HYDROLOGY PROJECT

Technical Assistance

World Bank & Government of The Netherlands funded

Training module # SWDP - 31

How to extrapolate rating curve

New Delhi, November 1999

CSMRS Building, 4th Floor, Olof Palme Marg, Hauz Khas,
New Delhi – 11 00 16 India
Tel: 68 61 681 / 84 Fax: (+ 91 11) 68 61 685
E-Mail: dhvdelft@del2.vsnl.net.in

DHV Consultants BV & DELFT HYDRAULICS

with
HALCROW, TAHAL, CES, ORG & JPS

Table of contents

Page

1. Module context

While designing a training course, the relationship between this module and the others, would be maintained by keeping them close together in the syllabus and place them in a logical sequence. The actual selection of the topics and the depth of training would, of course, depend on the training needs of the participants, i.e. their knowledge level and skills performance upon the start of the course.

2. Module profile

Title	:	How to extrapolate rating curve
Target group	:	Assistant Hydrologists, Hydrologists, Data Processing Centre Managers
Duration	:	One session of 120 minutes
Objectives	:	After the training the participants will be able to: • Appreciate the need for extrapolating rating curve • Extrapolate the rating curve
Key concepts	:	• Absence of stage-discharge data during high and low flows • Double log plot • Conveyance method • Velocity-area method • Steven's method • Station correlation method
Training methods	:	Lecture, software
Training tools required	:	Board, OHS, Computer
Handouts	:	As provided in this module
Further reading and references	:	

3. Session plan

No	Activities	Time	Tools
1	***General*** • Overhead – Extrapolation of rating curve (text)	5 min	
2	***Highflow extrapolation*** • Overhead – High flow extrapolation (text) • Overhead – Double log plot method (text) • Overhead – Cross-section Khamgaon, 1997 • Overhead - Double logarithmic extrapolation • Overhead – Stage-area/stage-velocity method (text) • Overhead – Illustration of stage-area-velocity method • Overhead – Manning's equation method (text) • Overhead - Manning's equation method, principle • Overhead – Manning’s equation method, K*=f(h) • Overhead – Cross-sections at Station Khamgaon • Overhead – Rating extrapolation, Station Khamgaon • Overhead - The conveyance slope method (text) • Overhead – Slope = f(h) • Overhead – Conveyance = f(h) • Overhead – Interpretation of wetted perimeter • Overhead – Extrapolation with HYMOS (text) • Overhead – Area = f(h) • Overhead – Width = f(h) • Overhead – Wetted perimeter = f(h) • Overhead – Velocity = f(h) • Overhead – Discharge versus Area • Overhead – S1/2Km = f(h) • Overhead – Velocity versus discharge	20 min	

4. Overhead/flipchart master

5. Handout

Add copy of Main text in chapter 8, for all participants.

6. Additional handout

These handouts are distributed during delivery and contain test questions, answers to questions, special worksheets, optional information, and other matters you would not like to be seen in the regular handouts.

It is a good practice to pre-punch these additional handouts, so the participants can easily insert them in the main handout folder.

7. Main text

Contents

How to extrapolate rating curve

1. General

- **Extrapolation of rating curves is required because the range of level over which gauging has been carried out does not cover the full range of observed levels.** The rating curve may fall short at both the lower and the upper end. Extreme flows are often the most important for design and planning and it is important that the best possible estimates are made.

- **Calibration at very high instantaneous flows is particularly difficult as they occur infrequently and are of short duration.** They may occur at night. Peak flow gauging requires the gauging team to be on site when the flood arrives - which may not be possible. It also requires that facilities are available for flood gauging in safety. In practice, the gauging site may be inaccessible, the gauging facilities no longer serviceable and the river may have spread from a confined channel to an inaccessible flood plain.

- **Extrapolation is not simply a question of extending the rating from existing gaugings to extreme levels** (although in some cases this may be acceptable); **a different control may apply, the channel geometry may change, flow may occur over the floodplain and form and vegetation roughness coefficients may change.**

  Applicable methods of extrapolation depend on the physical condition of the channel, whether inbank or overbank and whether it has fixed or shifting controls. Consideration must also be given to the phenomenon of the kinematic effect of open channel flow when there may be reduction in the mean velocity in the main channel during inundation of the flood plain. Methods given below are suitable for rivers with defined banks and fixed controls, as well as for a channel with spill.

- **Extrapolation of stage discharge relationships will be carried out at the State Data Processing Centre.**

2. High flow extrapolation

The following methods are considered below:

- double log plot method
- stage-area / stage-velocity method
- the Manning's equation method
- the conveyance slope method

2.1 The double log plot method

Where the hydraulic characteristics of the channel do not change much beyond the measured range, then simple extrapolation of the logarithmic stage discharge relationship may be applied. Graphically, the relationship in this case can simply be extended beyond the measured range by projecting the last segment of the straight line relationship in log-log domain. Such an extrapolation is illustrated by the dashed straight line in Fig. 2.2 for the cross-sectional profile shown in Figure 2.1.

Figure 2.1 Cross-section of river at Khamgaon used in examples in this module

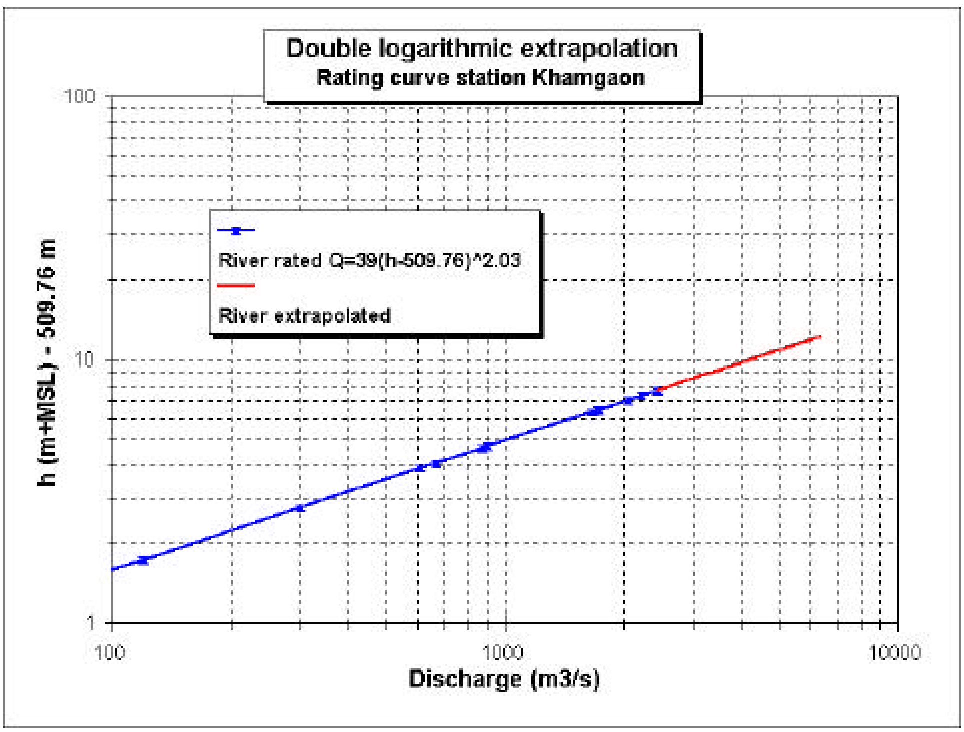


Figure 2.2 Example of double logarithmic extrapolation of rating curve

In the example presented in Figure 2.2 a rating curve has been established for the river flows up to flood plain level. This curve had to be is extended to cover the highest observed water level, which was about 4 m above flood plain level. Double logarithmic technique was applied for this extrapolation. Double-logarithmic extrapolation implies that the same power type equation is used for the higher stages as well. The correctness of the use of this technique for the cross-section shown in Figure 2.1, which shows the existance of a flood plain, is doubtful. One of the basic conditions for the application of the double logarithmic method, namely no change in the hydraulic characteristics at the higher stages, is not fulfilled. It is likely that this method will lead to an underestimation of the discharge, since the contribution of the floodplain flows to the total river flow is not taken into consideration.

2.2 Stage-area / Stage-velocity method

Where extrapolation is needed either well beyond the measured range, or there are known changes in the hydraulic characteristics of the control section, then a combination of stage-area and stage-velocity curves may be used. Stage-area and stage-mean velocity curves are extended separately. For stable channels the stage-area relationship is fixed and is determined by survey up to the highest required stage. The stage-velocity curve is based on current meter gaugings within the measured range and, since the rate of increase in velocity at higher stages diminishes rapidly this curve can be extended without much error for in-bank flows. Discharge for a given (extended) stage is then obtained by the product of area and mean velocity read using extrapolated stage-area and stage-mean velocity curves (Fig. 2.3). This method may be used for extrapolation at both the upper and lower end of the rating.

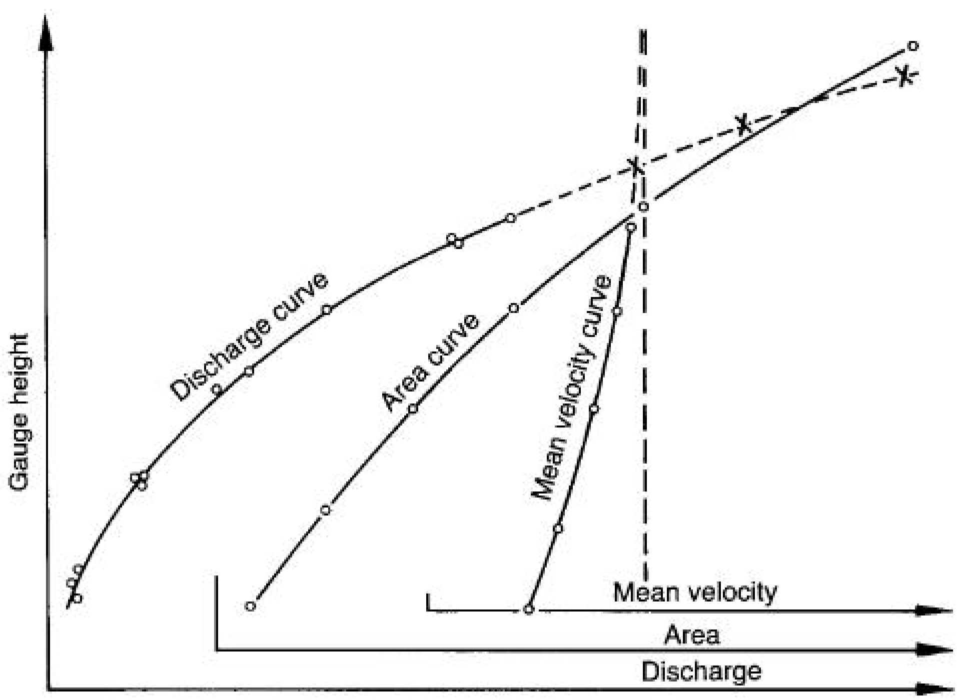


Figure 2.3 Extrapolation based on stage-area/stage-velocity technique

The mean velocity curve can also be extrapolated by the use of a logarithmic plot of mean velocity against hydraulic radius. The hydraulic radius can be found for all stages from the cross section by survey. The logarithmic plot of mean velocity and hydraulic radius generally shows a linear relationship and thus can be extended linearly beyond the extent of measurements. Mean velocity in the extrapolated range can be obtained from this curve. Extrapolated discharge as before is obtained as the product of mean velocity thus estimated and the corresponding area from the stage-area curve.

2.3 The Manning's equation method

A slight variation of the stage-area-velocity method is the use of Manning's equation for steady flow. In terms of the mean velocity the Manning equation may be written:

$$v = K_m R^{2/3} S^{1/2} \quad (1)$$

Since for higher stages the value of $K_m S^{1/2}$ becomes nearly constant, the equation can be rewritten:

$$v = K^* R^{2/3} \quad (2)$$

or $$K^* = v / R^{2/3} \quad (3)$$

The relationship of stage (h) to K^* is plotted from discharge measurements. This curve often approaches a constant value of K^* at higher stages (Fig. 2.4). This value of K^* may then be used in conjunction with extrapolated relationships between h and A and, h and $R^{2/3}$ based on survey. Discharge for extrapolated stage is then obtained by applying the Manning equation with K^* and extrapolated values of A and $R^{2/3}$

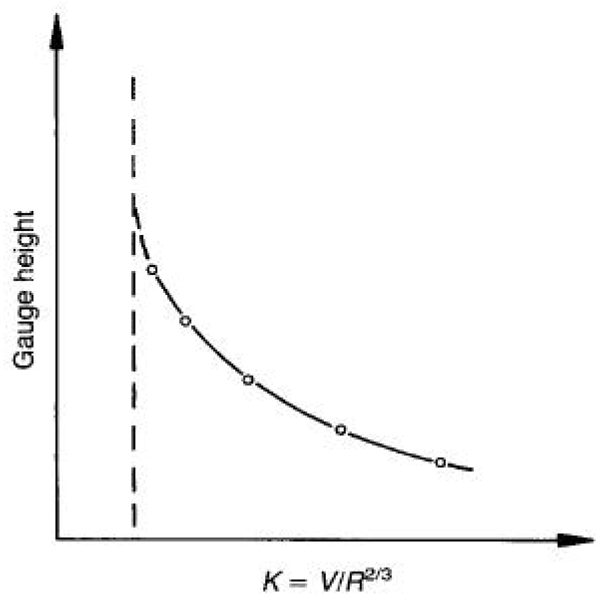
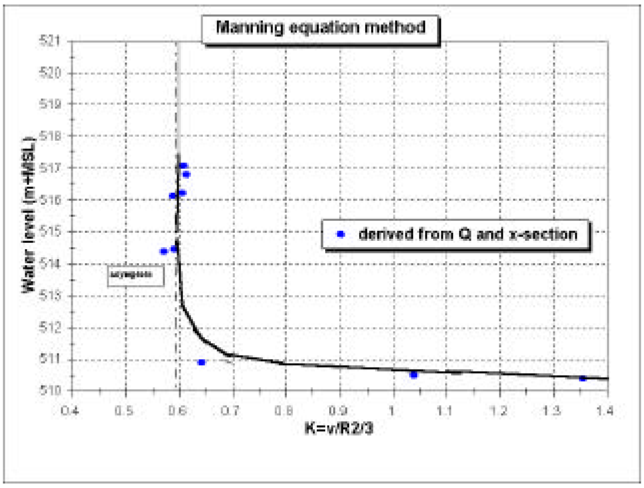
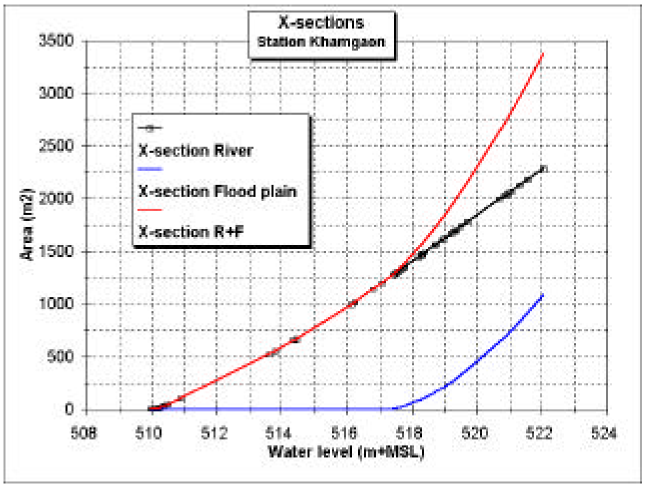


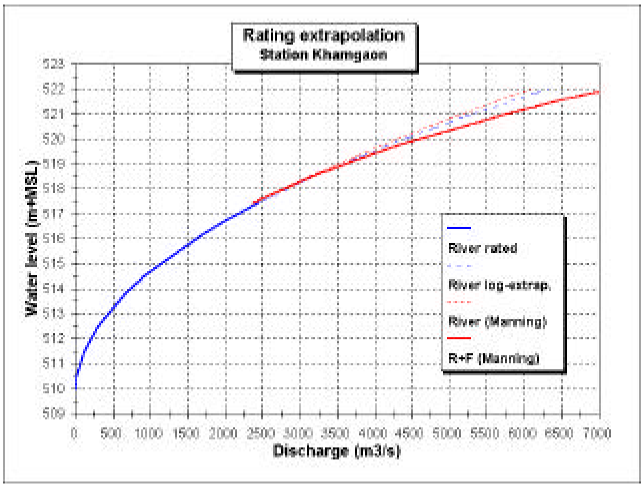
Figure 2.4 K^* versus gauge height

Above bankfull stage the discharge on the floodplain must be determined separately by assuming an appropriate K_m value as done using the conveyance slope method.

This method was applied to the Khamgaon river cross-sectional data shown in Figure 2.1 and observed discharges. The results are shown in the Figures 2.5 to 2.7. From Figure 2.5 it is observed that K^* indeed tends to an approximately constant value for the higher stages, which was subsequently applied in the extrapolation. Together with the cross-sectional area and the hydraulic radius the river the flow through the main section was computed. For the flood plain the Manning equation was applied separately. The result is shown in Figure 2.7. In this Figure also the result of the double logarithmic extrapolation technique is shown for reference purposes. It is observed that the flow through the main river is approximately the same between the two methods, however the total flow with the Manning technique is larger since in this method due account is given to the flood plain flow.







Figures 2.5 (upper left)
K* versus gauge height for Kangaon example

Figure 2.6 (upper right)
Cross-sectional areas of river and flood plain in Khamgaon example

Figure 2.7 (left)
Extrapolation based on Manning equation method compared with double-logarithmic extrapolation

2.4 The conveyance slope method

In the conveyance slope method, the conveyance and the energy slope are extrapolated separately. It has greater versatility than the methods described above and can be applied in sections with overbank flow. It is therefore recommended for use. It is normally, again, based on the Manning equation:

$$Q = K_m R^{2/3} S^{1/2} A \qquad (4)$$

or: $$Q = K S^{1/2} \qquad (5)$$

where the conveyance is

$$K = K_m A R^{2/3} \qquad (6)$$

For the assessment of K for given stage, A and R are obtained from field survey of the discharge measurement section and values of n are estimated in the field. Values of K are then plotted against stage up to the maximum required level (usually on natural graph paper) (Fig. 2.8)

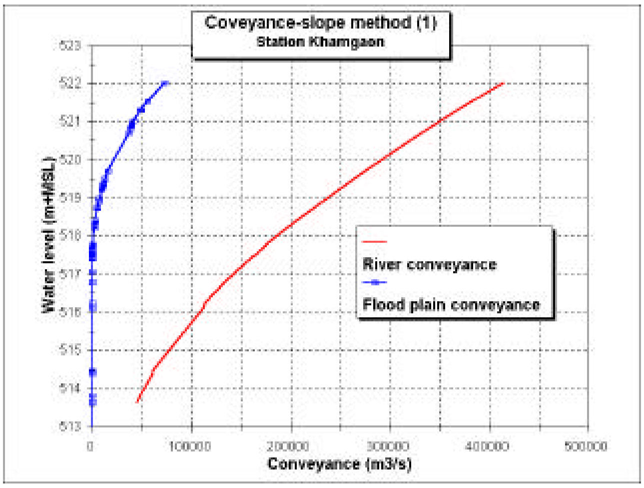


Figure 2.8 Conveyance as f(h)

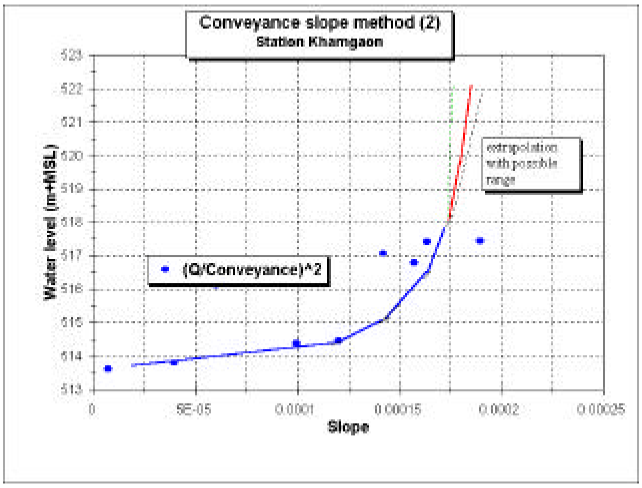


Figure 2.9 Slope extrapolation

Values of S, which is the energy gradient are usually not available but, for measured discharges, $S^{1/2}$ can be computed by dividing the measured discharge by its corresponding K value. S is then calculated and plotted against stage on natural graph paper and extrapolated to the required peak gauge height, in the knowledge that S tends to become constant at higher stages at the limiting slope of the stream-bed, (see Figure 2.9 for the Khamgaon case).

The discharge for given gauge height is obtained by multiplying the corresponding value of K from the K curve by the corresponding value of $S^{1/2}$ from the S curve. It should be noted that in this method, errors in estimating K_m have a minor effect, because the resulting percentage error in computing K is compensated by a similar percentage error in the opposite direction in computing $S^{1/2}$.

The whole procedure can be accomplished in various stages as given below:

Computation of cross-sectional data

First of all the cross-sectional contour is obtained from:

- distance (x) from an initial point
- depth (y) and
- depth correction (y_c)

The depth correction y_c may be introduced to evaluate quickly the effects of changes in the cross-section on geometric and hydraulic parameters.

The actual depth y_a is computed from:

$$y_a = y + y_c$$

A plot can be made of the cross section and for levels at fixed interval the following quantities are computed (see Table 2.1):

- surface width, (B)
- wetted perimeter, (P)
- cross-sectional area, (A)
- hydraulic radius, (R): R = A/P
- factor {area x (hydraulic radius)$^{2/3}$}, (AR$^{2/3}$)

Table 2.1 Example of HYMOS Report on stage-discharge extrapolation

```
 Computation of cross-sectional data

     Computation of cross-sectional parameters

     Station    : KHAMGAON
     Date       : 1997 1  1


     Coordinates of profile

     Dist. from initial point       Level
             m                        m

           -160.00               521.54
           -150.00               521.30
           -140.00               520.90
           -130.00               520.68
              .                     .
            390.00               521.03
            400.00               520.93
            410.00               521.30
            420.00               522.03

       Section  1

     Left bound -160.00 m, right bound     .00 m from initial point
     Water boundaries included

     K-Manning: 30.0, Sqrt(S).K-Manning:     .4135

     Stage      Width     Wetted       Area   Hydraulic  A*R**2/3      Q
                          Perimeter             radius
        m          m          m        sq-m          m   m**(8/3)     m3/s

   512.00       .000       .000       .000        .000       .00       .00
   513.00       .000       .000       .000        .000       .00       .00
   514.00       .000       .000       .000        .000       .00       .00
   515.00       .000       .000       .000        .000       .00       .00
   516.00       .000       .000       .000        .000       .00       .00
   517.00      7.143      8.738       .715        .082       .13       .06
   518.00     45.568     47.233     25.858        .547     17.30      7.16
   519.00    106.139    107.976    113.077       1.047    116.61     48.22
   520.00    125.143    127.195    230.063       1.809    341.53    141.23
   521.00    142.500    144.755    360.636       2.491    662.77    274.07

     Section  2

     Left bound     .00 m, right bound  230.00 m from initial point
     Water boundaries included

     K-Manning: 40.0, Sqrt(S).K-Manning:     .5514

     Stage      Width     Wetted       Area   Hydraulic  A*R**2/3      Q
                          Perimeter             radius
        m          m          m        sq-m          m   m**(8/3)     m3/s

   512.00    158.042    158.482    277.671       1.752    403.55    222.50
   513.00    163.946    164.716    438.664       2.663    842.81    464.69
   514.00    181.982    182.984    608.462       3.325   1355.54    747.39
   515.00    195.834    196.996    798.552       4.054   2030.17   1119.36
   516.00    205.888    207.247    999.412       4.822   2852.65   1572.84
```

517.00	226.337	227.860	1218.693	5.348	3727.16	2055.02
518.00	230.000	232.731	1447.878	6.221	4897.61	2700.35
519.00	230.000	234.731	1677.878	7.148	6226.16	3432.87
520.00	230.000	236.731	1907.878	8.059	7669.16	4228.48
521.00	230.000	238.731	2137.882	8.955	9219.35	5083.20

Section 3

Left bound 230.00 m, right bound 420.00 m from initial point
Water boundaries included

K-Manning: 30.0, Sqrt(S).K-Manning: .4135

Stage	Width	Wetted Perimeter	Area	Hydraulic radius	A*R**2/3	Q
m	m	m	sq-m	m	m**(8/3)	m3/s
512.00	.000	.000	.000	.000	.00	.00
513.00	.000	.000	.000	.000	.00	.00
514.00	.000	.000	.000	.000	.00	.00
515.00	.000	.000	.000	.000	.00	.00
516.00	.000	.000	.000	.000	.00	.00
517.00	.000	.000	.000	.000	.00	.00
518.00	62.393	63.274	27.705	.438	15.98	6.61
519.00	100.209	101.231	99.981	.988	99.16	41.00
520.00	134.521	135.689	219.425	1.617	302.31	125.01
521.00	167.389	168.803	359.942	2.132	596.30	246.58

Stage	Discharge/section			>>> Total Discharge
512.00	.00	222.50	.00	222.50
513.00	.00	464.69	.00	464.69
514.00	.00	747.39	.00	747.39
515.00	.00	1119.36	.00	1119.36
516.00	.00	1572.84	.00	1572.84
517.00	.06	2055.02	.00	2055.07
518.00	7.16	2700.35	6.61	2714.12
519.00	48.22	3432.87	41.00	3522.09
520.00	141.23	4228.48	125.01	4494.72
521.00	274.07	5083.20	246.58	5603.85

These parameters may be determined for the whole cross-section or for parts of cross-section, e.g. for main river and flood plain separately.

It must be noted that when the cross-section is divided, the wetted perimeter for each part may be determined in two ways:

- the water boundary not considered:
  - for flood plain : $P_{floodplain}$ = ABC
  - for the main river: P_{river} = CEFG
- the water boundary is treated as a wall:
  - for the flood plain : $P_{floodplain}$ = ABCD
  - for the river : P_{river} = DCEFG

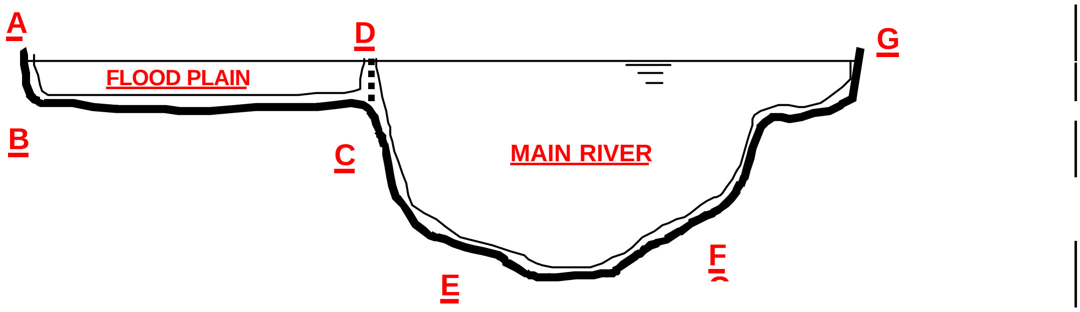


Fig.2.10: River flow in main channel and flood plain during high stages

To account for the lateral transport of momentum between river and flood plain the latter option appears to be more realistic. It reduces generally the discharge capacity of the main channel. However, to obtain consistency with hydraulic computations, where generally the first approach is used, both options are included.

Computation of hydraulic quantities in the measured range

Next, the geometric and hydraulic quantities are obtained in one of the following ways:

- from stage-discharge database, provided that the cross-sectional parameters are also given
- from a combination of the cross-section profile and the rating curve

The following parameters are obtained for various depths:

- surface width, (B)
- wetted perimeter, (P)
- cross-sectional area, (A)
- hydraulic radius, (R): R = A/P
- factor {area x (hydraulic radius)$^{2/3}$}, (AR$^{2/3}$)
- discharge, (Q)
- average velocity. (v): v = Q/A
- Conveyance, (K): K = (1/n)(AR$^{2/3}$) ; where n is an estimated value
- Slope (S): S = $(v/K)^2$

Estimation of discharge in the extrapolated range

The estimated values of slope (S) in the measured range is plotted against stages and since this curve is asymptotic to the bed slope at higher stages extrapolation is accordingly. The conveyance curve is also plotted making use of the estimated values of K in the full range of stages. Now, for any stage in the extrapolated range the value of K and S are read from the two curves and the product of these two quantities and the area of cross section (A) yield the estimated value of discharge (Q).

After synthetic data stage-discharge data have been obtained for the extrapolated range, these data are incorporated in the set of stage-discharge data. Subsequently, new attempts can be made to fit rating equation to the measured and estimated stage-discharge data.

3. Low flow extrapolation

Manual low flow extrapolation is best performed on natural graph paper rather than on logarithmic graph paper because the co-ordinates of zero flow can not be plotted on such paper. An eye-guided curve is drawn between the lowest point of the known rating to the known point of zero flow, obtained by observation or by survey of the low point of the control. There is no assurance that the extrapolation is precise but improvement can only come from further low flow discharge measurements. However low flows persist for a sufficient period for gaugings to be carried out and there is little physical difficulty in obtaining such measurements.

In HYMOS the power type equation used for the lowest segment with stage-discharge observations is assumed applicable also below the measured range. The shift parameter 'a' is either determined based on the measurements by the system or is introduced based on cross-sectional information.