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FIELD DISCHARGE CALIBRATION OF HEAD REGULATORS, MIRPURKHAS SUB-DIVISION JAMRAO CANAL, NARA CIRCLE, SINDH PROVINCE, PAKISTAN

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FOREWORD

The International Irrigation Management Institute (IIMI) opened an office at Hyderabad in Sindh Province on 1 September 1995. This was done to undertake a pilot study on Farmer-Managed Irrigated Agriculture under the Left Bank Outfall Drain Stage-I Project. About 16 months earlier, planning had been completed to support this research effort with a program on Decision Support Systems (DSS) under the project, Managing Irrigation for Environmentally Sustainable Agriculture in Pakistan, funded by The Netherlands.

The planning for this DSS program began in early 1996. A few months later, Mr. Abdul Hakeem Khan was transferred from Lahore to Hyderabad. Mirpurkhas Sub-division of Jamrao Canal was selected for the initial effort because:

1. One of our three pilot distributaries was located in this command area;
2. The remodeling of Jamrao Canal had been completed in June 1994; and
3. A telecommunications system was to be installed for Nara Canal, which includes Jamrao Canal.

Several meetings were held with staff of the Department of Irrigation and Power, Province of Sindh. Also, a one-day seminar on DSS was conducted in Hyderabad. The Inception Report was completed during the summer of 1996.

A field team of five people were recruited in August 1996 and trained in Malik Sub-division near Bahawalnagar in Southeastern Punjab during August-September 1996. The Mirpurkhas Field Station (DSS) was opened in September 1996. Then, the field research program was underway.

This report on field calibration of the distributary head regulators in Mirpurkhas Sub-division represents one of the essential requirements for DSS. There is a lot of learning contained in this report. An example is the procedure for analyzing current metering field data to arrive at the discharge rating for a gate structure. The lesson is that small details make a large difference!

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This report presents the work done by the "Decision Support System" team of IIMI Pakistan during the period November, 1996 to October, 1997. This study includes some basic data regarding the study area from the Irrigation Department, Sindh, field observation by IIMI staff and the Analysis of the observed data.

We would like to thank Mr. Khadim Ali Memon, S.E. Nara Canal, Mr. Junaid Ahmad Memon, Executive Engineer Jamrao Canal, Mr. Iqbal Ali Shah, former S.E. Nara Canal and Mr. Ghulam Mustafa Ujjan, Assistant Executive Engineer Mirpurkhas Sub-division for all kind of support in furnishing the required information and visiting our activities from time to time. We also appreciate them for their valuable suggestions during the study.

Thanks are also due to Mr. Saqlain Shah and Mr. Sohrab Shah of the Irrigation Department for their kind help in providing the various data and maps regarding the system from time to time. In fact these two gentlemen have very long association (more than thirty years) with the Jamrao Canal and are more informed about it than anybody else. Thanks are also due to Ms. Vinnie for editing the draft.

At last, we feel very grateful to Dr. Yameen Memon, Dr. Shafqat Ejaz, Mr. Asghar Ali Memon, Mr. Ahsan Ali Qazi and Mr. Ayaz Anwar Solangi for all kind of support that was needed in the office or outside the office. Special thanks are also due to Mr. Tabrez Ahmad, Secretary, and Mr. Mohammad Akram Khan, Executive Secretary, IIMI-Pakistan, for their efforts in formatting, compiling and printing this report.

Chapter 1

INTRODUCTION

1.1 BACKGROUND

The growing global awareness for the necessity to improve the agricultural productivity of existing irrigated lands is increasing. A major thrust in these efforts is to improve irrigation water management practices, but knowledge about the resource being managed is required in order to do so. This would imply that, as a minimum, the water must be measured at strategic locations within the system. The ideal situation would be to measure the discharge of every division in the system, including the quantity of water delivered to each farmer.

Water management is a fundamental basis to evaluate the operational performance of the system and management practices, and also to quantify the effects of improvements in those practices. This also includes the regime of channel, variability with space and availability in time of water supply in the channel . Therefore, reliable information pertaining to flow rates would help the manager to develop a decision support system.

Collection of reliable data is necessary to operate and maintain the system according to specification. Unreliable data mislead the manager in operation and maintenance of the system, as well as future planning to improve the system. Enhance the agriculture production would not be achieved. The management of irrigation water is dependent on reliable measurements of flow rates.

Discharge measurements are normally taken by the current meter in canals and distributaries, while in smaller watercourses, by Cutthroat Flume as well as current meter. However, using these instruments is a time-consuming process and if regular monitoring is needed, then it is not possible to use these instruments every time and collect discharge data.

In irrigation projects, discharge measurements are made only at head works; however, there are other numerous structures which could be used for discharge measurements if properly converted into flow measurement devices. These structures are: culverts, inverted siphons, drop structures, weirs, etc.

In the Jamrao Canal, Mirpurkhas Sub-division, the irrigation control structures are head regulators, cross regulators and outlets. Under the LBOD project, the sub- project, Nara Canal remodeling, all these structures are remodeled. Unfortunately, all these structures are not being calibrated. The technology to measure irrigation water is simple and has been available for a long time, but not implemented into routine operation practices.

Since initiating a research study on operational performance of the Jamrao Canal, Mirpurkhas Sub-division in 1996, it has been observed that all the offtakes and cross regulators are being operated without knowing the actual discharge in the canal and its offtakes. However,

the information being collected by the management are the water levels observed through gauges installed at the downstream control structures. The gauges being used to record the water levels have not been calibrated for a long time. The zeros of the gauges have silted up for a few feet.

In order to ascertain the flow rate at each irrigation control structure, two methods are generally implied: (1) Calibration of downstream gauges, and (2) Calibration of control irrigation structures.

In Pakistan, the downstream gauges are normally practiced to measure the flow rate in canals, distributaries and minors. These gauges are calibrated using the formula $Q=KD^n$; the relationship which is to be obtained using this formula is called "water level - discharge relationship". This methodology is generally simple and easy to understand, but the method needs fairly uniform depth, parallel flow lines and fairly uniform velocity throughout the cross section.

The disadvantages of this method are, for aggregation or degradation, a change in cross section just upstream or downstream of gauges, backwater effect and sudden closure of nearby outlets. Thus, the accurate discharge measurements can not be achieved, the relationship will not be applicable, and periodical calibration would be required.

Another method to measure the discharge in the canals, distributaries and minors is the calibration of irrigation control structures. The structure is said to be calibrated if the discharge coefficient, C_d, is determined. C_d is to be used in conjunction with measurements of gate opening and water levels to calculate the actual flow rate.

The calibration of the structures, such as head regulators and cross regulators, provides more accurate discharge data if all the variables, i.e, recording upstream and downstream water levels, gate opening, velocity measurements and area of the flowing water, are very carefully and precisely measured and analyzed. The advantage of calibrating structures is that it does not need periodical calibration unless some changes in the structure are made, such as increased leakage resulting from inadequate maintenance, which occurs over a number of years. The calibration should be a good tool to practical engineers, who could use it at any time. They could manage the network of water distribution properly and keep the record every time available. This reliable set of data would help the planner and designer to formulate a future strategy.

Mirpurkhas Sub-division of the Jamrao Canal has eleven head regulators (Offtakes). Six are on the main Jamrao Canal and five on the West Branch Canal. All the structures have been calibrated. The discharge coefficients and gate corrections for each structure have been computed. The methodology, and results, are explained in the following chapters.

Chapter 2

DESCRIPTION OF THE FLOW CONTROL STRUCTURES

2.1 GENERAL

Jamrao Canal offtakes from the Nara Canal at RD 575 on the right bank to carry 3,400 cusecs (1932 design capacity; the existing usual discharge is above 4,000 cusecs) to serve an area of about 935,000 acres. This system has been faced with the serious problem of sedimentation since its inception, which has caused the banks to raise from time to time. The bed level has been raised by about 8 feet due to sedimentation and some lift channels (e.g. Shahu Branch) have been converted into gravity.

Jamrao Canal is about 124 (canal) miles long, while the network of distributaries and minors is stretched to about 426 miles. There are three branch canals emanating from the Jamrao Canal; Dim Branch, Shahu Branch and West Branch Canals, offtaking at RDs 87, 163 and 291, respectively. The Dim and Shahu Branch Canals were remodeled to form part of the Jamrao Canal Remodeling Project in 1994, while the West Branch remains in its original condition.

As a part of the Left Bank Outfall Drain, Stage 1 Project, the Jamrao Canal has been remodeled in order to accommodate extra flow to be made available after the remodeling of the Nara Canal. A parallel channel has been constructed from RD 0 to 240 of the Jamrao Canal. Similarly, the cross and head regulators of distributaries and minors along the main canal, from RD 0 to 448, have been newly constructed. Some of the distributaries and minors have also been remodeled by providing new outlet structures and strengthening the banks.

From the management point of view, the Jamrao Canal and its distribution system has been divided into five sub-divisions, as shown in Figure 2.1. The culturable command area (CCA) and location of these sub-divisions along the system are given in Table 2.1.

Table 2.1. Major Sub-divisions of Jamrao Canal, with location and CCA.

S.NO.	Name of Sub-division	Location (RD)	CCA (ac)
1	Khadro	0 – 163 of Jamrao Canal	194,874
2	Jhol	163 – 291 of Jamrao Canal	157,523
3	Mirpurkhas	291 – 443 of Jamrao Canal & 0 – 143 of West Branch Canal	236,612
4	Kot Ghulam Muhammad	443 – 620 of Jamrao Canal	131,545
5	Digri	143 – 303 of West Branch Canal	194,669

This study was conducted in the Mirpurkhas Sub-division, the largest of the five sub-divisions composed of six offtakes from the Jamrao Canal, and five from the West Branch Canal. Half of the Jamrao Canal's offtakes in this sub-division are on the right side and the remaining half on the left side, while all the offtakes of the West Branch Canal Section are serving the area on the left side only, as shown in Figure 2.2. There are 36 direct outlets from the Jamrao Canal Section and 64 from the West Branch Canal Section. More than 90 percent of the outlet structures have been broken and tampered with by the farmers so that they can draw extra water. The salient features of the distributaries and minors of this sub-division are given in Table 2.2.

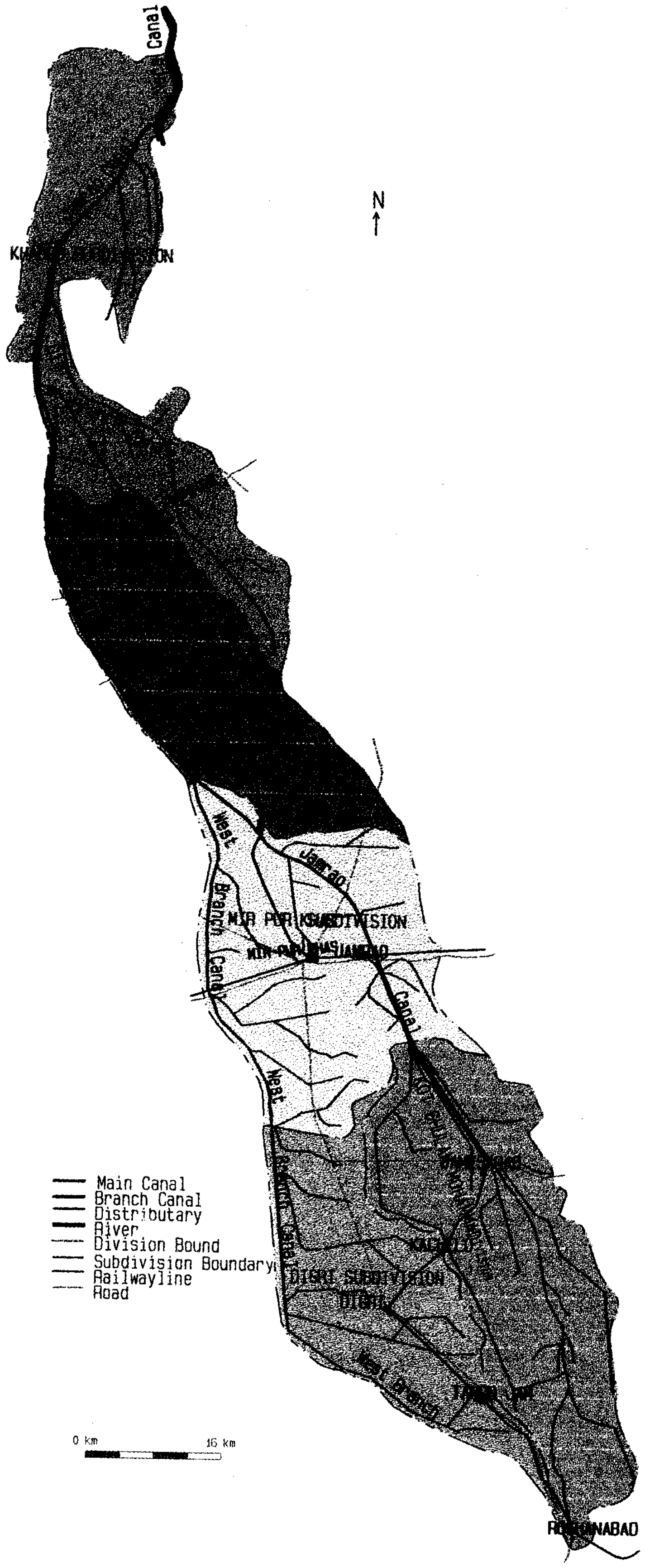

Figure 2.1. Jamrao Canal Command with the Sub-divisional Boundaries.

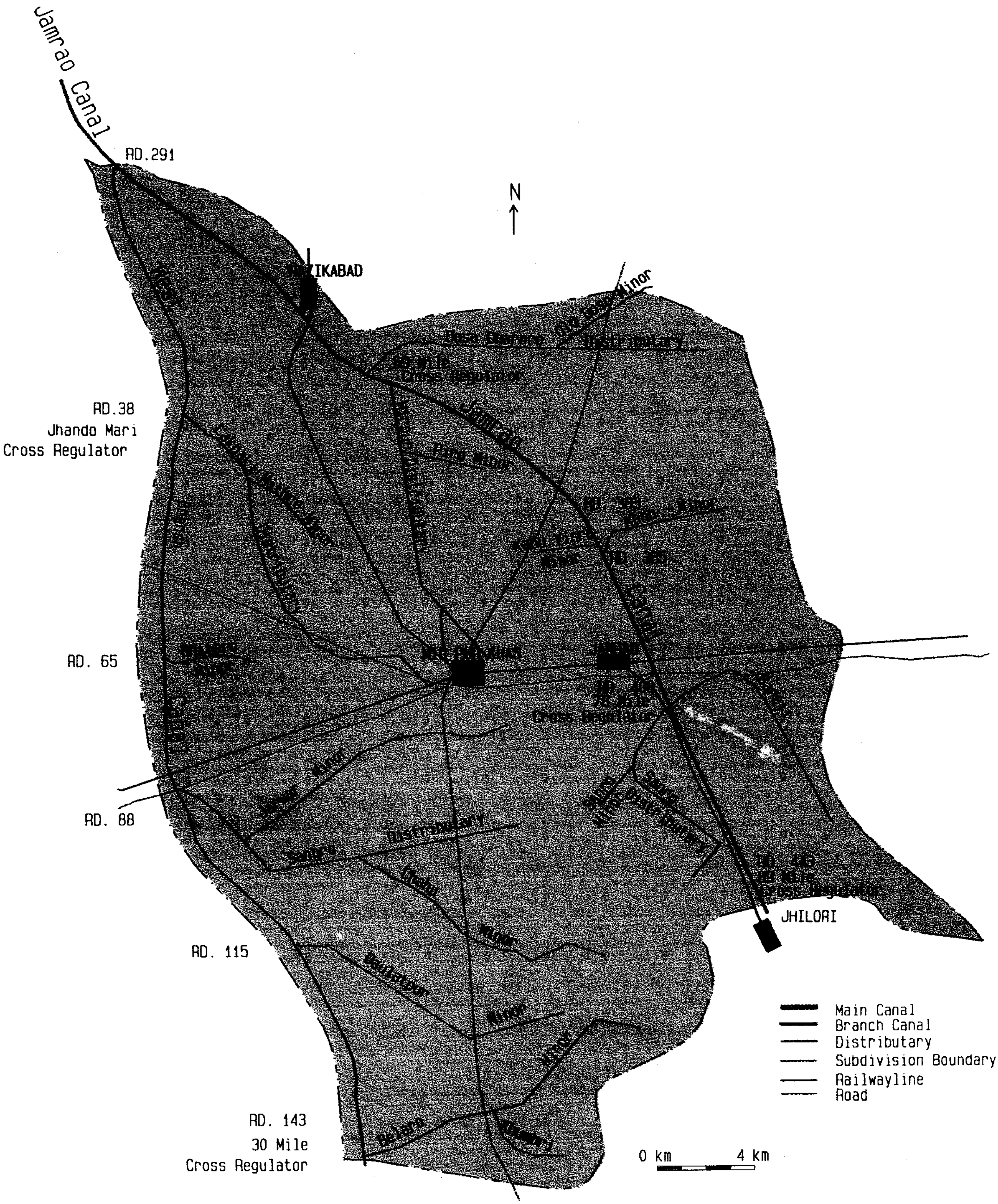

Figure 2.2. Mirpurkhas Sub-divisional Command with Major Offtakes.

The Mirpurkhas Sub-division receives water from the Jhol Sub-division at RD 291, where the West Branch Canal also offtakes from the right bank, feeding two sub-divisions; the Kot Ghulam Muhammad Sub-division at RD 443 of Jamrao Canal and the Digri Sub-division at RD 143 of the West Branch Canal.

Table 2.2 Salient features of Distributaries and Minors of Mirpurkhas Sub-division.

Parent Channel	Distributary/Minor	Offtake (RD)	CCA (ac)	Discharge (cfs)
Jamrao Canal	Mirpurkhas Disty	343	16815	64
	Doso Dharoro Disty	343	22743	66
	Kahu Visro Minor	383	3622	11.9
	Kahu Minor	385	12018	43.51
	Bareji Disty	408	14032	41.5
	Sanro Disty	408	15475	53.77
West Branch Canal	Lakhakhi Disty	38	17606	64
	Bhittaro Minor	65	3690	11.36
	Sangro Disty	88	30954	103.7
	Daulatpur Minor	115	10766	49
	Bellaro Minor	143	17124	54.78

Source: Jamrao Canal Division, Sindh Irrigation Department, 1998.

The portion of the Jamrao Canal forming the Mirpurkhas Sub-division was remodeled as a part of the overall Jamrao Canal Remodeling Project, whereby all the cross and head regulators in this sub-division were newly constructed in 1993-94. So, all the major structures in this part arc in good physical condition. Those of the West Branch Canal offtakes are several decades old and have been poorly maintained. All the distributaries and minors have mechanical gated head regulators, except the Bhittaro Minor, which has a rectangular iron orifice without any extra control. New gauges were mounted, both at the upstream and downstream of the head regulators of the Jamrao Canal after the remodeling in 1994. However, most of these have become illegible. The West Branch Canal Section either does not have the gauges, or are having their zero levels referred to the old design of the channel, which has changed considerably because of the sedimentation in the main canal, as well as that of the distribution system.

The number and size of gates is different for different channels of the Mirpurkhas Sub-division, depending upon the capacity of the channel and the age of the head regulator. The head regulators of the West Branch Canal Section offtakes have either one or two gates each, mostly with 6 feet width, while those of the Jamrao Canal Section have 1 to 3 gates of 5 feet width each. The operation of the gates is very asymmetrical. Usually, in the case of a three-gated head regulator, the middle gate is kept more open than those on the sides. The number of gates, their width, flow conditions and crest elevations, of all the head regulators is given in Table 2.3.

Table 2.3. Number of Gates, Widths, Flow Conditions and Crest Elevations of the Mirpurkhas Sub-division Offtakes.

Name of channel	Number of gates	Width of each gate (ft)	Flow condition	Crest elevation (ft)
Mirpurkhas Disty	3	5	S.O.F.	61.59
Doso Dharoro Disty	3	5	S.O.F.	61.59
Kahu Visro Minor	1	5	F.O.F.	56.68
Kahu Minor	3*	5	F.O.F.	56.68
Bareji Disty	3	5	F.O.F.	54.75
Sanro Disty	2	5	F.O.F.	54.75
Lakhakhi Disty	1	10	S.O.F.	61.60
Bhittaro Minor	Fixed orifice of 1.25x1.25 feet having F.O.F.			63.42
Sangro Disty	2	6	S.O.F.	54.60
Daulatpur Minor	2	6	S.O.F.	51.20
Bellaro Minor	1	6	F.O.F.	58.61

Note: S.O.F. = Submerged orifice flow
F.O.F. = Free orifice flow
* = Only two gates are operated, the left gate is closed.

2.2 Physical Condition Of The Head Regulators

2.2.1 Mirpurkhas Distributary Head Regulator (RD 343)

The head regulator of this distributary was replaced with a new one in 1993-94, and is in good physical condition. However, the present poor quality lubrication and maintenance would affect the operation of the gates and shorten their life. Small leakages occur from the bottom of the gates when closed.

The operation of the gates is comparatively symmetrical. Most often the opening of all of three gates is kept almost similar, with a difference of 0.01 to 0.08 feet.

2.2.2 Doso Dharoro Distributary Head Regulator

This distributary has a new head regulator to supply water to a sediment -ridden higher irrigation channel. Usually, the removed sediment is deposited on the banks of the distributary, which quickly finds its way back in. The head regulator is in good physical condition, which makes the operation easy. Normally, the opening of all three gates is similar, with a submerged flow condition.

2.2.3 Kahu Visro Minor Head Regulator

This is a small minor where flow is regulated with a single-gate head regulator. The regulator is in good condition and is almost free of problems. The crest level is much higher than the bed level of the minor, which results in free-orifice flow at this structure.

2.2.4 Kahu Minor Head Regulator

The physical condition of the head regulator is good; however, there is a leakage from the bottom, when closed. Although, the gates have been provided with the right and the left spindles, these are still operated from one side only, which, sometimes, gives a significant difference in the same gate top elevations for the right and the left sides. The operation of this head regulator has been quite asymmetrical during the study period. Most times, only two gates are operated and the third kept closed. Sometimes, only one gate is operated. Usually, the middle and the right gates are operated and the left gate is kept closed, which has caused sedimentation (almost equal to the maximum gate opening) in front of this gate.

2.2.5 Bareji Distributary Head Regulator

The head regulator of this distributary is new and in good physical condition. The operation of gates is quite asymmetrical and irregular, which causes problems in individual gates flow conditions. The opening of the middle gate is usually kept higher than those on the sides. Sometimes, when the opening of the side gates is less, it is difficult to assess whether the flow condition of individual gates is submerged or free flow.

2.2.6 Sanro Distributary Head Regulator

This is the last distributary of the Jamrao Canal Section and offtakes in front of the Bareji Distributary from the right side. The head regulator consists of two gates, which are in good physical conditions, but are faced with the common problem of leakage, when closed. The crest level of the head regulator has been found to be 0.10 feet lower than that of the Bareji Distributary, but the official record shows that they are at the same level.

2.2.7 Lakhakhi Distributary Head Regulator

The single-gated head regulator of this distributary is in working condition, but has been poorly maintained. The gate opening at the right and left ends of the gate is different. The sediment deposition in the distributary has raised the bed elevation much higher than the head regulator sill level. However, flows could be passed from the main canal because of higher full supply level. As Lakhakhi Distributary is the first major off-take of the West Branch Canal, a lot of trash and vegetation flowing in the main canal accumulates near its head regulator, which affects flow into the channel. At present it is impossible to see the seat of the gate as it is always drowned in the water, even during the annual closure period. A considerable amount of water leaks through the sides of the gate.

2.2.8 Bhittaro Minor

This minor is the only off-take of the Mirpur Sub-division that does not have a gated head regulator. The flows are diverted through a rectangular orifice with a good working head and modular flow condition. The structure is intact and has no specific problems. Opening and closing this structure, either from the upstream or downstream side is a difficult job. The water depth of more than four feet from the inlet side does not permit easy operation, while the high pressure shoot of water at the downstream side is also a constraint.

2.2.9 Sangro Distributary Head Regulator

This is the largest distributary of the West Branch Canal in Mirpurkhas Sub-division. The head regulator is an old structure with significant leakages all over; bottom (when closed), sides and even from the middle of the gates. Some repair work had been carried out during the 1997 annual closure, however, no significant change has been effected to the working of the head regulator. Also, the gates are not balanced properly, which results in different gate openings at the right and left sides. The trash flowing in the main canal accumulates upstream of the head regulator, which affects the discharge of the distributary. Usually, there is a considerable variation in the openings of the two gates, and rarely are gate openings similar.

2.2.10 Daulatpur Minor Head Regulator

The two-gated head regulator is an old structure characterizing poor maintenance with the passage of time. Both gates work, but are not in a good condition. The bed level of the channel has risen considerably because of sedimentation, and is even higher than the crest level of the head regulator. Frequent accumulation of trash near this head regulator affects its performance considerably, which also causes sediment deposition upstream. In order to avoid sediment deposition, the opening of the right gate is mostly kept higher than the left. Like most of the other head regulators, leakage from the sides of the gates is a common phenomenon.

2.2.11 Bellaro Minor Head Regulator

This is the last off-take of the Mirpurkhas Sub-division from the West Branch Canal, upstream of the 30-Mile Cross Regulator. The single-gated head regulator is in comparatively good working condition to pass the available flows into the channel.

Chapter 3

METHODOLOGY

Mirpurkhas Sub-division of the Jamrao Canal comprises of eleven distributaries/minors. Ten of these channels are controlled by gated head regulators, while the remaining one has a fixed orifice. The adjustment of gate opening is normally done mechanically.

Usually, the depth of flowing water in this sub-division is taken by recording the downstream gauge levels, if available. However, these gauges have silted up to a certain depth and do not indicate accurate measurements. Also, these gauges have not been recalibrated, therefore, the observed water levels could not be converted into flow rates.

Due to the problem of aggradation and degradation in the channels, the downstream gauges do not give the real degree of accuracy in discharge measurements, though this method is simple and easy to use. Realizing the problems of downstream gauge calibration from time to time, another method for measuring discharge is used, called the "calibration of irrigation control structure" calibration. The method is dependent on gate opening and the governing head . This method is permanent and more accurate as long as no changes are made in the structures.

3.1 FLOW CONDITIONS

Generally, there are two types of flows; free flow and submerged flow. To calibrate the structure, attempts to know the flow condition in each distributary/minor of the sub-division were made and then the corresponding equation was applied. During field measurements, the following criteria was used to identify the type of flow:

- The downstream water level is not touching the lower lip of the gate, then the flow is considered to be free flow.
- Reversely, when the downstream water level does touch the lower lip of the gate, the flow is considered to be submerged flow.

The steps followed to collect the required variables for calibrating the irrigation control structures are explained in subsequent paragraphs.

3.2 WATER DEPTH AND GATE OPENING MEASUREMENT

As the gauges were either not available or in poor condition, benchmarks (BMs) were established at the upstream (u/s) and downstream (d/s) sides of the head regulator structure. These BMs were established to observe the upstream (h_u) and downstream (h_d) flow depths using a tape, or staff gauges. They were referenced to the crest of the head regulator level so that the water depth above the crest could be computed. While establishing benchmarks, care should be taken that flow at the selected point is tranquil. Then, the selected points were rubbed and cleaned with a gauze brush, followed by a white mark (WM) painted at each location. The lower side of the WM is the reference elevation.

Similarly, two bench marks were marked on the frame of gate, one on the right and another on the left side to avoid error due to improper functioning of the gate. The elevations of the benchmarks were taken from the top of the gate, when the gate was completely closed. Using these benchmarks, average gate opening was obtained and used for calculation . The summary of the elevations of these benchmarks is presented in Table 3.1.

Table.3.1 Summary of Benchmarks Elevations with Reference to Crest of each Head Regulator of the Mirpurkhas Sub-division.

Channel	Bench mark Elevations (ft), taking crest as the zero level								
	U/S	D/S	Gate 1		Gate 2		Gate 3		F.C.
			L	R	L	R	L	R	
Mirpurkhas Disty	5.05	3.02	3.47	3.45	3.49	3.48	3.74	3.72	S.O.F.
Doso Dharoro Disty	6.87	4.49	3.95	3.95	3.77	3.79	3.73	3.74	S.O.F.
Kahu Visro Minor	5.76	.18	3.19	3.17					F.O.F.
Kahu Minor	6.78	1.89	2.45		2.54	2.51	2.56	2.53	F.O.F.
Bareji Disty	5.75	2.49	2.38		2.52		2.31		F.O.F.
Sanro Disty	4.3	0.12	2.81		2.85				F.O.F.
Lakhakhi Disty	7.48	4.66	1.87	1.91					S.O.F.
Bhittaro Minor	6.67	3.32	1.25 1.25						F.O.F.
Sangro Disty	7.48	4.07	2.90	2.9	2.96	2.92			S.O.F.
Daulatpur Minor	8.06	4.48	2.68	3.01	2.65	3.09			S.O.F.
Bellaro Minor	7.48		2.36	2.39					F.O.F.

Note. Gate numbering starts from the right side looking downstream.

U/S = upstream; D/S= downstream; S.O.F.= submerged orifice flow; FOF= free orifice flow; L= left; R= right; F.C.= flow conditions L/R = left / right

3.3 STRUCTURES WITH ADJUSTABLE GATES

Adjustments to the basic orifice equations for free-and submerged-flow are often made to represent the structure rating as a function of flow depths and gate openings more accurately. The following sections present some alternative equation forms for taking into account the variability in the discharge coefficient under different operating conditions. These sections are explained in detail so that the logic for which these sections are used could be understood clearly before applying the form of equation.

3.3.1 Free-flow Rectangular Gate Structures

For a rectangular gate having a gate opening and width, the free flow discharge can be obtained from the following equation, assuming that the dimensionless velocity head coefficient is unity.

$$Q_f = C_d G_o W \sqrt{2gh_u} \qquad (3.1)$$

Where:

Q_f = free orifice flow discharge:

C_d = discharge coefficient
G_o = Gate opening
W = gate width
g = acceleration due to gravity
h_a = upstream water depth

The upstream flow depth, h_u, can be measured upstream of the gate where benchmarks are established, including the upstream face of the gate.

3.3.2 Submerged-flow Rectangular Gate Structures

Submerged-flow gate structures are the most common constrictions employed in irrigation networks. The gates are used to regulate the water levels upstream and the discharge downstream. For this reason, they are very important structures that need to be field calibrated. Fortunately, they are one of the easiest structures to field calibrate for discharge measurement.

The submerged-flow discharge equation for a rectangular gate having an opening, G_o , and a width, W, is given as

$$Q_s = C_d G_o W \sqrt{2g(h_u - h_d)} \qquad (3.2)$$

Where,
Qs = submerged orifice flow discharge, and
hd = downstream water depth

The upstream flow depth, h_u , and downstream flow depth, h_d, can be measured from the white marks which are referenced to certain permanent benchmarks.

All information in the previous section regarding the measurement of gate opening, G_o ,applies equally well for submerged gates.

3.4 GATE CORRECTION (ΔG_o)

Gate opening is a very sensitive variable which directly affects the discharge ratings. Error may occur if the gate is not completely seated at the same elevation as the gate sill. There might be some leakages from the sides and the bottom of the gate when the gate is totally closed. This implies that the datum for measuring the gate opening is below the gate sill. Thus, the gate correction factor, ΔG_o, has been introduced so that the leakage effect on discharge rating could be avoided. Similarly, taking an accurate gate opening reading is highly difficult.

As mentioned earlier, during the physical survey of the structures there was often leakage from the sides and bottom of the gate. To determine a proper gate opening, a gate correction factor is included in all the head regulator structures. Assuming a different range of ΔG_o, and employing a by-trial-and-error method, a single value of C_d is determined for a certain value of ΔG_o. Equations 3.1 and 3.2 are rewritten as:

$$Q_f = C_d(G_o - \Delta G_o)W\sqrt{h_u - \Delta G_o} \quad (3.3)$$

for free orifice flow, and

$$Q_s = C_d(G_o - \Delta G_o)W\sqrt{h_u - h_d} \quad (3.4)$$

for submerged orifice flow.

Where ΔG_o = a measure of the zero datum level below the gate sill.

As in the case of the free-flow orifice calibration in the previous section, a by-trial-and-error approach can be used to determine a more precise zero datum for the gate opening.

3.5 DISCHARGE MEASUREMENTS BY CURRENT METER

A current meter is an instrument used to measure the velocity of flowing water in the channel, and it is widely used. The accuracy in the results using a current meter depends upon the proper operations, adjustment and maintenance of this instrument.

Using current meter measurements, the discharge is calculated, which is the summation of the products of the subsection areas of the stream cross section and their respective average velocities. The following continuity equation is used.

$$Q = \sum av \quad (3.5)$$

Where;
Q= total discharge
a = an individual subsection area, and
v = the corresponding mean velocity of the flow normal to the subsection.

3.6 VELOCITY MEASUREMENT

Using current meter, different methods are employed to measure the velocity in rivers, canals and distributaries/minors, depending upon the depth of the stream. These are briefly narrated below.

3.6.1 Two Points Method

This is the more common method used to determine the mean velocity in a vertical. This is used when the water depth is more than one foot deep which is when the price Type A current meter was used. In this method, current meter measurements are made at two relative water depths; 0.2 and 0.8 below the water surface. The average of the two measurements is taken as the mean velocity in the vertical.

3.6.2 One Point Method

When the depth of the water was less than 2.0 ft, the 0.6 depth method was used. For both ends of the cross-section adjacent to the left and right bank, the velocity was assumed as some percentage of the first section velocity. These assumptions were made on the basis of the physical situation at the ends of the cross-section. To obtain an accurate discharge measurement, the following steps were adopted.

1. Location of current metering was selected considering proper shape of cross sections, parallel flow lines, the distance from the outlets and non existence of vegetation.
2. Usually, the current meter time was fixed as 50 seconds and revolutions were noted. In the case of inconsistent revolution value, the reading was repeated after verifying the proper direction of current meter, or anything else interfering with the propeller.
3. During current metering, the upstream and downstream water levels were frequently observed. In the case of water level changes due to fluctuations, the discharge computation was conducted accordingly.
4. Discharge computation was conducted on the spot, and calculation checked a couple of times.

3.7 DETERMINATION OF DISCHARGE COEFFICIENT, C_d, AND GATE CORRECTION FACTOR, ΔG_o

The discharge coefficient, C_d, and gate correction factor, ΔG_o, for head regulator structures of the Mirpurkhas Sub-division are determined. The steps to determine the above two parameters are followed as under.

1. Several discharge measurements, with varying head and gate openings are obtained, using current meter.
2. The field data, such as water levels at upstream, downstream and gate openings, are measured for the periods when the discharge measurements are taken. Using Equations 3.1 & 3.2 (free orifice flow and submerged orifice flow, respectively), discharge coefficient, C_d, for each set of data is determined.
3. The variation between gate openings, G_o, and discharge coefficients, C_d, is shown in Figure 3.1. The value of C_d decreases as the gate opening increases.
4. A series of gate correction factor, ΔG_o, values is assumed to allow for leakages from the gate bottom and sides and new values of C_d are computed using Equations 3.3 and 3.4 depending upon the flow condition.
5. The resulting C_d and $G_o - \Delta G_o$ from step 4 are plotted to arrive at an appropriate value of ΔG_o. The value of ΔG_o giving comparatively less difference is selected as an appropriate value.
6. In order to find a constant value of C_d, the least square regression method was employed. A range of values (expected to be the final C_d value) is selected from the computed C_d values in step 4.

7. The value for which the sum of the square of the difference was minimum was taken as the final value for the respective flow control structure.

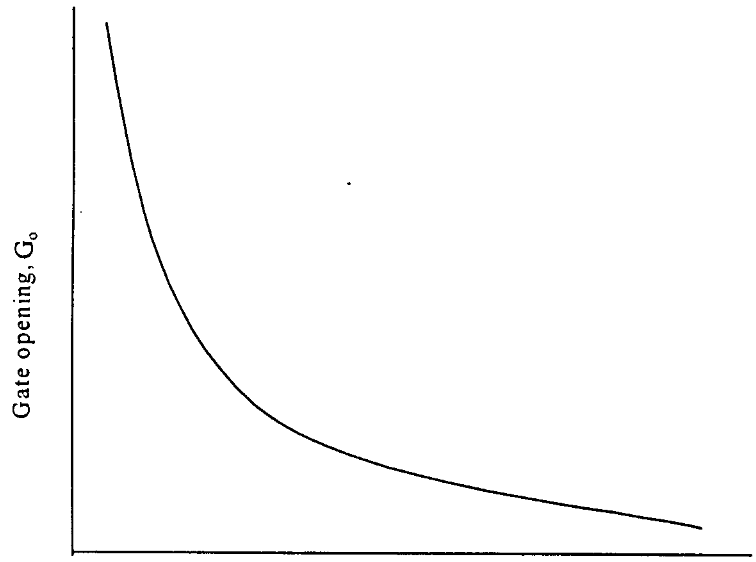

Figure 3.1. Schematic Showing a Typical Variation in Discharge Coefficient, C_d with Gate Opening, G_o.

However, some C_d values were not fitting quite well (the square of the difference was higher) as compared to others and were discarded. The discarded measurements have been indicated in tables in Annexure A.

The sum was computed again after excluding the erroneous measurements and then value with minimum sum was taken as the constant C_d for the respective structures.

The above procedure has been explained with an example in Annexure B on developing discharge rating for Sangro Distributary Head Regulator.

3.8 PRECAUTIONS

Earlier in this chapter the methods used to obtain the required variables for calibrating the head regulator structures have been explained in detail. Following those steps, some precautions were taken, which are briefly narrated below.

1. Dimensions of the gates were measured very carefully, and then checked at regular intervals.
2. Current meter is checked very carefully before use; whether it is properly maintained or not.
3. Velocity measurements were taken very carefully, because the least negligence in counting revolutions would lead to error in discharge, giving rise to an erroneous effect on discharge coefficient.

4. During current metering, the upstream and downstream water levels at the structure are frequently observed. If any change occurred, it was recorded and discharge computations made accordingly.
5. Discharge calculation is made on the spot. Calculation is checked a few times.
6. All the observations, such as upstream and downstream water depths and gate openings are very precisely and carefully measured. These are checked a few times by field staff. Both people involved checked the readings.
7. Care should be taken for the gate setting not to be changed while the current metering is in progress , otherwise the process has to be stopped.
8. The person holding the current meter in the channel should not stand too close to the current meter in order not to affect velocity.

Chapter 4

DISCHARGE RATINGS OF HEAD REGULATORS

4.1 GENERAL

Discharge ratings have been developed for all the eleven channels using Equations 3.1 to 3.4, depending upon the flow condition of the respective head regulator. Discharge measurements over a normal range of gate opening of the concerned flow control structures were taken, and the discharge coefficient, C_d, computed. Normally, these channels are operated over a small range of G_o and cannot tolerate extreme conditions. However, in a few cases where possible, minimum and maximum G_o were also taken, and C_d computed.

In order to arrive at a constant value of C_d for each head regulator, a correction factor ΔG_o has also been computed for each channel. The values of ΔG_o and C_d have been established, which vary from channel to channel. For the established values of C_d and ΔG_o, a comparison of the computed discharge values from the developed ratings and the field measurements was made, which turned out to be quite satisfactory.

4.2 ESTABLISHED DISCHARGE RATINGS

As mentioned earlier in Chapter 3 and explained in Annexure B, several field data sets were collected to secure an accurate and reliable discharge rating for the major flow control structures. The data sets not giving the desired results were not used in the analysis, but have been kept as a record and given in Annexure A.

4.2.1 Mirpurkhas Distributary Head Regulator

Thirteen field data sets have been used to calibrate the head regulator of the Mirpurkhas Distributary. The average G_o varies from 0.68 to 1.217 feet, resulting in C_d values ranging from 0.61 to 0.64 (Table 4.1). Usually, the gate opening of all the three gates is similar, which is an uncommon situation in this system. A rectangular coordinate plot of C_d versus the average G_o is shown in Figure 4.1.

To determine an appropriate value of ΔG_o, different ΔG_o values were used by-trial-and-error in Equation 3.4 and plotted against the resulting C_d. These values ranged from -0.01 to -0.05 feet and the promising results were obtained from ΔG_o equal to -0.04 feet.

The least square regression analysis was carried out to obtain a constant value of C_d. The sum of the square of the C_d values was minimum for C_d equal to 0.60 and was taken as the final C_d for the Mirpurkhas Distributary Head Regulator.

Table 4.1. Field Data for the Calibration of Mirpurkhas Distributary Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Q_m	Q_{rev} (cfs)	C_d
29.8.97	3.494	2.518	1.172	87.16	86.06	0.62
26.8.97	3.514	2.383	1.044	83.9	84.28	0.63
23.9.97	3.974	2.463	0.965	89.63	89.96	0.63
18.9.97	3.769	2.648	1.217	95.49	95.38	0.61
27.11.96	3.371	2.373	0.96	71.29	71.64	0.62
4.7.97	3.129	2.313	1.212	82.06	82.17	0.62
20.6.97	3.784	2.633	1.15	92.56	92.62	0.62
5.4.97	3.634	2.113	0.77	91.35	70.84	0.62
10.10.96	3.846	2.26	0.73	68.86	68.96	0.62
9.10.96	4.095	2.34	0.68	69.30	69.37	0.64
24.4.97	3.462	2.173	0.879	75.06	75.29	0.63
1.7.97	3.364	2.453	1.183	86.01	86.81	0.64
28.6.97	3.795	2.473	1.006	86.29	86.52	0.62

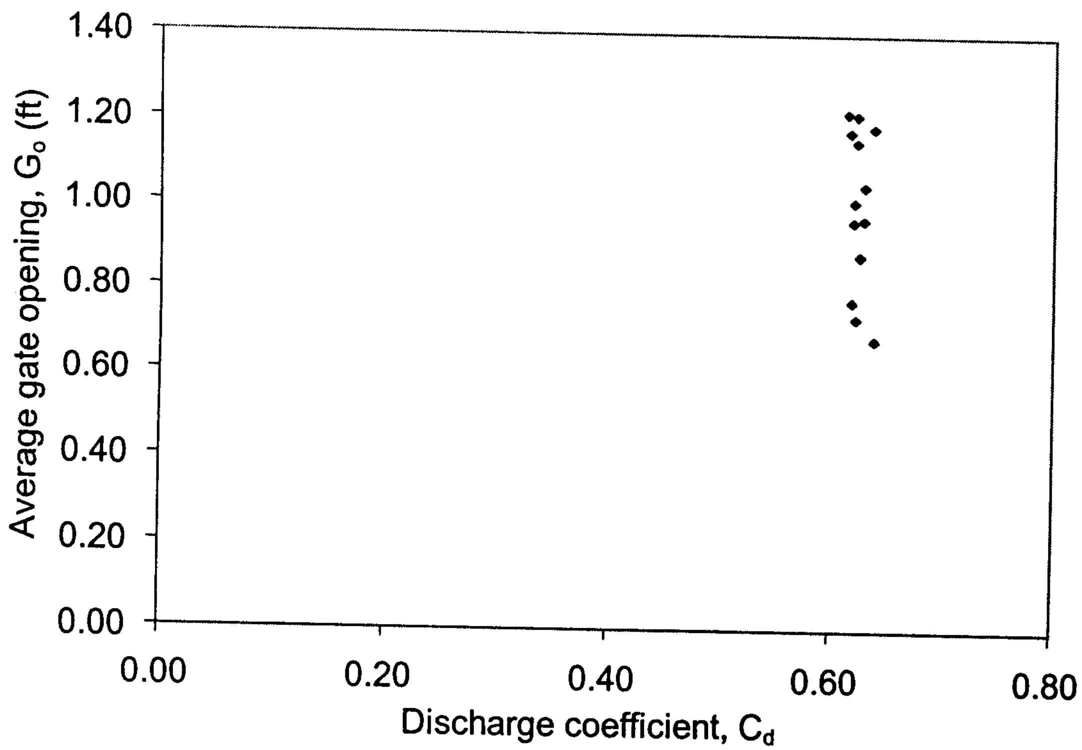

Figure 4.1. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Mirpurkhas Distributary Head Regulator with Submerged Orifice Flow.

4.2.2 Doso Dharoro Distributary Head Regulator

As mentioned earlier, the Doso Dharoro is a sediment-ridden distributary where the bed level has risen significantly. There is little difference in the water surface levels of the main canal and that of the distributary, and consequently, the flow condition is always submerged-orifice flow. Thirteen discharge measurements were taken out of which three were discarded and the remaining ten have been used to develop a discharge rating for this flow control structure. The G_o of this distributary is usually higher than the rest of the channels in the Mirpurkhas Sub-division, and the measured range is from 1.20 to 1.49 feet. The computed C_d varies between 0.692 to 0.722, as given in Table 4.2 and plotted in Figure 4.2. Different ΔG_o values from -0.01 to -0.05 feet were assumed and the corresponding values of C_d computed. Following the procedure explained in the example, the ΔG_o and C_d have been calculated to be -0.04 feet and 0.684, respectively.

Table 4.2. Field Data for the Calibration of Doso Dharoro Distributary Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
20-10-96	3.707	3.246	1.49	87.09	86.88	0.715
30-9-97	3.878	3.05	1.45	112.60	111.10	0.702
8-10-97	3.958	3.09	1.41	109.77	110.21	0.699
9-10-97	4.578	3.32	1.30	122.18	124.18	0.709
10-10-97	4.238	3.19	1.25	108.57	108.70	0.706
14-10-97	3.788	2.92	1.25	101.49	101.11	0.722
15-10-97	3.948	3.03	1.20	96.05	96.01	0.694
17-10-97	3.816	3.05	1.36	100.97	101.02	0.705
18-12-97	3.478	3.025	1.49	83.98	84.91	0.702
18-10-97	3.648	2.95	1.31	91.06	91.21	0.692

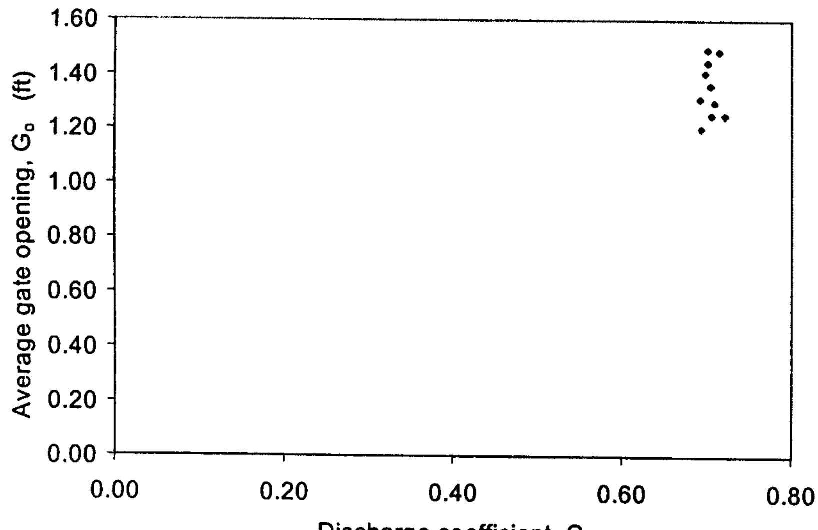

Figure 4.2. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Doso Dharoro Distributary Head Regulator with Submerged Orifice Flow.

4.2.3 Kahu Visro Minor Head Regulator

The head regulator of Kahu Visro Minor comprises of one gate of a 5 feet width, under free-orifice flow. Five field data sets have been used to establish a discharge rating. The minor is normally operated at G_o in the range of 0.30 to 0.50 feet. For the field discharge measurements, the G_o varies from 0.34 to 0.49 feet and the C_d varies from 0.585 to 0.616. The difference of Q_m and Q_{rev} is a fraction of a cusec, as given in Table 4.3. A rectangular plot of C_d versus G_o is shown in Figure 4.3.

Different values of ΔG_o from -0.01 to -0.09 feet were assumed and the C_d calculated using Equation 3.3. The best result was given by ΔG_o equal to –0.05 feet. From the regression analysis, the constant C_d was found to be 0.528.

Table 4.3. Field Data for the Calibration of Kahu Visro Minor Head Regulator.

Date	h_u (ft)	G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
6-10-96	4.750	0.380	19.80	19.48	0.586
29-10-96	4.497	0.430	21.44	21.39	0.585
20-3-97	4.672	0.420	21.44	21.57	0.592
3-4-97	4.312	0.335	17.32	17.20	0.616
11-9-97	4.182	0.490	23.52	23.51	0.585

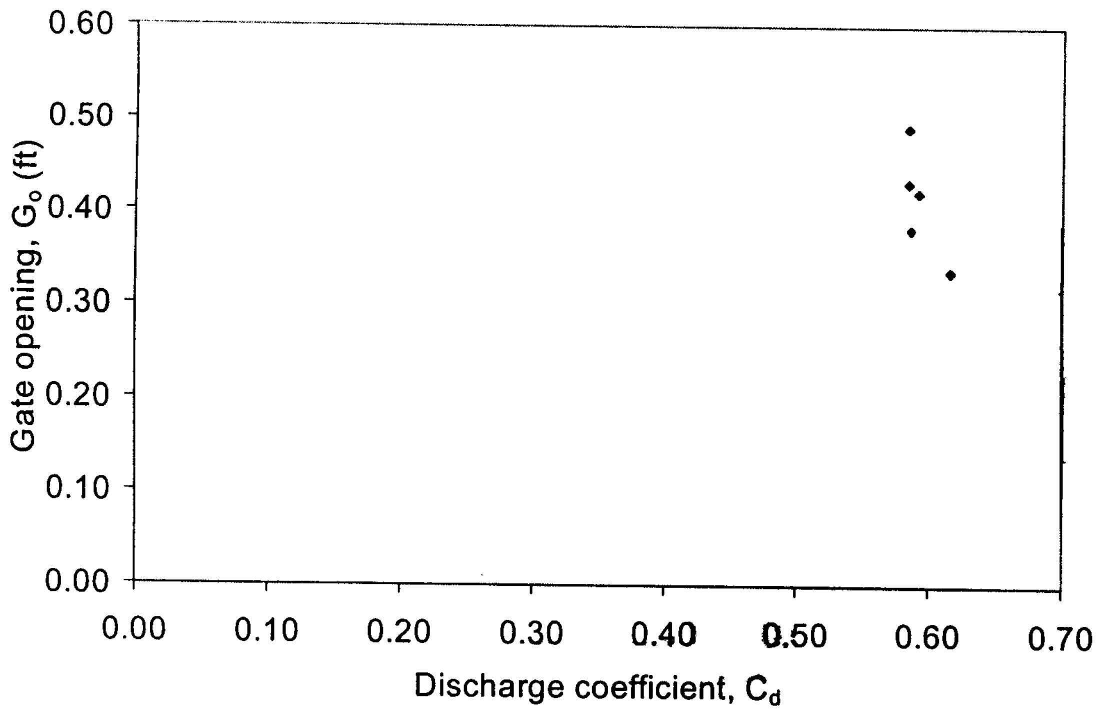

Figure 4.3. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Kahu Visro Minor Head Regulator with Free Orifice Flow.

4.2.4 Kahu Minor Head Regulator

Eleven discharge measurements were taken at different gate openings and the corresponding C_d computed, as given in Table 4.4 and plotted in Figure 4.4. There was a problem with the operation of this head regulator, i.e., the gate openings are quite different from each other, and two gates (middle plus one side gate) out of three were operated to regulate flow into the minor. Assuming different values of ΔG_o, an appropriate value of C_d equal to 0.432 was obtained from ΔG_o equal to -0.12 feet.

Table 4.4. Field Data for the Calibration of Kahu Minor Head Regulator.

Date	h_u (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
29.11.97	4.32	0.63	53.14	52.73	0.506
07.10.97	4.71	0.96	83.51	82.91	0.498
02.10.97	4.13	0.96	73.62	73.45	0.471
29.9.97	4.45	0.85	72.84	72.53	0.506
27.9.97	4.32	0.90	75.26	75.26	0.500
26.9.97	4.22	0.89	71.70	72.22	0.492
22-9-97	4.15	0.90	69.00	68.89	0.468
3-4-97	4.29	0.61	54.16	55.00	0.542
19-4-97	4.34	0.48	44.55	43.97	0.547
29-10-96	4.47	0.75	66.21	66.27	0.521
5-10-96	4.28	0.65	59.06	58.60	0.543

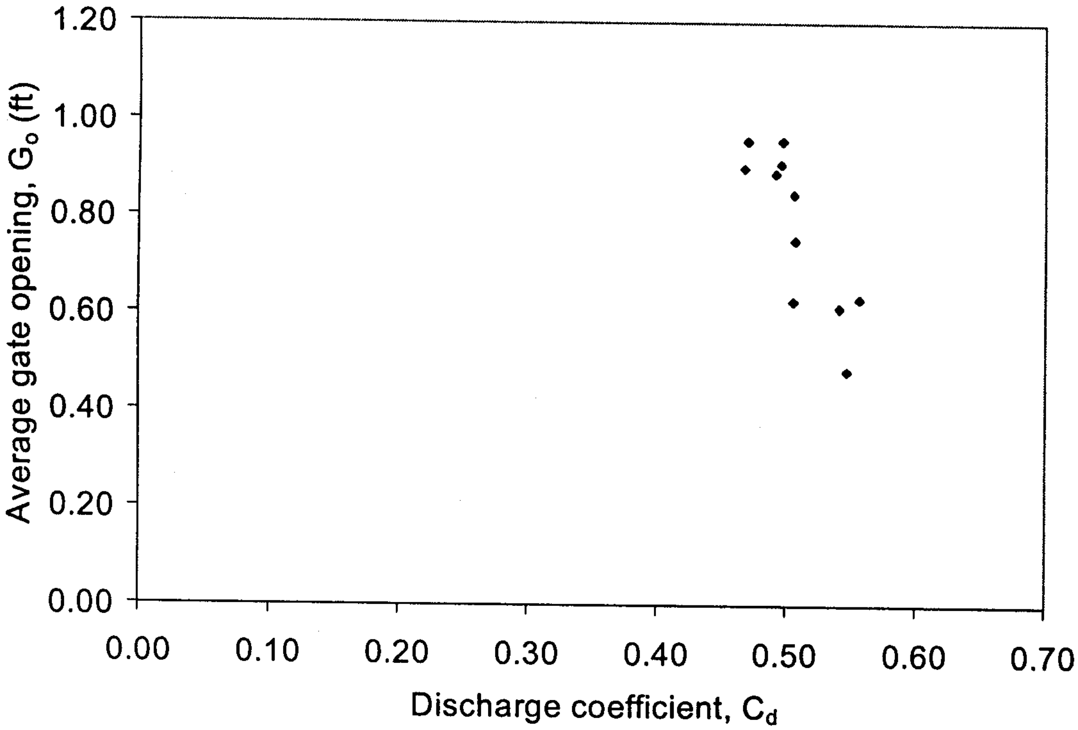

Figure 4.4. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Kahu Minor Head Regulator with Free Orifice Flow.

4.2.5 Bareji Distributary Head Regulator

Ten discharge measurements were taken to calibrate the head regulator of Bareji Distributary. These measurements were taken at different gate openings at different time periods, as listed in Table 4.5a. This table indicates that the flow conditions of the distributary head regulator were different at different times and were even different for individual gates in some cases. Thus, the flow condition of this distributary was almost unstable. Realizing the situation, the analyses were carried out separately depending on the flow condition. The data Table 4.5a shows that there are five data sets where each gate has free orifice flow, two data sets have submerged orifice flow for each gate and the remaining data sets have mixed flow (mixed flow means one or two gates have submerged orifice flow and the remaining have free orifice flow). Only two data sets (of 19 October 1996 and 29 June 1997) with free orifice flow and closer C_d values were used for initial analysis. Usually, the gate with a higher opening has free orifice flow.

The gate correction factor, ΔG_o, and a constant discharge coefficient, C_d, were determined separately for each flow condition. Again, the range of ΔG_o (-0.02 and –0.09 feet for free orifice and submerged orifice flows, respectively) was used to determine C_d for each data point for the free orifice and submerged orifice flows. Using the average of the two C_d values for the respective flow conditions, discharge was calculated for all of the measurements as shown in Table 4.5b. For mixed flow, appropriate equation was used to calculate discharge for each gate by using the actual measured G_o for the respective gate. The difference in the measured discharge and the calculated discharge was calculated from $\{(Q_m-Q_{rev})^2\}^{0.5}/Q_{rev}$. The sum of difference for each column was computed as shown in Table 4.5c, which turned out to be minimum for ΔG_o equal to –0.02 foot and C_d equal to 0.527 and 0.630 for free orifice and submerged orifice flows, respectively. Some of the measurements giving comparatively higher difference than others were discarded.

Rating curves have been developed for both the submerged-orifice and free-orifice flows and given in Figures C.5 and C.6 , respectively, in Annexure C. Appropriate equation should be used for individual gates in case of mixed flow.

Table 4.5a. Field Data for the Calibration of Bareji Distributary Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Flow condition of individual gates			Q_m (cfs)	Q_{rev} (cfs)	C_d
				Left	Centre	Right			
19-10-96	3.273	-	0.593	F.O.F.	F.O.F.	F.O.F.	69.33	69.36	0.537
23-10-96	3.363	-	0.512	F.O.F.	F.O.F.	F.O.F.	59.43	59.56	0.527
2-4-97	2.440	1.285	0.537	S.O.F.	S.O.F.	F.O.F.	61.49	62.10	0.615
7-4-97	3.380	1.510	0.620	S.O.F.	S.O.F.	S.O.F.	66.42	66.39	0.484
8-4-97	3.310	1.670	0.767	S.O.F.	S.O.F.	S.O.F.	76.21	76.42	0.455
3-6-97	3.180	1.130	0.536	F.O.F.	F.O.F.	F.O.F.	61.34	63.32	0.550
5-6-97	3.325	1.280	0.604	F.O.F.	F.O.F.	F.O.F.	72.29	72.73	0.549
29-6-97	3.170	1.130	0.557	F.O.F.	F.O.F.	F.O.F.	65.93	66.57	0.558
1-7-97	3.005	1.310	0.683	F.O.F.	S.O.F.	S.O.F.	69.94	68.74	0.482
12-8-97	3.185	1.340	0.646	S.O.F.	F.O.F.	S.O.F.	71.77	71.82	0.518

Table 4.5b Measured and Calculated Discharge at Bareji Distributary Head Regulator.

	$(C_d)_{so}$	0.630	0.621	0.613	0.604	0.596	0.588	0.581	0.573
	$(C_d)_{fo}$	0.527	0.518	0.509	0.500	0.491	0.483	0.475	0.467
	G_o (ft)	-0.02	-0.03	-0.04	-0.05	-0.06	-0.07	-0.08	-0.09
Date	$Q_{rev.}$	Q_{calc}	Q_{calc}	Q_{calc}	Q_{calc}	Q_{calc}	Q_{calc}	Q_{calc}	Q_{calc}
19.10.96	69.40	69.55	69.53	69.518	69.48	69.46	69.45	69.43	69.41
23.10.96	59.56	62.11	62.23	62.34	62.45	62.55	62.65	62.75	62.85
2.4.97	62.10	50.04	50.17	50.31	50.38	50.47	50.58	50.72	50.78
7.4.97	66.38	66.37	66.47	66.56	66.65	66.74	66.83	66.91	66.99
8.4.97	76.42	76.40	76.29	76.18	76.08	75.98	75.89	75.79	75.70
3.6.97	63.32	63.13	63.20	63.27	63.34	63.41	63.47	63.54	63.60
5.6.97	72.73	72.44	72.38	72.32	72.26	72.21	72.15	72.10	72.05
29.6.97	66.20	65.96	65.99	6.01	66.04	66.06	66.09	66.11	66.14
1.7.97	68.73	72.37	72.31	72.29	72.18	72.10	72.05	72.05	71.94
12.8.97	71.82	71.97	71.95	71.95	71.86	71.80	71.78	71.79	71.71

Note: All the discharge values are in cusecs.

Table 4.5c. Difference of Measured and Calculated Discharge at Bareji Distributary Head Regulator by using $\{(Q_{rev} - Q_{cal})^2\}^{0.5} / Q_{rev}$ and excluding three data points.

Date								
19.10.96	0.00218	0.00187	0.00156	0.00127	0.00098	0.00070	0.00043	0.00017
23.10.96	Data point discarded.							
02.04.97	Data point discarded.							
07.04.97	0.00019	0.00125	0.00265	0.00402	0.00536	0.00667	0.00794	0.00918
08.04.97	0.00023	0.00166	0.00305	0.00440	0.00570	0.00697	0.00821	0.00940
03.06.97	0.00303	0.00188	0.00076	0.00032	0.00136	0.00238	0.00336	0.00432
05.06.97	0.00394	0.00478	0.00559	0.00638	0.00714	0.00788	0.00859	0.00929
29.06.97	0.00359	0.00318	0.00277	0.00238	0.00200	0.00163	0.00127	0.00092
01.07.96	Data point discarded.							
12.08.97	0.00212	0.00177	0.00178	0.00052	0.00036	0.00065	0.00050	0.00162
Sum	0.01529	0.01638	0.01817	0.01927	0.02291	0.02688	0.03031	0.03490

4.2.6 Sanro Distributary Head Regulator

The field data used to compute C_d for the Sanro Distributary Head Regulator is given in Table 4.6. The C_d versus G_o plot is shown in Figure 4.6. ΔG_o values varying from -0.01 to 0.11 foot were used by employing the trial-and-error method to determine an appropriate value of ΔG_o. Similarly, the constant value of C_d was obtained from the least square regression analysis. The best results were obtained from C_d equal to 0.518 for ΔG_o equal to –0.09 foot.

Table 4.6 Field Data for the Calibration of Sanro Distributary Head Regulator.

Date	h_u (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
6-10-96	3.183	0.57	49.98	50.31	0.616
23-10-96	3.293	0.61	51.94	52.01	0.584
19-10-96	3.121	0.60	50.64	51.02	0.601
28-10-96	3.102	0.98	78.86	78.86	0.569
11-12-96	3.133	0.58	48.82	48.89	0.594
2-4-97	3.203	0.75	63.62	62.00	0.579
7-4-97	3.143	0.72	59.56	59.88	0.581
8-4-97	3.178	0.81	65.06	65.24	0.562

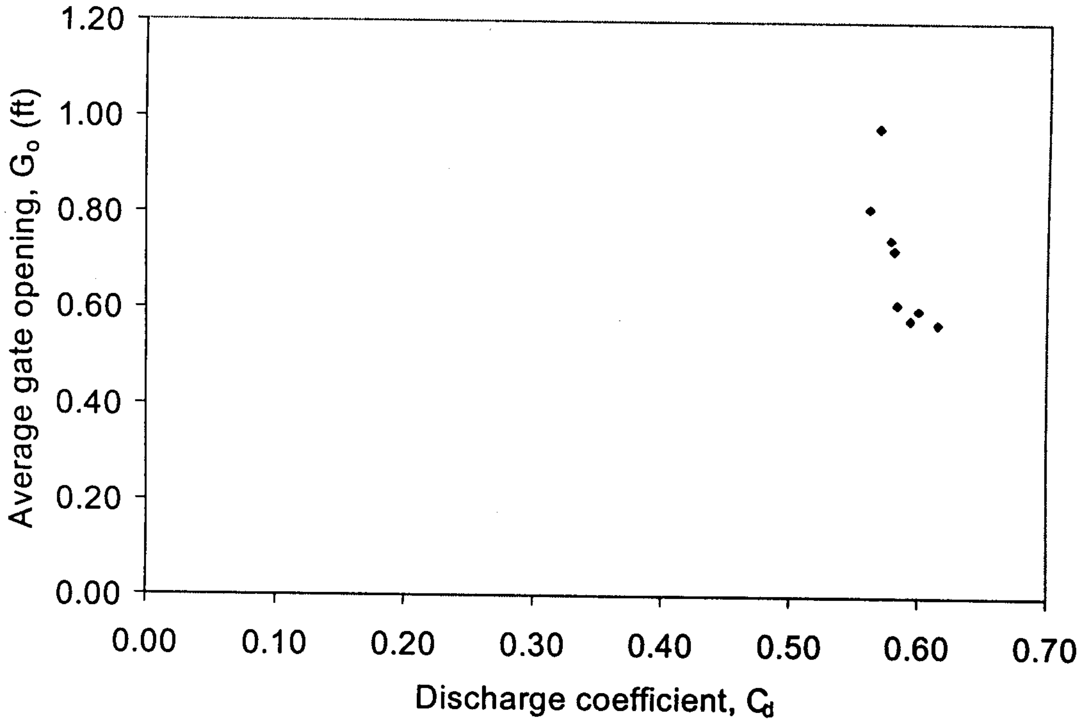

Figure 4.5. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Sanro Distributary Head Regulator with Free Orifice Flow.

4.2.7 Lakhakhi Distributary Head Regulator

The single gated head regulator is an old structure supplying water to a silted channel. The discharge measurement data from the field is given in Table 4.7 and shown in Figure 4.6. These measurements were taken over a normal range of gate operations of Lakhakhi Distributary. The G_o varies from 0.928 to 1.359 feet and C_d varies from 0.715 to 0.749.

ΔG_o values from -0.05 to -0.12 feet were assumed to obtain a constant value of C_d. The best result was obtained from ΔG_o equal to -0.10 feet for a corresponding C_d value of 0.674.

Table 4.7. Field Data for the Calibration of Lakhakhi Distributary Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
13-10-97	5.745	4.163	0.97	73.12	73.35	0.749
26-09-97	5.455	4.038	1.22	85.97	85.8	0.736
25-09-97	5.55	3.993	1.08	80.03	80.19	0.741
28-08-97	5.67	4.34	1.359	91.24	91.18	0.725
03-07-97	5.245	4.388	1.705	90.79	90.75	0.716
19-06-97	5.53	4.243	1.31	84.05	85.03	0.713
22-10-96	6.017	3.782	0.928	8.67	83.02	0.746
04-09-97	5.53	4.24	1.31	85.41	85.39	0.715

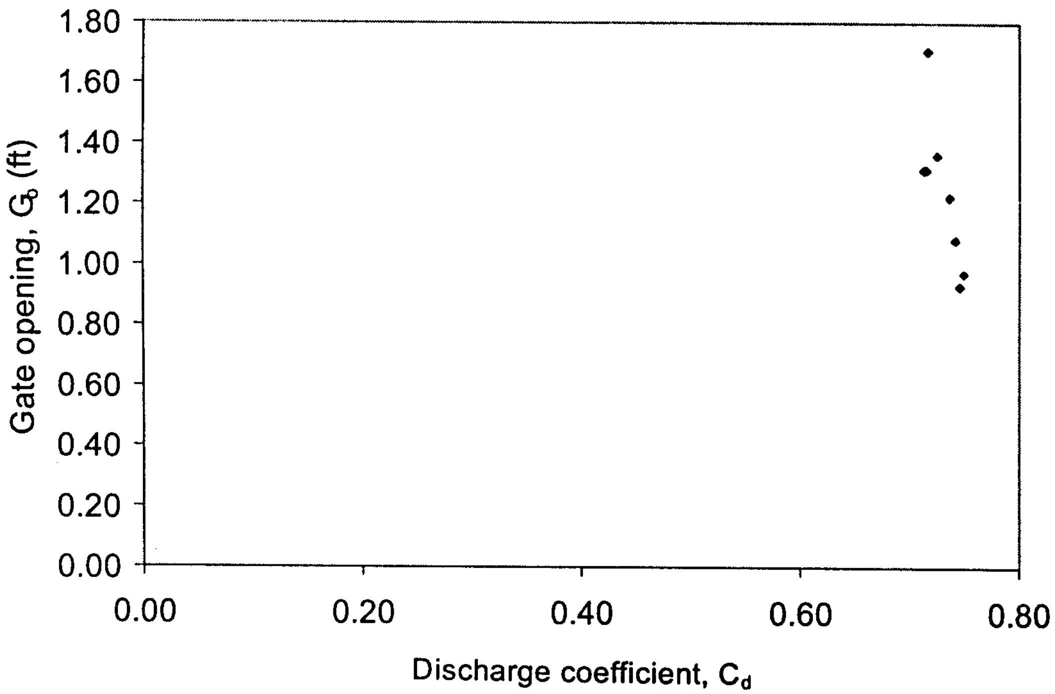

Figure 4.6. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Lakhakhi Distributary Head Regulator with Submerged Orifice Flow.

4.2.8 Bhittaro Minor

This minor has a fixed orifice of 1.25 x 1.25 feet with a free-orifice flow. The discharge coefficient, C_d, was computed from Equation 3.1. The data collected in the field is given in Table 4.8. The average of the C_d values from the four data sets has been taken as C_d for Bhittaro Minor, which is equal to 0.617.

Table 4.8. Discharge Data of Bhittaro Minor.

Date	h_u (ft)	Flow condition	Q_m (cfs)	Q_{rev} (cfs)	C_d
21.1.97	5.76	Free-orifice flow	18.88	18.90	0.627
11-5-98	5.36	"	17.61	17.50	0.606
11.10.97	6.07	"	18.64	18.60	0.603
16.10.97	5.78	"	18.75	19.01	0.630
				Average	0.617

4.2.9 Sangro Distributary Head Regulator

Ten discharge measurements were taken downstream of Sangro Distributary Head Regulator in order to develop a discharge rating. Usually, the operation of the two gates is asymmetrical; however, there are a few instances when the opening of the gates is almost similar. The distributary is normally run at full supply level. However, discharge measurements were taken for an average gate opening varying from 0.366 to 1.49 feet, as given in Table 4.9 and shown with C_d in Figure 4.7.

Assuming ΔG_o values from -0.01 to -0.05 feet, a constant value of C_d equal to 0.710 was found for ΔG_o equal to -0.03 feet.

Table 4.9. Field Data for the Calibration of Sangro Distributary Head Regulator.

Date	$h_u - h_d$ (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
13-4-97	3.77	0.366	51.14	51.15	0.748
11-7-97	2.62	1.062	121.93	124.18	0.750
27-3-97	1.86	1.070	103.10	102.47	0.727
6-10-97	3.27	1.123	142.34	144.07	0.737
17-9-97	2.78	1.170	136.01	139.80	0.744
8-10-97	3.03	1.250	153.54	150.74	0.719
25-9-97	2.52	1.347	154.65	157.83	0.756
4-10-97	2.88	1.370	160.43	158.94	0.710
9-9-97	2.01	1.440	138.84	142.73	0.726
8-10-96	2.47	1.490	156.41	158.35	0.704

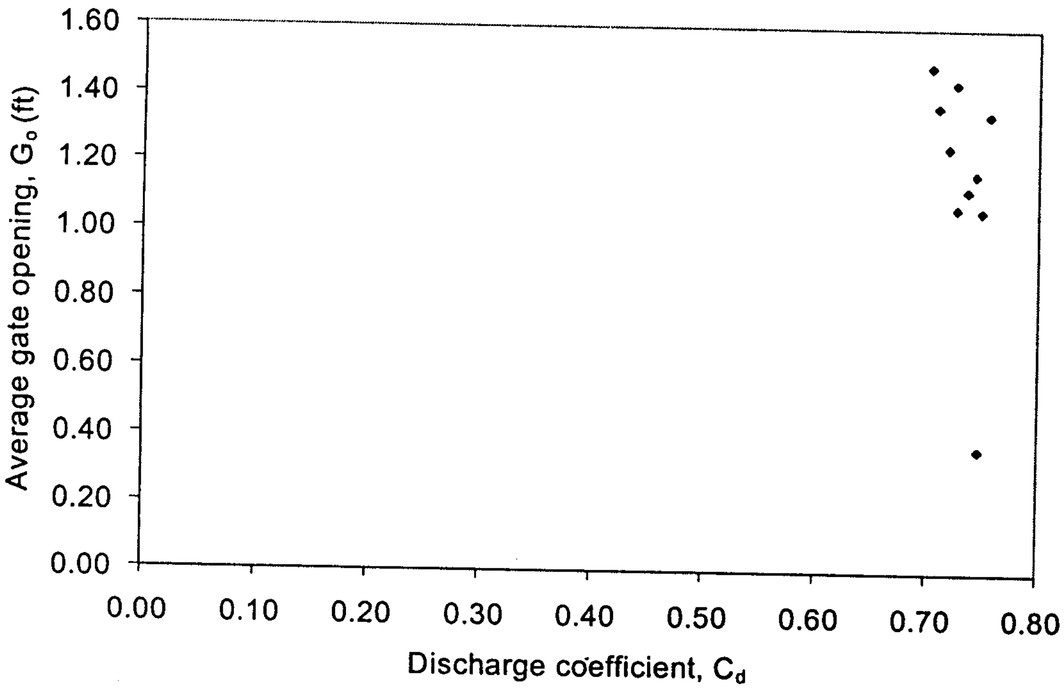

Figure 4.7. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Sangro Distributary Head Regulator with Submerged Orifice Flow.

4.2.10 Daulatpur Minor Head Regulator

The field data for computing the discharge coefficient is given in Table 4.10. G_o varies from 0.39 to 0.73 feet. Operation of Daulatpur Minor at G_o equal to 0.39 or 0.40 feet is not a normal phenomenon. The usual G_o varies from 0.50 feet and above. A coordinate plot of C_d versus G_o is shown in Figure 4.8.

Table 4.10. Field Data for the Calibration of Daulatpur Minor Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
3-4-97	6.76	3.73	0.39	32.30	31.50	0.58
1-8-97	7.22	4.37	0.66	52.24	51.73	0.58
16-9-97	6.61	4.32	0.73	48.56	49.00	0.55
17-9-97	6.70	4.29	0.69	48.21	48.54	0.56
9-10-97	9.96	4.37	0.65	47.31	47.15	0.56
9-12-97	7.54	4.26	0.50	44.43	44.24	0.61
24-12-97	7.54	4.24	0.49	42.92	42.95	0.60

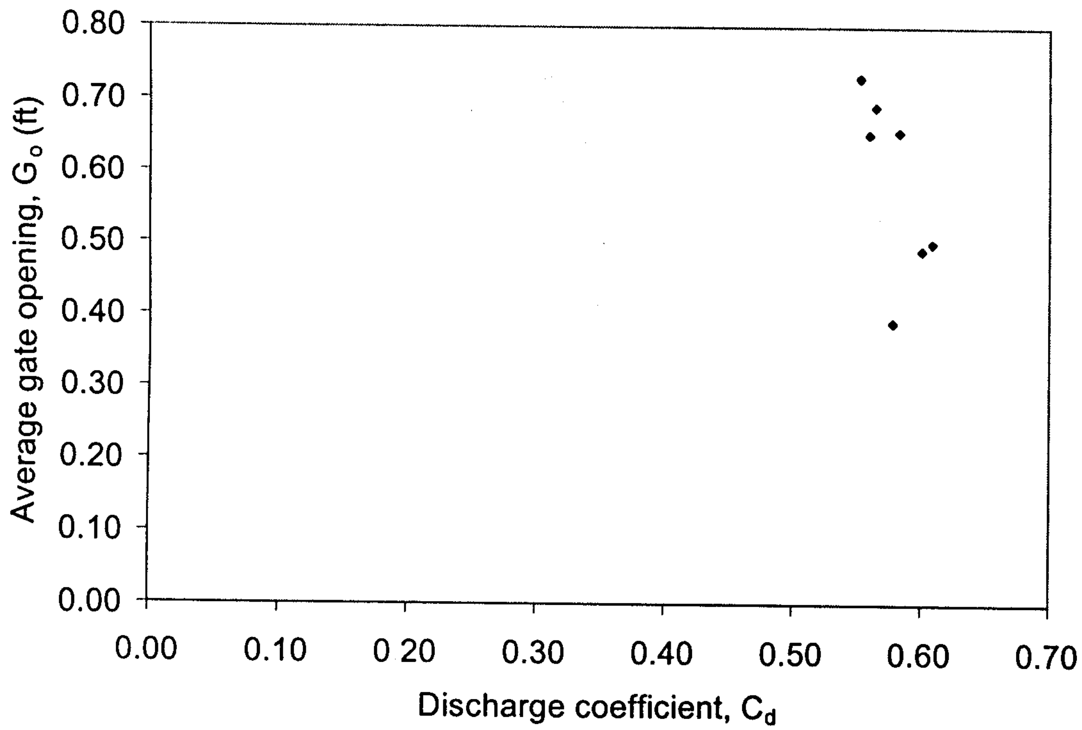

Figure 4.8. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Daulatpur Minor Head Regulator with Submerged Orifice Flow.

By-trial-and-error, the best result was obtained from ΔG_o equal to -0.04 feet, for which the corresponding constant C_d value is 0.540.

4.2.11 Bellaro Minor Head Regulator

The normal range of G_o is from 0.91 to 1.20 feet in Rabi and Kharif. Seven data sets have been used to calibrate this head regulator (Table 4.11). Bellaro Minor's Head Regulator is a poorly maintained old structure with leakages from the sides as well as the bottom, when closed. A coordinate plot of C_d versus G_o is shown in Figure 4.9.

Using the range of ΔG_o values from -0.01 to -0.08 feet, an appropriate value of ΔG_o equal to –0.06 foot was obtained. The regression analysis of the data resulted in 0.49 to be the value of C_d.

Table 4.11 Field Data for the Calibration of Bellaro Minor Head Regulator.

Date	h_u (ft)	G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
15-10-97	6.205	0.94	59.11	58.99	0.523
17-10-96	5.755	1.18	69.61	70.01	0.514
26-10-96	6.19	0.950	58.95	59.40	0.522
24-3-97	3.885	1.07	51.58	51.53	0.507
26-6-97	5.34	1.01	58.16	58.21	0.518
27-8-97	5.28	0.965	56.66	56.00	0.525
18-9-97	5.12	0.91	52.25	52.15	5.526

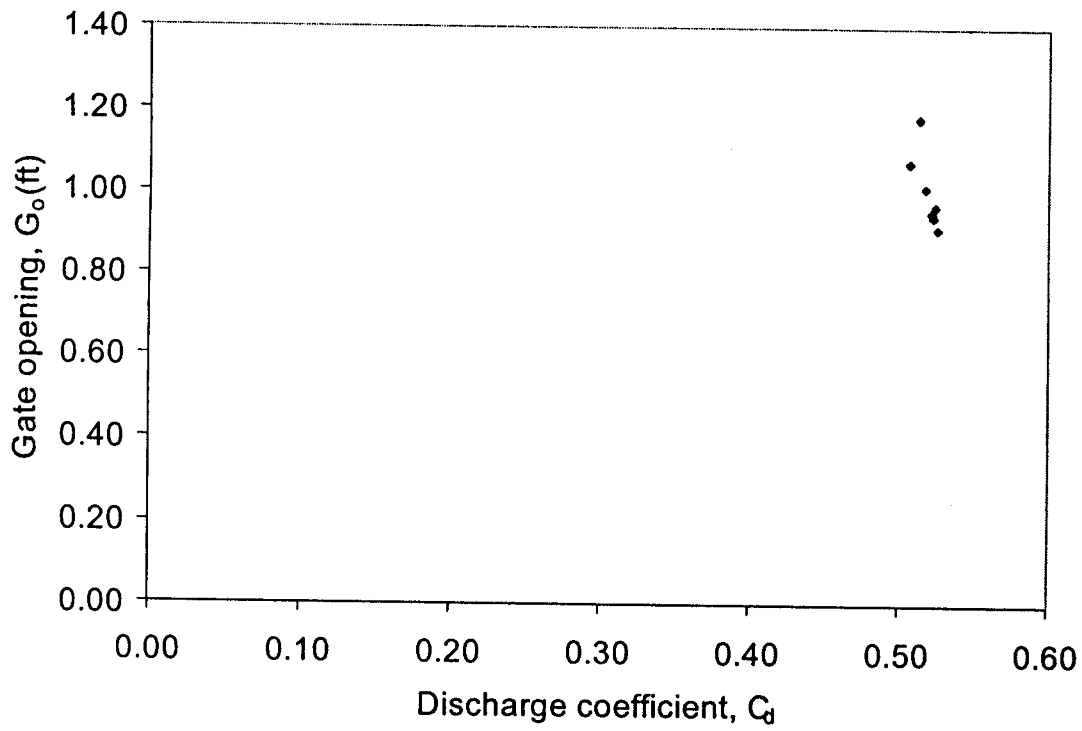

Figure 4.9. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o, for Bellaro Minor Head Regulator with Free Orifice Flow.

4.3 SUMMARY OF HEAD REGULATOR RATINGS

The channels of Mirpurkhas Sub division are offtaking from the Jamrao Canal of the Nara Canal as mentioned in the previous chapters. The physical conditions of head regulator structures of these channels were fully checked and are explained in the text. For observing the upstream and downstream water levels and gate openings, the white marks were established at the visible and accessible locations. Using these white marks the data pertaining to h_u, h_d, G_o and Q at the downstream of head regulator were collected for several times. These data have been mentioned in detail structure wise in the beginning of this chapter. Discharge coefficient for each data set of each structure was computed using the appropriate equation (Free orifice flow equation or submerged orifice flow equation). A relationship between discharge coefficient and gate opening was developed for each structure. As the physical condition of the head regulator was showing that there is leakage from the sides and the bottom of the gate, a factor "gate correction" was introduced. Assuming different values of gate correction factor for each structure, the discharge coefficient was computed using the appropriate equation of discharge computation. To arrive at a constant value of discharge coefficient, the least squared regression method was employed. The discharge coefficient and corresponding gate correction factor as determined are listed in Table 4.12. Moreover, the values of discharge coefficient and gate correction have been put into general form of equation and final equation for each head regulator has been developed. The summary of these equations is given in Table C.1 of Annexure C. Using these developed equations, rating curves for each head regulator have been developed as are given in Annexure C, Figures C.1 to C.12. These ratings could be permanently used until physical changes are made in the structure and/or flow conditions are changed due to heavy deposition/erosion of sediment at the downstream of head regulator structure.

Table 4.12. Established values of C_d and ΔG_o for the head regulators of Mirpurkhas Sub-division offtaking channels.

Parent Channel	Disty/Minor	C_d	ΔG_o (ft)	Flow Condition	Number of gates	Each gate width (ft)
Jamrao Canal	Mirpurkhas Distributary	0.600	-0.04	S.O.F.	3	5
	Doso Dharoro Distributary	0.684	-0.04	S.O.F.	3	5
	Kahu Visro Minor	0.528	-0.05	F.O.F.	1	5
	Kahu Minor	0.432	-0.12	F.O.F.	3 (only two are operated)	5
	Bareji Distributary	0.630	-0.02	F.O.F.	3	5
		0.527	-0.02	S.O.F.		
	Sanro Distributary	0.518	-0.09	F.O.F.	2	5
West Branch Canal	Lakhakhi Distributary	0.674	-0.10	S.O.F.	1	10
	Bhittaro Minor	0.62	-	F.O.F.	Fixed orifice	
	Sangro Distributary	0.710	-0.03	S.O.F.	2	6
	Daulatpur Minor	0.540	-0.04	S.O.F.	2	6
	Bellaro Minor	0.490	-0.06	F.O.F.	1	6

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ANNEXURES

ANNEXURE A FIELD DISCHARGE MEASUREMENTS FOR HEAD REGULATORS IN MIRPURKHAS SUB-DIVISION

Table A-1. Field Discharge Measurements at Mirpurkhas Distributary Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
29.8.97	3.494	2.518	1.172	87.16	86.06	0.62
26.8.97	3.514	2.383	1.044	83.9	84.28	0.63
23.9.97	3.974	2.463	0.965	89.63	89.96	0.63
18.9.97	3.769	2.648	1.217	95.49	95.38	0.61
27.11.96	3.371	2.373	0.96	71.29	71.64	0.62
4.7.97	3.129	2.313	1.212	82.06	82.17	0.62
20.6.97	3.784	2.633	1.15	92.56	92.62	0.62
5.4.97	3.634	2.113	0.77	71.35	70.84	0.62
10.10.96	3.846	2.26	0.73	68.86	68.96	0.62
9.10.96	4.095	2.34	0.68	69.39	69.37	0.64
24.4.97	3.462	2.173	0.879	75.06	75.29	0.63
1.7.97	3.364	2.453	1.183	86.01	86.81	0.64
28.6.97	3.795	2.473	1.006	86.29	86.52	0.62
23.9.97*	4.011	2.358	0.863	86.63	89.27	0.67
25.6.97*	3.415	2.498	1.21	92.59	91.23	0.65
2.10.96*	4.0	2.385	0.695	77.86	77.82	0.73

* Discarded

Table A.2. Field Discharge Measurements at Doso Dharoro Distributary Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
20-10-96	3.707	3.246	1.49	87.09	86.88	0.715
26-3-97*	2.268	2.22	1.98	28.08	27.97	0.538
30-9-97	3.878	3.05	1.45	112.60	111.10	0.702
3-10-97*	3.578	2.83	1.38	93.11	91.02	0.634
8-10-97	3.958	3.09	1.41	109.77	110.21	0.699
9-10-97	4.578	3.32	1.30	122.18	124.18	0.709
10-10-97	4.238	3.19	1.25	108.57	108.7	0.706
14-10-97	3.788	2.92	1.25	101.49	101.11	0.722
15-10-97	3.948	3.03	1.20	96.05	96.01	0.694
17-10-97	3.816	3.05	1.36	100.97	101.02	0.705
17-12-97*	3.528	3.04	1.59	84.94	85.09	0.636
18-12-97	3.478	3.025	1.49	83.98	84.91	0.702
18-10-97	3.648	2.95	1.31	91.06	91.21	0.692

*Discarded

Table. A-3. Field Discharge Measurements at Kahu Visro Minor Head Regulator.

Date	h_u (ft)	G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
6-10-96	4.750	0.380	19.80	19.480	0.586
12-10-96*	4.229	0.301	18.28	18.190	0.732
29-10-96	4.497	0.430	21.44	21.390	0.585
20-3-97	4.672	0.420	21.44	21.570	0.592
3-4-97	4.312	0.335	17.32	17.200	0.616
2-9-97*	4.017	0.313	21.68	21.800	0.867
11-9-97	4.182	0.490	23.52	23.510	0.585

* Discarded

Table. A-4. Field Discharge Measurements at Kahu Minor Head Regulator.

Date	h_u (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
29.11.97	4.32	0.63	53.14	52.73	0.506
07.10.97	4.71	0.96	83.51	82.91	0.498
02.10.97	4.13	0.96	73.62	73.45	0.471
29.9.97	4.45	0.85	72.84	72.53	0.506
27.9.97	4.32	0.91	75.26	75.26	0.496
26.9.97	4.22	0.89	71.70	72.22	0.492
22-9-97	4.15	0.90	69.00	68.89	0.468
28-6.97*	4.16	0.54	25.54	25.54	0.289
24-4-97*	4.05	1.09	48.78	47.68	0.270
3-4-97	4.29	0.61	54.16	55.00	0.542
19-4-97	4.34	0.48	44.55	43.97	0.547
1-12-97*	4.75	1.03	46.22	46.11	0.256
29-10-96	4.75	0.75	66.21	66.27	0.507
12-10-96*	4.12	1.30	56.25	56.16	0.266
5-10-96	4.28	0.63	59.06	58.60	0.557

* Discarded

Table 4.5. Field Discharge Measurements at Bareji Distributary Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Flow condition of individual gates			Q_m (cfs)	Q_{rev} (cfs)	C_d
				Left	Centre	Right			
19-10-96	3.273	-	0.593	F.O.F.	F.O.F.	F.O.F.	69.33	69.36	0.537
23-10-96*	3.363	-	0.512	F.O.F.	F.O.F.	F.O.F.	59.43	59.56	0.527
2-4-97*	2.440	1.285	0.537	S.O.F.	S.O.F.	F.O.F.	61.49	62.10	0.615
7-4-97	3.380	1.510	0.620	S.O.F.	S.O.F.	S.O.F.	66.42	66.39	0.484
8-4-97	3.310	1.670	0.767	S.O.F.	S.O.F.	S.O.F.	76.21	76.42	0.455
3-6-97	3.180	1.130	0.536	F.O.F.	F.O.F.	F.O.F.	61.34	63.32	0.550
5-6-97	3.325	1.280	0.604	F.O.F.	F.O.F.	F.O.F.	72.29	72.73	0.549
29-6-97	3.170	1.130	0.557	F.O.F.	F.O.F.	F.O.F.	65.93	66.57	0.558
1-7-97*	3.005	1.310	0.683	F.O.F.	S.O.F.	S.O.F.	69.94	68.74	0.482
12-8-97	3.185	1.340	0.646	S.O.F.	F.O.F.	S.O.F.	71.77	71.82	0.518

* Discarded

Table. A.6. Field Discharge Measurements at Lakhakhi Distributary Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
13-10-97	5.745	4.163	0.97	73.12	73.35	0.749
01-10-97*	5.355	3.858	1.00	67.43	69.31	0.706
29-09-97*	5.505	3.863	1.015	73.67	73.95	0.709
26-09-97	5.455	4.038	1.22	85.97	85.80	0.736
25-09-97	5.55	3.993	1.08	80.03	80.19	0.741
12-09-97*	5.235	4.383	1.607	91.15	92.17	0.750
28-08-97	5.67	4.34	1.359	91.24	91.18	0.725
03-07-97	5.245	4.388	1.705	90.79	90.75	0.716
19-06-97	5.53	4.243	1.31	84.05	85.03	0.713
22-10-96	6.017	3.782	0.928	82.67	83.02	0.746
07-10-96*	5.96	3.99	1.17	104.53	104.20	0.791
04-09-97	5.53	4.24	1.31	85.41	85.39	0.715

*Discarded

Table. A.7. Field Discharge Measurements at Sangro Distributary Head Regulator.

Date	$h_u - h_d$ (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
13-4-97	3.77	0.366	51.14	51.15	0.748
27-6-97*	3.12	1.002	132.82	132.56	0.778
11-7-97	2.62	1.062	121.93	124.18	0.750
27-3-97	1.86	1.070	103.10	102.47	0.727
6-10-97	3.27	1.123	142.34	144.07	0.737
17-9-97	2.78	1.170	136.01	139.80	0.744
8-10-97	3.03	1.250	153.54	150.74	0.719
27-10-96*	3.02	1.293	142.65	143.35	0.663
4-4-97*	2.31	1.315	122.81	123.54	0.641
24-9-97*	2.52	1.347	159.16	159.18	0.761
25-9-97	2.52	1.347	154.65	157.83	0.756
4-10-97	2.88	1.370	160.43	158.94	0.710
9-9-97	2.01	1.440	138.84	142.73	0.726
8-10-96	2.47	1.490	156.41	158.35	0.704

*Discarded

Table A.8. Field Discharge Measurements at Daulatpur Minor Head Regulator.

Date	h_u (ft)	h_d (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	C_d
3-4-97	6.76	3.73	0.39	32.30	31.50	0.58
1-8-97	7.22	4.37	0.66	52.24	51.73	0.58
16-9-97	6.61	4.32	0.73	48.56	49.00	0.55
17-9-97	6.70	4.29	0.69	48.21	48.54	0.56
9-10-97	9.96	4.37	0.65	47.31	47.15	0.56
9-12-97	7.54	4.26	0.50	44.43	44.24	0.61
24-12-97	7.54	4.24	0.49	42.92	42.95	0.60
31-12-97*	7.56	4.37	0.69	47.43	48.40	0.49

* Discarded

ANNEXURE B DEVELOPMENT OF DISCHARGE RATING FOR A GATE STRUCTURE: EXAMPLE OF SANGRO DISTRIBUTARY HEAD REGULATOR.

B.1 SANGRO DISTRIBUTARY HEAD REGULATOR DISCHARGE MEASUREMENTS

The head regulator of Sangro Distributary consists of two gates of 6 feet width each and is flowing under submerged orifice flow. The location selected for the discharge measurements was about 150 feet downstream of the head regulator and about 25 to 30 feet upstream of the first two outlets on the left side. A typical cross-section of the discharge measurement location is shown in Figure B.1, where the left half of the total width is deeper than the right one, probably because of the heavy sediment withdrawal by the downstream outlets.

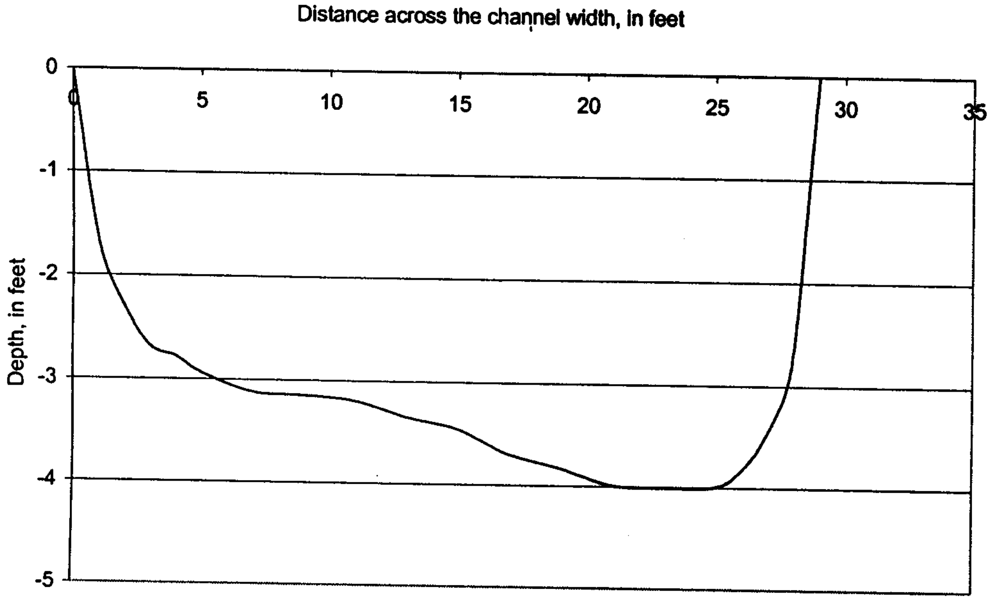

Figure B.1. A typical cross-section of the current metering point, 150 feet downstream of the Sangro Distributary Head Regulator.

Usually, the top width of the Sangro Distributary at this point is 28 to 30 feet and the depth varies from 2 to 4 feet depending upon the discharge. The cross-section was usually divided into 25 segments for measuring velocity. The two-points (0.2d and 0.8d) method was used at each segment and the average of the two was taken as the velocity of the vertical. The sum of the discharges of all of the sections was taken as the discharge at the Sangro Distributary Head Regulator.

To verify that the discharge measurements were accurate, velocity profiles at relative depths of 0.20 and 0.80 were drawn along the cross-sectional width of the channel. In case of any discrepancy in the observations, the velocity was adjusted as desired and the new discharge was computed. As an example, the measured and the revised velocity profiles are shown in Figure B.2.

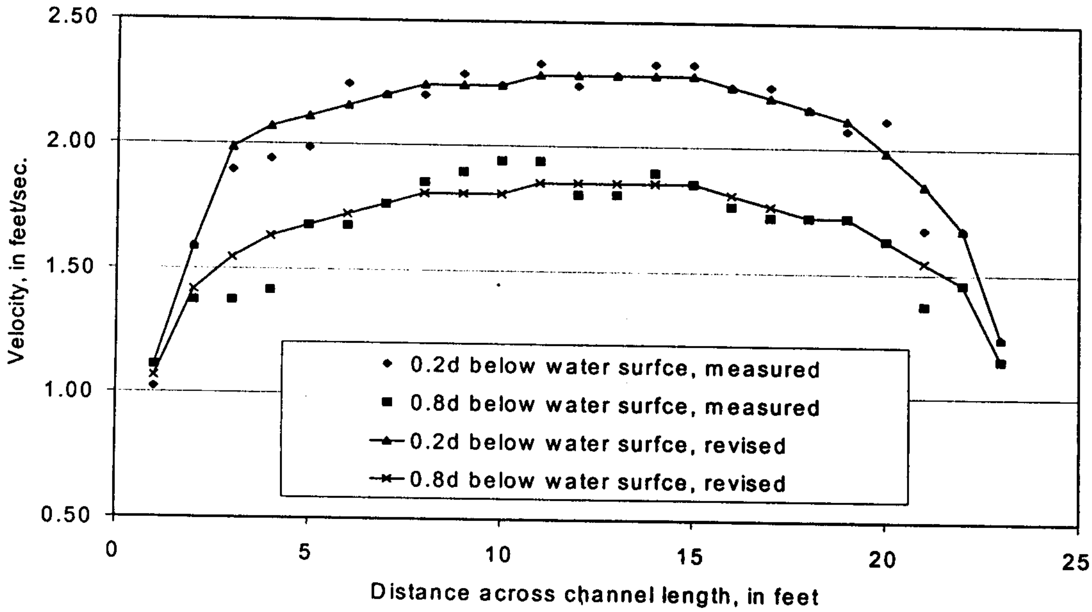

Figure B.2. Measured and revised velocity profiles at Sangro Distributary head.

The same procedure was repeated for all of the fourteen discharge measurements taken at the Sangro Distributary Head. A comparison of the measured and the revised discharges is given in Table B.1. The maximum difference between the measured and the adjusted values of discharge was found to be 3.89 cusecs, which is 2.80 percent of the measured discharge.

Table B.1. A comparison of the measured and revised discharges at Sangro Distributary Head Regulator.

Date	$h_u - h_d$ (ft)	Avg. G_o (ft)	Q_m (cfs)	Q_{rev} (cfs)	Difference (cfs)	C_{drev}
13-4-97	3.77	0.366	51.14	51.15	0.01	0.748
27-6-97	3.12	1.002	132.82	132.56	-0.26	0.778
11-7-97	2.62	1.062	121.93	124.18	2.25	0.750
27-3-97	1.86	1.070	103.10	102.47	-0.63	0.727
6-10-97	3.27	1.123	142.34	144.07	1.73	0.737
17-9-97	2.78	1.170	136.01	139.80	3.79	0.744
8-10-97	3.03	1.250	153.54	150.74	-2.71	0.719
27-10-96	3.02	1.293	142.65	143.35	0.70	0.663
4-4-97	2.31	1.315	122.81	123.54	0.73	0.641
24-9-97	2.52	1.347	159.16	159.18	0.02	0.761
25-9-97	2.52	1.347	154.65	157.83	3.18	0.756
4-10-97	2.88	1.370	160.43	158.94	-1.49	0.710
9-9-97	2.01	1.440	138.84	142.73	3.89	0.726
8-10-96	2.47	1.490	156.41	158.35	1.94	0.704

B.2. SANGRO DISTRIBUTARY HEAD REGULATOR DISCHARGE CALIBRATION

Fourteen discharge measurements were taken about 150 feet downstream of the head regulator in order to develop a discharge rating for this flow control structure. These discharge measurements were taken over a range of gate openings set by the Irrigation Department for usual operation of this Distributary. The discharge coefficient, C_d, was computed using Equation B1.

$$Q_s = C_d G_o W \sqrt{2g(h_u - h_d)} \quad \text{(B1)}$$

The C_d was plotted against the average gate opening, G_o, of the two gates on a normal graph paper (Figure B.3) resulting in a scattered plot.

Obtaining an accurate G_o measurement is a difficult job. Errors are introduced if the gate is not completely horizontal or the gate lip and the sill are not at the same elevation and/or there is leakage from the bottom and sides of the gate. This implies that the datum for measuring the gate opening is below the gate sill. In order to overcome this problem, a correction factor, G_o, was introduced in Equation B1 and rewritten as

$$Q_S = C_d (G_O - \Delta G_O) W \sqrt{2g(h_u - h_d)} \quad \text{(B2)}$$

Different values (e.g. -0.02, -0.03, - 0.04 and - 0.06 feet) of ΔG_o were used to arrive at an appropriate value. The results for ΔG_o equal to -0.03 feet were more promising than others (Figure B.4) and was finally selected for the Sangro Distributary Head Regulator.

In order to find a constant value of C_d, the least square regression method was employed. The square of the difference of the C_d values computed from Equation B2 and some selected values (0.67,0.68,0.69,0.70,0.71 and 0.72) was summed, which turned out to be minimum for C_d = 0.71 as given in Table B.2. However, some C_d values (0.648, 0.627, 0.744 and 0.756) were not fitting quite well as compared to others. First of all, the value of 0.627 was taken out and then the remaining values as given in Tables B.3 and B.4, respectively.

The resulting sum for C_d equal to 0.71 improved significantly by excluding the measurements for the above mentioned values. These C_d values (Tables B.4 and B.5) were plotted against their respective G_o - ΔG_o values as shown in Figures B.5 and B.6. Finally, 0.71 and -0.03 have been taken as the C_d and ΔG_o for the Sangro Distributary Head Regulator, respectively and the resulting equation is given as

$$Q_s = 0.71(G_o + 0.03) W \sqrt{2g(h_u - h_d)} \quad \text{(B3)}$$

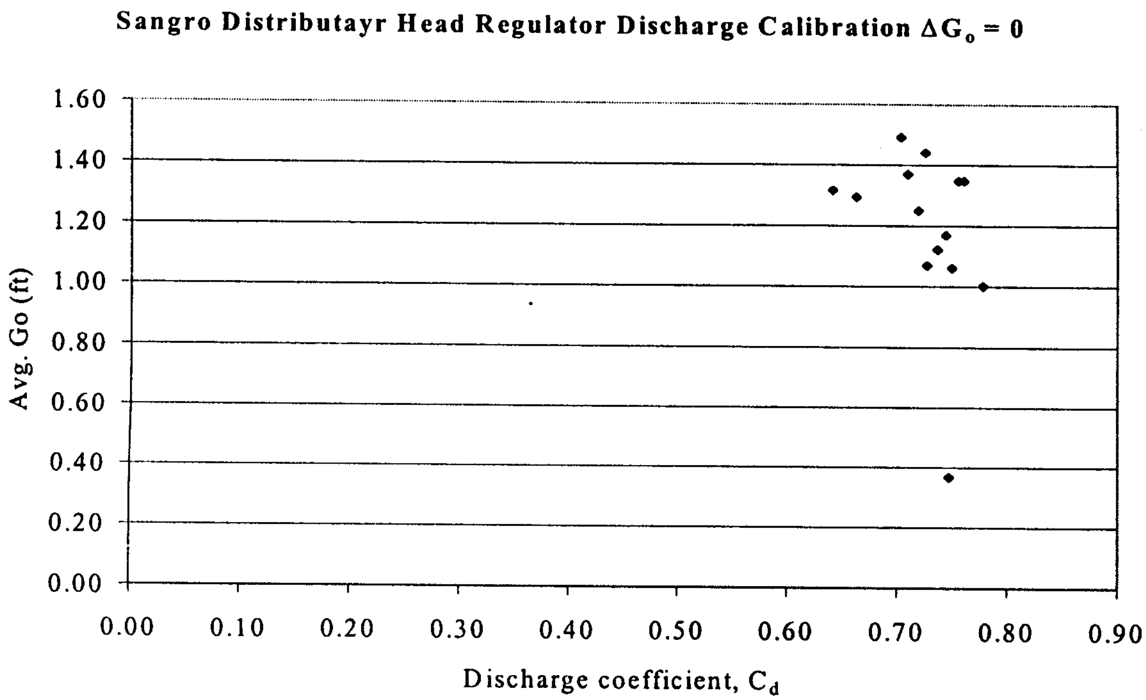

Figure B.3. Variation in Discharge Coefficient, C_d, with Gate Opening, G_o.

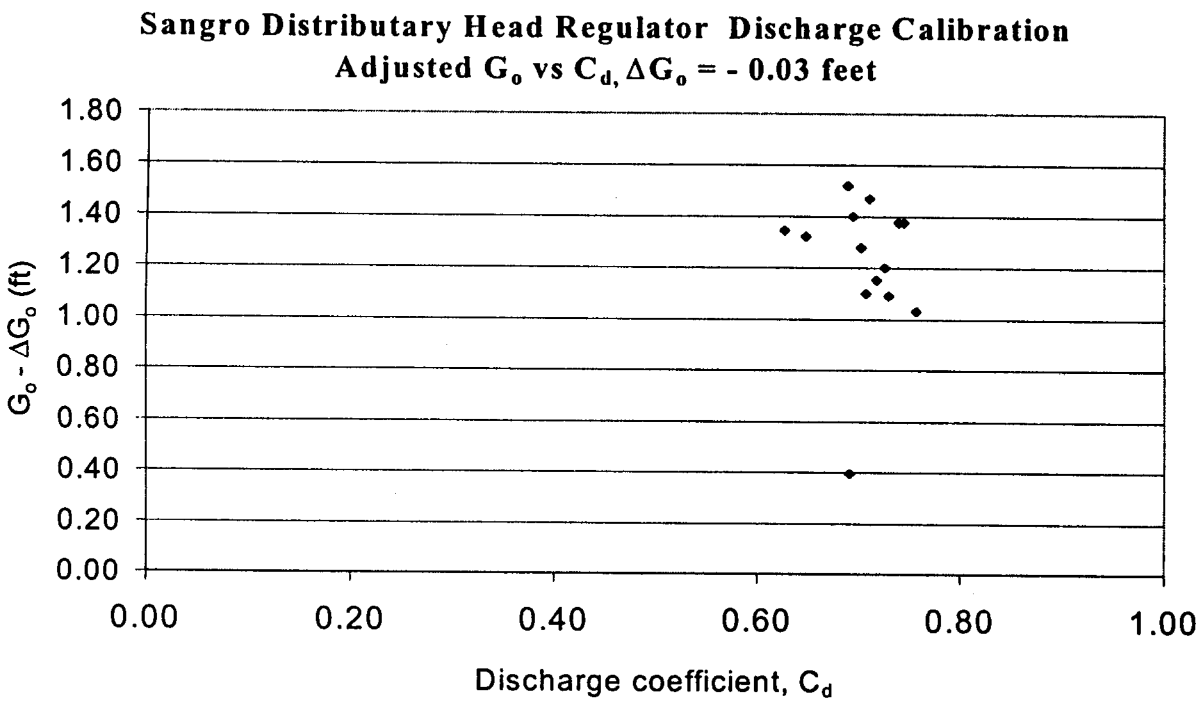

Figure B.4. Variation in Discharge coefficient, C_d with the adjusted Gate Opening, $G_o - \Delta G_o$.

Table B.2 Sum of the square of the difference of different C_d values.

C_d	0.67	0.68	0.69	0.70	0.71	0.72
	(Cd - 0.67)2	(Cd - 0.68)2	(Cd - 0.69)2	(Cd - 0.70)2	(Cd - 0.71)2	(Cd - 0.72)2
0.691	0.0004405	0.0001207	0.0000010	0.0000812	0.0003614	0.0008417
0.756	0.0074580	0.0058308	0.0044036	0.0031764	0.0021492	0.0013220
0.730	0.0035460	0.0024551	0.0015641	0.0008731	0.0003821	0.0000912
0.707	0.0013980	0.0007502	0.0003024	0.0000546	0.0000068	0.0001590
0.718	0.0022601	0.0014093	0.0007585	0.0003077	0.0000569	0.0000061
0.726	0.0030880	0.0020766	0.0012652	0.0006538	0.0002424	0.0000310
0.703	0.0010591	0.0005082	0.0001573	0.0000065	0.0000556	0.0003047
0.648	0.0004843	0.0010245	0.0017646	0.0027048	0.0038449	0.0051851
0.627	0.0018475	0.0028072	0.0039668	0.0053265	0.0068861	0.0086458
0.744	0.0055449	0.0041556	0.0029663	0.0019770	0.0011878	0.0005985
0.740	0.0048405	0.0035490	0.0024576	0.0015661	0.0008746	0.0003831
0.695	0.0006091	0.0002155	0.0000219	0.0000283	0.0002347	0.0006411
0.711	0.0016953	0.0009718	0.0004483	0.0001249	0.0000014	0.0000779
0.690	0.0003895	0.0000948	0.0000001	0.0001054	0.0004106	0.0009159
SUM	0.0346609	0.0259693	0.0200778	0.0169862	0.0166947	0.0192031

Table B.3. Sum of the square of the difference of different C_d values without $C_d = 0.627$

C_d	0.67	0.68	0.69	0.70	0.71	0.72
	(C_d-0.67)2	(C_d-0.68)2	(C_d -0.69)2	(C_d -0.70)2	(C_d -0.71)2	(C_d -0.72)2
0.691	0.0004405	0.0001207	0.0000010	0.0000812	0.0003614	0.0008417
0.756	0.0074580	0.0058308	0.0044036	0.0031764	0.0021492	0.0013220
0.730	0.0035460	0.0024551	0.0015641	0.0008731	0.0003821	0.0000912
0.707	0.0013980	0.0007502	0.0003024	0.0000546	0.0000068	0.0001590
0.718	0.0022601	0.0014093	0.0007858	0.0003077	0.0000569	0.0000061
0.726	0.0030880	0.0020766	0.0012652	0.0006538	0.0002424	0.0000310
0.703	0.0010591	0.0005082	0.0001573	0.0000065	0.0000556	0.0003047
0.648	0.0004843	0.0010245	0.0017646	0.0027048	0.0038449	0.0051851
0.744	0.0055449	0.0041556	0.0029663	0.0019770	0.0011878	0.0005985
0.740	0.0048405	0.0035490	0.0024576	0.0015661	0.0008746	0.0003831
0.695	0.0006091	0.0002155	0.0000219	0.0000283	0.0002347	0.0006411
0.711	0.0016953	0.0009718	0.0004483	0.0001249	0.0000014	0.0000779
0.690	0.0003895	0.0000948	0.0000001	0.0001054	0.0004106	0.0009159
sum	0.0328134	0.0231622	0.0161109	0.0116597	0.0098085	0.0105573

Table B.4 Sum of the square of difference by excluding $C_d = 0.627, 0.744, 0.756, 0.648$

C_d	0.67	0.68	0.69	0.70	0.71	0.72
	(C_d -0.67)2	(C_d -0.68)2	(C_d -0.69)2	(C_d -0.70)2	(C_d -0.71)2	(C_d -0.72)2
0.691	0.0004405	0.0001207	0.0000010	0.0000812	0.0003614	0.0008417
0.730	0.0035460	0.0024551	0.0015641	0.0008731	0.0003821	0.0000912
0.707	0.0013980	0.0007502	0.0003024	0.0000546	0.0000068	0.0001590
0.718	0.0022601	0.0014093	0.0007585	0.0003077	0.0000569	0.0000061
0.726	0.0030880	0.0020766	0.0012652	0.0006538	0.0002424	0.0000310
0.703	0.0010591	0.0005082	0.0001573	0.0000065	0.0000556	0.0003047
0.740	0.0048405	0.0035490	0.0024576	0.0015661	0.0008746	0.0003831
0.695	0.0006091	0.0002155	0.0000219	0.0000283	0.0002347	0.0006411
0.711	0.0016953	0.0009718	0.0004483	0.0001249	0.0000014	0.0000779
0.690	0.0003895	0.0000948	0.0000001	0.0001054	0.0004106	0.0009159
sum	0.0193261	0.0121513	0.0069764	0.0038015	0.0026266	0.0034517

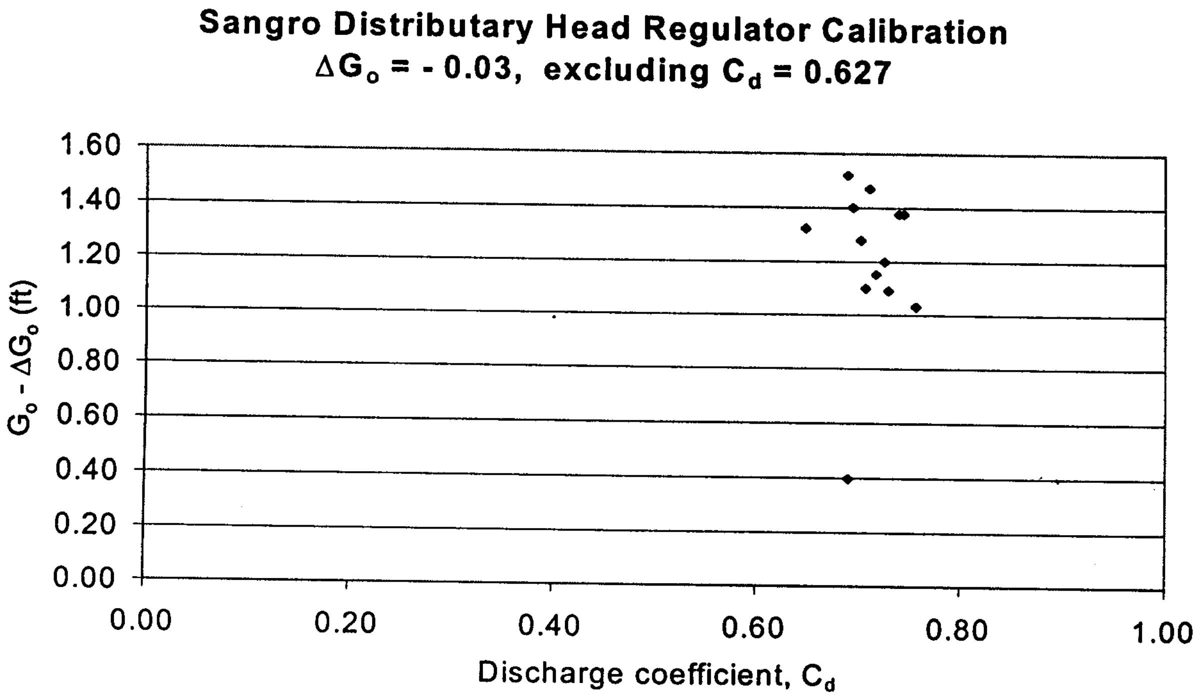

Figure B.5. Variation in Discharge Coefficient, C_d , with the adjusted Gate Opening, $G_o - \Delta G_o$, by excluding C_d =0.627.

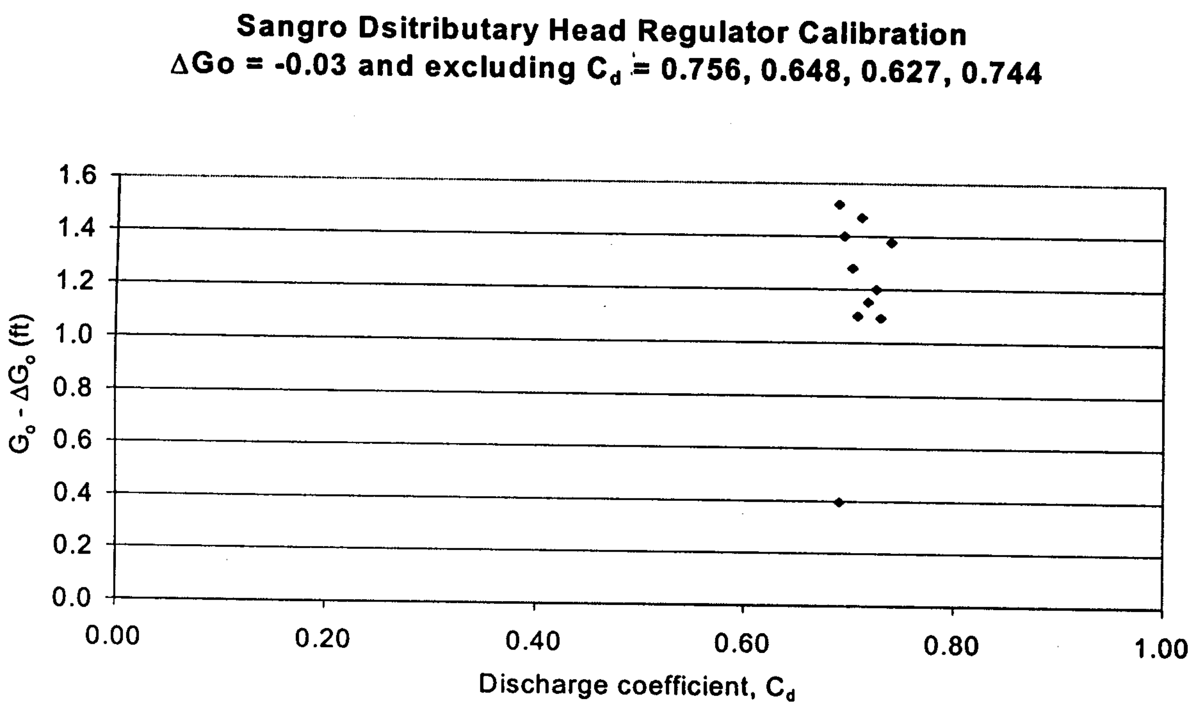

Figure B.6. Variation in Discharge Coefficient, C_d , with the adjusted Gate Opening, $G_o - \Delta G_o$, by excluding C_d =0.627, 0.756, 0.648, 0.744

ANNEXURE C. DISCHARGE RATINGS FOR HEAD GEGULATORS IN MIRPURKHAS SUB-DIVISION

Table C.1. Summary of Discharge Ratings of the Mirpurkhas Sub-Division Head Regulators.

Name of Channel	Flow Condition	Developed Equation
Jamrao Canal Section		
Mirpurkhas Distributary	Submerged Orifice Flow	$Q_s = 0.60(G_o+0.04)W\sqrt{2g(h_u - h_d)}$
Doso Dharoro Distributary	Submerged Orifice Flow	$Q_s = 0.684(G_o+0.04)W\sqrt{2g(h_u - h_d)}$
Kahu Visro Minor	Free Orifice Flow	$Q_f = 0.528(G_o+0.05)W\sqrt{2g(h_u + 0.05)}$
Kahu Minor	Free Orifice Flow	$Q_f = 0.432(G_o+0.12)W\sqrt{2g(h_u + 0.12)}$
Sanro Distributary	Free Orifice Flow	$Q_f = 0.518(G_o+0.09)W\sqrt{2g(h_u + 0.09)}$
Bareji Distributary	Free Orifice Flow	$Q_f = 0.527(G_o+0.02)W\sqrt{2g(h_u + 0.02)}$
	Submerged Orifice Flow	$Q_s = 0.630(G_o+0.02)W\sqrt{2g(h_u - h_d)}$
West Branch Canal Section		
Lakhakhi Distributary	Submerge Orifice Flow	$Q_s = 0.674(G_o+0.10)W\sqrt{2g(h_u - h_d)}$
Bhittaro Minor	Free Orifice Flow	$Q_f = 0.617\ A\ \sqrt{2gh_u}$
Sangro Distributary	Submerge Orifice Flow	$Q_s = 0.710(G_o+0.03)W\sqrt{2g(h_u - h_d)}$
Daulatpur Minor	Submerged Orifice Flow	$Q_s = 0.540(G_o+0.04)W\sqrt{2g(h_u - h_d)}$
Bellaro Minor	Free Orifice Flow	$Q_f = 0.490(G_o+0.06)W\sqrt{2g(h_u + 0.06)}$

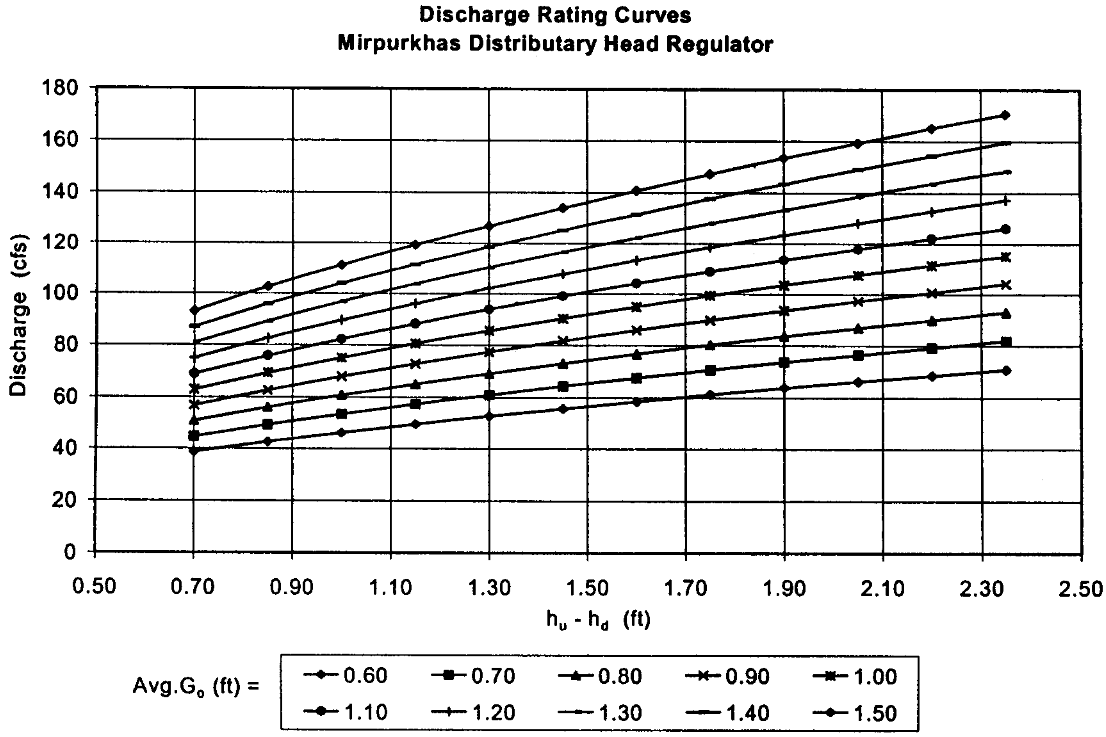

Figure C.1. Discharge Rating Curves for Mirpurkhas Distributary Head Regulator.

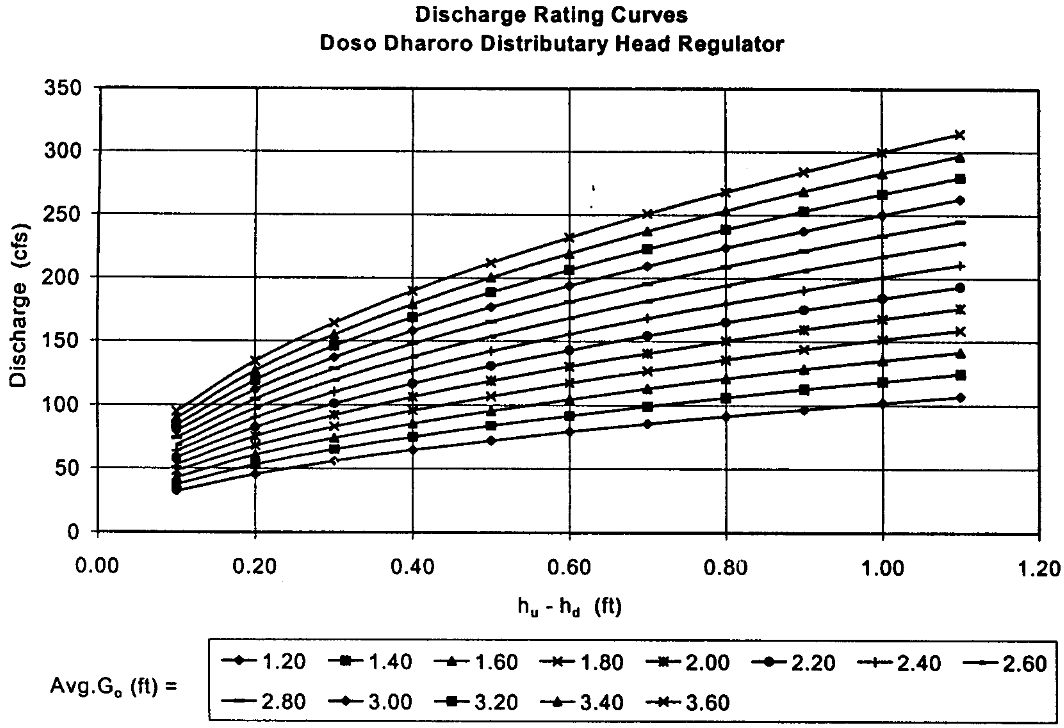

Figure C.2. Discharge Rating Curves for Doso Dharoro Distributary Head Regulator.

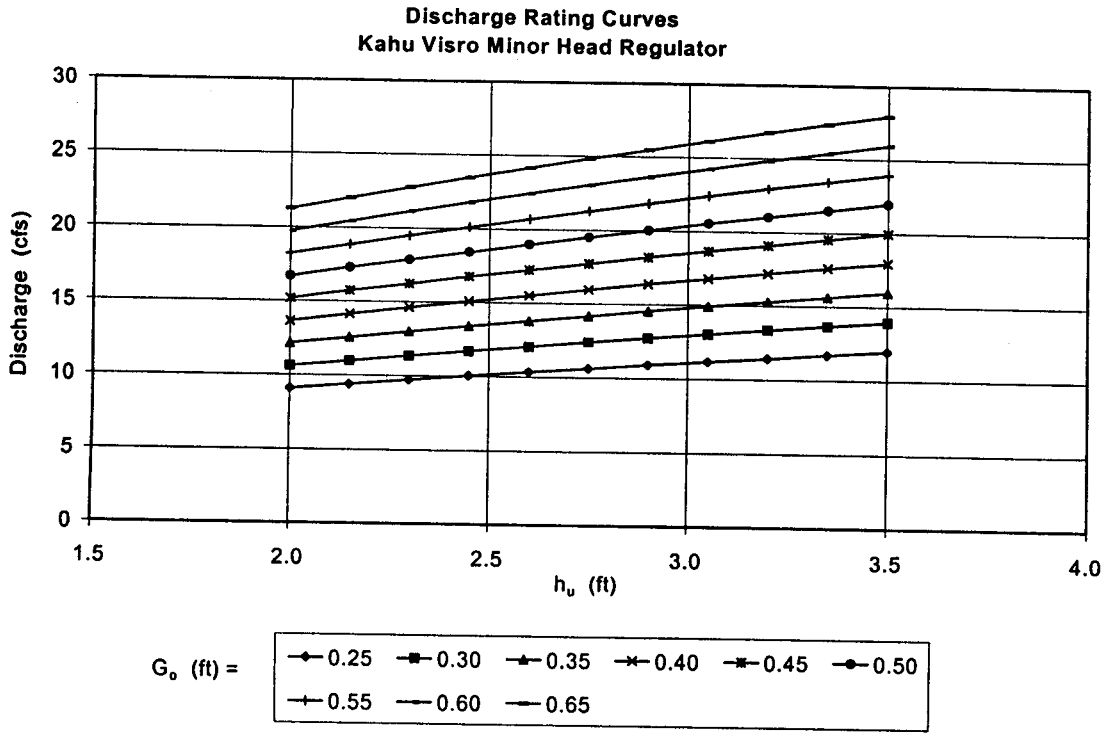

Figure C.3. Discharge Rating Curves for Kahu Visro Minor Head Regulator.

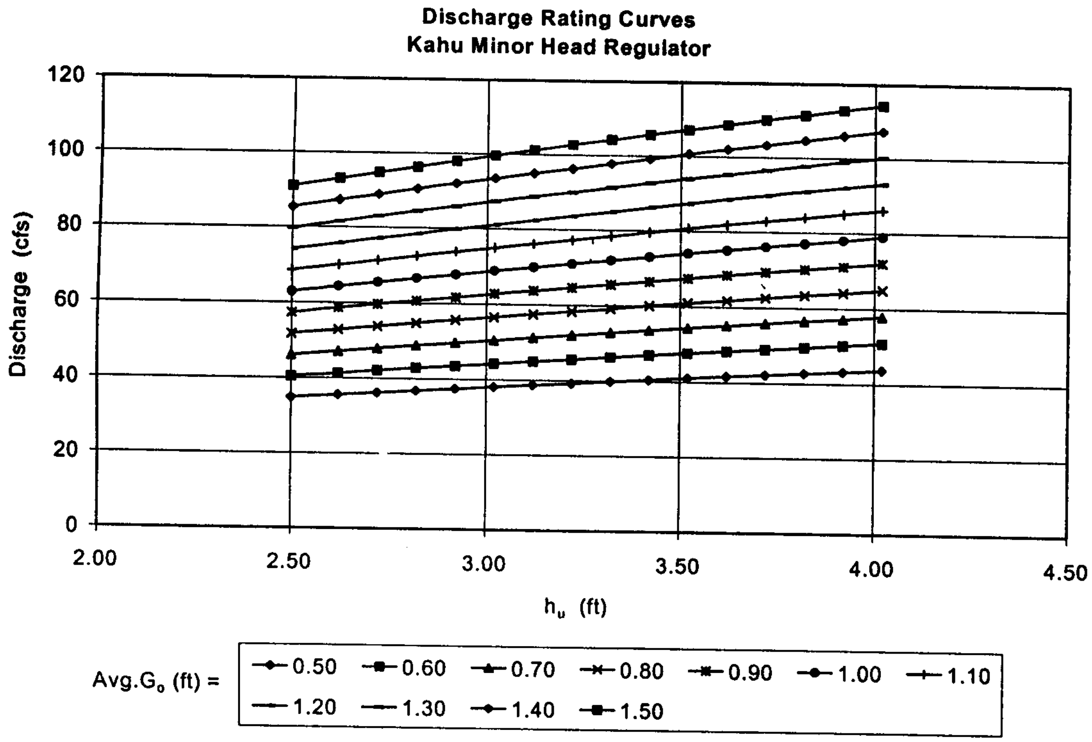

Figure C.4. Discharge Rating Curves for Kahu Minor Head Regulator.

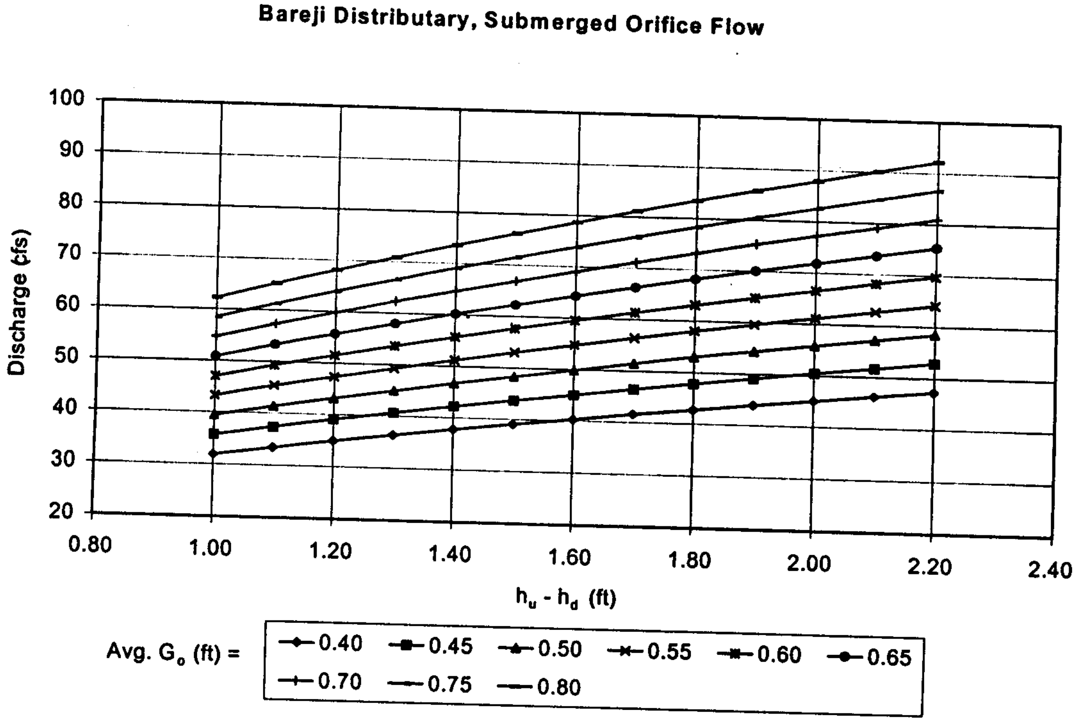

Figure C.5. Discharge Rating Curves for Bareji Distributary Head Regulator with Submerged Orifice Flow.

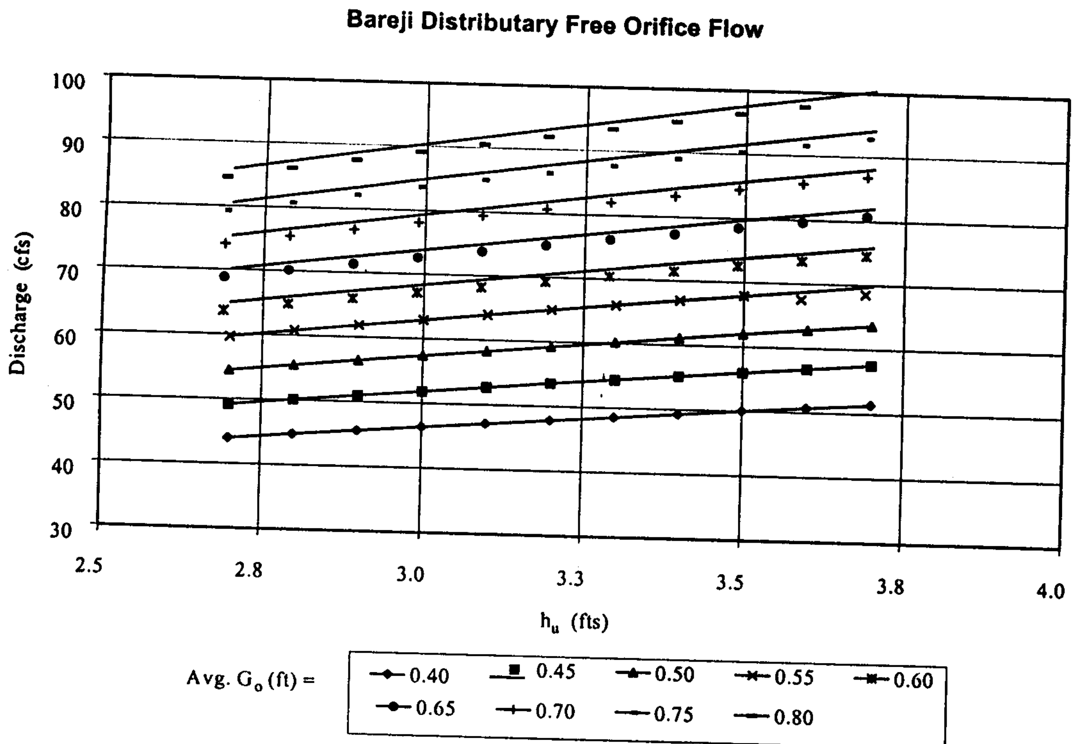

Figure C.6. Discharge Rating Curves for Bareji Distributary Head Regulator Free Orifice Flow.

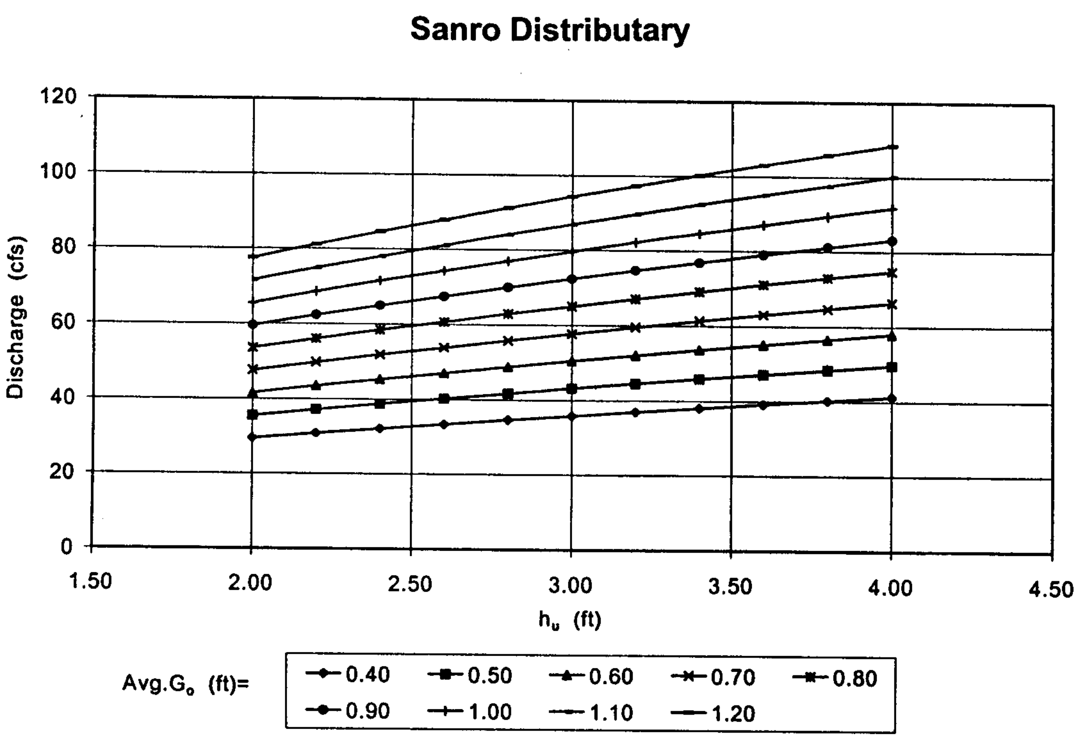

Figure C.7. Discharge Rating Curves for Sanro Distributary Head Regulator.

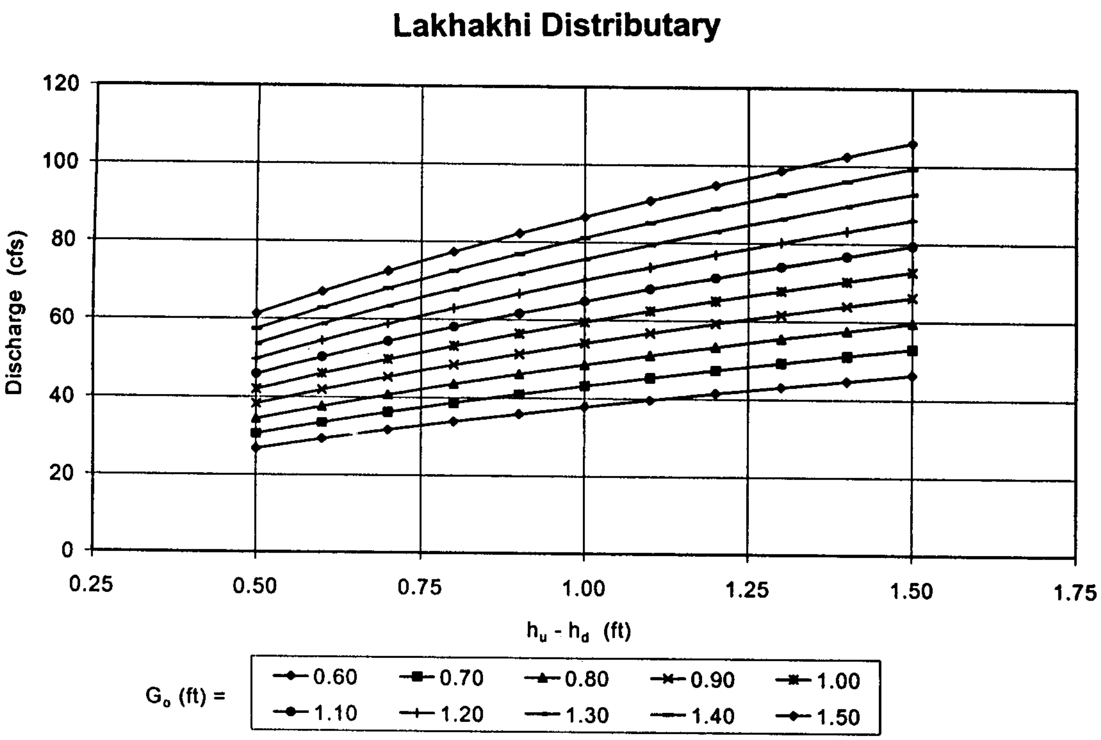

Figure C.8. Discharge Rating Curves for Lakhakhi Distributary Head Regulator.

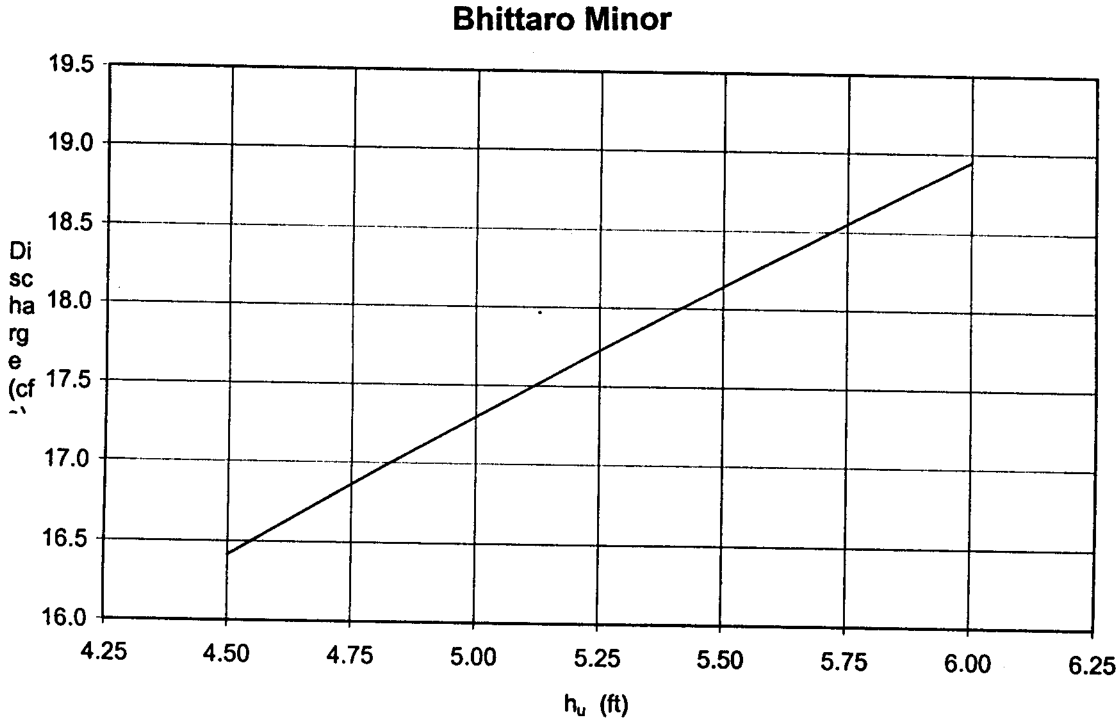

Figure C.9. Discharge Rating Curve for Bhittaro Minor Head Regulator.

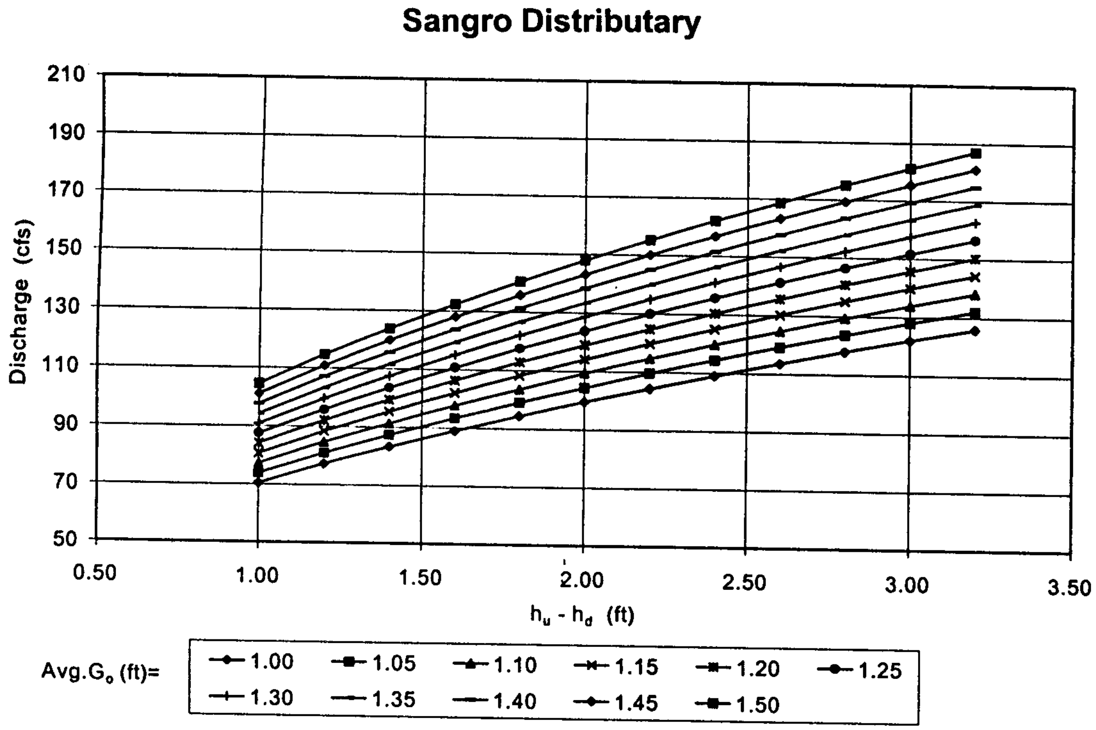

Figure C.10. Discharge Rating Curves for Sangro Distributary Head Regulator.

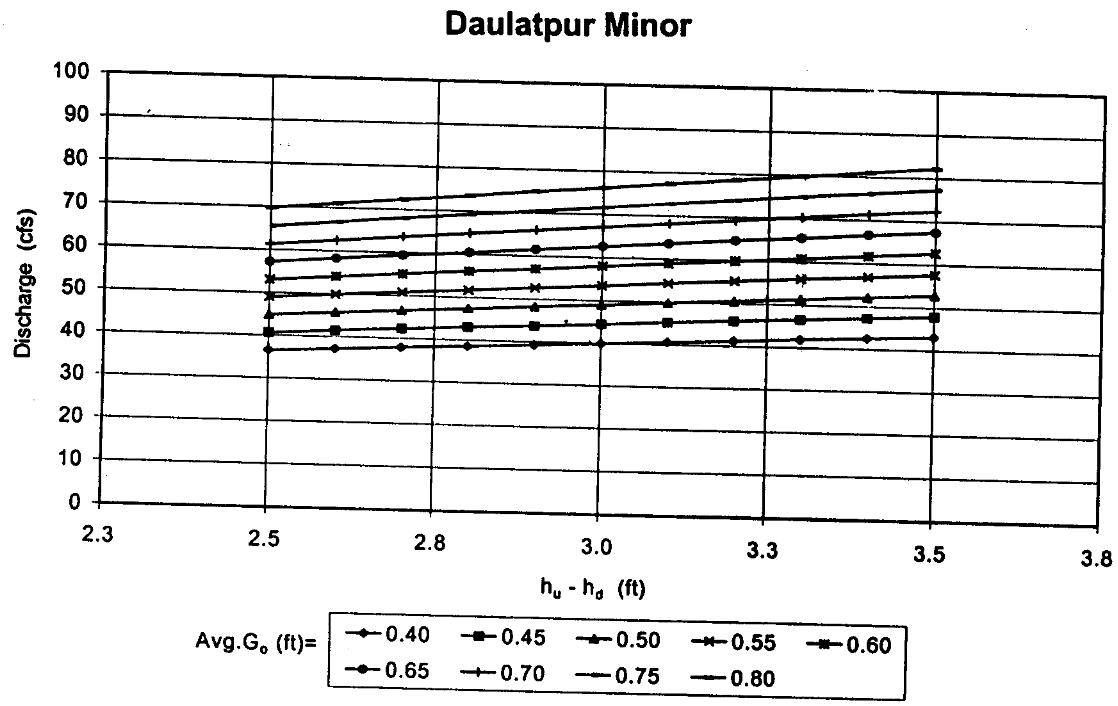

Figure C.11. Discharge Rating Curves for Daulatpur Minor Head Regulator.

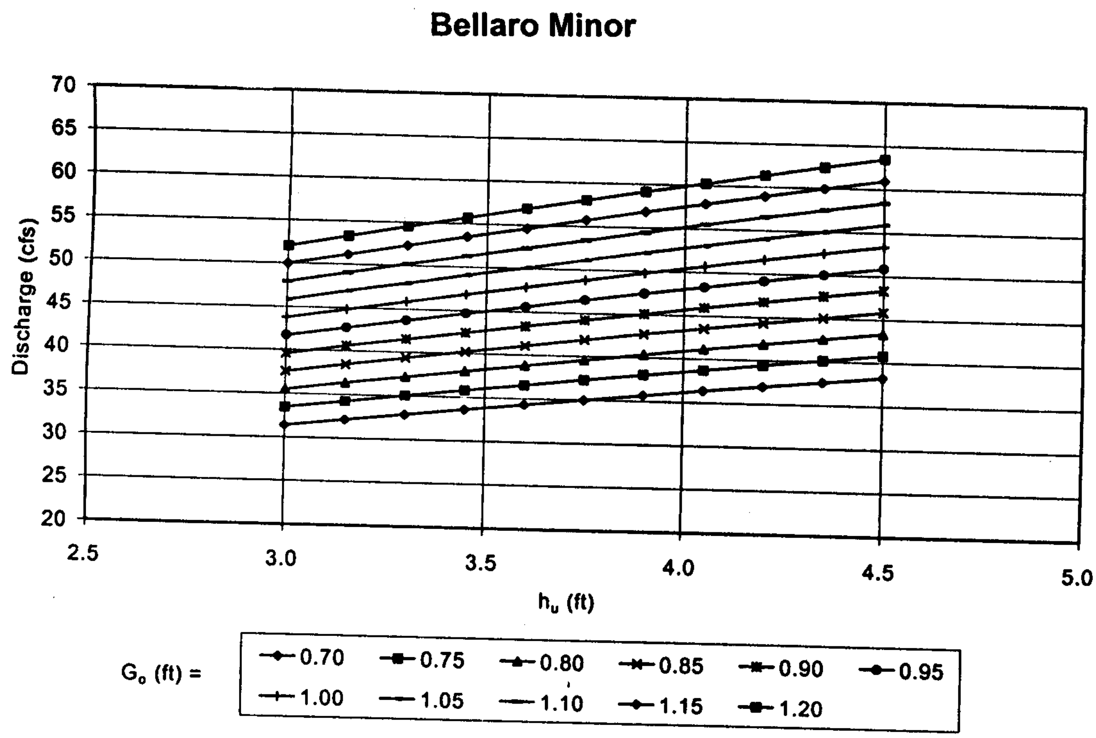

Figure C.12. Discharge Rating Curves for Bellaro Minor Head Regulator.

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