Manual of British Columbia Hydrometric Standards

Prepared by
Ministry of Environment
Science and Information Branch
for the
Resources Information Standards Committee

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Preface

The Manual of British Columbia Hydrometric Standards, version 1.0 is an updated and revised version of the Manual of Standard Operation Procedures for Hydrometric Surveys in British Columbia **(**SOPHS**)**, version 1.1, 1998. It defines a set of standards with detailed procedures for the acquisition of water quantity data, assessing the data, quality and quantifying data grades. This manual supersedes SOPHS, version 1.1 (1998). The changes to the previous document are based on comments of reviewers and users. It incorporates some of the National Standards (Environment Canada) and adds new information and ideas. Some of the improvements are:

- There are new RISC forms for recording the data and calculations. These forms are designed for entry of the data into the ministry's Water Information Data Management (WIDM) system.
- There is a detailed validation process that includes the steps required in reviewing the data and a way of quantifying the quality of the data using data grades. The criteria for the data grades are explained in detail and the information can be obtained directly from the new RISC forms.
- New equipment available for hydrometric surveys is identified and discussed.

The technologies for collecting, calculating, and storing hydrometric data are continually being modified and upgraded. This manual represents the best technologies and procedures available at the time of writing. As new procedures and software are developed, the manual will be updated.

The Science & Information Branch, Ministry of Environment (MOE) will accept and compile all relevant materials and comments in preparation for the next version of this manual. Please submit such material to Ashfaque Ahmed, Science & Information Branch, Ministry of Environment, 4-395 Waterfront Crescent, Victoria, BC, V8T 5K7, or Email to: Ashfaque.Ahmed@gov.bc.ca

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March, 2009

Abstract

This revised manual describes the BC Ministry of Environment procedures for all aspects of hydrometric surveys in an open channel: fundamentals of hydrometric operations, stage measurement, discharge measurement, and stage-discharge rating and discharge calculations. Each topic represents a chapter in the manual. This revised manual includes a new chapter on the development and use of data grades and also provides an overview of the new data review process. All of the forms that are needed to document the procedures, including the characteristics of the equipment are included.

Acknowledgments

The Government of British Columbia provides funding for the Resources Information Standards Committee (RISC) work, including the preparation of this document. RISC supports the effective, timely and integrated use of land and resource information for planning and decision making by developing and delivering focused, cost-effective, common provincial standards and procedures for information collection, management and analysis. For further information about the Resources Information Standards Committee, please access the RISC website at http://ilmbwww.gov.bc.ca/risc/index.html

This edition supersedes “Manual of Standard Operation Procedures for Hydrometric Surveys in British Columbia **(**SOPHS**)**, version 1.1, 1998".

This method standard was based on revision to the previous standards and with consideration to national standards developed by Environment Canada, which has been utilized extensively along with other sources listed in Appendix VI. The project author was Ashfaque Ahmed, P.Eng., assisted with technical input by Bruce Boyd, Science and Information Branch of the B.C. Ministry of the Environment. The author gratefully acknowledges following individuals and their organizations for providing their professional review, comments and contributions: George Butcher (B.C. Ministry of Environment), Bruce Letvak (B.C. Ministry of Environment), Jeptha Ball (B.C. Ministry of Environment), Scott Babakaiff (B.C. Ministry of Environment), Chelton van Geloven (B.C. Ministry of Environment), Tony Cheong (B.C. Ministry of Environment), Paul Marquis (B.C. Ministry of Environment), Peter Jordan (BC Ministry of Forest), Chris Thomson (Environment Canada), Jeff Woodward (Environment Canada), Stuart Hamilton (Environment Canada), Sigi Gudavicius (Capital Regional District, BC), Mike Miles (M. Miles and Associates Ltd.), Linda Gregory (Consultant), Kelly Eakins (Eakins Hydrological Consulting), Lars Uunila (Summit Environmental Consultants Ltd.), Chris Cole (Golder Associates Ltd.), Craig Kipkie (Kerr Wood Leidal Associates Ltd.), Angela Prince (Westslope Fisheries Ltd.), Gordon Clark (Clark Hydrological Services), Craig Nistor (Knight Piesold Ltd.), Frank van der Have (Hoskin Scientific Ltd.).

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Chapter 1: Introduction to Provincial Standards

1.1 General

The purpose of hydrometric survey is to obtain high quality stage/water level and discharge or stream-flow data that can be used by different individuals and agencies. To date, hydrometric data collected in British Columbia are mainly of two types: Integrated and Non–Integrated. Integrated data are from Canada-BC hydrometric network; collected according to Environment Canada (i.e., Water Survey of Canada) standards from hydrometric stations operated under Canada-BC Agreement. These are high frequency nearly continuous (time-series) data. Non-integrated data (i.e., data from monitoring sites outside of the Canada-BC network) on the other hand, are collect under RISC[1] hydrometric standards, captured and distributed through Water Inventory Data Management (WIDM) system. Non-integrated hydrometric stations are operated by a large variety of agencies, firms or individuals and the data may or may not be continuous. However, the data collected are only as good as the quality assurance and quality control measures incorporated into the measurement program. To ensure the quality and accuracy of these water levels (or stage) and discharge (or stream flow) data, a provincial standard system has been developed to provide uniform guidelines for production, review and archiving of hydrometric information**.** A provincial hydrometric standard is required to affirm the credibility of data for any application, anywhere in the province.

This manual (or standards) describe the procedures, documentation, and analyses that must be used to meet RISC standards for hydrometric surveys in British Columbia. Chapter 2 to5 of this manual explains the steps and calculations that should be used to obtain and correct hydrometric data. Once the data are recorded, they must be validated and reviewed. Chapter 6 of the manual outlines the validation and review processes. New terms are introduced in the text and there is a glossary of terms at the end of the manual.

1.2 Who Should Use the Manual

The primary users of this document will be agencies, industry, and consultants, or individuals who collect or review and manage hydrometric data to RISC standards. Other users will include provincial agencies that fund specific data collection or use the data for resource management, other resource user groups such as Improvement Districts, and educational users. In general, users of the provincial hydrometric database will refer to the document to understand the quality of the data that falls within the different categories.

1.3 Disclaimer

The purpose of this document is to provide information and standards for activities connected with production of hydrometric data. The reader is reminded that field operations for hydrometric surveys can involve some risk. All field operations should be carried out with

[1] Resources Information Standards Committee

appropriate safety measures, and in keeping with all relevant regulations including the Work Safe BC Occupational Health and Safety Regulation. None of the material in this manual (including text, photos, and diagrams) is intended to suggest deviation from safe field practice.

Brand names of products and manufacturers are occasionally used in text and illustrations to describe various hydrometric operations. This is for the purpose of explanation and/or illustration only, and is not intended as a recommendation or otherwise of any brand names mentioned.

1.4 RISC Hydrometric Standards and Data Grades

1.4.1 Introduction

By definition, the "**RISC hydrometric standards**", are "the field procedures, calculations, validation steps and documentation mandated by Resources Information Standards Committee of British Columbia for conducting a hydrometric survey" (see the Glossary).

Hydrometric standards described here are a set of information, which when followed will ensure the quality and accuracy of data product in regard to measurement of water level and discharge. A provincial standard is needed so that government programs, contractors, and partners have uniform guidelines for the collection of hydrometric data, and to facilitate the maintenance of a hydrometric data archive.

RISC Hydrometric Standards will:

- support the collection of hydrometric inventory data to known standards using equipment with verifiable calibration, by a variety of parties using standard methods and record keeping
- provide for regulation and data quality by review processes and audits
- support archiving of data of known quality, and use of such data for resource management

Hydrometric data collected or used for provincial resource management purposes, including Forest Investment Accounts (FIA), water licensing, and others are required to meet RISC standards.

The standards for RISC complement the National Standards developed and used by Water Survey of Canada but unlike the National Standards they accommodate different levels of rigour and thus quality. The overall quality is based on four criteria for both the water level data and the discharge data (Table 1). The four criteria are: instrumentation, stream channel condition, field procedures, and data calculation and assessment. For each criteria there are five levels called grades: A, B, C, E (estimated) and U (unknown data grade). For Discharge data, Grade A has a sub-class defined as A/RS, for rated structures such as weirs and flumes. The criteria for each level are discussed in Section 1.4.2. Once data are acquired, calculated and compiled, the data must then be reviewed to assign a 'standards grade' by the reviewer according to Standards requirements criteria (Table 1).

RISC hydrometric standards do not cover all types of operations such as ice conditions. At this time, it is recommended that work beyond the scope of the provincial standard be referred to Water Survey of Canada, or some other group with appropriate expertise.

1.4.2 Data Grades

Each of the data grades from Table 1 is discussed below.

Grade A

This standard is the highest level of data quality in the hierarchy of provincial standards (Table 1). The accuracy of data in the Grade A standard is similar to that in the National standards. The procedures described in this manual are oriented to the Grade A standard level. Grade A/RS is a sub-Grade of A, and is a method of data collection which can result in a very high level of accuracy and reliability. Grade A/RS is discussed in more detail below.

Grade B

The Grade B provincial standard is a lower quality than Grade A. The operational techniques are the same, but allowance is made for more difficult operating conditions and thus a less rigorous standard.

Grade C

Discharge data from manually operated sites (e.g. staff gauge readings of water level) generally cannot meet higher grades, and will typically fall into this level. This grade also allows for less rigorous procedures in development of the rating curve, and greater scatter between the individual measurements relative to the best fit curve.

Grade E

Hydrometric data should be graded as "E" (i.e., Estimated) when stations are operated using RISC Standards (i.e., water level or discharge data could be either Grade A/RS, A, B or C) but data were estimated because of instrument anomalies, shift correction, missing data, or rating-curve extrapolation beyond maximum or minimum measured discharge level.

Grade U

Grade "U" data is of an unknown quality and unable to grade into any standards. These are typically low quality data collected and managed using procedures not consistent with the RISC hydrometric standards Grade A, B or C. However access to these data has been identified as important by users of hydrometric information. The Ministry intends to capture these data and make them available after review and quality labelling (i.e., assigning data grade "U") through the provincial water database, WIDM system with an appropriate disclaimer for future use and general distribution.

Grade A/RS - Rated Discharge Structures

The accuracy of rated structures is achieved by the precise geometry of the unit and the details of the installation. Stage-discharge relationships have been defined in both laboratory and field tests. With accuracies in the 5% range, the data fit into the Grade A/RS category defined in Table 1. Correct installation of these structures is essential to achieve the hydraulic conditions necessary for their proper function. To achieve the Grade A/RS standard, station records must confirm the correct installation, and include all other appropriate data. Where installation of the structure does not meet specifications, leakage is significant and/or documentation is missing, it may be impossible to assign any standard level to the data. It should be noted that with rated structures, certain apparently minor deviations from ideal conditions can have major impacts on accuracy of discharge measurement.

In some cases, rated structures cannot be installed or maintained to the required hydraulic conditions for the specified rating. An example of this would be a weir where the pond fills up with sediment. In these cases, the structure is essentially an improved streambed control, and the station should be rated with other discharge measurements.

Table 1: Standards requirement criteria.

Data Quality Indicator	**Standard Grade for Discharge Data**					
	Grade A/RS	**Grade A**	**Grade B**	**Grade C**	**Grade E** (Estimated)	**Grade U** (Unknown data quality)
Instrumentation						
Meter calibration (When applicable)	N/A	Meter calibrated and the validity of calibration is confirmed	Meter calibrated and the validity of calibration is confirmed	Meter calibrated and the validity of calibration is confirmed	Meter previously calibrated but validity of calibration is not confirmed	Undefined
Meter field verification	N/A	At least annually	At least annually	Less often than annually	See Notes below	Undefined
Water level gauge type	Recorder	Recorder	Recorder	At least manual gauge	See Notes below	Undefined
Water level gauge reading/sensor accuracy	2 mm or less	2 mm or less	5 mm or less	1 cm or less	See Notes below	Undefined
Stream Channel Condition						
Channel condition or other condition affecting control or discharge measurements using current meter or rated structure	Fixed Control, stable channel, straight reach, measurements are consistent with rating curve, no weeds, boulders or debris	Stable channel, measurements are consistent with rating curve, relatively straight reach, minimal weeds or boulders	Minor hydraulic problems related to channel instability, measurements are not consistent with rating curve, weed growth or occasional boulders	Unstable channel due to erosion or aggradations, variable backwater, turbulence, significant weed growth or boulder bed	See Notes below	Undefined

Table 1. Standards requirement criteria (Contd.)

Data Quality Indicator	Standard Grade for Discharge Data					
	Grade A/RS	Grade A	Grade B	Grade C	Grade E (Estimated)	Grade U (Unknown data quality)
Field Procedure						
Minimum number of bench marks	3	3	3	1	See Notes below	Undefined
Number of verticals in manual flow measurements when current meter is used	N/A	20 or more and not more than 10% of total flow in each panel	20 or more and not more than 10% of total flow in each panel	10 or more and not more than 20% of total flow in each panel	See Notes below	Undefined
Number of manual flow measurements per year	N/A	5 or more, or at least once when Rating Curve is stable	3 or more, or at least once when Rating Curve is stable	2 or more, or at least once when Rating Curve is stable	See Notes below	Undefined
Number of level checks per year	2 or more, or at least once when Ref. Gauge, Bench Marks are stable	2 or more, or at least once when Ref. Gauge, Bench Marks are stable	1 or more	1 or more	See Notes below	Undefined
Data Calculation & Assessment						
Discharge rating accuracy	<5%	<7%	<15%	<25%	See Notes below	Undefined
Data and calculation reviewed for anomalies	Yes	Yes	Yes	Yes	See Notes below	Undefined
Results are compared with other stations and/or other year for check	Yes	Yes	No	No	See notes below	Undefined

[**Notes:** Hydrometric data should be graded as "E" (i.e., Estimated) when stations were operated using RISC Standards i.e., water level or discharge data could be either Grade A/RS, A, B or C but data were estimated because of instrument anomalies, shift correction, missing data or rating curve extrapolation beyond measured discharge level. Hydrometric data should be graded as "U" (i.e., Unknown data quality), when RISC Hydrometric Standards are not followed for data collection and/or data quality is unknown]

Table 1. Standards requirement criteria (Contd.)

Data Quality Indicator	**Standard Grade for Stage / Water Level Data Only**				
	Grade A	**Grade B**	**Grade C**	**Grade E** (Estimated)	**Grade U** (Unknown data quality)
Instrumentation					
Water level gauge type	Recorder	Recorder	At least manual gauge	See Notes below	Undefined
Water level gauge reading/sensor accuracy	2 mm or less	5 mm or less	1 cm or less	See Notes below	Undefined
Stream Channel Condition					
Channel condition or other condition affecting control or discharge measurements using current meter or rated structure	Stable control, relatively straight reach, minimal weeds or boulders (for water level only stations)	Minor hydraulic problems related to control instability, weed growth or occasional boulders (for water level only stations)	Unstable control due to erosion or aggradations, variable backwater, turbulence, significant weed growth or boulder bed (for water level only stations)	See notes below	Undefined
Field Procedure					
Minimum number of bench marks	3	3	1	See Notes below	Undefined
Number of level checks per year	2 or more, or at least once when Ref. Gauge, Bench Marks are stable	1 or more	1 or more	See Notes below	Undefined
Data Calculation & Assessment					
Data and calculation reviewed for anomalies	Yes	Yes	Yes	See Notes below	Undefined
Results are compared with other stations and/or other year for check	Yes	No	No	See Notes below	Undefined

[**Notes:** Hydrometric data should be graded as “E” (i.e., Estimated) when stations were operated using RISC Standards i.e., water level or discharge data could be either Grade A/RS, A, B or C but data were estimated because of instrument anomalies, shift correction, missing data or rating curve extrapolation beyond measured discharge level. Hydrometric data should be graded as “U” (i.e., Unknown data quality), when RISC Hydrometric Standards are not followed for data collection and/or data quality is unknown]

1.5 Overview of the RISC Hydrometric Standards Process in British Columbia

There are several steps through which Provincial RISC hydrometric operation must proceed in order to satisfy the need for long-term consistency and reliability of hydrometric data (Figure 1).

1. Hydrometric field operations
2. Compile the preliminary dataset
3. Check the preliminary dataset
4. Review the dataset and assign a data grade
5. Submit a dataset
6. Review and audit the selected dataset (details are not included in this manual)
7. Archive and distribute the data

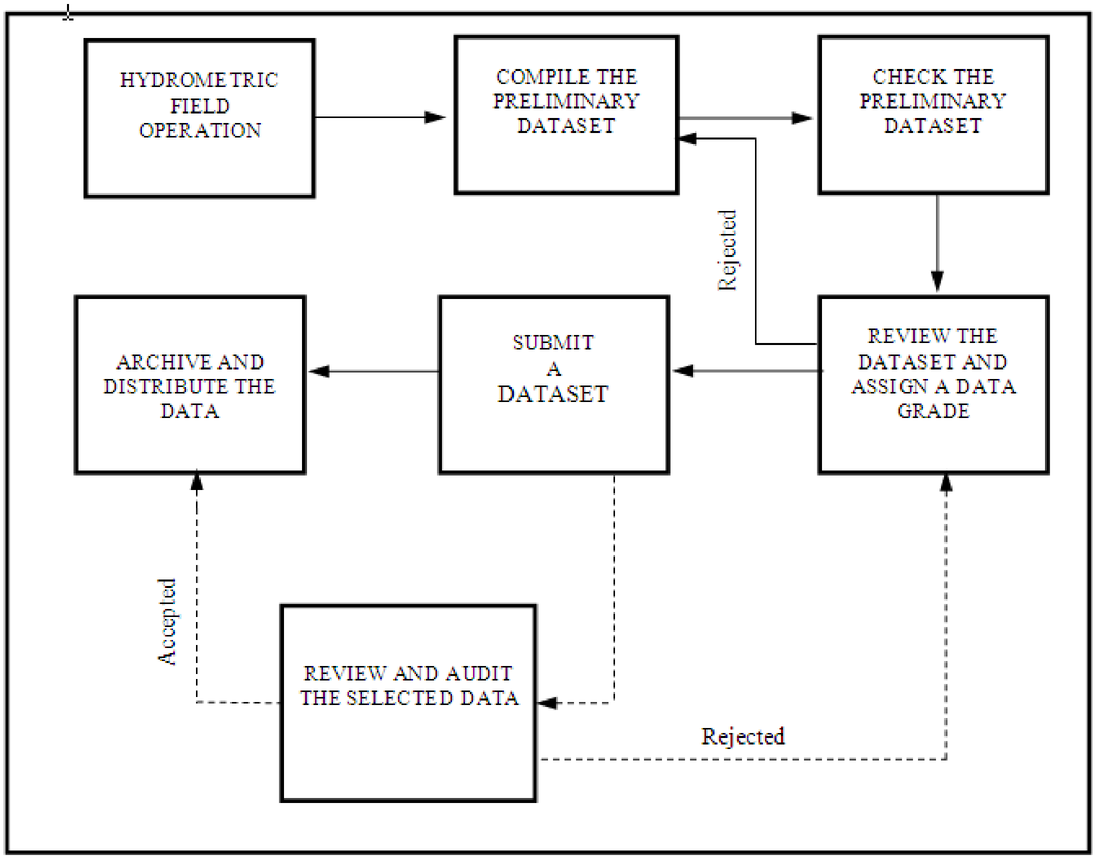

Figure 1: Flow chart of RISC Hydrometric Standards Process in British Columbia

Hydrometric field operations:

The hydrometric field operation includes the selection, construction and operation of hydrometric stations of any type. The operation covers maintenance, elevation control, stage and discharge measurement, data extraction and record keeping.

Under the RISC hydrometric standards system in BC, hydrometric data could be collected for a variety of projects by field staff with a range of hydrometric experience. The person collecting the hydrometric data – called the hydrometric operator – must be qualified to carry out the hydrometric operations, and must follow the BC Hydrometric Standards.

Compile the preliminary dataset:

Includes collection of gauge data, level notes, application of gauge correction/adjustment factors, station history compilation, discharge computation, stage-discharge derivation and plotting, preparation of rating table and the computation of mean daily (or other) discharge. The responsible hydrometric operator must complete all the computations and generate the necessary documentation in addition to completing the Station Analysis form (RISC HYD-06). This form describes the complete analysis of data collected, procedures used in processing the data, and the logic upon which the computations are based.

Check the preliminary dataset:

The field operator should check the preliminary dataset or, preferably, have the dataset checked by another experienced and accredited hydrometric operator. If the basin review or regional hydrologic analysis has been done and is available, then the preliminary dataset (e.g., hydrographs, monthly and annual unit discharge etc.) for the stations within the basin should be checked against this information for comparison. These comparisons of data may reveal anomalies that could necessitate further checking of the records.

It is anticipated that the hydrometric field operator will carry out the steps 1 to 3 and forward the information to the Hydrometric Data Reviewer for reviewing the dataset and assigning data grades. Activities involved in steps 1-3 are presented in Figure 2.

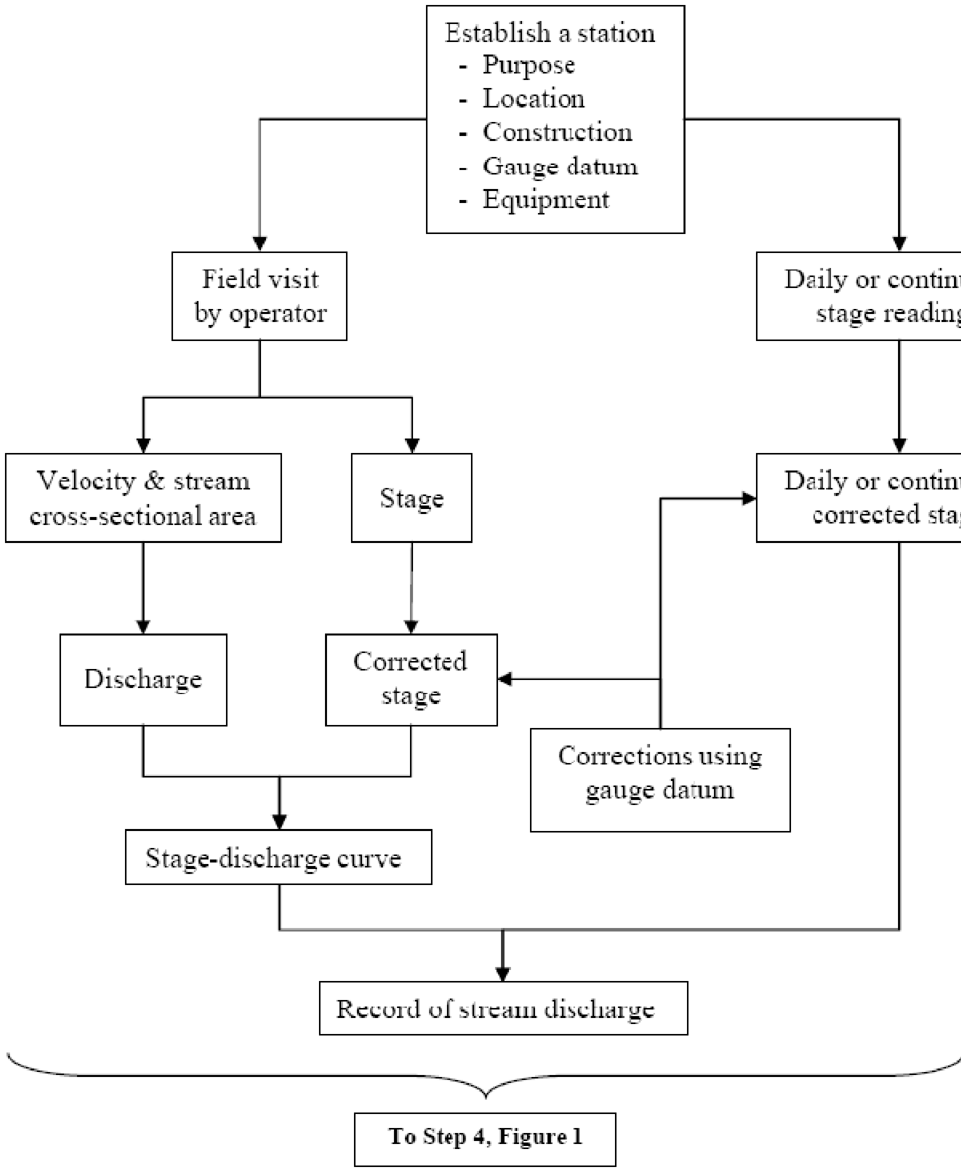

Figure 2: An overview of the hydrometric data collection activities during the field visit and between visits

Review of dataset and assigning a data grade:

The Qualified Hydrometric Data Reviewer or Reviewer will review all transcriptions and computations. The Reviewer will review all dataset and assign data grades according to the standards requirements criteria (Table 1) before submission to the provincial water database for archival and distribution. A detail descriptions of the data review process and the role and responsibilities of a Qualified Hydrometric Data Reviewer are presented in Chapter 6.

Submit a dataset:

For provincially funded projects: All time series raw data, completed forms, corrected and reviewed time series data with data grade must be submitted for archiving. All time series corrected and reviewed data must be submitted in standard digital format after having been assigned an appropriate data grade. Reviewers should also submit a copy of any final or annual station reports including all forms, rating curves, and analyses in PDF[2] format for entry into EcoCat[3] to make the work available to other interested parties and for the purpose of future audits.

However, data not reviewed by a qualified hydrometric data reviewer or not meeting any standards i.e., Grade A, B or C, but still useful for qualitative assessment can be submitted as Grade "U" (indicating unknown data quality) for archiving into the provincial database for internal use or for public access with an appropriate disclaimer.

[Note: See section 6.2 for detail data submission requirements]

Review and audit the selected data:

Data are subject to audit. Data audits are performed on archived data by qualified individuals and/or firms selected by the Ministry to verify that the information does indeed meet the standards required by the RISC hydrometric standards and is correctly graded. The data selection process for audit review is not yet established but it is proposed that audits be performed on randomly selected data. Audited data may be returned for further work, or its approval confirmed and sent for archiving.

Archive and distribute the data:

The data archive is a corporate database developed by the Province of British Columbia to capture publicly funded, high frequency time series data from automated monitoring sites located throughout British Columbia. Currently, the Water Inventory Data Management (WIDM) system is the repository of provincial non-integrated hydrometric, automated snow pillow, manual snow surveys, observation wells and continuous water quality data.

In addition to time series data, WIDM has the capacity to capture site and sample information including images, personnel, contacts, field notes, data source information, and discrete measurements, which are critical in the validation, grading and quality control of any obtained data. Access to WIDM functions and data are available to government employees, external agencies and contractors who have delegated database access. The security aspect of the application allows the assigning of roles to individuals that restrict their ability to view, edit, delete, or update information.

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[2] Adobe Portable Document Format

[3] EcoCat or Ecological Reports Catalogue is a document and file management system that allows users self-access to reports for various ecological projects within British Columbia.

Chapter 2: Fundamentals of Hydrometric Operations

2.1 Establishing a Gauging Station

2.1.1 General

A Hydrometric gauging station can be a natural or constructed location on a watercourse where records of water quantity are systematically obtained. It is referred to as a gauging station or a hydrometric station. In some cases the site may be used also as a Continuous Water Quality Sampling (CWQ) Site (RISC, 2006).

The purpose of any water quantity data collection program must be clearly defined before selecting a site. In addition, the benefits of archived data to other agencies or individuals should be considered, particularly when public money forms any part of the funding for establishing and/or operating the station(s). The following are some of the reasons for establishing a hydrometric station.

- To obtain data on runoff volume to use for quantifying storage volumes or issuing water licenses.
- To determine the timing and quantities of peak flows to use in designing spillways, culverts, or bridges.
- To determine the peak flows to incorporate into flood control measures.
- To determine the levels of lakes and reservoirs to use for flood control, storage capacity, recreation potential, and septic tank locations.
- To determine the timing and quantities of low flows that is necessary for managing fish habitats and assessing available water supplies.
- To determine baseline information to use in assessing water quality.
- To study the causal relationships between watershed and flow regime changes.

2.1.2 Types of Gauging Stations

This manual focuses on measuring the smaller streams — from 0 to 10 m^3/s. Gauging stations and methods for measuring greater flows are referred to, but not detailed.

There are five station variables considered in this manual: type of operation, type of gauge, type of station, equipment requirements, and datum. These subcategories of these variables are identified below.

- Type of Operation
  - Annual - operates January to December.
  - Seasonal - selected period to satisfy the data purpose (open water, or low flow).
  - Miscellaneous - e.g., individual, periodic flow measurement.
- Type of Gauge
  - Manual - read periodically (e.g., daily, weekly) by a site operator.
  - Recording - continuous record of water level either as an analogue or digital record.
- Type of Station
  - Water level only - lake or stream where discharge is of no concern.

- Water level and discharge - miscellaneous discharge at a specified location, recorded by date and time, may be used to assess the potential of a stream if referenced to an active hydrometric station on an adjacent/nearby watershed.
- Other parameters - sediment or other water quality characteristics may affect the configuration of the station.

- Special Equipment Requirements
  - Type of housing required - governed by the number and type of sensors, and the equipment present.
  - Real-time or automated equipment and sensors will govern positioning of signal relays.
  - Automated sediment and water quality samplers will determine degree of automation, i.e. multi-channel data loggers.
- Datum
  - Assumed (local) - placed at the zero of the gauge, which should be below low water for lakes or below zero flow for streams (such as for rated structures).
  - Geodetic Survey of Canada (GSC) Datum - where feasible, the gauging station should be related to GSC datum.

2.1.3 Desirable Criteria for a Basic Station

A well-planned, well-constructed gauging station meets the following criteria:

1. It is possible to get an accurate water level reading from the gauge at all stages.
2. The control, whether natural or artificial, is stable.

   a) A stable natural control (Figure 3) may be a:

   - bedrock outcrop, or other stable riffle (shoal) for measuring during low flow
   - channel constriction for measuring at high flow
   - falls or cascade that is not submerged at any water level

   b) A stable artificial control may be a:

   - rated structure (flume, weir, etc.) (Figure 4)
   - fish barrier (drop structure)
   - streambed sill (log, concrete, etc.) (Figure 5)
3. Discharge can be measured accurately at all stages, either through a rated measurement structure or by means of a current meter.
4. The site is accessible during the operational season.
5. The station is structurally sound, e.g., can withstand being overtopped.

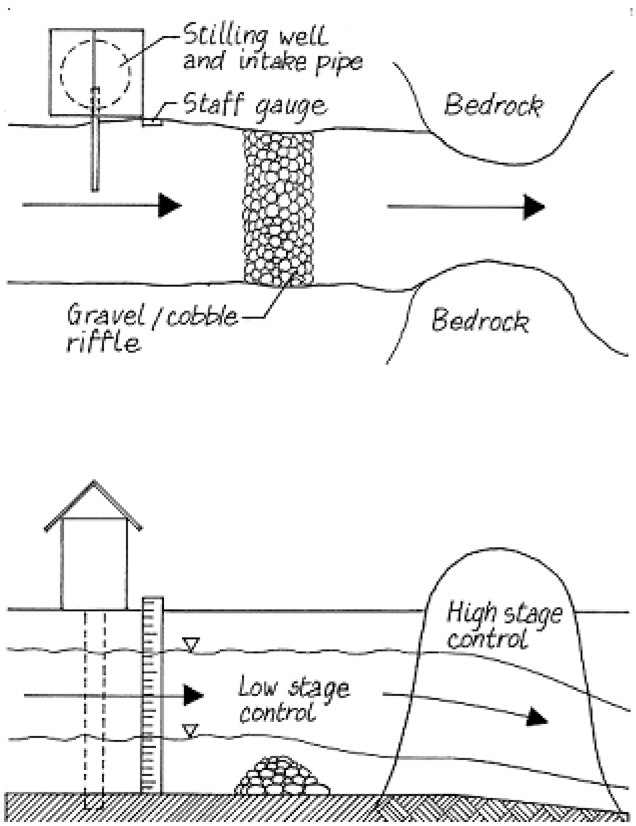


Figure 3: A Stable natural control.

Figure 4: A Stable artificial control (weir).

Figure 5: A Stable artificial control (log sill).

2.1.4 Selecting a Site for the Gauging Station

2.1.4.1 Pre-Reconnaissance Work

To select an appropriate site for establishing a gauging station, the purpose of the station must first be clearly identified.

The watercourse and basin should be studied in some detail prior to making any field trips. Obtain available maps-topographical, geological; and recent air photos. If possible, talk to people who are familiar with the watercourse and region, e.g. residents, water users, loggers, First Nations, other technical specialists, etc. Ask about the characteristics of the watercourse, including flood history, and find out if any activities are under way in the area that might affect the watercourse, e.g. logging, bridge construction, reservoirs, diversions.

Ideally, sites for a gauging station should be uniform, and have the following characteristics:

- Straight, aligned banks.
- Good current meter measuring sites, e.g. single channel, no undercut banks, minimal obstructions, no turbulence, no slow-moving pools (deadwater or backwater effects), no eddies.
- Reasonable means of access.
- No tributaries between gauge and metering sites.
- No swamps downstream or in vicinity of gauge.

Study the maps and air photos. Look for the characteristics of a suitable site, realizing that no site will be perfect. Select two or three potential locations and prioritize them.

Prepare a plan to reconnoitre the site identified as having the most potential, but be prepared to move on to other potential sites if the first one does not work out.

Before setting out on a field trip, be sure to check if written or verbal permission is needed from the land owner or manager to access the property.

2.1.4.2 Field Reconnaissance and Site Selections

To complete the selection of a site for the gauging station, take a field trip to the potential site. The field trip is an opportunity to make a detailed evaluation of the site in terms of the objectives and the characteristics listed in Section 2.1.3.

Reconnaissance should include careful observation of the following:

- ***Low Flow Conditions.***

  Look for a stable well-defined low water control. A raised culvert invert at a road crossing can be an ideal site for a gauging station, particularly in areas with flat gradients.

  If a stable control is not available, consider the feasibility of building an artificial low water control. Investigate the options, and gather and record preliminary survey data.

  If a site with a movable streambed must be accepted, i.e. one with a mobile granular channel, it is best to locate the gauge in as uniform a reach as possible, avoiding any channel obstruction that may intensify scour and fill.

  Where the watercourse emerges from an area of steeper gradients onto an alluvial fan, the reconnaissance must include discharge measurements to determine where the seepage of water into the alluvium becomes significant. The station should be located upstream of the area of water seepage if the maximum yield of the watercourse is required.

- ***High Flow Conditions.***

  To determine the magnitude of maximum discharge, look for evidence of past flooding, e.g. trash lines. Consider how easy it would be to safely access the gauge at all stages, and if it will be possible to position the recorder stilling well so as to avoid damage from high water levels or velocities and floating debris.

- ***Flow Measurement Conditions.***

  Ensure that the site has a suitable location for measuring discharge, either with a current meter or by other means. Make enough observations, including taking photographs, to prepare reasonable alternative conceptual designs and cost estimates.

Ideally, the metering section should have the following characteristics:

1. Well defined single channel for all range of flows.
2. Fairly uniform depth and velocity with parallel flow lines across the section.
3. One or more locations at which the full range of flows can be measured with available equipment. For flows that cannot be waded, it is more economical to use an existing bridge or culvert for high flow measurements. In the absence of a suitable structure, a site for a metering bridge or other alternative method should be available. See section 2.2, Constructing a Gauging Station and Figure 6, Trout Creek metering bridge.
4. Reasonable proximity to the gauge. This is particularly important in manual gauge installations where rapid changes in stage may occur during the course of a measurement and several gauge readings would be required.
5. No inflows or outflows between the gauging point and the measurement section. If this is unavoidable, an auxiliary station will be required to gauge these flows.
6. No aquatic growth or vegetation. Both the low flow and high flow measurement sections should be clear of aquatic growth. The portions of the bank subject to inundation during high flows should be cleared of any vegetation that could affect the measurement.

7. Backwater effect. Where the site is affected by a variable backwater, care must be exercised to remain within the instrument's threshold velocity.

Record the results of the reconnaissance in a report, with supporting survey data. The report will be a key reference in making decisions regarding the design, costing, construction, and operation of the gauging station.

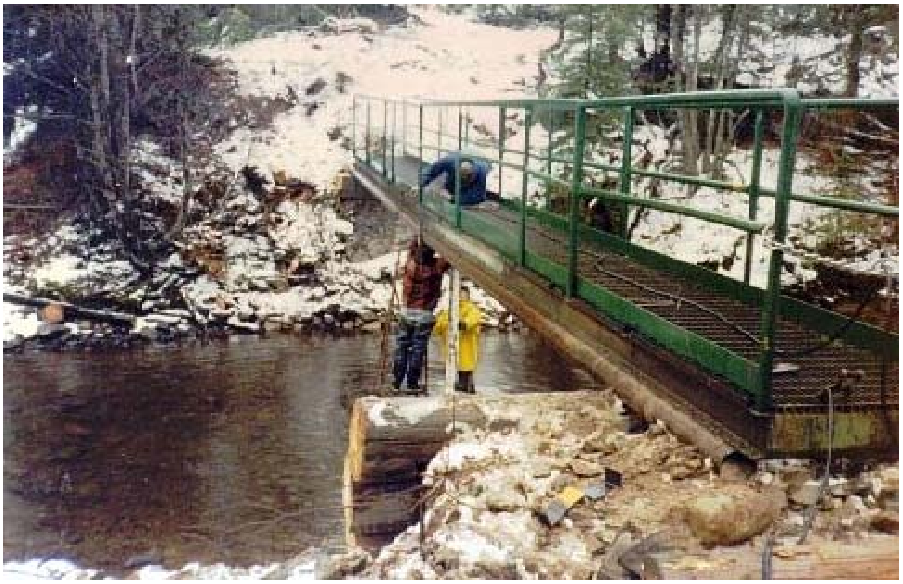


Figure 6: Trout Creek metering bridge.

2.2 Constructing a Gauging Station

2.2.1 Design Costing

The reconnaissance report and survey data should provide the information necessary for preparing preliminary conceptual designs and costs.

The factors to consider when producing a cost estimate are:

- Planned period of record and/or period of operation (seasonal, low flow, etc.).
- Requirements for artificial control in the absence of channel stability.
- Discharge measurement structure vs. ongoing metering in an unstable channel.
- The cost of transporting personnel, equipment, and materials to the construction site.
- The availability of suitable native material at or near the site.
- Construction methods.
- Selected instrumentation.
- Scheduling constraints based on flow magnitude and fishery regulations for in-stream construction.
- Future operational resources.

2.2.2 Permissions

Obtain written permission from the landowner or manager before you enter private land to carry out any proposed construction work. The scope of the permission should include access for construction as well as for the future operational period.

Any individual or agency carrying out any type of construction in any watercourse in British Columbia must obtain approval from the Regional Water Manager, MOE.

2.2.3 Bench Marks

[**Note:** Portion of the material presented in section 2.2.3.1, 2.2.3.2 and 2.2.3.3 have been prepared from: 1. Hydrometric Field Manual – Levelling, Inland Waters Directorate, Water Resources Branch, Environment Canada, 1984., and 2. Hydrometric Technician Career Development Program, Lesson Package No. 3: Bench Marks and Gauge Datum, by C.C. Handkamer, Water Survey of Canada, Environment Canada, 1999, (http://www.wsc.ec.gc.ca/CDP/Lesson3/index_ie_e.htm).]

2.2.3.1 General

Bench marks are permanent, fixed reference points of known elevation which are required for obtaining accurate hydrometric data. Bench marks are established at recording stations to ensure that gauge heights can be confirmed or adjusted relative to a constant datum or reference elevation. Bench marks are generally used for:

1. establishing gauge datum elevations,
2. maintaining current datum values,
3. referring gauges to their respective datum's,
4. obtaining instantaneous, direct water levels.

All gauging stations require some form of bench mark. When a station is established, it should be assumed that a permanent datum will be maintained at the site. To maintain a permanent datum, each gauging station should have 3 or more bench marks (for data grade A). The water level reading must be referenced to these marks, which in turn are referenced to the station datum. The location, related bench marks, and the relationships to any other gauges must be carefully included in the "Description of Hydrometric Station" (RISC HYD-01 form Figure 9, 10).

Various types of bench marks are used in hydrometric operations, the criteria being that they are stable, identifiable, and accessible at all stages of water. Commonly used markers include:

- Brass tablet or lead plug
- chisel mark or paint mark on large rock
- spike or lag bolt in tree
- painted bolt in hydro tower
- concrete gravity anchor
- lag bolt in wingwall of bridge
- ground rod for permafrost

2.2.3.2 Temporary Bench Marks

Temporary bench marks, as the name implies, are only used for relatively short periods, usually until permanent bench marks can be established. They are used for newly constructed stations and for existing stations whose permanent bench marks have recently been destroyed. Lag bolts and nails or marks on stable structures are widely used in these cases. It is important to maintain the continuity of gauge datum when the temporary bench marks are finally tied into the permanent bench marks.

2.2.3.3 Bench Mark Stability

When installing bench marks, it is imperative to choose sites that will provide a high degree of stability. The ability of the bench mark to maintain its relative position in the local terrain is essential to its operation. Bench marks must be spread out, well away from the river bank and preferably above the floodplain. Whenever bench marks are established, they must be clearly marked so that they will be easy to find at a later date. Unmarked bench marks cause confusion and are often lost or destroyed.

2.2.4 Reference Gauge Installation

2.2.4.1 General

A reference gauge is the gauge to which the recording instrument is set. All gauging stations require some form of water level reference gauge in addition to any water level recording device that may also be installed. The chart pen or sensor reading must be referenced to this gauge which in turn is referenced to station datum with bench marks. The most common, standard reference gauge is vertical staff gauge while a non-standard reference gauge can be reference marks, chain gauge, wire-weight gauge, incline gauge etc.

2.2.4.2 Standard Vertical Staff Gauge

The most commonly used manual or non-recording gauge is the vertical staff gauge (Figure 7, 8). It consists of one or more 1m sections of enamelled steel plate accurately graduated to either 0.01 or 0.002 of a metre. Each decimetre is numbered and intermediate 5cm graduation marks are wedge shaped. The 0.01m graduated type of plate is preferred for its less cluttered appearance; the third decimal value is estimated by reading the bottom of the meniscus.

Install staff gauges so that they are protected from damage by moving ice or other floating debris and are not affected by local drawdown or pileup of water. Reduce small local effects by mounting the gauge so that the face is parallel to the current; attach a length of half round wood moulding to streamline the upstream edge of the backing board (2”x 6”). When the gauge is to be used as a reference for a recording device, position the gauge as close as possible to the stilling well intake. In most cases it is necessary, and even preferable, to install the gauge near the bank below low water.

Slotted mounting holes for gauge plates allow for limited vertical adjustment of the plate during the initial installation, or to eliminate minor gauge corrections identified at subsequent gauge level checks. The gauge plates are fastened to a 0.15m wide backing board. In most small watercourses, the most convenient method of installation is to fasten the gauge plate(s), and metre numeral plates, to the backing which is then secured to a convenient vertical face such as a bridge abutment, pier, or piling. In some instances, shimming may be required to achieve a vertical installation. Attachments on concrete or steel structures require concrete fastening tools, anchors, or plumber’s strapping Figure 7. If no suitable anchorage is available, a steel angle iron driven into the streambed is acceptable.

Figure 7: Gauge plate and in-stream recorder (data logger) installation. (Note the brass tablet 'bench mark' located near the top of the gauge)

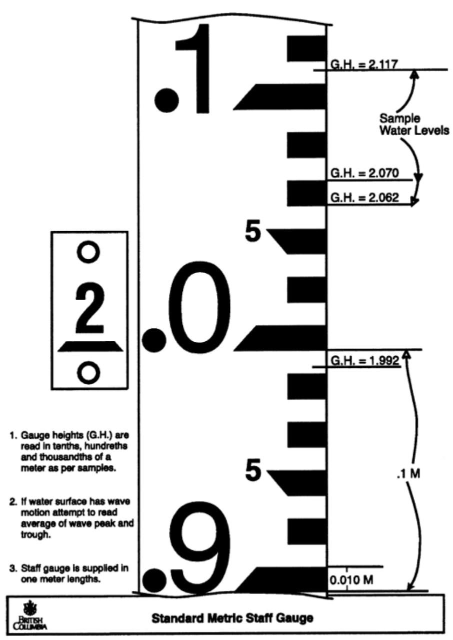


Figure 8: Illustration of a staff gauge.

2.2.4.3 Non-Standard Reference Gauges

In some locations a standard staff gauge may be subject to damage or destruction due to ice or debris. Or, if a staff gauge is exposed to high velocities it may be difficult or impossible to make an accurate reading. In these cases, another form of reference gauge should be installed. Commonly used non-standard reference gauges are reference marks, chain gauge, wire-weight gauge, inclined gauge etc. These types of gauges may be installed as either the reference gauge or as the primary gauge. Description of the reference mark is provided below while description of chain gauge, wire-weight gauge, and inclined gauge are provided in Chapter 3.

Reference Mark

This is a stable, well-defined position that is above the water surface at all stages. It may be a spike or lag screw in a tree overhanging the gauging pool from which the observer may measure down to the water surface. The mark could also be some existing object such as a bridge rail bolt. In all cases, the location, related bench marks, and the relationships to any other gauges must be carefully included in the station description (RISC HYD-01, see Figure 9, 10). This type of gauge may be a primary gauge for short-term stations, or it may be installed as a back-up or auxiliary gauge. A suitable measuring device, such as a metric fibreglass tape and weight, is needed. If a weight is added, a correction may be required i.e. to compensate for the distance from tape zero to bottom of weight.

If it is necessary to locate the reference mark above a position that dries out during low water periods, or if the station is a short-term, low flow measuring section, an underwater reference mark may be identified or installed in the watercourse. In the former case, determine the difference in the elevation of the two reference marks.

A series of reference marks linked to a common datum, together with a regular observation program, are often employed to provide the hydraulic grade lines necessary for engineering design, e.g. dike and bank protection, crest elevations.

BRITISH COLUMBIA

RISC HYD-01: Description of Hydrometric Station

☒ Original ☐ Revised

Station Operating Agency/Firm: ***Water Stewardship Inc***

Station Name: ***Ayum Creek Near Mouth*** EMS ID[1]: ***E123456***

Station No: ***1AHA040*** (if any) Project No: ***99HYD040*** (if any e.g., FIA)

Action (Station Established, Relocated, Closed)	Date (yyyy/mm/dd)	By Whom
Established	***2006/03/27***	***bb***
Modified (Intake Installed)	***2006/07/21***	***bb***

Site Description:
2.0 m high water gauge attached to stilling well, 1.0 m gauge attached downstream edge of large boulder in channel, located 4.0 m upstream of stilling well. Station located 25 meters upstream of HWY 14 bridge and situated on the right bank

Location Type: ☐ Lake or Pond ☒ River, Stream or Creek ☐ Marine

Region (from pick list):

☒ Vancouver Island	☐ Kootenay (Nelson)
☐ Lower Mainland (Surrey)	☐ Cariboo (Williams Lake)
☐ Southern Interior (Kamloops)	☐ Skeena (Smithers)
☐ Southern Interior (Penticton)	☐ Omineca-Peace (Prince George)

Nearest Community: ***Sooke***

Site Access Description: ***Located on Hwy14, 12 kilometres east of Sooke and 23 kilometres west of Hwy1 turnoff at Veterans Way***

Drainage area above station (km^2): ***11.2*** (if known)

Coordinates: ☒ Geographical ☐ UTM

Latitude (DD MM SS.SS): ***48 23 40.1234*** Longitude (DDD MM SS.SS): ***123 39 36.1579***

or

UTM Northing: ________ UTM Easting: ________ UTM Zone: _____

Geo Reference Source: ***GPS***

Site Elevation (m): ***7.0 GSC***

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Water Level Gauge:

☐Manual	☒Recorder
Types: ☐Standard Vertical Staff Gauge ☐ Chain Gauge ☐ Wire Weight Gauge ☐ Reference Marks	Types: ☐ Graphical ☒ Digital If Digital, Sensor Types: ☐ Pressure Transducer ☐ Bubbler ☒ Shaft Encoder ☐ Radar/ Ultrasonic ☐ Other
Reading Accuracy: ☐ 2mm or less ☐ 5mm or less ☐ 1cm or less ☐ Undefined	Reading/Sensor Accuracy: ☒ 2mm or less ☐ 5mm or less ☐ 1cm or less ☐ Undefined

Reference Gauge Type: ☒ Standard Vertical Staff Gauge ☐ Chain Gauge ☐ Wire Weight Gauge ☐ Reference Marks

Zero Flow at Gauge Height (m): ***0.238***

Benchmarks:

Benchmark	Date Established (yyyy/mm/dd)	Elevation above station datum [zero of the gauge when first established] (m)	GSC Datum Elevation if any (m)
BM#1	***2006/03/27***	***4.459***	***7.336***
BM#2	***2006/03/27***	***1.737***	***4.614***
BM#3	***2006/03/27***	***2.036***	***4.913***

Channel Description (A description of channel/morphology at station and the location of hydrometric equipment with respect to channel features):

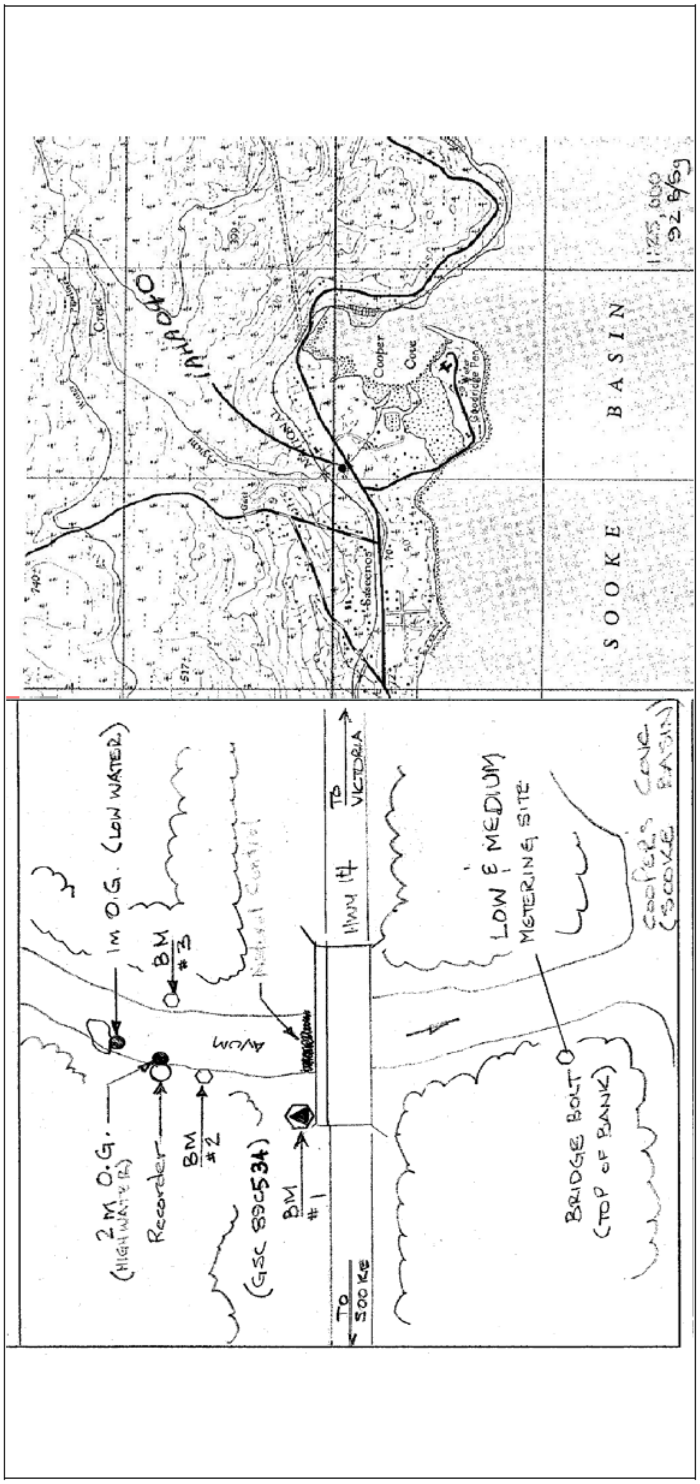
Natural rock/cobble control at bridge centreline & subject to debris build-up. Some in stream vegetation evident immediately upstream of control. High flow measurements can be obtained from bridge.

Stream Flow: ☒ Regulated ☐ Natural

Station Type: ☐ Water level only ☐ Discharge/Flow only ☒ Both

Figure 9: Example of completed Form RISC HYD-01, Description of Hydrometric Station (front). See Appendix III for blank forms

Location /Site Sketch: (1: General location on a standard base map 2: Sketch of station showing access and major landmarks, 3: Sketch of site showing location of all equipment, benchmarks, channel morphology in the vicinity of the station including conditions that could affect the measurements. Please use standard symbols)



[Note: Location /Site Sketch can be scanned and saved as JPEG format for electronic submission into the provincial water database. If possible submit/upload digital photograph of the site viewed upstream and downstream into the provincial water database (i.e., WIDM)].

Remarks (Site condition or any significant issues): ***Low and medium flows (GH>0.9 m) measurement site located 50 metres downstream of Hwy bridge. High flow measurement (GH>0.9 m) from bridge using Bridge Rod. Ayum Creek has no surface flow in August/September.***

Figure 10: Example of completed Form RISC HYD-01, Description of Hydrometric Station (back). See Appendix III for blank forms

2.2.5 Establishment of Gauge Datum and its Maintenance

[**Note:** Portion of the material presented in this section have been prepared from: 1. Hydrometric Field Manual – Levelling, Inland Waters Directorate, Water Resources Branch, Environment Canada, 1984., and 2. Hydrometric Technician Career Development Program, Lesson Package No. 3: Bench Marks and Gauge Datum, by C.C. Handkamer, Water Survey of Canada, Environment Canada, 1999, (http://www.wsc.ec.gc.ca/CDP/Lesson3/index_ie_e.htm).]

To obtain accurate and reliable stage data, the station gauge and bench marks must be referred to a fixed datum, which is normally an arbitrarily selected plane. This plane, to which all stage records are referred, is called the gauge datum (Figure 11).

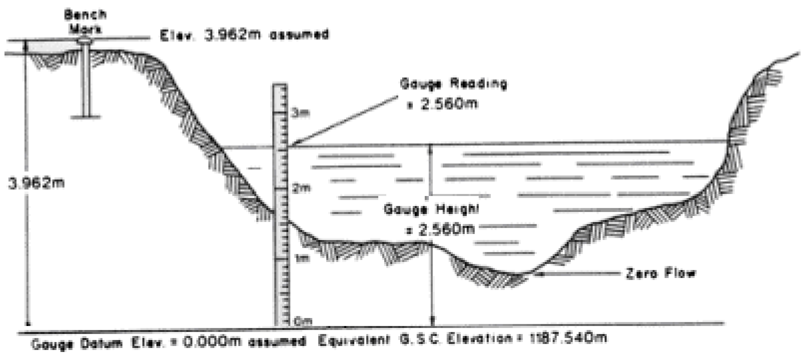


Figure 11: Gauge datum example (Courtesy: WSC).

A gauge datum is lower than the elevation at which zero flow is ever likely to occur and yet it allows for the convenience of recording relatively low gauge heights. By placing the gauge datum below the elevation at which zero flow occurs, it is possible to avoid recording negative stage data. The gauge datum should be low enough to allow positive stage data to be recorded for unusual occurrences, such as extreme low flows or flow in scoured channels. The continuity of the gauge datum at a gauging station is a very important part of data collection, and every reasonable effort should be made to maintain it throughout the entire period of the record. To ensure its continuity, the gauge datum at a station must be based on three stable bench marks (for Stations with data grade A) that are independent of each other and independent of the gauge or gauging structure.

The datum at each gauging station should be periodically checked by running levels from the bench marks to the gauges at the station, details of hydrometric levelling procedure are described in Section 2.3. If an assumed local datum plane is used, it is desirable that it be referred by levels to a bench mark of known elevation, so that the arbitrary datum may be recovered if the gauge and reference marks are destroyed. When datum changes are made for whatever reason, a record of the change should be a part of the published station description (i.e., under Action of RISC form, RISC HYD-01 front page, Figure 9).

2.3 Hydrometric Levelling Procedures

2.3.1 Introduction

Hydrometric levelling is an integral part of station establishment and its maintenance. Before a stage/discharge curve can be developed, gauge heights must be confirmed or adjusted. This section sets out the procedures and note-keeping format to be used for levelling in hydrometric operations (measurement of stage and the maintenance of station datum). The methods described must be strictly adhered to so that the data can be properly reviewed at a later date. Many of the methods in the section could be described as basic survey practice.

The following sections have been prepared from: 1. Hydrometric Field Manual – Levelling, Inland Waters Directorate, Water Resources Branch, Environment Canada, 1984., and 2. Hydrometric Technician Career Development Program, Lesson Package No. 7: Levelling Instruments and Procedures, by E. Mayert and, D.G. Goller, Water Survey of Canada, Environment Canada, 1999, (http://www.wsc.ec.gc.ca/CDP/Lesson7/index_ie_e.htm).

2.3.2 Level Adjustments

Regardless of the precision of the manufacturer, levelling instruments should be checked for accuracy frequently, but rarely will they need to be adjusted. It is strongly recommended that a levelling test be carried out prior to any level checks, and after any accidental rough usage. The operator should ensure that if an adjustment is required, it is due to the condition of the instrument and not to carelessness in the testing procedure. The instrument should not be adjusted unless the test indicates the same magnitude of error at least two times. A common procedure known as the Two-Peg test is usually carried out to test the levelling instrument and determine whether any adjustment is required.

Procedure for Conducting the Two-Peg Test

The two-peg test ensures that the level is accurately calibrated, i.e. that the line of sight through the telescope is parallel to the axis of the level tube (Figure 12).

Establish two firm points, A and B, about 60 m apart. Each point can be marked with a peg or a stake.

1. Set up the instrument midway between points A and B.
2. Stand rod on point A and take reading (a).
3. Stand rod on point B and take reading (b).
4. Record the difference in these readings (a-b). The correct difference in elevation between points A and B is *a - b*; this is true even if the level is not sighting a true horizontal line, because the instrument is set up exactly midway.
5. Set up the instrument at a point 3 to 4 m from point A at right angles to line A – B.
6. Take second readings on a rod set on points A (c) and B (d).
7. The difference in readings found between points A and B in step 4 should be unchanged (i.e., a-b = c-d) for the instrument to be in proper adjustment.
8. Should these second readings give a greater or lesser difference of 0.004m (0.013ft) than in step 4, the instrument is out of adjustment and must be adjusted until the horizontal cross-hair is equal to the correct reading of (d) If the last reading at d does not check, i.e., (c - a + b = e), the instrument is out of adjustment. The instrument must be adjusted until the horizontal cross-hair is equal to the correct reading of (d), that is (e = d).

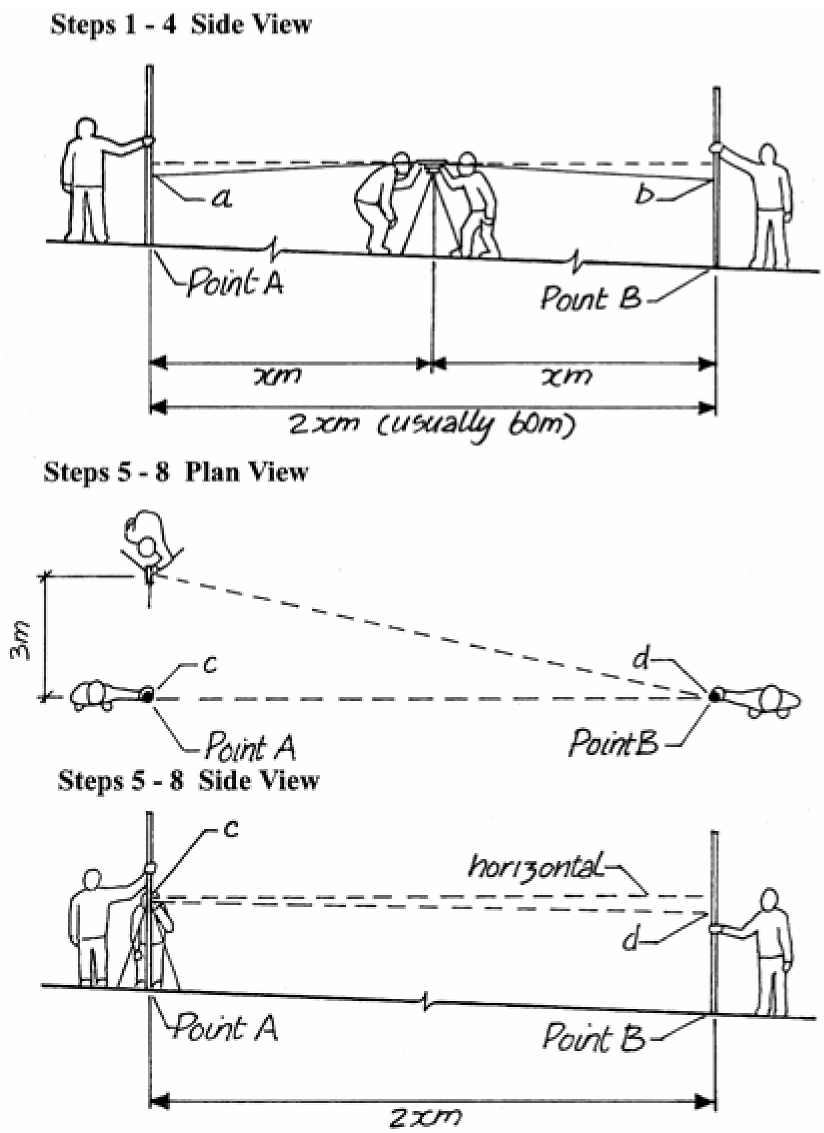


Figure 12: Principles of the two-peg test.

To adjust the horizontal cross-hairs.

a) Without moving the instrument at Point A, remove protective cover to reveal capstan-headed adjusting screw located directly above the viewing eyepiece
b) Take the difference obtained in step 4 and add/subtract to the reading obtained for Step 6 at Point A. This is the true value for the horizontal line of sight.
c) Using an adjusting pin, carefully turn the adjusting screw until the horizontal hair gives the correct reading on the rod at Point B as previously calculated.
d) Check by repeating steps 5 thru 7.

[**Note:** Adjustment for each type of instrument varies and the operator should refer to the instruction manual for the instrument to be adjusted for the proper procedure].

See the following examples.

Example 1: Level in adjustment

a = 1.510
b = 2.230
a - b = -0.720

c = 1.730
d = 2.450
c - *d* = -0.720

Example 2: Level out of adjustment

a = 1.390
b = 2.110
a - b = -0.720

c = 1.630
d = 2.310
c - *d* = -0.680

Adjust level until the horizontal cross-hair is equal to the correct reading of (d), that is (e = d) where, e = *c - a + b = 2.350*. (So when *d* = 2.350, then *c-d* = 1.630-2.350 = -0.720 = *a-b*)

Any adjustments to the instrument must be carried out while the instrument is still in position at point A. The manual supplied with the level instrument will describe the method of adjustment for each type of instrument. If adjustment is required, it is recommended that the entire level check process be repeated.

2.3.3 Levelling Procedures

2.3.3.1 Setting up the Instrument

The levelling instrument person should give some thought as to where it will be positioned before setting it up. The tripod should be set on firm ground so that the person using it has secure footing and can conduct the level circuit.

Accuracy of levelling can be increased by ensuring that all backsights and foresights are equidistance, this will eliminate any instrument or physical errors.

The level and tripod are placed in a desired location midway between the backsight (BS) and foresight (FS) with the tripod legs spread well apart and firmly pressed into the ground by standing on the feet at the base of the tripod. The tripod head should be nearly level with the telescope and at a convenient height for sighting. On hillsides, place one leg of the tripod uphill and two downhill for better stability. If the tripod has a domed head, the instrument can be shifted so that the circular bubble is near level. Coarse level adjustment can be obtained by using the foot-screws on the base so that the circular bubble can be carefully centered in the middle of its setting circle.

The level must first be adjusted so the crosshairs are in focus for the operator, which requires the following steps. Point the telescope towards a uniformly light-coloured surface, or a sheet of white paper. Turn the telescope eyepiece until the reticule crosshairs appear sharp and absolutely black. Turn the eyepiece slowly until the image starts to go out of focus. A small rotation in the opposite direction will refocus the hairs correctly. This setting corresponds to the operator's eyesight; it is constant, but individual to each operator.

The telescope can be pointed roughly at the levelling rod, by looking along the open sight and turning the instrument by hand. Set the vertical hair of the reticule cross along the middle of the rod image by turning the horizontal adjustment screw. Turn the focussing knob until the image of the rod graduations is sharp. The observer should move his/her eye up and down and from side to side behind the eyepiece, to ensure parallax does not exist (there should be no movement between the staff image and the reticule cross when viewed in slightly different positions). If such parallax is observed, the instrument must be refocused, as described in the previous paragraph. In the case of self-levelling instruments, the line of sight is now horizontal and the rod is ready to be read.

With a tilting level, the line of sight must be set horizontally using the tubular bubble. Position the fixed reflector for optimum illumination of the tubular bubble as seen through the bubble viewing eyepiece. The split bubble image seen in that eyepiece must be set to coincidence, by turning the tilting knob below the eyepiece. When the bubble ends are far from coincidence, an arrow in the bubble image indicates the proper direction to turn the tilting screw to obtain coincidence. The split bubble should be checked before each reading of the rod.

2.3.3.2 Positioning and Reading the Rod

The rod is positioned properly by placing it vertically on the point of a stable object. The rod must then be held plumb. The instrument person can tell if the rod is plumb in one direction by observing if the rod is parallel to the vertical cross-hair, but he/she can not tell whether it is tipped forward or backward. Therefore, the rodperson should use a rod level to plumb the rod in this direction. If the rodperson does not have a rod level, plumbing of the rod can be accomplished by balancing the rod between two fingers (if there is no wind). Waving the rod slowly towards and away from the instrument and observing the lowest reading on the rod is another method of ensuring that the rod is vertical, as in Figure 13.

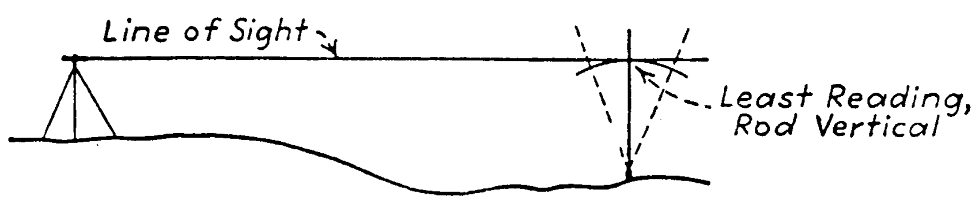


Figure 13: Positioning the rod (Source: Davis, Foote and Kelly, Surveying Theory and Practice, 5th edition, 1966, p. 172).

Errors created by not holding the rod plumb are much greater for readings taken near the top of the rod than for those taken at the bottom.

When the instrument is properly levelled and the rod is in a vertical position, the operator observes and records the reading indicated by the horizontal crosshair on the rod as seen through the telescope. To verify the accuracy of the reading, observe the split bubble and the rod reading again.

The telescope reticule has stadia lines, one above and one below the centre crosshair. The average of the readings of stadia lines on the rod represents the actual horizontal reading. The difference of the two stadia readings multiplied by 100 represents the distance between the instrument and the rod (Figure 14).

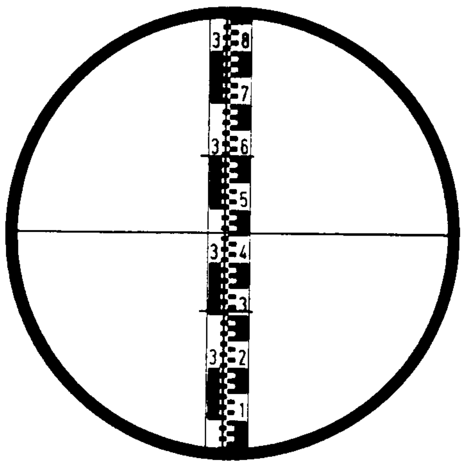


Figure 14: Reading the rod height 3.45 m, distance 29.2 m, (Source: Automatic Level, Wild NAO, Instructions for Use, Manual G2 106e - IX.80, p.9).

Normally, rod readings to 0.002 m are sufficient. Reading to 0.001 m implies a degree of accuracy that does not exist and is generally inconsistent with the sensitivity of the equipment used to gather other stage data.

2.3.3.3 Level Notes

Recording accurate and complete field notes is the most important part of the levelling operation. Notes and sketches constitute a permanent record of the survey, and it should be possible for them to be interpreted with ease by anyone having knowledge of levelling. Non-standard notes that can be interpreted only by the note keeper are unacceptable.

RISC field form, Gauge Level Field Notes provide a standard hydrometric format for recording level notes during routine level checks of gauges and normal line or differential levelling between bench marks (with backsights, BS and foresights, FS approximately balanced) is shown in Figure 15.

Hydrometric level note forms are divided into columns for recording observations and computing elevations. The right side of the level sheet is used for recording the necessary descriptive notes.

When recording notes, enter the existing elevation of the bench mark or reference mark on the line in the column headed Elevation as Given. The bench mark identification number is entered in the column headed Station. On the top line, in the column headed BS (backsight), the reading obtained with the levelling rod held on the bench mark or point of known elevation is entered as the backsight. The value for the column, Ht.Inst. (height of instrument) is computed by adding the backsight value to the known bench mark elevation. One line down, in the next column, headed foresight (FS), the foresight reading for the point for which an elevation is to be determined is observed and recorded. Commonly called a turning point

(TP), this value is then subtracted from the Ht.Inst. and the result is the elevation of the foresight point. This is entered in the elevation column and on the same line as the foresight just observed. When the instrument is moved, the new height of instrument is determined by a backsight on the TP. The observation and notes are continued in this manner until the circuit is closed by levelling back to the original starting Station. When performing level circuits, the operator should turn on all the points on which he/she is determining elevations. In the example given in Figure 15 the operator is using each Bench mark (BM) as a turning point (TP).

Level notes may be recorded on Gauge Level Field Notes (Figure 15). Using this format of note keeping, the information on each horizontal line pertains to the bench mark or turning point noted in the station column.

BRITISH COLUMBIA

Gauge Level Field Notes

[Note: Hydrometric operator can use this form in the field to prepare RISC HYD-02: History of Gauge Levels (Summary)]

Station Operating Agency/Firm: ***Water Stewardship Inc.***

Station Name: ***Ayum Creek Near Mouth*** EMS ID[1]. ***E123456***

Station No: ***1AHA040*** (if any) Project No: ***99HYD040*** (if any e.g., FIA)

Date (yyyy/mm/dd): ***2006/03/27*** Time, PST (24hh: mm): ***12:35***

Gauge Height/Stage (m): ***0.555***

Station	BS (m)	Ht. Inst. (m)	FS (m)	Elevation (m)	Elevation as Given (m)
Gge Direct	3.427	3.427		0.000	0.000
BM3	1.444	3.480	1.390	2.037	2.036
BM2	3.115	4.852	1.743	1.737	1.737
BM1			0.393	4.459	4.459
BM1	0.298	4.757		4.459	4.459
BM2	1.359	3.096	3.020	1.737	1.737
BM3	1.524	3.560	1.060	2.036	2.036
Gge Direct			3.560	0.000	0.000

Elevation Means:

BM # (e.g., 1, 2, 3 etc.)	Established Elev. (m)	Mean Elev. [this date] (m)	Difference (m)
1	4.459	4.459	0.000
2	1.737	1.737	0.000
3	2.036	2.036	0.000

Comments on Elevation Changes:
No elevation changes required-Gauge and Benchmarks stable

Gauge Correction (m): ***0.000***

Date of Change (yyyy/mm/dd) ______________________ (if known)

Surveyed by: ***B. Booker***

Computation by: ***B. Booker*** Date (yyyy/mm/dd) ***2006/03/27***

Checked by: ***D. Checkoff*** Date (yyyy/mm/dd) ***2006/03/30***

Additional Notes:
This form can be used to record the rod readings during a gauge level check. Results can be transferred to the RISCH Hyd-02 form. This form can be printed onto water –proof paper for field use.

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Figure 15: Gauge Level Field Notes at Ayum Creek gauging station. See Appendix III for blank forms

2.3.3.4 Gauge Checks or Level Checks

Staff gauges are subject to many extreme conditions and are often displaced or even destroyed by the action of frost and ice. Stream bank instability, stream bed erosion, and vandalism are other reasons for lost data. To help ensure that stage records remain reliable, the datum of the gauge must occasionally be checked against the original reference elevation. How often this is done is largely determined by the conditions. Under normal conditions a gauging station may require checking only two or three times during a season. However, for a gauge with a history of instability, or in an area of fluctuation due to frost, a level check during each visit to the station is required. When running levels to check for the possible movement of a gauge, THE CIRCUIT MUST BE CLOSED IN ALL CASES. Even where the situation involves one set-up between the bench mark and the gauge, the instrument must be moved to close the return run to the bench mark.

Procedure – Level circuit to staff gauge

The procedure for determining the elevation of a staff gauge in relation to the elevation of a bench mark involves several steps. First, set up the levelling instrument in a convenient location midway between the staff gauge and the bench mark, so that a clear rod reading is obtainable at both points, but no attempt is made to stay directly on the line between the two. A backsight on the bench mark is then observed and recorded. Next the rod person goes to the staff gauge and holds the rod on the staff gauge while the instrument person observes and records a foresight reading. Move the instrument and set up again for another backsight(BS) reading on the staff gauge. The rod person then returns to the bench mark where the instrument person observes and records a foresight.

By adding the recorded backsight value to the known elevation of the bench mark, the height of instrument is determined. The foresight is then subtracted from the height of instrument to obtain the elevation of the staff gauge. Also, the difference between the backsight taken on a given point and the foresight taken on the following point is equal to the difference in elevation between the points. In this example, only one bench mark was used, BUT THE ACCEPTABLE PROCEDURE WOULD BE TO TIE IN AT LEAST THREE BENCH MARKS. When a number of turning points are required to obtain the water level reading, it is advisable to run a closed circuit between the bench marks first to minimize the closure error corrections due to the turning points.

> **Note:** Both examples shown (Figures 16) are acceptable, the difference being that Example 1 determines the elevation at the bottom of the gauge; Example 2 determines the elevation of a point on the gauge.

Example 1: Gauge A

Gauge Reading = 2.592 m

Gauge Correction = -0.122 m

Gauge Height = 2.470 m

Example 2: Gauge B

Gauge Reading = 2.348 m

Gauge Correction = 0.122 m

Gauge Height = 2.470 m

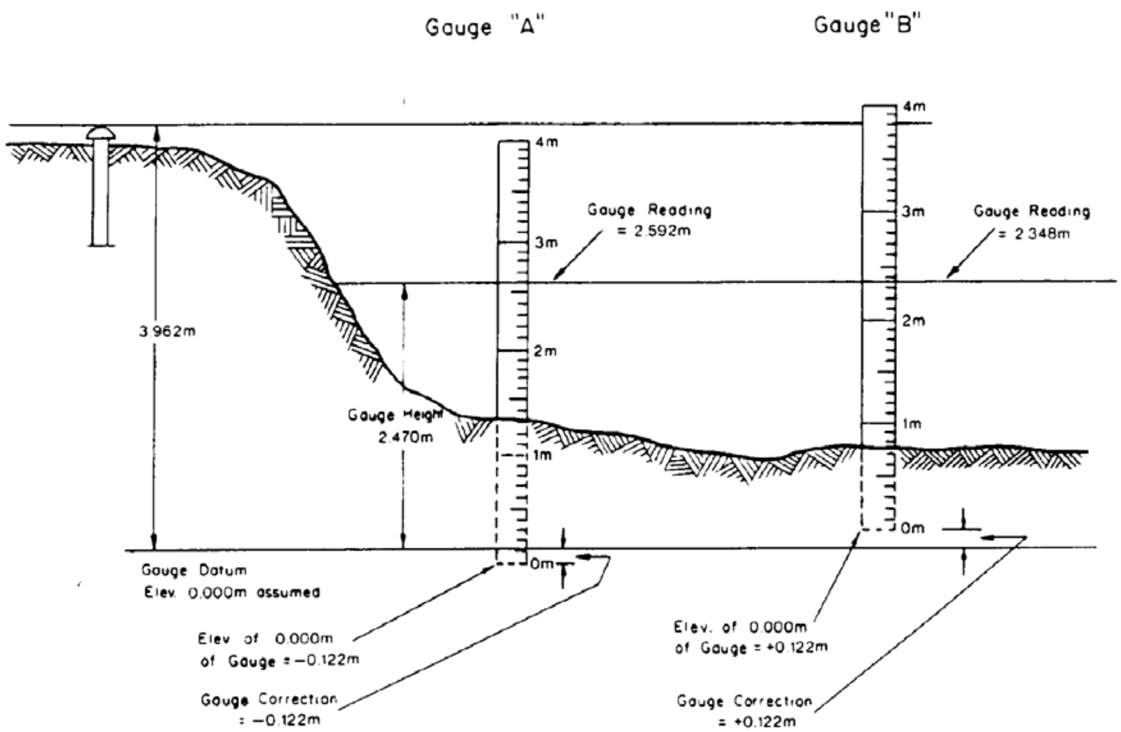


Figure 16: Illustration of corrections to staff gauges (Courtesy: WSC).

This procedure, however, presents a problem when checking wire-weight gauges without the assistance of a rod person. Completely repositioning the instrument tripod after initially sighting on the weight makes it difficult to resight the level on the graduated portion of the weight when closing the circuit. In this case, and only in this case, the following procedure can be used. Raise the level head very slightly by extending one of the level legs a small amount, and ensure the instrument is levelled. This should allow for a foresight on the graduated weight (Figure 20).

> [**Note:** The graduations on weights are usually in the form of 2-mm grooves with 2-mm spacing.]

Of course, this approach is not necessary when assistance is available. The return portion of the circuit is completed by taking level readings back to the original bench mark from which the circuit began. See Figures 17, 18, 19 and 20 for illustrations of corrections to wire-weight and staff gauges and for samples of level notes.

When levelling staff gauges, both inside and outside gauges, the same general procedure is used. However, the instrument must be repositioned when closing the circuit. As mentioned in the previous example, the circuit must be closed by returning to the original bench mark.

To check for closure error in a closed circuit, the sum of all backsights minus the sum of all foresights should = 0.000. For smaller closed level circuits, if the closure error exceeds ±0.004m, then the level check should be repeated.

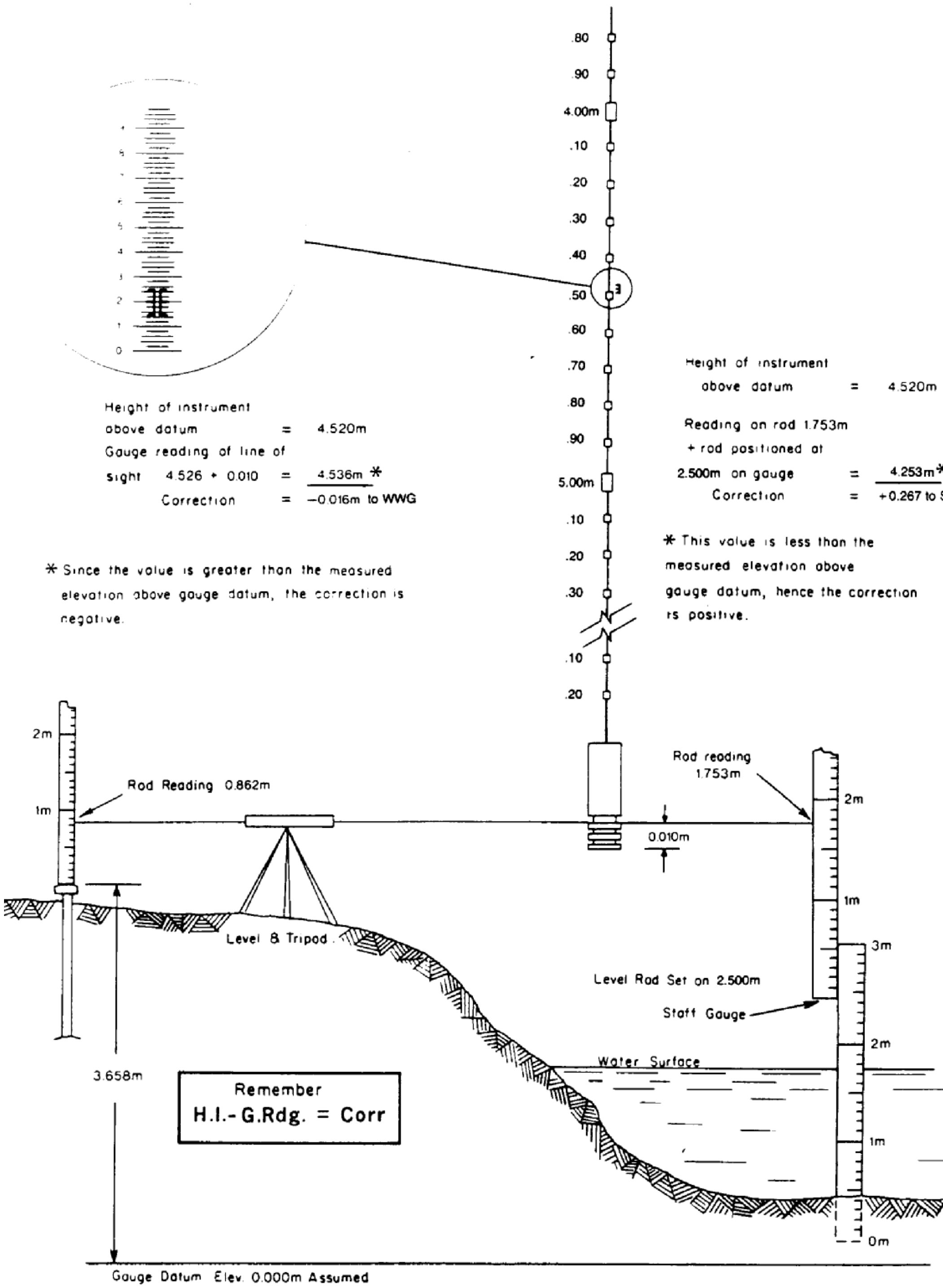


Figure 17: Gauge corrections and how they are derived for a wire-weight gauge (Courtesy: WSC).

LEVEL NOTES at BIG RIVER AT LITTLE BEND

STATION	B.S.	HT. INST.	F.S.	ELEVATION	
BM A70-2	0.152	14.782		14.630	BM on R.B 3 m W of Br. abut.
TP1	0.305	11.887	3.200	11.582	
TP2	0.152	8.381	3.658	8.229	
W.W.G.			0.012		Sight on grooves of weight
			8.376		W.W.G. reading corr. to W.W.G.
W.W.G.	0.043				@10:30 P.S.T.
	8.376				
	8.419	8.412			
TP3	3.810	11.734	0.488	7.924	
TP4	3.566	14.995	0.305	11.429	
BM A70-2			0.363	14.632	
	16.404		16.402		
			16.404		
		Diff. =	0.002		Closure O.K.

SKETCHES

NOTE: Use correction of -0.007 m

Figure 18: Sample level notes and illustration of wire-weight gauge corrections, Big River at Little Bend. (Courtesy: WSC).

LEVEL NOTES at CLEAR RIVER AT LITTLE BEND

STATION	B.S.	HT. INST.	F.S.	ELEVATION	
BM A70-2	0.152	14.782		14.630	BM ON R.B. 3 m W. of BR. abut.
TP1	0.305	11.887	3.200	11.582	
TP2	0.152	8.381	3.658	8.229	
W.W.G.	*8.419	8.412	*8.388	-0.007	Sight on bottom of weight
					@10:30 P.S.T.
TP3	3.810	11.734	0.488	7.924	
TP4	3.566	14.995	0.305	11.429	
BM A70-2			0.363	14.632	
B.S. =	16.404	F.S.	= 16.402	0.002	Closure error
					acceptable

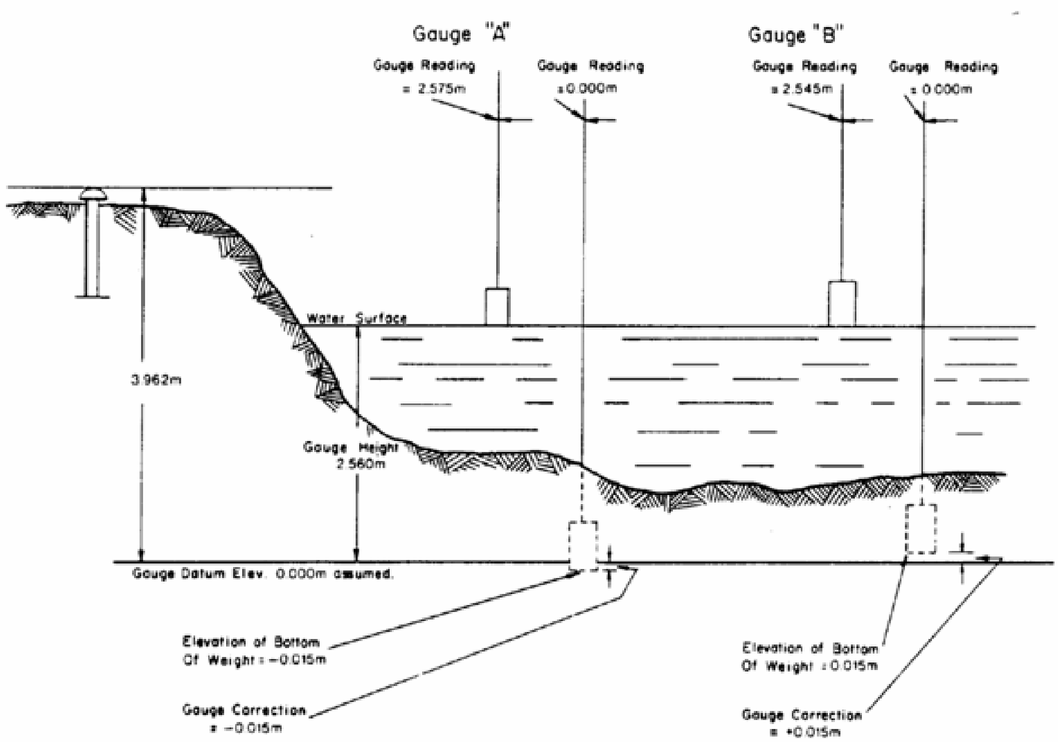
SKETCHES

NOTE: * is wire weight reading
Use correction of -0.007 m

Figure 19: Sample level notes and illustrations of wire-weight gauge corrections, Clear River at Little Bend. (Courtesy: WSC).

In all cases the level circuit must be completed prior to determining the correction that is to be applied to the gauge. It is strongly recommended that a water elevation be obtained at the time the level circuit is run. Among other things, the water level obtained will indicate if the intake pipes are silted or frozen.

An example of RISC HYD form for Gauge Level Field Notes is presented in Figure 15. The form (blank form is available in Appendix III) can printed on water proof paper for field use and the levelling results are used to complete the RISC HYD-02 form i.e., History of Gauge Levels (Figure 21).



Gauge A		*Gauge B*	
Gauge Reading	= 2.575 m	Gauge Reading	= 2.545 m
Gauge Correction	= -0.015 m	Gauge Correction	= +0.015 m
Gauge Height	= 2.560 m	Gauge Height	= 2.560 m

Figure 20: Illustration of Wire-weight gauge corrections (Courtesy: WSC).

BRITISH COLUMBIA

RISC HYD-02: History of Gauge Levels

[Note: Hydrometric operator can use "Gauge Level Field Notes" sheet to complete this form]

Station Operation Agency/Firm: ***Water Stewardship Inc*** EMS Id[1]: ***E123456***

Station Name: ***Aym Creek Near Mouth*** Station No. ***1AH040*** (If any) Project No. ***99HYD040*** (If any e.g., FIA)

Benchmark	Date Established (yyyy/mm/dd)	Original Elevation (m)	Description (Description of benchmark as well as reference distances from known points to assist in locating benchmarks at a later date by someone other than the person who installed it. The "bolt in base of tree" may be hard to find when there are a number of trees in the general area of the BM.)
BM# ***1*** (e.g., 1, 2, 3 etc.)	***2006/03/27***	***4.459***	***GSC BM89C534 Hwy 17 bridge. Brass tablet set horizontally in concrete from upstream right bank abutment. Elevation 7.336 m GSC***
BM# ***2*** (e.g., 1, 2, 3 etc.)	***2006/03/27***	***1.737***	***Lag Bolt situated on R/B of Ayum Creek, 4 m D/S of well in northerly base of 0.2m alder. Elevation 4.614 m GSC.***
BM# ***3*** (e.g., 1, 2, 3 etc.)	***2006/03/27***	***2.036***	***Lag Bolt situated on left bank of Ayum Creek, directly opposite of well in northerly base of 0.4m alder. Elevation 4.614 m GSC.***
BM#____ (e.g., 1, 2, 3 etc.)			

Elevation of Station Datum, m (GSC if any): ***2.877m GSC*** (Note: Local datum is always zero)

History of Level Checks, Gauge Corrections, Changes to Benchmarks and Auxiliary Gauges

Gauge Correction Data (m)							
Date & Time (yyyy/mm/dd 24hh:mm PST)	Gauge Reading (m)	Gauge Correction (m)	BM# 1 or Ref.#__ (e.g., 1, 2, 3 etc.)	BM# 2 or Ref.#__ (e.g., 1, 2, 3 etc.)	BM# 3 or Ref.#__ (e.g., 1, 2, 3 etc.)	BM#__ or Ref.#__ (e.g., 1, 2, 3 etc.)	Notes (on Installation or Removal of Gauges, Benchmarks, Auxiliary Gauges, Dates of Changes, Gauge Readings etc.)
2006/03/27 13:15	***0.449***	***0.000***	***4.459***	***1.737***	***2.036***		***Establish BM 1,2 & 3***
2006/07/22 15:30	***0.285***	***0.000***	***4.459***	***1.737***	***2.036***		***In take Installed***
2007/04/22 12:45	***0.431***	***0.000***	***4.459***	***1.737***	***2.036***		
2007/05/19 10:20	***0.243***	***0.000***	***4.459***	***1.737***	***2.036***		

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[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Figure 21: . Example of completed Form RISC HYD-02, History of Gauge Levels. See Appendix III for blank forms.

2.3.3.5 Line, or Differential Levelling

To determine the difference in elevation between two widely separated bench marks, a level circuit is run between the two stations (e.g., Geodetic Survey of Canada bench mark to a hydrometric gauging station). A number of intermediate instrument set-ups are selected; so that sighting distance for backsights and foresights are approximately equal (range 50 to 90 m). At the first instrument set-up, the rod is held vertically on the bench mark of known elevation with its face turned to the instrument. The backsight (BS) reading on the rod is added to the known elevation to obtain the height of instrument (HI). Next, the rodperson carries the rod to the instrument, counting the number of paces from the bench mark to the instrument. He/she then proceeds the same number of paces away from the instrument and finds or establishes a suitable turning point (TP1) (e.g., a hub driven into the ground or a high point on a rock). The HI minus the foresight (FS) rod reading at the turning point is the elevation of the turning point (TP1).

When the turning point has been established, the instrument is carried to the next set-up. The distance to the next set-up is determined in the same manner as the distance to the first turning point. The reason for balancing backsights and foresights is to eliminate instrument and physical errors (see two-peg test). (If it is not possible to balance the backsights and foresights when using the Wild N2 level, the rod should be read in both positions of the telescope [bubble right and bubble left] and the two readings averaged to eliminate the instrument error.) When sighting distance is over 70 m, influences of the earth's curvature and refraction may be noticeable, and they are not eliminated by reading the rod in two positions. The difference in elevation of the two bench marks should equal the difference in the sum of all backsight readings minus the sum of all foresight readings (from the first bench mark to the second bench mark).

Some of the turning points can be temporarily marked and used again when returning from the circuit to the original bench mark. If there is an error in the levels, only a portion of the circuit may have to be re-run. Refer to Figure 22 for a schematic of the level run, and Figure 23 for differential level notes.

In all cases the circuit must be closed, even when it involves only one set-up to check gauge movement, to do a bench mark tie, or to obtain a direct water level.

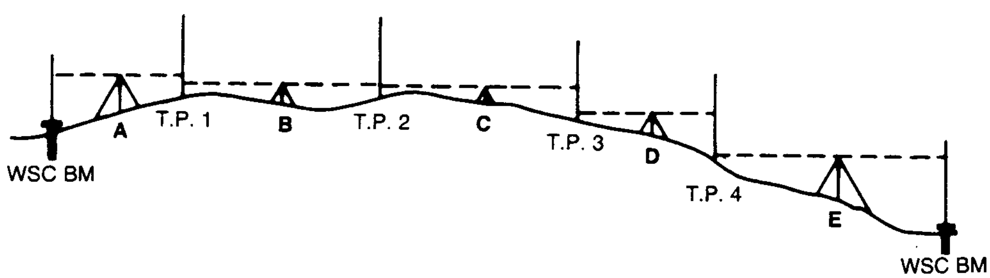


Figure 22: Differential levelling (Courtesy: WSC).

LEVEL NOTES at From GSC EM 785193 to WSC EM'S

STATION	B.S.	HT. INST.	F.S.	ELEVATION	
GSC 785193	1.241	877.767		876.526	Concrete monu. @ station
TP1	0.901	877.095	1.573	876.194	Rock
TP2	0.532	875.222	2.405	874.690	2" X 2" hub
TP3	0.202	873.552	1.872	873.350	tree stump
TP4	0.004	870.454	3.102	870.450	2" X 2" hub
S 87-101	2.754	870.954	2.254	868.200	steel rod 8 m S.
S 87-102	2.370	870.623	2.701	868.253	steel rod 2 m E.
TP4	2.975	873.425	0.173	870.450	2" X 2" hub
TP3	1.962	875.314	0.073	873.352	tree stump
TP2	2.392	877.086	0.620	874.694	2" X 2" hub
TP1	1.527	877.725	0.888	876.198	rock
GSC 785193			1.195	876.530	monument
			Closure =	-0.004 m	Closure O.K.

SKETCHES

NOTE: Geodetic elevation of WSC BM's are

S 87-101 = 868.198 m
S 87-102 = 868.251 m

Figure 23: Level note for differential levelling (Courtesy: WSC).

2.3.3.6 Reciprocal Levelling

Occasionally it is necessary to transfer a known elevation from one side of a large river channel to the other. This may result from the need to relocate an existing gauging station with a known datum or to carry a line of levels from an established bench mark when installing a new gauging station. The continuation of an existing datum and the transfer of an established elevation for a gauging station site are essential parts of hydrometric work.

The procedure to perform reciprocal levelling is as follows:

1. Set up the instrument near the point of known elevation (point A). Observe and record backsight readings at point A and foresight readings at the point across the channel to which the elevation is to be transferred (point B).
2. Now set up the instrument near point B. Observe and record backsight readings at point A and foresight readings at point B.
3. Often the horizontal distance between points is large, making it necessary to fit a rod target on the distant rod. To obtain precise results, take a series of foresight readings, re-centering the bubble and re-setting the target after each observation.
4. The difference between the mean value of the backsight readings and the mean value of the foresight readings is the difference in elevation of the two points.

This method of reciprocal levelling assumes that the conditions under which observations are taken remain unchanged during the procedure. When levelling points are far apart, two factors may affect the accuracy of readings: unequal expansion of the instrument parts and variations in atmospheric refraction. It is best to carry out this task on a cloudy day when temperature and atmospheric conditions remain constant; otherwise protect the instrument from the sun's rays. Complete the procedure in shortest time period as possible.

2.3.3.7 Adjustment of Elevation

It can be assumed that the principal errors of levelling are accidental and that most of the level circuits run in hydrometric surveys are relatively short.

When a line of levels makes a complete circuit, almost invariably the final elevation of the initial bench mark as computed from the notes does not agree with the initial elevation. The difference in value between the bench mark's known elevation and its computed elevation according to the level circuit is known as the error of closure. This is the true error value incurred while running the level circuit. It is obvious that the elevation of the intermediate points established while running the circuit will also be in error.

When significant errors of closure are experienced in level circuits over small distances such as the immediate vicinity of a hydrometric station, the survey should be repeated. In the case of a long distance circuit, there are statistical techniques for computing corrections to intermediate points.

2.3.3.8 Levelling Errors

One of the most important factors required to achieve accurate levelling is the skill of the field operator. Field operators must be aware of potential problems that will produce errors in levelling and the steps necessary to limit them. The following list discusses many of the common errors committed while performing levelling work:

1. *Improper Adjustment of Instrument.* This condition occurs when the line of sight is not parallel to the axis of the level tube. This error can be minimized by careful adjustment of the instrument and by balancing backsight and foresight distances.
2. *Parallax.* The eyepiece of the telescope must be adjusted until the crosshairs appear sharp and distinct. If there is an apparent movement of the crosshairs on the target with a corresponding slight movement of the observer's eye (vertically or horizontally), the condition of parallax exists. This condition can be reduced to a negligible quantity by careful focussing of the eyepiece on the objective lens.

   Alternate procedure:

   - Focus the telescope to the greatest distance.
   - Tilt the level to view the sky.
   - Adjust eyepiece until crosshairs are as sharp as possible.
   - Note the reading on the dioptric refraction scale for further checks.
   - Proceed to use the instrument.
3. *Inaccurate Reading of Rod.* This error can be greatly reduced by using shorter sights and by checking each reading before recording it.
4. *Rod Not Plumb.* A rod level can be used or the rod can be waved to eliminate this type of error. When the rod is tipped backward, ensure that it still rests on the front edge of the base.
5. *Improper Turning Points.* Turning points that are not both well-defined and stable are potential sources of error. If reasonable care is exercised when selecting turning points that are both solid and have rounded tops, this error can be kept to a minimum.
6. *Tubular Bubble Not Centered.* The magnitude of this error will vary with the distance between the instrument and the rod. It follows that the greater the distance to be sighted, the greater the care that should be exercised when levelling the instrument.

7. *Settlement of the Instrument Tripod.* Some settlement of the tripod is likely to occur when levelling over soft, muddy, or thawing ground. Under these conditions backsight and foresight observations should be made in quick succession in order to minimize any effect from the instrument settling.
8. *Incorrect Rod Length.* Level rod lengths should be checked periodically with a steel tape. Dirt or snow can become trapped in the sleeve of sectional rods which may prevent sections from fitting together properly. Rods should be assembled and carried so that the upper portion is never in contact with the ground.
9. *Mud, Snow, or Ice Accumulation on Base of Rod.* Mud, snow, or ice accumulations on the rod must be removed before each reading is taken so that level circuits will close. Note that ice accumulation is sometimes unavoidable when obtaining direct water levels in the winter. Uniform wear of the rod base causes no error.

Chapter 3: Stage Measurement Procedures

3.1 Introduction

The main purpose of a gauging station is to provide a means of systematically gathering hydrometric data. Discharge measurements are related to stage observations at time of measurement and, used to produce a stage-discharge relationship. Once this relation has been determined, it may be used together with daily stage data to produce a daily record of discharge. The measurement and recording of stage are important, as the stage record provides the means by which daily discharge computations are made. In addition, some gauging stations are operated exclusively for the collection of stage data. This chapter covers the techniques of stage measurements generally used and the basic equipment required for stage measurement.

3.2 Water Level Gauges

The instrumentation required to collect water level data is essentially two types:

1. Manual or Non-recording Gauges;
2. Recording Gauges i.e., automated continuous data recorder which produce a continuous record of water levels (e.g., pressure gauge with data logger)

Descriptions of different gauges normally used for collecting water level information are provided in the following sections.

3.2.1 Manual or Non-recording Gauges

[**Note:** This section has been abstracted from 1. Hydrometric Field Manual-Measurement of Stage, Inland Waters Directorate, Water Resources Branch, Ottawa, pp. 47 and 2. Hydrometric Technician Career Development Program, Lesson Package No. 4: Measurement of Stage - Instrumentation Non-Recording Manual Gauges, by F. Slabosz, Water Survey of Canada, Environment Canada, 1999, (http://www.wsc.ec.gc.ca/CDP/Lesson4/index_ie_e.htm).]

3.2.1.1 General

A non-recording gauge is a gauge used to get a manual water level reading at a hydrometric station. Non-recording gauges must be activated and read by the gauge observer; these gauges do not record water levels automatically. At stations not equipped with an automatic water level recorder, a non-recording gauge is the prime gauge for the station. At stations equipped with a recording gauge as the prime gauge, non-recording gauges are used as either a reference gauge or as an auxiliary gauge.

Manual gauges represent one of the main pieces of equipment used for obtaining water levels. In comparison to other equipment used for hydrometric operation, manual gauges are quite inexpensive and normally last indefinitely. Most gauges, if properly installed, are very reliable and very easy to read. A non-recording gauge can be installed regardless of the conditions at a gauging station. This gauge may be a vertical staff gauge, chain gauge, wire-weight gauges, inclined gauge etc.

Vertical Staff Gauge

For details of a Standard Vertical Staff Gauge see Section 2.2.4.2 of Chapter 2.

Chain Gauge

A chain gauge consists of brass or galvanized stove chain with a weight attached to the outer end, and passing along a horizontally mounted scale (usually a standard gauge plate). The horizontal section can be a fixed bridge component, a cantilever or a boom (Figure 24), to place the chain over open water.

The gauge plate is attached to the top of the horizontal support arm and the tagged chain is read against this plate. If the range of stage exceeds 1 m, two or more tags are required and these should be spaced precisely 1 m apart and colour coded with pairs of metre numerals. Alternatively, several gauge plates may be used with one tagged position pointer.

Initial and subsequent level checks on wire/weight or chain gauges is accomplished by setting up the level so that you can sight the bottom of the weight on the instrument cross-hairs. Lower the weight until it coincides with the height of instrument, and read the position of the pointer on the gauge. (This is the equivalent of a direct reading on a staff gauge.) Establishing at least one bench mark that can be sighted from this setup will greatly facilitate the operation of the station.

Figure 24: Chain gauge (Courtesy: WSC).

Wire-Weight Gauge

The wire-weight gauge consists of a length of steel wire cable attached to a spooling device. A weight attached to the free end and the assembly is enclosed in a lockable weatherproof box. This gauge may be mounted on a bridge member over the water surface or it can form part of a cantilever or boom gauge assembly installed on a streambank. The weight is lowered to the water surface to obtain the water level reading, taking care not to kink the cable (Figures 25 and 26).

Figure 25: Boom wire weight gauge.

Figure 26: Wire-weight gauge and mounting brackets. Athabasca River, near Windfall (Courtesy: WSC).

The point on the water surface at which the wire-weight gauge reading is taken should have minimal local disturbance. To reduce the effect of surface tension, read the gauge when the weight first touches the water surface. After contact has been made with the water surface, the weight can be raised by as much as 6 mm without breaking the contact. To obtain a good gauge reading it may be necessary to take several observations and then average the results. During periods of high wind, the wind drag on the wire and the roughness of the water surface will reduce the accuracy of the reading.

The wire-weight gauge is used as an outside gauge when conditions at a gauging station make it difficult to read or to maintain a staff gauge. At stations where there is no recording equipment, the wire-weight gauge is the primary gauge. It is usually read by a gauge observer. The wire-weight gauge can also be used as an auxiliary gauge.

Inclined Gauges

In most cases, inclined staff gauges (Figure 27) are attached to existing structural components, such as wing walls or along the edge of a boat launch ramp, and they are usually installed at or near the ground. If the site has silting problems, the gauge should be raised.

Inclined gauges are used primarily where the bank slope is very low and water level range high, and where it is impractical to use a series of staff gauges or a cantilever gauge. Because the slope distance can be 30 m or greater, this type of gauge is very suitable for use on lakes, or reservoirs and for use as an auxiliary gauge. However, an inclined gauge is seldom used because it is difficult to prevent the gauge from moving during frost action. Also, gauges mounted directly on the ground are subject to siltation problems, while gauges mounted above the ground are subject to damage by ice or floating debris.

Figure 27: Inclined gauge with metal tags between the metre markers (Courtesy: WSC).

3.2.1.2 Procedure for Manual Gauge Measurements

A record of stage may be obtained by systematic observations of the above non-recording type gauges. The basic principle that can be used to determine stage or gauge height is direct observation. It involves a measurement of the height from the water level to a datum line. “It is often difficult to accurately detect the water line when making staff-gauge 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 gauge and thereby define the water line. When the water surface is surging rapidly as a result of wave action, the stage is the mean value of the elevations of the peak and the trough of the waves” (Rantz et al, 1982, p. 64).

3.2.2 Recording Gauges

3.2.2.1 General

This section describes the instrumentation used to automatically collect continuous water level records, and methods of installation. There are two distinctive recording systems common to hydrometric surveys: analogue, or graphic; and digital. The analogue recorder has been in use since early in the 20th century and is still widely used in many places. The digital system, on the other hand, came into common use for water level recording only in recent years. The digital recording system has replaced the analogue recorder for many applications, although neither system is foolproof. All automatic water level recorders require some form of manual reference to the water level at the time of installation, and again at all subsequent visits to the station by the technician. The reference gauge should be installed in close proximity to the recording device.

3.2.2.2 Graphic Recorders

A graphic water level recorder is an instrument that provides a permanent and continuous long-term record of water level variation. A counter movement controls the rate at which a strip chart advances. At the same time, a float in contact with the water surface activates a marking stylus or pen which reproduces the float's vertical movement on the strip chart. Graphic recorders can record a virtually unlimited range of stage. They provide a low cost record of stage when installed at lakes or reservoirs, and they may be used to provide a record of flow rates, for licensing purposes, below diversion structures in rated channels designed to transport water at a near constant rate.

The use of the graphic recorder is in general decline and has been replaced by electronic digital recorders and sensors.

3.2.2.3 Digital Recorders

General

The advent of electronic sensors and data loggers, with their ability to record and store information in database-ready digital format, was made the importing and compilation of recorded values much easier and faster.

Today there are a variety of data loggers on the market, some being multi-purpose in nature, while others configured for specific tasks. Determining the best one for the application involves evaluating the hardware and software which make up the system (Figure 28) with specific emphasis on sensor and programming capabilities, ease of software use, data transmission options and especially manufacturer support.

In addition, it is also important to check the accuracy and resolution of the instrument. Accuracy is the amount of uncertainty between the measured value and the appropriate absolute standard and Resolution is the smallest amount of incremental change that can be detected. It is important to be aware that just because the sensor or data logger can display a value to three decimal places, it may only be accurate to one.

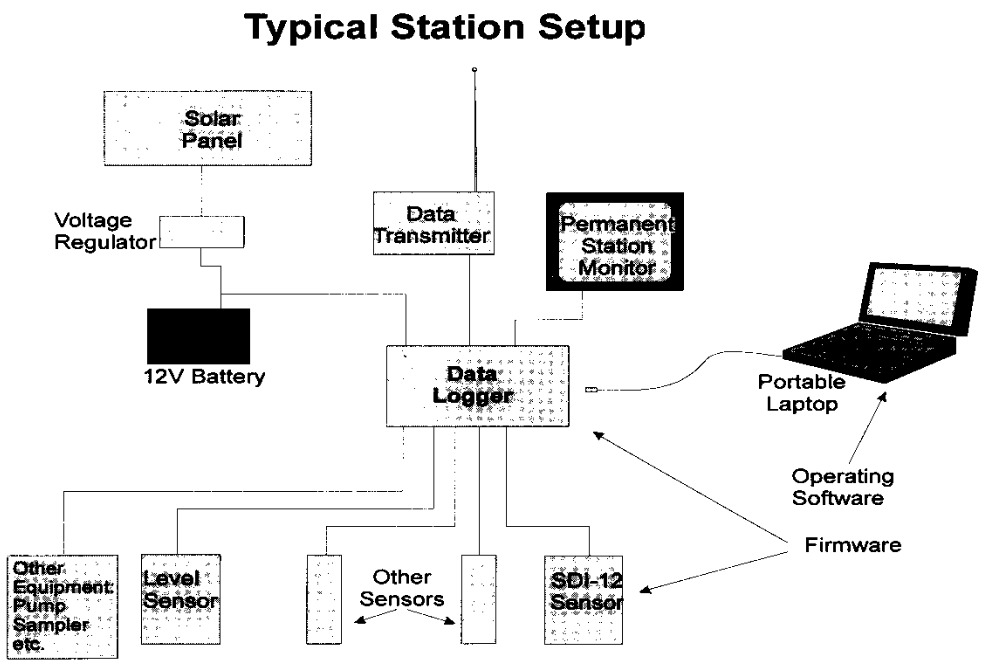


Figure 28: Typical flow diagram for electronic monitoring station showing various components required to measure and log stage data.

Data Logging Frequency

The data logger should allow programming to acquire data from a stage sensor at preset intervals. The proper data sampling frequency is essential to obtain a data set that is representative of the actual time series of stage data. Extended sampling intervals may miss important peaks while short sampling intervals will unnecessarily fill memory space with redundant data. The suggested interval is one instantaneous stage reading every 15 minutes commencing at the top of the hour (00:00–23:45). This is a minimum requirement, however, site specific flow regimes may necessitate a shorter frequency, but generally, a 15 minute interval will provide an accurate representation of actual stage behaviour for most streams without creating large volumes of raw data.

Selection Criteria for Electronic Data Loggers

The choice of a data logger is a key part of the site planning process. All manufacturers will supply documentation describing in detail the capabilities and prices of their various product. Review these carefully to ensure the model selected meets the site requirements (see Table 2).

Table 2: Selection criteria for electronic data loggers with comments and notes.

Selection Criteria	Comments & Notes
Memory	• How much data? • Sampling frequency?
Type of sensor	• Must communicate with the sensor
Analog (voltage output)	• Most common • Environmental changes expressed as electricity changes • Limit to cable length
Pulse	• Easiest for data loggers • Sensor changes opens & closes a circuit giving a pulse e.g. wind speed & tipping buckets
Digital	• Translate analog to digital within the sensor • Signal is mathematical • Very accurate & little signal corruption • Compatibility is important
SDI-12	• The Serial Data Interface Protocol is a set of rules defining how sensors communicate with data loggers. It was developed to ensure uniformity among low-power sensors. • SDI-12 might also be described as "smart sensor" technology. • Typically, some intelligence and memory are added to the sensor. This permits the user to program some instructions to the sensor itself. • Easiest to use
Analog to digital conversion	• Resolution required defines the accuracy
Programmability	• Depends on logging precision required
Sample range	• Depends on frequency of data & polling frequency
Output	• Format of output data (e.g. ASCII, Binary)
Counter accuracy	• Is sample timing critical
Data retrieval	• Transcribe data to a field notebook using an on-site data monitor? Collect data manually on site with a laptop computer and operating software? Transmit data via telephone, radio, satellite etc. back to the user's PC using operating software?

Sensors for Stage Measurement

There are a variety of different methods for automated continuous measurement of the water "stage". Each system has its advantages depending upon the conditions in which the measurement is to be conducted (see Table 3).

Some of the products currently used are:

- Shaft Encoders with Float Assemblies.
- Submersible Pressure Sensors.
- Pressure Measurement Sensors (Bubbler Gauges).
- Ultrasonic and Radar Level Sensors.

<u>Shaft Encoders</u>

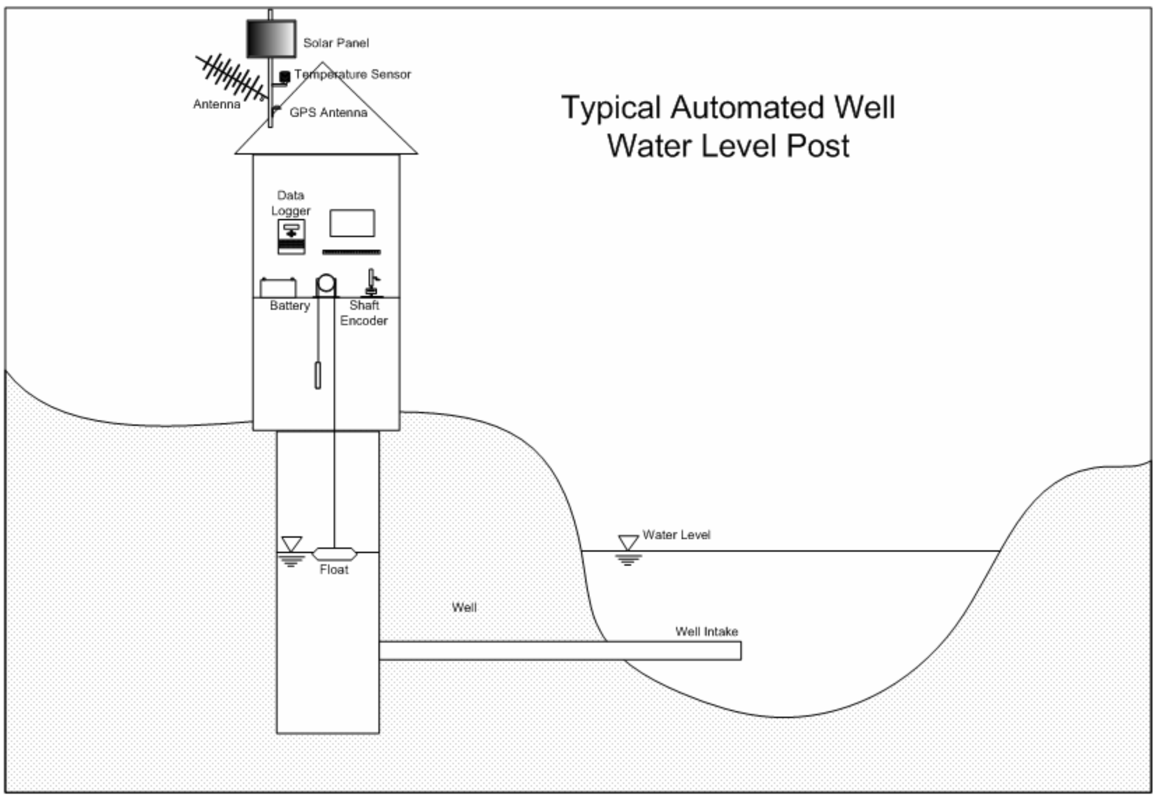


Figure 29: An example of a Shaft Encoder (Courtesy: WSC).

The use of Shaft Encoders (Figure 29 and 30) was a natural progression from the mechanical chart recorders. Similar to mechanical chart recorders a stilling well is required for Shaft Encoders. The existing float and pulley arrangement is removed from the mechanical recorder and is mounted directly to the shaft of the encoder. Depending upon the type of encoder it provides an output, representing an incremental change, based on the system resolution. As the float position changes with the 'stage", the encoder provides a positive or negative signal depending upon the direction of movement.

Figure 30: Thalimedes (Shaft Encoder) installed in 12" ABS. This site originally set up with Stevens A71 Chart Recorder. Thalimedes used to retrofit existing well and shelter.

There are generally two types of encoder used, "Incremental" and "Absolute".

> The Incremental encoders report only relative position, and as a result, are required to be powered continuously. Should the power be interrupted, the encoder loses its position and defaults back to zero. Due to the nature of the output, incremental encoders cannot be used on all data loggers.
>
> Absolute encoders differ in that each increment on the encoder has a unique value. As a result, an Absolute Encoder can be turned off between sampling intervals, and when re-powered it retains the direction and magnitude of change since the last reading.

Points to Consider: Encoders require a proper infrastructure to function properly. This includes a stilling well and possible an intake pipe. This may pose challenges if the well is required to work throughout the winter.

Submersible Pressure Sensors

Submersible Pressure Sensors (Figure 31) represent the largest segment of products for measuring surface and groundwater levels. Their popularity is due to a number of factors including ease of installation, small size, and low cost. As the name implies the system consists of a pressure transducer immersed in the water at a fixed depth. The sensor transmits an analogue or digital signal via underwater conductors back to the data logger In addition to the signal wires there in normally a vent tube as well. The vent tube allows the sensor to equilibrate itself to changes in barometric pressure. If the sensor did not do this then an increase or decrease in barometric pressure would be reflected in the recorded readings, creating another source of error.

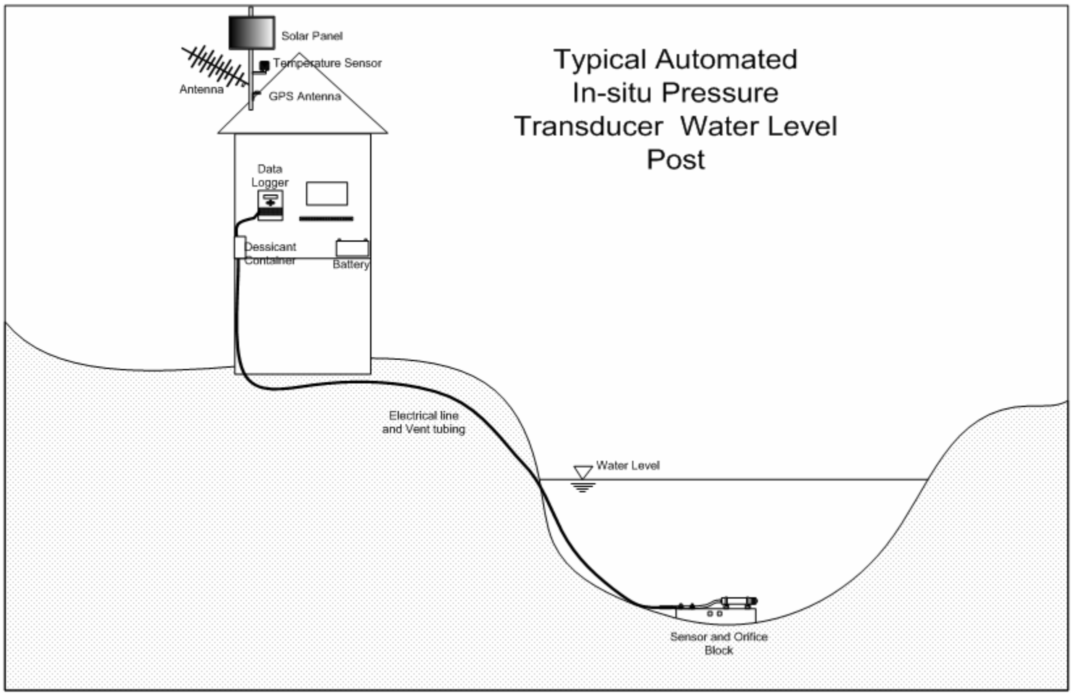


Figure 31: Thalimedes (Shaft Encoder) installed in 12” ABS. This site originally set up with Stevens A71 Chart Recorder. Thalimedes used to retrofit existing well and shelter.

Submersible analogue sensors can have accuracy as good as 0.1% of Full Scale Output (FSO), while digital sensors are available with accuracy’s of 0.02% FSO or better. The main advantage of the submersible sensor is that it is relatively inexpensive and easy to install. Some of the disadvantages include variances in accuracy (depending upon make and model). A pressure transducer inaccuracy is usually based on the following characteristics:

- Non-linearity - the deviation of the sensor’s signal curve from that of a straight line.
- Repeatability - the ability of the sensor to reproduce an output reading when subjected to identical pressures.
- Hysteresis - the difference in value for the same measured point when pressure is first increased, then decreased past the point.

In addition there are errors caused by sensor drift (especially analogue sensors), or sensor leakage where the electronics are damaged beyond repair and the sensor must be replaced. Digital submersible sensors offer high accuracy and excellent long-term stability, but usually at a substantial cost over their analogue counterparts.

Installation: The sensors must be properly installed. If not, the results will show an error. As with encoders, pressure sensors should be installed in a properly constructed stilling well. Also, the sensors should be mounted vertically, with the sensing diaphragm parallel with the stream flow or stilling well bottom. This ensures that the flow velocity does not become a component of the level measurement.

Points to Consider: Submersible sensors are easy to install but have some limitations. First, the sensor must be removed before the water freezes. Ice expands and can over pressurise the diaphragm, causing the sensor to fail or at least require recalibration at the factory. Second, pressure sensors require periodic adjustments to level datum because they drift with time. Third, the sensors must be removed if flooding is expected. If water enters the electronics via the vent tube, the sensor could be irreparably damaged.

Pressure Measurement (Bubbler) Sensors

Pressure Measurement (Bubbler) Sensor (Figure 32) is an extremely accurate digital sensor which is used to measure the gas pressure required to generate a bubble at the end of a submerged orifice line. The pressure required to create the bubble is proportional to the water head above the orifice. These "bubbler" gauges are similar to the submersible digital sensors, with the exception that they are typically mounted in a walk-in shelter along with the pressure source (nitrogen tank or battery compressor) and pressure regulator. Bubbler sensors are widely used by Water Survey of Canada as a means of measuring "stage" in areas where the installation of a stilling well would be impractical or extremely expensive. The main advantages of this type of sensor are 1) its lower cost compared to its submersible counterpart, and; 2) the fact that the only component in the water itself is the low-cost orifice line.

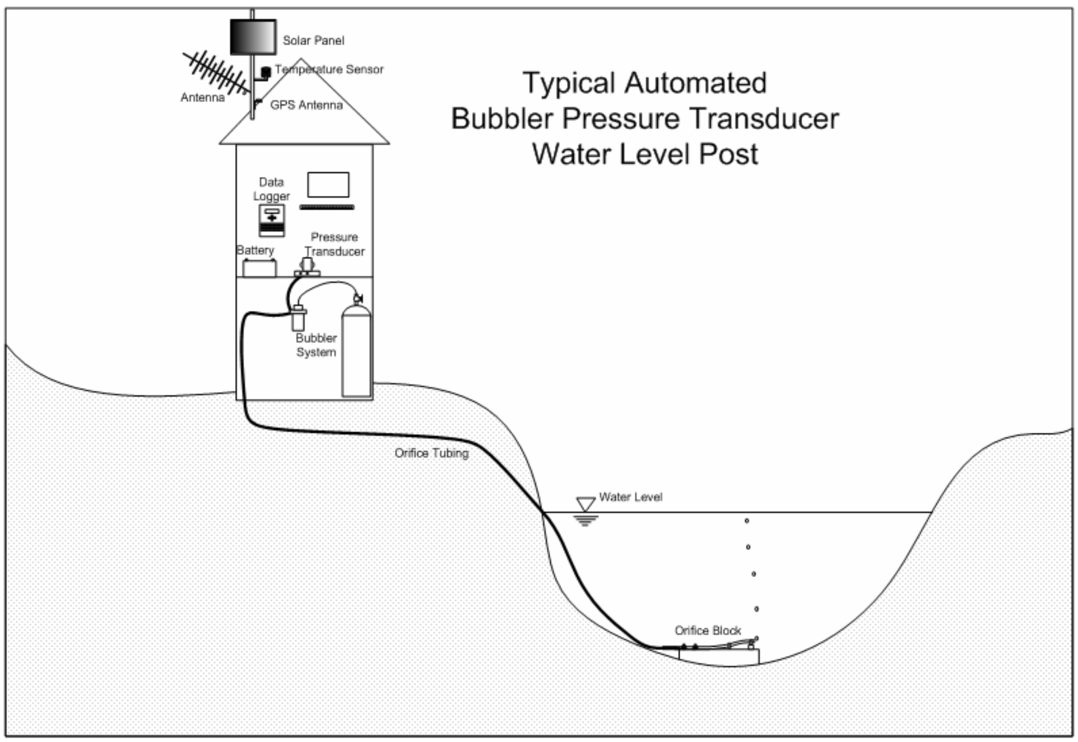


Figure 32: An example of a gas purge sensor (Courtesy: WSC).

Points to Consider: A stilling well is not needed but a shelter for the tank, control valves and sensor must be fabricated. Therefore, the total cost of this system is more expensive than encoders or pressure sensors. In addition, there are numerous mechanical connections required to route the gas. The use of proper hydraulic fittings of similar material constructions is highly recommended. The main disadvantage of this system is the requirement of a bulky pressure tank or external pressure source and loss of pressure due to leakage.

Ultrasonic and Radar Sensors

Ultrasonic Sensors (Figure 33) send out a series of sound waves, which travel through the air and strike a target (water surface). An echo is returned back to the sensor and the transit time taken to send the wave and return is related to the distance traveled. Ultrasonic and radar based sensors operate by transmitting a signal which in turn is reflected from the surface of the water. The transit time to send and receive this signal is in turn related to the distance travelled. Unlike pressure sensors or encoders, where a “snapshot” value is measured, Ultrasonic and Radar sensors can emit a series of signals in succession, which are then processed to provide an average value. The purpose of the series of signals is to smooth out the variance in the transit time that is caused by wave action.

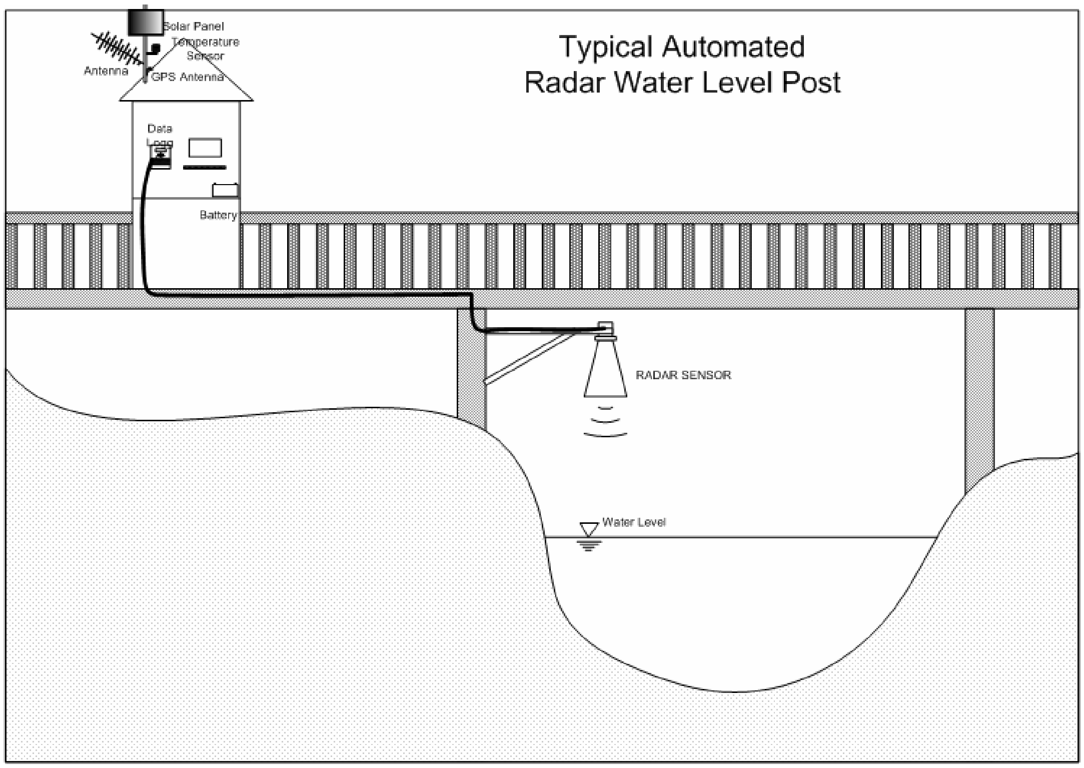


Figure 33: Examples of ultrasonic and radar sensors (Courtesy: WSC).

The main advantage of this sensor technology is that it is non-invasive; there is no physical contact with the media being measured and consequently relatively easy and inexpensive to install. In areas where flooding may destroy or move a conventional gauge station, an ultrasonic or radar sensor could be safely mounted above the high water mark. The main disadvantage of the ultrasonic sensor is that the sound wave can travel at different speeds depending upon the prevalent environmental conditions particularly temperature, thus affecting accuracy. Radar based sensors are considered a logical alternative to Ultrasonic sensor because radar signals are not affected by temperature. However radar based sensors can not be used in areas where ice forms. There is a change in the dielectric constant from water to ice that makes it difficult to determine how far into the water/ice column is the signal penetrating before being reflected.

Points to Consider: All sensors have a maximum range but only Ultrasonic and Radar sensors have a minimum range. This is because a minimum amount to time is needed to emit, receive and process a signal. Time is equal to distance and thus there is a minimum distance or zone, called the “blanking distance” in which no measurements can take place. Also, temperature varies in the air column through which the sonic wave travels and this will affect the accuracy.

Table 3: Summary information for the four main kinds of sensors.

Type of Sensor	Sensor location	Associated instrumen-tation	Advantages	Limitations
Shaft Encoder / Float Gauge Assembly	Stilling well only	• Analog • Digital • SDI-12 • Pulse	• Easy to upgrade paper chart recorder site with shaft encoder. • Accurate • Instrumentation inexpensive-can be offset by cost of well installation depending on size required.	• Float Gauge assembly is fragile. Should only be installed in a stilling well. • Must be protected from freezing. • May require large enclosure.
Bubbler System	In-stream	• Analog • Digital • SDI-12	• Accurate • Only the bubbler tube can be lost. • Good method for all-year deployment in freezing streams. • Stable - yearly calibration of pressure sensor OK	• Most expensive. • Heavy gas cylinders or expensive air pump required. • Larger enclosure required. • Bubbler tube can easily change position in-stream.
Submersible Pressure Transducer	In-stream or stilling well	• Analog • Digital • SDI-12	• Accurate • Less expensive than bubbler • Easy to install in-stream • Versatile • Stable - yearly calibration sufficient	• Risk of loss in-stream • Requires vented cable to datalogger. • Must not be allowed to freeze (in water). • Sensor must be kept moisture free.
Ultrasonic and Radar Sensor	From structure overhanging the water	• Analog • Digital	• Inexpensive • Easy to install	• Inaccurate when surface chop present • Must be temperature compensated

3.3 Stilling Wells

3.3.1 General

A stilling well is a vertical pipe-shaped enclosure placed vertically in or near the streambank. It is watertight, except for restricted access to the outside body of water. The purpose of the stilling well is to dampen water level fluctuation and protect the float sensor components. Figures 34 to 37 show various stilling wells and shelters.

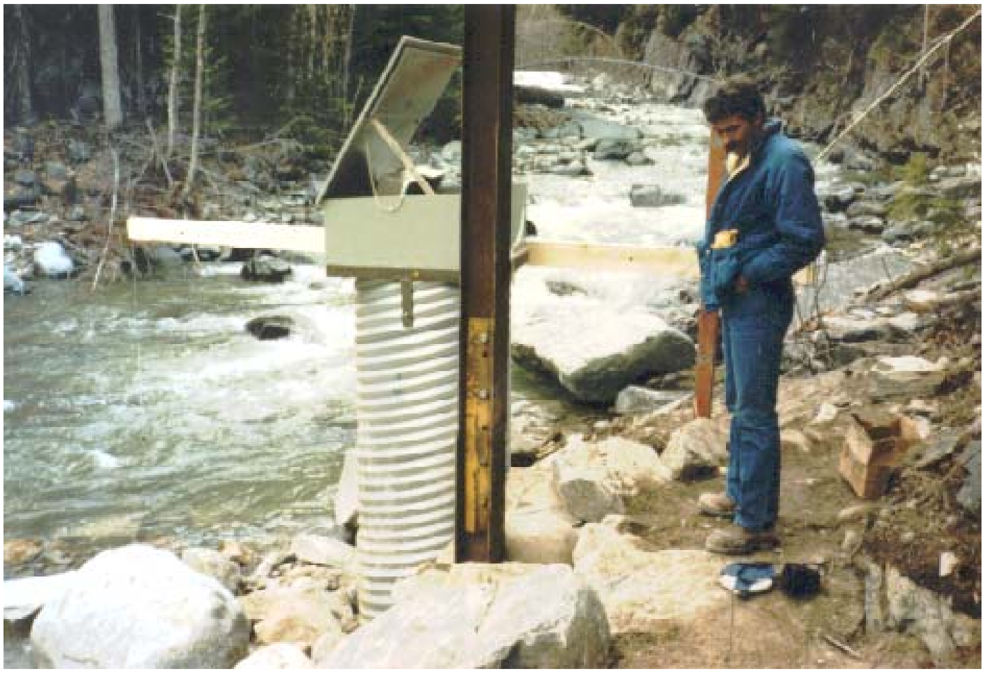


Figure 34: In-bank stilling well.

Site conditions and related equipment dictate the stilling well's construction materials and positioning. Proper design is required to meet the site's physical and climatic conditions, and to ensure constant passage of water flow. The size, shape, and materials for constructing a stilling well vary, but the well must be large enough to allow free and unobstructed movement of floats and counterweights. Space must be allowed for other components and equipment, such as flushing lines. The well is connected with the body of water by intake pipes made of steel or thick-walled plastic (in-bank installation), or simply by hole(s) drilled directly into the well. All stilling wells require screen-covered vent holes near the top to allow humidity to escape.

Intake pipes used for transferring the water level of the stream must be positioned level and at right angles to the direction of flow. The direction of the flow past the intake pipe may vary at different stream levels. If so, the effect of the flow velocity past the end of the intake pipe may cause drawdown or pileup of the water level in the stilling well. Drawdown causes the water level in the stilling well to be lower than that of the stream; pileup has the opposite effect. The drawdown or pileup of water in a stilling well can be reduced by attaching a static tube to the stream end of the intake pipe. A static tube is a short length of perforated pipe attached to an elbow on the end of the intake pipe and extended horizontally downstream. The end of the static tube is capped. Water enters or leaves through the perforations. The general arrangements of a stilling wells and intake pipes are shown in Figure 35.

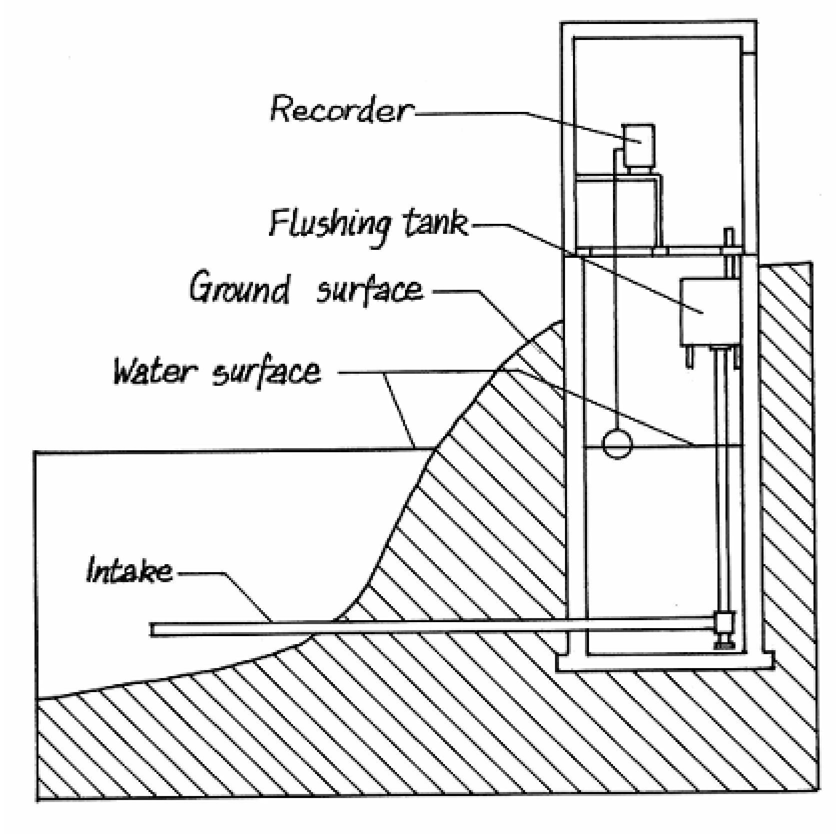


Figure 35: General structure of a stilling well with associated intake.

3.3.2 Shelters for Stilling Wells

Protecting instruments against varied and severe climate and operating conditions is very important. In addition to shielding the recording equipment, an instrument shelter protects the contents of the stilling well. Shelters are built of metal, wood, concrete, or reinforced plastics. Some locations may require certain design standards and construction materials to conform with site surroundings.

Shelters should be built as securely as practicable and designed to discourage unauthorised entry. Posting a sign on the entry door that identifies the instrumentation, its owner, and its role in a water management program may help deter some visitors from trying to enter or damage the shelter. Safety of operators must also be considered. Shelters that are elevated above ground level must have safe stairs and/or walkways to the entry door.

Shelters are generally classified by size and utility. Which type to construct depends on expected station life, instrumentation, importance, and security concerns. If the gauging station will be operated in winter, the shelter should be winterized to help control heat and condensation, and to protect the equipment. All shelters must be watertight.

3.3.2.1 Types of Shelters

Stilling wells shelters are generally two types: look-in or walk-in. The look-in shelter (Figure 36) is the most common, especially for smaller streams; it is mounted on top of a small-diameter stilling well. Although it can vary in size and shape, usually it measures about 0.8 x 0.8 x 0.6 m high, with a hinged front, and lid for entry. The lid is sloped to shed rain and snow. The base, fastened flush with the well top, has a removable section, or a semi-circular opening to accommodate the float lines, which permits visual access into the well and access to the fasteners connecting the shelter to the stilling well pipe. Shelters, while secure in the closed position, must be easily removable in order to clear ice or install frost tubes. These shelters must be ventilated near the top. The vent opening should be fitted with an insect barrier.

Figure 36: Look-in shelter.

Walk-in shelters (Figure 37) are the most convenient to work with. The average size is 1.6 x 1.6 x 2.2 m high with a standard-size entry door. A portion of the floor is removable for access to the stilling well. This trap door should be inspected for safety on each visit. Never leave it open, nor the well unprotected under any circumstances. Walk-in shelters should be solidly positioned over top of the stilling well so that the floor forms a secure cover for the stilling well. Inside the shelter, a solid, level bench for mounting the recorder is positioned about 1.0 m above the stilling well. Positioning the recorder at this level makes it possible to access the well without interfering with the free movement of the float and float wire. Holes are drilled through the bench top and floor where necessary to accommodate the float wire. A trap door in the shelter floor provides safe, convenient access to the ladder within the stilling well. The flushing tank or portable pump connectors with connecting riser pipes and shut-off valve control rods are usually located above floor level and opposite the recorder mounting bench. Adequate ventilation is important.

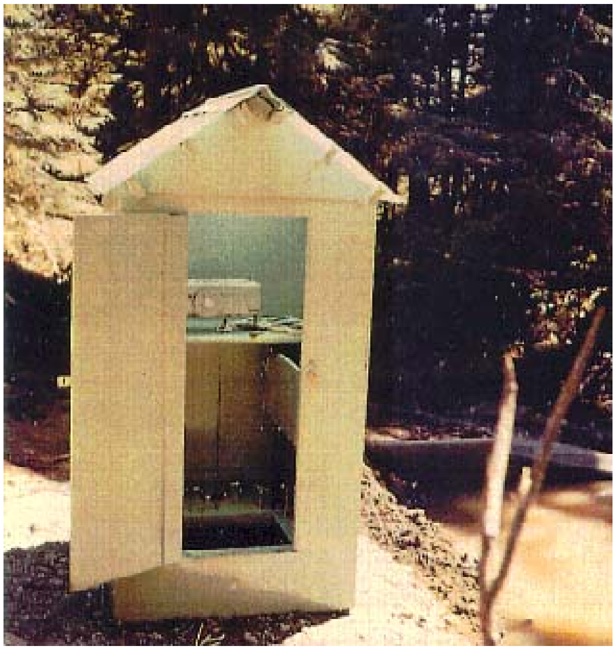


Figure 37: Walk-in shelter.

3.3.3 Operation and Maintenance of Stilling Wells

The operation of stilling wells is affected by seasonal changes, runoff patterns, and weather. Work performed on or around stilling wells is subject to safe working conditions. Operating staff should look for and correct any unsafe conditions before beginning hydrometric work.

3.3.3.1 Open Water Season

Open water season is that part of the year when no ice is present on the watercourse. Each time the technician visits the station, the shelter and site must be inspected for any potential problems such as damaged flooring, broken or bent intake pipes, inoperative shutoff valves, and insecure ladders. Any observed faults should be repaired immediately if possible, or scheduled for repair at the earliest opportunity. Check for obstructions in the well that may impede the float, float line, or counter weight travel.

Check the well for silt deposition by sounding with a weighted tape; compare this measurement to the original clean depth of the well.

Promptly remove excessive silt deposits by using a pump and discharge hose to place the accumulated silt into a suspension and to build the water head inside the well. Discharge the water head out through the intake pipes to remove the suspended silt. Continue flushing until the plume of silt being discharged through the intakes is no longer visible. Stilling well system accuracy and reliability depend upon the free flow of water through the intakes.

Flush all intakes immediately before, during and immediately following seasonal high stage. For the rest of the season, flush the intakes during each station visit, or as required. Frequent flushing may be necessary where silting is an obvious problem.

Flush all intakes prior to obtaining a discharge measurement. Make sure the intake valves are open after flushing and before you leave the site. Check to verify that the float, float lines and counter-weight line are not tangled together and see that they are free from obstructions. Also ensure that the float tape or line has not been knocked out of position on the float pulley.

3.3.3.2 Seasonal Operation

The open water season described above excludes ice conditions normally associated with spring start-up and fall shut-down.

The operational 'open water' period for many hydrometric stations is April 1st to October 31st, whether ice is present on the watercourse or not. However, before and after this period the hydrometric operator must undertake both pre-season and post-season activities.

Pre-season Operations

Pre-season activities involve clearing ice from the stilling well, repairing winter damage, and activating recorders. Many stilling wells are constructed with 12-inch-diameter (305-mm) ABS water pipe, sealed at the bottom with a glued-on pipe cap. Ice removal from these relatively small diameter wells can prove quite a challenge even when the ice is no longer attached to the wall of the pipe. Preparations for ice removal must take place before freeze-up in the fall (see below).

If ice is frozen to the pipe wall, start-up can be delayed; however water can be added to the top to speed melting. The judicious application of heat to warm the pipe sufficiently to detach the ice block is suggested, if the stream ice is beginning to break up. If the ice block is freed from the sides of the stilling well, it may be removed by lifting, although it may weigh up to 40 kg. The shelter must be removed from the stilling well first.

Post-season Operations

In all locations subject to winter freeze-up, ice may present problems if it occurs before the end of the operating season. Regardless of the operational period, all recording stations require some degree of winterization if they are to be easily reactivated on time in the spring. Some preventive measures taken at the end of the season will make the following season start-up, much easier. The usual problem found on arrival at station start-up is a large block of ice remaining in the stilling well. If the float has been left activated, it will almost certainly be stuck in the ice and will have to be freed before the ice can be removed. The following shut-down procedures are recommended at the end of the season. Remove the float, counterweight and float lines (carefully coil and secure lines to avoid kinking) from the well.

Winter Operation

Water which freezes in the stilling well and/or intakes during the winter period, presents serious problems. Continuous operations in cases where there is no ice free zone in the stream are extremely difficult.

Ice Formation: If the intake pipes are below frost level and the end of the lowest intake does not become encased in ice, the stilling well can continue to operate. Formation of ice within the stilling well can be prevented or controlled with an insulated frost floor, heaters or an oil cylinder (see *Frost Tubes* for details).

Fully exposed metal wells present the greatest problem. At freezing temperatures, ice forms quickly around the inside wall of the well and on the inside water surface which traps the float. Further freezing produces a cylindrical plug of ice.

Ice Effects on Floats: Warming temperatures may free the ice plug, but if the float is trapped within it, records of the response to water level changes will be inaccurate. For an accurate record, the technician must free the float and remove the ice from the well.

Severe damage to the water level recorder can occur if both the float and counterweight become trapped in an ice plug. If the water level below the ice plug recedes, the weight of the ice will place extreme stress on the float pulley shaft and float wire above.

Frost Floor: A frost floor is an insulated sub-floor within the stilling well positioned below the frost line of the surrounding ground. The cold air spilling into the well is partially confined to the area above the frost floor, while the warmer air from below can not escape easily. This warmth retards the formation of ice within the well. Holes cut in the frost floor allow the float and counterweight line to pass through.

Wells in the stream bank are normally encased with back-filled earth, which provides some insulation. However, ice plugs can still form in the well if cold air spills into it. A frost floor may be enough to stop ice from forming as long as the water level remains below the frost level of the surrounding soil.

Frost Tubes: Frost tubes have proven quite effective in overcoming ice in both exposed metal and earth-protected stilling wells. A frost tube is an open-ended cylinder, usually 25 cm in diameter, fastened vertically inside the stilling well. The bottom end is elevated slightly above the well bottom; the top end extends to the well top, or to an elevation above the maximum expected winter water level.

At stations where 305 mm ABS stilling wells have been installed, the well becomes the frost tube and a quantity of oil sufficient to extend below the frost line or ice thickness is poured into it. A 10cm column of oil in this diameter of pipe will require 7.3 litres of oil. To prepare a frost tube, a non-toxic oil is poured into the top of the cylinder. The column of oil that forms above the water forces the water surface in the cylinder below the surrounding water level in the stilling well. The recorder float is then positioned in the cylinder where it will respond to the variation in the oil surface level. Since the oil surface level stands higher than the true water level, a compensating correction must be made to the record. The degree of correction will be proportional to the amount and specific gravity of the added oil.

To quantify this initial correction, reinstall the float assembly and record data logger reading and reference gauge. Remove the float from the tube before pouring the oil. Reinstall the float, and repeat readings as above. Differences in the relationship between data logger readings and outside gauge are the correction for the quantity of oil and its specific gravity. Set the recorder to the outside gauge for this and subsequent station visits.

Oil Specification: An acceptable oil is ‘Esso Bayol 35M’ with a specific gravity of 0.815. This oil is tasteless, colourless, odourless, and is used in food processing. Do not let the oil spill from the frost tube into the stilling well, because it causes bacteria to grow on the water surface within the well. Non-toxic oil must be used. Kerosene and other petroleum oils must not be used for environmental reasons.

Discontinue using the frost tube at spring break-up time. If the cylinder is not designed and installed as a permanent fixture, the oil and cylinder must be removed from the stilling well before the rising water level forces the oil over top of the tube. Frost tubes do not produce heat nor do they require any heat to be effective.

Spring Operations

Prior to spring break-up, stilling wells must be cleared of winter operations fixtures and any ice remaining in the well. Where the intakes are blocked with ice, the use of a steam generator may be needed to remove ice from the intakes and the well.

Inspect the well for possible structural damage that may have occurred during the winter season. Check especially for vertical movement caused by frost heave. If signs of frost heave are evident, give special attention to the intake pipes, as they may be damaged at the point of entry to the well. Inspect the outer ends of the intakes and remove any attached ice from them.

Clean deposited silt from the stilling well bottom. Remember, in the next few months water will carry most of the annual silt deposit to the well. Flush all intake pipes and make sure they are free and clear of obstruction. When flushing the intakes, observe the discharge from the upper intakes. Finally be sure the intake valves are open before leaving the site.

In general, it is essential that the stilling well and the intakes are in good working order if the well is to provide accurate records through the upcoming spring runoff season. Corrective action for potential problems is far more difficult during spring when the well is full and the intakes are all under water. Under these conditions, repairs or maintenance work may not be possible. Many water level records are lost as a result of improper preparations prior to spring. Ensure that the float and the suspension lines move freely and that they are clear of any possible obstruction.

Spring Runoff

During high flows the water surface in the well appears to be excessively turbulent. To dampen the oscillation, close one of the upper intake valves and look for improvement. Slowly open the valve until you achieve a tolerable level of disturbance. For in-stream installations, when the water level exceeds the elevation of the top vent holes, block the holes to avoid further velocity turbulence. Note these actions on the station record or log.

If the water level should exceed the upper limit of float travel in the well, cut a hole in the floor to allow passage of the float. This measure will provide additional distance for float travel which will in turn add to record collection. Manually pull the float through the hole in the floor to its upper limit of travel. Check to see if the counterweight hits the well bottom. If it does, shorten the float line proportionately. Remove all buoyant material from the floor to prevent it from obstructing the float line or restricting the float's return passage through the hole when the water level recedes.

Inspect the streambank for possible cave-in or excessive erosion. If the stilling well is endangered, arrange for emergency corrective action. Until proper corrective actions can be taken, the stilling well should be secured with a strong cable which can be anchored to inshore trees or other stable objects. This will prevent tilting or loss of the well.

3.4 Documentation of Station Water Level

Accurate documentation of the information is extremely important. It establishes the identity of the location and the base values for future evaluation, and it ensures accurate transfer of the information from the field to the office. The information is gathered for various reasons: to route the original data in a different direction, to cross-reference the accuracy of the documentation, or to provide convenient access to the information on the original record. For proper documentation of gauge readings and other information, the following should be considered:

- Documentation must be complete and legible;
- Always complete the documentation immediately following the observations;
- Do <u>not</u> depend on memory; never wait for a more convenient time or location.

The Water Stage Recorder-Station Log (RISC form, RISC HYD-04), Figure 38 (Blank forms are included in Appendix III), posted within the instrument shelter should be used for systematically recording the gauge reading, time and date and other information on this form. [**Note:** See subsection "Gauge and Water-Level Recorder" in section 4.2.4.3 for details]

Forms can also be completed electronically on a laptop computer. This form also provides a ready reference to the operating history of the station. The "Remarks" column shows the method used for past measurements, and indicates a safe limit of stage for stream wading. Extra information can always be listed on these forms if necessary. RISC HYD-04 form should be updated before leaving the site.

BRITISH COLUMBIA

RISC HYD-04: Water Stage Recorder-Station Log

Station Operation Agency/Firm: ***Water Stewardship Inc*** EMS Id[1]: ***E123456***

Station Name: ***Ayum Creek Near Mouth*** Station No. ***1AHA040*** (if any) Project No. ***99HYD040*** (If any e.g., FIA)

Date (yyyy/mm/dd)	Arrival					Departure					Initials	Remarks on Stage Observations & Procedure, Metering, Level Check, etc.
	Time, PST (24hh:mm)		Gauge Height/Stage (m)			Time, PST (24hh:mm)		Gauge Height/Stage (m)				
	Watch	Recorder/ Data Logger	Ref. Gauge	Inside Gauge	Recorder	Watch	Recorder/ Data Logger	Ref. Gauge	Inside Gauge	Recorder		
2006/11/12	11:12	11:12	0.799		0.799	12:45	12:45	0.789		0.789	aa	2 flow measurements-max wading
2006/12/18	12:15	12:15	1.056		1.052	13:30	13:30	1.052		1.052	aa	
2007/01/14	11:15	11:15	1.430		1.430	15:27	15.27	1.214		1.214	bb	2 high flow measurements @ bridge
2007/02/24	12:00	11:58	0.962		0.957	12:40	12:40	0.962		0.962	bb	Battery replaced
2007/03/29	13:10	13:10	0.765		0.765	14:22	14:22	0.759		0.759	aa	Gauge level check-ok
2007/04/29	11:09	11:09	0.549		0.249	12:15	12:15	0.547		0.547	bb	Float cable replaced
2007/06/01	13:11	13:11	0.333		0.333	14:00	14:00	0.333		0.333	bb	1 flow measurement
2007/06/28	12:00	12:00	0.245		0.245	13:30	13:30	0.245		0.245	bb	1 flow measurement

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Figure 38: Example of RISC HYD-04: Water Stage Recorder-Station Log.

3.5 Power Supply

Electronic stream monitoring equipment generally requires a 12V power supply. There are three commonly used power options at a stream monitoring site.

- Use of an existing on-site 110 AC power supply with a 12V converter.

  Maintain a backup power supply at such a site that instantly "takes over" during power failures.

- Operate the site with battery(s) only.

  If the site is low-power, a heavy 12V RV type or deep-cycle battery will likely operate the site for many months between charges. The equipment manufacturer should supply the power requirements of their equipment, and estimates of how long such a battery will last through a series of temperature ranges. Some newer data logger/sensor equipment can operate for extended periods using only “C” type 1.5V batteries.

- Use solar panels and storage battery(s).

  A solar panel is usually necessary at sites where more "power hungry" data transmission components are required. Solar panels are available in different sizes. There are four points to consider when using solar power.

  a) Add up the power requirements of all system electronics. Provide this figure to the solar panel supplier or equipment manufacturer – they can calculate the size of panel required.

  b) At the site, ensure that the panel will have an unobstructed view of the sun through all months that the installation must operate. A mast may be required near the enclosure to hold the solar panel for maximum exposure to the sun.

  c) For the system battery, use only heavy-duty deep-cycle 12V storage batteries. They are more expensive, but are designed for this type of usage.

  d) A solar system must use a high quality voltage regulator that also monitors the temperature of the storage battery. The failure to use these will almost certainly result in premature battery failure due to over/under charging.

3.6 Data Transmission Components

Often hydrometric monitoring sites are at remote locations. Therefore, transmission components can be installed, providing the means to have the data logged on site and periodically transmitted back to the user’s PC. Where telemetry is not available or affordable, direct download of data into a portable storage device can be carried out during routine site visit.

There are a number of technologies available to provide site telemetry:

- Telephone/Modem

  If the site has a land-line telephone available, it is possible to install a modem on site and transmit data back to the user’s PC equipped with modem and operating software. The data logger chosen for the site must be able to communicate via modem.

- Cellular Telephone/Modem

  The site must have medium to strong cellular coverage. Different types of cellular antenna can be used to compensate for lower strength signals.

- Radio/ Modem

The site must be in range of a base radio near the user's PC or within range of a radio repeater system. Once installed, this method is inexpensive, as there is no further expense for transmission time. However, usually a dedicated frequency is required, or some means of ensuring radio silence during data transmissions.

- Satellite

  There are number of different satellite technologies available including but not limited to: GOES, MSAT, Iridium. Each has "pros and cons" and the technology is undergoing continuous changes.

Chapter 4: Discharge Measurement Procedures

4.1 Introduction

Discharge measurements can be carried out using several methods depending on the size and nature of the stream. The procedures that are commonly used are the area-velocity method, the rated structure methods (flumes and weirs), and the volumetric method. Current meter method can be used for both small and large streams, discharge measurement structures can be scaled to fit small to medium streams, and volumetric methods are normally used for smaller streams. Another procedure, the tracer dilution method is available for use in highly turbulent streams where the other procedures are problematic. In this chapter, the equipment, procedures, and documentation for discharge measurements using current meters and rated structures are described in detail.

4.2 Discharge Measurement using Current Meters

4.2.1 General

The area-velocity method, commonly known as current meter method is based on determining the mean discharge using the velocity and the cross-sectional area. If the mean streamflow velocity (V) is normal to the direction of flow, and the cross-sectional area (A) of flow is known, then the product of these variables determines the stream discharge (Q); that is $Q=V.A$.

The hydrometric operator measures the stream depth and velocity at selected intervals across a stream either by wading, cableway, bridge, or in a boat. The water depth and the positions across the stream are obtained using a rod for depth and a survey tape for distance.. A current meter is used to measure the stream velocity at each selected interval.

The objective of this section is to review the techniques and instruments used to measure stream velocity and cross-sectional area, to explain the calculations required to obtain stream discharge, and to outline the factors affecting the accuracy of the discharge measurements.

4.2.2 Current Meters

An ideal current meter should respond instantly and consistently to any changes in water velocity. Also, the meter should be durable, easily maintained, and simple to use under a variety of environmental conditions. Consistent meter performance depends on the design and the manufacturing tolerance.

There are different types of current meter available on the market. They are grouped into three major categories: mechanical current meters, electromagnetic current meters, and the more recently introduced acoustic Doppler velocity meters.

4.2.2.1 Mechanical Current Meters

All mechanical-current meters measure velocity by translating linear motion into angular motion. Two common types of current meters are used in British Columbia: the vertical-axis meter, and the horizontal-axis meter .With either meter, the rate of rotation of the rotor or propeller is used to determine the velocity of the water at the point where the current meter is set. Before the current meter is used, the relationship between the rate of rotation and the velocity of the water is established in a towing tank.

Three models of vertical axis meters are in general use in Canada: the Price Type AA meter, the WSC winter meter, and the Pygmy meter. The Price Type AA meter (Figures 39) is the most common vertical shaft meter and is often considered the standard for discharge measurement. It has been subjected to extensive research and experimentation and shown to be well suited to a wide variety of field conditions. The Price Type AA is the principal meter used by the WSC and many other agencies to determine discharge.

Horizontal axis meters are capable of very accurate flow measurement in areas of local turbulence. The component effect of the rotors compensates for angular flow in both the horizontal and vertical planes, and the orientation of the rotor provides for a balanced translation of the linear motion when measuring near the vertical faces at either edge of a channel. All models use the magnetic reed switch to generate the rotational pulse count, thus avoiding the variable frictional component. A small horizontal axis current meter (Figure 40) continues to be the principle instrument used by Provincial agencies in British Columbia to measure small shallow streams, while the larger models are preferred for use with bank-controlled cableways and bridge rods.

Detailed descriptions of various types of mechanical current meters, their operation and maintenance are provided in Appendix II.

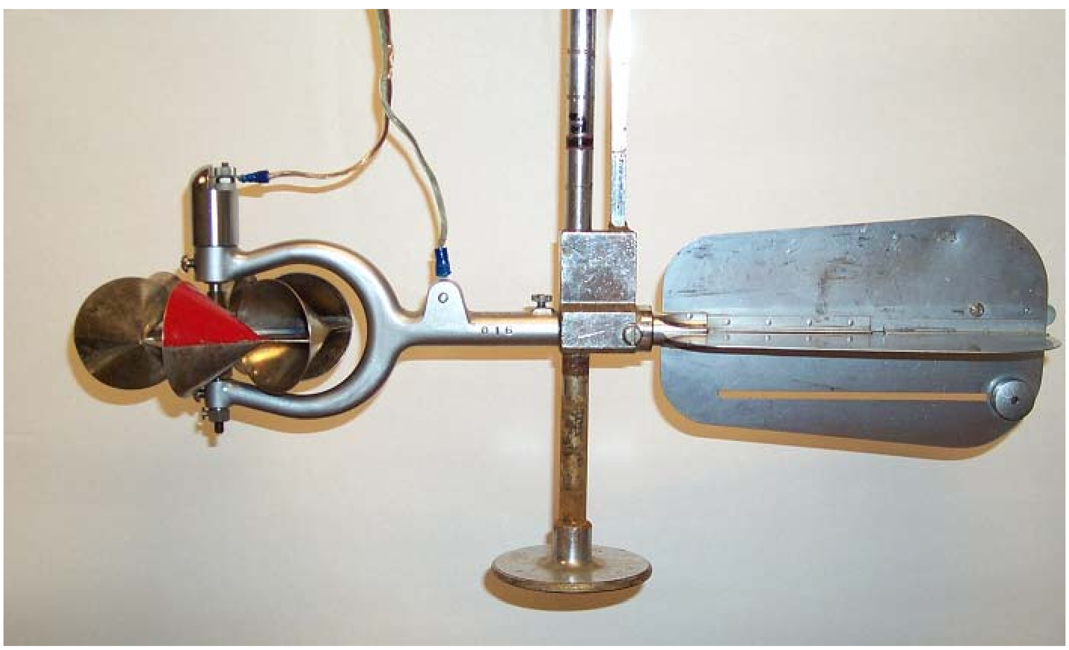


Figure 39: Price Type (622) AA meter (Vertical Axis Meter) .

Figure 40: OTT C2 Current Meter (Horizontal Axis Meter) .

4.2.2.2 Electromagnetic Current Meter

An electromagnetic current meter (Figure 41) measures velocity using Faraday's Law, which states that a conductor (water) moving in a magnetic field (generated by the current meter probe) produces a voltage that varies linearly with the flow velocity. Electrodes in the probe detect the voltages generated by the flowing water and convert the voltage into velocity readings for numeric display. As these meters have no moving parts they are not subject to many of the operational and maintenance problems associated with mechanical current meters. The electromagnetic flow sensors are designed for the portable measurement of very low flow velocities and for site conditions where the conventional current meters can no longer be used: areas with large numbers of aquatic plants, contaminated water, shallow water, and low velocity water. Their use is generally confined to fish habitat studies.

Figure 41: OTT Nautilus C 2000 Electromagnetic Flow Sensor (0 – 2.5m/s).

4.2.2.3 Acoustic Doppler Velocity Meter

Acoustic flow meters measure the water velocity using acoustic signals and combine the results with a stage measurement to calculate the discharge. In general, mechanical current meters were the standard in collecting river discharge measurements. However, recent development of acoustic doppler technologies for use in discharge measurements provides viable alternatives to mechanical meters.

A hand held Acoustic Doppler Velocity (ADV) meter (Figure 42) is an example of an acoustic device developed to measure water velocity in two or three dimensions. It uses bi-static (separate transmitting and receiving) transducers to measure either two or three dimensional flow in a 0.25cc sample volume located 10cm from the probe. A transducer transmits a pulse to the sample volume and the acoustic signal is reflected back by particles suspended in the water to the receiving transducers.

In comparison to mechanical cup meters, the ADV meter offers advantages such as a wider velocity range, measurement in more shallow water, and no need for recalibration. The acoustic Doppler velocity meter has been designed to allow a technologist trained to make conventional wading measurements using a mechanical cup meter to quickly adapt to the use of the probe and accompanying hand-held interface to produce discharge estimates based on the area-velocity method. The instrument could potentially offer increased data quality under very low flow conditions and reduced operational costs over the life cycle of the instrument. However, acoustic meters can be affected by both high and very low levels of suspended solids or entrained air and thus site selection is important. United States Geological Survey presently is using this technology for their routine discharge measurements while Water Survey of Canada is actively considering using this technology.

Figure 42: FlowTracker (0.001 – 4.0 m/s) (Courtesy: SonTek/YSI) .

4.2.3 Other Equipment and Assemblies

The current meters are attached to rods and depending on the water depth weights with handlines and hangers may be required to hold the meter in position reels may be needed to deploy and return the current meters. The use of this accessory equipment is outlined below.

4.2.3.1 Rods

Standard (Conventional) Wading Rods

A conventional wading rod is an option available with all Price current meters. It usually consists of four ~13 mm diameter graduated rods that assemble to make up a rod 2.44 m long. The length of these rods can be extended by ordering additional sections for use in large culverts or low bridges. An adjustable sliding support attached to the rod holds the meter and meter tailpiece in place. Electrical connections are provided for hook-up to headsets or counters. To adjust of the depth of observation setting, the rod must be raised from the streambed.

European and Australian manufacturers provide three-piece 9 mm diameter graduated rods with the small horizontal current meters. The top section of the rod is drilled to accept the negative plug from the counter. For the larger model meters such as the OSS B1, and the OTT C31 and C5, a 20mm diameter conventional rod is provided. The current meter can be clamped directly on this diameter of rod while adapters may be supplied to accept Price AA and small current meters such as the OSS PC1 or the OTT C2. The rod is supplied in 1m sections, which are graduated in centimetres and numbered in decimetres. A suitable length of connector cable(s) to match the meters is needed. A meter relocating device for this rod is described later in this section.

Top Setting Wading Rods

Top setting rods (Figure 43) are designed to securely position Price type AA or Pygmy current meter at any desired depth while the hydrometric operator wades the stream. Adapters for the smaller horizontal propeller meters are available from the manufacturer. The design incorporates a graduated stainless steel hexagonal rod and a parallel round aluminum rod (earlier versions are round and square respectively), connected by a cast aluminum handle. The current meter and tailfins are attached to a sliding support on the base of the aluminum rod which is allowed to slide vertically for rapid positioning of the meter. A vernier on the handle permits automatic setting of the meter to any desired depth i.e., 0.6, 0.2 or 0.8 depth (Table 4).

After the wading rod is placed into a stream and the water depth is read from the graduated hexagonal (round) rod, the vernier is used to position the current meter to the desired depth. To set the 0.2 depth position on the rod, simply double the value of the observed depth. Determine the 0.8 depth position by setting the value of one-half the observed depth on the rod. For example, if the observed depth is 1.0 m then to get 0.2 depth, set 2.0 on the rod and for the 0.8 depth, set 0.50 on the rod.

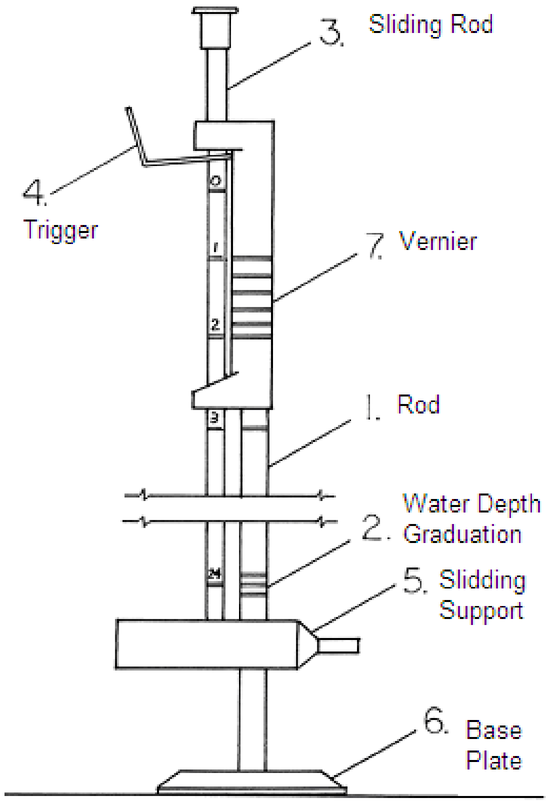


Figure 43: Components of top setting wading rod.

Table 4: Vernier settings for top setting rod.

Vernier setting	Actual current meter position
Observed water depth	0.6 depth from water surface or 0.4 depth up from streambed
Twice observed water depth	0.2 depth from water surface or 0.8 depth up from streambed
Half observed water depth	0.8 depth from water surface or 0.2 depth up from streambed

Bridge Rods with Relocating Device

The 20mm rods described in Section 4.2.3.1 can be supplied in 1m sections to a maximum practical length of 7m with sequentially number graduations. The OSS B1 and OTT C31 can be directly attached to this rod. Other meters may be attached using a variety of available clamping adapters; however, changing the placement of the meter to obtain the correct depth of observation can be awkward and exposes the meter to damage at sites where a long rod is required. To avoid these problems a relocating device should be employed (Figure II-7 in Appendix II).

The manufacturers of the OTT and OSS current meters provide an assembly that gives top setting capability to a 20mm rod of any length. The assembly consists of two or more 1m sections of tube with locking connectors that fit over the 20mm rod, providing an attachment point for the current meters. The use of the relocating device offers the advantage that the current meter can be positioned along the vertical in the measuring point without taking the equipment out of the water. The device, designed primarily for use with the B1, C31, and C5 meters, can also accommodate small current meters such as the PC1 and the C2, as well as Price meters. Adapters are required.

4.2.3.2 Handlines, Hangers, and Weights

The handline (Figure 44) provides a simple and effective method for suspending a meter and weight assembly and is an alternative to the bridge rod. The handline requires hangers and weights (Figure 45) to counteract the effects of moving water.

The handline is lightweight, compact, and easy to operate. These features make it particularly useful for obtaining measurements at remote sites. The hydrometric operator normally uses the handline to meter from footbridges and on ice cover. However, the handline is also a useful substitute when regular equipment malfunctions. The factors that limit its use in some cases are high velocities, excessive depths, and heavy weights.

Most current meter suppliers offer handline kits for use with the type of meter specified. The kits supplied for use with propeller meters usually include a weight of about 5-10 kg with matching hanger and pins. Meter calibration varies with weight size and type and position of the meter on hanger; the user must ensure that the correct meter rating is used.

Figure 44: Handline.

A handline can be made from 15 m or less of 16 gauge cabtire electrical cord. The hangline has a Cinch-Jones plug at one end and a cable thimble at the other with a clevis-type connector fitted to the thimble. The cord is marked at 0.1m intervals with strips of adhesive tape. The markings can be accomplished in the following manner: one strip for 0.1m marks, two strips for 0.5m marks and three strips to denote 1m intervals.

Another way to make a handline is to spiral wrap a length of 1/16 inch galvanised aircraft cable with 16 or 18 gauge insulated automotive wire. The spiral wrap ensures that the aircraft cable carries the full load of the meter and weight assembly. The entire length of the wire and cable is then double wrapped with a cloth type friction tape. The aircraft cable is secured to a clevis-type connector and the automotive wire is joined to the meter lead. The weight hanger and galvanised cable function as the return conductor.

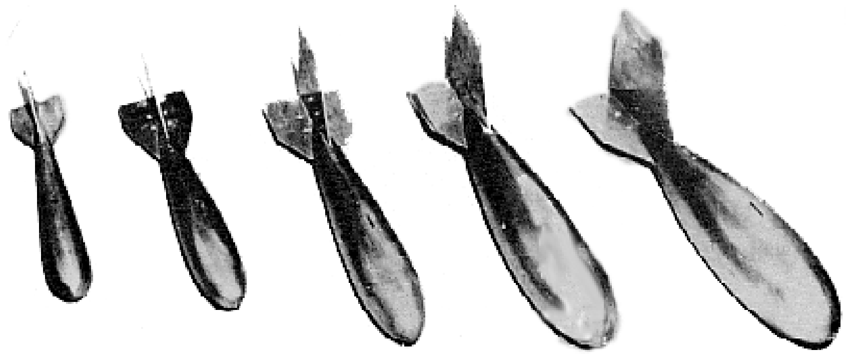


Figure 45: Columbus weights.

A handline can also be made using Kevlar line instead of aircraft cable. However, because Kevlar is a non-conductor, two-conductor automotive wire must be used to transmit the electrical signal.

4.2.3.3 Reels

The American-made A55 sounding reel and a similar Australian model (Figure 46) are light-duty sounding reels with a maximum load capacity of 45 kg. The reels are well suited for use in streams of low-to-moderate water velocity where cable length need not exceed 24 m. Reels can be utilized in a variety of situations such as bridge and boat boards (Figure 54), bridge cranes, and cable cars. The meter pulses are transmitted by the two conductors Ellsworth suspension cable through an electrical brush arrangement to the reel terminals. A two-position handle provides sufficient leverage for handling loads up to 45 kg, and the spring ratchet stop provides positive locking of the reel at any desired depth. Digital or analogue depth counters display depth.

Figure 46: San sounding reel, made in Australia.

4.2.4 Pre-Measurement Activities

4.2.4.1 Field Data Book and Forms

It is important that the hydrometric operator establish a system for recording on-site information. This is usually in the form of a field data book. All pertinent notes and information should be well organized in the field data book to facilitate planning, scheduling, decision making, equipment management, and overall record keeping.

The actual organization of the field data book is up to the individual, but it should be logically organized and kept up to date at all times. If for any reason hydrometric operator can not undertake or complete the field work, the field data book should give colleagues a clear understanding of the design, function, and history of the station.

The field data book should contain the following information for each gauging station.

- Form RISC HYD-01, Description of Hydrometric Station.
- Gauge Level Field Notes
- Form RISC HYD-02, History of Gauge Level.
- Discharge Measurement Field Form –this form is also available as an excel spreadsheet which calculates the velocity-area discharge from measurements carried out by the operator. Copies of this program are available from the Ministry of Environment website. Calculated values can be used to populate RISC HYD-03, Summary of Discharge Measurements.
- Form RISC HYD-03, Summary of Discharge Measurements.
- Form RISC HYD-04, Water Stage Recorder - Station Log.
- Form RISC HYD-05, Stage-Discharge Rating Curve and Table (including Rating Curve))
- Form RISC HYD-06, Station Analysis for the Period.
- Special instructions regarding equipment, maintenance, techniques, conditions, etc.
- Names of field staff, and contact information.

Appendix III at the end of this manual contains blank forms.

4.2.4.2 Before Departing for the Field

Before departing on a field trip to gauging stations, there are duties that the hydrometric operator should complete.

- Review the information and notes from the previous field visits in the field data book.
- Address the problems that were noted on previous field trips, and be prepared to handle them if they come up again.
- Assemble any equipment that might be needed for different possible stream conditions - high, medium, or low flows..
- Check and test all of the equipment to ensure that it is functioning correctly.
- Charge all equipment and ensure backup supply of batteries for data loggers, counters, etc.
- Check the current meter calibration and make sure that the calibration is still valid to achieve grade A, B or C data under RISC hydrometric standard
- Check the field verification status of the current meter to confirm the meter accuracy using a traceable standard or master such as Price Type AA. [**Note:** To achieve grade A, or B data under RISC hydrometric standard, meter must be field verified at least once in a year].

4.2.4.3 On Site Observations and Servicing

Upon arrival at the site, the operator should conduct an overall inspection to determine the site safety, the stream conditions, and any anomalies. Information must be recorded on the channel conditions, the gauge and water level recorder, the working condition of the current meter, and the water velocity. These data are recorded in RISC forms as outlined below.

Assessing Channel Conditions

One purpose of assessing the overall channel conditions is to be aware of conditions that will affect the measurement and the stage-discharge relationship since the last time the station was visited. Select the appropriate box on the "Discharge Measurement Field Form" (Figure 47 and 48) to assign channel condition.

Assessing the channel conditions is also important in deciding whether or not to go ahead with the measurement. In some conditions it will be unsafe or impractical to proceed with a measurement.

To assess the conditions of the watercourse, look for the following conditions and make note in the "Remarks" area of Discharge Measurement Field Form and RISC HYD-04: Water Stage Recorder-Station Log.

- The presence of aquatic plants at the metering section or on the control (see the Glossary).
- The presence of debris floating or lodged in or near the gauge or control
- Signs of human or animal activity in the vicinity of the station
- The deposition of gravel or the development of sand bars in the vicinity of the gauge
- Any obstructions in the vicinity of the gauge
- Signs of erosion of the channel banks
- The presence of overflow channels that are bypassing the metering section. If present these must be measured (or estimated)
- High winds
- Ice conditions

Gauges and Water-Level Recorder

After assigning the channel conditions read the gauges and water-level recorder and complete the following steps.

1. Note the date and time (Arrival) in RISC HYD-04: Water Stage Recorder-Station Log (Figure 38) included in the field data book.
2. Record all the gauge and recorder readings and information to complete the RISC HYD-04 form (use Arrival Column for recording information).
3. If site is without telemetry, download data logger readings since last visit and review the data for anomalies, missing periods, battery status etc. Operator should attempt to trace origins of any data anomalies or issues and service equipment to correct or avoid continued problems.
3. For well installations, flush the intakes and make certain they are not obstructed. Observe and record any differences that occur after the flushing.
4. Service the recorder. Check the battery condition and voltage, all of the cables and connections, solar panel(s), sensor(s), antennae, etc and repair deficiencies. Record the repairs that were required and completed.
5. Do a level check of the gauge or gauges, if required.
6. Write notes in "Remarks" area of RISC HYD-04 (Figure 38) form about observations and procedures, level check, metering etc.

After taking the discharge measurement, obtain another gauge reading and observe whether the recorder is operating properly. Use Departure Colum for recording time and gauge reading in RISC HYD-04 form). By this time the recorder will have been operating for approximately one hour and any error in the settings should be apparent.

BRITISH COLUMBIA

Discharge Measurements Field Form
[This form can be used to prepare RISC HYD-03]

Station Operating Agency/Firm: ***Water Stewardship Inc***
Station Name: ***Ayum Creek Near Mouth*** EMS ID[1] ***E123456***
Station No: ***1AH040*** (if any) Project No: ***99 HYD040*** (if any e.g., FIA)

Date (yyyy/mm/dd): ***2007/05/13*** Metered by: ***B.Booker***
Air Temp (°C): ***10.8*** Water Temp (°C): ***5.4***

Channel condition or other condition affecting control or discharge measurements: (variable, backwater, turbulence, vegetation etc.)

☒	☐	☐	☐	☐
Fixed Control, stable channel, straight reach, measurements are consistent with rating curve, no weeds, boulders or debris	Stable channel, relatively straight reach, measurements consistent with rating curve, minimal weeds or boulders	Minor hydraulic problems related to channel instability, measurements are not consistent with rating curve, weed growth or occasional boulders	Unstable channel due to erosion, degradation or aggradations; variable backwater, turbulence, significant weed growth, boulder bed	Undefined

Location of Metering Section: ***23 metres d/s of recorder***

	Time (24hh:mm)	Ref. Gauge Reading (m)	Inside Gauge Reading (m)	Data Logger /Recorder Reading (m)
Begin	*11:47*	*0.894*		*0.894*
End	*12:37*	*0.875*		*0.875*

Mean Time, PST (24hh: mm): ***12:12***

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Gauge Correction (m): ***0.000***

Corrected Gauge Height/Stage: (m): ***0.885***

Method of Discharge Measurement:
☐ Weir/Flume ☒ Current Meter/Acoustic Sensor
☐ Volumetric ☐ Others

If Current Meter/Acoustic Sensor:
Type (e.g., Price Type AA): ***OSS PC1*** SL No. ***93-07***
Measurement Range (m/sec): ***0.035*** to ***6.0***

Meter Calibration:
☒ Meter calibrated and the validity of calibration is confirmed
☐ Meter previously calibrated but validity of calibration is not confirmed
☐ Undefined
Date of Calibration (yyyy/mm/dd): ***2007/01/01*** (if known)

Meter Field Verification/Comparison Frequency:
☒ At least annually
☐ Less often than annually
☐ Undefined

Water surface Width (m): ***11.1*** No. Verticals Used: ***24***

X-sectional Area [when area velocity e.g., current meter/Acoustic Sensor method is used[2]] (m^2): ***7.636***

Discharge, Q (m^3/sec): ***4.543***

Average Velocity, V [when area-velocity e.g., current meter/acoustic sensor velocity meter is used[1]] (m/sec): ***0.595***

Remarks:
This is an example of a discharge measurement using the "Discharge Measurement Field data and Calculation" excel spreadsheet which is available from ministry website.

[2] [Note: "Discharge measurement field data and calculation sheet (using XL)" can be used as field form to get total area (A) and average velocity (V) when current meter method is used]

Figure 47: Discharge Measurement Field Form sheet 1.

BRITISH COLUMBIA

Discharge Measurements Field Form (Discharge Computations)

Current meter equations (mechanical current meters are used).

Where V= Velocity (m/s) and n = Revolution/sec

Select following equations:

(1) For Single Range Meters:

V =	n	X	Slope	+	Intercept	(m/Sec)
V =	n	X		+		(m/Sec)

(2) For Multiple Meters:

	n (Min)		n (Max)	V= n X	Slope	+	Intercept	(m/Sec)
IF	0	<n<	5.5	: V= n X	0.1048	+	0.0084	(m/Sec)
IF	5.5	<=n=<	99	: V= n X	0.1008	+	0.0304	(m/Sec)
IF		<n>		: V= n X		+		(m/Sec)

Method Description:
2= Two Point measurement. 0.2 and 0.8 depths are measured
3= Three Point measurement. 0.2, 0.6 and 0.8 depths measured
5= Point Five measurement. 0.5 depth is measured (only used for under ice conditions, 0.88 coefficient applied)
6= Point Six measurement. 0.6 depth is measured
B= Water edge, used at start of all measurements and after any 'S' method
E= Estimated Velocity, entered in Cos column as a % of adjacent measured velocity i.e., 66% entered as .66
S= Temporary Stop to exclude portion of channel e.g. bridge pier
T=Terminates measurement session-absolute end.

Discharge Computation Table

OBSERVATION							COMPUTATION				
Method	Dist. From Initial Point (m)	Depth (m)	Depth of obs. (m)	Revs (no.)	Time (sec)	Cosine of flow angle	Velocity At Point (m/sec)	Velocity Mean in vert. (m/sec)	Width (m)	X-sectional Area (m^2)	Disch. (m^3/sec)
1	2	3	4	5	6	7	8	9	10	11	12
B	3.400	0.000									
6	3.500	0.090		39	50		0.090	0.090	0.300	0.027	0.002
6	3.900	0.360		42	50		0.096	0.096	0.300	0.108	0.010
6	4.100	0.540		84	50		0.184	0.184	0.300	0.162	0.030
6	4.500	0.680		107	50		0.233	0.233	0.450	0.306	0.071
6	5.000	0.640		150	50		0.323	0.323	0.500	0.320	0.103
6	5.500	0.600		199	50		0.426	0.426	0.500	0.300	0.128
6	6.000	0.630		252	50		0.537	0.537	0.500	0.315	0.169
6	6.500	0.690		280	50		0.595	0.595	0.500	0.345	0.205
6	7.000	0.710		288	50		0.611	0.611	0.500	0.355	0.217
6	7.500	0.730		279	50		0.593	0.593	0.500	0.365	0.216
6	8.000	0.760		274	50		0.583	0.583	0.500	0.380	0.221
6	8.500	0.720		305	50		0.645	0.645	0.500	0.360	0.232
6	9.000	0.760		346	50		0.728	0.728	0.500	0.380	0.277
6	9.500	0.840		351	50		0.738	0.738	0.500	0.420	0.310
6	10.000	0.840		370	50		0.776	0.776	0.500	0.420	0.326
6	10.500	0.810		342	50		0.720	0.720	0.500	0.405	0.292
6	11.000	0.810		389	50		0.815	0.815	0.500	0.405	0.330
3	11.500	0.920		504	50		1.046	0.865	0.500	0.460	0.398
				403	50		0.843				
				346	50		0.728				
3	12.000	0.900		455	50		0.948	0.724	0.500	0.450	0.326
				314	50		0.663				
				294	50		0.623				
3	12.500	0.900		368	50		0.772	0.606	0.500	0.450	0.273
				278	50		0.591				
				220	50		0.470				
6	13.000	0.800		267	50		0.568	0.568	0.500	0.400	0.227
6	13.500	0.550		272	50		0.579	0.579	0.500	0.275	0.159
6	14.000	0.400		56	50		0.126	0.126	0.350	0.140	0.018
6	14.200	0.220		10	50		0.029	0.029	0.400	0.088	0.003
T	14.500	0.000									
Totals									11.100	7.636	4.543

Figure 48: Discharge Measurement Field Form –sheet 2.

Current Meter

Before using a Price type AA current meter, inspect it to be sure the bearing surfaces are in good order. This can be done quite easily:

1. Loosen the bucket wheel raising nut so that the pivot wheel bearing rests on the pivot.
2. Gently rotate the bucket wheel and observe it as it comes to a stop. If the stop is gradual, then the bearing surfaces and the pivot are in satisfactory condition. If the bucket wheel comes to an abrupt halt or the motion is abnormal in any way, the pivot and bearings should be closely inspected.
3. Inspect the pivot and bearings if necessary. If there is evidence of wear, the meter should not be used. Have the meter professionally serviced and re-calibrated.
4. If the pivot and bearings are in good order, then go ahead with the discharge measurement.
5. Horizontal shaft "propeller" meters should be spun to confirm that the bearings and shaft are in satisfactory condition.

Observing Velocity

The guidelines for observing velocity (Figure 49) are as follows:

- Allow sufficient time for the current meter to adjust to water conditions. The adjustment time will be a very few seconds at high velocities, and significantly longer at low velocities. This adjustment period is very important at low velocities, i.e. <0.3 m/s, and the failure to allow for it could produce errors.
- Observe velocities for 40 to 70 seconds.
- Observe time to the nearest 1/2 second (stopwatch/meter rating table use), or the exact displayed time, when using the meter calibration equation to determine the velocity.
- Where water depth in the vertical is >1.0 m, the velocity is measured at both 0.2 and 0.8 depth (from the water surface) with the current meter, and the mean velocity is calculated.
- Where water depth in the vertical is <0.75 m, observations are made at 0.6 depth (from the water surface) only. Using the 0.2 and 0.8 depth method in shallow watercourses places the current meter too close to the water surface and the channel bed to give reliable results.
- Where water depth is between 0.75 m and 1.0 m, the hydrometric operator can choose the method.
- Depth should be recorded to the nearest centimetre. This is for calculating the total cross-sectional area.

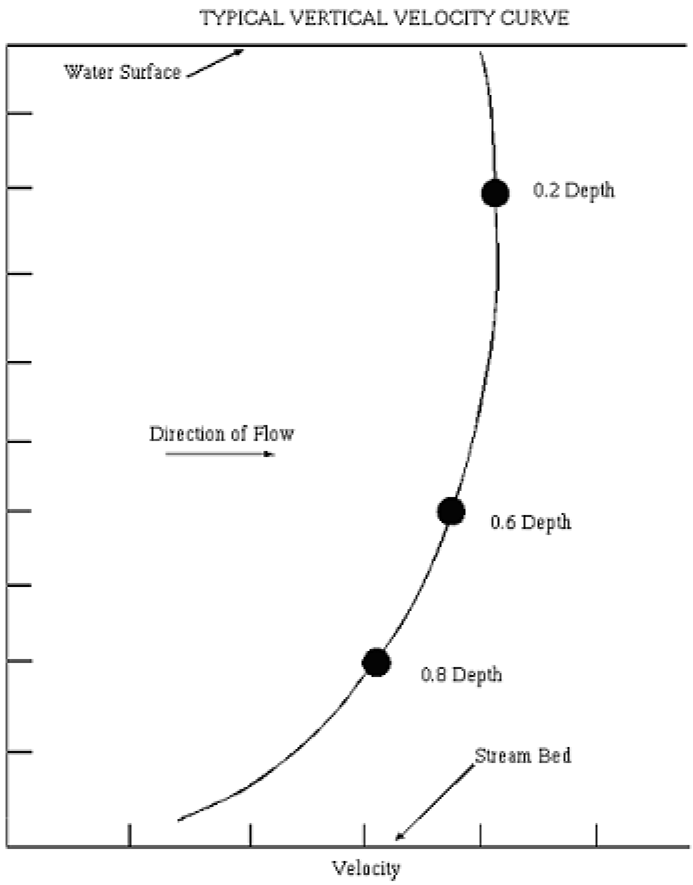


Figure 49: Example of typical vertical velocity curve.

4.2.5 Discharge Measurement

This section presents three basic techniques for making discharge measurements using current meter:

1. Measuring by wading (Section 4.2.5.1)
2. Measuring from a bridge (Section 4.2.5.2)
3. Measuring from a bank-controlled cableway (Section 4.2.5.3)

4.2.5.1 Measuring by Wading

General

If conditions permit, wading measurements are preferred to those obtained by other means. Wading measurements are relatively easy to carry out, and computing the discharge can be simpler than for other techniques. However, in very small watercourses, e.g. ditches, the presence of the hydrometric operator in the water may significantly affect the flow. In this case, the hydrometric operator should stand on a plank or log placed across the watercourse (Figure 50).

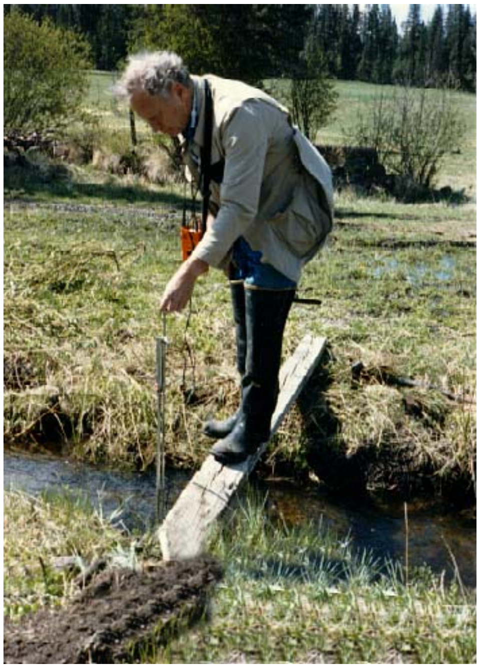


Figure 50: Ditch flow measurement using planks.

Equipment Selection and Testing

If the metering section is very narrow or shallow, or if most of the verticals have depths of <0.15 m, use a small current meter. The Price meter tends to over-register if the buckets are only partially submerged; preferably, use it only where average depths are >0.15 m. Do not use an unmodified Price Pygmy meter in velocities under 0.5 m/s.

Test the current meter's electrical circuit before making the measurement:

1. Attach the meter to the wading rod.
2. Connect the electrical lead on the rod to one of the terminals on the meter contact.
3. Attach the headset, beeper, or counter to the receptacle on the handle of the rod.
4. Rotate the bucket wheel. If a headset or beeper is used, a series of sharp clicks or beeps should be heard. With a counter, the rotor revolutions will register in the viewing window.

Locating the Metering Section

During the initial site reconnaissance and selection, the operator would have assessed the channel to select several locations to carry out discharge measurements.

The location of the metering section may vary with changes in stage or channel conditions. The best location for measuring high and medium flows from a cableway, boat, or bridge may not be acceptable for low water wading. Ideally, once the metering sections for low, medium, and high flow measurements have been selected, they should not be changed.

1. The metering section should be confined to a single channel for all stages.
2. The metering section should be perpendicular to the general direction of flow. (A procedure for determining angle of flow corrections is described in subsection "Direction of Flow" in Section 4.2.6.1.
3. The metering section should be located where the bed and banks of the watercourse are straight and uniform:

- Upstream - for a distance of approximately five times the width of the metering section.
- Downstream - for a distance of approximately twice the width of the metering section.

4. The channel bed at the metering section should be as uniform as possible. It should be free from vegetation, immovable rocks, and obstructions such as bridge piers.
5. The metering section normally should accommodate 20 verticals/subsections of uniform discharge and flow in each subsection or panel should not be more than 10% of the total flow. However, measurement points should not be closer than 0.15 m when price type AA meter is used. This factor should be considered during site selection.
6. The spacing of verticals along the metering section is not usually uniform. Where the water is shallow and/or slow moving, the spacing will be greater than where the water is deep and swift. Spacing depends largely on the following factors:
   - Overall width of the watercourse.
   - Unevenness of the channel bed.
   - Variation in velocity across the channel.
7. The spacing of each vertical should be referenced to a permanent initial point on the shore. The initial point should be well defined, usually by an iron pin driven into the ground above the high water mark. This initial point in turn should be referenced to another permanent feature near the metering section or gauging station. These data are often required for detailed studies long after the gauging station has been established or discontinued, and is particularly important where it is desirable to define channel erosion or deposition. As changes are usually determined by creating a series of cross-section plots, an iron pin is usually set above the high water mark at the far end of the cross-section. The distance between the two points is used to maintain the horizontal/vertical ratio in successive computer-generated plots.

If the gauging station has been in operation for some time, a wading section for making measurements will already have been established (Figure 51). Inspect the wading section, and the reach immediately above and below it, to make sure it is still the most suitable.

Figure 51: Conducting a discharge measurement with tagline across the wading section, Bridge Creek below Deka Creek.

Setting Up the Tagline and Establishing Verticals

To begin the discharge measurement, a tagline must first be placed across the watercourse.

1. Make a preliminary crossing before stringing the tagline. Use the wading rod as a support when crossing the watercourse. Turn the rod so that the meter is on the high end, or remove the meter from the rod so that it will not be damaged if a slip or fall occurs.
   Try to obtain an overall impression of the depths and velocities while wading. This is also a good time to look for rocks and debris that might be removed from the channel bed to improve the metering section. Be certain, particularly for very small watercourses, that removing rocks will not affect or alter the control.
2. Anchor the tagline with the zero referenced to the initial point. The initial point is a permanently marked point at the start of a cross-section, normally located above the high water mark on the right bank.
3. Wade across the watercourse, stringing the tagline at a right angle to the direction of the current.
4. Secure the tagline on either shore, and determine the overall width of the metering section.
5. Assess the approximate spacing of the verticals, according to the flow pattern. Follow the guidelines described in subsection “Locating the Metering Section” in Section 4.2.5.1.
6. Proceed with the measurement.

Discharge Measurement Procedure: Mid-Section Method

The mid-section method of discharge measurement is described below, and illustrated in Figure 59. Refer to Discharge Measurement Field Form (Figure 47 and 48).

1. Record the starting time and gauge height reading on Discharge Measurement Field Form.

   [**Note:** An accurate determination of the mean gauge height is essential for plotting the results of the discharge measurement. If the stage appears to change while the measurement is in progress, it is necessary to obtain additional readings during the progress of the measurement.]
2. Record the tagline distance for the edge of the water. If there is a steep drop at the edge of the stream, the first “vertical” depth and velocity observation should be taken close to the edge.
3. Move to the next vertical. Record the distance indicated by the numbered marker on the tagline. Observe and record the depth.
4. Set the current meter to the correct depth to obtain the velocity.
5. To obtain the velocity, count and record the number of revolutions the bucket wheel makes for duration of time between 40 and 70 seconds.
6. Observe and record the time to the nearest 1/2 second.
   To use the current meter rating table, the number of revolutions counted should be one of the 13 that are listed. Current meter rating tables are designed so that the velocity in meters per second can be obtained directly, for a given number of revolutions within the required time frame. The 13 choices of pre-selected revolutions are 5, 10, 15, 20, 30, 40, 50, 80, 100, 150, 200, 250, and 300.
7. If the procedure described above is not used, a double interpolation of both time and count is necessary to use the table to compute velocity.

8. Repeat the above procedure until the watercourse is traversed and the measurement is completed.
9. After completing the measurement, note and record the time and gauge height reading.

Precautions and Tips

To obtain accurate measurements by wading, the hydrometric operator must pay attention to detail and technique. If followed carefully, these suggestions will help obtain reliable results:

1. *Position the tagline correctly.* Take the time to ensure that the tagline is placed in a position that is perpendicular to the direction of the current.
   Even when this precaution is taken, there will still be instances where angular flow occurs. When this happens, record the cosine of the horizontal angle.
2. *Improving the metering section.* Where necessary, take the time to improve the metering section by removing boulders and debris from the metering section and the area immediately above it. Remove weeds for a distance of about three times the depth from the area upstream and downstream from the section. On smaller watercourses it may be possible to construct small dikes to cut off sections of shallow flows and dead water. After the modifications are made, be certain to allow sufficient time for conditions to stabilize before proceeding with the measurement. Note if the modifications have an influence on the gauge reading. All improvements to the metering section should be completed before starting the measurement, i.e. do not make changes to the metering section (such as by moving rocks) during the course of the discharge measurement.
3. *Spacing of Verticals.* Obtain 20 - 25 observations of both depth and velocity for one complete measurement (see Section 4.2.6.1 Error Affecting Accuracy). For very narrow cross-section, use a small meter and space the verticals more closely. However, measurement points should not be closer than 0.15 m when price type AA meter is used. The small propeller meters are usually supplied with 50-mm diameter propellers, and 30-mm interchangeable types are also available.
4. *Position of the hydrometric operator.* The hydrometric operator's position with respect to the current meter is very important when making a discharge measurement by wading. The hydrometric operator should stand to the side and downstream from the meter so as not to influence the velocity. Studies show that the following position has the least effect on the operation of the current meter: stand in a comfortable and safe place facing either shore, and no less than 0.4-m downstream and to the side of the current meter.
5. *Position of the current meter.* Hold the wading rod in a vertical position and the current meter parallel to the direction of flow while making the velocity observation.
   Vertical axis meters - if the axis of the meter is not kept vertical, the meter will tend to under-register.
   Horizontal axis meters - many propellers are designed to compensate for angular flow. Consequently any deviation from the vertical position of the rod will introduce an error in velocity.
6. *Observing Velocities.* If depths are sufficient (>1.0m), the 0.2 and 0.8 method should be used for observing velocities. It is quite easy to make the settings on the top setting wading rod (see subsection "Top Setting Wading Rods" in Section 4.2.3.1).
   To set the current meter on 0.2 depth position (or 0.8 up from streambed) on the wading rod, simply doubles the value of the observed depth and for 0.8 depth position (or 0.2 up from streambed) one-half of the observed depth on the vernier setting of top setting wading rod.

Example: Observed depth = 1.10 m.
For the 0.2 depth (or 0.8 up from streambed), set 2.20 on vernier setting.
For the 0.8 depth (or 0.2 up from streambed), set 0.55 on vernier setting.

[**Note:** The 0.2-0.8 method is not entirely satisfactory if the channel bed is very rough, irregular, or covered with aquatic growth. These conditions will often produce erratic results for the observation at the 0.8 depth. In some situations, more reliable results will be obtained by computing the average velocity on the basis of the 0.2 and 0.8 depths and averaging the computed value with the velocity from the 0.6 depth. This is known as the three-point (3 Pt.) method.]

7. *Uneven Channel Bed.* Sounding a channel bed that is extremely soft or strewn with boulders requires a great deal of extra care and attention. Be careful not to over-sound by allowing the bottom of the wading rod to sink into soft channel bed material. If the channel bed is very rough, take time to adjust the observed depths so that they reflect both the tops of the boulders and the depths between them. Measuring verticals should be equidistant around the vertical line which defines the breakpoint on the edge of the submerged obstruction (Figure 52).

   Sometimes there may be a near-vertical boundary separating zones of different depth or velocity. In this case, position the adjacent measuring verticals equidistant from this boundary, so that the boundary coincides with the common boundary of the partial sections.

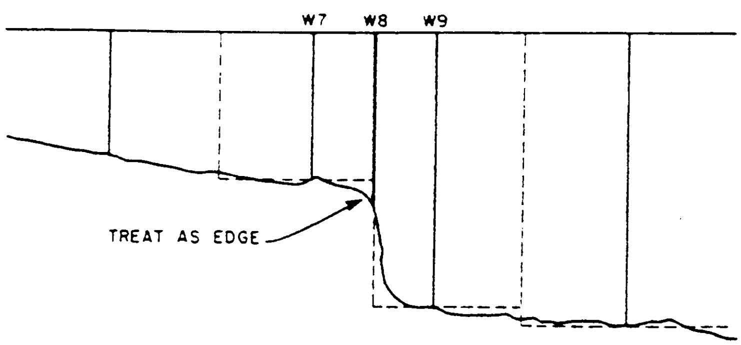


Figure 52: Defining the breakpoint (Courtesy: WSC).

4.2.5.2 Measuring from a Bridge

If a watercourse can not be waded, discharge measurements can be made from a bridge or cableway. Measurement cross-sections under bridges are often satisfactory for current meter measurements, but cableway sections are usually superior.

Either a bridge rod (Figure 53) or a cable/weight suspension system can be used to position the current meter in the watercourse.

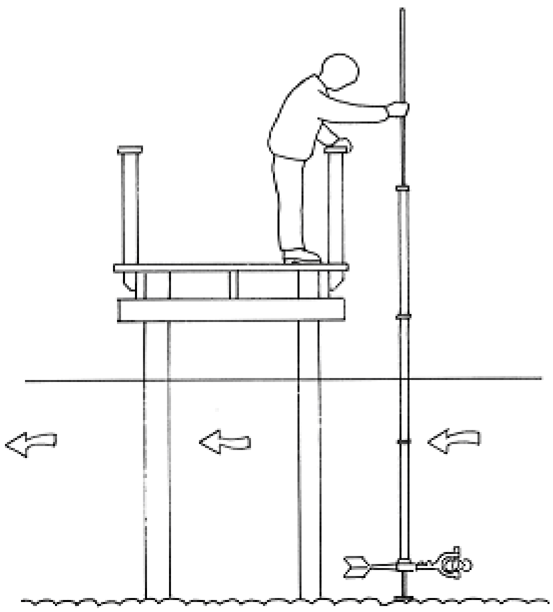


Figure 53: Bridge rod in use on upstream side of bridge.

The cable supporting the sounding weight and current meter may be suspended from a handline or one of several models of sounding reels. Handlines and sounding reels mounted on bridge boards (Figure 54) are especially useful when carrying out measurements from logging or farm bridges with no guard rails; however, these assemblies are limited to sounding weights less than 22 kg. Three- or four-wheeled bridge cranes can accommodate sounding weights of up to 77 kg, depending on the model of sounding reel, but can be used only on bridges with strong guard rails.

The discharge measurement can be made from either the upstream or downstream side of the bridge. Make this decision independently for each bridge, according to the advantages and disadvantages in each case. Also consider the physical conditions at the bridge, such as location of the walkway, traffic hazards, and accumulation of trash on pilings or piers.

The advantages of measuring from the upstream side of the bridge are:

1. Hydraulic characteristics on the upstream side of bridges are usually more favourable.
2. Drift material can be avoided more easily because it can be seen it coming downstream. With downstream measuring, an assistant may be needed to watch for floating debris.
3. The channel bed at the upstream side of the bridge is not likely to be scoured as badly as the downstream side.

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

1. Bridge rods are less likely to suffer damage from bending over the edge of the bridge if caught by the current and/or debris.
2. The vertical angle of a cable-suspended current meter is more easily observed.
3. Bridge abutments and piers can straighten flow lines in some cases.
4. If the bridge is angled across the channel, a single horizontal correction for angular flow can be applied to the measured discharge.

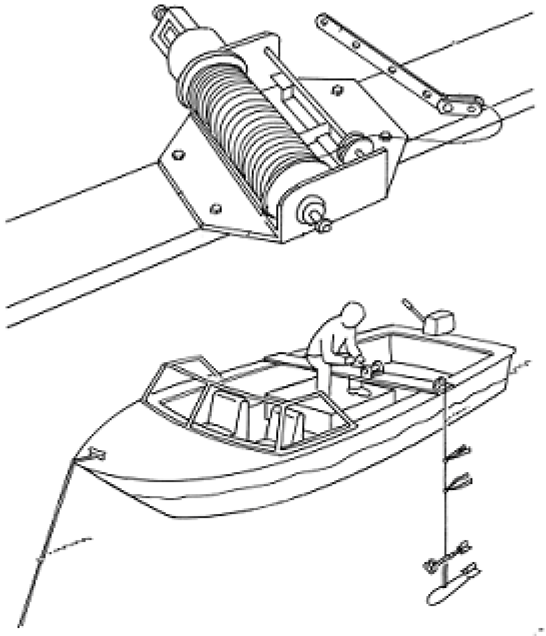


Figure 54: Sounding reel/bridge board mounted on a boat.

Measuring with a Bridge Rod

1. Assemble sufficient sections of rod to reach the deepest point of the channel bed. Probe the channel bed with the rod to determine the range of depths along the metering section. Then determine the number of outer rod sections required, based on the following criteria:
    a) To determine the depth, raise the meter to the surface, and read the graduated inner rod where it emerges at the top of the location device. From this value, subtract the number of outer sections (1 m per section) to obtain the depth.
    b) Multiply the depth by 0.2, and lower the meter to the obtained value. Again this is done by subtracting the number of metric sections of outer rod.
    c) The two values above represent the maximum range of readings to be made from the bridge deck. They also determine the number of inner and outer rod sections required.
2. Complete assembly of bridge rod and current meter. Attach two conductor electrical cables between meter and counter or headphones. Tape the cables to the outer rod sections at several points. Make sure the wires will not touch the propeller or meter cups.
3. Depending on the type of site, stretch the tagline along the top of the bridge rail, the edge of the culvert headwall, or across the face of the culvert barrel.
4. Locate the initial point. It will usually be the bridge abutment, and should be on the right bank.
5. Prepare the discharge measurement field notes. From the initial exploration of depth and velocity distribution, decide on the spacing of the verticals and the mode of

measurement required, e.g. a 0.6 depth measurement if depths in the panel <0.75 m (see subsection "Observing Velocity" in Section 4.2.4.3).

6. Read the gauge. Note the time before starting the measurement.
7. Record the tagline distance from the initial point to the edge of the water. Record the depth at water's edge.
8. Position rod at the 1st vertical. Position the meter at the water surface with the propeller or cups half submerged. Lock the locating device and read the graduated rod at the top of the outer rod. Subtract the number of 1-m sections of outer rod and record distance from the initial point (station) and depth.
9. Calculate the meter depth setting(s).

   [**Note:** Meter settings are referenced to the water surface.]
10. Set the meter at the required depth, allow it to stabilize, and start the counter or stopwatch. The number of revolutions divided by the interval in seconds produces the value "n".
11. Continue measuring distance, depth, and velocity along the cross-section.
12. End the measurement at the water's edge on the left bank. Record distance from initial point (i.e. tagline distance), depth, time, and water level.

    [**Note:** The distance between the face of the structure and nearest vertical should never be less than the diameter of the rotor or propeller of the meter, and then only when the hydrometric operator can maintain precise control over the lower end of the rod when it is being positioned.]

<u>Precautions and Tips</u>

The following suggestions will help in obtaining reliable measurements with the bridge rod:

1. *Securing the Stayline.* The assistant can double as the controller of a stayline secured to the base of the bridge rod. Usually a line may be floated under a bridge or through the barrel of a culvert and hooked up on the downstream side. The stayline will also aid in repositioning the rod, and it will help stabilize the meter during velocity measurement.
2. *Dealing with Pilings and Piers.* If bridge pilings or piers are in the cross-section, treat the intervening stretches of water as separate channels in order to remove the combined area of piers from the computed total cross-sectional area of the watercourse. If the pilings or piers are recessed from the outer edge of the bridge, then ensure a vertical is positioned at the point of convergence of the flow lines downstream of the pier, and that the adjacent verticals are equidistant (Figure 55).

   [**Note:** In the example shown, the locations chosen for the three verticals downstream of the bridge support are designed so that the segment boundaries between verticals upstream piles.

   When measuring the velocity downstream of an obstruction by cable-suspended assemblies, i.e. (22.5), the behaviour of the meter must be closely observed both for angled orientation and erratic revolution patterns. The existence of such conditions will indicate a gross over-registered revolution count. Estimating the velocity would be the best choice. Rod-mounted meters fitted with wide-angle compensating propellers will usually produce reasonably accurate velocities under these circumstances.]

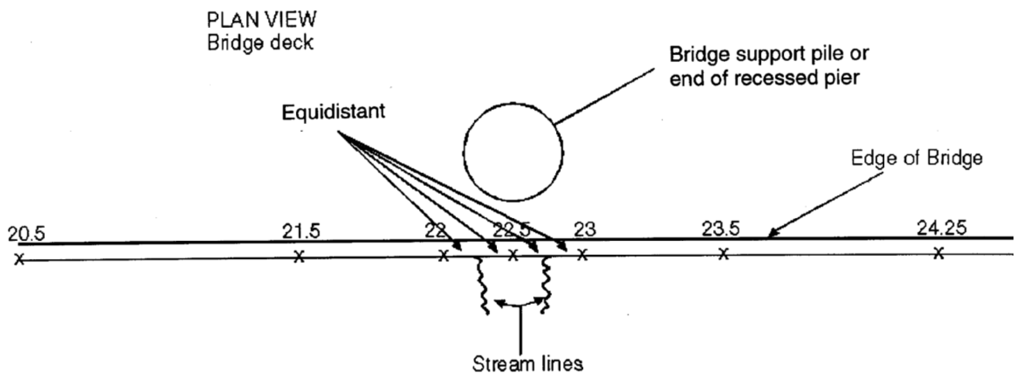


Figure 55: Position of meter in cross-section downstream of pier/pile.

Measuring with a Cable-Suspended Current Meter

General

Another alternative to wading is to make discharge measurements when the current meter is suspended on a cable by a handline suspension (Figure 56) or a reel suspension (Figure 57).

Preparations and Procedures Common to All Cable-Suspended Systems

1. Note: to determine the appropriate size of weight (in kg.) multiply the maximum depth (m) and the maximum velocity (m/s) by 5.
2. Depth and velocity observation settings can be accomplished in a number of ways, depending on whether or not floating debris is present, and the type of equipment to be used:
   a) Place tags (usually streamers of survey tape) on the sounding line at known distances above the center of the meter cups or propeller blades. Attach the tags to the cable by carefully threading the tape under a single strand of sounding cable wire, and position the tags at 0.5-m intervals above the center of the meter. The tags are required to determine stream depth and depth of meter for velocity observation. They also allow the meter to remain submerged throughout the discharge measurement, thus avoiding floating debris.
   A 0.5-m measuring stick or steel tape is also required.
   b) The Price type AA current meter is designed to be mounted above Columbus-type weights (Figure 45) by means of a hanger bar (known as an M2 hanger) and hanger pin. The M2 hanger provides for the correct spacing between the meter and the various sizes of Columbus weights (Table 5).
   c) Meter calibration varies with weight size and type and position of the meter on hanger; the user must ensure that the correct meter rating is used. A table of various suspensions and minimum operating depths is shown (Table 5).
3. In cases where current drag deflects the cable in excess of 10 degrees from the vertical, a correction for depth should be applied. Information and tables for this correction can be found in the literature. Generally, this applies only to deep and fast rivers.

Figure 56: Handline in operation (Source: USGS Water Supply Paper 2175 Vol. 1).

Figure 57: A55 reel and bridge board mounted in boat (Nechako River).

The previous sections about rod suspension of current meters pointed out that although all settings of the current meter in the vertical plane are referenced to the water surface, reciprocal values are used to position the current meter on the rod relative to the channel bed. Likewise, all cable-suspension measurement values, such as depth of observation, are directly related to the water surface.

Table 5: Columbus Weights: Suspensions and Operating Depths.

Position of meter above bottom of weight	Minimum operating depth	
	0.6 method (m)	0.2 & 0.8 method (m)
15 lb @ 0.15 m 30 lb @ 0.15 m	0.37	0.76
50 lb @ 0.17 m	0.43	0.85
50 lb @ 0.27 m	0.67	1.37
100 lb @ 0.30 m 150 lb @ 0.30 m	0.76	1.52

Cable Suspension Control with a Handline

If discharge measurements made from a bridge require light sounding weights (i.e. 15 to 30 lb; 5- to 15-kg Ott weights) the weight and meter are often suspended on a handline.

A handline is the cheapest and most compact assembly for suspending weights. A handline is easy to assemble, and easy to use from certain types of bridges, particularly logging or farm bridges without guard rails, and truss bridges that do not have cantilevered sidewalks. See Section 4.2.3.2 for a description of handlines.

However, the handline does have disadvantages. Its has a lesser degree of accuracy in determining depth of water than a sounding reel, more physical exertion is required, and the velocity/depth combination is limited by the maximum weight the hydrometric operator can manipulate.

Measuring with a Handline

1. Select a weight. Connect it to the hanger using the special connector pin.
2. Mount the current meter in the lower hanger hole.
3. Attach the sounding cable connector to the top hole of the hanger.
4. Measure the distance from the bottom of the weight to the center of the meter and record it on the Discharge Measurement Field Form. Check the distance of sounding cable streamers (tags) from center of meter (normally 0.5 m intervals)
5. Stretch the tagline over cross-section. Prepare the Discharge Measurement notes sheet, noting gauge reading and time.
6. Connect headphones or counter to handline; spin meter, and check circuits.
7. Estimate or measure water depth at the deepest point on the cross-section and unwind sufficient sounding cable from the reel (at least one tag marker should be showing above the water).
8. Using the sounding line as a plumb-bob to define the water's edge, record the horizontal (tagline) distance and depth (depth may be zero).
9. Move assembly to the first selected vertical (as close as possible to the bridge abutment), and start the measurement.
   Use the following method to measure depth and meter depth settings (Figure 58).
10. To determine depth, first lower the sounding weight to the channel bed and then raise the weight until one of the tags is at the water surface.
    Measure the distance that the weight is raised. Using a reference point on the bridge, measure along the rubber-covered cable with a steel tape or graduated rod.

Total depth of water = distance of the particular tag above the meter cups + distance the meter and weight were raised + distance from the bottom of the weight to the meter center.

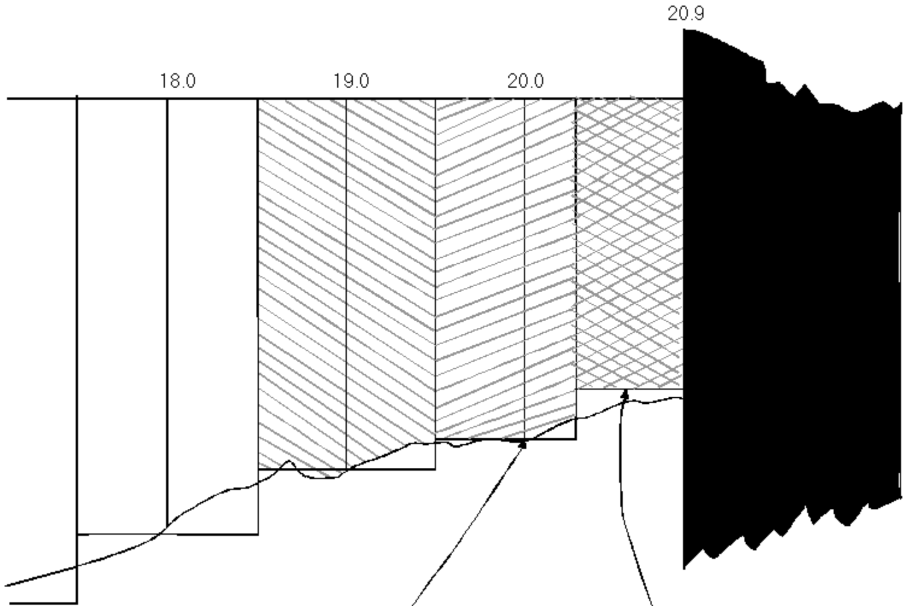
11. To set the depth of observation for velocity, multiply the depth by 0.6, or 0.2 and 0.8, and position the meter by means of the tag markers and measuring tape on rod. Weights up to 25 kg can be held in position by standing on the rubber-coated cable inside the bridge rail or guard.

Measuring with a Sounding Reel

A sounding reel is an alternative to using a handline to suspend the current meter in the watercourse.

The steps for determining depth and position of the current meter in the vertical are the same as described for the handline.

1. Select a weight. Connect it to the meter/weight hanger.
2. Measure and note the distance from the bottom of weight to the center of the current meter. If floating debris is present, attach a streamer tag to the cable 0.5 m above the center of the meter so that the meter can remain submerged.
3. To observe depth, lower the center of the meter to the water surface and set the depth counter to zero. Lower the weight to the channel bed. Read the counter and add to it the distance from bottom of weight to the center of meter. This is the observed depth.
4. To set the depth of observation for velocity, calculate the value for depth below the surface (multiply depth by 0.2, 0.6, or 0.8). Raise the meter until the obtained value is displayed in the counter.
   If debris is present, position the tag at the water surface and set the tag distance above the meter on the reel counter. Lower the weight to the channel bed and read the counter.
   Depth = counter reading + distance from bottom of weight to center of meter + distance from center of meter to tag.
5. To set the depth of observation, raise the assembly until the counter registers the calculated depth below the surface.



OBSERVATIONS							COMPUTATIONS				
							Velocity				
Method	Distance from initial Pt.	Depth	Depth of observation	Revolutions	Time in seconds	Cosine of flow angle	At Point	Mean in vertical	Width	Area	Discharge
2 pt.	18.0	2.40									
2 pt.	19.0	2.02									
2 pt.	20.0	1.84		50	44.5		0.757	0.700	0.80	1.472	1.0304
				40	42		0.642				
	20.9	E 1.6	Edge pier	66%	of 20.0			0.462	0.60	0.96	0.4435

Figure 58: Spacing of verticals when measuring around piers.

[**Note:** To avoid equipment damage, the vertical closest to the face of an abutment or pier must be located a sufficient distance from the edge to allow for the lateral swing of the meter/weight assembly, and estimate the average depth and velocity. The width of the estimated discharge panel is two-thirds the distance between the face of the structure and the nearest measured vertical.]

4.2.5.3 Measuring from a Bank-Controlled Cableway

Conducting the measurement with a cableway is generally preferred to doing it from boats or from bridges with piers. The lengthy set up time required for boat measurements is eliminated as are areas of disturbed flow caused by bridge abutments and piers.

Bank-controlled cableways employ a capstan drive arrangement that moves a traveller across the river and positions the meter vertically and horizontally. They also send a signal from the meter through the suspension cable to the operator on shore, for velocity measurement.

Measuring with a Cableway

1. Record the size of weight and the position of the meter above the bottom of the weight or bottom feeler plate.
2. Locate the initial point. It will usually be located near the top of bank on the control side of the watercourse.

3. Position the meter over the initial point, and set the horizontal displacement at zero. Move the meter assembly directly over the nearest water edge and note distance from the initial point. **Do not touch the horizontal reset lever during the course of the measurement**.
4. Observe and record soundings to the nearest 2 cm at each vertical. Be careful not to overestimate depth by allowing the cable to extend beyond the point when the sounding weight initially touches bottom. The distribution of verticals must be in accordance with that outlined in subsection “Locating the Metering Section” in section 4.2.5.1.
5. At each vertical, set meter to appropriate depths for velocity measurement. Observe and record the time and revolutions of the current meter.
6. At the end of the measurement, record the time of completion and make some notes to identify the edge of the channel. Record any pertinent information that may have had an effect on the measurement results.

Precautions and Tips

1. *Marking the Initial Point.* The initial point should be marked very clearly because all distances, observations of depth, and velocities must be referenced to this point. This information must be included in the field data book.
2. *“Zeroing” the Meter.* Soundings are usually made with the meter at the water surface, that is, with the bottom half of the bucket wheel or propeller submerged and the horizontal section of the tail assembly at the water surface. The distance between the meter and the bottom of the weight must be added to the soundings indicated on the reel counter to obtain the correct depth. The slight amount of drag on the meter and weight when the “meter is zeroed” has a stabilizing effect that makes the process of sounding quicker and easier than when attempting to “zero” the bottom of the weight. There is also the convenience of not having to apply a correction each time the meter is positioned in the vertical.
3. *Effects of Vertical Movement of the Meter.* Some cables may undulate from the pulling motion required to move the traveler block from one vertical to the next, or from vigorous cranking movements when sounding with heavy weights. This motion must be allowed to subside before carrying out the depth and velocity observations. This is of particular importance when measuring velocities below 0.75 m/s, because the effects of vertical movement on the current meter are significant in this range.
4. *Direction of Flow.* The direction of flow is often not perpendicular to the metering section. Even worse, the flow may be inconsistent throughout the section, or the flow may change from vertical to vertical with the section, and vary with changes in stage. In these cases, measure the cosine value; make the appropriate correction for angular flow.

4.2.6 Post-Measurement Activities and Discharge Measurement Computation

[**Note:** Portion of the material presented in this section have been prepared from: 1. Hydrometric Field Manual – Measurement of Streamflow by Terzi, R.A., Inland Waters Directorate, Water Resources Branch, Environment Canada, 1981, and 2. Hydrometric Technician Career Development Program, Lesson Package No. 10.1: Principles of Discharge Measurement by Roy J. Lane, Water Survey of Canada, Environment Canada, 1999, (http://www.wsc.ec.gc.ca/CDP/Lesson10.1/index_ie_e.htm).]

4.2.6.1 Errors Affecting Accuracy

General

The purpose of this section is to identify some of the common factors that lead to inaccuracies when observing widths, depths, and velocities. Inaccuracies can occur during the measurement of any of these parameters through errors introduced by technique or the type of equipment used. Errors can be categorized as human, systematic, or random.

Width Measurement

Human error can be a factor when measuring permanently marked cross-sections on bridge rails or other structures if unconventional spacing has been employed. Wind can oscillate the tape and lead to movement of the tape anchorage points and/or mistakes in observing values.

Record keeping errors can occur during boat measurements when the boat is positioned by electronic or survey equipment operated on shore with the rest of the data recorded in the boat. To avoid errors, good communication and post-measurement record comparison are essential.

Depth Measurement

Depth observations made by rod are subject to random errors such as the sinking of the rod into a soft streambed, failure to identify obstructions in the cross-section between soundings, and incorrect reading of the graduated rod.

The opportunity for error is far greater when cable suspension systems are employed. In addition to the errors listed for rod measurements, certain techniques used in the measurement process can result in errors in the recording of depth. The most obvious and most common error is the failure to add the distance from the bottom of the weight to the center of the meter when the latter point of reference has been used to "zero" the reel or handline at water surface. Other errors peculiar to the handline suspension occur as a result of mistakes in the method of subdividing the distance between cable markers (streamers) and applying to obtain exact depths.

Measurement of Velocity

Other sources of significant error in a discharge measurement are those that relate to the measurement of velocity. Among the more readily apparent are those associated with the calibration of current meters, the direction of flow, the duration of the observation time, and the number of observation verticals as well as the number of observation points in each vertical.

<u>Calibration</u>

Calibration is defined as the cleaning, lubricating, and adjustments required to achieve prescribe limits. Under RISC Hydrometric Standards, all individual meters must be calibrated to achieve grade A, B, or C data. These are obtained by towing the meters through a tank of still water at velocities of between 4.5 to 300 cm/s, and from this individual calibration curves are developed.

<u>Field Verification</u>

Field Verification is defined as act of confirming the equipment accuracy using a traceable standard or master. To achieve grade A or B data under RISC Hydrometric Standards, every meter must be verified in the field at least once in a year. Verification of the meter can be done by comparison to the readings of a recently calibrated industry standard current meter such as Price type AA, ADV meter, and OTT or OSS mechanical current meter.

Direction of Flow

Discharge measurement cross-sections are usually chosen so that the flow is perpendicular to the cross-section. Even though they are carefully selected, it is not always possible to avoid oblique flows at some of the verticals. At these verticals the velocities must be corrected by applying an appropriate cosine coefficient. Random errors may be introduced when observing the angle of flow if it is assumed that the angle observed at or near the surface remains the same throughout the entire depth.

Other sources of error can be introduced when using rod suspensions and in particular when used in deep fast-flowing water. Although the current meter can be misaligned both vertically and horizontally with the direction of flows, the most significant error will result from vertical misalignment. The current meter will under register if tilted above or below the horizontal, and the magnitude of the error will depend upon both the velocity of the water and the angle of departure.

Duration of Observation Time

Pulsations in velocity are evident in all streams even though flow conditions are essentially steady. Because pulsations are random in nature, the effects of pulsation will be eliminated when velocities are observed for a sufficient length of time. In actual practice during a discharge measurement, velocities are observed for relatively short periods of time. The expectation is that a sufficient number of observations will be made so that pulsation effects will tend to cancel each other during the course of a measurement. Studies have shown that at low velocities, pulsation effects are usually greatest. Studies have also shown that the optimum observation duration is between 40 and 60 seconds and that accuracy decreases significantly if duration of less than 30 seconds is used; for durations longer than 60 seconds, the increase in accuracy is generally negligible.

Number of Observations

There are two ways in which the accuracy of a discharge measurement can be significantly affected by the number and distribution of observation verticals. First, the observation verticals are used to define the channel cross-sectional area. Appreciable errors will be introduced if the numbers of observations made to define the cross-section are not sufficient. This particular problem can be overcome by obtaining additional depth observations.

Secondly, the velocity observations in the verticals are used to define the mean velocity in the cross-section; therefore, the verticals should be spaced so that the velocities observed are more representative of those in the preceding half panel and the following half panel.

The spacing of observation verticals can be accomplished on the basis of either the equal flow method, the equal width method, or a combination. With the equal flow method, the width segment can change frequently, and using the mid-section method for computations the horizontal velocity profile tends to be distorted. That is, if the width segments change frequently, the observed velocities will not occur at the midpoint of the panels.

A good compromise is to use the equal width method and to change the spacing of verticals only a few times during a measurement to accommodate any significant changes in flow distribution.

Studies on measurement accuracy have shown that accuracy tends to be low when fewer than 15 verticals are used but the improvement becomes negligible when more than 35 verticals are used. All else being equal, the use of 20 - 25 verticals is considered optimum. However spacing of the measurement points should not be closer than 0.15m when using the price type AA meter, since the distance between verticals must be greater than the diameter of the current meter bucket wheel. To achieve Grade A data, flow in each subsection or panel should not be more than 10% of the total flow.

Number of Observation Points in a Vertical

The mean velocity in a vertical is normally obtained by measuring at one or two points in that vertical. Comparing these observations with those obtained by some detailed method (a mean of observations at every tenth of the depth, plus half the value observed at the surface and half the value at the bottom), indicated that random errors do occur when determining the mean velocity in any given vertical. Furthermore, the one-point method is usually not as accurate as the two-point method. Nevertheless, surface and bottom effects become significant as the stream depths decrease, and when depths are less than 0.75 m, the one-point method (0.6 depths) should be used.

Conclusions

Errors in the measurement of width, depth, and velocity as well as the lack of care in choosing the number of verticals and observations in a vertical, all combine to reduce the overall accuracy of a discharge measurement. To a large extent, human errors can be avoided by careful attention to detail and by adhering to established and proven techniques and routines. Systematic errors can be reduced significantly by proper maintenance and calibration of instruments and equipment, and by adequate training. However, random errors will always occur. A significant reduction in these errors can be achieved if the hydrometric operator obtaining the measurement can recognize the potential problem areas and can take the appropriate precautionary measures to avoid or minimize them. One possible indication of measurement accuracy can be obtained by conducting several consecutive or simultaneous measurements, and by using different sets of equipment and different techniques.

4.2.6.2 Computation Procedure for Mid-Section Method

The mid-section method of computing discharge measurements is carried out as follows:

1. Observed depth at the vertical is considered to be the mean depth for the section or panel.
2. It is assumed that the mean velocity at the observation vertical represents the mean velocity for the section.
3. Width for each section is computed as one-half the distance from the preceding vertical plus one-half the distance to the following vertical.
   In Figure 59, the discharge for the heavily outlined section at distance b6 from the initial point is computed as:

$$q = V_6 d_6 \times \frac{(b_7 - b_5)}{2}$$

The calculations for the first and last sections of a discharge measurement are handled in much the same manner as just described. The main difference is in the determination of the widths. Because at the beginning and the end of a measuring section there is no preceding or following vertical, the width becomes one-half the distance from the edge to the first vertical or from the last vertical from the edge. Figure 60 shows typical edge sections. As a result of the computational procedures, in these instances the area and discharge are not derived for the edge sections. Therefore, when making a discharge measurement, the first and last verticals should be taken as close to the edge as possible. The two edge sections will then be very small in proportion to the total measurement and an estimated discharge for these sections will introduce very little if any appreciable error.

An edge section will also occur where there is a vertical drop at the water's edge, such as at a pier, a bridge abutment, or a wing wall. Again, the width calculation is one-half the distance from the previous or to the following vertical as shown in Figure 60. Here, however, an area and discharge can be computed. Once again, soundings should be arranged so that edge sections are made as small as possible.

Keep in mind that caution must be exercised when observing depths and velocities close to piers and abutments. At times, it may be necessary to estimate these values to avoid the possibility of the meter and weight assembly being damaged against the pier or abutment. In some instances, debris will have lodged on or against the pier and this further complicates matters. Where these situations are encountered, it becomes necessary to estimate the depth from the previous vertical and the velocity which is expressed as a percentage of that observed at the previous vertical.

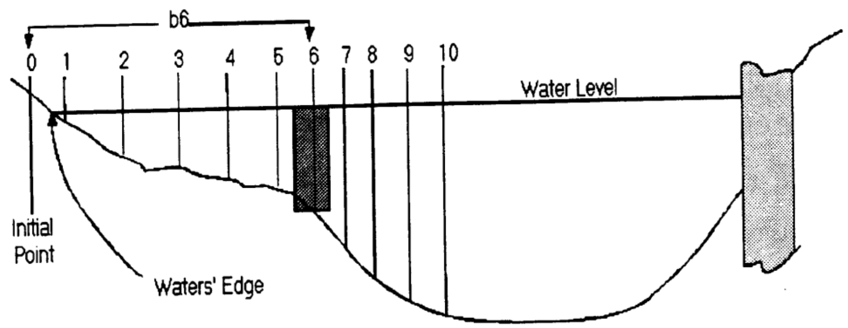


Figure 59: Mid-Section method of discharge measurement.
(Typical stream cross-section with numbered verticals, Panel 6 is highlighted).

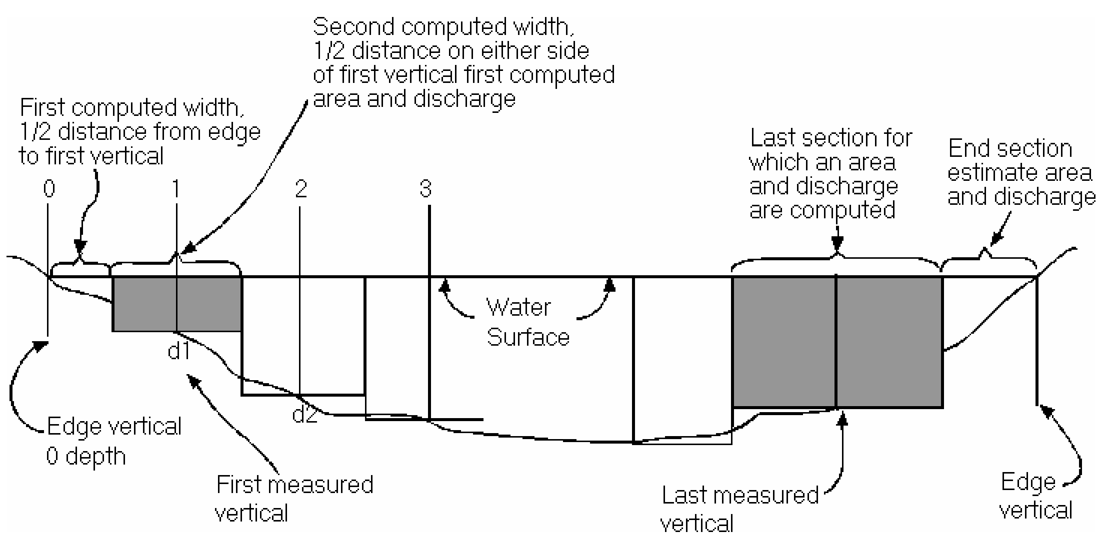


Figure 60: Method for selection of edge verticals.

4.2.7 Documentation of Discharge Measurements

It is easiest to evaluate a hydrometric record successfully when the supportive values and observations have been well documented. Each segment of the record must contain the necessary identification, support values and information. As mentioned earlier documentation must be complete and legible and necessary information must be documented immediately following the observations. “Discharge Measurement Field Form” (Figure 47, 48) can be used to record the necessary information and observed readings systematically. RISC form RISC HYD-03: Summary of Discharge Measurements (Figure 77) can be prepared using this field form.

4.3 Discharge Measurement using Rated Structure

4.3.1 Introduction

This section is intended to serve as a guide to the selection and installation of permanent and semi-permanent structures with a predetermined rating. The sampling of common pre-fabricated units included, each of which has been rated in laboratory test programs. In addition, all have effective discharge coefficients of less than 3% error when operated within their modular range and the other limits of application have been satisfied. With the exception of larger rectangular weirs, the capacities of the structures described do not exceed 4 m^3/s.

Larger units are available, but the cost of engineering and construction place them beyond routine applications. The need for rating verification for these structures becomes more important for the larger units or where the design is modified in any way. Reference to standard texts is recommended (e.g., “Discharge Measurement Structures” Edited by M.G. Bos. International Institute for Land Reclamation and Improvement. Delft Hydraulics Laboratory, Wageningen, The Netherlands. 1989) as no details on the hydraulics or modular limits are provided.

4.3.2 Purpose

The measurement of flow in natural streams is hampered by many factors, which undermine the reliability of metering equipment. These conditions include:

- Remote locations interfering with regular and timely visits.
- Access difficulty, steep banks, seasonal or poorly maintained roads.
- Movable bed and high sediment transport conditions resulting in control shifts, perhaps several during a single season.
- Poor metering sites, for example steep rocky gradients.
- Shallow flows where normal metering equipment is not acceptable.

Rated structures can be used in such situations to minimize or eliminate many of these problems.

4.3.3 Design

The selection of alternate flow measurement methods, particularly if involving larger streams with potentially destructive flows, should only be made after consultation with an hydraulic engineer or hydrometric specialist. Larger measuring structures may require the services of a structural engineer for final design.

4.3.3.1 Design Considerations

The selection of a discharge measuring device, its location and installation should be based on sound information acquired before the design is finalized. Much or all of the following information should be acquired:

1. Duration of the proposed project

2. Expected range of discharge to be measured
3. Likelihood of flows above the expected range should be assessed in terms of:
   - device withstanding the stress of being over-topped
   - extreme events being measured
4. Geometry of the channel reach
5. Streambed gradient above and below the proposed site
6. Presence and extent of bedload and/or sediment transport
7. Presence of any downstream constriction which may cause elevated tail water levels at higher flows
8. Permeability of streambanks, streambed and underlying strata
9. Frost line depth
10. Proximity of vehicle access (this may possibly include access by redi-mix truck or small load mix-trailer and travel time from depot)
11. Construction window for in-stream work

4.3.3.2 Selecting the Measuring Device

Initially, the choice of a measuring device for a particular location will depend on the conditions set out in the items 2 to 7 in the previous sub-section. Table 6 enumerates the maximum and minimum discharges for the various sizes of devices together with their ability to prevent sedimentation and pass bedload and debris. With reference to Table 6, and Figures 61 and 62, the placement of weir crests has an important dimension, **p** that is defined as the depth of the approach channel below the crest on the upstream side of the weir. It also is required in the ratio **h^1/p,** listed with **p** in right hand column, and must be used to specify the placement of the various weir crests when these weirs are operating at capacity.

4.3.3.3 Installation

The installation of a rated structure is straightforward, but does require attention to a number of factors. These include:

1. Grade setting - two conditions must be satisfied to ensure accurate measurement. The approach velocity to the crest must be sufficiently low to maintain a negligible velocity head and the nappe must not be subject to downstream influences.
2. Sealing the streambed against seepage under the structure - any granular bed is susceptible to seepage. Prevention may involve the placement of a watertight membrane (plastic sheet or geotextile) on the streambed upstream of the structure.
3. Structural foundation - required for support, anchorage and preventing leakage.
4. Mounting the rating device - the primary concern is that it be level, aligned with the streamline, and well anchored
5. Wing walls - designed to maintain the minimum pool elevation and be watertight, and remain intact in the event of over-topping.

The information in Table 6 illustrates the superiority of flume type measuring structures in situations where sediment and/or low bank geometry must be factored into the design. In addition flumes, particularly the H type, are more sensitive at low flows because the sides converge at the invert. For example, the capacities of the 2-m rectangular weir and the 4-foot HL flume are similar; however the sensitivity of low flow measurement in the HL flume is maintained to a flow rate which is one tenth that of the weir. In addition, the weir crest, in order to remain fully contracted at full capacity, must be set at an elevation of 2.0 m above the bed of an approach channel of at least 6 m breadth. The resulting pond characteristics must be maintained during the operating period of the weir so that approach velocities remain negligible. On the other hand, the throat elevation of the types of flumes listed require little or no elevation above the streambed and the dimensions of the approach channel need be no greater than those of the flume entrance. For purposes of comparison, the site geometry and other requirements are set out in Table 7.

Table 6: Operating limits for rated structures included in this Manual.

Device type	Device size	Max. $h^{1\ a}$ (m)	Max. Q (m^3/s)	Min. h^1 (m)	Min. Q (m^3/s)	Debris capacity	Sediment capacity	h^1/p^b	Min. P^C (m)
V-notch	90^0	0.60	0.390	0.05	0.0008	Very poor	Very poor	$\leq$1.2	$\geq$0.45
Montana flume	3-inch	0.339	0.33	0.03	0.0008	Very good	Good	N/A	N/A
	6 inch	0.457	0.111	0.03	0.0015	Very good	Good	N/A	N/A
	9 inch	0.610	0.251	0.03	0.0025	Very good	Good	N/A	N/A
	12 inch	0.760	0.455	0.03	0.0033	Very good	Good	N/A	N/A
H flume	2.0 feet	0.604	0.309	0.03	0.0005	Fair	Fair	N/A	N/A
	2.5 feet	0.756	0.542	0.03	0.0008	Fair	Fair	N/A	N/A
	3.0 feet	0.908	0.857	0.03	0.0010	Fair	Fair	N/A	N/A
	4.5 feet	1.364	2.336	0.03	0.0014	Fair	Fair	N/A	N/A
HL flume	4.0 feet	1.218	3.292	0.05	0.0054	Good	Fair	N/A	N/A
Rectang. weir	b=1.0m	0.500	0.585	0.06	0.0267	Poor	Poor	$\leq$ 0.5	$\geq$ 0.3
	b=1.5m	0.750	1.612	0.06	0.0402	Poor	Poor	$\leq$ 0.5	$\geq$ 0.3
	b=2.0m	1.000	3.308	0.06	0.0537	Poor	Poor	$\leq$ 0.5	$\geq$ 0.3
	b=3.0m	1.500	9.117	0.06	0.0807	Poor	Poor	$\leq$ 0.5	$\geq$ 0.3

[a] Head over the weir crest.
[b] Ratio of head over the crest and the height of the crest above the upstream bed.
[C] Height of crest above the upstream bed.

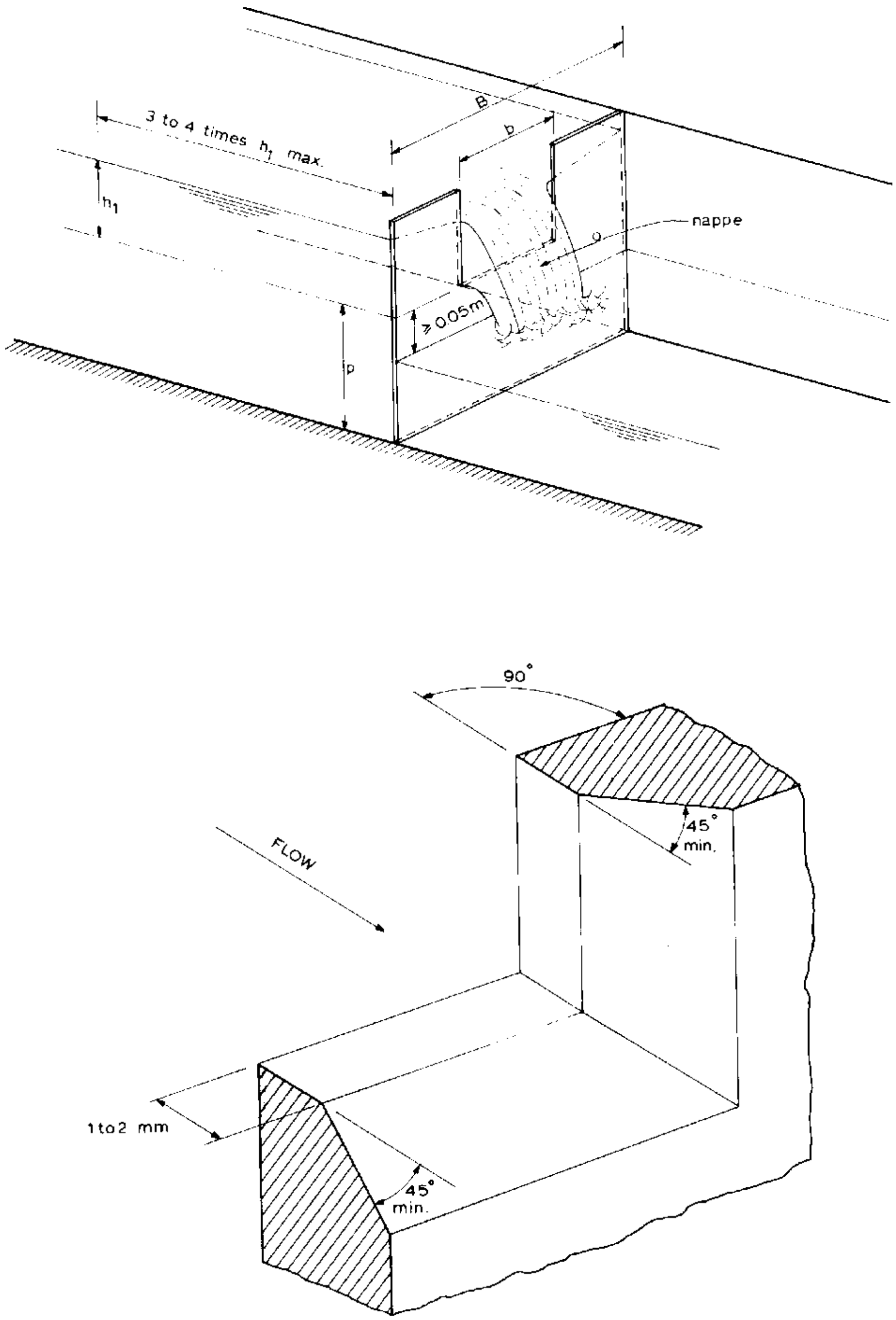


Figure 61: Top - Rectangular sharp-crested weir (thin-plate weir).
Bottom - Enlarged view of crest and side of rectangular sharp-crested weir.

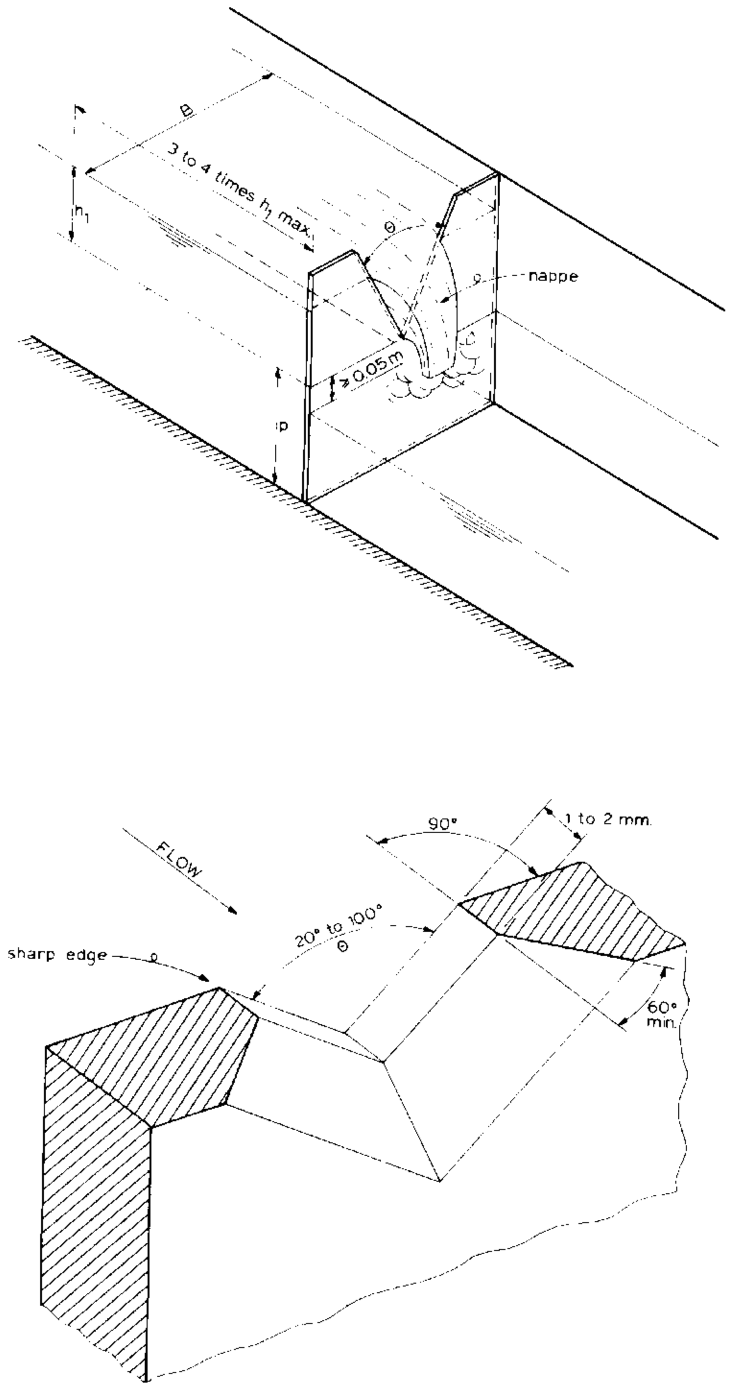


Figure 62: Top - V-notch sharp-crested weir. Bottom-Enlarged view of V-notch.

Table 7: Comparison of two selected rated structures.

Rectangular weir, b = 3.0 m	4.0-foot HL flume
Rectangular weir, fully contracted with notch opening of 3.0 m wide x 1.0-m deep.	HL Flume with free-flowing nap.
Minimum width of approach channel =6 m.	Width of approach channel = 2.7 m.
Minimum height of banks, approach 3 m + freeboard for 1 in 50-year flood.	Height of rectangular channel walls 1.22 m + freeboard.
Length of weir notch bulkhead (must extend at least 1.5 m into each bank), 6 + 3 = 9 m. This bulkhead must also extend at least 0.75-m below the streambed.	The upstream ends of the approach channel walls should be keyed into their respective banks. This should extend at least 1.5-m into the banks and 0.75-m below the streambed.
The width and depth of the weir pond should be maintained for a distance upstream of the bulkhead equal to 9 times the maximum depth of flow over the crest. The upstream end of the pool should be designed to distribute flow across the approach channel to minimize the approach velocity during high flow.	The minimum length of the level rectangular approach channel is 2D (2.44-m).
If bedload movement and suspended sediment transportation is present, the upstream depth below the crest must be retained by a maintenance program. Failure to maintain the dimensions will result in a change to the coefficient of discharge with a resulting error which varies with stage. The infilling of weir ponds may be avoided by constructing a gravel/sediment arrestor pond a short distance upstream.	Sediment deposition seldom occurs within the flume and it has been observed that the flume gauge reading does not change when sediment deposits.

4.3.3.4 Site Conditions

Site conditions will usually determine the choice of a control structure for the measurement of flow at the desired location. The preceding subsection clearly shows the advantages of flume installations over weirs in most stream channels. The exception to such a choice is an installation at the outlet of a lake, pond or storage reservoir where neither sediment nor upstream excavation need be considered. In such a case a weir may be the most suitable choice.

4.3.3.5 Erosion Protection

Unless a weir or flume is founded on bedrock, downstream erosion protection of both streambed and banks will be required. The protection may include, but must not be restricted to, some form of stilling basin or a concrete slab. These are themselves structures which require protection against undermining and eventual failure. In the past, the downstream protection has usually consisted of properly sized rip-rap placed on a filter layer of coarse gravel overlying a layer of fine gravel. If broken rock is employed, the bank protection may be constructed, typically, with 1.5:1 slopes rising from a rock filled toe the depth of which must be at least twice the dimension of the rip-rap. The downstream end of the rip-rap must be keyed in to both the banks and streambed.

Geotextiles may also be used in conjunction with rip rap, concrete or other materials as part of the erosion protection. Engineering design may be required for erosion protection systems for large installation. Engineered systems based on proprietary materials are available.

4.3.4 Continuous Stage Recording

4.3.4.1 Flumes

The location of water level recorder intakes is defined in the fabrication sketches for the two types of flumes listed and described in section 4.3.3.2 (Figure 61 and 62). Descriptive information on H-flumes (Figure 63) is added in Figure 64 with the associated dimension table. Related discharge tables are included in Appendix IV.

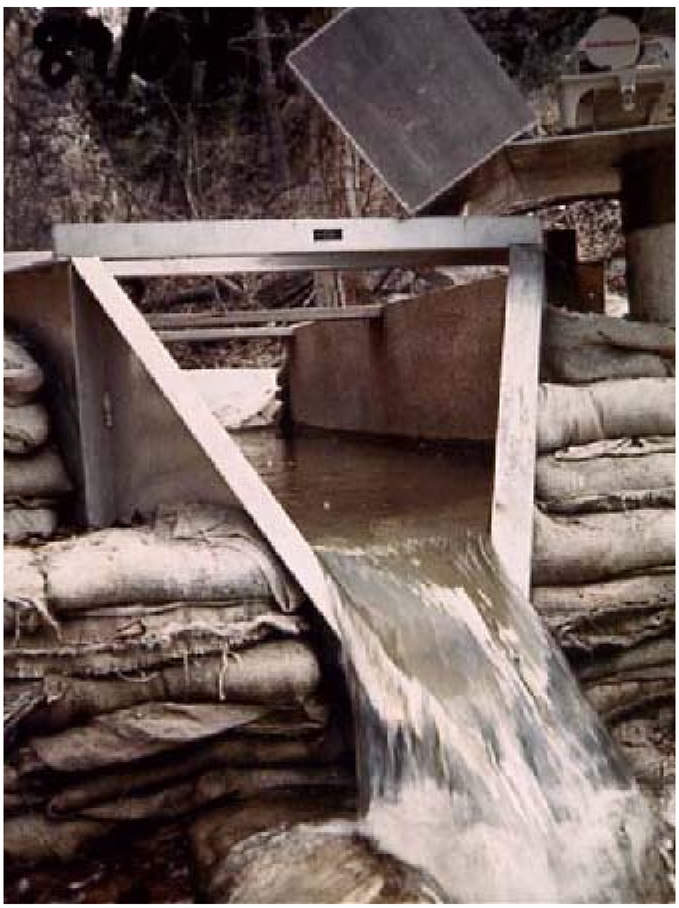


Figure 63: 2.5 foot H Flume set in concrete filled sacks. Cuisson Creek above Gibraltar Mine.

The stilling well for use with these flumes is normally mounted against the outer face of the prefabricated flume and centered opposite the flumes point of measurement. This permits the use of a very short easily-cleared intake pipe which should be threaded and screwed through a double thickness of stilling well wall which is drilled and tapped to suit.

[**Note:** Assuming ABS pipe is used for both stilling well and intake (metal pipe should be avoided as rapid heat conduction will result in frost formation) all fabrication can be accomplished on site. To form a double thickness wall, cut a patch from a length of scrap pipe (same diameter); using the correct solvent/glue and two large hose clamps, bond the patch in place.

Note: A threaded socket (and removable threaded plug) at the outer end of the intake can facilitate the sealing of the stilling well. The well can be pumped out when the station is deactivated over the winter. Both well and intake will remain ice free making reactivating in the spring less onerous.]

The base of the stilling well should be positioned at least 15 cm below the floor of the flume.

In some instances Montana or Parshall flumes have been installed at sites where the maximum flume capacity may occasionally be exceeded. If these events are quantified by current meter measurements, a reference gauge and recorder installed upstream will provide a more complete station record. A flume gauge is provided and both gauge readings recorded at each station visit. Installation requirements for an upstream gauge are the same as for weirs, see Section 4.3.3.3.

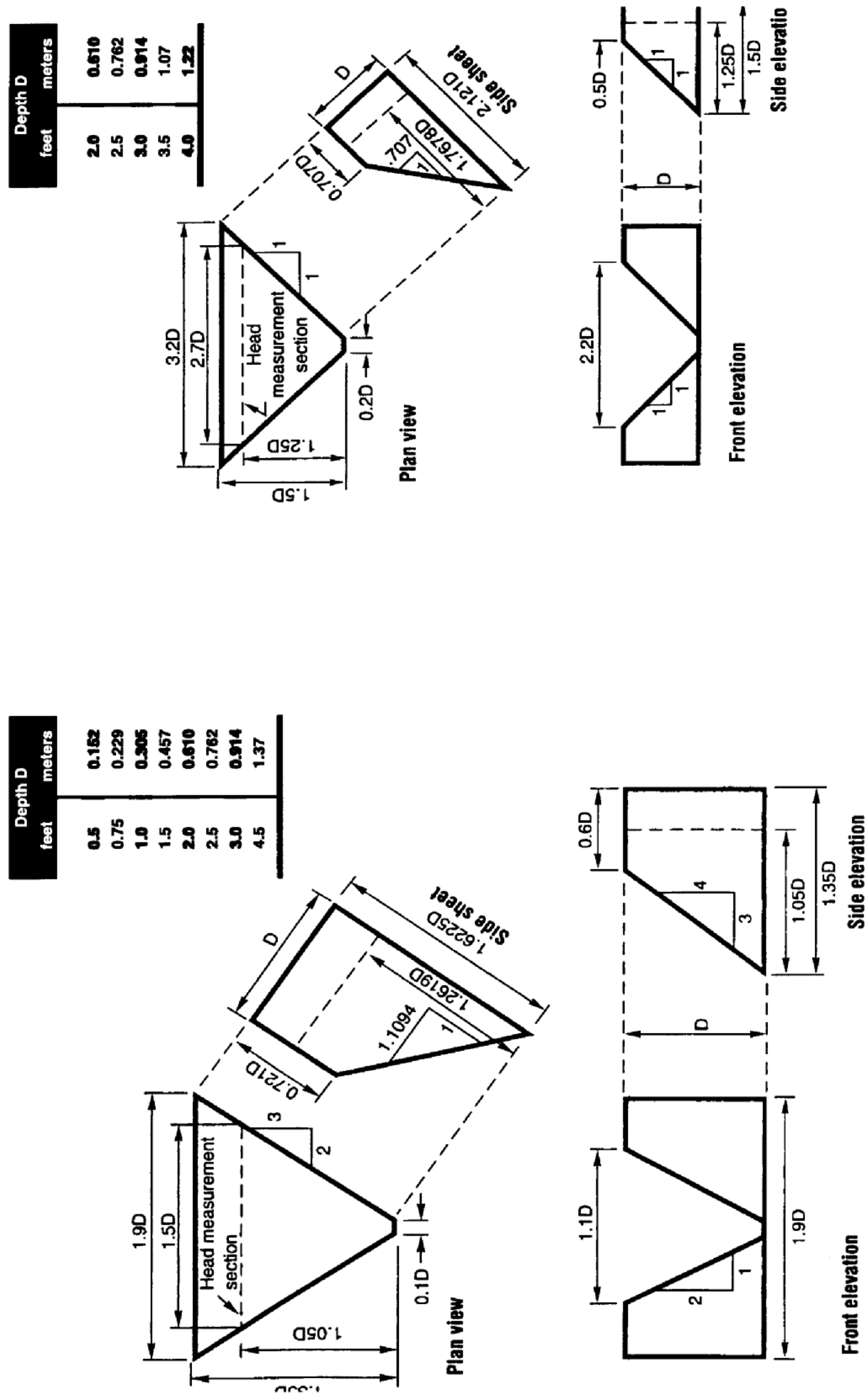


Figure 64: Dimensions of HL-type (top) and H-type (bottom) Flumes.

4.3.4.2 Weirs

Stilling wells should be installed in the weir pond against a stabilized vertical bank or wall (see Figure 65). The well must be secured near the base and above the high water elevation. The reference gauge and intake must be positioned upstream of the crest at a distance 3 to 4 times the maximum height of water over the crest (to avoid drawdown effect).

Figure 65: Stilling well installed in the weir pond.

4.3.5 Discharge Measurement Using Portable Montana Flumes

A properly installed small portable Montana flume (Figures 66 and 67), which is a truncated version of a Parshall flume, can provide a convenient method of making accurate measurements of small streams and ditches. The common sizes (i.e. throat dimensions) for portable use are 76.2 mm (3 inches) and 152 mm (6 inches). Commercially available versions of the Parshall and Montana flumes are typically constructed of fibreglass; they may also be built of plywood or sheet metal) provided the dimensions shown in Table 8 and Figure 68 are followed precisely.

Installation: When installing either type of flume, the crest should be used as an index. Careful levelling is necessary in both the longitudinal and transverse directions if standard discharge tables are to be used. In addition, a Montana flume should be used only under free flow conditions, i.e. where the maximum submergence limit (50% for 3 inches, and 60% for 6 inches) will not be exceeded. A submerged flow condition will exist if the tail water level divided by the flume gauge water level exceeds the percentages shown. Under free flow conditions a phenomenon known as the hydraulic jump forms and is a certain indication of free flow conditions. When a standing wave occurs downstream from the flume, submergence may be indicated.

> [**Note:** When portable flumes are used to collect individual discharge measurements, the upstream backwater effect caused by the installation should be allowed to stabilize prior to obtaining the final gauge reading. This may take some time in watercourses with low gradients. In addition, ensure that any temporary changes to

channel geometry due to the installation or removal of the flume do not affect the operation of a permanent reference gauge.]

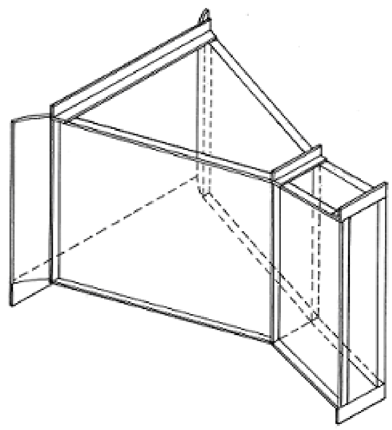


Figure 66: Montana flume.

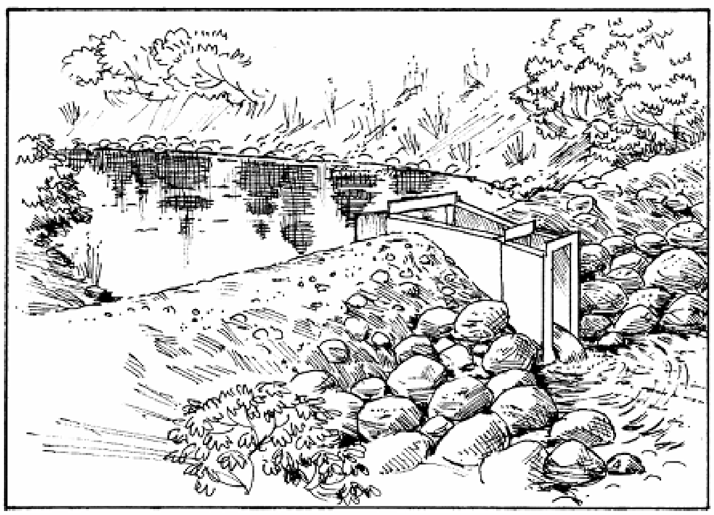


Figure 67: Montana flume installation.

Table 8: Dimensions for fabricating a Montana flume.

W	A mm	2/3A mm	B mm	C mm	D mm	E mm	F mm	G mm	R mm	Max. Head mm	Max. Free flow disch. L/s	Min. Free flow disch. L/s
3 in. or 76 mm	467	311	457	609	259	457	152	552	-	0.330	32	0.77
6 in. or 152 mm	621	414	610	915	397	610	305	800	406	0.457	110	1.5
9 in. or 229 mm	879	587	864	1169	575	762	305	952	406	0.610	251	2.5
12 in. or 305 mm	1372	914	1343	1953	845	914	610	1219	508	0.760	455	3.3

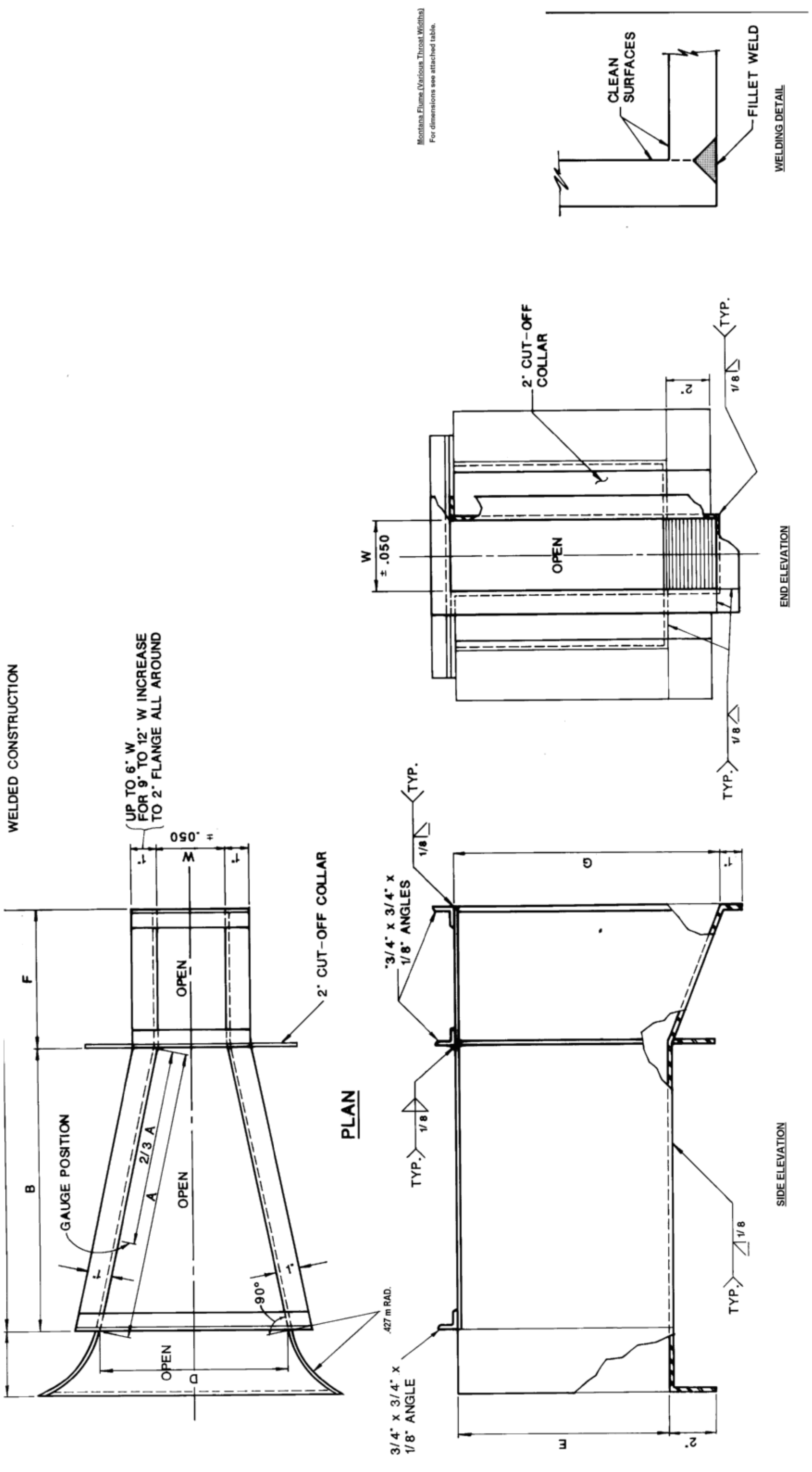


Figure 68: Various throat widths for the Montana flume.

4.4 Volumetric Measurement

Volumetric measurement is used to carry out fast, accurate measurement of flow. The sites chosen for such measurements are usually limited to the exits of culverts or below cascades with a clear confined nap.

Volumetric measurements may be made at the outlets of elevated pipes, culverts, and flumes. Individual measurements may be related to stage either by a staff gauge reading or by measuring the water level above or below a fixed reference point. Where outlets are too close to the downstream bed, it is sometimes possible to temporarily divert the flow through a flume (Figure 69).

In many cases culvert exits are too close to the streambed to catch the discharge in a suitably sized container. To convert these awkward sites to measurable ones may be accomplished by installing a 2- or 3-m length of plastic pipe in a sandbag and sheet plastic headwall. Setting the pipe to a level grade will often provide sufficient elevation above the streambed at the downstream end. In the absence of suitable piping, custom-made flumes can be constructed on site using 1x6-inch stock.

Volumetric containers should be calibrated by commercial standard weigh scales, stopwatches should be water resistant and rubber cased.

Figure 69: Culvert with low outlet and flow led into flume for volumetric measurement.

4.5 Comparison of Small Gauging Station Installation

Several types of gauging stations are suitable for use on small-to-medium watercourses. Each has advantages/disadvantages in terms of accuracy/efficiency, installation cost, and operational cost.

- Discharge measurement structure fitted with a digital water level data logger.

  This is the most efficient type of gauging station, as it has the potential to be multi-use. As well as recording water levels, a multi-channel data logger can record values from water and climate data quality sensors as well as water levels from other nearby installations. Several other applications are possible.

  [**Note:** Rated structures built and installed to tested standards require no further rating. Designs for nonstandard or modified structures must be accompanied by a theoretical stage/discharge curve, and then confirmed by taking a series of current meter discharge measurements.]

- A continuous water level recording device set in a pool where the water level is sensitive and stable over the full range of stage.

  The control for this type of installation can be a natural or an existing artificial structure. Either could be modified to bring about the required hydraulic characteristics. If necessary, design and construct an artificial control. This type of station must be rated by a series of current meter measurements over the full range of stage, confirmed by further two or more measurements per year in subsequent years (Figures 70 and 71).

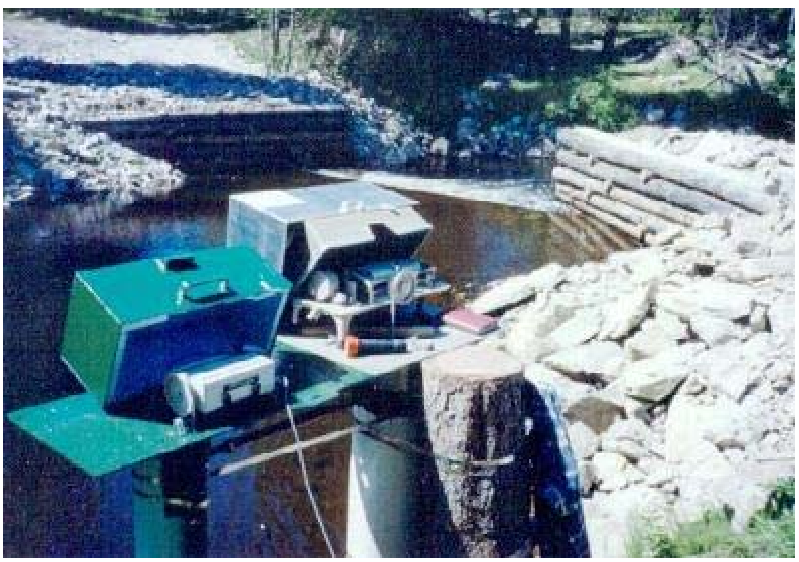


Figure 70: Two water level recorders: a data logger and an analogue recorder.

Figure 71: Pool formed by a modified Crump Weir, where both a digital and an analogue recorder are installed.

- A continuous water level recording device set in a pool where the water level is controlled by a downstream riffle composed of boulders, cobbles, or gravel.

  This type of installation may be subject to shift caused by erosion of the streambed and/or banks, and will be subject to temporary shifts due to the deposition of granular or floating debris. Therefore, an ongoing program of discharge measurement will be required. The water level record will also require careful examination and interpretation (Figure 72).

  [**Note:** A manually read gauge, no matter how stable, will not produce an accurate average daily water level reading, particularly on a small stream, because of diurnal fluctuations in the rate of snowmelt, or short storm events. Accuracy improves with the number of readings during the day.]

Figure 72: Boulder control (subject to debris build-up) and water level recorder stilling well and shelter. Narcosli Creek, above Ramsay Creek, West Fraser.

- Portable flumes.

  This type of discharge measuring device may be used to produce a series of individual miscellaneous discharge measurements, or it may be used in conjunction with a permanent gauge to produce a stage/discharge relationship. In the latter case, the flume must be located in a position that will not affect the water level at the gauge while the flume is installed, or after removal. Installations of this type are frequently used during low flow measurement programs or for checking ditch flows during irrigation periods. Because of the requirements for flume operation, these devices are favoured over portable weir installations. This is important in a low gradient stream. A 3 inch portable Montana Flume in shown in Figure 73.

Figure 73: Three-inch Portable Montana flume set in a temporary mud dam.

- Portable weir plates.

  Sharp-crested weir plates may be installed in locations where the upstream channel banks are high enough and wide enough to contain the elevated water levels and provide the end contractions necessary for fully contracted weir operation. Downstream channel geometry should provide free-flow conditions throughout the range of stage to be measured. Static head (h) is measured at a distance equal to 3.5 h (max. h), upstream of the weir crest (Figure 74). For example, if the water level in the weir pool can reach 0.6 m above crest, the gauge should be situated 2.1 m upstream of weir.

Figure 74: V-notch weir plate, portable installation.

- Elevated pipes, culverts, and flumes.

  Volumetric measurements may be made at the outlets of elevated pipes, culverts, and flumes (Figure 69). Individual measurements may be related to stage either by a staff gauge reading or by measuring the water level above or below a fixed reference point. Where outlets are too close to the downstream bed, it is sometimes possible to temporarily divert the flow through a flume

- High water conditions.

  In locations where higher stage discharge measurement may not be possible due to the unavailability of suitable measuring facilities or equipment, the channel reaches lying within the designated station limits should be explored to find a suitable site for measurements using indirect methods. Selected sites should be surveyed, permanently marked and the required values recorded. One of the most commonly used methods of indirect measurement is the slope area method (for details please see Chapter A2 of Book 3, *Measurement of Peak Discharge by the Slope-Area Method,* U.S. Geological Survey, 1984)

Chapter 5: Rating Streams and Computing Discharge

5.1 Introduction

A thorough understanding of the relationship between stage and discharge is the foundation of hydrometric work. This section details the steps involved in converting the field data to actual flow data set to provincial standards.

Discharge is the volume of water flowing through a given cross-section of a watercourse during a given or implied time period. A measurement of discharge at a given point in time has limited value by itself because it does not allow determination of daily or monthly flows or other flow parameters which are required to understand the streamflow regime. But for any stream location there is a correlation between water level and discharge, that once established, allows one to record the water level, which is relatively easy to do on a continuous basis, and estimate discharge from this correlation (water level, when recorded against a fixed reference is referred to as gauge height or stage).

Daily discharges are rarely measured directly because of the effort required. On occasion, when the effort is justified, it can be approximated by near continuous metering.

This Section will describe the stage-discharge relation and attempt to portray its importance to the practice of hydrometric surveying.

5.2 Stage-Discharge Relationship

Daily or continuous discharge data can not practically be obtained directly. It is however possible to obtain daily or continuous water level/stage data and from that a continuous discharge record can be estimated based on this relationship of water level and flow. The result is a correlation called the stage-discharge relationship.

To develop this relationship, discharge measurements are obtained at the gauging station over the maximum range of gauge heights possible. A history of the relationship evolves over time, as each discharge measurement and corresponding stage is plotted, and a smooth curve is drawn that best represents these points. This curve is converted to a table of discharge values for incremental gauge heights, which in turn is referred to as a stage-discharge table. Daily or continuous discharge can be derived from this table using a daily or continuous stage record.

> [**Note:** To develop the rating curve, a minimum of 10 discharge measurements, well distributed through the range of flows is recommended to use]

5.2.1 Development of a Stage-Discharge Rating Curve

The stage-discharge rating curve has historically been drawn by hand on standard arithmetical forms. Rating curve drawing can be performed mathematically by computer using standard graphics software as well as more specific applications. However, few hydrometric sites can be well represented by this method and therefore hand drawn curve is more desirable. Rating table can be derived from the digitization of this rating curve.

However, recent technological changes in graphing software can produce a reasonable discharge rating curve(s) as long as the following restrictions and criterion are considered:

- Stream geometry can change with depth and may require more than one equation.
- The relationship between plotted points is affected by chronological order. In the curve, dates should be added and must be constantly referenced.
- Confidence in data is not constant. Field personnel must give weight to the measurements based on experience.
- The difference between an errant measurement and a shift in the stage-discharge curve is a grey area therefore, skilled judgment is required when a curve fit equation is used.

There are a number of specialized software packages that can expedite the hydrometric data processing but do not replace the knowledge and skill of a competent hydrometric operator. The judgments required at various stages of the process must be suitably documented, whether manual or computerized processing is used.

5.2.2 Manual Curve Plotting

To determine the stage-discharge relationship, assemble all stage-discharge information, plot the measurements on a graph paper using X axis as Discharge (dependent variable) in m^3/sec and Y axis as Gauge Height (independent variable) in metres, then determine the best fit curve or curves. This procedure has been extracted and modified from the Manual of Hydrometric Data Computation and Publication Procedures, Fifth Edition, Inland Waters Directorate, Water Resources Branch, Environment Canada, 1980.

Proceed as follows:

Select scales on the curve sheet so that the significant figures, as required for the stage-discharge table, can be read with reasonable accuracy. Gauge heights are plotted on the vertical scale and the discharges on the horizontal scale. Suggested scales for the gauge height are 1 cm = 0.1, 0.2, 0.5, 1.0, or 2.0 m and for the discharge, 1 cm = 1, 2, 5, 10, 50, 100, 200, or 500 m^3/s. Make adequate provision for the entire range in stage which is known to have occurred during the history of the station. The stage-discharge relationship may have to be shown in one or more curves to obtain the degree of accuracy required for the computation of the stage-discharge table. Designate each curve as “low flow curve,” “high flow curve,” etc. Where feasible, carry each curve down to or near the “zero flow” stage. Allow for at least 0.3 m of overlap between curves and use more than one sheet, if necessary, to avoid cramping and confusion.

When a new curve sheet becomes desirable, first plot all extreme high or low discharge measurements from former years on the new sheet. Then on this new sheet, plot the latest applicable stage-discharge curve. Finally, plot all new open water measurements and, if necessary, plot a new stage-discharge curve.

Field discharge measurements will have been computed in the field and plotted in the Field Data Book. Any measurement that is considered an outlier should have a supplemental measurement completed before leaving the site. The supplemental measurement will confirm an error in the first or indicate a shift.

Indicate the plotted point for each discharge measurement by a dot surrounded by an open circle about 2 mm in diameter. Circles that indicate measurements for previous years should be color coded to distinguish them from the measurements made during the current year. Designate a discharge measurement by its date (e.g., June 12, 1997) with a diagonal line from the plotted point (use the same angle, say 60°, on each sheet or draw the diagonal line about perpendicular to the curve).

Any set of points which lie within 7% of a selected curve can be defined as Curve 1. Calculate deviations in Form RISC HYD-03. Positive and negative deviations should balance out.

Measurements known to be affected by backwater may be plotted in pencil or by use of a distinctive symbol. To identify measurements made by another organization, use a different symbol (e.g., a triangle, square, or cross) with an explanatory note in the lower right-hand corner of the curve sheet.

5.2.3 Determining Zero Flow Gauge Height

The presence of shallow flow and low gradients, often make it difficult to obtain discharge measurements at very low flows. Extending the low end of the stage-discharge curve to zero flow is desirable, but problematic, because of the lack of accurate measurements. A graphical technique for determining the gauge height for zero flow is explained below (Figure 75).

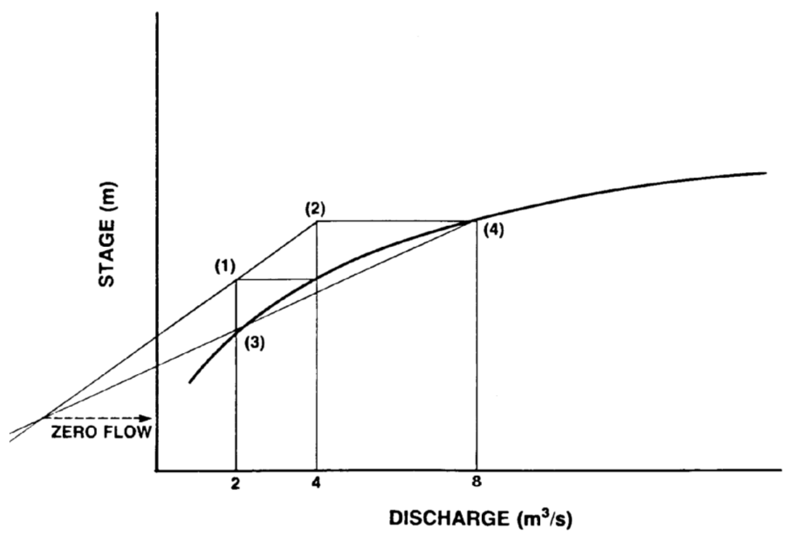


Figure 75: Graphical method for obtaining zero flow gauge height.

a. Refer to the current stage-discharge curve (example in Figure 75).
b. Take three discharges that are in a geometric progression. (For example, 2, 4 and 8 m^3/s).
c. Plot up from 2 m^3/s and across from 4 m^3/s to obtain point (1).
d. Plot up from 4 m^3/s and across from 8 m^3/s to obtain a second point (2).
e. Draw a line through these two points.
f. Draw a line through the points where 2 m^3/s and 8 m^3/s intersect the stage-discharge curve (points (3) and (4)).
g. The intersection of these two lines identifies the best estimate of the zero-flow gauge height.

[**Note:** For a stream where flow actually decreases to zero, it is possible to verify the estimate. This is more likely where there is a good control, however, it must be remembered that the water level can and does fall below the actual zero flow level.]

5.2.4 Extending the Rating Curve

For relatively new stations with few discharge measurements, it is often desirable to extend the stage-discharge curve beyond the highest discharge measurement available. This can be accomplished with the use of double logarithmic plotting paper. Plot the full range of measured discharges against stage. In most cases, this logarithmic plot of measurements will form a straight line in the high flow range. This makes it a useful tool in extending curves beyond the highest discharge measurement. The "curve" as determined in the log plot is then transferred to the standard stage discharge plot. However, according to RISC hydrometric standards curve can be extended up to the bank level i.e., either bank overtopped and data beyond measured discharge level will be graded as "E" i.e., estimated

Discharges estimated by indirect methods may be used to confirm the high end of the curve extension developed by the log plot. Indirect measurement of discharge is determined after the high water event has passed and involves engineering surveys to determine the geometry of the channel, and the application of hydraulic formulae. The most commonly used procedure is the slope-area method, which is described in various engineering texts.

5.2.5 Curve Labelling

The stage-discharge curve must now be numbered and labelled. Use the following procedure:

a) The first curve used in the first year of operation will usually be designated "Curve No. l." However, another number, such as 31, may be selected if desired, but always increase curve numbers in chronological order of when the curve was derived.

b) Use a diagonal line from the curve to the notation.

c) Label any succeeding curves as "Curve No. 2," "Curve No. 3," etc. (or "Curve No. 32," "Curve No. 33," etc.).

d) Enter the dates for the period of use of each curve in the space provided.

5.2.6 Stage-Discharge Tables

Having established a best-fit curve, complete with zero flow stage, the next step is to prepare a stage-discharge table (RISC HYD-05 Form, Figure 76) from the curve. The following procedure is used to compile a stage-discharge table from the stage-discharge curve:

- Identify the number of the stage-discharge table, which must correspond to the stage-discharge curve number. The data processor's initials and the date the table was compiled are recorded as well.
- When compiling the stage-discharge table, deviate as little as possible from the exact coordinates, as indicated by the curve. Express discharges to at least the same number of significant figures as required for daily discharges.
- When the stage-discharge table is completed, plot the values on the curve sheet to ensure that the original delineation of the curve is consistent with the table.
- In some cases, a new stage-discharge curve is exactly the same as a former curve through part of the range in stage. In preparing the new stage-discharge table for these areas, copy the data from the former table through the range of stage in which the new curve and the former curve are identical. Then compile the new table in the range of stage where the two curves diverge. The new table will cover the entire range of stage.

- If a stage-discharge curve is extended above or below the original range, an explanatory note should be added on the Remarks of RISC HYD-05 Form (Figure 76), as well as the date when this extension was made. Note that this applies only if the curve is extended and not if it is revised.

RISC HYD-05: Stage Discharge Rating Curve and Table

BRITISH COLUMBIA

Station Operation Agency/Firm: ***Water Stewardship Inc*** EMS Id[1]: ***E123456***

Station Name: ***Ayum Creek Near Mouth*** Station No.:***1AHA040*** (if any) Project No:***99HA040*** (if any e.g., FIA)

Stage Discharge (H/Q) Curve No. : ***1*** Creation Date (yyyy/mm/dd): ***2006/03/27***

☒ H/Q Curve Not Revised ☐ H/Q Curve Revised, Date of Revision (yyyy/mm/dd):________________

Number of H/Q points used to generate the curve: ***12*** Curve Period (yyyy/mm/dd): From ***2006/03/27*** To ***Present***

Highest Measured Discharge: ***15.743*** (m^3/sec). Corresponding Gauge Height/Stage: ***1.401*** (m)

Lowest Measured Discharge: ***0.000*** (m^3/sec). Corresponding Gauge Height/Stage: ***0.239*** (m)

Zero flow at Gauge Height/Stage: ***0.239*** (m). Approximate Bank Full Elevation (either bank overtopped): ***1.880*** (m)

Stage-Discharge Rating Table (i.e., Stage-Discharge Data from Rating Curve)

Stage, H (m)	Discharge, Q (m^3/sec)	Diff. in Discharge, (m^3/sec)	Stage, H (m)	Discharge, Q (m^3/sec)	Diff. in Discharge, (m^3/sec)	Stage, H (m)	Discharge, Q (m^3/sec)	Diff. in Discharge (m^3/sec)
0.239	*0.000*		*0.440*	*0.079*	*0.018*	*0.600*	*0.760*	*0.085*
0.255	*0.001*	*0.001*	*0.450*	*0.100*	*0.021*	*0.700*	*1.650*	*0.890*
0.278	*0.002*	*0.001*	*0.460*	*0.127*	*0.027*	*0.800*	*2.940*	*1.290*
0.340	*0.004*	*0.002*	*0.470*	*0.164*	*0.037*	*0.900*	*4.550*	*1.610*
0.350	*0.006*	*0.002*	*0.490*	*0.205*	*0.041*	*1.000*	*6.410*	*1.860*
0.360	*0.009*	*0.003*	*0.500*	*0.250*	*0.045*	*1.100*	*8.510*	*2.100*
0.370	*0.012*	*0.003*	*0.510*	*0.298*	*0.048*	*1.200*	*10.700*	*2.190*
0.380	*0.015*	*0.003*	*0.520*	*0.347*	*0.049*	*1.300*	*13.100*	*2.400*
0.390	*0.022*	*0.007*	*0.540*	*0.400*	*0.053*	*1.400*	*15.700*	*2.600*
0.400	*0.029*	*0.007*	*0.550*	*0.456*	*0.056*	*1.500*	*18.600*	*2.900*
0.410	*0.037*	*0.008*	*0.570*	*0.520*	*0.064*	*1.600*	*21.600*	*3.000*
0.420	*0.048*	*0.011*	*0.580*	*0.595*	*0.075*			
0.430	*0.061*	*0.013*	*0.590*	*0.675*	*0.080*			

[Note: To represent full range of the rating curve, enough data points should be presented in the above Table. Data points beyond the measured discharge level i.e., from curve extrapolation should be indicated in the Remarks.]

Remarks: ***Data points > GH1.401m estimated by extrapolation of curve***

Computed by: ***B. Booker*** Date (yyyy/mm/dd): ***2007/01/22***

Checked by: ***D. Checkoff*** Date (yyyy/mm/dd): ***2007/02/13***

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must

Figure 76: Example of completed RISC-05, Stage-Discharge Rating Curve and Table.

5.2.7 Daily Discharges

[**Note:** Portion of the material presented in section 5.2.7 have been prepared from Manual of Hydrometric Data Computation and Publication Procedures, Fifth Edition, Inland Waters Directorate, Water Resources Branch, Environment Canada, 1980.]

5.2.7.1 General

One of the basic objectives of hydrometric operation is to gather data for the determination of daily discharge. A detailed knowledge of the procedures involved in preparation of these data to publishable standards is essential.

While several automated procedures have been developed for the computation of open water discharges, the following sub-sections explain the procedures used in the manual preparation of Daily Discharges. Procedural mistakes could well arise if one is not aware of the functions the computer is performing during automatic computations. To truly understand the basic concepts of discharge computations, the procedures for manual data processing must be understood.

For daily mean discharge, gauge heights must be compiled. In the simplest case, a daily mean stage (or gauge height) is determined from the stage records. This is then used with the stage-discharge table to determine the daily mean discharge.

5.2.7.2 Subdivided Day Method

Computation of Daily Mean Discharge

The daily mean gauge height is often used to compute the daily mean discharge, as described above. However, a daily mean discharge determined directly from the daily mean gauge height may be in error for a number of reasons.

These reasons include:

(a) the rate of change as indicated by the shape of the stage hydrograph for the day and the proportion of time during which the stage is relatively high or low; and
(b) the relative curvature in the stage-discharge curve in the range of stage recorded during the day.

To obtain a more accurate determination of the daily discharge, it may be necessary to subdivide the day into two or more parts, determine the mean gauge height for each part, and determine the discharge for each mean gauge height. From these, compute the weighted mean discharge for the day. If the resultant weighted mean discharge differs from that determined using the mean gauge height by more than the selected allowable limit of 2% for discharge above a predetermined amount, then subdivision is necessary for all similar conditions.

To determine whether it is necessary to subdivide, examine the data and select a few sample days that may be critical because of the conditions listed in (a) to (b). Compute the daily mean discharge for these days: (1) from the daily mean gauge height, and (2) by subdivision. A few tests of this nature will provide the necessary experience for the particular station upon which to base future decisions regarding the necessity of subdivision. It should be noted, that with the availability of computers, calculations for each stage reading can easily be converted to discharge and resultant mean daily discharge will negate the requirement to subdivide the daily mean gauge height as outlined above.

Allowable Range Tables

Allowable range tables may be used to determine if a day for a particular station needs to be subdivided. The following trial and error procedure is used for drawing up allowable range tables. A hypothetical example extracted from the Manual of Hydrometric Data Computation and Publication Procedures, page 27 (Environment Canada 1980), is used to illustrate the procedure:

a. From the stage-discharge table, select a range in stage during medium flow, for example, from 3.0 to 4.0 m.

   Suppose that the discharge at gauge height 3.0 m equals 186 m^3/s and the discharge at gauge height 4.0 m equals 339 m^3/s. The mean discharge for this range in stage would then equal 262 m^3/s.

   However, you observe that at a mean gauge height of 3.5 m, the discharge is only 252 m^3/s. This represents a difference of 4% (10 divided by 262 x 100) which is not allowable.

b. Select a smaller range, for example from 3.0 to 3.4 m. Calculate the mean discharge for this range in stage. Compare the mean discharge with the actual discharge at the mean gauge height for this range. Now you get a difference of 1%. This is too low, but 3.0 to 3.6 m gives 2%, which is satisfactory.

c. Now try a range between 4.0 and 4.6 m. This gives a 1% difference, which is too low. Try between 4.0 and 5.0 m, which give a 3% difference. Therefore, an allowable range of 0.8 m is about right.

d. The range from 6.5 to 7.5 m will give 2%.

e. After several such attempts, you will develop an approximate allowable range table. When in doubt, subdivide.

5.2.7.3 Computation of Daily Discharge Using Application Software

The daily discharges, as well as the daily maximum/minimum and the annual instantaneous maximum/minimum discharges, can be computed using application software.

One of the benefits of using the computer for discharge computations is that the discharges are computed for each water level value, instead of for the daily mean only. This eliminates the need for computing using “sub-divided days”.

5.3 Summary of Discharge Measurements

5.3.1 Introduction

Notes and records obtained in the field are the basis of the office computation of hydrometric survey data. It is essential that all data be identified at every step in the computation process. Once the daily gauge heights have been determined the Summary of Discharge Measurements Form, RISC HYD-03 (Figure 77) must be completed for all discharge measurements obtained during the period. The steps for completing this form are as follows:

- Enter the date and time of the discharge measurement. If a non-conventional technique, such as 1/4 point velocity culvert etc., was used in measuring the discharge, indicate the method of measurement in the “Remarks” column.
- Enter the name of the person and/or the organization who made the measurement, as appropriate.

- Enter the channel conditions, meter information (i.e., type, recalibration, and field verification), number of verticals used, width, total area, mean velocity and total discharge using 3 significant figures in the appropriate column of RISCHYD-03 form (Figure 77). If ice is present in the stream, or if the discharge is estimated, insert the appropriate reference or symbol in the "Remarks" column.
- Extract the weighted mean gauge observation corresponding to the measured discharge from reference gauge reading and data logger gauge reading on the front sheet of the Discharge Measurement Field Form. Apply the appropriate gauge correction from History of Gauge Levels, RISC HYD-02 form to this observation and enter the result in the "Mean Corrected Gauge Height" column. If there are unusual conditions affecting the stage-discharge relation, such as inflow between the gauge and the measuring section, note this in the "Remarks" column. Gauge height must be recorded to 3 decimals (e.g., 1.342 m).
- If discharge measurements at a station are made at more than one location, a symbol should be entered under "Remarks" to distinguish them in the event that it is necessary to use the cross-sectional area or the mean velocity.
- If any other information pertinent to the discharge measurement is obtained, note this in the "Remarks" column.

RISC HYD-03: Summary of Discharge Measurements

BRITISH COLUMBIA

Station Operation Agency/Firm: ***Water Stewardship Inc*** EMS Id[a]: ***E123456***

Station Name: ***Ayum Creek Near Mouth*** Station No. ***1AHA040*** (if any) Project No. ***99HYD040*** (if any e.g., FIA)

Date (yyyy/mm/dd)	Time 24hh:mm PST	Metered by	Channel Cond. (use Code 1,2,3,4 or 5)[b]	Meter Type (e.g. Price type AA)	Meter Calibration (use Code 1,2,or 3)[c]	Meter Field Verification (use Code 1,2,or 3)[d]	Width (m)	No of Verticals used	Mean Correct. Gauge Height/ Stage (m)	Total Area (m^2)	Mean Velocity (m/sec)	Total Disch (m^3/sec)	From Stage Discharge Table: Table No. 1			Table No.			Remarks
													Disch (m^3/sec)	Diff.	%	Disch (m^3/sec)	Diff.	%	
2007/03/02	*12:15*	*bb*	*1*	*OSS PC1*	*1*	*1*	*10.1*	*23*	*0.490*	*0.625*	*0.349*	*0.218*	*0.217*	*0.001*	*0.50*				
2007/04/15	*13:02*	*bb*	*2*	*OSS PC1*	*1*	*1*	*10.1*	*22*	*0.511*	*2.607*	*0.124*	*0.322*	*0.305*	*0.017*	*5.60*				
2007/05/22	*14:10*	*aa*	*1*	*Braystock*	*2*	*3*	*9.3*	*23*	*0.386*	*0.285*	*0.063*	*0.018*	*0.019*	*-0.001*	*-5.30*				
2007/05/22	*09:30*	*aa*	*1*	*FloTracker*	*1*	*1*	*9.2*	*20*	*0.340*	*0.230*	*0.022*	*0.005*	*0.005*	*0.00*	*0.00*				
2007/07/12	*10:30*	*bb*	*1*					*0*	*0.239*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*				*Obs "0" Flow*
2007/10/10	*11:30*	*aa*	*2*	*Price AA*	*2*	*1*	*9.2*	*22*	*0.621*	*4.349*	*0.198*	*0.863*	*0.864*	*-0.001*	*-0.01*				
2007/11/03	*15:50*	*bb*	*1*	*OSS PC1*	*1*	*1*	*9.4*	*19*	*0.742*	*5.486*	*0.399*	*2.187*	*2.134*	*0.053*	*2.50*				
2007/11/30	*14:35*	*bb*	*1*	*OSS PC1*	*1*	*1*	*9.3*	*20*	*0.886*	*6.753*	*0.606*	*4.089*	*4.278*	*-0.189*	*-4.40*				
2007/12/28	*16:10*	*bb*	*1*	*OSS PC1*	*1*	*1*	*11.4*	*23*	*1.400*	*10.242*	*1.486*	*15.252*	*16.20*	*-0.948*	*-5.90*				

Computed by: ***B. Booker*** Date (yyyy/mm/dd): ***2008/01/15*** Checked by: ***D. Chekoff*** Date (yyyy/mm/dd): ***2008/01/22***

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[a] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

[b] Channel Condition Code
- 1: Fixed Control, stable channel, straight reach, measurements consistent with rating curve, no weeds, boulders or debris
- 2: Stable channel, relatively straight reach, measurements consistent with rating curve, minimal weeds or boulders
- 3: Minor hydraulic problems related to channel instability, measurements are not consistent with rating curve, weed growth or occasional boulders
- 4: Unstable channel due to erosion, degradation or aggradations; variable backwater, turbulence, significant weed growth, boulder bed
- 5: Undefined

[c] Meter Calibration Code
- 1: Meter calibrated and the validity of calibration is confirmed
- 2: Meter previously calibrated but validity of calibration is not confirmed
- 3: Undefined

[d] Instrument Field Verification/Comparison Frequency Code
- 1: At least annually
- 2: Less often than annually
- 3: Undefined

Figure 77: Example of completed Form RISC HYD-03 Summary of Discharge Measurements (see Appendix-III for blank form)

5.3.2 Shift and Backwater Corrections

5.3.2.1 General

A shift is defined as a temporary change in the stream control which alters the stage–discharge relation. The stage–discharge relation is not permanent at most stations but varies gradually or abruptly because of changes in the physical features of the control. If the change in the rating persists for several months, this may be an indication that a new rating curve should be prepared for the period of time during which the new stage–discharge relation is in effect. If the change is of short duration and is easily reversible (e.g., an obstacle hung up on the control), the original rating curve is still effective but, during this period, shifts or adjustments must be applied to the recorded stage before determining the corresponding discharge. Frequent discharge measurements must be made during any period to define the magnitude of the shift(s) when the condition is not correctable. For most gauging stations the stage-discharge curve represents the best-fit or average line and may not necessarily pass through all plotted points. That is, the stage-discharge relation is usually subject to minor random fluctuations.

Backwater is defined as a temporary rise in stage produced by an obstruction in the stream channel downstream of the gauge caused by ice, weeds, control structure, etc. The difference between the observed stage for a certain discharge and the stage as indicated by the stage-discharge relation for the same discharge is reported as the backwater at the station.

5.3.2.2 Computation of Shift and Backwater Corrections

The computation of shift and backwater corrections is as follows, (adapted from the Manual of Hydrometric Data Computation and Publication Procedures, Fifth Edition, Inland Waters Directorate, Water Resources Branch, Environment Canada, 1980.)

a. For many stations, a shift in the station control or a backwater condition may occur at certain times during the year as a result of weed effect, beaver action or ice conditions. During such periods, shift or backwater corrections are determined from available discharge measurements.

b. However, apart from these measurements which plot off the curve for reasons indicated above, most of the measurements will plot somewhat off the curve as a result of normal scatter. For these, no correction is computed; however, it is normally found useful for purposes of expressing mathematically the degree of scatter to indicate for each measurement the percentage difference between measured discharge and the discharge indicated by the stage-discharge relation. These percentage differences are entered in the "Diff." column on RISC HYD-03 form (Figure 77).

c. The following is an example of the computation of shift and backwater corrections, and the "difference" between measured discharge and the indicated discharge from the stage–discharge table:

    1. From a discharge measurement, the mean gauge height is 1.621 m and the discharge is 3150 m^3/s. From the stage–discharge table, the discharge of 3150 m^3/s corresponds to a gauge height of 1.323 m, indicating that a shift correction of -0.298 m would have to be applied to the mean gauge height for the day to produce results consistent with the discharge measurement.
    2. From a discharge measurement (in RISC HYD-03 form, Figure 77), the mean gauge height is 0.511 m and the discharge is 0.322 m^3/s. From the stage–

discharge table, the gauge height of 0.511 m corresponds to a discharge of 0.305 m^3/s.

The difference between the measured discharge and that indicated by the stage–discharge table is :

$$\frac{(0.322 - 0.305)}{0.305} \times 100 = 5.60\ \%$$

d. A discharge measurement made during the computation period may plot substantially off the stage-discharge curve. It is recommended that discharge measurements be computed and plotted on site and redone if it plots off the curve. This can often determine if it is a bad measurement or if a shift has occurred. However, sometimes the second measurement can not be done, or sometimes it is done and the departure can not be explained. If, after careful analysis and review, no satisfactory cause of its departure from the stage-discharge curve can be determined, the measurement should be eliminated from use in the computation. In this instance, do not enter any figure in the “Diff.” column but enter an explanatory note in the “Remarks” column on RISC HYD-03 form (Figure 77). This should be a rare occurrence for good hydrometric stations and experienced hydrometric operators.

5.3.2.3 Distribution of Shift and Backwater Corrections

Several methods of distributing shifts may be used. Two of the more common methods are linear distribution by time and stage-shifting. These techniques will be briefly discussed here. A more comprehensive treatment of shifts may be found in Rantz *et al.* (1982), pages 354-360.

Linear Distribution by Time

If the date on which the change occurred is not known, assume that the change occurred uniformly and distribute the correction in accordance with one of the two following methods:

1. Divide the change in the correction by the number of days to find the “change per day”. For example: Suppose the correction was found to be +0.005 on March 20 and +0.009 on March 30. The number of days involved is 10 and the change in correction is 0.004. The change per day is 0.0004. The corrections to be applied are shown to the nearest thousandth of a metre.
2. When the change is small and the number of days is large, the preferable method is to divide the number of days by the change in correction. For example:

    A correction of +0.003 is applicable on May 25, but on October 15 is +0.006, a period of 144 days.

    Solution: Three 0.001 m increments are applied at intervals of 48 days as follows:

    No change in correction will be applied during the first one-half interval of 24 days, i.e., the correction +0.003 will be continued from May 25 to June 17; an increase of 0.001 in the correction will be applied during each of the next two intervals of 48 days, i.e., a correction of +0.004 from June 18 to August 4 and +0.005 from August 5 to September 21.

    The remaining 0.001 change will be applied during the remaining one-half interval, i.e., the final correction of +0.006 will be applied from September 22 to October 15.

Stage-Shifting

Stage-shifting is normally done because of a temporary, or short-term condition at a gauging station. For example, perhaps a minor peak has occurred at a station, and discharge measurements indicate a significant change to the stage-discharge curve at higher stages. A short time later, a major flood drastically alters the stage-discharge relationship, requiring an entirely new stage-discharge curve. Instead of drawing two new curves with accompanying rating tables, the minor peak may be stage-shifted, and a new curve can be drawn for conditions following the major flood.

5.3.3 Station Analysis

Although the Station Analysis Form, RISC HYD-06 will not be dealt with in this section, the reader should be aware that pertinent facts regarding the open water computations should be noted for eventual inclusion in the station analysis.

For instance, the reasons for the distribution of the gauge and shift corrections, including the stage-shifting; the period of use of stage-discharge tables; etc.

In particular, any deviation from the commonly practiced computation procedure should be tabulated in the station analysis.

Chapter 6: Standard Process for Review of Hydrometric Data

6.1 Introduction

Water quantity monitoring stations are operated by a large variety of agencies, firms or individuals. To ensure the quality of such data or to archive the data of known quality within the provincial database the information must be reviewed for accuracy and approved by individuals who are qualified to assess the information.

An archival data collection system should include a validation or review process in order to maintain its scientific credibility. This process consists of a review encompassing station setting and facilities, data records, and all supporting documentation.

6.2 Role & Responsibility of a Qualified Hydrometric Data Reviewer

The Qualified Hydrometric Data Reviewer or Reviewer is identified as the individual responsible for reviewing the dataset and for assignment of data grade. The Reviewer should be involved throughout all stages of hydrometric program. The Reviewer may initiate their activities after the end of the calendar year (or part of it as assigned) when data compilations and checking are completed however, they must understand the details associated with how the data are collected, must be able to identify any non-standard information, recognize the underlying causative factors and make sure the calculations are correct. The Reviewer will assess the forms, plots, relevant documentation, verification procedures that support the data presented. When all is in order, the subject dataset will be signed (and sealed if appropriate) by a Qualified Hydrometric Data Reviewer (e.g., a P.Eng., P.Geo., RPF, P.Ag., RPBio, AScT, CTech with appropriate qualifications, please see Section 6.3.2 for details) after assigning standard data grade according to standards requirement criteria (Table 1).

The Reviewer should first review the Station Analysis from (RISC HYD-06) for the designated period and ***must sign*** (and seal if appropriate) it for compliance to RISC hydrometric standards before submission for archiving. If available, the comparison hydrographs and regional analysis should be inspected. Before assigning grade A/RS for discharge data from rating structure (e.g., weirs, flumes etc.), the Reviewer must ensure that the appropriate conditions for using rating structure and its rating equations were met.

The Reviewer should also verify the following documentation for clarity and completeness:

- Description of Hydrometric Station (RISC HYD-01)
- Gauge Level Field Notes
- History of Gauge Levels (RISC HYD-02)
- Gauge Corrections
- Discharge Measurement Field Form
- Summary of Discharge Measurements (RISC HYD-03)
- Water Stage Recorder-Station Log (RISC HYD-04) plus any other pertinent information
- Stage-discharge tables (in spreadsheet format) (RISC HYD-05)
- Daily Gauge Height (manual gauging station)
- Daily Discharges

- Hydrographs
- Worksheets

In addition, the Reviewer must judge the extent of the review necessary to approve the data based on:

a) problems arising from the above review;
b) measuring site condition, watershed hydrology, land use and water use;
c) knowledge of the regional stream flow regime;
d) number of years the station has been operating;
e) confidence in the experience of the data collector;
f) extent of missing data due to observer negligence or instrument malfunctioning;
g) completeness and clarity of the documentation.

The review should include an evaluation of the following items that require judgment and interpretation and are often a source of error:

Gauge Level Field Notes: for correct procedure, reliability of bench marks and stability of gauges, and adequate frequency of level checks.

Discharge Measurement: for suitability of meter type, calibration, appropriate number of verticals and velocity sample points, and gauge height.

Water level recorder plots: for time corrections, evidence of siltation or plugged intakes

Stage-discharge curve: for correct plotting of discharge measurements, shift corrections and timing, and deviations from curve; review for adequate number of measurements; extrapolation for high and low flow range; stability of the channel control.

Stage-discharge table: for change dates, number of coordinates from curve, smooth rate of change, reasonable extrapolations (high and low flows), low flow rating, coverage of full recorded range.

Daily Gauge Height: for consistent recorder/gauge height readings, and continuity between the end of the previous year's water level and the beginning of the current year.

Daily Gauge Height Hydrograph: for anomalies in hydrograph (steps, spikes, recession curve)

Daily Discharges: for method used to estimate discharges for missing data periods, and continuity between the end of the previous year's discharge and the beginning of the current year.

Daily Discharge Hydrograph: for anomalies in hydrograph (steps, spikes, recession curve)

Once the data are checked and verified, the Reviewer must determine what standard grade (i.e., according to Table 1: Standards requirement criteria) should be assigned to the dataset. Assigning of a standard grade to the dataset may appear to be a simple matter, but in reality a great deal of judgment may be required. By signing the Station Analysis, RISC HYD-06 form (Figure 78), the Reviewer ***must*** accept the responsibilities for their evaluation and gradation of dataset.

After having been assigned an appropriate data grade the Reviewer must submit the following at least annually:

1. Raw and corrected time series stage and discharge data (15 minutes interval, 00:00-23:45 and daily mean with timestamp of 23:59) with data grade [i.e., date and time, stage in in metres to 3 decimal accuracy; discharge in m^3/sec to 3 decimal accuracy and, data grade].

2. All completed RISC HYD forms (RISC HYD-01 to RISC HYD-06) in digital format, or PDF only if digital format is not available.

3. Completed Gauge Level Field Notes and Discharge Measurements Field Forms (in digital / PDF format).

4. A copy of any final or annual station reports including all completed RISC HYD forms, Gauge Level Field Notes and Discharge Measurements Field Forms, rating curve(s), and analyses in PDF[4] format.

Detailed specifications for data submission (e.g. formats) will be available from designated Ministry of Environment staff.

Where data is later revised for any reason (for example revision to rating curve), the Reviewer must submit revised time series datasets or other revised data or metadata, as described above. The Reviewer should retain all pertinent data and deliverables for a period of ten (10) years for future audits (if required).

[4] Adobe Portable Document Format

BRITISH COLUMBIA

RISC HYD-06: Station Analysis for the Period:

From *2007/01/01* (yyyy/mm/dd) **To *2007/12/31*** (yyyy/mm/dd)

[Note: This form must be signed by hydrometric data approver with appropriate professional seal and submitted both original and a PDF copy to the database administrator to capture in provincial water database]

Station Operation Agency/Firm: ***Water Stewardship Inc*** EMS Id: ***E123456***

Station Name: ***Ayum Creek Near Mouth*** Station No.***1AHA040*** (if any) Project No.***99HYD040*** (If any e.g., FIA)

Number of Level Checks Made Per Year: ☒ 2 or more ☐ 1 or more ☐ None/Undefined

☒Gauge Correction NOT Required

☐Gauge Correction Required (see table at right):

Date and Time (yyyy/mm/dd 24hh:mm)	Correction (m)

Discharge Record

Discharge (m^3/s)		Corresponding Gauge Height (m)	Date and Time (yyyy/mm/dd 24hh:mm PST)
Max. Inst. Discharge	***20.30***	***1.584***	***2007/12/29 13:00***
Max. Inst. Measured Discharge	***15.25***	***1.400***	***2007/12/08 16:20***
Min. Inst. Measured Discharge	***0.00***	***0.240***	***2007/07/12 10:10***

Number of Manual Flow Measurements Per Year: ☒ 5 or more ☐ 3 or more ☐ 2 or more ☐ Less than 2/ Undefined

Missing Period		Reason
From (yyyy/mm/dd)	To (yyyy/mm/dd)	
2007/04/15	***2007/04/29***	***Float cable broken at weight mount***

Stage Discharge Relationship

	Curve No.	Start Date (yyyy/mm/dd)	End Date (yyyy/mm/dd)	Cause for the Shift
Previous Year	***1***	***2006/03/27***		
Present Year	***1***			

Remarks: Discharge estimates for missing periods derived by graphical comparison to:

Climate Station(s): ***Victoria*** Other Hydrometric Station(s): ***Sooke River 08HA039***

Standard Procedure followed for hydrometric operation:

☒ RISC Standards (i.e., *Manual of British Columbia Hydrometric Standards*)

☐ None/Unknown ☐ Other, Specify: _______________

All field forms including notes, RISC HYD Forms RISC HYD-1 through HYD-6, data and calculations were reviewed for anomalies: ☒ Yes ☐ No

Instruments and methods used for hydrometric operation were appropriate for the field condition: ☒ Yes ☐ No

Reviewed time series water level and discharge data with metadata were submitted to the Provincial Water Database: ☒ Yes ☐ No

Results were compared with other stations and/or other year for check: ☒ Yes ☐ No

Data can be made available to public: ☒ Yes ☐ No

DATA DECLARATION

I, ***Data Checkoff, P.Eng.***, have reviewed all data and operating information for this hydrometric station. Data Grades have been assigned as per standards requirement criteria as defined by the *Manual of British Columbia Hydrometric Standards*.

Date (yyyy/mm/dd)	Professional Seal/Signature	Designation	Professional/Technological Association
2008/02/14	*D. Checkoff*	***P.Eng***	***Association of Professional Engineers and Geoscientist British Columbia (APEGBC)***

Figure 78: Example of completed Form RISC HYD-06 Station Analysis for the Period:

6.3 Qualified Hydrometric Data Reviewer

The review of hydrometric dataset requires a thorough knowledge of the mechanics of flow measurement and data collection. The specific role of the Reviewer is to ensure that the field procedures used to obtain the discharge and water level data comply with the standard procedure; to ensure that the required documentation is complete; to ensure that the computation procedures are correct and appropriate; to assign a standard grade; and to designate the data as official for archiving and publication. The extent of the review process will generally consist of fairly rigorous and focussed spot-checking. Because the data may come from a variety of sources with minimal prior checking and review and the Reviewer must be prepared to carry out a detailed inspection. Thus, a Reviewer should have experience with the installation, and operation of a hydrometric station, which should include gauge level surveys, measurement and calculation of discharge, rating table development, gauge correction, and so forth. Equally important, however, is training in open channel hydraulics, hydraulic structures, river hydraulics and morphology, surveying, mathematics and statistics. Acceptance of the necessity of these training areas limits the range of professions that are able to comply. Therefore, a member of a legally incorporated professional/ technological association, having appropriate experience, training & academic background will be required for data review within the RISC hydrometric standards. The obligation will be on the professionals of other specializations to establish their training and experience credentials in this field, which should include experience gained in British Columbia. Only a person who fulfills the requirements for Qualification of Hydrometric Data Reviewer see Section 6.3.2) can review hydrometric data and assign standard Grade according to RISC hydrometric standards.

6.3.1 Rationale for Reviewer's Qualifications

The role of the Reviewer requires intimate familiarity with all aspects of hydrometric operations, from site selection to the compilation of annual or seasonal water level and discharge data. The Reviewer must be able to view the documentation and records provided by the data collector and judge the level of review and checking required to approve and determine a standard Grade for the data. The use of the appropriate equipment and procedures for the site conditions must be assessed which requires experience in hydrometric field operations covering a variety of flow regimes and channel conditions, water level recording methods and instruments, flow measurement devices and methods.

The steps leading to the compilation of daily discharge and water level are clearly defined, but there can be a large amount of technical judgment and interpretation guided by experience at certain points due to instrument malfunction, missing records, and inaccurate flow measurements. The better the understanding of hydrometric survey procedures, hydraulics, hydrology, mathematical methods, and instrumentation, the better the chance of obtaining a complete and reliable set of data. The Reviewer must understand exactly how the data were computed and how any estimated data were generated. It is obvious that without some kind of training from hydrometric experts and a substantial amount of field and office experience it would be difficult to obtain the knowledge and skills necessary to be act as a Hydrometric Data Reviewer.

6.3.2 Qualifications of Hydrometric Data Reviewer

Suitable candidates for "Hydrometric Data Reviewer" fall into 2 categories of **minimum** requirements. Category (I) is qualified on the basis of substantial practical training and experience in all aspects of hydrometric operations. Category (II) is qualified on the basis of post-secondary level education combined with additional practical experience.

Category (I).

- is a graduate from an accredited university, technical institute or community college with a diploma in engineering or resource discipline

- is registered as a member of a legally incorporated professional/technological association (i.e., APEGBC, ABCPF, BCIA, CABBC, or ASTTBC as an example)
- has completed a formal, comprehensive training program in hydrometric surveys
- has 7 full-time years of hydrometric survey experience in site selection, operation and maintenance, of which, a significant portion must include experience in supervising other hydrometric technicians and reviewing hydrometric data workup prior to approval.

Category (II).

- is a graduate from an accredited post secondary institute with a degree in engineering or a resources discipline,
- is registered as a member of a legally incorporated professional/technological association (i.e., APEGBC, ABCPF, BCIA, CABBC or ASTTBC as an example),
- has successfully completed courses at technical institute, college or university in:

    Hydrology

    Open channel hydraulics

    Plane Surveying

    Mathematical methods

    Statistics and probability

    and, not necessary, but desirable:

    Electricity and electronics

    Computer Application

    Fluid mechanics

    Climatology and weather

    Fluvial geomorphology, and

- has at least two (2) years full-time employment conducting hydrometric surveys with field and office duties in hydrometric operations, or
  has:
    - selected sites, installed water level recording and metering equipment, and operated for at least two years, five hydrometric stations on streams with both rated structures and natural control
    - carried out at least 10 discharge measurements by wading or from bridge and calculated discharge, and;
    - computed and compiled two years of daily water level and discharge data for five stations for both manual and automated water level installations.

Knowledge for categories (I) and (II) must also include operational expertise in the following:

- use, maintenance and limitations of velocity meters, flumes and weirs
- installation and levelling of manual water level gauges
- float-activated water level recorders-digital and analogue
- data loggers, water level sensors and programming software
- is familiar with all methodologies and principles in the *British Columbia Hydrometric Standards*

(Appendix V gives descriptions of general course content required, and lists courses available from a selection of Canadian universities.)

APPENDICES

Appendix I. Glossary

The following glossary of selected hydrometric terms is derived from two sources: 1) ISO Standards (ISO T72: 1988(E) for all terms related to hydrometric operations, river hydraulics and stream sedimentation, and 2) Resources Information Standards Committee for Aquatic terms, including Hydrometric terms.

Accuracy: The degree of closeness of individual measurements or calculated quantity to its actual (true) value.

Approach channel: The reach of the channel upstream of the gauging structure in which suitable flow conditions shall be established to ensure correct gauging.

Backwater: A rise in stage produced by an obstruction in the stream channel caused by ice, weeds, control structure, etc. It may be caused by channel storage for which the reservoir properties vary with the depth of flow at the given location. The difference between the observed stage for a certain discharge and the stage as indicated by the stage-discharge relation for the same discharge is reported as the backwater at the station.

Bank, right or left: The margin of a channel as viewed facing ***downstream***. The expression “right” or “left” applies similarly to right or left abutments, cableway towers, etc.

Bankfull Discharge: In a single channel stream, the discharge which just fills the channel without flowing on to the floodplain; the point at which overbank flow begins.

Bench mark: A permanent, fixed reference point for which the elevation is known. It may, when practicable, be related to GSC datum.

Broad-crested weir: A weir of such crest length in the direction of flow that critical flow occurs on the crest of the weir.

Calibration: Calibration is defined as the cleaning, lubricating, and adjustments required to achieve prescribe limits.

Control: The condition downstream from a gauging station that determines the stage discharge relation. It may be a stretch of rapids, a weir or other artificial structure. In the absence of such features, the control may be a less obvious condition such as a convergence of the channel or even simply the resistance to flow through a downstream reach. A shifting control exists where the stage-discharge relation tends to change because of impermanent bed or banks.

Critical flow: The flow in which specific energy (depth of flow + velocity head) is a minimum for a given discharge; under this condition a small surface disturbance can not travel upstream. The ratio of inertia to gravity forces (Froude Number) is equal to unity.

Cross-section of a stream: A specified vertical plane through a stream bounded by the wetted perimeter and the free surface.

Current meter: A piece of equipment used to measure the stream velocity.

Data grade: Quantitative ranking of water level and discharge data based on four criteria: instrumentation, stream channel condition, field procedures, and data calculation and assessment.

Data logger: An instrument used to record the monitoring data. It may internal or external.

Discharge, Q: The volume of liquid flowing through a cross-section per unit of time. It is not synonymous with "flow".

Discharge coefficient: A coefficient in the discharge equation, in general relating the actual discharge to a theoretical discharge.

Discharge measurement: The determination of the rate of discharge at a gauging station on a stream, including an observation of 'no flow', which is classed as a discharge measurement.

Drowned flow; submerged flow: The flow which is influenced by the water level downstream from the measuring structure.

EcoCat: EcoCat or Ecological Reports Catalogue is a document and file management system that allows users self-access to reports for various ecological projects within British Columbia. Web address of EcoCat: http://www.env.gov.bc.ca/ecocat/

Float gauge: A manual gauge consisting of a float that rides on the water surface, rising and falling with the surface. The float's movements are transmitted to an indicating device.

Flood mark: A trace of any kind left by a flood on the banks, obstacles or flood plain. It may be used to determine the highest level attained by the water surface during the flood.

Floodplain: Any flat or nearly flat lowland that borders a watercourse and is covered by its waters at flood stage.

Flow: The movement of water in a channel without reference to rate, depth, etc.

Flow Character: The surface expression of the water, described as follows:

P-Placid-tranquil, sluggish

S-Swirling –eddies, boils, swirls

R-Rolling- unbroken wave forms numerous

B-Broken-standing waves are broken, rapids, numerous hydraulic jumps

T-Tumbling-cascades, usually over large boulders or rock outcrops

Flume: A specially shaped open channel flow section that may be installed in a channel to measure discharge. Depending on the shape of the section, flumes may be termed Parshall, Montana H-flumes, cut-throat, etc.

Free flow; modular flow: A flow which is not influenced by the level of water downstream from the measuring device.

Gauge correction: Any correction that must be applied to the gauge observation or gauge reading to obtain the correct gauge height.

Gauge datum: The elevation of the zero of the gauge (referenced to bench marks, or Geodetic Survey of Canada, GSC datum) to which the level of the liquid surface is related.

Gauge height: See **Stage**.

Gauge observation; Gauge reading: An actual notation of the height of the water surface as indicated by a gauge, it is the same as a "gauge height" only when the 0.000 metre mark of the gauge is set at the "gauge datum".

Gauging section; measuring section: The cross-section of an open channel in the plane of which measurements of depth and velocity are made.

Gauging station: The complete installation at a measuring site where systematic records of water level and/or discharge are obtained.

Head on (or over) the weir: Elevation of the water above the lowest point of the crest, measured at a point upstream. The distance upstream for the point of measurement depends on the type of weir used but is upstream of the transition zone from sub- to supercritical flow at full weir flow.

Hydraulic jump: The sudden passage of water in an open channel from super-critical depth to sub-critical depth, accompanied by energy dissipation.

Hydrometric operator: The person collecting the hydrometric data.

Inclined gauge; ramp gauge: A gauge on a slope, generally graduated directly to indicate vertical gauge height.

Left [right] bank: The bank to the left [right) of an observer looking downstream.

Level check: The procedure followed to determine the movement of a gauge with respect to the gauge datum.

Manual gauge: A non-recording type of gauge from which observations of stage are obtained.

Mean velocity at a cross-section: The velocity at a given cross-section of a stream, obtained by dividing the discharge by the cross-sectional area of the stream at that section.

Mean velocity depth: The depth below the surface at which the mean velocity on a vertical occurs.

Metadata: Metadata is data about data. In other words, it is a structured summary of information that describes the data. In case of this Manual, Metadata is the data associated with the RISC HYD forms.

Modular limit; point of incipient submergence: The condition of flow where a rising downstream level just begins to affect the discharge.

Open channel: The longitudinal boundary surface consisting of the bed and banks or sides within which the liquid flows with a free surface. The term “channel” generally means the deep part of a river or other waterway, and its meaning is normally made clear by a descriptive term**,** either stated or implied, such as “low water” channel, “main” channel, “artificial” channel.

Painting: This refers to the wide ink trace on water level recorder analogue charts that is caused by short term water level fluctuations or by a malfunction in a recorder having a gas purge system.

Panel: The area at a vertical defined by the depth at that vertical multiplied by one-half of the distance between the preceding and the succeeding verticals.

Peak stage: The maximum instantaneous stage during a given period.

Point method (one-; two-; three-; five-; six-): Method of measuring the velocity in a vertical by placing a current-meter at a number of designated points in the vertical.

Processed data: Data that has been corrected for errors, invalid data spikes, drift, shift and correction factors applied in case of water level as an example.

Quality assessment: The System of activities used to ensure that quality assurance procedures are implemented and quality control elements are evaluated.

Quality assurance: All the procedures used to manage/control the component of hydrometric operations.

Quality Control: The system of activities used to verify that data are of acceptable quality and they are complete and correct.

Range: The lowest to highest value that a sensor or instrument can detect with the same resolution and accuracy.

Reach: A length of open channel between two defined cross-sections.

Reference point: A point of known elevation from which measurements may be made to a water surface. It is also known as a “measuring point”.

Resources Information Standards Committee (RISC): A committee that ensures that required standard method are developed and used in environmental monitoring.

Resolution: The smallest interval that a sensor can detect.

RISC hydrometric standards: The field procedures, calculations, validation steps and documentation mandated by Resources Information Standards Committee of British Columbia for conducting a hydrometric survey.

Sensitivity (of the stage-discharge relation): A measure of the change in stage at a gauging station due to a change in discharge. When a small increase in discharge produces a relatively large increase in stage, the relation is said to be sensitive. When a large increase in discharge produces a relatively small increase in stage, the relation is said to be insensitive.

Sensor: An instrument used to measure one or more water quantity parameter.

Shift: A change in the stream control which alters the stage-discharge relationship. This change can be either temporary or permanent.

Slope-area measurement: A method of computing peak flow at a gauging station by determining the water surface profiles and channel dimensions over a short reach of a stream.

Slope-area method: An indirect method of discharge estimation in a reach based on the surface slope, the reach roughness, the wetted perimeter and flow areas of the various cross-sections in the reach.

Sounding: The operation of measuring the depth from the free surface to the bed.

Stable [unstable] channel: A channel in which the bed and the sides remain stable [unstable] over a substantial period of time and in which scour and deposition during the rising and falling stages are negligible [appreciable].

Staff gauge: A manual gauge consisting of a graduated plate or rod that is set vertically in streambed or attached to a solid structure.

Stage: The elevation of the free surface of a stream, lake or reservoir relative to a gauge-datum. it is used interchangeably with the terms “gauge height” and “water level”.

Stage-discharge relation: A curve, equation or table which expresses the relation between the stage and the discharge in an open channel at a given stream cross-section.

Steady flow: Condition in which the discharge does not change [changes] in magnitude with respect to time.

Stilling basin: A pool downstream of a structure in which the velocity and the energy of the flow are reduced.

Stilling well: A well [tube] connected with the stream in such a way as to permit the measurement of the stage in relatively still conditions (natural surging is dampened).

Stilling-well lag: During conditions of rising and falling stage in a channel, the difference at a given time between the channel stage and the stilling-well stage.

Stream: The generic term for water flowing in an open channel, e.g., including creeks and rivers.

Stream gauging: All of the operations necessary for measuring discharge.

Sub-critical flow: The flow in which the Froude number is less than unity and surface disturbances can travel upstream.

Submergence ratio: The ratio of the downstream measured head to the upstream total head over a weir, the crest being taken as the datum.

Sub-surface float: A float with its greatest drag below the surface for measuring sub-surface velocities.

Surface float: A float with its greatest drag near the surface for measuring surface velocities.

Throat: The minimum cross-sectional area within a flume. The throat may be rectangular, trapezoidal, U-shaped or of another specially designed shape.

Validation: A systematic evaluation of all of the data to find and deal with errors.

Velocity-area method: Method of discharge determination deduced from the area of the cross-section, bounded by the wetted perimeter and the free surface, and the integration of the component velocities in the cross-section.

Velocity of approach; approach velocity: The mean velocity in an open channel at a known distance upstream of a measuring section.

Verification: The act of confirming the equipment accuracy using a traceable standard or master.

Vertical: The vertical line in which velocity measurements or depth measurements are made.

Vertical velocity coefficient: The coefficient applied to a single, or an equivalent single, velocity determination at any depth in a vertical to infer the mean velocity on that vertical.

Wading rod: A light, hand-held, graduated, rigid rod, for sounding the depth and positioning the current meter in order to measure the velocity in shallow streams suitable for wading. It may also be used from boats or ice cover, at shallow depths.

Water level: see **Stage**

Water level recorder: An instrument that records water levels in an analogue or digital form. The recorder may be actuated by a float or by any one of several other sensor types.

Weir: An overflow structure built across an open channel to measure the discharge in the channel. Depending on the shape of the opening, weirs may be termed rectangular, trapezoidal, triangular, etc.

Wetted perimeter, P: The wetted boundary of an open channel at a specified section.

Wire-weight gauge: A gauge consisting essentially of a graduated wire or chain, weighted and lowered to make contact with the surface of the water. Contact with the water surface is determined visually.

Appendix II: Current Meters

II.1 Introduction

The purpose of this section is to review several commonly used current meter types and models available in Canada and to describe the care, maintenance and testing of the current meter.

II.2 Comparison of Vertical Axis and Horizontal Axis Current Meters

Table II-1 lists the current meters have been used for the collection of discharge data by BC government staff. All current meters are periodically calibrated by the National Calibration Service at the National Water Research Institute, Burlington, Ontario.

Hydrologists of the U.S. Geological Survey have studied both the laboratory and field results for meter precision, linearity, and response to oblique flow angles. The current meter types tested included most of the meters shown below and compare the performance of vertical and horizontal axis mechanical meters. The electromagnetic meter was also tested.

Percent standard error for all meters tested was less than 2% with the vertical axis meters providing the most consistent response.

Both horizontal and vertical-axis meters tested had good precision (percent standard errors < 0.75 % for velocities >24.4 cm/s) and a similar linearity of response (Root Mean Square < 2.01 cm/s).

Table II-1. Commonly used current meters.

Vertical Axis Current Meters	Horizontal Axis Current Meters
Price Type AA	Valprot BFN 002 (Braystoke)
Price Type AA Magnetic	OTT 5 (Arkansas), 2 impellers (replaced by C31)
Price Type AA Photo-Fibre Optic (Swoffer retrofit #2200)	OTT, C31, 3 impellers
Price Winter Model AA	OSS, B1, 2 impellers (identical to C31)
Price Pygmy	OTT, C1, 3 impellers (replaced by C2 & OSS, PC1)
Price Pygmy Photo-Fibre-Optic (Swoffer retrofit #2200)	OSS, PC1, 2 impellers (identical to C2)
	Swoffer 2100, 1 impeller

II.3 Oblique Flow Tests

The magnitude of error for horizontal-axis meters is usually smaller than those for vertical-axis meters in oblique flows. Two horizontal-axis meters, the Ott C-31 meter with A and R impellers had the smallest error in oblique flows. At angles between $\pm 10^0$, errors ranged from -7.87% to 8.92% for the vertical-axis meters and from 2.02% to 3.77% for the horizontal-axis meters.

Unfortunately neither the Ott C2 nor the OSS PC1 was included in the above study. (The Ott and OSS meters are identical - components are interchangeable). However, the impellers supplied with these meters accurately compensate for angular flow to the limits specified by the manufacturers (Table II-5). These meters have, together with the earlier model Ott C1, served as the preferred meter for the measurement of flow in watercourses less than 0.3 m deep.

The Swoffer retrofitted Price type AA and the Price Pygmy do not have relatively large chambers on the upper section of yoke and therefore present a more symmetrical shape to the current. The presence of the contact chamber is one of the factors listed as a possible cause of the rather large errors encountered in the oblique flow tests on standard Price meters It is therefore likely that the absence of these chambers on the retrofit models will produce more accurate results in oblique flows.

The electromagnetic current meter has smaller errors than the vertical axis meters for most angles tested.

II.4 Vertical Axis Current Meters

II.4.1 General

Three models of vertical axis meters are in general use in Canada: the Price 622AA meter, the WSC winter meter, and the Pygmy meter. This section describes these meters.

II.4.2 Price Type AA

The Price Type AA meter (Figures II-1 and Figure II-2) is the most common vertical shaft meter and is often considered the “standard” for discharge measurement. It has been subjected to extensive research and experimentation and shown to be well suited to a wide variety of field conditions. The Price Type AA is the principal meter used by the WSC and many other agencies to determine discharge.

Only one bucket wheel assembly is required for the entire range of velocities encountered during normal stream gauging operations. Providing that it is properly maintained, the meter responds accurately to velocities ranging from 2.0 to 300 cm/s. Although the Price Type AA has been in use for 80 years and has an established record of dependability and durability, this meter must be treated with the same care and attention given to any scientific instrument. Damaged components can cause erroneous measurements, which can go undetected for long periods of time.

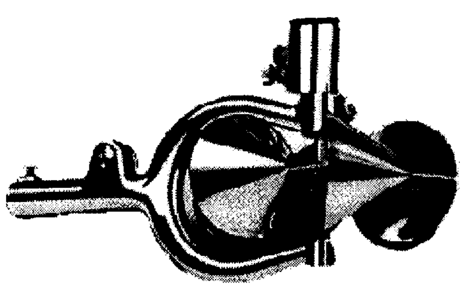

Figure II-1. Price Type AA current meter (622 AA).

The main components of the current meter are the pivot and rotor, the contact chamber, and the yoke and tail assembly (see Figure II-2). The rotor has six cone-shaped elements and is 125 mm in diameter. The letter “T” stamped on the inner portion of the frame indicates the top side of the bucket wheel. When in use, the rotor moves in a counter clockwise direction.

The key feature of the Price meter is the location of both the upper and lower bearing surfaces in fairly deep, inverted cavities which trap air when the meter is submerged. This effectively excludes water-borne silt from the bearing surfaces, which eliminates undue wear. Worn bearings or any other damage to the cup wheel will result in change in the meter rating. This meter may be attached to the standard USGS top-setting rod or the Columbus weight hanger. Mounting adapters, with or without the relocating device, are available from the manufacturers of the 20-mm bridge rods.

On the upper extension of the rotor is a chamber where cup rotation produces an electrical pulse for conversion of angular motion to stream velocity. This contact chamber is fitted with a bearing, a penta gear, and two insulated binding posts. Each post has a fine contact wire.

The top of the rotor shaft is rounded to provide a smooth surface where it comes in contact with the bottom of the chamber cap. Immediately below the rounded end, an eccentric is cut in the shaft. This is the means by which the shaft makes contact with the upper contact wire once during each revolution of the rotor. The next section of the shaft fits into the contact chamber bearing lug. A short section of acme thread is cut into the shaft below the bearing section. This meshes smoothly with the penta gear fitted in the bottom of the contact chamber. The penta gear has two tabs, each of which brushes the lower contact wire once during every five revolutions of the rotor.

Generally, the standard Price type AA meter does not provide a signal suitable for use with an electric pulse counter in lower velocity regimes. When an eccentric makes a single contact with the “ cat’s whisker”, several pulses may be generated and registered on the counter. The usual method of operation is to time the revolutions of the rotor either visually, or by means of an electrically generated audio signal. The Price meter can, however, be modified for use with a counter; see the next section.

The design and use of current meter vanes in cable suspension assemblies may be a problem in certain forms of turbulent flow. The problem lies with the suspension point (hanger bar) being equidistant between the rotor axis (of a vertical axis meter) and the hydrodynamic centre of the directional vanes, as is the case for the standard Price meter. This meter is inherently sensitive to lateral turbulent fluctuations due to low degree of directional stability, and can introduce an error to the measurement of velocity. The effect the hanger, rotor and vane relationship can only be assessed during field tests in streams over a complete range of turbulent length scales, these conditions can not be duplicated during tow tank calibrations.

1. Eccentric for single count
2. Acme thread
3. Rotor shaft
4. Rotor hub
5. Hub nut
6. Raising nut
7. Rotor pivot
8. Pivot adjusting nut
9. Set screw
10. Contact chamber cap or head cap
11. Connection to power source
12. Binding posts
    upper-single count
    lower – penta count
13. Contact chamber (contains gearing for penta count)
14. Yoke (upper and lower limb)
15. Hanger connection
16. Tailfin or top-setting wading rod connection
17. Rotor or impeller

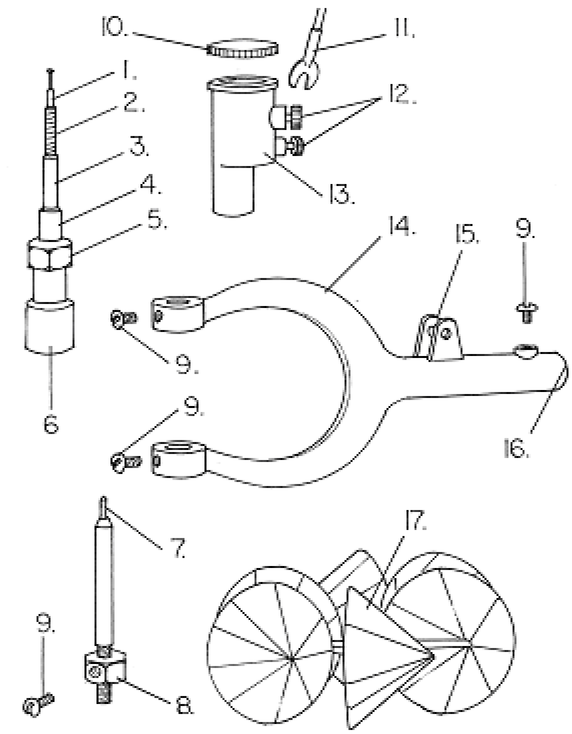

Figure II-2. Components of the Price 622AA current meter.

II.4.3 Modified Price Type AA Meter

The standard Price Type AA (622) meter can be modified in two ways, using retro-fit kits, to compensate for the low-velocity limitations.

1. *Magnetic Switch Contact Chamber*-Price Type "AA" Magnetic Head (AA-MH). This accessory produces a “clean” signal for triggering an automatic electric pulse counter.

   A 13-mm long permanent magnet is embedded in the top portion of the rotor shaft. This shaft fits into the centre of a special contact chamber (Figure II-3). A magnetic reed switch, which is accessible from the top of the assembly, is located in a chamber adjacent to the rotor chamber. The binding post and the insulating bushing seal this chamber. During each revolution of the rotor shaft, the magnet passes the chamber and closes the reed switch for a moment. Price 622AA current meters supplied with magnetic reed switches are usually referred to as low velocity models. However, in this case the maximum measurable velocity depends on the pulse rating (pulse/s) of the counter unit employed. The electronic revolution counters manufactured by OTT, Sherlock, and

Braystoke, for example, have a maximum counting frequency of 20 pulses/s while some earlier electro-mechanical units were limited to 10 pulses/s In either case the maximum velocity measurable exceeds 5 meters/s while low velocity measurement accuracy is increased due to the absence of friction caused by contact wires.

2. Fibre-Optic Contact Chamber (Figure II-3 and II-4). A retrofit kit, consisting of a fibre-optic sensor electrically connected to a digital readout indicator replaces the contact chamber, bucket-wheel shaft, earphones, and stopwatch on both Price 622AA and Pygmy meters. The model 2200 indicator, and other supplied parts, are designed and manufactured by Swoffer Instruments, Seattle, Washington.

   The counter may be set to read direct velocity (display averaging 10 s for the 622AA, and 5 s for the Pygmy), or seconds vs. revolutions. Also, a calibration mode allows the continued use of a damaged meter for a limited time period, by electronically compensating for a meter that does not rotate according to its original specifications.

   > [**Note:** This feature does not absolve an organization, working to Provincial Standards, of the requirement for regular calibration of current meters by the National Water Research Institute.]

   One of the most important features of this retrofit is its ability to measure accurate low velocities while using both the 622AA or Pygmy current meters. Because the fibre-optic sensor does not require that physical contact be made and broken to produce a signal, as in the “cat’s whisker” type, nearly all friction has been eliminated. This means that velocities lower than 3 cm/s can be accurately determined while the counter is in the seconds/revolutions mode. The maximum velocity range of a retrofitted current meter is 4.5 m/s.

   > [**Note:** The fibre optic sensor should not be used with reel or handline suspension systems using the suspension cable as the sensor signal wire. Problems have been encountered in connecting to, and signal strength through, the Ellsworth type two conductor cable used by these systems. The fibre optic sensor, which attaches to the replacement meter head, is housed at the end of a two conductor cable. The sensor to counter cable connection is supplied in a standard length of 3 m for use with a wading rod but may be ordered in lengths up to 300 m. Ordering a factory 7-m or 10-m sensor cable for use with a bridge rod will also expand the capabilities of the retrofit for use with a handline or reel.]

1. Yoke
2. Binding posts
3. Contact chamber or head
4. Impeller or rotor
5. Connection to power source
6. Travel cap
7. Connection to power source

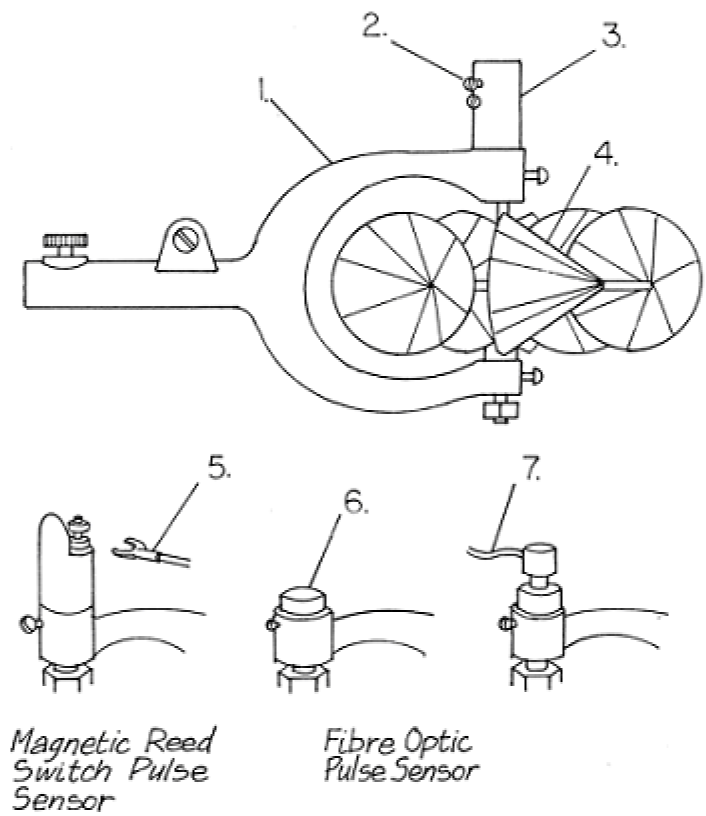

Figure II-3. Price 622AA meter with alternative pulse sensors.

Figure II-4. Fibre optic retrofitted Price 622AA.

II.4.4 Pygmy Meter

The Pygmy meter is approximately two-fifths the size of the Price 622AA meter. It is designed for measuring streams that are too shallow to use the Price meter.

> [**Note:** This meter is not recommended for measuring velocities under 0.3 m/s because the leverage exerted by the small-diameter rotor is insufficient to consistently overcome the variable frictional component in the contact chamber; the result is poor accuracy at low velocity. The fibre-optic sensor retrofit kit, described earlier, converts the Pygmy meter to an instrument capable of accurately measuring velocities as low as 0.03 m/s.]

As with all other current meters, individual calibrations are maintained for the Pygmy meters. The major difference is that the Pygmy meters are towed at lower velocities, from 2.5 to 140 cm/s.

The two meters differ in other significant ways. The Pygmy meter contact chamber and yoke are one unit. The chamber has only one contact wire that signals each revolution of the bucket wheel shaft. The meter is meant to be mounted on a wading rod. Because it is used in very shallow depths, it has no tailpiece nor can it be suspended from a cable.

The bucket wheel is only 50.8 mm in diameter, and it revolves 2*3* times faster than the larger Price meter. Unless an automatic pulse counting device is used, the rapidly revolving bucket wheel limits the meter to measuring velocities that are 1 m/s or less. When not in use, the steel meter pivot must be replaced with the special brass shipping pivot. The bucket wheel is not equipped with a raising nut, and the pivot and bearing can be damaged if the steel pivot is not replaced when the meter is not being used.

II.4.5 Maintaining the Meter

The life expectancy and daily efficiency of a current meter depend largely on the thoroughness with which the operator cleans and lubricates the moving parts of the instrument.

Cleaning and lubricating the Price type current meters is simple. It takes only a few minutes and should <u>not</u> be postponed or neglected. During this process, all parts must be carefully examined to ensure that they are working. It is normal practice to clean and lubricate at the end of each day. However, if the meter has been used in a stream that is heavily laden with suspended sediment, clean the meter immediately after the measurement. This helps to prevent abrasive particles from causing premature and unnecessary wear to the bearing surfaces. Maintenance instruction of a Price 622AA meter is presented in Table II-2.

> [**Note:** If water is already trapped in the head, and in the pivot bearing on the underside of the bucket wheel, applying oil to the pivot may increase the wear. Adding oil keeps the water in contact with the finely machined surfaces, and carries grit and silt to the bearings. This causes wear and corrosion.]

Table II-2. Maintenance Instructions for the Price Type AA meter.

Part(s)	Part No.(see Figure II-2)	Procedure
Head cap	10	• Remove, wipe dry and clean lower face. • *Oil* the underside.
Contact chamber	13	• Remove by slackening setscrew in upper limb of yoke. • Dry & wipe out inside of head.
Shaft	3	• Clean & wipe dry, paying particular attention to the bearing journal at the upper end and the worm and the ball head on the top of the shaft. • *Oil* the top of the shaft. • *Oil* the worm gear.
Pivot bearing on underside of bucket wheel	17	• Wipe • *Oil*
Pivot (points & sides)	7	• *Oil*

[**Note:** All of the cleaning and drying should be completed before the parts are oiled.]

II.4.6. Information summary for vertical axis meters.

Summary of vertical axis current meters including advantage and disadvantages are presented in Table II-3

Table II-3. Information summary for vertical axis meters.

Name and Model of Meter and Type of Pulse Generation	**General Comments**	**Advantages & *Limitations***
• Price Type AA • Scientific Instruments Inc. Model # 1210 • Wire-contact penta chamber	• Cup-type • One cup usually painted red to facilitate visual revolution count. • Designed for either cable (hanging bar) or wading rod suspension.	• Robust • Easily maintained • Capable of measuring full flow range. • *Angular flow corrections must be applied.* • *Poor definitions in turbulent conditions.* • *Inaccuracies may occur at very low velocities.* • *Unsuitable for use with electronic counters.*
• Price Type AA Magnetic • Scientific Instruments Inc. Model # 215 622AA retrofit kit available. • Magnetic-reed switch	• Penta chamber replaced by a magnetic reed switch contact chamber and a permanent magnet in the upper post. • The single, insulated electrical binding post is behind a shield on the upper surface.	• The design of this meter allows for improved low flow sensitivity. • The sensor produces a clean signal for use with electronic counters. • *Angular flow corrections must be applied.* • *Poor definitions in turbulent conditions.*

Table II-3. Information summary for vertical axis meters (*Cont*.).

Name and Model of Meter and Type of Pulse Generation	General Comments	Advantages & *Limitations*
• Price AA Optic • Swoffer Instruments Model # 2200 Retrofit • Fiber-optic sensor	• The fiber optic sensor is threaded on to the infrared generator lying almost flush with the yolk.	• Rotational friction is brought to a minimum by the non-contacting photo-fiber-optic device. • Accurate readings down to and below 0.03 m/s are attainable. • *Angular flow corrections must be applied.* • *Poor definitions in turbulent conditions.*
• Price 625 Pygmy • Scientific Instruments Inc. Model # 1205 • Wire-contact penta chamber.	• Two-fifths the size of the Price 622AA. • Designed for use in shallow streams. • No tail piece • Always used with a rod mount.	• *The low leverage exerted by the 49-mm d. rotor over the variable resistance of the wire contact signal sensor can produce inaccurate results at low velocities.*
• Price 625 Optic • Swoffer Instruments Model 2200 Retrofit • Fiber-optic sensor	• Similar to Price 625 Pygmy but the upper post and wire-contact chamber are replaced by an infrared generator. • The light pulses are converted to electrical pules by a fiber-optic sensor.	• The reduced frictional component (see above) of the retrofit can producer accurate measurements in velocities of 0.03 m/s.

II.5 Horizontal Axis Current Meters

II.5.1 General

Horizontal axis meters are capable of very accurate flow measurement in areas of local turbulence. The component effect of the rotors compensates for angular flow in both the horizontal and vertical planes, and the orientation of the rotor provides for a balanced translation of the linear motion when measuring near the vertical faces at either edge of a channel. All models use the magnetic reed switch to generate the rotational pulse count, thus avoiding the variable frictional component inherent in ‘make and break’ systems.

A small horizontal axis current meter continues to be the principle instrument used by Provincial agencies in British Columbia to measure small shallow streams, while the larger models are the preferred for use with bank-controlled cableways and bridge rods.

> [**Note:** The criteria for surface and bottom observations using horizontal axis meters is that the axis of the current meter should not be situated at a distance less than 1½ times the rotor height from the water surface, nor should it be situated at a distance less than 3 times the rotor height from the streambed. The rotor heights (diameter) of the meters vary from a minimum of 30 mm to a maximum of 125 mm.]

II.5.2 Braystoke BFN 002 Meter

This current flow meter is supplied in kit form, the accessories include a sturdy 1.5-m, 2 section wading rod graduated in 1-cm divisions, a control unit and 3-m connecting cable with quick release connectors. An optional cable suspension kit includes a 30-m suspension/signal cable, suspension bar and current meter tailfin. Longer sectional rods can be supplied as an option.

The Braystoke current meter, manufactured by Valeport Developments Ltd. UK, is designed for the measurement of flow velocities in fresh water or salt water, and is not affected by water quality. The meter will operate in shallow streams of only 6 cm or suspended to any depth and covers the entire range of velocities from 0.03 to 5.0 m/s with the 50-mm-diameter x 0.10-pitch impeller. The manufacturer does not specify the extent of oblique flow up to which the propeller measures the true velocity value; however, field and laboratory tests conducted by others indicate the impeller follows the rule of cosine in oblique flows of up to 10° with an accuracy of ±2%.

II.5.3 OTT C2 and OSS PC1 Meters

The OSS PC1 is identical to the OTT C2. OSS PC1 is manufactured in Australia and the OTT C2 in Germany. These models are designed to measure water velocity in small natural watercourses, ditches, flumes, small pipes, and laboratory river models. The meter can be mounted on a standard 9-mm wading rod. Adapters are available for use with the 20-mm bridge rod and the U.S. Geological Survey (USGS) top setting rod (Table II-4, and Figures II-5, and II-6).

> [**Note:** Both models require special oil for operation. The use of any other type of oil will affect the calibration rating of the meter. This oil, Shell Telus 5, is not sold in North America and must be ordered from Europe or Australia.]

The OTT C2 provides the choice of six 50-mm and two 30-mm propellers, while the OSS PC1 has a choice of three 50-mm and one 30-mm (Table II-5).

Table II-4. Specifications of the OSS PC1 and OTT C2 meters.

Switch	Propeller	Mounting
• Encapsulated reed, with permanent magnet set into rotating shaft • Single contact/revolution. • 9-V DC. • Max. power 1.6 watts (if spark suppression in counter).	• Slip-on type. • Anodized aluminum alloy. • Supported on bearings within the oil-filled hub of the propeller assembly.	• 9-mm diam. wading rod. • 20-mm diam. bridge rod with clamp (which can also be attached to bottom section of the locating device). • USGS top setting rod with adapter.

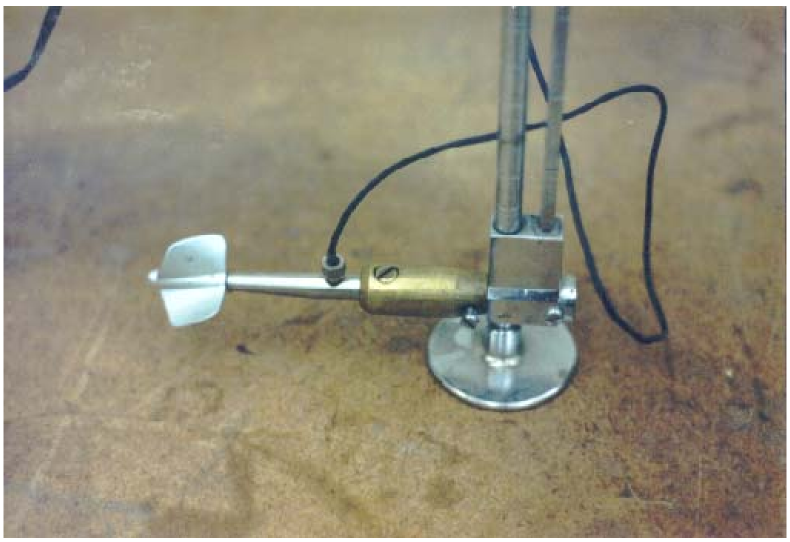

Figure II-5. OSS PC1 with adapter for use on a USGS top setting rod.

1. Impeller
2. Body
3. 9 mm wading rod
4. Adapter for top-setting wading rod
5. Wrench for disassembly for oiling
6. Shaft and bearing assembly removed
7. Special oil

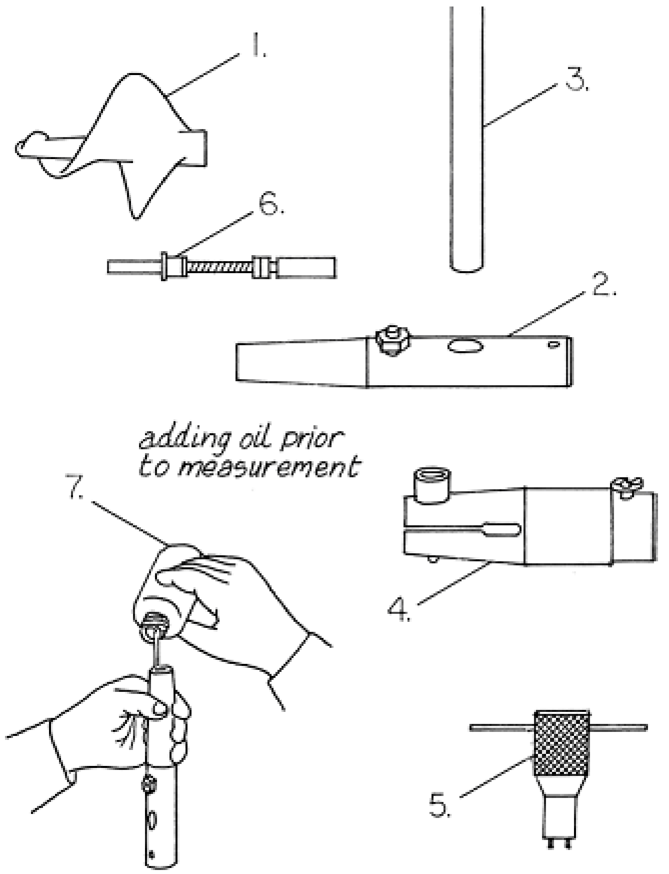

Figure II-6. Components of the OSS PC1 meters.

Table II-5. Description of propellers for the OTT C2 and OSS PC1 meters.

Propeller number (engraved)	Diam. & pitch (mm & m)	Max. water velocity (m/s)	Starting speed (m/s)	Range of component effect (degrees)
1 [a]	50 0.05	2.0 (1.0) [b]	0.025	30
2	50 0.10	4.0 (2.0)	0.030	20
3 [a]	50 0.60	6.0 (4.0)	0.035	10
4	50 0.60	7.5 (5.0)	0.060	5
5 [a]	30 0.05	2.0 (1.0)	0.050	20
6	30 0.10	4.0 (2.0)	0.055	10

[a] Propellers supplied by OTT are also available with the OSS PC1. All propellers can be used with either meter.
[b] Maximum water velocities, shown in brackets, are when the meters are used with electro-mechanical type counters such as the OTT-Z21 (10 pulses/s). Electronic counters such as the Z210, CMC 20, or 200 accept 20 pulses/s.

II.5.4 Universal OTT C31 and OSS B1 Meters

The OTT C31 is identical to the OSS B1; the former is manufactured in Germany and the latter in Australia. These current meters are used to determine the flow velocity of water in open channels and the sea, as well as in pressure pipes. These meters can be used under extreme conditions with the following methods of suspension:

- 20-mm wading or bridge rods with direct connection to the rod or the relocating device casing (Figures II-7).
- Two conductor cable and weight assemblies of the following types, available from either manufacturer:
  - Handline and hanger with a choice of 5-kg or 10-kg weights.
  - Portable winch, standard weights, and hanger.
  - Portable winch or double drum (shore-controlled) cableway winch with 25-, 50-, or 100-kg “middle piece” weights equipped with electrical ground feeler (Figure II-8).

Other special options are available for integration measurements, e.g. pressure pipe installations and sliding meter attachments.

Table II-6 lists propellers available from the two manufacturers for the OTT C31 and the OSS B1, together with the velocity range and component effect for each propeller. The maximum water velocities shown can be measured only by means of counters with a counting rate of up to 20 rev/s.

As with the small propeller meters, the components of the OTT and OSS meters are interchangeable.

Figure II-7. OTT C31 current meter fitted on a 20-mm rod, with relocating device. Note that the locating device, at top, is aligned with a meter.

Figure II-8. OSS B1 current meter mounted on a 30-kg sounding weight (middle), with a bottom feeler.

Table II-6. Description of propellers for the OTT C31 and OSS B1 meters.

Meter	Type	Diam. & pitch (mm & m)	Max. water velocity (m/s)	Starting speed (m/s)	Range of component effect (degrees)
OTT-C31	brass	125 0.25	5.0	0.025	5
	plastic	125 0.25	5.0	0.035	5
	brass	125 0.50	6.0	0.040	5
	plastic	125 0.50	6.0	0.060	5
	brass	1.25 1.00	10.0	0.055	5
	brass	80 0.125	3.0	0.040	5
	brass	100 0.125	2.5	0.030	45
	aluminum	100 0.25	5.0	0.035	15
OSS-B1	stainless steel	100 0.125	4.0	0.030	45
	stainless steel	125 0.50	10.0	0.040	5
	stainless steel	80 0.125	4.0	0.040	5

II.5.5 Maintenance of Horizontal Axis Current Meters

II.5.5.1 Care and Maintenance

During storage, the propeller should be removed from the meter and the oil drained from the body. If bearings need to be cleaned, they should be flushed with clean white spirits or gasoline. Spare bearings have a protective grease coating which should be removed before they are used.

Before the meter is used, clean oil should be added to the body by holding it upright and half filling as shown in Figure II-6 (Fig.7). As the axle bush is screwed back onto the carrier, any excess oil will be forced up through the capillary gap around the axle and should be wiped away. Spin the propeller for about a minute to check the condition of the bearings and to ensure proper oil distribution. Maintenance instruction of an OSS PC1 meter is presented in Table II-7.

Table II-7. Maintenance instructions for the OSS PC1 meter.

Part(s)	Part No.(see Figure II-6)	Procedure
• Propeller	1	For storage, remove from meter & drain oil.
• Bearings	6	Clean, flushed with white spirits or petrol.
• Main body	2	• Wipe dry • Oil, as the axle bush is screwed back onto the carrier, excess oil will be forced up through the capillary gap around the axle and should be wiped away. Spin the propeller for about one minute to check the condition of the bearings and to ensure proper oil distribution. • Check the manual as to whether oiling should be added before &/or after use.
• Electric pulse counting mechanism	6	• Use procedure in manual to ensure that it is operating correctly.

II.4.6. Information summary for vertical axis meters.

Summary of horizontal axis current meters including advantage and disadvantages are presented in Table II-8.

Table II-8. Information summary of horizontal current meters

Name, Type of Pulse Generation and Model Number	**General Comments**	**Advantages and *Limitations***
• OSS – PC1 Pygmy Meter or Ott – C2 • Magnetic-reed switch • These two meters are identical, with interchangeable parts.	• Both meters are supplied with slip-on type impellers that accommodate different velocities. • Single pulses are transmitted by encapsulated reed switch to quartz-timed counters fitted with spark depression. • Designed for direct clamping to 9 mm rods • Using adapters, can be fitted to Top setting wading rods and 20 mm bridge rods (with or without relocating device).	• The impeller design compensates for varying degrees of angular flow. • *Damage to the shaft can not be repaired in the field.* • *Special Shell Telus 5 oil must be used. Use of non-standard oil will change the calibration values.*
• General purpose pygmy meter. • Fiber-optic pulse generation • Swoffer Model # 2100	• Low mass 50 mm plastic impeller is replaced easily and inexpensively. • May be mounted on a variety of well-designed wading or bridge rods.	• Counter displays direct or time-averaged velocity for periods up to 30 s. (in m/s mode). • Velocity range is 0.03 – 7.5 m/s.

Continued on next page

Table II-8. Information summary of horizontal current meters (*Cont.*)

Name, Type of Pulse Generation and Model Number	General Comments	Advantages and *Limitations*
• Braystoke Model BFN.002 • Magnetic-reed switch	• Low mass plastic impeller runs on water lubricated jewel bearings. • Designed for use on standard-type wading rod or optional cable suspension. • No tail piece required for rod mount.	• Supplied with robust wading rod. • No lubrication required. • Quickly & easily assembled. • Operating range (single impeller) is 0.03 – 5.0 m/s.
• Ott C31 or OSS-B1 • Magnetic-reed switch • These two meters are identical, with interchangeable parts.	• The body is machined to be mounted directly on 20 mm rods and relocating devises; in front of middle piece sounding weights with electronic bottom feelers; or on hangers above standard sounding weights. • Impellers are generally of stainless steel or high impact plastic ranging from 80 – 125 mm d & pitches 0.125 – 0.5.	• The "A" type 100 mm has a starting velocity of 0.03 m/s, a max. velocity of 4.0 m/s & an angular flow compensation up to 45º. • *Special Shell Telus 5 oil should be added before each discharge measurement.* • *Use of non-standard oil will change the calibration values*

Appendix III. Hydrometric Forms

BRITISH COLUMBIA

RISC HYD-01: Description of Hydrometric Station

☐ Original ☐ Revised

Station Operating Agency/Firm: ____________________

Station Name: ____________________ EMS ID[1]. __________

Station No: __________ (if any) Project No: __________ (if any e.g., FIA)

Action (Station Established, Relocated, Closed)	Date (yyyy/mm/dd)	By Whom

Site Description: ____________________

____

Location Type: ☐ Lake or Pond ☐ River, Stream or Creek ☐ Marine

Region (from pick list):

☐ Vancouver Island	☐ Kootenay (Nelson)
☐ Lower Mainland (Surrey)	☐ Cariboo (Williams Lake)
☐ Southern Interior (Kamloops)	☐ Skeena (Smithers)
☐ Southern Interior (Penticton)	☐ Omineca-Peace (Prince George)

Nearest Community: ____________________

Site Access Description: ____________________

____

Drainage area above station (km^2): ____________ (if known)

Coordinates: ☐ Geographical ☐ UTM

Latitude (DD MM SS.SS): ________ Longitude (DDD MM SS.SS): ________ or

UTM Northing: ________ UTM Easting: ________ UTM Zone: _____

Geo Reference Source: ____________________

Site Elevation (m): __________

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Water Level Gauge:

☐ Manual	☐ Recorder
Types: ☐ Standard Vertical Staff Gauge ☐ Chain Gauge ☐ Wire Weight Gauge ☐ Reference Marks	Types: ☐ Graphical ☐ Digital If Digital, Sensor Types: ☐ Pressure Transducer ☐ Bubbler ☐ Shaft Encoder ☐ Radar/ Ultrasonic ☐ Other
Reading Accuracy: ☐ 2mm or less ☐ 5mm or less ☐ 1cm or less ☐ Undefined	Reading/Sensor Accuracy: ☐ 2mm or less ☐ 5mm or less ☐ 1cm or less ☐ Undefined

Reference Gauge Type: ☐ Standard Vertical Staff Gauge ☐ Chain Gauge ☐ Wire Weight Gauge ☐ Reference Marks

Zero Flow at Gauge Height (m): __________

Benchmarks:

Benchmark	Date Established (yyyy/mm/dd)	Elevation above station datum [zero of the gauge when first established] (m)	GSC Datum Elevation if any (m)

Channel Description (A description of channel/morphology at station and the location of hydrometric equipment with respect to channel features):

____

____

____

Stream Flow: ☐ Regulated ☐ Natural

Station Type: ☐ Water level only ☐ Discharge/Flow only ☐ Both

Figure III-1a. Form RISC HYD-01 Description of Hydrometric Station (front)

Location /Site Sketch: (1: General location on a standard base map 2: Sketch of station showing access and major landmarks, 3: Sketch of site showing location of all equipment, benchmarks, channel morphology in the vicinity of the station including conditions that could affect the measurements. Please use standard symbols)

[Note: Location /Site Sketch can be scanned and saved as JPEG format for electronic submission into the provincial water database. If possible submit/upload digital photograph of the site viewed upstream and downstream into the provincial water database (i.e., WIDM)].

Remarks (Site condition or any significant issues):

Figure III-1b. Form RISC HYD-01 Description of Hydrometric Station (back)

BRITISH COLUMBIA

RISC HYD-02: History of Gauge Levels

[Note: Hydrometric operator can use "Gauge Level Field Notes" sheet to complete this form]

Station Operation Agency/Firm: ________________________________ EMS Id[1]: ______________

Station Name: __________________ Station No.__________ (If any) Project No._______ (If any e.g., FIA)

Benchmark	Date Established (yyyy/mm/dd)	Original Elevation (m)	Description (Description of benchmark as well as reference distances from known points to assist in locating benchmarks at a later date by someone other than the person who installed it. The "bolt in base of tree" may be hard to find when there are a number of trees in the general area of the BM.)
BM#____ (e.g., 1, 2, 3 etc.)			
BM#____ (e.g., 1, 2, 3 etc.)			
BM#____ (e.g., 1, 2, 3 etc.)			
BM#____ (e.g., 1, 2, 3 etc.)			

Elevation of Station Datum, m (GSC if any) :_____________ (Note: Local datum is always zero)

History of Level Checks, Gauge Corrections, Changes to Benchmarks and Auxiliary Gauges

Gauge Correction Data (m)							
Date & Time (yyyy/mm/dd 24hh:mm PST)	Gauge Reading (m)	Gauge Correction (m)	BM#__ or Ref.#__ (e.g., 1, 2, 3 etc.)	BM#__ or Ref.#__ (e.g., 1, 2, 3 etc.)	BM#__ or Ref.#__ (e.g., 1, 2, 3 etc.)	BM#__ or Ref.#__ (e.g., 1, 2, 3 etc.)	Notes (on Installation or Removal of Gauges, Benchmarks, Auxiliary Gauges, Dates of Changes, Gauge Readings etc.)

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Figure III-2. Form RISC HYD-02 History of Gauge Levels

British Columbia

Gauge Level Field Notes

[Note: Hydrometric operator can use this form in the field to prepare RISC HYD-02: History of Gauge Levels (Summary)]

Station Operating Agency/Firm: ______________________________

Station Name: ________________________ EMS ID[1]. __________

Station No: ____________ (if any) Project No: ________ (if any e.g., FIA)

Date (yyyy/mm/dd):_______________ Time, PST (24hh: mm): _______

Gauge Height/Stage (m):________

Station	BS (m)	Ht. Inst. (m)	FS (m)	Elevation (m)	Elevation as Given (m)

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Elevation Means:

BM # (e.g., 1, 2, 3 etc.)	Established Elev. (m)	Mean Elev. [this date] (m)	Difference (m)

Comments on Elevation Changes: ___________________________

Gauge Correction (m): ___________________________

Date of Change (yyyy/mm/dd):_______________________ (if known)

Surveyed by: ___________________________

Computation by: ____________ Date (yyyy/mm/dd)_____________

Checked by: _______________ Date (yyyy/mm/dd)_____________

Additional Notes: ___________________________

Figure III-3. Gauge Level Field Notes

RISC HYD-03: Summary of Discharge Measurements

BRITISH COLUMBIA

Station Operation Agency/Firm: ______________________ EMS Id[a]: ______________

Station Name: ______________________ Station No.__________ (if any) Project No.__________ (if any e.g., FIA)

Date (yyyy/mm/dd)	Time 24hh: mm PST	Metered by	Channel Condition (use Code 1,2,3,4 or 5)[b]	Meter Type (e.g., Price type AA)	Meter Calibration (use Code 1,2,or 3)[c]	Meter Field Verification (use Code 1,2,or 3)[d]	Width (m)	No of Verti-cals used	Mean Correct. Gauge Height/ Stage (m)	Total Area (m^2)	Mean Velocity (m/sec)	Total Disch. (m^3/ sec)	From Stage Discharge Table						Remarks
													Table No.			Table No.			
													Disch. (m^3/ sec)	Diff.	%	Disch. (m^3/ sec)	Diff.	%	

Computed by: ______________ Date (yyyy/mm/dd): ______________ Checked by: ______________ Date (yyyy/mm/dd): ______________

[a] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

[b] Channel Condition Code
- 1: Fixed Control, stable channel, straight reach, measurements consistent with rating curve, no weeds, boulders or debris
- 2: Stable channel, relatively straight reach, measurements consistent with rating curve, minimal weeds or boulders
- 3: Minor hydraulic problems related to channel instability, measurements are not consistent with rating curve, weed growth or occasional boulders
- 4: Unstable channel due to erosion, degradation or aggradations; variable backwater, turbulence, significant weed growth, boulder bed
- 5: Undefined

[c] Meter Calibration Code
- 1: Meter calibrated and the validity of calibration is confirmed
- 2: Meter previously calibrated but validity of calibration is not confirmed
- 3: Undefined

[d] Instrument Field Verification/Comparison Frequency Code
- 1: At least annually
- 2: Less often than annually
- 3: Undefined

Figure III-4. Form RISC HYD-03 Summary of Discharge Measurement

BRITISH COLUMBIA

Discharge Measurements Field Form
[This form can be used to prepare RISC HYD-03]

Station Operating Agency/Firm: ____________________
Station Name: ________________ EMS ID[1]. __________
Station No: ________ (if any) Project No: ________ (if any e.g., FIA)

Date (yyyy/mm/dd):__________ Metered by: ____________
Air Temp (°c):__________ Water Temp (°c):__________

Channel condition or other condition affecting control or discharge measurements: (variable, backwater, turbulence, vegetation etc.)

☐	☐	☐	☐	☐
Fixed Control, stable channel, straight reach, measurements are consistent with rating curve, no weeds, boulders or debris	Stable channel, relatively straight reach, measurements consistent with rating curve, minimal weeds or boulders	Minor hydraulic problems related to channel instability, measurements are not consistent with rating curve, weed growth or occasional boulders	Unstable channel due to erosion, degradation or aggradations; variable backwater, turbulence, significant weed growth, boulder bed	Undefined

Location of Metering Section: ____________________

	Time (24hh:mm)	Ref. Gauge Reading (m)	Inside Gauge Reading (m)	Data Logger /Recorder Reading (m)
Begin				
End				

Mean Time, PST (24hh: mm): ________________

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Gauge Correction (m):____________________________
Corrected Gauge Height/Stage (m):____________________

Method of Discharge Measurement:
☐ Weir/Flume ☐ Current Meter/Acoustic Sensor
☐ Volumetric ☐ Others

If Current Meter/Acoustic Sensor:
Type (e.g., Price Type AA): __________SL No.________
Measurement Range (m/sec):__________ to__________

Meter Calibration:
☐ Meter calibrated and the validity of calibration is confirmed
☐ Meter previously calibrated but validity of calibration is not confirmed
☐ Undefined
Date of Calibration (yyyy/mm/dd): ________________ (if known)

Meter Field Verification/Comparison Frequency:
☐ At least annually
☐ Less often than annually
☐ Undefined

Water surface Width (m):__________ No. Verticals Used: ______
X-sectional Area [when area velocity e.g., current meter/Acoustic Sensor method is used[2]] (m^2): ________________

Discharge, Q (m^3/sec): ______________

Average Velocity, V [when area-velocity e.g., current meter/acoustic sensor velocity meter is used[1]] (m/sec): ____________

Remarks:
____
____
____

[2] [Note: "Discharge measurement field data and calculation sheet (using XL)" can be used as field form to get total area (A) and average velocity (V) when current meter method is used]

Figure III-5a. Discharge Measurements Field Form (front)

BRITISH COLUMBIA

Discharge Measurements Field Form
(Discharge Computations)

Current meter equations (mechanical current meters are used).

Where V= Velocity (m/s) and n = Revolution/sec

Select following equations:

(1) For Single Range Meters:

V =	n	X	Slope	+	Intercept	(m/Sec)
V =	n	X		+		(m/Sec)

(2) For Multiple Meters :

	n (Min)		n (Max)	V= n X	Slope	+	Intercept	(m/Sec)
IF		<n<		: V= n X		+		(m/Sec)
IF		<=n=<		: V= n X		+		(m/Sec)
IF		<n>		: V= n X		+		(m/Sec)

Discharge Computation Table

OBSERVATION							COMPUTATION				
Method.	Dist. From Initial Point (m)	Depth (m)	Depth of obs. (m)	Revs. (no.)	Time (sec)	Cosine of flow angle	Velocity		Width (m)	X-sectional Area (m^2)	Disch. (m^3/sec)
							At Point (m/sec)	Mean in vert. (m/sec)			
1	2	3	4	5	6	7	8	9	10	11	12
Totals											

Figure III-5b. Discharge Measurements Field Form (back)

BRITISH COLUMBIA

RISC HYD-04: Water Stage Recorder-Station Log

Station Operation Agency/Firm: ____________________ EMS Id[1]: ____________________

Station Name: ____________________ Station No. ____________ (if any) Project No. ____________ (If any e.g., FIA)

Date (yyyy/mm/dd)	Arrival					Departure					Initials	Remarks on Stage Observations & Procedure, Metering, Level Check, etc.
	Time, PST (24hh:mm)		Gauge Height/Stage (m)			Time, PST (24hh:mm)		Gauge Height/Stage (m)				
	Watch	Recorder/ Data Logger	Ref. Gauge	Inside Gauge	Recorder	Watch	Recorder/ Data Logger	Ref. Gauge	Inside Gauge	Recorder		

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Figure III-6. Form RISC HYD-04 Water Stage Recorder-Station Log

BRITISH COLUMBIA

RISC HYD-05: Stage Discharge Rating Curve and Table

Station Operation Agency/Firm: ______________________________EMS Id[1]: ___________

Station Name: ___________________Station No.__________ (if any) Project No._________ (if any e.g., FIA)

Stage Discharge (H/Q) Curve No.: ___________________ Creation Date (yyyy/mm/dd): ______________________________

☐ H/Q Curve Not Revised ☐ H/Q Curve Revised, Date of Revision (yyyy/mm/dd):_____________________

Number of H/Q points used to generate the curve: ____Curve Period (yyyy/mm/dd): From ____________To _____________

Highest Measured Discharge: ______________ (m^3/sec). Corresponding Gauge Height/Stage: __________________ (m)

Lowest Measured Discharge: ______________ (m^3/sec). Corresponding Gauge Height/Stage: __________________ (m)

Zero flow at Gauge Height/Stage: _______ (m). Approximate Bank Elevation (either bank overtopped): ______ (m)

Stage-Discharge Rating Table (i.e., Stage-Discharge Data from Rating Curve)

Stage, H (m)	Discharge, Q (m^3/sec)	Diff. in Discharge (m^3/sec)	Stage, H (m)	Discharge, Q (m^3/sec)	Diff. in Discharge (m^3/sec)	Stage, H (m)	Discharge, Q (m^3/sec)	Diff. in Discharge (m^3/sec)

[Note: To represent full range of the rating curve, enough data points should be presented in the above Table. Data points beyond the measured discharge level i.e., from curve extrapolation should be indicated in the Remarks.]

Remarks: ____

____

____

Computed by: ____ Date (yyyy/mm/dd):_____________________

Checked by: ____ Date (yyyy/mm/dd): _____________________

[1] EMS ID is the identification number assigned by Environmental Monitoring System (EMS) when station is established in the EMS database. All WIDM sites must be first established in EMS.

Figure III-7. Form RISC HYD-05 Stage Discharge Rating Curve and Table

BRITISH COLUMBIA

RISC HYD-06: Station Analysis for the Period:

From ____________ (yyyy/mm/dd) **To** _____________ (yyyy/mm/dd)

[Note: This form must be signed by hydrometric data approver with appropriate professional seal and submitted both original and a PDF copy to the database administrator to capture in provincial water database]

Station Operation Agency/Firm: ______________________________________EMS Id: ________________

Station Name: __________________________ Station No.________ (if any) Project No.________ (If any e.g., FIA)

Number of Level Checks Made Per Year: ☐ 2 or more ☐ 1 or more ☐ None/Undefined

☐Gauge Correction NOT Required

☐Gauge Correction Required (see table at right):

Date and Time (yyyy/mm/dd 24hh:mm PST)	Correction (m)

Discharge Record

Discharge (m^3/s)		Corresponding Gauge Height (m)	Date and Time (yyyy/mm/dd 24hh:mm PST)
Max. Inst. Discharge			
Max. Inst. Measured Discharge			
Min. Inst. Measured Discharge			

Number of Manual Flow Measurements Per Year: ☐ 5 or more ☐ 3 or more ☐ 2 or more ☐ Less than 2/ Undefined

Missing Period		Reason
From (yyyy/mm/dd)	To (yyyy/mm/dd)	

Stage Discharge Relationship

	Curve No.	Start Date (yyyy/mm/dd)	End Date (yyyy/mm/dd)	Cause for the Shift
Previous Year				
Present Year				

Remarks: Discharge estimates for missing periods derived by graphical comparison to:

Climate Station(s):_____________________________Other Hydrometric Station(s):__________________________________

Standard Procedure followed for hydrometric operation:

☐ RISC Standards (i.e., *Manual of British Columbia Hydrometric Standards*)

☐ None/Unknown ☐ Other, Specify: ______________

All field forms including notes, RISC HYD Forms RISC HYD-1 through HYD-6, data and calculations were reviewed for anomalies: ☐ Yes ☐ No

Instruments and methods used for hydrometric operation were appropriate for the field condition: ☐ Yes ☐ No

Reviewed time series water level and discharge data with metadata were submitted to the Provincial Water Database: ☐ Yes ☐ No

Results were compared with other stations and/or other year for check: ☐ Yes ☐ No

Data can be made available to public: ☐ Yes ☐ No

DATA DECLARATION

I, ________________________________, have reviewed all data and operating information for this hydrometric station. Data Grades have been assigned as per standards requirement criteria as defined by the *Manual of British Columbia Hydrometric Standards.*

Date (yyyy/mm/dd)	Professional Seal/Signature	Designation	Professional/Technological Association

Figure III-8. Form RISC HYD-06 Station Analysis for the Period:

Appendix IV. Discharge Tables for Rated Structures

Table IV- 1. Operating limits for rated structures

Table #	Device type	Device size	Max. h^{1}[a] (m)	Max. Q (m^3/s)	Min. h^{1} (m)	Min. Q (m^3/s)	Debris capacity	Sediment capacity	(h^1/p)[b]	Min. p[c] (m)
IV-2	V-notch	90^0	0.60	0.390	0.05	0.0008	Very poor	Very poor	$\leq$1.2	$\geq$0.45
IV-3	Montana flume	3-inch	0.339	0.33	0.03	0.0008	Very good	Good	N/A	N/A
IV-4		6 inch	0.457	0.111	0.03	0.0015	Very good	Good	N/A	N/A
IV-5		9 inch	0.610	0.251	0.03	0.0025	Very good	Good	N/A	N/A
IV-6		12 inch	0.760	0.455	0.03	0.0033	Very good	Good	N/A	N/A
IV-7	H flume	2.0 feet	0.604	0.309	0.03	0.0005	Fair	Fair	N/A	N/A
IV-8		2.5 feet	0.756	0.542	0.03	0.0008	Fair	Fair	N/A	N/A
IV-9		3.0 feet	0.908	0.857	0.03	0.0010	Fair	Fair	N/A	N/A
IV-10		4.5 feet	1.364	2.336	0.03	0.0014	Fair	Fair	N/A	N/A
IV-11	HL flume	4.0 feet	1.218	3.292	0.05	0.0054	Good	Fair	N/A	N/A
IV-12	Rectang. weir	b=1.0 m	0.500	0.585	0.06	0.0267	Poor	Poor	$\leq$ 0.5	$\geq$ 0.3
IV-13		b=1.5 m	0.750	1.612	0.06	0.0402	Poor	Poor	$\leq$ 0.5	$\geq$ 0.3
IV-14		b=2.0 m	1.000	3.308	0.06	0.0537	Poor	Poor	$\leq$ 0.5	$\geq$ 0.3
IV-15		b=3.0 m	1.500	9.117	0.06	0.0807	Poor	Poor	$\leq$ 0.5	$\geq$ 0.3

[a] Head over the weir crest.
[b] Ratio of head over the crest and the height of the crest above the upstream bed.
[c] Height of crest above the upstream bed.

Table IV- 2. Rating Curve For Thin Plate 90º V - Notch Weirs.

Discharge (m^3/s) for specified head (m) for fully contracted weir.

$Q = C_e \frac{8}{15}(2g)^{0.5} \tan\frac{\theta}{2} h_1^{\,2.5}$ (m^3/sec), Where, C_e is coefficient = 0.58 for $\theta = 90^o$, h_1 is head in meter

Therefore the simplified equation is $Q = 1.370 h_1^{\,2.5}$ (m^3/sec)

[Note: ‘Fully contracted weir’, i.e. a weir which has an approach channel whose bed and sides are sufficiently remote from the edges of the V-notch to allow for a sufficiently great approach velocity component parallel to the weir face so that the contraction is fully developed.]

Head	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.050	0.0008	0.0008	0.0008	0.0009	0.0009	0.0010	0.0010	0.0011	0.0011	0.0012
0.060	0.0012	0.0013	0.0013	0.0014	0.0014	0.0015	0.0015	0.0016	0.0017	0.0017
0.070	0.0018	0.0018	0.0019	0.0020	0.0020	0.0021	0.0022	0.0023	0.0023	0.0024
0.080	0.0025	0.0026	0.0026	0.0027	0.0028	0.0029	0.0030	0.0031	0.0031	0.0032
0.090	0.0033	0.0034	0.0035	0.0036	0.0037	0.0038	0.0039	0.0040	0.0041	0.0042
0.100	0.0043	0.0044	0.0046	0.0047	0.0048	0.0049	0.0050	0.0051	0.0053	0.0054
0.110	0.0055	0.0056	0.0058	0.0059	0.0060	0.0061	0.0063	0.0064	0.0066	0.0067
0.120	0.0068	0.0070	0.0071	0.0073	0.0074	0.0076	0.0077	0.0079	0.0080	0.0082
0.130	0.0083	0.0085	0.0087	0.0088	0.0090	0.0092	0.0093	0.0095	0.0097	0.0099
0.140	0.0100	0.0102	0.0104	0.0106	0.0108	0.0110	0.0112	0.0114	0.0115	0.0117
0.150	0.0119	0.0121	0.0123	0.0125	0.0128	0.0130	0.0132	0.0134	0.0136	0.0138
0.160	0.0140	0.0142	0.0145	0.0147	0.0149	0.0152	0.0154	0.0156	0.0158	0.0161
0.170	0.0163	0.0166	0.0168	0.0171	0.0173	0.0176	0.0178	0.0181	0.0183	0.0186
0.180	0.0188	0.0191	0.0194	0.0196	0.0199	0.0202	0.0204	0.0207	0.0210	0.0213
0.190	0.0216	0.0218	0.0221	0.0224	0.0227	0.0230	0.0233	0.0236	0.0239	0.0242
0.200	0.0245	0.0248	0.0251	0.0254	0.0258	0.0261	0.0264	0.0267	0.0270	0.0274
0.210	0.0277	0.0280	0.0284	0.0287	0.0290	0.0294	0.0297	0.0301	0.0304	0.0307
0.220	0.0311	0.0315	0.0318	0.0322	0.0325	0.0329	0.0333	0.0336	0.0340	0.0344
0.230	0.0348	0.0351	0.0355	0.0359	0.0363	0.0367	0.0371	0.0375	0.0379	0.0383
0.240	0.0387	0.0391	0.0395	0.0399	0.0403	0.0407	0.0411	0.0415	0.0420	0.0424
0.250	0.0428	0.0432	0.0437	0.0441	0.0445	0.0450	0.0454	0.0459	0.0463	0.0468
0.260	0.0472	0.0477	0.0481	0.0486	0.0491	0.0495	0.0500	0.0505	0.0509	0.0514
0.270	0.0519	0.0524	0.0529	0.0533	0.0538	0.0543	0.0548	0.0553	0.0558	0.0563
0.280	0.0568	0.0573	0.0579	0.0584	0.0589	0.0594	0.0599	0.0605	0.0610	0.0615
0.290	0.0620	0.0626	0.0631	0.0637	0.0642	0.0648	0.0653	0.0659	0.0664	0.0670
0.300	0.0675	0.0681	0.0687	0.0692	0.0698	0.0704	0.0710	0.0715	0.0721	0.0726
0.310	0.0733	0.0739	0.0745	0.0751	0.0757	0.0763	0.0769	0.0775	0.0781	0.0786
0.320	0.0794	0.0800	0.0806	0.0812	0.0819	0.0825	0.0831	0.0838	0.0844	0.0849
0.330	0.0857	0.0864	0.0870	0.0877	0.0883	0.0890	0.0897	0.0903	0.0910	0.0915
0.340	0.0923	0.0930	0.0937	0.0944	0.0951	0.0958	0.0965	0.0972	0.0979	0.0984
0.350	0.0993	0.1000	0.1007	0.1014	0.1021	0.1029	0.1036	0.1043	0.1051	0.1056
0.360	0.1065	0.1073	0.1080	0.1088	0.1095	0.1103	0.1110	0.1118	0.1125	0.1131
0.370	0.1141	0.1149	0.1156	0.1164	0.1172	0.1180	0.1188	0.1196	0.1204	0.1210
0.380	0.1219	0.1228	0.1236	0.1244	0.1252	0.1260	0.1268	0.1276	0.1285	0.1291
0.390	0.1301	0.1310	0.1318	0.1326	0.1335	0.1343	0.1352	0.1360	0.1369	0.1376
0.400	0.1386	0.1395	0.1404	0.1412	0.1421	0.1430	0.1439	0.1448	0.1457	0.1464

Head	0.000	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.410	0.1475	0.1484	0.1493	0.1502	0.1511	0.1520	0.1529	0.1538	0.1548	0.1555
0.420	0.1566	0.1576	0.1585	0.1594	0.1604	0.1613	0.1623	0.1632	0.1642	0.1649
0.430	0.1661	0.1671	0.1680	0.1690	0.1700	0.1710	0.1720	0.1730	0.1739	0.1747
0.440	0.1759	0.1769	0.1779	0.1789	0.1800	0.1810	0.1820	0.1830	0.1840	0.1848
0.450	0.1861	0.1871	0.1882	0.1892	0.1903	0.1913	0.1924	0.1934	0.1945	0.1953
0.460	0.1966	0.1977	0.1988	0.1998	0.2009	0.2020	0.2031	0.2042	0.2053	0.2061
0.470	0.2075	0.2086	0.2097	0.2108	0.2119	0.2130	0.2142	0.2153	0.2164	0.2172
0.480	0.2187	0.2198	0.2210	0.2221	0.2233	0.2244	0.2256	0.2267	0.2279	0.2287
0.490	0.2303	0.2314	0.2326	0.2338	0.2350	0.2362	0.2374	0.2386	0.2398	0.2406
0.500	0.2422	0.2434	0.2446	0.2458	0.2471	0.2483	0.2495	0.2507	0.2520	0.2529
0.510	0.2545	0.2557	0.2570	0.2582	0.2595	0.2608	0.2620	0.2633	0.2646	0.2655
0.520	0.2671	0.2684	0.2697	0.2710	0.2723	0.2736	0.2749	0.2762	0.2775	0.2784
0.530	0.2802	0.2815	0.2828	0.2841	0.2855	0.2868	0.2882	0.2895	0.2909	0.2918
0.540	0.2936	0.2949	0.2963	0.2977	0.2990	0.3004	0.3018	0.3032	0.3046	0.3055
0.550	0.3073	0.3087	0.3101	0.3116	0.3130	0.3144	0.3158	0.3172	0.3186	0.3196
0.560	0.3215	0.3229	0.3244	0.3258	0.3273	0.3287	0.3302	0.3316	0.3331	0.3341
0.570	0.3361	0.3375	0.3390	0.3405	0.3420	0.3435	0.3450	0.3465	0.3480	0.3490
0.580	0.3510	0.3525	0.3540	0.3555	0.3571	0.3586	0.3601	0.3617	0.3632	0.3642
0.590	0.3663	0.3679	0.3694	0.3710	0.3726	0.3741	0.3757	0.3773	0.3789	0.3799
0.600	0.3820									

Table IV- 3. 3" Montana Flume - under free-flow discharge in L/s.

Computed from the Formula $Q = 0.1771h_a^{1.55}$ m^3/sec where h_a is head in meter

Head	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.02										
0.03	0.77	0.81	0.85	0.90	0.94	0.98	1.02	1.07	1.11	1.16
0.04	1.21	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65
0.05	1.70	1.76	1.81	1.87	1.92	1.98	2.03	2.09	2.15	2.20
0.06	2.26	2.32	2.38	2.44	2.50	2.56	2.62	2.68	2.75	2.81
0.07	2.87	2.94	3.00	3.06	3.13	3.20	3.26	3.33	3.40	3.46
0.08	3.53	3.60	3.67	3.74	3.81	3.88	3.95	4.02	4.09	4.17
0.09	4.24	4.31	4.39	4.46	4.53	4.61	4.69	4.76	4.84	4.91
0.10	4.99	5.07	5.15	5.23	5.30	5.38	5.46	5.54	5.62	5.70
0.11	5.79	5.87	5.95	6.03	6.12	6.20	6.28	6.37	6.45	6.54
0.12	6.62	6.71	6.79	6.88	6.97	7.05	7.14	7.23	7.32	7.41
0.13	7.50	7.59	7.68	7.77	7.86	7.95	8.04	8.13	8.22	8.32
0.14	8.41	8.50	8.60	8.69	8.78	8.88	8.97	9.07	9.16	9.26
0.15	9.36	9.45	9.55	9.65	9.75	9.85	9.94	10.04	10.14	10.24
0.16	10.34	10.44	10.54	10.64	10.75	10.85	10.95	11.05	11.15	11.26
0.17	11.36	11.46	11.57	11.67	11.78	11.88	11.99	12.09	12.20	12.31
0.18	12.41	12.52	12.63	12.74	12.84	12.95	13.06	13.17	13.28	13.39
0.19	13.50	13.61	13.72	13.83	13.94	14.05	14.16	14.28	14.39	14.50
0.20	14.62	14.73	14.84	14.96	15.07	15.19	15.30	15.42	15.53	15.65
0.21	15.76	15.88	16.00	16.11	16.23	16.35	16.47	16.59	16.70	16.82
0.22	16.94	17.06	17.18	17.30	17.42	17.54	17.66	17.79	17.91	18.03
0.23	18.15	18.27	18.40	18.52	18.64	18.77	18.89	19.01	19.14	19.26
0.24	19.39	19.51	19.64	19.77	19.89	20.02	20.15	20.27	20.40	20.53
0.25	20.66	20.78	20.91	21.04	21.17	21.30	21.43	21.56	21.69	21.82
0.26	21.95	22.08	22.21	22.34	22.48	22.61	22.74	22.87	23.01	23.14
0.27	23.27	23.41	23.54	23.67	23.81	23.94	24.08	24.21	24.35	24.49
0.28	24.62	24.76	24.89	25.03	25.17	25.31	25.44	25.58	25.72	25.86
0.29	26.00	26.14	26.28	26.42	26.56	26.70	26.84	26.98	27.12	27.26
0.30	27.40	27.54	27.68	27.83	27.97	28.11	28.25	28.40	28.54	28.68
0.31	28.83	28.97	29.12	29.26	29.41	29.55	29.70	29.84	29.99	30.14
0.32	30.28	30.43	30.58	30.72	30.87	31.02	31.17	31.32	31.46	31.61
0.33	31.76	31.91	32.06	32.21	32.36	32.51	32.66	32.81	32.96	33.12

Table IV- 4. 6" Montana Flume - under free-flow discharge in L/s.

Computed from the Formula $Q = 0.3812h_a^{1.580}$ m^3/sec where h_a is head in meter

Head	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.03	1.5	1.6	1.7	1.7	1.8	1.9	2.0	2.1	2.2	2.3
0.04	2.4	2.5	2.5	2.6	2.7	2.8	2.9	3.0	3.1	3.2
0.05	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.4
0.06	4.5	4.6	4.7	4.8	5.0	5.1	5.2	5.3	5.5	5.6
0.07	5.7	5.8	6.0	6.1	6.2	6.4	6.5	6.6	6.8	6.9
0.08	7.0	7.2	7.3	7.5	7.6	7.8	7.9	8.0	8.2	8.3
0.09	8.5	8.6	8.8	8.9	9.1	9.2	9.4	9.6	9.7	9.9
0.10	10.0	10.2	10.3	10.5	10.7	10.8	11.0	11.2	11.3	11.5
0.11	11.7	11.8	12.0	12.2	12.3	12.5	12.7	12.8	13.0	13.2
0.12	13.4	13.6	13.7	13.9	14.1	14.3	14.4	14.6	14.8	15.0
0.13	15.2	15.4	15.5	15.7	15.9	16.1	16.3	16.5	16.7	16.9
0.14	17.1	17.3	17.4	17.6	17.8	18.0	18.2	18.4	18.6	18.8
0.15	19.0	19.2	19.4	19.6	19.8	20.0	20.2	20.4	20.7	20.9
0.16	21.1	21.3	21.5	21.7	21.9	22.1	22.3	22.5	22.8	23.0
0.17	23.2	23.4	23.6	23.8	24.1	24.3	24.5	24.7	24.9	25.2
0.18	25.4	25.6	25.8	26.1	26.3	26.5	26.7	27.0	27.2	27.4
0.19	27.6	27.9	28.1	28.3	28.6	28.8	29.0	29.3	29.5	29.7
0.20	30.0	30.2	30.5	30.7	30.9	31.2	31.4	31.7	31.9	32.1
0.21	32.4	32.6	32.9	33.1	33.4	33.6	33.9	34.1	34.3	34.6
0.22	34.8	35.1	35.4	35.6	35.9	36.1	36.4	36.6	36.9	37.1
0.23	37.4	37.6	37.9	38.2	38.4	38.7	38.9	39.2	39.5	39.7
0.24	40.0	40.2	40.5	40.8	41.0	41.3	41.6	41.8	42.1	42.4
0.25	42.6	42.9	43.2	43.5	43.7	44.0	44.3	44.5	44.8	45.1
0.26	45.4	45.7	45.9	46.2	46.5	46.8	47.0	47.3	47.6	47.9
0.27	48.2	48.4	48.7	49.0	49.3	49.6	49.9	50.1	50.4	50.7
0.28	51.0	51.3	51.6	51.9	52.2	52.5	52.7	53.0	53.3	53.6
0.29	53.9	54.2	54.5	54.8	55.1	55.4	55.7	56.0	56.3	56.6
0.30	56.9	57.2	57.5	57.8	58.1	58.4	58.7	59.0	59.3	59.6
0.31	59.9	60.2	60.5	60.8	61.1	61.4	61.8	62.1	62.4	62.7
0.32	63.0	63.3	63.6	63.9	64.2	64.6	64.9	65.2	65.5	65.8
0.33	66.1	66.4	66.8	67.1	67.4	67.7	68.0	68.4	68.7	69.0
0.34	69.3	69.6	70.0	70.3	70.6	70.9	71.3	71.6	71.9	72.2
0.35	72.6	72.9	73.2	73.6	73.9	74.2	74.5	74.9	75.2	75.5
0.36	75.9	76.2	76.5	76.9	77.2	77.5	77.9	78.2	78.6	78.9
0.37	79.2	79.6	79.9	80.3	80.6	80.9	81.3	81.6	82.0	82.3
0.38	82.6	83.0	83.3	83.7	84.0	84.4	84.7	85.1	85.4	85.8
0.39	86.1	86.5	86.8	87.2	87.5	87.9	88.2	88.6	88.9	89.3
0.40	89.6	90.0	90.3	90.7	91.0	91.4	91.8	92.1	92.5	92.8
0.41	93.2	93.5	93.9	94.3	94.6	95.0	95.3	95.7	96.1	96.4
0.42	96.8	97.2	97.5	97.9	98.3	98.6	99.0	99.4	99.7	100.1
0.43	100.5	100.8	101.2	101.6	101.9	102.3	102.7	103.1	103.4	103.8
0.44	104.2	104.6	104.9	105.3	105.7	106.1	106.4	106.8	107.2	107.6
0.45	108.0	108.3	108.7	109.1	109.5	109.9	110.2	110.6	111.0	111.4

Table IV- 5. 9" Montana Flume - under free-flow discharge in L/s.

Computed from the Formula $Q = 0.5354h_a^{1.530}$ m^3/sec where h_a is head in meter

Head	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.03	2.5	2.6	2.8	2.9	3.0	3.2	3.3	3.5	3.6	3.7
0.04	3.9	4.0	4.2	4.3	4.5	4.7	4.8	5.0	5.1	5.3
0.05	5.5	5.6	5.8	6.0	6.2	6.3	6.5	6.7	6.9	7.0
0.06	7.2	7.4	7.6	7.8	8.0	8.2	8.4	8.6	8.8	9.0
0.07	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	10.8	11.0
0.08	11.2	11.4	11.7	11.9	12.1	12.3	12.5	12.8	13.0	13.2
0.09	13.4	13.7	13.9	14.1	14.4	14.6	14.8	15.1	15.3	15.6
0.10	15.8	16.0	16.3	16.5	16.8	17.0	17.3	17.5	17.8	18.0
0.11	18.3	18.5	18.8	19.0	19.3	19.6	19.8	20.1	20.4	20.6
0.12	20.9	21.2	21.4	21.7	22.0	22.2	22.5	22.8	23.1	23.3
0.13	23.6	23.9	24.2	24.4	24.7	25.0	25.3	25.6	25.9	26.2
0.14	26.4	26.7	27.0	27.3	27.6	27.9	28.2	28.5	28.8	29.1
0.15	29.4	29.7	30.0	30.3	30.6	30.9	31.2	31.5	31.8	32.1
0.16	32.4	32.7	33.1	33.4	33.7	34.0	34.3	34.6	34.9	35.3
0.17	35.6	35.9	36.2	36.6	36.9	37.2	37.5	37.9	38.2	38.5
0.18	38.8	39.2	39.5	39.8	40.2	40.5	40.8	41.2	41.5	41.8
0.19	42.2	42.5	42.9	43.2	43.6	43.9	44.2	44.6	44.9	45.3
0.20	45.6	46.0	46.3	46.7	47.0	47.4	47.7	48.1	48.5	48.8
0.21	49.2	49.5	49.9	50.2	50.6	51.0	51.3	51.7	52.1	52.4
0.22	52.8	53.2	53.5	53.9	54.3	54.6	55.0	55.4	55.8	56.1
0.23	56.5	56.9	57.3	57.6	58.0	58.4	58.8	59.2	59.5	59.9
0.24	60.3	60.7	61.1	61.5	61.9	62.2	62.6	63.0	63.4	63.8
0.25	64.2	64.6	65.0	65.4	65.8	66.2	66.6	67.0	67.4	67.8
0.26	68.2	68.6	69.0	69.4	69.8	70.2	70.6	71.0	71.4	71.8
0.27	72.2	72.6	73.0	73.5	73.9	74.3	74.7	75.1	75.5	75.9
0.28	76.4	76.8	77.2	77.6	78.0	78.4	78.9	79.3	79.7	80.1
0.29	80.6	81.0	81.4	81.8	82.3	82.7	83.1	83.6	84.0	84.4
0.30	84.9	85.3	85.7	86.2	86.6	87.0	87.5	87.9	88.3	88.8
0.31	89.2	89.7	90.1	90.5	91.0	91.4	91.9	92.3	92.8	93.2
0.32	93.7	94.1	94.6	95.0	95.5	95.9	96.4	96.8	97.3	97.7
0.33	98.2	98.6	99.1	99.5	100.0	100.5	100.9	101.4	101.8	102.3
0.34	102.8	103.2	103.7	104.2	104.6	105.1	105.6	106.0	106.5	107.0
0.35	107.4	107.9	108.4	108.8	109.3	109.8	110.3	110.7	111.2	111.7
0.36	112.2	112.6	113.1	113.6	114.1	114.5	115.0	115.5	116.0	116.5
0.37	117.0	117.4	117.9	118.4	118.9	119.4	119.9	120.4	120.8	121.3
0.38	121.8	122.3	122.8	123.3	123.8	124.3	124.8	125.3	125.8	126.3
0.39	126.8	127.3	127.8	128.3	128.8	129.3	129.8	130.3	130.8	131.3
0.40	131.8	132.3	132.8	133.3	133.8	134.3	134.8	135.3	135.8	136.3
0.41	136.8	137.4	137.9	138.4	138.9	139.4	139.9	140.4	141.0	141.5
0.42	142.0	142.5	143.0	143.5	144.1	144.6	145.1	145.6	146.1	146.7
0.43	147.2	147.7	148.2	148.8	149.3	149.8	150.3	150.9	151.4	151.9
0.44	152.5	153.0	153.5	154.1	154.6	155.1	155.7	156.2	156.7	157.3
0.45	157.8	158.3	158.9	159.4	159.9	160.5	161.0	161.6	162.1	162.6
0.46	163.2	163.7	164.3	164.8	165.4	165.9	166.5	167.0	167.6	168.1
0.47	168.7	169.2	169.7	170.3	170.9	171.4	172.0	172.5	173.1	173.6
0.48	174.2	174.7	175.3	175.8	176.4	177.0	177.5	178.1	178.6	179.2
0.49	179.8	180.3	180.9	181.4	182.0	182.6	183.1	183.7	184.3	184.8
0.50	185.4	186.0	186.5	187.1	187.7	188.2	188.8	189.4	190.0	190.5
0.51	191.1	191.7	192.2	192.8	193.4	194.0	194.6	195.1	195.7	196.3
0.52	196.9	197.4	198.0	198.6	199.2	199.8	200.3	200.9	201.5	202.1
0.53	202.7	203.3	203.9	204.4	205.0	205.6	206.2	206.8	207.4	208.0
0.54	208.6	209.2	209.7	210.3	210.9	211.5	212.1	212.7	213.3	213.9
0.55	214.5	215.1	215.7	216.3	216.9	217.5	218.1	218.7	219.3	219.9
0.56	220.5	221.1	221.7	222.3	222.9	223.5	224.1	224.7	225.3	225.9
0.57	226.6	227.2	227.8	228.4	229.0	229.6	230.2	230.8	231.4	232.0
0.58	232.7	233.3	233.9	234.5	235.1	235.7	236.4	237.0	237.6	238.2
0.59	238.8	239.4	240.1	240.7	241.3	241.9	242.6	243.2	243.8	244.4
0.60	245.0	245.7	246.3	246.9	247.6	248.2	248.8	249.4	250.1	250.7
0.61	251.3									

Table IV- 6. 12" Montana Flume - under free-flow discharge in L/s.

Computed from Formula $Q = 0.6909h_a^{1.522}$ m^3/sec where h_a is head in meter

Head	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.03	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.6	4.8	5.0
0.04	5.1	5.3	5.5	5.7	6.0	6.2	6.4	6.6	6.8	7.0
0.05	7.2	7.5	7.7	7.9	8.2	8.4	8.6	8.8	9.1	9.3
0.06	9.5	9.8	10.0	10.3	10.6	10.8	11.0	11.3	11.5	11.8
0.07	12.1	12.3	12.6	12.9	13.2	13.4	13.7	14.0	14.2	14.5
0.08	14.8	15.1	15.4	15.6	16.0	16.2	16.5	16.8	17.1	17.4
0.09	17.7	18.0	18.3	18.6	18.9	19.2	19.5	19.8	20.1	20.5
0.10	20.8	21.1	21.4	21.7	22.1	22.4	22.7	23.0	23.3	23.7
0.11	24.0	24.3	24.7	25.0	25.4	25.7	26.0	26.4	26.7	27.1
0.12	27.4	27.8	28.1	28.5	28.8	29.2	29.5	29.9	30.2	30.6
0.13	31.0	31.3	31.7	32.1	32.5	32.8	33.2	33.5	33.9	34.3
0.14	34.7	35.0	35.4	35.8	36.2	36.6	36.9	37.3	37.7	38.1
0.15	38.5	38.9	39.3	39.7	40.1	40.5	40.9	41.3	41.7	42.1
0.16	42.5	42.9	43.3	43.7	44.1	44.5	44.9	45.3	45.7	46.2
0.17	46.6	47.0	47.4	47.8	48.3	48.7	49.1	49.5	50.0	50.4
0.18	50.8	51.2	51.7	52.1	52.6	53.0	53.4	53.8	54.3	54.7
0.19	55.2	55.6	56.1	56.5	57.0	57.4	57.8	58.3	58.7	59.2
0.20	59.6	60.1	60.6	61.0	61.5	61.9	62.4	62.9	63.3	63.8
0.21	64.2	64.7	65.2	65.6	66.2	66.6	67.1	67.5	68.0	68.5
0.22	69.0	69.4	69.9	70.4	70.9	71.4	71.8	72.3	72.8	73.3
0.23	73.8	74.3	74.8	75.3	75.8	76.2	76.7	77.2	77.7	78.2
0.24	78.7	79.2	79.7	80.2	80.8	81.2	81.7	82.2	82.8	83.3
0.25	83.8	84.3	84.8	85.3	85.9	86.3	86.8	87.4	87.9	88.4
0.26	88.9	89.4	90.0	90.5	91.1	91.5	92.1	92.6	93.1	93.6
0.27	94.2	94.7	95.2	95.8	96.4	96.8	97.4	97.9	98.5	99.0
0.28	99.5	100.1	100.6	101.2	101.8	102.3	102.8	103.4	103.9	104.4
0.29	105.0	105.6	106.1	106.7	107.3	107.8	108.3	108.9	109.4	110.0
0.30	110.6	111.1	111.7	112.2	112.9	113.4	113.9	114.5	115.1	115.6
0.31	116.2	116.8	117.4	117.9	118.6	119.1	119.7	120.2	120.8	121.4
0.32	122.0	122.6	123.1	123.7	124.4	124.9	125.5	126.1	126.6	127.2
0.33	127.8	128.4	129.0	129.6	130.2	130.8	131.4	132.0	132.6	133.2
0.34	133.8	134.4	135.0	135.6	136.2	136.8	137.4	138.0	138.6	139.2
0.35	139.8	140.4	141.0	141.6	142.3	142.8	143.5	144.1	144.7	145.3
0.36	145.9	146.5	147.2	147.8	148.5	149.0	149.6	150.3	150.9	151.5
0.37	152.1	152.8	153.4	154.0	154.7	155.3	155.9	156.5	157.2	157.8
0.38	158.4	159.1	159.7	160.3	161.0	161.6	162.3	162.9	163.5	164.2
0.39	164.8	165.5	166.1	166.8	167.5	168.0	168.7	169.3	170.0	170.6
0.40	171.3	171.9	172.6	173.3	174.0	174.6	175.2	175.9	176.5	177.2
0.41	177.9	178.5	179.2	179.8	180.6	181.2	181.8	182.5	183.2	183.8
0.42	184.5	185.2	185.8	186.5	187.3	187.9	188.5	189.2	189.9	190.6
0.43	191.2	191.9	192.6	193.3	194.0	194.6	195.3	196.0	196.7	197.4
0.44	198.0	198.7	199.4	200.1	200.9	201.5	202.2	202.9	203.5	204.2
0.45	204.9	205.6	206.3	207.0	207.8	208.4	209.1	209.8	210.5	211.2
0.46	211.9	212.6	213.3	214.0	214.8	215.4	216.1	216.8	217.5	218.2
0.47	219.0	219.7	220.4	221.1	221.9	222.5	223.2	223.9	224.6	225.4
0.48	226.1	226.8	227.5	228.2	229.0	229.7	230.4	231.1	231.8	232.6
0.49	233.3	234.0	234.7	235.5	236.3	236.9	237.7	238.4	239.1	239.8
0.50	240.6	241.3	242.0	242.8	243.6	244.2	245.0	245.7	246.5	247.2
0.51	247.9	248.7	249.4	250.2	251.0	251.6	252.4	253.1	253.9	254.6
0.52	255.4	256.1	256.9	257.6	258.4	259.1	259.9	260.6	261.4	262.1
0.53	262.9	263.6	264.4	265.2	266.0	266.7	267.4	268.2	268.9	269.7
0.54	270.5	271.2	272.0	272.8	273.6	274.3	275.1	275.8	276.6	277.4
0.55	278.1	278.9	279.7	280.4	281.3	282.0	282.8	283.5	284.3	285.1
0.56	285.9	286.6	287.4	288.2	289.1	289.8	290.5	291.3	292.1	292.9
0.57	293.7	294.5	295.2	296.0	296.9	297.6	298.4	299.2	300.0	300.8
0.58	301.5	302.3	303.1	303.9	304.8	305.5	306.3	307.1	307.9	308.7
0.59	309.5	310.3	311.1	311.9	312.8	313.5	314.3	315.1	315.9	316.7
0.60	317.5	318.3	319.1	319.9	320.8	321.5	322.4	323.2	324.0	324.8
0.61	325.6	326.4	327.2	328.0	328.9	329.7	330.5	331.3	332.1	332.9
0.62	333.8	334.6	335.4	336.2	337.1	337.9	338.7	339.5	340.3	341.2

Head	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
0.63	342.0	342.8	343.6	344.5	345.4	346.1	347.0	347.8	348.6	349.5
0.64	350.3	351.1	352.0	352.8	353.7	354.5	355.3	356.1	357.0	357.8
0.65	358.6	359.5	360.3	361.2	362.1	362.9	363.7	364.5	365.4	366.2
0.66	367.1	367.9	368.8	369.6	370.6	371.3	372.2	373.0	373.9	374.7
0.67	375.6	376.4	377.3	378.1	379.1	379.9	380.7	381.6	382.4	383.3
0.68	384.1	385.0	385.9	386.7	387.7	388.5	389.3	390.2	391.0	391.9
0.69	392.8	393.6	394.5	395.4	396.3	397.1	398.0	398.9	399.7	400.6
0.70	401.5	402.3	403.2	404.1	405.1	405.8	406.7	407.6	408.5	409.4
0.71	410.2	411.1	412.0	412.9	413.8	414.6	415.5	416.4	417.3	418.2
0.72	419.1	419.9	420.8	421.7	422.7	423.5	424.4	425.3	426.2	427.1
0.73	427.9	428.8	429.7	430.6	431.6	432.4	433.3	434.2	435.1	436.0
0.74	436.9	437.8	438.7	439.6	440.6	441.4	442.3	443.2	444.1	445.0
0.75	445.9	446.8	447.7	448.6	449.6	450.5	451.4	452.3	453.2	454.1
0.76	455.0	455.9	456.8	457.7	458.7	459.6	460.5	461.4	462.3	463.2

Table IV- 7. 2.0' H-Flume under free flow conditions in L/s.

Head	0.0	0.002	0.004	0.006	0.008
0.02			0.47	0.54	0.61
0.03	0.68	0.76	0.84	0.93	1.02
0.04	1.12	1.22	1.33	1.44	1.55
0.05	1.67	1.79	1.82	2.05	2.19
0.06	2.33	2.48	2.63	2.79	2.95
0.07	3.11	3.29	3.46	3.64	3.83
0.08	4.02	4.21	4.41	4.62	4.83
0.09	5.04	5.27	5.49	5.72	5.96
0.10	6.20	6.45	6.70	6.96	7.22
0.11	7.49	7.76	8.04	8.33	8.62
0.12	8.91	9.22	9.52	9.84	10.2
0.13	10.5	10.8	11.1	11.5	11.8
0.14	12.2	12.5	12.6	13.3	13.7
0.15	14.0	14.4	14.8	15.2	15.6
0.16	16.1	16.5	16.9	17.3	17.8
0.17	18.2	18.7	19.1	19.6	20.1
0.18	20.5	21.0	21.5	22.0	22.5
0.19	23.0	23.5	24.1	24.6	25.1
0.20	25.7	26.2	26.8	27.3	27.9
0.21	28.5	29.1	29.7	30.2	30.9
0.22	31.5	32.1	32.4	33.3	34.0
0.23	34.6	35.3	35.9	36.6	37.3
0.24	38.0	38.7	39.4	40.1	40.8
0.25	41.5	42.2	42.9	43.7	44.4
0.26	45.2	46.0	46.7	47.5	48.3
0.27	49.1	50.0	50.7	51.5	52.3
0.28	53.2	54.0	54.9	55.7	56.6
0.29	57.3	58.3	59.2	60.1	61.0
0.30	61.9	62.9	63.8	64.7	65.7
0.31	66.6	67.6	68.6	69.5	70.5
0.32	71.5	72.5	73.5	74.6	75.6
0.33	76.6	77.7	78.7	79.7	80.8
0.34	81.9	83.0	84.1	85.2	86.3
0.35	87.5	88.6	89.7	90.9	92.0
0.36	93.2	94.4	95.6	96.7	97.9
0.37	99.2	100	102	103	104
0.38	105	107	108	109	110
0.39	112	113	114	116	117
0.40	118	120	121	123	124
0.41	128	127	128	130	131
0.42	132	134	135	137	138
0.43	170	141	143	144	146
0.44	147	148	150	152	154
0.45	155	157	158	160	162
0.46	163	165	167	168	170
0.47	172	173	175	177	179
0.48	180	182	184	186	187
0.49	189	191	193	195	196
0.50	198	200	202	204	206
0.51	208	210	211	213	215
0.52	217	219	221	223	225
0.53	227	229	231	233	235
0.54	237	240	242	244	246
0.55	248	250	252	254	256
0.56	259	261	263	265	267
0.57	270	272	274	276	279
0.58	281	283	286	288	290
0.59	293	295	297	300	302
0.60	305	307	309		

Table IV- 8. 2.5' H-Flume under free flow conditions in L/s.

Head	0.0	0.002	0.004	0.006	0.008
0.02				0.65	0.73
0.03	0.82	0.91	1.01	1.11	1.22
0.04	1.33	1.45	1.57	1.69	1.82
0.05	1.96	2.10	2.25	2.40	2.55
0.06	2.71	2.88	3.05	3.23	3.41
0.07	3.59	3.78	3.98	4.18	4.39
0.08	4.60	4.82	5.04	5.27	5.51
0.09	5.75	5.99	6.24	6.50	6.76
0.10	7.02	7.30	7.58	7.86	8.15
0.11	8.44	8.75	9.05	9.36	9.68
0.12	10.0	10.3	10.7	11.0	11.4
0.13	11.7	12.1	12.4	12.8	13.2
0.14	13.6	14.0	14.4	14.8	15.2
0.15	15.6	16.0	16.4	16.9	17.3
0.16	17.6	18.2	18.7	19.1	19.6
0.17	20.1	20.6	21.1	21.6	22.1
0.18	22.6	23.1	23.6	24.2	24.7
0.19	25.2	25.8	26.4	26.9	27.5
0.20	28.1	28.7	29.2	29.8	30.5
0.21	31.1	31.7	32.3	33.0	33.6
0.22	34.2	34.9	35.6	36.2	36.9
0.23	37.6	38.4	39.0	39.7	40.4
0.24	41.1	41.9	42.6	43.4	44.1
0.25	44.9	45.6	46.4	47.2	48.0
0.26	48.8	49.6	50.4	51.2	52.0
0.27	52.9	53.7	54.6	55.4	56.3
0.28	57.2	587.1	59.0	59.9	60.8
0.29	61.7	62.7	63.5	64.5	65.4
0.30	66.4	67.3	68.3	69.3	70.3
0.31	71.3	72.3	73.3	74.3	75.3
0.32	76.4	77.4	78.5	79.5	80.6
0.33	81.7	82.8	83.9	85.0	86.1
0.34	87.2	88.3	89.5	90.6	91.8
0.35	93.0	94.1	95.3	96.5	97.7
0.36	98.9	100	101	102	104
0.37	105	106	108	109	110
0.38	112	113	114	115	117
0.39	118	119	121	122	124
0.40	125	126	128	129	131
0.41	132	134	135	136	138
0.42	139	141	142	144	145
0.43	147	149	150	152	153
0.44	155	156	158	160	161
0.45	163	165	166	168	169
0.46	171	173	175	176	178
0.47	180	181	183	185	187
0.48	198	190	192	194	196
0.49	198	199	201	203	205
0.50	207	209	211	213	215
0.51	216	218	220	222	224
0.52	226	228	230	232	234
0.53	236	239	241	243	245
0.54	247	249	251	253	255
0.55	257	260	262	264	266
0.56	268	271	273	275	277
0.57	280	282	284	286	289
0.58	291	293	296	298	301
0.59	303	305	308	310	313
0.60	315	317	320	322	325
0.61	327	330	332	335	337

Head	0.0	0.002	0.004	0.006	0.008
0.62	340	343	345	348	350
0.63	353	355	358	361	363
0.64	366	369	371	374	377
0.65	380	382	385	388	391
0.66	393	396	399	402	405
0.67	408	410	413	416	419
0.68	422	425	428	431	434
0.69	437	440	443	446	449
0.70	452	455	458	461	464
0.71	467	470	474	477	480
0.72	483	486	489	493	496
0.73	499	502	506	509	512
0.74	515	519	522	525	529
0.75	532	535	539	542	

Table IV- 9. 3.0' H-Flume under free flow conditions in L/s.

Head	0.0	0.002	0.004	0.006	0.008
0.02					
0.03	0.96	1.06	1.18	1.29	1.41
0.04	1.54	1.67	1.81	1.95	2.09
0.05	2.25	2.40	2.57	2.74	2.91
0.06	3.09	3.27	3.46	3.66	3.86
0.07	4.06	4.28	4.49	4.72	4.95
0.08	5.18	5.42	5.66	5.92	6.17
0.09	6.43	6.70	6.98	7.26	7.54
0.10	7.83	8.13	8.44	8.75	9.06
0.11	9.38	9.71	10.0	10.4	10.7
0.12	11.1	11.4	11.8	12.2	12.5
0.13	12.9	13.3	13.7	14.1	14.5
0.14	14.9	15.4	15.8	16.2	16.7
0.15	17.1	17.6	18.0	18.5	19.0
0.16	19.4	19.9	20.4	20.9	21.4
0.17	21.9	22.4	13.0	23.5	24.0
0.18	24.6	25.1	25.7	26.3	26.8
0.19	27.4	28.0	28.6	29.2	29.8
0.20	30.4	31.1	31.7	32.3	33.0
0.21	33.6	34.3	35.0	35.6	36.3
0.22	37.0	37.7	38.4	39.1	39.8
0.23	40.5	41.3	42.0	42.8	43.5
0.24	44.3	45.1	45.8	46.6	47.4
0.25	48.2	49.0	49.8	50.7	51.5
0.26	52.3	53.2	54.0	54.9	55.8
0.27	56.6	57.5	58.4	59.3	60.2
0.28	61.2	62.1	63.0	64.0	64.9
0.29	65.9	66.8	67.8	68.8	69.8
0.30	70.8	71.8	72.8	73.8	74.9
0.31	75.9	77.8	78.0	79.1	80.2
0.32	81.2	82.3	83.4	84.5	85.7
0.33	86.8	87.9	89.1	90.2	91.4
0.34	92.5	93.7	94.9	96.1	97.3
0.35	98.5	99.7	101	102	103
0.36	105	106	107	109	110
0.37	111	112	114	115	116
0.38	118	119	120	122	123
0.39	125	126	127	129	130
0.40	132	133	135	136	138
0.41	139	141	142	144	145
0.42	147	148	150	151	153
0.43	154	156	158	159	161
0.44	163	164	166	167	169
0.45	171	173	174	176	178
0.46	179	181	183	185	186
0.47	188	190	192	194	195
0.48	197	199	201	203	205
0.49	207	208	210	212	214
0.50	216	218	220	222	224
0.51	226	228	230	232	234
0.52	236	238	241	243	245
0.53	246	248	251	253	255
0.54	257	259	261	263	266
0.55	268	270	272	274	277
0.56	279	281	283	286	288
0.57	290	293	295	279	300
0.58	302	304	307	309	312
0.59	314	317	319	321	324
0.60	326	329	331	334	336
0.61	339	341	344	347	349

Head	0.0	0.002	0.004	0.006	0.008
0.62	352	354	357	360	362
0.63	365	368	370	373	376
0.64	378	381	384	387	389
0.65	392	395	398	400	403
0.66	406	409	412	415	418
0.67	420	423	426	429	432
0.68	435	438	441	444	447
0.69	450	453	456	459	462
0.70	465	468	471	475	478
0.71	481	484	487	490	491
0.72	497	500	503	506	510
0.73	513	516	519	523	526
0.74	529	533	536	539	543
0.75	546	550	553	556	560
0.76	563	567	570	574	577
0.77	581	584	588	592	595
0.78	599	602	606	610	613
0.79	617	620	624	628	632
0.80	635	639	643	647	650
0.81	654	658	662	666	669
0.82	673	677	681	685	689
0.83	693	697	701	705	709
0.84	713	717	721	725	729
0.85	733	737	741	745	749
0.86	753	757	762	766	770
0.87	774	778	783	787	791
0.88	759	800	804	808	813
0.89	817	821	826	830	835
0.90	839	843	848	852	857

Table IV-10. 4.5' H-Flume under free flow conditions in L/s.

Head	0.0	0.002	0.004	0.006	0.008
0.02					
0.03	1.39	1.53	1.68	1.84	2.00
0.04	2.17	2.35	2.53	2.72	2.91
0.05	3.12	3.32	3.53	3.76	3.98
0.06	4.22	4.46	4.70	4.95	5.21
0.07	5.48	5.75	6.02	6.31	6.60
0.08	6.90	7.20	7.52	7.83	8.16
0.09	8.49	8.82	9.17	9.52	9.88
0.10	10.2	10.6	11.0	11.4	11.8
0.11	12.2	12.6	13.0	13.4	13.8
0.12	14.3	14.7	15.1	15.6	16.1
0.13	16.5	17.0	17.5	18.0	18.5
0.14	19.0	19.5	20.0	20.5	21.0
0.15	21.6	22.1	22.7	23.2	23.8
0.16	24.4	25.0	25.6	26.2	26.8
0.17	27.4	28.0	28.6	29.2	30.0
0.18	30.5	31.2	31.9	32.5	33.2
0.19	33.9	34.6	35.3	36.0	36.7
0.20	37.4	38.2	38.9	39.7	40.4
0.21	41.2	42.0	42.7	43.5	44.3
0.22	45.1	45.9	46.8	47.6	48.4
0.23	49.3	51.1	51.0	51.8	52.7
0.24	53.6	54.5	55.4	56.3	57.2
0.25	58.1	59.1	60.0	61.0	61.9
0.26	62.9	63.9	64.8	65.8	66.8
0.27	67.8	68.9	69.9	70.9	72.0
0.28	73.0	74.1	75.1	76.2	77.3
0.29	78.4	79.5	80.6	81.7	82.8
0.30	84.0	85.1	86.3	87.4	88.6
0.31	89.8	91.0	92.2	93.4	94.6
0.32	95.8	97.0	98.3	99.5	101
0.33	102	103	105	106	107
0.34	109	110	111	113	114
0.35	115	117	118	119	121
0.36	122	124	125	126	128
0.37	129	131	132	134	135
0.38	137	138	140	141	143
0.39	144	146	148	149	151
0.40	152	154	155	157	159
0.41	160	162	164	165	167
0.42	169	170	172	174	176
0.43	177	179	181	183	184
0.44	186	188	190	192	193
0.45	192	197	199	201	203
0.46	205	207	208	210	212
0.47	214	216	218	220	222
0.48	224	226	228	230	232
0.49	234	236	238	240	243
0.50	245	247	249	251	253
0.51	255	257	260	262	264
0.52	266	268	271	273	275
0.53	277	280	282	284	287
0.54	289	291	294	296	298
0.55	301	303	305	308	310
0.56	313	315	317	320	322
0.57	325	327	330	332	335
0.58	337	340	343	345	348
0.59	350	353	355	358	361
0.60	363	366	369	371	375
0.61	377	380	382	385	388

Head	0.0	0.002	0.004	0.006	0.008
0.62	390	393	396	399	402
0.63	405	407	410	413	416
0.64	419	422	425	427	430
0.65	433	436	439	442	445
0.66	448	451	454	457	460
0.67	463	466	470	473	476
0.68	479	482	485	488	491
0.69	495	498	501	504	537
0.70	511	514	517	520	524
0.71	527	530	534	537	540
0.72	544	547	551	554	557
0.73	561	564	568	571	575
0.74	578	582	585	589	592
0.75	596	599	603	606	610
0.76	614	617	621	625	628
0.77	632	636	639	643	647
0.78	650	654	658	662	666
0.79	669	673	677	681	685
0.80	689	693	696	700	704
0.81	708	712	716	720	724
0.82	728	732	736	740	744
0.83	748	752	757	761	765
0.84	769	773	777	781	786
0.85	790	794	798	802	807
0.86	811	815	820	824	828
0.87	833	837	841	846	850
0.88	855	859	863	868	872
0.89	877	881	886	890	894
0.90	899	904	909	913	918
0.91	922	927	932	936	941
0.92	946	950	955	960	965
0.93	969	974	979	984	988
0.94	993	998	1000	1010	1010
0.95	1020	1020	1030	1030	1040
0.96	1040	1050	1050	1060	1060
0.97	1070	1070	1080	1080	1090
0.98	1093	1098	1103	1108	1114
0.99	1119	1124	1129	1134	1140
1.00	1145	1150	1156	1161	1166
1.01	1172	1177	1182	1188	1193
1.02	1198	1204	1209	1215	1220
1.03	1226	1231	1237	1242	1248
1.04	1253	1259	1265	1270	1276
1.05	1281	1287	1292	1299	1304
1.06	1310	1316	1321	1327	1333
1.07	1339	1345	1350	1356	1362
1.08	1368	1374	1380	1386	1392
1.09	1398	1403	1409	1415	1421
1.10	1427	1434	1440	1446	1452
1.11	1458	1464	1470	1476	1482
1.12	1489	1495	1501	1507	1513
1.13	1520	1526	1532	1539	1545
1.14	1551	1558	1564	1570	1577
1.15	1583	1590	1596	1603	1609
1.16	1616	1622	1629	1635	1642
1.17	1648	1655	1661	1668	1675
1.18	1681	1688	1695	1701	1708
1.19	1715	1722	1728	1735	1742
1.20	1749	1756	1763	1769	1776
1.21	1783	1790	1797	1804	1811
1.22	1818	1825	1832	1839	1846
1.23	1853	1860	1867	1875	1882
1.24	1889	1896	1903	1910	1918
1.25	1925	1932	1939	1947	1954

Head	0.0	0.002	0.004	0.006	0.008
1.26	1961	1969	1976	1983	1991
1.27	1998	2006	2013	2020	2028
1.28	2035	2043	2050	2058	2066
1.29	2073	2081	2088	2096	2104
1.30	2111	2119	2127	2134	2142
1.31	2150	2158	2165	2173	2181
1.32	2189	2197	2205	2212	2220
1.33	2228	2236	2244	2252	2260
1.34	2268	2276	2284	2292	2300
1.35	2308	2317	2325	2333	2341
1.36	2350	2360	2370	2349	2357

Table IV- 11. 4.0' HL-Flume under free flow conditions in L/s.

Head	0.0	0.002	0.004	0.006	0.008
0.02				2.00	2.23
0.03	2.48	2.74	3.01	3.30	3.59
0.04	3.90	4.22	4.55	4.89	5.24
0.05	5.61	6.98	6.37	6.77	7.18
0.06	7.60	8.04	8.48	8.94	9.41
0.07	9.89	10.4	10.9	11.4	11.9
0.08	12.5	13.2	13.6	14.2	14.8
0.09	15.4	16.0	16.6	17.2	17.9
0.10	18.6	19.2	19.9	20.6	21.3
0.11	22.1	22.8	23.5	24.3	25.1
0.12	25.9	26.7	27.5	28.3	29.1
0.13	30.0	30.9	31.3	32.6	33.5
0.14	34.5	35.4	36.3	37.3	38.3
0.15	39.2	40.2	41.2	42.3	43.3
0.16	44.4	45.4	46.5	47.6	48.7
0.17	49.8	50.9	52.1	53.2	54.4
0.18	55.6	56.8	58.0	59.2	60.5
0.19	61.6	63.0	64.3	65.6	66.9
0.20	68.2	69.6	70.9	72.3	73.7
0.21	75.1	76.5	77.9	79.4	80.8
0.22	82.3	83.8	85.3	86.8	88.3
0.23	89.9	91.4	93.0	94.6	96.2
0.24	97.8	99.5	101	103	104
0.25	106	108	110	111	113
0.26	115	117	118	120	122
0.27	124	126	128	130	131
0.28	133	135	137	139	141
0.29	143	145	147	149	151
0.30	154	156	158	160	162
0.31	164	166	169	171	173
0.32	175	177	180	182	184
0.33	187	189	191	196	196
0.34	199	201	203	206	208
0.35	211	213	216	219	221
0.36	224	226	229	231	234
0.37	237	239	242	245	248
0.38	250	253	256	259	262
0.39	264	267	270	273	276
0.40	279	282	285	288	291
0.41	294	297	300	303	306
0.42	309	312	315	319	322
0.43	325	328	331	335	338
0.44	341	345	348	351	355
0.45	358	361	365	368	372
0.46	375	379	382	386	389
0.47	393	396	400	404	407
0.48	411	415	418	422	426
0.49	430	433	437	441	445
0.50	449	453	457	460	464
0.51	468	472	476	480	481
0.52	488	493	497	501	505
0.53	509	513	517	522	526
0.54	530	534	539	543	547
0.55	552	556	560	565	569
0.56	574	578	583	587	592

Head	0.0	0.002	0.004	0.006	0.008
0.57	596	601	606	610	615
0.58	620	624	629	634	638
0.59	644	648	653	638	662
0.60	667	672	677	682	687
0.61	692	697	702	708	712
0.62	717	722	727	733	738
0.63	743	748	753	759	764
0.64	769	775	780	785	791
0.65	796	802	807	813	818
0.66	824	829	835	840	846
0.67	851	857	863	869	874
0.68	880	886	892	897	903
0.69	909	915	921	927	933
0.70	939	945	951	957	963
0.71	969	975	981	987	993
0.72	1000	1006	1012	1018	1025
0.73	1031	1037	1044	1050	1056
0.74	1063	1069	1076	1082	1089
0.75	1095	1102	1109	1115	1122
0.76	1128	1135	1141	1149	1155
0.77	1162	1169	1176	1183	1189
0.78	1196	1203	1210	1217	1224
0.79	1231	1238	1245	1252	1260
0.80	1267	1274	1281	1288	1296
0.81	1303	1310	1317	1325	1332
0.82	1339	1347	1354	1362	1369
0.83	1377	1384	1392	1399	1407
0.84	1415	1422	1430	1438	1445
0.85	1453	1461	1467	1477	1485
0.86	1492	1500	1508	1516	1524
0.87	1532	1540	1548	1556	1564
0.88	1573	1581	1589	1597	1608
0.89	1613	1622	1630	1639	1647
0.90	1655	1664	1672	1681	1689
0.91	1698	1706	1715	1723	1732
0.92	1741	1749	1758	1767	1776
0.93	1784	1793	1802	1811	1820
0.94	1829	1838	1847	1856	1865
0.95	1874	1883	1892	1901	1910
0.96	1919	1929	1938	1947	1956
0.97	1966	1975	1984	1994	2003
0.98	2013	2022	2031	2041	2051
0.99	2060	2070	2080	2089	2099
1.00	2109	2118	2128	2138	2148
1.01	2158	2168	2177	2187	2197
1.02	2207	2217	2227	2237	2248
1.03	2258	2268	2287	2288	2299
1.04	2309	2319	2329	2340	2350
1.05	2360	2371	2382	2392	2403
1.06	2413	2424	2434	2445	2446
1.07	2466	2477	2488	2499	2509
1.08	2520	2531	2542	2553	2564
1.09	2575	2586	2597	2608	2619
1.10	2630	2641	2652	2664	2675
1.11	2686	2697	2709	2720	2732
1.12	2743	2754	2766	2777	2789
1.13	2800	2812	2824	2835	2847
1.14	2859	2870	2882	2894	2906
1.15	2918	2930	2941	2953	2965

Head	0.0	0.002	0.004	0.006	0.008
1.16	2977	2989	3002	3014	3026
1.17	3038	3050	3062	3074	3087
1.18	3099	3111	3124	3136	3149
1.19	3161	3147	3186	3199	3211
1.20	3224	3236	3249	3262	3274
1.21	3287	3300	3313	3326	

Table IV-12. 1-m rectangular Weir with End Contractions Discharge Table with Head in Meters. Formulas: Discharge (L/s) = 1838 (1.0-0.2H) $H^{1.5}$

Head	Discharge	Head	Discharge
0.005		0.255	224.6
0.010		0.260	231.0
0.015		0.265	237.4
0.020		0.270	243.9
0.025		0.275	250.5
0.030		0.280	257.1
0.035		0.285	263.7
0.040		0.290	270.4
0.045		0.295	277.1
0.050		0.300	283.9
0.055		0.305	290.7
0.060	26.69	0.310	297.6
0.065	30.06	0.315	304.5
0.070	33.56	0.320	311.4
0.075	37.19	0.325	318.4
0.080	40.92	0.330	325.4
0.085	44.77	0.335	332.5
0.090	48.73	0.340	339.6
0.095	52.80	0.345	346.8
0.100	56.96	0.350	353.9
0.105	61.22	0.355	361.2
0.110	65.58	0.360	368.4
0.115	70.03	0.365	375.7
0.120	74.57	0.370	383.1
0.125	79.20	0.375	390.4
0.130	83.91	0.380	397.8
0.135	88.71	0.385	405.3
0.140	93.58	0.390	412.7
0.145	98.54	0.395	420.2
0.150	103.6	0.400	427.8
0.155	108.7	0.405	435.4
0.160	113.9	0.410	443.0
0.165	119.1	0.415	450.6
0.170	124.5	0.420	458.3
0.175	129.8	0.425	466.0
0.180	135.3	0.430	473.7
0.185	140.8	0.435	481.4
0.190	146.4	0.440	489.2
0.195	152.1	0.445	497.1
0.200	157.8	0.450	504.9
0.205	163.6	0.455	512.8
0.210	169.4	0.460	520.7
0.215	175.4	0.465	528.6
0.220	181.3	0.470	536.6
0.225	187.3	0.475	544.5
0.230	193.4	0.480	552.6
0.235	199.5	0.485	560.6
0.240	205.7	0.490	568.7
0.245	212.0	0.495	576.7
0.250	218.3	0.500	584.8

Table IV-13. 1.5-m rectangular Weir with End Contractions Discharge Table with Head in Meters. Formulas: Discharge (L/s) = 1838 (1.50-0.2H) $H^{1.5}$

Head	Discharge	Head	Discharge	Head	Discharge
0.005		0.255	342.9	0.505	922.8
0.010		0.260	352.8	0.510	935.9
0.015		0.265	362.8	0.515	949.0
0.020		0.270	372.9	0.520	962.1
0.025		0.275	383.0	0.525	975.3
0.030		0.280	393.2	0.530	988.6
0.035		0.285	403.5	0.535	1002
0.040		0.290	413.9	0.540	1015
0.045		0.295	424.4	0.545	1029
0.050		0.300	434.9	0.550	1042
0.055		0.305	445.5	0.555	1056
0.060	40.20	0.310	456.2	0.560	1069
0.065	45.29	0.315	466.9	0.565	1083
0.070	50.58	0.320	477.8	0.570	1096
0.075	56.06	0.325	488.7	0.575	1110
0.080	61.72	0.330	499.6	0.580	1124
0.085	67.55	0.335	510.7	0.585	1137
0.090	73.55	0.340	521.8	0.590	1151
0.095	79.71	0.345	533.0	0.595	1165
0.100	86.02	0.350	544.2	0.600	1179
0.105	92.49	0.355	555.5	0.605	1193
0.110	99.11	0.360	566.9	0.610	1207
0.115	105.9	0.365	578.4	0.615	1221
0.120	112.8	0.370	589.9	0.620	1235
0.125	119.8	0.375	601.5	0.625	1249
0.130	127.0	0.380	613.1	0.630	1263
0.135	134.3	0.385	624.8	0.635	1277
0.140	141.7	0.390	636.6	0.640	1291
0.145	149.3	0.395	648.4	0.645	1305
0.150	157.0	0.400	660.3	0.650	1320
0.155	164.8	0.405	672.2	0.655	1334
0.160	172.7	0.410	684.2	0.660	1348
0.165	180.7	0.415	696.3	0.665	1363
0.170	188.9	0.420	708.4	0.670	1377
0.175	197.1	0.425	720.6	0.675	1391
0.180	205.5	0.430	732.8	0.680	1406
0.185	214.0	0.435	745.1	0.685	1420
0.190	222.5	0.440	757.5	0.690	1435
0.195	231.2	0.445	769.9	0.695	1449
0.200	240.0	0.450	782.3	0.700	1464
0.205	248.9	0.455	794.8	0.705	1479
0.210	257.9	0.460	807.4	0.710	1493
0.215	267.0	0.465	820.0	0.715	1508
0.220	276.1	0.470	832.7	0.720	1523
0.225	285.4	0.475	845.4	0.725	1537
0.230	294.8	0.480	858.2	0.730	1552
0.235	304.2	0.485	871.0	0.735	1567
0.240	313.8	0.490	883.9	0.740	1582
0.245	323.4	0.495	896.8	0.745	1597
0.250	333.1	0.500	909.8	0.750	1612

Table V-14. 2-m Rectangular Weir with End Contractions Discharge Table with Head in Meters. Formulas: Discharge (L/s) =1838 (2.0-0.2H)H$^{1.5}$

Head	Discharge	Head	Discharge	Head	Discharge	Head	Discharge
0.005		0.255	461.3	0.505	1253	0.755	2229
0.010		0.260	474.7	0.510	1271	0.760	2250
0.015		0.265	488.2	0.515	1289	0.765	2271
0.020		0.270	501.8	0.520	1307	0.770	2293
0.025		0.275	515.5	0.525	1325	0.775	2314
0.030		0.280	529.4	0.530	1343	0.780	2335
0.035		0.285	543.4	0.535	1362	0.785	2356
0.040		0.290	577.4	0.540	1380	0.790	2377
0.045		0.295	571.6	0.545	1398	0.795	2399
0.050		0.300	585.9	0.550	1417	0.800	2420
0.055		0.305	600.3	0.555	1436	0.805	2441
0.060	53.70	0.310	614.8	0.560	1454	0.810	2463
0.065	60.52	0.315	629.4	0.565	1473	0.815	2484
0.070	67.60	0.320	644.1	0.570	1492	0.820	2506
0.075	74.94	0.325	658.9	0.575	1511	0.825	2527
0.080	82.51	0.330	673.9	0.580	1530	0.830	2549
0.085	90.32	0.335	688.9	0.585	1549	0.835	2571
0.090	98.36	0.340	704.0	0.590	1568	0.840	2592
0.095	106.6	0.345	719.2	0.595	1587	0.845	2614
0.100	115.1	0.350	734.5	0.600	1606	0.850	2636
0.105	123.8	0.355	749.9	0.605	1625	0.855	2658
0.110	132.6	0.360	765.4	0.610	1645	0.860	2680
0.115	141.7	0.365	781.0	0.615	1664	0.865	2702
0.120	151.0	0.370	796.7	0.620	1683	0.870	2723
0.125	160.4	0.375	812.5	0.625	1703	0.875	2745
0.130	170.1	0.380	828.4	0.630	1722	0.880	2768
0.135	179.9	0.385	844.3	0.635	1742	0.885	2790
0.140	189.9	0.390	860.4	0.640	1762	0.890	2812
0.145	200.0	0.395	876.5	0.645	1781	0.895	2834
0.150	210.4	0.400	892.8	0.650	1801	0.900	2856
0.155	220.8	0.405	909.1	0.655	1821	0.905	2878
0.160	231.5	0.410	925.5	0.660	1841	0.910	2901
0.165	242.3	0.415	942.0	0.665	1861	0.915	2923
0.170	253.3	0.420	958.6	0.670	1881	0.920	2945
0.175	264.4	0.425	975.2	0.675	1901	0.925	2968
0.180	275.7	0.430	992.0	0.680	1921	0.930	2990
0.185	287.1	0.435	1009	0.685	1941	0.935	3013
0.190	298.7	0.440	1026	0.690	1962	0.940	3035
0.195	310.4	0.445	1043	0.695	1982	0.945	3058
0.200	322.2	0.450	1060	0.700	2002	0.950	3080
0.205	334.2	0.455	1077	0.705	2023	0.955	3103
0.210	346.3	0.460	1094	0.710	2043	0.960	3126
0.215	358.6	0.465	1111	0.715	2064	0.965	3148
0.220	371.0	0.470	1129	0.720	2084	0.970	3171
0.225	383.5	0.475	1146	0.725	2105	0.975	3194
0.230	396.2	0.480	1164	0.730	2125	0.980	3217
0.235	408.9	0.485	1181	0.735	2146	0.985	3240
0.240	421.8	0.490	1199	0.740	2167	0.990	3263
0.245	434.9	0.495	1217	0.745	2188	0.995	3285
0.250	448.0	0.500	1235	0.750	2209	1.000	3308

Table V- 15. 3-m Rectangular Weir with End Contractions Discharge Table with Head in Meters. Formulas: Discharge (L/s) =1838 (3.0-0.2H) $H^{1.5}$

Head	Discharge	Head	Discharge	Head	Discharge
0.005		0.255	98.0	0.505	1912
0.010		0.260	718.3	0.510	1940
0.015		0.265	738.9	0.515	1968
0.020		0.270	759.7	0.520	1996
0.025		0.275	780.6	0.525	2024
0.030		0.280	801.7	0.530	2052
0.035		0.285	823.0	0.535	2081
0.040		0.290	844.5	0.540	2109
0.045		0.295	866.1	0.545	2138
0.050		0.300	887.9	0.550	2167
0.055		0.305	909.9	0.555	2195
0.060	80.71	0.310	932.1	0.560	2224
0.065	90.98	0.315	954.4	0.565	2254
0.070	101.6	0.320	976.8	0.570	2283
0.075	112.7	0.325	999.5	0.575	2312
0.080	124.1	0.330	1022	0.580	2341
0.085	135.9	0.335	1045	0.585	2371
0.090	148.0	0.340	1068	0.590	2401
0.095	160.4	0.345	1092	0.595	2430
0.100	173.2	0.350	1115	0.600	2460
0.105	186.3	0.355	1139	0.605	2490
0.110	199.7	0.360	1162	0.610	2520
0.115	213.4	0.365	1186	0.615	2550
0.120	227.4	0.370	1210	0.620	2581
0.125	241.7	0.375	1235	0.625	2611
0.130	256.2	0.380	1259	0.630	2641
0.135	271.0	0.385	1283	0.635	2672
0.140	286.1	0.390	1308	0.640	2703
0.145	301.5	0.395	1333	0.645	2733
0.150	317.1	0.400	1358	0.650	2764
0.155	333.0	0.405	1383	0.655	2795
0.160	349.1	0.410	1408	0.660	2826
0.165	365.5	0.415	1433	0.665	2858
0.170	382.1	0.420	1459	0.670	2889
0.175	399.0	0.425	1484	0.675	2920
0.180	416.0	0.430	1510	0.680	2952
0.185	433.3	0.435	1536	0.685	2983
0.190	450.9	0.440	1562	0.690	3015
0.195	468.6	0.445	1588	0.695	3047
0.200	486.6	0.450	1615	0.700	3079
0.205	504.8	0.455	1641	0.705	3111
0.210	523.2	0.460	1668	0.710	3143
0.215	541.8	0.465	1694	0.715	3175
0.220	560.6	0.470	1721	0.720	3207
0.225	579.7	0.475	1748	0.725	3239
0.230	598.9	0.480	1775	0.730	3272
0.235	618.3	0.485	1802	0.735	3304
0.240	637.9	0.490	1830	0.740	3337
0.245	657.8	0.495	1857	0.745	3370
0.250	677.8	0.500	1885	0.750	3402
0.755	3435	1.005	5183	1.255	7104
0.760	3468	1.010	5220	1.260	7144
0.765	3501	1.015	5257	1.265	7184
0.770	3534	1.020	5294	1.270	7224
0.775	3568	1.025	5331	1.275	7264
0.780	3601	1.030	5368	1.280	7304
0.785	3634	1.035	5405	1.285	7344
0.790	3668	1.040	5443	1.290	7384

Head	Discharge	Head	Discharge	Head	Discharge
0.795	3701	1.045	5480	1.295	7424
0.800	3735	1.050	5517	1.300	7465
0.805	3769	1.055	5555	1.305	7505
0.810	3803	1.060	5592	1.310	7545
0.815	3837	1.065	5630	1.315	7586
0.820	3871	1.070	5668	1.320	7626
0.825	3905	1.075	5705	1.325	7667
0.830	3939	1.080	5743	1.330	7708
0.835	3973	1.085	5781	1.335	7748
0.840	4007	1.090	5819	1.340	7789
0.845	4042	1.095	5857	1.345	7830
0.850	4076	1.100	5895	1.350	7871
0.855	4111	1.105	5933	1.355	7911
0.860	4145	1.110	5971	1.360	7952
0.865	4180	1.115	6009	1.365	7993
0.870	4215	1.120	6048	1.370	8034
0.875	4250	1.125	6086	1.375	8075
0.880	4285	1.130	6124	1.380	8117
0.885	4320	1.135	6163	1.385	8158
0.890	4355	1.140	6201	1.390	8199
0.895	4390	1.145	6240	1.395	8240
0.900	4425	1.150	6279	1.400	8281
0.905	4461	1.155	6317	1.405	8323
0.910	4496	1.160	6356	1.410	8364
0.915	4532	1.165	6395	1.415	8406
0.920	4567	1.170	6434	1.420	8447
0.925	4603	1.175	6473	1.425	8489
0.930	4639	1.180	6512	1.430	8530
0.935	4674	1.185	6551	1.435	8572
0.940	4710	1.190	6590	1.440	8613
0.945	4746	1.195	6629	1.445	8655
0.950	4782	1.200	6668	1.450	8697
0.955	4818	1.205	6708	1.455	8739
0.960	4855	1.210	6747	1.460	8781
0.965	4891	1.215	6787	1.465	8822
0.970	4927	1.220	6826	1.470	8864
0.975	4963	1.225	6865	1.475	8906
0.980	5000	1.230	6905	1.480	8948
0.985	5036	1.235	6945	1.485	8990
0.990	5073	1.240	6984	1.490	9033
0.995	5110	1.245	7024	1.495	9075
1.000	5146	1.250	7064	1.500	9117

Appendix V: Relevant Course Descriptions

[This section is mainly prepared based on report written by Reksten, D.E., titled: "Qualifications for Certified Reviewers for RIC Standard Hydrometric Survey Data, September 30, 1998"]

The following are generalized descriptions of courses considered relevant to an understanding of hydrometric survey operations. Examples of specific courses available for each subject are listed below:

HYDROLOGY

Hydrologic cycle and water balance - precipitation, evaporation, interception, infiltration, soil water, snowmelt, glacier melt, surface runoff, groundwater; climate; watershed hydrology; hydrologic data analysis probability and statistics; frequency analysis – rainfall intensity-duration, peak and low flows; time series analysis; channel and reservoir routing; hydrologic modelling – unit hydrograph theory, watershed runoff models, rural and urban simulation models, design storms; measurement of hydrologic variables; estimating hydrologic variables for ungauged watersheds; hydrologic aspects of environmental change

OPEN CHANNEL HYDRAULICS

Steady open channel flow; energy and momentum principles; non-uniform steady flow; lake discharge and control sections; unsteady open channel flow; kinematic waves; flood routing; sediment transport and erosion; flow through transitions, bends and obstructions; backwater curves and water profile computations; floodplain analysis and flood control; reservoir analysis; design and modelling of channels and hydraulic structures – weirs, dikes, dams, culverts, diversions, tunnels and conduits; natural channels; river morphology.

PLANE SURVEYING

Theory and application of plane surveying methods. Use of compass, tape and level; horizontal and vertical control; topographic mapping; reduction of field data; distance and angular measurement; traversing and transit surveys. Demonstration of modern instruments, remote sensing methods and geographical information systems (GIS).

MATHEMATICAL METHODS

Solution of linear and non-linear algebraic equations; numerical solution of differential equations; curve fitting techniques; matrix manipulation; calculus; power series methods; interpolation; error analysis.

STATISTICS AND PROBABILITY

Data analysis; decision-making; assessing risk and uncertainty; probability distributions; random variables; estimation theory; regression analysis; hypothesis formulation; analysis of variance; goodness of fit; quality control; joint probability distributions; multiple linear regression; confidence intervals; time series data analysis; transforming data.

ELECTRICITY AND ELECTRONICS

Fundamental electrical concepts and units; source of electrical energy; terminal properties of voltage and current sources, resistors, capacitors and inductors; network analysis; power and energy; electric and magnetic fields; measurement techniques; DC resistive networks; steady-state sinusoidal theory; three phase systems; transient analysis; state equation methods;

computer-oriented solution techniques; semiconductors, dielectrics, piezolectrics, ferroelectrics, ferrites and their applications in sensors and transducers; digital circuit technologies; circuit analysis and electronic circuits; characteristics and application of electronic instruments; principles of analog and digital measuring instruments.

COMPUTER APPLICATIONS

Computer graphics; interactive programming and use of numerical algorithms; organization and operation of microcomputers; operating systems and languages; mathematical analysis, including functions and graphical curve fitting; hardware; software; solution of linear algebraic equations with real and complex coefficients; error analysis, root finding and interpolation; data representation in digital computers.

FLUID MECHANICS

Fluid properties; hydrostatics; viscosity; boundary layer development; energy and momentum equations; dimensional analysis; velocity and pressure fields; flow in pipes and pipe networks – friction losses, roughness, turbulence, velocity distributions; forces on immersed objects; pipe network analysis; open channel flow – specific energy, roughness, velocity distributions, channel design, laminar and turbulent flow.

CLIMATOLOGY AND WEATHER

Basic physical principles and processes governing atmospheric circulation, energy exchanges and the water cycle; principles of meteorology and climatology at the scales typical of weather systems and global climate; physical and geographical aspects of different ice forms; measurement of snow and ice; processes involved in weather, climate and surface waters; physical processes that determine the variation in climate and weather; application of physical principles to practical problems in climatology; basic principles and processes involved in physical and dynamic climatology; radiation, energy and water balances.

FLUVIAL GEOMORPHOLOGY

Morphology of rivers and river systems; erosion, transportation and deposition of sediments, and resulting landforms; estuaries; computation of water profiles; flood control; floodplain analysis.

Appendix VI. List of References

Bos, M.G. (1989), Discharge Measurement Structures, Edited by M.G. Bos, International Institute for Land Reclamation and Improvement, Delft Hydraulics Laboratory, Wageningen, The Netherlands. 1989.

Environment Canada (1980), Manual of Hydrometric Data Computation and Publication Procedures, Fifth Edition, Inland Waters Directorate, Water Resources Branch, Ottawa, pp. 51.

Environment Canada (1983), Hydrometric Field Manual-Measurement of Stage, Inland Waters Directorate, Water Resources Branch, Ottawa, pp. 47.

Environment Canada (1984), Hydrometric Field Manual – Levelling, Inland Waters Directorate, Water Resources Branch, Ottawa, pp.14.

Environment Canada (1999), Hydrometric Technician Career Development Program, Lesson Package No. 3: Bench Marks and Gauge Datum, by C.C. Handkamer, Water Survey of Canada, Environment Canada, 1999. (http://www.wsc.ec.gc.ca/CDP/Lesson3/index_ie_e.htm).

Environment Canada (1999), Hydrometric Technician Career Development Program, Lesson Package No. 4: Measurement of Stage - Instrumentation Non-Recording Manual Gauges, by F. Slabosz, Water Survey of Canada, Environment Canada, 1999. (http://www.wsc.ec.gc.ca/CDP/Lesson4/index_ie_e.htm).

Environment Canada (1999), Hydrometric Technician Career Development Program, Lesson Package No. 7: Levelling Instruments and Procedures, by E. Mayert and, D.G. Goller, Water Survey of Canada, Environment Canada, 1999. (http://www.wsc.ec.gc.ca/CDP/Lesson7/index_ie_e.htm).

Environment Canada (1999), Hydrometric Technician Career Development Program, Lesson Package No. 10.1: Principles of Discharge Measurement by Roy J. Lane, Water Survey of Canada, Environment Canada, 1999. (http://www.wsc.ec.gc.ca/CDP/Lesson10.1/index_ie_e.htm).

Rantz, S.E., et al. (1982), Measurement and Computation of Streamflow, Volume 1, Measurement of Stage and Discharge, USGS Water Supply Paper 2175, Washington, D.C., pp. 284.

Reksten, D.E. (1998), Qualifications for Certified Reviewers for RIC Standard Hydrometric Survey Data, Prepared for Water Inventory Section, Resources Inventory Branch, Ministry of Environment, Lands and Parks, September 30, 1998.

RIC (1998), Manual of Standard Operating Procedures for Hydrometric Surveys in British Columbia, Version 1.1, November 2, 1998, Resources Inventory Committee, Province of British Columbia, Canada.

RISC (2006), Continuous Water Quality Sampling Programs: Operating Procedure, Resources Information Standards Committee, Province of British Columbia, Canada.

Terzi, R.A. (1981), Hydrometric Field Manual – Measurement of Streamflow, Environment Canada, Inland Waters Directorate, Water Resources Branch, Ottawa, pp.23.

USGS (1984), Measurement of Peak Discharge by the Slope-Area Method, Techniques of Water-Resources Investigations of the United States Geological Survey, Book 3, Chapter A2, USGS, 1984.