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RSR – 01

APPLIED RESEARCH

ON

EVALUATION OF DISCHARGE CO-EFFICIENT OF BROAD CRESTED MASONRY WEIRS

REPORT NO. 01/98-99

HYDRAULIC RESEARCH DIRECTORATE
RIVER RESEARCH INSTITUTE
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ABSTRACT

A study is undertaken in a glass-sided tilting flume at Hydraulic Laboratory of River Research Institute (RRI), Faridpur with a view to find out the discharge co-efficient of broad-crested masonry weirs using usual discharge formula and to evaluate the performance of weir with respect to upstream and downstream slopes and their crest height. Weirs of different sizes and shapes are used to measure the flow passed through barrage, regulator, sluice, spillway, over road when acts as weir or any other irrigation, drainage and hydraulic structures. In some cases instantaneous flow measurement is required for operation and maintenance of the structures. A proper calibration of such types of structure is pre-requisite for instantaneous flow measurement. Co-efficient of discharge (C) is the dominant parameter which greatly influence on accurate flow measurement. In the present study, percentage of error in flow measurement due to error in determination of co-efficient of discharge are discussed.

In this study, total water head above the weir crest, crest width, upstream and downstream conditions have been considered as variables. The head varied within the range of 91.40 mm to 335.3 mm. Whereas crest width varied between 4 to 8 inches for different test conditions. A total of twenty two test runs are conducted to get desired values of Co-efficient of discharge (C).

The co-efficient of discharge (C) is increased with the increase in water head above the crest. The co-efficients are found to be higher in downstream sloping conditions than those in upstream sloping conditions. The co-efficient of discharge is found to be more realistic in downstream sloping condition with crest width of 4 inches rather than wider crest.

Higher regression co-efficient between head and discharge are found which implies that a good correlation between head and discharge in almost all tests is encountered and it is anticipated that the test results could easily be used to calculate the unknown parameters against the known value of discharge or head in a similar condition.

ACKNOWLEDGMENTS

The study has been carried out by the Hydraulic Research Directorate of River Research Institute, Faridpur.The authors acknowledge their sincere gratitude and indebtedness to Dr. M. R. Kabir, Associate Professor, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology (BUET) for his guidance, co-operation and valuable suggestions and comments extended to this study. The services given by RRI officers' and staff are gratefully acknowledged.

1. Introduction

Weir may be defined as a structure used to determine the volume of water from measurement of its depth on a crest. Generally, timber and masonry dams having various shapes of section, reservoir overflows etc. may be described as weirs. Weirs are broadly two types : sharp-crested and broad-crested. The broad-crested weirs are generally constructed in an open channel for measuring flow in a desired flow condition. Different shapes of weirs provided in the channel to minimize or increase afflux, to reduce head loss, to reduce energy dissipation, to increase co-efficient of discharge and to reduce flashing out of accumulated sediment behind a barrage, regulator, sluice, spillway etc. Commonly, rectangular, trapezoidal and parabolic weirs are designed to use in these structures. A study is carried out in a glass-sided tilting flume at Hydraulic Laboratory of River Research Institute (RRI), Faridpur with a view to find out the discharge co-efficient of broad-crested masonry weirs as shown in Figure 1 using usual discharge formulae ($Q=CLH^{3/2}$) and to evaluate the performance of weir with respect to upstream and downstream slopes and their crest height.

Available formulas are certainly inadequate to compute discharge for special type of weirs. The co-efficient of discharge 'C' varies with the conditions changes.

2. Background of the study

Hydraulic structures like culverts, sluices, spillways and regulators are constructed in different rivers, rivulets and canals to facilitate optimum water use in irrigation and drainage works. Sometimes it is necessary to know that how much water will have to be spilled over these structures. Also these structures experience a substantial sedimentation and scouring problems. In order to minimize these problems, a compromise between flow and dimensions of the structures are necessary. Flow passing through the structures are measured by constructing masonry weirs across the rivers, rivulets or canals. The weirs should be designed so that the discharge co-efficient (C) is high vis-a-vis the upstream afflux, downstream scour and sedimentation at the entrance.

Generally, experimental results on broad-crested weirs with vertical and steeper upstream slopes are available in text books. This work was undertaken to find out such configurations of masonry works which can work on the problems mentioned above also can be used as a good device for measuring the flowing discharge through these structures.

In this study, different types of masonry broad-crested weirs are constructed based on crest height and slope of upstream and downstream faces. A series of tests are conducted under different heads.

3. Objectives of the study

The main objectives of the study are :

- to find out the discharge co-efficient (C) of broad-crested masonry weirs using usual discharge formula ($Q=CLH^{3/2}$) and

- to evaluate the performance of weir with respect to upstream and downstream slopes and their crest height.

4. Description of the flume

The flume is a self contained unit and provision has been made both for conventional sump return system and also for continuous circulation (Figure 2). The salient features of the flumes are as follows:

Length (Including inlet and outlet tank)	23.98 m
Width	0.762 m
Sump capacity	21.5 m^3

The bed of the channel is metallic and can conveniently be drilled for pressure tapping or for other purposes, if necessary. A tailgate is provided at the downstream end of the channel for depth control in the channel.

The channel is fitted with double jacking system from the center pivot point. The center distance between the jacks and pivot point is 7.98 m. The jacks are mechanically connected and manually operated. The tilting of the flume is done by turning the wheel at the pivot point. The direction of rotation of the flume is same as the direction of rotation of the wheel. One turn of the wheel will cause a rise of 0.4 mm in one side and a fall of 0.4 mm on the either side of the pivot point. One complete turn of the wheel in the anticlockwise direction will produce a normal (positive) slope of 0.000051 from horizontal. Similarly, one complete turn of the wheel in the clockwise direction will give a reverse (negative) slope of 0.000051 from horizontal.

The channel and the pipe network is designed to circulate a total flow of 0.34 m^3/s through two centrifugal pumps. The circulation of water in the channel is accomplished by a suitable designed two pipe lines system. The internal diameter of two pipes are 254 mm and 305 mm respectively. The pipe lines are fitted with control valves at the inlet (pump end) and outlet (pipe end). The flow through the pipe is measured by orifice meter fitted with each pipe line.

5. Weir Installation

Masonry broad-crested weirs with different upstream and downstream conditions are constructed in the laboratory and placed in the bed of the tilting flume. The weirs are placed at the downstream of the flume in such way that steady uniform flow is ensured at the upstream. The downstream tail gate is fitted with the rotating wheel to ensure the free fall at the downstream end.

The flume width is reduced by 92 mm providing 2.1 m long and 46 mm thick timber plate in both sides covering overall depth at the weir section in order to prevent the breaking of side glass. The joint between timber plate and the weir filled with pooting. The timber plate is extended towards upstream until minimizing end contraction at the upstream of the weir to acceptable limit. Some arrangements are made with baffles (perforated bricks) at the upstream of the measured section to dissipate excess energy due to incoming turbulent flow from the delivery pipe ultimately to distribute uniform flow across the flume.

During test operation, required head is given in a point gauge fitted with movable rail. Required head is ensured by operating controlling valves at the upstream and the corresponding discharge is measured from the fitted mercury manometer.

6. Calibration of Discharge Co-effiecient (C)

The weir co-efficient varies as a function of the total water head above the weir crest and also as a function of the upstream and downstream faces. The discharge co-efficient (C) for each of the head (H) corresponds to discharge (Q) is calculated from the well known equation;

$$\text{i.e. } C = \frac{Q}{LH^{3/2}} \quad \text{------------------------ (1)}$$

For each test, measured discharge (Q) are plotted against known heads (H) and standard Q-H relationships are established by least square method. From these relationships, single intercept and exponent are obtained for each relationship. Here, the intercept stands for co-efficient of discharge (C). These co-efficients are than compared with individual 'C' values obtained from standard equation (1). Percentage of error in calculation of discharge are obtained by $\frac{Q_{obs} - Q_{cal}}{Q_{obs}}$.

The variation of 'Q' values for different sloping face with different crest width are also investigated and compared with each other. From the established relationships, one can easily choose the desired value of 'C' for design of hydraulic structures like sluice, regulator, rivulets or spillways. In addition, overflowing discharge during flood over roads, dams, levees etc. can be computed when these acts as a broad-crested weir by knowing the value of 'C' for a particular case.

7. Test Runs

A total of twenty two tests are designed and planned to determine the discharge co-efficients in different conditions. Of them, seven tests are planned for upstream face slope, eight tests for downstream face slope and seven tests for both upstream and downstream face slope of the weir. The test runs are conducted for different slopes such as 1:1, 1:2, 1:3 and 1:4. For each of the test, length of the weir normal to the direction of flow is kept constant while the crest width is variable.

8. Data Analysis and Discussions

For each test, standard Head (H) - Discharge (Q) relationship is established and shown in Figure 3 to 24. From the H-Q relationships, 'C' values are computed. Runwise H-Q relationships with test condition are presented in Table 1.

Table 1: H-Q Relationships

Run	Test Condition		Crest Width	H-Q Relationship	'C' Value
	Upstream Slope	Downstream slope			
BCW01	Vertical	1:1	4"	$Q=2.44\ L\ H^{1.58}$	2.44
BCW02	-Do-	1:2	4"	$Q=2.44\ L\ H^{1.63}$	2.44
BCW03	-Do-	1:3	4"	$Q=2.54\ L\ H^{1.62}$	2.54
BCW04	-Do-	1:4	4"	$Q=2.75\ L\ H^{1.70}$	2.75
BCW05	-Do-	1:2	8"	$Q=2.77\ L\ H^{1.74}$	2.77
BCW06	-Do-	1:3	8"	$Q=2.99\ L\ H^{1.82}$	2.99
BCW07	-Do-	1:4	8"	$Q=2.61\ L\ H^{1.70}$	2.61
BCW08	1:1	Vertical	4"	$Q=2.46\ L\ H^{1.57}$	2.46
BCW09	1:2	-Do-	4"	$Q=2.27\ L\ H^{1.50}$	2.27
BCW10	1:3	-Do-	4"	$Q=2.30\ L\ H^{1.51}$	2.30
BCW11	1:4	-Do-	4"	$Q=2.83\ L\ H^{1.69}$	2.83
BCW12	1:1	-Do-	8"	$Q=1.88\ L\ H^{1.54}$	1.88
BCW13	1:2	-Do-	8"	$Q=2.57\ L\ H^{1.62}$	2.57
BCW14	1:3	-Do-	8"	$Q=2.40\ L\ H^{1.58}$	2.40
BCW15	1:4	-Do-	8"	$Q=2.14\ L\ H^{1.50}$	2.14
BCW16	1:1	1:2	8"	$Q=2.54\ L\ H^{1.64}$	2.54
BCW17	1:3	1:2	8"	$Q=3.20\ L\ H^{1.82}$	3.20
BCW18	1:4	1:2	8"	$Q=2.84\ L\ H^{1.68}$	2.84
BCW19	1:2	1:4	4"	$Q=3.01\ L\ H^{1.73}$	3.01
BCW20	1:1	1:4	8"	$Q=3.04\ L\ H^{1.77}$	3.04
BCW21	1:2	1:4	8"	$Q=2.90\ L\ H^{1.82}$	2.90
BCW22	1:3	1:4	8"	$Q=2.58\ L\ H^{1.65}$	2.58

BCW Broad-Crested Weir

The discharge against known head is calculated from H-Q relationships in different test conditions and then the calculated discharge values are compared with observed values and errors in discharge are computed which are shown in Table 2.

Table 2: Errors in calculation of Discharge (Q) and Co-efficient of Discharge (C)

Run	Test Condition		Crest Width	Percent error in Discharge, Q	Percent error in Co-efficient, C
	Upstream Slope	Downstream slope			
BCW01	Vertical	1:1	4"	+5.49 / -11.60	6.13
BCW02	-Do-	1:2	4"	+4.87 / - 6.67	11.17
BCW03	-Do-	1:3	4"	+4.28 / -8.79	11.79
BCW04	-Do-	1:4	4"	+4.97 / -10.79	24.02
BCW05	-Do-	1:2	8"	+8.66 / -10.88	24.59
BCW06	-Do-	1:3	8"	+7.23 / -26.37	44.06
BCW07	-Do-	1:4	8"	-31.92	25.75
BCW08	1:1	Vertical	4"	+28.7 / -11.43	4.08
BCW09	1:2	-Do-	4"	+4.84 / -4.34	4.84
BCW10	1:3	-Do-	4"	+4.94 / - 6.84	3.58
BCW11	1:4	-Do-	4"	+3.34 / -9.37	26.58
BCW12	1:1	-Do-	8"	+33.41	26.72
BCW13	1:2	-Do-	8"	+7.05 / -4.35	10.11
BCW14	1:3	-Do-	8"	+7.51 / -7.14	3.54
BCW15	1:4	-Do-	8"	+5.67 / -10.78	3.52
BCW16	1:1	1:2	8"	+4.77 / -11.38	13.41
BCW17	1:3	1:2	8"	+23.63 / -22.45	11.7
BCW18	1:4	1:2	8"	+6.66 / -7.68	15.59
BCW19	1:2	1:4	4"	+8.13 / -6.11	27.10
BCW20	1:1	1:4	8"	+5.48 / -7.06	36.92
BCW21	1:2	1:4	8"	+18.86 / -12.62	27.46
BCW22	1:3	1:4	8"	+8.50 / -26.79	9.35

It is evident from the test results that the co-efficient of discharge (C) increased with the increase in water head. In all tests, the shape of curves are similar to each other. The regression co-efficients lies between 0.90 to 0.98 which reveals that the relationships are found to be reliable. In comparing observed discharge with the computed discharge, maximum about 12% and minimum 3.34% error is found in 16 tests and rest of the tests show larger variation. Errors in 'C' values lies within 3.54 to 44 percent. From the analysis it is revealed that the head-discharge relationships are consistent with the variation in exponent. Error in discharge also increases with the increases in crest width for upstream and downstream face slope or slopes in both side. Keeping downstream slope constant, error in discharge increases with flatter slope. The co-efficient of discharge is found to be more realistic in downstream sloping condition with crest width of 4 inches.

9. Conclusions

Discharge co-efficient depends on total water head above the weir crest, upstream and downstream condition. From the test results, the following conclusions can be made:

- The co-efficient of discharge (C) is increased with the increase in water head above the crest. The co-efficients are found to be higher in downstream sloping conditions than those in upstream sloping conditions.

- A good correlation between head and discharge is found in almost all tests which implies that the test results could easily be used to calculate the unknown parameters against the known value of discharge or head in a similar condition.

- The co-efficient of discharge is found to be more realistic in downstream sloping condition with crest width of 4 inches rather than wider crest.

- Based on the calibrated weirs, large size weirs can be designed to use in barrage, sluices, regulators, spillways or any other irrigation, drainage and hydraulic structures.

10. Recommendations

The fluctuation in water level at the upstream of the weir is found during the test runs at higher heasd which could be minimized by increasing the length of the flume in upstream direction or measure water level in a stilling basin attached to the section. Although baffles placed at the upstream end to minimize turbulence of incoming flow, steady uniform flow could not be ensured.

During the test runs with higher discharge, the mercury in the differential manometer fitted with the circular pipe fluctuates frequently which results inaccuracies in discharge calculation. These inacuracy could be minimized by connecting a tube of reduced section.

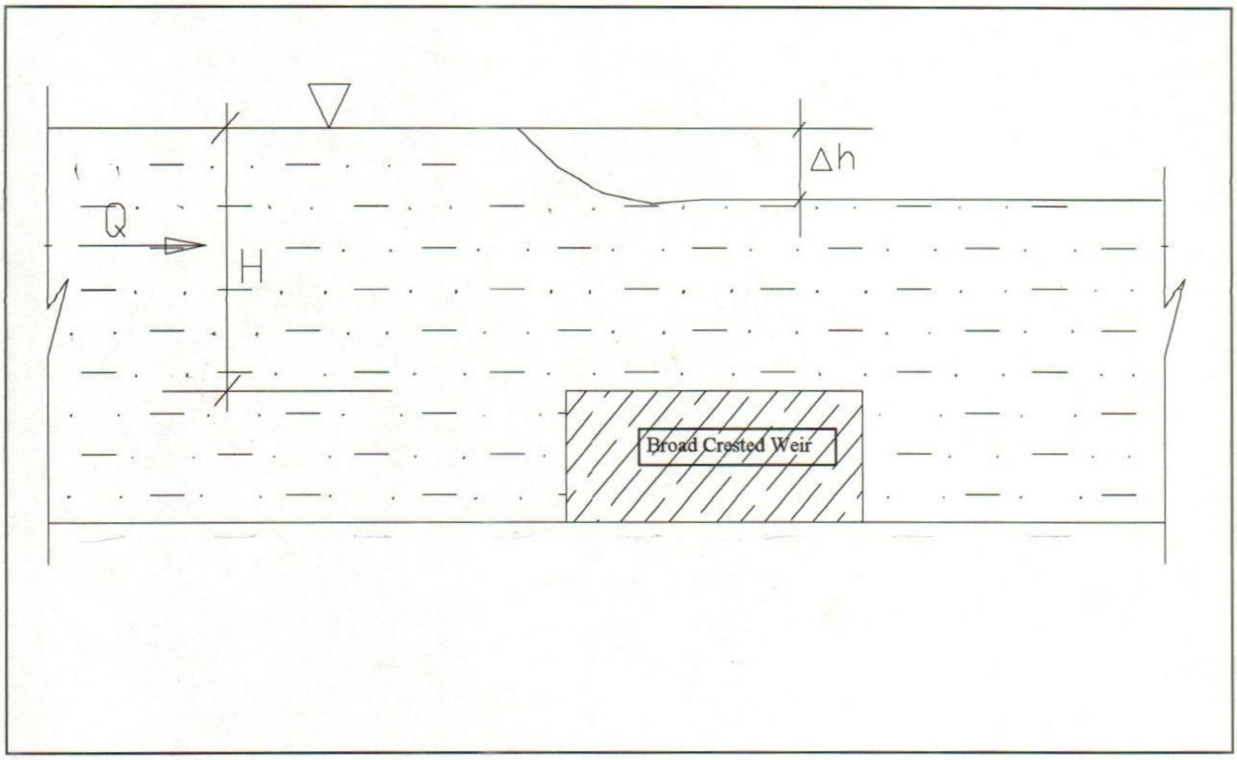
The errors in calculation of discharge as well as co-efficient of discharge is influenced by constant flume width and depth. In this study water surface slope is kept constant. A good calibration can be encapsulated with the variable flume size and water surface slope.

References

Horton, R.E. (1906) **Weir Experiments**, Co-efficients and Formulas, US Geological Survey, Washington D.C., USA.

Hussain, S.M. (1995) **Hydraulic Performance of Broad-Crested Weirs of Different Shapes (A Case Study)**, Technical Journal of River Research Institute, Vol. 02, No. 01, January 1995, Faridpur.

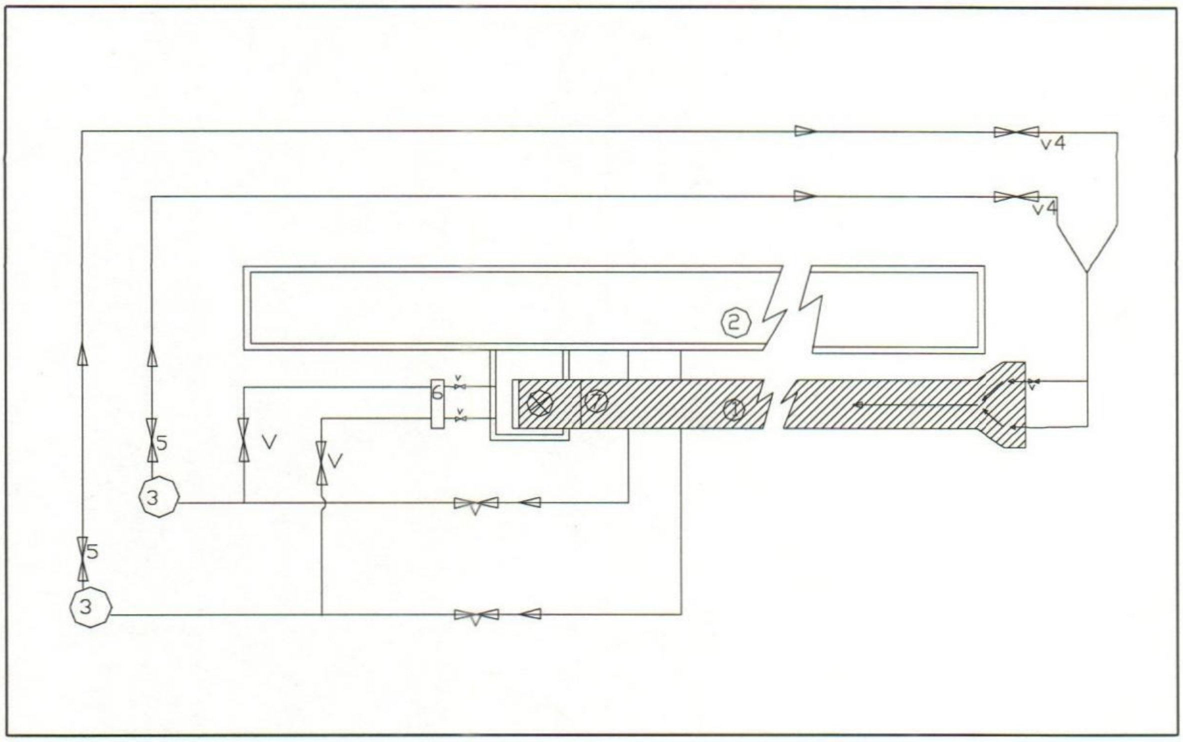
Smith, A.R. (1959) **Calibration of a Submerged Broad-Crested Weir**, Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol 03, March 1959, USA.



Legend

Q Discharge
H Head Above the Weir Crest
Δh Head Loss

Figure 1 : Definition Sketch of a Broad Crested Masonry Weir



<u>**Legend**</u>

1 Glass Sided Flow Channel
2 Sump Tank
3 Centrifugal Pump
4 Control Valve at the Pipe End
5 Control Valve at the Pump End
6 Manifold
7 Tale Gate

Figure 2 : Experimental Setup

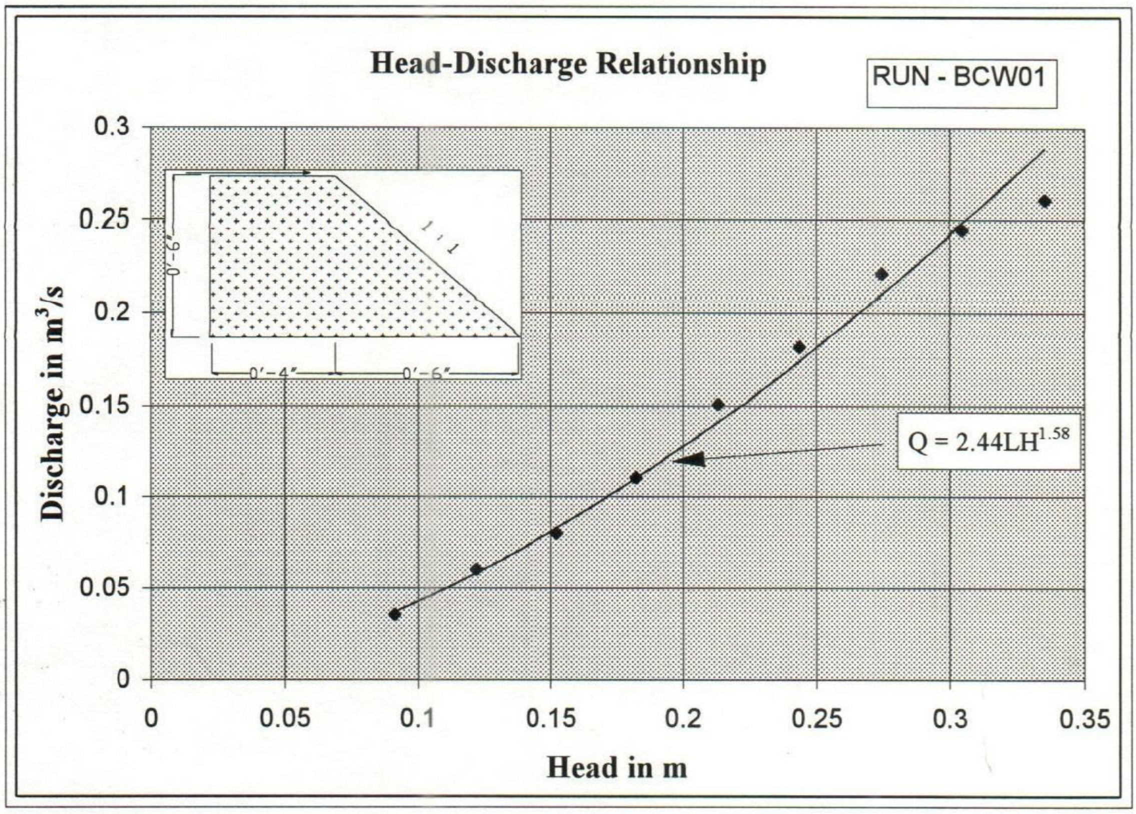


Figure 3 : Head Discharge Relationship

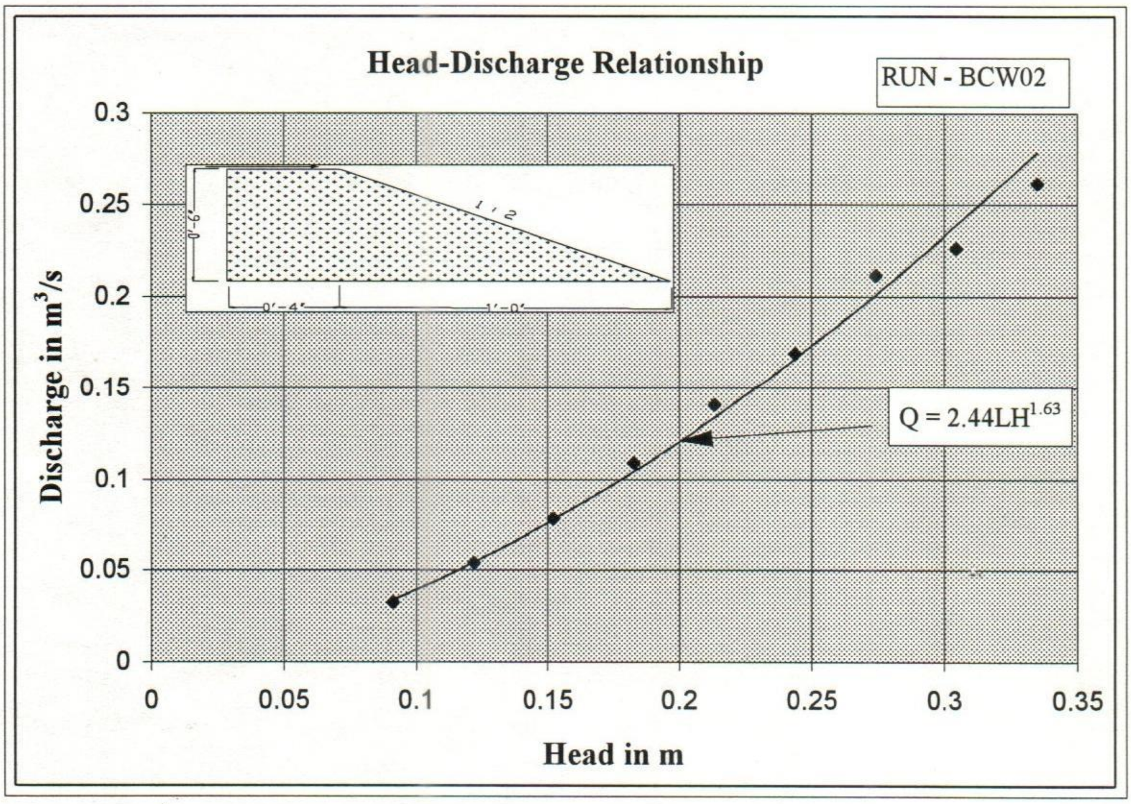


Figure 4 : Head Discharge Relationship

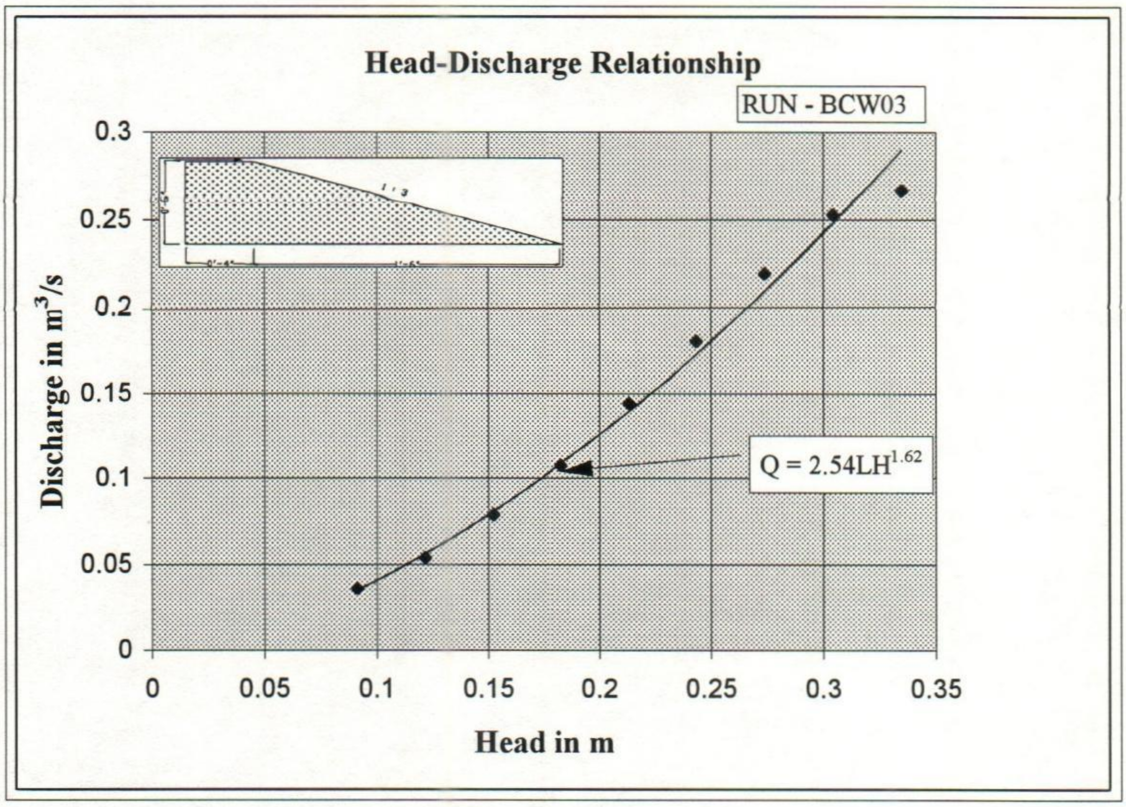


Figure 5 : Head Discharge Relationship

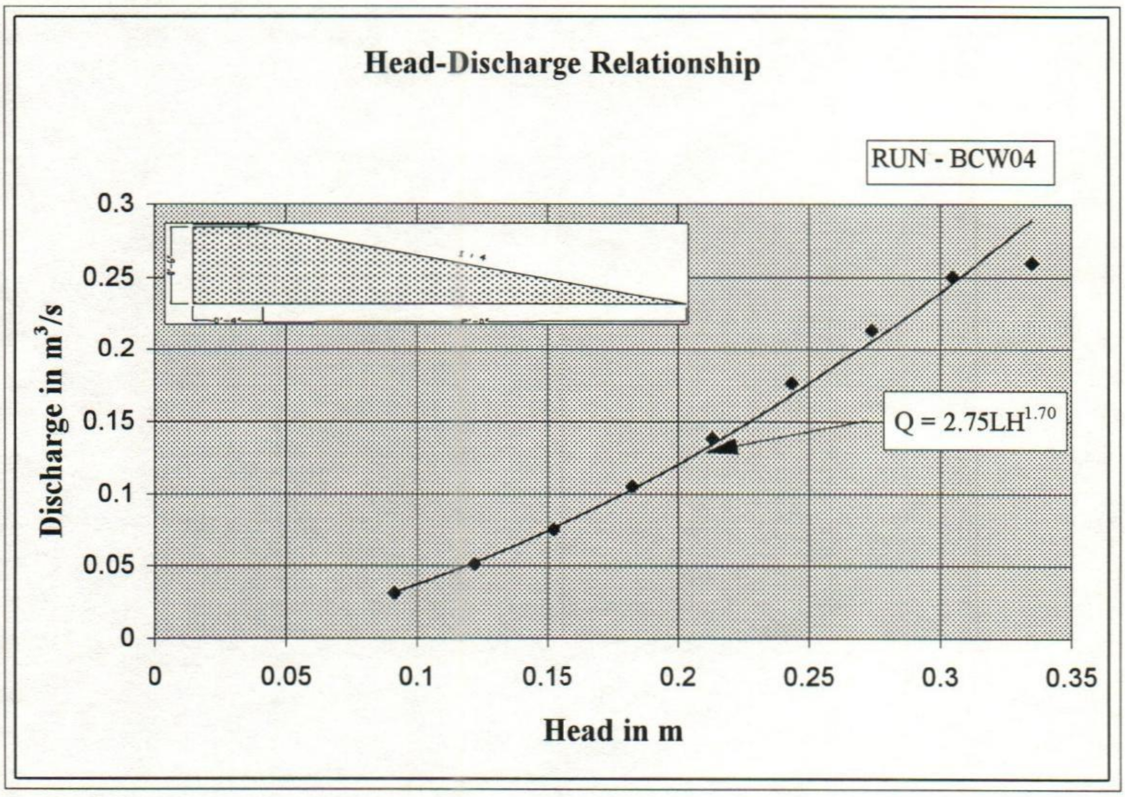


Figure 6 : Head Discharge Relationship

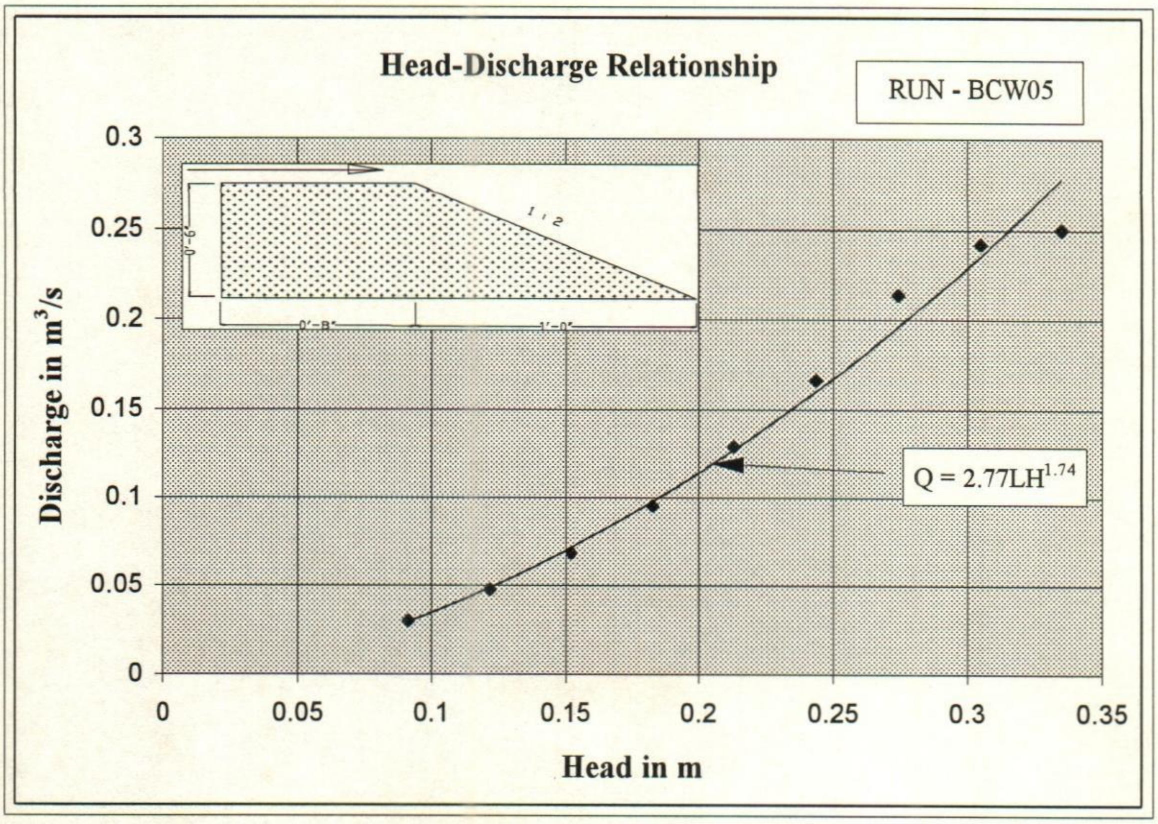


Figure 7 : Head Discharge Relationship

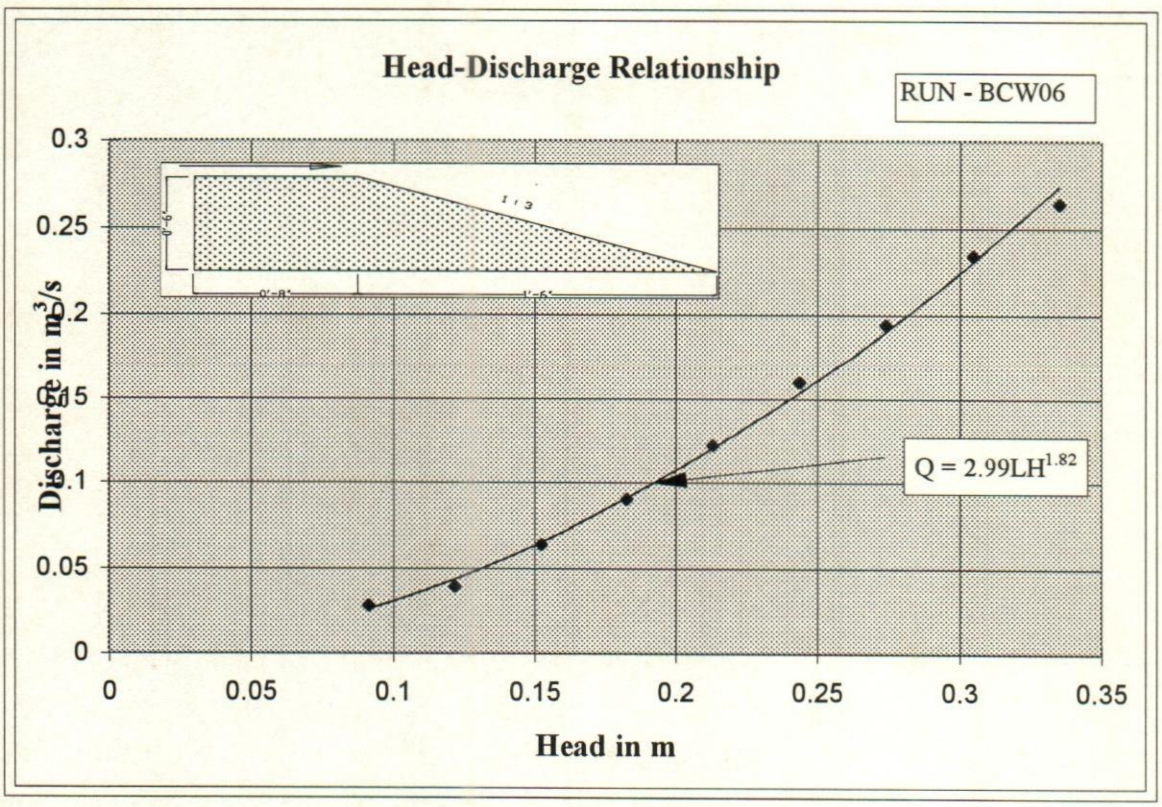


Figure 8 : Head Discharge Relationship

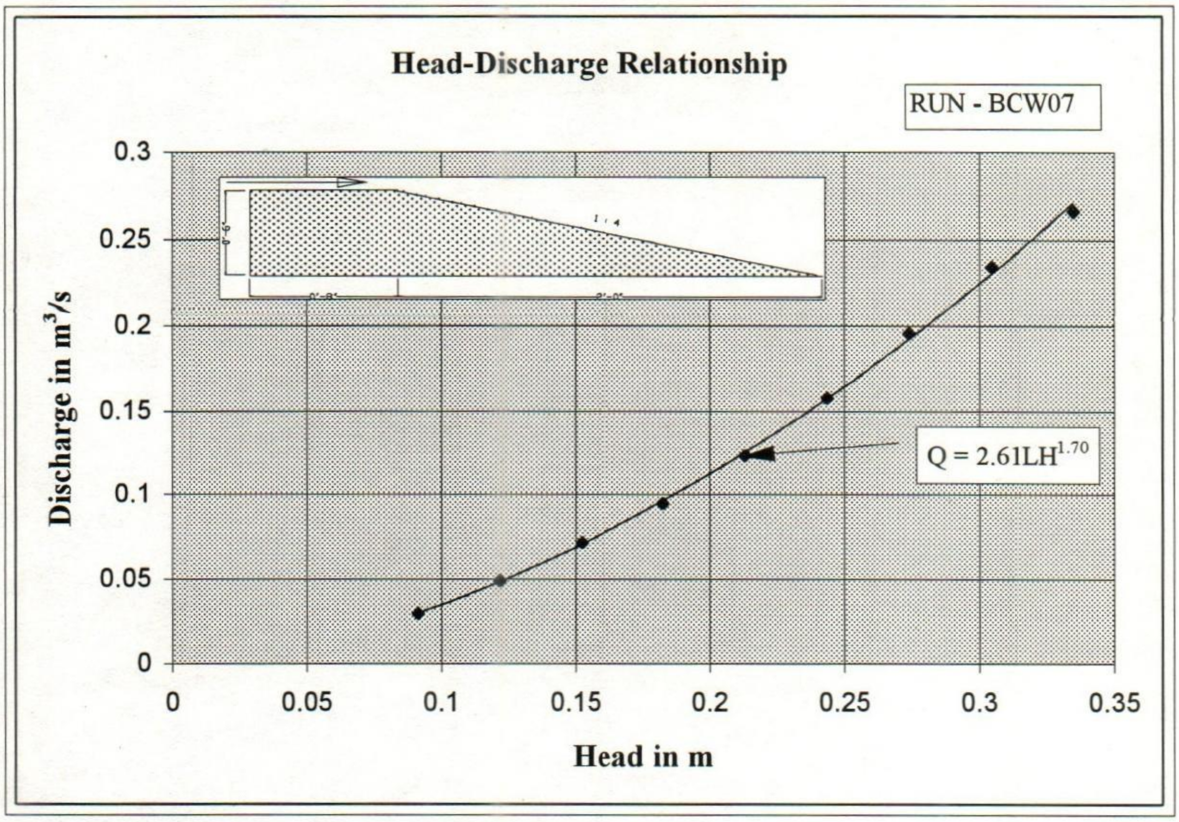


Figure 9 : Head Discharge Relationship

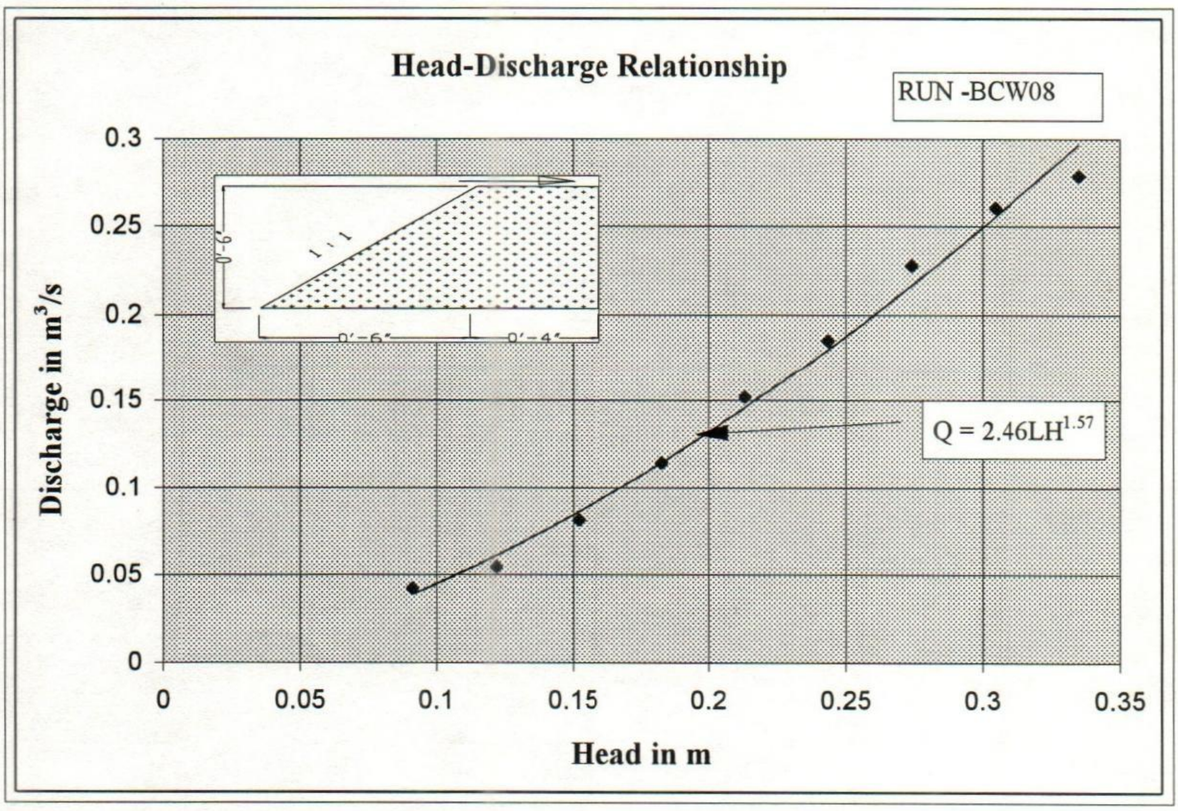


Figure 10 : Head Discharge Relationship

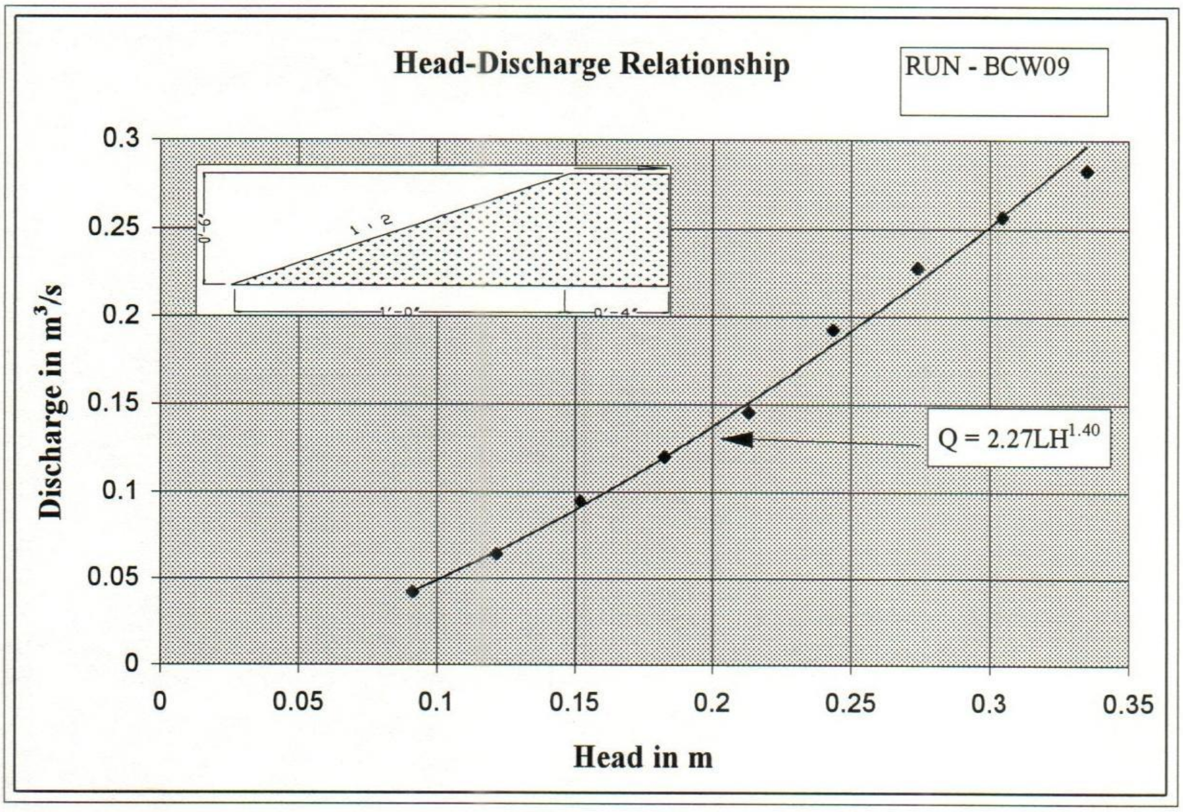


Figure 11 : Head Discharge Relationship

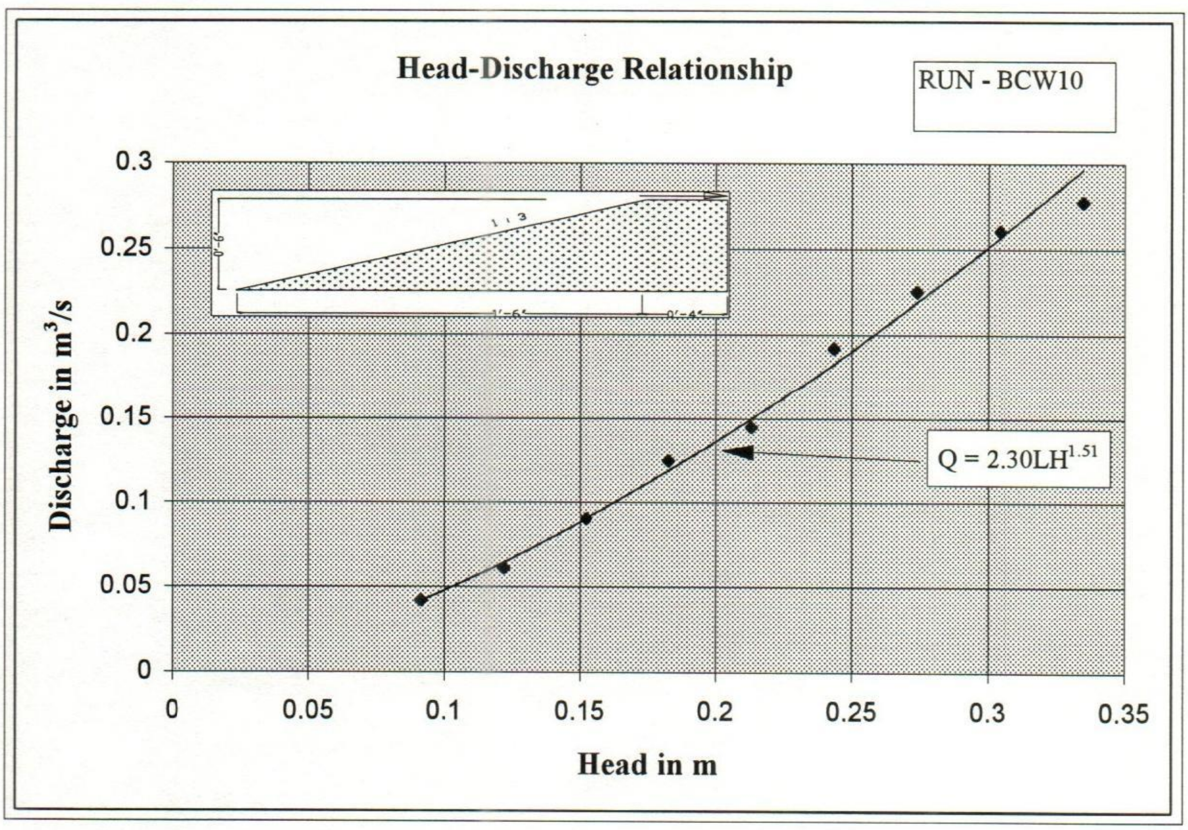


Figure 12 : Head Discharge Relationship

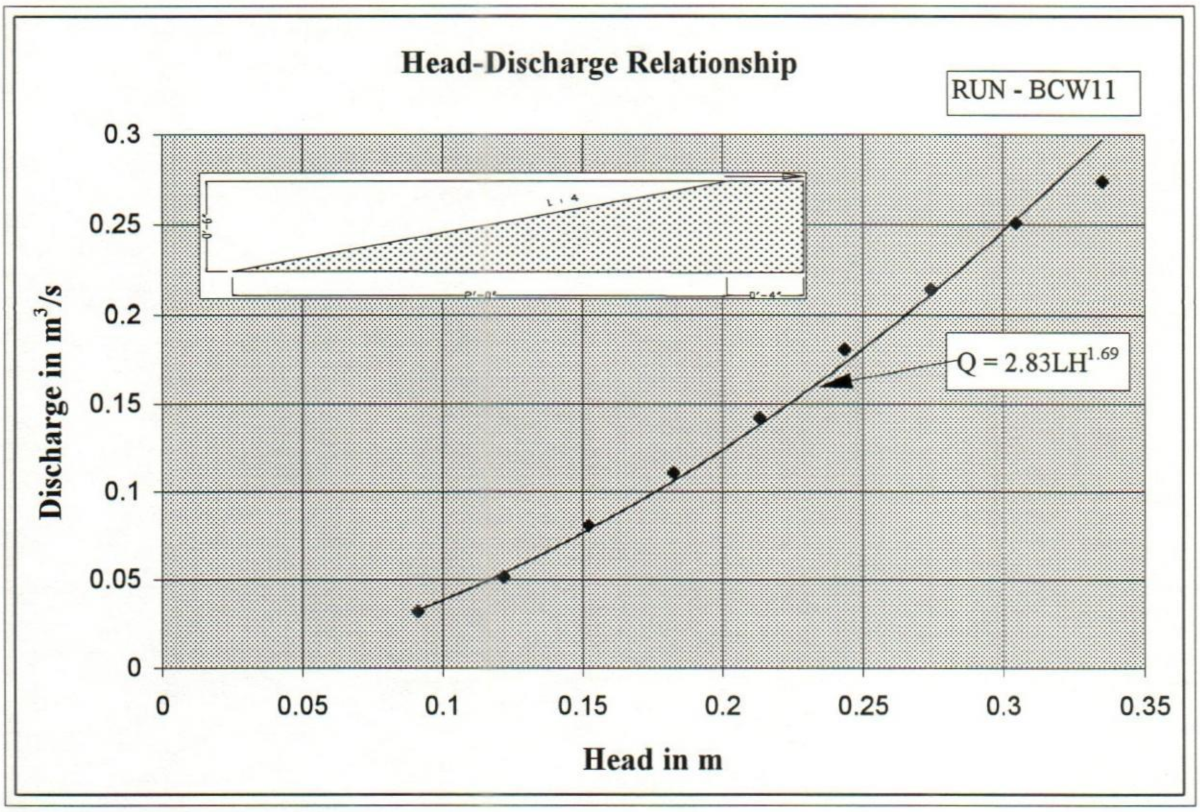


Figure 13 : Head Discharge Relationship

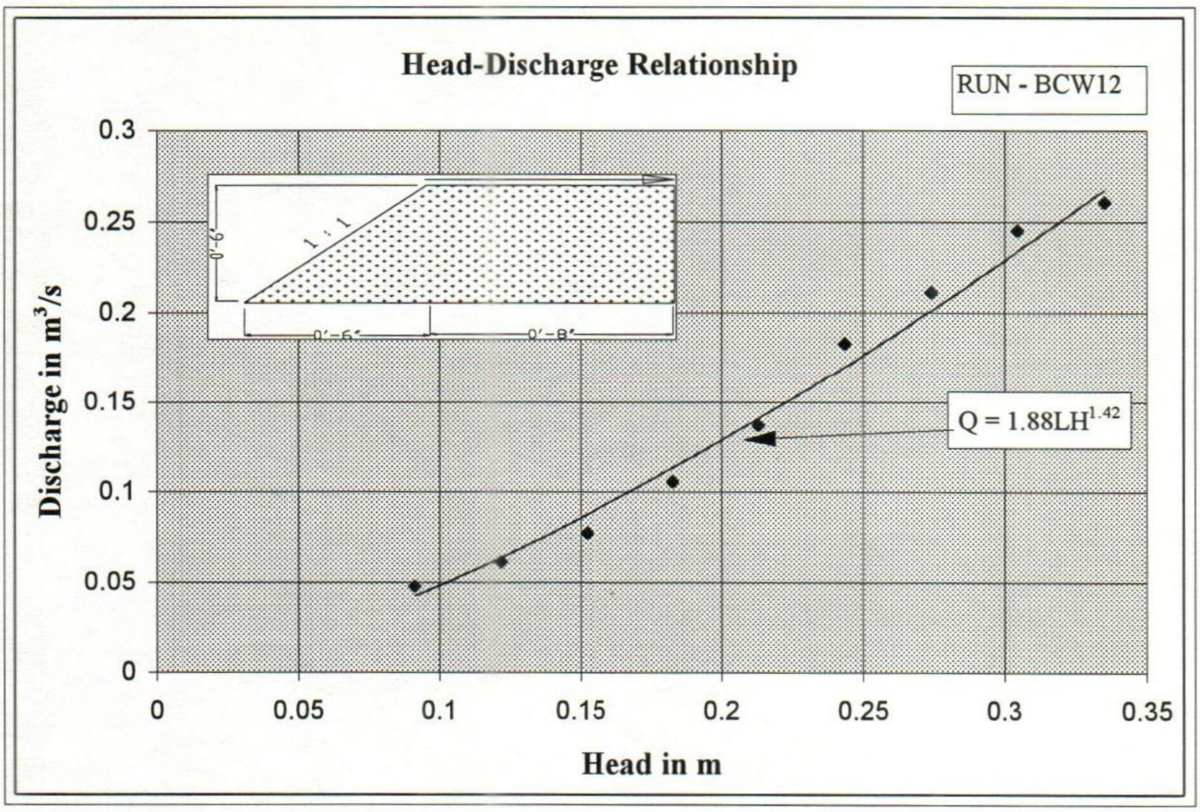
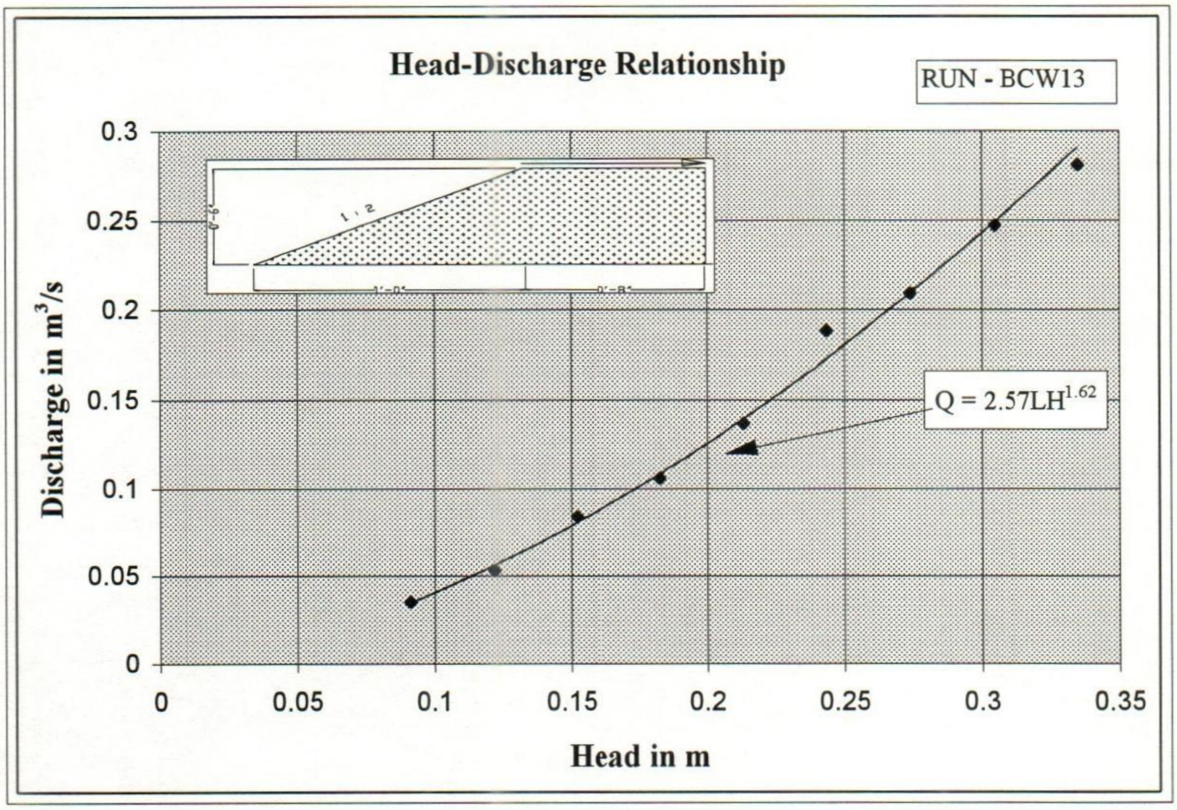


Figure 14 : Head Discharge Relationship



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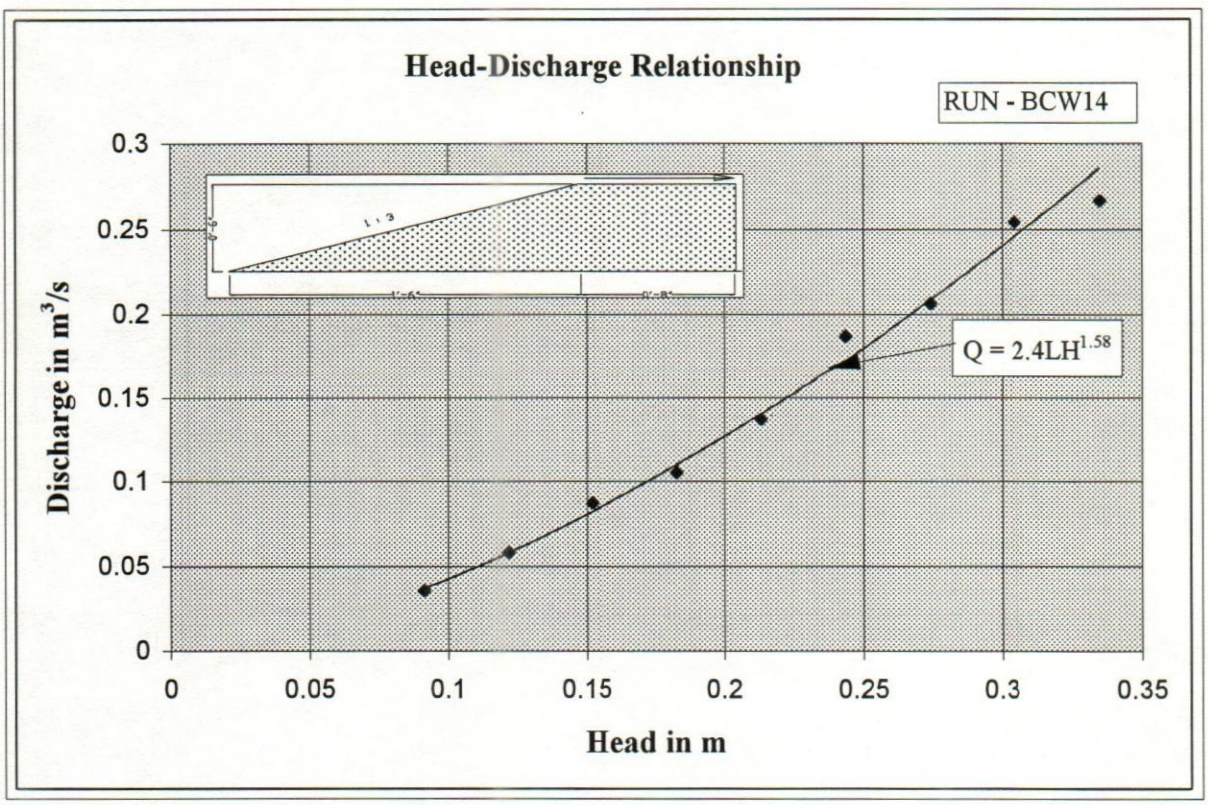


Figure 16 : Head Discharge Relationship

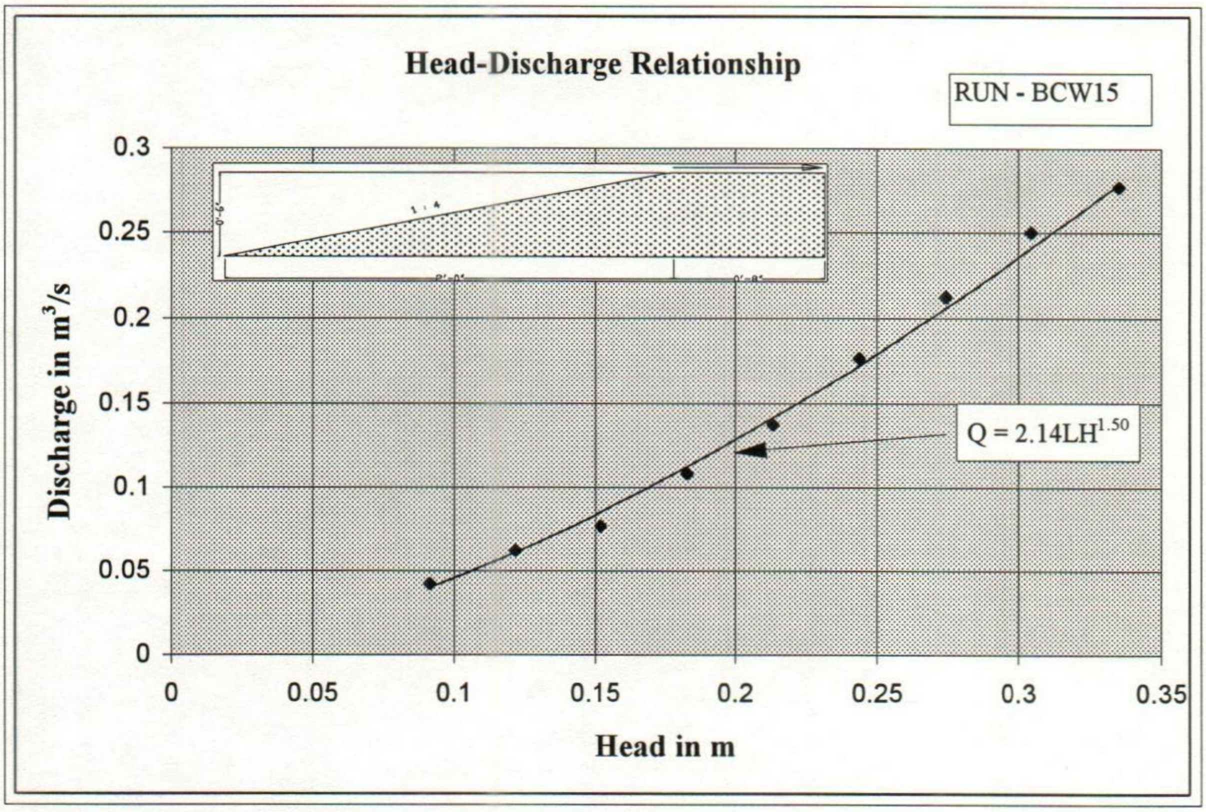
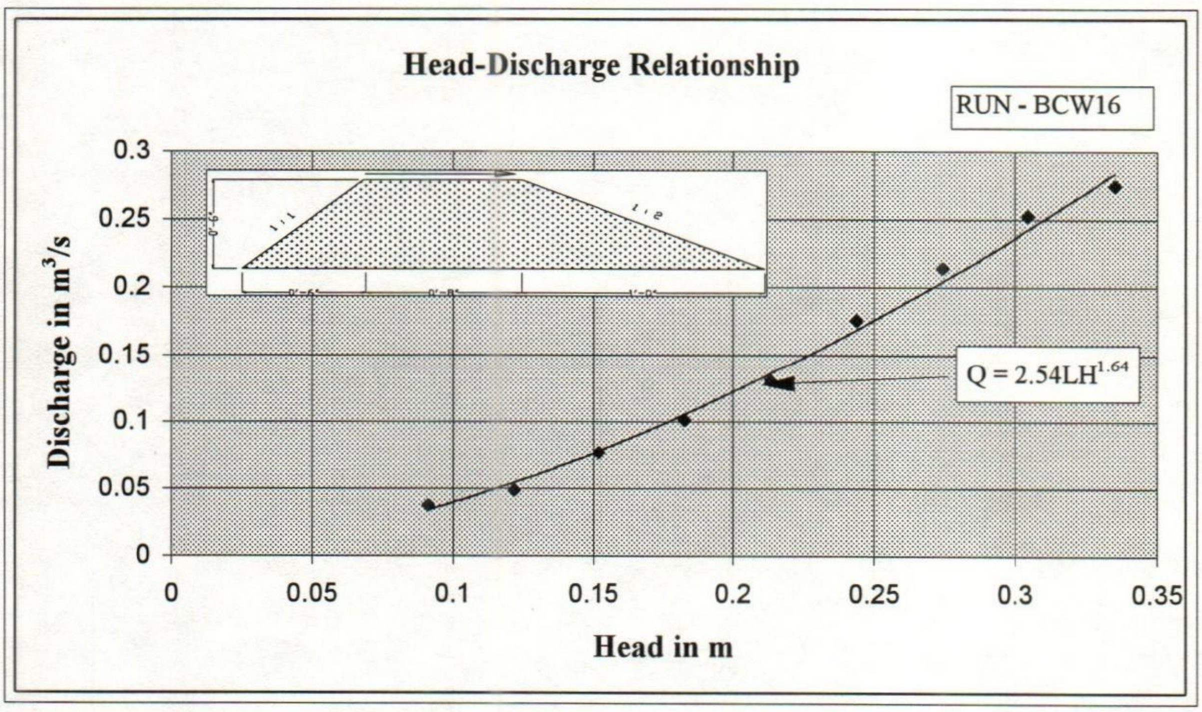


Figure 17 : Head Discharge Relationship



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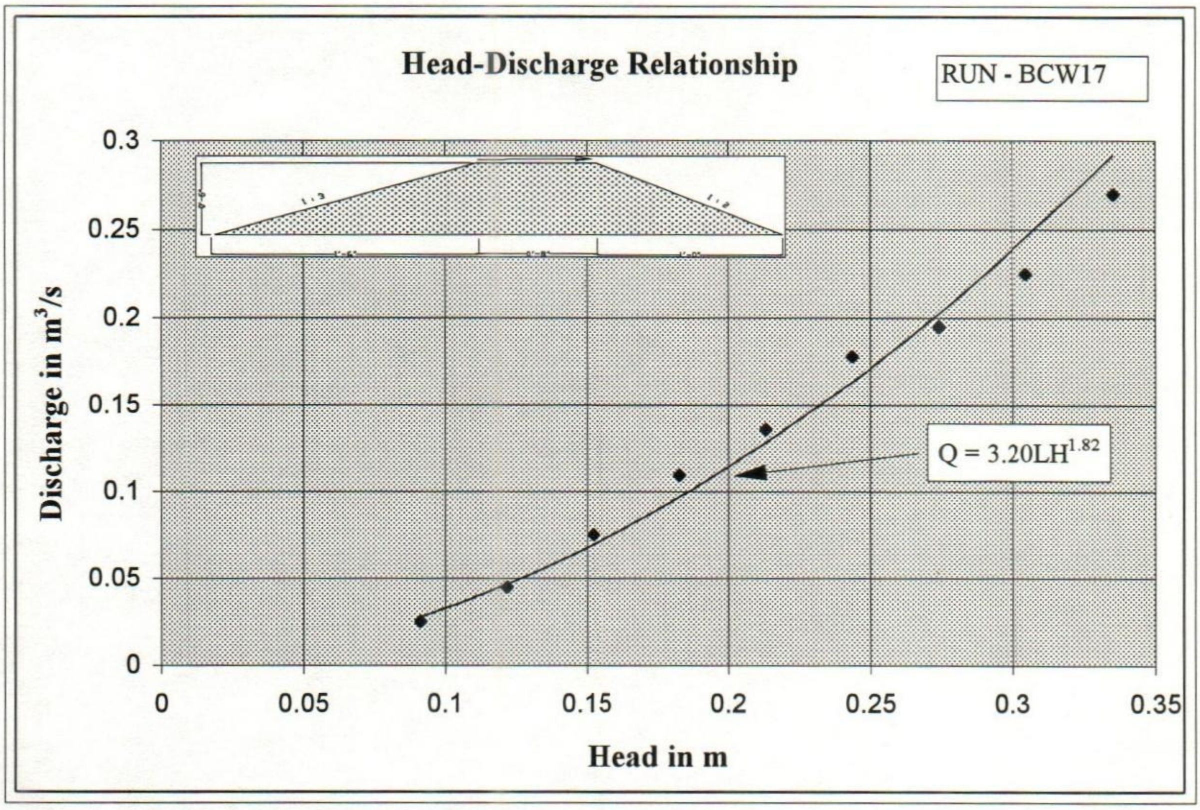

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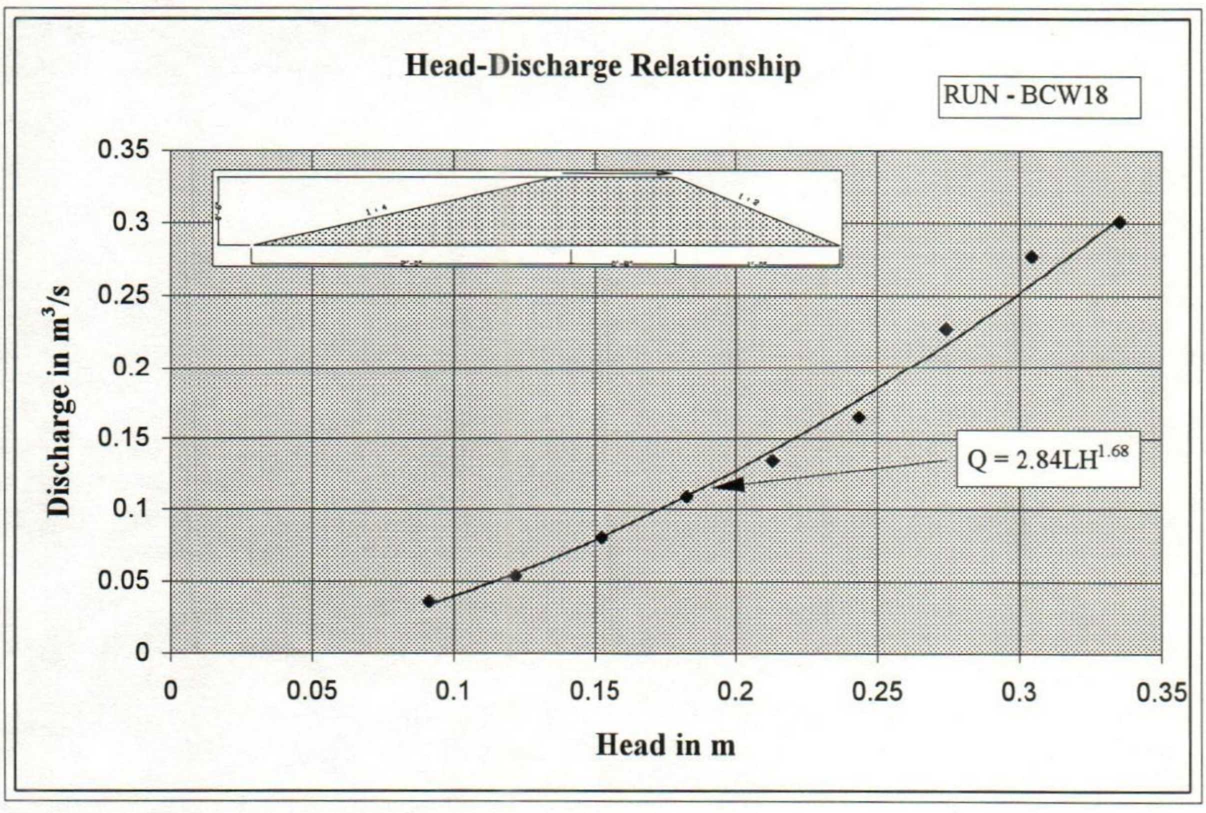

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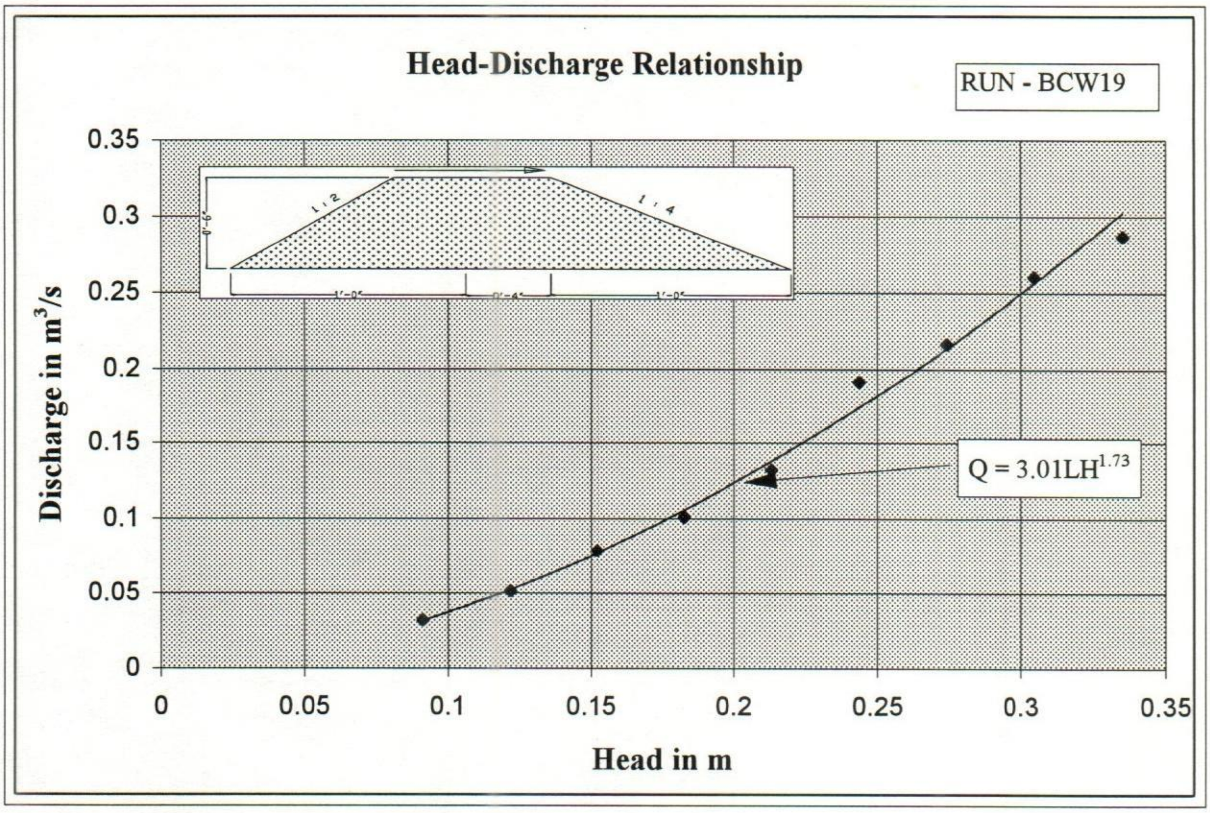

Figure 21 : Head Discharge Relationship

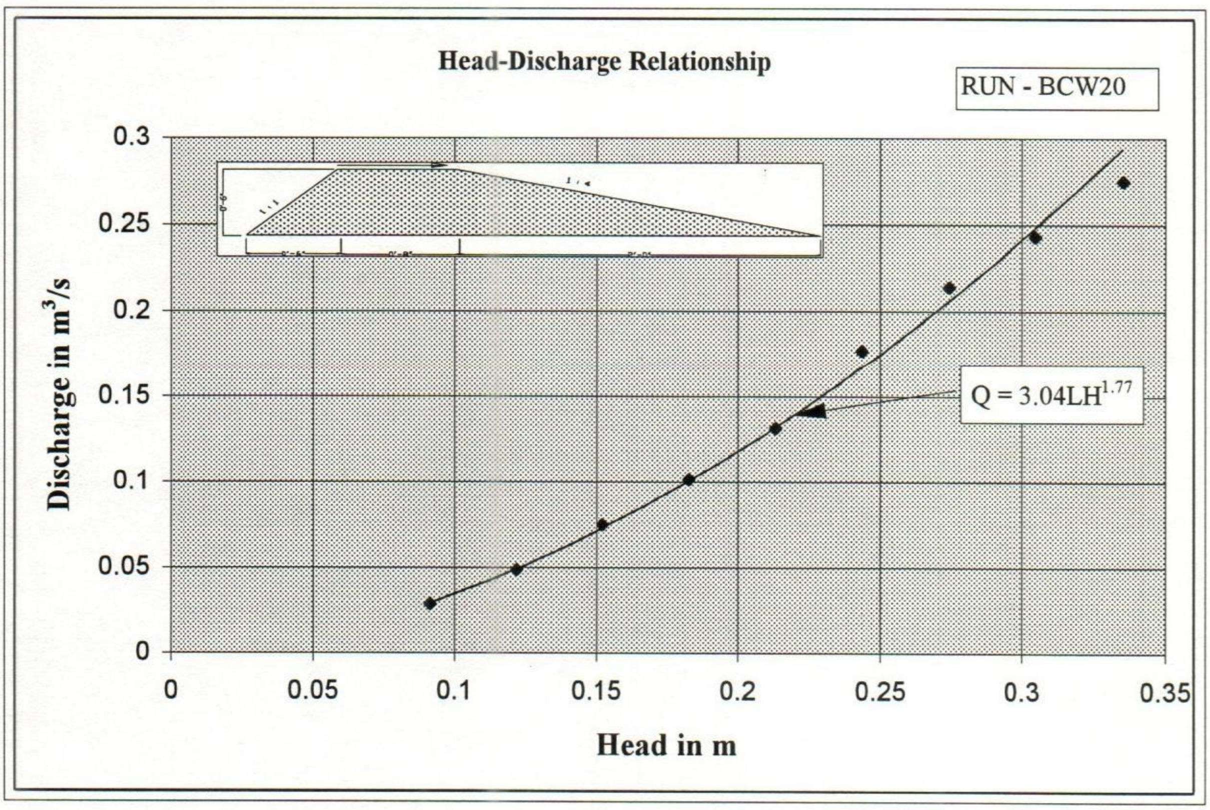

Figure 22 : Head Discharge Relationship

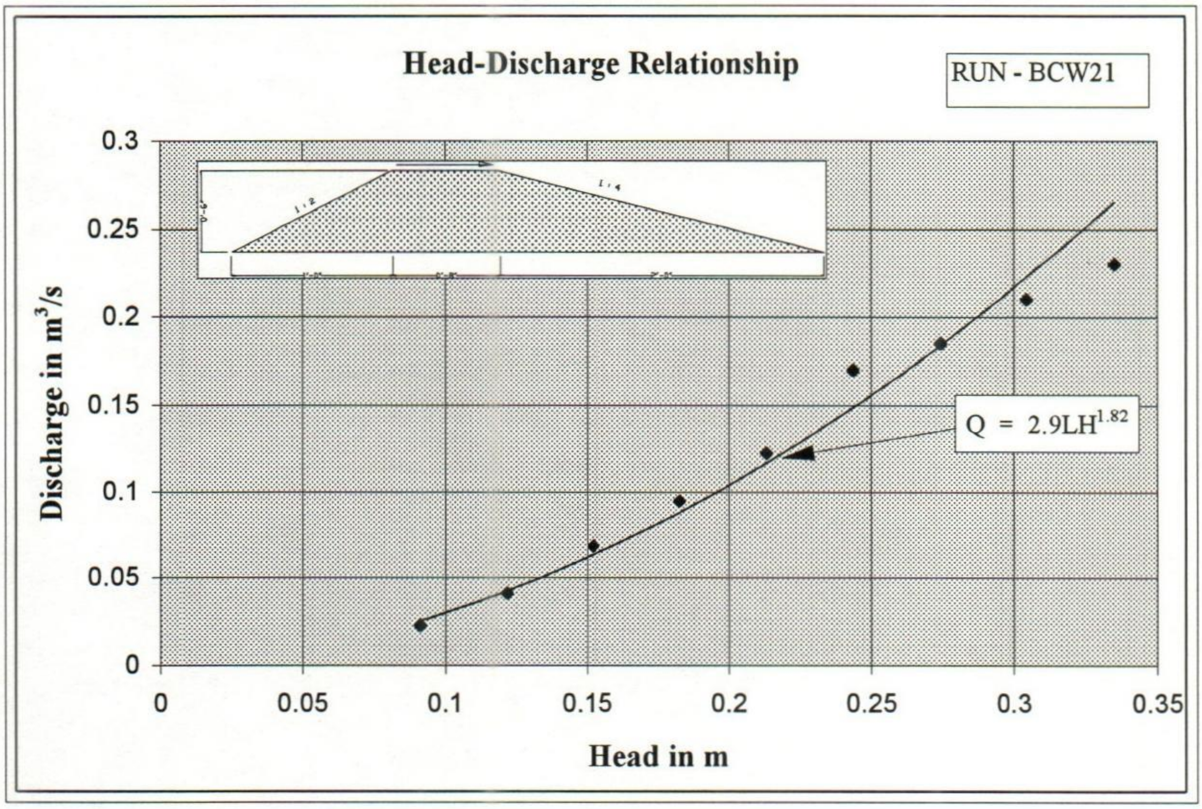

Figure 23 : Head Discharge Relationship

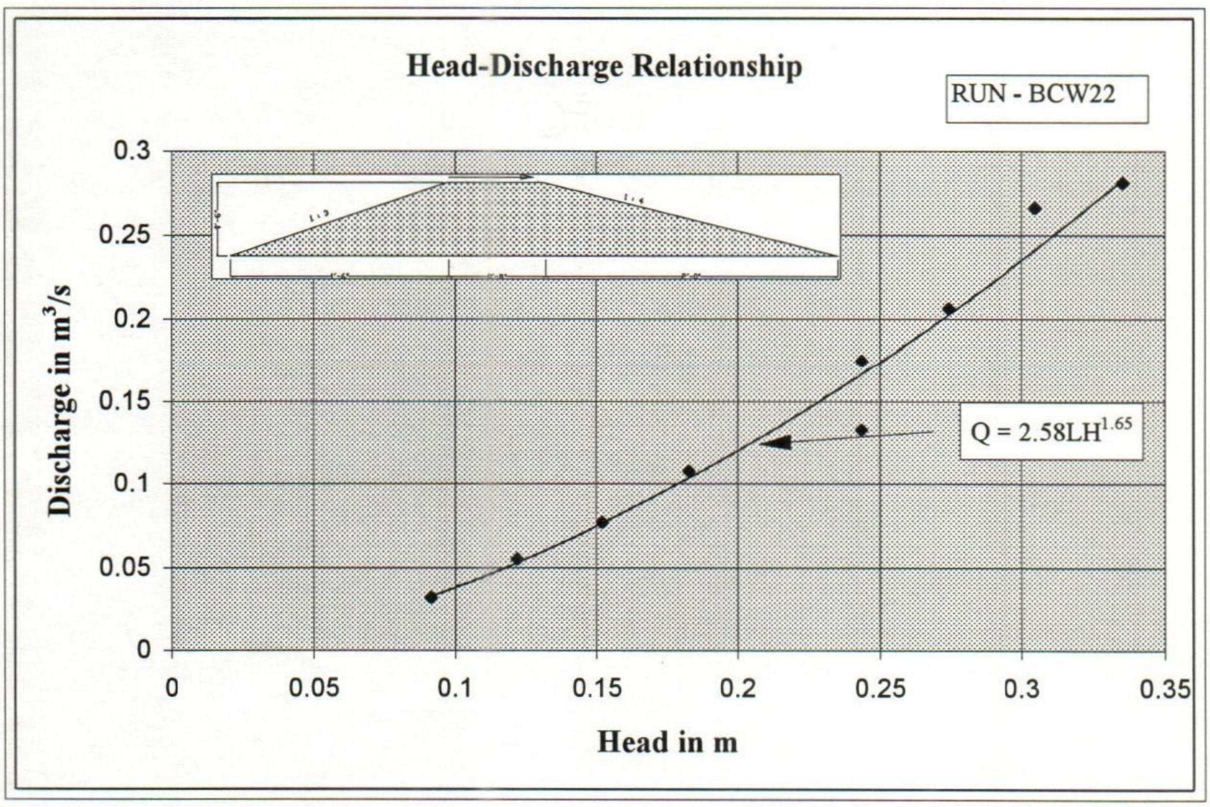

Figure 24 : Head Discharge Relationship

Personnel Associated with this Study

Sl. No.	Name	Designation
1	Md. Nazrul Islam Siddique	Principal Scientific Officer (In Charge)
2	Md. Monirul Islam	Senior Scientific Officer
3	A M M Motaher Ahmed	Scientific Officer
4	Md. Abul Ala Moududi	Scientific Officer
5	Md. Manjurul Haque	Scientific Officer
6	Syed Akmal Ali	Model Technician "C"
7	Md. Shah Shamsuzzoha	Laboratory Attendant