Manual of British Columbia Hydrometric Standards

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for the
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Preface

The Manual of British Columbia Hydrometric Standards, version 2.0 is updated and revised from version 1.0, 2009. It defines a set of standards with detailed procedures for acquiring water quantity data, assessing the data, and qualifying and quantifying data grades. This manual supersedes The Manual of British Columbia Hydrometric Standards, version 1.0, 2009. Changes incorporated in this revision are based on comments of reviewers and users. Version 2.0 incorporates some of the National Standards (Environment and Climate Change Canada) and adds new information and technologies.

Some of the specific improvements of version 2.0 are:

- Streamlined and updated data grading criteria based on user feedback and availability of new technologies and instrumentation.
- A new data grade, BP (Best Practice) is introduced for streamflow data from salt dilution gauging. Detailed procedures and metadata requirements to achieve a BP data grade are discussed.
- New equipment available for hydrometric surveys is identified and discussed.
- Revised and updated hydrometric forms for capturing data and information.
- 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 Knowledge Management Branch, Ministry of Environment and Climate Change Strategy 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, Knowledge Management Branch, Ministry of Environment and Climate Change Strategy, 4th Floor - 525 Superior Street, Victoria, BC V8V 0C5 or email to: Ashfaque.Ahmed@gov.bc.ca

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Abstract

This revised manual describes the B.C. Ministry of Environment and Climate Change Strategy 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 manual also includes a chapter on the development and use of data grades and provides an overview of the data review process. All the hydrometric forms that should be used to document the metadata and procedures, including the characteristics of the equipment are included.

Acknowledgements

The Government of British Columbia provides funding of the Resources Information Standards Committee (RISC) work, including the preparation of this document. The Resources Information Standards Committee supports the effective, timely, and integrated use of land and resource information for planning and decision making by developing and delivering focussed, cost-effective, common provincial standards and procedures for information collection, management, and analysis. Representatives to the Committee and its Task Forces are drawn from the ministries and agencies of the Canadian and the British Columbia governments, academia, industry, and First Nations.

The Resources Information Standards Committee evolved from the Resources Inventory Committee (RIC), which received funding from the Canada–British Columbia Partnership Agreement on Forest Resource Development (FRDA II), the Corporate Resource Inventory Initiative (CRII), and by Forest Renewal BC (FRBC), and addressed concerns of the 1991 Forest Resources Commission.

For further information about the Resources Information Standards Committee, please access the RISC website at: www.gov.bc.ca/risc-standards or email RISCWeb@gov.bc.ca

This edition supersedes Manual of British Columbia Hydrometric Standards, version 1.0, 2009.

This method standard is based on revisions to the previous standard and with consideration to national standards developed by Environment and Climate Change Canada, which have been utilized extensively along with other sources listed in Appendix VI. The project author was Ashfaque Ahmed, P. Eng., assisted with editorial input by Blair Irwin, Knowledge Management Branch of the B.C. Ministry of Environment and Climate Change Strategy. The author gratefully acknowledges the following individuals and their organizations for providing their professional review, comments, and contributions: Robin Pike (B.C. Ministry of Environment and Climate Change Strategy), Jon Goetz (B.C. Ministry of Environment and Climate Change Strategy), Kyle Terry (B.C. Ministry of Environment and Climate Change Strategy), Neil Goeller (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development), Christian St. Pierre (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development), Sarah Crookshanks (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development), Chelton van Geloven (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development), William Floyd (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development), Heather Johnstone (B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development), Livia Meret (B.C. Ministry of Attorney General), Stephanie Moore (Environment and Climate Change Canada), Tyler Williams (Environment Yukon), Anthony Bier (Environment Yukon), Tobi Gardner (Capital Regional District, B.C.), Daniel Moore (University of British Columbia), Drew Lejbak (Associated Environmental Consultants Inc.), Sid Kwakkel (Associated Environmental Consultants Inc.), Brian Guy (Associated Environmental Consultants Inc.), Glenn Cumyn (SFE Global), Andre Zimmerman (Northwest Hydraulic Consultants), Gabe Sentlinger (Aquarius RandD Inc.), Jaime Cathcart (Knight Piesold Ltd.), Scott Jackson (Lorax Environmental Services Ltd.), Colin Fraser (Lorax Environmental Services Ltd.), and Frank van der Have (Hoskin Scientific Ltd.).

Revision History

Version	Date	Description/Rationale for Change
1.0	2009	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. This revised manual includes updated data-grading criteria and a detailed data review and validation process. New RISC hydrometric forms for recording the data and calculations are also included.
2.0	2018	Manual of British Columbia Hydrometric Standards, version 2.0 introduced a new Best Practice (BP) data grade for discharge data using salt dilution gauging. Data grading criteria have been revised and updated based on user feedback and availability of new technologies and instrumentations.

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Chapter 1: Introduction to Provincial Standards

1.1 General

The purpose of hydrometric surveying 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 produced by the Canada-BC hydrometric network, which is collected in accordance with Environment and Climate Change Canada (i.e., Water Survey of Canada) standards. These hydrometric stations are operated under a Canada-BC Agreement that produces 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 collected under RISC[1] hydrometric standards. Non-integrated data are captured and distributed through a provincial data management 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 that water level (or stage) and discharge (or stream flow) data are produced to an acceptable level of quality and accuracy, a provincial standard has been developed to provide uniform guidelines for production, review, and archiving of hydrometric information**.** The provincial hydrometric standard is required to affirm the credibility of data for any application, anywhere in the province.

This manual (or standard) describes the procedures, documentation, and analyses that must be used to meet RISC standards for hydrometric surveys in British Columbia. Chapter 2 to Chapter 5 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.

1.2 Who Should Use the Manual

The primary users of this document will be government organizations, industries, 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, and user groups such as Improvement Districts and educational users. In general, users of the provincial hydrometric database will refer to this document to understand the quality of the data that falls within the different categories (i.e., data grades described in Section 1.5).

[1] Ressources Information Standards Commette

1.3 Limitations of the Manual

This manual focusses on measuring stream flows that range between **0 m^3/s and 10 m^3/s.** In addition, this manual does not cover all types of operations, such as ice conditions. At this time, it is recommended that work beyond the scope of this provincial standard be referred to the Water Survey of Canada, or some other group with appropriate expertise.

1.4 Disclaimer

The purpose of this manual is to provide information and standards for activities carried out in the production of hydrometric data. It is the responsibility of all users of this Manual to independently confirm and verify how and when specific standards apply to their individual circumstances. The manual should not be relied upon as specific advice regarding those circumstances. The user is responsible for reviewing their particular circumstances and for determining, with the assistance of suitably qualified professionals, the relevancy, suitability, reliability, usability, completeness, timeliness, accuracy, or applicability of this information and these standards to their circumstances.

While the information and standards provided within this manual are believed to be accurate at the time of publication, the British Columbia government does not confirm their ongoing currency, accuracy, or completeness or their applicability to or suitability for individual circumstances. The users of this manual are responsible for securing their own professional advice.

Also, users of this manual are reminded that field operations for hydrometric surveys or related activities can involve some risk. All field operations should be carried out with appropriate safety measures, and in accordance with all relevant regulations or directions, including those of the Work Safe BC Occupational Health and Safety Regulation. No information or standards provided in this manual (including text, photos, and diagrams) are intended to deviate from safe field practice. Under no circumstances will the British Columbia government take on any liability or responsibility for the safety of persons who use this manual in their hydrometric operations.

Please note that brand names of products and manufacturers are occasionally used in the text and illustrations to describe various hydrometric operations. The inclusion of such is provided for the purpose of explanation and/or illustration only, and is not intended as an endorsement, recommendation, or advertisement of those products or manufacturers.

Finally, the British Columbia government accepts no liability or responsibility for the relevancy, suitability, reliability, usability, completeness, timeliness, accuracy, or applicability of any of the information and standards in this manual to individual circumstances, nor for any results obtained from their use. Users of this manual are wholly responsible for independently verifying the appropriateness of the information and standards herein provided to their individual circumstances based on their own professional advice.

1.5 RISC Hydrometric Standards and Data Grades

1.5.1 Introduction

By definition, the “**RISC hydrometric standards**” are the field procedures, calculations, validation steps and documentation mandated by the Resources Information Standards

Committee of British Columbia for conducting a hydrometric survey" (see the Glossary in Appendix I).

Hydrometric standards described here are a set of information, which when followed should ensure the quality and accuracy of data produced in regard to the 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 water licensing, mine effluent permits issued under the *Environmental Management Act*, baseline environmental impact assessments (e.g., "Water and Air Baseline Monitoring Guidance Documents for Mine Proponents and Operators", British Columbia Ministry of Environment 2016), and others are required to meet RISC standards.

The RISC hydrometric standards 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 three criteria for both the water level data and the discharge data (Table 1-1). The three criteria are: instrumentation; field procedures, and data calculation and assessment. Each criterion is reported as one of five grades as described in Section 1.5.2. Once data are acquired, calculated and compiled, the data must then be reviewed to assign a 'standard grade' by the hydrometric data reviewer according to the standards requirements criteria (Table 1-1). Discharge data also have a temporary or special data grade called BP (Best Practice) when best practices methods have been followed for the field conditions, but standards are yet to be developed.

1.5.2 Data Grades

Grade A

This grade standard is the highest level of data quality in the hierarchy of provincial standards (Table 1-1). 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 that can result in a very high level of accuracy and reliability. Grade A/RS is discussed in more detail below.

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 meet the Grade A/RS category requirements as defined in Table 1-1. 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 correct installation, and include all other appropriate data. In circumstances where the installation of the structure does not meet specifications, leakage is significant, and/or documentation is missing, it may not be possible to assign a standard grade to the data. It should be noted that with rated structures, minor deviations from ideal conditions can have major impacts on the accuracy of the 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.

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

This data grade allows for less rigorous procedures in the development of the rating curve, and greater scatter between individual measurements relative to the best fit curve. Discharge data from manually operated sites (e.g., staff gauge readings of water level) may fall into this level if gauge reading accuracy for data Grade B cannot be achieved.

Grade BP- Best Practice

Discharge data should be graded as “BP” (i.e., Best Practice) when the standard procedure for discharge measurement such as the use of a current meter or rated structure cannot be used due to flow conditions. This grade should be applied only where best practice methods have been followed, such as salt dilution gauging (i.e., tracer technique) for monitoring a discharge in steep gradient and highly turbulent streams. Ongoing work is contributing to improved protocols and best practices for tracer injection methods. Guidelines and data requirements for salt dilution gauging as a best practice method are described in Chapter 4.

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 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 levels.

Grade U

Grade U data are data of an unknown quality that cannot be assigned to a standard grade. These are typically low-quality data collected and managed using procedures not consistent with the RISC hydrometric standard Grades 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 with an appropriate disclaimer for future use and general distribution.

Table 1-1: 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 (When applicable)	N/A	At least annually	At least annually	Less often than annually	See Notes below	Undefined
Water level gauge reading/sensor accuracy	Either 3 mm or 0.2% of effective stage, whichever is greater	Either 3 mm or 0.2% of effective stage, whichever is greater	Either 5 mm or 0.2% of effective stage, whichever is greater	1 cm or better	See Notes below	Undefined
Field Procedure						
Minimum number of benchmarks	3	3	3	3	See Notes below	Undefined
Number of verticals in manual flow measurements when current meter is used	N/A	20 or more (if sufficient channel width to meet minimum flow meter panel widths) and not more than 10% of total flow in each panel	20 or more (if sufficient channel width to meet minimum flow meter panel widths) and not more than 10% of total flow in each panel	10 or more (if sufficient channel width to meet minimum flow meter panel widths) and not more than 20% of total flow in each panel	See Notes below	Undefined
Number of manual flow measurements per year	Minimum of one field measurement for rating verification	5 or more over adequate range of streamflows	3 or more over adequate range of streamflows	2 or more over adequate range of streamflows	See Notes below	Undefined

Table 1-1: 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)
Number of benchmark elevation and ref. gauge elevation level checks per year	2 or more, or at least once when ref. gauge and the benchmarks have been documented to be stable	2 or more, or at least once when ref. gauge and the benchmarks have been documented to be stable	2 or more, or at least once when ref. gauge and the benchmarks have been documented to be stable	1 or more	See Notes below	Undefined
Data Calculation and Assessment						
Discharge rating accuracy /Rating curve shift deviation threshold	<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 years for consistency	Yes	Yes	No	No	See Notes below	Undefined

Table 1-1: 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 reading/sensor accuracy	Either 3 mm or 0.2% of effective stage, whichever is greater	Either 5 mm or 0.2% of effective stage, whichever is greater	1 cm or better	See Notes below	Undefined
Field Procedure					
Minimum number of benchmarks	3	3	3	See Notes below	Undefined
Number of benchmark elevation and ref. gauge elevation level checks per year	2 or more, or at least once when ref. gauge and the benchmarks have been documented to be stable	2 or more, or at least once when ref. gauge and the benchmarks have been documented to be stable	1 or more	1 or more	See Notes below
Data Calculation and Assessment					
Data and calculation reviewed for anomalies	Yes	Yes	Yes	See Notes below	Undefined
Results are compared with other stations and/or other years for consistency	Yes	No	No	See Notes below	Undefined

[**Notes:** 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. 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]

1.6 Overview of the RISC Hydrometric Standards Process in British Columbia

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

Step 1. Hydrometric field operations

Step 2. Compile the preliminary dataset

Step 3. Check the preliminary dataset

Step 4. Review the dataset and assign a data grade

Step 5. Submit a dataset

Step 6. Review and audit the selected dataset (details are not included in this manual)

Step 7. Archive and distribute the data

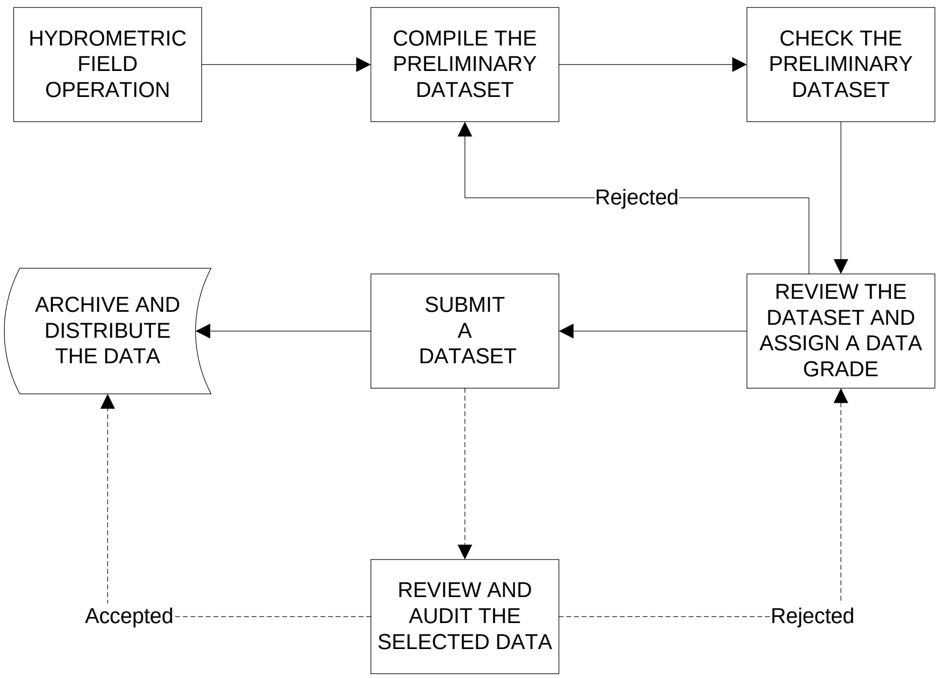


Figure 1-1: Flow chart of RISC Hydrometric Standards Process in British Columbia.

Step 1. Hydrometric field operations:

The scope of hydrometric field operations 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 British Columbia, 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, must follow the British Columbia hydrometric standards, and must have completed all relevant safety trainings. The qualifications of a hydrometric operator must be acceptable to the Qualified Hydrometric Data Reviewer (or “Reviewer”). The Reviewer will review the dataset and assign data grades according to the standards.

Step 2. Compile the preliminary dataset:

The compilation of the preliminary dataset includes the collection of gauge data and level notes, the application of gauge correction/adjustment factors, station history compilation, discharge computation, stage-discharge derivation and plotting, the preparation of a rating table, and the computation of mean daily (or other) discharge. The hydrometric operator must complete all of the computations and generate the necessary documentation in addition to completing the “Station Analysis” form (see Figure II-7 in Appendix II). This form describes the complete analysis of data collected, procedures used in processing the data, and the logic upon which the computations are based.

Step 3. Check the preliminary dataset:

The hydrometric operator should check the preliminary dataset. If a basin review or regional hydrologic analysis has been completed 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 steps 1–3 and forward the information to the Reviewer who will review the dataset and assign data grades. The Reviewer should be involved throughout the process of data collection in order to competently review and assign the data grades. Activities involved in steps 1–3 are presented in Figure 1-2.

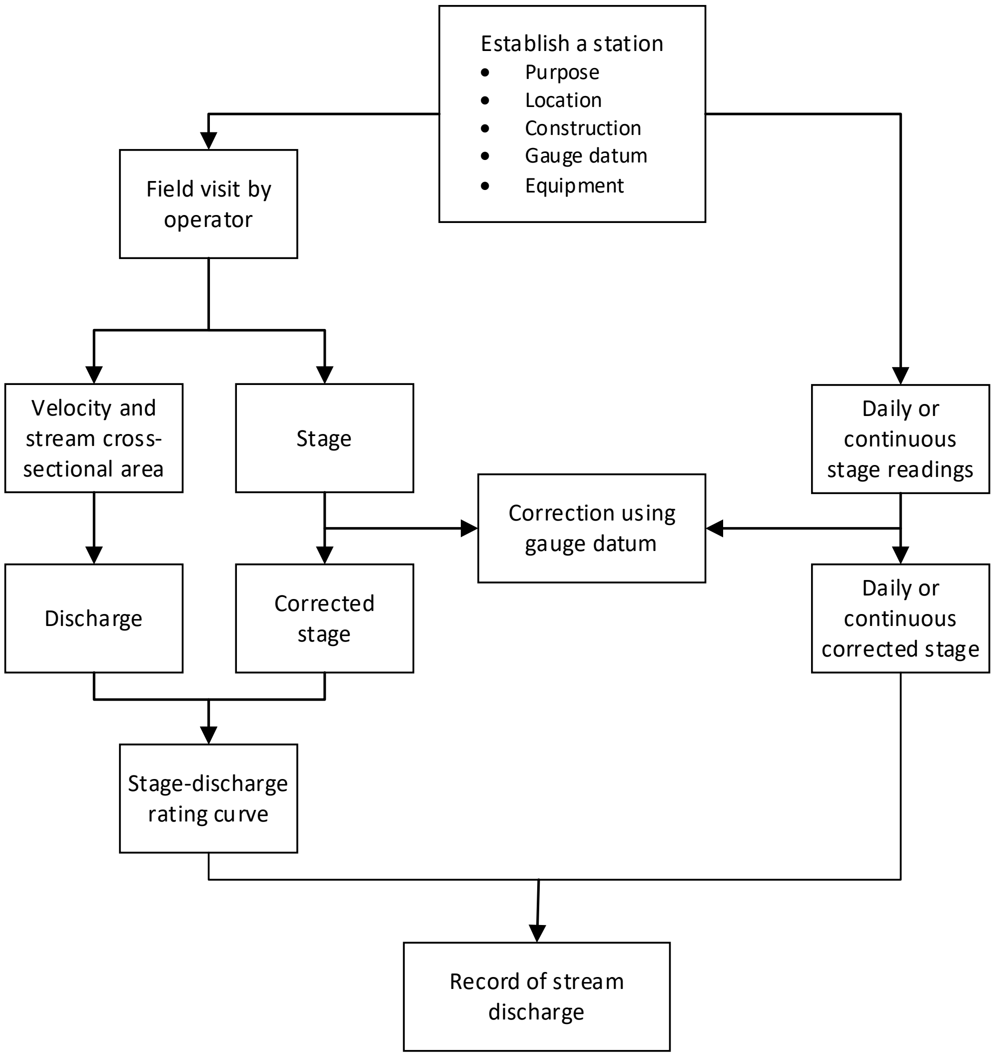


Figure 1-2: An overview of the hydrometric data collection activities during the field visit and between visits.

Step 4. 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 of the data in the dataset and assign data grades in accordance with the standards requirements criteria (Table 1-1) before submission to the provincial water database for archiving and distribution. A detailed description of the data review process and the role and responsibilities of a Qualified Hydrometric Data Reviewer are presented in Chapter 6.

Step 5. Submit a dataset:

For provincially funded projects: Time series raw data, metadata (or completed hydrometric forms), and 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 metadata, rating curves (or rating equations with their limiting conditions), and rating table (for manual rating curve) with analyses in PDF format.

Data that have not been reviewed by a Qualified Hydrometric Data Reviewer or data that do not meet the standard grades A, B, C, BP, or E but do provide useful information for qualitative assessment can be submitted as Grade “U” data.

Step 6. 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 RISC hydrometric standards and is correctly graded. Audits are performed on randomly selected data. Audited data are either approved/confirmed or returned for further work.

Step 7. Archive and distribute the data:

Currently, the AQUARIUS database is the repository of provincial non-integrated hydrometric data. Data generated by automated snow pillows, manual snow surveys, and observation wells, and continuous water quality data are also stored in the AQUARIUS database. All of these data can be viewed and downloaded through the Aquarius web portal.

Chapter 2: Fundamentals of Hydrometric Operations

2.1 Establishing a Gauging Station

2.1.1 General

A gauging station or hydrometric station is a natural or constructed location on a watercourse where records of stage (water level) and discharge are systematically obtained. 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 stage data to produce a record of discharge. The stage record is referenced to a station datum or benchmark elevation, which is set when the gauging station is established.

The purpose of any hydrometric 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).

There are two types of gauging stations:

- manual (non-recording) gauge
    - read periodically (e.g., daily, weekly) by a site operator, and
- recording or automatic gauge
    - continuous record of water level (i.e., digital record)

Both manual and automatic gauges can be used to collect stage and discharge data. Many variations or combinations of instrumentation and equipment can be used at each type of station. Details of manual and automatic gauges and their instrumentation and equipment are provided in chapter 3.

2.1.2 Desirable Criteria for a Basic Station

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

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

a) A stable natural control (Figure 2-1) 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
- long reach of stable bed

b) A stable artificial control may be a:

- rated structure (flume, weir, etc.) (Figure 2-2)
- fish barrier (drop structure)
- streambed sill (log, concrete, etc.) (Figure 2-3)

- Discharge can be measured accurately at all stages, either with a current meter or by other means.
- The site access is secure and safe during the operational season. The station is structurally sound (e.g., can withstand being overtopped).

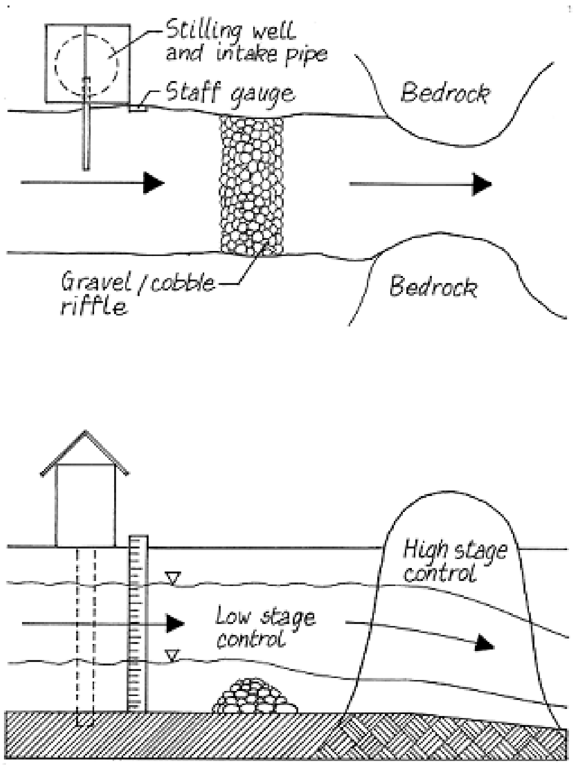


Figure 2-1: A stable natural control.

Figure 2-2: A stable artificial control (weir).

Figure 2-3: A stable artificial control (log sill).

2.1.3 Selecting a Site for the Gauging Station

2.1.3.1 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. Review available maps (topographical, geological), and recent air photos. If possible, query people who are familiar with the watercourse and the region such as residents, water users, loggers, First Nations, or other technical specialists. 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, or seasonal installation of fish counting fences).

For site selection, particularly when both stage and discharge will be measured, a number of factors including hydraulic properties need to be considered:

Site Access

- safe access of the site over the full range of measurements
- the ability to carry materials to the site and the suitability of the site to accommodate machinery during construction
- safe access to river edge
- a long-term agreement with any land owner whose land must be crossed to gain access to the site

Safety and Security

- hazards for observers, the public, livestock, and wildlife related to the location and the measurement activity should be identified and minimized

- any possibility of vandalism or curiosity that would affect the measurements should be identified and minimized

Hydraulic Properties

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

- location of a suitable control either natural of artificial
- stable channel, no likelihood of degradations, and aggradation and free from weeds
- high stream banks to contain all flows
- good current meter measuring sites; for example, metering section should be straight and uniform, total flow should be confined to one channel at all stages, no undercut banks, minimal obstructions, no turbulence, no slow-moving pools (dead water or backwater effects), no eddies
- no inflows between gauge and metering sites
- no wetlands or pooling of water downstream or in vicinity of gauge to cause backflow

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 inspect 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 a land owner or manager to access the property. For site access permission and legal requirements please see Section 2.2.2 for details.

2.1.3.2 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. Reconnaissance should include careful observation of the following:

Low Flow Conditions

Look for a stable, well-defined low water control.

If a stable control is not available, consider the feasibility of building an artificial low water control; however, it should not create a fish migration barrier and may require approval from the Province of British Columbia under Section 11 of the *Water Sustainability Act* (http://www.bclaws.ca/civix/document/id/complete/statreg/14015), see Section 2.2.2 for details. 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.

For accurate measurements of stage in low flow conditions, select a location that ensures that a stage datalogger/sensor is under sufficient water depth during summer and winter low flows, as well as under the presence of ice. A pool (small or large) with a stable control is generally a good installation location to ensure that stage is recorded throughout the year.

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.

To avoid damage from high water levels or velocities and floating debris, locate associated recording equipment that needs to remain dry above the highest flood levels.

Flow Measurement Conditions

Ensure that the site has a suitable location for measuring discharge, either with a current meter or by other means.

Ideally, the metering section using the mid-section method should have the following characteristics:

- a well defined single channel for all range of flows
- a reasonably uniform depth and velocity with parallel flow lines across the section
- 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
- a manual gauge or reference gauge should, if possible, be located in the same metered/rated section
- 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
- no aquatic growth or vegetation. Both the low flow and high flow measurement sections should be clear of aquatic growth

Backwater Effect

Variable backwater effects must be carefully considered. According to Rantz and others (1982), p.7: "*Given a choice of several acceptable gaging sites on a stream, the gaging site selected should be the one farthest upstream from the possible source of variable backwater. If it is necessary to accept a site where variable backwater occurs, a uniform reach for measurement of slope should be sought, along with a site for the installation of an auxiliary gage.*"

Conditions for Stilling Wells or Water Level Sensors

The following factors should be considered when selecting a suitable site for stilling wells or water level sensors:

- public safety and site security
- constructability and durability
- maintenance of the datum (i.e., surrounding site should be stable), installation of suitable benchmarks and reference gauges
- a suitable location for the reference gauge in the same pool as the stage sensor, gauge intakes, or orifice. This will ensure that the reference gauge provides readings that are indicative of the data recorded by the stage sensor
- water level sensors and reference gauge location should be accessible and safe during all flow conditions

- when the gauge is located at or near a bridge, it should be on the downstream side of the bridge. If this is not possible, it should be installed upstream of the bridge at a location free of any drawdown effects that may be caused by the bridge during medium and high water
- if a stilling well is used for water level measurements, the intakes or orifice should be located in a pool where stream velocity and turbulence is low. If this is not possible, place the intakes or orifice in a slack-water zone where they are protected from high velocity
- provision of a sufficient power supply from solar, mains, or other power sources
- no interruption for telemetry communications
- a sensor or intake can be deployed to cover the full range of levels

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 recording and/or the period of operation (seasonal, low flow, etc.)
- requirements for artificial control in the absence of channel stability
- the 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

Examples of different gauging station installations for water level sensors and data loggers are provided in chapter 3.

2.2.2 Site Access Permission and Legal Requirements

Obtain written permission from the landowner or manager before entering 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 work in the stream may require approval from the Province of British Columbia under Section 11 (Changes in and about a stream) of the *Water Sustainability Act* (http://www.bclaws.ca/civix/document/id/complete/statreg/14015). For necessary approval please check the link at: https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/water-licensing-rights/water-licences-approvals/apply-for-a-change-approval-or-submit-notification-of-instream-work.

2.2.3 Signage and Security

When necessary, signage should be installed to notify the public for any potential hazards. A brief explanation about the purpose of the station, who operates it, and the contact name can be provided.

When necessary, the station should be protected, and security gates or systems should be installed for safety and security.

2.2.4 Station Identification and Station Name

All stations must have a unique identifier (i.e., station number) and a station name. It is the responsibility of the station operator to collect the station number from the British Columbia provincial hydrometric business unit at Hydrometric@gov.bc.ca. To obtain a station number, the operator should submit the latitude and longitude co-ordinates of the station in standard format. The "Geo-referencing of Water Survey of Canada Hydrometric Stations" document published by the Water Survey of Canada (Water Survey of Canada 2004) provides a standardized method for the collection and documentation of co-ordinates at hydrometric stations.

2.2.5 Station History

Hydrometric stations must maintain a station history (or Hydrometric Station History). A station's historical records are an essential component of the station's metadata. The station history provides information such as site location, the station's purpose, the types of data collected, records of installations, the types of equipment deployed at the station, benchmarks and levels, etc. The recording of station history must begin as soon as the station is established. A station's historic records should be checked and updated during periodic site visits and whenever there are changes to parameters or changes to what is recorded in the form. An example of "Hydrometric Station History" is provided in Appendix II (see Figure II-1).

2.2.6 Establishment of Gauge Datum

[**Note:** Materials presented in this section have been modified from "Hydrometric Field Manual – Levelling," Water Survey of Canada, Environment and Climate Change Canada 2017.]

To obtain accurate and reliable stage data, the reference gauge and benchmarks 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 2-4).

A gauge datum is typically lower than the elevation at which zero flow is ever likely to occur, so 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 flows 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. The datum at each gauging station should be periodically checked by running levels from the benchmarks (please see the "Number benchmarks elevation and ref. gauge elevation level checks per year" row in Table 1-1 for data grade requirements). Details of hydrometric levelling procedures are described in the "Hydrometric Field Manual, Levelling" published by Environment and Climate Change Canada (Environment and

Climate Change Canada 2017). If an assumed local datum plane is used, it must be referred to by levels to a benchmark of known elevation, so that the arbitrary datum may be recovered if the gauge and reference marks are destroyed.

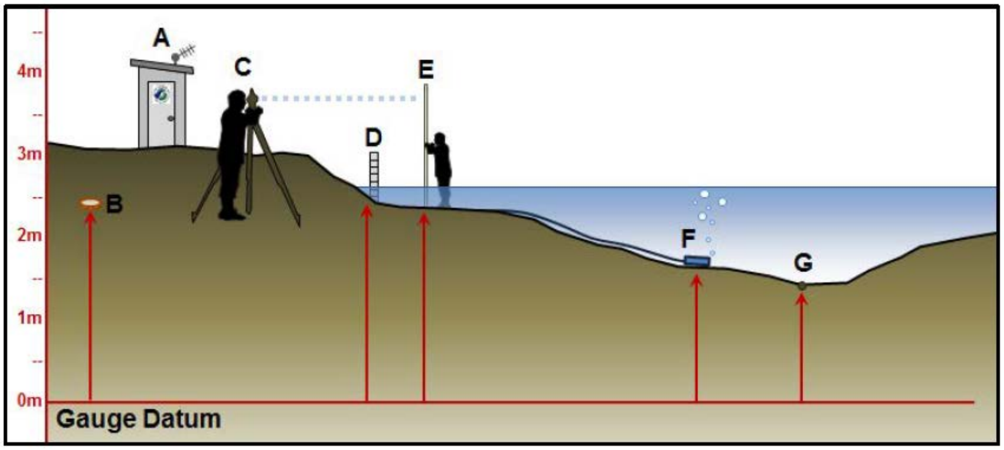


Figure 2-4: Gauge datum. (Adapted from: Environment and Climate Change Canada 2017)

[Figure showing benchmark, reference gauge, and stage sensors referenced to gauge datum. (A) gauge house, (B) benchmark, (C, E) direct water level reading, (D) reference gauge, (F) stage sensor or orifice, (G) point of zero flow.]

2.2.7 Reference Gauge Installation

A reference gauge is the gauge to which the recording instrument is set. Readings from the stage sensor are routinely compared to readings from the reference gauge at each station. <u>All gauging stations require some form of water level reference gauge in addition to any water level recording device that may also be installed.</u> The sensor reading must be referenced to this gauge, which in turn is referenced to station datum with benchmarks. The reference gauge should be installed at a location with the same stage control as the sensor and as close as is practicable to where the sensor continuously measures stage and in a zone of minimal local turbulence. The gauging station should not have more than one reference gauge to reduce the error in applying gauge corrections. The most common reference gauge is the vertical or “staff” gauge. Other reference gauges include an inclined gauge and a wire weight gauge, or a reference point on a bridge, pier, abutment, or stilling well from which the vertical distance to the surface of the water may be measured using a weighted tape such as a wire weight gauge. The elevation of the reference point must be determined via levelling from the primary benchmark. A benchmark can also be a reference gauge when stage is observed by direct levelling from it to the water surface; it is referred to as a direct water level. If a direct water level is used as the reference water level measurement, it should be taken at the same location on each site visit (note the measurement location in the station history).

Reminder: A reference water level measurement should be made during each site visit.

2.2.8 Benchmarks

Benchmarks are permanent, fixed reference points of known elevation installed at a gauging station when stations are established. These are essential for obtaining accurate hydrometric data. Stable benchmarks facilitate the confirmation or adjustment of gauge height or stage relative to a constant datum or reference elevation. When a station is destroyed, removed, or reactivated, benchmarks can be used to recover the station datum.

Various types of benchmarks are used in hydrometric operations, the criteria being that they are stable, identifiable, and accessible at all stages of water. Currently two types of standard benchmarks are used by Water Survey of Canada: a brass plug attached either vertically or horizontally in a rock or concrete surface, and a brass cap, a screw-type benchmark that is screwed onto attached threaded rods that have been augured into the ground to their full length using a hydraulic crane or power drill (i.e., a pneumatic hammer drill). Other types (but not preferred for their likelihood of instability) are: a chisel mark or paint mark on a large rock, a lag bolt in a wing wall of a bridge, a painted bolt in a hydro tower, etc. Benchmarks must be spread out, well away from the river bank and preferably above the floodplain. The most suitable locations for benchmarks are bedrocks or large masonry structures that provide stability. Whenever benchmarks are established, they must be clearly marked so that they will be easy to find at a later date. Unmarked benchmarks cause confusion and are often lost or destroyed. The location, related benchmarks, and relationships to any other gauges must be carefully included in the hydrometric station history.

2.2.8.1 Temporary Benchmarks

Temporary benchmarks, as the name implies, are used for only relatively short periods; usually until permanent benchmarks can be established. They are used for newly constructed stations and for existing stations whose permanent benchmarks 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 benchmarks are finally tied into the permanent benchmarks.

2.2.8.2 Number of Benchmarks

All gauging stations require some form of benchmarks. When a station is established, it should be assumed that a permanent datum will be maintained at the site. To maintain a permanent datum, <u>each gauging station should have a minimum of three independent benchmarks</u>. The water level reading must be referenced to one of these marks, which in turn are referenced to the station datum.

2.2.9 Gauge Checks or Level Checks

[**Note:** Materials presented in this section have been taken from the “Hydrometric Field Manual – Levelling,” Water Survey of Canada, Environment and Climate Change Canada 2017.]

Staff gauges or reference gauges are subject to extreme conditions and are often displaced or even destroyed by the action of frost and ice. Streambank instability, streambed erosion, and vandalism are other reasons for lost data. To help ensure that stage records remain reliable, vertical movement of the reference gauge must be regularly monitored by running levels from the benchmarks to evaluate its stability (i.e., to determine the movement of zero elevation or the gauge datum) and to determine if gauge corrections are required for stage records. How often this is done is largely determined by the conditions at the site. <u>Levels should be run between all benchmarks and reference gauges once a year at stable sites, preferably after spring thaw and twice a year or more at unstable sites</u>. However, the elevation of the reference gauge with a history of instability may have to be monitored more frequently depending on its stability. When running levels to check for the possible movement of a gauge, <u>the circuit must be closed</u> in all cases and closure error must be within survey tolerance to be acceptable. Any changes should be documented in the station history.

2.2.9.1 Closure Error and Survey Tolerance

When a level circuit is closed, the surveyed elevation of the last point (which is also the first point) may not equal the elevation used at the start of the circuit due to the different sources of error such as an improper adjustment of an instrument, parallax, an inaccurate reading of the rod with optical levels, settlement of the instrument tripod, improper turning points, etc. This difference in elevation is called the closure error, CE, or misclosure:

$CE = E_{start} - E_{Surveyed}$

The maximum allowable closure error is referred to as the survey tolerance. For levelling circuits with three or fewer setups, the survey tolerance is ±0.003 m. Therefore:

- if the absolute value of CE >0.003 m, the circuit should be rejected and redone until a CE of ≤ 0.003 m is achieved
- if the absolute value of CE ≤0.003 m, elevations of objective points should be recorded as surveyed on the forward run

When levelling circuits with four or more setups, the survey tolerance is $\pm 0.01\sqrt{D}$ m, where D is the circuit length in kilometres. For example, if a circuit with 4 or more setups is 1 km long, the survey tolerance is ±0.01 m; if it is 400 m long, the tolerance is ±0.006 m. The circuit length is the sum of all sighting distances.

For circuits with four or more setups:

- if the absolute value of CE is $>0.01\sqrt{D}$ m, the circuit should be rejected and redone until it is within tolerance
- if the absolute value of CE is $\leq 0.01\sqrt{D}$ m and it exceeds 0.003 m, the error should be distributed following the steps outlined in the “Hydrometric Field Manual – Levelling,” published by Environment and Climate Change Canada (2017)
- if the absolute value of CE is ≤0.003 m, the elevations obtained on the forward run should be used as the surveyed elevations for the benchmark history.

2.2.9.2 Gauge Corrections

Gauge corrections (GC) compensate for temporary vertical movement of the reference gauge (Figure 2-5). They are computed each time that the reference gauge is surveyed by subtracting the established elevation, E_e, of the reference gauge from its surveyed elevation, E_s, recalling that elevations are always given relative to the gauge datum:

$GC = E_s - E_e$

If the absolute value of GC is ≤ 0.003 m, no correction should be applied. If it exceeds 0.003 m, a gauge correction is applied to all stage data. Gauge corrections are applied until the elevation of the reference gauge returns to its previously established elevation, until a new gauge correction is determined via levelling, or until a new established elevation is determined via Benchmark History Analysis. Detailed procedures for surveying the reference gauge elevation and determining gauge correction are described in the “Hydrometric Field Manual, Levelling” published by Environment and Climate Change Canada (2017).

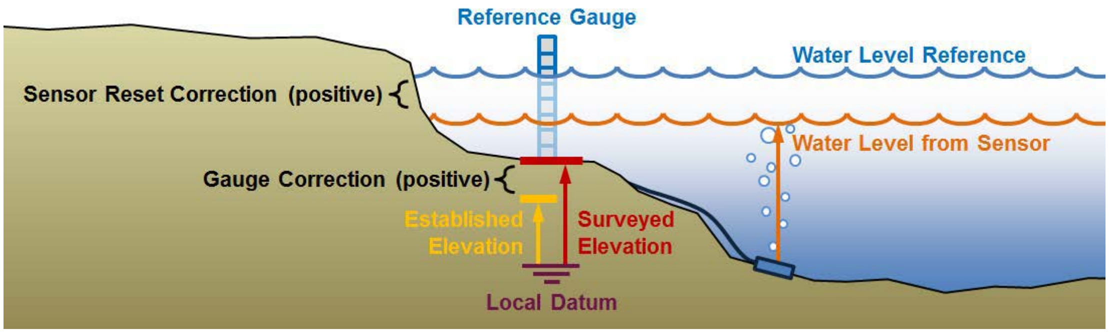


Figure 2-5: Gauge correction and sensor reset correction. (Adapted from: Environment and Climate Change Canada 2017)

2.2.10 Documentation for Levelling

Level Notes

Recording accurate and complete field notes is the most important part of the levelling operation. Hydrometric level notes are divided into columns to facilitate the recording of observations and computing elevations. The *Station* column is used to record the name of the objective point (e.g., benchmark identification number, turning point number, type of reference gauge) and the information on each horizontal line pertains to that objective point. There are columns for backsight, height of instrument, foresight, and elevation. The right side of the level notes is used to record the necessary descriptive notes. The lower part of the level sheet can be used to record further descriptive notes. Table 2-1 provides an example of a completed level note used by Water Survey of Canada for a closed circuit between benchmarks (BM), BM3, BM6, and BM7 during routine level checks. A blank “Level Notes” is provided in Appendix II (see Figure II-2).

Table 2-1: Level notes

Station	Backsight	Height of instrument	Foresight	Elevation	Notes
BM3	2.103 m	3.804 m		1.701 m	Est. elevation
TP1	2.212 m	5.275 m	0.741 m	3.063 m	Screwdriver
BM6			1.384 m	3.891 m	Brass cap
BM7			1.620 m	3.655 m	Screw anchor
TP2	2.444 m	5.919 m	1.800 m	3.475 m	Rock in river
BM7			2.265 m	3.654 m	
BM6			2.026 m	3.893 m	
TP1	1.310 m	4.379 m	2.850 m	3.069 m	
BM3			2.679 m	1.700 m	
4 setups and a circuit length of 150 m. Survey tolerance is $\pm 0.01\sqrt{0.15}$ m = ± 0.004 m.					

When recording notes, enter the benchmark identification number of the starting point, (BM3) in the first line of the column entitled *Station* and enter its established elevation (1.701m) in the column entitled *Elevation*. On the column entitled *Backsight*, the reading obtained with the levelling rod held on benchmark BM3 is entered as the backsight value (2.103 m). The value for the column entitled *Height of instrument* is computed by adding the backsight value to the known benchmark elevation (i.e., Height of Instrument = 2.103 m + 1.701 m = 3.804 m). On the second line of the first column, the second objective point is listed. This is the first point for which the elevation must be determined; in this case the second objective point is "turning point 1" (TP1). The reading acquired with the levelling rod held on TP1 is entered as a foresight (0.741 m). This value is then subtracted from the *height of instrument* value recorded in the previous line (the current height of instrument) to obtain the elevation of that objective point (3.804 m - 0.741 m = 3.063 m). Foresights on BM6, BM7, and TP2 are taken from this same instrument height. The instrument is then repositioned for the return run of the level circuit and a backsight is taken on TP2. The observations and notes are continued in this manner until the circuit is closed by levelling back to the original starting point (BM3). Figure 2-6 showing instrument setup, foresight (FS), and backsight for spirit levelling.

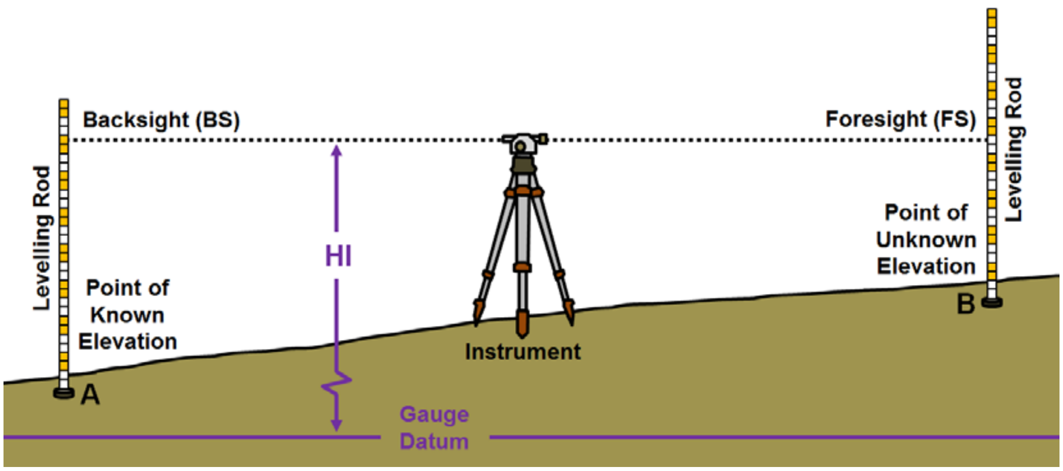


Figure 2-6: Diagram showing instrument setup, foresight (FS), and backsight (BS) for spirit levelling. (Adapted from: Environment and Climate Change Canada 2017)

Chapter 3: Stage Measurement

3.1 Introduction

The measurement and recording of water level or stage are important, as the stage record provides the means by which discharge computations are made. In addition, some gauging stations are operated exclusively for the collection of stage data. This chapter begins with the general requirements for stage measurements and covers basic instrumentation, selection of stage measurement sensors and data loggers, and documentation requirements for stage measurements.

3.2 General Requirements

For the stage measurements, the following table (Table 3-1) provides the general requirements (where relevant):

[**Note:** Please see "Table 1-1 Standards requirements criteria" for specific requirements of different data grades or standards.]

Table 3-1: General requirements for stage measurements

Stage measurements	Unit of Measurements	Express units in: • metres (m), or • millimetres (mm)
Timing of measurements	Maximum recording interval or data logging frequency	15 min
	Averaging	Instantaneous value (**Note:** Defined as no greater than 20 seconds averaging)
	Resolution	1 seconds
	Time	Pacific Standard Time (PST) **Note:** Do not use Daylight Saving Time
	Date format	YYYYMMDD
Supplementary measurements	Barometric pressure	Required for unvented pressure transducers
Calibration	Frequency	Where relevant follow manufacturer's specifications
	Method	Where relevant follow manufacturer's specifications

Validation Method	Sensor test	Required pre-deployment Follow manufacturer's instructions
Metadata	Recording metadata	Metadata should be recorded for all measurements
Processing of data		All changes from raw data should be recorded and available
Archiving	Original and final record	The following should be archived indefinitely and backed-up regularly: • raw and processed data • primary reference data • supplementary measurements • validation check • calibration records • metadata

[**Note:** Modified from NEMS 2016.]

3.3 Water Level Gauges

The instrumentation required for collecting water level or stage height is essentially two types:

- manual gauges, and
- recording gauge or automated stage sensors for continuous monitoring of water levels.

3.3.1 Manual Gauges

3.3.1.1 General

In a manual gauging station, stage readings can be obtained either from a permanently installed manual gauge or by the direct survey of water level referenced to the station's datum or benchmarks.

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. Manual gauges must be read by the gauge observer as these gauges do not record water levels automatically. Most gauges, if properly installed, are very reliable and very easy to read. 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 and others1982, p. 64).*

A manual gauge is used as the prime gauge at stations not equipped with an automatic stage sensor. The most commonly used manual gauge is the vertical (staff) gauge. Other types are: inclined gauge, wire-weight gauge, chain gauge, etc. A detailed description of these gauges is provided in the "Hydrometric Field Manual – Measurement of Stage" published by Environment Canada (1983).

3.3.1.2 Vertical (Staff) Gauge

The vertical (staff) gauge (Figure 3-1) consists of one or more 1-m sections of enamelled steel plate accurately graduated to either 0.01 or 0.002 of a metre. Each decimetre is numbered, and intermediate 5-cm graduation marks are wedge shaped. The 0.01-m graduated type of plate is preferred for its less cluttered appearance; the third decimal value is estimated by reading the bottom of the meniscus.

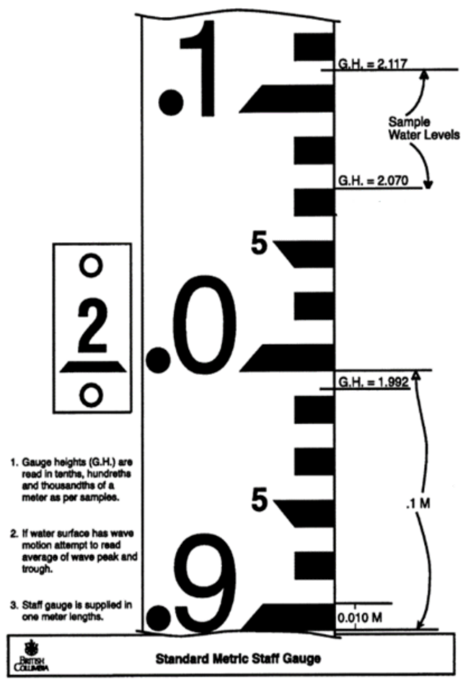


Figure 3-1: Illustration of a staff gauge.

Install staff gauges so that they are protected from damage by moving ice or other floating debris and are not affected by a 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") to reduce velocity head differences on the up and downstream sides of the gauge. 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 or to where the sensor continuously measures stage. 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 0.15-m 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.

3.3.2 Recording Gauge or Automated Stage Sensors

3.3.2.1 General

Automated stage sensors are installed at gauging stations to automatically record the continuous stage to observe the short-duration fluctuations. Ideally, all gauging stations should be equipped with automatic stage sensors.

There have been significant technological changes in the last decades on how hydrometric data are collected specifically, a transition from analog or graphical technologies (i.e., floats) to electronic digital alternatives. Mainly three types of sensors are presently used to detect stage height:

- float system–float type sensors for using in stilling wells (e.g., shaft encoders)
- pressure system–pressure activated sensors (both submersible such as pressure transducer and non-submersible such as bubbles sensor), and
- non-contact system (e.g., ultrasonic or radar sensor)

More information on the description of equipment and methods for observation, sensing, and recording of stage can be found in "Stage Measurement at Gaging Stations" published by the USGS, Sauer and Turnipseed (2010) and the summaries of old and new stage measurement equipment, as well as installation options, can be found in "Manual on Stream Gauging: Volume I – Fieldwork" published by the World Meteorological Organization (WMO) (2010a).

3.3.2.2 Float System-Shaft Encoders

The use of Shaft Encoders (Figure 3-2) 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.

> [**Note:** Encoders require proper infrastructure to function properly. This includes a stilling well and possibly an intake pipe. This may pose challenges if the well is required to work throughout the winter.]

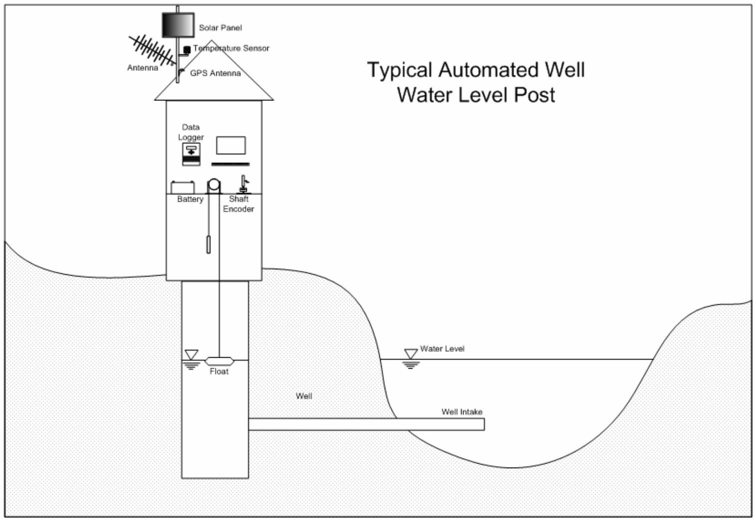


Figure 3-2: An example of a shaft encoder (Courtesy: WSC).

3.3.2.3 Submersible Pressure Sensors (Pressure Transducers)

Submersible Pressure Sensors (Figure 3-3) represent the largest segment of products for measuring surface water 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. Note that these sensors require correction for barometric pressure, and this is accomplished either through venting the sensor to the atmosphere or monitoring and correcting for barometric pressure with a local barometric sensor.

> [**Note:** “It is not normally possible to set the sensor at the recording zero, so an offset is usually needed. It must be recorded in the logbook at the time of installation and applied to the record either in the logger or when processed. In any case, transducers must be checked frequently for drift; an offset or change in offset may subsequently be required” (NEMS 2016).]

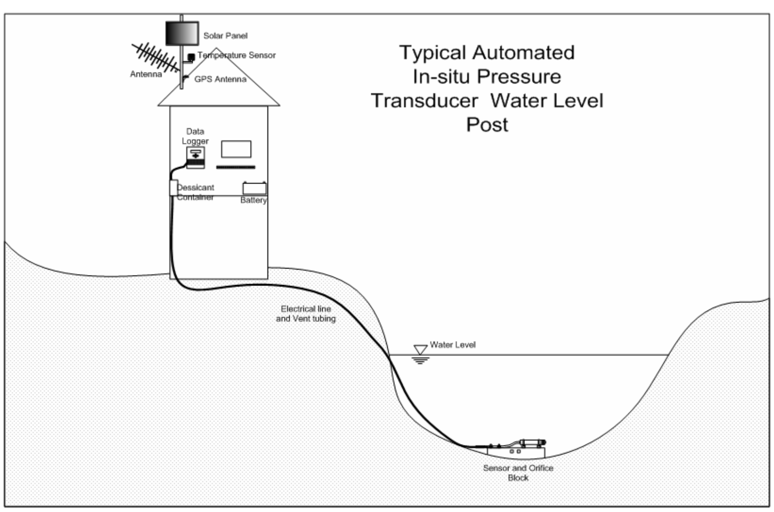


Figure 3-3: An example of an in-situ pressure transducer (Courtesy: WSC).

3.3.2.4 Non-submersible Pressure Sensors (Bubbler Sensors)

A bubbler sensor (Figure 3-4) is a digital sensor 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. 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.

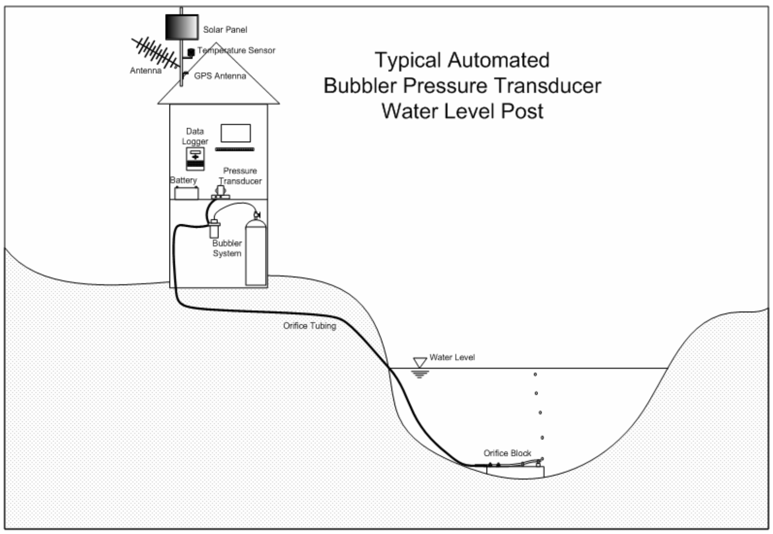


Figure 3-4: An example of a gas purge sensor (Courtesy: WSC).

3.3.2.5 Ultrasonic and Radar Sensors

Ultrasonic and radar-based sensors (Figure 3-5) operate by transmitting a signal that 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.

The main advantage of this technology is that it is non-invasive: there is no physical contact with the media being measured. Another advantage is that nothing is installed within channel so there is very little risk of damage during high flows. The main disadvantage of ultrasonic technology is that the speed of the sound wave is affected by environmental conditions, particularly temperature, thus affecting accuracy. Another notable disadvantage/risk is that these are often highly visible installations and can be easy targets for vandalism compared to other monitoring equipment options.

Radar-based sensors are considered a logical alternative to ultrasonic sensors because radar signals are not affected by temperature. However, radar-based sensors cannot 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 the signal penetrates before being reflected.

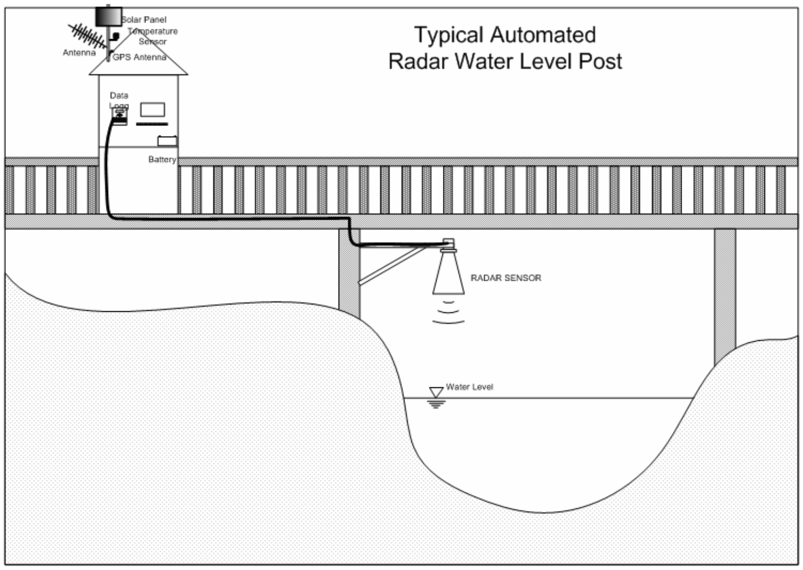


Figure 3-5: Examples of ultrasonic and radar sensors (Courtesy: WSC).

3.3.2.6 Data Logging Frequency

The data logger should allow programming to acquire data from a stage sensor at pre-set 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. 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 interval requirement; site specific flow regimes may necessitate a shorter interval, 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.

3.3.2.7 Selection of Sensors and Data Loggers

Today’s data collectors have a greater number of options available to transfer data from the field to the office. Technologies can be selected based on a variety of criteria, including site conditions, budget, physical size of watercourse etc. There are many data loggers on the market, some being multi-purpose in nature, while others are configured for specific tasks. Determining the best one for the application involves evaluating the hardware and software that make up the system (Figure 3-6) with specific emphasis on sensor and programming capabilities, ease of software use, data transmission options, and especially manufacturer support.

When establishing an automatic gauging station, the sensors and data logger should be selected to meet the accuracy criteria stipulated for the RISC hydrometric standard required to be met by the station, the full range required, and any present and future data needs. When choosing the appropriate data loggers, the following capabilities and factors should as a minimum be considered:

- accuracy and resolution of the instrument
- ability to interface with the sensors
- sampling and data logging programmability (i.e., are the channels individually programmable?)

- data processing capability (e.g., instantaneous, maximum-minimum, mean computations)
- operational temperature range (i.e., summer and winter temperatures to support seasonal or annual monitoring)
- operating system (e.g., Windows, Mac OS, Android)
- telemetry capability (i.e., landline or cellular modem, radio, satellite, GOES)
- reliability, compactness, and cost
- power consumption (i.e., sufficient power using internal power or solar recharge required)
- storage capacity
- clock accuracy.

In addition to the aspects listed above, the following should be considered when selecting the most appropriate technology for the application:

- monitoring duration–year-round or seasonal.
- suitability of technology for the water conditions (for example, bubblers have an inherent lag responding to rapid changes in stage)
- overall accuracy (for example, vented submersible pressure transducers have better accuracy than non-vented sensors).

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 products. Review these carefully to ensure that the model selected meets the requirements. For data grade A, the sensors must have an accuracy of 3 mm or 0.2% of effective stage, whichever is greater. However, manufacturer stated sensor accuracies are reported in different formats; for example, accuracy may be reported in in terms of full-scale error (%FS); that is, error as a percent of maximum sensor range, or percent of measured value. <u>A sensor with its accuracy stated in %FS error can be used if the calibration relationship is known and falls within the accuracy tolerance</u> (such as the greater of 3 mm or 0.2% of effective stage for data grade A). This information can be requested from the manufacturer prior to the purchase of sensors. Table 3-2 provides a comparative review of stage measurement sensors and data loggers for various field conditions and levels of accuracy.

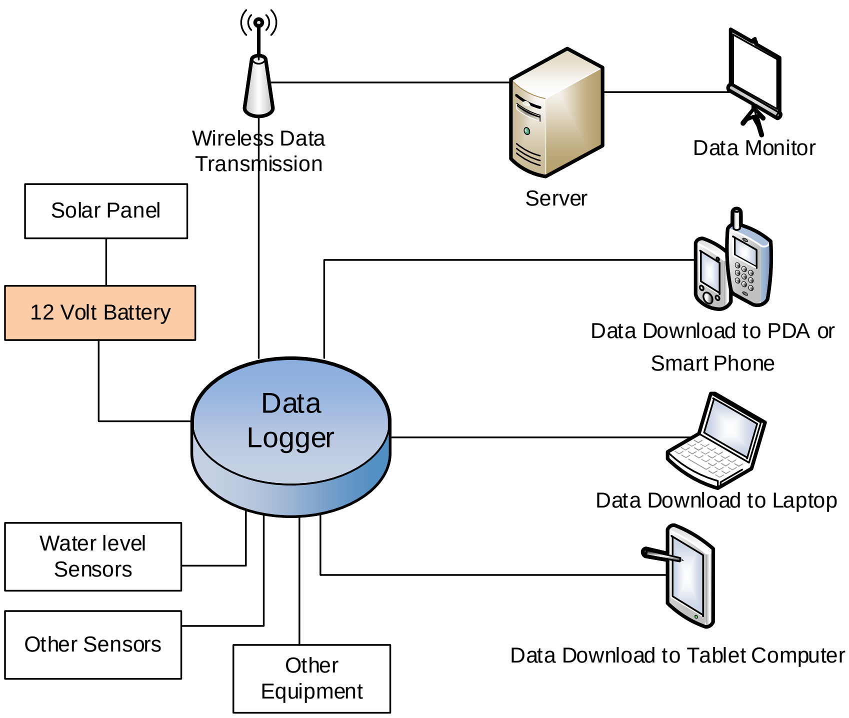
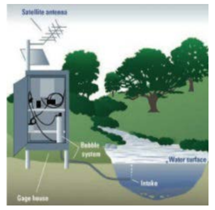


Figure 3-6: Typical flow diagram for electronic monitoring station showing various components required to measure and log stage data.

Table 3-2: Comparison of stage measurement equipment

Instrument Type	Preferred Installation	Range of Measurement	Resolution and Accuracy	Programming and Datalogging Options	Power Supply Options	Maintenance and Calibration Interval	Advantages	Limitations
Submersible Pressure Sensors – Non-vented 	• Instream – sensor inside stilling well (e.g., pipe, culvert) • Installed in sufficient water depth to measure full range of stage • Fresh water applications	• Min 3.5 mm • Max >4.0 m	• Resolution = 1 mm • Accuracy = ± 0.15% Full Scale • Accuracy based on combined errors from water level and barometric pressure sensors	• Self-contained datalogger (instream) with manual communication; or • External communication cables available; or • User able to program sampling rate as well as averaging intervals; or • Software should compensate water level values for changes in barometric pressure from an external source	• Internal battery; or • 12V battery converter; or • AC / Solar power options (if part of monitoring design)	• Sensor will drift – compared to actual stage reading each site visit • Calibrate as per manufacturer's recommendations (generally every 1–2 years)	• Can be used under all streamflow conditions. • Available in both cabled and non-cabled versions. • Sensors are totally sealed against water ingress. • Stand-alone systems are very compact allowing them to be deployed inconspicuously. • Real-time communication with sensor and data download with cable option. Thus, sensor remains in place. Loggers can now be programmed by Bluetooth, laptop, and miscellaneous connectors using tablets or smartphones. • Stand-alone systems (i.e., self-contained datalogger) are relatively inexpensive.	• Requires external compensation for changes in barometric pressure. Most software requires barometric correction from same make or specific models or loggers. • Pressure diaphragm can be damaged if left to freeze in shallow waters during winter. • Decrease in overall system accuracy due to the use of two sensors (water level and barometric pressure). • Stand-alone systems typically need to be extracted from the water to recover data, which may be problematic depending upon site and streamflow conditions. • Internal battery cannot be replaced. • For self-contained datalogger sensor options, risk of records loss if sensor is lost or damaged due to high water, vandalism, etc. • Limited sensor datalogging options (i.e., non-flexible recording options).
Submersible Pressure Sensors – Vented 	• Instream – sensor inside stilling well (e.g., pipe, culvert) • Installed in sufficient water depth to measure full range of stage • Fresh water applications	• Min 3.5 mm • Max >4.0 m	• Resolution = 1 mm; • Accuracy = ± 0.1% Full Scale	• Self-contained datalogger (instream) with external communication; or • Output signal to an external datalogger (in enclosure) via hardwired connection; or • Able to set water level, sample rate, averaging period through software	• Internal battery; or • 12V battery converter; or • AC / Solar power options (if part of monitoring design)	• Sensor will drift – compare to actual stage reading each site visit; • Calibrate as per manufacturer's recommendations (generally every 1–2 years)	• Can be used under all streamflow conditions. • Real-time communication with sensor and data download. Thus, sensor remains in place. • Greater system accuracy (in comparison to non-vented sensors) as barometrically corrected. • Real-time telemetry options available with cellular modems, radio, and satellite transmitters (if part of monitoring design).	• Presence of vent line requires more work to install, as vent line needs to be protected against insect inhabitation, debris, etc., which may block the line and affect barometric compensation. • Pressure diaphragm can be damaged if left to freeze in shallow waters during winter. • May need backup barometric data in case of line failure. • Periodic changing of desiccant is required to keep vent tube free of moisture. • Vent line poses snag risk for debris in stream. • Possibility of moisture entering internal electronics and damaging them if the cable integrity is compromised. • Internal battery option not ideal for extended deployment. Battery replacement under this option is difficult to complete in the field. • For self-contained datalogger sensor options, risk of records loss if sensor is lost or damaged due to high water, vandalism, etc.

Instrument Type	Preferred Installation	Range of Measurement	Resolution and Accuracy	Programming and Datalogging Options	Power Supply Options	Maintenance and Calibration Interval	Advantages	Limitations
Dry Gas Pressure Sensors (Bubbler) 	• Instream sensor (orifice) securely anchored to channel bottom and hardwired to pressure generating hardware • Pressure hardware located in enclosure above high water mark • Installed in sufficient water depth to measure full range of stage • Fresh, brackish, and salt-water applications	• Min 0 m • Max 35 m	• Resolution = 1 mm • Accuracy = ± 0.1% Full Scale	• Self contained datalogging available in compressor type systems; or • Current water levels can be viewed on unit and adjusted via keypad or PC; or • Sensor programming to include user-defined averaging periods; or • Sensors can be connected to an external datalogger (in enclosure)	• 12V battery converter; or • AC / Solar power options (if part of monitoring design)	• Sensor will drift – compare to actual stage reading each site visit; • Calibrate as per manufacturer's recommendations (generally every 2 years); • Purging of orifice line required each visit to reduce sedimentation effects in the orifice line.	• Can be used under all streamflow conditions. • Real-time communication with sensor and data download. Thus, sensor remains in place. • Enclosure and datalogger can be installed above the high-water mark; therefore, data loss due to damage is limited. • Instream components (i.e., orifice line and anchor) are relatively low cost and can easily be replaced should they be lost during a high-water event.	• Slow response to rapid changes in stage. • High initial cost of hardware. • Requires infrastructure (shelter/enclosure) to house components, resulting in higher installation cost. Aside from infrastructure cost, there is the effort to install (i.e., burying and armouring the orifice line and anchoring the orifice). • Nitrogen tanks (heavy and bulky) require periodic replacement. • Compressor-type systems draw more power, thus larger batteries or solar panels are required. • Orifice outlet can be blocked by silting, resulting in poor or no data. • System is complicated to operate and maintain; may require staff with ability to do maintenance on-site.
Shaft Encoders 	• Instream or bank mounted inside stilling well (i.e., culvert or shelter) • Requires float and pulley system to operate • Fresh, brackish, and salt-water applications	• Min 50 mm, but varies with float size • Max >2 m, but varies with pulley diameter and cable length	• Resolution = 1 mm • Accuracy = 2mm (based on 203 mm diameter float)	• Encoders typically include a display with the ability to adjust values to current water levels; or • Self-contained dataloggers programmable through keypad or PC; or • Encoders typically store instantaneous values only; or • Output data to external datalogger (in enclosure) using hardwired connection	• Internal battery; or • 12V battery converter; or • AC / Solar power options (if part of monitoring design)	• Sensors do not drift, but comparison to actual stage reading is recommended during site visit; • Factory recalibration not required.	• Very accurate depending upon float used. • No sensor drift. • Real-time telemetry options available with cellular modems, radio, and satellite transmitters (if part of monitoring design). • Enclosure and datalogger can be installed above the high-water mark; therefore, data loss due to damage is limited.	• Stilling well infrastructure can be very costly and limit application in many watercourses. • Range of measurement is also a function of stilling well height, to run both float and weight. • Float and pulley system is fragile. These systems are mechanically simple, but they do require regular maintenance to ensure that they are working properly due to fragile nature. • Limited use of float and pulley system during winter due to ice buildup in stilling well (unless protected from freezing). • Long pulley lines between the float and counterweight can twist during rapid stage changes resulting in data loss.

Instrument Type	Preferred Installation	Range of Measurement	Resolution and Accuracy	Programming and Datalogging Options	Power Supply Options	Maintenance and Calibration Interval	Advantages	Limitations
Ultrasonic Stage Sensors 	• Non-contact - mounted off a bridge or an extended bank-mounted boom (preferably over the main channel) • Fresh and brackish water applications	• Min 2 mm • Max 10 m	• Resolution = ±1 mm • Accuracy = ±0.1% Full Scale, but air temperature dependent	• Sensors typically output data to an external datalogger (in enclosure) through hardwired connection; or • Sensors should be programmable using a PC for averaging of data and filtering of temporary events (e.g., standing waves, floating debris)	• 12V battery converter; or • AC / Solar power options (if part of monitoring design)	• Sensor should be stable but compare to actual stage reading each site visit; • Recalibration not required unless sensor is physically damaged •	• Requires little in the way of mounting infrastructure. • Very low maintenance. • Able to measure very low water levels if the footprint is unobstructed. • Safe from damage caused by debris transported during flood event. • Real-time telemetry options available with cellular modems, radio, and satellite transmitters (if part of monitoring design). • Relatively low power requirements.	• Suitable for open water measurements only. • Need solid non-vibrating permanent structure to attach this device above the stream. can be problematic. • Maintenance of the device can be complicated. • Measuring low water level can be problematic as it may be affected by surroundings such as submersed rocks • Requires temperature compensation and resultant accuracy is very dependent upon air temperature. • False values caused by temporary external events. • Increased inaccuracies in turbulent water applications.
Radar Level Sensors 	• Non-contact - mounted off a bridge or an extended bank mounted boom (preferably over the main channel) • Fresh, brackish, and saltwater applications	• Min 2 mm • Max > 35 m	• Resolution = ±1 mm • Accuracy = ± 2-3% over total range	• Sensors typically output data to an external datalogger (in enclosure) through hardwired connection; or • Sensors should be programmable using a PC for averaging of data and filtering of temporary events (e.g., standing waves, floating debris)	• 12V battery converter; or • AC / Solar power options (if part of monitoring design)	• Sensor should be stable but compare to actual stage reading each site visit; • Recalibration not required unless sensor is physically damaged •	• Requires little in the way of mounting infrastructure. • Very low maintenance. • Able to measure very low water levels. • Safe from damage caused by debris transported during flood event. • Real-time telemetry options available with cellular modems, radio, and satellite transmitters (if part of monitoring design). • Relatively low power requirements.	• Suitable for open water measurements only. • False values caused by temporary external events (unless sensor has the ability to filter data). • Increased inaccuracies in turbulent water applications (unless sensor has the ability to filter data). • Sensor mount needs to be robust with minimal influence from vibration.

Source: Adapted from "Evaluation of the 2009 Resource Information Standards Committee (RISC) Manual of British Columbia Hydrometric Standards, Final Report, June 2017," by Associated Environmental for B.C. Ministry of Environment.

3.3.3 Stage Measurement for Rated Structure

Flow rate over a weir or through a flume in theory is a function of head or stage and proper installation is essential to measure accurate flow. For proper stage measurements the following recommendations are extracted and modified from NEMS (2016):

- the water level recorder and staff gauge should be at least three times the maximum head distance away from the structure to avoid any drawdown caused by flow over the crest
- the approach channel should be straight with a uniform cross-section and be free from obstructions
- the flow in the approach channel should be uniform and steady, and the approach velocity should be negligible. A pool upstream of the rated structure may be required to minimize the approach velocity.

3.4 Power Supply

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

1. 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.
2. 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.
3. 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.

3.5 Site Visits and Checks

During site visits, verification checks of instruments should be carried out to ensure that the data collected are free from error and bias (both stage value and corresponding time). The frequency of site visits and checks depends on individual site requirements; however, they should be often enough to ensure that the data quality is as planned. Detailed activities to be performed during the site visits are provided in section 4.4.4.3 "On Site Observations" of Chapter 4.

3.5.1 Measuring Peak Stage between Site Visits

[**Note:** The material presented in this section has been prepared from the draft document "Measurement of Stage-SOP," Water Survey of Canada, Environment and Climate Change Canada (2018)]

When stage sensors stop working or incur damage due to flood or other reasons, alternative sources of information such as observations of peak stage are necessary to fill in gaps in the stage record. Four methods for obtaining peak stage are presented below.

3.5.1.1 Crest Stage Gauge

Crest stage gauges are simple devices for measuring the elevation of flood crests. A common crest stage gauge is a galvanized pipe that is capped at both ends, with holes drilled in the bottom cap to permit entry of water while keeping surge effects to a minimum. A vent hole is drilled in the top cap. A wooden or aluminum rod with a small container for cork dust attached at the lower end is placed inside the pipe so that it cannot float. As the water rises in the pipe, the cork dust floats free of the container and adheres to the rod at the point to which the water has risen. The entire assembly is firmly fixed to a bridge or pier and levelled to the gauge datum. The gauge is read by measuring from the top or bottom of the rod to the cork dust line. At each visit, the wooden rod must be cleaned, and the cork dust container refilled before the rod is replaced in the pipe so that it can be used to measure peak stage between visits.

3.5.1.2 High Water Marks

High-water marks are evidence of the highest stage of floods and they can be used to fill in gaps in stage records or to calculate discharge using an indirect method such as the slope-area method. Since water marks can also result from water pile-up, each potential high-water mark must be scrutinized. High water marks should be identified as soon as possible after an event because they will morph and degrade with time. Proper identification of these marks requires experience and an understanding of how floodwaters create them. For details please see "Identifying and Preserving High-Water Mark Data" published by USGS (Koenig et.al. 2016).

3.5.1.3 Water Level by Stakes

When rivers overflow their banks and extend to the floodplains or when the gauge house cannot be accessed during a site visit, the water level can be identified with stakes placed at the water's edge. When using this method be sure to mark the water level on the stake along with the date and time. The elevation of each stake can then be determined via levelling, and the water level relative to the gauge datum can be calculated accordingly.

3.5.1.4 Images and videos of the water surface

When the reference gauge at a site is inaccessible, a video or image of the water surface may be used to determine the water level. The field of view must contain some form of marker at the water surface that can be surveyed at a later date to determine its elevation. Examples of markers include a staff-gauge or a painted stake. Any images or video should be accompanied by a description of the event. All photos and videos should be dated and the point from which they are taken should be referenced to permanent site features such as bridges or gauge houses.

3.6 Documentation for Stage Measurements

Accurate documentation of the inspection record for water stage 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. 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 not depend on memory; never wait for a more convenient time or location.

As a minimum, an inspection record for water stage (i.e., station log) should contain:

- station name and station identifier
- date and time of the logger and reference time
- reference gauge readings
- a concurrent instantaneous value of logger or sensor.

The Water Stage Log (An example of "Water Stage Log" form is included in Appendix II, see Figure II-3), which is usually posted within the instrument shelter, may be used for systematically recording the gauge reading, time and date, and other information during a site visit. This information is particularly useful in support of data corrections (e.g., sensor drift). 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. However, if this form is not used, the relevant information should be captured in sufficient detail to support data corrections, to meet the QA/QC reviews by qualified hydrometric data reviewers and to meet the hydrometric monitoring program audits. Station Log information should be updated before leaving the site. For details on gauge readings, see "Gauge Reading" in section 4.4.4.3 "On Site Observations" of Chapter 4.

3.7 Data Collection and Data Retrieval

Collection of stage data depends on the type of recorder used and the data retrieval process. Currently, many different telemetry systems such as satellite, radio, cell-phone, etc. are used to transmit, decode, and enter the stage data in to the database. From a site, data can also be downloaded manually to a computer or mobile device. All stage data retrieved by manual download or transmitted via telemetry should be considered as original data and must be preserved. Recorded data in various forms must be converted into conventional engineering units using a standard format.

3.8 Data Processing and Data Corrections

Methodologies used for data processing and preservation should be documented as they can vary depending on the software used. All data should be graded according to the standards listed in Table 1-1. The potential for missing data and the need for data corrections due to site conditions or instrument malfunction are inherent aspects of monitoring. Corrections applied to raw data should be recorded and archived with the data. Data modifications should be traceable and scientifically defensible, and must be graded according to the standards provided in Table 1-1. Detailed procedures for data corrections and data computations are provided in "Hydrometric Manual, Data Computations," Environment Canada (2012).

Preservation of Records

The following information should be captured and retained indefinitely:

- unedited original raw data
- final checked and verified data, and
- associated metadata, including:
    - data comments
    - site details
    - recording accuracy and resolution
    - station history inspections and surveys of references gauges
    - equipment calibration history and any other information affecting data quality

All original records and supporting data should be retained indefinitely by the station operating agency (or by the Hydrometric Data Reviewer). Final time series graded data and all metadata should be submitted to the provincial database and all other information should be available when requested.

Chapter 4: Discharge Measurement

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. The area-velocity method can be used for both small and large streams, rated 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. One of the more commonly used and studied tracers is salt, which is increasing in use for monitoring discharges in steep gradients and highly turbulent stream reaches. Ongoing work is contributing to improved protocols and best practices for this method.

This chapter begins with the general requirements for discharge measurements and covers the basic equipment, procedures, and documentation for discharge measurement using current meters (i.e., area-velocity method), rated structures, and volumetric method. A table providing a comparative review of discharge measurement equipment and methods as well as their advantages and limitations is also provided in this chapter (see Table 4-2).

4.2 General Requirements

For the discharge measurements, the following table (Table 4-1) provides the general requirements (where relevant):

> [**Note:** Please see "Table 1-1: Standards requirements criteria" for specific requirements of different data grade or standards.]

Table 4-1: General requirements for discharge measurements

Discharge Measurements	Unit of Measurements	Depth and width should be expressed as: • metres (m) to two decimal places Cross-sectional area should be expressed as: • m^2 to two decimal places Velocity should be expressed as: • m/s to three decimal places Discharge should be expressed as: • m^3/s to three decimal places
Discharge Calculations	Velocity Area Method (when used)	Mid-section method
Timing of Measurements	Instrument Resolution	1 second
	Time	Pacific Standard Time (PST) *Note: Do not use Daylight Saving Time*

	Date Format	YYYYMMDD
	Discharge Result	Assign date and time for mean gauge height
Calibration Check	Frequency	Mechanical current meter: 2–3 years (depending on level of use) ADV: follow manufacturer's specifications
	Method	Follow manufacturer's specifications
Validation Method	Instrument Test	Required pre-deployment and post deployment for rotating element current meters Follow manufacturer's instructions Meter should be validated (i.e., Field Verifications) at least annually for data grade A and B
Metadata	Recording Metadata	Metadata should be recorded for all measurements
Archiving	Original and Final Record	The following should be archived indefinitely and backed up regularly: • raw and processed data • supplementary measurements • validation check/field verification • calibration records • metadata
	Results for Provincial Database	Minimum requirements are: • stage for computed discharge in metres (m) or millimetres (mm) • computed discharge in m^3/sec or litre/sec • date and time for corresponding stage and discharge • cross-sectional area (where applicable) • mean velocity of discharge (where applicable) • method code for discharge measurement • data grade

[Note: Modified from NEMS 2013]

4.3 Discharge Measurement Procedures

The document "Discharge Measurements at Gaging Stations" published by the USGS (Turnipseed and Sauer 2010) provides detailed descriptions of the techniques uesd for making discharge measurements at streamflow gauging stations. The "Manual on Stream Gauging: Volume I – Fieldwork" published by the World Meteorological Organization (WMO) (2010a) also provides a detailed summary of conducting discharge measurements using conventional current meters, electromagnetic and acoustic meters, rated structures, and dilution gauging, as well as other miscellaneous methods. Although all technologies allow for the measurement of a range in streamflows, their usage can be limited by site conditions. For example, wading techniques are only applicable until a stream channel becomes unwadable, the volumetric method and rated structure (weir and flume) are useful for low flow measurements, while the indirect method of discharge measurement using slope-area might be the only option for peak flows in some instances. Accordingly, hydrometric operators must be flexible in the technologies deployed, as well as the field measurement techniques implemented. Table 4-2 provides a comparative review of discharge measurement equipment and methods as well as their advantages and limitations. This can be used to identify the optimal equipment (or types) for various field conditions and level of accuracy requirements.

4.4 Area-Velocity Discharge Measurement

4.4.1 General

The area-velocity method, commonly known as the 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 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.

4.4.2 Current Meters

An ideal current meter should respond instantly and consistently to any changes in water velocity. Also, the meter should be durable, easy to maintain, and simple to use under a variety of environmental conditions.

There are different types of current meters available on the market. They are grouped into three major categories: mechanical current meters, electromagnetic current meters, and acoustic Doppler velocity meters. A detailed description of the different types of current meters and their maintenance requirements are available in Section 5.3 of the "Manual on Stream Gauging: Volume I – Fieldwork" published by the World Meteorological Organization (WMO) (2010a).

4.4.2.1 Mechanical Current Meters

All mechanical current meters measure velocity by translating linear motion into angular motion. Two common types of current meters used in British Columbia are 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 current meter (Figure 4-1) was the standard for discharge measurement until the early 2000s at which point Acoustic Doppler technology became more commonplace.

Horizontal-axis meters are capable of very accurate flow measurement in areas of local turbulence. A small horizontal-axis current meter (Figure 4-2) used to be the principal instrument used by Provincial agencies in British Columbia to measure small shallow streams.

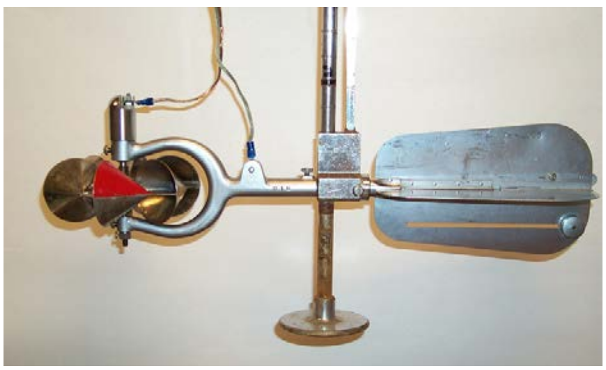


Figure 4-1: Price Type AA meter (Vertical-axis Meter).

Figure 4-2: OTT C2 current meter (Horizontal-axis Meter).

4.4.2.2 Electromagnetic Current Meters

An electromagnetic current meter measures velocity using Faraday's principle (electromagnetic induction), which states that a moving conductor (i.e., water) in a magnetic field will generate a voltage proportional to the speed of the conductor. Electrodes in the probe detect a voltage induced by the flowing water and convert the voltage into a velocity reading 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 conventional current meters can no longer be used such as areas with large numbers of aquatic plants, contaminated water, shallow water, and low-velocity water.

4.4.2.3 Acoustic Doppler Velocity Meter

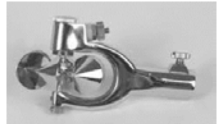
Acoustic flow meters measure the water velocity using acoustic signals and combine the results with a stage measurement to calculate the discharge.

A hand-held Acoustic Doppler Velocity (ADV) meter (Figure 4-3) 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 0.25-cc sample volume located 10 cm 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, and measurement in more shallow water. 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 too much entrained air and thus site selection is important. The Water Survey of Canada has officially adopted the use of ADVs (specifically Sontek's FlowTracker ADV) to support their national hydrometric monitoring program and have established standardized field procedures (i.e., "Measuring Discharge with FlowTracker Acoustic Doppler Velocimeters," Environment Canada 2015) for conducting a discharge measurement using wading techniques.

Figure 4-3: FlowTracker2 (Courtesy: SonTek).

Table 4-2: Comparison of discharge measurement equipment and methods

Instrument Type	Technology	Deployment Method	Range of Measurement	Accuracy	Maintenance/Calibration	Advantages	Limitations
Current Meter Options							
Price Type AA 	• Mechanical • Manual counting or digital readout options • Digital readout battery powered	• Mid/Mean-section method using top-setting rod, ice rod, or cable and weight assembly. • Field applications: o Wading o Bridge o Boat o Cableway o Ice	• Velocity: o 0.06 – 7.6 m/s • Water Depth: o >0.15 m	• Accuracy = ±2.6% in velocities from 0.229 m/s to 2.438 m/s	• Meters should be calibrated every 2 – 3 years (depending on level of use), unless meter has been damaged. • A spin test should be conducted prior to using to ensure that the bucket assembly rotates easily.	• Robust and simple to use. • Does not have to be oriented parallel to streamflow to read accurately. • Repeatable readings. • Recognized as standard equipment by the WSC. • Can be calibrated to National Calibration Services Standards.	• Requires regular maintenance to ensure minimal friction in operation. • Possible human error with older “click” systems. • Does not give flow angles, requires knowledgeable operator. • May not be suitable for shallow or narrow channels. • Not ideal for very low flows. • Off-axis (oblique) streamflows must be manually corrected. • Debris/vegetation within the water column can affect meter readings.
Pygmy Meter 	• Mechanical • Manual counting or digital readout options. • Digital readout battery powered	• Mid//Mean-section method using top-setting rod. • Field applications: o Wading	• Velocity: o 0.02 to 0.9 m/s • Water Depth: o 0.076 m up to height of rod	• Accuracy = ±4% in velocities from 0.229 m/s to 0.914 m/s	• Meters should be calibrated every 2 – 3 years (depending on level of use), unless meter has been damaged. • A spin test should be conducted prior to using to ensure that the bucket assembly rotates easily.	• Robust and simple to use. • Intended for use in small channels. • Does not have to be oriented parallel to streamflow to read accurately. • Repeatable readings. • Recognized as standard equipment by the WSC. • Can be calibrated to National Calibration Services Standards.	• Off-axis (oblique) streamflows must be manually corrected. • Variability in accuracy depending upon velocity. • Debris/vegetation within the water column can affect meter readings.
Horizontal Axis Meter – Component Propeller 	• Mechanical • Digital (counting) readout • Digital readout battery powered	• Mid/Mean-section method using top-setting rod. • Field applications: o Wading	• Velocity: o 0.02 – 0.9 m/s • Water Depth: o 0.03 m (depending on propeller type) up to height of rod	• Accuracy = ±2% (when using a component propeller and provided with a rating from the National Calibration Service)	• Meters should be calibrated every 2 – 3 years (depending on level of use), unless meter has been damaged. • A spin test should be conducted prior to using to ensure that the propeller assembly rotates easily.	• Propeller disturbs streamflow less than the Price Type meter. • Propellers are less prone to becoming entangled with debris. • Lower starting threshold compared to vertical axis meters. • Some propellers can be specifically chosen to suit shallow waters, low streamflows, or turbulent conditions. • Component propellers are capable of compensating for off-axis (oblique) streamflows. • Can be calibrated to National Calibration Services Standards.	• A propeller's response to increases in velocity is non-linear, so a multi-point calibration should be done for entire measurement range. • Higher maintenance when compared to vertical-axis meter as the meter should be serviced at the end of each discharge measurement.
Electromagnetic Flow Meters 	• Electronic • Digital measurement and datalogging	• Mid/Mean-section method using top-setting rod. • Field applications: o Wading	• Velocity: o 0.001 – 6 m/s • Water Depth: o 0.032 m up to height of rod	• Accuracy = 2% to 4% (based on velocity measurement)	• Considered permanently calibrated by manufacturer. • Run self-check diagnostics prior to field use to ensure proper instrumentation operation.	• No moving parts to wear out. • Calibration will not change over time. • Able to measure low flows. • Direct velocity and discharge readout. • Works well in high sediment conditions, turbulent waters, and areas subject to aquatic plant growth.	• Sensor performance and accuracy can be affected in low electrical conductivity waters (<200 µS/cm). • Proximity to ferrous material boundaries (e.g., culverts, metal grates) can affect the measurement accuracy. • Expensive.

Instrument Type	Technology	Deployment Method	Range of Measurement	Accuracy	Maintenance/Calibration	Advantages	Limitations
Acoustic Doppler Velocimeters 	• Electronic • Digital measurement and data logging	• Mid/Mean-section method using top-setting rod. • Field applications: o Wading o Or Deployment from ice	• Velocity: o 0.001 – 4 m/s (Point velocity) • Water Depth: o 0.02 m (Point velocity) up to height of rod o 0.05 m (Pulse Coherent) up to height of rod	• Accuracy = ±1% (of measured velocity)	• Considered permanently calibrated by manufacturer. • Run self-check diagnostics prior to field use to ensure proper instrumentation operation.	• Significant advantage in software for data collection, real-time error warnings and minimizing data transfer errors. • No moving parts to wear out. • Calibration will not change over time. • Able to measure low flows – point velocity style has better accuracy and resolution. • Direct velocity and discharge readout. • Works well in high sediment conditions. • Modern digital units have many advantages in data post-processing	• Clear water conditions are a challenge for Doppler instruments because they require particulate matter in the water to reflect sound (point velocity type less so than the pulse coherent type). • Aquatic vegetation can interfere with measurement. • May not be suitable at low flows where substrate is coarse; requires clear line of site of about 10 cm from sensor unit to measurement volume. • Does not perform well in turbulent conditions. • Expensive.
Other Discharge Measurement Options							
Rated Structures – Weirs and Flumes 	• Manual	• Direct installation of structure instream. • Field applications: o All channel conditions (if not impacted by ice upstream)	• Depends upon selected structure and size	• Accuracy = ±2.5% – ±10% (dependent upon installation and stage measuring instrument used)	• Sedimentation effects and vegetation growth should be assessed during each visit. • Rating verification should be completed annually using a different discharge measurement technique (e.g., current meter).	• Stage measurement is directly converted to a discharge using standard equations. No rating curve required. • No moving parts. • Suitable for low and very low streamflows.	• Design and installation can be expensive. • Suitable locations for installation can be difficult to find or access. • Range of streamflow is required to ensure proper design and installation. • Changing channel/pool conditions will affect accuracy. • Accuracy also depends on ability to capture flow and leakage. • Unit needs to be properly constructed and installed to work, but once calibration is confirmed, should be good unless damaged, bent, etc. • Cost of construction is moderate, but need to make sure it is built to specifications. • Installations require provincial regulatory approval (i.e., Section 11 of the WSA). • Location where stage is measured can influence the calculated discharge value.
Volumetric Flow Method 	• Manual (bucket and stop watch) • Mechanical (tipping-bucket)	• Volume measurements taken in-line with streamflow • Mechanical methods require streamflow to be channeled into collection hopper by pipe or culvert. • Field applications: o All channel conditions	• Applicable to low streamflows • Tipping-bucket can measure 0.5 L/min – 25 L/min	• Dependent upon the capture of entire streamflow • Manual accuracy = variable based on reproducibility of measurements • Mechanical accuracy = 2% for low volume applications to 25% for high volume measurements	• Not applicable for manual methods • Mechanical devices should be calibrated annually.	• Able to measure low volume streams. • Very simple to operate (both manual and mechanical approaches). • Very low maintenance.	• Variable accuracy depending upon streamflow. • Finding a good location to measure or mount a mechanical device can be difficult.

Instrument Type	Technology	Deployment Method	Range of Measurement	Accuracy	Maintenance/Calibration	Advantages	Limitations
Best Practice Options							
Dilution Gauging 	• Electronic (electrical conductivity meter or fluorometer) • Manual injection of tracer – Salt or Dye (rhodamine WT)	• Slug injection and constant-rate methods require the direct injection of a known volume or mass of tracer to streamflows. • Tracer concentrations measured using electrical conductivity meter (salt) or fluorometer (rhodamine WT). • Field applications: o All channel conditions, but primarily for steep, turbulent channels.	• Dependent upon volume injection limitations. • Rule of thumb – 1 kg of tracer (salt) solution per $1 m^3/s$. • Fluorometer can measure tracer (rhodamine) concentrations to parts per billion (ppb), so greater measurement range than salt applications.	• Accuracy = variable based on whether complete lateral mixing occurs within the measurement reach, with limited recirculation. • Uncertainty based on reproducibility of measurements and uncertainty analysis calculations.	• Electrical conductivity meters (salt) and fluorometer (rhodamine WT) calibrated prior to each field visit.	• Ideal for highly turbulent channels and watercourses where conventional metering instruments can be problematic, or where there are limited high water measurement options. • Does not require a defined cross-section. • Salt is inexpensive and easy to purchase, even in remote communities. • Calibration can be cheap and easy; electrical conductivity meters are generally quick and easy to calibrate. • Can be used to measure streamflows under complete ice cover (but ensures that complete in-channel mixing may be more challenging than under open-water conditions).	• This method is not for all channel conditions, requires full mixing. • Limited application (salt could be a contaminant in some places). • Accuracy highly dependent upon measurement reach and volume of injected tracer solution. • Tracer must be fully dissolved and laterally mixed within the measurement reach, which is difficult to verify in the field. • Should avoid sites that have soft sediment or aquatic vegetation as these may absorb or adsorb tracers (dye especially). • Hyporheic flow can remove tracer from stream. • Post-processing of recorded tracer waves required. • On-site calibrations required to support dilution calculations. • Larger volumes or masses of tracer solutions are required to measure high streamflows. • The location of the tracer concentration meter (electrical conductive or fluorometer) can affect the results. • Method has a high barrier to use; it is complicated and requires training and practice. No two sites are alike, so each one requires calibration and decision on injection volume.
Other Options Not Covered by RISC Hydrometric Standards							
Acoustic Doppler Current Profilers (ADCP) 	• Electronic • Digital measurement and datalogging	Used primarily on non-wadable watercourses. • Multiple non-mounted applications: o Complete channel measurement from bridge (tethered line), boat (mounted or remote controlled), and/or cableway/clothesline system. o Mid/Mean-section method application under ice conditions. • Multiple mounted instream applications (bottom and bank installed).	• Velocity (maximum velocity depends on the instrument model): o ±0.001 – 20 m/s (non-mounted sensors) o ±0.001 – 7 m/s (mounted sensors) • Water Depth (depends on the instrument model): o 0.10 m – 0.30 m (minimum) up to 40 m (non-mounted) o >0.05 m (mounted sensors)	• Resolution = $0.001 m^3/s$. • The accuracy depends on the instrument's internal signal processing. Usually: Accuracy = ±0.25% of measured velocity (non-mounted) o Minimum exposure time >720 seconds and at least two transects (for moving platform applications.) Accuracy = ±0.10% of measured velocity (mounted).	• Considered permanently calibrated by manufacturer. • Run self-check diagnostics prior to field use to ensure proper instrumentation operation. • For non-mounted applications, perform compass calibration at each measurement location. • For mounted applications, calibration to discharge values measured by other methods required.	• No moving parts to wear out. • Calibration will not change over time. • Measurements can be made much faster compared to mid-section method. • Provides a bathymetric profile and calculates discharge of the measured section. • Mounted applications can provide continuous discharge values without the need for a stage-discharge rating curve. • Mounted and non-mounted applications can both be used to measure streamflows under ice.	• Not suitable for very shallow waters (less than 0.10 – 0.30 m deep). • Clear water conditions can reduce effective range. • Operating in aerated waters is problematic. • Aquatic vegetation can interfere with measurement. • For non-mounted applications, bottom tracking can be an issue with a moving channel bed. • Expensive.

Instrument Type	Technology	Deployment Method	Range of Measurement	Accuracy	Maintenance/Calibration	Advantages	Limitations
Radar Discharge Sensors 	• Electronic • Digital measurement and datalogging • Measures both stage and surface velocity	Used primarily on non-wadable watercourses. • Multiple mounted applications on a bridge or boom.	• Surface Velocity: o 0.30 – 15 m/s • Water Depth: o >0.03 m (velocity) o 0.35 – 0.50 m distance to water surface required (stage)	• Accuracy = ±1% of measured surface velocity and ±2 – 3 mm for stage measurement	• Considered permanently calibrated by manufacturer. • Run self-check diagnostics prior to field use to ensure proper instrumentation operation. • Calibration to discharge values measured by other methods required.	• Calculates discharge without a rating curve. • Able to provide accurate discharge measurements in back-water conditions. • Mounting infrastructure can be relatively basic as long a sensor is securely affixed to avoid excessive vibration. • Works very well in high-velocity waters with waves. • Instream vegetation not normally an issue. • Minimal maintenance; no moving components. • Able to measure low- and high-water conditions, and during winter if no ice is below the sensor.	• Measurement area should be in the main channel. • Not suitable for low-velocity conditions, where water surface lacks wavelets. • Unable to measure streamflows under ice conditions. • Measures surface velocity only.

Source: Adapted from “Evaluation of the 2009 Resource Information Standards Committee (RISC) Manual of British Columbia Hydrometric Standards, Final Report, June 2017,” by Associated Environmental for B.C. Ministry of Environment (Associated Environmental 2017).

4.4.3 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. A detailed description of different equipment used for discharge measurements is available in Section 5.3 of "Manual on Stream Gauging: Volume I – Fieldwork," published by World Meteorological Organization (WMO) (2010a).

Top Setting Wading Rods

Top setting rods (Figure 4-4) are designed to securely position most current meters 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 4-3).

After the wading rod is placed into a stream and the water depth is read from the graduated 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.

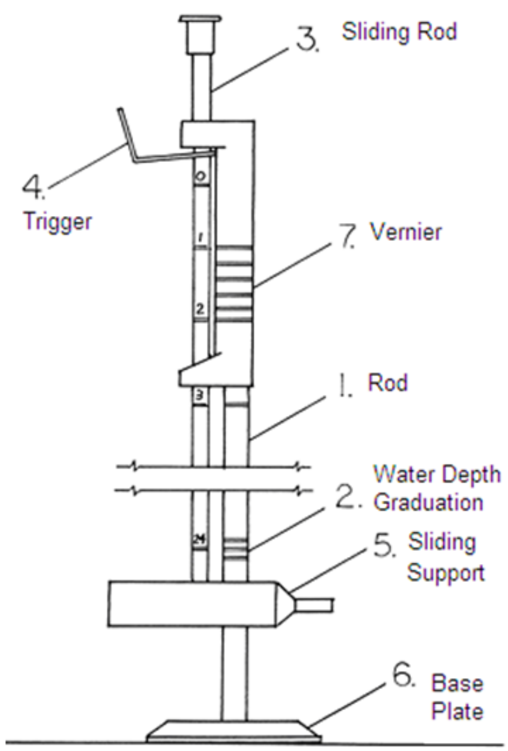


Figure 4-4: Components of top setting wading rod.

Table 4-3: 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

4.4.4 Pre-measurement Activities

4.4.4.1 Field Data Book

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 the hydrometric operator cannot 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:

- Hydrometric Station History (see Figure II-1 in Appendix II).
- Water Stage Log (see Figure II-3 in Appendix II).
- Discharge Measurement Field Form (see Figure II-4 in Appendix II) or similar form

  [**Note:** This form is not required for the FlowTracker or other devices where information can be generated automatically.]
- Summary of Discharge Measurements (see Figure II-5 in Appendix II).
- Stage-Discharge Rating Curve
- Station Analysis (see Figure II-7 in Appendix II).
- Special instructions regarding equipment, maintenance, techniques, conditions, etc.
- Names of field staff, and contact information.

4.4.4.2 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 and there is no systematic bias.

- 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 requirements are met for achieving desired data grade.
- 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 or FlowTracker.

  [**Note:** To achieve data grade A or B under RISC hydrometric standard, meter must be field verified at least once in a year.]

4.4.4.3 On-site Observations

Upon arrival at the site, the hydrometric 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, the stage recorder/data logger, the working condition of the current meter, and the water velocity. For weirs and flumes, the operator should check whether the structure is clean, there is no damage or leakage. Structure should be free from sedimentation and debris, which can result in backwater, which may change the rating. All this information should be recorded in the station log.

Assessing Channel Conditions

One purpose of assessing the overall channel conditions is to be aware of conditions that will affect the discharge measurement and the stage-discharge relationship since the last time the station was visited. 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 a note (use “Remarks” area of “Water Stage Log” if this form is used).

- 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/deposition
- The presence of overflow channels that are bypassing the metering section; if present, these must be measured (or estimated)
- High winds
- Ice conditions

Gauge Reading

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

- Record the date and time (arrival) in the station log, record the reference gauge and recorder readings and information to complete the station log (use Arrival Column for recording information if “Water Stage Log” form is used).

- If the site is without telemetry, download data logger readings since the 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.
- For well installations, flush the intakes and make certain they are not obstructed. Observe and record any differences that occur after the flushing.
- Service the recorder. Check the battery condition and voltage, all the cables and connections, solar panel(s), sensor(s), antennae, etc. and repair deficiencies. Record the repairs that were required and completed.
- Do a level check of the gauge or gauges, if required.
- Record the information on stage observations and procedures, level check, metering, etc. (use "Remarks" area for recording information if "Water Stage Log" form is used).

After taking the discharge measurement (when applicable), obtain another gauge reading and observe whether the recorder is operating properly (use Departure Colum for recording time and gauge reading if "Water Stage Log" form is used). By this time the recorder will have been operating for approximately 1hour and any error in the settings should be apparent.

Observing Velocity

> [**Note**: For FlowTracker, please follow the instruction in "Measuring Discharge with FlowTracker Acoustic Doppler Velocimeters," Environment Canada (2015)]

The guidelines for observing velocity (Figure 4-5) using mechanical current meters 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 – 70 seconds.
- Observe time to the nearest 1/2 second, 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 (i.e., 0.6 depth or 0.2/0.8 depth).
- Depth should be recorded to the nearest centimetre. This is for calculating the total cross-sectional area.
- Where velocity profiles may seem irregular, observations can be made at multiple depths (0.2, 0.6, and 0.8 for example), if necessary to fully integrate the velocities.

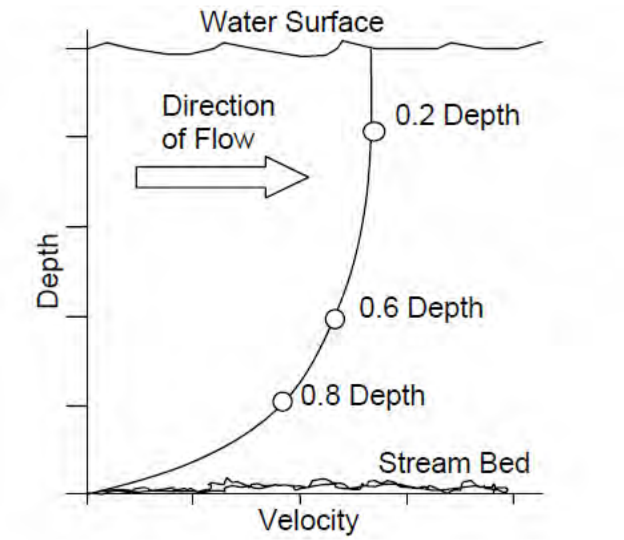


Figure 4-5: Example of typical vertical velocity curve.

4.4.5 Discharge Measurement

There are three basic techniques for making discharge measurements using a current meter: measuring by wading, measuring from a bridge, and measuring from a bank-controlled cableway. However, cableways are normally used for larger streams (>10 m^3/sec) and not covered under these standards. A detailed summary of conducting discharge measurements using current meters, ADVs and other techniques is provided in [“Manual on Stream Gauging: Volume I – Fieldwork”] published by World Meteorological Organization (WMO) (2010a).

4.4.5.1 Measuring by Wading

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.

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 or FlowTracker ADV. 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.

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 4.4.6.1.)
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 a 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.

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

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,"
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 4-10. The "Discharge Measurement Field Form" (see Figure II-4 in Appendix II) or a similar form can be used to calculate total discharge for Price AA or other types of mechanical current meters.

When using SonTek's FlowTracker, follow the instructions in "Measuring Discharge with FlowTracker Acoustic Doppler Velocimeters," (Environment Canada 2015).

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. Obtain the velocity by recording the observed velocity averaged over 40 – 70 seconds.
6. Repeat the above procedure until the watercourse is traversed and the measurement is completed.
7. 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 close attention to detail and technique. The following steps should be taken:

1. *Position of the tagline.* The tagline should be 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, the cosine of the horizontal angle must be recorded.
2. *Improving the metering section**.*** The metering section should be improved by removing boulders and debris from the metering section and the area immediately above it. First record the reference gauge reading before any activities in the channel begin. Weeds should be removed 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, sufficient time should be allowed for conditions to stabilize before proceeding with the measurement. Read the reference gauge water level at the end. Note if the modifications have an influence on the gauge reading. All improvements to the metering section should be completed before starting the measurement; that is, changes to the metering section (such as by moving rocks) should not be made during the course of the discharge measurement.

3. *Spacing of verticals.* More than 20 observations of both depth and velocity should be obtained for one complete measurement (see Section 4.4.6.1 Error Affecting Accuracy). For very narrow cross-section, use an appropriate meter and space the verticals more closely. However, measurement points should not be closer than 0.15 m when a Price Type AA meter is used.

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 have shown 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 orient the current meter perpendicular to the tag line 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. *Velocity observations.* If depths are sufficient (>1.0 m), 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 4.4.3).

   [**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.* A channel bed that is extremely soft or strewn with boulders requires a great deal of extra care and attention during sounding. Care should be taken 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, care should be taken 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 that defines the break point on the edge of the submerged obstruction (Figure 4-6). Depth and velocity observations are made just before and just after the point where the change takes place.

Some cross-sections may have a near-vertical boundary separating zones of different depth or velocity. In this case, the adjacent measuring verticals are positioned equidistant from this boundary, so that the boundary coincides with the common boundary of the partial sections.

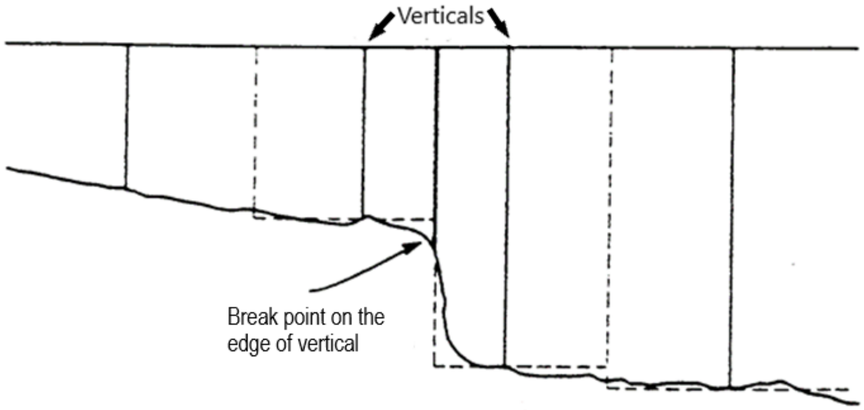


Figure 4-6: Defining the break point (Courtesy: WSC).

4.4.5.2 Measuring from a Bridge

If a watercourse cannot be waded, discharge measurements can be made from a bridge. Measurement cross-sections under bridges are often satisfactory for current meter measurements. A bridge rod (Figure 4-7) can be used to position the current meter in the watercourse.

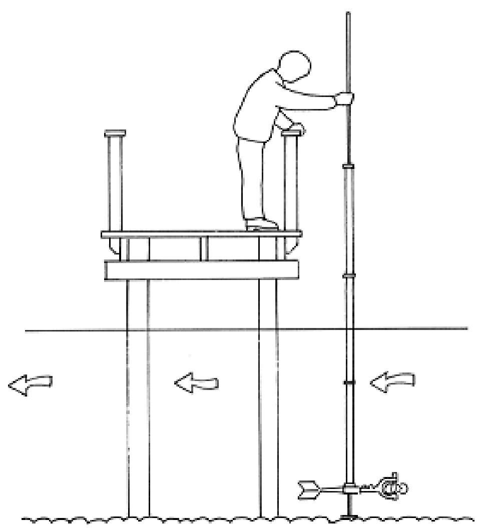


Figure 4-7: Bridge rod in use on upstream side of bridge.

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:

- hydraulic characteristics on the upstream side of bridges are usually more favourable

- drift material can be avoided more easily because it can be seen coming downstream. With downstream measuring, an assistant may be needed to watch for floating debris
- 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:

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

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.
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 4.4.4.3).
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 current meter to the required depth; allow it to stabilize to obtain the velocity.
11. Obtain the velocity by recording the observed velocity averaged over 40 – 70 seconds.
12. Continue measuring distance, depth, and velocity along the cross-section.
13. End the measurement at the water's edge on the left bank. Record the distance from initial point (i.e. tagline distance), depth, time, and water level.

    [**Note:** The distance between the face of the structure and the 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.]

4.4.6 Post-measurement Activities and Discharge Measurement Computation

[Note: Material presented in this section has been modified from "Hydrometric Field Manual – Measurement of Streamflow," published by Environment Canada (Terzi 1981)]

4.4.6.1 Errors Affecting Accuracy

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.

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.

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.

Calibration

Calibration is defined as the process of comparing the response of a measuring device with a calibrator or a measuring standard over a range. Under RISC Hydrometric Standards, all individual meters must be calibrated as per manufacturer's specifications to achieve grade A, B, or C.

Field Verification

Field Verification is defined as the act of confirming the equipment accuracy and specifications using a traceable standard or master. To achieve grade A or B data under RISC Hydrometric Standards, every meter must be verified 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, etc. or by following manufacturer's instructions.

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 (note: FlowTracker does this correction automatically). 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. 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. To eliminate the pulsation effect, it is recommended to observe the velocities for 40 – 70 seconds.

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 the equal flow method, the equal width method, or a combination of the two. With the equal flow method, the width segment can change frequently, and using the mid-section method for computations tends to distort the horizontal velocity profile. 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 0.15 m 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 data grade A or B, flow in each subsection or panel should not be more than 10% of the total flow and when setting up the vertical interval the operator should target 5%.

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 minimized 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.

4.4.6.2 Computation Procedure for Mid-section Method

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

- observed depth at the vertical is considered to be the mean depth for the section or panel
- it is assumed that the mean velocity at the observation vertical represents the mean velocity for the section.
- 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 4-8, 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 4-9 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 4-9. 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 that is expressed as a percentage of that observed at the previous vertical.

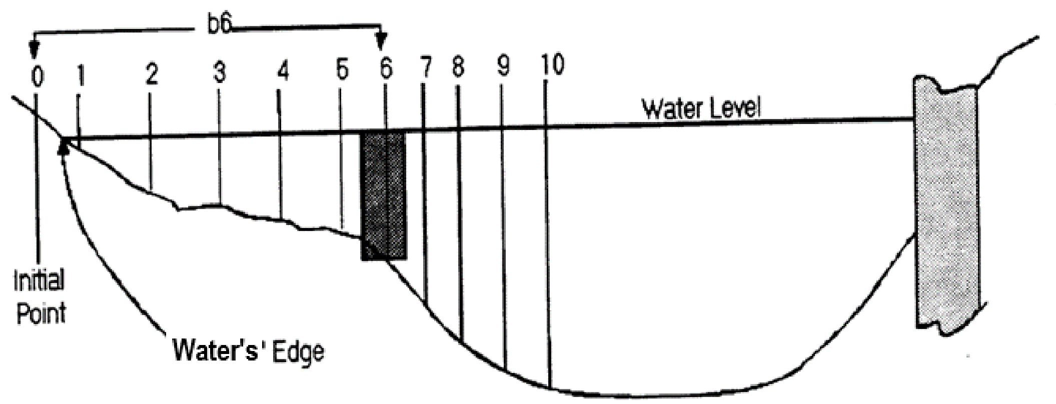


Figure 4-8: Mid-section method of discharge measurement.
(Typical stream cross-section with numbered verticals, Panel 6 is highlighted.)

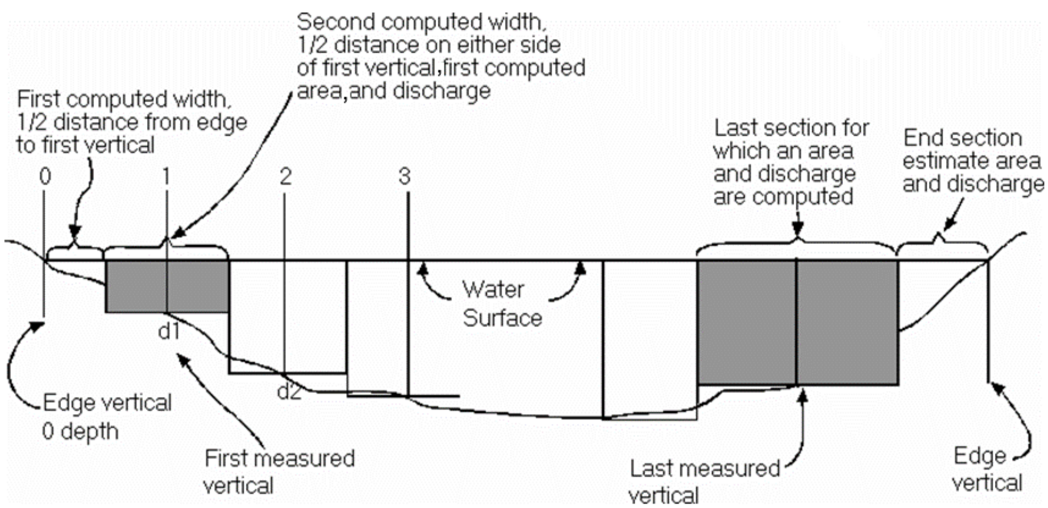


Figure 4-9: Method for selection of edge verticals.

4.4.7 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. The "Discharge Measurement Field Form" (see Figure II-4, Appendix II) can be used to record the necessary information and observed readings systematically. Summary of Discharge Measurements (see Figure II-5, Appendix II) can be prepared using this field form.

4.5 Discharge Measurement Using Rated Structure

4.5.1 Introduction

The measurement of flow in natural streams can be 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 (e.g., steep rocky gradients)
- shallow flows (i.e., low flows) where normal metering equipment is not acceptable

Rated structures can be used in such situations to minimize or eliminate many of these problems. Rated structures alleviate the need for velocity measurements and once they are installed properly, only water depth is required to be measured to calculate discharge using the rating equation. This is a major advantage when attempting to obtain accurate streamflow measurements, particularly for small watercourses with low streamflows. However, to ensure accurate flow measurements, verification of the rating should be performed for all rated structures on a regular basis using other methods (e.g., current meter). This will confirm discharge coefficients and proper installation of the structure.

> [**Note:** Discharge measurement using rated structure may also require approval from the Province of British Columbia under Section 11 (Changes in and about a stream) of the *Water Sustainability Act* (http://www.bclaws.ca/civix/document/id/complete/statreg/14015)]

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 is 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 m³/s.**

Larger units are available, but the cost of engineering and construction place them beyond routine applications. Reference to standard texts is recommended (e.g., Bos 1989) as no details on the hydraulics or modular limits are provided.

4.5.2 Design

The selection of alternative discharge measurement methods, particularly in larger streams with potentially destructive flows, should be made only after consultation with a hydraulic engineer or hydrometric specialist. Any larger measuring structures must be designed by a structural engineer.

4.5.2.1 Design Factors

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

- duration of the proposed project
- expected range of discharge to be measured
- expected flow characteristics through the channel once the rated structure is installed (i.e., approach velocity, backwater/flooding ahead of the structure, spill characteristics, risk of surcharge)
- strength of the device withstanding over-topping by extreme flows
- measurement of extreme flows
- geometry of the channel reach
- streambed gradient above and below the proposed site
- presence and extent of bedload and/or sediment transport
- presence of any downstream constriction that may cause elevated tail water levels at higher flows
- permeability of streambanks, streambed, and underlying strata
- frost line depth
- proximity of vehicle access (this may possibly include access by a redi-mix truck or a small-load mix trailer, and travel time from the depot)
- construction window for in-stream work

- permitting

4.5.2.2 Selecting the Discharge Measuring Device

Initially, the choice of the discharge measuring device for a particular location will depend on the conditions set out in the previous sub-section. Table 4-4 enumerates the maximum and minimum discharges for the various sizes of devices together with their ability to prevent sedimentation and pass bedload and debris.

For the placement of weir crests, an important dimension is **p,** the depth of the approach channel below the crest on the upstream side of the weir. **p** is also required in the ratio **h^1/p** (see Table 4-4, and in Figures 4-10 and 4-11), and must be used to specify the positioning of the various weir crests when these weirs are operating at capacity.

Sometimes a combination of rectangular and V-notch weir (e.g., compound weir) is used in situations where streamflows are expected to vary widely. A compound weir commonly consists of two stages, a rectangular notch with a 90º V-notch cut into the centre of the crest (but not exclusively the centre) and is designed for low, medium, and high streamflows and to provide better ranges and accuracies than a standard rectangular weir. Detailed description of a compound weir is not provided here however, but can be found in USBR (2001) and Grant (2016). Bos (1989) provides detailed, and comprehensive descriptions of different types of discharge measurement structures and their selection for different conditions (see their Chapter 3: Selection of structures, and Table 3.1- Data on various structures). WMO (2010a) also presented similar information (see their Chapter 7: Measurement of Discharge by Pre-calibrated Measuring Structures).

4.5.2.3 Installation

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

- grade setting – 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 (i.e., having an unobstructed and free spilling nappe is a critical component for a properly operating rated structure. If the nappe clings to the downstream face of the weir, discharge can be overestimated)
- streambed – the streambed must be sealed against seepage under the structure – any granular bed is susceptible to seepage. To prevent seepage, watertight membrane (plastic sheet or geotextile) can be placed on the streambed, upstream of the structure
- structural foundation – this is required for support and anchorage, and to prevent leakage.
- rating device mount – the primary concern is that the device is level, aligned with the streamline, and well anchored
- wing walls – these are designed to maintain the minimum pool elevation, to retain watertightness, and to remain intact in the event of over-topping

The information in Table 4-4 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 that 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 4-5.

Table 4-4: 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	≤1.2	≥0.45
Montana flume	3-inch	0.330	0.032	0.03	0.0008	Very good	Good	N/A	N/A
	6-inch	0.450	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	0.457	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=1.0 m	0.500	0.585	0.06	0.0267	Poor	Poor	≤ 0.5	≥ 0.3
	b=1.5 m	0.750	1.612	0.06	0.0402	Poor	Poor	≤ 0.5	≥ 0.3
	b=2.0 m	1.000	3.308	0.06	0.0537	Poor	Poor	≤ 0.5	≥ 0.3
	b=3.0 m	1.500	9.117	0.06	0.0807	Poor	Poor	≤ 0.5	≥ 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.

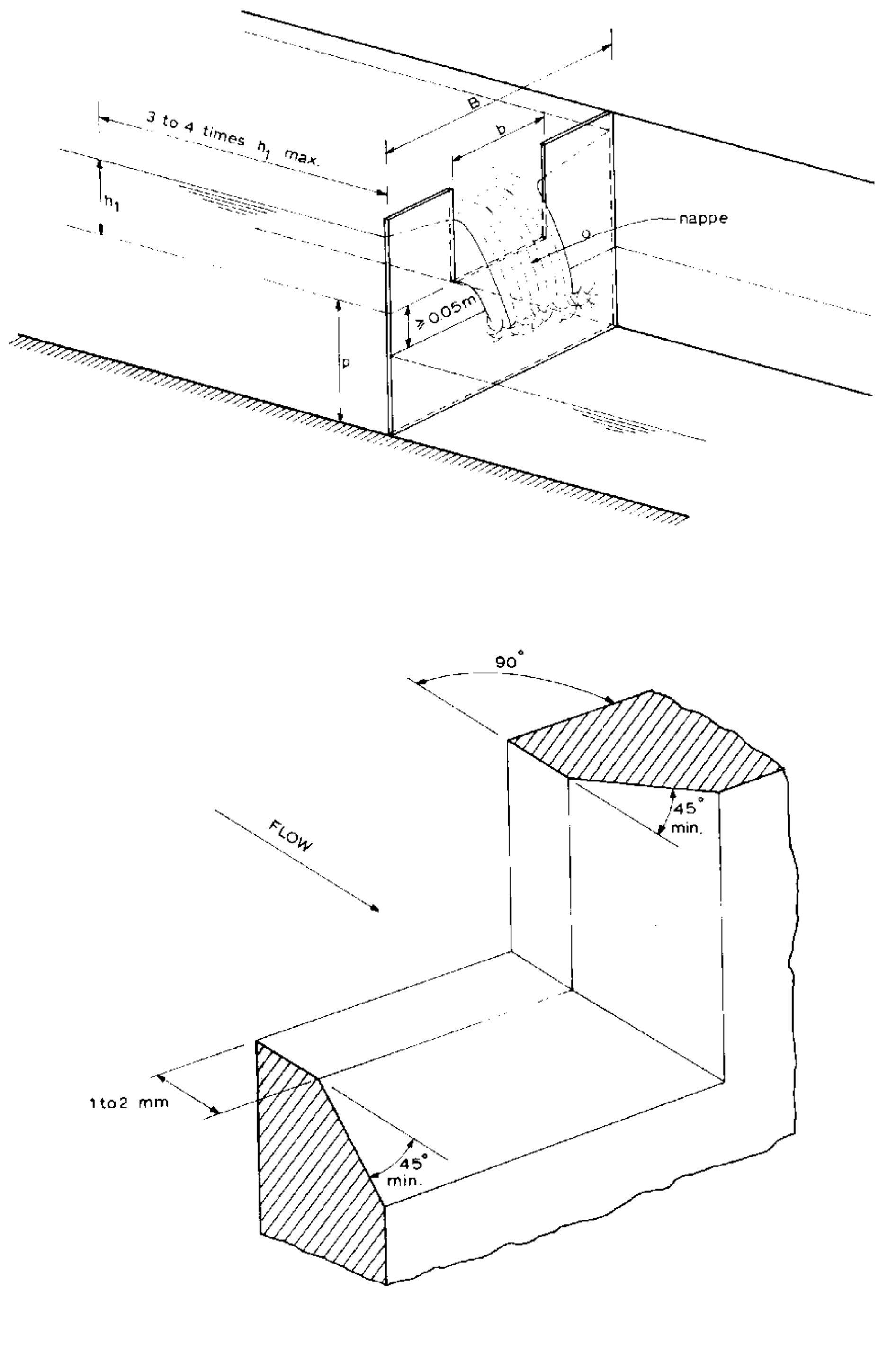


Figure 4-10: Rectangular sharp-crested weir (thin-plate weir) with enlarged view of the crest and the side.

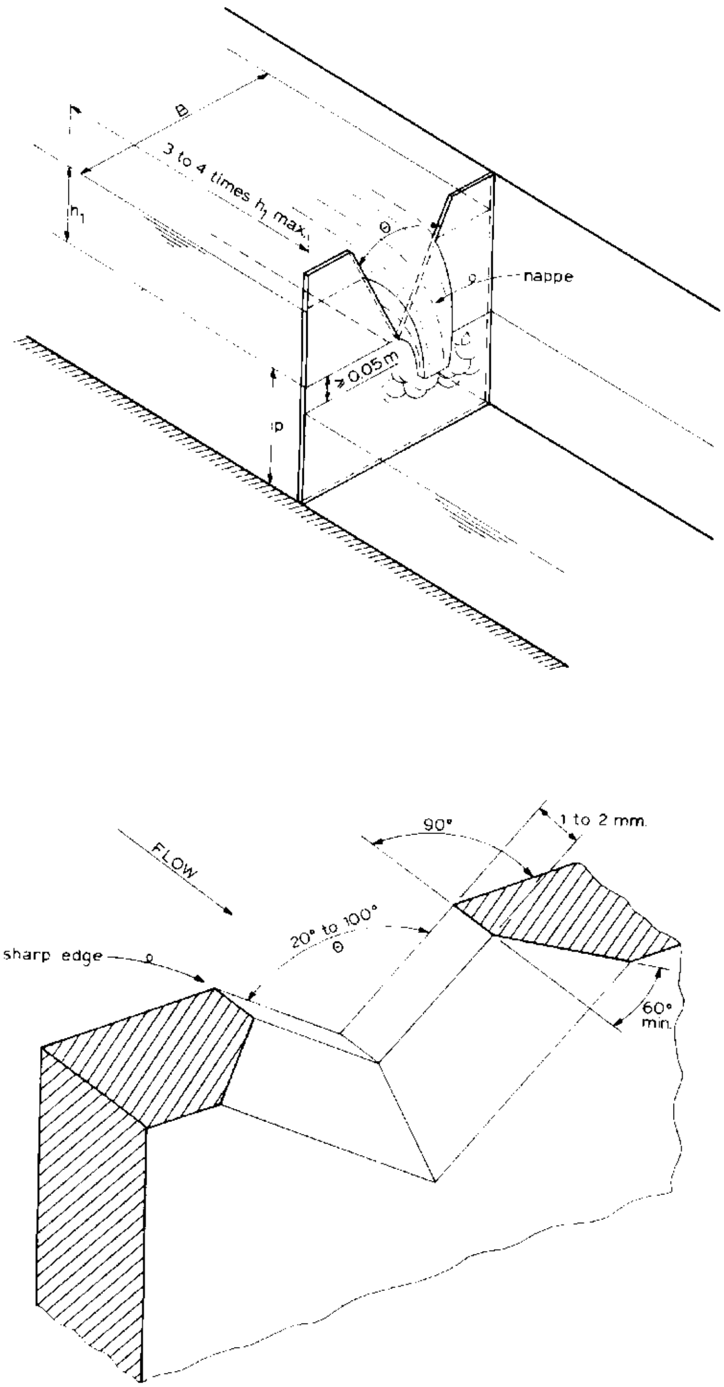


Figure 4-11: V-notch sharp-crested weir with enlarged view of V-notch.

Table 4-5: 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 nappe.
Minimum width of approach channel = 6 m.	Width of approach channel = 2.7 m.
Minimum height of banks, approach 3 m + freeboard.	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 regular 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.

4.5.2.4 Site Conditions

Conditions of the measurement site will usually determine the choice of a control structure for the discharge measurement. The preceding subsection clearly shows the advantages of flume installations over weirs in most stream channels. An 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 this case a weir may be the most suitable choice. Any stream designated as fish bearing requires approval from the Province of British Columbia under Section 11 of the *Water Sustainability Act* (http://www.bclaws.ca/civix/document/id/complete/statreg/14015).

4.5.2.5 Erosion Protection

Unless a weir or flume is positioned 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 structures also require protection against undermining and eventual failure. 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.

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

4.5.3 Continuous Stage Recording

4.5.3.1 Flumes

Descriptive information on H-flumes (Figure 4-12) is added in Figure 4-13 with the associated dimension table. Related discharge tables are included in Appendix III.

Figure 4-12: A 2.5-foot H-flume set in concrete-filled sacks.

The stilling well for use with these flumes is normally mounted against the outer face of the prefabricated flume and centred opposite the flume's 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 that 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, a patch from a length of scrap pipe (same diameter) can be used with the correct solvent/glue and two large hose clamps, to 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 are recorded at each station visit. Installation requirements for an upstream gauge are the same as for weirs, see Section 4.5.2.3.

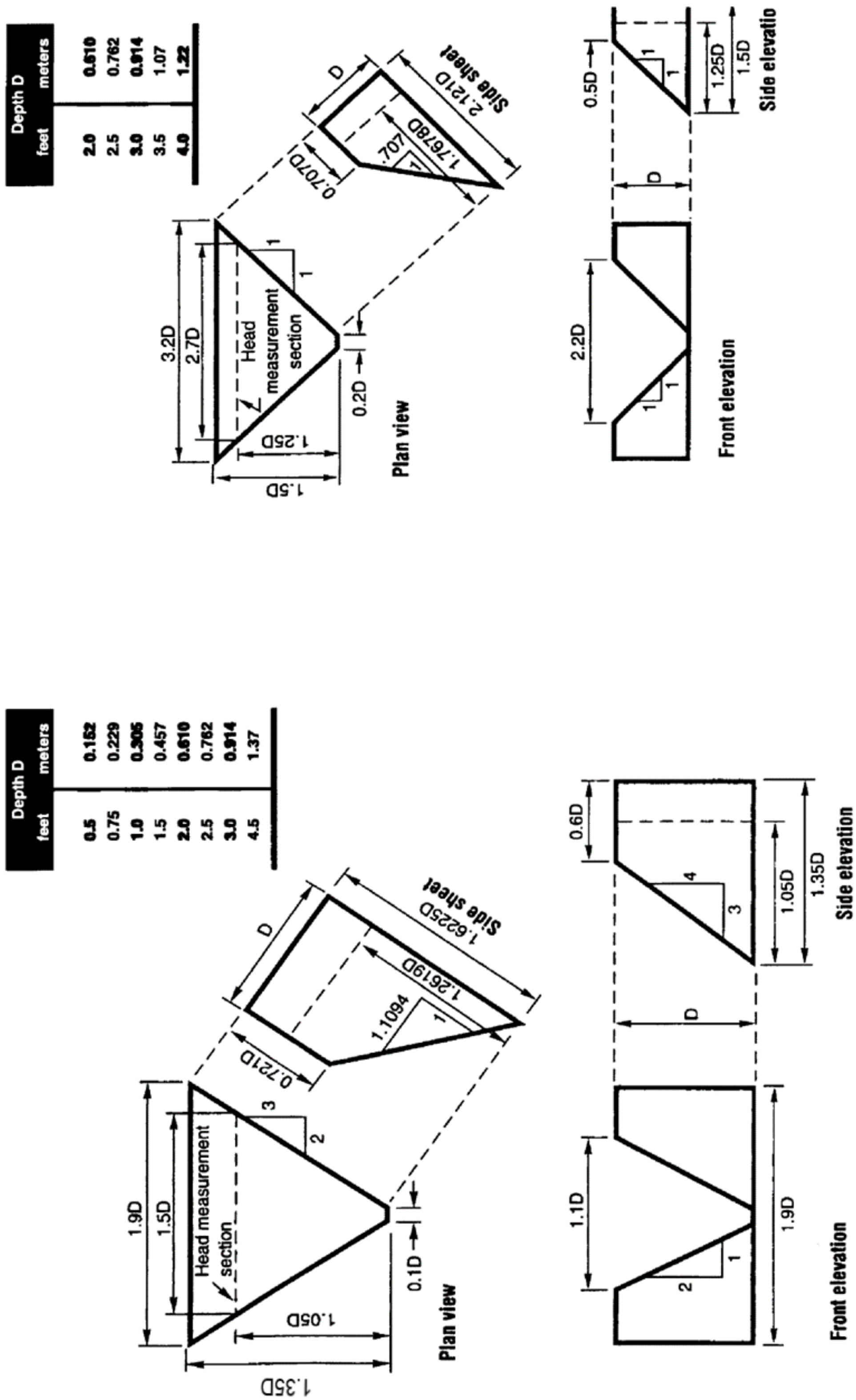


Figure 4-13: Dimensions of HL-type (top) and H-type (bottom) flumes.

4.5.3.2 Weirs

Stilling wells should be installed in the weir pond against a stabilized vertical bank or wall (see Figure 4-14). 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 – 4 times the maximum height of water over the crest (to avoid drawdown effect).

Figure 4-14: Stilling well installed in the weir pond.

4.5.4 Discharge Measurement Using Portable Montana Flumes

A properly installed small portable Montana flume (Figures 4-15 and 4-16), 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 4-6 and Figure 4-17 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; that is, 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.]

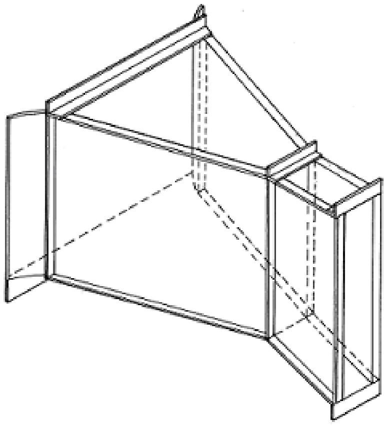


Figure 4-15: Montana flume.

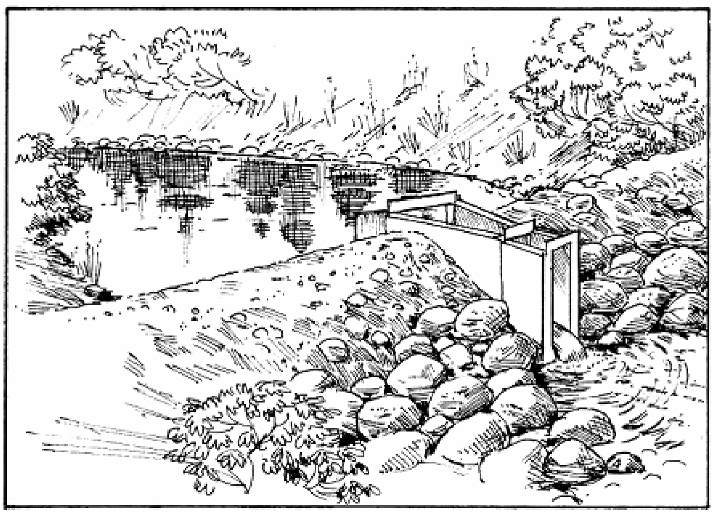


Figure 4-16: Montana flume installation.

Table 4-6: 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 m	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	32.1	0.77
6 in. or 152 mm	621	414	610	915	397	610	305	800	406	0.450	111	1.50
9 in. or 229 mm	879	587	864	1169	575	762	305	952	406	0.610	251	2.50
12 in. or 305 mm	1372	914	1343	1953	845	914	610	1219	508	0.760	457	3.32

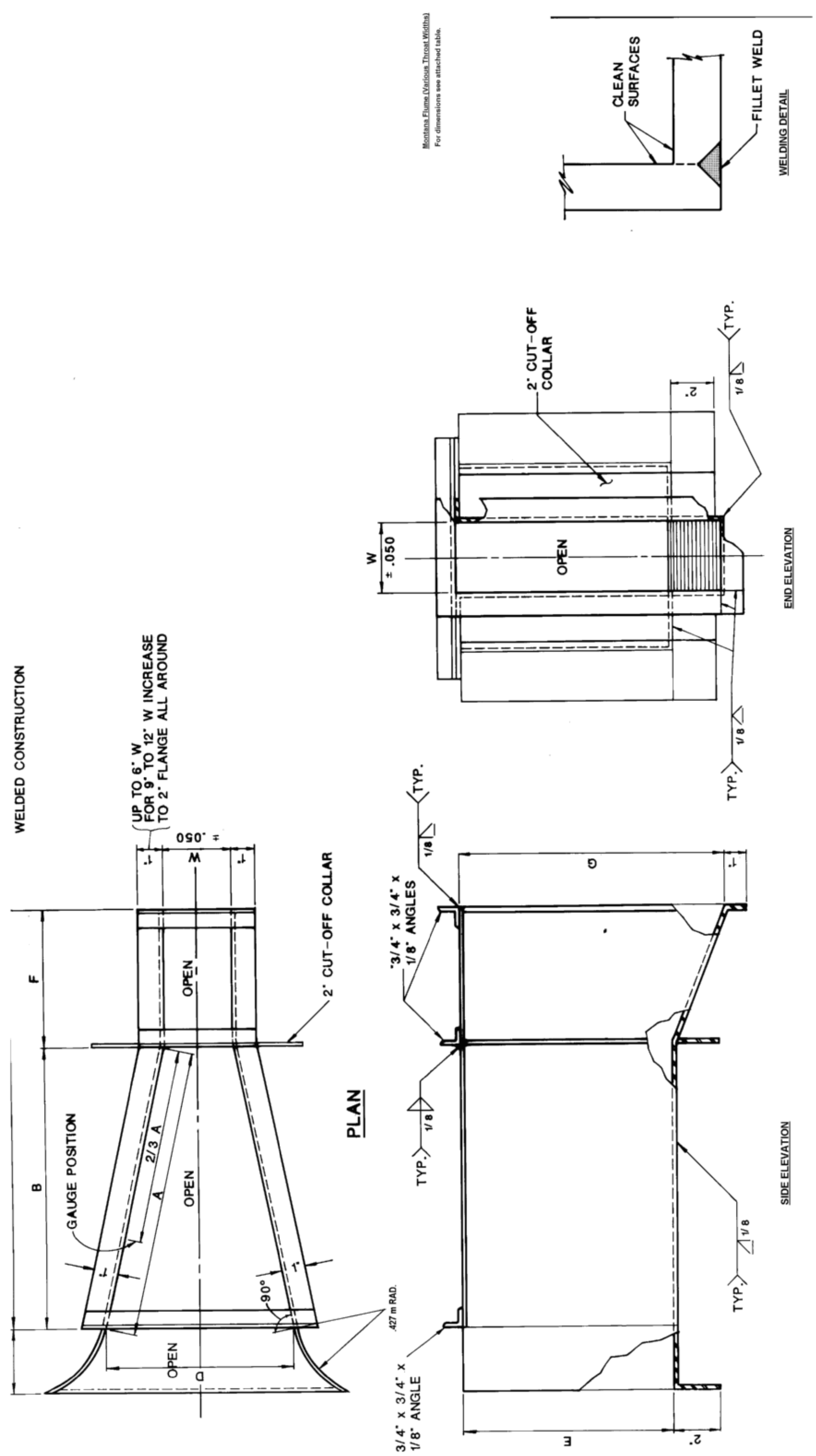


Figure 4-17: Various throat widths for the Montana flume.

4.5.5 Data Collection and Data Submission for Rated Structure

For weir and flumes, only upstream head measurements are needed to calculate the discharge using an equation or rating table; however, for accurate head measurements, streamflow must be stabilized after installing the structure. A couple of upstream head measurements should be taken for a period of time and the average of these should be used to determine the discharge.

For rated structure, filed notes should contain the following information and must be submitted as the original achievable record along with completed Summary of Discharge Measurement form:

- head measurements – the recommended number of observations is ten (10), one observation every 30 seconds for a period of 5 minutes
- average head, h
- calculated Discharge, Q (using a rating table or equation). Rating tables and/or equations should be included.

4.6 Volumetric Measurement

Volumetric measurement is used to carry out fast and accurate measurement of small discharge where the flow is concentrated in a narrow stream, or where the entire flow can be diverted into a container. A calibrated container and a stop watch are the only equipment required to measure the flow. In this method the flows are measured by diverting the flow into a calibrated container, and measuring the time required to fill the container. Usually two people are needed, one for filling the container and the other for timing the event. The flow is calculated by:

$$Flow = \frac{Volume\ of\ container}{Time\ to\ fill\ (in\ seconds)}$$

Standard requirements criteria for this method are as follows:

- for volume measurement:
  - container should be calibrated (e.g., graduated cylinder)
  - container size should be manageable
- for time measurement:
  - time required to fill the container should be measured with a stop watch
  - at least five (5) separate filling measurements should be made and the differences between the measurements should be within 5% [**Note:** More measurements are needed if variation exceeds 5%].

The total discharge is computed by dividing the total volume (sum of the volume measurements from each repetitive run) by the total time (sum of the time measurements from each repetitive run), in seconds.

The sites chosen for volumetric measurements are usually limited to the exits of culverts or below cascades with a clear confined nappe. 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 4-18).

In some 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.

For volumetric discharge measurement, field notes should contain the following information and must be submitted as the original achievable record along with the completed "Summary of Discharge Measurement" form:

- container volume
- fill time for each repetitive run
- total volume – this is a summation of the individual flow volumes of each run
- total time – this is a summation of the individual fill times of each run
- discharge – this is the total volume divided by the total time.

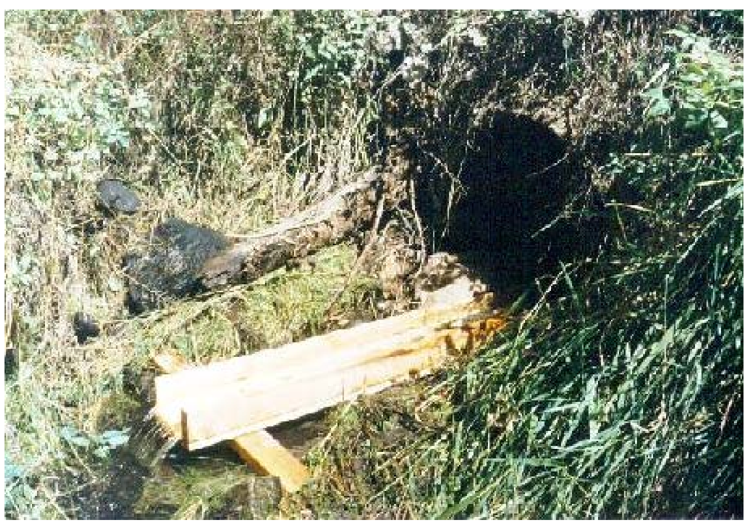


Figure 4-18: Culvert with low outlet and flow led into flume for volumetric measurement.

4.7 Indirect Discharge Measurements

This section provides information on estimating discharge in open channels using indirect methods and should only be used for flood or peak flows when it is impossible or too dangerous to measure the discharge using direct measurements. These types of measurements are always made after the flood event rather than during the flood, and all discharge data from indirect measurements should be graded as "Estimated (E)."

There are several of methods available for indirect measurement including slope area, contracted opening, culvert, and flow over dams and embankments; however, only the slope area method is described in detail.

4.7.1 Slope Area Method

The slope area method is one of the most commonly used techniques for indirect discharge estimation. A detailed description of this method is provided in the USGS publication "Measurement of Peak Discharge by the Slope-Area Method" by Dalrymple and Benson (1968). In this method, Manning's equation is used to derive velocity from channel parameters and slope. These values are calculated for the reach rather than a single cross-section (values from two or more cross-sections are averaged).

Manning's equation for computing velocity is:

$$V = \frac{1}{n}\, R^{\frac{2}{3}} {S_f}^{\frac{1}{2}}$$

and discharge (Q) is computed as = velocity (V) x area (A);

$$Q = \frac{1}{n} A\, R^{\frac{2}{3}} {S_f}^{\frac{1}{2}}$$

Where:

V is mean velocity (m/s)

Q is discharge (m^3/s)

R is hydraulic radius = A/P (m)

A is mean cross-sectional area (m^2)

P is wetted perimeter (m)

n is Manning's roughness coefficient (for n values see USGS Water Supply Paper 2339, Arcement and Schneider 1989)

S_f is friction slope, where:

$$S_f = \frac{\Delta H + \Delta H_v - k(\Delta H)}{L}$$

Where:

ΔH is the change in water surface elevation between upstream and downstream cross-sections

ΔH_v is the change in velocity head between upstream and downstream cross-sections, where:

$$H_v = \frac{\alpha V^2}{2g}$$, where α is usually assumed to be 1

g is acceleration due to gravity

k is assumed to be zero for contracting reaches and 0.5 for expanding reaches

L is the length of the reach

For this method data collection and computation procedures are significantly different than the standard measurements. For discharge estimation, the following data are required:

- surveyed high water level locations and elevations (see Koenig et al. 2016 for identifying high-water mark)
- geometry of cross-sections along the reach

- selection of roughness coefficient for the reach (for roughness coefficient see Arcement and Schneider 1989)

However, only final discharge estimates and summary information are required to submit in the provincial database while all other information should be retained indefinitely and be available when requested.

4.8 Dilution Gauging

[**Note:** Content for this section was developed through contributions from a number of British Columbia salt dilution researchers and professionals (Robin Pike, Dan Moore, Gabe Sentlinger, Andre Zimmerman, Jon Goetz, Kyle Terry, William Floyd, and Sarah Crookshanks). Content was drawn from these individuals, key references, and a report prepared by Associated Environmental (2017) for the Province of British Columbia in review of the 2009 Hydrometric RISC manual. The authors thank these professionals for their valued contributions to the updated RISC document.]

Dilution gauging is a streamflow measurement method that involves measuring a tracer's dilution, a sufficient distance downstream from a point of injection such that the tracer is fully mixed across the stream channel (Moore 2004a). Although a range of tracers can be used, food-grade table salt (NaCl) is preferred as it is generally non-toxic at the concentrations typically involved in stream gauging (but see further comments below). Furthermore, NaCl is readily available and inexpensive, and can be accurately detected by monitoring changes in electrical conductivity of stream water.

Dilution gauging is generally used where traditional velocity–area methods are not reliable (e.g., irregular or cascading channels) or where it is difficult to impossible to use traditional mid-section methods due to high velocities, turbulence, or debris (WMO 2010a). Dilution gauging methods are all based on the law of conservation of mass for a tracer introduced into a channel. The main variation in methods can be distinguished in terms of:

- mode of injection (constant-rate versus slug injection)
- whether the tracer mass balance is expressed in terms of tracer mass (kg) ("mass balance method") or in terms of the volume of a solution comprising the tracer mixed with water ("relative concentration method")
- the type of tracer used.

For all methods, tracer concentration requires complete mixing between the point of injection and the location at which the tracer mass is observed. However, for the slug injection methods, it is not the instantaneous concentrations that need to be uniform across the channel, but the time-integral of the conductivity exceedance over background.

The development and practice of salt dilution stream gauging procedures have been evolving for almost 50 years in British Columbia, with several early adopters (Church and Kellerhaus 1970; Kite 1993; Moore 2004a, 2004b, 2004c; Hudson and Fraser 2005) working to refine the science. At present, while there are no standard operating procedure (SOP) documents available for practitioners, several reports support the development of the following RISC standards for salt dilution techniques (Moore 2004a, 2004b, 2004c; Moore 2005; Moore et al. 2008; Richardson et al. 2017a; Richardson et al. 2017b; Zimmermann et al. 2017b). The following suggestions draw upon and extend those key references to define requirements for a best practices (BP) hydrometric data grade (see section 1.5.2). It is expected that the meta-data requirements suggested in this report will support the evaluation and potential retro-grading of salt dilution data. As a result, this document stresses the importance of comprehensive metadata documentation of: i) instrumentation, ii) field procedures, and iii) data processing and assessment methods to accompany each paired gauging measurement (water level and discharge). The points below assume that the reader is familiar with both *Mass Balance* and *Relative Concentration* salt dilution field procedures.

Instrumentation

Minimizing uncertainty in application of salt dilution methods begins with ensuring that all instrumentation is properly setup and calibrated. Salt tracers need to be free of harmful added chemicals, and uncertainty is best minimized by ensuring that the dose of salt is precisely measured. The following are five key things to consider with respect to minimizing instrumentation and salt tracer uncertainty.

1) Temperature Compensation of Electrical Conductivity (*EC*) Measurements

Electrical conductivity (*EC*) is a measure of the ability of charged ions to move through a solution and is generally measured in the units of µS/cm (micro-Siemens per cm). The *EC* of stream water depends on the ionic species present, the background concentrations of ions, and temperature. Temperature compensation of *EC* measurements must be completed using linear or non-linear functions referenced to 25ºC (EC_T) for stream temperatures > 2ºC and conductivities > 3 µS/cm. These compensations are standard options on most electrical conductivity loggers. Linear corrections below these specific conditions (<2 ºC, < 3 µS/cm) are not recommended as the non-linear function appears to perform better (Moore et al. 2008).

2) Conductivity Sensor Resolution

Sensor resolution is generally a function of a stream's background conductivity (EC_{BG}), as most conductivity loggers have an auto-ranging function that in turn influences the resolution of output measurements. Recommendations:

- for EC_T measurements <200 µS/cm, a minimum instrument resolution of 0.1 µS/cm
- for EC_T measurements >200 µS/cm, a minimum instrument resolution of 1 µS/cm

  [**Note:** Please note both sensor resolution and background conductivity noise affect the injection ratios (aka salt dosing) required to achieve a sufficiently high signal to noise ratio (SNR) to achieve low measurement uncertainty. Higher salt concentrations (injection ratios) are generally required for EC_{BG} > 200 µS/cm due to this change in instrument resolution.]

3) EC and Temperature Sensor Calibration

Instruments should be calibrated (sometimes referred to as cell constant calibration) following manufacturer's instructions, using a known laboratory grade conductivity standard (e.g., 1,413 µS/cm) that has not expired and needs to be completed no more than **6 months** previous to the date of salt dilution measurement. In all instances, an initial "flushing/rinsing" step should precede calibration to ensure that calibration standard strength has not been altered by contaminants on the sensor. Temperature measurements from equipment should also be periodically verified with a reliable thermometer of similar resolution. Records on instrument calibration and maintenance must be documented.

Permanent sensor installations, calibrated in situ, should follow the *Continuous Water Quality Sampling Programs – Operating Procedures* for calculating possible effects of fouling, calibration drift, sensor malfunction, and noise parameter readings (see B.C. Ministry of Environment 2006) prior to performing a calibration of cell constant.

[**Note:** For legal related applications and/or compliance monitoring, instrument calibration protocol may vary and be required to occur immediately before and after field measurements.]

4) Tracer Composition and Consistency

Salt tracers must be food-grade sodium chloride (NaCl). For the protection of aquatic life, products such as road salt, pool salt, water softeners, etc. are not permitted as they contain added chemicals. Consistency in tracer composition is important; hence, metadata on brand and make of table salt should be tracked.

5) Salt Weight or Volume

Uncertainty in salt weight or volume generally translates into an equivalent percent uncertainty in calculated final discharge value. Improperly stored salt (i.e., in wet areas) can result in tracers becoming moist thereby resulting in altered weights if weighed out when damp. It is therefore recommended that all salt be stored in a warm, dry area and notes on NaCl storage and handling should be included in collected metadata.

Practitioners can minimize salt weight uncertainty by using accurate, recently calibrated scales. Tracer salt should be weighed to ± 1% or better to account for uncertainty caused by small changes in moisture content, losses during transport, and scale uncertainty. Small salt amounts measured for use in CF_T (temperature compensated calibration factor for mass balance method) derivation should be weighed on a scale with a resolution of 0.01 g or better. Greater precision in this step (e.g., using a scale to 4 decimal places) will help to render this source of uncertainty negligible. Weighing scales are recommended to be calibrated, at minimum, annually.

Measurement uncertainty of all volumetric measurements used for relative concentration methods should also be included in metadata. Volumetric measurements should record the type of equipment used, brand, and uncertainty of volumetric measurements (if available).

Field Procedures – Stream Channel Conditions, Dosing, Calibration, and other Field Procedures

Key to the success of dilution methods is the validity of the assumption of complete mixing of the tracer across the channel at the end of the mixing reach. Ideal measurement reaches will have boulder beds with numerous constrictions that promote rapid lateral mixing. Sharp bends promote overturning streamflow, which can enhance lateral mixing as well. An ideal site would be a location where a tracer could be injected upstream of a constriction with the measurement point downstream of another constriction, and minimal pool volume and no tributaries between the two locations. The following are three key things to consider with respect to ensuring adequate stream channel conditions for minimizing uncertainty in the salt dilution methods.

1) Channel and Mixing Reach Properties

The mixing reach should ideally have minimal pooling and lateral storage at the specific flow level being measured. It is important to note that mixing properties depend on water level (discharge) and inadequate mixing conditions may occur at certain flows.

Additional surface water inputs should not occur between the injection point and the downstream measurement location, unless the reach being rated is located below the tributary surface water input and is sufficiently far downstream that the tributary flow is fully mixed with the main channel flow. Measuring ECBG and temperature along the mixing reach, prior to tracer injection, can help identify areas of lateral inflow or groundwater discharge (Moore et al. 2008). For more information, see Richardson et al. (2017b).

Descriptions of channel conditions must include features that facilitate mixing and enhance turbulence (e.g., irregular bottoms, steps, boulders). Documentation including the type and amount of mixing features (i.e., number of constrictions, spreading flow points, etc.) within a mixing reach is recommended.

2) Injection (Upstream) and Measurement (Downstream) Location Properties

Injection points ideally should be located in, or above, an area of flow constriction, whereas measurement points should be in or below a flow constriction.

Measurement locations should avoid placement within aeration zones, lateral pools and areas of recirculating flow (i.e., back eddies or in the lee of large substrate). Measurement points with substantial pool volumes and re-circulating streamflow should be avoided, as tracers moving into these zones can be stored and gradually released, significantly extending the duration of the tracer breakthrough curve (i.e., the EC exceedance over background). Streams with significant in-stream vegetation are also not suitable, as the zone of reduced velocity and mixing (due to the presence of vegetation) will store and slowly release the tracer.

3) Mixing Reach Length

Studies have shown that a mixing length of 10-25 wetted channel widths below the tracer injection point is typically required for complete mixing, and no mixing reaches are to be less than 7 wetted channel widths (Richardson et al. 2017b). However, for some reaches, even a mixing length of 25 wetted widths may be inadequate. Therefore, completeness of mixing should always be confirmed using appropriate protocols. While not required for BP grade, recording of GPS coordinates at the injection and measurement locations may augment salt dilution meta-data.

Dosing, Calibration and other Field Procedures

Dosing, calibration, and other field procedures can have an important effect on the accuracy of any dilution measurement. To minimize uncertainty, it is critical that practitioners properly calculate and adjust tracer dose based on conservative approaches to protect aquatic life while ensuring an adequate signal to noise ratio. Practitioners must also use methods to verify full mixing and ensure that k (*calibration factor for salt in solution methods*) and CF_T *(calibration factor for mass balance method)* are properly performed. Finally, field methods to control for potentially variable, and possibly shifting, backgrounds must be employed. The following seven points provide more details on these subjects.

1) Tracer Dose

It is recommended that practitioners stay below[2] B.C. Water Quality Guidelines for Chloride for the most sensitive designated use (British Columbia Ministry of Environment 2003). In cases where sensitive species exist (whether known or not), or exceedances above guidelines are likely, please contact a local Environmental Protection representative (B.C. Ministry of Environment) for more information prior to commencing measurements. Please note that permits or permissions may also be required by other jurisdictions (e.g., Provincial, Federal, and others) prior to conducting streamflow measurements.

General guidance from literature and practitioner experience is to dose no more than 1 kg of NaCl per m^3/s of streamflow. At sites with previously constructed rating curves, use the rating information to assist in estimating the appropriate salt dose. When operating at a new

[2] Further research is currently being conducted on the subject and practitioners should be aware that this guidance may change in the future.

site, to prevent exceedance of water quality guidelines for chloride, practitioners are encouraged to derive two conservative estimates of flow. For example, one estimate could be based on a visual estimate of discharge and the guideline of 500 –1000 mg NaCl per m^3/s, and another based on Eq. 11 in Richardson et al. (2017b), which is based on estimates of width and depth and the measured length of the mixing reach. The lower of the two values should be used for an initial trial, and new practitioners should strongly consider reducing the calculated dose on the first tracer run at a new site. Adjustments of subsequent doses can then be based on results of the initial, conservative trial run.

Tracer dosing for the constant rate method is typically less than for slug injection methods (see exceedance over background guidance, below). It is important that the typical solution strengths of 1 kg of salt to 6 litres of water <u>not be used</u> for the constant rate method as the strength of such an injection solution is likely too high for typical constant injection rates and will cause very large exceedances over background. Guidance on dosing for the constant rate method can be found in Moore (2004c).

2) <u>Exceedance over Background, Shape of Breakthrough Curve</u>

For all slug injection methods, recommendations on the magnitude, duration, and shape of the breakthrough curve are not available at this time. Salt dose for any system must stay below environmental thresholds throughout the mixing reach for B.C. Water Quality Guidelines for the most sensitive designated use. Dose strength required is dependent on signal to noise ratio that in turn is a function of both EC sensor resolution and EC_{BG} stability. In the interim, a recommendation is to target 25 – 40 µS/cm over background (Figure 4-19). This recommendation does not imply that lower exceedances will not meet the BP grade; rather, it is a general field procedure that, as far as possible, will provide adequate signal strength against background conductivity while attempting to minimize potential exceedances of B.C. Water Quality Guidelines over a wide range of conditions.

Plateau exceedance over background (i.e., when EC_T remains at a constant elevated value) for the constant rate method is a function of injection solution strength and injection rate and, in general, is lower than for slug injection-based methods. See Moore (2014c) for more details.

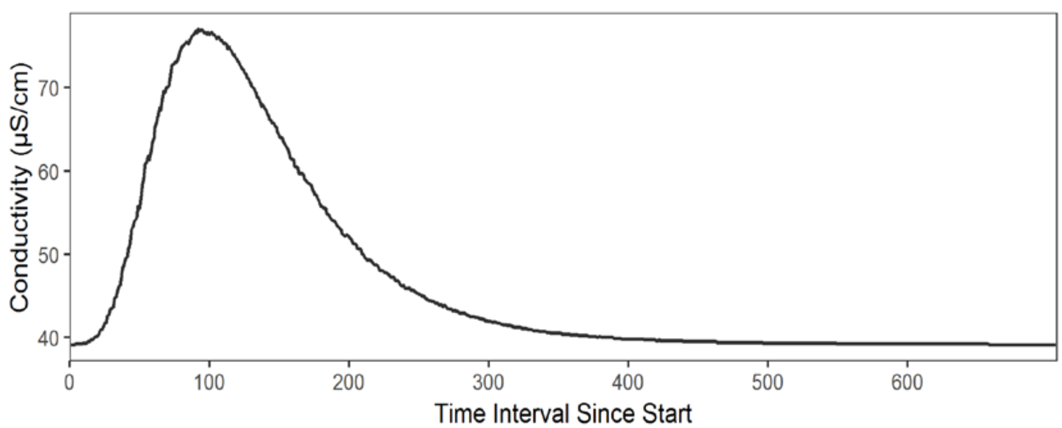


Figure 4-19: Typical breakthrough curve, with 38 µS/cm exceedance over background. EC_{BG} = 39.1 µS/cm.

3) <u>Derivation of *k* constant for Relative Concentration Methods</u>

Relative concentration methods (bulk solution injection and constant rate) must have *k* constants derived using samples of stream water collected at the time of measurement and using a sample from the same injection stock (batch) for derivation of a secondary solution (for more information, see Moore 2004c, 2005). For automatic tracer injection methods, or repeated manual measurements, where multiple values of *k* have been pre-derived under varying background stream conductivities, it may be possible to use a "pre-rated, site specific *k*" constant provided that practitioners can demonstrate consistency in injection solution between batches (at minimum, start and end) or across the range of background values of *EC* for which the *k* constant is applied (assuming that consistent injection solution strength can be maintained between brine batches). In all cases, a calculated *k* constant is required if a new injection solution (batch) is mixed, topped up or suspected of being altered (e.g., evaporation) to confirm consistency and validation in the pre-rated, site specific *k* constant. Furthermore, best practices to quantify any variability and/or to confirm that a single *k* constant derivation is not in error can be achieved through performing multiple *k*-constant calibrations per visit (i.e., 2–3). A review of the effects of equipment on the calibration procedure can be found in Richardson et al. (2017a) and Moore (2004a).

In all cases, individual *k* constants must be calculated for each sensor used in a measurement.

4) <u>Derivation of CF_T constant for Mass Balance Method - Calibration in-situ vs. Laboratory-derived</u>

For mass balance methods, the user may derive CF_T calibration coefficients either by: i) deriving in situ CF_T at time of measurement (preferred); ii) using a site-specific, sensor-specific CF_T derived over multiple measurements; or iii) using the published lab derived constant (Richardson et al. 2017a) (more below). Secondary solutions made with distilled water for CF_T derivation must use the "distilled water correction" procedures outlined in Richardson et al. (2017a) to correct for dilution effects.

For mass balance applications, site specific CF_T values are acceptable, provided that the sensors and laboratory standards meet the above requirements (i.e., sensors are calibrated properly) prior to deriving the site-specific value. It is recommended that a minimum of five in situ measurements over the range of background stream conductivities are used to establish the site specific CF_T.

Use of a laboratory-published CF_T (Richardson et al. 2017a) is valid only if temperature-compensated sensors have recently been calibrated using a non-expired laboratory conductivity standard and, at least once, have been demonstrated to produce a CF_T similar to the laboratory CF_T (verification can be laboratory based). Use of laboratory-derived CF_T constants (Richardson et al. 2017a) without recent sensor calibration will negate assignment of the BP data grade for salt dilution methods.

In all cases, individual CF_T constants must be calculated for each sensor.

5) <u>Determining Complete Mixing - Number of Measurement Conductivity Sensors per Tracer Run</u>

For all methods except constant rate, two downstream measurement locations (sensors) are recommended, spatially separated laterally (preferred), or separated by at least two channel widths (upstream/downstream) for each salt injection. It is noted that any dual sensor measurement configuration can be in error if the mixing reach is too short (i.e., insufficient mixing properties over the reach). Where sensors are installed on the same bank, measurement probes should also be placed at different distances from the wetted edge to avoid potential false positives of complete mixing (Figure 4-20). The difference in final measurements between sensors should not differ by more than 7%.

Figure 4-20: Example of a site with poor lateral mixing (as observed by the concentration of rhodamine WT dye in the centre of the channel with limited dispersal toward the banks) (photograph credit D. Hutchinson, Water Survey of Canada). EC sensors placed in the centre channel upstream/downstream in these situations may produce false indications of complete mixing.

If only one *EC* sensor is available, a minimum of two salt runs are required per derived discharge measurement, and the single sensor (or the point of injection) should be moved between runs to lengthen the mixing reach length to encourage more complete mixing. In these cases, water levels should remain constant among runs. Results should not vary by more than 7% between measurements when the probe is moved between salt runs. Alternatively, a single run may be acceptable if the measured value plots no more than 5% off of an established, stable rating curve.

For constant rate methods, a single sensor is acceptable provided that complete mixing is verified (i.e., plateau conductivity reached) by taking point measurements, side to side and upstream/downstream in the mixing reach. The stability in final tracer mixed concentration must be documented through three sets of consecutive verification measurements including measurements upstream of the injection site.

6) <u>Sampling Interval for Slug Injection Methods</u>

It is recommended that sampling intervals between consecutive EC_T/temperature measurements be not more than 5 seconds apart (1 second preferred), and for runs with very short-duration salt pulses (i.e., less than 3 min), be no longer than 1 second apart.

7) <u>Shifting Background EC_T - Control in the Field</u>

For all methods, EC_T must return to the pre-injection background conductivity (EC_{BG}) at the end of the breakthrough curve. In instances where the EC_{BG} is changing (via snowmelt, rain, or glacial melt, etc.), measurement of EC_{BG} upstream of the injection point is the preferred method to control for shifting background (point or continuous). Control of shifting background can also be compensated in the office (see below) using appropriate algorithms.

For the constant rate method, shifting background can be controlled for by measuring EC_{BG} upstream of the injection point as part of the required three sets of mixing verification measurements.

Data Calculations and Assessment

The assessment of data veracity and the calculation of final discharge value is the final place where uncertainty in salt dilution measurements can be minimized. The majority of the recommendations in this section encourage good meta-data practices and data processing procedures that are transparent and reproducible.

1) Shifting EC_T Background - Control in the Office

Application of appropriate algorithms to address changing background (no return to pre-injection level) is an acceptable alternative to use of measurements upstream of injection (above), provided that it can be shown that the maximum potential error only increases measurement uncertainty in the final discharge values by less than 5%. For example, suppose EC_{BG} exhibited an increasing trend prior to injection, and EC_T displayed a peak followed by a decrease and then a shift to an increasing trend. In such a case, one reasonable approach would be to assume that EC_{BG} exhibited an approximately linear increase through time, and an appropriate correction approach would be to fit a linear regression between the pre-injection trend and the post-peak rising portions, and then to subtract this estimated time-varying EC_{BG} from the observed EC_T values.

2) Data Spikes and Other Outliers

Breakthrough curves should be examined for the presence of data outliers, spikes, or other out of range measurements prior to calculating discharge values (Figure 4-21). Filtering and filling of such values should affect fewer than five instances per salt run.

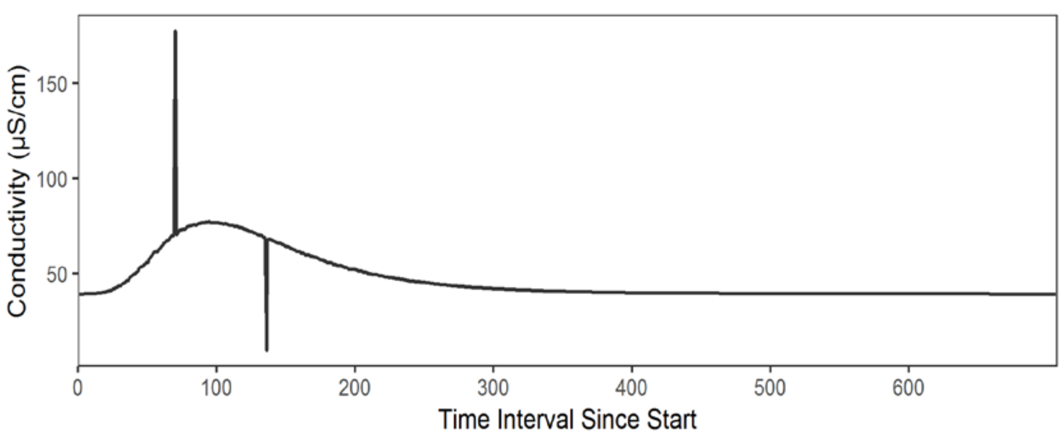


Figure 4-21: Breakthrough curve with outliers.

3) Shape of the Breakthrough Curve

At present there are no criteria for determining acceptable shapes (duration/magnitude) of breakthrough curves. As noted by Richardson et al. (2017b), “choppy” breakthrough curves typically indicate inadequate mixing, but “smooth” breakthrough curves do not necessarily guarantee complete mixing. In the interim, shape should be documented (imaged) through metadata for each measurement, overall length (number of observations), and maximum exceedance over background.

4) Data Calculations and Review

Table 4-7 summarizes the equations used to compute discharge from field measurements for the four variations of salt dilution gauging. Occasionally, a variable EC_{BG} (0.1 – 0.3 µS/cm) may result at a site, for a number of different reasons. Office procedures generally use rolling averages (e.g., 3, 7, 10, or more consecutive conductivity measurements) to determine the initiation and conclusion of the breakthrough curve. Metadata on the definition of appropriate averaging intervals (i.e., number of averaged observations) should be documented.

Table 4-7: Summary of the equations used to calculate stream discharge based on salt dilution field measurements (Table modified from Associated Environmental 2017)

Method	Equation for Discharge
Constant rate – relative concentration	$Q = \frac{q}{k(EC_{SS} - EC_{BG})}$
Constant rate – mass balance	$Q = \frac{q \cdot C_{is}}{CF_T(EC_{SS} - EC_{BG})}$
Slug injection – relative concentration	$Q = \frac{V}{k \cdot A_{BC}}$
Slug injection – mass balance	$Q = \frac{M}{CF_T \cdot A_{BC}}$

Q = stream discharge; q = salt solution injection rate; k = relative concentration method calibration coefficient; EC_{SS} = steady state, temperature compensated electrical conductivity; EC_{BG} = initial background state, temperature compensated electrical conductivity; CF_T = mass balance method calibration coefficient; C_{is} = concentration of injection solution (kg/m^3); V = volume of salt solution injected; M = mass of salt injected; A_{BC} is the area under the EC breakthrough curve, A_{BC} is computed as $A_{BC} = \Delta t \sum(EC_T - EC_{bg})$, where Δt is the sampling interval (s) for EC_T and the summation is conducted for all recorded values of $EC_T > EC_{BG}$.

Currently there are no requirements for reproducible workflows in salt dilution data analysis, although practitioners are strongly encouraged to develop and adopt such strategies for transparent and reproducible analyses and to facilitate future grading.

4.8.1 Metadata Collection and Data Submission for Salt Dilution Methods

A suggested list of metadata for salt dilution methods is presented in Appendix V. Practitioners are encouraged to work within their own data collection systems to ensure that all metadata requirements are completed and submitted to the provincial database. All original records and supporting data should be retained indefinitely by the station operating agency (or by the Hydrometric Reviewer). Final time series graded data and all metadata should be submitted to the provincial database; however, all other information should be available when requested.

It is noted that missing metadata may affect the ability to adjudicate future grading for salt dilution measurements.

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 time. 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 when flow is not highly unsteady, there are no bidirectional flows, there is no variable backwater or there are no changes in control; once that correlation established, allows one to record the water level, which is relatively easy to do on a continuous basis, and estimate discharge from this correlation.

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 cannot practically be obtained directly. It is however possible to obtain daily or continuous water level/stage data and from those 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.

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 (e.g., Aquarius software). If the flow is approximately steady and uniform, the stage-discharge ratings can be based on Manning's simplified hydraulic equation. Therefore, proper site selection for discharge measurements is integral to allowing the use of this simplified hydraulic equation.

Manning's simplified hydraulic equation can be expressed as:

$$Q = C(H - h_o)^b$$

Where:

Q is discharge in m^3/s (dependent variable).

C is a constant (calibration parameter influenced by width, slope, bed roughness, and other channel characteristics).

H is the gauge height in metres relative to the station datum (independent variable).

h_o is the gauge height for zero flow in metres, also called the *offset*.

b is an exponent (the calibration parameter varies with cross-section shape or *control* geometry, see Table 5-1).

The equation can be expressed as a linear equation if the logarithm is applied to both sides (i.e., plots as a straight line on logarithmic scales):

$$Log\ (Q) = Log(C) + bLog(H - h_o)$$

Where, *b* is the slope and *Log (C)* is the intercept.

Table 5-1: Rating exponent, *b*, values to expect for a different channel shape.
(Adapted from: Environment and Climate Change Canada 2016)

Shape	General Range for exponent b
Triangular	2.5 – 3.0
Parabolic	1.7 – 2.3
Rectangular	1.3 – 1.8

A simple rating curve may have several segments generally defining low, medium, and high (overbank) flows governed by the *control* and connected by short *transitions* (Figure 5-1). Usually low flows are governed by *section controls* (features such as a bedrock sill, a channel constriction, a sand bar, or an accumulation of debris), higher flows are governed by *channel controls* (channel reach features such as channel geometry, slope, curvature, bed roughness, etc.), and mid-range flows are governed by the combinations of controls. For detail on curve development and its maintenance, please see Environment and Climate Change Canada (2016). Sauer (2002) also provides detailed description of the rating curve development using the electronic method.

[**Note**: For equation rating curve, ideally 6 calibration measurements are required for single segment rating, 14 measurements for 2 segments rating (2 segments x 6 + 1 transition x 2) and 22 measurements for 3 segments rating. *"Measurements should be evenly spread over the entire range of the rating, ensuring that each segment and transition is defined by sufficient and significant information"* (Environment and Climate Change Canada 2016, p.15.)]

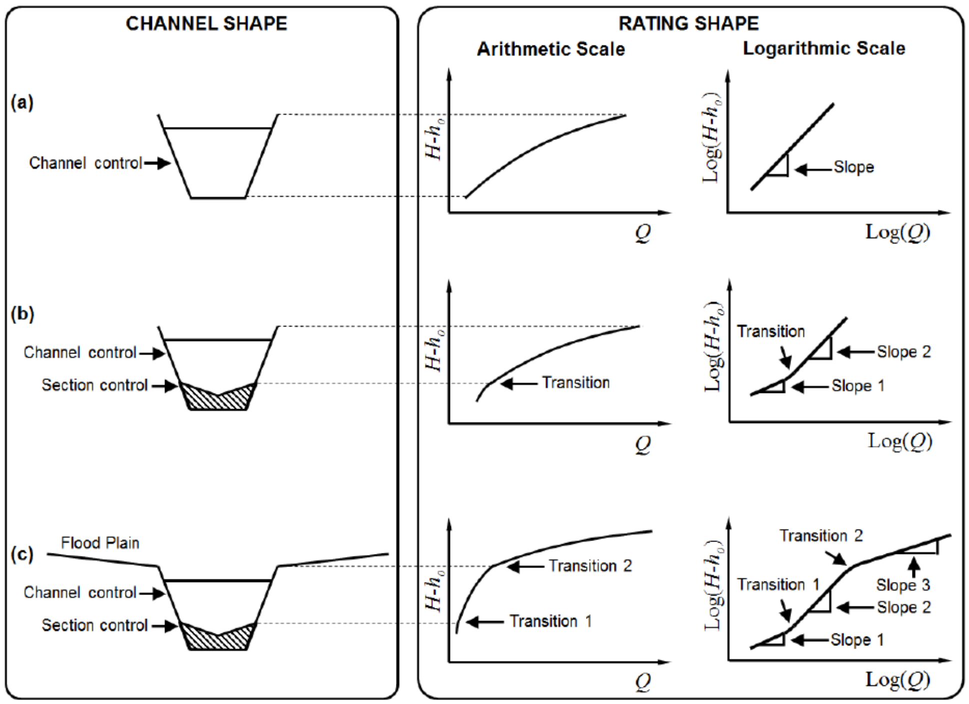


Figure 5-1: Relation between control properties and rating shape. (Adapted from: WMO No.1044, Vol 2, WMO, 2010b)

Limitations and Requirements for Rating Equations

For equation ratings, only Manning's simplified hydraulic equation should be used; other types of equations are not recommended for stage-discharge rating curves. When submitting rating equations, upper and lower equation limits in terms of independent variable (i.e., gauge height) must be submitted along with the equation. Other requirements are curve number, creation date, curve validity period (from-to), highest and lowest measured discharge and corresponding gauge height, gauge height for zero flow, and approximate bank elevation (either bank overtopped).

> [**Note:** According to RISC hydrometric standards, the 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).]

When multiple equations are used to define a rating curve, the lower limit for the lower equation and the upper limit for the upper equation must be specified. For defining a rating curve, a maximum of three equations is recommended; however, for very complex controls more equations can be used. Breakpoints between two consecutive equations for defining the exact point of the ending of one equation and the beginning of the next equation must be submitted in terms of gauge height. Consecutive equations must intersect at the given breakpoint.

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 Stage or Gauge Height (independent variable) in metres, then determine the best fit curve or curves. The detailed procedure for manual curve plotting, determining zero flow gauge height, preparing a stage-discharge table (also known as point pairs) from the curve, and, the shift and backwater corrections are described in the previous version of this manual, RISC (2009) and in “Manual of Hydrometric Data Computation and Publication Procedures, Fifth Edition, Inland Waters Directorate, Water Resources Branch, Environment Canada, 1980.

Data Submission Requirements for Manual Rating Curve

For a manual rating curve, a stage-discharge table (also known as point pairs) with a minimum of twenty (20) point pairs covering the full range of flows must be submitted to the provincial database. Point pairs always should be entered in ascending order of the gauge height (or stage), starting with the lowest point on the rating curve. Other requirements are curve number, number of point pairs used to generate the curve, creation date, curve validity period (from-to), highest and lowest measured discharge and corresponding gauge height, gauge height for zero flow, and approximate bank elevation (either bank overtopped). The “Stage-Discharge Rating Table” form (see Figure II-6 in in Appendix II) can be used for data submission.

5.2.2 Daily Discharges

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.

For daily mean discharge, all stage data recorded during the day must be compiled first. Then discharge should be computed for all stage data using the stage-discharge rating curve. The average of these discharges should be used as the daily discharge.

5.3 Summary of Discharge Measurements

Discharge data from all types of measurements must be summarized in chronological order to provide a history of information. 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 (see Figure II-5 in Appendix II) 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. Enter the name of the person and/or the organization who made the measurement, as appropriate
- enter the method code for the discharge measurement method used (see Appendix IV: Discharge Measurement Method Codes), meter information (i.e., calibration and field verification), number of verticals used, width, total area, mean velocity, and total discharge using three significant figures in the appropriate column of the “Summary of Discharge Measurements” form. If ice is present in the stream, or if the discharge is estimated, indicate in the “Remarks” column
- extract the weighted mean gauge height corresponding to the measured discharge from reference gauge reading and data logger (e.g., from “Water Stage Log” when used). Apply the appropriate gauge correction and enter the result in the “Mean Corrected Gauge Height” column of the “Summary of Discharge Measurements” form. 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 three decimals (e.g., 1.342 m)

- if any other information pertinent to the discharge measurement is obtained, note this in the “Remarks” column.

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, and individuals. To ensure that the data generated by each station meet provincial quality standards, the information must be reviewed for accuracy and approved by individuals who are qualified to assess the information. This step is crucial for data that will be stored on the provincial database.

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 and Responsibility of a Qualified Hydrometric Data Reviewer

The Qualified Hydrometric Data Reviewer (the "Reviewer") is identified as the individual responsible for reviewing the dataset and the assignment of a data grade for the dataset. The Reviewer should be involved throughout all steps of a hydrometric program. The Reviewer may initiate their activities after the end of the calendar year, or a portion thereof, when data compilations and checks are completed. A Reviewer must have access to data collection details, be able to identify non-standard information, be qualified to recognize underlying causative factors where applicable, and ensure that calculations are correct. The Reviewer is responsible for assessing metadata/forms, plots, notes, and relevant documentation. When all is in order, the subject dataset will be signed (and sealed if appropriate) by a Qualified Hydrometric Data Reviewer. A Qualified Hydrometric Data Reviewer can be a Professional Engineer (P. Eng.), Professional Geoscientist (P. Geo.), Registered Professional Forester (RPF), Professional Agrologist (P. Ag.), Registered Professional Biologist (R.P. Bio.), Applied Science Technologist (AScT), or Certified Technician (CTech). In addition to one of the aforementioned professional designations, the Reviewer must have appropriate qualifications as described in Section 6.3.2. Standard grades are assigned in accordance with the standards requirement criteria listed in Table 1-1.

The Reviewer should first review the "Station Analysis" form (see Figure II-7 in Appendix II) for the designated period and **must sign** (and seal if appropriate) it for compliance with 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), the Reviewer must ensure that the appropriate conditions for using a rating structure and its rating equations were met.

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

- Hydrometric Station History
- Level Notes
- Gauge Corrections
- Water Stage Log

- Discharge Measurements
- Summary of Discharge Measurements plus any other pertinent information
- Stage-Discharge Rating Curve(s) and/or Rating Equation(s), and Rating Tables (when applicable)
- Daily Gauge Heights (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:

- problems arising from the documentation review
- site conditions, watershed hydrology, land use, and water use
- knowledge of the regional stream flow regime
- number of years the station has been operating
- confidence in the experience of the data collector
- extent of missing data due to observer negligence or instrument malfunctioning
- completeness and clarity of the documentation.

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

Level Notes: for correct procedure, reliability of benchmarks and stability of gauges, and adequate frequency of level checks.

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

Water Level Plots: for time corrections, evidence of siltation, or plugged intakes

Stage-Discharge Rating 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 Rating Table (when applicable): for change dates, number of co-ordinates from curve, smooth rate of change, reasonable extrapolations (high and low flows), low flow rating, and 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).

When the data have been checked and verified, the Reviewer must assign a standard grade for the data. Assigning of a standard grade to the dataset may appear to be a simple matter, but in reality, a great deal of judgement may be required. By signing the Station Analysis form, the Reviewer **must** accept the responsibilities for their evaluation and gradation of dataset.

The flowchart provided in Figure 6-1 outlines the steps involved in data grading discharge measurements. The flowchart provided in Figure 6-2 outlines the steps involved in data grading for water level measurements.

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

- Raw and corrected time series stage and discharge data (15-minute intervals, 00:00 – 23:45 and daily mean with a timestamp of 23:59) with data grade.
- Completed Hydrometric Station History; Level Notes; Water Stage Log; Discharge measurements field notes and files (or Discharge Measurements Field Form); Summary of Discharge Measurements form; rating curve(s) with rating equations and their limits (or Stage-Discharge Rating Table); and signed Station Analysis form.
- A copy of any final or annual station reports including all field notes and analyses in PDF format.

Where data are later revised for any reason (e.g., revision to rating curve), the Reviewer must submit revised time series datasets or other revised data or metadata, as described above. The Reviewer (or Station Operating Agency) should retain all pertinent data and deliverables permanently for future audits (if required).

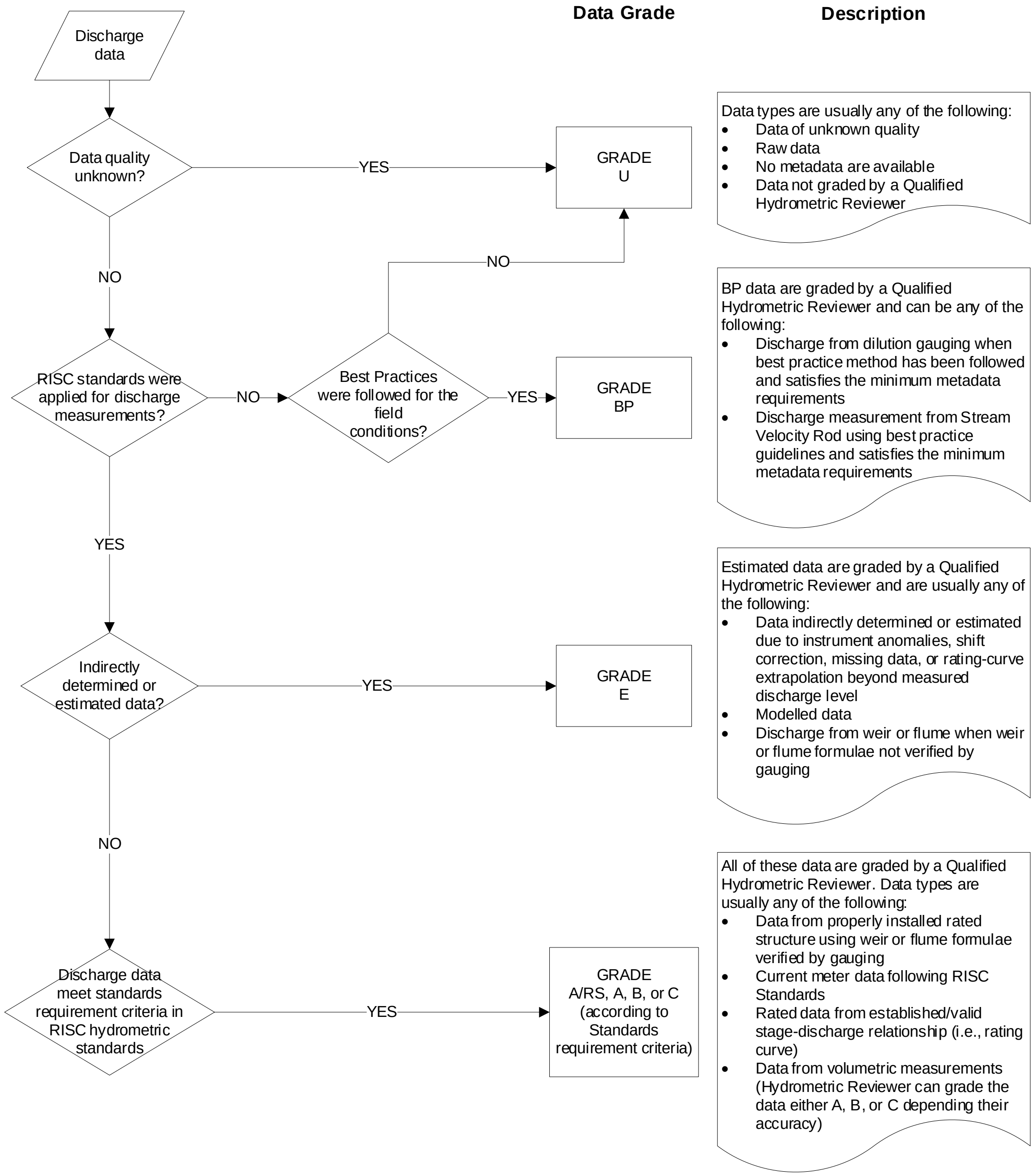


Figure 6-1: Data grading flowchart – discharge measurements.

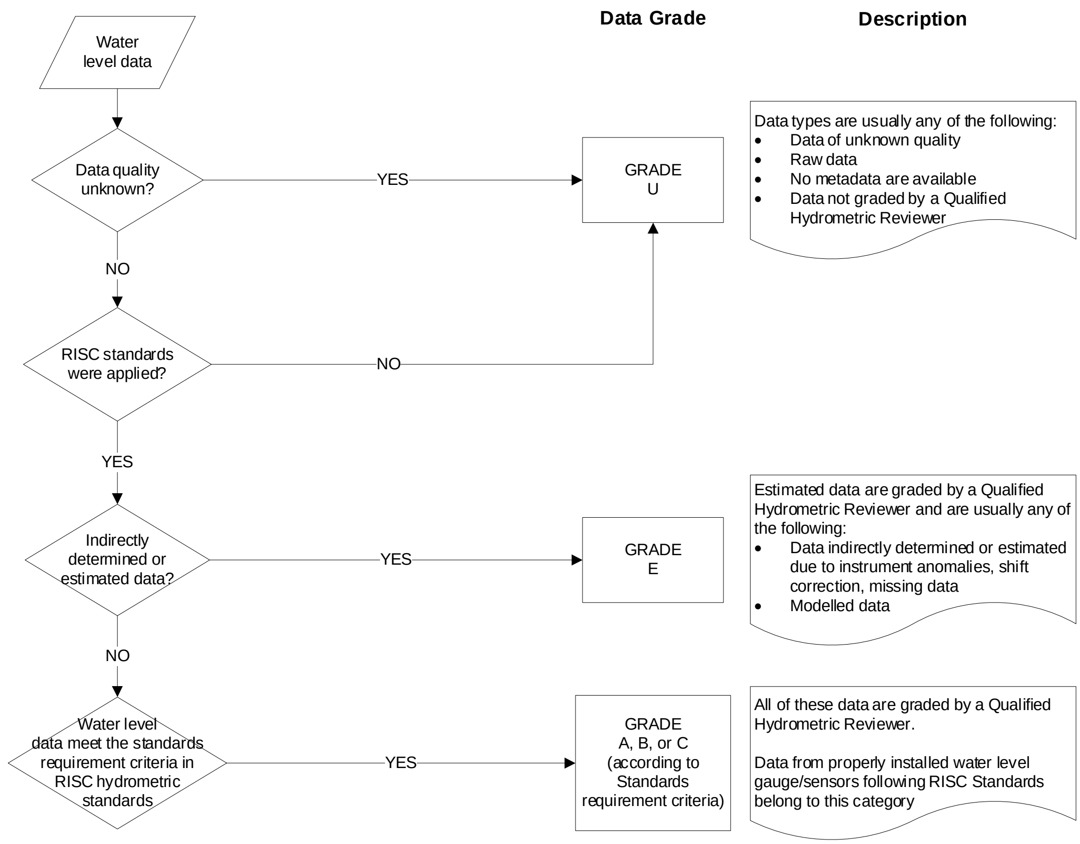


Figure 6-2: Data grading flowchart – water level measurements.

6.3 Qualified Hydrometric Data Reviewer

The review of hydrometric datasets requires a thorough knowledge of the mechanics of flow measurement and data collection. The role of the Qualified Hydrometric Data Reviewer includes several responsibilities including:

- to ensure that the field procedures used to obtain the discharge and water level data comply with the standard procedure described in this manual
- to ensure that the required documentation is complete; to ensure that the computation procedures are correct and appropriate
- to assign a standard grade
- to validate the data 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 and with minimal prior checking and review, the Reviewer must be prepared to carry out a detailed review. 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 curve 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. Reviewers must therefore be a member of a legally incorporated professional/ technological association, and have appropriate experience, training, and academic background as 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 grades according to RISC hydrometric standards.

6.3.1 Rationale for Reviewer's Qualifications

The role of the Reviewer requires an 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 judgement 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 a Hydrometric Data Reviewer.

6.3.2 Qualifications of Hydrometric Data Reviewer

Suitable candidates for "Hydrometric Data Reviewers" meet the criteria in either of two categories of minimum requirements. Category (I) Reviewers are qualified on the basis of substantial practical training and experience in all aspects of hydrometric operations. Category (II) Reviewers are qualified on the basis of post-secondary education combined with additional practical experience.

Specific criteria for the two categories are:

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 in British Columbia (e.g., Engineers and Geoscientists British Columbia, Association of BC Forest Professionals, British Columbia Institute of Agrologists, College of Applied Biology, or Applied Science Technologists and Technicians of BC),
- 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 in British Columbia (e.g., Engineers and Geoscientists British Columbia, Association of BC Forest Professionals, British Columbia Institute of Agrologists, College of Applied Biology, or Applied Science Technologists and Technicians of BC),
- has successfully completed courses at a 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 applications

    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.

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
- all methodologies and principles in the *Manual of British Columbia Hydrometric Standards.*

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 that just fills the channel without flowing onto 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: The process of comparing the response of a measuring device with a calibrator or a measuring standard over a range.

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 cannot 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 three criteria: instrumentation; 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.

Discharge rating (or **Stage-discharge relation)**: A curve (or rating equation/s) that expresses the relation between the stage and the discharge in an open channel at a given stream cross-section.

Drowned flow; Submerged flow: The flow that 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/

Field verification (Validation): Field verification is defined as act of confirming the equipment accuracy and specifications using a traceable standard or master.

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 floodplain. 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 that 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 benchmarks, 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 super-critical 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 bank: The bank to the left 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 information about data. In other words, it is a structured summary of information that describes the data.

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, or "artificial" channel.

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 have 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.”

Resolution: The smallest increments that are measured by a particular instrument.

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

Right bank: The bank to the right of an observer looking downstream.

RISC hydrometric standards: The field procedures, calculations, validation steps and documentation mandated by the 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 that alters the stage-discharge relationship. This change can be either temporary or permanent.

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 channel: A channel in which the bed and the sides remain stable over a substantial period of time and in which scour and deposition during the rising and falling stages are negligible.

Staff gauge: A manual gauge consisting of a graduated plate or rod that is set vertically in the 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: see **Discharge rating**.

Steady flow: Condition in which the discharge does not change 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, 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.

Unstable] channel: A channel in which the bed and the sides remain unstable over a substantial period of time and in which scour and deposition during the rising and falling stages are appreciable.

Validation (or **Field Verification):** The action of checking or proving the accuracy of specifications (i.e., a check to determine if the device or procedure confirms to specifications).

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. Hydrometric Forms

Hydrometric Station History

Station Identification Number: ______________________________

Station Name: ______________________________

Gazetted Stream Name: ______________________________

Station Location (in Decimal Degree with 5 decimal points):

Latitude/Northing: ____________ (e.g., 49.72963), Longitude/Easting: ______________ (e.g., -124.92941)

Geo Reference Source: ______________________________

Drainage Area (if known): ______________ km² Site Elevation (if known): ______________m

EMS ID. (if available): __________________NESDIS ID (if available): ____________________

Description of Location: ______________________________

____

Location Type: ☐Lake ☐ River ☐ Stream ☐Other: ______________________________

Station Type: ☐Water Level only ☐Flow only ☐Both ☐Other: ______________________________

Stream Flow: ☐Regulated ☐ Natural ☐Other: ______________________________

Upstream Allocation: ☐Yes ☐No ☐Other: ______________________________

Other Parameters Collected: ☐Water Temp ☐Air Temp ☐Barometric Pressure ☐Other: __________

____

Station Description and Purpose: ______________________________

____

Station Operating Agency/Firm and Contact Details: ______________________________

____

Section 1: Station Maintenance

Action (Station Established, Relocated, Modified, Closed)	Date (YYYYMMDD)	Remarks	Updated by	
			Initial	Date (YYYYMMDD)

Section 2: Records Collected

Primary, Backup, Telemetry Logger /Sensor Type	Date Started (YYYYMMDD)	Date Ended (YYYYMMDD)	Remarks

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Section 3: Benchmarks

Benchmark (BM) No.	Date Established (YYYYMMDD)	Reduced Level (R.L.) [Elevation above station datum] (m)	Datum [Local datum always set at zero meter] (m)	GSC Datum Elevation [if any] (m)	Description

Modification of Benchmarks

Benchmark (BM) No.	Date Modified (YYYYMMDD)	From (R.L.) (m)	To (R.L.) (m)	Reasons and Remarks	Updated by	
					Initial	Date (YYYYMMDD)

Section 4: Staff Gauge or Reference Gauge

Type	Date Installed (YYYYMMDD)	Location Description	R.L. Zero [Zero flow at gauge height] (m)	Gauge Reading Accuracy (mm)	Updated by	
					Initial	Date (YYYYMMDD)

Section 5: Recording Gauge

Type and Make	Date Installed (YYYYMMDD)	Date Removed (YYYYMMDD)	R.L. Zero [Zero flow at gauge height] (m)	Accuracy and Range	Remarks	Updated by	
						Initial	Date (YYYYMMDD)

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Section 6: Rated Structure

Type and Description	Date Installed (YYYYMMDD)	Date Removed (YYYYMMDD)	R.L. of invert (m)	R.L of sensor head (if any) (m)	Updated by	
					Initial	Date (YYYYMMDD)

Levels:

RL invert lower inlet pipe.. (m) RL invert top inlet pipe.................................... (m)

RL invert stilling well.. (m) RL invert underside recorder floor....................... (m)

Transducer:

Standard RL of sensor head........................... .... (m) Standard offset... (m)

Section 7: Level Checks

Date (YYYYMMDD)	Item Checked (BM, Staff Gauge or Reference Gauge)	Remarks and Results	Survey Team (Initials)

Section 8: Controls and Channel Description

Description of Control: ____

____

____

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

____

____

____

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Section 9: Site Plan/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. Digital photographs views upstream, downstream, across and showing gauging reaches including site control can be used. Photos must be date stamped and properly indexed and achieved)

Site Plan 1 (original): Drawn by: …………………………………………….. Date (YYYYMMDD): ……………………………..

Site Plan 2 Drawn by: …………………………………………….. Date (YYYYMMDD): ……………………………..
(Use when major changes from original installation, benchmarks, reaches, etc.)

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Figure II-1. Hydrometric Station History.

Level Notes

Station Identification Number: ____________________________

Station Name: ____________________________

Gazetted Stream Name: ____________________________

Station Operation Agency/Firm and Contact Details: ____________________________

____

Date (YYYYMMDD): ____________________________Time, PST (24hh: mm): ____________________

Gauge Height/Stage (m): ____________________________

Station	Backsight (m)	Height of Instrument (m)	Foresight (m)	Elevation (m)	Notes
Survey tolerance (m) =					**Gauge correction (m) =**

Elevation Means:

BM # (e.g., 1, 2, 3 etc.)	Established Elevation (m)	Mean Elevation [this date] (m)	Difference (m)

Comments on elevation change and date of change (if known): ____________________________

____

____

Additional Notes: ____________________________

____

Surveyed by: ____________________________

Reviewed by: ____________________________ Date (YYYYMMDD): ____________________

Figure II-2. Level Notes.

Water Stage Log

Station Identification Number. ______________________ Station Name: ______________________

Gazetted Stream Name: ______________________

Station Operation Agency/Firm and Contact Details: ______________________

____

Date (YYYYMMDD)	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	Data Logger	Ref. Gauge	Inside Gauge (If any)	Data Logger	Watch	Data Logger	Ref. Gauge	Inside Gauge (If any)	Data Logger		

Figure II-3. Water Stage Log.

Discharge Measurements Field Form

[This form can be used to prepare the Summary of Discharge Measurements form]

Station Identification Number: ____________________

Station Name: ____________________

Gazetted Stream Name: ____________________

Station Operation Agency/Firm and Contact Details: ____________________

____

Date (YYYYMMDD): ____________________

Metered by: ____________________

Air Temp (°C): __________ Water Temp (°C): __________

Weather (e.g., recent rain or current weather): ____________________

____

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

____

____

____

Location of Metering Section: ____________________

____

Water level gauge type (staff gauge only, automatic gauge, etc.) ______

____

Water level gauge reading/sensor accuracy:

- ☐ At least, 3 mm or 0.2% of effective stage
- ☐ At least, 5 mm or 0.2% of effective stage
- ☐ 1 cm or better
- ☐ Undefined

	Time (24hh:mm)	Ref. gauge reading (m)	Inside gauge reading (if any) (m)	Data logger reading (m)
Begin				
End				

Mean Standard Time, PST (24hh: mm): ____________________

Gauge correction (m): ____________________

Corrected gauge height/Stage (m): ____________________

Discharge measurement method code: __________ (From Appendix IV)

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 (YYYYMMDD): ______________ (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 method is used] (m^2): __________

Discharge, Q (m^3/sec): __________

Average Velocity, V [when area-velocity used] (m/sec): __________

Remarks: ____________________

____

____

____

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Figure II-4a. Discharge Measurements Field Form (front).

Discharge Measurements Field Form

(Discharge Computations for Mechanical Current Meters)

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)

Observation 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 are measured
6= Point six measurement. 0.6 depth is measured
B= Water edge, used at start of all measurements and after any "S" method
S= Temporary stop to execute portion of channel e.g., bridge pier
T= Terminates measurement session i.e., 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		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											

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Figure II-4b. Discharge Measurements Field Form (back).

Summary of Discharge Measurements

Station Identification Number. ____________________ Station Name: ____________________

Gazetted Stream Name: ____________________

Station Operation Agency/Firm and Contact Details: ____________________

____

Date (YYYYMMDD)	Time 24hh:mm PST	Measured by	Measur-ement Method Code (See Appendix IV)	Meter Calibration (use Code 1,2,or 3)[a]	Meter Field Verification (use Code 1,2,or 3)[b]	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 Curve/Table			Remarks
												Curve/Table No.			
												Disch. (m^3/sec)	Diff.	%	

Checked by: ____________________ Date (YYYYMMDD): ____________________

[a] 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

[b] Instrument Field Verification Code
- 1: At least annually
- 2: Less often than annually
- 3: Undefined

Figure II-5. Summary of Discharge Measurements.

Stage-Discharge Rating Table

Station Identification Number: ______________________________

Station Name: ______________________________

Gazetted Stream Name: ______________________________

Station Operation Agency/Firm and Contact Details: ______________________________

____

Stage Discharge (H/Q) Curve No.: ____________ Creation Date (YYYYMMDD): ____________

☐ H/Q Curve Not Revised ☐ H/Q Curve Revised, Date of Revision (YYYYMMDD):____________

Number of H/Q points used to generate the curve: ________

Curve Period (YYYYMMDD): 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 (YYYYMMDD):____________

Checked by: ______________________ Date (YYYYMMDD): ____________

Figure II-6. Stage-Discharge Rating Table.

Station Analysis for the Period:

From ____________________ (YYYYMMDD) To ____________________ (YYYYMMDD)

[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 Identification Number: ___________________________________

Station Name: ____

Gazetted Stream Name: ____

Station Operation Agency/Firm and Contact Details: ____

____

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

☐ Gauge Correction NOT Required

☐ Gauge Correction Required (see table below):

Date and Time (YYYYMMDD 24hh:mm PST)	Correction (m)

Discharge Record

Discharge (m^3/s)		Corresponding Gauge Height (m)	Date and Time (YYYYMMDD 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 of Discharge Record		Reason
From (YYYYMMDD)	To (YYYYMMDD)	

Stage Discharge Relationship

	Curve No.	Start Date (YYYYMMDD)	End Date (YYYYMMDD)	Cause for the Shift
Previous Year				
Present Year				

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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: ____________________________________

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

All metadata, field notes and calculations were reviewed for anomalies: ☐ Yes ☐ No

Results were compared with other stations and/or other years for consistency: ☐ Yes ☐ No

Reviewed time series water level and discharge data with associated metadata were submitted to the Provincial Database: ☐ 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 (YYYYMMDD)	Professional Seal/Signature	Designation	Professional/Technological Association

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Figure II-7. Station Analysis.

Appendix III. Discharge Tables for Rated Structures

Table III- 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)
III-2	V-notch	90^0	0.60	0.390	0.05	0.0008	Very poor	Very poor	≤1.2	≥0.45
III-3	Montana flume	3-inch	0.330	0.032	0.03	0.0008	Very good	Good	N/A	N/A
III-4		6-inch	0.450	0.111	0.03	0.0015	Very good	Good	N/A	N/A
III-5		9-inch	0.610	0.251	0.03	0.0025	Very good	Good	N/A	N/A
III-6		12-inch	0.760	0.457	0.03	0.0033	Very good	Good	N/A	N/A
III-7	H flume	2.0 feet	0.604	0.309	0.03	0.0005	Fair	Fair	N/A	N/A
III-8		2.5 feet	0.756	0.542	0.03	0.0008	Fair	Fair	N/A	N/A
III-9		3.0 feet	0.908	0.857	0.03	0.0010	Fair	Fair	N/A	N/A
III-10		4.5 feet	1.364	2.336	0.03	0.0014	Fair	Fair	N/A	N/A
III-11	HL flume	4.0 feet	1.218	3.292	0.05	0.0054	Good	Fair	N/A	N/A
III-12	Rectan-gular weir	b=1.0 m	0.500	0.585	0.06	0.0267	Poor	Poor	≤ 0.5	≥ 0.3
III-13		b=1.5 m	0.750	1.612	0.06	0.0402	Poor	Poor	≤ 0.5	≥ 0.3
III-14		b=2.0 m	1.000	3.308	0.06	0.0537	Poor	Poor	≤ 0.5	≥ 0.3
III-15		b=3.0 m	1.500	9.117	0.06	0.0807	Poor	Poor	≤ 0.5	≥ 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 III- 2. Rating curve for thin-plate 90º V-notch weirs (discharge in m³/sec)

Discharge (m³/s) for specified head (m) for fully contracted weir.

$$Q = C_e \frac{8}{15}(2g)^{0.5} \tan\frac{\theta}{2} h_1^{2.5} \text{ (m}^3\text{/sec),}$$

Where, C_e is coefficient = 0.58 for θ = 90º, h_1 is head in metre
Therefore, the simplified equation is:

$$Q = 1.37 h_1^{2.5} \text{ (m}^3\text{/sec)}$$

[**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 III - 3. 3" Montana flume under free-flow conditions (discharge in litres/sec)

Computed from the Formula $Q = 0.1771h_a^{1.55}$ m^3/sec where h_a is head in metre

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 III - 4. 6" Montana flume under free-flow conditions (discharge in litres/sec)

Computed from the Formula $Q = 0.3812h_a^{1.580}$ m^3/sec where h_a is head in metre

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 III - 5. 9" Montana flume under free-flow conditions (discharge in litres/sec)

Computed from the Formula $Q = 0.5354 h_a^{1.530}$ m^3/sec where h_a is head in metre

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

Head	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
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 III - 6. 12" Montana flume under free-flow conditions (discharge in litres/sec)

Computed from Formula Q = $0.6909h_a^{1.522}$ m^3/sec where h_a is head in metre

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

Head	0.0	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009
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
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 III - 7. 2.0' H-flume under free-flow conditions (discharge in litres/sec)

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

Head	0.0	0.002	0.004	0.006	0.008
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 III - 8. 2.5' H-flume under free-flow conditions (discharge in litres/sec)

Head in metre

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

Head	0.0	0.002	0.004	0.006	0.008
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
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 III - 9. 3.0' H-flume under free-flow conditions (discharge in litres/sec)

Head in metre

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

Head	0.0	0.002	0.004	0.006	0.008
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
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 III -10. 4.5' H-flume under free-flow conditions (discharge in litres/sec)

Head in metre

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

Head	0.0	0.002	0.004	0.006	0.008
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
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

Head	0.0	0.002	0.004	0.006	0.008
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
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 III - 11. 4.0' HL-flume under free-flow conditions (discharge in litres/sec)

Head in metre

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

Head	0.0	0.002	0.004	0.006	0.008
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
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

Head	0.0	0.002	0.004	0.006	0.008
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
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 III -12. 1-m rectangular weir with end contractions discharge table with head in metre (discharge in litres/sec) Formula: Discharge (in litres/sec) = 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 III -13. 1.5-m rectangular weir with end contractions discharge table with head in metre (discharge in litres/sec) Formula: 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 III -14. 2-m Rectangular weir with end contractions discharge table with head in metre (discharge in litres/sec) Formula: 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 III - 15. 3-m Rectangular weir with end contractions discharge table with head in metre (discharge in litres/sec) Formula: 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

Head	Discharge	Head	Discharge	Head	Discharge
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
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 IV. Discharge Measurement Method Codes

Instrument/method	Code
Price AA current meter	01
Pygmy meter	02
Other vertical-axis current meter	03
OTT or OSS horizontal-axis current meter	04
ADV (e.g., FlowTracker) current meter	05
Electromagnetic current meter	06
ADCP	07
Weir or flume	08
Rated discharge value (from rating curve)	09
Volumetric measurement	10
Indirect measurement (e.g., slope-area, modelling, estimation)	11
Velocity head rod	12
Dilution gauging methods	
• Conductivity (constant rate)	13
• Conductivity (slug injection)	14
• Other	15
Miscellaneous method (i.e., none of the above)	16

Appendix V. Metadata List for Salt Dilution Method

Instrumentation				
Sensor ID:	**Make:**	**Model:**	**Serial:**	**Metadata**
Temperature Compensation	Non-Linear (25ºC) Linear (25ºC)	☐ ☐		☐
EC Sensor Resolution	EC_T measurements <______μS/cm EC_T measurements >______μS/cm	Resolution: _______ μS/cm Resolution: _______ μS/cm		☐
EC Sensor Calibration	Standard: ____________ μS/cm Expiry Date: ____________	Calibration Date < 6 months Date: _____________		☐
Temperature Verification	Sensor Reading ________ ºC Manual Reading ________ ºC	Temp Verified < 6 months Date: _____________		☐

Tracer Data			
Maker:	**Brand:**	**Lot #:**	**Metadata**
Tracer Composition	Are salt tracers of food grade quality?		Y☐ / N☐
Tracer Weight	Scale recently calibrated (< 1 year)? Scale Calibration Date: ___________ Measured to __________ % or +/- _______ g		Y☐ / N☐ ☐
Tracer Volume (Relative Concentration)	Measured with _________________ rated to +/- ______________ ml		☐

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Field Procedures – Channel Reach Properties				
Stream:		**Stage (m):**	**Date:**	**Metadata**
Mixing Reach Properties	Pictures: ☐ ______________________________			☐
	Is there a lack of additional water inputs (streams, ditches, groundwater) within measurement reach? Describe: ___________________________________ ____			Y☐ / N☐
	Channel properties that facilitate lateral mixing and enhance turbulence at the stage measured are present? Describe: ___________________________________ ____			Y☐ / N☐
	Channel does not contain substantial storage, pool volumes, and re-circulating streamflow? Describe: ___________________________________ ____			Y☐ / N☐
	Channel does not contain any vegetation or other features that could affect the storage and release of the tracer? Describe: ___________________________________ ____			Y☐ / N☐
	Are there at least 2 constrictions or other mixing features to promote lateral mixing? Describe: ___________________________________ ____			Y☐ / N☐
Injection Point Properties	Pictures: ☐ ________________________________			☐
	Injection point is located above a feature (e.g., constriction) that promotes lateral mixing? Description:_________________________________ ____ ____			Y☐ / N☐
Measurement Point Properties and Sensor Placement - Slug Injection	Pictures: ☐ ______________________________			☐
	Were all measurement points (sensors) located in areas lacking back eddies, recirculating flow, and aeration?			Y☐ / N☐

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	_________ m from Point of Injection (estimate) (probe 1) _________ m from Point of Injection (estimate) (probe 2) _________ m from Point of Injection (estimate) (probe 3)	☐
	Was complete mixing confirmed and mixing length > 7 wetted channel widths?	Y☐ / N☐
	Average Reach Width ________m Wetted Channel Width Equivalent ________m Description:_______________________________________	☐
Measurement Point Properties and Sensor Placement - Constant Rate	Pictures: ☐ ______________________________________	☐
	Were all measurement points located in areas lacking back eddies, recirculating flow, and aeration?	Y☐ / N☐
	Describe all locations measured and approximate distances from injection point ________________________________ ____ ____	☐
	Were each of these points measured at least 3 times to confirm a stable exceedance level over background? If no, describe why _______________________________ ____	Y☐ / N☐
	Average Reach Width ________m Wetted Channel Width Equivalent ________m	☐

Field Procedures	**Run #**			
Stream:		**Stage:**	**Date:**	**Metadata**
Tracer Dose: General	No permissions or permits were required?			Y☐ / N☐
	No sensitive species were present?			Y☐ / N☐
	Was dosing designed to be below BC Water Quality guidelines for chloride for most sensitive designated use?			Y☐ / N☐
Tracer Dose: Mass Balance	Estimated Flow ______________ m^3/sec Estimated Flow(2) ______________ m^3/sec Dose Ratio _______________ kg/m^3/sec Mass Injected _______________ kg			☐

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Tracer Dose: Relative Concentration – Salt in Solution	Batch # ____________________ Estimated Flow ____________ m³/sec Estimated Flow(2) ____________ m³/sec Solution Concentration _____kgs /_____ L Dose Ratio ____________L/m³/sec Volume Injected: ____________L	☐
Tracer Dose: Relative Concentration – Constant Rate	Batch # ____________________ Estimated Flow ___________ m³/sec Estimated Flow2 ___________ m³/sec Dose ____________ L/m³/sec Solution Concentration _____kgs / _____ L Injected Rate: ________________ml/s	☐
Derivation of *k* Constant for Relative Concentration Methods	In Situ ____________________ ☐	☐
	Were separate *k* constants developed per EC sensor, per injection solution batch?	Y☐ / N☐
	Site Specific (automatic salt injection) _________ ☐	☐
	Were site-specific *k* constants developed per EC sensor, per site that were confirmed > 2 times (i.e., start and end of injection solution batch)?	Y☐ / N☐
Derivation of CF_T Constant for Mass Balance Method	In Situ ____________________ ☐	☐
	Were separate CF_T constants developed per EC sensor?	Y☐ / N☐
	Site Specific ________________ ☐	☐
	Were site-specific CF_T constants developed per EC sensor, per site that were confirmed > 5 times?	Y☐ / N☐
	Lab Derived:________________ ☐	☐
	Were all EC sensors recently calibrated (< 6 months) and demonstrated to produce a value that was close to the lab-derived CF_T?	Y☐ / N☐
Sampling Interval	Manual: every ______ secs Automatic Data Logging: __________ sec Point (constant rate only) ____ locations, ____ times Breakthrough Curve Duration ____________mins	☐
EC_T Measurements (outside of range)	Were all stream temperatures > 2ºC and electrical conductivities measured > 3 µS/cm?	Y☐ / N☐
Background EC_T Sensor (*optional if data correction method applied*)	Placed above injection point or measured above POI before and after salt run?	Y☐ / N☐

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Measurement Sensor(s) Placement	See *Channel Reach Properties* form	☐
Shifting Background/ Variable Background/Exceedance over Background	Water Level Start: ______ m Start EC_{BG} _____ µS/cm Water Level End: _______ m End EC_{BG} ______ µS/cm Level Change _______m/hr EC_{BG} Change ______ µS/cm Max. Exceedance over Background_______ µS/cm	☐
	Was the EC_{BG} steady? If no, list range: _______ µS/cm to _______ µS/cm	Y☐ / N☐

Data Calculations and Assessment				
Stream:		**Stage:**	**Date:**	**Metadata**
Data Spikes, Errors and Outliers	Were more than 5 measurements or 0.5% of the data set adjusted? If yes, describe____ ____			Y☐ / N☐
Shape of Break-through Curve	Image/ File Name: ________________________________			☐
Shifting Background	Were corrections for a shifting EC_{BG} applied? Method description: ________________________________ ____ ____			Y☐ / N☐
Variable Background: Breakthrough Curve Detection and Separation	Were methods applied to define the start and end of the breakthrough curve due to a variable EC_{BG}? Method description: ________________________________ ____ ____			Y☐ / N☐
Difference between EC Probes per Runs	Were two or more EC Probes used per tracer run? Probe 1 ____________ m³/sec, Probe 2____________ m³/sec Probe 3 ____________ m³/sec, Probe 4____________ m³/sec			Y☐ / N☐
	Is the % difference between sensors, per run > 7%?			Y☐ / N☐
Number of Salt Runs per Discharge Measurement	Were two or more runs used per derived discharge value? Run 1 ______________ m³/sec, Run 2 ______________ m³/sec Run 3 ______________ m³/sec, Run 4 ______________ m³/sec			Y☐ / N☐
	Is the % difference between the runs > 7%?			Y☐ / N☐

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Appendix VI. List of References

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