Land and Water British Columbia Inc.
A corporation of the government of British Columbia

Surrey Regional Office
Land and Water Management Division
Suite 200-10428 153rd Street
Surry BC V3R 1E1
Phone: (604) 586-4417
Fax: (604) 586-4434

DRAFT GUIDELINES FOR INSTREAM FLOW MEASUREMENT FOR WATERPOWER PROJECTS

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INTRODUCTION

Establishing an instream flow measurement program is an important preliminary step in the investigation of a potential waterpower project (WPP) site. The following guide presents the current provincial standard for hydrometric surveys, and provides a framework for the hydrological information a proponent will need to supply to LWBC in support of a flow measurement program.

As every potential WPP site has its own specific measurement challenges, the guidelines presented here are ***focused on deliverables*** rather than on prescriptive measures. To achieve these deliverables, recommended best practices are described. However, ***it is left to the discretion of hydrological consultants to customize the measurement program in order to achieve the desired results.***

The installation, maintenance and operation of a hydrometric station is expected to follow Resources Information Standards Committee (RISC) standards. The RISC standards provide a variety of options relating to instrumentation and station set up, in order to accommodate natural site-to-site variability. A brief overview of the RISC manual, standards criteria, and data certification process is provided. Alternative discharge measurement methods are also discussed.

Instream flow measurement programs specific to waterpower project proposals are relatively short term (1 to 2 years), with the specific purpose of establishing reliable baseline data with which to correlate to long term records[1]. This requires a relatively intense sampling regime, in order to better capture the distribution of flows. Established standards which relate to sampling frequency, such as those of the Water Survey of Canada (WSC), are typically intended for long term flow measurement programs. These standards have been adapted here in order to address the specific challenges encountered in a short term flow measurement program. Best practices guidelines and deliverables are provided.

[1] Guidelines and best practices on correlating on-site flow measurements to neighboring long term station data are currently under development.

RISC STANDARDS

The provincial standard for hydrometric surveying is provided by the Resources Information Standards Committee:

> Manual of Standard Operating Procedures for Hydrometric Surveys in BC; Prepared by Ministry of Environment, Lands and Parks, Resources Inventory Branch for the Aquatic Inventory Task Force Resources Inventory Committee, November 2, 1998. Version 1.1
>
> http://srmwww.gov.bc.ca/risc/pubs/aquatic/hydro/index.htm

The RISC manual prescribes the procedures for the measurement and recording of water level and discharge in an open channel. It describes all aspects of hydrometric surveys including stream reconnaissance, site selection, station design and construction, instrumentation, gauge height measurement, discharge calculation, stage-discharge rating and discharge compilation.

STANDARDS CRITERIA

Table 1 defines the various RISC standard levels and the anticipated tests needed to confirm any data set. ***For the purposes of waterpower project investigations, class A is recommended.***

Table 1. STANDARDS REQUIREMENT CRITERIA

Standard Class	Discharge Rating Accuracy	Number of Verticals	Number of Benchmarks	Water Level	Gauge Accuracy
Class A/RS	<5%	N/A	3	Recorder	2 mm
Class A	<7%	20+	3	Recorder	2 mm
Class B	<15%	20+	3	Recorder	5 mm
Class C	<30%	10+	1	Undefined	1 cm
Approximate Methods	>30%	N/A	N/A	Undefined	2 cm

As shown in Table 1, Class A requires 3 benchmarks, a 2 mm gauge accuracy, and the use of a digital recorder to measure water level. ***At a minimum, water levels should be recorded on an hourly basis.*** However, recording the water level every 15 minutes is preferable and will be more representative. WSC calculates mean annual discharge, MAD, as the average of mean daily discharge values, which in turn are averages of discharges collected hourly. It is recommended that all averages (be they daily, monthly or annual) be from the finest-scale data available.

SAMPLING METHODOLOGY

Rating curves are usually determined empirically by means of periodic measurements of discharge and stage. Established hydrometric stations only require periodic discharge measurements to either confirm the permanence of, or follow shifts in, the rating curve. For example, discharge is measured approximately seven times a year at established Water Survey of Canada stations. However, new stations require more intensive discharge measurements in order to define the stage-discharge relation throughout the entire range of stage. This is the key challenge for waterpower project investigations working within a one-to-two year timeframe.

A relatively intense sampling program, which addresses both frequency and coverage, is required in order to adequately define flow timing and quantity. Sampling frequency and coverage are closely interrelated concepts: Sampling frequency is defined here as the number of measurements recorded for a specified time period. Sampling coverage is defined here as the range of flows that have been measured, for instance some portion of bankfull width or MAD.

It is difficult to specify sampling coverage *a priori*, particularly with less than one year of data. Therefore in order to achieve reasonable coverage, sampling targets are specified primarily by effort:

▲For nival/nival glacial regimes (melt-dominated), discharge measurements should be made on a weekly basis during the period of spring freshet. After peak has occurred, the frequency of discharge measurements may drop to every two weeks. In low flow periods, monthly measurements are acceptable.

▲For synoptically-driven regimes (rain-dominated), it is generally more difficult to predict/measure high flow. Therefore the sampling frequency will have to increase to weekly measurements in late fall (October – November) in an attempt to capture the peaks associated with the autumn-winter rainy season.

▲For streams with transitional regimes, whose hydrological response falls somewhere between nival and synoptic regimes, weekly discharge measurements would be required during both the autumn-winter rainy season and the spring freshet.

Some variability in the sampling frequency is acceptable and expected. For example, a data point may be identified as an outlier and subsequently thrown out as a result of equipment malfunction. There may also be episodic difficulties in accessing the field site (e.g., road washouts). A lower sampling frequency may be sufficient in melt-dominated streams as it is easier to predict the high flow periods compared to synoptically driven regimes. While there will be some variability in the sampling frequency, ***a minimum of 10 discharge measurements, well distributed through the range of flows, is required.***

While discharge measurements should be well distributed through the range of flows***, a priority is placed on precisely defining stage-discharge relations for flows less than 200% MAD***. This should be attainable, as discharge measurements are typically easier to collect during lower flow conditions. While design flows vary from project-to-project, they typically fall within 100 to 200% MAD. Lower flows ultimately determine instream flow requirements and power plant capacity.

SITE SELECTION

There are many difficulties associated with collecting high quality hydrometric data. Selecting an appropriate site to establish the gauging station is of primary importance. ***A poorly chosen site will result in poor data.*** Section B.1.3 of the RISC standards describes the ideal characteristics associated with gauging station sites and current metering sections. ***The gauging station should be in reasonable proximity to the proposed intake site.***

MEASUREMENT OF DISCHARGE

The RISC standards address discharge measurements through cross-sectional current metering, or the use of weirs and flumes. Current metering is best suited to large, low-gradient rivers. Weirs are commonly used in small channels with relatively low flow volume. However, the streams targeted for waterpower projects are typically small and steep. Standard current metering does not perform well in small steep streams, particularly those with a boulder-cascade or step-pool morphology and relative roughness values >1. In streams of this nature, ***dilution methods are recommended***.

The basic idea of any dilution method is to add a measured quantity of a tracer to the flow and then observe its concentration at a point downstream where it is completely mixed with the flow. The tracer typically used is common table salt, as there is a linear relationship between salt concentration and electrical conductivity. The salt dilution method compares favorably in accuracy with current metering as a method of measuring streamflow, and appears to be capable of superior measurement precision where in-stream turbulence might interfere with current metering (Hudson and Fraser, 2002).

Dilution methods are easy to apply, economical, and have been well described by several authors (Church and Kellerhals, 1970; Day, 1976; Johnstone, 1988; Elder et al., 1990; and Okunishi et al., 1992). Salt dilution techniques have an upper limit related to the quantities of salt solution that can be effectively mixed and injected. Church and Kellerhals (1970) provide an example where a flow of ~18 m^3/s was measured using 40 L of injection solution. It is important to note that the salt dilution method should not be viewed as a replacement for current metering; the two methods are complementary. It is left to the discretion of the hydrological consultants to select appropriate discharge measurement techniques.

Both RISC and WSC standards do not currently provide guidelines for salt dilution measurements. However, the following methods and operational guides are available on the web:

USGS: Volume 1. Measurement of stage and discharge, Chapter 7 – Measurement of discharge by tracer dilution.
http://water.usgs.gov/pubs/wsp/wsp2175/html/WSP2175_vol1_pdf.html

Alternative methods of flow rating in small Coastal streams
http://www.for.gov.bc.ca/rco/research/hydropub.htm

ISO standards are also available for purchase over the web:

ISO 1100-1:1996. Measurement of liquid flow in open channels – Part 1: Establishment and operation of a gauging station.
http://www.iso.ch/iso/en/CatalogueDetailPage.CatalogueDetail?CSNUMBER=5611&ICS1=17&ICS2=120&ICS3=20

EXTENDING THE RATING CURVE

Shallow flow and low gradients often make it difficult to obtain discharge measurements at very low flows. While it is desirable to extend the low end of the stage-discharge curve to zero flow, the lack of accurate measurements makes it a problematic task. Section F.2.3 in the RISC manual outlines a graphical technique for determining the gauge height for zero flow.

There are many difficulties associated with the measurement of peak flows. In synoptically driven watersheds with flashy hydrological responses, it is often difficult to reach the field in time for the peak. For WPP flow measurement programs, the prime limiting factor will most likely be the short timeframe involved. In a one or two year period, it is doubtful that flows as large as bankfull discharge will be captured, and as a result the rating curve will need to be extended.

If there are a reasonable number of discharge measurements, rating curves may be extended by simply plotting the full range of measured discharges against stage on double logarithmic plotting paper. In most cases, the logarithmic plot of measurements will form a straight line in the high flow range, which can easily be extended (see the RISC manual, section F.2.4). The "curve" as determined in the log plot is then transferred to the standard stage discharge plot.

CONFIRMING THE CURVE EXTENSION

Discharges estimated by indirect methods should be used to confirm the high end of the curve extension developed by the log-log plot. The slope-area method is the most commonly used procedure, where discharge is computed on the basis of a uniform-flow equation involving channel characteristics, water-surface profiles, and a roughness coefficient. The slope-area method is commonly used to estimate flow directly after a large magnitude event. This involves the identification of high water marks (see Benson and Dalrymple, 1968).

During a one to two year study period, there is no guarantee that a large magnitude event will occur. In such a situation, the slope area method can also be used to estimate bankfull discharge. This involves the identification of bankfull width, rather than high water marks associated with a specific event. While this is an approximate method, it is most likely a worthwhile endeavour that will better characterize the stage-discharge relation.

Slope-Area Method

Channel reaches lying within the designated station limits should be reconnoitred to find suitable sites for measurements. A minimum of three cross sections are recommended. The fall of the reach should be equal to or greater than 0.15 m (Benson and Dalrymple, 1968). Selected sites should be surveyed and permanently marked:

▲ Evidence of bankfull width, or high water marks, must be clearly evident on both sides of the river.

▲ The reach of river between the cross sections must have similar roughness characteristics

▲ No major tributaries should enter between the measuring site and the point at which the discharge is desired.

▲ The measuring site should be close to the point at which the discharge is desired. It is sometimes preferable to accept less favourable conditions at a site nearer to the gauge.

▲ There should not be any bridges or other "disruptions" to the stream course between the cross sections.

▲ Estimation of bankfull stage should be carried out at or very near to the gauging station. Stage is estimated in order to plot the estimated discharge on the rating curve.

The selection of a suitable reach is probably the most important element of a slope-area measurement. Difficulties commonly associated with the slope-area method in mountain streams include: variable hydraulic characteristics over the reach, estimation of (average) roughness, and supercritical flow. Due to a number of factors, peak flow estimates derived from the slope-area method may not reconcile with the rating curve extension values. If no agreement is found when comparing values derived from graphical curve extension and slope-area computation flow, estimates must be determined based on the judgement of an experienced hydrological consultant.

DELIVERABLES

The following information should be submitted in support of a flow measurement program:

▲ A discussion of the physical setting of the project area, including a description of surficial materials, hypsometry, stream order based on TRIM maps, drainage area and glacial coverage.

▲ A description of the site (RIC-AQ1) plus photographs of the site at the high and low flow limits of the discharge and stage measurements.

▲ Chronological record of site visits (RIC AQU-06)

▲ Chronological summary of gauge levels checks indicating all applicable gauge corrections (RIC AQU-04)

▲A fully documented methodology for generation of rating curve and flow estimates.

▲ Rating curve(s):
- all data points plotted, with dates of measurement
- axes scaled to bankfull discharge, or the highest recorded discharge (whichever is greater)
- curve(s) identified with number and period of use

▲ A spreadsheet summary (RIC AQU-05)

▲ A chronological plot of percentage departures of the measured discharges from the rating curve values.

▲ A flow duration curve.

▲ Quantitative estimates of error and bias. A discussion on measurement errors/biases should also be provided.
- Measurement error can be quantified through the replication of measurements.
- Measurement replication should be repeated if different equipment is used at different levels of stage.
- Errors associated with the slope-area method are primarily related to site selection. A full discussion of site selection criteria for the slope-area method is presented in detail by Benson and Dalrymple (1967).

▲ List of equipment used for the project, including make, model and calibration dates of sensors, dataloggers, and meters.

▲ An appendix containing:
- raw data in graphical form
- copies of original gauging notes and level check notes

RECOMMENDED BEST PRACTICES

In order to meet the requirements specified in the deliverables section, the following recommended best practices should be applied:

▲ Site selection is paramount to ensuring quality data is collected. A good gauging station site includes the following characteristics:

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

▲ Discharge measurements should be carried out over a wide range of flows in order to construct/calibrate the rating curve. A minimum of 10 discharge measurements, ***well distributed over the range of flows***, is required.

▲ In small, steep, turbulent streams, dilution methods are recommended for measurement of discharge.

▲ Class 'A' RISC standards are recommended (3 benchmarks, 20+ verticals, digital recorder, and 2mm gauge accuracy). Level surveys should be completed a minimum of 2 times per year, in order to ensure the gauge has not moved.

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