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Calibration of the different outlets (Moghas) for equitable distribution of the agriculture water: A case study at rahuki distributary

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Abstract
It is essential to make the best use of water resources management to create a good plan and development strategy. As such, water is a important source for a diversity of users such as irrigation, industrial manufacturers, and residential clients. Therefore, this study was conducted to determine the appropriate value of the discharge coefficient (C_d) for the selected outlet calibration. In this connection, six watercourses in which 3 Adjustable Proportionate Module (APM) and 3 Open Flume (OF) of Rahuki distributary were selected. The actual discharge was determined by using Cutthroat Flume and Current meter, and the empirical formula was used to determine the theoretical discharge, then the C_d values (minimum, maximum and average) for both types of the selected outlets were computed the calibration purpose. The rating/calibrated curves were developed for all chosen watercourses on the basis of computed C_d values. These calibrated, stage vs discharge curves can be used to govern the discharge of nominated watercourses. Using established empirical formulas, the flow rate of the selected water cources can be determined with confidence. The results suggested that the APM module generates higher C_d value than the OF module. Therefore, it is recommended to use the APM module in the field to increase accuracy.

Keywords: calibration of outlets, water management, water delivery

Introduction

In the coming time, world future food production can have adverse impacts due to the several difficulties, problems, and issues related agriculture sector such as unexpected climate changes, rising costs of agribusiness, increasing urbanization water shortages, water misusage, water pollution and others as predicted by reseachers [1, 3]. In this regrad, the proper mangement of the avaialbe water resource is important for world future food production. Because water is a critical resource for a variety of users including irrigation, residential customers and industrial producers. It is accepted that the future water demand and supply relationship will be greatly influenced by human actions that would greatly affect water availability and accessibility. The developing and developed countries could deal with water crises due to rapid urbanisation and industrialization [4].

Pakistan is an agriculture country which is in developing phase where agriculture is considered as a main pillar or income source for many people of the country. Besides, it contributes to 24.7% and 47.3% of the total gross domestic production (GDP) and employment strength of the country, respectively [5]. In addition, irrigation system in Pakista is one of the largest systems in the World. Its irrigated area of the country has increased from 9 million hectares (Mha) in 1950 to 18 Mha in 2006 [6]. Despite having the world's biggest irrigation system, a huge amount of water is lost in the conveyance system. According to estimates only 30% of water diverted into the canal system reaches the farmers' fields [7]. This is attributable to the uncertainty and inequityof water distribution at the head reaches of watercourses. Besides, farmers at the head reaches get more water, which results in the unavailability of water at the tail reaches [8, 9]. Outl*et al*so known as farm turnouts in some countries, is a device constructed at the head of a watercourse, which admits designed discharge of water from government-owned distributary or minor to public-owned watercourse [10]. Moreover, the common types of outlets found in Pakistan particularly in Sindh are orifice type module, adjustable proportional Module (APM), and open flume (OF) outlet. However, there are several other structures like orifices, weirs, and flumes [11, 13] are used directly to measure the water for irrigation by taking reading in the scale in an open channel or closed conduit [14]. However, outlet partially restricts the flow in an open channel and supplies irrigation water wisely on their due right basis [15]. The accuracy in the measurement of designed discharge is crucial for equitable distribution of water [16, 17]. Flow measurements are usually made on distributaries, canals and lined water cources, but in unlined watercourses, cutthroat flumes or current meter can be successfully used. However, using these devices can take time if regular monitoring is required, so it is difficult to use these devices every time to assemble discharge data. As a result, the outlet of the channel is calibrated so that it can be measured simply by measuring upstream and downstream heads. Therefore, calibration of outlets plays an important role to ensure correct and equitable water distribution of in watercourses, when the structure is appropriately calibrated for the stationary channel region, precise data is provided so that the relationship of discharge vs flowdepth can be established. Qureshi *et al*. [18] observed in one of distributary of Rohri main canal that canal water was fluctuating with crop season that is in summer (Kharif), it was short of 26% of crop water requirement; however, in winter (Rabi) it was in surplus of about 20%. Hence, they suggested that the water conservation can be made by constructing small storage reservoirs at the head of the command area of the distributary which can be used in the case of shortage of water. Under this study, three APM and three OF outlets of Rahuki distributary has been calibrated. In this activity, rating curves and empirical formulas have been developed to ensure accurate discharge data collection when spending valuable time.

Materials and Methods

Study area and experiment arrangement

The current research study was performed at Rahuki distributary, Hyderabad, Sindh, Pakistan which is off taking water from Hyderabad branch of Rohri main canal. Moreovere, the total length of the distributary is 47 RDs i.e. about 14.32 km. The gross command area of the distributary is 51,597 acres and its cultivable command area is 50,962 acres, consisting of 55 outlets. For present study, two types of outlets were chosen for the calibration purpose which were 3 OF and 3 APM. Howevere, the one outlet was taken from right side of the distributary and five were taken from the left side of the distributary. The location map of the study area is shown in Figure 1. Besides, the salient features of the selected watercourses are illustrated in Table 1.

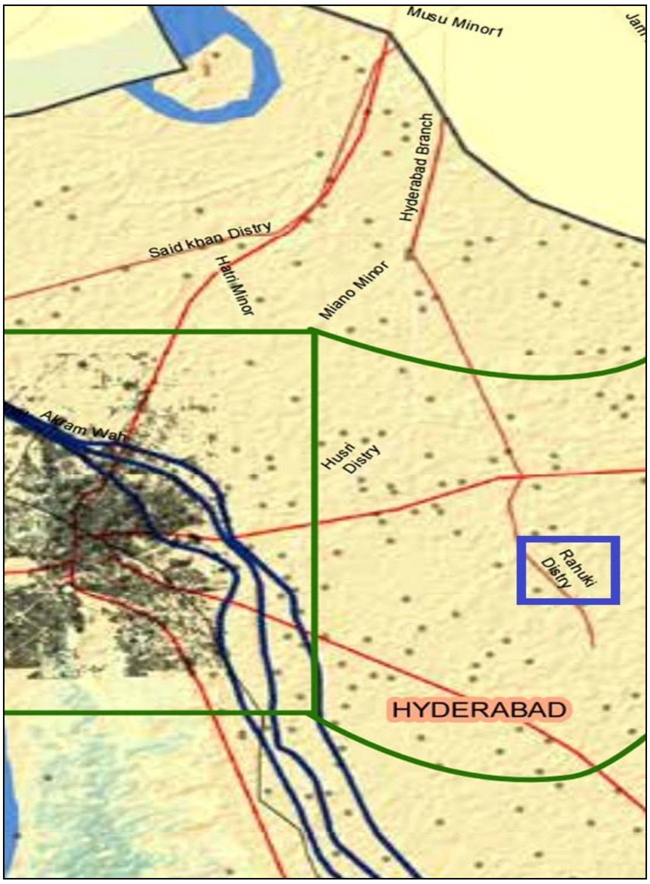

Fig 1: Location map of Rahuki distributary

Table 1: Selected watercourses with their salient features

No.	Watercourse name	Dimensions	Outlet
		B_t (ft) Y(ft)	
1	8L	0.38 0.85	APM
2	9L	0.37 0.85	APM
3	7CL	0.20 0.60	APM
4	7L	0.45 -----	OF
5	9AL	0.45 -----	OF
6	2CR	0.70 -----	OF

Discharge Measurement

The actual discharge of selected watercourses passing through the outlet was measured by Cutthroat flume. While the theoretical discharge was measured by using empirical formulas at different heads (from min till max) as reported by IWMI [19]. In addition, three readings were taken with the help of Cutthroat flume at different upstream heads, and the average value was used for statistical analysis. Figure 1 displays the discharge measurent of the study area.

Fig 2: Discharge measurement from the the upstream of watercourse with cut throat flume installed.

Calibration of APM outlet

The flow discharge in the APM outlet is a function of level and outlet dimensions. When free flow occurs, different in crest elevation of the outlet and elevation of water surface in the canal called head at upstream (h_u) that is used to compute the flow rate, whereas the flow rate (discharge), in case of submerged flow, is the function of difference in water surface elevation between the minor and watercourse, $h_u - h_d$. This process was repeated with the increasing water level in the distributary. The theoretical discharge was measured using Equations 1 and 2.

Condition of free flow

$$Q = B_t \times Y \times \sqrt{2gh_s} \quad (1)$$

Condition of submerged flow

$$Q = B_t \times Y \times \sqrt{2g(h_u - h_d)} \quad (2)$$

Where Q is discharge (cusec), B_t is throat width of the outlet (ft), Y is distance between crest of outlet and lower tip of roof block (ft), C_d represents discharge co-efficient depends upon both upstream and downstream water depth, h_s represents upstream water level height and suffix of roof block (ft), g is acceleration due to gravity is 32.2 (ft/sec²), h_u and h_d represents upstream and downstream flow depths (ft).

Calibration of OF outlet

This is usually brick masonry structure, built at head of the water course, theoretical discharge by this structure can be computed using Equations 3 and 4 for free and submerged flow condition, respectively.

Condition of free flow

$$Q = k \times B_t \times Y \times G^{\frac{5}{2}} \quad (3)$$

Condition of submerged flow

$$Q = k \times B_t \times \left((h_u - h_d)\right)^{\frac{5}{2}} \quad (4)$$

Where additionally, k represents coefficient, G represents head (depth of water above crest in ft) is F.S.L of canal – crest level, Max F.S.L of watercourse is F.S.L of canal – H_m, H_m is 0.2G, h_u is Head of upstream in ft, h_d is Head of downstream in watercourse in ft.

The values vary with the change of B_t which are given in Table 2.

Table 2: Values of B_t and k in FPS system

B_t (ft)	K
0.2-0.29	2.90
0.3-0.4	2.95
> 0.40	3.0

Cutthroat Flume

Empirical formula of cut-throat cut flume followed as Equations 5 and 6:

Condition of free flow (if S < 0.68)

$$Q = C_f (h_u)^{nf} \quad (5)$$

Condition of submerged flow (if S > 0.68)

$$Q = C_s (h_u - h_d)^{nf} / (-\log S)^{ns} \quad (6)$$

Table 3: Unified discharge parameters for cutthroat flume

Flume size	Cf	nf	S_t	C_s	n_s	Q_f (max) (Cusecs)
4'' * 3'	1.404	1.84	0.580	0.942	1.384	1.40
8'' * 3'	2.858	1.826	0.674	1.600	1.489	2.86
12''*3'	4.330	1.811	0.754	2.048	1.567	4.33

Pygmy current meter

Pygmy current meter is common equipment which is used for measuring the water flow in water channels. There are many types of current meters which are used around the world; some are more complex than others in their operation, accuracy, etc. The value of velocity is then used in the general Equation 7 to determine the flow as:

$$Q = A \times V \quad (7)$$

Where, Q represents discharge (cusecs), a represents area (ft^2), and V is velocity (ft/s).

Statistical analysis

All the data were subjected to the statistical analysis using one-way ANOVA. Means were compared using Duncan method at $p = 0.05$.

Results and Discussion

The Calibration of Adjustable Proportional Modules was carried for followings three watercourses; the theoretical and actual discharges are observed and coefficient of discharges was computed.

Calibration for APM moutles

a. 8L watercourse

For computing the theoretical discharge in the APM outlet of 8L watercourse, the upstream heads (h_s) were observed vary from 0.87 to 1.50 ft. The cutthroat flume was used to measure the actual discharge. Moreovere, the C_d values were calculated which were varying from 0.753 to 0.789 with an average value of 0.769, as shown in Table 4

Table 4: Theoretical discharge, actual discharge and C_d values for APM outlet of 8L watercourse

No.	APM Outlet Bt = 0.380 ft, Y = 0.850 ft [Table 1]	Cutthroat Flume with size (8" *3') Cf = 2.858, nf = 1.826 [Table 3]	Cd = Qact / Qth
	A1 A2 A3		
1 2 3	0.87 2.41 FF	A4 A5 A6 A7 A8	0.753
	1.20 2.83 FF	0.78 0.52 0.66 FF 1.81	0.766
	1.50 3.17 FF	0.86 0.54 0.62 FF 2.16	0.789
	Average	0.93 0.58 0.62 FF 2.50	0.769

Note: In Table different letter are A1= hs (ft), A2= Qth (cusecs) [Equation 1], A3= Flow Condition, A4= hu (ft), A5= hd (ft), A6= S =hd//hu, A7= Flow Condition and A8= Qact (cusecs) [Equation 5].

b. 9L watercourse

Theoretical discharge for APM outlet of 9L watercourse were calculated for upstream head (h_s) vary from 0.62 to 1.05 ft. the actual discharge for crosses ponding (h_s) C_d values were computed which were observed from 0.752 to 0.786 with an average value of 0.771. The measured results are shown in Table 5.

Table 5: Theoretical discharge, actual discharge and C_d values for APM outlet of 9L watercourse

No.	APM Outlet Bt = 0.370 ft, Y = 0.850 ft [Table 1]	Cutthroat Flume with size (8" *3') Cf = 2.858, nf = 1.826 [Table 3]	Cd = Qact / Qth
	A1 A2 A3		
1	0.62 1.98 FF	A4 A5 A6 A7 A8	0.752
2	0.86 2.33 FF	0.70 0.46 0.65 FF 1.49	0.776
3	1.05 2.58 FF	0.78 0.48 0.61 FF 2.81	0.786
	Average	0.83 0.55 0.66 FF 2.03	0.771

Note: In Table different letter are A1= hs (ft), A2= Qth (cusecs) [Equation 1], A3= Flow Condition, A4= hu (ft), A5= hd (ft), A6= S =hd//hu, A7= Flow Condition and A8= Qact (cusecs) [Equation 5].

c. 7CL watercourse

Similarly for APM, outlet of 7CL watercourse the theoretical discharge were calculated for upstream head (h_s) vary from 0.97 to 1.72ft, the actual discharge were measure and C_d values were computed i.e. 0.750, 0.780 and 0.793 respectively with an average C_d value of 0.775 as shown in Table 6

Table 6: Theoretical discharge, actual discharge and C_d values for APM outlet of 7CLwatercourse

No.	APM Outlet B_t = 0.20 ft, Y = 0.60 ft [Table 1]	Current meter	Cd = Qact / Qth
	A1 A2 A3		
1	0.97 0.948 FF	A4 A5 A6 A7 A8	0.750
2	1.30 1.09 FF	1.31 1.96 2.56 0.278 0.711	0.780
3	1.72 1.26 FF	1.47 1.96 2.88 0.295 0.849	0.793
	Average	1.64 1.96 3.21 0.311 1.00	0.775

Note: In Table different letter are A1= hs (ft), A2= Qth (cusecs) [Equation 1], A3= Flow Condition, A4= Depth (ft), A5= Bed width (ft), A6= Area (ft^2), A7= Velocity (ft/sec) and A8= Qact (cusecs) [Equation 7].

Calibration for OF outlets

a. 7L watercourse

The calculated results of 7L watercourse for upstream head (G) vary from 1.15 to 1.50 ft, while the calculated C_d value was recorded from 0.716 to 0.784 with an average value of 0.742, as shown in Table 7.

Table 7: Theoretical discharge, actual discharge and C_d values Open flume outlet of 7L watercourse.

No.	OF Outlet Bt = 0.45 ft, K = 3 ft [Table 2]	Cutthroat Flume with size (8" *3') Cf = 2.858, nf = 1.826 [Table 3]	Cd = Qact / Qth
	A1 A2 A3		
1	1.15 1.66 FF	A4 A5 A6 A7 A8	0.716
2	1.48 2.43 FF	0.62 0.40 0.64 FF 1.19	0.728
3	1.50 2.48 FF	0.77 0.50 0.64 FF 1.77	0.784
	Average	0.81 0.55 0.67 FF 1.94	0.742

Note: In Table different letter are A1= G (ft), A2= Qth (cusecs) [Equation 1], A3= Flow Condition, A4= hu (ft), A5= hd (ft), A6= S =hd//hu, A7= Flow Condition and A8= Qact (cusecs) [Equation 5].

b. 9AL watercourse

Similarly, the calculated results OF 9AL watercourse for upstream head (G) Vary from 0.50, 0.58 and 0.63 ft., with the calculated C_d values of 0.731, 0.740 and 0.760, as shown in Table 8.

Table 8: Theoretical discharge, actual discharge and C_d values for OF outlet of 9AL watercourse.

No.	OF Outlet B_t = 0.45 ft, K = 3.0 [Table 2]	Current meter	Cd = Qact / Qth
	A1 A2 A3		
1	0.50 0.742 FF	A4 A5 A6 A7 A8	0.731
2	0.58 0.926 FF	1.24 2.13 2.64 0.206 0.543	0.740
3	0.63 1.05 FF	1.47 2.13 3.13 0.219 0.685	0.760
	Average	1.64 2.13 3.49 0.229 0.800	0.744

Note: In Table different letter are A1= G (ft), A2= Qth (cusecs) [Equation 1], A3= Flow Condition, A4= Depth (ft), A5= Bed width (ft), A6= Area (ft^2), A7= Velocity (ft/sec) and A8= Qact (cusecs) [Equation 7].

c. 2CR watercourse

The coefficient of discharge for 2CR watercourse i.e. Open flume outlet for the upstream head (G) values were computed as 0.88, 0.95 and 1.04 ft., was calculated as 0.701.0.726 and 0.738 respectively with an average value of 0.721, as shown in Table 9.

Table 9: Theoretical discharge, actual discharge and C_d values for OF outlet of 2CR watercourse.

No.	OF Outlet Bt = 0.70 ft, K = 3 ft [Table 2]	Cutthroat Flume with size (8" *3') Cf = 2.858, nf = 1.826 [Table 3]	Cd = Qact / Qth
	A1 A2 A3		
1	0.88 1.74 FF	A4 A5 A6 A7 A8	0.701
2	0.95 1.94 FF	0.63 0.40 0.63 FF 1.22	0.726
3	1.04 2.22 FF	0.68 0.40 0.58 FF 1.41	0.738
	Average	0.74 0.50 0.67 FF 1.64	0.721

Note: In Table different letter are A1= G (ft), A2= Qth (cusecs) [Equation 1], A3= Flow Condition, A4= hu (ft), A5= hd (ft), A6= S =hd//hu, A7= Flow Condition and A8= Qact (cusecs) [Equation 5].

Development of the ratting curves and empirical equations for selected APM and OF oultlets

The rating curves (stage vs discharge relationships) for selected six (3 APM and 3 OF) were developed; and their empirical relationship between stage vs discharge were establishe, which are represented in Figure 3 the regression analysis of the developed equation shows that the value of the correlation equation (R^2) in all cases was equal to 1. Moreovere, the curves showed that maximum fluctuation occurs in Open flume outlet, followed by APM modules with respect to water level in the distributary.

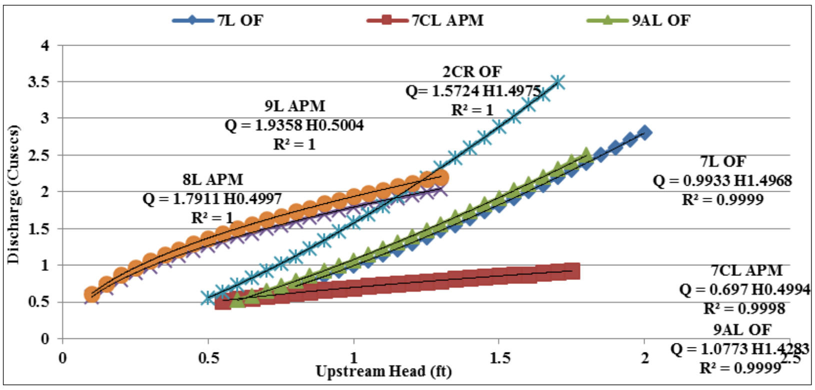

Fig 3: Stage discharge (rating) curve) of various OF and APM Outlets

Conclusions and suggestions

Based on the field survey, the selected Adjustable Proportionate Outlet (APM) and Open Flume (OF) outlets of the study area were calibrated with Cutthroat Flume (CTF) and Current meter and the corresponding values of coefficient of discharge (C_d) 0.769, 0.771, 0.775 for APM outlets and 0.721, 0.742, 0.743 OF outlets were obtained. From the C_d values, the conclusions are as follows:

a. The average C_d value in APM outlet was calculated 0.775 and the average C_d value for OF outlet was calculated 0.720. APM produce higher C_d values compared to OF outlet hence the APM module outlet could be used for higher accuracy. Also, it was found that the C_d values had direct relationship with upstream head as head is increased, the C_d values also increase, therefore, it is concluded that adjustable proportionate module is more efficient than open flume.
b. The co-efficient of discharge of APM was higher than OF outlets. The APM structures are beneficial to increase velocity of water. However, open structures are used where the maximum amount of water to the field/crop.
c. It is suggested that at the head of watercourse, gages for calibration must be installed, and there will be useful for irrigation staff and farmers for their ready reference of knowing the discharges.

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