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RESEARCH ARTICLE

DEVELOPMENT OF STAGE-DISCHARGE RATING CURVE AND RATING TABLE OF PIYARO MINOR AND DILWARO MINOR

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ABSTRACT

Developing a gauge-discharge relationship in rivers, canals, and minor flow is vital for controlling floods, managing water resources, Spatio-temporal analysis, socio-economic development, and sustaining the ecosystem. Accurate and consistent data of irrigation networks are perilous to scheduling and managing for accurate application of irrigation water. Most of the hydrologic engineering activities like hydraulics structure, designs, flood monitoring, surplus water, reservoir, canal, and minor's operation depend on flowing water derived from Rating Curve (RC). The effective management of irrigation water is necessary for crop water requirements and seepage losses estimation. In this context, the present study showed the actual field level work tested at two minors of the Ghotki feeder canal namely Pyaro minor and Dilwaro minor. The main object of the study is to develop gauge-discharge relation and development of RC and Rating Table (RT). The current meter was used for taking discharge measurements with the area velocity technique in both minors. Moreover, stage-discharge RC and RT were developed for different flows of water for both minors in Origin Software. From the calculated results, Power equations were developed for both minors for the actual requirement of crop water in the command area. The results of the study calculated in RT of Piyaro minor between 0.5-5ft stage gave discharge 0.053 cusecs to 90.616 cusecs. While the RT of Dilwaro minor showed the range between 0.5ft-4ft stage gave 26.575cusec to 168.888 cusecs. Hence, the present study suggested that for both minors, automatic gauging stations should be established for the actual demand of irrigation water in the command area and di-siltation should be done on both minors to make availability of water at the tail section.

KEYWORDS

Rating Curve, Discharge, Current Meter, Piyaro Minor, Dilwaro Minor

1. INTRODUCTION

The discharge of rivers, canals, small irrigation networks, and their water level observation is an essential issue in hydrologic modeling. The issue indicates vital source information for water resources management and planning. (Gericke et al 2014) stated that the design flow of different hydraulic structures such as bridges, canals, and culverts need to estimate accurate gauge-discharge data. On the other hand, mostly in a compound river, or canals, the direct measurement of discharge is not easy or not feasible (Mohanty et al 2019). Human activity in the hydrologic regime may affect the natural flow of water and the ecological system and disturb the accessibility of water resources. (Bonacci et al 2015). The variation in hydrologic regime can occur due to fluctuation in obtainability of water through runoff, rainfall, surplus water, groundwater recharge, and discharge. (Beavis et al 2010) stated that this may also be affected by season, duration, frequency, length, and flow interval events. Rivers, canals, distributaries, and minors are scrutinized by the technologically advanced countries for better management, allocation of water resources (Barrows 1998). Furthermore, in developing countries, these resources of water are understudied like Pakistan. Pakistan is blessed with an intricate irrigation network consisting of a wide network of rivers, canals, minors, distributaries, and watercourses. The challenging job of the Hydraulics Engineer is to determine the flow rate (Discharge) in a river, canal, channel, and distributaries for various purposes. According to the study of hydrology, the river is well-defined as natural streamflow in a channel. For the monitoring of streamflow at a hydrometric station, the easiest and common technique is to develop the stage-discharge or rating curve (Rantz, 1982; Schmidt, 2002) which is used to convert continuously recorded water levels into discharge time series.

Rating Curve (RC) is defined as, in an open channel, the relation between water level and flow rate or stage-discharge relation. In many of the research studies, hydraulic engineers studied about analysis of flow area, hydraulic parameters of rivers, and channels. The flow rate (Q) can

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calculate from the field velocity (V) and cross-sectional area (A). For developing stage-discharge curve, several measurements i.e., 10 to 12 points on a low, high, and medium level of flow at all illustrative gauges' points are required (Gupta, 2001). (Kennedy, 1966) stated that a straight relation between stage height and discharge referred to a simple relation. The current meter method for measuring discharge is accurate, and the other methods contain the practice of dynamometers, floats, Pitot tubes, chemical, and electrical methods at the gauging locations which cover different stages of the canal or channel. Velocities and allied cross-section areas, the discharge is calculated for numerous stages on the increasing and deteriorating side of a canal or channel flow and a stage-discharge. It should cover the full range of flow rates to get a suitable relation. Then using this data, a curve is plotted between the stage and the corresponding flow rate of the canal or minor.

In rivers and canals under unstable or unsteady flow conditions, the two slants do not assure exact assessment of the flow rate (Timbadiya et al 2011) because due to fundamental steady-state assumptions and the extrapolation of the RC beyond the range of actual measurements used to derive it (Muste and Lee, 2013). In addition, the direct flow rate measurement of canal or minor at different heights and time includes a great deal of labour, funds, risk, and take for granted a complex and wide-ranging measuring investigation that must be repetitive regularly to keep the RC updated (Bozzi et al 2015). Finally, the RC may vary over time due to seasonal changes in vegetation, human activities, and flooding (Baldassarre and Claps, 2011; Baldassarre and Montanari, 2009; Vanmaercke et al 2010). Many irrigation canals or channels have a significant number of structures for regulating flow rate and water level by use of gates all through the network. In irrigation networks at many locations, there is a use of a vertical staff gauge at the downstream side of the structures. After the measuring stage-discharge relation by using the current meter method, the RT provides the operator with the required water level on the downstream gauge for any discharge rate specified by the Irrigation Engineer. The stage-discharge curve is an essential method that worked at the calculation of discharge. The accurate and precise data about stage discharge is substantial for hydrological applications i.e., hydrological modeling, reservoir operation, water resources planning as well as sediment handling. While the RC seems to be an important empirical task, a wide theoretical practice is needed to create a dependable too to switch from measured water height to discharge. To develop the reliable stage-discharge RC and RT, numerous discharge data from the lowest to the highest stage should be observed over a long period. Keeping in view, this research study reveals that three discharge measurements were taken on typical gauges' height (low, medium, and high level) by using the current meter method. The discharges were taken at the head of the Piyaro minor and Dilwaro minor for the development of stage-discharge RCs and stage-discharge RT.

2. Materials and Methods

2.1 Study Area

The fieldwork was conducted on two minors Piyaro and Dilwaro minor (Figure. 1) in Ghotki Feeder Canal Area Water Board (GFCAWB). Piyaro Minor is a lined channel. The minor is in the administrative unit of the Daharki subdivision. The head regulator is located at latitude 69.745721° and longitude 28.021987°. The minor draws its supply from the Narli Minor at its RD No.27. Piyaro minor has a design discharge size of 16.2 cusecs and its total length is 45 RD (3.8miles), (20064ft). The minor has 14 outlets/watercourses. The cultural command area under this minor is 2900 acres.

Dilwaro minor is an unlined channel. It is located in the subdivision of Ubauro. The head regulator of this minor is situated at Longitude 69.778867° and Latitude 28.266647°. The channel off takes from Ghotki Feeder. The design discharge of the minor is 76.68 cusec with a total length of 99RD, (8.4Miles), (44352ft). Total 33 outlets/watercourses off-take from this channel. The total cultural command area of the minor is 6464 acres.

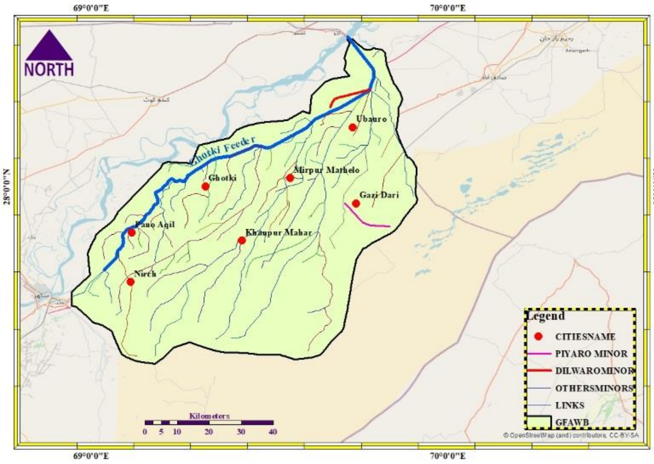

Figure 1: Layout base map of Piyaro minor and Dilwaro minor in Ghotki feeder canal area water board

2.2 Data Collection

2.2.1 Discharge Measurement

The most common practice is the area-velocity technique, commonly the Current meter method is depending on the calculation of mean discharge (Q) using velocity (V) and cross-sectional area (A). If the mean channel flow is normal to the direction of flow and also the cross-sectional area of flow is known, then the product of these variables concludes the discharge (Q) of the channel.

$$\mathbf{Q = AV} \tag{1}$$

Where, Q= Discharge/flow rate in cusecs, V= Velocity of cross-sectional in m/s2, A= Cross-sectional area in feet.

The Hydrologists determine the depth of the channel and the velocity at particular intervals across a channel by wading or boat. The depth or height (h) of flowing water and the positions across the channel are attained by using the staff rod for depth and measuring the tap for distances. The current meter is used to measure the velocity at each selected interval.

2.2.2 Current Meter

It is an instrument used for measuring the velocity of flow water in a river, streamflow, canal, or minors. The current meter should respond instantaneously and constantly to any differences in the velocity of the water. It should be durable, easily maintained, and simple to use under a change of environmental conditions. Consistent meter performance depends on the design and the manufacturing tolerance. There are different types of current meters available on the market. They are grouped into three major categories namely mechanical current meter, electromagnetic current meter, and the more recently introduced Doppler velocity meters.

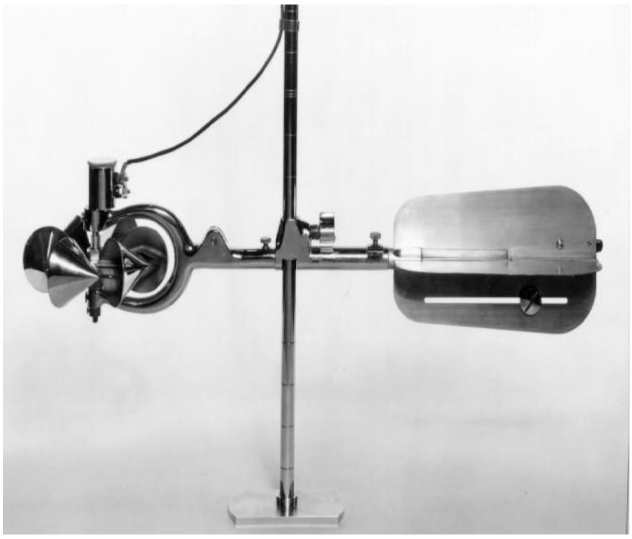

Figure 2: Pictorial view of Pygmy type Current meter

2.3 Development of Rating Curve (RC) and Rating Table (RT)

Stage-Discharge RC is termed as a relation between the stage level and flow rate of channel cross-section (Shah et al., 2021). It is a well efficient relationship of both stage-discharge. Thus, it is procured as a plan and uninterrupted curve with a reasonable degree of sensitivity. If the flow of the channel is not uniform it should not be a unique stage-discharge relationship due to the changeable nature of channel or river flow and not be uniform. Therefore, its relation defines approximation, not the truth (Henderson, 1966). Several measured discharges, when plotted via stages, provide a connection that characterizes the integrated effect of a wide range of channel and flow parameters. The combined effect of these parameters is generally categorized as permanent and shifting. In shifting control, the parameters are not static and it varies with time. In permanent control, the parameters are constant (Subramanya, 2006). In this paper, the RC and RT were created after the calculation of measured three discharges on different heights of gauges/stages. The discharge data was put into Origin software environment and plotted a graph for the development of the power equation and RC. The measured discharge values are shown in the curve in (Figures 3 and 5) of both minors. From the linear curve, the power equation formed for both minors (Equation 2 and 3). By using equations, RT was created for both minors for the different flows of water that are required in the season cropping season sowing to harvesting.

$$Q = 0.4988H^{3.2323} \quad \text{Piyaro Minor} \quad (2)$$

$$Q = 49.225H^{0.8893} \quad \text{Dilwaro Minor} \quad (3)$$

3. Results and Discussion

3.1 Discharge Measurement of Piyaro Minor

Three sets of discharges were measured at the head of the Piyaro minor approximately 150ft away from the gates due to the fluctuation of flowing water. The cross-section of minor measured 20ft. The discharge measurements were taken on different gauge heights 2.78ft, 3.6ft, and 4ft. The flow rates were taken at different levels (full level, medium level, low level). The current meter was used for discharge measurement. Flow rates data were prepared in MS Excel and plotted in Origin software, and the discharges were calculated on representative gauge heights. The discharges were calculated at 13.640 cusecs, 30.944 cusecs, and 44.45 cusecs (Figure. 3). For plotting of RC, these flow rates were used and a power equation was formed to calculate discharges on the different gauge heights. Therefore, the regression model was developed via plotting the stage-discharge data in the form of RC in Origin software (Figure. 4).

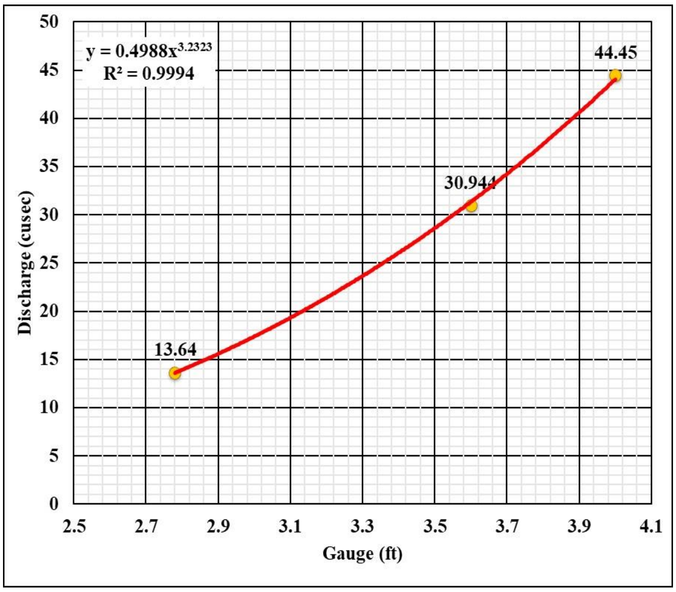

Figure 3: Represents a linear curve of measured discharge on different stage height

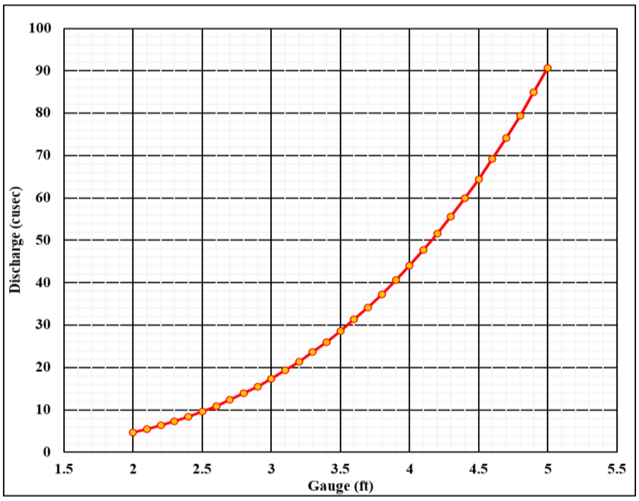

Figure 4: Illustrate the RC of the stage-discharge relationship

Table 1: Illustrates RT for the different stage-discharge relationship

Piyaro Minor			
Gauge (ft)	**Discharge, Q (cusec)**	**Gauge (ft)**	**Discharge, Q (cusec)**
0.5	0.053	2.8	13.908
0.6	0.096	2.9	15.579
0.7	0.157	3	17.383
0.8	0.242	3.1	19.327
0.9	0.355	3.2	21.415
1	0.499	3.3	23.655
1.1	0.679	3.4	26.051
1.2	0.899	3.5	28.610
1.3	1.165	3.6	31.337
1.4	1.480	3.7	34.239
1.5	1.850	3.8	37.322
1.6	2.279	3.9	40.591
1.7	2.772	4	44.052
1.8	3.335	4.1	47.712
1.9	3.971	4.2	51.577
2	4.688	4.3	55.653
2.1	5.488	4.4	59.946
2.2	6.379	4.5	64.462
2.3	7.364	4.6	69.208
2.4	8.451	4.7	74.191
2.5	9.642	4.8	79.415
2.6	10.946	4.9	84.888
2.7	12.366	5	90.616

3.2 Discharge Measurement of Dilwaro Minor

Three sets of discharges were measured at the head of the Dilwaro minor approximately 150ft away from the gates due to the fluctuation of flowing water. The cross-section of minor measured as 20ft the measurements were taken on different gauge heights 1.4ft, 1.75ft, and 2.6ft. The current meter was used for discharge measurement. After the collection of data, MS Excel was used to calculate the total discharge on representative gauge heights. The discharges were 65.753 cusecs, 82.210 cusecs, and 114.510 cusecs were noted (Figure. 5). For the plotting of RC, these discharges were used for developing power equations. And the developed equation was employed for calculating the discharges on the different gauge heights. As from calculated results, the stage-discharge relationship for Q=f(h) was developed using statistical analysis from the observed discharges and water height data of the minor. Consequently, the regression model has been developed via plotting stage-discharge data in the form of RC (Figure. 6).

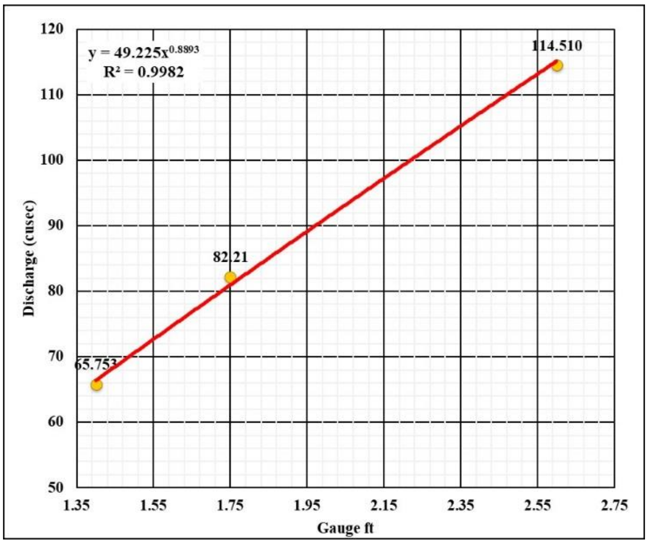

Figure 5: Represents a linear curve for measured discharge at a different gauge height

Table 2: Illustrates RT for the different stage-discharge relationship

Dilwaro Minor			
Gauge (ft)	Discharge, Q (cusec)	Gauge (ft)	Discharge, Q (cusec)
0.5	26.575	2.3	103.245
0.6	31.253	2.4	107.228
0.7	35.845	2.5	111.192
0.8	40.365	2.6	115.139
0.9	44.822	2.7	119.069
1	49.225	2.8	122.983
1.1	53.579	2.9	126.881
1.2	57.890	3	130.764
1.3	62.161	3.1	134.634
1.4	66.395	3.2	138.489
1.5	70.597	3.3	142.331
1.6	74.767	3.4	146.160
1.7	78.909	3.5	149.977
1.8	83.023	3.6	153.782
1.9	87.113	3.7	157.575
2	91.178	3.8	161.357
2.1	95.222	3.9	165.128
2.2	99.244	4	168.888

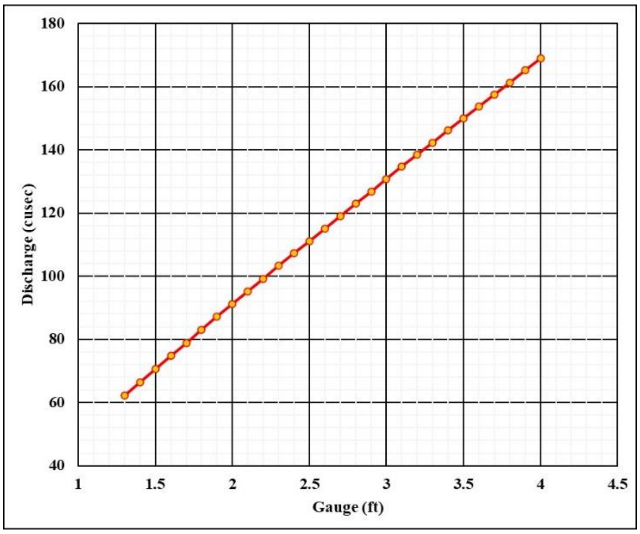

Figure 6: Represents RC of the stage-discharge relationship

4. Conclusion

Monitoring of hydrological regimes has achieved imperative concern due to climate change impacts and water resources management. Irrigation canals monitoring and management of flowing water forms a critical basis for water management. The total volume of the irrigation network is controlled by hydrological methods that can be defined by the topographic surface, geological parameters, and climate of the agricultural command area, as well as the intervention of humans. Regular monitoring information and data of canals, channels, and minors encourages justifiable use of irrigation water and enables a periodic record for the hydrologists, policymakers, and farmers. The management of precious irrigation water for crops is much crucial than how much quantity of irrigation water is needed for crops. Based on past and present literature, fieldwork, we concluded that this factual data and information benefits for improving water productivity, water accessibility, and optimum allocation of water resources.

- The specific conclusion of the study is that the created stage-discharge relationship (Equation 2) can be utilized for measuring the flow rate in the Piyaro minor at a different stage.
- (Equation 3) can also be used for the flow discharge of Dilwaro minor at a different stage.
- The Piyaro minor RT was developed using a power equation. The range of stage-discharge was calculated from 0.5 (0.053 cusecs) to 5ft (90.616 cusecs).
- The Dilwaro minor RT was developed using a power equation. The range of stage discharge was calculated from 0.5ft (25.575cusecs) to 4ft (168.888 cusecs).

5. Discussion

This study aims to manage fairness, consistency, and irrigation efficiency among the water distribution at the farmer level. Calibration of minors and canals is a prerequisite for operative service conveyance and better concert of the irrigation system. It is projected to calibrate stages and hydraulic structures of all the minors in different water area boards. It is necessary to develop RCs for actual discharge on daily basis, seasonal, and annually based on stage readings. Based on discharge measurement, capability, and reliability of flow for future designs and use of data in farm preparation and management. Development of RCs, RTs, and equations for irrigation network or hydrometric stations have huge potential benefits including the timely establishment of the gauge-discharge relationship, a good understanding of flow rate conditions within the section and on reaches (head, middle, and tail) of the streams. It expands the reliability of the irrigation network as well as improves the cost-effectiveness and productivity of the hydrographic work. The RC is the only reliable flow estimation technique available. Routine activities including height and flow rate measurements, flood marking, and vegetation density surveying are still critical in improving the confidence of RCs. It is vital to have knowledge that each RC is unique to a particular river, canal, or minor. Because the geometry of each stream changes, so the RC also changes. A rating curve should never be applied anywhere except for the location where the stage-discharge relationship was developed.

Suggestion

The main limitation of the present research study suggested that an automatic gauging station should be established on both minors and also di-siltation should be done on the minors.

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Declaration

The authors declare that there is no conflict of interest regarding the publication of this manuscript. Above and beyond, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication, falsification, double publication or submission, and redundancy have been completely observed by the authors.

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