

# Entropy based Expeditive Methodology for Rating Curves Assessment

D. Mirauda, M. Greco and P. Moscarelli

**Abstract**—The river flow forecasting represents a crucial point to employ for improving a management policy addressed to the right use of water resources as well as for conjugating prevention and defense actions against environmental degradation. The difficulties occurring during the field activities encourage the development and implementation of operative computation and measuring methods addressed to time reduction for data acquisition and processing maintaining a good level of accuracy. Therefore, the aim of the present work is to test a new entropy based expeditive methodology for the evaluation of the rating curves on three gauged sections with different geometric and morphological characteristics. The methodology requires the choice of only three verticals along the measure section and the sampling of only the maximum velocity. The results underline how in most conditions the rating curves drawn can replace those built with classic methodologies, simplifying thus the procedures of data monitoring and calculation.

**Keywords**—gauged station, entropic approach, expeditive methodology, rating curves.

## I. INTRODUCTION

The evaluation of the flow passing through a river section is very important in the management, planning and projects developed for the performance of ordinary and extraordinary operations of environmental preservation and conservation as well as in the prevention and/or reduction of the natural hazard.

Rating curve knowledge is fundamental to these aims and it can be obtained on the basis of velocity measurements sampled in the flow area. The rating curve accuracy is strictly connected to experimental data availability both in conditions of low and high water discharges.

The necessity to dedicate long periods of time and effort to the direct field measures as well as the relevant costs of the monitoring activities, due to the equipment and to presence of qualified technicians, represent a weakness in control and forecasting procedures.

Besides, the inaccessibility of the site and the unfavorable atmospheric conditions make the measurements operations difficult.

The hydrological and hydraulic numerical models, although

D. Mirauda is with the Department of Environmental Engineering and Physics, University of Basilicata, Potenza, PZ 85100 ITALY (phone: +39-0971-205211; fax: +39-0971-205160; e-mail: domenica.mirauda@unibas.it).

M. Greco, is with the Department of Environmental Engineering and Physics, University of Basilicata, Potenza, PZ 85100 ITALY (e-mail: michele.greco@unibas.it).

P. Moscarelli is with the Department of Environmental Engineering and Physics, University of Basilicata, Potenza, PZ 85100 ITALY (e-mail: moscarelli.patrizia@gmail.com).

able to correctly evaluate the flows, must be still tested and calibrated with measures of water discharges acquired in many fluvial sections.

Such conditions in the last few years have led different researchers to develop quick and accurate models and methodologies for the determination of the water discharges.

Among the various approaches is the mathematical model derived from the application of maximization theories of the informational entropy ([1]-[4]), able to compute the water discharge from the solid of the velocity reconstruction.

The entropy model requires the assessment of one parameter only,  $M$ , which can be obtained through the knowledge of the mean-maximum flow velocities ratio ([1]). The invariability of such parameter at the change of the flow regimes, verified by various authors ([5] - [14]) in different fluvial sections, allowed the entropic model to become a useful, efficient and quick method to estimate the flow rate. This procedure has been investigated and applied to different rivers sites located in America and Europe ([5], [15]) furnishing interesting results, even though in some cases the estimation of mean flow velocity was not accurate (absolute percentage errors greater than 30%).

On the basis of the considerations above, the paper aim is to develop a new expeditive methodology that combines quick methods of velocity measure, already discussed by the same authors ([9], [16]), with the entropic approach in order to reduce the time of data acquisition and processing without having to sacrifice the measurement precision. Such procedure has been preliminarily tested on three gauged sections presenting different geometric and morphological characteristics and whose data acquisition was processed with different equipment.

## II. DESCRIPTION OF THE INVESTIGATED FLUVIAL SECTIONS

The results presented and discussed below are referred to field measurements collected on one section located along the Alzette river in Grand-Duchy of Luxembourg and on two gauged sections located on the Basento river of Basilicata region (Southern-Italy.)

The Alzette river is born in France to around 4 kilometers from the frontier of Luxembourg and is the main tributary of the Sûre, flowing into the Moselle river, which is tributary of the Rhine river (Fig.1). It is characterized by a seasonal variation of the flows: elevated levels in winter and low summer levels, with minima levels during the month of September.

The section, named Mersch, is located in the northern part

of the river in the valley where the slope presents values of about 0.1%. The reach is straight and the bed is characterized by the presence of fine sand and silt sediments. The banks are covered by shrubby and cane vegetation. The measure section has the banks and the bed covered by reinforced concrete (Fig.1). The measure of the water level is processed manually with a graduated rod.

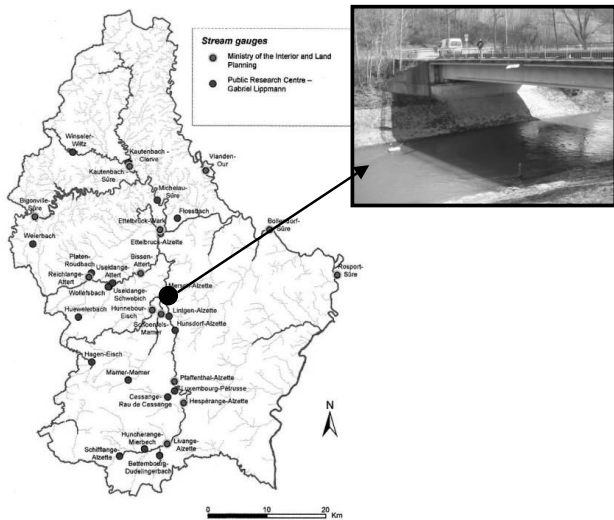


Fig. 1 Alzette river and Mersch section

Instead, the two sections of Basilicata region are hydrometric stations. The Fig. 2 reports the basins of Basento with the location of the two sections.

The Basento river originates in the northern Lucanian Appennines and flows into the Gulf of Taranto after about 149 km. The river has an exclusively pluvial regimen with significant floods in autumn and in winter and low river discharges in the summer.

The first gauged station, named Campomaggiore, is located in the upper part of the river, where the slope is relatively high, about 1%-2%, and the river bed narrows and engraves more deeply the sides (Fig. 3a). The banks are very steep and covered by shrubby vegetation mainly. No-submerged rigid vegetation is even present. The main channel is characterized by the presence of boulders and cobbles carried down during relevant flood events.

The second equipped site, named Torre Accio, is located in the valley part of the river, where the slope reduces at about 0.1% (Fig. 3b). Here, the reach is characterized by the presence of fine sand and silt sediments and the bank slope and cross section remain sufficiently stable during ordinary flood events. In this reach, the Basento river can be considered meandering and sometimes the presence of aquatic vegetation influences the flow, mainly in the case of low stages. The banks are covered by shrubby and cane vegetation.

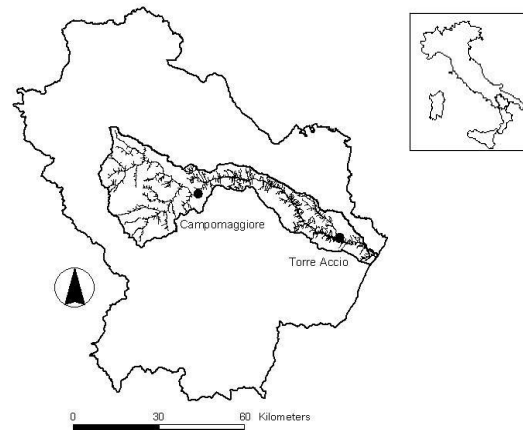


Fig. 2 Investigated gauge stations along Basento river



(a)



(b)

Fig. 3 (a) Campomaggiore and (b) Torre Accio section

The velocity measurements for the section of Campomaggiore and Torre Accio were performed using a current meter stabilized by a heavy weight lowered from the bridges with a mobile trolley system while for the Mersch section the velocity measurements have been acquired by Workhorse Rio Grande ADCP.

III. EXPEDITIVE METHODOLOGY AND DISCUSSION OF THE RESULTS

The evaluation of the rating curve in a fluvial cross section requires the knowledge of the river discharge.

The evaluation of river discharge has been performed according to [17], using the velocity-area method which represents an efficient and reliable tool.

Operatively, computations require to divide the section areas into several verticals and a further subdivision of each vertical into discrete points, in order to evaluate the mean velocity of the flow along each vertical.

The number of verticals and the distribution inside the cross section has been chosen case by case based on section width, riverbed geometry and flow regimes and characteristics, while the measurement points are fixed according to the measurement methodology used, that is, by wading or bridge, and to technique.

The main objective was to obtain a correct evaluation of the mean velocity for each vertical and measurement section which is related to a reliable reconstruction of flow field obtained through velocity point measurements in several marks of hydraulic sections generally distributed from bottom up to the free surface flow (Fig. 4). Depending on the velocity measure points, the mean velocity has been calculated.

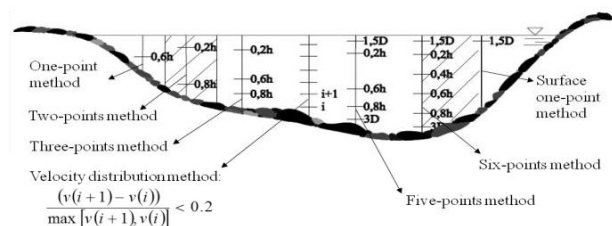


Fig. 4 Different methods for the evaluation of mean velocity on the vertical

Once evaluated the mean velocity for each vertical, the river discharge has been calculated with the mid-section method.

In this method the partial discharge between two verticals is obtained as the product of each value of the mean velocity, times the depth and the sum of the semi-distance between the adjacent verticals. The total discharge is obtained by summing these partial discharges.

The choose of the mid-section method between those proposed by [17] is because this method offers some advantage and it yields slightly more accurate results and affords a saving of time in computation.

The Table I shows the observed ranges of the maximum depths and the water discharges in the investigated sites.

TABLE I  
RANGES OF THE MEAN DEPTHS AND THE WATER DISCHARGES IN THE INVESTIGATED SITES

| Gauged section | Maximum depth (m) | Water discharge (m <sup>3</sup> /s) |
|----------------|-------------------|-------------------------------------|
| Mersch         | 0,74-2,71         | 2,30-43,90                          |
| Campomaggiore  | 1,23-2,97         | 1,30-57,10                          |
| Torre Accio    | 0,92-5,65         | 0,60-180,30                         |

In order to reduce the time of data acquisition and processing we have implemented a new expeditive methodology which combines some quick methods for the measure of the water discharge with the entropic approach.

The quick methods, already discussed in a previous work [16], acquire the velocity measures only in a set of points along three verticals placed at 1/4, 1/2 and 3/4 (Fig. 5a) or at 1/3, 1/2 and 2/3 of the section width (Fig. 5b).

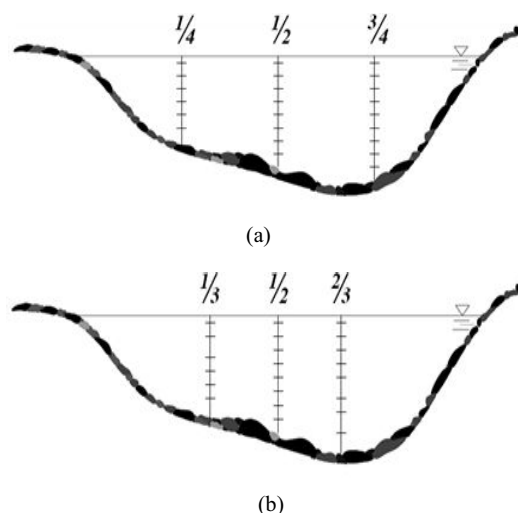


Fig. 5 Layout of the quick methods; (a) verticals placed at 1/4, 1/2 and 3/4; (b) verticals placed at 1/3, 1/2 and 2/3

The entropic model, instead, considers the mean velocity,  $u_m$ , as a function of the maximum velocity,  $u_{max}$ :

$$\phi(M) = u_m / u_{max} = e^M / e^M - 1 - 1/M \tag{1}$$

and  $M$  is the entropy parameter. Equation (1) shows that, the parameter  $\phi(M)$ , can be estimated, for the investigated gauged river site, on basis of pairs  $(u_m; u_{max})$  of available data from measurements sampling. It is necessary to point out that  $u_{max}$  is unknown, but it can be considered as the maximum value in the data set of velocity points sampled during the velocity measurements.

Therefore, once  $M$  is estimated at gauged section and  $u_{max}$  is sampled in the upper portion of flow area, then (1) can be

applied obtaining the mean velocity for each measure of water discharge.

As a result, we have calculated the parameter  $\Phi(M)$  on the basis of mean and maximum velocity pairs of the fluvial section obtained considering the velocity measurement points acquired on the verticals only at 1/4, 1/2, and 3/4, and at 1/3, 1/2, and 2/3.

Figs. 6, 7, and 8 show the entropic linear relationship between the mean and maximum velocity for the three investigated fluvial sections.

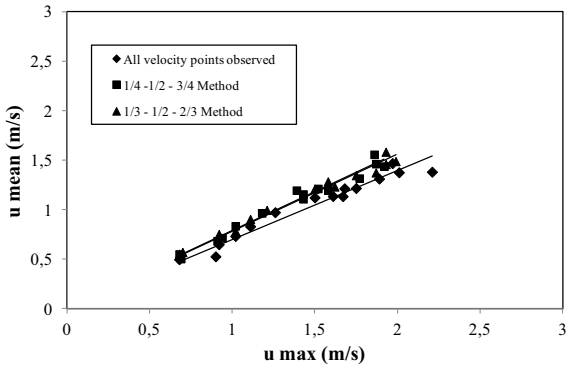


Fig. 6 Mean versus maximum velocity, observed and computed for the Mersch section

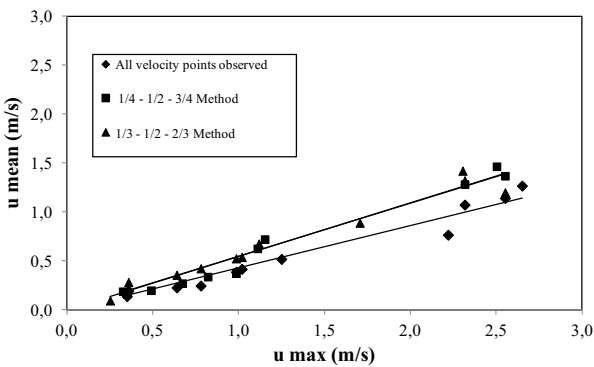


Fig. 7 Mean versus maximum velocity, observed and computed for the Campomaggiore section

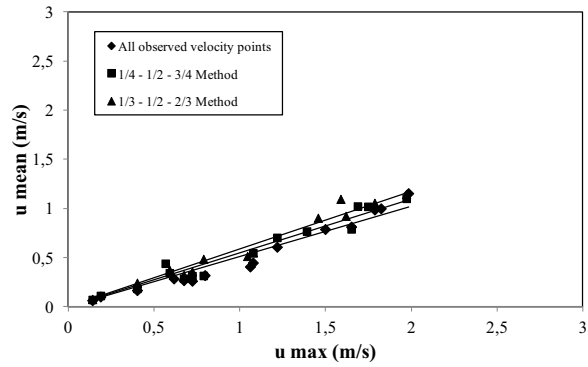


Fig. 8 Mean versus maximum velocity, observed and computed for the Torre Accio section

The Table II reports the values of the parameter  $\Phi(M)$  and those of the correlation coefficient.

TABLE II  
VALUES OF THE  $\Phi(M)$  PARAMETER AND CORRELATION COEFFICIENT FOR THE THREE STATIONS

|                                       | Mersch | Campomaggiore | Torre Accio |
|---------------------------------------|--------|---------------|-------------|
| <b><math>\Phi(M)</math> parameter</b> |        |               |             |
| All velocity points                   | 0,70   | 0,43          | 0,51        |
| 1/4-1/2-3/4 Method                    | 0,79   | 0,54          | 0,55        |
| 1/3-1/2-2/3Method                     | 0,78   | 0,55          | 0,59        |
| <b>Correlation coefficient</b>        |        |               |             |
| All velocity points                   | 0,95   | 0,96          | 0,95        |
| 1/4-1/2-3/4 Method                    | 0,97   | 0,97          | 0,95        |
| 1/3-1/2-2/3Method                     | 0,98   | 0,96          | 0,96        |

As we can see, for all considered methods a strong correlation exists between the mean and maximum velocities with the correlation  $R^2$  generally greater than 0.95.

We can observe a slight increase of  $\Phi(M)$  switching from one method to the other, of about 11% for the Mersch section, of about 20% for the Campomaggiore section and of about 13% for the Torre Accio section.

Besides, note that for the Mersch section the  $\Phi(M)$  parameter assumes a value very close to that obtained for the fluvial sections of north Italian and Algerian rivers, confirming the results shown in [12].

For Campomaggiore and Torre Accio sections, instead, the values of  $\Phi(M)$  are smaller because of its different morphological characteristics.

Once the parameter  $\Phi(M)$  has been estimated, we have recalculated the mean velocity from the (1).

With the availability of topographical surveys at gauged sites we have evaluated the water discharges and built the rating curves.

Figs. 9, 10, and 11 report the theoretical rating curves obtained by the combination of quick methods of surveying and the entropic approach and experimental data considering

all velocity measurement points.

Such curves are represented in logarithmic scale.

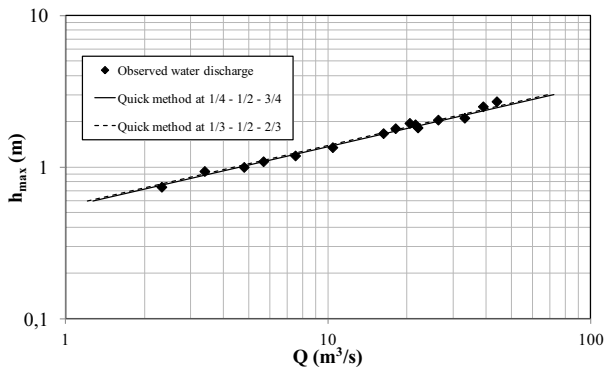


Fig. 9 The observed and computed rating curves for the Mersch section

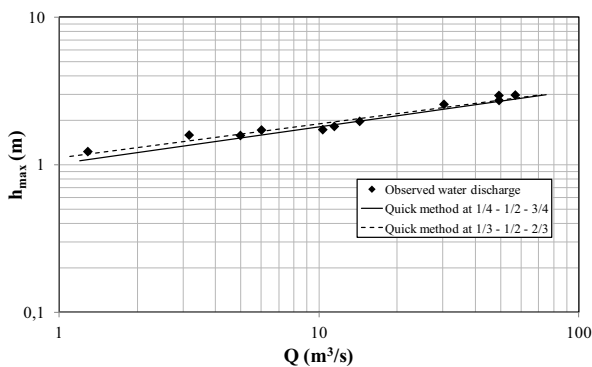


Fig. 10 The observed and computed rating curves for the Campomaggiore section

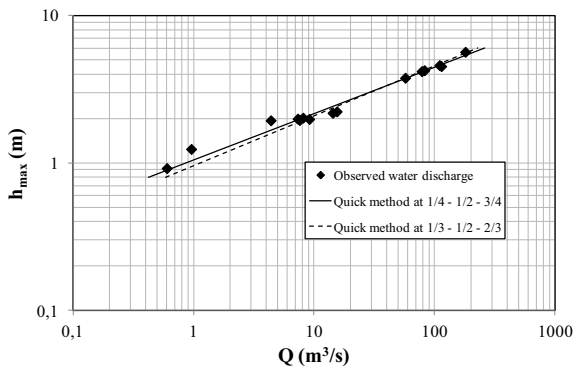


Fig. 11 The observed and computed rating curves for the Torre Accio section

In order to verify if every theoretical curve is able to interpolate the experimental points in an accurate way the

standard error ([18]) has been evaluated:

$$s_e = \left[ \sum (\ln Q - \ln Q_c) / N - 2 \right]^{0.5} \quad (2)$$

where  $Q$  is the measured discharge,  $Q_c$  is the discharge calculated from the curve built with the expeditive methodology, and  $N$  is the number of measures.

The Table III reports for each section and for each method the error between the rating curves and the experimental data.

TABLE III  
THE STANDARD ERRORS FOR THE THREE GAUGED SECTIONS

| Gauged section | Quick method at<br>1/4 - 1/2 - 3/4 | Quick method at<br>1/3 - 1/2 - 2/3 |
|----------------|------------------------------------|------------------------------------|
|                | Standard error (%)                 |                                    |
| Mersch         | 12                                 | 14                                 |
| Campomaggiore  | 24                                 | 25                                 |
| Torre Accio    | 22                                 | 21                                 |

As we can observe in Table III, the error range is always within 25% and, particularly for the Mersch section, it is as low as around 14%, whereas for the Campomaggiore section it is around 25% and for the Torre Accio is around 22%.

Moreover, there is no noticeable difference between the two methodologies.

The reason for such a different behavior between the Mersch section and Lucanian ones could be found in the different equipment and methodology used for the velocity data acquisition which in the latter would result more precise.

In fact, the Mersch section measures have been conducted through the Workhorse Rio Grande ADCP which, besides being more precise, allows to sample a bigger amount of points on each vertical than through the current meter used for Campomaggiore and Torre Accio.

Moreover, the Lucanian sections show an irregular geometry, slightly changing at increasing stages ([16]), and are characterized by the presence of shrubby, cane vegetation and boulders along the banks and the fluvial bed, which generally slows down the velocity. The Mersch section is much more regular, being the banks and the bed covered by reinforced concrete.

#### IV. CONCLUSION

The development of a new entropy based expeditive methodology for the evaluation of the rating curves in a free surface flow represents an essential element for the monitoring of the rivers, not only to reduce the computational time and data analysis, but also the costs of the field activities.

The methodology proposed in this paper combines two approaches: the entropic model, which requires the knowledge of only the maximum velocity through the  $M$  parameter, and the procedure of data acquisition, concentrating the velocity

measures only on three verticals of the gauged section.

This methodology has been preliminarily tested only on three gauged sections presenting different geometric and morphological characteristics and whose data acquisition was processed with different equipment.

The obtained results outline the robustness and good reliability of the method, underlining the standard errors stay within 25%. Moreover, if a more precise equipment like the ultrasonic one is used instead of a classic equipment like the current meter one, the error is lowered down to 14%.

Finally, because of the positive results obtained, it would be advisable to extend the procedure to other fluvial sections in future.

#### REFERENCES

- [1] C. L. Chiu, "Entropy and probability concepts in hydraulics," *Journal of Hydraulic Engineering*, vol. 113, no. 5, pp. 583–600, May 1987.
- [2] C. L. Chiu, "Entropy and 2-D velocity distribution in open channels," *Journal of Hydraulic Engineering*, vol. 114, no. 7, pp. 738–756, July 1988.
- [3] C. L. Chiu, "Velocity distribution in open channel flow," *Journal of Hydraulic Engineering*, vol. 115, no. 5, pp. 576–594, May 1989.
- [4] C. L. Chiu, "Application of entropy concept in open-channel flow," *Journal of Hydraulic Engineering*, vol. 117, no. 5, pp. 615–628, May 1991.
- [5] R. Xia, "Relation between mean and maximum velocities in a natural river," *Journal of Hydraulic Engineering*, vol. 123, no. 8, pp. 720–723, August 1997.
- [6] C. L. Chiu, and C. A. A. Said, "Maximum and mean velocities and entropy in open-channel flow," *Journal of Hydraulic Engineering*, vol. 121, no. 1, pp. 26–35, January 1995.
- [7] M. Greco, and D. Mirauda, "Experimental analysis for the entropic parameter evaluation," in *Proc. 2nd Int. Conf. New Trends in Water and Environmental Engineering for Safety and Life: Eco-compatible Solutions for Aquatic Environments*, Capri (Italy), June 2002.
- [8] M. Greco, and D. Mirauda, "Valutazione globale del parametro entropico di velocità," *L'Acqua*, vol. 5, pp. 17–23, 2002.
- [9] M. Greco, and D. Mirauda, "Expeditive methodology for river water discharge evaluation," in *Proc. 2nd Int. Conf. on Fluvial Hydraulics, River Flow 2004*, Napoli (Italy), June 2004.
- [10] C. L. Chiu, and N. C. Tung, "Maximum velocity and regularities in open-channel flow," *Journal of Hydraulic Engineering*, vol. 128, no. 4, pp. 390–398, April 2002.
- [11] T. Moramarco, C. Saltalippi, and V.P. Singh, "Estimation of mean velocity in natural channels based on Chiu's velocity distribution equation," *Journal of Hydrologic Engineering*, vol. 9, no. 1, pp. 42-50, January 2004.
- [12] T. Moramarco, A. Ammari, A. Burnelli, D. Mirauda, and V. Pascale, "Entropy Theory Application for Flow Monitoring in Natural Channels," in *Proc. of the iEMSs 4th Biennial Meeting International Congress on Environmental Modelling and Software*, Barcelona, Spain, July 2008.
- [13] C. L. Chiu, and S. M. Hsu, "Probabilistic approach to modeling of velocity distributions in fluid flows," *Journal of Hydrology*, vol. 316, pp. 28–42, 2006.
- [14] A. Burnelli, D. Mirauda, T. Moramarco, and V. Pascale, "Applicability of entropic velocity distributions in natural channel," in *Proc. 4th Int. Conf. on Fluvial Hydraulics, River Flow 2008*, Izmir-Cesme (Turkey), September 2008.
- [15] T. Moramarco, and C. Saltalippi, "Entropic characterization of the mean flow velocity in natural channels," in *Proc. of the IASTED International Conference Environmental Modelling and Simulation*, St. Thomas, US Virgin Islands, November 2004.
- [16] D. Mirauda, M. Greco, and P. Moscarelli, "Practical methods for water discharge measurements in fluvial sections," in *Proc. 6th International Conference on River Basin Management including all aspects of Hydrology, Ecology, Environmental Management, Flood Plains and Wetlands*, Riverside, California, USA, May 2011.
- [17] ISO 748/1997, "Measurement of liquid flow in open channel – Velocity-area methods", 1997.
- [18] ISO 1100-2/1998, "Measurement of liquid flow in open channel - Part 2: Determination of the stage-discharge relation", 1998.