CHAPTER 5: GENERATION OF RATING CURVE FOR RIVER GANGA AT VARANASI BEND

5.1 INTRODUCTION

The most important basic technique to determine discharge in open channel flow (like river) is to measure gauge followed by calculation of discharge using an empirically generated gauge discharge rating curve. This oldest approach was in practice since 1890 to gauge the Riogrand at Embudo, New Maxico. The empirical rating curve for a river is developed from combined measurement of gauge and discharge. Direct measurements of flow velocity are made at one or more vertical positions below the water surface within multiple subsections across the channel. The velocity measurements are made using current meters (Rantz 1982a), or more recently, using acoustic Doppler current profilers (Simpson, 2001). The discharge at any section is the summation of the products of subsection areas and their respective estimated average velocities (Rantz, 1982a). Although this method of determining discharge is well made and accurate, it has many drawbacks. First, direct flow velocity measurements are very difficult or impossible during floods with help of current meters or ADCPs. Second, the development and maintenance of rating curve of any river is quite expensive and difficult due to need of very huge skilled men power. Third, for measurement convenience and safety, gauge sites are often located at geomorphically difficult sites which include bridges, or narrow sections suitable for cableways, and wide sections suitable for wading. Due to characteristics of these sites, they often are vulnerable to erosion and deposition, which requires extra flow measurements to define stage-dependent or post flood shifts to the rating curves. Recently developed methods for calculating velocity and shear stress fields in streams and rivers for sediment transport and geomorphic purposes can help to alleviate some of these difficulties.

In the last few decades effort was made to improve conventional gauging methods. The improved methods emphasized on developing techniques to measure gauge and discharge remotely. The advantage of these techniques is that there is no loss of human life as well as no damage of measuring instruments.

It may be noted that, measurements of surface velocity made remotely from the river's edge with Doppler radar have been used to obtain estimates of discharge at a cross-section for which ground penetrating radar suspended from a cableway is used to measure cross-sectional geometry remotely (Costa et al., 2000; Spicer et al., 1997; Cheng et al., 2004). But this requires costly equipment; it is particularly well suited for measuring discharge in channels with unstable beds. Surface velocities measured remotely using video cameras and particle image velocimetry algorithms also have been used successfully to determine discharge (Bradley et al., 2002; Creutin et al., 2003). The latter technique has the advantage of being relatively inexpensive and portable; however, it requires the existence of clearly identifiable tracers in the flow, which, if not present naturally in the form of foam or floating debris, must be supplied artificially. Moreover, like the former method, the cross-sectional geometry must be determined independently.

It is well known that currently available stream flow routing packages e.g. HEC-RAS (U.S. Army Corps of Engineers, 2002) may not be suitable to solve the purpose of rating curve extension or its development at a site under the above situation, due to their prohibitive requirement of channel cross-section details and roughness information at closer intervals. However, approximate flood routing techniques may serve the intended purpose more usefully, as these techniques could cope with sparse spatial details. As the rating curve sites, where the extension or development of rating curves are sought, are usually located on mainstreams, the approximate routing technique to be employed should also be capable of routing flows in compound channels consisting of a main channel and an adjoining floodplain channel. This type of investigation requires a deep knowledge of the work related to the topic concern.

In this chapter, a rating curve is developed for the river gauge at the M-1 (as discussed in chapter four) cross-section with the help of the 59 days data during Nov-2012 to march-2013 which is obtained with the help of ADCP and it is validated with the help of remaining 28 days data taken during the same time of cross-section investigation.

For the generation of the rating curve for the river gauge the M-1 profile is selected as suitable cross-section. It locates the downstream at Rajghat Bridge, Varanasi (India). The clear view of the selected location is shown in Fig (5.1).

5.2 METHOD FOR DEVELOPMENT OF RATING CURVE

As it was discussed earlier that measurement of discharge by the direct method involves a two-step procedure; the development of the stage-discharge relationship which forms the first step is of utmost importance. Once the stage-discharge (G-Q) relationship is known, the second step is to measure the stage (G) to get the discharge (Q) from the (G-Q) relationship. This second part is a routine operation. Finally the aim of all current-meter and other direct-discharge measurements is to prepare a stage-discharge relationship for the given channel gauging section. The stage- discharge relationship is known as the rating curve. The plot of measured value of discharge against the corresponding stage provides the relationship that represents the integrated effect of a wide range of channel and flow parameters. The combined effect of these parameters is termed control. If the (G-Q) relationship for a gauging section is constant and does not change with time, the control is said to be permanent. If it changes with time, it is called shifting control.

5.2.1 Permanent Control

A majority of streams and rivers, especially non alluvial rivers show permanent control. For such a case, the relationship between the stage and the discharge is a single-valued relation which is expressed as

$$Q = Cr\,(G - a)^{\beta} \text{---------------------------------} (5.1)$$

in which Q = stream discharge, G = gauge height (stage), a = constant which represent the gauge reading corresponding to zero discharge, Cr and β are rating curve constants. This relationship can be expressed graphically by plotting the observed relative stage (G-a) against the corresponding discharge values in an arithmetic or logarithmic plot (Figure 5.1 a. and b.). Logarithmic plotting is advantageous as Eq. (5.1) plots as a straight line in logarithmic coordinates.

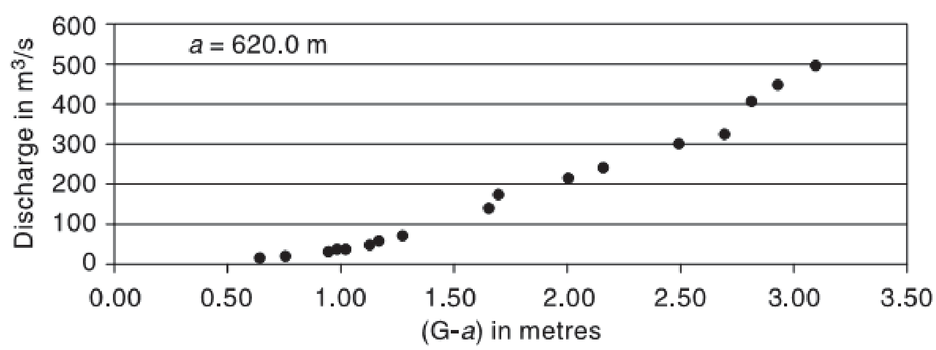

Figure 5.1 a. Arithmetic plot between discharge and gauge height After (Subramanya, 2009)

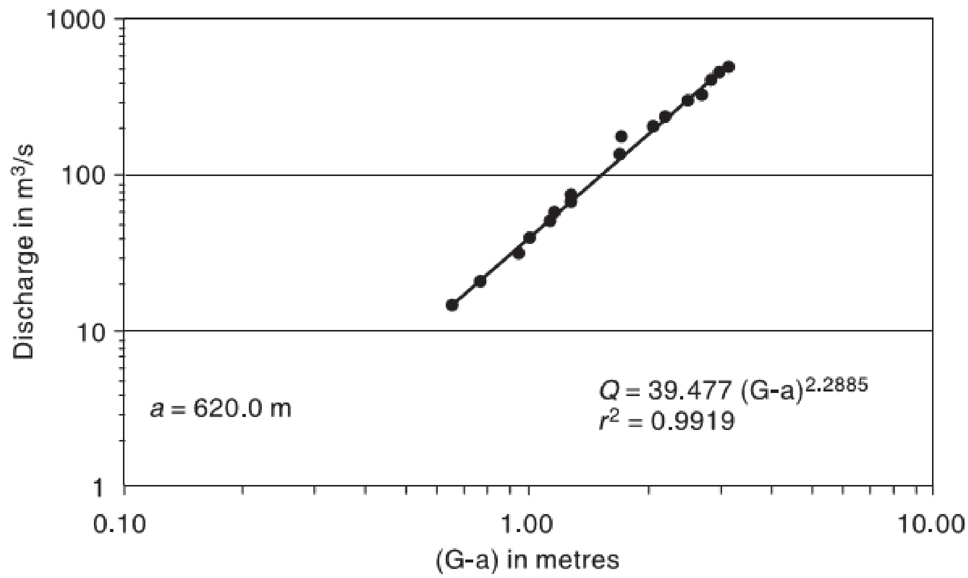

Figure 5.1 b. Logarithmic plot between discharge and gauge height After (Subramanya, 2009)

In Fig. 5.1 (b) the straight line is drawn to best represent the data plotted as Q vs (G -a). Coefficients Cr and b need not be the same for the full range of stages. The best values of Cr and b in Eq. (5.1) for a given range of stage are obtained by the least-square-error method. Thus by taking logarithms,

$$\textbf{Log Q} = \beta \textbf{ log (g-a) + log Cr}$$

$$\textbf{Y} = \beta \textbf{X+b}$$

Where,

Dependent variable Y

Y=log Q

Independent variable X

X=log (G-a)

And b=log Cr

For the best fit line of N observations of X & Y, by regression.

$$r = \frac{N(\sum XY) - (\sum X)(\sum Y)}{\sqrt{[N(\sum X^2) - (\sum X)^2][N(\sum Y^2) - (\sum Y)^2]}}$$

$$\beta = \frac{N(\sum XY) - (\sum X)(\sum Y)}{N(\sum X^2) - (\sum X)^2}$$

$$b = \frac{\sum Y - \beta(\sum X)}{N}$$

Here r reflects the extent of linear relationship between the two data sets. For a perfect correlation r = 1.0. If r is between 0.6 and 1.0 it is generally taken as a good correlation. It should be noted that in the present case, as the discharge Q increases with (G-a) the variables Y and X are positively correlated and hence r is positive. Equation (4.26),

$$Q = Cr(G - a)^{\beta}$$

is called the rating equation of the stream and can be used for estimating the discharge Q of the stream for a given gauge reading G within range of data used in its derivation.

5.2.1.1 Calculation of stage for zero discharge (theoretically)

In above mentioned Eq. (5.1) the constant “a" representing the stage (gauge height) for zero discharge in the stream is a hypothetical parameter and cannot be measured in the field. As such, its determination poses some difficulties. The following alternative methods are available for its determination.

1. Plot Q vs. G on an arithmetic graph paper and draw a best-fit curve. By extrapolating the curve by eye judgment find "a" as the value of G corresponding to Q =0. Using the value of "a", plot log Q vs. log (G - a) and verify whether the data plots as a straight line. If not, select another value in the neighborhood of previously assumed value and by trial and error find an acceptable value of a which gives a straight line plot of log Q vs. log (G -a).

2. A graphical method in which the Q vs. G data are plotted to an arithmetic scale and a smooth curve through the plotted points are drawn. Three points A, B and C are selected on the curve in such a way that their discharges are in geometric progression (Figure 5.2.), i.e.

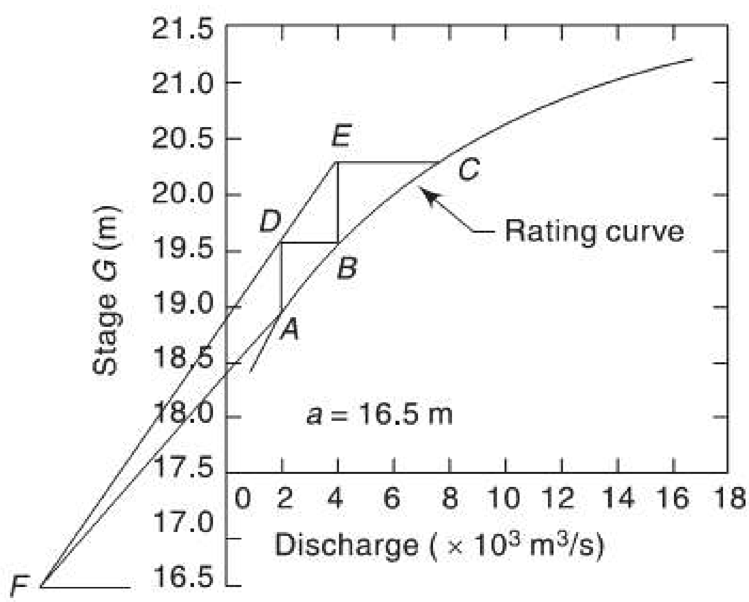

Figure 5.2. Graphical method for estimating the Zero discharge constant 'a'

$$\frac{Q_A}{Q_B} = \frac{Q_B}{Q_C}$$

At A and B vertical lines are drawn and then horizontal lines are drawn at B and C to get D and E as intersection points with the verticals. Two straight lines ED and BA are drawn to intersect at F. The ordinate at F is the required value of “a”, the gauge height corresponding to zero discharge. This method assumes the lower part of the stage-discharge curve to be a parabola.

3. Plot Q vs. G to an arithmetic scale and draw a smooth good-fitting curve by eye-judgment. Select three discharges Q1, Q2 and Q3 such that Q1/Q2 = Q2/Q3 and note from the curve the corresponding values of gauge readings G1, G2 and G3. From Eq. (5.1)

$$(G1 - a)/(G2 - a) = (G2 - a)/(G3 - a)$$

i.e.

$$a = \frac{G_1 G_3 - G_2^{\,2}}{(G_1 + G_3) - 2G_2}$$

4. A number of optimization procedures are available to estimate the best value of “a”. A trial-and-error search for “a” which gives the best value of the correlation coefficient is one of them.

5.3 FIELD MEASUREMENT

For the development of rating curve of river Ganga at M-1 cross-section, the continuous measurement of cross-section is done with the help of ADCP and auto level for a period of five month i.e. from Nov-2012 to March-2013. The water level at the cross-section was measured thrice in a day i.e. at 8.00 A.M., 01.00 P.M. and 6.00 P.M. with the help of auto level continuously. For the development of rating curve, the gauge data have been taken as the average of the three reading taken in whole day for improvement of the rating curve equation. Another measurement for the discharge data, ADCP was used at the cross-section M-1. For the measurement of discharge at the cross-section, whole cross-section marked with the help of total station at the both ends of the river. After the marking of the points at both ends a motor boat at which the ADCP mounted with the recording laptop connected with the ADCP, used for the measurement of discharge and this process was repeated for the measurement of discharge at M-1 section of the River Ganga. The calculation of 'a' (Gauge height at zero discharge theoretically) is done with the help of the method discussed in step 3 in section of Calculation of Stage for Zero Discharge (Theoretically) (Subramanya, 2009).

Table 5.1. Date used for Rating curve development

Sr.No.	Average Water level (G)	Average Discharge(Q)	G-59.54	Log (G-a)=X	Log Q = Y	XY	X2	Y2
1	60.32	629.26	0.77	-0.11	2.80	-0.31	0.01	7.83
2	60.35	768.66	0.80	-0.10	2.89	-0.28	0.01	8.33
3	60.39	755.35	0.84	-0.07	2.88	-0.22	0.01	8.28
4	60.39	678.03	0.84	-0.07	2.83	-0.21	0.01	8.02
5	60.42	616.68	0.87	-0.06	2.79	-0.17	0.00	7.78
6	60.42	740.24	0.87	-0.06	2.87	-0.17	0.00	8.23
7	60.47	716.64	0.92	-0.04	2.86	-0.10	0.00	8.15
8	60.47	743.90	0.92	-0.04	2.87	-0.10	0.00	8.25
9	60.49	719.30	0.94	-0.03	2.86	-0.07	0.00	8.16
10	60.49	825.33	0.94	-0.03	2.92	-0.08	0.00	8.51
11	60.57	780.82	1.02	0.01	2.89	0.02	0.00	8.37
12	60.58	892.45	1.03	0.01	2.95	0.04	0.00	8.71
13	60.61	810.23	1.06	0.03	2.91	0.08	0.00	8.46
14	60.61	909.97	1.07	0.03	2.96	0.08	0.00	8.76
15	60.64	787.46	1.09	0.04	2.90	0.11	0.00	8.39
16	60.67	836.04	1.12	0.05	2.92	0.14	0.00	8.54
17	60.7	865.65	1.15	0.06	2.94	0.18	0.00	8.63
18	60.72	838.75	1.17	0.07	2.92	0.20	0.00	8.55

19	60.74	850.35	1.19	0.08	2.93	0.22	0.01	8.58
20	60.75	867.25	1.20	0.08	2.94	0.23	0.01	8.63
21	60.79	1032.85	1.24	0.09	3.01	0.28	0.01	9.08
22	60.79	935.76	1.24	0.09	2.97	0.28	0.01	8.83
23	60.8	948.77	1.25	0.10	2.98	0.29	0.01	8.86
24	60.81	993.99	1.26	0.10	3.00	0.30	0.01	8.98
25	60.82	849.44	1.27	0.10	2.93	0.31	0.01	8.58
26	60.82	1031.89	1.27	0.10	3.01	0.31	0.01	9.08
27	60.82	993.50	1.27	0.10	3.00	0.31	0.01	8.98
28	60.84	1021.02	1.29	0.11	3.01	0.33	0.01	9.05
29	60.86	938.85	1.31	0.12	2.97	0.35	0.01	8.84
30	60.86	910.33	1.31	0.12	2.96	0.35	0.01	8.76
31	60.88	1043.77	1.33	0.12	3.02	0.37	0.02	9.11
32	60.89	955.34	1.34	0.13	2.98	0.38	0.02	8.88
33	60.9	1058.40	1.35	0.13	3.02	0.40	0.02	9.15
34	60.93	924.91	1.38	0.14	2.97	0.41	0.02	8.80
35	60.94	1058.57	1.39	0.14	3.02	0.43	0.02	9.15
36	60.94	1033.23	1.40	0.14	3.01	0.44	0.02	9.09
37	60.95	1110.38	1.41	0.15	3.05	0.45	0.02	9.27
38	60.96	1064.93	1.42	0.15	3.03	0.46	0.02	9.16
39	60.98	1000.25	1.43	0.16	3.00	0.47	0.02	9.00
40	60.99	1067.67	1.44	0.16	3.03	0.48	0.03	9.17
41	61.03	958.40	1.48	0.17	2.98	0.51	0.03	8.89
42	61.03	1031.34	1.48	0.17	3.01	0.51	0.03	9.08
43	61.06	1046.80	1.51	0.18	3.02	0.54	0.03	9.12
44	61.12	1039.90	1.57	0.20	3.02	0.59	0.04	9.10
45	61.2	1147.32	1.66	0.22	3.06	0.67	0.05	9.36
46	61.32	1261.48	1.78	0.25	3.10	0.77	0.06	9.62
47	61.52	1278.69	1.97	0.29	3.11	0.92	0.09	9.65
48	61.56	1313.20	2.01	0.30	3.12	0.94	0.09	9.72
49	61.59	1360.31	2.04	0.31	3.13	0.97	0.10	9.82
50	61.61	1355.08	2.07	0.32	3.13	0.99	0.10	9.81
51	61.75	1517.96	2.20	0.34	3.18	1.09	0.12	10.12
52	61.87	1579.84	2.33	0.37	3.20	1.17	0.13	10.23
53	61.93	1630.69	2.38	0.38	3.21	1.21	0.14	10.32

54	61.96	1645.77	2.41	0.38	3.22	1.23	0.15	10.35
55	62.12	1714.94	2.57	0.41	3.23	1.33	0.17	10.46
56	62.17	1817.41	2.62	0.42	3.26	1.36	0.17	10.62
57	62.28	1847.76	2.74	0.44	3.27	1.43	0.19	10.67
58	62.44	1984.64	2.90	0.46	3.30	1.52	0.21	10.87

5.4 RATING CURVE DEVELOPMENT

Total 86 data for the discharge were collected in the duration of 5 months i.e. from (Nov-2012 to March-2013). Out of these 86 data the 58 data (67% of total) is used for the development of the rating curve for River Ganga at M-1 cross-section and remaining 28 data (33 % of total data) were used for the validation of the generated rating curve equation. The rating curve equation is obtained from the discharge & gauge data of the River at cross-section M-1 is shown in Figure 5.3. a. & b. in arithmetic and logarthmatic scale respectively. The gauge height is taken at the X-axis and the discharge measurement is taken at Y-axis respectively as (Subramanya, 2009). The developed rating curve equation at arithmetic scale is

$$\mathbf{Y=787.06\ X^{0.8038}}$$

Where

Y= Discharge

X= (G-a) in meters

And R^2 value for the Rating Curve is 0.9495

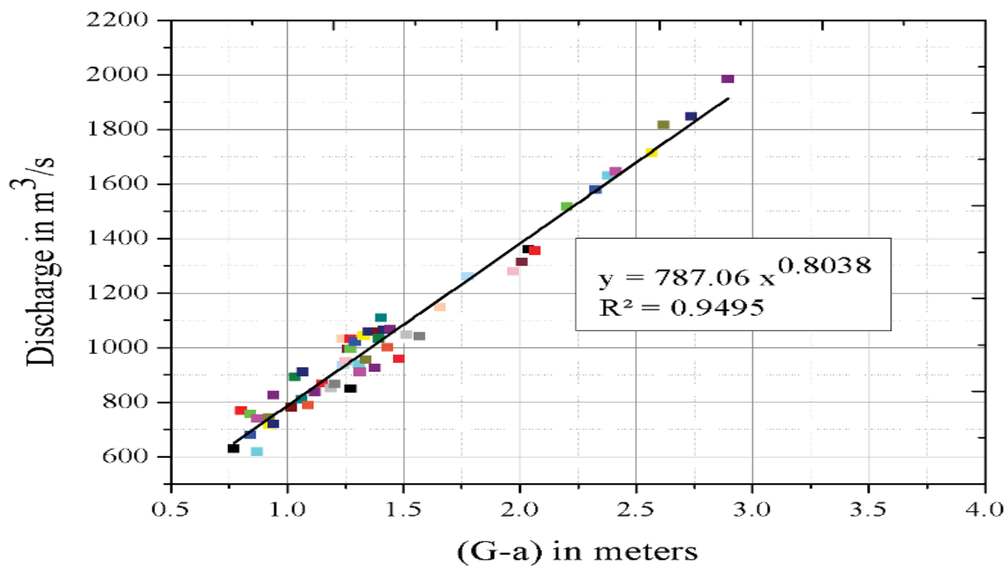

Figure 5.3. Arithmatic plot of Rating curve for River Ganga at M-1 section

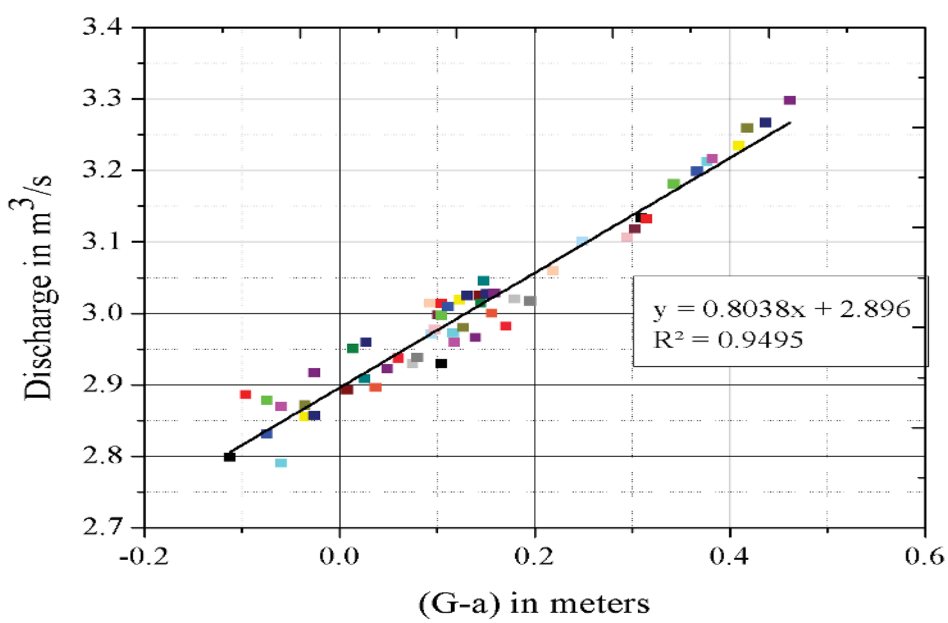

Figure 5.4. Logarthmatic plot of Rating curve for River Ganga at M-1 section

5.5 VALIDATION OF THE RATING CURVE EQUATION

The validation of rating curve generated for the river Ganga with the help of remaining 30 data of discharge and gauge height respectively. These data are randomly selected from the complete data of 86 days from the measurement of 5 months that is November 2012 to march 2013. Percentage error obtained from the equation is maximum 11.74% and minimum 0.0351% as shown in Table 5.2. It is observed that only around 10% error is obtained in the development of the rating curve which is not a very large error as the complete measurement is done by electronic measurement and lots of human error possible during measurement because the river cross-section is very large and it is not possible to measure all thing 100% accurate so this error is acceptable.

Table 5.2. Validation data set of 28 days during five months i.e. from Nov-2012 to March-2013

Sr.No.	Average Water level (G)	Average Discharge(Q)	G-59.54	$x^{0.8038}$	787.06 X $x^{0.8038}$	(Q1-Q2) /Q1	% Error
1	60.38	733.77	0.84	0.87	681.08	0.07	7.18
2	60.40	650.56	0.85	0.88	691.98	-0.06	-6.37
3	60.46	672.61	0.91	0.93	730.89	-0.09	-8.67
4	60.48	821.90	0.93	0.95	743.75	0.10	9.51
5	60.53	878.73	0.98	0.99	775.65	0.12	11.73
6	60.58	888.23	1.03	1.03	807.24	0.09	9.12
7	60.61	921.22	1.07	1.05	828.13	0.10	10.10
8	60.69	992.20	1.14	1.11	875.71	0.12	11.74
9	60.72	948.70	1.17	1.14	894.15	0.06	5.75
10	60.77	971.62	1.22	1.17	924.69	0.05	4.83
11	60.80	945.54	1.25	1.20	942.89	0.00	0.28
12	60.82	968.93	1.27	1.21	954.98	0.01	1.44
13	60.82	963.72	1.27	1.21	954.98	0.01	0.91

14	60.84	978.98	1.29	1.23	967.03	0.01	1.22
15	60.87	934.57	1.32	1.25	985.04	-0.05	-5.40
16	60.89	925.69	1.34	1.27	997.00	-0.08	-7.70
17	60.93	1024.99	1.38	1.30	1020.82	0.00	0.41
18	60.95	999.39	1.40	1.31	1030.70	-0.03	-3.13
19	60.98	975.46	1.43	1.33	1050.40	-0.08	-7.68
20	61.02	1012.19	1.47	1.36	1071.97	-0.06	-5.91
21	61.04	1111.65	1.50	1.38	1087.58	0.02	2.17
22	61.16	1118.29	1.61	1.47	1155.28	-0.03	-3.31
23	61.38	1278.98	1.83	1.62	1278.53	0.00	0.04
24	61.57	1363.17	2.02	1.76	1386.10	-0.02	-1.68
25	61.67	1387.29	2.12	1.83	1440.94	-0.04	-3.87
26	61.92	1637.83	2.37	2.00	1574.11	0.04	3.89
27	62.02	1680.07	2.47	2.07	1628.01	0.03	3.10
28	62.24	1843.45	2.69	2.21	1742.89	0.05	5.46

5.6 RESULTS & DISCUSSIONS

The rating curve of the river Ganga at Varanasi bend is developed to shows the relationship between stage and discharge at M-1cross-section. In most cases, Rating curves usually have a break point, which is around the stage at which the river spreads out of its banks, or it could be at a lower stage if the river bed cross-section changes dramatically. Above that stage, the river does not rise as fast, given that other conditions remain constant. It is not possible to measure the discharge of the river continuously. However, the discharge can be obtained by applying the stage-discharge relation (also called rating). Stage-discharge relations are developed for stream gauges by physically measuring the flow of the river with a mechanical current meter or ADCP at a wide range of stages; for each measurement of discharge there is a corresponding measurement of stage as shown in the Tables 5.1. and 5.2. Besides that these relations must be continually checked against ongoing discharge measurements because stream channels are constantly changing. Changes in stream channels are often caused by erosion or deposition of streambed materials, seasonal vegetation growth, debris, or ice. New discharge measurements plotted on an existing stage-discharge relation graph would show this, and the rating could be adjusted to allow the correct discharge to be estimated for the measured stage. This chapter can be concluded with the following points

1. The rating curve equation is developed from the measured discharge & gauge data of the River at cross-section M-1 by ADCP where gauge height is taken at the X-axis and the discharge measurement is taken at Y-axis respectively. The developed rating curve equation is given below:-

$$\mathbf{Y=787.06\ X^{0.8038}}$$

Where

Y= Discharge

X= (G-a) in meters

2. The developed equation is validated for the measured data of 27 days and result is given in Table 5.2. The Table 5.2. represents that the discharge obtained from rating curve equation and measured discharge data are within the maximum error of ±10% which is within the limit of acceptance of the equation because it is very difficult to measure the discharge during flood condition of river Ganga at Varanasi.

3. The proposed equation of rating curve is valuable for measuring the discharge of River Ganga at Varanasi during flood condition. During flood condition after getting the gauge height the discharge of the river may effectively estimate.