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SUBJECT: Manual on Streamflow 2016 Edition

The Manual on Streamflow 2016 Edition has been prepared to provide a comprehensive description of standardized stream gaging procedures within the scope of streamflow data collection and processing of data for the determination of stage-discharge relationship. The manual is based on several international standards in streamflow data collection and processing which are already being implemented in different countries around the world and are considered appropriate for use in the Philippines as well.

The Manual on Streamflow is hereby prescribed for use as a training guide and reference for the National Hydrologic Data Collection Program (NHDCP) of the DPWH.

This Order shall take effect immediately.

RAUL C. ASIS
Undersecretary for Technical Services
Officer-in-Charge

5.1 DBP

Department of Public Works and Highways
Office of the Secretary
WIN7R01390

USAID
FROM THE AMERICAN PEOPLE

MANUAL ON STREAMFLOW

Technical Services for Support to the National Hydrologic Data Collection Program – Digitization of Streamflow Data

OCTOBER 2016

This publication was produced for review by the United States Agency for International Development. It was prepared by Royal Haskoning DHV with Woodfields Consultants, Inc.

MANUAL ON STREAMFLOW

Technical Services for Support to the National Hydrologic Data Collection Program – Digitization of Streamflow Data

Submitted to:

USAID Philippines

Prepared by:

Royal Haskoning DHV with Woodfields Consultants, Inc.

Report No. 24

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1. INTRODUCTION

1.1 Purpose and Scope

The purpose of this manual is to provide a comprehensive description of standardized stream gaging procedures within the scope of streamflow data collection and processing of such data for the determination of stage-discharge relation. This manual was prepared by adopting several international standards in stream gaging which are already being implemented in different countries around the world and are considered appropriate for use in the Philippines as well. The list of the international standards is presented in the succeeding section. These standards have been used extensively in the preparation of this manual; hence citations of sources are made accordingly.

The procedures discussed in this manual includes: (a) Establishing streamflow stations, (b) Operation and maintenance of these stations to collect basic streamflow data, and (c) Processing, compiling and presenting the collected data. It should be mentioned that procedures on field measurements are limited to the equipment's that are currently being used by Department of Public Works and Highways (DPWH) and the associated observational techniques only. This manual will require updating in the future when the use of new and modern equipment is implemented to include the standardized procedures associated with the new technologies for streamflow gaging.

This manual is intended for use as a training guide and reference text, primarily for the Hydrographers of DPWH Regional Offices and Engineers at the Bureau of Design (BOD) or other stream-gaging practitioners.

1.2 Streamflow Records

Streamflow serves man in many ways. It supplies water for domestic, commercial, and industrial use; irrigation water for crops; dilution and transport for removal of wastes; energy for hydroelectric power generation; transport channels for commerce; and a medium for recreation. Records of streamflow are the basic data used in developing reliable surface water supplies because the records provide information on the availability of streamflow and its variability in time and space. The records are therefore used in the planning and design of surface-water related projects, and they are also used in the management or operation of such projects after the projects have been built or activated.

Occurrence of excess stream flow can create floods causing extensive damage and hazard to life. Records of flood events obtained at gaging stations serve as the basis for the design of bridges, culverts, dams, and flood-control reservoirs, and for flood-plain delineation and flood-warning systems.

1.3 General Stream Gaging Procedures

After the general location of a gaging station has been determined from a consideration of the need for streamflow data, its precise location is so selected as to take advantage of the best locally available conditions for stage and discharge measurement and for developing a stable stage-discharge relation.

A continuous record of stage is obtained by installing a structure (non-recording gage in the case of DPWH) to be monitored by a competent local observer and record the water-surface elevation in the stream. Discharge measurements are initially made at various stages to define the relation between stage and discharge. Discharge measurements are then made at periodic intervals, usually monthly, to verify the stage-discharge relation or to define any change in the relation caused by changes in channel geometry and (or) channel roughness. At many sites the discharge is not a unique function of stage; variables other than stage must also be continuously measured to obtain a discharge record. For example, stream slope is measured by the installation of a downstream auxiliary stage gage at stations where variable backwater occurs. At other sites a continuous measure of stream velocity at a point in the cross section is obtained and used as an additional variable in the discharge rating. The rate of change of stage can be an important variable where flow is unsteady and channel slopes are flat. However, for this manual, only the simple stage-discharge relation has been discussed.

Artificial controls such as low weirs or flumes are constructed at some stations to stabilize the stage-discharge relations in the low flow range. These control structures are calibrated by stage and discharge measurements in the field.

The data obtained at the gaging station are reviewed and analysed by engineering personnel at the end of the water year. Discharge ratings are established, and the gage-height record is reduced to mean values for selected time periods. The mean discharge for each day and extremes of discharge for the year are computed. The data are then prepared for publication.

1.4 International Standards in Stream Gaging

The following are standards used extensively in the preparation of this Manual:

- The World Meteorological Organization (WMO) which was formed in 1950 is a specialized agency of the United Nations for meteorology. It provides a framework for international cooperation in the development of meteorology and operational hydrology and their practical application. WMO publishes guides and technical reports on stream gaging which are circulated to its 191 member countries. The Manual on Stream Gaging (WMO-No. 519) first released in 1980 and later updated by WMO-No. 1044 in 2010 encompasses the topics of gage height measurement, stream velocity and stream discharge in Volume I while Volume II focuses on the discharge rating relationship.

- The United States Geologic Survey (USGS) has several publications, in particular the manuals on Measurements and Computation of Streamflow (Water Supply Paper 2175, 1982 by S.E. Rantz and others), Volume I - Measurement of Stage and Discharge and Volume II – Computation of Discharge. These manuals were prepared with the purpose of providing a comprehensive description of standardized stream gaging procedures and are intended for use as a training guide and reference text, primarily for USGS personnel but also for use by other stream gaging practitioners in the USA and elsewhere in the world. Likewise, Discharge Measurements at Gaging Stations Chapter 8 of Book 3, Section A (Techniques and Methods 3-A8) as well as the Standards for the Analysis and Processing of Surface Water Data and Information Using Electronic Method – USGS Water Resources Investigation Report 01- 4044 which provide standards from which a completely automated electronic processing system is developed have also been used as references in the preparation of this Manual.

- The Manual on Procedures in Operational Hydrology prepared jointly by the Ministry of Water, Energy and Minerals of Tanzania and the Norwegian Agency for International Development (NORAD). Authored by Osten A. Tilrem, senior hydrologist at the Norwegian Water Resources and Electricity Board, the manual consists of five volumes dealing with establishment and operation of stream gaging station, discharge measurement by current meter method and relative salt dilution, stage-discharge relations at stream gaging stations and sediment transport in streams.

- The International Organization for Standardization (ISO) in 1964 set up a technical committee on streamflow measurement known as ISO/TC 113. The technical committee deals with the standardization of methods, procedures, instruments, and equipment relating to techniques for hydrometric determination of gage height, velocity, discharge and sediment transport in open channels, precipitation and evapotranspiration, availability and movement of groundwater, including: terminology and symbols, collection, evaluation, analysis, interpretation and presentation of data and evaluation of uncertainties. To date ISO/TC 113 have 19 participating countries and 16 observing countries and have published a total of 65 ISO Standards.

- The Indian Bureau of Standards published several standards on Measurement of Liquid Flow in Open Channels which are mostly adaptation of ISO published standards.

2. SURFACE WATER DATA AND INFORMATION

Surface water data and information are composed of a number of measured and computed variables. This section describes some of these variables, and will define some of the terminology used throughout the manual. These definitions will be the adopted standards by the DPWH – BOD for stream gaging.

2.1 Definition

Common terms as defined by Sauer (2002) and presented in the WMO and USGS standards, the words data and information have special meanings. The term data is used for the results obtained from the measurement of basic variable, which cannot be repeated. Data can be accepted as they are, qualified, or rejected, but they cannot be modified without compromising their identity as data. Any change or modification of a data value converts that value into information. Gage height observations submitted by Gage Keepers are considered data as well as the discharge measurement values obtained by the Hydrographic Engineers when they conduct the measurements in the field.

In such a case that the original gage heights have to be adjusted due to correction in gage datum elevation, then the new value of gage heights are considered information. Another example is the conversion of gage height into discharge value through the stage-discharge relationship or rating curve. The computed discharge value is information. Unlike data, information can be modified, as in the case when stage-discharge relation has to be revised due to changes in river condition. Data are generally treated as primary record, whereas information are usually treated as secondary record.

2.2 Gage height, stage and elevation

Gage height, stage and elevation are interchangeable terms used to define the height of the surface of a water feature, such as a stream, reservoir, lake, or canal. For a stream gaging station, gage height is the more appropriate terminology, but the more general term "stage" is sometimes used interchangeably. For lakes, reservoirs and tidal streams, the height of the water surface usually is referred to as elevation. Gage height (also stage) is measured above an arbitrary gage datum whereas elevation is measured above an established vertical datum, such as mean sea level. Gage heights and elevations are principal data elements in the collection, processing, and analysis of surface-water data and information. Gage heights and elevations are measured in various ways, such as by direct observation of a gaging device, or by automatic sensing through the use of floats, transducers, gas-bubbler manometers and acoustic methods. Gage heights and elevations should be measured and stored as instantaneous unit values. Subsequent data processing and analysis will provide the means for any required analysis, such as averaging.

2.3 Stream Velocity

Stream velocity is another data element in a stream gaging system. Unit values of stream velocity are measured at some sites for the purpose of computing stream discharge. This is done most commonly where variable backwater conditions are present. Unit values of stream velocity are measured at some sites where variable backwater is not present to improve the calculation of discharge.

2.3.1 Discharge Information

Streamflow or river discharge is the volume of water flowing past a given point in the river in a given period of time. It is the variable usually required for hydrological analysis but continuous measurement of flow past a river section is usually impractical or prohibitively expensive. Discharge cannot be computed directly. It is computed from other measured variables namely; gage height, stream depth, stream width and stream velocity. Therefore, discharge is considered to be information rather than data. Since gage heights can be observed continuously with comparative ease and economy, hence it is common practice to develop a rating curve which is the relationship between gage height and discharge at a cross-section of a river to transform the observed gage heights into the corresponding discharges. Daily mean values of discharge are computed from the daily mean values of gage height.

2.3.2 Unit value

Unit value used to denote a measured or computed value of a variable parameter that is associated with a specified instantaneous time and date. In addition, unit values generally are part of a time-series data set. For surface water records, unit values for all parameters always should be instantaneous values. Some parameters, such as velocity, tend to fluctuate rapidly and a true instantaneous value would be difficult to use in the analysis and processing of the records. Some instruments are designed to take frequent (for example, every second) readings, temporarily stored these readings, and then compute and store a mean value for a short time period. For these situations, the field instruments are programmed to record mean unit values for very short time intervals, so they can be considered for practical purposes to be instantaneous unit values. Data recorded for very short time intervals are sometimes referred to as a high-resolution data.

2.3.3 Daily values

Daily values are measured or computed values for a specific date only. The time of the daily value is not usually required although for certain values, time is stated. Examples of daily values are daily mean gage heights, maximum instantaneous gage height for a day and minimum instantaneous gage height for a day, which are also considered extreme values. In the case of maximum and minimum instantaneous values for a day, the time of occurrence usually is stated.

2.4 Units of measurement

The units of measurement used for this manual is the International System of Units (SI) units in accordance with the appropriate parts of ISO 31, which is revised by ISO 80000-1:2009 and ISO 1000:1992.

3. Selection Of Gaging Station Sites

3.1 Considerations in specific site selection

After the general location of a gaging station has been determined, a specific site for its installation must be selected. For example, if the outflow from a reservoir is to be gaged to provide the streamflow data needed for managing reservoir release, the general location of the gaging station will be along the stretch of stream channel between the dam and the first stream confluence of significant size downstream from the dam. From the standpoint of convenience alone, the station should be established close to the dam, but it should be far enough downstream from the outlet gates and spillway outlet so that the flow is fairly uniformly established across the entire width of the stream. On the other hand the gage should not be located so far downstream that the stage of the gaged stream may be affected by the stage of confluent stream. Between those upstream and downstream limits for location of the gage, the hydraulic features should be investigated to obtain stage and discharge measurement and for developing a stable stage-discharge relation if the velocity area method is to be used.

If the proposed gaging station is to be established for purely hydrologic purposes, unconnected with the design or operation of a project, the general location for the gage will be the reach of channel between two large tributary or confluent streams. The gage should be far enough downstream from the upper tributary so that flow is fairly uniformly established across the entire width of stream; and far enough upstream from the lower steam confluence to avoid variable backwater effect. Those limits often provide a reach of channel of several kilometers whose hydraulic features must be considered in selecting a specific site for the gage installation.

The ideal gage site satisfies the following criteria as stated in the WMO Manual on Stream Gaging Volume I, many of which are defined in ISO 1100-1 and adapted by IS 15119-1:

a. The general course of the stream is straight for about 10 times the stream width, upstream and downstream from the gage site if the control is a river reach (channel control). If the control is a section control, the downstream conditions must be such that the control is not drowned. The water entering a section control should have low velocity;
b. The total flow is confined to one channel at all stages and no flow bypasses the site as subsurface flow;
c. The stream-bed is not subject to scour and fill and is relatively free of aquatic vegetation;
d. Banks are permanent, high enough to contain floods, and are free of brush;
e. Unchanging natural controls are present in the form of a bedrock outcrop or other stable riffle for low flow and a channel constriction for high flow – or a waterfall or cascade that is un-submerged at all stages. If a natural control is not available, then channel conditions should allow for the construction of an artificial control such as weir or flume;

f. A pool is present upstream from the control at extremely low stages to ensure a recording of stage at extremely low flow. The sensitivity of the control should be such that any significant change in discharge should result in a measurable change in stage;
g. A gage site is far enough upstream from the confluence with another stream or from tidal effect to avoid any variable influence the other stream or the tide may have on the stage at the gage site;
h. A satisfactory reach for measuring discharge at all stages is available within reasonable proximity of the gage site. It is not necessary for low and high flows to be measured at the same stream cross-sections;
i. The site is readily accessible for ease in installation and operation of the gaging station;
j. Within reach of a suitable telemetry system, for future development.

Rarely will an ideal site be found for a gaging station and judgment must be exercised in choosing between adequate sites, each of which has some shortcomings. More often, it is possible these adverse conditions are present in considering the installation of an essential gaging station, and that such condition must be accepted. For example, all streams in a given region may have unstable beds and banks, which result in continually changing stage-discharge relations.

4. Gaging Station Controls

4.1 Types of Controls

The conversion of a record of gage height to a record of discharge is done by use of a stage-discharge relation. The physical element or combination of elements that controls the relation is known as the control. The channel characteristic forming the station control include the cross-sectional area and shape of the stream channel, the channel sinuosity, the expansions and restrictions of the channel, the stability and roughness of the stream bed and banks, and the vegetation cover, all of which collectively constitute the factors determining the channel conveyance.

Controls are mainly differentiated as section controls and channel controls. Another classification differentiates between natural and artificial controls. Artificial controls are structures built for the specific purpose of controlling the stage-discharge relation, such as weir, flume, or small dam (a highway bridge or paved floodway channel that serves incidentally as a control is not classed as an artificial control). A third classification differentiates between complete, partial, and compound controls.

4.2 Section control

A section control exists when the geometry of a single cross section a short distance downstream from the gage is such as to constrict the channel, or when a downward break in bed slope occurs at the cross section. The constriction may result from a local rise in the streambed; at a natural riffle or rock ledge outcrop, or at a constructed weir or dam; or it may result from a local constriction in width, which may occur naturally or be caused by some man-made channel encroachment, such a bridge whose waterway opening is considerably narrower than the width of the natural channel. Examples of a downward break in bed slope are the head of a cascade or the brink of a falls.

4.2.1 Channel control

Channel control exists when the geometry and roughness of a long reach of the channel downstream from the gaging station, are the elements that control the relation between the stage and discharge. The length of channel that is effective as a control increases with discharge. Generally speaking, the flatter the stream gradient, the longer the reach of channel controls.

4.2.2 Permanent Controls

Regardless of how stable and permanent a control may appear, it is always possible that a change may occur in the original physical features forming the control. The fact that a change in a generally recognized permanent control may not be readily identified is no assurance that the stage-discharge relation has remained unchanged. The nature of the change is more often a result of non-observance of changes in the controlling elements during routine inspections. On the other hand, some of the physical characteristics of a control may appear to have changed, yet the nature of the change may be such as not to include those features which materially affect the stage-discharge relation. Positive assurance that a change has not occurred in the stage-discharge relation is attainable only by comparing the results of discharge measurements with the previously established discharge rating curve.

4.2.3 Shifting Controls

The term shifting controls as used in stream gaging signifies that the stage-discharge relation does not remain permanent but varies or changes with time. In such cases, the physical features forming the station control undergo changes, either abruptly or gradually; the stage-discharge relation will also vary in that the stage corresponding to a given discharge will deviate from the discharge rating curve as defined before the change.

It should be recognized that most natural controls shift slightly. However, shifting control exists where the stage-discharge relation changes frequently, either gradually or abruptly because of changes in the physical features that form the control of the station. The frequency and magnitude of such shifts are generally dependent upon the climatic, physiographic, geologic, and vegetal and soil conditions in the drainage basin. Usually, shifts in a control are caused by erosion of the stream channel, deposition of sediment, or vegetal and aquatic growth in the stream channel.

4.3 Attributes of a satisfactory control

The two attributes of a satisfactory control are permanence (stability) and sensitivity. If the control is stable, the stage-discharge relation will be stable. If the control is subject to change, the stage-discharge relation is likewise subject to change, and frequent discharge measurements are required for the continual recalibration of the stage-discharge relation. In this case, it increases the operating cost of a gaging station, and results in impairment of the accuracy of the streamflow record. The primary cause of changes in natural controls is the high velocity associated with high discharge. Of the natural section controls, a rock ledge outcrop will be unaffected by high velocities, but boulder, gravel, and sand-bar riffles are likely to shift, boulder riffles being the most resistant to movement and sand bars the least resistant. Of the natural channel controls those with unstable bed and banks, as found in sand-channel streams, are the most likely to change as a result of velocity-induced scour and deposition. Another cause of changes in natural controls is vegetal growth. The growth of aquatic vegetation on section controls increases the stage for a given discharge, particularly in the low-flow range. Vegetal growth on the bed and banks of channel controls also affects the stage-discharge relation by reducing velocity and the effective waterway area. In the temperate climates, accumulations of waterlogged fallen leaves on section controls each autumn clog the interstices of alluvial riffles and raise the effective elevation of all natural section controls. The first ensuing stream rise of any significance usually clears the control of fallen leaves.

Controls, particularly those for low flow, should be sensitive; that is, a small change in discharge should be reflected by a significant change in stage. To meet that requirement it is necessary that the width of flow at the control be greatly constricted at low stages. In a natural low-water control such constriction occurs if the control is in effect notched, or if the controlling cross section roughly has a flat V-shape or a flat parabolic shape. Those shapes will ensure that the width of flow over the control decreases as discharge decreases. Generally speaking, a low-water control is considered to be sensitive if a change of no more than 2 percent of the total discharge is represented by a change of one unit of recorded stage.

This unit is usually taken to be 3 mm in the United Kingdom of Great Britain and Northern Ireland and the USA, and may also be adopted in the Philippines. Therefore, for the low-water control to be regarded as sensitive, a change in stage of 0.003 m or 3 mm should represent a change of no more than about 2 percent of the total discharge.

In the interest of economy a gaging station should be located upstream from a suitable natural control. However, where natural conditions do not provide the stability or the sensitivity required, artificial controls should be considered. The artificial controls are all section controls; it is not feasible to pave or otherwise improve a long reach of channel solely for the purpose of stabilizing the stage-discharge relation.

5. STREAM GAGING STATION STRUCTURES

There are several structures used at gaging stations namely;

1. Water level gage and benchmark. The gage is usually a non-recording vertical staff gage or an inclined staff gage set at a chosen datum and referred to a benchmark;
2. Automatic water-level recorder. The automatic recorder is usually a float-actuated recorder with house and stilling well;
3. A structure for taking current-meter measurements, usually a cableway or a footbridge;
4. An artificial control such as flume or a weir.

At present, only the first item is available in all the stream gaging stations nationwide. There used to be gaging stations equipped with an automatic water level recorder with housing and stilling well operated by the then National Water Resources Council (NWRC), however it was reported that none of these stations are operational. The third item may or may not be needed depending on the gaging conditions at existing bridges and the natural condition at site.

The highway bridges used in making streamflow measurements must be utilized as they are found. The only problem they present is whether or not they will be practicable for making discharge measurements. The only advantage of using existing bridges is the saving in construction and maintenance costs that is associated with cableways, but this advantage is often outweighed by the poor measuring conditions at the bridge; the inconvenience entailed in using some bridges, and the safety hazard caused by traffic conditions. A bridge that is used regularly for discharge measurements is marked at suitable intervals on the handrail or some similar feature of the bridge for convenient spacing of the verticals during discharge measurements. No standard design for footbridges for stream gaging is recommended, because each footbridge installation presents its own particular and unique condition. The type of footbridge used will depend on span, availability of material, stability of banks, accessibility of the site, type of equipment to be used and funds available. Footbridges should be designed so that they give the hydrographer room to move about and to operate the current meter equipment comfortably.

If there are plans to construct facilities for a gaging station, it should be very carefully planned to be certain that the resulting structures are correctly located, safe, and economical to operate and maintain.

5.1 The Staff Gage

The staff gage is the type of gage ordinarily used at non-recording gaging stations. The staff gage may be either vertical or an inclined gage following the contour of the bank of the stream. The vertical staff gage usually consists of standard painted wood. The graduations of a gage may be marked directly on the surface of the wood. The sections are supplied in lengths of 1.00 and 0.50 meter and are graduated in 0.01 or 0.02 meter. The sections are usually screwed to a board which is fastened to a suitable support. Preferably, the gage should be placed near the side of the stream so that a direct reading of the water level may be made.

The gage should be located near to the current meter measuring section without affecting the flow conditions at this point. It should not be placed where the water is disturbed by turbulence or where there is danger of damage by drift. Bridge abutments or piers are generally unsuitable locations. Where ever the gage is situated, it must be readily conveniently accessible so that the observer may make readings as near as possible at eye level. Where necessary, the construction of a flight of steps to give convenient access is recommended. Gages may also be fixed to piles, either driven firmly into the river bed or banks or set in concrete in order to avoid sinking, tilting or washing away. In either case, the anchorage should extend below the ground surface to a level free of any disturbing effects. Where the range of water levels exceeds the capacity of a single vertical gage section, additional sections may be installed on the line of the cross section normal to the direction of flow.

An inclined gage usually consists of heavy wood securely attached to a permanent foundation. The graduations of an inclined gage may be marked directly on the surface of the wood or may be carried on manufactured gage plates designed to be set for particular slopes. Except where use is made of manufactured gage plates, an inclined gage should be calibrated in situ by accurate levelling from the station benchmark. Usually, various sizes of bronze numerals are used for the graduations. An inclined gage should be installed so that it follows the contour of the bank. The profile of the bank may be such that a gage of a single slope may be installed; frequently, however, it may be necessary to construct the gage in several sections, each with a different slope. It is often convenient to construct a flight of steps alongside the inclined gage to facilitate taking readings. The accuracy of readings of an inclined gage may be improved if a small portable stilling tube made of transparent material is used when reading it.

5.2 Datum of Gage

For gage height data to be useful for their intended purposes, requirements for maintaining a permanent gage datum and meeting specified accuracy limits are important. The datum of the gage may be a recognized datum, such as mean sea level, or an arbitrary datum plane chosen for convenience. An arbitrary datum plane is selected for the convenience of using relatively low numbers for gage heights. The arbitrary datum plane for a stream gaging site should be selected so that negative values of gage height do not occur. This requires the arbitrary datum plane to be below the lowest expected gage height, which will be at, or below, the elevation of zero flow on the control for all conditions.

A permanent gage datum should be maintained, if at all possible, so that only one datum for the gage height record is used for the life of the gaging station. To maintain a permanent datum, each gaging station requires at least two or three reference marks; that is, permanent points of known gage-height elevation that are independent of the gage structure. The datum at each gaging station is periodically checked by running levels from the reference marks to the gages at the station. If an arbitrary datum plane is used, it is desirable that it be referred by levels to a benchmark of known elevation above mean sea level, so that the arbitrary datum may be recovered if the gage and reference marks are destroyed. Levels should be run at least once a year at new gage sites and at sites where the datum is not stable. After it is confirmed that the datum is fairly stable, levels can be run every 2 or 3 years, and in some cases an even longer time between levels may be acceptable.

The gage datum may require a change when excessive channel scour, or a manmade channel change, occurs. It is recommended that such a change be in increments of whole meter so the new datum can be easily related to the old datum. In some instances the gage itself may need to be relocated to another site. The relation between the datum for the new gage site and the datum for the old gage site should be defined by levelling; however, it is not usually necessary to use the same datum at both sites. A permanent record of all datum changes should be maintained.

5.3 The Local Observer (Gage Keeper)

The reading of staff gauges is the first basic step in hydrometric work. It is important that this task is performed accurately and properly, if not, the rest of the activities related to operating a gaging station will have a greatly reduced value. The frequency of gauge readings for non-recording gauges will be an important factor in the accuracy of the continuous discharge record to be converted from these readings. In order to ensure uninterrupted operation of a non-recording station, the routine attendance of a competent local observer is essential, especially under extreme conditions (i.e. during typhoons or torrential rains). Normally, the staff gage is read three times a day, additional readings are required when the gage height is changing more rapidly than usual especially during storm events.

Given this case, an observer will be needed at a gaging station; the site selected should be near a populated area where people of sufficient ability to perform the duties of an observer are available. The necessity of having a station near adequate roads becomes more important if an observer is needed, because few people are willing to move great distances to become a gaging station caretaker/observer.

6. COLLECTION OF STREAMFLOW DATA

6.1 Measurement of Gage Height

The collection of stage data, either manually or automatically, requires that various instruments be installed at a gaging site. For stage data to be useful for their intended purposes, requirements for maintaining a permanent gage datum and meeting specified accuracy limits are important. This section of the Manual provides definitions of the components, as well as the basic accuracy requirements.

6.1.1 General

Records of gage height are used with a stage-discharge relation in computing records of stream discharge. The reliability of the discharge record is therefore dependent on the reliability of the gage height record as well as on the accuracy of the stage-discharge relation. Records of stream stage are also useful in themselves for such purposes as the design of structures affected by stream elevation and the planning of flood-plain use. The gage-height record of a lake or reservoir provides, in addition to elevations, indexes of surface area and volume of the water body.

A record of stage may be obtained by systematic observations of a non-recording gage or by means of a water-stage recorder. The advantages of the non-recording gage are the low initial cost and the ease of installation. The disadvantages are the need for an observer and the lack of accuracy of the estimated continuous-stage graph drawn through the plotted points of observed stage. For long-term operation the advantages of the recording gage far outweigh those of the non-recording gage. While DPWH continues to use the non-recording gages, future upgrading and expansion of the gages will have to migrate to recording-gages. In this case, one or more non-recording gages should be maintained as auxiliary gages for the operation of the recording station.

6.1.2 Basic requirements for collecting gage height data

The collection of gage height data requires installation of instruments at a gaging site. For gage height data to be useful for their intended purposes, requirements for maintaining a permanent gage datum and meeting specified accuracy limits are important. A record of gage height could be obtained by systematic observation of a non-recording gage. As mentioned earlier, the main advantage of a non-recording gage is the low initial cost however; disadvantages include the need for an observer and lack of accuracy as the observation is as good as the observer.

The currently used type of non-recording station in the Philippines is the staff gage. At such stations the staff gage is read three times daily by an observer, preferably at 8:00 AM, 12:00 NOON and 5:00 PM. Additional readings should be made during periods of rapidly changing gage height possibly every hour as long as the life and safety of the observer will not be put at risk. The observer systematically records and reports his readings to headquarters. The record book is used to log permanent gage height readings. This will also serve as a back-up copy of gage height observations should the electronic files of such are destroyed or corrupted.

On each routine visit to a non-recording stream-gaging station, the gagekeeper also visits the observer to collect and enter in the stage-record book the gage reading(s) that the gagekeeper has made. At that time, he also inspects the record book to check for discrepancies in the observer's readings.

6.1.3 Factors affecting the accuracy of the Gage Height Record

Continuous records of discharge at a gaging station are computed from the record of stage and the stage-discharge relation. For that purpose stage records having an accuracy of 0.01 ft. (0.003 m) are generally required. The accuracy of any gage concerns the maintenance of the gage datum to the accuracy criterion of 0.003 m. That is achieved by running levels to reference marks for the gage and, if necessary, adjusting the gage to restore the original datum. Levels should be run at least once every 2-3 years and more often if conditions are known to be unstable.

6.1.4 Non-recording gages (Staff gage)

Settlement or uplift of the structure(s) supporting the staff gage may disturb the gage datum. Where levels from a reference mark show that the datum of an inclined staff gage has been disturbed, the gage is recalibrated by removing the staples used for the graduations and replacing them at the proper elevations. Vertical staff gages are usually made up of several lumber boards, each about 1.0 m to 2.0 m long and bearing permanent graduations. Where levels from a reference mark show disturbance of the datum of a vertical staff gage, it is necessary to reset the individual gage sections.

It is often difficult to accurately detect the water line when making staff-gage observations under the conditions of poor light and (or) clear water. Under those conditions it is helpful to float a matchstick or some similar floatable material against the gage and thereby define the water line. When the water surface is surging rapidly as a result of wave action, the stage to be recorded is the mean of the elevations of the peak and trough of the waves.

6.1.5 Stage accuracy requirements

The primary use of gage height data is for computation of streamflow records, consequently gage height accuracy requirements are very stringent. In accordance with this primary use and because the use of gage height data cannot be predicted, the overall accuracy of gage height data established for gaging station is either 0.003 m, or 0.2 percent of the effective height, whichever is greater. For example, the required accuracy would be 0.02 m at a 10 m effective height, 0.006 m at 3 m and 0.003 m for at all effective stages less than 1.75 m.

The accuracy criteria applies to the complete stream gaging station configuration and is a composite of errors, or total error, from all of the components necessary for recording and retrieving the data. When field conditions such as high velocities, wave action or channel instability make it impossible to collect accurate gage height data or to define an accurate stage-discharge relation, gage height data should be collected with the greatest accuracy feasible.

6.1.6 Sources of stage measurement errors

The measured stage of a stream or other water body at any given point in time is subject to numerous sources of incremental errors. The combined effect of these errors should be within the accuracy requirements stated in section 6.1.5. The accuracy requirement for any single component of a stage measuring system will generally be more stringent than the requirement for the system as a whole. However, it is not always possible to isolate, or pinpoint an error and attribute it to one specific component. This part of the report describes the various sources of error in general.

6.1.6.1 Datum errors

The gage datum is described in Section 6 of this manual. Movement of a gage caused by uplift or settlement of the supporting structure can cause datum errors that can only be detected by running levels. Gage datum for reference gages should be maintained to an accuracy of 0.003 m, which can usually be achieved by running levels to established reference marks every 2 or 3 years. Levels may be required at more frequent intervals where conditions are not stable. Generally, gages need not be adjusted unless datum discrepancies exceed 0.006 m.

6.1.6.2 Gage reading errors

Errors can result from inaccurate gage readings where it may be difficult to detect the water line against a staff gage because of poor lighting or very clear water. In other instances accurate gage readings may be difficult to make because of water surge. These errors can be reduced or eliminated by careful observation and in the case of surge by averaging several observations. Other errors can be caused by site conditions such as the reading of a wire-weight gage with the weight lowered from a very high bridge. In almost all cases gages should be read to the nearest 0.003 m. If gages cannot be read to this accuracy, notes should be made and the error magnitude estimated.

6.1.6.3 Verification errors

Stage readings require frequent and consistent verification to ensure that errors are reduced or eliminated. Failure to perform proper verification standards can be significant in some cases. Verification procedures include frequent observation of high water marks, redundant recording of peaks and troughs by the use of maximum/minimum indicators, and regular maintenance of gage datum by levels.

6.1.7 Field Procedure

The local observer (gage keeper) collects the gage height data in the field regularly three times a day. Preferably, the readings shall be made at 8:00 AM, 12 NOON and 5:00 PM. However, arrangements were made to have additional readings when the gage height is changing more rapidly than usual especially during storm events. If possible, readings should be made every hour so long that the observer is safe to stay in the gaging site. It is important that the local observer record the exact time and the correct date of each gage observation. The station gage keeper will be provided with a mobile device and the gage keeper is required to transmit the observed gage height promptly.

6.1.7.1 Field Notes

Field Notes are documents used to annotate and record information gathered at the station. They are data sheet and should be treated as such. Therefore, they should be written, legible, and complete. To avoid confusion and loss of data, a new sheet should be used every month at each gaging station. Field notes should be initialled and dated by the collecting gagekeeper.

6.1.7.2 Data Storage

All completed paper copies of forms and data sheets should be maintained with the appropriate station notebook. The data from the field notes data sheets should be collected by the Regional Hydrographers every month and should be stored properly.

6.1.7.3 Data Transmission

Onsite gage height observations should be sent immediately to the server through SMS by the designated gage keeper. The instruction for sending the field measurement data is shown below and should be followed strictly to avoid error and failure of transmission to the server. The gage keeper is also instructed to remain at the station until the server sends a message confirming the receipt of the transmitted data.

Gage height: 0.00
Date: DDMMMYYYY
Time: 00:00
Comment: any text

GAGE HEIGHT space DATE space TIME space COMMENT
GAGE HEIGHT␣ DATE␣ TIME␣ COMMENT

Example: 2.35␣ 02Jun2016␣ 07:00␣ No rain

Figure 6-1 shows the standard data flow, from the field observation of gage heights to transmission to the server, validation and verification of Regional Hydrographers to the accuracy and integrity of the data and finally submission of such data to the central server to be archived as collected streamflow data. **Figure 6-2** shows the detail of SMS transmission to the server.

Quality assurance of the data collected includes the timely transmission of field observations through SMS and accurate documentation in paper records, regional personnel auditing of such records consistently and conscientiously using the procedures to ensure integrity and data quality.

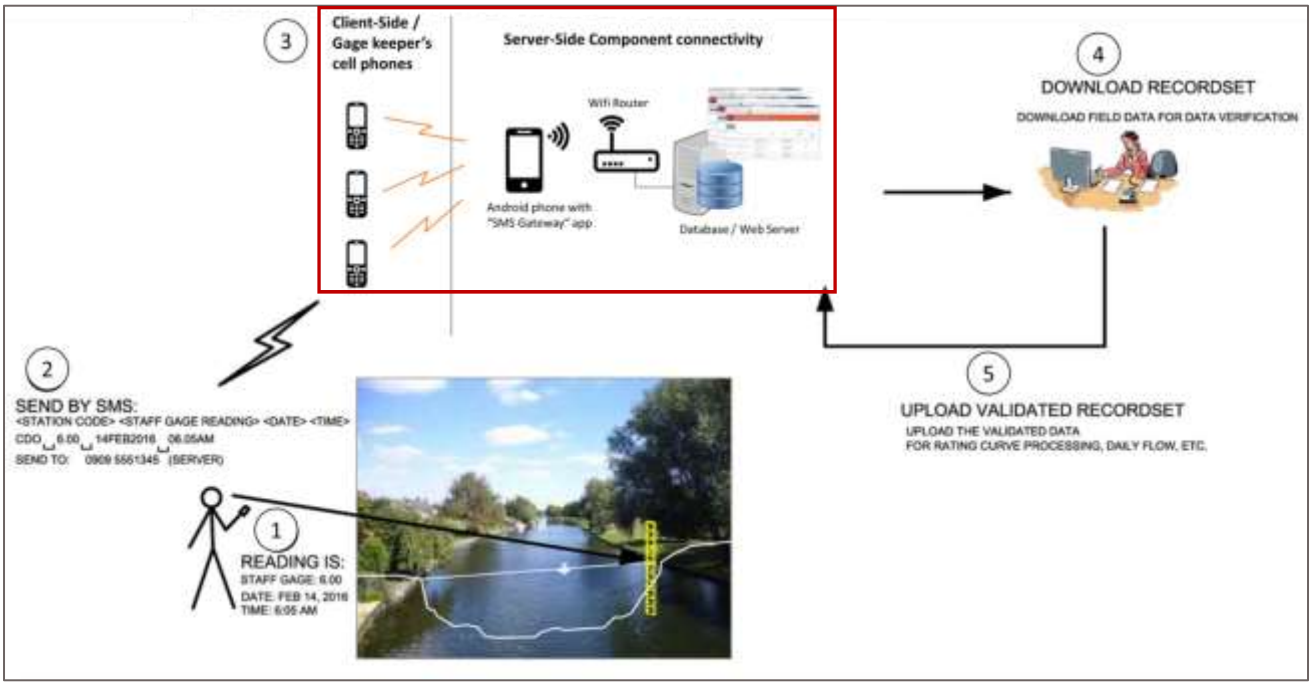


Figure 6-1. Data flow for Water Level Data Collection

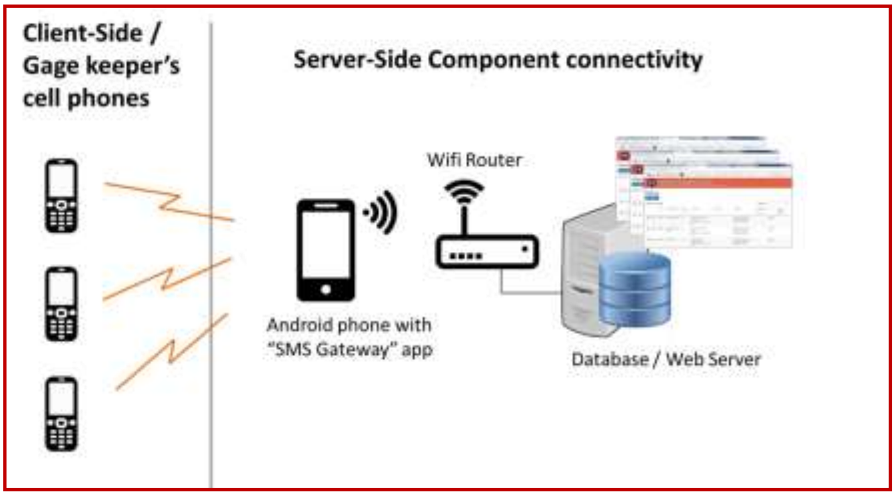


Figure 6-2. Detail of SMS transmission to the server

6.2 Measurement of Discharge

6.2.1 Introduction

Streamflow, or discharge of a stream, is defined as the volume of water flowing through a cross-section of the stream per unit of time, including any substances suspended or dissolved in the water. Discharge is usually expressed in cubic meters per second (m^3/s). Discharge is the most important parameter in hydrology; its measurement usually involves consideration of both gage height and velocity of flow.

Discharge measurements are made at each gaging station to determine the discharge rating for the site. The discharge rating may be a simple relation between stage and discharge or a more complex relation in which discharge is a function of stage, slope, rate of change of stage, or other factors. Initially the discharge measurements are made with the frequency necessary to define the station rating as early as possible, over a wide range of stage or gage heights. Measurements are then made at periodic intervals, usually monthly, to verify the rating or to define any changes in the rating caused by changes in stream channel conditions.

The Current Meter Method is the method employed by the DPWH in discharge measurements. Also known as the area-velocity method, because of its flexibility to a wide range of flow velocities and is practically unrestricted with respect to the total discharge which can be measured, provided the flow is not turbulent. Stream discharge is by definition the product of velocity and cross-sectional area of flow and this method evaluates these two terms for a particular cross section at a particular time. This section describes the discharge measurement using the conventional current-meter method.

With velocity-area method, discharge of a stream is computed as the product of the area and velocity. A current-meter measurement is the summation of the products of the subsection areas of the stream cross section and their respective average velocities. Equation 1 represents the computation of discharge.

$$\boldsymbol{Q} = \sum_{i=1}^{n}(\boldsymbol{a}_i \boldsymbol{v}_i) \qquad (1)$$

Where

Q = total discharge in cubic meter per second,

a_i = cross-section area, in square meter, for the *i*th segment of the *n* segments into which the cross section is divided, and,

v_i = the corresponding mean velocity, in meter per second of the flow normal to the *i*th segment, or vertical

6.2.2 Instrument and Equipment

6.2.2.1 Current Meters

A point-velocity current meter is a precision instrument calibrated to measure the velocity of flowing water in a single point. There are several types of current meters available for use that include the rotating-element mechanical meters, electromagnetic meters, acoustic Doppler Velocimeters (ADVs or FlowTrackers), acoustic digital current meters (ADCs), and optical meters. However, the rotating-element mechanical meter is the only instrument currently being used by the Regional Hydrographers of DPWH. The principle of operation for a mechanical meter is based on the proportionality between the velocity of the water and the resulting angular velocity of the meter rotor. By placing a mechanical current meter at a point in a stream and counting the number of revolutions of the rotor during a measured interval of time, the velocity of water at that point can be determined from the meter rating.

The meter most commonly used by the USGS to measure open-channel velocities in rivers and streams as well as in the Philippines, is the vertical-axis, mechanical current meter. The original prototype for this kind of current meter was designed and built in 1882 by W.G. Price, while he was working with the Mississippi River Commission. The Price current meter has evolved through a number of different models and refinements since 1882, but the basic theory and concepts remain the same. The Price AA meter is the most commonly used mechanical current meter for discharge measurements made by the USGS; however there are other variations of this meter, such as the Price AA slow velocity, the Price pygmy, and the Price AA winter meter. In the Philippines, aside from the Price AA, only the Price pygmy type is being used by the DPWH.

1. Price AA Meter

Historically, most current-meter measurements made by the USGS and adopted in the Philippines since the start of streamflow data collection activities in the country have been made with the vertical-axis Price AA and the Price pygmy current meters, as shown in **Figures 6-3A** and **6-3B**. The basic components of the Price AA meter include the shaft and rotor (bucket wheel) assembly, the contact chamber, the yoke, and the tailpiece. **Figure 6-4** shows the assembly drawing of Price AA current meter where the different parts are components of the meter are shown. The rotor, or bucket wheel, is 0.127 m (5 in.) in diameter and 0.0508 m (2 in.) high with six cone-shaped cups mounted on a stainless-steel shaft. A vertical pivot supports the vertical shaft of the rotor, hence the name vertical-axis current meter. The contact chamber houses the upper part of the shaft and provides a method of counting the number of revolutions the rotor makes. A reduction gear (commonly referred to as the penta gear) on the lower part of the shaft allows counting every fifth revolution of the rotor when it is activated. The penta gear is used in discharge measurements with very high velocities. Contact chambers that can be used on the Price AA meter are described in a later section of this chapter. The yoke is the framework that holds the other components of the meter. A tailpiece is used for balance and keeps the meter pointing into the current.

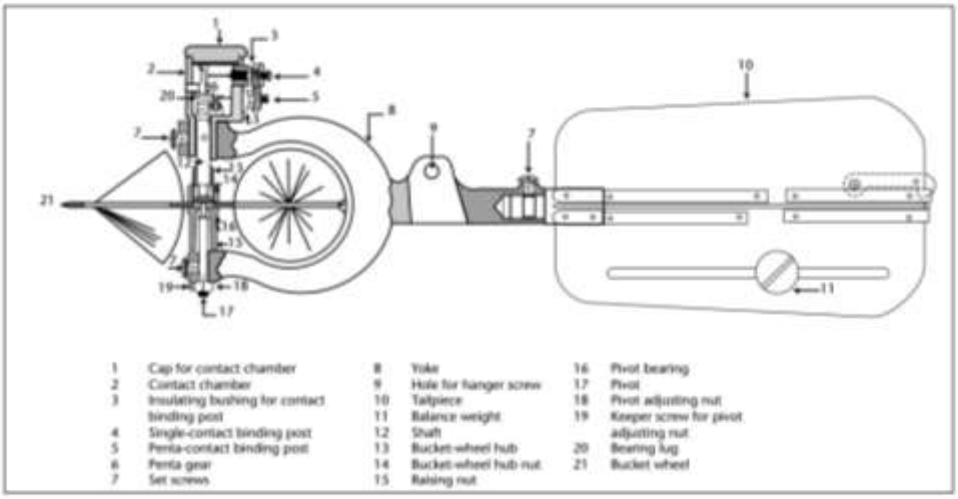
When placed in flowing water, the rotors of the Price current meters turn at a speed proportional to the speed of the water. For practical purposes, these current meters are considered non-directional because they register the maximum velocity of the water, even though they may be placed at an angle to the direction of flow.

Advantages of the vertical-axis current meter are:

- They operate in lower velocities than do horizontal-axis meters.
- Bearings are well protected from silt-laden water.
- The rotor is easily repairable in the field without adversely affecting the rating.
- USGS standard ratings apply to the Price AA and Price pygmy meters.
- A single rotor serves for the entire range of velocities.

Source: V.B., 2010, Discharge measurements at gaging stations
U.S. Geological Survey Techniques and Methods

Figure 6-3. A-Price AA current meter, B-Price Pygmy Current Meter



Source:2010, Manual on Stream Gaging, Volume I –Fieldwork, WMO-1044

Figure 6-4. Assembly drawing of the Price AA current meter

2. Price Pygmy Meter

A miniature version of the Price AA meter is the Price pygmy meter, as shown in **Figure 6-3B**, which is used for measuring velocities in shallow depths. The Price pygmy meter is scaled two-fifths the size of the standard meter and has neither a tailpiece nor a penta gear. The contact chamber is an integral part of the yoke of the meter. The Price pygmy meter makes one contact for each revolution and is used only for rod suspension.

3. Rating of Mechanical Current Meters

In order to determine the velocity of the water from the revolutions of the rotor of a mechanical current meter, a relation must be established between the angular velocity of the rotor and the velocity of the water turning it. This relation is referred to as the current-meter rating, and is expressed in an equation or in tabular format.

Standard current-meter ratings have been defined for the Price AA and the Price pygmy. There is a standard rating equation that can be used for the two types of Price current meters using the field observation data of revolution and time obtained during measurements. However, some Regional Hydrographers prefer the use of the established current meter ratings in determining the corresponding velocity for the observed revolution and time. **Table 6-1** show the velocity rating table for Price AA. In the table, the velocities corresponding to a range of 1 to 200 revolutions of the rotor within a period of 40 to 70 seconds are listed. It should be noted that the table applies when the measurements are made with meter suspended by cable such as during bridge and boat measurements. When meter is suspended by rod, the value of tabulated velocities should be reduced by 2 per cent.

The same Table 6-1 should be applied for Pygmy current meter. However, the tabular velocity in meter per second equals 0.30 or (30%) of revolutions per second.

Table 6-1 Standard Rating Table for AA Current Meters

METRIC RATING TABLE FOR No. 622 CURRENT METER

VELOCITY IN METERS PER SECOND

Time in Secs	1 Rev	2 Rev	3 Rev	5 Rev	10 Rev	20 Rev	30 Rev	40 Rev	50 Rev	60 Rev	70 Rev	80 Rev	90 Rev	100 Rev	150 Rev	200 Rev	Time in Secs
40	0.027	0.046	0.064	0.094	0.177	0.344	0.512	0.680	0.847	1.018	1.189	1.356	1.527	1.695	2.542	3.389	40
41	0.027	0.046	0.061	0.091	0.174	0.335	0.500	0.664	0.828	0.994	1.161	1.323	1.490	1.655	2.481	3.307	41
42	0.027	0.043	0.061	0.091	0.171	0.326	0.488	0.649	0.808	0.969	1.134	1.292	1.454	1.615	2.423	3.228	42
43	0.027	0.043	0.061	0.088	0.165	0.320	0.475	0.634	0.789	0.948	1.106	1.262	1.420	1.579	2.368	3.152	43
44	0.027	0.043	0.056	0.085	0.162	0.314	0.466	0.619	0.771	0.927	1.082	1.231	1.387	1.542	2.313	3.079	44
45	0.027	0.043	0.058	0.085	0.156	0.308	0.457	0.607	0.756	0.905	1.058	1.204	1.356	1.509	2.262	3.008	45
46	0.027	0.043	0.058	0.085	0.155	0.302	0.448	0.594	0.741	0.884	1.033	1.180	1.326	1.475	2.213	2.941	46
47	0.024	0.043	0.055	0.082	0.152	0.296	0.439	0.582	0.725	0.866	1.012	1.155	1.298	1.445	2.167	2.880	47
48	0.024	0.043	0.055	0.079	0.149	0.290	0.430	0.570	0.710	0.847	0.991	1.131	1.271	1.414	2.121	2.819	48
49	0.024	0.040	0.055	0.079	0.146	0.283	0.421	0.558	0.695	0.829	0.969	1.106	1.247	1.384	2.076	2.761	49
50	0.024	0.040	0.052	0.079	0.143	0.277	0.411	0.546	0.680	0.814	0.951	1.085	1.222	1.356	2.033	2.710	50
51		0.040	0.052	0.076	0.140	0.274	0.402	0.533	0.668	0.799	0.933	1.064	1.198	1.329	1.993	2.658	51
52		0.040	0.052	0.076	0.140	0.268	0.393	0.524	0.655	0.783	0.914	1.042	1.173	1.305	1.957	2.609	52
53		0.040	0.049	0.073	0.137	0.262	0.387	0.515	0.643	0.768	0.896	1.024	1.152	1.280	1.920	2.560	53
54		0.040	0.049	0.073	0.134	0.259	0.381	0.506	0.631	0.753	0.678	1.006	1.131	1.256	1.884	2.512	54
55		0.040	0.049	0.073	0.131	0.253	0.375	0.497	0.619	0.741	0.863	0.988	1.109	1.234	1.850	2.466	55
56		0.037	0.049	0.070	0.131	0.250	0.369	0.488	0.607	0.728	0.847	0.969	1.091	1.213	1.817	2.423	56
57		0.037	0.049	0.070	0.128	0.244	0.363	0.479	0.597	0.716	0.832	0.951	1.073	1.192	1.786	2.360	57
58		0.037	0.046	0.067	0.125	0.241	0.357	0.469	0.580	0.704	0.817	0.936	1.055	1.170	1.756	2.341	58
59		0.037	0.046	0.067	0.125	0.238	0.351	0.460	0.579	0.692	0.802	0.920	1.036	1.149	1.725	2.301	59
60		0.037	0.046	0.067	0.122	0.235	0.344	0.451	0.570	0.680	0.789	0.905	1.018	1.131	1.693	2.252	60
61		0.037	0.046	0.067	0.119	0.229	0.338	0.445	0.561	0.668	0.777	0.890	1.003	1.113	1.667	2.225	61
62		0.034	0.046	0.064	0.119	0.226	0.332	0.439	0.552	0.658	0.765	0.875	0.988	1.094	1.640	2.188	62
63		0.034	0.043	0.064	0.116	0.223	0.326	0.433	0.543	0.649	0.753	0.860	0.972	1.076	1.615	2.155	63
64		0.034	0.043	0.064	0.116	0.219	0.320	0.427	0.533	0.640	0.741	0.844	0.957	1.061	1.591	2.121	64
65		0.034	0.043	0.061	0.113	0.216	0.314	0.421	0.524	0.631	0.728	0.832	0.942	1.045	1.567	2.080	65
66		0.034	0.043	0.061	0.113	0.213	0.311	0.415	0.515	0.622	0.716	0.820	0.927	1.030	1.542	2.057	66
67		0.034	0.043	0.061	0.110	0.210	0.308	0.408	0.506	0.613	0.707	0.808	0.911	1.015	1.518	2.027	67
68		0.034	0.043	0.061	0.110	0.207	0.305	0.402	0.500	0.604	0.698	0.796	0.899	1.000	1.497	1.996	68
69		0.034	0.040	0.058	0.107	0.204	0.302	0.396	0.494	0.594	0.689	0.783	0.887	0.985	1.475	1.966	69
70		0.034	0.040	0.058	0.107	0.201	0.299	0.390	0.488	0.585	0.680	0.771	0.875	0.969	1.454	1.939	70

This table applies when measurements are made with meter suspended by cable When measurements are made with meter suspended by rod, reduce the tabular velocities by 2 per cent

Source: Hydrological Instruments, Teledyne Gurley Revised 1981

4. Care and Maintenance of the Vertical-Axis Mechanical Current Meter

There are a number of documents describing the care and maintenance of the vertical-axis current meters. Among these, the most important have originated from the USGS, are by Smoot and Novak (1968) and by Rantz (1982), and Office of Surface Water Technical Memorandum No. 89.07 (1989) and Office of Surface Water Technical Memorandum No. 99.06 (1999). These instructions represent a long history of experience based on field use of the meters, as well as from individuals in the Office of Surface Water Hydraulic Laboratory who have repaired and adjusted current meters to calibrate them within close tolerances. A brief description of the recommended procedure for checking the condition of a current meter, and for its care and cleaning during daily field use, is presented in the next few paragraphs. For complete details, consult the above-mentioned documents.

5. Recommended Procedure Before, During, and After Each Discharge Measurement

– Before each discharge measurement, make a visual examination of the meter cups or vanes, pivot, bearing, and shaft for damage, wear, or faulty alignment. Inspect the bearing surface for water. This will usually appear as a milky emulsification of oil and water on the lower bearing and pivot, and in the contact chamber. If water is found, dry the meter parts and re-oil because the presence of water will affect the performance of the meter. The lower bearing is probably the most susceptible to the entrance of water.

– Spin the rotor to make certain it operates freely, and allows it to slowly return to a resting position. If the rotor does not turn smoothly, or if it stops abruptly, then it is a sign of some problem and it should be corrected before using the meter. Check the balance and alignment of the meter on the hanger or wading rod. Be sure that the conductor wire does not interfere with meter balance and rotor spin.

– During measurements, check the meter periodically when it is out of the water to be sure that the rotor spins freely, and that there is no debris or other substance obstructing it.

– After a measurement is completed, make another visual inspection as described above to ensure that nothing was damaged or caused the meter to malfunction during the measurement. If there is a problem, you may have to make another discharge measurement.

– Timed spin tests (described later in this section) are not required for each discharge measurement. The visual inspection described above (No. 4 is) preferred over timed spin tests made in the field.

6. Recommended Procedure after a Day of Use in the Field

– Examine the pivot and bearing surfaces for wear and damage, especially the pivot point. The pivot should feel sharp, not rounded or dull. It should not have a burr detectable visually or with the fingernail. A magnifying glass is helpful in making this examination. If the pivot is dull or burred, replace it with a new one.

– Clean and lightly oil the pivot, bearing, and upper shaft with current-meter oil. Do not use regular machine oil, such as "3-in-1," because it tends to become gummy when exposed to water.

– Check and carefully adjust cat's-whisker contacts, if necessary. Cat's whiskers should be made of simple bronze wire, not beaded wire.

– After replacing the contact-chamber cap, spin the meter to see if it is operating correctly, as previously described. A timed spin test is not required.

7. Recommended Procedure after Each Field Trip

After each field trip, completely disassemble, inspect, and clean current meters. Make any necessary repairs. Detailed instructions for the disassembly, inspection, and adjustment of Price AA (both standard and magnetic head) and pygmy current meters are contained in the attachments to Office of Surface Water Technical Memorandum No. 99.06 (1999). A timed spin test may also be performed after each field trip, and after meter repairs.

8. Inactive Current Meters

Disassemble, inspect, and clean current meters as described above, prior to storing them. If the period of storage is less than 1 year, the meter may be used without further maintenance if an inspection and a spin test indicate it is operating properly. If the meter has been in storage longer than 1 year, or an indeterminate period, complete inspection, cleaning, and adjustment before using the meter.

9. Spin Tests

A timed spin test, made in the field before and after each discharge measurement, is no longer a requirement as it was in the past. The visual tests as described above are adequate for checking the meter in the field. Note "OK" or "free" in the spaces on the front sheet of the discharge measurement for spin test information to indicate that the visual check of the meter was acceptable. Perform the full-timed spin test under controlled conditions between field trips, when the meter is suspect, and before and after repairs. Place the meter on a stable, level surface to perform the spin test. There should be no wind currents or drafts that can affect the rotor spin. Sharply spin the rotor while starting a stopwatch. Stop the stopwatch when the rotor comes to a complete stop. The minimum, acceptable spin times are as follows:

All types of Price pygmy meters	0:45 seconds
All types of Price AA meters	2:00 minutes

These are considered to be absolute minimum spin times. Meters in good condition will perform substantially better.

6.2.2.2 Sounding and Suspension Equipment

Sounding (determination of stream depth) is always done when making current-meter measurements. Therefore, sounding equipment as used in stream gaging serves the dual purpose of measuring the depth of water and suspending the current meter at the desired points.

Sounding is commonly done mechanically, the equipment used depending on the type of measurement being made. The depth of water and the position of the current meter below the water surface are measured by means of a rigid rod or a sounding weight suspended on a line or cable. The line is controlled by a gaging reel.

a. Sounding and Suspension Rods

The sounding rod or suspension rod is a graduated rigid rod with a base plate. The rod is used for the measurement of depth and as a support for the current meter up to depths of 4-5 m in medium velocities (about 2 m/s). The current meter is made to slide on the rod and it is fixed in position with a clamp screw. A standard rod is made of 20 mm diameter metal tubing in sections of 1 m or 2 m in length and is graduated at intervals of 10 cm. For smaller streams that can be waded, the lower 2 m portion of the rod is used only, it is then termed wading rod.

b. Sounding and Suspension Lines

A sounding line, or suspension line, is used from a cableway, boat or bridge when the stream is too deep and swift for a rod to be used. A sounding line is essentially a cable to which a sounding weight or sinker is attached. The current meter is generally attached to this cable. The higher the velocity and the greater the water depth, the heavier the sounding weight required will be. For guidance in the choice of sounding weights, the following formula may be used:

$$m = 5vd \qquad (2)$$

where

m = weight of the sounding weight (kg),
v = mean velocity (m/s),
d = depth (m).

The sounding weight should preferably be suspended below the current meter. In this way it prevents damage to the current meter when the assembly is lowered to the stream bed to determine the depth of the water. Weights are generally made in sizes of 10, 25, 50 and 100 kg and are usually made of lead. They are streamlined and furnished with tail vanes to orient them parallel to the current. The weight may be equipped with a ground contact which produces a signal when the weight touches the stream bed.

The sounding and suspension lines are controlled by means of a gaging reel or winch, or by a handline. Usually, the suspension line also serves for the transmission of the electrical impulses from the current meter to the electrical counter by an inner insulated two-conductor electrical cable.

Gaging reels consist of a drum for winding the suspension cable. a crank and ratchet for raising and lowering the current meter assembly and for holding it in any desired position, and a counting device indicating the length of line played out.

Handline suspension is a simple device operated by hand. It is used for making discharge measurements from bridges, using weights up to 20 kg and for velocities up to 2 m/s. The advantages of the handline are that it is easier to set up, eliminates the use of a gaging reel and the equipment to support the reel, and makes discharge measurements from bridges with vertical and diagonal members quicker and easier. The disadvantages of the handline are that it requires more physical exertion, especially in deep streams, and there is a greater possibility of making errors in determining the depths.

A handline consists of the following parts:
1. A hand cable made up of a heavy rubber-covered two-conductor electrical cable, tagged at 0.5-m intervals and about 10 m long.
2. Small hand reel.
3. A reverse-lay steel cable of diameter 2.5 - 3 mm with an inner insulated two-conductor electrical cable, about 12 m long.
4. Connector and plugs for current meter.
5. Plugs for electrical revolution counter.

6.2.2.3 Width Measuring Equipment

The spacing of the gaging verticals in a cross section is measured from an initial point on the bank of the stream. Bridges used regularly for making discharge measurements are commonly marked at 2, 5 or 10 m intervals by point marks. Spacing of verticals between the markings is measured with a rule or pocket tape. For measurements made by wading, from unmarked bridges or from boats, measuring tapes or tag lines are used.

The tag line is made of galvanized steel cable about 2 mm in diameter and brass tags at measured intervals are used to indicate the distances. The standard lengths are 25, 50 and 100 m, but other lengths can be obtained by special order. It is practical to wind the tag line on a canvas hand-reel of 20-30 cm diameter.

6.2.2.4 Equipment for Measurement from Bridge

Streamflow measurements are frequently made from a bridge. The meter and sounding weight can be supported by a handline, a bridge board, or by a sounding reel mounted on a crane. The Price AA current meter is commonly used in this method of measurement.

a. Bridge Canes

Hand-operated portable cranes for bridge measurements are designed so that the superstructure can be tilted forward over the bridge rail far enough to enable the current meter and weight to clear the rail. Cranes can be easily moved by hand along the sidewalk or floor of the bridge. **Figure 6-5** shows a type A crane mounted on a three-wheel base. The hand-operated crane had been widely used in the past for measuring discharge around the country using bridges. However, there might only few units that exist at present.

Source: V.B., 2010, Discharge measurements at gaging stations
U.S. Geological Survey Techniques and Methods

Figure 6-5. Type A crane mounted on a three-wheel base

b. Bridge Boards

A bridge board is a portable platform made from wood or metal upon which a small reel can be mounted. It is usually about 1.8 to 2.4 m long, with a sheave at one end over which the meter cable passes, and a reel seat near the other end. The board is placed on the bridge rail so that the force exerted by the sounding weight suspended from the reel cable is counterbalanced by the weight of the sounding reel. The bridge board may be hinged near the middle to allow one end to be placed on the sidewalk or roadway. **Figure 6-6** shows a bridge board in use.

Source: V.B., 2010, Discharge measurements at gaging stations
U.S. Geological Survey Techniques and Methods

Figure 6-6. Discharge Measurement from a bridge using a bridge board

6.2.2.5 Equipment for Measurements from Boat

Measurements made from boats require some special equipment that is not used for any other type of measurement:

1. A boat of sufficient size to support the gaging crew and the equipment.

2. Extra-large tag-line reel for use on wide streams.
3. A pair of oars.
4. A bailing device.
5. A life jacket for each crew member.
6. Outboard or inboard engine to power the boat.

An engine is required for gaging large rivers. The engine must be able to power the boat at a speed at least 25 per cent greater than the expected maximum speed of the flow. The length of the boat must be sufficient to ensure safe manoeuvrability. A simple rule for the selection of boats is presented in equation below:

$$v = 1.3\, v'L \qquad (3)$$

where

v' = the maximum relative speed of the boat in m/s and

L = the waterline length of the boat in m

An engine is usually not required on small streams where the boat can be attached to a cable stretched across the river.

In a boat measurement, the current meter may be suspended on a rod or on a cable using a bridge board. Specially designed extendable boat-booms or boat cranes are available for boat measurements. By means of a boom, the current meter may be placed and operated so as to be unaffected by any disturbance in velocities that may be caused by the boat itself.

6.2.2.6 Miscellaneous Equipment

Several other items of equipment that have not been mentioned are necessary when current meter measurements are made. These are the timers, headset, and waders.

a. Timers

In order to determine the velocity at a point with a current meter, it is necessary to count the revolutions of the rotor during a certain interval of time, usually 40 to 60 seconds. The velocity is then obtained from the current-meter rating table. The time interval is measured to the nearest second with a stop watch.

The stop watch commonly used is a still-movement type graduated to the fifth of a second. One complete revolution of the large hand is made in 60 seconds. A smaller dial on the face of the watch indicates the number of minutes the watch has been running up to 30 minutes. Depressing the stem of the watch starts it, a second depression of the stem will stop it, and a third depression resets the watch to zero. The watches should be checked periodically to be certain they are correct and accurate.

b. Headset

The revolutions of the current-meter rotor must be counted during the observation of velocity. An electrical circuit built into the current meter closes every time the rotor of the current meter has made a set number of revolutions intervals. A battery and headphone, as shown in **Figure 6-7**, are parts of the electrical circuit, and an audible click can be heard in the headphone at each electrical closure. Some Hydrographers have adapted compact, comfortable hearing-aid-type phones to replace headphones. Beepers that can be heard without the headset are also sometimes used. Do not use a headset, or similar device, with the magnetic contact chamber because arcing can weld the contacts. Measure the time interval to the nearest second with a stopwatch.

Source: V.B., 2010, Discharge measurements at gaging stations
U.S. Geological Survey Techniques and Methods

Figure 6-7. A-Analog stopwatch, B-current meter headset

c. Waders

Waders or high boots are needed when wading measurements are made. The waders should be loose-fitting for easy removal in case of emergency. Unfortunately, waders are not available for use by the Regional Hydrographers.

6.2.3 The Current Meter Measurement Site

A prospective gaging station location should be examined for the availability of discharge measuring sites for the various stages expected. One of the aspects of this examination is to ascertain that there will be a measuring site at low flow where the velocities will be in the range where the current meter can measure them accurately. The suitability of cross sections at bridges for accurate discharge measurements at high stages and the suitability of the bridges themselves as measuring structures should be evaluated. If there are no suitable bridges, a site for a cableway or footbridge should be selected. In the following, some characteristics of a good gaging site are discussed. It is usually not possible to satisfy them all. However, these criteria should be used and the best site available selected. Sometimes, different measuring cross-sections will be required for the different stages of flow, especially for the low-water measurements.

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

a) The channel at the measuring site should be straight and of uniform cross-section and slope in order to minimize abnormal velocity distribution. When the length of the channel is restricted, it is recommended for current-meter measurement that the straight length upstream should be at least twice that downstream.
b) Flow directions for all points on any vertical across the width should be parallel to one another and at right angles to the measurement section.
c) The bed and margins of the channels should be stable and well defined at all stages of flow in order to facilitate accurate measurement of the cross section and ensure uniformity of conditions during and between discharge measurements.
d) The curves of the distribution of velocities should be regular in the vertical and horizontal plans of measurement.
e) Conditions at the section and in its vicinity should also be such as to preclude changes taking place in the velocity distribution during the period of measurement.
f) Sites displaying vortices, reverse flows or dead water should be avoided.
g) The measurement section should be clearly visible across its width and unobstructed by trees, aquatic growth or other obstacles.

h) Measurement of flow from bridges can be a convenient and sometimes safer way of sampling width, depth and velocity. When gaging from a bridge with divide piers, each section of the channel should be measured separately. Particular care should be taken in determining the velocity distribution when bridge apertures are surcharged or obstructed.
i) The depth of water at the section should be sufficient at all stages to provide for the effective immersion of the current-meter or float, whichever is to be used.
j) If the site is being considered as a permanent station, it should be easily accessible at all times with all necessary measurement equipment.
k) The section should be sited away from pumps, sluices and outfalls, if their operation during a measurement is likely to create unsteady flow conditions.
l) Sites where there is converging or diverging flow should be avoided.
m) In those instances where it is necessary to make measurements in the vicinity of a bridge, it is preferable the measuring site be upstream of the bridge. However in certain cases and where accumulation of ice, logs or debris is liable to occur, it is acceptable that the measurement site be downstream of the bridge.
n) It may, under certain conditions of river flow or level, prove necessary to carry out current-meter measurements on sections other than the original chosen location. This is quite acceptable if there are no substantial unmeasured losses or gains to the river in the intervening reach and so long as all flow measurements can be related to any stage value recorded at the principal reference section.

6.2.4 The Current Meter Measurement Procedures

6.2.4.1 Measurement of Width

The first measurement made in a discharge measurement is usually the determination of horizontal stationing (width) in the cross section being measured. Width needs to be measured using the proper equipment and procedures that apply to the type of measurement being made (that is, wading, bridge or boat). The measurement of the width of the channel and the widths of the individual segments (to the verticals) may be obtained by measuring the distances from or to a fixed reference point (initial point) on the bank of the stream. The distance is usually determined by use of a measuring tape or tag line stretched across the stream. The intervals between the verticals, that are the widths of the segments, shall be similarly measured.

6.2.4.2 Spacing of the Measuring Verticals

Measurement of depth shall be made at intervals close enough to define the cross-sectional profile accurately. Based on IS 1192.1981 which is identical with ISO 748:2007 "Hydrometry – Measurement of Liquid flow in Open Channels using Current Meters and Floats", that in judging the specific number n of verticals in small channels (<5 m) that are to be defined for the purpose of determining flow at a particular location, the following criteria could be applied. These criteria shall be the minimum requirement and only practical constraints of time, costs, or on site conditions should result in a reduction of these numbers.

Channel width < 0.5 m	n = 5 to 6
Channel width > 0.5 m and < 1 m	n = 6 to 7
Channel width > 1 m and < 3 m	n = 7 to 12
Channel width > 3 m and < 5 m	n = 13 to 16
Channel width > 5 m	$n \geq 22$

For channel widths >5 m, the number of verticals shall be chosen so that the discharge in each segment is less than 5% of the total, insofar as possible, and that in no case should exceed 10%. In all instances, measurements of depth made at the water's edge are additional to the above. The first and the last verticals should be as close as practically possible to the water edge.

6.2.4.3 Measurement of Depth

The second measurement normally made at a vertical is the stream depth. Measurement of depth shall be made at intervals close enough to define the cross-sectional profile accurately. The number of points at which depth shall be measured should be the same as the number of points at which velocity is measured. Depth should be measured using the proper equipment and procedure depending on the type of measurement being made (wading, bridge or boat).

The depth of the vertical and the position of the current meter in the vertical are measured by a graduated rod (wading rod) on which the current meter slides, or by a sounding line on which the current meter and the streamlined sounding weight are suspended. The line is usually controlled by a gaging reel with a depth indicator.

In order to obtain accurate depths by the sounding line, the sounding weight must be equipped with an electrical bottom-contact which gives a signal when the weight touches the stream bed. If the sounding weight is not sufficiently heavy to keep the line with 5% of the perpendicular to the water surface, the angle between the sounding line and the vertical should be measured to the nearest degree with a protractor. The angle should not exceed 30%.

In certain cases, for example during flooding events, it may be impossible to determine an adequate profile of cross-section during the measurement. For such cases, the full profile shall be determined by surveying methods, either before or after the measurement. However, it should be recognized that this method is subject to errors due to possible erosion or deposition in the cross-section between the time the profile is determined and the time of discharge measurement.

6.2.4.4 Measurement of Velocity

By definition, the discharge of a stream is the product of a stream cross-section and the component of the flow velocity normal to that section. Consequently, in current-meter measurements, the measuring cross-section is placed normal to the general direction of flow. This is checked either visually or by a protractor.

The velocity is measured at one or more points in the vertical by observing the number of revolutions of the current-meter rotor during a period of 40-60 seconds. Where the vertical-velocity distribution is approximately parabolic and the depth is greater than about 60 cm, velocity observation is made at 0.20 and 0.80 of the depth below the surface. There are other methods available in the measurement of velocity such as Vertical-Velocity Curve, Two-Tenths-Depth method and Three-Point methods. However in the Philippines, only the Sixth-Tenths-Depth and the Two-Point method are commonly used and hence, only discussions of these two methods are made in this section.

a. Two-Point Method

This is the preferred method for making midsection discharge measurements with point velocity meters. In the two-point method of measuring velocities, observations are made in each vertical at 0.20 and 0.8 of the depth below the surface. The average of these two observations is used as the mean velocity in the vertical. According to USGS, this method is based on many studies of actual observation and on mathematical theory. Their experience has shown that this method gives more consistent and accurate results than any of the other methods, except for the vertical-velocity curve method which is not commonly applied in the country. **Table 6-3** shows the depths where the two-point method can be used for the Price AA as well as the Pygmy type current meter.

Table 6-3. Depth of Two-point Method

Depth, in m	Current meter	Velocity method
0.75 and greater	Price Type AA	0.2 and 0.8
0.5 – 0.75	Price Type AA	0.6
0.1 – 0.5	Price Pygmy	0.6
0.5 and greater	Price Pygmy	0.2 and 0.8

b. Six-Tenths-Depth Method

In the 0.6-depth method, an observation of velocity made at 0.6 of the depth below the water surface in the vertical is used as the mean velocity in the vertical. This method is mostly applicable whenever the depth is between the 0.5 – 0.75 m for a Price AA and between 0.1 – 0.5 m for Price Pygmy type current meter. During times when the gage height in a stream is changing rapidly and a quick measurement must be made, this method can also be employed.

6.2.4.5 Performing the Current Meter Measurement

When the width of the measuring cross-section has been measured and the positions of the verticals in the cross-section have been determined, the appropriate equipment for the current-meter measurement is assembled and the Measurement Notes are prepared in order to record the observations. **Figure 6-8** shows an example of the Field Measurement Note used by the Regional Hydrographers which include the following information:

1. Name of River
2. Location of the Station
3. Gaging Station ID
4. Date
5. Time and gage height at the start of the measurement
6. Type of the current meter used
7. Spin time of the rotor before the measurement
8. Type of Measurement (wading, bridge or boat)
9. Method of velocity measurement (0.6, 0.2 and 0.8, float)
10. Name of Hydrographers
11. Other pertinent information regarding the accuracy of the discharge measurement and conditions which might affect the stage-discharge relationship

STREAM DISCHARGE MEASUREMENT

		DATE:
1. STREAM STATION	2. MEASUREMENT NO.	3. OBSERVER (Name of Gagekeeper)

4. RESULTS OF COMPUTATION					5. CONDITIONS	
WIDTH	AREA	VELOCITY			CROSS SECTION	FLOW
		MEAN	MAX.	MIN.	☐ STABLE ☐ UNSTABLE	☐ TURBULENT ☐ NORMAL ☐ LOW
DISCHARGE	GAGE HEIGHT	% DIFFERENCE FROM PREVIOUS			WEATHER ☐ RAINY ☐ CLOUDY ☐ SUNNY	

6. MEASUREMENT				7. COEFFICIENT		
METHOD	SECTIONS	GAGE HEIGHT CHANCE	WATER SUSPENSION	METHOD	HOR. ANGLE	SUSPENSION

8. CURRENT METER				9. SPIRIT LEVEL CHECK	
DATE RATED	METHOD OF SUSPENSION Cable - 1, Suspension Rod - 2	WATER SPIN CHECK (sac)		CHECK BAR FOUND	CHANGED TO AT
		BEFORE	AFTER		
METER NO.	SUSPENSION (above bottom of weight			LEVELS OBTAINED	ADJUSTMENT

11. METHOD OF CROSSING STREAMS AND LOCATION OF MEASURING CROSS SECTION				
METHOD	LOCATION (bridge only)	DISTANCE	GAGE	MEASUREMENT ERROR EVALUATION
☐ WADING ☐ CABLE ☐ BOAT ☐ BRIDGE	☐ UPSTREAM ☐ DOWNSTREAM		☐ ABOVE ☐ BELOW	☐ EXCELLENT ☐ GOOD ☐ FAIR ☐ POOR (over 8%)

12. GAGE READING					
TIME	START	FINISH	RECORDER	INSIDE	OUTSIDE

WEIGHTED MEAN GAGE HEIGHT

GAGE HEIGHT CORRECTION

CORRECT MEAN GAGE HEIGHT

13. GAGE			
RECORD REMOVE YES NO	INTAKE FLUSHED YES NO	GAGE HEIGHT OF ZERO FLOW	ELEVATION ZERO OF GAGE:
REMARKS:			MEMBER OF THE PARTY:
NAME OF PARTY LEADER:			SIGNATURE

angle coef.	dist. from I.P.	width	depth	W	rev	time/ secs.	vel at pt.	vel mean	for hor.ang.	area	discharge

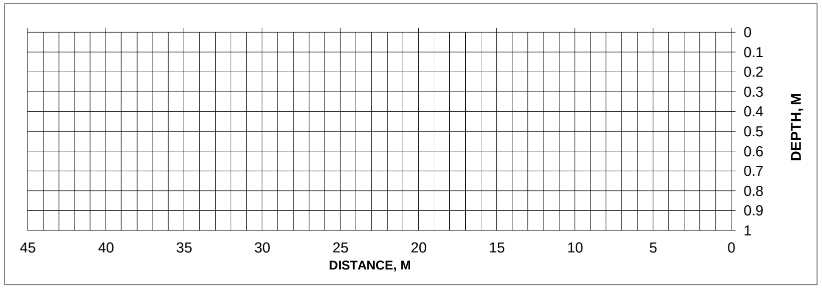


Figure 6-8. Example of Field Measurement Note

Once the equipment and the measurement notes have been prepared, the measurement can begin.

a. Wading Measurement

Current-meter measurement by wading are preferred, if conditions permit. Wading measurement offer advantage over measurement from bridges and boats because the hydrographer can usually choose the best of several available cross-sections for the measurement.

A tag line or tape spanned across the measuring cross-section at right angles to the general direction of the flow. If the same measuring cross-section is used always and if it is practicable, cross-section should be defined by clearly visible markers, one on each bank, for easy identification and for holding the tag line. While placing the tag line, the hydrographer should obtain a general idea of the proper spacing of the measuring verticals by observing the total width of the cross-section and the geometry of the stream bed. The first velocity observation should always be taken as close as possible to the bank.

With the current meter supported on a graduated wading rod, the velocity observations are taken at the appropriate distances along the tag line keeping the rod in a vertical position. The hydrographer should stand in a position that affects the flow of the water passing the current meter as little as possible. This position is usually obtained by standing close to the tag line on the downstream side, facing the bank with water flowing against the side of the leg and holding the rod at the tag line at arm's length.

Avoid standing in the water if the feet and legs would occupy a considerable part of the cross-section of a narrow stream. In smaller streams where the width permits, stand on a plank or other support rather than in the water.

With the use of Price meter, keep the wading rod in a vertical position and the meter parallel to the direction of flow while observing the velocity. If the flow is not at right angles to the tag line, measure the angle coefficient carefully. During measurements of streams with shifting beds, the scoured depressions left by the hydrographer's feet can affect soundings or velocities. Generally, place the meter ahead of and upstream from the hydrographer's body and feet. Record an accurate description of streambed and water-surface configuration each time a discharge measurement is made in a sand-channel stream.

b. Bridge Measurement

Highway or railway bridges may often be utilized for current-meter measurements. However, measurements from bridges are usually less accurate than other types of measurements. Contracted sections, piers and other obstructions affect the distribution of the velocities and it is therefore necessary to use a large number of verticals as well as more observation points in each vertical, especially close to the bridge piers and banks. Generally, there are two types of bridge measurement using either rod or line suspension.

Rod Suspension from Bridge

Foot bridges may sometimes be used for gaging small streams. Although the procedure low flow velocities may be the same as for a wading measurement, at high velocities it is often advisable to measure the depth in the following manner:

1. For each selected vertical, a point is established on the bridge.
2. With this point as an index, the distance to the water surface is measured by lowering the suspension rod until the base plate touches the water.
3. The rod is then lowered to the bottom of the stream and the rod reading is again noted at the index point. The difference in the readings is the depth of water at the vertical.

Measuring the depth in this manner tends to eliminate errors that may be cause by the piling up of water on the upstream face of the rod. The natural flow of water is not disturbed when measuring from a foot bridge as is often the case when measuring from a boat or by wading.

Line Suspension from Bridge

For higher bridges and for greater depths, the current meter and weight have to be suspended on a cable. The cable is controlled by a gaging reel mounted on a bridge crane. A handline may be used with the smaller weights. No set rule can be given for selecting the upstream or downstream side of a bridge for discharge measurements.

The advantages of using the upstream side of the bridge are:

1. The hydraulic conditions at the upstream side of the bridge opening are usually more favourable.
2. Approaching drifts can be seen and avoided more easily.
3. The stream bed at the upstream side of the bridge is not like to be scoured as badly as the downstream side.

The advantages of using the downstream side of the bridge are:

1. Vertical angles are easily measured on the downstream side as the sounding line will move away from the bridge.
2. The streamlines may be straightened out when passing through a bridge opening with piers.

Whether to use the upstream or the downstream side of a bridge for a current-meter measurement should be decided individually for each bridge after considering the factors mentioned above and the conditions at the bridge such as location of the way-say and traffic hazards.

c. Boat Measurement

Discharge measurement taken from a boat is a common way of measuring discharges when the stream is too deep to wade. One limiting factor in the use of boats is high velocity of the water, as personal safety has to be considered.

A heavy tag line is spanned across the river at the measuring section. The tag line serves the dual purpose of holding the boat in position during the measurement, and of measuring the width of the river and positioning the measuring verticals. The tag line is wound on a reel which is operated from the stern of the boat as the boat is propelled across the river. On the bank, the slack of the cable is taken up by means of a block and tackle attached to the reel and to an anchored support on the bank. If there is traffic on the river, one man must be stationed on the bank to lower and raise the tag line to allow the traffic to pass. Streamers should be fixed on the tag line so that it may be seen by boat pilots.

A permanent supporting cable, crossed across the river, to which the boat is anchored during discharge measurements, will often prove advantageous. This method is less laborious and safer for the personnel performing the measurement, especially at high water conditions. A permanent cable must be erected well above the highest flood level expected.

When a boat is used, the current meter should be held such that it is not affected by the disturbances of flow caused by the boat and measurements should be taken at the front of the boat. The minimum distance from the point of observation to the boat should preferably be greater than 0.6 times the maximum width of the boat.

For measurements made by the one-point method, the current meter should be exposed for 120 seconds or for 150 revolutions whichever occurs later. If measurements are made at more than one point in each vertical, the current meter should be exposed for a period of at least 30 seconds at each point in the vertical. If the water velocity is known to be subject to periodic pulsations, it is advisable that the current meter should be exposed at each selected point for at least two (preferably three consecutive periods) consecutive periods of 60 seconds or for periods of sufficient duration to cover at least two periods of pulsation and the average of all the separate readings is taken as the velocity at the point. The velocity at the point should then be taken to be the average of all the separate readings, unless it is apparent that the difference is due to some cause other than pulsation of the flow.

The current meter should be removed from the water at intervals for examination, usually when passing from one vertical to another.

More than one current meter may be used in determining velocities in the individual verticals; different current meters being used for consecutive verticals. The averaging effect may tend to reduce the systematic error of measurement.

In channels where the flow is unsteady, it is useful to correct for the variations in the total discharge during the period of the measurement not only by observing the change in the stage, but also by continuously measuring the velocity at some conveniently chosen point. Experience has shown that, provided the variations in the discharge are small, the velocity distribution is not modified significantly.

6.2.5 Computation of Current Meter Measurement

6.2.5.1 The Arithmetic Mid-section Method

In the midsection method of computing a current-meter measurement, it is assumed that the velocity sample at each vertical represents the mean velocity in a rectangular subsection. The subsection area extends laterally from half the distance from the preceding observation vertical to half the distance to the next, and vertically from the water surface to the sounded depth.

The cross section is defined by depths at verticals *1,2,3,4 . . . n*. At each vertical the velocities are sampled by current meter to obtain the mean velocity for each subsection. The subsection discharge is then computed for any subsection at vertical x by use of the equation,

$$q_i = v_i \left[\left(\frac{(b_i - b_{(i-1)}}{2} \right) + \left(\frac{b_{(i+1)} - b_i}{2} \right) \right] d_i$$

$$= v_i \left[\frac{b_{(i+1)} - b_{(i-1)}}{2} \right] d_i \qquad (4)$$

Where

q_i	= discharge through subsection i,
v_i	= mean velocity at vertical i,
b_i	= distance from initial point to vertical i,
$b_{(i-1)}$	= distance from initial point to preceding vertical,
$b_{(i+1)}$	= distance from initial point to next vertical, and
d_i	= depth of water at vertical i.

Thus, for example, the discharge through subsection 4 (heavily outlined in **Figure 6-9**) is

$$q_4 = v_4 \left[\frac{b_5 - b_3}{2} \right] d_4 \qquad (5)$$

The procedure is similar when x is at an end section. The "preceding vertical" at the beginning of the cross section is considered coincident with vertical *1*; the "next vertical" at the end of the cross section is considered coincident with vertical n. Thus,

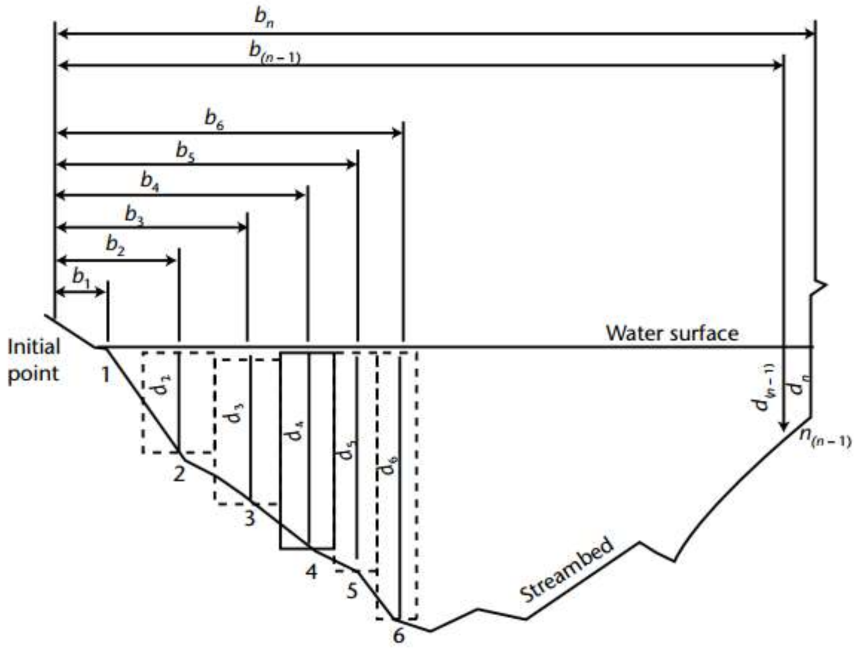
$$q_1 = v_1 \left[\frac{b_2 - b_1}{2} \right] d_1 \qquad (6)$$

and

$$q_n = v_n \left[\frac{b_n - b_{(n-1)}}{2} \right] d_n b \qquad (7)$$

For the example shown in **Figure 6-9**, *q1*, is zero because the depth at observation point *1* is zero.

However, when the cross-section boundary is a vertical line at the edge of the water as at location n, the depth is not zero and velocity at the end section may or may not be zero. Equations 6 and 7 are used whenever there is water only on one side of an observation point such as at the edge of the stream, piers, abutments and islands. It usually is necessary to estimate the velocity at an end section because it normally is impossible to measure the velocity accurately with the current meter close to a boundary. There also is the possibility of damage to the equipment if the flow is turbulent. The estimated velocity is usually made as a percentage of the adjacent section. The summation of the discharges for all the partial sections is the total discharge of the stream. An example of the measurement notes is shown in **Figure 6-10**.



Note:

1,2,3……*n* : Observation verticals

b1, b2, b3,……. Bn : Distance, in meters, from initial point to the observation vertical

d1, d2, d3,……. Dn : Depth of water, in meters, at the observation vertical

Dashed lines : Boundaries of subsections, the one heavily outlined is discussed in text.

Figure 6-9. Definition sketch of mid-section method of computing Cross-section area for discharge measurement

A summary of the discharge measurement, including gage readings before, during, and after the discharge measurement, is prepared as a part of the discharge measurement. This summary is sometimes referred to as a front sheet. This form will also be available for download from the Streamflow Management System website where Regional Hydrologists can use to record their discharge measurement data. Summary sheets can be enhanced to show additional information about the gage, the discharge measurement, and other measurements made during the course of the visit to the gaging station.

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		Revision No.:	0
	STREAM DISCHARGE MEASUREMENT	Page No.:	1 of 2

STREAM DISCHARGE MEASUREMENT

DATE: October 26, 2007

1. STREAM STATION: Rio Chico River, Zaragoza, Nueva Ecija

2. MEASUREMENT NO.

3. OBSERVER (Name of Gagekeeper): Froilan Escosa

4. RESULTS OF COMPUTATION

WIDTH	AREA	VELOCITY MEAN	VELOCITY MAX.	VELOCITY MIN.
44.00	45.59	0.572	0.928	0.161

DISCHARGE	GAGE HEIGHT	% DIFFERENCE FROM PREVIOUS
26.078	11.63	

5. CONDITIONS

CROSS SECTION: ☐ STABLE ☐ UNSTABLE

FLOW: ☐ TURBULENT ☐ NORMAL ☐ LOW

WEATHER: ☐ RAINY ☐ CLOUDY ☐ SUNNY

6. MEASUREMENT

METHOD	SECTIONS	GAGE HEIGHT CHANCE	WATER SUSPENSION
0.60, 0.20, 0.80 d	12		

7. COEFFICIENT

METHOD	HOR. ANGLE	SUSPENSION
2		

8. CURRENT METER

DATE RATED	METHOD OF SUSPENSION	WATER SPIN CHECK (sac) BEFORE	WATER SPIN CHECK (sac) AFTER
622-G	Cable - 1, Suspension Rod - 2		

METER NO.

SUSPENSION (above bottom of weight): 80

9. SPIRIT LEVEL CHECK

CHECK BAR FOUND

CHANGED TO

AT

LEVELS OBTAINED

ADJUSTMENT

11. METHOD OF CROSSING STREAMS AND LOCATION OF MEASURING CROSS SECTION

METHOD	LOCATION (bridge only)	DISTANCE	GAGE	MEASUREMENT ERROR EVALUATION
☐ WADING ☒ CABLE ☐ BOAT ☐ BRIDGE	☐ UPSTREAM ☐ DOWNSTREAM ☒ ALONG THE GAGE		☐ ABOVE ☐ BELOW	☐ EXCELLENT ☐ GOOD ☐ FAIR ☐ POOR (over 8%)

12. GAGE READING

TIME	START	FINISH	RECORDER	INSIDE	OUTSIDE
3:30 PM	11.63				
4:15 PM		11.63			

WEIGHTED MEAN GAGE HEIGHT

GAGE HEIGHT CORRECTION

CORRECT MEAN GAGE HEIGHT

13. GAGE

RECORD REMOVE	INTAKE FLUSHED	GAGE HEIGHT OF ZERO FLOW	ELEVATION ZERO OF GAGE:
YES NO	YES NO		30 486 m

REMARKS:

MEMBER OF THE PARTY: Gerardo Orteo, Rommy Sicat, Eulogio Sigua

NAME OF PARTY LEADER: Rosalinda P. Tapang

SIGNATURE

angle coef.	dist. from I.P.	width	depth	W	rev	time/ secs.	vel at pt.	vel mean	for hor.ang.	area	discharge
	89.0 LWE										
	95.0	4.50	0.92		50	42	0.811	0.870		4.140	3.600
					60	44	0.928				
	98.0	3.00	2.70		44	42	0.715	0.796		8.100	6.444
					54	42	0.876				
	101.0	3.00	2.00		40	46	0.595	0.670		6.000	4.017
					48	44	0.744				
	104.0	3.00	2.70		36	40	0.615	0.632		8.100	5.119
					38	40	0.649				
	107.0	3.00	1.50		20	40	0.345	0.457		4.500	2.054
					34	41	0.568				
	110.0	3.00	0.90		30	41	0.502	0.577		2.700	1.557
					40	42	0.651				
	113.0	3.00	0.70		20	40	0.345	0.345		2.100	0.725
	116.0	3.00	0.65		24	42	0.393	0.393		1.950	0.766
	119.0	3.00	0.55		18	42	0.297	0.297		1.650	0.490
	122.0	3.00	0.45		16	44	0.253	0.253		1.350	0.342
	125.0	3.00	0.80		12	42	0.200	0.227		2.400	0.544
					16	44	0.253				
	128.0	3.00	0.65		10	44	0.161	0.161		2.600	0.419
	133.0	5.00									
		RWE									

Figure 6-10. Example of measurement notes

6.2.5.2 The Arithmetic Mean-section Method

The mean-section method was used by the Bureau of Research and Standards (BRS) prior to the transfer of streamflow data collection and processing to the Bureau of Design. It differs from the midsection method in computation procedure. Partial discharges are computed for partial sections between successive verticals. The velocities and depths at successive verticals are each averaged, and each partial section extends laterally from one vertical to the next. Discharge is the product of the average of two mean velocities, the average of two depths, and the distance between verticals. This is repeated for each partial section. The additional discharge in the partial sections adjacent to each bank is estimated on the assumption that the velocity and depth at the banks are zero. If, however, this discharge is a significant part of the total flow then the mean velocity in the vicinity of the bank should be estimated, or measured if possible. The total discharge is obtained by summing the discharges from all of the partial sections, including the end sections near each bank. A study by Young (1950) concluded that the midsection method is simpler to compute and is a slightly more accurate procedure than the mean section method. This is also the conclusion stated in ISO 748.

6.2.6 Accuracy of Current Meter Measurements

The accuracy of a discharge measurement is dependent on many factors, including the equipment used, the location and characteristics of the measuring section, the number and spacing of verticals, the rate of change in stage, the measurement of depth and velocity, presence of debris in the measuring section, wind, experience of the hydrographer, and various conditions that can occur during the process of making the measurement. The evaluation of the accuracy of a measurement has long been a qualitative assessment that takes some or all of these factors into account. A quantitative measure of the accuracy for some discharge measurements can also be made. The following two sections of this chapter describe these methods.

6.2.6.1 Qualitative Evaluation

Every discharge measurement should be evaluated for accuracy using the qualitative method. Historically, this has been the preferred method, and the hydrographer should make this evaluation immediately after making the measurement. It is difficult to provide written guidelines for making a qualitative evaluation of accuracy. A good qualitative evaluation depends mostly on the experience and training of the hydrographer. Several of the factors that should be considered by the hydrographer are as follows:

Measuring section—Consider factors such as the uniformity of depths, the smoothness of the streambed, the streambed material (that is, smooth sand; small, firm gravel; large rocks; soft muck; and so forth), the ability to accurately measure the depth, the approach conditions, presence of bridge piers, and other conditions that would affect measurement accuracy.

Velocity conditions—Consider smoothness of velocity, uniformity of velocity, very slow velocity, very high velocity, turbulence, obstructions that may affect the vertical velocity distribution, use of one-point or two-point method, length of counting (40 or more seconds versus half-counts), and other factors that affect accuracy of velocity measurements.

Equipment—Consider the type of current meter used (Price AA, Price pygmy, acoustic, or electromagnetic), the type of depth-sounding equipment, and the condition of the equipment.

Spacing of observation verticals— Stream width ≤ 5 m, the number of observation verticals is given in Section 6.4.2.2. However, if width is > 5 0, use about 25 to 30 verticals for a discharge measurement, spaced so that no more than 5 percent of the total discharge is contained in each subsection. Although this is frequently difficult to attain, except in unusual cases, no more than 10 percent of the total discharge should be in a subsection. Otherwise, the accuracy will be negatively affected.

Rapidly changing stage—although discussed in previous sections of this chapter, this condition should also be considered when assessing the accuracy of the measurement. Using the shortcut methods previously described will result in less accurate measurements of discharge.

Wind—Wind can affect the accuracy of a discharge measurement by obscuring the angle of the current, or by creating waves that make it difficult to sense the water surface prior to making depth soundings. Wind can also affect the vertical-velocity distribution, particularly near the surface, and can cause vertical and (or) horizontal movement of the current meter while making a boat measurement, introducing possible error in velocity measurements

The qualitative method of assessing the accuracy of a discharge measurement requires that the hydrographer consider all of the above items and their cumulative effect on the measurement accuracy.

The front page of the discharge measurement note sheet has space for describing (1) the cross section, (2) the flow, (3) the weather, and (4) any other flow conditions that relate to the accuracy. These descriptions, along with the type of equipment, number of verticals, velocity measurement method, and other measurement conditions, should provide the basis for rating the measurement as excellent (2 percent), good (5 percent), fair (8 percent), or poor (more than 8 percent). For instance, a measurement might be rated as excellent (2 percent) if (1) the cross section is smooth, firm, and uniform; (2) the velocity is smooth and evenly distributed; (3) the equipment is in good condition; (4) the two-point velocity measurement method was used; and (5) weather conditions are good (no wind). On the other hand, if several of these factors make it difficult to accurately measure depth and (or) velocity, the measurement might be rated fair (8 percent), or even poor (more than 8 percent).

6.2.7 Uncertainties in Discharge Measurements

All discharge measurements, no matter how carefully made, are subject to uncertainty. The measurement uncertainty can be thought of as a quantitative measure of the dispersion of the measured discharge about the true discharge. This uncertainty arises because each measurement is subject to errors of unknown magnitude. The total uncertainty in a discharge measurement may arise from several sources, including:

- Uncertainty in the measurement of the cross-sectional area, which in turn arises from the following:
  – uncertainty in measurements of width; and
  – uncertainty in measurements of depth;
- Uncertainty in the measurement of the water-velocity profile, which in turn arises from the following:
  – instrument uncertainty;
  – pulsation and turbulence in open-channel flow;
  – deviation from our assumptions about the vertical velocity distribution; and
  – uncertainty due to oblique angles in the flow velocity;
- Uncertainty due to deviation from assumptions used in the computation procedures; and
- Other random or systematic errors.

These component uncertainties can be combined to estimate the total uncertainty of a single discharge measurement. Where feasible, values for these component uncertainties should be estimated independently for each site. The uncertainty is often expressed as a standard deviation. If we assume that measurement errors are normally distributed, then this uncertainty can be used to construct confidence intervals for the measured discharge value. For example, the true discharge can be expected to be within one standard deviation of the measured value at the 68-percent confidence level. At the 95-percent confidence level, the true discharge can be expected to be within two standard deviations of a single measured value.

6.2.8 Measurement of Discharge by Float Method

When conditions are such that it is not feasible to use mechanical current meter equipment, other methods maybe employed for measuring discharge. In the Philippines, only the float method is the only available option aside from the current meter method.

Floats are seldom used in stream gaging but are useful in an emergency for measuring high discharges under the following circumstances:

1. No conventional or optical current meter is available.
2. A current meter is available but the measurement structure-bridge or cableway-has been destroyed, and equipment for measuring from a boat is unavailable.

Surface floats are used in those situations, and they may be almost any distinguishable article that floats, such as wooden disks; bottles partly filled with water, soil, or stones; or oranges. Floating distinguishable pieces of drift may be used if they are present in the stream.

Two cross sections are selected along a reach of straight channel for a float measurement. The cross sections should be far enough apart so that the time the float takes to pass from one cross section to the other can be measured accurately. A travel time of at least 20 seconds is recommended, but a shorter time may be used for streams with such high velocities that it is not possible to find a straight reach of channel having adequate length. The water-surface elevation should be referenced to stakes along the bank at each cross section and at one or more intermediate sites. Those elevations will be used at a later date, when conditions permit, to survey cross sections of the measurement reach, and the end stakes will be used to obtain the length of the reach. The surveyed cross sections will then be used to derive an average cross section for the reach.

In making a float measurement a number of floats are distributed uniformly across the stream width, and the position of each with respect to distance from the bank is noted. The floats should be introduced a short distance from the upstream cross section so that they will be traveling at the speed of the current when they reach the upstream section. A stopwatch is used to time their travel between the end cross sections of the reach. The estimated position of each float with respect to the bank is also noted at the downstream cross section.

In the absence of a bridge or cableway from which to introduce the floats in the stream, the floats will have to be tossed in from the stream bank. If that situation exists, at a wide stream, it may be impossible to position any floats in the central core of the stream where most of the flow occurs. A measurement of discharge made under those conditions would be meaningless. However, the difficulty of introducing floats at intervals across the entire width of a wide stream can be overcome if a boat can be obtained for the purpose.

The velocity of a float is equal to the distance between the ends cross sections divided by the time of travel. The mean velocity in the vertical is equal to the float velocity multiplied by a coefficient whose value is dependent on the shape of the vertical-velocity profile of the stream and on the depth of immersion of the float with respect to stream depth. A coefficient of 0.85 is commonly used to convert the velocity of a surface float to mean velocity in the vertical.

The procedure for computing the discharge is similar to that used in computing the discharge for a conventional current-meter measurement. The discharge in each subsection of the average cross section is computed by multiplying the area of the subsection by the mean vertical velocity for that subsection. The total discharge is equal to the sum of the discharges for all subsections.

Float measurements of discharge that are carefully made under favourable conditions may be accurate to within ±10 percent. Wind may adversely affect the accuracy of the computed discharge by its effect on the velocity of the floats. If a non-uniform reach is selected and few floats are used in the cross section, measurement results may be in error by as much as 25 percent.

6.2.9 Quality Assurance and Quality Control

It should be the goal of each hydrographer to make discharge measurements of the highest quality and with as little error as possible. As explained in the earlier sections of this chapter there are many actions that must be performed before, during, and after the actual measuring process. In the many implicit decisions that must be made during the course of a discharge measurement, the hydrographer, through training and experience, must develop a keen sense of what is correct and incorrect through hydrologic/engineering judgment, and strive to continually take the correct course of action in making a discharge measurement. This is commonly known as quality assurance and quality control, sometimes referred to as QA/QC. Some of the QA/QC functions are implicit; that is, they are generally understood, performed automatically, and are not specifically defined in the measurement notes and sometimes must be accomplished through hydrologic/engineering judgment. Careful regard for safety, good hydrologic/engineering judgment, and observance of proper procedure are implicit functions that cannot be over-stressed in making a precise and accurate discharge measurement. On the other hand, some actions are explicit, such as performing regular spin tests of current meters, or making check measurements when the first measurement may be suspect. Following are some of the QA/QC actions that should be observed for making high-quality discharge measurements. These are not all inclusive, and each hydrographer should always include and document any other actions that relate to the quality of the measurement. These QC/QA actions are highly recommended for adaptation in the Philippines.

- Care of current meters, current profilers, and sounding equipment - Previous sections of this chapter describe the proper care of current meters, current profilers, and sounding equipment. Current meters are especially susceptible to damage and misalignment while in use, as well as in transit, if they are not properly protected. The hydrographer should follow all established guidelines to ensure that the stream gaging equipment, especially the current meter and (or) profiler, are in good working condition. While making a discharge measurement, the current meter should be periodically observed and checked to be sure it is operating smoothly and has not become fouled by debris, ice, or other obstructions.

- Spin tests of current meters - one of the requirements for maintaining and checking current meters is a periodic, timed spin test under controlled conditions. The procedure for making a timed spin test is described in a previous section of this chapter. In addition, before, during, and after every discharge measurements, check that the rotor is turning smoothly and does not come to an abrupt stop.

- Carefulness, good judgment, and proper procedure - it is the Hydrographers responsibility to apply proper procedures with care and good judgment while making streamflow measurements. These implicit functions of QA/QC should be observed at all times.

- Computing and plotting the measurement on site - Compute a discharge measurement as soon as possible after it is completed. Do this at the site before leaving. If the measurement does not plot within 5 percent (or other specified percentage) of the rating curve in use, or if it is not in line with the previous trend of measurements, try to find an explanation. For instance, there may be an obvious change of the control that would explain the deviation. All such explanations should be documented in the measurement notes. If a satisfactory explanation cannot be found, then make a check measurement.

- Making check measurements - If possible, while making a check measurement, select a different cross section from the original section and use a different current meter. Make the check measurement as close in time and gage height to the original measurement as possible.

- Checking discharge measurements - In general, hand- computed discharge measurements are not checked for mathematical errors. Nevertheless, check measurements that do not plot within an acceptable percentage of the rating curve, or within the previous trend of measurements. Likewise, check measurements that define a significant extrapolation of the low end or high end of a rating curve.

- Documentation of QA/QC - Document in the measurement notes, if possible, all measures taken to ensure that discharge measurements are accurate and of high quality. Some QA/QC measures require specific documentation independent of the measurement notes. For example, current-meter spin tests have specific forms that document the spin-test results and all repairs to the meter.

6.2.10 Safety Requirements

Practicing personal and overall safety is of utmost importance when working near, in, and above water. Detailed description of the safety requirements is not included in this Manual; however, each hydrographer should be familiar with, and should observe the necessary safety requirements when they are in the field during discharge measurements.

6.2.11 Field Procedures

As mentioned in the earlier section of this Manual that after the width of the measuring cross-section has been measured, the positions of the verticals in the cross-section have been determined, and the appropriate equipment for the current-meter measurement is assembled, the Measurement Field Notes should then be prepared in order to record the observations.

a. Field Notes

Field Measurement Note used by the Regional Hydrographers should include all important information pertinent to the gaging station and the data obtained during the conduct of discharge measurement. An example of Stream Discharge Measurement form used by the Regional Hydrographers is shown in **Figure 6-10** and includes the following:

1. Name of River
2. Location of the Station
3. Gaging Station ID
4. Date
5. Time and gage height at the start of the measurement
6. Type of the current meter used
7. Spin time of the rotor before the measurement
8. Type of Measurement (wading, bridge or boat)
9. Method of velocity measurement (0.6, 0.2 and 0.8, float)
10. Name of Hydrographers
11. Other pertinent information regarding the accuracy of the discharge measurement and conditions which might affect the stage-discharge relationship

b. Data Storage

All completed paper copies of Stream Discharge Measurement forms should be collated within the appropriate station folder and stored properly for safekeeping. The data from the field notes should be transmitted by the Regional Hydrographers through the web-based entry form for discharge measurement as soon as the Hydrographers return to the office or anywhere they have access to the internet after their field measurement.

c. Transmission

Shown in **Figure 6-11** is the path the collected discharge measurement data will follow from the field to transmission through the web-based entry form and into the central server of the Streamflow Management System in DPWH Main.

Each region will be provided with a username and password in order for them to login and access the "Data Encoding" Option of the website where they can download the data entry forms (as shown in **Figure 6-12** and **6-13**) to input their collected field data and upload it back to the website.

An important advantage with the development of the streamflow website is that field data can reach DPWH-BOD within a shorter period of time, and in most cases data is retrieved real-time. In the existing system, collection of field notes and stream discharge measurement sheets takes one to three months. It takes another month for the field data from the regional offices to finally reach the DPWH Central Office in Metro Manila.

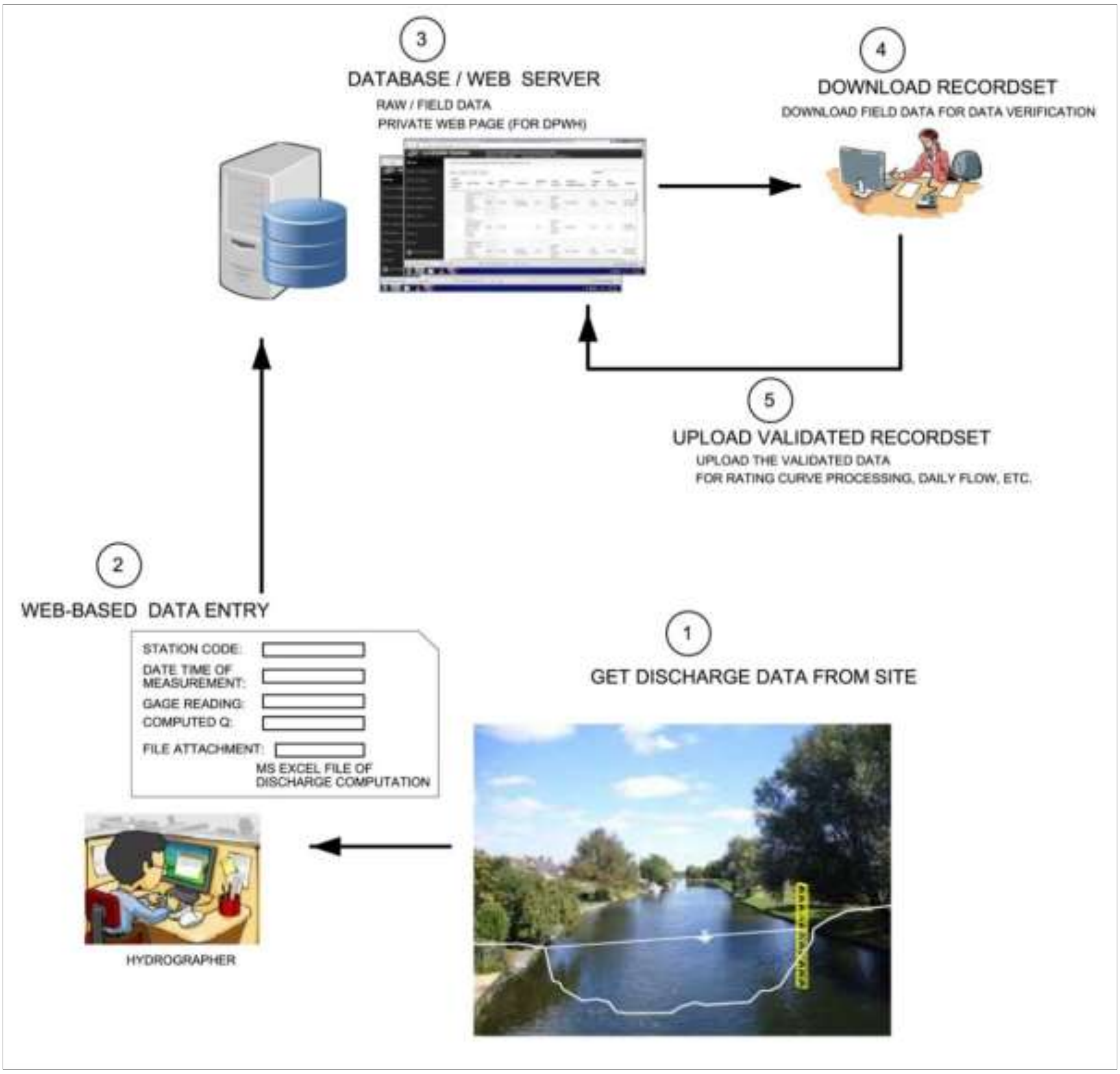
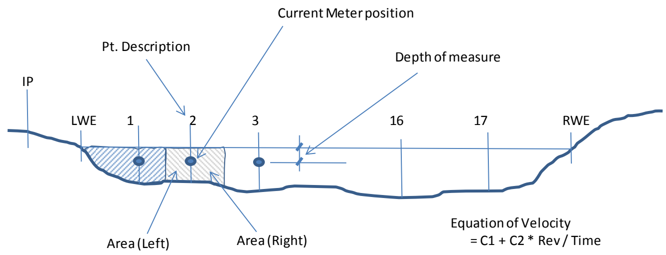


Figure 6-11. Data flow for Discharge Measurement Collection

Figure 6-12. Streamflow Management System Homepage and Login window

Method **Current Meter**

Station	A SAMPLE STATION
Gage Ht	1.42
Date	2014-10-23
Time	08:00 AM
Elev of Zero gage	17.21
Condition of flow	Turbulent
Weather	Cloudy
Conducted by	Edgar B. Garcia
Checked by	Adelina P. Gomez



CROSS SECTION
(STANDARD: FACING DOWNSTREAM)

equation of velocity = c1 + c2 * Rev / Time

Pt.Desc	Dist From IP	Depth	Depth of Measure	Rev	Time	c1	c2	Velocity	Mean Vel	Area Left	Area Right	Area	Q	WS Elev	Bed Elev
	m	m	m	N	s			m/s	m/s	sq.m	sq.m	sq.m	cu.m/s	m	m
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LWE	3													18.63	18.63
1	4.4	0.18	0.6D	46	40.00	0.007538	0.675303	0.78	0.784	0.126	0.180	0.306	0.240	18.63	18.45
			0.8D			0.007538	0.675303								
2	6.4	0.15	0.6D	43	40.00	0.007538	0.675303	0.73	0.733	0.158	0.150	0.308	0.226	18.63	18.48
			0.8D			0.007538	0.675303								
3	8.4	0.13	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.135	0.130	0.265	0.201	18.63	18.50
			0.8D	43	40.00	0.007538	0.675303	0.73							
4	10.4	0.12	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.123	0.120	0.243	0.184	18.63	18.51
			0.8D	43	40.00	0.007538	0.675303	0.73							
5	12.4	0.08	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.090	0.080	0.170	0.129	18.63	18.55
			0.8D	43	40.00	0.007538	0.675303	0.73							
6	14.4	0.02	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.035	0.015	0.050	0.038	18.63	18.61
			0.8D	43	40.00	0.007538	0.675303	0.73							
7	16.4	0.00	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.005	0.000	0.005	0.004	18.63	18.63
			0.8D	43	40.00	0.007538	0.675303	0.73							
8	18.4	0.00	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.000	0.000	0.000	0.000	18.63	18.63
			0.8D	43	40.00	0.007538	0.675303	0.73							
9	20.4	0.06	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.060	0.045	0.105	0.080	18.63	18.57
			0.8D	43	40.00	0.007538	0.675303	0.73							
10	22.4	0.00	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.015	0.000	0.015	0.011	18.63	18.63
			0.8D	43	40.00	0.007538	0.675303	0.73							
11	24.4	0.05	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.050	0.050	0.100	0.076	18.63	18.58
			0.8D	43	40.00	0.007538	0.675303	0.73							
12	26.4	0.05	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.050	0.050	0.100	0.076	18.63	18.58
			0.8D	43	40.00	0.007538	0.675303	0.73							
13	28.4	0.15	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.125	0.150	0.275	0.209	18.63	18.48
			0.8D	43	40.00	0.007538	0.675303	0.73							
14	30.4	0.26	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.233	0.260	0.493	0.374	18.63	18.37
			0.8D	43	40.00	0.007538	0.675303	0.73							
15	32.4	0.42	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.380	0.420	0.800	0.607	18.63	18.21
			0.8D	43	40.00	0.007538	0.675303	0.73							
16	34.4	0.19	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.248	0.190	0.438	0.332	18.63	18.44
			0.8D	43	40.00	0.007538	0.675303	0.73							
17	36.4	0.22	0.6D	46	40.00	0.007538	0.675303	0.78	0.759	0.213	0.054	0.266	0.202	18.63	18.41
			0.8D	43	40.00	0.007538	0.675303	0.73							
RWE	37.05													18.63	18.63
											TOTAL =	3.937	2.988		

SUMMARY:

Area =	3.937	sq.m
Velocity =	0.759	m/s
Q =	2.988	cu.m/s

0.42

Figure 6-13. Example of Excel spreadsheet template for Discharge Measurement available for download from the website

7. Computation of Discharge using Simple Stage-Discharge Relation

7.1 Introduction

This chapter describes methods and procedures for the determination of the stage-discharge relation by correlating water level to discharge. A stream gaging station is a selected site on an open channel for making systematic observations for the purpose of determining records of the discharge and gage heights of the stream. At present, most stations nationwide are non-recording stations equipped with wooden staff gage and read regularly three times a day by an observer. The term gage height is often used interchangeably with stage, the former being the more appropriate term when referring to a gage.

Stage (gage height) and discharge of a stream both vary most of the time. In general, it is not practical to measure the discharge continuously. However, to obtain a continuous record of the gage height at a site is relatively simple and less expensive. Then, if a relation between gage height and discharge exists, an observed record of gage height can easily be converted into a record of discharge, which is the information more commonly used in the design of structures, floodplain management plans, etc.

The operations necessary to develop the stage discharge relation at a station include making a sufficient number of discharge measurements usually by current meter and establishing a discharge rating curve and are called the calibration or rating of the station. The rating curve is developed by plotting measured discharge against the corresponding gage height and drawing a smooth curve of relation between these two quantities.

At a new station many discharge measurements are needed to define the stage-discharge relation throughout the entire range of stage. Periodic measurements are needed thereafter to either confirm the permanence of the rating or to follow changes (shifts) in the rating. A minimum of 10 discharge measurements per year is recommended, unless it has been demonstrated that the stage-discharge relation is unvarying with time. In that event the frequency of measurements may be reduced. It is of prime importance that the stage-discharge relation be defined for flood conditions or as a result of the variable channel and control conditions. It is essential that the stream-gaging program have sufficient flexibility to provide for the non-routine scheduling of additional measurements of discharge at those times.

If the discharge measurements cover the entire range of stage experienced during a period of time when the stage-discharge relation is stable, there is little problem in defining the discharge rating for that period. On the other hand, if, as is usually the case, discharge measurements are lacking to define the upper end of the rating, the defined lower part of the rating curve must be extrapolated to the highest stage experienced. Such extrapolations are always subject to error, but the error may be reduced if the analysis has knowledge of the principles that govern the shape of rating curves.

7.2 The Stage-Discharge Relation

7.2.1 General

When a new river gaging station has been established, the general practice is initially to carry out a series of discharge measurements well-distributed over the range of discharge variation, in order to establish quickly the discharge rating curve. Usually, there are no difficulties involved in measuring the lower and medium discharges. However, to obtain measurements at the higher stages is often a difficult task and may take time. Thus, at a majority of gaging stations, discharge measurements are not available for the high flood stages and the rating curve must be extrapolated beyond the range of available measurements.

Very few rivers have absolutely stable characteristics. The calibration, therefore, cannot be carried out once and for all, but has to be repeated as frequently as required by the rate of change in the stage-discharge relation. Thus, it is the stability of the stage-discharge relation that governs the number of discharge measurements that are necessary to define the relation at any time and to follow the temporal changes in the stage-discharge relation. If the channel is stable, comparatively few measurements are required. On the other hand, in order to define the stage-discharge relation in sand-bed streams up to several discharge measurements a month may be required because of random shifts in the stream geometry and the station control.

Sound hydrological practice requires that the discharge rating curve is determined as rapidly as possible after the establishment of a new station. Unless the discharge rating curve is properly established and maintained, the record of stage for the station cannot be converted into a reliable record of discharge.

7.2.2 The Stage-Discharge Control

The subject of stage-discharge controls has been discussed earlier in Chapter 6, but a brief discussion is given below.

The relation of stage to discharge is usually controlled by a section or reach of channel downstream from the gage that is known as the station control. A section control may be natural or manmade; it may be a ledge of rock across the channel, a boulder-covered riffle, an overflow dam, or any other physical feature capable of maintaining a fairly stable relation between stage and discharge. Section controls are often effective only at low discharges and are completely submerged by channel control at medium and high discharges. Channel control consists of all the physical features of the channel that determine the stage of the river at a given point for a given rate of flow. These features include the size, slope, roughness, alignment, constrictions and expansions, and shape of the channel. The reach of channel that acts as the control may lengthen as the discharge increases, introducing new features that affect the stage-discharge relation.

Knowledge of the channel features that control the stage-discharge relation is important. The development of stage-discharge curves where more than one control is effective, and where the number of measurements is limited, usually requires judgment in interpolating between measurements and in extrapolating beyond the highest measurements. That is particularly true where the controls are not permanent and the various discharge measurements are representative of changes in the positioning of segments of the stage-discharge curve.

7.2.3 The Point of Zero Flow

When constructing discharge rating curves, the gage height of zero flow, also termed the "point of zero flow" is important information especially helpful when shaping the lower part of the curve. The point of zero flow is the gage height at which the water ceases to flow over the control. This gage height should be determined by field surveys whenever the flow is sufficiently low to allow an accurate determination. Stream gages are usually established at an arbitrary datum. The elevation of gage zero is decided on the day of establishment and set below the lowest stage anticipated at the site. It is therefore only in a very few cases that the zero of the gage will correspond by coincidence to the point of zero flow. The control section is defined by surveying a close grid of spot-levels over a reach of the stream downstream from the station site or by surveying a sufficient number of cross-sections.

The point of zero flow will be the lowest point in the controlling section. In those cases the control is well-defined by a rocky barrier over which the water flows, usually, it is very easy to locate the point of zero flow and obtain its correct gage height value.

Determination of the point of zero flow from soundings taken during current meter measurements is not possible. These soundings might have been taken in any cross-section of the river in the vicinity of the gage and will only give the correct point if the soundings happened to be taken in that particular cross-section containing the control.

7.2.4 Complexities of Stage Discharge Relations

Stage-discharge relations for stable controls such as a rock outcrop and manmade structures such as weirs, flumes and small dams usually present few problems in their calibration and maintenance. However, complexities can arise when controls are not stable and/or when variable backwater occurs. For unstable controls, segments of a stage-discharge relation may change position occasionally, or even frequently. This is usually a temporary condition which can be accounted for through the use of the shifting-control method.

Variable backwater can affect a stage-discharge relation, both for stable and unstable channels. Sources of backwater can be downstream reservoirs, tributaries, tides, ice, dams and other obstructions that influence the flow at the gaging station control. Methods of developing complex ratings for variable backwater conditions will not be covered in this Manual.

Another complexity that exists for some streams is hysteresis, which results when the water surface slope changes due to either rapidly rising or rapidly falling water levels in a channel control reach. Hysteresis ratings are sometimes referred to as loop ratings, and are most pronounced in relatively flat sloped streams. On rising stages the water surface slope is significantly steeper than for steady flow conditions, resulting in greater discharge than indicated by the steady flow rating. The reverse is true for falling stages. Details on hysteresis ratings will not be discussed in this Manual as well.

Future updating of this Manual will be necessary when cases of variable backwater conditions or hysteresis have been reported to exist in any of the gaging stations nationwide.

7.3 Establishment of Discharge Rating Curve

7.3.1 General

The discharge rating curve is established from a graphical analysis of discharge measurements that are plotted on graph paper or with the use of computer, either arithmetically or logarithmically ruled. A correct analysis of the proper shape and position of the rating curve requires knowledge of the channel characteristics at the particular gaging site being considered, knowledge of open channel hydraulics and considerable experience and judgment.

In all stream gaging stations nationwide, single-gage stations are employed. The employment of a single-gage station depends upon the assumption that the stage in a cross-section of a stream is a unique function of the discharge only. This manual deals with the simple stage-discharge only and where variable backwater effects are not present.

7.3.2 Simple Stage-Discharge Relations

7.3.2.1 List of Discharge Measurements

The first step before making a plot of stage versus discharge is to prepare a list of discharge measurements that will be used for the plot. At a minimum this list should include at least 12 to 15 measurements, all made during the period of analysis. If the rating is segmented then more measurements may be required. These measurements should be well distributed over the range in gage heights experienced. It should also include low and high measurements from other times that might be useful in defining the correct shape of the rating and for extrapolating the rating. Extreme low and high measurements should be included wherever possible.

For each discharge measurement in the list, it is important that at least the following items are included:

(a) Unique identification number;
(b) Date of measurement;
(c) Gage height of measurement;
(d) Total discharge;
(e) Accuracy of measurement;
(f) Rate-of-change in stage during measurement, a plus sign indicating rising stage and a minus sign indicating falling stage.

Other information might be included in the list of measurements that is as important as well. For instance, names of Hydrographers making the measurement, time of measurement, difference between inside and outside gage readings (if any), location of measurement, method of measurement and notes about the condition of the control. **Table 7-1** shows a typical list of discharge measurements summarized from the field notes (**Figure 7-1**), listing the above items including a number of items in addition to the mandatory items. The discharge measurement list may be handwritten for use when hand-plotting is done or the data may be a computer list where a computerized plot is developed.

7.3.2.2 Graphical Plot of Discharge Measurements

The rating curve as developed for a single gage station will give the value of the normal discharge, that is, the discharge under uniform steady flow conditions for a given stage. Stage-discharge relations are usually developed from a graphical analysis of the discharge measurements plotted on either rectangular coordinate or logarithmic plotting paper. In a preliminary step the discharge measurements available for analysis are summarized in a table. Discharge is then plotted as the abscissa, corresponding gage height is plotted as the ordinate, and a curve or line is fitted by eye to the plotted points using ship curves on a rectangular coordinate. The plotted points carry the identifying measurements which are numbered consecutively in chronological order so that time trends can be identified.

A peculiarity of most rating curve plots is the parameters plotted along the ordinate and abscissa scales are interchanged from the standard engineering practice. For rating curves where gage height is the independent variable, gage height always is plotted as the ordinate, and the dependent variable as the abscissa. This designation allows gage height, which is measured in a vertical direction, to be plotted in a vertical direction. The rating curve slope for this method of plotting is defined as a horizontal distance divided by a vertical distance.

Table 7-1. Typical List of Discharge Measurements

Station: Rio Chico River, DPWH Zaragosa, Nueva Ecija

No.	Date	Width (m)	Area (sq.m.)	Velocity (m/s)			Discharge (m3/s)	Gage Height (m)	Method of Measure-ment	Sections	Method of Crossing Stream	Location of Measuring Cross Section
				Mean	Max.	Min.						
1	10-25-06	36.00	70.28	0.564	0.784	0.143	39.620	11.58	0.2, 0.8 d	8	Cable	Along the gage
2	05-31-07	41.00	76.20	0.432	0.717	0.233	32.881	12.04	0.6, 0.2, 0.8 d	16	Cable	Along the gage
3	06-28-07	41.00	72.40	0.411	0.717	0.192	29.766	11.73	0.6, 0.2, 0.8 d	16	Cable	Along the gage
4	07-30-07	41.00	85.30	0.421	0.652	0.165	35.900	12.60	0.6, 0.2, 0.8 d	16	Cable	Along the gage
5	08-22-07	81.00	194.65	0.505	0.683	0.176	98.286	14.20	0.6, 0.2, 0.8 d	16	Cable	Along the gage
6	09-12-07	81.00	185.92	0.499	0.653	0.176	92.724	13.80	0.6, 0.2, 0.8 d	16	Cable	Along the gage
7	10-26-07	44.00	45.59	0.572	0.928	0.161	26.078	11.63	0.6, 0.2, 0.8 d	12	Cable	Along the gage
8	11-22-07	53.05	205.06	0.491	0.859	0.150	100.620	13.52	0.6, 0.2, 0.8 d	10	Cable	Along the gage
9	12-14-07	42.30	67.45	0.344	0.480	0.274	23.183	11.32	0.6, 0.2, 0.8 d	10	Cable	Along the gage
10	01-16-08	40.00	89.88	0.470	0.652	0.250	42.220	11.85	0.2, 0.8 d	16	Cable	Along the gage
11	02-22-08	37.00	64.68	0.409	0.586	0.225	26.444	10.84	0.2, 0.8 d	16	Cable	Along the gage
12	03-26-08	37.00	66.29	0.443	0.586	0.264	29.356	11.46	0.2, 0.8 d	16	Cable	Along the gage
13	04-29-08	37.00	53.00	0.356	0.499	0.253	18.882	10.42	0.2, 0.8 d	16	Cable	Along the gage
14	08-20-08	57.00	169.67	0.574	0.739	0.420	97.324	14.12	0.6 d	9	Wading	Along the gage
15	09-18-08	59.00	231.43	0.589	0.968	0.200	136.206	14.50	0.2, 0.8 d	11	Wading	Along the gage
16	10-29-08	38.00	79.66	0.520	0.653	0.298	41.385	11.28	0.2, 0.8 d	6	Wading	Along the gage
17	04-22-09	40.00	95.20	0.587	0.715	0.463	55.838	11.90	0.6, 0.2, 0.8 d	16	Cable	Along the gage
18	05-19-09	40.00	73.42	0.306	0.446	0.221	22.474	11.54	0.2, 0.8 d	16	Cable	Along the gage
19	06-23-09	41.00	79.78	0.303	0.393	0.259	24.205	14.48	0.2, 0.8 d	13	Cable	Along the gage
20	07-30-09	42.00	104.61	0.568	0.852	0.479	59.462	14.50	0.2, 0.8 d	9	Cable	Along the gage
21	08-25-09	42.00	121.68	0.562	0.717	0.376	68.358	14.39	0.2, 0.8 d	13	Cable	Along the gage
22	09-16-09	42.00	106.95	0.702	0.972	0.621	75.056	14.74	0.2, 0.8 d	13	Cable	Along the gage
23	10-21-09	80.00	238.50	0.452	0.619	0.314	107.719	14.84	0.2, 0.8 d	15	Cable	Along the gage
24	04-28-10	36.00	5.40	0.314	0.446	0.000	1.693	10.90	0.6 d	9	Wading	Upstream
25	06-30-10	36.00	9.00	0.474	0.651	0.000	4.265	12.80	0.6 d	9	Wading	Upstream
26	07-30-10	36.00	64.50	0.527	0.744	0.305	34.013	12.80	0.2, 0.8 d	11	Wading	Upstream

STREAM DISCHARGE MEASUREMENT

DATE: August 25, 2009

1. STREAM STATION	2. MEASUREMENT NO.	3. OBSERVER (Name of Gagekeeper)
Rio Chico River, Zaragoza, Nueva Ecija		Froilan Escosa

4. RESULTS OF COMPUTATION

WIDTH	AREA	VELOCITY MEAN	VELOCITY MAX.	VELOCITY MIN.
42.00	121.68	0.562	0.717	0.376

DISCHARGE	GAGE HEIGHT	% DIFFERENCE FROM PREVIOUS
68.358	14.39	

5. CONDITIONS

CROSS SECTION: ☐ STABLE ☐ UNSTABLE

FLOW: ☐ TURBULENT ☐ NORMAL ☐ LOW

WEATHER: ☐ RAINY ☐ CLOUDY ☐ SUNNY

6. MEASUREMENT

METHOD	SECTIONS	GAGE HEIGHT CHANCE	WATER SUSPENSION
0.60, 0.20, 0.80 d	13		

7. COEFFICIENT

METHOD	HOR. ANGLE	SUSPENSION
2		

8. CURRENT METER

DATE RATED	METHOD OF SUSPENSION	WATER SPIN CHECK (sac) BEFORE	WATER SPIN CHECK (sac) AFTER
622-G	Cable - 1, Suspension Rod - 2		

METER NO.	SUSPENSION (above bottom of weight		
		80	

9. SPIRIT LEVEL CHECK

CHECK BAR FOUND	CHANGED TO
	AT
LEVELS OBTAINED	ADJUSTMENT

11. METHOD OF CROSSING STREAMS AND LOCATION OF MEASURING CROSS SECTION

METHOD	LOCATION (bridge only)	DISTANCE	GAGE	MEASUREMENT ERROR EVALUATION
☐ WADING				☐ EXCELLENT
☒ CABLE	☐ UPSTREAM		☐ ABOVE	☐ GOOD
☐ BOAT	☐ DOWNSTREAM		☐ BELOW	☐ FAIR
☐ BRIDGE	☒ ALONG THE GAGE			☐ POOR (over 8%)

12. GAGE READING

TIME	START	FINISH	RECORDER	INSIDE	OUTSIDE
5:00 AM	14.39				
5:45 AM		14.39			

WEIGHTED MEAN GAGE HEIGHT

GAGE HEIGHT CORRECTION

CORRECT MEAN GAGE HEIGHT

13. GAGE

RECORD REMOVE	INTAKE FLUSHED	GAGE HEIGHT OF ZERO FLOW	ELEVATION ZERO OF GAGE:
YES NO	YES NO		30 486 m

REMARKS:

MEMBER OF THE PARTY: Neil Edwin Timbol, Rommy Sicat, Eulogio Sigua

NAME OF PARTY LEADER: Rosalinda P. Tapang

SIGNATURE

angle coef.	dist. from I.P.	width	depth	W	rev	time/ secs.	vel at pt.	vel mean	for hor.ang.	area	discharge
	80.0	LWE									
	83.0	3.00	5.24		32	40	0.548	0.616		15.720	9.676
					40	40	0.683				
	86.0	3.00	4.23		38	42	0.619	0.619		12.690	7.855
					38	42	0.619				
	89.0	3.00	4.00		30	42	0.490	0.587		12.000	7.038
					40	40	0.683				
	92.0	3.00	3.34		34	40	0.582	0.565		10.020	5.661
					32	40	0.548				
	95.0	3.00	3.00		30	40	0.514	0.599		9.000	5.387
					40	40	0.683				
	98.0	3.00	3.05		32	42	0.522	0.620		9.150	5.668
					42	40	0.717				
	101.0	3.00	3.10		30	40	0.514	0.507		9.300	4.710
					32	44	0.499				
	104.0	3.00	3.20		34	42	0.554	0.570		9.600	5.472
					36	42	0.586				
	107.0	3.00	2.90		30	44	0.468	0.499		8.700	4.337
					34	44	0.529				
	110.0	3.00	2.70		30	44	0.468	0.495		8.100	4.010
					32	42	0.522				
	113.0	3.00	2.50		30	44	0.468	0.495		7.500	3.713
					32	42	0.522				
	116.0	3.00	2.40		32	42	0.522	0.506		7.200	3.643
					30	42	0.490				
	119.0	3.00	0.90		30	40	0.514	0.445		2.700	1.202
					24	44	0.376				
	122.0	RWE									

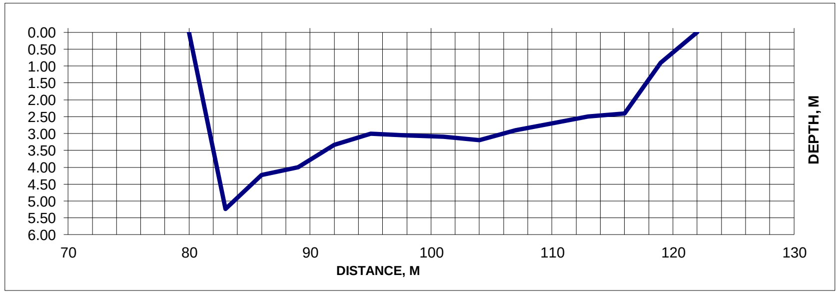


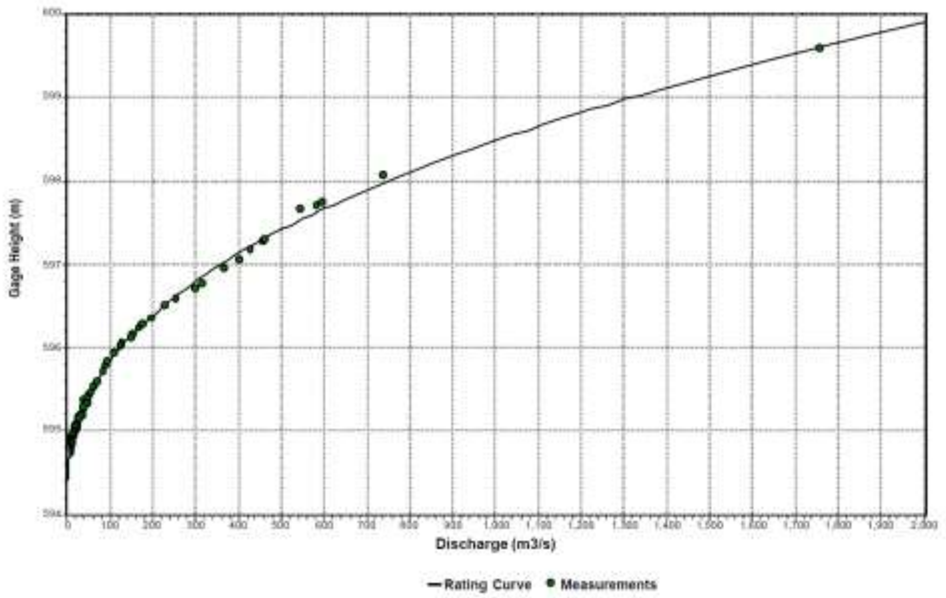
Figure 7-1. Example of Discharge Measurement Notes

a. **Arithmetic Plotting Scales**The simplest type of plot uses an arithmetically divided plotting scale as shown in **Figure 7-2**. Scale subdivisions should be chosen to cover the complete range of gage height and discharge expected to occur at the gaging site. Scales should be subdivided in uniform, even increments that are easy to read and interpolate.

They should also be chosen to produce a rating curve that is not unduly steep or flat. Usually the curve should follow a slope of between 30° and 50°. If the range in gage height or discharge is large, it may be necessary to plot the rating curve in two or more segments to provide scales that are easily read with the necessary precision. This procedure may result in separate curves for low water, medium water and high water. Care should be taken to see that, when joined, the separate curves form a smooth, continuous combined curve.

The use of arithmetic coordinate paper for rating analysis has certain advantages, particularly in the study of the pattern of rating shifts in the lower part of the rating. A change (shift) in the low-flow rating at many sites results from a change in the gage height of effective zero flow, which means a constant shift in gage height. A shift of that kind is more easily visualized on arithmetic coordinate paper because on that paper the shift curve is parallel to the original rating curve. The two curves are separated by a vertical distance equal to the change in the value of the gage height of zero flow. A further advantage of arithmetic coordinate paper is the fact that the gage height of zero flow can be plotted directly on arithmetic coordinate paper, thereby facilitating extrapolation of the low water end of the rating curve. That cannot be done on logarithmic paper because zero values cannot be shown on that type of paper.

For analytical purposes arithmetic scales have practically no advantage. For this reason, logarithmic plotting should always be used initially in developing the general shape of the rating. The final curve may be displayed on either type of graph paper and used as a base curve for the analysis of shifts. A combination of the two types of graph paper is frequently used with the lower part of the rating plotted on an inset of rectangular coordinate paper or on a separate sheet of rectangular coordinate paper.



Source: How to establish stage-discharge rating curve, Hydrology Project, New Delhi 1999

Figure 7-2. An example of stage-discharge rating curve

b. Logarithmic Plotting Scales

General

The logarithmic representation of the stage discharge relation is commonly used because it produces the best graphical form of a standard rating curve and readily adapts to the use of ship drafting curves. Also, the logarithmic form of the rating curve can be made to approach a straight line, or straight line segments, by adding or subtracting a constant value to the gage height scale on the logarithmic graph paper. There are several other advantages that the logarithmic form has, as:

1) A percentage distance off the curve is always the same regardless of where it is located. Thus, a measurement that is 10 percent off the curve at high stage will be the same distance away from the curve as a measurement that is 10 percent off at low stage,
2) Halving, doubling or adding a percentage to the gage height has no effect, the curve will merely shift position but retain the same shape,
3) It is easy to identify the range in stage, for which different controls are effective,
4) The logarithmic form may be described by a simple mathematical equation that is easily handled by electronic computers,
5) The curve can easily be extrapolated.

Regarding extrapolations, however, one has to be careful. If the control does not change character at the higher stages, the same discharge equation will cover the whole range in stage and the rating curve can be extrapolated up to the highest observed water level. If the control changes either shape or character as the stage increases, the rating curve will consist of more than one segment. In these cases, an extrapolation of the first segment up to the higher stages will of course introduce serious errors.

Logarithmic Equation

The general equation of the relation between stage and discharge is given as:

$$Q = K(H - H_o)^n \qquad (8)$$

Taking logarithms of the power type equation results in a straight line relationship of the form:

$$\log(Q) = n\log(H - H_o) + \log(K) \qquad (9)$$

Or

$$Y = B\,X + A \qquad (10)$$

Where:

- Q = Discharge (m3/s)
- H = Measured gage height (m)
- H_o = Gage height corresponding to Q=0
- B = n, slope of the line (gradient)
- A = $\log(K)$, intercept on the (log y)-axis, where log x = 0

Equation (8) is a parabolic equation which plots as a straight line on double logarithmic graph paper. The equation will apply to cross-sections of rectangular, triangular, trapezoidal, parabolic and other geometrically simple sections. Many natural streams approximate to these shapes making equation (8) a general discharge equation.

The logarithmic discharge equation is seldom a straight line or a gentle curve for the entire range in stage at a gaging station. Even if the same channel cross-section is the control for all stages, a sharp break in the contour of the cross-section causes a break in the slope of the rating curve. Also, the other constants in Equation (8) are related to the physical characteristics of the stage-discharge control.

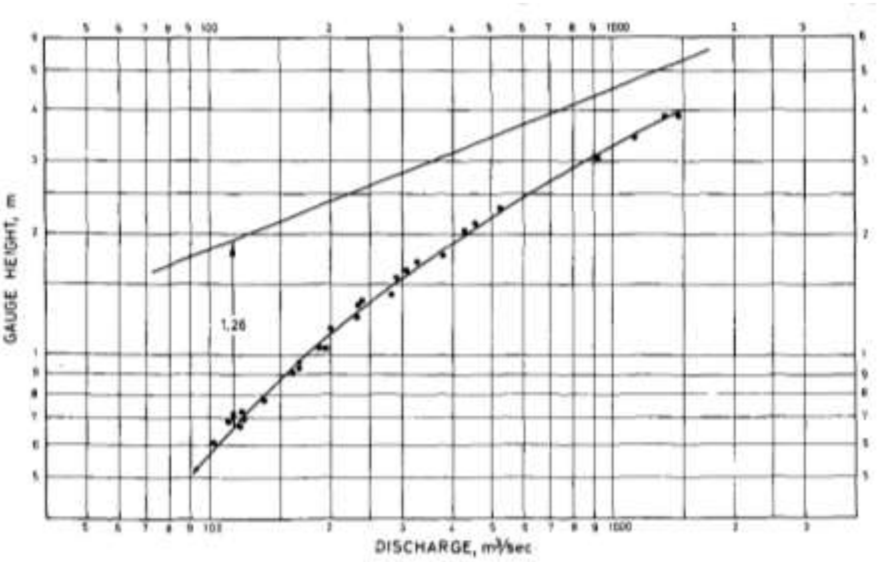
If the control section changes at various stages, it may be necessary to fit two or even more equations, each corresponding to the portion of the range over which the control is the same. If, however, too many changes in the parameters are necessary in order to define the relationship, then possibly the logarithmic discharge equation may not be suitable and a curve fitted by visual estimation would be better.

Estimating Gage Height of Zero Flow (a)

There are three methods of estimating the point of zero flow apart from making a field survey. However, if at all possible, the estimates should always be sought verified by field visits and inspection of longitudinal and cross-sectional profiles at the measuring section.

Trial and Error Procedure

All discharge measurements available are plotted on log-log paper and a median line balanced through the scatter of data points. Usually, this line will be a curved line. Various trial values, one value for each trial, are added or subtracted to the gage heights of the measurements until the plot obtained forms a straight line. The trial value forming the straight line is the value of H_O (**Figure 7-3**).

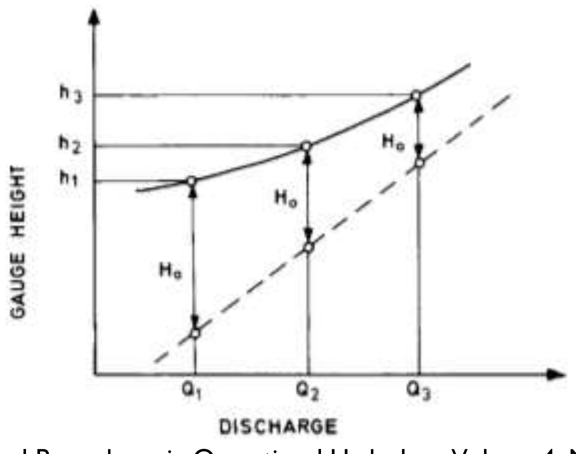


Source: Manual Procedures in Operational Hydrology Volume 4, NORAD 1979

Figure 7-3. Trial and error method of finding *Ho*

All the plotted data points may be used in the trial operation. However, it is better to use only a few points selected from the median line first fitted to the points. Note that when a quantity has to be added to the gage height readings of the measurements in order to obtain a straight line, then H_O will have a negative value, and vice versa. That is, the zero of the gage is in this case positioned at a level above the point of zero flow and the point of zero flow will consequently give a negative gage reading.

Note that when a quantity has to be added to the gage height readings of the measurements in order to obtain a straight line, then *Ho* will have a negative value, and vice versa. That is, the zero of the gage is in this case positioned at a level above the point of zero flow and the point of zero flow will consequently give a negative gage reading.



Source: Manual Procedures in Operational Hydrology Volume 4, NORAD 1979

Figure 7-4. Schematic illustration of how a curved line is transformed into a straight line on logarithmic paper

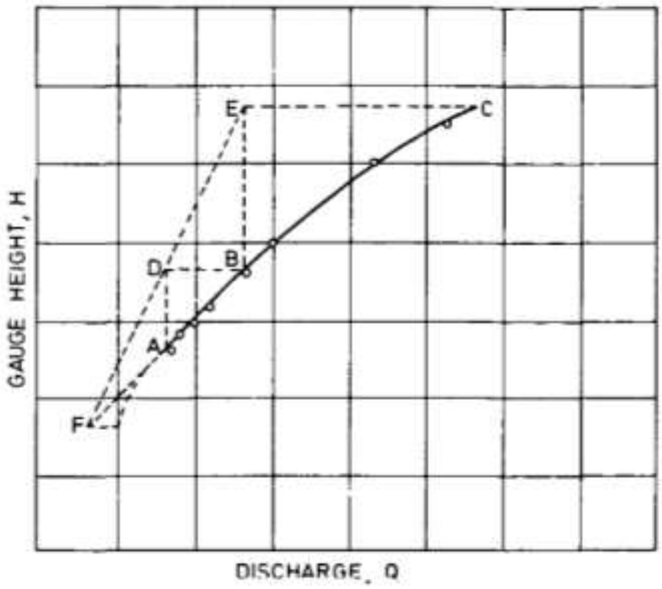
Arithmetical Procedure
All discharge measurements are plotted on log-log paper (**Figure 7-4**). An average line drawn through the scatter of points has resulted in the solid curved line. Three values of discharge Q_1, Q_2, and Q_3 are selected in geometric progression, that is, two values Q_1 and Q_3 are chosen from the curve, the third value Q_2 is then computed according to

$$Q_2^2 = Q_1 Q_3 \qquad (9)$$

The corresponding gage heights read from the plot are h_1, h_2, and h_3. It is now possible to verify that

$$Ho = \frac{h_1 h_3 - h_2^2}{h_1 + h_3 - 2h_2} \qquad (10)$$

The solid curved line may now be transformed into a straight line by subtracting H_o from each value of the gage height h and re-plotting the new values.



Source: Manual Procedures in Operational Hydrology Volume 4, NORAD 1979

Figure 7-5. Graphical determination of H_0

Graphical Procedure
As above in **Figure 7-5**, three values of discharge in geometric progression are selected, but this time from a plot on arithmetical graph paper. The points are A, B, and C as illustrated in **Figure 7-5**. Vertical lines are drawn through A and B and horizontal lines are drawn through B and C intersecting the verticals at D and E respectively. Let DE and AB meet at F. Then the ordinate of F is the value of Ho.

The last two methods are based on the assumption that the lower part of the stage-discharge relation including the selected points is a part of a parabola. In most cases this assumption holds and the method will give acceptable results on the condition that there are enough discharge measurements available to satisfactorily define the curvature of the lower part of the rating curve.

Estimating the Constants K and n

After a straight line plot of the discharge measurements on double logarithmic graph paper has been obtained, the constant B and A of flow equation (8) can be worked out in three ways; namely, arithmetically, statistically and graphically.

The stage-discharge relation must first be analyzed from a plot on log-log graph paper in order to establish whether the rating curve is composed of one or several straight line segments, each having its own constants B and A. The constants for each separate segment must be calculated separately.

A least square method is normally employed for estimating the rating curve coefficients. The values of $\boldsymbol{c}$ and $\boldsymbol{b}$ may be worked out statistically according to the Method of the Least Squares. That is, the sum of the squares of the deviations between the logarithms of the discharges measured and estimated by a mean curve should be a minimum.

According to this the values of B and A are obtained from the following equations:

$$\sum(X) - N\,Log\,K - n\sum(X) = 0 \qquad (11)$$

$$\sum(XY) - \sum(X)\;Log\,K - n\sum(X^2) = 0 \qquad (12)$$

Where:

$\sum(Y)$ = the sum of all values of log Q
$\sum(X)$ = the sum of all values of log (h-a)
$\sum(X)^2$ = the sum of all values of the square of (X)
$\sum(XY)$ = the sum of all values of the product of (X) and (Y)
N = the number of observations

$$B = \frac{N\sum_i^N(X_iY_i) - (\sum_i^N X)(\sum_i^N Y)}{N(\sum_i^N X^2) - (\sum_i^N X)^2} \qquad (13)$$

$$A = \frac{\sum_i^N Y_i - B\sum_i^N X_i}{N} \qquad (14)$$

The value of coefficients, K and n of power type equation can then be finally obtained as:

$B = n$ and $K = 10^A$

It should be emphasized however that it is a common practice when using the Method of Least Squares, to give all the discharge measurements an equal statistical weight in spite of the fact that most of the measurements available for defining the relation will always be located at the low and medium stages. Thus, an extrapolation of the discharge formula to the higher stages, where at best very few and usually no data points are available, will be biased by the greater number of low-lying data points. It follows that extrapolation of discharge formulas developed by use of the Method of Least Squares should be done carefully and always checked against other methods of extrapolation.

c. Computer plotting of discharge measurements and rating curves

Plotting of discharge measurements and rating curves, either arithmetic plots or logarithmic plots, is best done by computer. These plots can be viewed on the computer monitor and/or plotted on paper forms. Advantages of computer plots are:

a) Selection of measurements for plotting can be made quickly and easily;
b) Scale changes can be made and measurements re-plotted quickly;
c) Various values of H_o can be easily tried for the purpose of defining a straight-line rating on logarithmic plots;
d) Separate rating segments, representing different control conditions, can be easily and quickly plotted;
e) Rating analysis, as described in the subsequent section, is accomplished easily;
f) Plotting errors are virtually eliminated.

Logarithmic plots of rating curves must meet the requirement that the log cycles are square. That is, the linear measurement of a log cycle, both horizontally and vertically, must be equal. Otherwise, it is impossible to hydraulically analyze the resulting plot of the rating. This requirement for square log cycles should always be tested because some computer programs do not include this as an automatic feature.

7.3.3 Procedures for Establishing the Discharge Rating Curve

The following steps have been found practicable:

1. All discharge measurements are plotted on ordinary arithmetical graph paper, gage height on vertical scale and discharge on horizontal scale. If the point of zero flow has been obtained by an actual field survey, this point must also be included in the plot. The scales should be so selected that the mean direction of the plot approximately follows the diagonal of the graph sheet from left to right. Uncommon odd scales should not be used; suggested scales for the gage height are 1:5, 1:10, and 1:20, preferably 1:10. A curve is fitted to the data points by visual estimation or computer plotting.

2. At equal gage height increments, the discharge is selected from the curve and tabulated together with its gage height. Usually, increments in gage height of 0.10 m are practical, however, at the lower part of the curve where the curvature is greatest, it may sometimes be better to use increments of 0.05 m; at the upper part of the curve increments of 0.20 m may often be preferable.

3. The 1st and 2nd series of differences of the discharges are calculated and smoothed. From the smoothed series of 1st differences, adjusted values of the discharge are calculated. Re-plot adjusted discharge values on arithmetical graph scale. Inspect the plot, adjust if necessary. When the rating curve is of a fairly regular shape, it is not considered necessary to use the 2nd differences in order to smooth the 1st differences.

4. Plot final adjusted discharges against their corresponding gage height on double logarithmic graph paper; draw a smooth curve through the data points by means of ship drafting curves if done manually or by computer plotting.

5. Estimate H_o by trial and error. That is, add or subtract trial values for H_o to the gage height until the curve drawn on log-log graph paper becomes transformed into a straight line, or into two or more straight line segments. Usually, the following instances will occur:

   a) One single straight line. Produced by a complete section control of regular shape, often the crest of a rapid or a waterfall.

   b) One single broken line consisting of two straight line segments, each with a different slope but the same H. Produced by a complete section control having a sharp break in the cross-sectional contour but otherwise of regular shape.

c) Two or more disconnected straight line segments each with its own slope n and H_0. The most common case produced by a compound control of various combinations, usually section control at low stage.

d) Sometimes it happens that the plotted curve cannot be transformed into straight line segments, or rather, the segments will be so short and numerous that the logarithmic representation of the curve would not be practical. Produced by a very irregular control, H_0 as obtained from a field survey or by the arithmetical and graphical techniques is valid for the lowest segment only and for one single line. The "trial and error" technique has to be used for the upper segment or segments. The trial and error technique is not too time consuming, after some practice it will be found that only few trials are necessary in order to find the correct H_0. It is not necessary to plot all the incremental data points of the table during the trials. Inspecting the straight line plot, one last adjustment of the tabulated discharges may prove necessary.

6. Inspect the straight line plot, one last adjustment of the tabulated discharges may prove necessary.

7. When the curve has been found acceptable, the mathematical equation for each segment is calculated.

7.3.4 Rating Tables

The rating table is a tabular representation of the rating curve and is a useful tool for converting gage height readings into discharges once established.

The discharges entered in the 0.00-column are the final adjusted values in the rating curve, and give the discharge for every 0.10 m increments in gage height. Intermediate values are obtained by interpolating between the values of the 0.00-column; the difference between adjacent discharges should increase smoothly or be the same as the preceding difference. With the use of computer, the rating table is easily established by means of the discharge equation.

7.3.4.1 Rating Table Smoothness analysis

One method of analyzing the smoothness of a rating curve and/or rating table can be done by studying the differences between successive values of the dependent variable. To make this task easy for the Hydrographer, the rating table should display the computed differences (traditionally referred to as first differences) of the dependent variable between every tenth values of the independent variable displayed in the rating table. For instance, if gage height is incremented every 0.01 m in the rating table, then the difference between discharges corresponding to gage heights at 0.01 m intervals should be computed and displayed.

7.3.4.2 Verification of the Rating Curve

The stage-discharge relation is checked from time to time by discharge measurements at a low stage and at a medium or high stage, and always during and after major floods. If a Significant departure from the established rating curve is found, further checks are made. If the difference is confirmed, sufficient discharge measurements are made to redefine the curve in the range in which the relation has altered and a new rating curve is made.

If a particular change of the rating curve can be attributed to a definable incident in the history of the station, the new curve should apply from the time of that incident.

7.3.5 Extrapolation of Rating Curves

7.3.5.1 General

Extrapolation of the rating curve in both lower and upper directions is often necessary. If the point of zero flow has been obtained, the curve may be interpolated between this point and the lowest discharge measurements without much error. But, if the point of zero flow is not available, it is not advisable to extrapolate far in this direction.

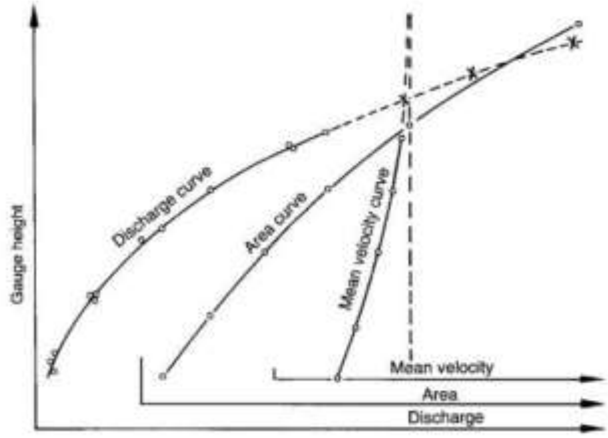
In the upper part of the curve extrapolation is almost always necessary. Only in very few cases have discharge measurements been obtained at about the highest flood peak observed. Though there are methods of extrapolation such as through the series of differences which is another way in establishing stage-discharge relations, however, such method is not commonly practised and hence not discussed in this manual.

For a logarithmic extrapolation has been proven to be a reliable method but only for shorter extensions only. If, however, extended extrapolations have to be made, special methods must be used, some of which will be described in the following section.

7.3.5.2 The Stage-Velocity-Area Method

The best method to use is the extension of the gage height against the mean velocity curve. A plot with stage as the ordinate and the mean velocity as the abscissa gives a curve which, if the cross-section is fairly regular and no bank overflow occurs, tends to become asymptotic to the vertical at higher stages. That is, the rate of increase in the velocity at the higher stages diminishes rapidly and this curve can therefore be extended without much error. Further, by plotting the stage-area curve (stage as ordinate, area as abscissa) for the same cross- section as that from which the mean velocity was obtained, the area can be read off at any stage desired. Discharge for a given (extended) gage height is obtained by the product of area and mean velocity read using extrapolated stage-area and stage-velocity curves (**Figure 7-6).**

The area is obtained by a field survey up to the highest stage required and is therefore a known quantity.



Source: Manual Procedures in Operational Hydrology Volume 4, NORAD 1979

Figure 7-6. Extrapolation of Rating Curve based on Stage-Area/Stage-Velocity Method

7.3.5.3 The Manning Formula Method

A slight variation of the stage-area-velocity method is the use of Manning's equation of steady flow. In terms of the mean velocity the Manning equation is given as:

$$Q = NAR^{2/3}S^{1/2} \qquad (14)$$

Where: $N = \frac{1}{n}$

Hence:

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \qquad (15)$$

where

n = Manning's roughness coefficient
A = area of cross-section, m^2
R = hydraulic radius, m
S = slope of water surface (m/m)
Q = discharge, m^3/s

may be used for extrapolation of rating curves. In terms of mean velocity the formula may be written

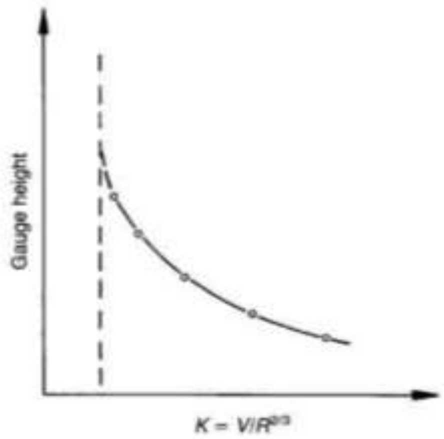
$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad (16)$$

For the higher stages, the factor $\frac{1}{n} S^{1/2}$ becomes approximately constant. Equation 15 and 17 can therefore be rewritten as:

$$Q = KAR^{2/3} \qquad (17)$$

and

$$V = KR^{2/3} \qquad (18)$$



Source: Manual Procedures in Operational Hydrology Volume 4, NORAD 1979

Figure 7-7. Extrapolation of K

By using various values of V from the known portion of the stage against mean-velocity curve and the corresponding values of R, values of K can be computed by equation 18 for the range in stage for which the velocity is known. By plotting these values of K against the gage height, a curve is obtained that should asymptotically approach a vertical line for the higher stages (**Figure 7-7**). This K-curve may then be extended without much error and values of K obtained from it for the higher stages. These high stage values of K combined with their respective values of A and $R^{2/3}$ using equation 7.3.8 will give values of the discharge Q which may be used to extrapolate the rating curve. A and R is obtained by field surveys and is known for any stage required.

7.3.6 Shifting Control

7.3.6.1 General

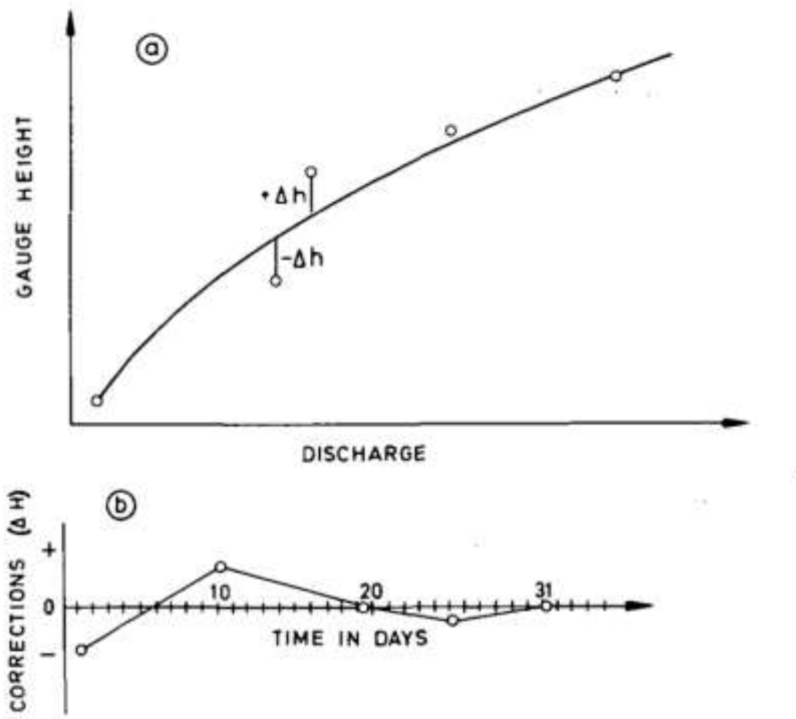
Shifts in the control features occur especially in alluvial sand-bed streams. However, even in solid stable stream channels shifts will occur, particularly at low flow because of aquatic and vegetal growth in the channel, or due to debris caught in the control section.

In alluvial sand-bed streams, the stage-discharge relation usually changes with time, either gradually or abruptly, due to scour and silting in the channel and because of moving sand dunes and bars. These variations will cause the rating curve to vary with both time and the magnitude of flow. Nevertheless, runoff records at a particular location may be of great importance and observations and measurements have to be carried out the best way possible.

7.3.6.2 The Stout Method

For making adjustment for shifting control, the Stout Method has been used by the National Water Resources Council (NWRC) and later the Bureau of Standards (BRS) in the streamflow data management. In this method, the gage heights corresponding to discharge measurements taken at intervals are corrected so that the discharge values obtained from the established rating curve may be the same as the measured values. From the plot of these corrections against the chronological dates of measurements, a gage height correction curve is made. Corrections from this curve are applied to the recorded gage heights for the intervening days between the discharge measurements.

An ordinary staff gage is established at the best available site on the river and readings taken at appropriate intervals, three (3) times a day. Discharge measurements are made as often as found necessary, and may be required as often as once or twice a week. How often discharge measurements need to be taken depends on several factors, such as the hydraulic conditions in the river, the accuracy and the feasibility based on economic and other factors.



Source: Manual Procedures in Operational Hydrology Volume 4, NORAD 1979

Figure 7-8. The Stout Method of correcting gage height readings when control is shifting

7.3.6.3 The Stout Method when control is shifting

The measurements are plotted against observed gage height on ordinary graph paper and a median curve is fitted to the points. Most of the subsequent discharge measurements will deviate from the established curve. For points lying above the curve, a small height, Δh, must be subtracted from the observed gage height in order to make these points lie on the curve. That is, minus corrections are applied to all points above the curve, plus corrections are applied to points lying below the curve (**Figure 7.8a**). Next, a correction graph is made as shown in **Figure 7.8b**. The plus and minus corrections are plotted on the date of measurement and the points connected by straight lines or a smooth curve. Gage height corrections for each day are now obtained directly from this correction graph, remembering that the parts of the graph below the abscissa axis give minus corrections and the parts above give plus corrections.

When discharge measurements plot within 5 percent of the rating curve, with some plus and some minus deviations, it is acceptable to use the curve directly without adjustment for shifting control.

It is not too important how the median curve is drawn between the measurements. Different curves will give different corrections and the final result will be approximately the same. Extrapolation of the curve, however, has to be done with care.
A rating of this type requires much work in order to obtain good results. The accuracy depends on the hydraulic conditions in the river and on the number and accuracy of the discharge measurements and the gage height readings. The reliability is much less than for a station with a permanent control. The Stout Method presupposes that the deviations of the measured discharges from the established stage-discharge curve are due only to a change or shift in the station control, and that the corrections applied to the observed gage heights vary gradually and systematically between the days on which the check measurements are taken.

In fact, the deviation of a discharge measurement from an established rating curve may be due to 1) gradual and systematic shifts in the control, 2) abrupt random shifts in the control, and 3) error of observation and systematic errors of both instrumental and personal nature.

The Stout Method is strictly appropriate for making adjustments for the 1st type of errors only. If the check measurements are taken frequently enough, fair adjustments may be made for the 2nd type of error also. However, the drawback of the Stout Method is that the error of observation and the systematic errors are disregarded as such and simply mixed with the errors due to shift in control, although the former errors may be at times of a higher magnitude than the latter. This means that "corrections" may be applied to a discharge record when in reality the rating is correct. The apparent error is not due to shifting control but to faulty equipment or careless measuring procedure.

7.3.6.4 Computation of Shifts for stage-discharge ratings

The shift information that should be computed for discharge measurements applicable to stage discharge rating curves is as follows:

(a) Rating shift, S_r – This shift is the numerical difference between the gage height, H_r, which corresponds with the rating curve discharge for the measurement, and the gage height, H_m, of the discharge measurement. The resulting algebraic sign should be observed. The equation is:

$$S_R = H_R - H_M \qquad (18)$$

(b) Measurement percent difference, D – This is the percent difference between the measured discharge, Q_m, and the rating curve discharge, Q_r, that corresponds to the gage height of the discharge measurement. This represents the difference between the measured discharge and rating discharge if no shift is applied. The equation is:

$$D = \frac{(Q_M - Q_R)}{Q_R} X100 \qquad (19)$$

(c) Shifts for the gage height of zero flow, *S_0* – If the gage height of zero flow, H_0, is determined either when a regular discharge measurement is made, or independently during a visit to the gaging station, then it is possible to compute a shift for that gage height if the rating curve is defined down to zero flow. This information can be very useful as an aid in defining the low end of a shift curve. The equation for computing the shift for the gage height of zero flow is similar to equation 5.6 for computing the rating shift, and is:

$$S_0 = H_R - H_0 \qquad (20)$$

Because the discharge corresponding to H_0 is by definition zero, it is not possible to compute a measurement percent difference.

8. PRIMARY COMPUTATIONS

Primary computations are the functions that convert input data of gage height into time series of unit values, daily values, monthly values and annual values of discharge. In the past primary computations were generally performed by hand. Today, almost exclusively, primary computations can be performed using computers.

The primary computation process will require the use of at least one rating curve. To carry out the conversion process previously developed data and information will be required, such as time series of input variables, shift curves and rating tables. The conversion should be carried out with minimal interaction from the Hydrographer and should produce files of information that can be used to produce tables and graphs that commonly are referred to as primary output.

8.1 Daily value computations

8.1.1 Daily Mean Values

Daily mean values, frequently referred to as daily values, consist of arithmetic mean of selected parameters and are computed from the files of unit values. Daily mean values may be computed for gage height and discharge. A file of all computed daily mean values should be saved for future use and archiving.

8.1.1.1 Daily Minimum and Maximum Values

The minimum and maximum values for some of the parameters, usually gage heights and discharge are required for each day. These values are determined from the unit value files for the various parameters, and the selection process should consider all recorded and interpolated unit values for each day, including the extra readings of gage heights for each day.

8.1.1.2 Summary of primary computations

Primary computations include the determination of unit values and daily values for numerous parameters. It is important and necessary to summarize these results in tables that can be used for review, analysis and publication. Standard formatted tables include unit values, primary computations and daily value tables.

8.1.1.3 Daily values

A daily values table is a listing of the daily values for each day of the year at a gaging station. Generally, daily values are the daily mean discharges for a gaging station. In addition, the daily values table should show monthly and annual totals, means and extremes, as appropriate.

8.2 Hydrograph plots

Hydrographs are useful for graphical viewing, verification, editing and comparisons of streamflow information, including most of the basic information that contributes to the primary computation of streamflow records. Hydrograph plots of unit values of discharge along with comparative plots of gage height and supplementary data such as peak discharge, peak stage and discharge measurements, provide an excellent means of reviewing and editing primary computations. Hydrograph plots provide a graphical summary of the records for visual presentation and publication.

Daily values hydrograph is one of the most common methods for displaying the results of streamflow computations for a gaging station. This hydrograph usually is a plot showing the daily values for a year. Daily value hydrographs usually are plots of daily mean discharge for a gaging station but can also be used to display gage height. When more than one daily values file is shown on a daily values hydrograph plot, each should be clearly identified by a distinctive plotting symbol.

Individual scales should be shown for each parameter, labelled with the correct parameter name and units of measurement.

The abscissa for daily values hydrographs is a time scale, with days being the primary subdivision. Months and years are secondary subdivisions. The ordinate should be logarithmic for discharge plots, unless otherwise specified by the Hydrographer. Other daily values parameters should be plotted using linear scales. The range of the ordinate scale for the primary parameter should default to one that will include the full range of the daily values for the time period being plotted.

8.3 Computation of Extremes

For most discharge gaging stations it is required that the maximum peak stage and discharge, the secondary peak stages and discharges and the minimum discharge be computed for each water year. The maximum peak stage and discharge, and the minimum discharge are referred to as the annual peak and annual minimum.

8.3.1 Annual peak stage and discharge

The annual peak stage and discharge are defined as the highest instantaneous (unit value) gage height and discharge associated with the highest flood peak that occurred during the year. The annual peak stage and discharge and the associated date and time, should be determined for every gaging site. With the Streamflow Management System, the date and time can be automatically given.

8.3.2 Annual minimum discharge

The annual minimum discharge is defined as the lowest instantaneous (unit value) discharge that results during the year. The electronic system should determine the annual minimum discharge and the associated date and time for the year.

8.4 Estimating missing records

Complete records of daily discharges, and other parameters, are necessary in order to compute monthly and annual totals and other statistics. Complete records are also needed to compute total runoff from a drainage basin, to calibrate runoff models and to compute chemical and sediment loads. Data sometimes are missing because of instrument failures and other reasons, thus not permitting the normal computation of daily records. Therefore, it is necessary to make estimates of discharge or other hydrologic parameters for these periods of missing records.

However, estimation of missing records should be kept to a minimum. For example, in some cases it may be reasonable to estimate unit values of gage height for the purpose of computing daily values of discharge, provided the gage height can be estimated with reasonable accuracy.

8.4.1 Simple Interpolation

Problem of missing data is widespread. Gages can be damaged during storm, power supplies may run out or observers might go walk-about. Various techniques are available for filling in estimates of missing data, and some of these can be used to extend a record back in time for statistical analyses.

Short gaps can be filled from straight-line interpolation (graphical or numerical) between correctly recorded discharges. A formula for linear interpolation is given in **Figure 8-1**. It should be emphasized that this method is applicable for missing data for short or limited duration only.

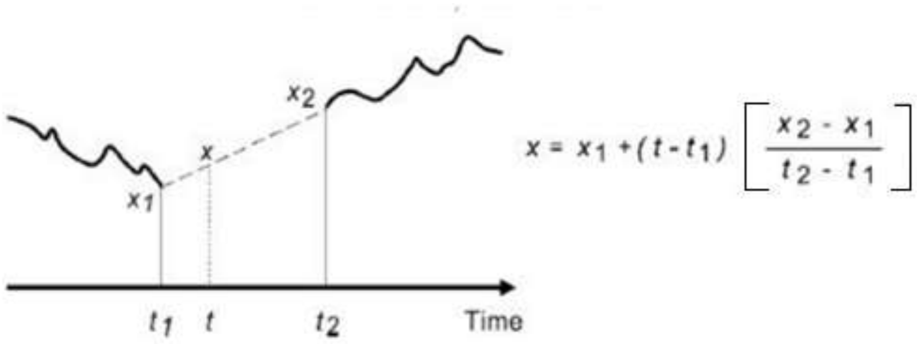


Figure 8-1. Simple linear interpolation

8.4.2 Drainage Area Weighting

Drainage area weighting or drainage area ratio method is a widely used technique in many cases where limited streamflow monitoring data are available or in some cases missing information. This method is applicable in areas where the drainage basins are of similar size, land use, soil types and experience the similar rainfall patterns. Discharge can be estimated by drainage area weighting using the following equation:

$$Q_{ungaged} = \frac{A_{ungaged}}{A_{gages}} x\, Q_{gaged} \qquad (20)$$

Where:

$Q_{ungaged}$ = Q at ungaged location
Q_{gaged} = Q at gaged location
$A_{ungaged}$` = Q at ungaged location
A_{gaged} = Q at ungaged location

8.4.3 Regression method

Multiple, stepwise, regression is a useful method of relating time series discharge data of one gaging station to concurrent time series discharge data of one or more nearby reference gages. Regression equations can be developed for specific ranges of discharge, for instance, low flows, medium flows, and/or high flows. They also can be developed for seasonal periods.

A regression equation can be applied to provide estimated discharges for periods of missing record. In addition, the same regression equation should be used to compute discharge values for short time periods adjacent to the estimated period where discharges are known. These adjacent periods sometimes can be used for verifying the accuracy of the regression results, and for adjusting the estimated discharges during the period of missing record to more closely fit the adjacent known records.

8.5 Monthly and annual value computations

Monthly and annual values of stage and discharge should be computed for each station as required. All computations of monthly values should be based on the rounded results of daily values and all computations of annual values should be based on rounded results or either daily or monthly values, as indicated. In the Philippines, annual values are commonly computed for each gaging station for the calendar year, January through December.

8.5.1 Monthly and annual values of stage

Monthly and annual values of stage should be computed for those stations where stage routinely is measured for defining the gage height fluctuations of a stream. For most of the gaging stations, gage height is measured for the purpose of computing the discharge.

The monthly discharge values that should be computed re the following

8.5.2 Monthly and annual values of discharge

Monthly and annual values of discharge should be computed for gaging stations where daily discharge is routinely computed and streamflow is the parameter of primary interest. Also included in the computations are generally designated on the basis of streamflow conditions, drainage basin size, natural runoff conditions and other factors that may affect the hydrologic value and need for the computed parameters.

Some of the monthly and annual values monthly values that are required are the following:
(a) Monthly total discharge – Total of all daily mean discharges for each month;
(b) Monthly mean discharge – The mean of all daily mean discharges for each month, and is computed by dividing the monthly total discharge by the number of days in the month;
(c) Monthly minimum daily discharge – The lowest daily mean discharge for each month;
(d) Monthly maximum daily discharge – The highest daily mean discharge for each month.

The monthly discharge values that are optional are as follows:
(a) Monthly runoff volume – This is the monthly total discharge, converted to a volume;
(b) Monthly runoff depth – The monthly total discharge volume, converted to a depth, millimeters, that would uniformly cover the drainage basin;
(c) Monthly mean unit runoff – The monthly mean flow that would emanate from 1 km^2 of drainage area, if the flow were uniformly distributed throughout the drainage basin.

The annual discharge values that are required are as follows:
(a) Annual total discharge – The total of all daily mean discharges for the year;
(b) Annual mean discharge – The mean of all daily mean discharges for the year, and is computed by dividing the annual total discharge by 365 or by 366 for leap years;
(c) Annual minimum daily discharge – The lowest daily mean discharge for the year;
(d) Annual maximum daily discharge – The highest daily mean discharge for the year.

The annual discharge values that are optional are as follows:
(a) Annual runoff volume – The annual total runoff volume is computed by summing the monthly values of runoff volume for the year;
(b) Annual runoff depth – The annual total runoff depth is computed by summing the monthly values of runoff depth for the year;
(c) Annual mean unit runoff – The annual mean unit runoff is computed by dividing the annual mean discharge by the drainage area.

9. Review, Approval, and Finalization of Records

Gaging station records are reviewed at various points during the process of entering, analysing, interpreting, and computing the streamflow information. These records generally are referred to as working reviews that usually are made by the user as the records are processed. This report refers to a number of places during the process of producing a streamflow record where such reviews should be made. Working reviews are a normal function of the record production process, and the electronic processing system provides the user with numerous aids to make this process as easy as possible.

A formal review should be made after the records have been processed and the user is satisfied that the records are complete and accurate. This final review should be made by a senior reviewer who is designated to make such reviews. This review ultimately results in the approval and finalization of the records for publication and archival if the reviewer finds that the records are complete and accurate. If this review reveals deficiencies in the records, the reviewer can return the records to working status.

The formal review should have access to all of the same review functions that are used in the record processing steps. These review functions would include all output tables, such as the discharge measurement summary tables, the level summary tables, the unit values tables, the primary computation tables, the daily values tables, and any other table produced during the record processing. Of even greater importance, the final reviewer should have easy access to graphs such as the rating curves, hydrographs, and daily values hydrographs. The reviewer also should have access to the comments file and should be allowed to enter comments. If a station analysis has been prepared, the reviewer should be allowed to review and edit, as appropriate.

When the review is complete and the records are considered acceptable and accurate, they should be designated as approved. The approved records are ready for publication and archiving. Records that are flagged as approved should be protected from any further changes or revisions. In the event that a change to an approved record is required, the records must be set back to working status.

10. ARCHIVING

Data archiving is a complex subject that deals with the permanent retention, protection, and accessibility of original records, and other records that support published scientific studies and analyses. With the advent of electronic media for collection and analysis of hydrologic data and information, it has become increasingly difficult to define the method by which these records should be archived. A brief summary of the archiving recommendations for electronic data and information will be given as follows: (Hubbard, 1992).

The following list of electronic data and information is not all inclusive, but at a minimum these items should be placed in permanent electronic archives.

- All original data for automated data-collection sites such as the gage height observations transmitted by the Gage Keepers
- All non-automated data collected in electronic format, such as discharge measurement notes
- All approved files of edited and calculated data, such as unit values and daily values of gage height, velocity, correction values, shift adjustments, discharge, and other parameters resulting from the processing of the gaging station records.
- All approved algorithms, rating curves and other transformation information required for the processing of the records.
- All documents specific to a gaging station, such as station descriptions, station analyses, station manuscripts, level summaries, and comment files.

11. Application of Streamflow Data

11.1 Flood Frequency Analysis

Flood frequency analyses are used to predict design flood for sites along a river. The objective of frequency analysis is to relate the magnitude of events to their frequency of occurrence through probability distribution. Log Pearson Type III is a frequency distribution widely used worldwide.

Design discharge magnitude and frequencies for rivers can be estimated using Log Pearson Type III distribution analysis with base 10 logarithmic transformation of annual maximum daily discharges. The peak discharge at selected recurrence intervals (Return Period) of 2, 5, 10, 25, 50 and 100 year, were computed with the equation:

$$\log Q_{Tr} = M + K_{Tr}\,S \qquad (21)$$

Q_{Tr}= T-year flood from log-Pearson Type III distribution, m³/sec
M= mean of the logarithmic annual mean monthly discharge
K_{Tr}= scale factor that is a function of the skew coefficient and recurrence interval
S= standard deviation of the logarithmic transformed annual maximum discharge

Frequency Factors K for Gamma and log-Pearson Type III Distributions (Haan, 1977) and skew coefficient is used to find the K_{Tr} values for the selected recurrence intervals. The computed skew coefficient that is between two given skew coefficients in Table 11-1 can be linearly extrapolated between the two numbers to get the appropriate K value.

The mean, standard deviation and skew coefficient of station data may be computed using the following equations:

$$Variance = \frac{\sum_i^n (\log Q - avg(\log Q))^2}{n-1} \qquad (22)$$

$$Standard\ deviation = \sigma \log Q = \sqrt{Variance} \qquad (23)$$

$$Skew\ Coefficient = \frac{n\sum_i^n (logQ - avg(logQ))^3}{(n-1)(n-2)(\sigma logQ)^3} \qquad (24)$$

Q = annual maximum daily discharge
n = number of items in data set

To show the results of the frequency analysis graphically, the annual maximum daily discharge is plotted against the corresponding non-exceedance probability in Log Pearson Probability paper:

$$Non - Exceedence\ Probabilty = \left(1 - \frac{1}{Tr}\right) * 100 \qquad (25)$$

$$Tr = \frac{n+1}{m} \qquad (26)$$

T_r = return period for each discharge value
m = the rank

11.2 Flow Duration Analysis

Flow duration curve is a cumulative frequency curve that shows the percent of time a specified discharge were equalled or exceeded during a given period. It also shows the flow characteristics of a river throughout the range of discharges, without regard to the sequence of occurrence. If the period upon which the curve is based represents the long-term flow of a river, the curve may be used to predict the distribution of future flows for water-related studies.

For flow-duration statistics to be reliable indicators of probable future condition, a minimum of 10 years of record typically is used (Searcy, 1959). The equation used to compute the exceedance probability, which also is referred to as the flow-duration percentile, is given as:

$$P = \left(\frac{m}{(n+1)}\right) * 100 \qquad (27)$$

Where:

P = the probability that a given flow will be equaled or exceeded (% of time)
m = the ranked position, from highest to lowest, of all daily mean flows
n = the total number of daily mean flows

To determine the flow for a specific flow duration percentile, interpolation between the discharges associated with percentiles on either side of the specific percentile may be needed. Flows that are equal to each other also would be given separate *m* rank values. With the equation above, high flows are assigned low percentiles and low flows are assigned high percentiles.

Table 11-1. Frequency Factors K for Gamma and log-Pearson Type III Distributions (Haan, 1977, Table 7.7)

	Recurrence Interval In Years							
	1.0101	**2**	**5**	**10**	**25**	**50**	**100**	**200**
SKEW	**Percent Chance (>=) = 1-F**							
COEFF. Cs	**99**	**50**	**20**	**10**	**4**	**2**	**1**	**0.5**
3	-0.667	-0.396	0.42	1.18	2.278	3.152	4.051	4.97
2.9	-0.69	-0.39	0.44	1.195	2.277	3.134	4.013	4.904
2.8	-0.714	-0.384	0.46	1.21	2.275	3.114	3.973	4.847
2.7	-0.74	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.36	0.518	1.25	2.262	3.048	3.845	4.652
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.8	4.584
2.3	-0.867	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.33	0.574	1.284	2.24	2.97	3.705	4.444
2.1	-0.946	-0.319	0.592	1.294	2.23	2.942	3.656	4.372
2	-0.99	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.294	0.627	1.31	2.207	2.881	3.553	4.223
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.14	-0.268	0.66	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-0.254	0.675	1.329	2.163	2.78	3.388	3.99
1.5	-1.256	-0.24	0.69	1.333	2.146	2.743	3.33	3.91
1.4	-1.318	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-0.21	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-0.195	0.732	1.34	2.087	2.626	3.149	3.661
1.1	-1.518	-0.18	0.745	1.341	2.066	2.585	3.087	3.575
1	-1.588	-0.164	0.758	1.34	2.043	2.542	3.022	3.489
0.9	-1.66	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-1.733	-0.132	0.78	1.336	1.993	2.453	2.891	3.312
0.7	-1.806	-0.116	0.79	1.333	1.967	2.407	2.824	3.223
0.6	-1.88	-0.099	0.8	1.328	1.939	2.359	2.755	3.132
0.5	-1.955	-0.083	0.808	1.323	1.91	2.311	2.686	3.041
0.4	-2.029	-0.066	0.816	1.317	1.88	2.261	2.615	2.949
0.3	-2.104	-0.05	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-2.178	-0.033	0.83	1.301	1.818	2.159	2.472	2.763
0.1	-2.252	-0.017	0.836	1.292	1.785	2.107	2.4	2.67
0	-2.326	0	0.842	1.282	1.751	2.054	2.326	2.576
-0.1	-2.4	0.017	0.846	1.27	1.716	2	2.252	2.482
-0.2	-2.472	0.033	0.85	1.258	1.68	1.945	2.178	2.388
-0.3	-2.544	0.05	0.853	1.245	1.643	1.89	2.104	2.294
-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.5	-2.686	0.083	0.856	1.216	1.567	1.777	1.955	2.108
-0.6	-2.755	0.099	0.857	1.2	1.528	1.72	1.88	2.016
-0.7	-2.824	0.116	0.857	1.183	1.488	1.663	1.806	1.926
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-0.9	-2.957	0.148	0.854	1.147	1.407	1.549	1.66	1.749
-1	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	0.18	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	0.21	0.838	1.064	1.24	1.324	1.383	1.424
-1.4	-3.271	0.225	0.832	1.041	1.198	1.27	1.318	1.351
-1.5	-3.33	0.24	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.88	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	0.268	0.808	0.97	1.075	1.116	1.14	1.155
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	0.294	0.788	0.92	0.996	1.023	1.037	1.044
-2	-3.605	0.307	0.777	0.895	0.959	0.98	0.99	0.995
-2.1	-3.656	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	-3.705	0.33	0.752	0.844	0.888	0.9	0.905	0.907
-2.3	-3.753	0.341	0.739	0.819	0.855	0.864	0.867	0.869
-2.4	-3.8	0.351	0.725	0.795	0.823	0.83	0.832	0.833
-2.5	-3.845	0.36	0.711	0.711	0.793	0.798	0.799	0.8
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	-3.932	0.376	0.681	0.724	0.738	0.74	0.74	0.741
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	-4.013	0.39	0.651	0.681	0.683	0.689	0.69	0.69
-3	-4.051	0.396	0.636	0.66	0.666	0.666	0.667	0.667

Source: http://streamflow.engr.oregonstate.edu/analysis/floodfreq/skew.htm

Glossary

Data Item / Term	Definition
Abutment	Structure at the two ends of a bridge used for transferring the loads from the bridge superstructure to the foundation bed and giving lateral support to the embankment.
Agency	Any of the various units of the national/local government, e.g. department, bureau, authority, office, instrumentality or GOCC and LGU.
Alluvial	Soil or earth material which has been deposited by running water.
Annual Flood Loss	The total value of damages caused by floods over a twelve month period.
Annual Maximum Flood Discharge	The highest momentary peak discharge in a year.
Annual Risk of Exceedance	The chance or probability of a natural hazard event (usually a rainfall or flooding event) occurring annually and is usually expressed as a percentage.
Area	A bounded, continuous, two-dimensional (2-D) surface.
Average Riverbed	The average riverbed profile in a cross section survey which is set in order to establish the elevation of the longitudinal profile and to compute the area of river cross section.
Backwater	The rise of water level that occurs immediately upstream from a structure (e.g. dam) or obstructions in a river to a considerable distance brought about by the presence of structure.
Bar	An alluvial deposit at the mouth of a stream or at any point in the stream itself which causes an obstruction of flow and to navigation, in the case of a bay or inlet.
Bare Slope Land	Hillside slopes on which the vegetation has entirely or partly vanished or declined.
Barrage	A weir equipped with series of sluice gates to regulate the water elevation at its upstream side.
Bed Material	The material of which the riverbed is composed.
Bedrock	Strong rock underlying surface deposits of soil and weathered rock.
Bridge	A structure carrying a road over a road, waterway or other feature, with a clear span over 3.0 meters along the centerline between the inside faces of supports. A bridge may have an independent deck supported on separate piers and abutments, or may have a deck constructed integral with supports.
Catchment Area Alias Catchment Basin, Watershed, Drainage Basin, River Basin	The area from which a lake, stream or waterway receives surface water which originates as precipitation.
Control Point	In a river, the place or location of observation point where the planned discharge is observed and fixed.
Control Surveying	The determination of the precise position of a number of stations which are distributed over a large area.

Crop	A ground cover plant that is grown and harvested for profit or subsistence.
Culvert	A structure (mostly pipe or box culvert) under a road, railway or embankment, whether of single or multiple barrel construction, generally with a width of less than five (5.0) meters per opening measured between inside wall faces.
Datum	Agreed standard point of stated elevation denoted by a permanent benchmark on solid immovable structure, from which elevations are measured or to which they are referred.
Debris	Any uprooted trees and other materials carried by the water in the creek or river.
Deposition	The mechanical or chemical processes through which sediments accumulate in a resting place.
Design Discharge	The calculated discharge based on the frequency of a return period.
Design Life	Period assumed in the design for which the infrastructure is required to perform its function without replacement or major structural repair.
Drainage Basin Alias, Catchment Area, Catchment Basin, Watershed, River Basin	The area from which a lake, stream or waterway receives surface water which originates as precipitation.
Drainage Network	An array of linear elements representing the flow of surface water.
Groundwater	Water that exists below the water table in the zone of saturation.
Groundwater Table	Depth at which soil pore spaces or fractures and voids in rock become completely saturated with water.
Land Use	A specific mode of activity and type of coverage applied or allocated to an earth surface area.
Maximum Flood Level	The highest recorded flood level.
Mean Sea Level	The average height of the sea for all stages of the tide. Mean sea level is obtained by averaging observed hourly heights of the sea on the open coast or in adjacent waters having free access to the sea, the average being taken over a considerable period of time.
Return Period	The probability, expressed in years, where phenomena (i.e., flood, rainfall) of a targeted size/magnitude will likely to occur.
Runoff	Surface water of an area of land.
Scour	Lowering of stream-bed or undermining of foundations by erosive action of flowing water.
Scoured Depth	Total depth of water from surface to a scoured bed level.
Tributary	A stream or other body of water, surface or underground, which contributes its water, either continuously or intermittently, to another and larger stream or body of water
Tributary River	A confluence river usually smaller that the main river.
Velocity	The rate and direction of change in the position of an object
Vertical Datum	A base measurement point, or set of points, from which all elevations are determined
Waterway	General term denoting a river, stream and other similar tributary area.
Weir	A low dam built across a river to raise the level of water upstream or regulate its flow.

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