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Technical Assistance
HYDROLOGY PROJECT

DHV CONSULTANTS & DELFT HYDRAULICS with HALCROW, TAHAL, CES, ORG & JPS

VOLUME 4
HYDROMETRY

FIELD MANUAL - PART VI

SLOPE-AREA METHOD

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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 hydro-meteorology, 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 OBSERVATION METHODOLOGY

The Slope Area Method requires water level data either observed from staff gauges or obtained from pressure transducers. Both methodologies are presented. Making use of autographic chart recorder records is due to difficulties with exact time keeping is considered not to be feasible. An important use of the Slope Area Method is for estimating peak discharges. Hence, observation of wrack marks after the passage of a flood is of importance.

Staff gauges:

1. The upstream and downstream gauges shall be read simultaneously. If only one observer is present and this is not possible, the upstream gauge shall be read, followed by the downstream gauge, followed by a second reading of the upstream gauge. If the upstream gauge has risen or fallen by more than 10 mm between the two sets of readings then, the gauge reading corresponding to the downstream stage reading shall be assumed to be the average of the two upstream readings. If the upstream and downstream gauges are not visible from each other the observers should read the gauges over the same pre-arranged time period.
2. The gauges shall be read from a position as to avoid all parallax errors.
3. Every effort should be made to read the gauges to at least the nearest centimetre or better, if possible.
4. The minimum period of observation at each gauge shall be two minutes or for a period of a complete oscillation, which ever is the longer and the maximum and minimum values taken and averaged.
5. At some sites intermediate gauge posts might have been installed to assess whether the slope is uniform along the whole length of the reach. If such gauges are installed, the gauges at these intermediate positions should also be read and the slopes between the upstream and intermediate gauges, and intermediate and downstream gauges estimated and compared with the slope obtained using the upstream gauges. If there is a significant difference in the three slope estimates, say greater than 10% then the validity of the estimates should be reconsidered.
6. The gauge readings shall be recorded onto the standard form (see Annexure 1). A separate form should be completed for each set of gauge posts.

DWLR's

The use of digital water level recorders with pressure sensors is a possibility for automatic collection of level data for use in slope-area estimation since such devices have highly accurate timing devices. As such the upstream and downstream water level records can be easily synchronised. For example it is possible that such a set up might be of interest for important sites where variable backwater conditions might occur and where it might not be possible to current meter gauge at higher discharges.

Wrack marks

One of the main uses of the slope area method is to make estimates of peak discharges, following a flood event. This normally involves identifying debris marks and undertaking topographic level surveys. Several types of high-water mark may be found, such as drift on banks, wash lines, seed lines on trees, mud lines, and drift in bushes or trees. Each high water mark should be rated as excellent, good, fair or poor. This information could be of assistance when interpreting the high-water profile. Sufficient wrack marks shall be identified on both banks in order to fully define the surface water profile over the measuring reach. Each wrack mark shall be identified by its position along a baseline. A graphical plot should be made to provide a visual profile of the high-water marks so that irregularities in the profile can be readily identified. It is recommended that a minimum of 10 points along the measuring reach be used to define the surface water profile.

Other observations and information required

Other observations and information to be estimated from the surveys include:

- Date;
- Time of start & finish;
- Observers;
- Distance between measuring points;
- Weather conditions e.g. windy;
- Vegetation conditions;
- Observers estimate of Manning's n value at each section (Note: This is only appropriate if the observer is a trained hydrologist or water engineer);
- Cross-sectional area of upstream and downstream measuring sections and if appropriate, intermediate sections;
- Wetted perimeter of the upstream and downstream measuring sections and if appropriate, intermediate sections.

At permanent sites with stable cross-sections the relationship between upstream and downstream stage and the corresponding cross-sectional area should be known. However, these relationships should be checked on a regular basis. A minimum of once every year, between consecutive Monsoon seasons is recommended. At permanent sites look-up tables relating stage at each cross-section to area and wetted perimeter should be prepared.

At new sites or sites where ad-hoc measurements are required the cross-sections will require surveying. The number of depth measurements undertaken to define the cross-section should not be less than 20. It will not usually be possible to undertake these surveys at the time of water level/stage measurement so it is important that whenever possible stable cross-sections are selected. Instability of the cross-sections can sometimes be a problem in post flood peak estimation using the technique.

2 COMPUTATION OF DISCHARGE

The discharge is estimated using the theory and equations described in Volume 4, Design Manual. The steps to follow are:

1. Estimate the fall (Z_1 - Z_2) over the measuring reach, i.e. between sections 1 (upstream) and 2 (downstream).
2. Estimate the surface water slope by dividing the fall by the horizontal distance (L) between sections 1 and 2:

   $S_w = (Z_1 - Z_2)/L$

3. Estimate the Manning's n value for each cross-section. This estimate can be based on earlier field observations and/or experience and the indicative values provided in Volume 4 of Design Manual on Hydrometry, Table 6.12.
4. Estimate the hydraulic radius for both the upstream downstream sections (R_1 & R_2) using the estimated cross-sectional areas and wetted perimeters.
5. Using the hydraulic radius estimated in 4) above, estimate the upstream and downstream conveyance in accordance with the following equations:

$$K_1 = \frac{1}{n_1} A_1 R_1^{2/3}$$

$$K_2 = \frac{1}{n_2} A_2 R_2^{2/3}$$

6. Substitute the values of K_1, K_2 and the surface water slope in the following equation to provide a first approximation of discharge;

$$Q = \sqrt{(K_1 K_2 S)}$$

7. Using the value of Q estimated in step 5 above, make first estimates of the velocity heads at sections 1 & 2 thus:

$$VH_1 = \frac{v_1^2}{2g} = \left(\frac{Q_1}{A_1}\right)^2 \times \frac{1}{2g}$$

$$VH_{2=} = \frac{v_2^2}{2g} = \left(\frac{Q_2}{A_2}\right)^2 \times \frac{1}{2g}$$

8. If $VH_1 < VH_2$ i.e. the velocity head difference is negative, then the reach is contracting and the following equation can be used as follows to obtain a second estimate of the slope of the energy line:

$$S = \frac{(Z_1 - Z_2) + \left(\frac{\alpha_1 v_1^2}{2g} - \frac{\alpha v_2^2}{2g}\right)}{L}$$

or

$$S = \frac{(Z_1 - Z_2) + (VH_1 - VH_2)}{L}$$

If $VH_1 > VH_2$ i.e. the velocity head difference is positive, then the reach is expanding **which should be avoided** for the reasons explained in the Design Manual. However, if an estimate is necessary, the following equations shall be used:

$$S = \frac{(Z_1 - Z_2) + 0.5\left(\frac{\alpha_1 v_1^2}{2g} - \frac{\alpha v_2^2}{2g}\right)}{L}$$

Or

$$S = \frac{(Z_1 - Z_2) + 0.5(VH_1 - VH_2)}{L}$$

9. Using the new estimate of the energy line obtained in step vii), repeat step v) above to obtain a second approximation of discharge (Q_2). If $(Q_2-Q_1)/Q_1$ > +/- 1% repeat the iteration procedure steps 6, 7 and 5 until the current approximation of Q is within 1 % of the previous estimate.
10. After the final discharge has been determined the Froude number should be computed for each cross-section to evaluate the state of flow.

$$Fr = \frac{V}{\sqrt{g\bar{d}}}$$

where: v = mean velocity
g = acceleration due to gravity
$\bar{d}$ = mean depth of the cross-section: cross-sectional area / surface water width

Annexure – I

Standard form Staff gauge observation