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Water flow measuring methods in small hydropower for streams and rivers - A study

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Abstract

This study represents application of various methods to measure rate of water flow in small hydropower. In hydropower, flow rate data is crucial to be applied in predicting the power output magnitude of the power house. Flow rate is the quantity of water available in a stream or river and may vary widely over the course of a day, week, months and year. By collecting the ample data of flow rate analysis, it will provide in summarizing the Flow Duration Curve (FDC). This study aims to provide a general guidance with regards to economical design and practical realization of a water flow rate measurement that would contribute to the feasibility study of small hydropower.

Keywords: flow rate; flow duration curve; small hydropower

INTRODUCTION

Hydropower is one of the most important renewable energy source which has much available capacity to supply electrical power production throughout the world. It may provide 19% of the global electricity needs that would cover millions of people need for electricity consumption. Certain part of rural areas have only small amount of water storage and dam. The application of "run-of-river" is the most popular selection to be applied as an effective electrification which also operate environmentally friendly.[1] In a run-off-river type, the water is diverted from the main river by using a weir before the water sources entering several other parts. This process is used to trap sediment, debris or unwanted item from entering a penstock. Apart from constant and enough water intakes, the basic structure of run-off-river hydropower must also consist of the following parts: penstock, governor, turbine, mechanical power transmission system to generator, generator, electricity transmission system (transformer, synchronizer, on grid connected system) to load centers and control system.

All hydroelectric power generation depends on falling water and the velocity of water flow before it hit a turbine to generate a kinetic energy. The power of falling water can be measured from the flow rate, density of water, heights of falling water, and the local acceleration due to gravity.[2] Based on equation 1 below, by using Standard International unit, the power was being calculated by;

$$P = Q * H * \rho * g * \eta \qquad (1)$$

Where P is power generation (kW), Q is stream flow (m^3/s), H is the effective head (m), ρ is the density of water (kg/m^3), g is acceleration due to gravity (m/s^2) and η is a system efficiency factor [3]. By referring to (1), the gross available head can be determined at a site after the layout of the hydropower plant is proposed, but for the determination of design flow FDC[4], it requires long term data or history of stream flow at the selected site. This paper presents various methods used for measuring water flow and the determination of potential generation for a small hydropower of an ungauged river site.

METHODOLOGY

Due to the development of new technology, the measurement method for stream water flow is becoming much easier. The evolution of sensor technology helps to get better accuracy of flow measurement. Besides that, the measurement equipment can be installed at site for a long duration of time for data recording without any human supervision. This can be done by connecting the sensor to a data logger. In comparison to the traditional method, the new technology offers significant advantages. The measurement can be done without any disturbance of weather condition such as heavy raining and water flooding. Additionally only a small group of people is needed to perform measurements and sensor installation. The data logging can also be done for any period of time. The traditional measurement method can only be done manually by a group of people at the site. Some traditional of measuring methods is explained as follows:

The Bucket Method

A simple method of finding small flows is to use a bucket and a stopwatch.[5] Any container size can be used for this measurement and it depends on the size of flow water. The container must be waterproof and indicates the volume of water when it's fully loaded. If there is no scale indicated at the container, use a smaller container with known volume (one liter water bottle) and fill the amount of water. Count how many liters are required to fill the bucket with water using small container. Mark the level in the bucket when the maximum number of complete liters has been filled. Next step is to find a right location to measure the flow. This was applied to ensure that the place of directing a water flow into the bucket as little as possible escapes. By using a stopwatch, record the time of water to fill to the marked level. The measurement can be done repeatedly 3 times and average the results. If the bucket holds 20 litres and takes 10 seconds to fill, then the flow is 20/10 liter/sec or 2.0 liters per second.

The Float Method

This method needs two types of information, which is cross sectional area of the water flowing in the stream and the other info is the speed that water is flowing. [6]Normally this method applied a plastic bottle weighted with half of water and capped to makes an ideal float as shown in Figure 1. The floating bottle will be timing its travel between two points a known distance part. The first step to consider is the cross sectional area (csa) of the stream.

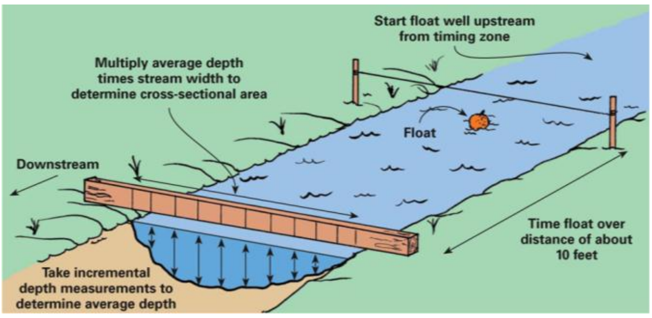


Figure 1: The float method

Select the part of the river which is relatively straight and has a uniform cross section. To specify also the distance of release point to the timing end for the traveling floater. The distance should be in meter. Measure the csa of the river by splitting it to several segments with at least 4 segments as in Figure 2. To calculate the csa is by using the (2).

$$A_n = l_n \times \frac{(d_{n-1} + d_n)}{2} \qquad (2)$$

Where *A* is the csa, *l* is distance or length of segment, *n* is a segment number or point number and *d* is depth of the point. The measurement position should be always in the downstream for not disturbing the water surface. To measure the depth of the stream, must be started from the bottom of the stream up to the surface. After completing all the required measurement, next is to calculate the area of each segment.

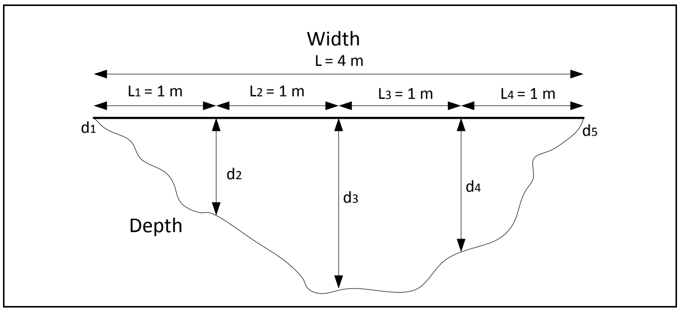


Figure 2: Divide the river into several segments to measure the csa

The example of depth measurement was listed as follows: d_1 = 0.2 m, d_2 = 0.24 m, d_3 = 0.45 m, d_4 = 0.33 m and d_5 = 0.2 m. By using (2) we can calculate the area of each segment:

- $A_1 = 1\text{m} \times (0.20\text{m} + 0.24\text{m})/2 = 0.22\text{m}^2$
- $A_2 = 1\text{m} \times (0.24\text{m} + 0.45\text{m})/2 = 0.35\text{m}^2$
- $A_1 = 1\text{m} \times (0.45\text{m} + 0.33\text{m})/2 = 0.39\text{m}^2$
- $A_1 = 1\text{m} \times (0.33\text{m} + 0.20\text{m})/2 = 0.27\text{m}^2$

$A = 0.22 + 0.35 + 0.39 + 0.27 = 1.23\text{m}^2$

After the csa (A) value has been determined, the floater (plastic bottle) can be drop a few meters before the starting line. Measured the time required by the floater to pass through the predetermined distance from the starting point up to measurement location. For this experiment we decided to take a 10 meter distance from start to the end point. Keep records accurately and to get a better results do repeatedly at least 10 times. From the experiment, the travel time (T) is obtained as in Table 1:

Table 1

No	Times	No	Times
T_1	15.56s	T_2	16.56s
T_3	18.97s	T_4	17.04s
T_5	16.30s	T_6	17.63s
T_7	18.32s	T_8	19.70s
T_9	16.33s	T_{10}	17.57s

Count the average travel time :

$$T = (T_1 + T_2 + T_3 + \ldots\ldots + T_{10}) / 10 \qquad (3)$$

From the average calculation in (3), Travel time T = 17.29 second. The velocity (v) value is determined by this formula (4):

$$V_f = \frac{Distance}{Time}\left(\frac{meter}{second}\right) \quad (4)$$

In the above experiment the flow velocity is :

V_f = 10 m / 17.29 s = 0.578 (m/s)

The average velocity can be calculated by using the formula (5):

$$V_a = V_f \times c \ (m/s) \quad (5)$$

Where V_f = flow velocity (run off / surface velocity) and c = correction factor. The correction factor is determined by using table 2.

Table 2

Type of stream	CSA (A) (m^2)	Velocity correction factor ©	Accuracy
A rectangular channel with smooth sides and concrete	-	0.85	Good
A wide and deep stream, calm, free flow	>10	0.75	Reasonable
A shallow stream, free flow	<10	0.65	Poor
A shallow stream (<0.5m), turbulence flow	-	0.45	Very poor
A very shallow (<0.2m), turbulence flow	-	0.25	Very poor

From the previous depth measurement was range between 20 cm to 45 cm, therefore the average velocity correction factor value for C=0.33:

V_a = 0.578 x 0.33 = 0.191 m/s

Finally, to determine a water flow by using (5):

$$Q = V_a \times A \ (m^3/s) \quad (5)$$

Q = 0.191 x 1.23 = 0.235 m^3/s

With dividing the value by 1000 to give a Q in litres per second if the formula is used.

The V-notch weir

A weir of V-notch design is usually the most appropriate for measuring of small flows up to 150 litres per second. A V-notch weir is simply a ‘v notch’ in a plate that is placed so that it obstructs an open channel flow, causing the water to flow over the v notch.[7-9] It is used to meter flow of water in the channel, by measuring the head of water over the v notch crest. The v notch weir is especially good for measuring a low flow rate, because the flow area decreases rapidly as the head over the v notch gets small. The v notch weir is one type of sharp crested weir and the diagram is shown as in Figure 3 and the v notch weir equations are write as (6) and (7).

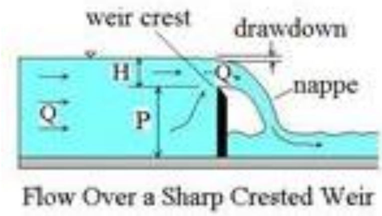


Figure 3: V-Notch Weir construction

The diagram above shows some parameters and terminology used with a sharp crested weir for open channel flow rate measurement. The **weir crest** is the top of the weir. For a v notch weir it is the point of the notch, which is the lowest point of the weir opening. The term **nappe** is used for the sheet of water flowing over the weir. The equations to meter flow in this article require **free flow**, which takes place when there is air under the nappe. The drawdown is the decrease in water level going over the weir due to the acceleration of the water. The head over the weir is shown as H in the diagram; the height of the weir crest is shown as P; and the open channel flow rate or discharge is shown as Q. The equation recommended by the Bureau of Reclamation in their *Water Measurement Manual,* for use with a fully contracted, 90°, v notch, sharp crested weir with free flow conditions and 0.2 ft $\leq H \leq$ 1.25 ft, is:

$$Q = 2.49H^{2.48} \quad (6)$$

where Q is discharge in cubic feet second and H is head over the weir in ft.

The conditions for the v notch weir to be fully contracted are:

$$P \geq 2H_{max},\ S \geq 2H_{max} \quad (7)$$

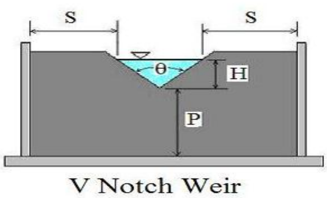


Figure 4: V-Notch Weir construction

The diagram in Figure 4 shows the parameters H, P, θ and S for a v notch weir as used for open channel flow rate measurement.

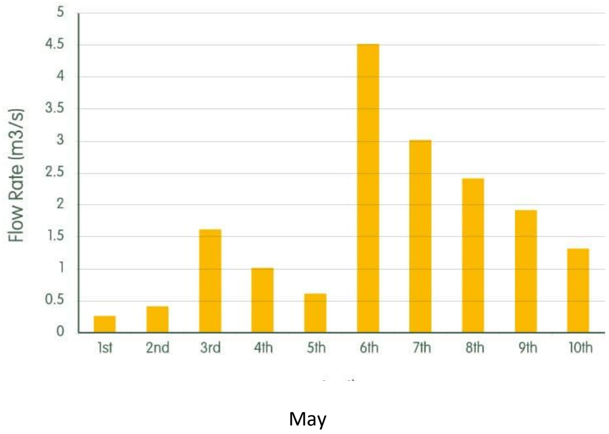
THE FLOW DURATION CURVE (FDC)

The Flow Duration Curve (FDC) is a convenient way of summarizing the hydrological frequency characteristics of river flow.[10] It provides information on the probability that a flow is equaled or exceeded and is derived by portioning the flow hydrograph, ranking the flows in descending order and sorting by the probability of a given flow being exceeded. [11]. FDC is usually constructed from time series of river flow data for a catchment that is thought to be representative of the underlying natural variability in river flows within that catchment. Flows are estimated by measuring, or gauging, water levels at a site by using the several technic that have been discussed previously in II. Any length of data can be used to derive a FDC. It also can be used to compare different seasons, and one year against another. Practically, in deriving flow duration statistics for hydropower design, it is recommended to collect a continuous data into mean daily flows, where the whole years are used (January-December). The easiest way to understand the FDC is to construct one from scratch. Let's assume a measured data of flow in a river for ten days. From each day of measurements, all data are recorded as in Table 2.

Table 2 : FDC Recorded for 10 days

Date	Flow Rate (Q)
May 1st	0.25 m^3/s
May 2nd	0.40 m^3/s
May 3rd	1.60 m^3/s
May 4th	1.00 m^3/s
May 5th	0.60 m^3/s
May 6th	4.50 m^3/s
May 7th	3.00 m^3/s
May 8th	2.40 m^3/s
May 9th	1.90 m^3/s
May 10th	1.30 m^3/s

Although useful, this doesn't really help much, and with any table of data it is often better represented as a graph. If the flow rates are plotted as a bar-chart, the result is called a hydrograph and shows how the flow rate varied over a period of time, as shown below.



Although the hydrograph makes it easier to see the extremes of high and low flows, it is still quite difficult to see what happened in-between. For this, it is necessary to plot a Flow Duration Curve.

To construct a Flow Duration Curve, rather than list the data in date order it is listed in order of the size of the flow rate, from highest to lowest. The data table would now look like this:

Table 3 : Sort of data Q (Max to Min)

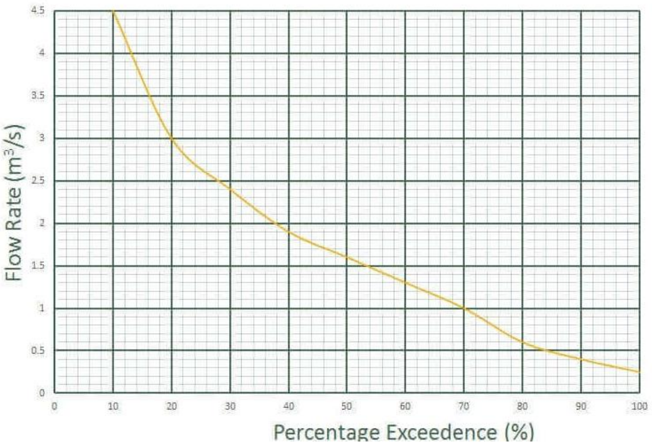
Date	Flow Rate (Q)
May 6th	4.50 m^3/s
May 7th	3.00 m^3/s
May 8th	2.40 m^3/s
May 9th	1.90 m^3/s
May 3rd	1.60 m^3/s
May 10th	1.30 m^3/s
May 4th	1.00 m^3/s
May 5th	0.60 m^3/s
May 2nd	0.40 m^3/s
May 1st	0.25 m^3/s

In our example there are ten flow rates, and the percentage exceedence scale will go from 0% to 100%, so each percentage exceedence increment will be 100% divided by the number of data points, so in this case 100% divided by 10 = 10 percentage exceedence points. This can be added to the table above to show at what percentage exceedence each flow rate occurred.

Table 4 : Data in Percentage Exceedence

Date	Percentage Exceedence
4.50 m^3/s	10%
3.00 m^3/s	20%
2.40 m^3/s	30%
1.90 m^3/s	40%
1.60 m^3/s	50%
1.30 m^3/s	60%
1.00 m^3/s	70%
0.60 m^3/s	80%
0.40 m^3/s	90%
0.25 m^3/s	100%

This data can then be plotted and a smoothed line drawn between each data point to produce the Flow Duration Curve shown below.



This is now a Flow Duration Curve. By referring to the flow value at '60% exceedence' it showed that it is at 1.3 m^3/s. This does not mean that the flow rate is 1.3 m^3/s for 60% of the time, but that the flow is equalled or exceeded for 60% of the time, so basically the flow is at this flow or at a higher flow for 60% of the time. In the situation when the flow at 20% exceedence it is show at 3 m^3/s; this is a higher flow rate, so the flow is only at or greater than this flow rate for a smaller proportion of the year. And finally if refer to 100% exceedence, it is read at 0.25 m^3/s, which is the lowest flow rate recorded, so by definition the flow in the river is at this flow rate or more for 100% of the time.

It is a strange concept but an important one to grasp. Flow rate is often referred to as 'Q', and the exceedence value as a subscript number, so Q95 means the flow rate equalled or exceeded for 95% of the time. Q_{mean} is often discussed, and this is the average or mean flow rate, and is the arithmetic mean of all of the flow points in the data set (in our example this is 1.695 m^3/s) and normally occurs between Q20 and Q40 on the FDC, depending on how 'flashy' or 'steady' the river being analysed is flow rates between Q0 and Q10 are considered high flow rates, and Q0 to Q1 would be extreme flood events. It is important that hydropower systems are designed to cope with such extreme flows. Flows from Q10 to Q70 would be the 'medium' range of flows and the developer would want their hydropower system to operate efficiently right across these flow rates. Flow rates from Q70 to Q100 are the 'low flows' when hydropower systems will just be operating but at a low power output, and as its move further to the right on the FDC hydro systems will begin to shut down due to low flow. As flow rates move from Q95 towards Q100 its move into the low-flow draught flows.

CONCLUSION

In defining the hydroelectric power generation depends on flow of intake water multiplied by the height of altitude of falling water as in Eq. (1). Various method of measurement the flow of water has been discussed accordingly to contribute a data for FDC. By plotting a sufficient data for FDC, the developer can ensure that there is sufficient water available to make the development of the hydroscheme economically viable. The accuracy of the FDC for defining key exceedences in terms of flow is important. The acceptable level of uncertainty for the developer is linked to the economic risk. For example, the right measurement of intake flow with an accuracy FDC findings was contribute to the upgrade additional power generated at one Mini Hydropower Scheme in peninsular Malaysia. In precedence the power provider manage to generate 4 MW, but after applying the right and accuracy of feasibility study, they manage to upgrade to 6 MW by using the same amount of water intake.

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