be suitably extended to the stage observed to give an estimate of the discharge. If this involves a large extrapolation, simple graphical extension may not be adequate. Logarithmic method or Stevens methods based on Chezy's formula or the Conveyances Slope methods etc. are generally adopted under such conditions.

PROCESSING AND ANALYSIS OF STREAMFLOW DATA

INTRODUCTION

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.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. Data processing consists of three basic steps: input, processing and output. These three steps which constitute the data processing cycle are shown below.



Data Processing Cycle

INPUTS :In this step the initial data, or input data are prepared in some convenient form for processing. The form will depend on the 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 this step the input data are changed, and usually combined with other information to produce data in a more useful form. The processing step usually involve a sequence of certain basic processing operation.

OUTPUT :Here the results of the preceding processing steps 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.

COMPILATION AND PROCESSING OF BASIC HYDROLOGICAL DATA

The data requirements vary considerably from project to project. Depending upon the objectives, the required data are identified. Attempt is made first to collect all the available information from the existing network. If necessary, hydrological investigations are especially carried out to collect the additional data specifically needed for the project. The data so collected are to be scrutinised and processed before storing them in the desired format.It is necessary to indicate the source of such data collected at the appropriate place.

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

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

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.

REASONABLE REPORTS

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.

QUALITY OF DATA

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

ii. Details of history of station, shift in the location, shift in the rating curves are to be identified. Sample calculation for discharge should be furnished.It has to be clearly mentioned whether the discharge data is observed or estimated from the rating curve or otherwise.iii. The development of stage discharge curves at discharge site and the methods used for the extrapolations etc. are to be verified by other methods such as hydraulic calculations etc.

FILLING UP OF SHORT DATA GAPS

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

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

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

CONSISTENCY OF DATA

Internal Consistency Check

The consistency of the observed data at specific control points is to be checked. The check can be done by study of stage discharge relationship for different periods. Large variations are to be investigated, corrected and explained suitably if required.

Trend analysis may be performed to detect a slowcontinuous variation of meteorological conditions or a long periodic variation of the climate and to observe the modification of catchment physiography especially through human activity.

External Consistency Check

The consistency of the observed stream flow data shouldbe checked with reference to the rainfall in the project catchment and observed data in adjacent locations/basins.

The consistency can be checked by :

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

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 regressions. 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 runoff.
* Checking for negative values during the computation of

inflow to a reservoir when the stage storage relationship and the outflow are known.

* Comparing the runoff at a station and runoff at upstream stations.
* Applying double mass curve analysis to identify shift in control.
* Applying time series analysis to detect changes in the homogeneity in time series.This is a valuable supplement to double mass analysis.
* Plotting a graph of the points at which measurement are made and comparison with the original cross section.
* Plotting the graph of the annual regime of specific discharges and regional comparison.
* Regional comparisons of monthly and annual stream flow deficits.

ADJUSTMENT OF RECORDS

The adjustment of flows to natural and virgin condition 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 adding upstream withdrawals, return flows have to be subtracted.

Note: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 or with a definite trend.

2. Adjustment with the flow records is required in the those cases where appreciable changes in land use have taken place.
3. Adjustment of floods and low flows to remove the effect of upstream regulation may be required where this is appreciable.

Secondary Data Processing

Specific tasks in secondary data processing include:
- Calculation of mean velocity and 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 annual value (means, totals, extremes or frequencies of occurrence) with elementary statistical parameters, discharge classified into ranges and probability envelope curves (table and graphs) and characteristics discharge and probability envelop curves etc.

Analysis of Processed Data

The following analysis are normally performed with the processed data :

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

STAGE DISCHARGE RELATIONSHIP (RATING CURVE)

The discharge measurement is very time consuming process and involves considerable costs.On the other hand the water levels can be very easily and economically observed at very short duration. The discharge data at shorter intervals are generally needed for various studies. This can be achieved by estimating the discharge using the data of water level observations. To enable such computation a relationship between stage and discharge is established. Such relationships are also known as the rating curves. In its simplest form, the rating curve is a plot of observed water levels and the corresponding discharge values at a site.

If the relation for a gauging section is constant and does not change with time, the control is said to be permanent. It is called shifting control if it changes with time. Generally, alluvial rivers pose the problems of shifting control.

Factors Responsible for shifting Control

At a gauging site the control that exists giving rise to a unique stage-discharge relationship can change due to:

(i) the changing characteristics caused by weed growth, dredging or channel encroachment

(ii) the accumulation of ice.

(iii) aggredation or degradation phenomenon in an alluvial channel,

(iv) variable back water effects affecting the gauging section

(v) the presence of flood plain where the flow characteristics are very much different than main channel

(vi) unsteady flow effects of a rapidly changing stages.

There are no permanent corrective measures to tackle the shifting controls due to causes (i),(ii), (iii) and (v) listed above. The only recourse in such cases is to have frequent current meter gauging and to update the rating curves. However, methods are available to tackle the shifting controls due to causes (iv) and (vi).

Development of Rating Curves

PERMANENT CONTROL

Generally non alluvial rivers exhibit permanent control. For such a case, the relationship between the stage and discharge is expressed in the following form:

$$Q = a(H-H_o)^b \qquad \text{..........} \qquad (1)$$

Where Q = stream discharge (m^3/sec)

H = Gauge height (stage) (metre)

H_o = A constant which represents the gauge reading corresponding to zero discharge

a and b = Rating curve constants

The relationship given by Eq. (1) can be graphically expressed by plotting the observed stage against the corresponding values of discharge in an arithmetic or logarithmic plot. Fig. 1

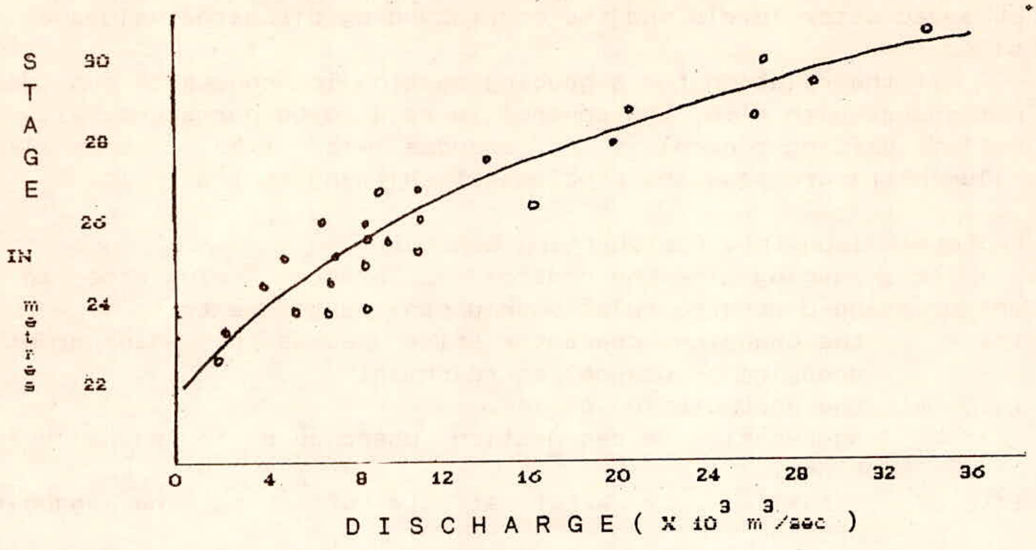


Fig. 1 : Stage Discharge Curve-Arithmetic Plot

and 2 illustrate the stage discharge curves on arithmetic and logarithmic plots respectively. Logarithmic plotting is advantageous as Eq (1) plots as a straight line in logarithmic scale. It is to be noted that the co-efficients a and b need not be the same for the full range of stages.

In case of no shifting controls, the rating curves may be developed using the following methods.

(a) Data analysis
(b) Physical analysis
(c) Double log plot
(d) Least Square method

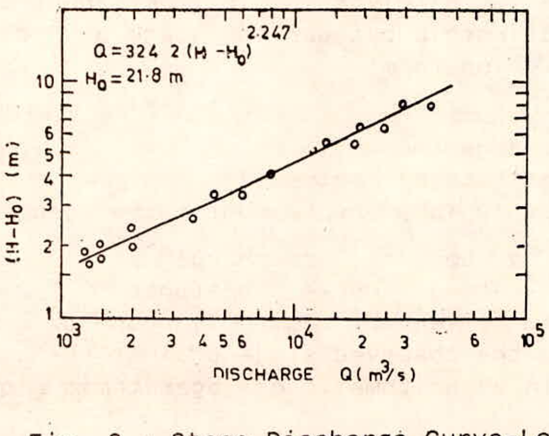


Fig. 2 : Stage Discharge Curve-Logarithmic Plot

(a) Data Analysis:The steps involved in developing the rating curve by this method are:

(i) Group the measured discharge and corresponding stage values for different years pertaining to the site under investigation.

(ii) Plot the data with stage on the Y-axis and discharge on the X-axis.

(iii) Mark off the data points which are obviously away from the general trend.

(iv) Do not be misled however to remove peak discharge measurements since the deviation could be a possible physical mechanism.

(b) Physical analysis : In physical analysis the cross section of the river reveals certain important information regarding the uniformity of rating curve. The following steps may be followed in physical analysis:

(i) Note the elevation up to which the cross section is uniform .

(ii) Choose the exponent b in the Eq. (1) as follows:

For rectangular shape : 1.6
For triangular shape : 2.5
For parabolic shape : 2.0
For irregular shape : 1.6 to 1.9

(iii) Take average bed level as the value for H_o in Eq.(1)

(iv) Compute the value of the co-efficient as appeared in Eq. (1) using the following relationship

$$a = \frac{1}{n} WS^{1/2} \qquad \text{......(2a)}$$

where,

W is the top width of the channel,
S is the bed slope, and
n is Manning's co-efficient

In Eq.(2a) W and s would be known from the available cross section of the river at the gauging site and longitudinal section of the river Fig. 3 shows a typical cross section of a river at the gauging site. the value of n can be evaluated as follows:

For gravel bed rivers the empirical equation given by Strickler may be used. The equation is :

$$n = 0.034\, d^{1/6} \qquad \text{...... (2b)}$$

where d is median size of the bed materials in mm.

Typical values of 'n' for natural rivers are

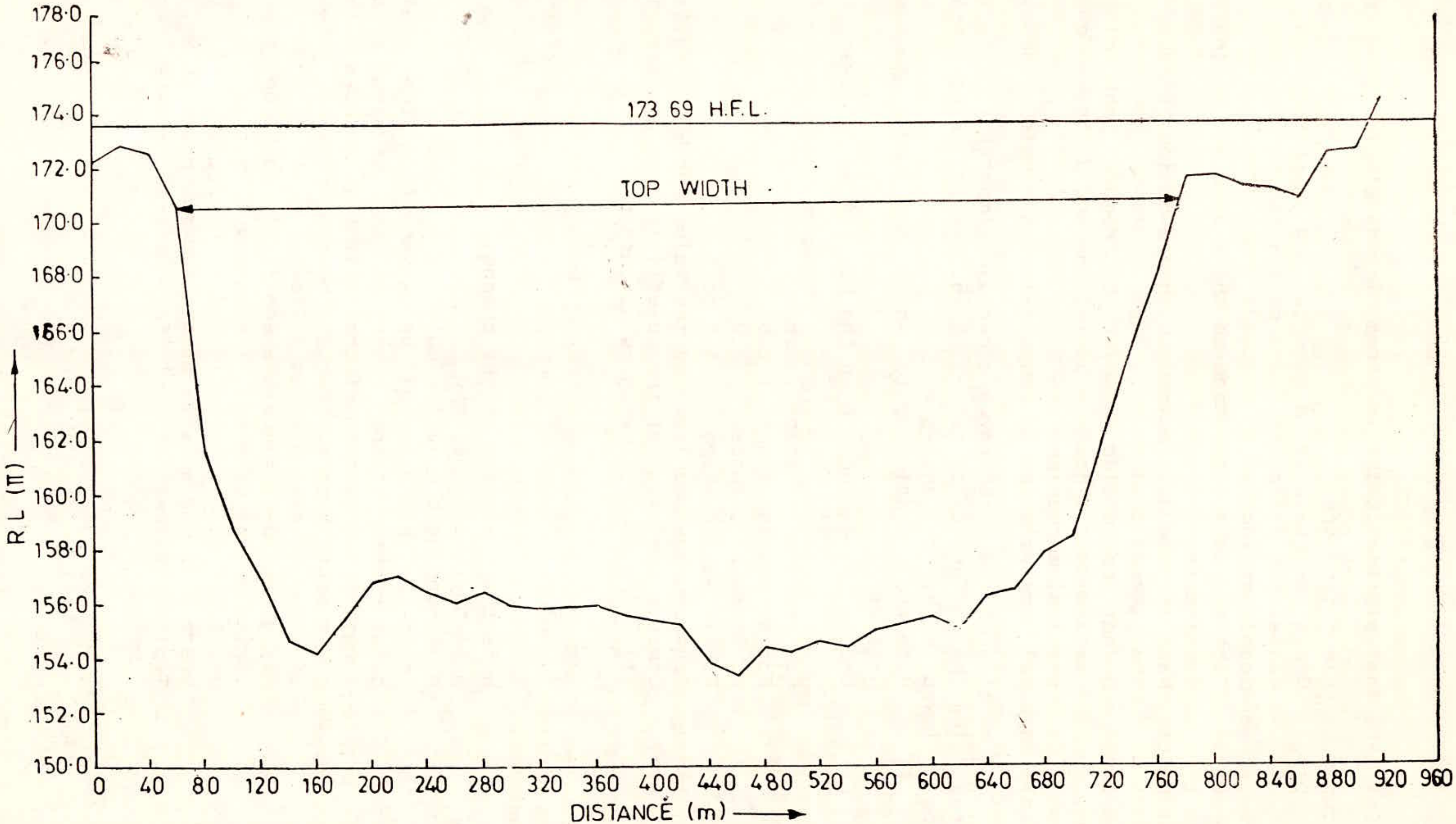


Fig. 3 : Cross Section of A Typical Gauging Site

(Henderson (1966)
clean and straight river channel 0.025-0.03
winding with pools and shoals 0.033-0.04
very weedy, winding and overgrown 0.075-0.15

(c) Double log plot :The grouped data obtained from step (i) of the data analysis are plotted on a double logarithmic paper. the advantage of using double logarithmic plot is two fold. Firstly, the plot would produce straight lines. Since general form of rating curve is parabolic. Secondly, different straight lines allow to further grouping of data. A part or the entire range of the stage may form a straight lines allow to further grouping of data. a part or the entire range of the stage may form a straight line . It gives an indication about the stage at which the slope of the straight lines changes if more than one straight lines are used for re-presenting the rating curve. Use of different symbols for different periods (Years) of data would enable one to identify the uniform deviations if any present from the mean. In case of such deviations either different rating curves should be developed from the mean. In case of such deviations either different rating curves should be developed for each year or use the methods discussed in later part of this lecture for correcting the observed stages depending upon the factors responsible for shifting control.

While plotting the data on double log plot a prior knowledge about the value of H_o in Eq. (1) is necessary. As a first approximation the value of H_o is assumed to be the level of the bottom of the channel as determined from the cross section of the gauging site. Marginal adjustment in the value of H_o may be required in order to produce a straight line giving better fit to the plotted points. In case if a single straight line could not be fitted in spite of trials with various values of H_o it should be concluded that the data need grouping for different relations and dealt accordingly as explained in the previous paragraph.

(d) Least Square Method : The best values of a and b in Eq. (1) for a given range of stage are obtained by the least square error method. Thus by taking logarithms of Eq. (1)

$$\log_e Q = \log_e a + b \log_e (H-H_o) \qquad ....(3)$$

or $$Y = \alpha + \beta X \qquad ....(4a)$$

where $Y = \log_e Q$ ....(4b)

$X = \log_e (H-H_o)$ ....(4c)

$\alpha = \log_e a$ ....(4d)

$\beta = b$ ....(4e)

For the best fit straight line or N observation of X and Y

$$\beta = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{N(\Sigma X^2) - (\Sigma X)^2} \quad ....(5)$$

and

$$\alpha = \frac{\Sigma Y - \beta(\Sigma X)}{N} \quad ....(6)$$

In the above it should be noted that H_o is an unknown and its determination poses some difficulties. The following alternate methods are available for its determination:

(i) Plot Q VS H on an arithmetic graph paper and draw a best fit curve. By extrapolating the curve by eye judgment find H_o as the value of H corresponding to Q = 0. Using this value of H_o plot log Q VS log $(H-H_o)$ and verify whether the data plots as a straight line. If not, select another value in the neighborhood of previously assumed value and by trial and error find an acceptable value of H_o which gives a straight line plot of log Q VS log $(H - H_o)$. In order to avoid the plotting for each trial value of a fitting parameter 'r' which may be computed using Eq. 7 are compared for each trial run. That value of H_o is finally accepted which gives the fitting parameter closest to one.

$$r = \sqrt{1 - \frac{F_i}{F_o}} \quad (7a)$$

Where

$$F_o = \sum_{i=1}^{N} (Y_i - \bar{Y})^2/(N-1) \quad (7b)$$

$$F_i = \sum_{i=1}^{N} (Y_i - \hat{Y}_i)^2/(N-2) \quad (7c)$$

Y_i = logarithms of observed discharge values

$\overline{Y}$ = Mean of the logarithms of observed discharge values

$\hat{Y}_i$ = logarithms of computed discharge values obtained from Eq. (4a)

(ii) a graphical method due to Running is as follows : (Wisler and Brater (1959).

The Q VS H data are plotted to arithmetic scale and smooth curve through the plotted points are drawn. Three points A,B and C on the curve are selected such that their discharges are in geometric progression (fig . 4) i.e.

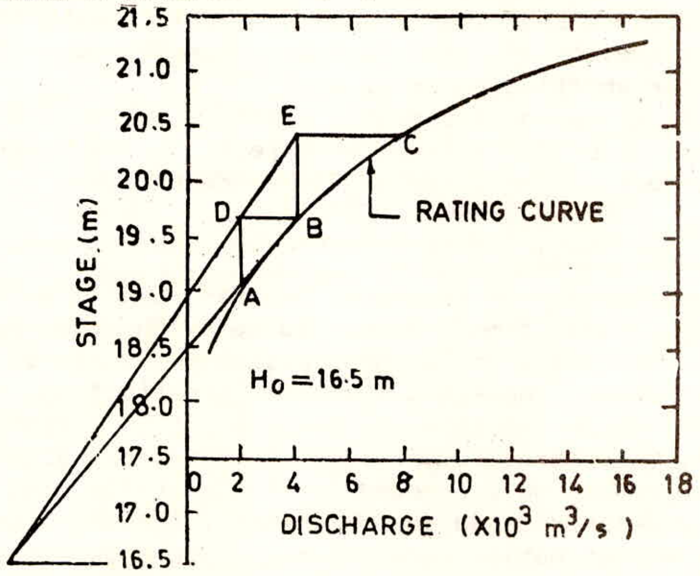


Fig 4 : Running's Method for Estimation of the Constant H_o

At A and B vertical lines are drawn and then horizontal lines are drawn at B and C to get D and E as intersection point with the verticals. Two straight lines ED and BA are drawn intersect at F. The ordinate at F is the required value of H_{or} the gauge discharge curve to be a parabola.

(iii) Plot Q VS H to an arithmetic scale and draw a smooth good fitting curve by eye judgment. Select three discharges $Q_1/Q_2 = Q_2/Q_3$ and note from the curve the corresponding values of gauge reading H_1, H_2 and H_3 . From Eq. (3):

$$(H_1 - H_o) / (H_2 - H_o) = (H_2 - H_o) / (H_3 H_o)$$

$$\text{i.e.}\quad H = \frac{H_1 H_3 - H_2^2}{(H_1 + H_3) - 2H_2} \qquad (9)$$

(iv) A number of optimisation procedures that are based on the use of computers are available to estimate the best value of H_o which gives the best value of the correlation co-efficient (fitting parameter 'r' as expressed by Eq. (7) is one of them.

SHIFTING CONTROL

As discussed earlier, the stage-discharge curve do change with time due to various factors. This section describes some of the method for applying the shifting control corrections with time and /or stage . the choice of the methods depends upon the factors responsible for shifting control.

(a) Correction for systematic shift
(b) Correction for back water effect
(c) Correction for unsteady flow effect

(a) Correction for systematic shift

Shift is defined as the difference between the observed stage and calculated stage from rating curve with the same discharge. On many sandy rivers it is not possible to find or construct a stable control. The sites used for constructing the controls are generally subjected to scour and deposit in irregular pattern. If the shift in control follow some systematic pattern, then the observed stages may be corrected for those shifts and a median rating curve developed based on permanent control concept may be used for the estimation of correct discharge values corresponding to the corrected stage values. the steps to be followed for applying the corrections for the systematic shifts are:

(i) Prepare a median rating curve
(ii) Calculate shift in stage values by subtracting the stage values obtained from the median rating curve and the observed stage with same discharge.
(iii) Plot the shift values obtained from step (ii) Vs time
(iv) Based on the systematic pattern observed in shifting control, draw a curve through the points plotted at step (iii).
(v) Use the curve of step (iv) to compute the shift corrections in stage values observed at different times. The following example illustrates the above procedure.

(b) Correction for back water effect

In case if the shifting is due to variable back water curves, the same will indicate different discharges depending upon the backwater effect. To remedy this situation another gauge, called the secondary gauge or auxiliary gauge is installed some distance upstream of the gauging site and readings of both gauges are taken. the difference between the main gauge and the secondary gauge given fall (F) of the water surface in the reach. The plotting of the observed stage-discharge values, with the value of fall (F) marked against each observation, will reveal whether the relationship is affected by variable slopes at all elevations or is affected only when the fall reduces below a particular value. In the absence of any channel control, the discharge would be affected by the fall at all times and a correction is applied by the fixed or the constant fall method, on the other hand, however, when the discharge is affected only when the fall reduce below a particular value, the normal fall method is applied. The above two methods are discussed herein brief.

(I)*Constant Fall Method :* In this method a constant value of fall (F) is selected at all stages. The actual fall(F) at all observed gauge values are estimated. An approximate Qo Vs H (Gauge height curve)for the constant fall Fo, called constant fall curve, is drawn (Fig. 5) . For each observed data, Q/ Qo and F/Fo values are calculated and plotted as Q /Qo VS F/Fo (Fig. 6). This curve is called the adjustment curve. Both the constant fall curve and adjustment curve are refined, by trial and error to get the best fit curves. Finally the two curves constant fall curve and adjustment curve, provide the stage-discharge information for gauging purpose. For example, if the observed stage is H_1 and fall F_i, first by using the adjustment curve the value of Q_1/Q_o is read for a known value at F_1/F_o. Using the constant fall rating curve, Q_O is read for the given stage H_1 and the actual discharge calculated as $(Q_1/Q_o)\,Q_o$.

(II) *Normal Fall Method :* This method is useful if the usual simple rating is applicable at sufficient falls when backwater effect is absent, while for low falls the discharge is affected by backwater. Critical values of the fall dividing these two regions are termed the normal fall . the value of normal fall at any discharge can be determined by studying the plot of stage against discharge. The point at which back water has no effect will group at the extreme right. This is the simple rating curve as shown in

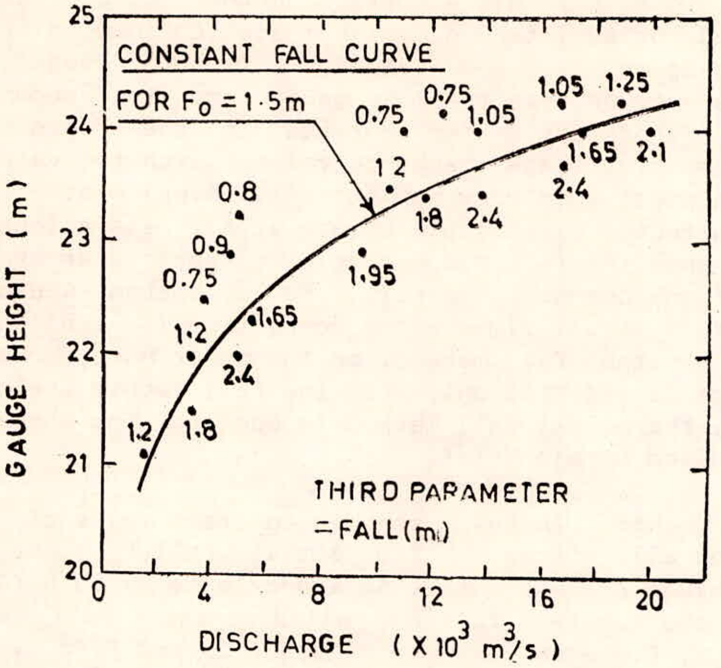


Fig. 5 Constant fall curve

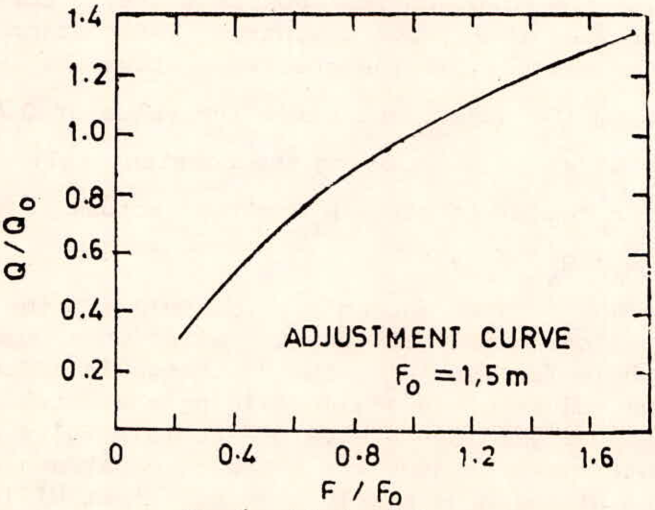


Fig. 6 Adjustment Curve

Fig. 7 a plot of the normal fall values vs corresponding stages is made as shown in Fig. 8 Such plots enable the drawing of a curve for discharge ratios where normal fall is used in place of constant fall.Fig. 9 shows a typical curve where the ratio of measured fall to normal fall is plotted against the ratio of measured discharge to normal discharge. The rest of the procedure is similar to that of the constant fall method.

(c) Correction for unsteady flow effect

The stage-discharge relationship for a single gauge station gives the value of the normal discharge i.e. the discharge under uniform steady flow conditions for a given stage. But infield it is very difficult to achieve the steady flow situations. When a flood wave passes a gauging site the approach velocities in the advancing portion of the wave are larger than in steady flow at corresponding stages. Thus, for the same stage, more discharge than in a steady uniform flow occurs.In the receding phase of the flood wave the converse situation occurs with reduced approach velocities giving lower discharges than in an equivalent steady state case. Thus, the stage-discharge relationship for an unsteady flow will not be a single valued relationship as in steady flow but it will be a looped curve as shown in Fig. 10. The looping in the stage discharge curve is called hysteresis in the stage-discharge relationship. From the curve, it can be easily noted that at the same stage, more discharge passes through the river during rising stages than in falling ones. Since the conditions for each flood may be different; different floods may give different loops.

Under certain conditions the normal discharge (Q_o) obtained from the stage-discharge curve and the actual discharge (Q) of an unsteady flow condition are related as:

$$Q = Q_o \sqrt{1 + \frac{1}{S_o V_w} \frac{\partial Z}{\partial t}} \quad .... \quad (10)$$

where S_o = channel slope,

= water surface slope at uniform flow;

$\frac{\partial Z}{\partial t}$ = rate of change of stage,

V_w = velocity of flood wave

The slope S_o may by determined from observation of gauges

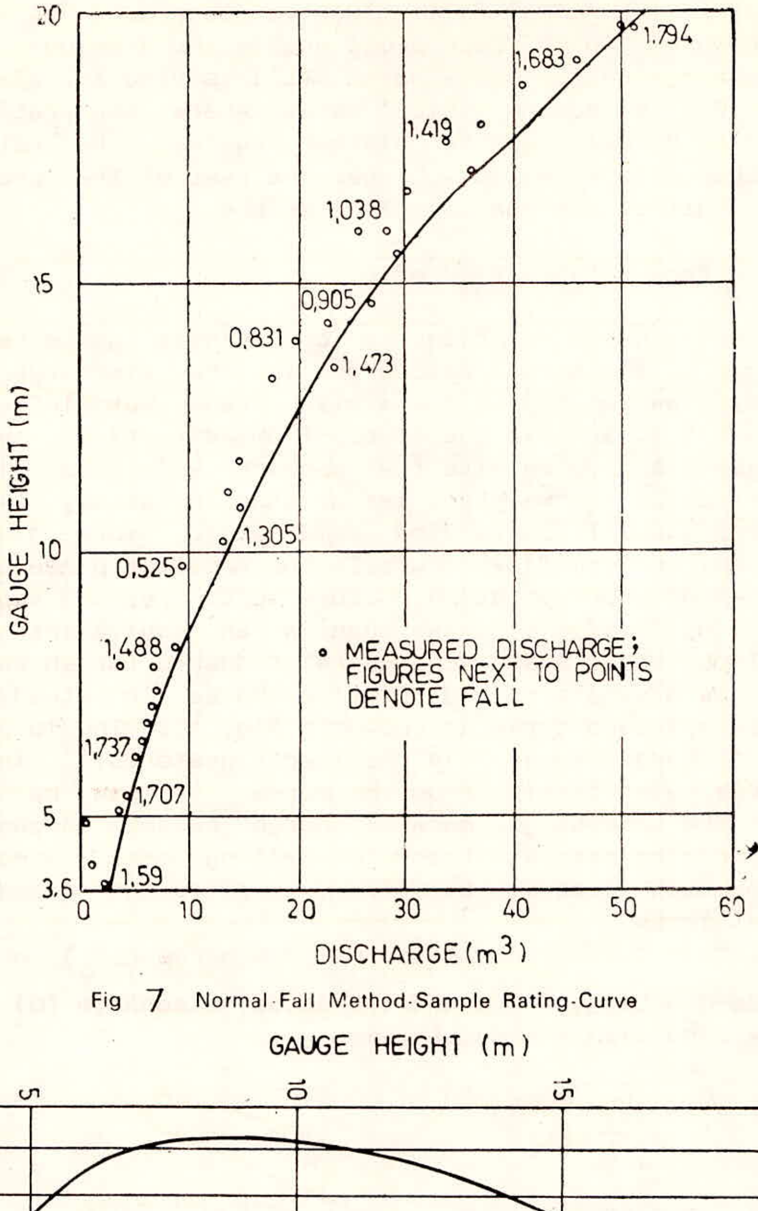


Fig 7 Normal-Fall Method-Sample Rating-Curve

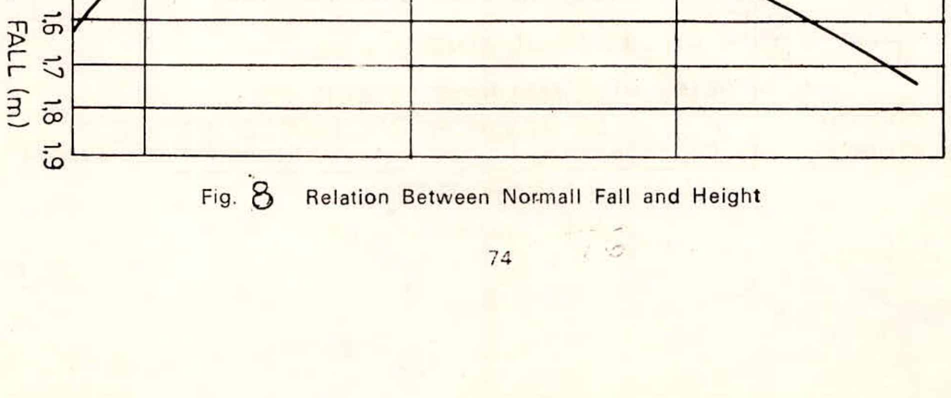


Fig. 8 Relation Between Normall Fall and Height

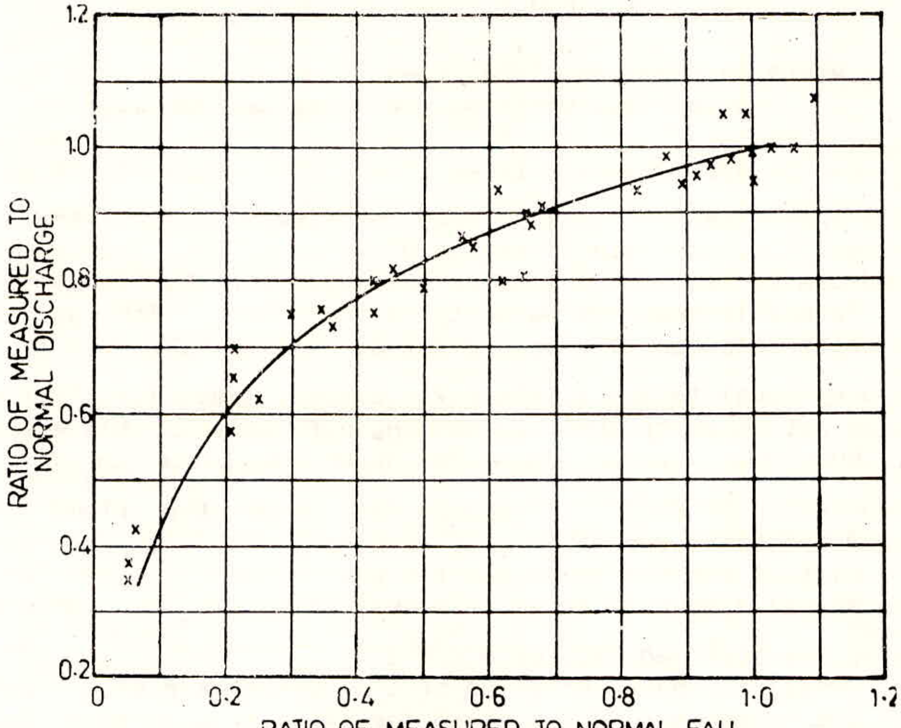


Fig. 9 Measured Discharge-Fall Relation

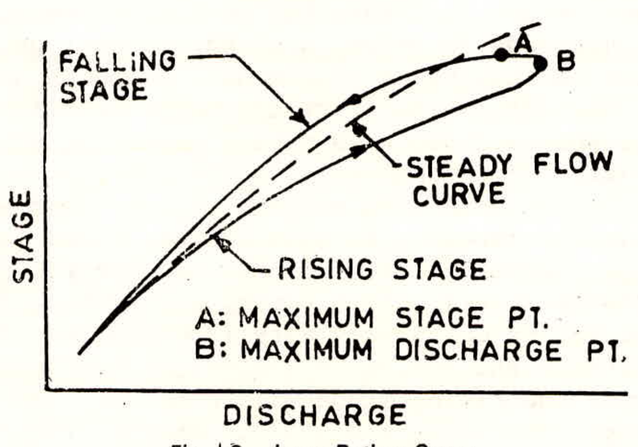


Fig. 10 Loop Rating Curve

during conditions of steady flow. Alternatively, Manning's or Chezy's formula may be used for computing the approximate value of S_o. The $\frac{\partial Z}{\partial t}$ may be obtained from observation of the gauge installed for the purpose. The wave velocity, V_w is given by the equation.

$$V_w = \frac{\partial Q}{\partial A} = \frac{1}{b}\frac{\partial Q}{\partial Z} \quad .... \quad (11)$$

where A= cross sectional area
b= surface width at the cross section

$\frac{\partial Q}{\partial Z}$ can be approximately taken from the stage-discharge curve. This approximation is valid when the rise or fall of the flood is gradual i.e. the rate of change of velocity or the acceleration head can be neglected. Another condition for the formulae to be applicable is that the velocity is not very high so that the velocity head can also be neglected. Alternately, V_w is usually assumed equal to 1.4 V, where V = average velocity for a given stage estimated by applying Manning's formula and the energy slope S_f. Also the energy slope is used in place of S_o in the denominator of Eq(10). If enough data about the flood magnitude and $\partial Z/\partial t$ are available, the term $(1/V_w S_o)$ can be calculated and plotted against the stage for use in Eq. (10). For estimating the actual discharge at an observed stage, Q/Q_n is calculated by using the observed data of $\partial Z/\partial t$.

Physical characteristics of the channel are also responsible for the hysteresis in the stage discharge relationship. Generally, the gauging sites are chosen at the river channel with sufficient steep gradient and sufficient capacity of the channel at downstream in order to ensure the consistent relationship between stage and discharge in which one particular gauge height will indicate one corresponding discharge. Although occasional changes in control may effect the stage discharge relationship. On the other hand, when a flood wave passes a gauging station located at the constricted river channel with flatter gradient the approach velocities in the advancing portion of the flood wave are larger than that in the receding portion of the flood wave. Thus , a looped stage discharge curve is obtained for floods with differing stage-discharge relations for rising and falling levels. The shape of the loop rating curves can vary from station to station, and also at the same station, with the height of flood, but generally the curve for the rising stage will plot to the right for the falling stage indicating a higher discharge for the same water level. The reason for this is that the flood wave front is significantly steeper than the steady state hydraulic gradient of the river during a rising flood while the reverse is true during the recession. There can be significant difference in discharge caused by this effect.

If discharge measurements are made equally on rising and falling states, an average rating curve falling between the two is obtained, which in most cases is usually of sufficient accuracy. In practice. however, there is a tendency for flood gauging to be made on falling stage only, especially on rivers which rise quickly and carry quantities of debris on the rising flood. On stations, therefore, where channel conditions are favourable for hysteresis, precaution should be taken to check the extent of the effect before a decision is made on whether to use an average rating curve or a series of looped curves.

Extrapolation of Stage-discharge relation

Most hydrological designs consider extreme flood flows. As an example in the design of hydraulic structures. such as barrages, dams and bridges one needs maximum flood discharges as well as maximum flood levels While the methods are available for the estimation of design flood magnitude, the stage-discharge relationship at the project site will have to be used to predict the stage corresponding to design flood discharges. Rarely will the available stage-discharge data include the design flood range and hence the need for extrapolation of the rating curve in the higher range. On the other hand low flows and corresponding stages are also required during the planning and design of water resources projects. The range of stage and discharge values observed in the field may not include the design low flow values. Therefore, it becomes necessary to extrapolate the stage-discharge curve in the lower end also.

Before going to discuss about the various methods for extrapolation, let us know the factors which effect the rating curve in the both of the extremes. Those factors include:

(i) Over bank spills at high stages

(ii) shift in controls at very low and very high stages

(iii) changes in rugosity co-efficients at different stages.

The above factors affect the nature of the relationship at the extreme ends must be taken into account. As far as possible, extrapolation should be avoided,. but where this is necessary the results obtained should be checked by more than one method. The physical condition of the channel, that is whether the channel has defined banks over the entire range or only up to a certain stage and over bank spill above that stage as well as whether the channel has fixed or shifting controls, should govern the methods to be used in the extrapolation. Consideration should also be given to the phenomenon of the kinematic effect of open channel flow when there may be a reduction in the mean velocity in the channel during inundation of the flood plain. there are many techniques available for the extrapolation of stage-discharge relationship for a gauging site of a river channel with defined banks and fixed controls as well as a channel with spills. Some of those techniques are described below:

DOUBLE LOG PLOT METHOD

If the control does not change beyond a particular stage, it may be possible to develop the rating curve relationship in the form given by the Eq. 1. In this technique the range is plotted against the discharge on double log paper. a best fit linear relationship is obtained for data points lying in the high stage range and the line is extended to cover the range of extrapolation Similarly a best fit linear relationship may be obtained for data points lying in the low stage range and the relationship thus developed may be used for the extrapolation in the lower range. Alternatively, least square method can be used to derive the equation for best fit line as discussed in the earlier section.

CONVEYANCE METHOD

The conveyance of a channel in non-uniform flow is defined by the relationship

$$Q = K \sqrt{S_f} \quad \text{........ (12)}$$

where Q = Discharge in the channel,

S_f = Slope of the energy line,and

K = Conveyance of the channel.

If Manning's formula is used for the discharge computations, then discharge Q is given as :

$$Q = \frac{A R^{2/3}}{n} S_f^{1/2} \quad \text{........(13)}$$

where R = Hydraulic radius,

A = Cross sectional area of the channel,

n = Manning's roughness co-efficient

From equation (12) and (13), the conveyance K is given by the relation,

$$K = \frac{1}{n} A R^{2/3} \quad \text{........ (14)}$$

The steps involved in extrapolating the stage values for corresponding discharge values using conveyance method are:

(i) Calculate A and R values corresponding to different stage values (A and R are the function of stage values).

(ii) Calculate conveyance K for various stage values by using Eq.(14).

(iii) Plot the values of K against their corresponding stage values.

(iv) Fit a smooth curve to the plotted points as shown in Fig. 11

(v) Compute the values of S_f from the available discharge and stage data by using Eq. (18)

(vi) Plot the values of $S_{f/n}$ against the stage values.

(vii) Fit a smooth curve through the plotted points as shown in Fig. 12

(viii) Extrapolate the fitted curve (Fig. 11) keeping in mind that S_f approaches a constant value at high stages.

(ix) Calculate the discharge at any stage using Eq. (12)for which the value K and slope S_f are obtained from conveyance and slope curves.

(x) Construct a stage-discharge curve covering the desired range of extrapolation.

(xi) Obtain the stage corresponding to any discharge value with the help of extrapolated rating curve.

VELOCITY-AREA METHOD

In velocity-Area method two curves viz.stage Vs Area and stage vs mean velocity are constructed. The stage vs mean velocity curve has little curvature under normal conditions and can be extended without significant error. The product of the corresponding values of area A and mean velocity V may be used for extending the discharge (Q) curve. Fig. 13 shows the stage-Area curve, stage-velocity curve and corresponding stage-discharge curve.

An alternative procedure involves the construction of a logarithmic plot of mean velocity (v) against the hydraulic mean radius (R) which generally shows a linear relationship for the higher stage values. This curve can be used to obtain the values of mean velocity V in the extrapolation range. Note that the hydraulic mean radius R can be estimated for all stages from the cross section. The velocity-hydraulic radius curve alongwith stage-area curve may be used for the construction of stage discharge curve covering the extrapolation range.

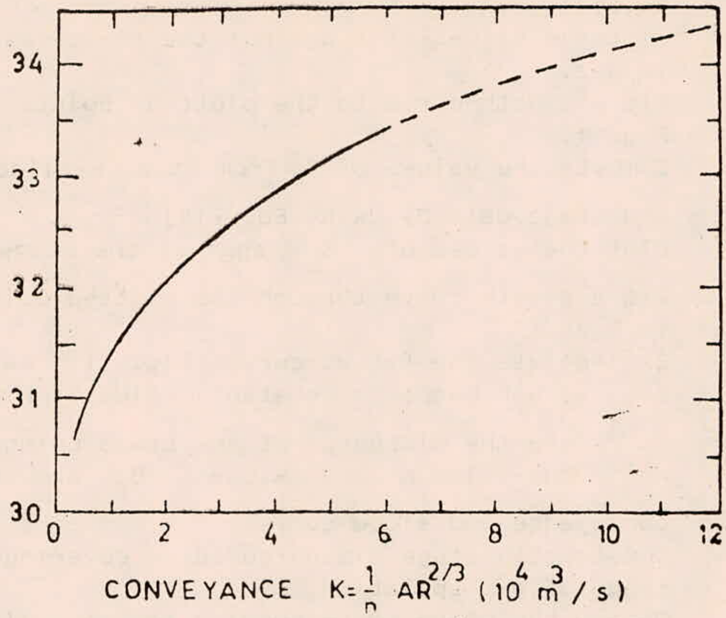


Fig. 11: Conveyance Method of Rating Curve Extension; K vs Stage

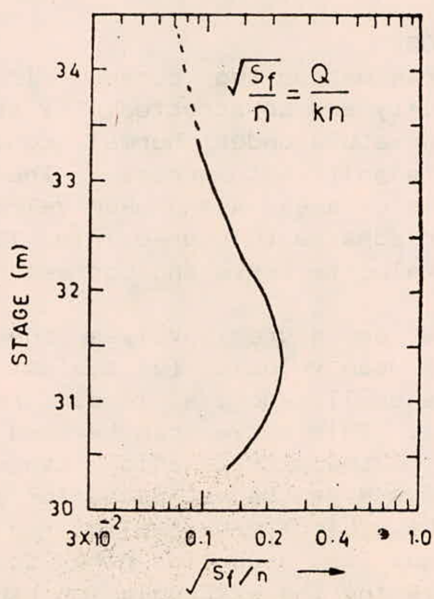


Fig. 12: Conveyance Method Rating Curve Extension; S_f Vs Stage

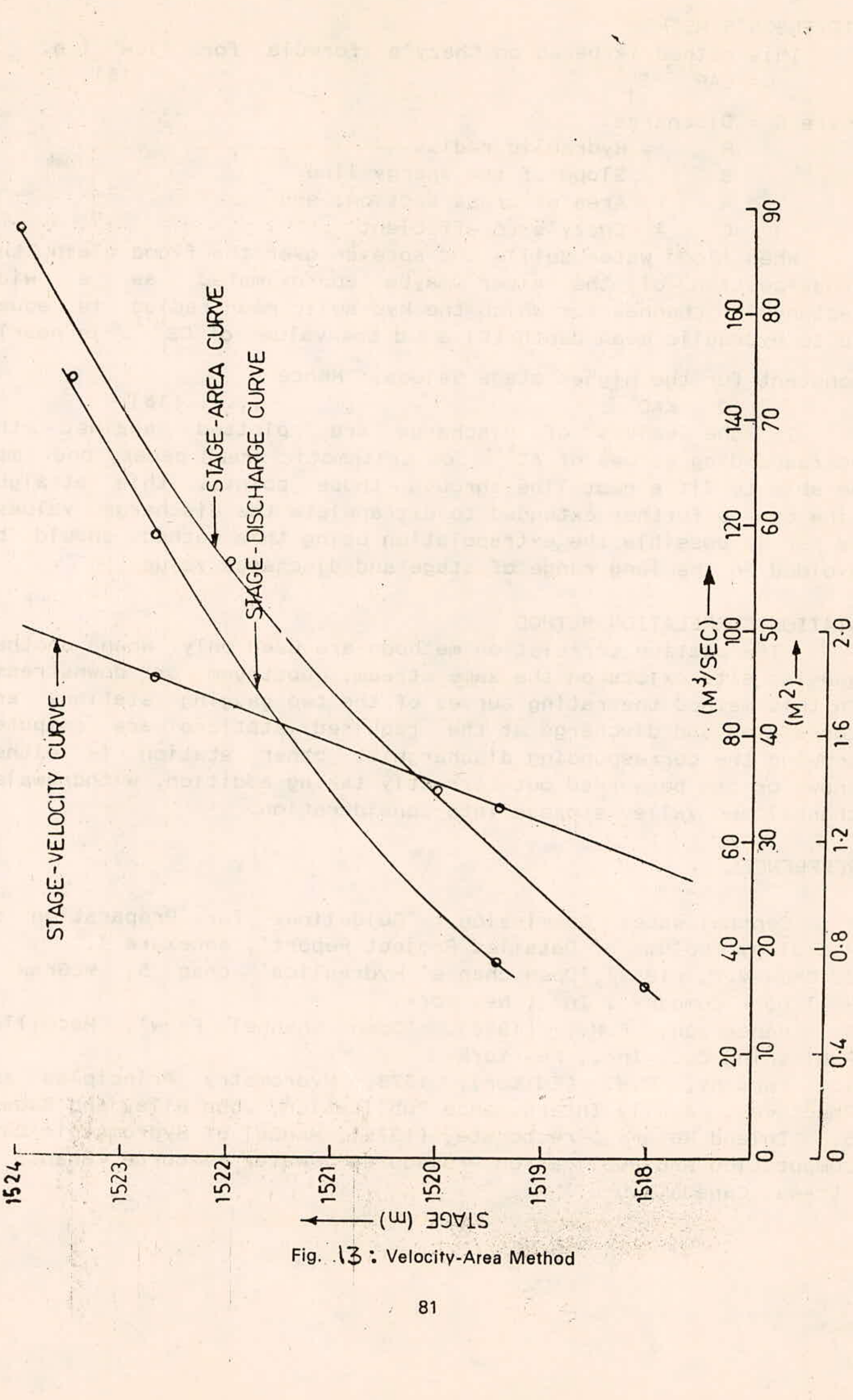


Fig. 13 : Velocity-Area Method

STEVENSON'S METHOD

This method is based on Chezy's formula for flow i.e.

$$Q= CAR^{1/2} S_f^{1/2} \qquad (15)$$

where Q = Discharge.

R = Hydraulic radius

S = Slope of the energy line

A = Area of cross section, and

C = Chezy's co-efficient

When flood water spills and spreads over the flood plain the cross-section of the river maybe approximated as a wide rectangular channel for which the hydraulic mean radius is equal to to hydraulic mean depth (D) a n d the value of $CS_f^{1/2}$ is nearly constant for the higher stage values. Hence

$$Q = KAD^{1/2} \qquad ......(16)$$

If the values of discharge are plotted against the corresponding values of $AD^{1/2}$ on arithmetic graph paper, one may be able to fit a best line through those points. this straight line can be further extended to extrapolate the discharge values. As far as possible the extrapolation using this method should be avoided in the long range of stage and discharge value.

STATION CORRELATION METHOD

The station correlation methods are used only when another gauging site exists on the same stream, upstream or downstream. In this method the rating curves of the two gauging stations are correlated and discharge at the required stations are computed knowing the corresponding discharge at other station is either known or can be worked out correctly taking addition, withdrawals, channel and valley storage into consideration.

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OBSERVATION AND PROCESSING OF SEDIMENT AND WATER QUALITY DATA

INTRODUCTION

Soil erosion and sedimentation by water primarily involve the processes of detachment, transport, and deposition of sediment by raindrop impact and run-off. Erosion and sedimentation are major problems that reduce cropland productivity, degrade water quality, carry along polluting chemicals, and clog water conveyance structures.

Detachment and transport process can be analyzed by examining the detachment and transport potential of the eroding agents, the susceptibility of the soil to detachment and transport and the presence of material that protects the soil from the direct action of the erosive agents. The erosion-sedimentation system is complex, and erosion and sediment yield are extremely variable in time and space. Long-term erosion can be estimated based on measures of climate, soil, topography, and land management. Considerable progress was made in the last couple of decades in developing techniques to estimate erosion and sediment yield for individual storms and for various Locations over a watershed.

A watershed erosion-sedimentation system is a group of inter relation components. Channels are often either sediment sources or sinks that react to inputs from the upland areas. A thorough, sound and fundamental understanding of the erosion-sedimentation systems promotes better solutions to current erosion & sedimentation problems.

Knowledge of sediment load carried by streams is essential for:

i) planning, design and operation of water resources projects and their components;

ii) a study of water quality of the stream in terms of both dissolved and undissolved load carried;

iii) study of stream morphology, stream mechanics and stream channel erosion;

iv) to determine soil and nutrient loss from contributing catchment;

v) to determine the extent of treatment/processing required before the stream flow is put to any particular use, say for drinking water supply, industrial use, irrigation or hydropower.

The quality and quantity of sediment carried by a stream depends upon the characteristics (such as geology, soil formation, hydrographic factors, nature of vegetation) of the catchment area which drains into the stream, the stream flow hydrograph and also the nature and morphology of the channel formation through which the stream flows. Other factors which influence sediment flow in a stream are man's interference with the vegetal cover, land use, interference by grazing animals, disturbance mining, and agriculture.

Sediment Sources and Sinks

Sediment sources produce sediment while sinks trap sediment sources include agricultural lands, construction sites, roadways, disturbed forest lands, surface mines, and natural geologic "badlands'. Control practices that are acceptable on one source area, may be totally unacceptable on another area because of different land uses and soil limitations. Sources may also be classified according to the dominant type of erosion: Sheet, rill gully, stream channel, or mass erosion.

Sediment sinks are at the base of concave slopes, strips of vegetation, flood plains, and reservoirs; areas where deposition occurs because the flow's transport capacity is reduced below its sediment load.

Hydrologically, a watershed may be conceptualized as having over land flow, channel flow, and sub surface flow components. The main influence of the subsurface component is to add to the flow in the channel. Upland and channel designations are conceptual and for conveniences rather than being strict geomorphological terms. Hydrologic and erosion sedimentation processes in the channels directly interrelated with processes on the uplands. A decrease or increase in run-off amount and/or rate from the uplands directly affects the detachment and major transport capacity in the channels.

Erosion and Sedimentation Processes

Detachment and transport are basic processes occurring on source areas while transport and deposition are basic processes occurring on sink areas. Soil particles are detached by either raindrop impact or flowing water. Individual raindrops strike the soil surface at velocities unto 9 m/sec, creating very intense hydrodynamic forces at the point of impact.

Overland flow detaches and/or entrains soil particles when its erosive, hydrodynamic forces, shear stress is a typical measure of these forces, exceed the resistance of the soil to erosion. While detachment by raindrops occurs over a broad area, detachment by flow is often concentrated in small definable channels. Rate of detachment is non-uniform in time and space due to variations in rainfall, run-off, soil, slope, and cover conditions. Long term soil loss can be reliably estimated. Sediment is deposited when the sediment load exceeds the flow's total transport capacity or flow loses capacity to transport coarser sized particles present in the sediment load. Bedload material deposits immediately when transport capacity decreases below the sediment load, while suspended load responds more slowly to a reduced transport capacity. The colloidal component of the suspended load is sensitive to changes in water chemistry which might induce floculation and to the strength of fluid forces that keep flocs from forming due to attractive bonding forces. If flocs form, large quantities of the colloidal load may deposit.

FACTORS AFFECTING EROSION-SEDIMENTATION

Climate, soil, topography, soil surface conditions, and their interactions are major factors affecting erosion-sedimentation processes. The semi arid west with low rainfall anhectare than the humid East with its highly erosive rains because ample moisture provides heavy natural ground cover to protect the soil.

Climate

Rainfall, run-off and temperature are the main climatic factors affecting catchment erosion and sediment yield. The splash capacity of raindrop increases with drop size, rainfall intensity and presence of overland flow. The temperature plays an important role in process of weathering which leads to disintegration of rocks. Sediment yield is found to increase if the precipitation is concentrated during one season instead of being nearly uniformly distributed over the years.

Topography

Catchment area, its average slope and drainage density are some of the factor related to catchment topography which are found to influence the erosion and sediment yield. Velocity of overland flow and hence the shear stress on the land surface and the transport capacity increases with catchment slope. The sediment yield per unit catchment area is found to decrease with increase in catchment area.

Soil Erodibility

Some soils are naturally more susceptible to erosion than are others. A highly erodible soil may erode 10 times faster than a less susceptible soil exposed to the same moderate to intense rainfall. Soil properties influencing soil erodibility include primary particle size distribution, organic matter, soil structure, iron and aluminum oxides, electro-chemical bonds, initial moisture content, and wetting aging.

Erodibility may decrease over time with good management practices. Conservely, it can increase as progressive erosion removes the surface soil and as tillage brings up a more erodible sub-surface soil.

Soil Surface Cover/Land Use

Vegetation or plant cover reduces the soil erosion, it's effectiveness depending upon the hight and continuity of canopy, density of ground cover and root density. If canopy is near the ground, it dissipates the kinetic energy of rain, canopy on the ground increases the roughness and reduces the velocity of flow. Roots play an important role in reducing erosion by binding the soil mass to increase it's resistance to flow. Generally forests are most effective in reducing erosion because of their canopy; dense grass is equally effective. In certain areas land slides and volcanic eruptions increase sediment yield.

Geology

Geology is also an important factor that controls upland erosion and channels erosion phases of sediment yield. The interdependence among climate land use and geology makes it difficult to detect the specific role played by geology on sediment yield production.

SEDIMENT CLASSIFICATION

Sediment is carried in suspension, transported by, or deposited in of its movement as under :

(i) The sediment which remains in suspension for a considerable period of time without coming in contact with the stream bed and banks and whose motion is governed by that of water is known as suspended sediment.

(ii) Bed load represents that portion of the moving sediment whose motion is governed appreciable by continuous contact with the bed and which is pushed or rolled along the bottom by the force of moving water.

(iii) The deposited material of which the bed is composed and is the result of either suspended load or bed load or both, and in some cases, the residual, is termed as the bed material.

(iv) The sediment that rolls or slides along the bed of the stream is substantially continuous contact with the bed is known as the contacts load.

(v) The sediment bouncing and hopping along the bed of the stream or moving directly or indirectly by the impact of the bouncing particles is called the saltation load.

Grading of Sediment

(a) Coarse Sediment : When particles are above 0.2 mm in diameter.

(b) Medium Sediment : When particles are between 0.2 and 0.07 mm diameter, and

(c) Fine Sediment : When particles are below 0.07 mm diameter.

SELECTION OF WATERSHED

In general one representative watershed out of 5 watersheds, is selected for establishing sediment monitoring station (SMS).

Selection of Sediment Monitoring Station

The selection of site for establishment of SMS is one of the most important part of the monitoring and it should be done keeping following points in view :

(a) Should be located at exit point as far as possible.
(b) Should be easily accessible.
(c) The upstream and downstream of site should be straight as far as possible.
(d) Location must be free from configuration, protrusion, confluence points, back water effects etc.
(e) If possible road bridge already construction may be utilized for collecting sediment samples.
(f) Site with constant soil action caused by the turbulence is preferred.

Sampling Procedure

The sampling of sediment is done on a daily basis, although it is an expensive undertaking and although sediment load carried by many streams in the non monsoon season is negligible. But due to the considerable number and range of samples available in the daily sampling method, a suspended sediment concentration graph correlating it with discharge can be usually drawn. This is very useful where discharge data is available and no sediment data is available.

The alternative of periodic sampling is less costly, but is generally not employed on Indian streams. In this alternative the sediment rating curve or sediment vs. discharge relationship is used. A correlation between sediment transported in tons/day as abscissa and discharge in m3/sec. as ordinate is drawn on a log log scale. The average suspended sediment yield is computed by means of the rating curve and a long term flow duration curve.

The width of the channel section at the observation site is divided into segments. The basic criteria in the location of sampling verticals is that samples collected should be representative of the quantity and character of the sediment load of stream section at the time of sampling. Preliminary experiments are conducted to determine the number of verticals which will give representative sediment concentration. Depending upon the width of the section, six to seven verticals are selected for daily observation.

Tables below give the guidelines of CWC and CBI&P about the number of verticals and their location.

Guidelines of Central Water Commission for location of verticals :

Width of river	Number of verticals	Location of verticals in normal section with sloping sides	Location of verticals in streams of uniform depth and velocity.
Less than 30.48 m (100 ft.)	3	25,50,75 percent of the width.	17,50, and 80 percent of the width
30.48 m to 304.8 m (100 ft. - 1000)	5	20,35,50,65,80 percent of the width.	10,30,50,70,90 percent of the width.
Over 304.8 m (over 1000 ft.)	7	15,30,40,50,60, 70,85 percent of the width.	7,21,36,50,64,79,93, percent of the width.

Guidelines of CBI&P for location of verticals :

Sl. No.	Channel capacity	Sampling verticals in terms of channel surface width.	Details of Sampling
1.	Channels above 3000 cusecs (85 cumecs) depth 8 ft. or above (2.5 m or above)	1/6, 1/2, 5/6	a) one litre samples each from surface 0.1.0.3, 0.7, 0.9D, mixed together and analysed to work sediment concentration and size distribution on verticals as a whole. b) Three litre samples each from surface 0.1,0.3,0.5,0.7,0.9D separately to work out sediment distribution along the vertical.
2.	Channel 500 to 3000 cusecs 15	1/6, 1/2, 5/6	Two numbers, one litre samples at each

85 cumecs) depth 4 ft. to 8 ft. (1.25 m to 2.5 m).		of the points 0.2, 0.5, and 0.8 D and mixed together.
3. Channels below 500 cusecs (15 cusecs) depth below 4 ft. (1.25 m)	1/6, 1/2, 5/6	Four numbers 1 litre samples at 0.6 D below the surface and mixed together.

Due to the variation of sediment concentration of medium and coarse grades and variation of velocity along a vertical depth sediment measurement with surface sampling will not represent true load. Different observations at 0.1 D, 0.2 D, 0.3 D upto 0.9 D for a wide range of discharge and depths of river are conducted to fix a depth indicating mean concentration. It has been, however, observed that a sample taken at 0.6D gives a fairly representative average. In some channels, however, 0.8D or an average of 0.2D and 0.8D gives representative average. Therefore, a few sets of observations in the beginning can give a good guide, for fixing the depth which will indicate the mean figure.

To collect samples, the sampler is lowered vertically to the required depth and at least one litre of water sample is taken at each depth on a vertical and put together in an enameled bucket. This process is repeated at each vertical and water samples from each depth are collected in separate buckets.

Buckets are allowed to stand till all the particles settle down. Alum is added in required quantity for quick settlement. Supernatant water is siphoned off to reduce the bulk of the sample. The buckets are covered with lids and then transported to the laboratory for analysis and estimation of coarse, medium and fine grades of sediment by volumetric and gravimetric methods.

Sediment Sampling can be further subdivided into:

(a) Sampling on rivers and canals in the plains;
(b) Sampling on torrents and flashy streams;
(c) Sampling in the higher catchment and deep channels.

FREQUENCY OF SAMPLING

Due to wide range of variation of sediment concentration in the stream and constant fluctuations in river discharge, it is important to fix the frequency of sampling of suspended sediment. However, it is advisable to increase the number of samplings during the rising period of stream till the attainment of the peak stage. For the day-to-day assessment of the sediment concentration for working out the annual sediment load carried by the stream, the practice followed at majority of the sites on rivers in India is to collect samples at least once in 24 hours.

SAMPLING EQUIPMENT

(a) Suspended sediment samplers

The design of the suspended sediment load sampler should be based on the following main technical requirements:

(i) The sampler should be stream-lined so as to reduce disturbance in the sediment flow.

(ii) The velocity of inflow at the mouth of the sampler should be equal to the velocity of stream flow.

(iii) The mouth of the sampler should face the direction of current.

(iv) Filling arrangement should be smooth.

(v) The sampler should be portable but sufficiently heavy to minimize deflection from the vertical due to current drag.

(vi) The sample collected by the sampler should be sufficient for analysis.

Various types of samplers have been developed in India and other countries of the world with a view to complying with most of the requirements.

(b) Bed material samplers

The functional requirements of an ideal bed material sampler are the following

(i) The sampler should be streamlined so as to reduce disturbance to the sediment flow.

(ii) The sampler should be able to cut a layer of 8 to 10 cm thickness of the material present on the stream bed.

(iii) The material cut should be so entrapped in the sampler that it remains intact, while the sampler is being raised from the bed to the water surface.

(iv) The sampler should have arrangements for operation from the boat, bridge etc.,

(v) The sampler should be capable for collecting bed material samples irrespective of the depth of flow.

Various types of bed material samplers have been developed to cater to a number of these requirements and may be grouped as follows :

a) Drag Buckets.
b) Scop Samplers.
c) USBMH-53.
d) USBM-54.

In CWC generally Scop-type samplers and USBM-54 samplers are used for collection of bed material samples.

Equipment Used for Sediment collection

Some of the common equipments used by CWC to collect sediment samples in the river are as under :

1. Boat fitted with OBE/Motor Launch
2. Current meter for velocity measurement
3. Suitable sediment sampler
4. Sounding rod/link chain with sufficient weight/echo-sounders for measurement of depth.
5. Water level recorder
6. Sextant/protractor for angle measurement

At some of the sites sophisticated and automatic gauge recorders are also available for hydrological observations.

ANALYSIS OF SEDIMENT SAMPLES

Suspended Sediment

After allowing the particles to settle at the bottom in the enameled bucket for two to three minutes, the supernatant water is decanted off and the residue is transferred completely into a numbered bottle to be taken to the field laboratory for subsequent analysis into coarse, medium and fine grades of the sediment.

COARSE SEDIMENT

The sample from each group is passed through a 100 mesh sieve. The residue on the sieve is washed with clean water several times, transferred to a clean, oven-dried and preweighed crucible and the final oven dried weight is measured. The difference of the weights gives the coarse sediment present in the group from which the concentration in grams/liter for the group is worked out.

MEDIUM SEDIMENT

The filtrate and washings from the coarse sediment is further passed through a 200 mesh sieve. The residue on the 200 mesh sieve is washed thoroughly and transferred to a clean, oven dried and pre-weighed crucible and the final oven dried weight is measured. The difference of weight gives the weight of the medium sediment in the group from which the concentration in grams/liter is measured.

In the field, sometimes the method based on Stoke's Law is also employed to separate medium size particles. The sediment particles are allowed to fall through a 10 cm. water column in a beaker for a certain period of time (seconds) depending upon the temperature of water in the beaker as shown below :

TIME TAKEN BY PARTICLES ABOVE 0.075 MM TO FALL THROUGH 10 CM COLUMN OF WATER AT DIFFERENT TEMPERATURES

Temperature, °C	Time, S
5	31
6-10	28.5
11-15	25
16-20	22
21-25	20
26-30	18
31-35	16.5

FINE SEDIMENT

The filtrate and washings from the separation of coarse and medium silt are allowed to stand in an enameled bucket for a period of twenty four hours or so. Next day, the supernatant liquid is carefully siphoned off and sediment is transferred from the bucket into a small beaker taking care that nothing sports out. The contents of the beaker are transferred carefully to a preweighed crucible/filter paper fitted in funnel with the help of a wash bottle. A few washings are given to bring all the particles from the sides of the filter paper to its cone. When the water is drained completely the wet filter paper with the residue is placed in an air oven, and dried at 105°C, cooled in a dissector and weighed to a constant weight. From the difference of the weights the weight of the fine silt is computed from which the concentration in grams/liter is worked out.

Analyses of Bed Material

he bed material sample is analyzed for determining its particle size distribution and mean diameter. Particles greater than 0.6 mm are analyzed by during and sieving through a set of 9 sieves with square openings of 4.75, 4.00, 3.35, 2.80, 2.36, 2.00, 1.40, 1.00 and 0.60 mm. The analysis of the portion of sediment that passes through 600 micron IS sieve (smaller than 0.60 mm) is done by Puri's siltometer. From the analysis of data, a table known as particle size distribution table, is prepared to present the data of the mechanical size analysis in the standard format. Graphical presentation of size distribution is done by cumulative curves or particle size summation curves.

DISSOLVED MATERIAL

100 CC of supernatant river water sample is pipetted in a pre-weighed porcelain dish and evaporated to dryness in hot air oven at 105°C. The difference in weight of porcelain dish plus residue and the porcelain dish alone gives the dissolved material present in 100 CC. The concentration of dissolved salts is expressed in parts per million (ppm).

Methods of Sediment Yield

At present, many sediment yield prediction methods are available for use or have been used for various purposes. In general, these methods can be grouped into two categories; those derived from statistical analysis and deterministic models which include empirical parametric approaches and those using time variant interactions of physical processes.

STATISTICAL METHODS

Usually, these equations are relating sediment yield to one or more watershed or climatic factors. Because of their nature, they require relatively large quantities of data both on watershed parameters and on sediment discharge. Flaxman (1972) developed a regression equation principally for reservoir design for rangeland watersheds in the western US relating sediment yields to five parameters. The expression is :

$$\text{Log}(Y+100) = 524.2-270.7\log(X1+100)+6.4\log(X2+100)$$
$$-1.7\log(X3+100)+4.0\log(X4+100)+\log(X5+100)$$

where,

Y = average annual sediment yield (t/mi^2) (t/mi^2 =351 kg/ha)

X1 = ratio of average annual precipitation (m) to average annual temperature (°F)

X2 = Watershed average slope (%).

X3 = Soil particles greater than 1.0mm (%).

X4 = Soil aggregation index (%).

X5 = Soil percent chance peak discharge (CSM) (1 CSM = 0.011 m^3 /Sec./ha).

These five parameters are expressions of vegetative growth (X1), topography (X2), Soil properties (X3and X4) and Climate (X5).

Dendy and Bolton (1976) have derived sediment yield equations having wide spread capability. They related deposition in about 800 reservoirs to drainage area size and mean annual run-off watershed areas ranged from 1 mi^2 to 30,000 mi^2 (1mile=1.616km) and run-off ranged from nearly zero to about 125 cm/hr. In areas where run-off is less than 5 cm, the equation derived as :

$$S = 1280\, Q^{0.46} (1.43 - 0.26 \log A)$$

for other areas

$$S = 1958\, Q^{0.55} (1.43 - 0.26 \log A)$$

where,

	S	=	Sediment yield (t/mi^2 /hr.)
and	Q	=	run-off (in)
	A	=	watershed area (mi^2)

The equations express a general relationship for sediment yields on a regional basis.

SEDIMENT DELIVERY RATIO METHODS

The sediment delivery ratio (SDR) is defined as the fraction or percentage of erosion (EROS) that is transported off a given area of land as sediment yield (SY).

SDR = EROS

Most com[illegible]y, the SDR is used as the fraction of gross erosion (GE) [illegible]at appears at some downstream point as SY. Here, GE is the sum of all sediment source estimates within the drainage basin, and SY is the total of all sediment passing a point in a channel, generally it is expressed as accumulated total load, which is the sum of suspended load and bed load. Thus, the SDR is a composite of delivery rates for sediments of all sizes and from all sources.

The equation given above can be rearranged for use where sediment yield data from a similar, nearby watershed is available. In such a case, gross erosion would be proportional to area, and the equation can be written as:

$$SY_{unmeasured} = 0.8\, SY_{measured} (Area_{unmeasured} / Area_{measured})$$

Other relationships of SDR and watershed parameters are

$$\log SDR = 1.8768 - 0.14191 \log (10\ \text{area})$$

Maner(1958) also developed a relationship depending on watershed relief - length ratio (R/L)

$$\log SDR = 2.94259 - 0.82363\ \text{colog}\ (R/L).$$

The above relationship is called the rolling and Red Plains curve and applied to Red Hills Physio-graphic area.

Deterministic Models

Deterministic models introduce numeric values to quantify the factors affecting erosion, transport, and deposition. These parameters can be derived empirically or by calibration using fitting techniques.

Williams (1975) has devised a set of equations to predict sediment yield and sediment concentration from watershed upto 2600 Km^2, divided into sub-watersheds upto to 26 Km^2. Sediment yield for an individual storm is computed from the modified wischmeier - Smith equation.

$$Y = 11.8\ (Q.q_p)^{0.56}\ K.C.P.Ls$$

where,

Q = runoff volume
q_p = peak runoff rate
Y = sediment rate (in metric tons).
K = soil erodibility
C = crop management
P = erosion - control practice
Ls = slope length and steepness.

The variables, Q and q_p are estimated from SCS curve number technique.

Onstad and Bowie (1977) developed a model based on the Wischmeier equation for estimating annual sediment yields from large watersheds. The routing function used by then are:

$$Y_i^{\bullet} = Y_{oi}\ e^{-d\ T_i}$$

Yi = sediment contribution at the outlet from increment i
Yoi = total erosion from increment i
d = routing co-efficient
Ti = $CLi^{0.77} / CSi^{0.385}$
CLi = nominal channel length measured from the center of increment i to the watershed outlet
CSi = slope of the nominal channel.

Effect of Sedimentation and Erosion on Water Quality

Erosion and sedimentation, including sediment transport through a watershed system, play important but complex roles in water quality management. Usually, sediments and erosion are singled out for attention early in the program because;

(i) Sediment has long been considered a major pollutant found in surface waters.

(ii) Most nonpoint source pollutants are thought to be directly proportional to erodible sediments.

(iii) A general, simple, and implemantable approach to nonpoint source pollution control is desired.

SEDIMENT AS POLLUTANTS

Sediments and their biotic and abiotic effects have been classified by Sorensen et al. 1977; as follows :

Sediment type	Biochemical chemical and physical effects	Biological effects
Clays, Silts, Sand	Sedimentation, erosion and abrasion, turbidity habitat change	Respiratory interference, habit destruction light limitation
Natural Organic Matter	Sedimentation, dissolved oxygen utilization	Food sources, dissolved oxygen effects.
Wastewater Organic Matter	Sedimentation, dissolved oxygen utilization, nutrient source	Dissolved Oxygen effects, eutrophication
Toxicants Sorbed to particles	All of the above	Toxicity

Sediments in surface waters are normally classified as wash load, suspended load, and bed load. Depending on flow rate, a given particle may from time to time be any one of these, but usually the wash load is comprised of silt and clay size particles, the suspended load is comprised of the wash load and larger particles moving just above the bed, and the bed load is comprised of sands and gravels moving in contact with the bed. Shen (1971) has proposed a convenient conceptual representation of sediment transport in terms of their source and as well as their properties. [Fig - 1]. The role of sediments as pollutants can be evaluated in light of this concept.

If the major impact results from particle size greater than d, than flow and sediment as a combination must be considered. Similarly if the major impact results from particle sizes less than d, then the sediment and its source as a combination must be considered.

If d>d* , bed load is the dominant concern and the sediment interaction with the biota and potential deleterious effects must be keyed to stream flow and not source. Sediment characterized by d<d* , are supply - limited and their occurrence in surface waters is more a function of land use and the associated erosion than the stream transport capacity. However, the implication

for water quality management can only be determined by a complete analysis of the watershed system response including channel transport.

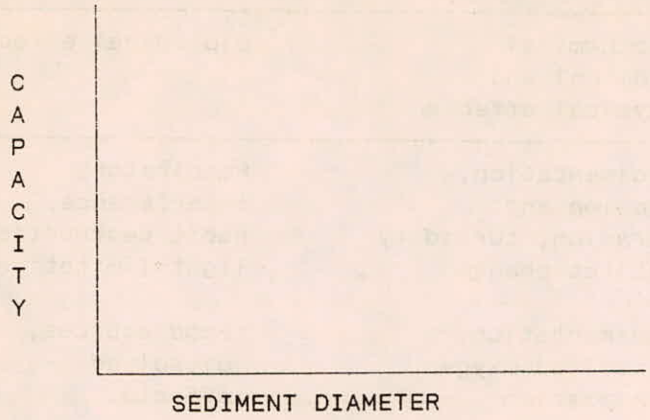

Fig.1 Relationship among sediment properties,sources and stream transport

SEDIMENTS AS A POLLUTANT TRANSPORT MEDIUM

Eroded and stream sediments have long been considered as a sorbent for both organic and inorganic substance, many of which can be pollutants. Concepts used to evaluate the relative importance of sediments as a pollutant transport medium are discussed below consider a certain volume of a water sediment pollutant mixture. The mass of water and sediment can be written as:

$$M_w = V P_w \left(\frac{P_s}{P_s + S}\right) \qquad (a)$$

where,

V = total volume of mixture
M_w = mass of water in V
P_w = density of water
P_s = sediment particle density
S = sediment concentration in water

Mass of sediment in volume (M_s)

$$= V.S \left(\frac{P_s}{P_s+S}\right) \qquad (b)$$

For any instant in time, the total pollutant (TP), in the volume, V can be written as

$$TP = C_s M_s + C_w M_v \qquad (c)$$

Putting the value of Ms & Mw in equation (c)

$$TP = V.Cs.S \left(\frac{Ps}{Ps+s} \right) + V.Cw.Pw \left(\frac{Ps}{Ps+s} \right)$$

where,

Cs = concentration of pollutant attached to sediment

Cw = concentration of pollutant dissolved in water.

Rearranging the above equation

$$\frac{V.Cs.S}{TP} \left(\frac{Ps}{Ps+s} \right) + \frac{V.Cw.Pw}{TP} \left(\frac{Ps}{Ps+s} \right) = 1.0$$

If a functional relationship between Cs and Cw exists, the above equation can be solved term by term. The fraction of pollutant asfor any given mixture.

REMARKS

Erosion and sedimentation, including the sediment transport through a watershed system, play important but complex roles in water quality management. Direct effects of sediment on biological productivity, habitat alteration, and aquatic organism mortality have been observed. Stream flow and watershed geomorphology are key determinants in the magnitude of the direct effect resulting from bed load sediments. Land use and upland erosion are the key factors in the direct effects of wash load (e.g.) light limitation) and the indirect effects of pollutant transport.

Erosion control can be effectively used as a surrogate for other nonpoint source pollutant control if the pollutant partition coefficient is sufficiently high and the pollutant is equally available throughout the year. For less persistent pollutants, like pesticides, use of application timing as a management variable may be more cost-effective.

The most meaningful way to evaluate the relative effectiveness of various erosion control methods for water quality management is via continuous simulation models capable of predicting the detachment, transport, deposition, and scour processes throughout a watershed system. If water quality goal attainment is attempted by application of source controls within some specified technology limits (including costs) then a more simplistic approach similar to the one proposed in this paper may be used for analysis if an adequate range of conditions are evaluated. Such an approach assumes a linear relationship between source controls and downstream "benefits".

The keys to accurate evaluation of nonpoint source controls, including erosion, for water quality management are:

* the ability to predict watershed erosion and sediment transport by particle size classes;
* the ability to estimate, measure, and extrapolate partition coefficients for application to specific problems;
* the ability to predict the existence of nonequilibrium sorption and formulate kinetic approaches where appropriate;
* the ability to predict the availability or persistence of specific pollutants within the soil profile; and
* the ability to predict the movement of water through watershed systems.

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