

Design of Hydro-meteorological Network

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1 Hydro-Meteorological Network Design

1.1 Introduction

A hydro-meteorological network is an organized system for collection of information of specific kinds such as precipitation, run off, water quality, sedimentation and other climate parameters. The accuracy in the estimation of both quality and quantity of water resources and thus for making the decisions for integrated water resources development and management depends on how much information are available for the region concerned. Data on temporal and spatial characteristics of water resources of a region are obtained by a network of observational stations. Setting up a station requires investment for infrastructure equipment, logistics, and for operation and maintenance. Scientific planning is necessary for network design so that the desired results could be achieved with minimum cost.

Having enough relevant and accurate hydrologic information reduces the chances of under-design or overdesign and thus minimizes the economic losses, which leads to the overall increase in the benefit/ cost ratio. It has not, so far, been possible to define the optimum level of hydrologic information required for planning, design and development of a specific project in a region, due to difficulties in developing a benefit cost function of hydrologic information. Furthermore the requirement of water resources data depends on their end use therefore, it is difficult to formulate general rules on network design. While designing hydro-meteorological networks, the decisions to be taken are:

- i. the variables to be measured and the frequencies and duration of observations;
- ii. the location of gauging stations;
- iii. the instruments to be installed and methods of observation; and
- iv. data observation and transmission system.

Since the hydro-meteorological data networks are operated by a number of independent agencies, a good coordination among them is important. This will reduce the expenditure and improve data quality. Of particular importance is the coordination between hydromet, water quantity and quality data networks.

1.2 Objectives of network design

The objectives for an observation network be identified and decided before the designing is taken up. Some of the important objectives are listed below:

- Water resources assessment at basin or sub-basin scale
- Water resources assessment for administrative geographical unit Water resources project planning including:
 - Irrigation,
 - Domestic (domestic use, livestock watering),
 - Hydroelectric power and other power generation,
 - Environmental requirements,
 - Industrial requirements,
 - Navigation,
 - Tourism,
 - recreation
- Flood management
- Assessing impacts of Climate Change on Water Resources

1.3 The basic network

The worth of the data that derive from a network is a function of the uses that subsequently are made of them. Nevertheless, many of the uses of hydrological data are not apparent at the time of the network design and, therefore, cannot be used to justify the collection of specific data that ultimately may be of great value. In fact, few hydrological data would be collected if a priori economic justifications were required. However, modern societies have developed a sense that information is a commodity that, like insurance, should be purchased for protection against an uncertain future. Such an investment in the case of hydrological data is the basic network, which is established to provide hydrological information for unanticipated future water-resources decisions. The basic network should provide a level of hydrological information at any location within its region of applicability that would preclude any gross mistakes in water-resources decision making. To accomplish this aim, at least three criteria must be fulfilled:

- i. A mechanism must be available to transfer the hydrological information from the sites at which the data are collected to any other site in the area;
- ii. A means for estimating the amount of hydrological information (or, conversely, uncertainty) at any site must also exist; and
- iii. The suite of decisions must include the option of collecting more data before

the final decision is made.

1.4 The minimum network

In the early stages of development of a hydrological network, the first step should be the establishment of a minimum network. Such a network should be composed of the minimum number of stations which the collective experience of hydrological agencies of many countries has indicated to be necessary to initiate planning for the economic development of the water resources. The minimum network is one that will avoid serious deficiencies in developing and managing water resources on a scale commensurate with the overall level of economic development of the country. It should be developed as rapidly as possible by incorporating existing stations as appropriate. In other words, a minimum network will provide the basic framework for network expansion to meet future needs for specific purposes. It is emphasized that a minimum network will not be adequate for the formulation of detailed development plans and will not meet the numerous requirements of a developed region for the operation of projects and the management of water resources.

1.5 Network Design Process

Design of networks is not a one-time affair. Factors affecting network design go on evolving with time and thus the networks also require periodic review and adjustments. Design of networks to measure stream gauge and discharge involves the following steps:

1. Network design activity begins with collection of basin maps and background information about the area/region. Usually 1:250,000 scale topographical maps of the river basin showing basin boundaries and river network will form the base map for the network design. Smaller scale maps are of limited use because it is difficult to identify the location of stations relative to key features. It is also important to use an updated map. Ideally, the following maps should also be collected:
 - i. Existing precipitation and gauge-discharge gauging stations operated by various departments.
 - ii. Location of existing and proposed water projects and command areas of irrigation projects.
 - iii. Land use map, also showing forests, main industries and population centres.
 - iv. Communications map showing roads, rails, power transmission lines, canals, etc.
 - v. Map showing soil classification, geological formation and mining areas.

- vi. Contour map or Digital Elevation Model (DEM) of the basin.
2. Identify the objectives of the network by define the data users and the purpose for which the data is needed. What is the required data frequency?
3. Critically evaluate the existing network and find out how well it meets the required objectives?
4. Review existing database to identify gaps, ascertain variability in catchment behaviour.
5. Identify the weather the existing network is over-design (if any) or under designed. New stations may be proposed and existing stations may be deleted/shifted (if required so).
6. Prioritise stations by following appropriate classification system.
7. Decide on approximate location of sites and carryout site surveys.
8. Review revised network in relation to overall objectives and available budget; adjust it as necessary.
9. Estimate average capital and recurrent costs of installing and maintaining different categories of stations and overall cost of operating and maintaining the network.
10. Prepare a realistic and achievable implementation plan.

1.6 WMO Criteria for Minimum Network Density

The World Meteorological Organisation (1976) has recommended the minimum network densities for general hydro-meteorological practices.

- i. For plain regions of temperate Mediterranean and tropical zones one station for 600-900 sq. km.
- ii. For mountainous region of temperate Mediterranean and tropical zones one station for 100-250 sq. km.
- iii. For arid and polar region one station for 1,500-10,000 sq. km.

Source: Guide to Hydrological Practices, Volume-I: “Hydrology - From Measurement to Hydrological Information”, WMO No. 168

1.7 Financial Aspects

In addition to technical financial considerations are also important in network design because the stations cannot be established without adequate money, equipment cannot be purchased and operated, and staff cannot be hired. Hence, after the preliminary design of the network has been completed, the expenditure to establish stations and the cost of operating them should be estimated. These monetary requirements should match with the budget so that the proposed network is sustainable. In case of deficit in the budget, the network should be re-aligned or additional budget should be arranged. Stations in the network may be prioritized to best attain the objectives, given the constraints.

2 Raingauge Network Design

2.1 IS: 4986-1968 guidelines

The Bureau of Indian Standard (BIS) suggests that one raingauge up to 500 sq. km might be sufficient in non-orographic regions. In regions of moderate elevation (up to 1000 m above msl), the network density might be one raingauge for 260 - 390 sq. km. In predominantly hilly areas and areas of heavy rainfall, the density recommended is one for

Table I.2.6. Recommended minimum densities of stations (area in km² per station)

Physiographic unit	Precipitation		Evaporation	Streamflow	Sediments	Water quality
	Non-recording	Recording				
Coastal	900	9000	50000	2750	18300	55000
Mountains	250	2500	50000	1000	6700	20000
Interior plains	575	5750	5000	1875	12500	37500
Hilly/undulating	575	5750	50000	1875	12500	47500
Small islands	25	250	50000	300	2000	6000
Urban areas	—	10–20	—	—	—	—
Polar/arid	10000	100000	100000	20000	200000	200000

130 sq. km.

2.2 C_v method

The problem of ascertaining the optimum number of raingauges in various

basins is of statistical nature and depends on spatial variation of rainfall. Thus, the coefficient of spatial variation of rainfall from the existing stations is utilised for determining the optimum number of raingauges. If there are already some raingauges in the catchment, the optimal number of stations that should exist to have an assigned percentage of error in the estimation of mean rainfall is obtained by statistical analysis as:

$$N = \left(\frac{C_v}{P} \right)^2$$

where,

N = optimal number of stations,

p = allowable degree of error in the estimate of mean rainfall and

C_v = coefficient of variation of rainfall values at the existing m stations.

If there are m stations in a catchment and P₁, P₂,P_m is the recorded rainfall at a known time at 1, 2,m station, then the coefficient of variation C_v is calculated as:

$$C_v = \frac{100 \times \sigma_{m-1}}{\bar{P}}$$

where

$$\sigma_{m-1} = \frac{\sqrt{\sum_{i=1}^m P_i^2 - m \times \bar{P}^2}}{(m-1)}$$

P_i is monthly average precipitation at i th station and P is the average rainfall of ‘m’ number of stations, given by:

$$\bar{P} = \frac{\sum_{i=1}^n P_i}{m}$$

It is usual practice to take p =10%. m₋₁ is used for calculation of C_v when number of stations, m, in the network is less than 30 otherwise m can also be used.

2.3 Key station network method

One of the most rational methods for determination of key station is as suggested by Hall (1972). In this method, at first, the correlation coefficient between the average of storm rainfall and the individual station rainfall are found. The stations are then arranged in the order of their decreasing correlation coefficients and the station exhibiting

highest correlation coefficient is called the first key station and its data is removed for determination of next key station. The procedure is repeated by considering the average rainfall of the remaining stations. The station showing the highest correlation coefficient after removing the data of first key station is called the second key station. Similarly third and successive key stations are determined after removing the data of already selected key stations. Now the sum of the squares of deviations of the estimated values of average rainfall from the actual rainfall in respect of 1st, 2nd, 3rd key station etc. is determined and a graph is plotted between the sum of the square of deviation and corresponding number of stations in combinations. It will be seen that a stage comes when the improvement in the sum of squares of deviation is very little with the addition of more stations. The corresponding number of stations at that stage is taken to be representative and key stations for the network in the catchment/ basin.

2.4 Spatial correlation method

Under the assumption that spatial variability of rainfall can be quantified through a spatial correlation function, a network of raingauges can be designed to meet a specified error criterion (Kagan, 1966 and WMO, 1972). However in applying such an approach, care must be taken to ensure that condition necessary for the existence of spatial correlation function, such as hydrological homogeneity and isotropy are fulfilled; flat areas with a relatively homogeneous surface are more appropriate for the application of the technique. A general theoretical spatial correlation method for the planning of meteorological networks has been given by Gandin (1970). Some details of the specific approach and its application have been given by Kagan (WMO, 1972). The basis of this method is the correlation function $\rho(d)$ which is a function of the distance between the stations, and the form of which depends on the characteristics of the area under consideration and on the type of precipitation. The function $\rho(d)$ can frequently be described by the following exponential form:

$$\sigma_1^2 = [1 - \rho(0)]\sigma_h^2$$

Where, $\rho(0)$ is the correlation corresponding to zero distance and d_0 is the correlation radius or distance at which the correlation is $\rho(0)/e$. Theoretically, $\rho(0)$ should equal to unity but is rarely found so in the practice due to random errors in precipitation measurement and micro climatic irregularities over an area. The variance of those random errors has been

given by Kagan (1966) as:

$$\rho(d) = \rho(0)e^{-d/d_0}$$

where σ^2 is the variance of the precipitation time series at a fixed point. The quantities $\rho(0)$ and d_0 provide the basis for assessing the accuracy provided by a network.

2.5 Entropy Method

One of the important objectives of network design is to estimate the probable magnitude of error or regional hydrological uncertainty arising from network density, distribution and record length. In entropy method, the hydrological information and regional uncertainty associated with a set of precipitation station are estimated using Shannon's entropy concept. Since time series of rainfall data can be represented by gamma distribution due to the presence of skewness, the entropy term is derived using single and bivariate gamma distribution.

3 Stream gauging Stations

3.1 Criteria for Location of site

With particular reference to India, location of stream gauging stations is influenced by the following factors:

- Places where major rivers cross State borders;
- Locations of proposed dams/diversion/run-of-river schemes including diversions or offtakes/joining points for (proposed) inter-basin water transfers link canals;
- Locations whose data may be needed for flood forecasting;
- Conservation areas and areas of ecological interest;
- Areas of water supply shortages;
- Areas expected to have significant land use change, e.g., de-forestation or re-forestation;

In general, a sufficient number of stream flow stations should be located along the main stems of large streams to permit interpolation of discharge between the stations. The specific location of these stations should be governed by topographic and climatic considerations. If the difference in flow between two points on the same river is not greater than the limit of error of measurement at the station, then an additional station is unjustified.

In this context, it must also be stressed that the discharge of a small tributary cannot be determined accurately by subtracting the flows at two mainstream gauging stations which bracket the mouth of the tributary. Where the tributary flow is of special interest in such a case, a station on the tributary will be required. It will usually take its place as a secondary station in the minimum network. Wherever possible, the base stations should be located on streams with natural regimes. Where this is impractical, it may be necessary to establish additional stations on canals or reservoirs to obtain the necessary data to reconstruct the natural flows at the base stations. Computed flows past hydroelectric plants or control dams may be useful for this purpose, but provisions will have to be made for calibration of the control structures and turbines and for the periodic checking of such calibrations during the life of the plants.

Stations should be located on the lower reaches of the major rivers of the country, immediately above the river mouths (usually above tidal influence), or where the rivers cross borders. Stations should also be located where rivers issue from mountains and above the points of withdrawal for irrigation water. Other hydrometric stations are situated at points, such as where the discharge varies to a considerable extent, below the points of entry of the major tributaries, at the outlets from lakes, and at those locations where large structures are likely to be built. To ensure adequate sampling, there should be at least as many gauging stations on small streams as on the main streams. However, for small streams, a sampling procedure becomes necessary as it is impracticable to establish gauging stations on all of them. The discharge of small rivers is strongly influenced by local factors. In highly developed regions, where even the smallest watercourses are economically important, network deficiencies are keenly felt even on streams draining areas as small as 10 km².

Stations should be installed to gauge the runoff in different geologic and topographic environments. Because runoff varies greatly with elevation in mountains, the basic network stations must be located in such a way that they can, more or less evenly, serve all parts of a mountainous area, from the foothills to the higher regions. Account should be taken of the varying exposure of slopes, which is of great significance in rough terrain. Similarly, consideration should be given to stations in districts containing numerous lakes, whose influence can be determined only through the installation of additional stations.

3.2 Evaluation and Adequacy of Networks

To evaluate the networks, the existing network and proposed new stations should be marked on a 1:250,000 map. The catchment area for each river gauging station could be estimated from the basin maps (hard copy or in GIS). Scanning the network systematically, the following questions need to be considered for each station:

- What purpose will the station fulfill?
- Does a better location exist nearby?
- Have any developments (e.g. dam construction) taken place or are likely which could affect this station?
- How close are the nearest upstream and downstream gauging stations? Two stations should not be very close unless there are specific reasons.
- Does any other organisation operate a gauging station in the vicinity? If yes, could the data from that station serve the purpose expected from this station?

Based on the answers, stations which can be added, deleted or relocated are identified.

3.3 Site Selection Surveys

Once the objectives have been defined and the techniques for measurement/recording water level and flow measurement have been finalized, the site selection process can begin. To select the most appropriate site for a station, site selection surveys are carried out. These surveys can be divided into four distinct phases:

- Desk study,
- Reconnaissance surveys,
- Topographic surveys, and other surveys.

By now, the target location for the gauging station will have already been identified on a 1:250,000 or similar map in earlier steps. However, 1:250,000 is too small a scale for final site selection purposes. Large-scale topographic maps (1:50,000) should be checked to identify possible sites within the target zone. Reconnaissance surveys should be undertaken by an experienced hydrologist along with a person familiar with the area. As the hydraulic conditions and river characteristics vary considerably from non-monsoon to monsoon season, reconnaissance survey in both the seasons would facilitate correct decision on the suitability of the site. When the establishment of site cannot wait that long, the suitability of the site for hydrological observation could be decided after single inspection assisted by toposheet studies and other relevant field investigations including measurements of width and depth. At

sites of interest, ownership of the land and approach should be ascertained. The site shall be accessible in all seasons and all weather. It is important to use updated maps since most surveys were completed several decades ago and things may have undergone large changes. Recent situation can be obtained from remote sensing images or internet sites such as Google Earth.

Information on the historical high flood level should also be collected (by local enquiry and / or by examining the available landmarks) during the inspection. An all weather accessible site located in a straight uniform reach free from weeds, rock outcrop, pools and back water effect with stable non-overflowing banks with flow confined to single channel normal to the selected cross-section of measurement would be an ideal site for stream gauging.

On completion of the reconnaissance surveys, one or more locations are shortlisted for further consideration. After this, field surveys are carried out and the cross-section of the proposed site is surveyed. If artificial controls (e.g. a weir) are planned, it will be necessary to survey the river for some distance upstream and downstream to ascertain the impact on flows and water levels. It will also be important to understand what type of control exists and to make sure that the location will not be impacted by variable backwater effect of any structure.

3.4 General site selection guidelines

The following are the general site selection guidelines. Specific recommendations for different types of stations are mentioned subsequently. It is emphasized that an ideal location which satisfies all requirements can be found in very few real-life cases. In practice, it is often required to take measurements in non-ideal conditions.

1. The approach channel should be of uniform cross-section and free from irregularities and the flow shall have a regular velocity distribution. This can most readily be provided by having a long, straight approach channel. There should be straight, uniform, well defined approach channel upstream of the measuring section to ensure parallel and non-turbulent flow. For rivers less than 100 m wide, a straight approach of 4 times channel width should be preferred. For rivers more than 100 m wide, a straight approach channel of minimum 400 m is desirable. When adequate length of straight channel is not present, the straight length upstream should be at least twice that downstream.
2. Sites where high sediment deposition or scouring occurs or those which are subject to weed growth should be avoided, if possible.
3. Locations which are subject to high turbulence or wind effects should be avoided.

4. It needs to be ensured that there is no parallel by-pass channel, natural or man-made, on the surface or sub-surface, around the station.
5. The channel bed should be solid, relatively smooth and free from obstructions and debris.
6. The control shall be sensitive, such that a significant change in discharge, even for the lowest discharges, should result in a significant change in stage. Small errors in stage readings during calibration at a non-sensitive station can result in large errors in the discharges indicated by the stage-discharge relationship.
7. The station should be located where the flood plain is at its narrowest and the out-of-bank flood flow is the minimum. It is often not possible to locate a gauging station so that all flood flows are contained within the river channel. At many locations, there is an elevation after which out-of-bank flow occurs.
8. The banks of the river should be high and steep and free from larger vegetation. Some vegetation is desirable since this helps maintain the stability of the banks.
9. River banks at the site should be well-defined, stable, and free from vegetation and other obstructions.
10. Downstream conditions should preferably be stable. Sites, which are influenced by downstream confluences with other rivers, river control structures, dams, tidal conditions or heavy weed growth, should be avoided. Such downstream conditions should be taken into account when designing the structure to assess the modular limit.
11. Factors such as unhindered access to the site in all seasons, availability of office accommodation, living space for the observers, electricity and other services should also be taken into account.
12. Enough land should be available near the site to install various instruments.
13. Human interference (out of curiosity or with malafide intention) with hydrometric installations is a problem in India. This issue has to be given serious consideration during the site selection process. For example if a choice has to be made between two hydraulically similar sites, the final selection should be made in favour of the site which has fewer problems due to human interference and law and order.
14. Sites with a tendency for formation of vortices, reverse flow or dead water shall be avoided.
15. The measuring section should be away from obstructions (artificial and natural) and control structures, e.g., dams, weirs.

16. Channel at measuring section should be free from weed growth, accessible at all times of the year and under all flow conditions, and must be safe to gauge.
17. For a station to be sustainable, manpower and logistic support to operate and maintain the installation are necessary. Local manpower with desired qualification and interest is always helpful.

3.5 Criteria for Water Level Gauging Sites

Water level or river stage is the primary variable that is measured at stream gauging sites and most frequent measurements pertain to river stage. Stage (height of water surface) is observed at all stream-gauging stations to determine discharge. There are places where additional observations of water level only are needed as part of a minimum network:

- a) At all major cities along rivers, river stages are used for flood forecasting, water supply, and transportation purposes; and
- b) On major rivers, at points between stream-gauging stations, records of river stage may be used for flood routing and forecasting purposes.

For stage monitoring, the following additional site selection guidelines apply.

1. Steep banks or sides are preferred; the location should be selected so that for manual observation the gauge posts are readable over the full water level range.
2. The stage measurement device should be installed as close to the edge of the stream as possible. Sections subject to high velocities should be avoided to the extent possible since drawdown effects can occur around the device.
3. To minimize the effects of turbulence and high velocities, water level measuring devices can be installed in a suitable stilling bay at the bank.
4. It is desirable to have access to the site and gauge posts at all times.
5. The site should not have a tendency to collect floating debris which may hinder working of water level measurement device.

3.6 Bureau of Indian Standards (BIS) criteria for selection of river gauging sites

The ideal requirements for a good gauging site as enunciated in the standard IS 1192-1981 "Velocity - Area methods for measurement of flow of water in open channels" are given below.

The accuracy of measurement of discharge by velocity area method is increased if the site is selected considering these aspects.

The site selected should comply, as far as possible, with the following essential requirements:

1. The reach of the open channel at the gauging site shall be straight and of uniform cross section and slope, as far as possible, in order to avoid irregularities in velocity distribution. The length of the reach need not be more than 1600 m and should not be less than 400m. When the length of the straight channel is restricted, it is recommended for current meter measurements and the straight length upstream of the measuring cross section should be twice that on the downstream.

(Note: In case of artificial channel, the minimum length of straight reach should preferably be such as to give a drop in water level of 0.06 m. or the minimum length should be equal to four times the width of the channel, whichever is larger.)

2. The depth of water in the selected reach shall be sufficient to provide for the effective immersion of either the current meters or floats, whichever are to be used.
3. When near a confluence, the site, if located on a tributary shall be sufficiently upstream preferably beyond the backwater effect; and if located on the main stream, upstream or downstream of the confluence it shall be beyond the disturbances due to the tributary.
4. The site should be easily accessible at all times of the year.

In addition to the above requirements, the following points shall be taken into consideration as desirable requirements in the selection of the gauging site.

- i. The flow should be confined in a single channel and there should be no overflow as far as possible. Where this is not possible, the site in which minimum number of channels exist and the flood plain has minimum width should be preferred.
- ii. Where these requirements cannot be met (for instance- when in alluvial rivers the river bed is changing during the period of measurement, or when, under flood conditions, the river is not confined to a single channel in embankments), a gauging site shall be chosen such that the bed change and/or overflow is minimum. Floodplain, if cannot be avoided, shall be of minimum width, as smooth as possible, with a distinct channel, and clear of bushes and trees. The flow in the over bank or floodplain section (s) shall be measured separately and added, treating the whole as a composite section.
- iii. The site shall be remote from any bend or natural or artificial obstruction if disturbances of the flow are likely to be caused thereby.
- iv. The orientation of the reach should be such that the direction of flow is as close as possible normal to that of the prevailing wind.

- v. Sites at which there is a tendency for vortex formation should be avoided.
- vi. The site should, as far as possible, be free from trees and obstructions which may interfere with flow and clear vision during observation.
- vii. The site shall be free from aquatic growth which is likely to interfere with the measurement of depth and the current meter reading.
- viii. The site shall be away from the back water zone caused by any structure on the river.
- ix. The site should be sufficiently away from the disturbance caused by rapids and falls. etc.

3.7 World Meteorological Organisation (WMO) criteria for selection of site

The following are the WMO recommendations for selection of a site:

- i. The general course of the stream should be straight for about 100 m upstream and downstream from the site.
- ii. No flow bypasses the site as subsurface flow.
- iii. The stream bed is not subject to scour and fill.
- iv. The banks are permanent and high enough to contain floods.
- v. Unchanging natural controls are present in the form of a bedrock outcrop or other riffle for low flow and a channel constriction for high flow.
- vi. Small pool is present upstream from the control at extremely low stages to ensure a recording of stage at extremely low flow and to avoid high velocities
- vii. A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gauge site.

3.8 Lake and reservoir stages

Stage, temperature, surge, salinity, ice formation, etc., should be observed at lake and reservoir stations. Stations should be established on lakes and reservoirs with surface areas greater than 100 km². As in the case of rivers, the network should sample some smaller lakes and reservoirs as well.

3.9 Criteria for Streamflow Measurement Sites

Current meter is a commonly used instrument and velocity area method is the preferred approach to measure river discharge. A stage and discharge measurement station should have appropriate conditions to install a stage measurement device and to measure discharge. The required features of a good discharge gauging site are as follows:

1. The measurement section should be clearly visible across its width and unobstructed by trees, aquatic growth or other obstacles.
2. There should be sufficient depth of flow across the whole cross-section:
3. Sites with mobile beds and bank shall be avoided. In some rivers, this is not possible and the site may be chosen so that the bed and bank changes are minimised.
4. Ideally, flow should be confined to a single channel. When this is not possible, each channel should be gauged separately to obtain the total flow.
5. The site shall be sufficiently far away from the disturbance caused by rapids and falls.
6. If the site is upstream of confluence of two rivers, it should be located sufficiently far upstream so that it is beyond backwater and any disturbance due to joining of two rivers.
7. Velocities should be well in excess of the minimum required speed of the current meter over the full flow range.

3.10 Criteria for Natural Control Sites

The factors that are important in selecting a good site with natural control are summarised below.

1. If possible a natural control should be selected where the relationship between stage and discharge is substantially consistent and stable.
2. The control should be sufficiently far upstream of another feature or control structure to avoid inconsistencies due to variable backwater effects. The channel should be stable.
3. The general course of the stream should be straight upstream and downstream of the site. Ideally the measuring reach should be straight for about 2 - 3 times the river width or a minimum of 400 m (whichever is less) both upstream and downstream of the site.

4. Stable (unchanging) controls should be available in the form of a bedrock outcrop or other stable riffle for low flows and a channel constriction for high flows; a fall or cascade, which remains un-submerged over the full range of stage is ideal.
5. A pool (deeper water) upstream of the control is helpful because it ensures the recording of stage at low flows and avoids/dampens high velocities at observing/recording, device during high flows.

3.11 Criteria for Artificial Control Sites

A variety of flow measurement structures are used and the choice depends on a variety of factors including objectives, flow range, afflux, size and nature of the channel, channel slope and sediment load, operation and maintenance, and cost. The applications and limitations of a structure will determine where its use is most appropriate. Each structure has its own specific site selection criteria. Some general criteria to be considered are described here.

1. Generally the use of artificial controls should be limited to small but important rivers (< 100 m wide) and for special investigations in artificial channels.
2. Existing structures may be adapted for the purpose of flow measurement, wherever feasible.
3. The sensitivity of upstream area to increased levels should be assessed. For example, will the installation of the structure cause a potential, increased risk of flooding.
4. A minimum length of straight approach channel of five times the maximum width of the water surface is recommended for most structures, except for thin plate weirs where ten times the maximum channel width is recommended. However, research has shown that for triangular profile weirs accurate results can be obtained even if the weir is only twice the channel width from an upstream bend.
5. Thin plate weirs are particularly sensitive to upstream velocity distribution.
6. Like all controls, it is essential that the structure creates a sensitive stage-discharge relationship. In wider rivers, this can be a problem at low flows. Structures such as the triangular profile flat “v” weirs provide such sensitivity.
7. The discharge coefficients of many structures vary when the velocity head in the upstream approach channel becomes large in relation to the depth of flow. A dimensionless number which describes this is the Froude number (Fr). To prevent water surface instability in the approach channel the Froude number should generally not exceed 0.5.

8. The design of the structure should be such as to minimise upstream sediment deposition or downstream scouring. In rivers with high bed loads the use of structures which significantly reduce the stream velocity is not recommended.
9. On rivers which are navigable or those which are important fish migration routes the use of flow measurement structures should be avoided and some other form of flow measurement considered.

4 Sediment discharge and sedimentation

Sediment stations may be designed either to measure total sediment discharge to the ocean or to measure the erosion, transport and deposition of sediment within a country, basin, etc. In designing a minimum network, emphasis should be placed on erosion, transport, and deposition of sediment within a country. An optimum network would contain a sediment station at the mouth of each important river discharging into the sea.

Sediment transport by rivers is a major problem in arid regions, particularly in those regions underlain by friable soils and in mountainous regions where, for engineering applications, the amount of sediment loads should be known.

Emphasis should be placed on those areas where erosion is known to be severe. After a few years of experience, it may be desirable to discontinue sediment measurements at those stations where sediment transport no longer appears to be of importance. Sediment-transport data may be supplemented by surveys of sediment trapped in lakes or reservoirs. Echo sounding devices are useful for this purpose. However, information obtained in this way is not considered a substitute for sediment-transport measurements at river stations.

5 Water quality stations

The usefulness of a water supply depends, to a large degree, on its chemical quality. Observations of chemical quality, for the purposes of this Guide, consist of periodic sampling of water at stream-gauging stations and analyses of the common chemical constituents. The number of sampling points in a river depends on the hydrology and the water uses. The greater the water quality fluctuation, the greater the frequency of measurement required. In humid regions, where concentrations of dissolved matter are low, fewer observations are needed than in dry climates, where concentrations, particularly of critical ions such as sodium, may be high.

6 References:

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