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VOLUME 4
HYDROMETRY

FIELD MANUAL - PART I

NETWORK DESIGN AND SITE SELECTION

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GENERAL

The Field Manual on Hydrometry, comprises the procedures to be carried out to ensure proper execution of design of the hydrometric network, and operation and maintenance of water level and streamflow gauging stations. The operational procedures are tuned to the task descriptions prepared for each Hydrological Information System (HIS) function. The task description for each HIS-function is presented in Volume 1 of the Field Manual.

It is essential, that the procedures, described in the Manual, are closely followed to create uniformity in the field operations, which is the first step to arrive at comparable hydrological data of high quality. Further, reference is made to the other volumes of the manual where hydrometeorology, sediment transport measurements and water quality sampling and analysis is described. It is stressed that hydrometry cannot be seen in isolation; in the HIS integration of networks and of activities is a must.

This Volume of the Field Manual consists of 8 parts:

- Part I deals with the steps to be taken for network design and optimisation. Furthermore, site selection procedures are included, tuned to the suitability of a site for specific measurement procedures.

- Part II comprises operation of water level gauging stations equipped with staff gauges, autographic chart recorders or digital water level recorders.

- Part III comprises the preparatory activities and execution of float measurements, including selection of float type, reach preparation, observation practice and discharge computation

- Part IV comprises the preparatory activities and execution of current meter measurements by wading, and from cableways, bridges and boats. The procedure for discharge computation is included.

- Part V deals with the field application of the Acoustic Doppler Current Profiler (ADCP). It covers operating modes and site conditions, deployment, operating set-up and measurement runs as well as the data handling and recording.

- Part VI presents the required activities for the execution of the Slope-Area Method and the procedure to be applied to arrive at a discharge.

- Part VII comprises Field Inspections and Audits, with required check lists and standard forms.

- Part VIII, finally, deals with routine maintenance of gauging stations and calibration of equipment.

The procedures as listed out in this manual are in concurrence with the ISO standards as far as available for the various techniques and applicable to the conditions in peninsular India.

1 STEPS IN THE NETWORK DESIGN PROCESS

In this chapter steps an overview of steps in the hydrometric network design process is presented. Guidelines are provided for the review of the network to get it tuned to the actual data need.

1.1 OVERVIEW OF STEPS

The main steps in the network design process can be summarised as follows:

1. Preliminaries - collection of maps and other background information.
2. Define the **purposes** of the network:- who are the data users and what will the data be used for? Define the **objectives** of the network:- What type of data is required and at what frequency?
3. Evaluate the existing network:- How well does the existing network meet the overall objectives?
4. Review existing data to identify gaps, ascertain catchment behaviour and variability.
5. Identify gaps and over-design in the existing network: Propose new stations and delete existing stations where necessary i.e. revise network.
6. Prioritise gauging stations: i.e. try use some simple form of classification system.
7. Estimate average capital and recurrent costs of installing and maintaining different categories of streamflow stations. Estimate overall cost of operating and maintaining the network.
8. Review revised network in relation to overall objectives, ideal network, available budgets and the overall benefits of the data.
9. Prepare a phased implementation plan. This has to be prioritised, realistic and achievable.
10. Decide on approximate location of sites, commence site surveys. If site not available review location and see if another strategy can be adopted e.g. gauge a tributary to estimate total flow at required spot rather than trying to measure total flow in the main stem river. Guidelines on site selection are contained in Chapter 2.
11. Establish framework for regular periodic network reviews.

These steps are further elaborated in the following Sections.

1.2 MAPS AND BACKGROUND INFORMATION

Obtain **1:250,000 topographical** maps of the State's area of responsibility and identify and define the main river basins and their catchment boundaries on these. These maps will form the base map for the network design. Smaller scale maps are of no use in this process other than to give a global picture of the gauging station network. On smaller scale maps it is not readily possible to identify the location of stations relative to tributaries and other key features. In addition to the basic basin map other mapping showing physical and/or land use information is important.

The following maps at scale 1:250,000, unless otherwise indicated should be obtained, or if these are not available, then the information required should be obtained and transferred onto 1:250,000 map sheets.

	Information	**Possible Source**
1.	Geological formation	Director of Mines and Geology
2.	Land use to indicate main industries and population centres	Remote sensing Agency, Director of Industries
3.	Mining area	Director of Mines and Geology
4.	Irrigation command areas showing existing and proposed projects including dam sites	CE Project Preparation, Irrigation Department

	Information	Possible Source
5.	Discharge observation sites and rain gauge station	CE Surface Water (Hydrology), Irrigation Department
6.	Communications map to show roads infrastructure	Survey of India maps have roads included by may need updating.
7.	Forests	Principal / Chief Conservator of Forest
8.	Fisheries	Director of Fisheries
9.	Soil classification	Agriculture and/or Soil Conservation Depts. All India Land Use and Soil Survey Organisation, Nagpur.
10.	Rainfall & Climate *	India Meteorological Department (IMD)

* - 1:1,000,000 scale

1.3 DEFINITION OF PURPOSES AND OBJECTIVES OF NETWORK

Procedures to identify Hydrological Data User needs, to be able to specify the objectives of the network are outlined in Volume 1, Design and Field Manuals on the Hydrological Information System. To assist with this process, it is important to study the basin(s) under consideration in detail, to identify the following factors which could influence the network design:

- Where major rivers cross State borders;
- Proposed dam site locations;
- Areas proposed for irrigation development;
- Places where irrigation return flows occur;
- Major river diversions and off-takes or basin transfers;
- Areas earmarked for industrial development;
- Proposed mining development areas;
- Areas of water supply shortages;
- Waste disposal sites;
- Areas earmarked or de-forestation or re-forestation;
- Conservation areas and areas of ecological interest;
- Physical characteristics - changes in topography, geology, soils
- Polluted areas.

On the basis of the review of data requirements and the above requirements the need for new or upgraded gauging stations should be considered.

1.4 INITIAL EVALUATION OF THE NETWORK, ADEQUACY OF EXISTING NETWORK AND PRIORITISATION

The existing network and any proposed new gauging stations should have been plotted on the 1:250,000 maps.

The catchment area above each gauging station should be estimated from the basin maps if this has not already been done.

Starting at the top of each main river basin i.e. the most upstream point in the catchment, move down the main stem of the river and consider each station one by one. Gauging stations in each main tributary (sub-basin) should be considered when its confluence with the main river is reached.

The following questions have to be asked about each station:

- What purpose does the station fulfil?
- What are the socio-economic consequences of not collecting streamflow data at the site?
- What are the alternatives to establishing a hydrometric station at the site under consideration?
- Can a gauging station be better established on a tributary?
- Have any developments e.g. dam construction taken place or about to take place which could effect the performance of the gauging station?
- How close are the nearest upstream and downstream gauging stations? The drainage areas computed from origin up to consecutive observation sites on a large river should preferably differ by more than 10% so that the difference in quantities of flow is significant.
- Do any other organisations operate stations in the vicinity and if so could that data serve the required purpose?

In order to assist with the evaluation of each network a table with headings similar to the following should be produced:

Site No.	Basin	River	Station name	Lat.	Long.	Catchment Area (km^2)	Purpose/ objectives	Type	Priority (A/B/C)	Decision (N/R/D)	Remarks

KEY: Type: Type of station i.e. G - gauge only, GD - gauge and discharge, GDS - gauge, discharge and sediment, GDSQ - gauge, discharge, sediment and water quality. An indication should be given as to whether and AWLR or DWLR is required. The method of discharge measurement e.g. bridge outfit should be stated if known, for new sites this will be decided during the site selection process

Priorities: A - high, B - medium, C - low.

Decision: N - Establish new station, R - retain existing station, D - discontinue station

The entries in the above table should be made in an ordered manner, catchment by catchment and in the order the stations are located in the river basin, i.e. moving from upstream to downstream. The entry of stations into the table in a random fashion makes the evaluation more complicated.

During the above evaluation, stations which can be deleted will be identified. Conversely, gaps in the existing network might be identified, such as a major ungauged tributary, in which case these should be added to the list.

1.5 COST OF NETWORK

Once the preliminary design and evaluation of the network has been completed the capital cost of establishing new stations and the recurrent cost of operating the network can be estimated. These costings need not be individual itemised costings for each individual station. Approximate estimates based on an average cost for each station type e.g. gauge - discharge with winch and cradle cableway, would suffice. The manpower requirements should also be assessed. These should be balanced against existing establishments and budgets. Once this has been undertaken it should be possible to ascertain whether the proposed network is **sustainable**. This is extremely important. If there is any doubt about the ability of the State or other organisation to maintain the proposed network to high level of quality then it must be reduced in size. The priority categorisations should be established during the review to assist in the optimisation process.

Category	Priority	Relative Importance
A	High	Major, multi-purpose water resources development site, State boundary river, operation of major scheme, major ungauged basin, heavily polluted major water supply source
B	Medium	Medium scale water resources development project site, secondary basin, industrial development area (i.e. potential water quality problems)
C	Low	Minor irrigation project site, secondary gauging station on tertiary tributary, major water course but already extensively gauged

Prior to deleting an existing or proposed gauging station from the network or abandoning an upgrading proposal, the main beneficiaries of the data (appropriate members of the HDUG) should be informed.

1.6 NETWORK IMPLEMENTATION PLAN

Once the preliminary optimum network design has been completed a network implementation plan should be prepared. **This should be realistic and achievable in the time scales allowed**.

The plan should allow for the following:

1. Site location surveys.
2. Preliminary design
3. Land acquisition/rental negotiations;
4. Preparation of detailed specifications and drawings;
5. Recruitment and training of staff;
6. Invitation to tender;
7. Tender period;
8. Evaluation of tenders and award of contract;
9. Construction period;
10. Procurement of equipment*
11. Commissioning.

* - Note: Equipment should **not** be procured until such time as the civil works are well advanced i.e. the equipment should be delivered to coincide with completion of the civil works. Equipment for new stations should not be bought in advance and stockpiled.

1.7 SITE SELECTION SURVEYS

Site selection and the associated surveys are discussed in detail in Chapter 2. However, this process has to be closely linked to Network design. If a suitable site cannot be found at the desired location then the network design should be reviewed to see if an alternative strategy can meet the same objectives. For example it is sometimes more straight forward to measure flows on tributaries than on a main stem river.

2 SITE SELECTION OF WATER LEVEL AND STREAMFLOW STATIONS

2.1 DEFINITION OF OBJECTIVES

Prior to embarking on the selection of a water level (stage) monitoring or streamflow-gauging site it is imperative that the objectives of the site are fully defined. In this regard the following factors have to be established:

1. What is the purpose of the station? e.g. planning and design of major water supply scheme, pollution monitoring, flood forecasting etc.
2. Define the required location of the site i.e. what are the most upstream and downstream limits e.g. the station might have to be located between two major tributaries;
3. Does the full flow range require monitoring or are low or high flows of greater importance?
4. What level of accuracy is required?
5. What period of record is required and what frequency of measurement is desirable?
6. Who will be the beneficiaries of the data?
7. Are there any constraints such as access and land acquisition problems and cost limitations?
8. Is a particular streamflow measurement methodology or instrument preferred?

2.2 SITE SURVEYS

Once the purpose and objectives have been defined and the Engineer responsible has considered what flow measurement and automatic water level recording techniques could be suitable, the site selection process can begin. The final choice of site will depend on the type and quality of the data required, the method to be deployed and other factors such as logistics and budgetary constraints. In particular the final site selection might be mainly determined by the choice of the most appropriate equipment or technique. Therefore, some guidance is provided in Chapter 6 of Volume 4, Design Manual, Hydrometry, on the advantages and limitations of different hydrometric methods used in, or which are suitable for Indian conditions.

In order to select the most appropriate site, considerable effort needs to be expended undertaking site selection surveys. The site selection surveys can be divided into four distinct phases, which are summarised in sub-sections below:

1. Desk study
2. Reconnaissance surveys
3. Topographic surveys, and
4. Other survey work

In order to ensure that all the pertinent information is obtained during the site selection process and surveys and to assist with the work, a standard form has been prepared. This list has been derived from the CWC checklist. A copy of this form is contained in the Appendix 2.1 to this Chapter.

2.2.1 DESK STUDY

The target location for the gauging station will have already been identified on a 1:250,000 map or similar during the network design process. However, this size of map is too small a scale for site selection purposes. The inspection of large-scale topographic maps (1:50,000) and aerial photographs if these are available, should be undertaken to identify possible sites within the target river reach.

2.2.2 RECONNAISSANCE SURVEYS

These should be undertaken by road, foot and for larger, navigable rivers by boat. It is important that the entire target reach of the river is inspected. Therefore, if travel by boat or road is not possible there is no substitute for walking the entire length of the target reach. An experienced hydrometrist probably at the Executive Engineer level and a hydrologist from the sub-divisional office within whose jurisdiction the location falls and who is familiar with the area should undertake the surveys. During the survey, interviews should be held with local people to try and build up a picture of local site conditions such as water level ranges. At sites of interest attempts could be made to ascertain who owns the land.

2.2.3 TOPOGRAPHIC SURVEYS

On completion of the reconnaissance surveys, one or more sites could have been identified which are worthy of further consideration. However, it is often not possible to make final decisions on site selection without the benefit of bed surveys. If the site is proposed as a current meter gauging site cross-sectional surveys of the possible gauging site should be undertaken. If the site is to be a rated section (conventional stage-discharge site) surveys will have to be undertaken at the proposed measuring section and upstream and downstream of the site. For artificial controls such as weirs it is necessary to undertake surveys both upstream and downstream of the site, possibly for several kilometres to ascertain the modular limit and the impact of the structure on upstream water levels.

For rated sections (stage-discharge sites) it is often important to undertake sufficient cross-sections to define the control and the upstream approach and downstream conditions. For a section control it is important to fully define the shape of the controlling section. Whereas for the more common in India, channel control it is important to define the cross-section and bed slope over the control reach. This might require surveys depending on the bed slope over several kilometres. If there is a reservoir or confluence downstream of the site it is important to ascertain whether such features will have a variable backwater effect. For all controls it is important to define the line along the length of a river which joins up the lowest points in each river cross-section i.e. the longitudinal profile. If the longitudinal profile is plotted it is possible to identify changes in bed slope. Therefore, this can assist in identifying potential controls and the positioning of controls. Also, in ephemeral rivers (ones that dry up) it is the position of the lowest bed levels at the control section which will define the level at which flow ceases and thus influence the positioning of the stage boards and water level recorder.

At unstable, shifting control sites the position of the cease to flow level will vary. As such it is important to carry out regular cross-sectional surveys following establishment of the gauging station in order to monitor such shifts. Even rated sections with stable controls should be checked on a regular basis prior to and after the monsoon, to ensure that the properties of the control have not significantly altered.

2.2.4 OTHER SURVEY WORK

It is useful if current meter flow measurements can be undertaken at the proposed site(s) prior to making the final site selection in order to obtain some idea of the velocity distribution across the measuring cross-section. If these discharge measurements are undertaken in parallel with surface water level measurements it will also be possible to make estimates of roughness coefficients for the site. If gauge posts are installed to measure surface water slopes to estimate roughness coefficients and/or variable backwater effects it is essential that these posts be sited sufficiently far apart. If there is a long lead in time prior to the construction of the gauging station it is extremely useful if temporary gauge posts can be installed and a local observer recruited in order to obtain an idea of water level variations. This is particularly important for high cost gauging station sites such as weirs. Existing sites which are to be rehabilitated some information should already be available to assist with the design.

If structures are to be installed it is possible that soils and geological surveys will be required to establish the stability of the banks and bed for founding the structure and the availability of construction material such as rip-rap.

2.3 SELECTION OF WATER LEVEL GAUGING SITES

The **stage** of a stream, river, lake or reservoir is the height of water surface at the measuring point above an established datum plane. The water surface elevation relative to the gauge datum is often referred to as the **gauge height**. Stage measurements are most commonly required in surface water hydrometry to determine the flow using relationships between stage and discharge or cross-sectional area and velocity. Therefore, in many circumstances the selection of a stage or water level measurement site will be to a certain extent governed by the suitability of the site for flow measurement purposes. The selection of a stage-discharge site is covered in Section 2.4. However, it is very important that extreme care is given to the selection of the location of stage monitoring devices since this is the basic raw data which is required to derive discharge. Also, in some situations, flow estimates will not be required but it is necessary to measure water level only e.g. reservoirs, flood warning.

Some general criteria to be aware of when selecting a stage-monitoring site are presented below. These criteria are based mainly on the location of gauge boards but generally apply equally to the location of stilling wells for float recorders or for digital water level recorder installations. It should be noted that reference gauge posts should always be installed along with the other stage measurement devices for checking purposes i.e. the stage board is the standard reference. Therefore, the other stage-monitoring device should be installed adjacent to the gauge boards (or vice versa).

For stage monitoring, the following site selection guidelines apply:

1. Avoid locations subject to high turbulence or in the case of reservoirs, wind effects.
2. The stage measurement device should be installed as close to the edge of the stream as possible. Whenever possible sections subject to high velocities should be avoided since drawdown effects can occur around the device.
3. In order to minimise the effects of turbulence and high velocities the gauge posts and other devices can be installed in a suitable permanent stilling bay set into the bank.
4. Steep riverbanks or reservoir sides are preferred.
5. Stable bank and/or bed for securing stage measurement device. Gauge posts in particular are very susceptible to slippage or uplift particularly during high floods. Bridge piers, reservoir walls and other similar structures sometimes provide good fixing positions provided the other hydraulic criteria can be satisfied.
6. Two permanent benchmarks of known level relative to mean sea level (msl) should be close to the site (within 5 km) for checking the level of the stage boards/gauge posts. If these are not available two independent sites as close to the river as possible, but above the maximum flood level (preferably less than 500 m from the river), should be available where station bench marks can be installed relative to an arbitrary datum. These sites should be whenever feasible, free from possible natural or human interference.
7. The location should be selected so that the gauge boards are readable over the full level range. It is preferable that readings are made as near as possible to eye level. This is obviously not always possible e.g. when measurements are made from a bridge. However, every effort should be made to make the gauges as readable as possible to avoid errors and/or difficulties for the Observer.
8. If recording water level monitoring devices are installed it may not be necessary, even though it is desirable to have access to the site at all times. However, the appropriate gauge post should be readily readable over the full measurement range.
9. Sections of river which are subject to scour or deposition should be avoided.

10. The water level measurement device should whenever possible be located in a position where it will not collect floating debris such as tree trunks e.g. the upstream side of bridge piers can be susceptible to the collection of debris.

2.4 SELECTION OF STREAMFLOW MEASUREMENT SITE

The majority of streamflow measurement techniques are based on the velocity area method. Even though the use of float measurements is sometimes inescapable, current meter gauging is the most widely favoured velocity-area method technique. For most situations the same general site selection criteria can be applied to each technique. The current Indian Standards on velocity-area method site selection (see Reference Manual) and current international practice (e.g. ISO 748) have been reviewed along with other considerations and a recommended set of guidelines have been prepared which are contained in this Section. Current meter gauging flow measurements might be required for a current meter gauging site only, a stage-discharge site, an artificial control site or to calibrate some other method. The site selection guidelines suggested in Section 2.4.1 are appropriate to all current meter gauging sites. Where appropriate additional site selection criteria have been included which are specific to different methods of gauging and current meter deployment. Some additional suggestions and guidelines are given for

- for float measurement proposed in Sub-section 2.4.2
- for discharge monitoring by Acoustic Doppler Current Profiler (ADCP) in Sub-section 2.4.3
- for Slope-area Method in Sub-section 2.4.4
- for selection of Natural Control (rated section) station site in Sub-section 2.4.5
- for selection of Artificial Control Sites in Sub-section 2.4.6.

For a stage-discharge station, both a stage measurement device and a current meter gauging site are required in the same locality. However, **it might not always be appropriate to locate the current meter gauging site immediately adjacent to the stage measurement device since some of their site selection criteria are different**.

2.4.1 GUIDELINES FOR SELECTION OF CURRENT METER GAUGING SITE

In practice there is very rarely an “ideal” location for current meter gauging. The hydrometrist by necessity is often required to take measurements in far from ideal conditions. The factors one looks for in selecting a good current meter gauging site are as follows:

1. Long, straight, uniform, well defined approach channel upstream of the measuring section to ensure parallel and non-turbulent flow and to minimise irregular velocity distribution. In practice, the approach length is related to the channel width. It is suggested that for rivers less than 100 m wide a straight approach of 4 x channel width be obtained if possible. For rivers greater than 100 m wide the current Indian minimum standard of 400 m straight approach should be adopted if possible. When the length of the straight channel is restricted it is recommended that the straight length upstream should be at least twice that downstream.
2. The measuring section should be remote from artificial and natural obstructions and from river control/release structures e.g. dams, control gates. When upstream of a confluence, the site shall be preferably located upstream of the backwater effect and beyond any disturbance due to the convergence of the two watercourses. If there is any doubt, investigations should be carried out to assess the extent of backwater effects. A method for estimating potential backwater effects is outlined in Section 2.5.
3. Uniform, symmetrical and homogeneous cross-section upstream, at and downstream of the measuring section.
4. Solid, regular, relatively smooth channel bed which is free from obstructions and debris.

5. Well defined, stable banks free from irregular vegetation and other obstructions.
6. The site shall be sufficiently far away from the disturbance caused by rapids and falls.
7. Sites where there is a tendency for the formation of vortices, reverse flow or dead water shall be avoided.
8. Sites with mobile beds or bank overflow shall be avoided. If this is not possible a gauging site shall be chosen so that the bed change and/or overflow is minimised. Where overflow occurs, sites with the minimum width of floodplain and least vegetation growth and other obstructions shall be selected if possible.
9. Whenever possible flow should be confined to a single channel. When this is not possible each individual channel should be gauged separately. The discharge estimates for each channel should then be summed to obtain the total flow. The choice of individual measuring sites should endeavour to minimise the amount of effort and time involved, while at the same time minimising the measurement uncertainties.
10. Velocities well in excess of the minimum response speed of the current meter (>0.15 m/s if possible) over the full flow range.
11. Velocities should not exceed the maximum calibration velocity of the current meter.
12. There should be sufficient depth of flow across the whole cross-section:
13. For wading: Minimum depth of four times the diameter of the impeller or the height of the cups;
14. For bridge and cableway gauging: Minimum depth of 2.5 times the distance between the centre line of the current meter and the base of the sinker weight i.e. allowance for the hanger bar;
15. For boat gauging (stationary, boat cableway and moving boat methods): minimum of twice the normal draft of the boat but not less than 1.0 m deep for greater than 5% of the cross-section.
16. The measurement section should be clearly visible across its width and unobstructed by trees, aquatic growth or other obstacles.
17. When gauging from a bridge with divide piers each section of the channel should be treated as individual cross-sections.
18. Channel should be free from weed growth.
19. Accessible at all times of year and under all flow conditions.
20. Must be safe to gauge.

2.4.2 REQUIREMENTS FOR FLOAT MEASUREMENTS FOR DISCHARGE ESTIMATION

Most of the same general principles, which apply to the selection of current meter gauging sites (see Sub-section 2.4.1) also apply to float measurement sites. However, the following are also important criteria:

1. Three cross-sections shall be selected along the reach of the channel one at the upstream end, at the commencement, middle and end of the reach.
2. The measuring length which should be straight and uniform in cross-section, should if possible be five times the average width of cross-sections;
3. If possible the time taken for the float to travel the length of the measuring reach should be at least 20 seconds;
4. It is useful if there is a bridge upstream of the measuring reach in order to drop the floats in the river at the desired position;
5. It should be possible to install distance marker poles on both banks directly opposite each other in order to determine accurately when the float has passed the start and finishing sections.
6. Sites, which are sheltered from high winds, are to be preferred. In this regard it is preferable if the direction of the prevailing wind is at right angles to the direction of flow.

2.4.3 SITE SELECTION REQUIREMENTS FOR USE OF ACOUSTIC DOPPLER CURRENT PROFILER (ADCP) FOR DISCHARGE MONITORING

The ADCP is a device for measuring velocity, direction and cross-section. As such it is a velocity area device. However, in view of its technology it can cope with irregular velocity distributions and skew flow conditions. The choice of measuring cross-section is therefore not so critical as other velocity-area methods. The site requirements such as minimum depth are dependent on the transducer frequency and the mode of operation (how the instrument processes the acoustic signals and what set up parameters are used). For Indian conditions it is envisaged that the instrument will be boat mounted. Therefore, there will be an upper velocity limit in the interests of operator safety.

The following additional site selection criteria which is based on experiences with an ADCP designed for the minimum limits of application are offered as a guide:

1. The minimum depth of operation should not be less than 1.5 m for more than 5% of the cross-section i.e. the depth of operation should be greater than 1.5 m for at least 95% of the transect. The **depth of operation** is not the actual depth but the distance from the ADCP transducers to the bed of the river. The ADCP transducers should be mounted at least 0.3 m below the surface or below any potential interference effects from the hull (underside) of the boat (whichever is the greater).
2. The average velocity in the measuring cross-section should not exceed 4 m/s. However, this will be governed to a certain extent by the boat engine size and the skill of the boat operator.
3. The minimum velocity should not be less than 0.1 m/s. It will work in lower velocities but this can lead to complications in the measurement technique.
4. The ADCP transducers should not be positioned in turbulent and/or aerated water i.e. where there is significant air entrainment, since this can cause attenuation and effect the acoustic signal. Turbulent, white sections of river should therefore be avoided.
5. The face of the transducers are susceptible to serious damage if they are struck heavily by a hard object. Therefore, the measuring section should be free of rocks, tree stumps and other objects in shallow water.
6. It is not essential, but preferable if the ADCP is run across the river in a line at right angles to the flow/banks. Also, the boat should try to follow the same line on each outgoing and incoming crossing of the river.
7. The equipment is fairly heavy, (approx. 45 kg), but it is difficult for more than two persons to carry it at once. Therefore, it would be useful if the ADCP mounting boat is fairly accessible by jeep. The ADCP is expensive so it should not be permanently stored on its deployment boat.

2.4.4 REQUIREMENTS FOR USE OF SLOPE-AREA METHOD FOR DISCHARGE ESTIMATION

The slope-area method is described in Chapter 6 of Volume 4, Design Manual, Hydrometry and in further detail in ISO 1070:1992(E). The site selection criteria can be summarised as follows:

1. Reaches of river with very flat surface water gradients should be avoided.
2. There should be no progressive tendency for the river to scour or deposit sediment.
3. The river reach should be straight, if possible and channels having significant curvature or meanders should be avoided. There should not be any abrupt change in the river bed slope.
4. The cross-section should be uniform throughout the reach and free from obstructions. Vegetation growth should if possible be minimal and uniform throughout the reach.
5. The bed material should be homogeneous throughout the reach.
6. The length of reach should be long enough to measure significant difference in water levels i.e. if the differences are relatively small the uncertainty in the slope measurement could be very large. If one assumes the uncertainty in level measurement at the upstream and downstream measurement points (gauges) are the same then the distance between the gauges should be

sufficient for the fall to be not less than twenty times the uncertainty in the measurement at one gauge.

7. The flow in the measuring reach should be free from disturbances due to the effect of tributaries.
8. The flow in the channel should be contained within defined boundaries. Reaches where over bank flow occurs should be avoided. If this cannot be avoided then a reach should be searched for which the flows over the flood plain are not very shallow.
9. Changes in flow regime from sub-critical to super-critical or super-critical to sub-critical should not occur in the measuring reach.
10. A converging reach should be selected in preference to an expanding reach. Rapidly expanding reaches should not be selected.
11. The physical characteristics of the reach shall be such that the time lag of flow in the reach shall be negligible.
12. If a permanent water level monitoring facilities are to be installed such as gauge posts, then the site selection process will also have to take account of the water level monitoring site selection requirements (See Section 2.3).

2.4.5 SELECTION OF NATURAL CONTROL (RATED SECTION) STATION SITE

In practice there is very rarely an "ideal" location for a natural control (rated section) gauging station. It is often required to compromise and to establish stations in far from ideal conditions. The factors one looks for in selecting a good rated section station site are summarised below. These guidelines are based on International Standards, World Meteorological Organisation (WMO) and other currently, widely accepted hydrometric practice. These site selection guidelines have been divided into two parts:

- Hydraulic criteria, and
- Tactical considerations.

Strategic and functional site selection considerations form part of the network design process and have been covered in Chapter 1.

Hydraulic Criteria

1. If possible a natural control should be selected where the relationship between stage and discharge is substantially **consistent and stable**, there should not be any significant backwater effect and the channel itself should be stable.
2. The control shall be **sensitive**, such that a significant change in discharge, even for the lowest discharges, should be accompanied by 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.
3. The general course of the stream should be straight upstream and downstream of the site. WMO recommends that the stream should be straight for 100 m upstream and downstream. This is probably not sufficient for very wide Indian rivers. It is therefore suggested that ideally the measuring reach should be straight for about 2 - 3 river widths or a minimum of 400 m (which ever is the lesser) both upstream and downstream of the site. Note: this criterion is similar to but slightly different from that specified for a current meter gauging site (see Sub-section 2.4.1)
4. If possible the total flow should be confined to one channel and controls where over bank flow and flood by-pass occurs should be avoided. No flow should by-pass the site as sub-surface flow.
5. Locations, which are subject to scour, sedimentation and weed growth should be avoided.
6. 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.

7. 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 unsubmerged over the full stage range, is ideal.
8. A pool (deeper water) is present upstream of the control to ensure the recording of stage at low flows, and to avoid/dampen high velocities at stage recorder intakes during periods of high flow.
9. The control should be sufficiently far upstream of another river or stream, the coast or a dam or river control structure to avoid inconsistencies due to variable backwater effects.
10. A satisfactory reach for the measurement of discharges should be available. This reach should ideally have the characteristics listed in Sub-section 2.4.1. Even though it is desirable, it is not necessary for the current meter gauging site to be immediately adjacent the stage-measuring device. However, there should be no significant increase or decrease in flow between the two locations. Also, it is not necessary for the full flow range to be measured at the same cross-section. For example at some sites it might be necessary to measure medium to high flows from a bridge and low flow by wading at an alternative section.

Tactical considerations

1. *Ungauged flows round the control (normal flows)*: care should be taken to ensure that there is no parallel by-pass channel, natural or man-made, round the station.
2. *Ungauged flows round the control (flood flows)*: it is often not possible to locate a gauging station so that all flood flows are contained within the river channel at that point. At many locations there will come a point where out-of-bank flow occurs. The station should nevertheless be located where the flood plain is at its narrowest and the river channel is well incised, in order to minimise out-of-bank flood flows.
3. *Ungauged flows under the control*: unless there are specific hydrometric reasons to the contrary, the station should be located where the risk of groundwater flow at depth beneath the control, whether inter-granular flow in superficial deposits or fissure flow in deeper strata, is minimised. The local hydrogeology must therefore be taken into account.
4. *Access and services*: Consideration must be given to access to the station, both during construction and in operation. Other factors such as the availability of living and office accommodation, potable water supplies, electricity and other services also have to be taken into account.
5. *Land acquisition*: Land should be available on which to establish the water level monitoring and current meter gauging installations. This should not be an over-riding factor in the initial site selection process but might ultimately become an issue if land acquisition becomes a problem.
6. *Security*: Human interference with hydrometric installations is a problem, which has to be faced by hydrologists throughout the world. As such it is an issue that 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 could be made in favour of the site which can be made more secure e.g. where a permanent caretaker can be provided.
7. *Sustainable*: The station has to be sustainable. Therefore, the local manpower, financial and logistic support resources have to be available to operate and maintain the station.

2.4.6 SELECTION OF ARTIFICIAL CONTROL SITES

There are a variety of different flow measurement structures. The choice of structure will depend on a variety of factors including objectives, flow range, afflux, size and nature of the channel, channel slope and sediment load, operation and maintenance, passage of fish and not least, cost. The applications and limitations of a structure will determine where its use is most appropriate. In this regard each type of structure has its own specific site selection criteria. Some of the main, general criteria to be considered when selecting sites are covered in this sub-section. More details on the types, use, choice and hydraulic design of structures are contained in Chapter 6 of Volume 4, Reference Manual, Hydrometry.

It is recommended that generally the use of purpose built artificial controls is limited to smaller, but important rivers (< 100 m wide) and to special investigations in artificial channels such as the estimation of return flows from irrigation schemes. However, the adaptation of non-purpose built structures such as spillways and anicuts, for flow measurement purposes should be undertaken when feasible.

Site selection guidelines

The following site selection guidelines are recommended:

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. Thin plate weirs are particularly sensitive to upstream velocity distribution.
2. 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.
3. 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. Therefore, sites should be selected where structures which provide this sensitivity can be constructed. Structures such as the triangular profile flat “v” weirs have been developed to provide such sensitivity.
4. 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), see Section 2.5. To prevent water surface instability in the approach channel the Froude number should generally not exceed 0.5.
5. The sensitivity of upstream area to increased levels should be assessed i.e. will the installation of the structure cause a potential, increased risk of flooding.
6. 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.
7. The sub-soil conditions should, whenever possible, provide a solid foundation for the structure and situations where seepage losses occur should be avoided.
8. Sites where high sediment loads or scouring occurs should be avoided if possible. 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.

Tactical considerations

These are similar to those recommended for stage - discharge (rated section) sites (See Sub-section 2.4.5).

2.5 FLOW PARAMETERS AND FORMULAE

In this section the quoted flow parameters and backwater formula are summarised, in a formulation valid for wide rectangular channels. Reference is made to Chapter 2 of Volume 4, Design Manual, Hydrometry, for an overview.

Equilibrium or normal flow depth h_n:

$$h_n = \left(\frac{q}{K_M S^{1/2}} \right)^{3/5} \tag{2.1}$$

where: q = discharge per unit width
K_M = K-Manning = 1/n-Manning
S = bed slope of the river

Critical flow depth h_c:

$$h_c = \left(\frac{q^2}{g} \right)^{1/3} \tag{2.2}$$

where: g = acceleration due to gravity

Froude number Fr:

$$Fr = \frac{v}{\sqrt{gd/\alpha}} = \left(\frac{h_c}{h_n} \right)^{3/2} \tag{2.3}$$

where: v = mean velocity in the approach cross-section
d = mean depth of flow, d = A/W
A = cross-sectional area
W = water surface width
α = kinetic energy coefficient (assume α = 1 for site selection and design purposes)

Backwater effect

Downstream tributaries, deltas, coasts, reservoirs, lakes, structures and aquatic vegetation growth can all cause variable backwater effects which can effect the stability and reliability of the stage-discharge relationship. Such effects should be avoided if possible during the site selection process. If a site is upstream of a reservoir or some other downstream influence it is possible using one of the following methods to obtain an initial estimate of the possible impact of backwater.

A decision can then be made whether the site under consideration would be better located further upstream. The terms used in the method are illustrated in Figure 2.1 below.

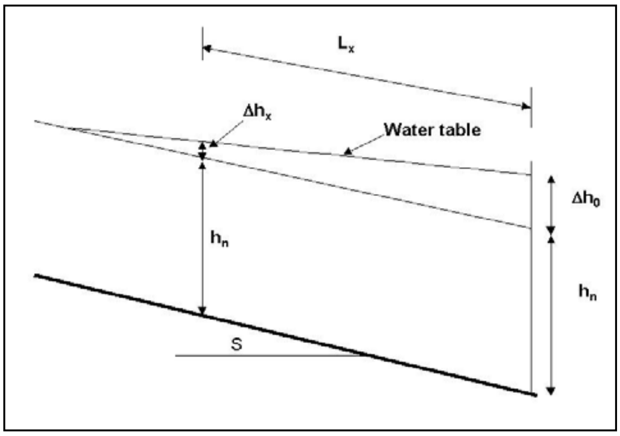

Figure 2.1:
Definition sketch for backwater effect

The following equation which has been derived on the basis of open channel flow formulae, assuming a gradually varied flow M1 type profile and a rectangular cross-section, can be used to make a first order, initial estimate of the extent of backwater:

$$\Delta h_x = \Delta h_0 \exp\left(\frac{-3SL_x}{h_n(1-Fr^2)}\right) \qquad \text{for :} \quad \Delta h_0 << h_n \tag{2.4)}$$

where: Δh_x = backwater effect at x = L_x
Δh_0 = initial set up of water level at x = 0
S = river bottom slope
L_x = distance

A crude order of magnitude for the distance over which the backwater is felt is obtained from:

$$L \approx \frac{h_n}{S} \tag{2.5}$$

For more accurate computations one can apply the Bresse function. The set of equations to solve reads:

$$L_x = -\frac{h_n}{S}\left[(\eta_x - \eta_0) - \gamma\{\psi(\eta_x) - \psi(\eta_0)\}\right] \tag{2.6}$$

where :

$$\eta_x = \frac{\Delta h_x + h_n}{h_n} \quad ; \quad \eta_0 = \frac{\Delta h_0 + h_n}{h_n} \quad ; \quad \gamma = 1 - Fr^2$$

and

$$\psi(\eta) = \frac{1}{6}\ln\left\{\frac{\eta^2 + \eta + 1}{(\eta - 1)^2}\right\} - \frac{1}{\sqrt{3}}\operatorname{arc\,cot\,g}\left\{\frac{2\eta + 1}{\sqrt{3}}\right\}$$

Note that the difference between (2.5) and (2.6) is the bracketed term […].

Example 2.1

In a river at x = 0 with bottom slope $S = 5x10^{-4}$, $K_M = 40$ and normal water depth $h_n = 5$ m the level is backed up with 2 m.

Using approximation

From (2.5) the approximate extent of the backwater reach is:

$L = 5/5x10^{-4}m = 10$ km

Using Bresse function

The distance at which the set up is diminished to 5% of the initial set up (= 0.10m) can be derived from (2.6) as follows:

$\eta_x = 5.1/5 = 1.02$, $\psi(\eta_x) = 1.191$, $\eta_0 = 7/5 = 1.4$, $\psi(\eta_0) = 0.304$,

$v = K_M h^{2/3} S^{1/2} = 40x5^{2/3} x(5x10^{-4})^{1/2} = 2.6$ m/s,

hence: $Fr^2 = v^2/gh = 2.6^2/9.81x5 = 0.14$, $\gamma = 1-0.14=0.86$,

So, $L_{0.05} = -5/(5x10^{-4})[(1.02-1.4)-0.86(1.191-0.304) = -10,000(-0.38-0.76)$ m = 11.4 km.

Comparison

Comparing the two results it is observed that they are quite similar. So, for a first estimate equation (2.5) will do, provided that the Froude number is small.

APPENDIX 2.1
CHECK LIST FOR SELECTION OF HYDROLOGICAL OBSERVATION SITES

Part 1 - General

1. Location information:

Name of watercourse:

Sub basin (river to be gauged):

Main Basin:

Upper limit for station: Latitude:

Longitude:

Lower limit for station: Latitude:

Longitude:

Location map to be prepared and attached to the check list.

2. Objectives and purpose(s):

2.1 Category of station:

Please tick the appropriate boxes:

Category	(✓)
Primary	
Secondary	
Special	
Primary + special	

2.2 Main purposes and functions of data:

Please tick the appropriate boxes:

Purpose/function	(✓)
State border	
Water supply	
Irrigation	
Hydro-electric power	
Flood management	
Pollution monitoring	
Conservation	
Other - please specify in section 2.3 below	
Representative flow series of river basin	

2.3 Justification:

Priority classification: High, Medium, Low

Provide a brief justification including the importance of the site and the potential benefits of the data.

2.4 Nearest gauging stations

State gauging station:

Above proposed gauging station: Site name:

Latitude:

Longitude:

Below proposed gauging station: Site name:

Latitude:

Longitude:

CWC gauging station:

Above proposed gauging station: Site name:

Latitude:

Longitude:

Below proposed gauging station: Site name:

Latitude:

Longitude:

2.5 Data requirements:

Data type	Tick approp. box(es)	Frequency (e.g. continuous, daily, etc.)	Remarks
Water level			
River flow			
Sediment			
Water quality			
Rainfall			
Weather station			
Other, please specify			

Flow range to be measured: Full/Low/High

2.6 Network design considerations:

	Consideration	Units	At upper limit	At lower limit
a.	Catchment area	km^2		
b.	Total length along longest course	km		
c.	Total catchment area of next existing key G&D site upstream of proposed site expressed as a % of (a)	%		
d.	Total catchment area of next existing key G&D site downstream of proposed site expressed as a % of (a)	%		
e.	Distance along stream from its origin along the longest course to the next upstream G&D site expressed as a % of (b)	%		
f.	Distance along stream from its origin along the longest course to the next downstream G&D site expressed as a % of (b)	%		
g. -	% of catchment area which is tapped by existing storage reservoirs on the u/s side	%		
-	% of catchment area which is tapped by existing and proposed reservoirs on the u/s side	%		
h. -	% of catchment which is tapped by existing storage reservoirs as well as diversion works	%		
-	% of catchment which is tapped by existing and proposed reservoirs and diversion works	%		

NOTE: If the upper and lower limits are almost the same, say within a few kilometres, then only one set of figures should be produced and entered in the upper limit column.

3. Survey

3.1 Desk top

Examine topographic maps and aerial photographs. Yes/No

Produce catchment map.Yes/No

Is there an existing gauging station in the locality i.e. is the station to be upgraded? Yes/No

If Yes provide details.

Is there any existing site data available e.g. stage readings? Yes/No

If yes provide details.

3.2 Reconnaissance surveys

Dates undertaken:..

Surveys undertaken by:...

Reach of river inspected:..

List details of sites considered in the next table:

No.	Location name	Latitude	Longitude	Suitable (Y/N)	Possible methods	Remarks

NOTE: For each site inspected Part 2 of the form should be referred to and completed.

Part 2 - Site Specific Details

Part 2 of the form should be completed for each specific site considered during the reconnaissance survey.

4. Location

Proposed site name:

Latitude:

Longitude:

Nearest village/town:

Description of access route:

5. General location considerations

	Consideration	Y/N	Remarks
a.	Is the site going to be submerged or affected by a future project?		
b.	Is there any quarrying activity or dumping activity at or near d/s area which can change the low flow regime from year to year?		
c.	Does the river have a straight reach?		
d.	Is the reach u/s and d/s of the site fairly uniform?		
e.	Is the cross-section uniform?		
f.	Are the river banks stable?		
g.	Are the banks high enough to contain the highest flood?		
h.	Is the reach free of weeds, trees and rock outcrops other than those considered as a possible control?		
i.	Is there a nearby bridge suitable for gauging? Comment on its suitability over the full flow range.		

What is the length of straight reach upstream of the site?.............................

What is the length of straight reach downstream of the site?........................

What is the length of straight reach upstream of the site expressed as a % of channel width?..

6. Hydrological & Hydraulic Considerations

6.1 Control

	Considerations	Y/N	Remarks
a.	Is there any rock outcrop or rapid bed fall, hydraulic structure etc. d/s of site which will act as a good control?		
b.	If the answer to a) is Yes please indicate in the remarks column the effective range of the control e.g. full, low flows only etc.	-	
c.	Does the river have a stable downstream section for a few kilometres which can provide a stable channel control? State any limitation of this control in the remarks column.		
d.	Is there a natural pool upstream of the site which would facilitate the measurement of water levels over the full range of flows		
e.	Is the site a suitable location for the installation of an artificial control?		

6.2 Low flow considerations

	Considerations	Y/N	Remarks
a.	Does the river cease to flow?		
b.	Does the site have a deep pool which will reduce the velocity and make it difficult to measure low flows?	-	
c.	Does low flow take place in multiple channels?		
d.	Does the low flow take place in a wide, shallow stretch, where good measurements and flow computation could be difficult?		
e.	If the answer to b), c) or d) is yes is it possible to find a better alternative low flow site nearby?		
f.	If the answer to d) is Yes are there possibilities of training low flow by temporary works?		

6.3 High flow and backwater considerations

	Considerations	Y/N	Remarks
a.	Is the H vs. Q relationship likely to be effected by floods in another channel joining the river downstream of the site?		
b.	Is the H vs. Q relationship likely to be effected by an existing or proposed d/s reservoir backwater can reach the proposed site?	-	
c.	Is the H vs. Q relationship likely to be affected by the operation of existing or proposed d/s gated, hydraulic structures?		
d.	If the station is near the coast is it likely to be effected by tides?		
e.	If it is found during high floods that it is difficult to measure flows by the normal means due to high velocities, non-functioning of the cableway or boats, is there an alternative? e.g. nearby bridge.		

6.4 Other hydraulic conditions

	Considerations	Y/N	Remarks
a.	If the site is situated downstream of bridge or any structure is at least three times of the width of the river d/s?		
b.	Is the flow normal to the cross-section of the river?	-	
c.	Is any dam/weir situated near the site? If so what are the likely impacts on flows at the site?		
d.	Is the stream perennial or ephemeral. If the latter what is the duration of no-flow?		
e.	Is the river at the site subject to sediment deposition and/or scouring?		

6.5 Level/flow ranges

What are the estimated stage, velocity and flow ranges?

Parameter	Units	Minimum	Maximum
Stage	m		
Velocity	m/s		
Discharge	m^3/s		

7. Inspection and other facilities and miscellaneous considerations

	Consideration	Remarks
a.	Name of nearest town or village and its distance from the site.	
b.	Extent of facilities like living and office accommodation on hire basis, market, medical facilities, P&T office, school etc. available nearby.	
c.	Is site approachable through out the year by vehicle? Is a four wheel drive vehicle required?	
d.	Distance to nearest town, railway station, and means of communication thereon.	
e.	Location of nearest inspection bungalow/rest house?	
f.	Is Government or private land available on lease for construction of stores?	
g.	Is land available for construction of cableway towers/stanchions and stilling wells?	
h.	How away is the nearest GTS bench mark?	
i.	Is there any wireless station or G&D station of the State Govt. or other agencies existing nearby and what is its status?	
j.	Are there any nearby industries which can pollute the river water?	
k.	Are there water and power supplies close to the site which could be readily connected to?	

8. Possible measurement methods

Method	Suitability (yes/no/marginal)	Remarks
Staff gauges		
Bank stilling well and float recorder		
Bridge mounted stilling well and float recorder		
Bubbler		
Pressure sensor - bank mounted		
Pressure sensor - bridge mounted		
Pressure sensor - tower mounted		
Look down ultrasonic		
Float measurements		
Wading gauging		
Unmanned cableway		
Manned cableway		
Bridge gauging		
Boat - cableway		
Boat - anchor/engine method		
Artificial control		
Moving boat method		
ADCP		

9. Surveys

9.1 Topographic Surveys

Cross-sections:

Longitudinal profiles:

9.2 Flow and water level measurements

Provide details of available level and flow data (if any)

9.3 Other surveys

Provide details of any other survey work undertaken e.g. geological, geophysical etc.

10. Overall Assessment

Is the site suitable for a gauging station? YES/NO

If YES what is the recommended set-up?

General observations, including advantages and limitations of the site.