ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

Discharge measurement in turbulent streams of the middle mountains in Nepal

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Abstract

In mountainous areas such as the mountain ranges of the Hindu Kush – Himalayan region, the measurement of discharge is very difficult. This is due to high variability of the flow and turbulent stream conditions mainly during monsoon season. For the planning and design of water resources projects, however, reliable information on water quality with its spatial and temporal variability is necessary. The selection of the most appropriate instrument or method for discharge measurement in different flow conditions is the first step to accurate information on surface water conditions.

In the PARDYP Nepal watershed, Yarsha Khola, three techniques are applied: current meter, salt dilution and Uranin tracer. Depending on which method is used, different values of discharge are obtained at the same location. This ultimately results in different stage – discharge relationships. Inaccuracies in the stage – discharge relationships can cause major errors in the estimation of available water resources or flood discharge.

The presented paper discusses which method is the most appropriate under given condition and which values are to be taken for the development of the stage – discharge relationships. The results are derived from three years field measurement at various sites in the Yarsha Khola watershed during different flow conditions in monsoon as well as dry season.

INTRODUCTION

In mountainous streams discharge measurement by using area-velocity method is difficult. This is mainly due to changing course of flow, flash floods and turbulent conditions in the rivers. Other methods are available, but they are not appropriate for all conditions. The selection of the appropriate method is important for obtaining accurate information. Proper selection of the appropriate method can be recommended after analyzing various results obtained by different techniques.

In the Yarsha Khola watershed (YKW), where the People and Resource Dynamics of Mountain Watersheds in the Hindu Kush- Himalayas Project (PARDYP) is monitoring hydrological parameters since July 1997, many discharge measurements have been carried out using salt dilution, Uranin tracer and area-velocity methods. Different discharge values are obtained by these methods depending on the season. For the establishment of the stage - discharge relationships some of the measurements had to be rejected. Field observations and personal judgement of the hydrologist are needed to screen the data and determine the values to be used for the stage-discharge relationships. This study presents two techniques particularly appropriate for discharge measurement of turbulent streams in mountainous regions, the salt dilution and Uranin methods. The values are then screened for subsequent selection and establishment of the stage-discharge relationships.

STUDY AREA

The YKW is located in the Middle Mountains of Nepal about 190 km east of Kathmandu. Its area is 53.38 sq.km and elevation is ranging from 1000 to 3000 m asl. There are six hydrological and ten meteorological stations established by PARDYP. The setup is considering the altitude and slope is following the nested approach as shown in detail in Hofer (1998). The main station on the Yarsha Khola is located at the outlet of the watershed. Gopi Khola is a sub catchment of the Yarsha Khola covering an area of 17.37 sq km. This paper focuses on the two hydrological stations Main Hydrological station and Gopi Khola.

PRINCIPALE OF THE APPLIED DISCHARGE MEASUREMENT METHODS

The area-velocity methods using current meter is used in many countries and is therefore not further described. Focus will only be given to the principle of integration methods, in this case tracer and salt dilution techniques. The selected tracer should be injected into the river and after complete mixing of the tracer with the water within the entire cross section of the river, its concentration can be measured on site or through analysis of water samples in the laboratory. The discharge is then calculated by the following equation **(**Spreafico et al., 1997).

$$Q = q * V \qquad (1)$$

Where, Q is Discharge, V is the Dilution ratio and q is the Quantity of the introduced substance. There are two different injection techniques of tracer, instantaneous and constant rate injection methods.

Instantaneous injection method

This method is mainly used for salt tracer with the on site concentration measurement using a conductivity meter. Before measurement a calibration factor has to be determined. For the calibration the same type of salt must be used. By adding a well-known concentration of salt (3g/l) to a volume of stream water, conductivity will increase linearly. The slope of the relation between salt concentration and conductivity will give the calibration coefficient in [(mg/l)/(µs/cm)]. The background conductivity of the river should be stable during the measurement and no ponding should be present between the injection and the sampling point. Stream flow must be turbulent between injection and sampling points and the water level should be constant during the measurement. There should be no water abstraction before complete mixing of the salt with the river water. For one hundred liters per second of discharge 3 to 5 grams salt is needed. In turbulent rivers discharge of up to 5 m^3/s, can be measured by the salt dilution method.

After homogeneous mixing of the tracer in the whole cross-section of the stream can be assumed conductivity is measured every five seconds for the duration of through passing of the salt cloud. This can take several tens of minutes depending on the discharge and the river size. Discharge can then be calculated by the following formula (Merz, 1998)

$$Q = \frac{S}{Cal * [\sum C_{(t)} - (N * C_0) * T]} \quad (2)$$

Where, Q is the discharge [l/s]), S is the amount of injected salt [mg], Cal is the calibration coefficient [(mg/l)/(µS/cm)], $\sum C_{(t)}$ is the sum of all conductivity values[µS/cm], N is the number of conductivity values, Co is the base level conductivity of river water[µS/cm], T is the measurement interval [s].

The following equipment is required: conductivity meter, watch for timing, note book or field protocol, pen, two plastic buckets (20 l), plastic or wooden spatula, common salt (NaCl) and a measuring tape.

Constant rate injection method

In the constant rate injection method, tracer solution of known concentration is injected continuously at a fixed volumetric rate and for a certain time. The sampling time has to be chosen in such a way that the tracer concentration in the river water at the sampling point is constant. Before the measurement enough river water has to be taken for measuring the initial tracer concentration (C_0) in the river. A precisely measured quantity of solution with a known concentration (C_1) is then added to the river. Several samples will be taken after complete mixing further down stream. Ideally all samples will be of the same concentration (C_2). According to the principles of mass conservation and continuity equation expressed as (Spreafico et al., 1997)

$$C_0 * Q + C_1 * q = C_2 * (Q + q) \quad (3)$$

Usually C_0 is very small in unpolluted rivers of mountainous areas. At the same time the injected amount of solution (q) is negligibly small in comparison with the discharge (Q) in the river during flood conditions. With the two preconditions above equation (3) can be expressed as (Spreafico et al., 1997)

$$Q = q * \frac{C_1}{C_2} [m^3 / s] \quad (4)$$

Where, Q is the discharge [m^3/s], C_0 is the background concentration of river water [mg/m^3], C_1 is the concentration of the injected solution [mg/m^3], q is the quantity of injected tracer solution [ml/s], and C_2 is the concentration of tracer in the samples of the downstream cross -section [mg/m^3].

This measurement is using a Mariotte flask or similar equipment as shown in Figure 1. The bottle used in PARDYP contains 12 litres and the used tracer is Uranin.

Figure 1. Constant injection method with a Mariotte flask.

COMPARISON OF DISCHARGE MEASUREMENTS

Since 1997 many discharge measurements have been carried out at the hydrological main station of Yarsha Khola and at Gopi Khola by applying the three techniques as explained above. Only a few observations were carried out simultaneously with the different methods. For the comparison of the results from the different discharge measurement methods some of the values are presented in Table 1.

In general there is a good relation between the different measurements, on average about ±5% between the different methods. However, there are some exceptionally high differences. The difference of –16% between current meter and Uranin methods is because of water level fluctuations during the measurement time as per hydro-graph report. The difference of -12% between current meter and salt methods was due to ponding problems and low water velocity. It is noted that current meter measurements usually are lower than total salt or Uranin measurements (minus tendency in the values presented in Table 1 and Figure 2).

Generally point six method was used, as the water depth was low under given conditions. This method does not always represent the whole cross-section of the river especially when measuring in natural streams. Dilution methods however account for the discharge through the entire cross-section. The difference between Uranin and salt is random, with some measurements overestimating, some underestimating. Due to these reasons it is believed that dilution methods are more appropriate than current meter values. For the construction of the stage - discharge relationship, dilution method values are therefore preferred.

Table 1. Comparison of discharge measurements at Main Hydrological station (1) and Gopi Khola station (2) YKW, 1997.

Station No	Gauge Height [m]	Discharge Measurement methods			Relative difference		
		C [m^3/s]	S [m^3/s]	U [m^3/s]	C & S [%]	C & U [%]	S & U [%]
1	0.44	-	0.437	0.477			-1
1	0.49	0.601	0.644	0.699	-7	-16	-9
1	0.70	2.947	-	3.065		-4	
1	0.52	0.715	0.798	-	-12		
1	0.37	0.464	0.470		-1		
1	0.54	2.243	-	2.260		-1	
1	0.42	0.956	0.944	-	1		
2	0.71	0.629	-	0.662		-5	
2	0.72	-	0.697	0.638			8
2	0.78	0.804	-	0.840		-4	
2	0.65	0.340	0.330	-	3		
Difference					(-) 4.8	(-) 6	(±) 6

C: Current meter; S: Salt dilution; U: Uranin tracer

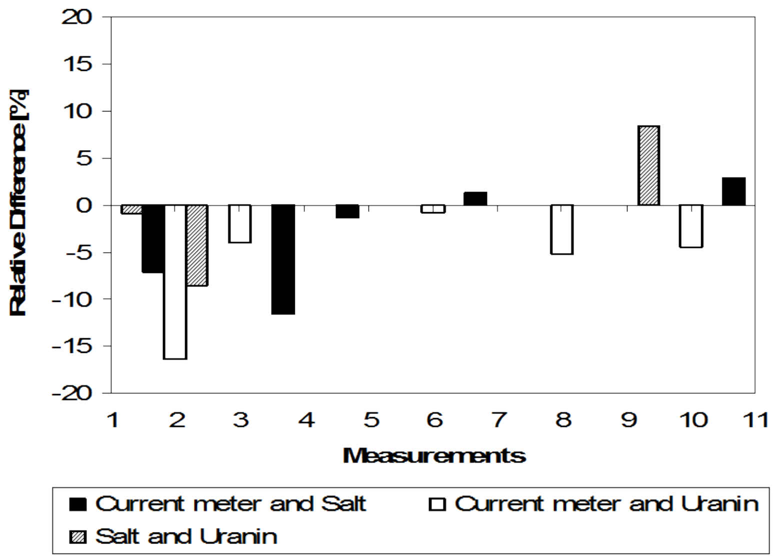

Figure 2. Comparison between three different measurement methods.

STAGE -DISCHARGE RELATIONSHIP OF YARSHA KHOLA MAIN STATION

Stage - discharge relationships for gauging sections are obtained by plotting measured stage on the ordinate and measured discharge on the abscissa. This relation is called rating curve and can be expressed as (Reddy, 1992)

$$Q = k*(y - a)^b \qquad (5)$$

Where, Q is the discharge, y is the water level, and a is a constant representing the stage at zero discharge, k and b are coefficients to be determined with the statistics of the deviation. The above equation was used for the establishment of the stage discharge relationship at Yarsha Khola main station.

Several measurements were carried out by three methods as shown above. Current meter discharge measurements were discarded due to presented reasons. Field comments and personal judgement filtered further unusual discharge data. The comparisons of the stage - discharge relationship parameters of salt dilution, Uranin tracer and the combination of the two calculated by least square regression analysis are presented in Table 2.

Table 2. Comparison of stage-discharge relationship of two methods.

Parameter	Salt dilution	Uranin tracer	Combine two methods
Zero flow (a)	0.145	0.255	0.307
Initial discharge (k)	21.278	22.996	25.745
Exponent (b)	3.198	2.363	2.172
Coefficient of correlation (r)	0.987	0.978	0.98
No. of measurement	18	27	45
Standard error	0.21	1.51	0.70
Acceptance limit of the measurement (P = 95 %)	38.927	31.777	41.579

Above comparison shows that the value of zero flow (0.145) in the rating curve derived for salt dilution data is very low compared to the Uranin (0.255) and the combination (0.307). According to field measurements 0.307 is acceptable.

The validation method applied is according to Reddy (1992). Firstly three discharge values are selected: one with low (Q_1), one with medium (Q_2) and one with high flow (Q_3). The selection of the three values have to satisfy the following condition (Reddy, 1992)

$$Q_2 = (Q_1 * Q_3)^{1/2} \qquad (6)$$

By applying equation (7) the zero flow a by regression methods can be validated with a zero flow without regression analysis (Reddy, 1992)

$$a = \frac{(y_1 \, y_3 - y_2^2)}{(y_1 + y_3) - (2y_2)} \qquad (7)$$

For explanations to the parameters of above equation please refer to Table 3.

Table 3. Three points discharge and water level.

Water Level [m]	Method	Discharge			Zero flow (a) [m]
		Low flow (Q_1) [m^3/s]	Medium flow (Q_2) [m^3/s]	High flow (Q_3) [m^3/s]	
0.48 (y_1)	Salt dilution	0.543			
0.70 (y_2)	Uranin tracer		2.77		0.307
1.20 (y_3)	Uranin tracer			13.295	

Table 3 shows that the value of zero flow a derived from the non-regression method is the same as the zero flow with regression analysis from combined data sets, i.e. 0.307. This is also reasonable according to field observations.

The rating curve established for salt dilution values shows higher correlation and lowers standard error than the other two rating curves. Its acceptance limit however is lower than the combination of the two methods due to the smaller amount of measurements. In addition to this it was shown that zero flow a is most likely form the combined method. Therefore, for final stage discharge relationship of Yarsha Khola main station the rating curve from the combined dataset was used. The rating curves of all methods are shown in Figure 3.

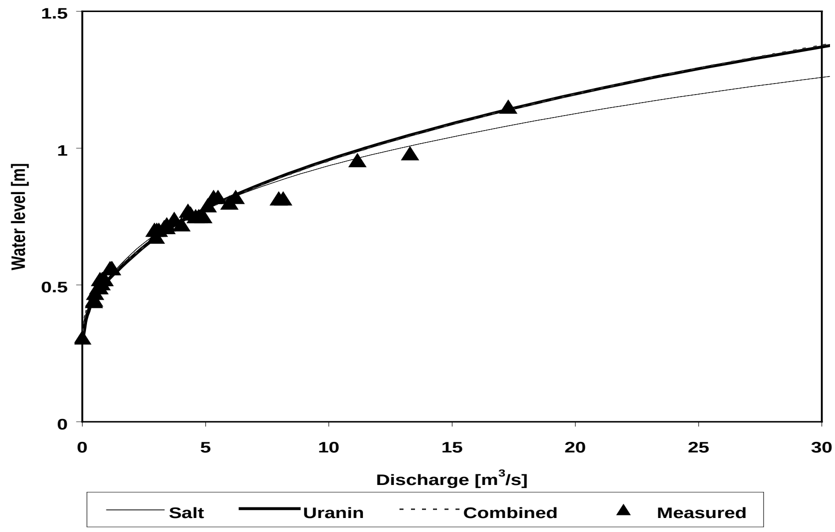

Figure 3. Rating curves of Yarsha Khola main station.

CONCLUSION

The comparison of the three discharge measurement methods observed that current meter is the least suitable for given conditions in turbulent and natural mountain streams. Salt dilution is the best method for measuring the discharge during low flows under these conditions. For high flows Uranin tracer is experienced to be the best method. The rating curve was then established with a combination of the measurement of the two most suitable methods. This was shown with the help of statistical considerations.

PARDYP Nepal is using only salt method in all small streams of the YKW. At Main Station and at Gopi Khola Uranin is used during high flows.

Acknowledgements

The authors are grateful to Mr. A. P. Pokharel, Director General of the Department of Hydrology and Meteorology (DHM), for providing access to the tracer laboratory for the Uranin sample analysis. The financial support for PARDYP of the Swiss Agency for Development and Cooperation (SDC), the International Development Research Centre (IDRC) and the International Centre for Integrated Mountain Development (ICIMOD) is highly appreciated. All PARDYP colleagues in the Nepal team are acknowledged for their support.

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