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Research Paper

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Seepage Losses Measurement of Desert Minor and Development of Gauge-Discharge Rating Curve: A case study in District Ghotki, Sindh

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Abstract— Pakistan is blessed with an intricate irrigation system typically comprising a wide network of canals, minors, distributaries, and watercourses. A huge amount of flowing water from irrigation channels is lost by seepage, which is the cause of waterlogging, salinity, and affects the conveyance efficiency of water to the field. This potential menace is solving efficiently by the Government, a lining of irrigation canals, minors, and distributaries to overcome the seepage losses. In this case study, seepage loss, conveyance efficiency, and calibration of the gauge rating curve are typically developed for a Desert Minor. There is a dire need to identify and prioritize the cause of losses in earthen channels so that rehabilitation and maintenance can be done accordingly. The general inflow-outflow technique was properly used to accurately estimate the seepage losses by using the current meter. The proper discharge was carefully measured for the seepage losses in a selected length in Desert Minor. Inflow was carefully measured at 28RD 159.933 and outflow 31.28 RD, 158.533 cusecs in a selected reach. The total selected reach length was 3.28 RD where the key difference of proper discharge of 1.35 cusecs was noted. Seepage loss of 2.35 cusecs was determined. The total wetted area of the minor was 2834093 ft² calculated. The total seepage loss of Desert Minor 17.46 CFS and 17.4% were carefully estimated. The conveyance efficiency of desert minor 83% was properly recorded. For calibration of the Gauge rating curve, three different discharges were measured head of Desert Minor 95.463, 163.198, and 202.534 cusecs on different gauge levels 0.95, 1.5 and 2 feet. An equation and rating table of a Desert minor was developed to calculate the different discharges with gauge height.

Keywords— Seepage Losses, Conveyance Efficiency, Desert Minor, Rating Curve

I. INTRODUCTION

Freshwater is becoming insufficient, and the continuous demand for adequate water supply is increasing day by day. Freshwater will be more difficult to find and accomplish the demands of the agricultural, industrial as well as domestic purpose in the coming years. Competing demands of freshwater resources sufficiently indicate the specific need for sustainable water management and quality research for evaluation of the cause of freshwater losses and to improve the water supply system accordingly. The agricultural economy serves as the lifeline of Pakistan, and it is dependant on a widespread network of canals for irrigation. For this key reason, it is amid the most heavily irrigated land on the earth. But this conveyance network is severely hampered by irrigation water loss in terms of seepage which realistically is a major water loss in the supplying channel. Seepage from the network of irrigation canals, distributaries, minors, and watercourses is a significant loss of available freshwater due to the inefficient storage and transportation of water the conservation practices. The term seepage can be defined as the movement of water in and out of earthen channels or irrigation canals through pores from the bank and in the bed. Several factors affect the seepage from canals [1]. Soil texture in bed and bank of irrigation channels and canals, silt deposition, water level changes, soil chemicals, water velocity, evapotranspiration, irrigation of adjacent agricultural lands are the particular factors. Many of the researchers and irrigation engineers conducted studies and gave solutions for the proper management, design, new techniques and policies to reduce the seepage due to water shortages, unavailability, and increasing demand. Waterlogging and salinity are the problems due to seepage which make agricultural land uncultivable and unproductive [2].

The seeped water can produce piping, erode the channel banks and disturb the operational function of canals. Physical, empirical, and mathematical (analytical and numerical) techniques are practised to sesses the seepage loss from the canal which has major impacts on the management of groundwater and surface water [3],[4],[5],[6]. In analytical methods, mathematical equations are solved to assess the water flow through the porous media surrounding the canals. Nothing but, it is challenging to solve efficiently the groundwater flow problems by resorting to analytical methods because of their complex and nonlinear nature. The recharging of groundwater from the irrigated fields can be measured by adopting an analytical approach. There is a vast body of concerned literature addressing the conveyance loss in irrigation network. [7] reported in their study and prominently mentioned the satisfactory results of seepage losses from lined and unlined watercourses of Pakistan. [8] assessed the conveyance ad seepage losses, water losses influence and proper maintenance of irrigation channels also 50% reduction in the yield of wheat and, maize crop along the irrigation channel from head to the tail section. There is a dire need to evaluate the water losses in the earthen channel so that necessary maintenance can be carried out to improve sufficiently the efficacy of the canal system.

The relationship between gauge discharge is commonly known as the rating curve. The rating curve is referred to as a significant tool in hydrology because of authentic facts of discharge which enormously dependent on a valid gauge discharge courting at the gauging station. The rating curve extremely convenient for interpolating and extrapolating go with the discharge measurement and for the model demonstrating. It is a significant practical task; a wide theoretical practice is obligatory to generate a dependable too to switch from measure water level to flow measurement. Rating curve generally two parameters height vs discharge relation. Measurement of velocity (V) and cross-section area (A) give discharge. To generate a rating curve, at different gauge points discharge have to be determined using a minimum of 10 to 12 representing points covering the low, medium and high flows [9]. If there's a direct relation between discharge and gauge height, the discharge rating is referred to as a fundamental relation. A simple rating can be only one curve however there is also a compound curve consisting precisely of three segments for low medium and high [10]. Keeping in view, the above-mentioned problems of seepage losses. This study is primarily focusing on two core objectives in the Desert minor.

- Estimation of the seepage losses in a Desert Minor.
- Calibration of Gauge-Discharge Rating Curve of Desert Minor.

II. MATERIALS AND METHODOLOGY

Study Area

The study was carried out on Desert minor which off takes from Ex- Dahar Wah Lower RD-63 of Ghotki feeder canal. The Desert minor is an earthen channel and is located in the subdivision of Yaro Lund at Mirpur Mathelo. The head regulator of the channel is located at N 27.869968° Latitude and E 69.633491° Longitude. The Minor draws its supply from the Dahar Wah lower at RD-63. The minor has a design discharge of 217.74 cusecs with a total length of 150 RD, 45.70 km (28.4 miles). The total Gross Command Area (GCA) of Desert Minor is 17664 acres and (CCA) Cultural Command Area is 10400 acres. The total number of watercourses/outlets are 13 at different RDs.

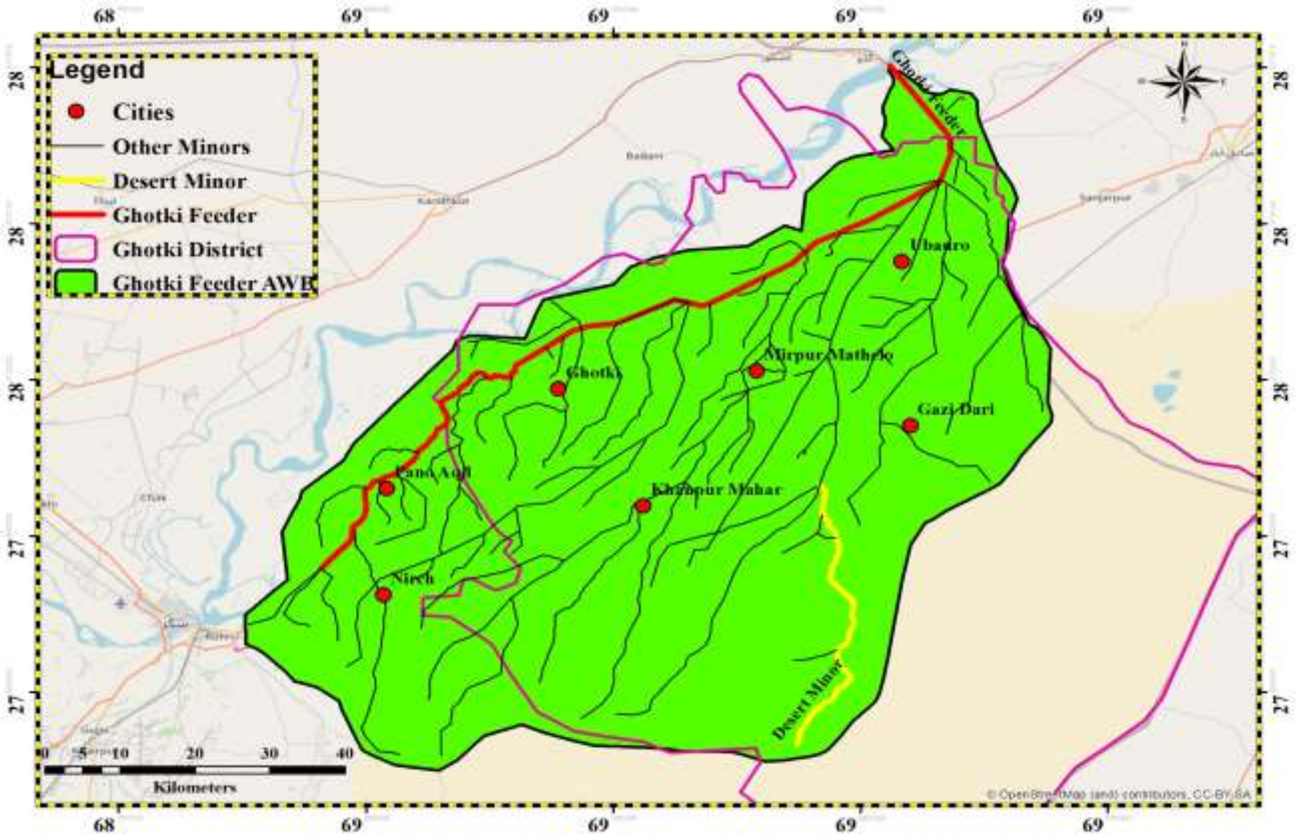

Figure 1 Layout Base map of Ghotki Feeder Area Water Board

Table 1 Illustrate Water course name, RD, GCA, CCA and Design Discharge on Desert Minor

S. No	Name of Water Course	RD	Gross Command Area	Total Cultural Command Area	Design Discharge (cusec)
1	1R	98	2865	1665	16.65
2	2L	100	1327	1199	11.99
3	3L	113	3832	3232	32.32
4	4L	114	2541	2341	23.4
5	5L	116	2972	1600	16
6	6R	116	1096	496	4.96
7	7R	128	1232	832	8.32
8	8L	128	4035	2235	22.35
9	9L	135	560	496	4.96
10	10R	135	1160	960	9.6
11	11L	146	932	632	7.32
12	12R	147	1430	980	9.8
13	13Tail	150	896	896	8.96
G. Total Area			24878	17564	176.63

Methodology

The proper methodology applied for carefully taking discharge measurements, and calibration is practically identical which has been applied in Pakistan and also followed to past literature. The procedure involved carefully measuring the various flow rates/discharges and calibrating them with water height observed on the standard gauge. Before the taking of discharge measurement, the gauge scale was installed on the Desert minor at a proper location where fluctuation has minimal and the gauge has to be readable and discharge can be measured appropriately. Initially, the minor has flowed on its design discharge with control structures and distinct stages were observed. The discharges were then varied at the rate of flow, middle, low and high of its respective design discharge and the water level was noted.

Preliminary Survey of Desert Minor

The preliminary survey was conducted before the computing of discharge measurement to ensure the current condition of the regulator, height and length of transition walls, working condition of gates, bed situation, weeds, bushes and path of the minor. Possible usage of the equipment and device for computing discharge measurement and methods to implement, outlet numbers, conditions and meeting with staff of irrigation to collect required information and data.

Estimation of Seepage Losses and Efficiency of Test Length

Seepage is the most leading issue by which water is lost in the conveyance irrigation network. It is important to make good and effective planning is required for the seepage losses in the conveyance system. However, in this study, seepage losses for the Desert minor were properly estimated through the standard technique inflow-outflow method. This effective method has widely been used in several studies in Pakistan. Flow measurements using the current meter have been carried out at the start and end of the selected reach and all off-taking outlets within the selected reach length. The key difference between inflow-outflow (at the end of selected reach plus total off-takes discharge of outlets) gives the losses in the channel within the selected reach. A schematic diagram showing a typical sample channel selected reach, and design measurement locations are presented in figure.2.

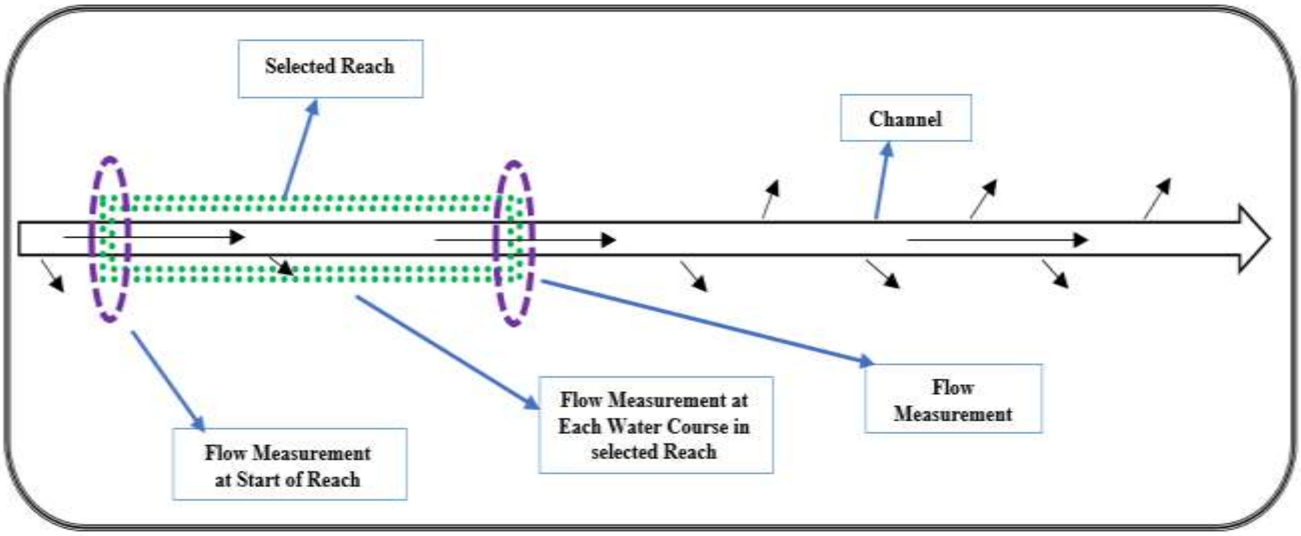

Figure 2 Represents schematic diagram of flow measurement in selected reach for estimation of seepage and conveyance efficiency in Desert Minor

After taking discharge measurement at the selected location (start and the end of reach), the conveyance loss has been calculated by the following equation.

$$\mathbf{QLoss = Qin - Qout - Qoff} \quad \textbf{(1)}$$

Q_{loss} = Conveyance loss in (CFS)
Q_{in} = Inflow at start of reach (CFS)
Q_{out} = Outflow at end of a section (CFS)
Q_{off} = Lateral outflow of outlets (CFS)
The Q_{loss} has been expressed in terms of cusecs/million square feet (CFS/MSF) as well as in percentage of inflow. The conveyance loss in term of percentage (% Qloss) has been further used for the assessment efficiency of the minor using the following equation:

$$\mathbf{Conv{:}\ Effiency(\%) = 100 - \%QLoss} \quad \textbf{(2)}$$

Conveyance losses in minor were also calculated in the wetted area by the following relationship

$$\mathbf{SL = (Qloss)/(P \times L) \times 10^6} \quad \textbf{(3)}$$

Where
SL = Seepage loss in cusec per million sq. ft
Qloss = Loss of water in minor reach in cusec
P = Wetter perimeter in ft
L = Length of selected reach of minor, ft

The wetted perimeter (P) is calculated for the portion of test length during inflow outflow for conveyance losses. For the determination of losses of the total length of the minor, the average wetted perimeter indicating total length is needed for the calculation. For this calculation, wetted perimeters were determined at the head, middle, and tail reaches of the Desert minor, and also the same process for a head, middle and tail reaches were measured for the average wetted perimeter. Again, the average of the average head, middle and tail sections were measured for wetted perimeter results. After that average head ratio was determined for the minor.

The seepage losses of test length were not enough for the total length of the minor. So, therefore, for total seepage losses for the full length of the minor, seepage losses per unit area that is 1 ft^2 was determined and multiplied with the total average wetted area of the full length of minor and for making average wetted area, the average of the head, middle and tail portions of minor were acquired and multiplied with the full length of the minor.

The factor is developed for average wetted perimeter by taking wetted perimeter at the head, middle, and tail portions along with the minor.

Flow Measurement Method

The full-section method was used for discharge measurement within minor reach. The discharge or flow rate of minor at a given time is the summation of measured discharge in number (n) of sub-section of the minor and is represented by the following equation.

$$\mathbf{Q = W\left(\frac{d_1+d_2}{2}\right)\left(\frac{v_1+v_2}{2}\right)} \quad \textbf{(4)}$$

Where:
$Q = q_1 + q_2 + q_3 + \ldots\ldots + q_n$
$q_1 = v_1$ x $((b_2-b_1)2)$ x $_1$
Q is minor discharge,
q is subsection discharge
v_1 is the velocity in mid of 1st subsection
w_1 is the start of the 1st subsection from the initial point w_2 is the end of the 1st subsection from the initial point d_1 is the depth of water in the mid of the 1st subsection.

Estimation of Seepage Loss and Efficiency on Desert Minor

Seepage losses measurement activity was conducted in Desert Minor. The inflow and outflow performance were employed for the evaluation of water losses. A length with a uniform channel shape of prism and minimum or no lateral off-takes was selected. The current meter was used for inflow and outflow at both the initial and the ends of the selected reach for the study undertaken. Seepage loss measurement was taken under steady flow conditions. Seepage loss has been calculated as the difference of measured discharges at the upstream and downstream end of the selected reach, and then corrected for any lateral off-takes. For the calculation of the wetted area, an average wetted perimeter was multiplied with the total channel length. The seepage losses rate is expressed in cusecs per million square feet of the wetted area (CFS/MSF).

Calibration of Gauge-Discharge Rating Curve of Desert Minor

Daily discharge determination of a channel or canal may be a very tough task and expensive however the incessant records of the canal stage can be acquired without difficulty. Hence for computing the daily flow of the channel there must be a sufficient relationship between gauge and discharge/flow rate. Discharge ratings for gauging stations are generally decided empirically via periodic measurements of discharge and stage. The discharge measurements are taken by the current meter. Measured discharges are then plotted against concurrent gauge readings on graph paper to define the rating curve of the channel. For plotting a Gauge-Discharge Rating Curve of Desert minor, three discharge measurements were taken on different gauge readings low, middle, and high level of discharge, and the equation was developed for the Dessert Minor.

$$Q = 102.54H^{1.0252} \quad (5)$$

III. RESULTS AND DISCUSSION

In this research study seepage losses of Desert Minor were calculated by using a general method of inflow and outflow. For losses, a segment of length was selected for seepage measurement which starts from 28 RD (inflow) to 31.4 RD (outflow) with a difference of 3.28 RD. The discharge was calculated by using the current meter. The total seepage losses were calculated in Desert Minor 17.46 CFS, and 17.4% overall. The conveyance efficiency of the minor was determined as 83% which is short of 17% water for conveyance in a minor. Table 2 shows the measured results of losses and efficiency.

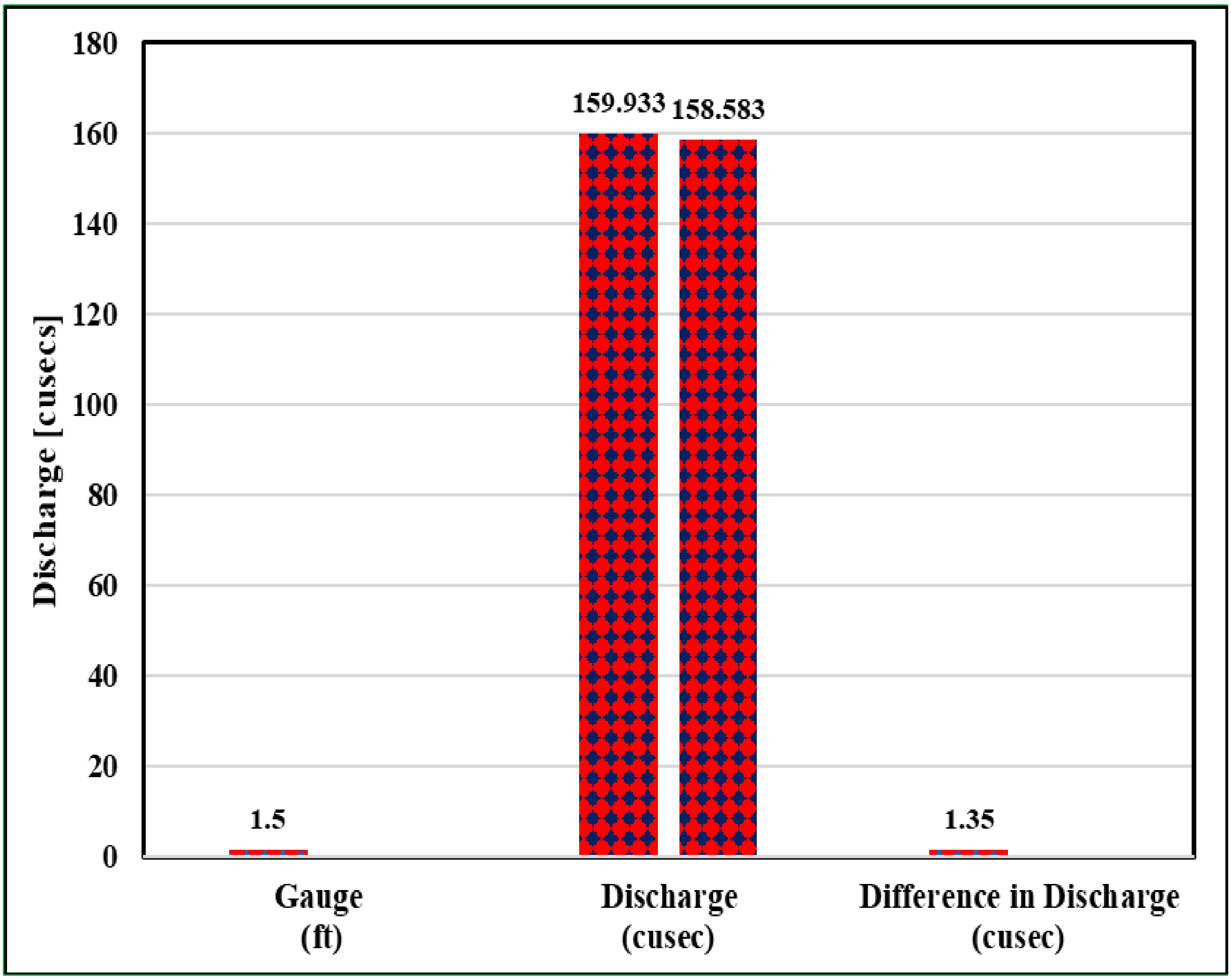

Figure 3 Represents Inflow-Outflow discharge of section

Table 2 Illustrate seepage losses and conveyance losses

Chanel Name		**Desert Minor**
Total Test Length (ft)		**3281**
Total Length (ft) of Minor		**149952**
Design Discharge of Minor (cusec)		**217**
No. of Off Takes Water Courses		**0**
Discharge (Q)	**Q_{Inflow}**	**159.933**
	$Q_{Outflow}$	**158.583**
	Difference	**1.35**
	Q_{Off}	**0**
	Losses	**0.0000098**
	Q_{seep}	**2.35**
Wetted Perimeter (ft)	**Head**	**42**
Wetted Perimeter (ft)	**Average**	**18.9**
Total Wetted Area (ft^2)		**2834093**
Seepage Losses	**cfs**	**17.46**
	%	**17.4**
Efficiency	**%**	**83**

Gauge-Discharge Rating Curve of Desert Minor

The discharges were taken using the current meter. The calibration technique consists of measuring the different flows rates and calibrating them with the water levels on gauges, before the measurement of discharges and correlating them with the stages, the gauge was installed at a suitable location where minimum undulations or fluctuations in water levels. the discharge was measured at the different levels low, middle and high of its respective design discharge. And gauges were noted at each discharge level. As a result, the Gauge-discharge relationship for Q=f(h) was developed using statistical analysis from the observed flow rates and water level data for the minor. Thus, it is possible to calculate the discharge released through the hydraulic structures from the designed calibration curve. The regression model was developed by plotting the gauge-discharge data in the shape of the rating curve.

For calibration of the Gauge-Discharge rating curve, three discharge measurements were conducted on different gauge height at a low, middle, and high level of flow. Downstream Gauge readings were noted for three discharges i.e. 0.95, 1.5, and 2 feet, and discharges were measured on these three-gauge readings 95.46, 163.20, and 202.50 cusecs.

Table 3 Illustrate Gauge height, the width of the section and discharge

S. No	**Gauge (ft)**	**Width (ft)**	**Discharge (cusec)**
1	**0.95**	**58.5**	**95.463**
2	**1.5**	**58.4**	**163.198**
3	**2**	**61**	**202.534**

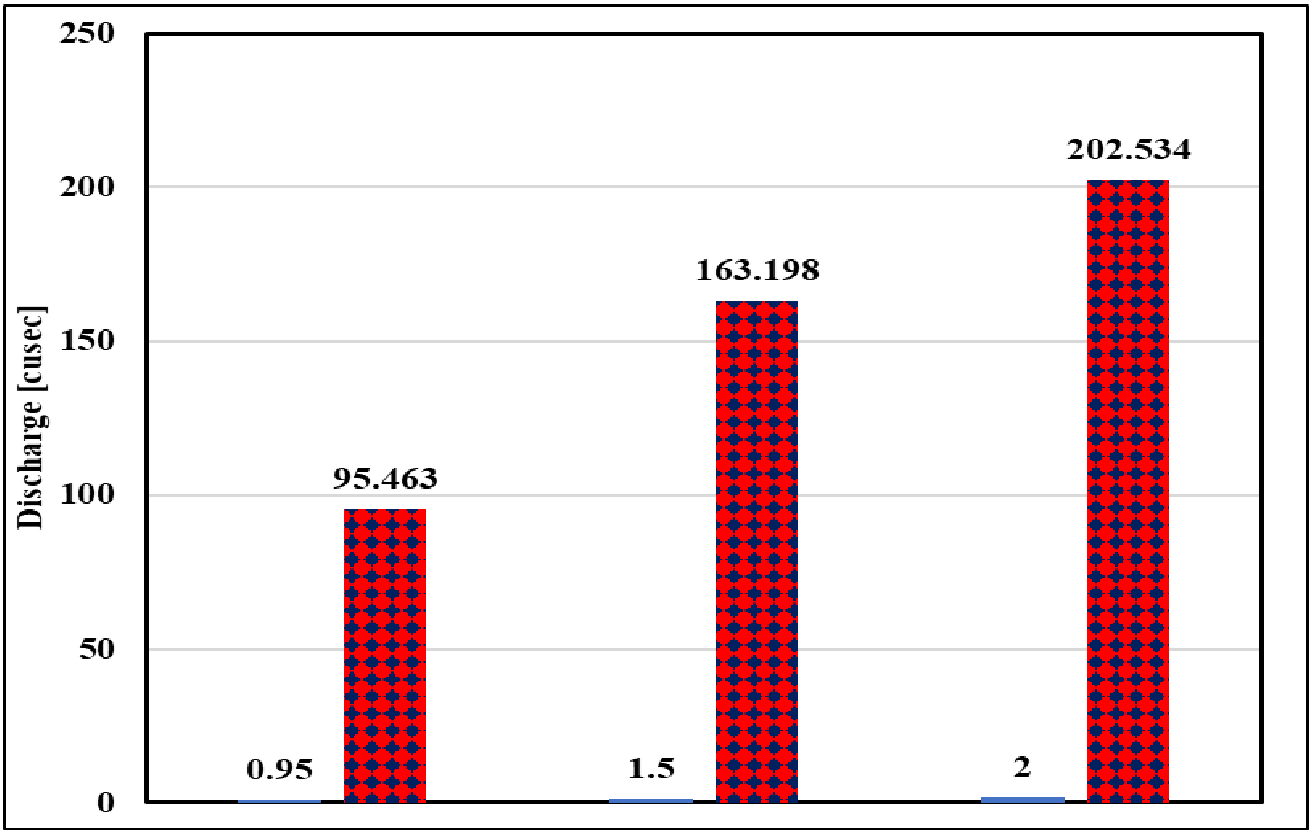

Figure 4 Represents Discharge at a different gauge height

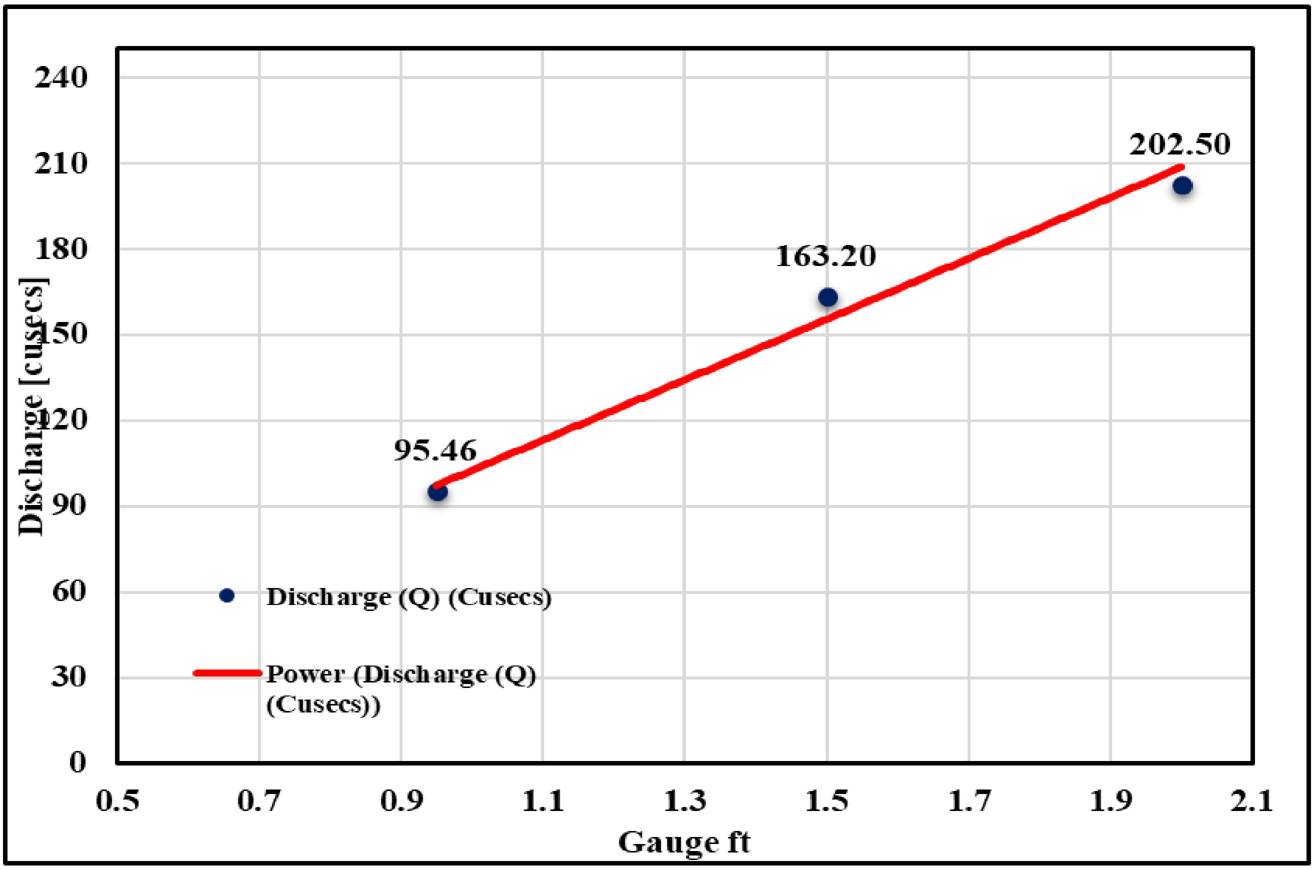

Figure 5 Represents Linear Curve on different discharge points

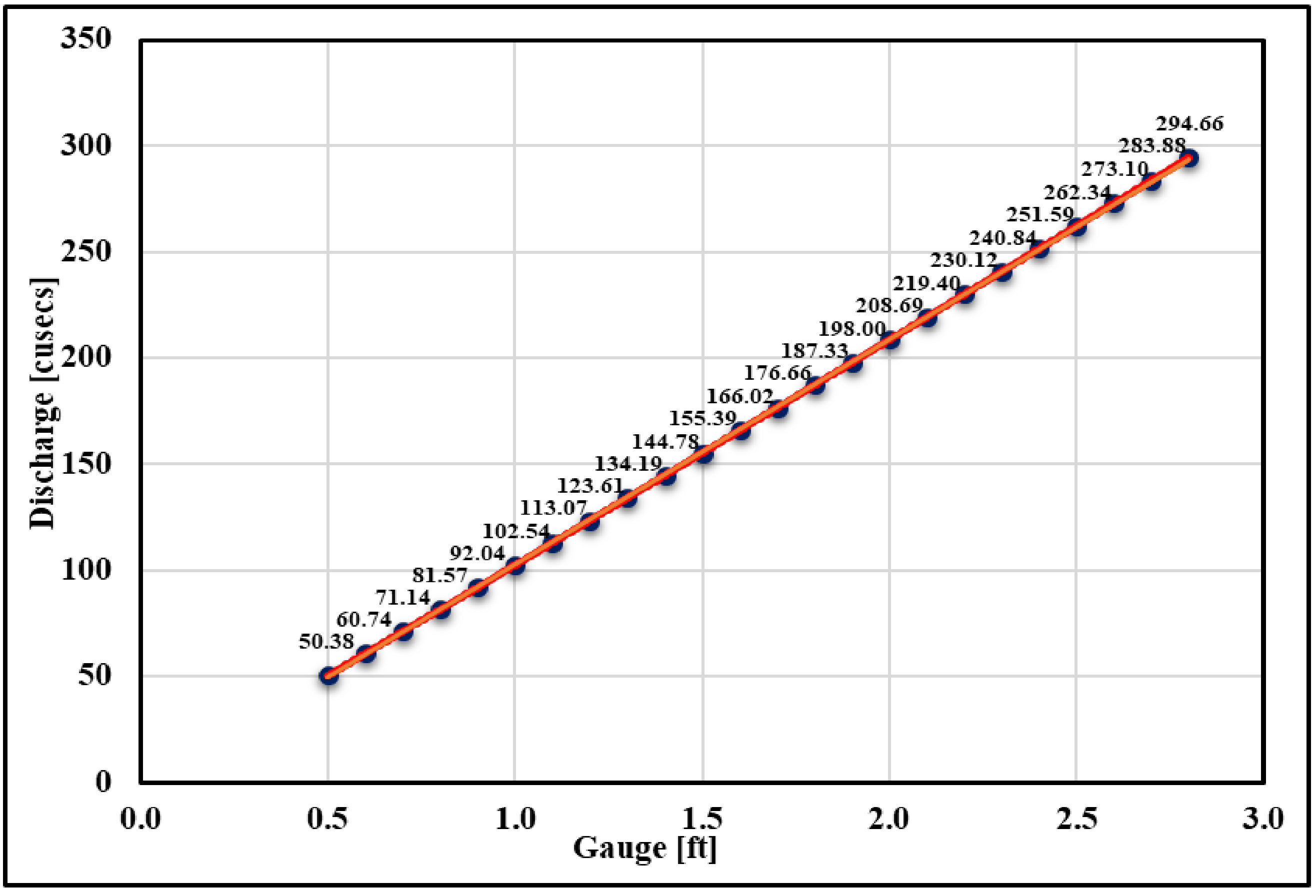

Figure 6 Represents Gauge-Discharge Rating Curve

Table 4 Illustrate Gauge-Discharge Rating Curve table for different Gauge height

Gauge (ft)	Discharge, Q (cusec)	Gauge (ft)	Discharge, Q (cusec)
0.5	50.38	1.7	176.66
0.6	60.74	1.8	187.33
0.7	71.14	1.9	198.00
0.8	81.57	2	208.69
0.9	92.04	2.1	219.40
1	102.54	2.2	230.12
1.1	113.07	2.3	240.84
1.2	123.61	2.4	251.59
1.3	134.19	2.5	262.34
1.4	144.78	2.6	273.10
1.5	155.39	2.7	283.88
1.6	166.02	2.8	294.66

IV. CONCLUSION AND FUTURE SCOPE

In irrigated agriculture, effective management of precious water resources in an effective way commences with knowing the quantity of water being distributed from the source and the quantity of water needed for crops. This factual information and collected materials benefit in finding the seepage losses and improving water productivity. After a comprehensive evaluation of these problems, this case study was properly conducted for unlined/earthen Desert minor in district Ghotki with aims to calculate the seepage losses, conveyance efficiency, and development of the rating curve. The inflow outflow method was adopted to carefully assess the seepage loss, operational efficiency, and different discharge measurements on the head of the Desert minor for typically developing the rating curve. The results were determined as the difference in inflow and outflow discharge takes the amount of water during conveyance of irrigation water in a Desert minor. The determined discharge at inflow was 159.93 and at outflow 157.93 cusecs. 1.35 cusec differences were noted and losses 2.35% in a selected segment length. The total seepage losses in a full length minor 17.46 CFS were determined. Wetted Perimeter has measured 42.533ft. During inflow and outflow, there was no off taking outlets or watercourse. The conveyance efficiency was calculated as 83% along with the minor. For calibration of the gauge rating curve, three discharges were measured on different gauge readings i.e., 0.95, 1.5, and 2, and discharge computed 95.46, 163.2, and 202.5 cusecs. An equation and rating table were developed for the Desert Minor.

Thus, the research study aimed to recover efficiency, consistency and fairness in the irrigation system and to familiarize water measurement, collect, store the actual data and distribute discharge for effective management of service conveyance and expand the performance of the irrigation network. The actual record, database and management information system is desirable to be recognized in other minors/channels or canals of area water board for the broadcasting of day-to-day flow data and other information on appropriateness and reliability of water flow to keep water users up to date for their preparation, planning and management of cropping system leading to saving of inputs and improved crop production.
Meanwhile, calibration of minors/distributes and canals is a prerequisite for operative service conveyance and better performance of the irrigation system, it is proposed to calibrate gauges and structures of all the channels distributors in the Ghotki Feeder Area Water Board. To developing rating curves for measurement of discharges on the day-to-day, scheduled, seasonally and yearly based on gauge readings. Based on flow measurement for the development of capability and reliability of flow for future calculations and usage of that information and data in farm preparation and management.

The key factor that largely influences the seepage losses is the soil factor that has been unstudied here, but the established equations are created only discharge which is a limiting factor for areas having problematic soil properties than those used in this research study.

ABBREVIATIONS

WAPDA	Water and Power Development Authority
RD	Reduced Distance
N	North
E	East
GCA	Gross Command Area
CCC	Cultural Command Area
P	Perimeter
A	Cross-sectional Area
V	Velocity

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Not applicable

AUTHOR’S CONTRIBUTION

Shoukat Ali Shah did fieldwork and collected the required data and analyzed it, Tahira Khurshid wrote the introduction of the study. Madheea developed images and excel work. All authors of this manuscript read, agreed and approved the final manuscript.

COMPLIANCE WITH ETHICAL STANDARDS

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AVAILABILITY OF DATA AND MATERIALS

Research data and other material are given in the research paper.

CONFLICT OF INTEREST

All authors declare that they have no conflict of interest.

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