Training Course

On

Predictions in Ungauged Basins

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CHAPTER-1

PROCESSING AND ANALYSIS OF HYDRO-METEOROLOGICAL DATA

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CHAPTER 1

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1.0 INTRODUCTION

Hydro-meteorological data collected from various sources/instruments are generally raw in nature and as such can not be used for most of the hydrological analysis. The hydrometeorological data collected from the field are required to be computerised. Furthermore, the primary validation of the computerised data is needed for its checking ensuring the quality. The secondary processing is required for bringing the data in the desired format for the hydrological studies. Therefore, primary as well as secondary processing of such data are essential requirements to make them usable for various studies.

Data processing is a broad term covering all activities from receiving records of observed raw data to making them available in a usable form. The raw data are in a variety of formats such as hand-written records, charts and digital records. Raw data as observed and recorded may contain many gaps and inconsistencies. These raw data are passed through a series of operations, typically: data entry, making necessary validation checks, filling missing values in a data series, processing of raw data to estimate required variables, compilation of data in different forms and analysis of data for commonly required statistics etc.

The rapid advance in computer technology, in hardware speed of operation and data storage capacity as well as the capability of hydrological software has greatly simplified the management of large quantities of hydrological data and has rendered obsolete those time-consuming manual methods which were formerly the norm. Computer-based hydrological information systems offer various advantages viz., to permit and promote the standardization of processing, validation and reporting procedures; to handle very large amounts of data and users can be provided with data in the required tabular or graphical format

1.1 HYDROLOGICAL DATA PROCESSING

The term hydrological data processing refers to the recording and handling of hydrological data that are necessary to convert it into more refined or useful form of information. The data processed should not be taken as an end in itself. It is rather the beginning step of achieving objectives which can vary as the nature of data. The data processing activities which come in cyclic way is called data processing cycle. In the data processing cycle first the information are gathered for data processing work. This is known as origination and collection. Then the collected data is considered as input for the processing. Subsequently it is stored for further processing and retrieval. The result and information obtained, as the products of data processing are subjected to feed back, which can be either negative or positive. Depending upon the type of feed back, corrections or modification are incorporated to get the new system. The obtained new system may be run for the subsequent operations.

1.2 PROCESSING OF RAINFALL DATA

Various operations to be carried out for processing of rainfall data are described in the following sub-headings.

1.2.1 Data Validation

Data validation procedure includes primary and secondary data validation. Data validation must never be considered as a purely statistical or mathematical exercise. Staff involved in it must understand the field practice. To understand the source of errors one must understand the method of measurement or observation in the field and the typical errors of given instruments and techniques. The method of measurement or observation influences our view of why the data are suspect.

Instruments and observational methods

Three basic instruments are in use at climatological stations for measurement of daily and shorted duration rainfall:

- Standard daily raingauge
- Syphon gauge with chart recorder
- Tipping bucket gauge with digital recorder

Daily rainfall gauge (SRG): ***Instrument and procedure***

Daily rainfall is measured using the familiar standard gauge (SRG). This consists of:

- **a circular collector funnel** with a brass or gun metal rim and a collection area of either 200 cm^2 (diameter 159.5 mm) or 100 cm^2 (diameter 112.8 mm), leading to a,
- **base unit**, partly embedded in the ground and containing,
- **a polythene collector bottle**

The gauge is read once or twice daily and any rain held in the polythene collector is poured into a **measuring glass** to determine rainfall in mm.

Typical measurement errors

- Observer reads measuring glass incorrectly
- Observer enters amount incorrectly in the field sheet
- Observer reads gauge at the wrong time (the correct amount may thus be allocated to the wrong day
- Observer enters amount to the wrong day
- Observer uses wrong measuring glass (i.e., 200 cm^2 glass for 100 cm^2 gauge, giving half the true rainfall or 100 cm^2 glass for 200 cm^2 gauge giving twice the true rainfall.
- Observed total exceeds the capacity of the gauge.
- Instrument fault - gauge rim damaged so that collection area is affected
- Instrument fault - blockage in rain gauge funnel so that water does not reach collection bottle and may overflow or be affected by evaporation
- Instrument fault - damaged or broken collector bottle and leakage from gauge

It may readily be perceived that errors from most of these sources will be very difficult to detect from the single record of the standard rain gauge, unless there has been a gross error in reading or transcribing the value. These are described below for upper warning and maximum limits.

Errors at a station are more readily detected if there is a concurrent record from an autographic rain gauge (ARG) or from a digital record obtained from a tipping bucket raingauge (TBRG). As these too are subject to errors (of a different type), comparisons with the daily raingauge will follow the descriptions of errors for these gauges.

The final check by comparison with raingauges at neighbouring stations will show up further anomalies, especially for those stations which do not have an autographic or digital raingauge at the site.

Autographic rain gauge (Natural Syphon): ***Instrument and procedure***

In the past short period rainfall has been measured almost universally using the natural syphon raingauge. **The natural syphon raingauge consists of the following parts:**

- **a circular collector funnel** with a gun metal rim, 324 cm^2 in area and 200 mm in diameter and set at 750 mm above ground level, leading to ,
- **a float chamber** in which is located a float which rises with rainfall entering the chamber,
- **a syphon chamber** is attached to the float chamber and syphon action is initiated when the float rises to a given level. The float travel from syphon action to the next represents 10 mm rainfall
- **a float spindle** projects from the top of the float to which is attached,
- **a pen** which records on,
- **a chart** placed on
- **a clock drum** with a mechanical clock.

The chart is changed daily at the principal recording hour. During periods of dry weather the rainfall traces a horizontal line on the chart; during rainfall it produces a sloping line, the steepness of which defines the intensity of rainfall. The chart is graduated in hours and the observer extracts the hourly totals from the chart and enters it in a register and computes the daily total.

Typical measurement errors

Potential measurement faults are now primarily instrumental rather than caused by the observer and include the following:

- Funnel is blocked or partly blocked so that water enters the float chamber at a different rate from the rate of rainfall
- Float is imperfectly adjusted so that it syphons at a rainfall volume different from 10 mm.
- In very heavy rainfall the float rises and syphons so frequently that individual pen traces cannot be distinguished.
- Clock stops; rainfall not recorded or clock is either slow or fast and thus timings are incorrect.
- Float sticks in float chamber; rainfall not recorded or recorded incorrectly.
- Observer extracts information incorrectly from the pen trace.

In addition differences may arise from the daily raingauge due to different exposure conditions arising from the effect of different level of the rim and larger diameter of collector. It has been traditional to give priority to the daily SRG where there is a discrepancy between the two.

Tipping bucket rain gauge: ***Instrument and procedures***

Short period rainfall is more readily digitised using a tipping bucket raingauge. It consists of the following components.

- **A circular collector funnel** with a brass or gunmetal rim of differing diameters, leading to a
- **Tipping bucket arrangement** which sits on a knife edge. It fills on one side, then tips filling the second side and so on.
- **A reed switch** actuated by a magnet registers the occurrence of each tip
- **A logger** records the occurrence of each tip and places a time stamp with the occurrence

The logger stores the rainfall record over an extended period and may be downloaded as required. The logger may rearrange the record from a non-equidistant series of tip times to an equidistant series with amounts at selected intervals. The digital record thus does not require the intervention of the field observer. For field calibration, a known amount of rainfall is periodically poured into the collector funnel and checked against the number of tips registered by the instrument.

Typical measurement errors

- Funnel is blocked or partly blocked so that water enters the tipping buckets at a different rate from the rate of rainfall
- buckets are damaged or out of balance so that they do not record their specified tip volume
- reed switch fails to register tips
- reed switch double registers rainfall tips as bucket bounces after tip. (better equipment includes a debounce filter to eliminate double registration.
- failure of electronics due to lightning strike etc. (though lightning protection usually provided)
- incorrect set up of measurement parameters by the observer or field supervisor

Differences may arise from the daily raingauge (SRG) for reasons of different exposure conditions in the same way as the autographic raingauge.

Primary validation of precipitation data

Preliminary processing and scrutiny of the data is an essential task before the analysis of observed data. The preliminary processing includes a number of operations on raw data viz.: verification, valid status, reasonable report, quality of data, filling up of short data gaps, consistency of data, quality control procedures, and adjustment of records.

1.2.2 SECONDARY VALIDATION OF PRECIPITATION DATA

Specific tasks included in secondary data processing of rainfall data are discussed below:

Screening of data series

The first step towards data validation is making the listing of dat. Further the time series rainfall data of various stations are screned keping in view the following main objectives:

i) To review the primary validation exercise by getting the data values screened against desired data limits.

ii) To get the hard copy of the data on wich any remarks or observation about the data validation can be maintained and communicated.

On the basis of historical data various data limits may be set for the daily, monthly and yearly rainfall maxima. The available rainfall data of various stations can be screened by setting these data limits.

Scrutiny by multiple time series graphs

This type of validation can be carried out for hourly, daily, monthly and yearly rainfall data. The validation of compiled monthly and yearly rainfall totals helps in bringing out those inconsistencies which are either due to a few very large errors or due to small systematic errors which persist unnoticed for much longer durations.

Scrutiny by tabulations of daily rainfall series of multiple stations

Under scrutiny by tabulation the rainfall data of various raingauge stations is listed side by side in tabular form. This helps in revealing the anomalies which were difficult to see on multiple time series graphs.

Checking against data limits for totals at longer durations

Many systematic errors are individually so small that they can not be easily noticed. If the observed data are accumulated for longer time intervals, then the resulting time series can again be checked against corresponding expected limits. Therefore, the daily rainfall data of each stations should be aggrigated to monthly and yearly valuesv and checked against the maximum monthly and yearly totals. When a significant difference is noticed it is varified with the available records of the same and nearby stations.

Spatial homogeneity testing of rainfall (Nearest neighbour analysis)

Rainfall exhibits some degree of spatial consistency. The degree of consistency is primarily based on the actual spatial correlation. The expected spatial consistency is the basis of investigating the observed rainfall values at the individual observation stations. For the suspected station in the basin an estimation of the spatially interpolated rainfall values can be made by selecting the neighbouring stations at the desired radial distance and then computing the weighted average of the rainfall of those neighbouring stations.

Identification of common errors

The rainfall data may also include following common errors:

- Entries on the wrong day - shifted entries
- Entries made as accumulations
- Missed entries
- Rainfall measurement missed on days of low rainfall.

1.3 CORRECTION AND COMPLETION OF RAINFALL DATA

After primary and secondary validation of rainfall data various errors and missing values in data series can be identified. Such incorrect and missing values can be replaced wherever possible by estimated values based on other observations at the same station or at neighbouring stations. Procedure adopted for correction and completion of data depend on type of error observed/indicated and the availability of suitable data. These are:

- ***Rraingauge station failure:*** Autographic/self recording raingauge data and standard raingauge data can be utilised for correction and completion depending on the nature and type of raingauge station failure.

- ***Accumulated rainfall data***: Where the daily raingauge has not been read for a period of days, the recorded total represents an accumulation over a period of days identified in validation. Such accumulated totals can be distributed over the period of accumulation by reference to rainfall at neighbouring stations over the same period.
- ***Long-term shift in rainfall data:*** The double mass analysis technique is generally used in validation to detect significant long-term shift in rainfall data.
- ***Missing or erroneous data:*** Missing data and data identified as erroneous can be substituted from neighbouring stations using suitable interpolation method.

1.3.1 Completion of Rainfall Data

Estimation of Missing Data

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

Normal ratio method

In this 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 the neighbouring stations for the period of missing data at the station under question.

$$R_A = \frac{\sum_{i=1}^{n} \frac{NR_A}{NR_i} x R_i}{n} \qquad \text{...(1)}$$

where R_A is the estimated rainfall at station A
R_i is the rainfall at surrounding station
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 used for estimation

Example 1.1

The observed rainfall at the estimator stations B, C and D are :

Station	B	C	D
Rainfall (mm)	98.9	120.5	110.0

The normal monthly, seasonal or annual rainfall at the estimated stations :

Station	A	B	C	D
Monthly rainfall (mm)	331.3	290.8	325.9	360.5

The rainfall at station A is :

$$P_A = \frac{\frac{331.3x98.9}{290.8} + \frac{331.3x120.5}{325.9} + \frac{331.3x110.0}{360.5}}{3}$$

$$= \frac{1.14x98.0 + 1.02x120.5 + 0.92x110}{3} = 112.3mm$$

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 of some power of distance of the estimator stations.

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

where R_A and R_i has the same notation as in Eq. (2) and D_i is the distance of estimator station from the estimated station. If A, B, C, D are the location of stations discussed in the example of normal ratio method, 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 formulae:

$$Di = [(x - xi)^2 + (y - yi)^2] \quad \ldots(3a)$$

where x and y are the coordinates of the station whose data is estimated and xi and yi are the coordinates of stations whose data are used in estimation.

Example 1.2

If A, B, C, D are the location of stations discussed in the example of normal ratio method, 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 formulae

$$Di = [(x - xi)^2 + (y - yi)^2] \quad \ldots(3b)$$

where x and y are the coordinates of the station whose data is estimated and xi and yi are the coordinates of stations whose data are used in estimation.

Weights $1/Di^2$ are computed for each station and rainfall at the station A is estimated as follows.

Station	Distance from Station A	$1/Di^2$	Rainfall (mm)	Weighted Rainfall (mm)
B	28	1.27×10^{-3}	98.9	125.6×10^{-3}
C	17.7	3.19×10^{-3}	120.5	384.6×10^{-3}
D	42.5	0.55×10^{-3}	110.6	60.5×10^{-3}
	Total	5.01×10^{-3}		570.7×10^{-3}

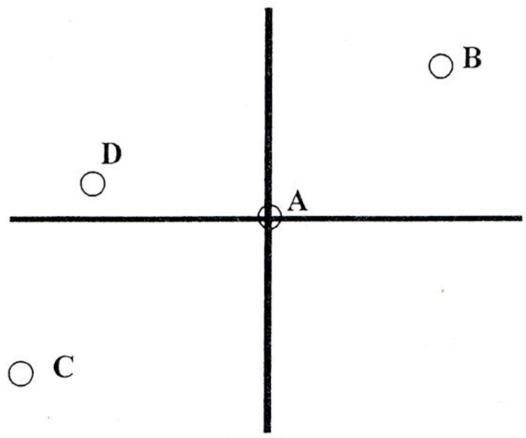

Figure 1.1 Location of Stations

$$\text{Rainfall at station A} = = \frac{570.7x10^{-3}}{5.01x10^{-3}} = 113.9mm$$

Internal consistency check

The internal consistency or self consistency checks are applied by using statistical information based on historical data of the station and current data in case of short duration rainfall. Example for checking the data by the internal consistency is given below:

Example 1.3

Hourly rainfall data reported at a station are as follows:

Hours	1	2	3	4	5	6
Rainfall	8.0	10.8	85.8	28.5	19.8	15.0

The hourly rainfall reported during 3rd hour is suspected though it could not be ruled out. When the 3 hourly total 1-3 hours is reported, the value in 3rd hour could be checked. If the 3 hourly total reported is 54.1 mm it could be seen that the value is 50.5 mm less than the three hourly total computed from the reported hourly data which is 104.6. Thus the value in the 3rd hour is 35.3 mm and not 85.8 mm as reported in the first place.

When the 6 hour total 117.4 mm is reported, the value of 35.3 mm is confirmed for the 3rd hour. Further checking for the erroneous value is carried out similarly.

Spatial consistency checks

Spatial consistency checks for precipitation data are carried out by relating the observations from surrounding stations for the same duration with the rainfall observed at the station. This is achieved by interpolating the rainfall at the station under question with rainfall data of neighbouring stations. An example of spatial consistency check is given below.

Data reported at a group of five stations is as follows:

Station	Jhabua	Sardarpur	Dhar	Manawar	Alirajpur
Rainfall(mm)	132.1	10.3	103.3	125.7	149.8

During the quality control process, the data at Sardarpur is identified as doubtful. The data at Sardarpur is checked by spatial consistency check. The rainfall data at Sardarpur is estimated using the distance power method and compared with the observed value. From the four quadrants around Sardarpur (Figure 1) on nearest from each quadrant is selected for the estimation of rainfall at Sardarpur.

Using the reference coordinate system, the distance of each of the estimator stations from Sardarpur is determined and the rainfall at Sardarpur is estimated using the Eq.(3).

Sl. No.	Station	Distance from Sardarpur (km)	$1/Di^2$	R/Di^2
1.	Jhabua	42	5.67×10^{-4}	.075
2.	Dhar	39	6.57×10^{-4}	.068
3.	Alirajpur	75	1.78×10^{-4}	.027
		Total	14.02×10^{-4}	.170

The estimated rainfall in Sardarpur in 121.3 mm and is very much different from the observed value. Therefore reported value is rejected and replaced by the estimated value.

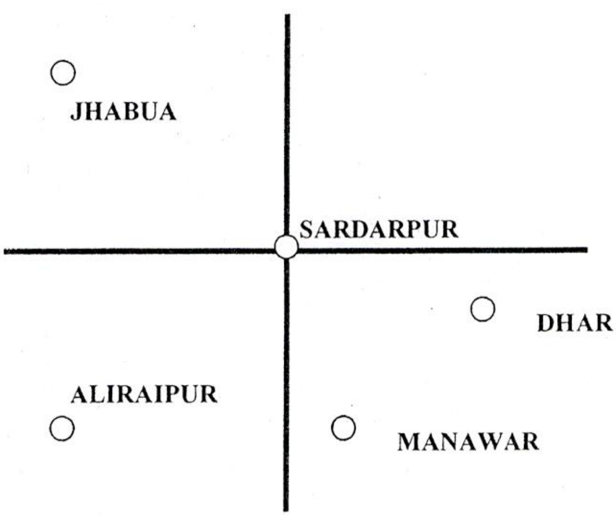

Figure 1.2: Location map of raingauges stations

Estimation of Mean Areal Precipitation

An accurate assessment of mean areal precipitation is a pre-requisite and basic input in the hydrological analysis. Numerous methods of computing areal rainfall from point raingauge measurements have been proposed. The most commonly used methods are:

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

The choice of the method is dependent on the quality and nature of data, importance of use and required precision, availability of time and computer. Some of the commonly used methods and other computerized methods are described below:

Arithmetic average

The simplest technique for computing the average precipitation depth over a catchment area is arithmetic average of the values at gauges within the area for the time period of concern. If the gauges are relatively uniformly distributed over the catchment and the values are not greatly different from the average value, this technique will yield reliable results.

Thiessen Polygon

The Thiessen Polygon method is used with non-uniform stations spacing and gives weights to stations precipitation data according to the area which is closer to that station than to any other station. This area is found by drawing the perpendicular bisector of the line joining the nearby station so that the polygons are formed around stations. The polygons thus formed around each station are the boundaries of the effective area assumed to be controlled by station. The area governed by each station is planimetered and expressed as a percentage of total area. Weighted average precipitation for the basin is computed by multiplying each station precipitation amount by its assigned percentage of are and totaling. The weighted average precipitation is given by:

$$\overline{P} = \frac{\sum_{i=1}^{n} P_i W_i}{\sum_{i=1}^{n} W_i} \qquad \ldots(4)$$

where $\overline{P}$ is the average catchment precipitation, Pi is the precipitation at station 1 to n, Wi the weights of respective station. An example of Thiessen network and computation of mean areal precipitation estimating using Thiessen weights is given below:

1.4 COMPILATION OF RAINFALL DATA

After correction and completion of missing and erroneous data an important task is to compile the data in various usable forms. Various tasks under rainfall data compilation are classified as:

- Aggregation of rainfall data from hourly to daily, daily to monthly and yearly etc.
- Raingauge measures rainfall at individual points and these are called as point rainfall. Various methods are available for estimating areal rainfall from point rainfall. A very popular Thiessen polygon method utilises the catchment boundary and locations of the raingauge stations supplied as GIS map layer in HYMOS and automatically develops a map layer of Thiessen polygons.

- For generating hydrological information, minimum, maximum, mean and median values can be extracted from time series data of various raingauge stations.

1.5 PROCESSING OF STREAMFLOW DATA

1.5.1 Preliminary Processing and Scrutiny

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

i. Methods of measurement/observation of hydrological data, standards followed, instruments used, frequency of observation etc. shall be discussed item wise.
ii. Details of history of station, shift in the location, shift in the rating curves should be identified. Sample calculation for discharge should be furnished. Mention shall be made as to whether discharge data is observed or estimated from the rating curve. Indicate the methods of estimation.
iii. Discuss development of stage discharge curves at discharge site bringing out the extrapolations shall be verified by other methods such as hydraulic calculations etc.

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

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

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

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

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

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

- Comparing monthly and annual rainfall with corresponding runoff.
- Comparing average annual specific flow expressed in depth unit with corresponding

figures at other sites of the same river or adjacent basins.
- Comparing hydrograph or daily discharge at the control point with adjacent sites etc.

1.5.2 Secondary Processing

Specific tasks in secondary data processing include :

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

1.5.3 Analysis of Processed Data

The following analysis are normally performed with the processed data:

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

1.6 STAGE-DISCHARGE RELATIONSHIP

The stage-discharge (S-Q) relationship is determined by using the observed stage and discharge values over a wide range of flows to define a continuous curve also known as rating curve. These stages and discharges can be observed by using any suitable measuring technique. The measured value of discharges when plotted against the corresponding stages show a definite relationship between the two and it represents the integrated effect of a wide range of channel and flow parameters. The combined effect of these parameters is termed control. If the S-Q relationship for a gauging section is constant and does not change with time, the control is said to be permanent. If it changes with time, it is known as shifting control.

1.6.1 Development of Rating Curve

A majority of streams and rivers, especially non-alluvial rivers exhibit permanent control. For such a case, the relationship between the stage and the discharge is a single-valued relation which is expressed as:

$$Q = a * (H-H_0)^b \qquad ...(5)$$

in which Q = stream discharge, H = gauge height (stage), H_o = a constant which represent the gauge reading corresponding to zero discharge, a and b are rating curve constants. This relationship can be expressed graphically by plotting the observed stage against the corresponding discharge values (in an arithmetic or logarithmic plot). Logarithmic plotting is advantageous as gauge-discharge relationship forms a straight line in logarithmic coordinates. The advantage of using the double logarithmic plot is two fold. Firstly, the plot would produce a straight line since the general form of rating curve is parabolic. Secondly, different straight lines allow to further grouping of data. A part of the entire range of stage may form a straight line. It gives an indication about the stage at which the slope of the straight line changes if more than one lines are used to fit the data points.

While plotting the data on double log plot a prior knowledge about the value of H_o 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 station. Marginal adjustment in the values of H_o may be required in order to produce a straight line giving better fit to the plotted points. There is a possibility that more than one straight lines are fitted if so required to represent the changing conditions at different stages.

1.6.2 Least square method

The best values of a and b for a given range of stage can be obtained by the least-square-error method. Thus by taking logarithms, Eqn.(5) may be represented as

$$\log Q = \log a + b \log (H - H_0) \qquad ...(6)$$

or

$$Y = m X + c$$

in which the dependent variable Y = log Q, independent variable X = log $(H-H_o)$ and c = log a. Values of coefficients for the best-fit straight line using data of N observations of X and Y are:

$$m = \frac{N\sum_{i=1}^{N}(X_i Y_i) - (\sum_{i=1}^{N} X_i)(\sum_{i=1}^{N} Y_i)}{N\sum_{i=1}^{N}(X_i)^2 - (\sum_{i=1}^{N} X_i)^2}$$

$$c = \frac{\sum_{i=1}^{N} Y_i - m\sum_{i=1}^{N} X_i}{N}$$

The Eqn. (6) is known as the rating equation of the stream and can be used for estimating the discharge Q of the stream for a given gauge reading H within the range of data used in its derivation. The constant H_o representing the stage (gauge height) for zero discharge in the stream is a hypothetical parameter and can not be measured in the field. As such, its determination poses some difficulties. Different alternative methods are available for its determination. However generally it is found by extrapolating the rating curve by eye judgement to find H_0 as the value of H corresponding to Q=0. Using the 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 neighbourhood 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 $(H-H_o)$.

1.7 CLIMATOLOGICAL DATA

Climatological data are required in hydrology for the computation of evapotranspiration by theoretical and empirical methods. Climatological data for the purpose of this module include the direct measurement of pan evaporation. There is a requirement to make all climatic data available on computer for validation processing and reporting - the first step is therefore data entry. All data entry of climatic data will be done through the primary module of dedicated hydrological data processing software (SWDES). Initial emphasis will be on the entry of current climatic data, but SWDES also provides a suitable means of entering historical data, from original data sheets where available and otherwise from published tabulations. SWDES provides a suitable format for entry of data for all standard instruments installed at the Full Climate Stations (FCS) and their frequencies of operation:

- Dry bulb temperature - read daily or twice daily
- Wet bulb temperature - read daily or twice daily
- Maximum thermometer - read daily or twice daily
- Minimum thermometer - read daily or twice daily
- Relative humidity - historical data previously computed
- Instantaneous wind speed - read daily or twice daily
- Daily wind run - read daily
- Wind direction - read daily or twice daily
- Pan evaporation - read daily or twice daily
- Pan water temperature - read daily or twice daily
- Atmospheric pressure - read daily or twice daily
- Autographic recording of relative humidity - tabulated values on chart
- Autographic recording of temperature - tabulated values on chart
- Autographic recording of atmospheric pressure - tabulated values on chart
- Sunshine hours - from Campbell stokes sunshine recorder card.

1.7.1 Primary validation of climatic data

Data validation is the means by which data are checked to ensure that the final figure stored in the HIS is the best possible representation of the true value of the variable at the measurement site at a given time or in a given interval of time. Validation recognises that values observed or measured in the field are subject to errors which may be random, systematic or spurious. Improvement in computing facilities now enables such validation to be carried out whereas in the past, the volume of data and the time required to carry out comprehensive manual validation was prohibitive. Primary validation of climatic data is concerned with data comparisons at a single station: for a single data series, between individual observations and pre-set physical limits for a single series between sequential observations to detect unacceptable rates of change and deviations from acceptable hydrological behaviour most readily identified graphically between two measurements of a variable at a single station, e.g. dry bulb thermometer and a thermograph recorder.

1.7.1.1 Primary validation of temperature

Temperature variation and controls

Temperature is a measure of the ability of a body (in this case the atmosphere) to communicate heat to other bodies and to receive heat from them (IMD definition). Temperature varies primarily with the magnitude of solar radiation and observes cyclic diurnal and seasonal patterns. It is influenced at particular times by prevailing air masses and by the incursion of air masses from other source areas with different insolation properties and by prevailing cloudiness which limits incoming radiation. These factors limit the maximum and minimum temperatures which are expected at a given location for given season and time of day. They also limit the rates of change expected from hour to hour and from day to day. With respect to location, temperature varies with latitude (which controls solar radiation), altitude and proximity to the ocean. Generally temperature is a spatially conservative element which has strong correlation (at least on an averaged basis) with neighbouring stations within the same air mass. There is normally a regular decrease in mean temperature with altitude at a rate of approximately 0.6°C per 100 metres for moist air and 0.9°C for dry air. Stations in close proximity to the sea have their temperature moderated by its influence so that maxima tend not to be so high, minima not so low, thus giving a reduced diurnal range.

Specific site conditions also affect the temperature measured. Stations in topographic hollows may experience temperature inversions in calm conditions, reversing the normal lapse rate of temperature with altitude. Stations sited in urban areas have generally higher temperatures than adjacent rural areas. The nearby prevailing ground cover, whether bare or vegetated, influences the measured temperature - including the proximity of trees which shade the site or of buildings which alternately shade and reflect heat to the station.

Temperature measurement

Temperature is periodically observed (once/twice daily) using four thermometers, located in a thermometer (or Stevenson) screen, which from its construction and installation provides a standard condition of ventilation and shade. Four thermometers are:

- Dry bulb thermometer - measuring ambient air temperature
- Wet bulb thermometer - which provides a basis for calculating relative humidity
- Maximum thermometer - to indicate the highest temperature reached since last setting
- Minimum thermometer - to indicate the lowest temperature reached since last setting.

Graduations are etched on the glass stem of the thermometer. In the case of the dry bulb, wet bulb and maximum thermometers, observations are of the position of the end of the mercury column but in the case of the minimum thermometer, the reading is taken of the position of the end of the dumb-bell shaped index furthest from the bulb. Each thermometer has a calibration card which shows the difference between the true temperature and that registered by the thermometer. Corrections for a given temperature are applied to each observation. When the maximum and minimum thermometers have been read they are reset (twice per day for minimum; once per day for maximum) using a standard procedure.

Temperature is also measured continuously using a thermograph in which changes in temperature are recorded through the use of a bi-metallic strip. The temperature is registered on a chart on a clock-driven revolving drum and the measurement (chart) period may be either one day or one week. The observer extracts temperatures at a selected interval from the chart. The manually observed reading on the dry bulb thermometer is measured and recorded at the beginning and end of the chart period and if these differ from the chart value, a correction is applied to the chart readings at the selected interval.

Typical measurement errors

- Observer error in reading the thermometer, often error of 1°C (difficult to detect) but sometimes 5°C or 10°C. These are more common in thermometers with faint etchings.
- Observer error in registering the thermometer reading
- Observer reading meniscus level in minimum thermometer rather than index
- Thermometer fault - breaks in mercury thread of the dry, wet or maximum thermometer
- Thermometer fault - failure of constriction of the maximum thermometer
- Thermometer fault - break in the spirit column of minimum thermometer or spirit lodged at the top or bubble in the bulb.
- Thermograph out of calibration and no correction made.

Thermometer faults will result in individual or persistent systematic errors.

Error detection

Many of the above faults will have been identified by the field supervisor or at data entry but others may be identified by setting up appropriate maximum minimum and warning limits for the station in question. These may be altered seasonally. For example, summer maximum temperature can be expected not to exceed 50°C nor winter maximum temperature to exceed 33°C. Other checks carried out by SWDES include:

- Dry bulb temperature should be greater than or (rarely) equal to the wet bulb temperature.
- Maximum temperature should be greater than minimum temperature
- Maximum temperature measured using the maximum thermometer should be greater than or equal to the maximum temperature recorded by the dry bulb during the interval, including the time of maximum observation. The value of the maximum will be set to the observed maximum on the dry bulb if this is greater.
- Minimum temperature should be less than or equal to the minimum temperature recorded by the minimum thermometer during the interval, including the time of observation of the minimum thermometer. The value of the minimum will be set to the observed minimum on the dry bulb if this is lower.
- Thermograph readings at time of putting on and taking off should agree with the manually observed readings.

1.7.1.2 Primary validation of humidity

Humidity variations and control

The standard means of assessing the relative humidity or moisture content of the air is by means of the joint measurement of dry bulb and wet bulb temperature. From these two measurements, the dew point temperature, actual and saturated vapour pressures may also be calculated. The relative humidity (%) is the ratio of the actual vapour pressure to saturated vapour pressure corresponding to the dry bulb temperature. Whilst the actual vapour pressure may vary little during the day (except with the incursion of a new air mass), the relative humidity has a regular diurnal pattern with a minimum normally coinciding with the highest temperature (when the saturation vapour pressure is at its highest). It also shows a regular seasonal variation. Generally relative humidity is a spatially conservative element which has strong correlation (at least on an average basis) with neighbouring stations within the same air mass. Stations in close proximity to the sea have higher relative humidity than those inland and a smaller daily range.

Humidity measurement

Wet and dry bulb thermometers used for temperature assessment also used for calculating various measures of humidity. The wet bulb is covered with a clean muslin sleeve, tied round the bulb by a cotton wick which is then led to a water container, by which the wick and muslin are kept constantly moist. The observer calculates the relative humidity from the wet bulb depression using a set of tables.

Relative humidity may also be measured continuously by means of hygrograph in which the sensor is human hair whose length varies with relative humidity. The humidity is registered on a chart on a clock-driven revolving drum and the measurement (chart) period may be either one day or one week. The observer extracts humidity at a selected interval from the chart. A manually computed reading from dry and wet bulb thermometers is recorded at the beginning and end of the chart period and if these differ from the chart value, a correction is applied to the chart readings at the selected interval.

Typical measurement errors

Measurement errors using dry and wet bulb thermometers in the assessment of humidity are the same as those for temperature. In addition an error will occur if the muslin and wick of the wet bulb are not adequately saturated. Similarly there will be an error if the muslin becomes dirty or covered by grease. These defects will tend to give too high a reading of wet bulb temperature and consequently too high a reading of relative humidity. Errors in the hygrograph may also result from poor calibration or the failure to correct for manually observed values at the beginning and end of the chart period.

Error detection

Errors may be detected by setting up upper and lower warning limits appropriate to the station and season. The maximum is set at 100%. If the wet bulb is greater than dry bulb and the resulting calculated relative humidity is greater than 100%, then the observation will be rejected by SWDES. Graphic inspection of the daily series can be used to identify any anomalous values. The observer calculated values of relative humidity may be compared with those calculated by the computer. However in view of the fact that the calculation can be done very simply in the office, field calculations are made except for calibrating the hygrograph.

1.7.1.3 Primary validation of wind speed

Windspeed variations and controls

Wind speed is of particular importance in hydrology as it controls the advective component of evaporation. Wind speed exhibits wide variation not only from place to place but also shows strong diurnal variation at the same place. Wind flow and speeds are controlled by local pressure anomalies which in turn are controlled by the temperature. It may also be influenced by local topographic features which may funnel the wind and increase it above the areal average; conversely some stations will have wind speeds reduced by shelter.

Measurement of wind speed and direction

Wind speed is measured using an anemometer, usually a cup counter anemometer. The rate of rotation of the anemometer is translated by a gear arrangement to read accumulated wind total (km) on a counter. By observing the counter reading at the beginning and end of a period, the wind run over the period can be determined and the average speed over the interval can be determined by dividing by the time interval. Standard Indian practice is to measure the wind speed over a three minute period as representing an effectively instantaneous wind speed at the time of observation. Daily wind run or average wind speed is also calculated from counter readings on successive days at the principal observation times. Wind direction is commonly measured and may be used in the calculation of evapo-transpiration with respect to finding the fetch of the wind. It is observed using a wind vane and reported as 16 points of the compass either as a numerical figure or an alpha character

Typical measurement errors

Errors in windspeed might arise as the result of observer errors of the counter total, or arithmetic errors in the calculation of wind run or average wind speed. Instrumental errors might arise from poor maintenence or damage to the spindle which might thus result in reduced revolutions for given wind speed.

Error detection

Because of extreme variability in wind speed in space and time, it is difficult to set up convincing rules to detect suspect values. Nevertheless simple checks are as follows:

- Wind speeds should be zero where the direction is reported as '0' (calm)
- Wind speeds cannot exceed 5 km/hr when the wind speed is reported as variable.
- Wind speeds in excess of 200 km per hour should be considered suspect

1.7.1.4 Primary validation of sunshine duration

Sunshine variations and controls

Sunshine duration is a very important contributor to the evapotranspiration equation and is widely used in the absence of direct measurements of radiation. The potential maximum sunshine duration varies regularly with latitude and with season. Actual sunshine also varies with ambient weather conditions and is generally lower during the monsoon than during the dry season. In urban areas the amount of bright sunshine may be reduced by atmospheric pollution and in coastal areas it may be reduced by sea mists.

Measurement of sunshine

The only instrument in common use in India for sunshine measurement is the Campbell Stokes sunshine recorder. This consists of a glass sphere mounted on a section of a spherical bowl. The sphere focuses the sun's rays on a card graduated in hours, held in the grooves of the bowl which burns the card linearly through the day when the sun is shining. The card is changed daily after sunset. Hence the sunshine recorder uses the movement of the sun instead of a clock to form the time basis of the record. Different grooves in the bowl must be used in winter summer and the equinoxes, taking different card types. The total length of the burn in each hour gives an hourly sunshine duration.

Typical measurement errors

The instrument is very simple in principle and the use of the sun rather than a clock as a time base avoids timing errors. Potential errors may arise from the use of the wrong chart which may result in the burn reaching the edge of the chart, beyond which it is not registered. Possible errors may result from extraction of information from the chart by the observer.

Error detection

SWDES may be used to detect and if necessary reject suspect values. Thus:

- Values of hourly sunshine greater than 1.0 or less than 0.0 are not permitted
- Sunshine records < 0500 and > 1900 are rejected. Daily totals > 14 hours are rejected.

Daily warning limits may be set seasonally within SWDES based on the maximum possible sunshine for the location and time of year.

1.7.1.5 Primary validation of pan evaporation

Pan evaporation variations and controls

Evaporation is the process by which water changes from the liquid to the vapour state. Pan evaporation provides an estimate of open water evaporation. It is a continuous process in which the rate of evaporation depends on a wide range of climatic factors:

- amount of incoming solar radiation (represented by sunshine hours)
- temperature of the air and the evaporating surface
- saturation deficit - the amount of water that can be taken up by the air before it becomes saturated (represented in measurement by the wet bulb depression)
- wind speed

Evaporation again maintains a regular seasonal pattern with highest totals before the onset of monsoon, during which evaporation is suppressed by decreasing saturation deficit.

Measurement of pan evaporation

The standard measurement in India is made using the US Class A pan evaporimeter. It is a circular pan 1.22 m in diameter and 0.255 m deep. It rests on a white painted wooden stand and is maintained level. The pan is covered by a wire mesh to avoid loss of water due to birds and animals. The inner base of the pan is painted white. A stilling well is situated in the pan within which there is a pointer gauge. Measurement must take account not only of evaporation losses but also gains due to rainfall; the raingauge nearby is used to assess the depth of rain falling in the pan. On days without rain at daily (or twice-daily) reading, water is poured into the pan using a graduated brass cylinder (cup) to bring the level up precisely to the top of the pointer gauge. The number of cups (and part cups) is recorded and represents a depth of evaporation. On days with rain since the last observation the rainfall may exceed evaporation and water must be removed from the pan to bring it to the hook level. The adjacent raingauge is used to assess the rainfall inflow. On days with forecast heavy rainfall a measured amount of water may be removed from the pan in advance of the rainfall occurrence (to avoid pan overflow)

Typical measurement errors

- Observer errors - the observer over- or underfills the pan - such values will be compensated for the following day
- Instrument errors
  - Animals may gain access to the pan, especially if the wire mesh is damaged

- Algae and dirt in the water will reduce the measured rate of evaporation
- Leakage: this is the most serious problem and it occurs usually at the joint between the base and the side wall. Small leaks are often difficult to detect in the field but may have a significant systematic effect on measured evaporation totals.
- Errors arise in periods of high rainfall when depth caught by the raingauge is different in depth from the depth caught in the pan as a result of splash or wind eddies round gauges.

1.8 WATER LEVEL DATA

The receipt of water level data at Sub-divisional offices from gauging stations is first recorded on a standard form with the date of the receipt. SWDES provides data entry checking, ensuring correct entry of station name and parameter name and rejection of alpha characters in a numeric field. Provision is also made for graphical inspection of time series graphs. Water level data are observed either with a staff gauge, or water level recorder. Data are then entered to computer using the keyboard for observed tabulated data on data sheets from staff gauges and data extracted from autographic charts, or directly loaded from data logger files for digital data. From the staff gauges the observations are generally made once in a day in lean season and at multiple times a day during flood times. For a flashy river staff gauges may even be read at hourly intervals during flood season. However, standard timings are generally followed for the observations during the day by different agencies. An autographic type of water level recorder on the other hand gives a continuous record of water level in time. Levels are extracted manually from these autographic records and the data are normally reported at hourly time interval. Digital data from a digital water level recorder can either be at equal intervals of time (usually at quarter, half hour or hourly intervals) or can be reported for only instances having change in water level more than a pre-set amount.

1.8.1 Primary validation of water level data

Data validation is the means by which data are checked to ensure that the final figure stored in the HIS is the best possible representation of the true value of the variable at the measurement site at a given time or in a given interval of time. Validation recognises that values observed or measured in the field are subject to errors which may be random, systematic or spurious. Stage or water level is the elevation of water surface above an established datum; it is the basic measure representing the state of a water body. Records of stage are used with a stage-discharge relation in computing the record of stream discharge. The reliability of the discharge record is dependent on the reliability of the stage record and on the stage discharge relation. Stage is also used to characterise the state of a water body for management purposes like the filling of reservoirs, navigation depths, flood inundation etc. Stage is usually expressed in metres or in hundreds or thousandths of a metre.

Instruments and observational methods

The method of measurement or observation influences our view of why data are suspect. To understand the source of errors we must understand the method of measurement or observation in the field and the typical errors of given instruments and techniques. Three basic instruments are in use at river gauging stations for measurement of water level.

- Staff gauges
- Autographic water level recorders
- Digital water level recorders

Staff gauges

Instrument and procedure

The staff gauge is the primary means of measurement at a gauging station, the zero of which is the datum for the station. It is a manually read gauge and other recording gauges which may exist at a station are calibrated and checked against the staff gauge level. Staff gauges are located directly in the river. An additional staff gauge may be situated within the stilling well but this must not be used to calibrate recording instruments as it may be affected by blockage of the intake pipe. Where the staff gauge is the only means of measurement at a station, observations are generally made once a day in the lean season and at multiple times a day during a flood period - even at hourly intervals during flood season on flashy rivers.

Typical measurement errors

Staff gauges like other manual measurements, are dependent on the observer's ability and reliability and it must not be assumed that these are flawless. Checking on the performance of the observer is mainly the task of the field supervisor, but the data processor must also be aware of typical errors made by observers. A common problem to note is the misplacement of decimal point for readings in the range .01 to .10. For example a sequence of level readings on the falling limb of a hydrograph:

4.12, 4.10, 4.9, 4.6, 4.3, 4.1, 3.99 - should clearly be interpreted as:
4.12, 4.10, 4.09, 4.06, 4.03, 4.01, 3.99.

Experience suggests that where the record is maintained by a single observer who is left unsupervised for extended periods of time, that it may contain some 'estimated' readings, fabricated without visiting the station. This may show up as sequences which are hydrologically inconsistent. Typical indicators of such 'estimates' are:

- Abrupt falls or a sudden change in slope of a recession curve.
- Long periods of uniform level followed by a distinct fall.
- Uniform mathematical sequences of observations, for example, where the level falls regularly by 0.05 or 0.10 between readings for extended periods. Natural hydrographs have slightly irregular differences between successive readings and the differences decline as the recession progresses.

In addition, precise water level measurement may be difficult in high flows, due to poor access to the gauge and wave action and, in flood flows the correspondence between staff gauges and recording gauges may not be as good as in low flows. Quality of gauge observations is of course, also affected if the gauge is damaged, bent or washed away. The station record book should be inspected for evidence of such problems.

Automatic water level recorders

Instrument and procedure

The vast majority of water level recorders in use in India use a float and pulley arrangement in a stilling well to record the water level as a continuous pen trace on a chart. The chart is changed daily or weekly and the recorder level is set to the current level on the staff gauge, which is also written on the chart at the time of putting on and taking off.

Typical measurement errors

Automatic water level recorders are subject to errors resulting from malfunction of the instrument or the stilling well in which it is located. Many of these errors can be identified by reference to the chart trace or to the level figures which have been extracted from it. The following are typical malfunctions noted on charts and possible sources of the problems.

(a) Chart trace goes up when the river goes down

- Float and counterweight reversed on float pulley

(b) Chart trace goes up when the river goes down

- Tangling of float and counterweight wires
- Backlash or friction in the gearing
- Blockage of the intake pipe by silt or float resting on silt

(c) Flood hydrograph truncated

- Well top of insufficient height for flood flows and float sticks on floorboards of gauging hut or recorder box.
- Insufficient damping of waves causing float tape to jump or slip on pulley.

(d) Hydrograph appears OK but the staff gauge and chart level disagree. There are many possible sources including operator setting problems, float system, recorder mechanism or the operation of the stilling well, in addition to those noted above. The following may be considered.

Operator Problems

- Chart originally set at the wrong level

Float system problems

- Submergence of the float and counterweight line (in floods)
- Inadequate float diameter and badly matched float and counterweight
- Kinks in float suspension cables
- Build up of silt on the float pulley affecting the fit of the float tape perforations in the sprockets

Recorder problems

- Improper setting of the chart on the recorder drum
- Distortion and/or movement of the chart paper (humidity)
- Distortion or misalignment of the chart drum
- Faulty operation of the pen or pen carriage

Stilling well problems

- Blockage of intake pipe by silt.
- Lag of water level in the stilling well behind that in the river due to insufficient diameter of the intake pipe in relation to well diameter.

(e) Chart time and clock time disagree

- Chart clock in error and should be adjusted

In particular it should be noted that the partial blockage of the stilling well or intake pipe will result in a serious systematic error in level measurement.

Digital water level recorders

Instrument and procedure

Like the chart recorder many DWLRs are still based on a float operated sensor operating in a stilling well. One significant improvement is that the mechanical linkage from the pulley system to the chart is replaced by the shaft encoder which eliminates mechanical linkage errors and the imprecision of a pen trace. The signal from the shaft encoder is logged as level at a selected time interval on a digital logger and the information is downloaded from the logger at regular intervals and returned for processing. The level is set and checked with reference to the staff gauge.

Alternative sensors for the measurement of water level do not require to be placed in still water, notably the pressure transducer. Loggers based on such sensors have the advantage that they do not need to be placed in a stilling well and thus can avoid the associated problems.

Typical measurement errors

Measurement except for the sensors noted above is still subject to the errors caused by the float system and by the operation of the stilling well. Many of the same or equivalent checks are therefore necessary to ensure the continuity and accuracy of records. In particular the comparison and noting of staff gauge and logger water levels (and clock time and logger time) at take off and resetting, in the Field Record Book are essential for the interpretation of the record in the office.

Procedures in the office for checking the reliability of the record since the previous data download will depend on the associated logger software but should include a graphical inspection of the hydrograph for indications of malfunction (e.g. flat, stepped or truncated trace). Comparisons as for the chart recorder should be made with the observer's readings and bad or missing data replaced by manual observations.

Scrutiny of tabular and graphical data - single record

The first step in validation is the inspection of individual records from a single recorder or manual measurement for violations of preset physical limits or for the occurrence of sequences of data which represent unacceptable hydrological behaviour.

Screening of some unacceptable values will already have been carried out at the data entry stage to eliminate incorrectly entered values. Numerical tests of physical limits may be considered in three categories:

(a) Absolute maximum and minimum limits
(b) Upper and lower warning limits
(c) Acceptable rates of rise and fall

Absolute maximum and minimum limits

Checking against maximum and minimum limits is carried out automatically and values violating the limits are flagged and listed. The values of the absolute maximum and minimum levels at a particular station are set by the data processor such that values outside these pre-set limits are clearly incorrect. These values are normally set for the full year and do not vary with month or season. The cross-section plot of the river gauging line in conjunction with the cross section of the control section at higher flow depths provides an appropriate basis for setting these minimum and maximum limits. With respect to minimum values for stage records, since it is normal to set the zero of the gauge at the level at which flow is zero then, for many stations a zero gauge level may be set as the absolute minimum. However, for some natural channels and controls negative stage values may be acceptable if the channel is subject to scour such that flow continues below the gauge zero. Such conditions must be confirmed by inspection of the accompanying Field Record Book.

Similarly, the absolute maximum is set at a value after considering the topography of the flood plains around the control section and also the previously observed maximum at the station. If long term data on water levels is already available (say for 15 –20 years) then the maximum attained in the past can be taken as an appropriate maximum limit.

Upper and lower warning limits

Validation of stage data against an absolute maximum limit does not discriminate those unusually high or low values which are less than the maximum limit but which may be incorrect. Less extreme upper and lower warning limits are therefore set such that values outside the warning range are flagged for subsequent scrutiny. The underlying objective while setting the upper and lower warning levels must be that such limits are violated 1–2 times every year by a flood event. This would ensure that on an average the one or two highest flood or deepest troughs are scrutinised more closely for their correctness. These limits may also be worked out using suitable statistics but care must be taken of the time interval and the length of data series under consideration. Statistics like 50% ile value of the collection of peak over the lowest maximum annual values used to set the upper warning level for the case of hourly data series of say 15-20 years. Of course, such statistics will also be subjected to the nature or shape of hydrograph which the station under consideration experiences. And therefore the appropriateness of such limits have to be verified before adopting them.

Rates of rise and fall limits

The method of comparing each data value with immediately preceding and following observations is of particular relevance to parameters exhibiting significant serial correlation such as water level data. The limit is set numerically as the maximum acceptable positive or negative change between successive observations. It should be noted however that what is an acceptable change in level during a rising flood hydrograph during the monsoon may be unacceptable during the dry season. Violations of rise and fall limits are therefore more readily identified from graphical plots of the hydrograph whilst numerical tests provide a relatively coarse screen. It is a good practice and an essential requirement for an organised data processing activity that the listing of the entered data is obtained as a result of the above checking against various data limits. Such a listing will provide an appropriate medium for recording remarks/comments of the data processing personnel while validating the data. Any glaring deviations of the entered data from the expected one will also be apparent from such a listing.

Graphical inspection of hydrographs

Visual checking of time series data is often a more efficient technique for detecting data anomalies than numerical checking and must be applied to every data set with an inspection of the stage hydrograph on screen. Screen display will also show the maximum and minimum limits and the upper and lower warning levels. Potential problems identified using numerical tests will be inspected and accepted as correct, flagged as spurious or doubtful and corrected where possible. An attempt must be made to interpret identified anomalies in terms of the performance of observer, instruments or station and where this has been possible to communicate this information to field staff for field inspection and correction.

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