INDIRECT FLOW MEASUREMENT

Coquitlam River above Coquitlam Lake

(08MH141)

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Indirect flow measurement :
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ABSTRACT

The slope-area method of computing flow was successfully carried out on the Coquitlam River above Coquitlam Lake to establish the upper end of the discharge rating curve. The extension of the stage-discharge curve agrees very closely with the rating curve established by the conveyance method.

1. INTRODUCTION

The slope-area measurement technique has been used successfully for many years in the United States for the calculation of extreme discharges and to provide an "n" value (Manning's) for future flow studies. The technique consists of obtaining water surface profiles from a selected reach of river for several discharge measurements that cover as near as possible the entire range of stage. A range of "n" and conveyance values can be obtained from this data and a conveyance rating curve can be calculated and extended to cover bankful flow.

This method lends itself to the situation during floods where it is impossible to measure the peak discharges as they occur. Access may be impossible, cableways destroyed, timing of peaks impossible to predict and weather may affect access by air.

2. PURPOSE

The purpose of this report is to provide an understanding of the slope-area method for obtaining peak flow estimates and the establishment of a rating curve for the high stages not normally defined by streamflow measurements. The purpose is also to encourage more technicians to apply this method on streams where peak discharge measurements are costly and near impossible to obtain and where backwater occurs at the higher stages and the simple extension of rating curves does not apply. Its purpose too is to provide a vehicle for publishing Manning's "n" value for this stream.

3. BASIN DESCRIPTION

The Coquitlam River basin above Coquitlam Lake drains an area of 54.7 square kilometres. It is a rectangular basin twice as long as it is wide, located between Indian Arm and Pitt Lake (see Figure 1). The basin is entirely forest covered and is typical of small coastal streams having a very spiked hydrograph due to heavy precipitation as shown in Figure 2. The stream profile is shown in Figure 3.

4. FIELD DATA

The slope-area site was chosen in that reach of river from the recorder upstream for 188 metres. This reach includes the recorder and two crest stage gauges as shown in Figure 4. One gauge is set at the bottom of a steep gradient in the river channel 89 metres from the recorder and the other 188 metres upstream. The profile is shown in Figure 5. These stations are tied into a level net that includes the recorder.Streamflow measurements and water surface profiles were taken over a small range of stage. The data are shown in Table 1. The range of stage obtained was limited because of the cost of access.

5. ANALYSIS

An analysis of the data indicated that the water surface slope for the reach between the two crest stage gauges was not suitably defined. The gradient was too steep for the low discharges as they are controlled by a series of drops rather than reflecting a continuous slope. Photographs of the upper reach show this physical feature (Figure 6). The lower reach (Figure 6a) from the recorder to the first crest stage gauge proved to be acceptable for the slope-area analysis.

The data were processed by the computer program "SAMFE" to calculate the area, hydraulic radius and wetted perimeter for each section to obtain the mean for the reach. The cross sections for the slope station are shown in Figure 7. The energy-slope, Manning's "n", and conveyance are computed for each measurement. The plot of the energy-slope is shown in Figure 8. It is a mean curve fitted by eye to reflect the physical shape of the channel.

An average "n" value (0.0292) was used to produce a conveyance table for the reach. The conveyance and energy slope were then used to compute the conveyance rating curve. A description of the Slope-Area computations is given in Appendix A.

5.1 RATING CURVES

A comparison has been made between the discharge measurement curve, the composite curve, and the conveyance rating curve. These are shown in Figure 9. The discharge rating curve has been extended from a gauge height of 2.125 metres. The flood flow values obtained from each curve are shown below for the maximum instantaneous stage of 3.207 metres. This is the maximum stage of record to date.

It will be observed that the composite curve developed from the H-Q curve computer program, using all previous measurement data, does not fit the physical features at the control section of this river.

ESTIMATED DISCHARGE - NOVEMBER 15, 1983

Method	Maximum Stage of Record	Discharge
Discharge Rating Curve	3.207	132 cms
Composite Rating Curve	3.207	170 cms
Conveyance Rating Curve	3.207	128 cms

5.2 STAGE-DISCHARGE CONTROL

The stage-discharge relationship obtained by plotting the discharge data on a Log-Log scale (1981 to 1985) is shown in Figure 10. The control has been stable over this period of time. At an approximate stage of 1.8 metres a change of slope occurs. This appears to be the region where the section control is drowned out and channel control becomes effective. The slope of the curve becomes slightly steeper at this point and should be reflected in the rating curve. The channel bed has also been stable over this time period as shown by cross section plots in Figure 11.

6. CONCLUSION AND RECOMMENDATIONS

The slope-area method has proved to be a viable method of defining the upper end of a rating curve that could not have been provided by the normal measurement technique. It has supplied some measure of assurance that the extended rating curve is fairly accurate.

It is recommended that the peak flow of 132 cms, as obtained from the extended discharge rating curve, be used for the historical record.

It is recommended that either the extended rating curve or the conveyance rating curve can be used to obtain discharge values but neither curve can be extended above the bankful flow level.

It is recommended that this method be employed whenever and wherever practical to establish the high end of streamflow rating curves.

ACKNOWLEDGMENTS

The author would like to acknowledge the contribution of Mr. I. Neufeld, Water Survey Technician from the Vancouver sub-office who initiated this study, established the control stations, measured the water surface profiles and provided the photographs of the stream channel.

BIBLIOGRAPHY

Barnes Jr., H.H. Roughness Characteristics of Natural Channels. Geological Survey Water-Supply Paper No. 1849. Washington: U.S. Government Printing Office, 1967.

Appendix A Description of the Slope-Area Program

1. Overview of the Model
2. Basic Input
3. Output of Program
4. Details of Computations

DESCRIPTION OF THE SLOPE-AREA PROGRAM

The slope-area method, as described in Technical Bulletin 79, is implemented in a friendly conversational program. It is written in BASIC language compatible with the PRO/350 MICRO computer

1. Overview of the Model

The slope-area method is based on a uniform flow equation which can be applied to a slightly contracting reach. However it can not be applied to a diverging reach without a loss of accuracy.

A reach of river is chosen to be as prismatic as possible and to provide an overall description of the reach a number of cross sections are surveyed along the river. The location of the cross sections are to account for the irregularities of the reach, and change in water surface slope due to river bed configuration.

A series of discharge measurements are taken to cover, as close as possible, the total range of stage and at the same time water surface elevations are taken at each cross section. Conveyance and energy slope curves are computed for the reach. Finally, the discharge for a given water surface profile is estimated from the conveyance curve and the energy slope equation.

2. Basic Input

Up to 5 sections can be used in order to describe the overall characteristics of the reach.

2.1 General Information

Station name

Station number

Title

Measurements units (metric or imperial)

Incremental elevation - area and hydraulic radius tables

Maximum elevation for curve extension

Total length of the reach

Number of cross sections

2.2 Cross sections

a. Geometry of each cross section as written in field notes: distance-depth or distance-elevation.

b, When the cross section geometry is entered in terms of distance-depth sets, the corresponding water surface elevation must be entered.

2.3 Measurements:

a. Discharge and profile for each measurement eg:

Section Number	W.S. Elevation in metres	Discharge in cms
1	3.21	420
2	3.15	400
3	3.04	365
4	2.90	315

b. Distances between sections along the reach.

2.4 The water surface profile at flood stage

3. <u>Output of Program</u>

- Table of area vs. elevation
- Table of hydraulic radius vs. elevation
- Plot of cross sections
- Estimated discharge
- Table of hydraulic parameters
- Table of geometric parameters
- H-K curve (conveyance)
- H-Q curve (rating)
- "n" (Water Resources Branch) for each measurement
- "n" (United States Geological Survey) for each measurement
- Chezy C
- Energy slope for each measurement
- Surface slope for each measurement

4. Details of Computation

4.1 Computation of Hydraulic Characteristics

The program computes an elevation table for each hydraulic characteristic; area (A), wetted perimeter (WP), and hydraulic radius (R) for each cross section used in the study and then computes the average tables for the reach.

$$A_m = 1/2 \sum_{i=1}^{m} (W_{i-1} + W_i)\ \Delta EL \qquad [1]$$

$$WP = \sum_{i=1}^{nv+1} \sqrt{(X_i - X_{i-1})^2 + (Y_i - Y_{i-1})^2}$$

Where

- x = abscissa of a vertical or an end point
- y = elevation of a vertical or an end point
- nv = number of verticals between the end points of each measurement
- i = subscript corresponding to the i^{th} vertical or end point
- m = subscript corresponding to the m^{th} elevation
- R_m = A_m/WP_m [2]
- ΔEL = incremental elevation

Computation of AA, AWP and AR

$$AA_m = 1/2 \sum_{i=1}^{m} (AW_{i-1} + AW_i)\ \Delta EL_i \qquad [3]$$

$$AWP_m = 1/ns \sum_{j=1}^{ns} WP_j \qquad [4]$$

$$AR_m = AA_m/AWP_m \qquad [5]$$

Where

$$AW_i = \frac{1}{ns} \sum_{j=1}^{ns} W_j$$

AA_m = Average area of reach
AW_i = Average width of reach
AR_m = Average hydraulic radius of reach
ns = Number of sections
j = Subscript corresponding to the j^{th} section
i = Subscript

4.2 Computation of K, n

K is computed by the following equation

$$K = \frac{Q}{S^{1/2}} \quad [6]$$

Where

$$S = (\Delta H + \Delta H_v)/L \quad [7]$$

$$\Delta H = H_{ns} - H_1 \quad [8]$$

$$\Delta H_v = Q^2/2g\ [1/A_{ns}^2 - 1/A_1^2]\ [1-k] \quad [9]$$

k = coefficient - 0.5 for expanding reaches and zero otherwise

$$n = \frac{1}{Q} AA(AR)^{2/3} S^{1/2} \quad [10]$$

The friction slope S is computed by equation 6 using the two end section areas A_1 and A_{ns}, interpolated from their respective tables with H_1 and H_{ns}.

AA and AR are interpolated from their respective tables with the value of the mean water surface elevation (AH) computed by the following equation:

$$AH = \frac{1}{2L} \sum_{i=1}^{ns} (H_i + H_{i+1})\ L_i \quad [11]$$

Where L_i = length between sections i and section i+1
H_i = water surface elevation at section i

A second method of computing "n" is provided by USGS Water Supply Paper. 1894 (Ref #1)

$$n = 1/Q \sqrt{\frac{S \times L}{\sum_{i=1}^{ns} L_i/(A_i R_i^{2/3} A_{i+1} R_{i+1}^{2/3})}}$$

where S is the friction slope of the reach:

$$S = -[(H_1 - H_{ns}) + Q^2/2g\ (1/A_1^2 - 1/A_{ns}^2)\ (1-k)]/L$$

4.3 Computation of H-K Curve

The regression equation has the following form:

$$K = CONS\ (H - AF)^{SLOPE}$$

Where AF, called zero flow height, CONS and SLOPE are obtained by the least square method.

4.4 Computation of the Peak Flow Discharge

The peak flow is estimated from the following equation.

$$Q = K\ S^{1/2}$$

Where K is estimated from the H-K curve at the stage of peak discharge.

a) The first estimation of Q is made assuming a uniform flow

$$Q = K\, S_w^{1/2} \qquad [12]$$

Where S_w is the water surface slope at peak discharge

$$S_w = (H_{ns} - H_1)/L \qquad [13]$$

b) The friction slope S is estimated from equation 6 with this last estimation of Q.

c) Finally Q is computed from equation 13

$$Q = K\, S^{1/2} \qquad [14]$$

If the new Q is considered close enough to the last computed one, the computation stops. Otherwise steps b) and c) are repeated until the solution stops converging.

TABLE

and

ILLUSTRATIONS

Table 1

DISCHARGE AND SLOPE MEASUREMENT DATA

Date of Measurement	Discharge in cms	Station	Water Level	Difference in Elevation	Water Surface Slope	Manning's Coefficient "n"
Aug. 15/84	2.04	CSG 3	2.218			
		CSG 2	1.619	0.599	0.0061	0.1919
		Recorder	1.612	0.007	0.00008	0.0425
June 15/84	13.6	CSG 3				
		CSG 2	2.059			
		Recorder	2.036	0.023	0.00026	0.0311
Oct. 3/84	1.04	CSG 3	2.158			
		CSG 2	1.521	0.637	0.0064	0.3255
		Recorder				
Oct. 7/84		CSG 3	3.816			
		CSG 2	3.334	0.482	0.0049	
		Recorder	3.124	0.210	0.0024	
Nov. 20/84	6.58	CSG 3	2.350			
		CSG 2	1.829	0.521	0.0053	0.0706
		Recorder	1.824	0.005	0.00006	0.0254
May 23/85	17.3	CSG 3	2.576			
		CSG 2	2.153	0.423	0.0043	0.0467
		Recorder	2.125	0.028	0.0003	0.0310
Jan. 25/85		CSG 3	2.691			
		CSG 2	2.314	0.377	0.0038	
		Recorder	2.302	0.012	0.00014	
Mar. 7/86		CSG 3	3.600			
		CSG 2	3.141	0.459	0.0046	
		Recorder	2.984	0.157	0.0018	
Nov. 15/83		Recorder	3.207	Maximum of Record		

Average Value of Manning's "n" used in the calculations of flow was 0.0292

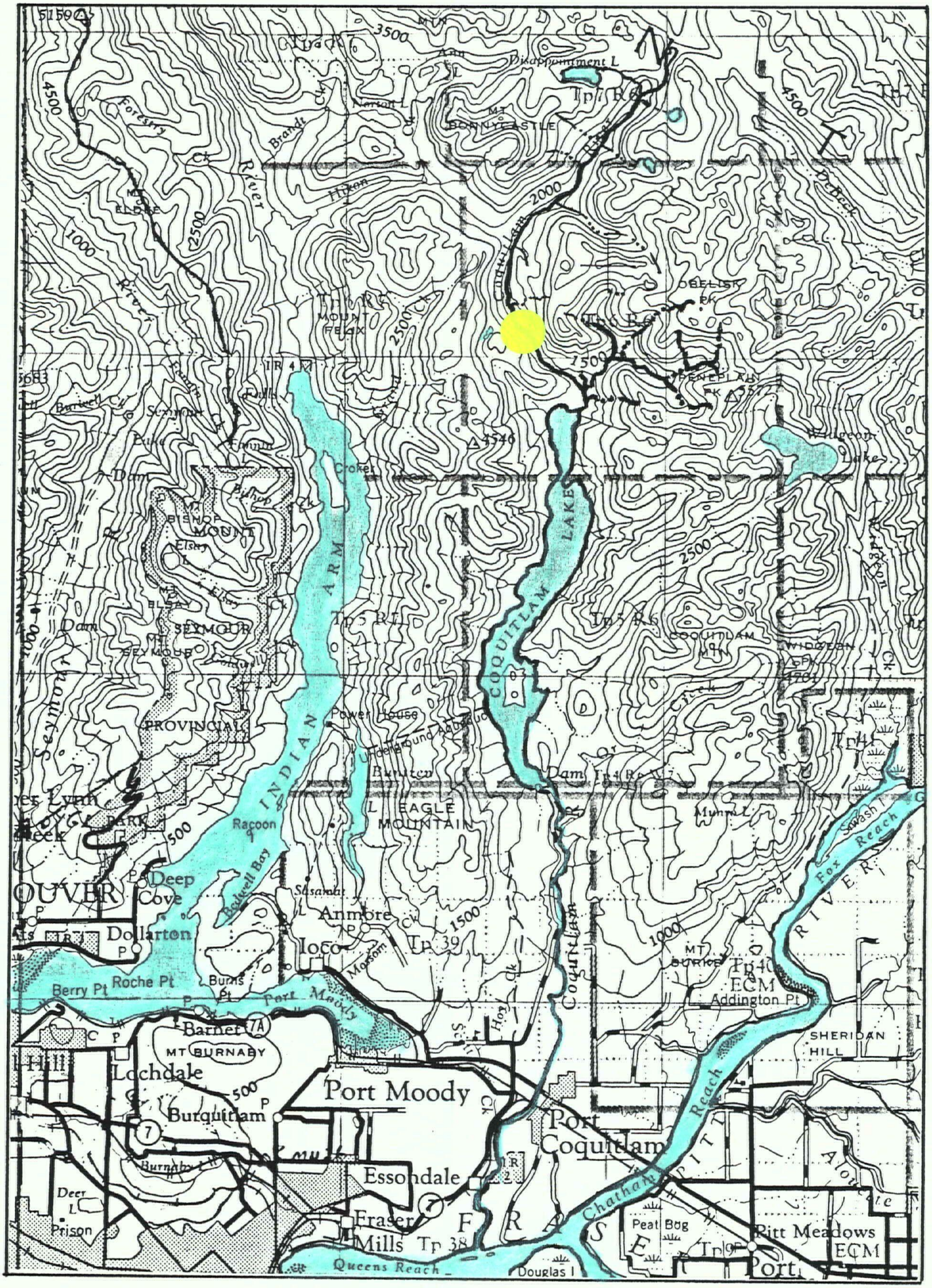


Figure 1 Map of Coquitlam River Basin Indicating Station Location

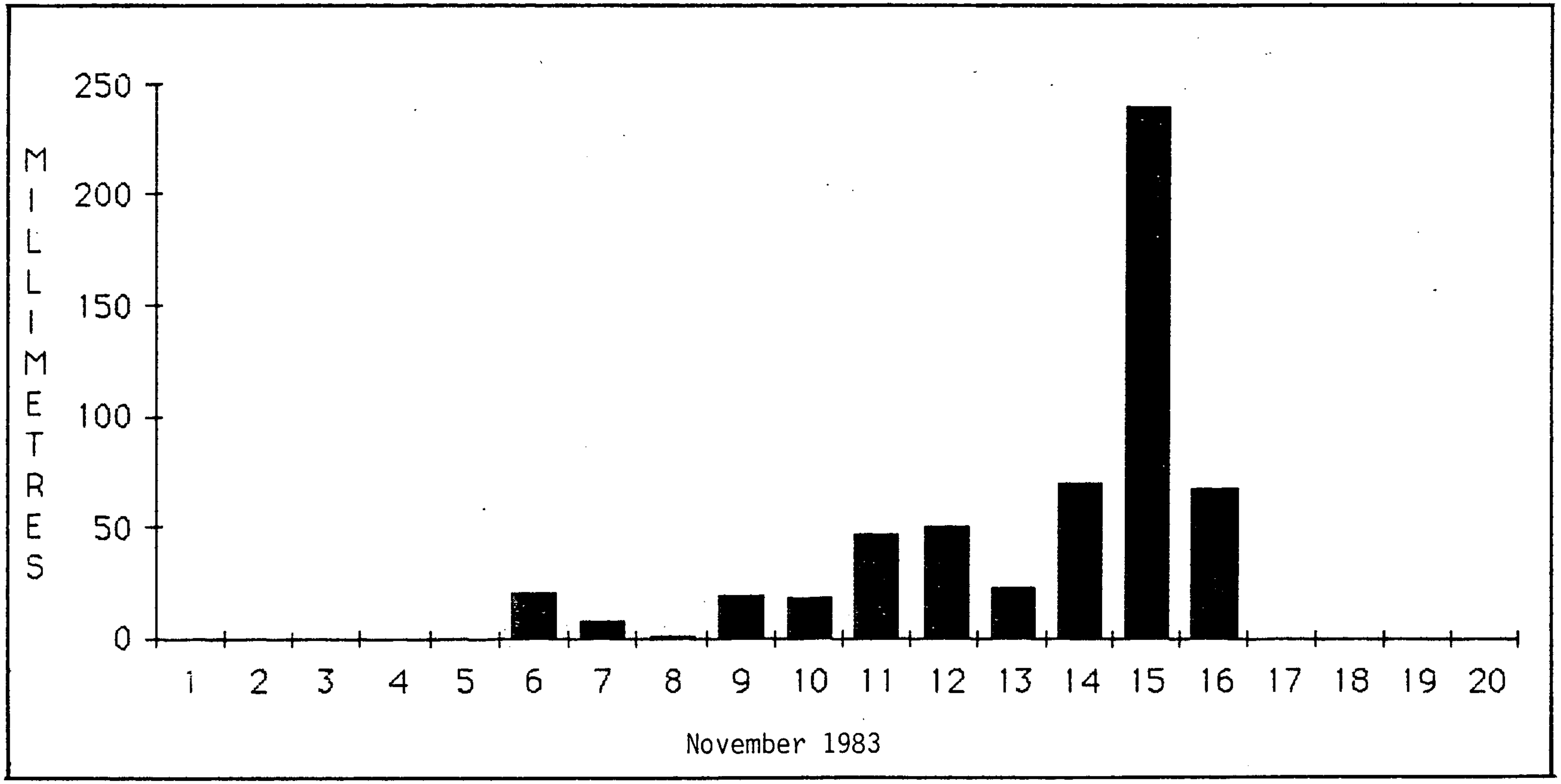


Figure 2 Histogram of Precipitation November 6-16, 1983

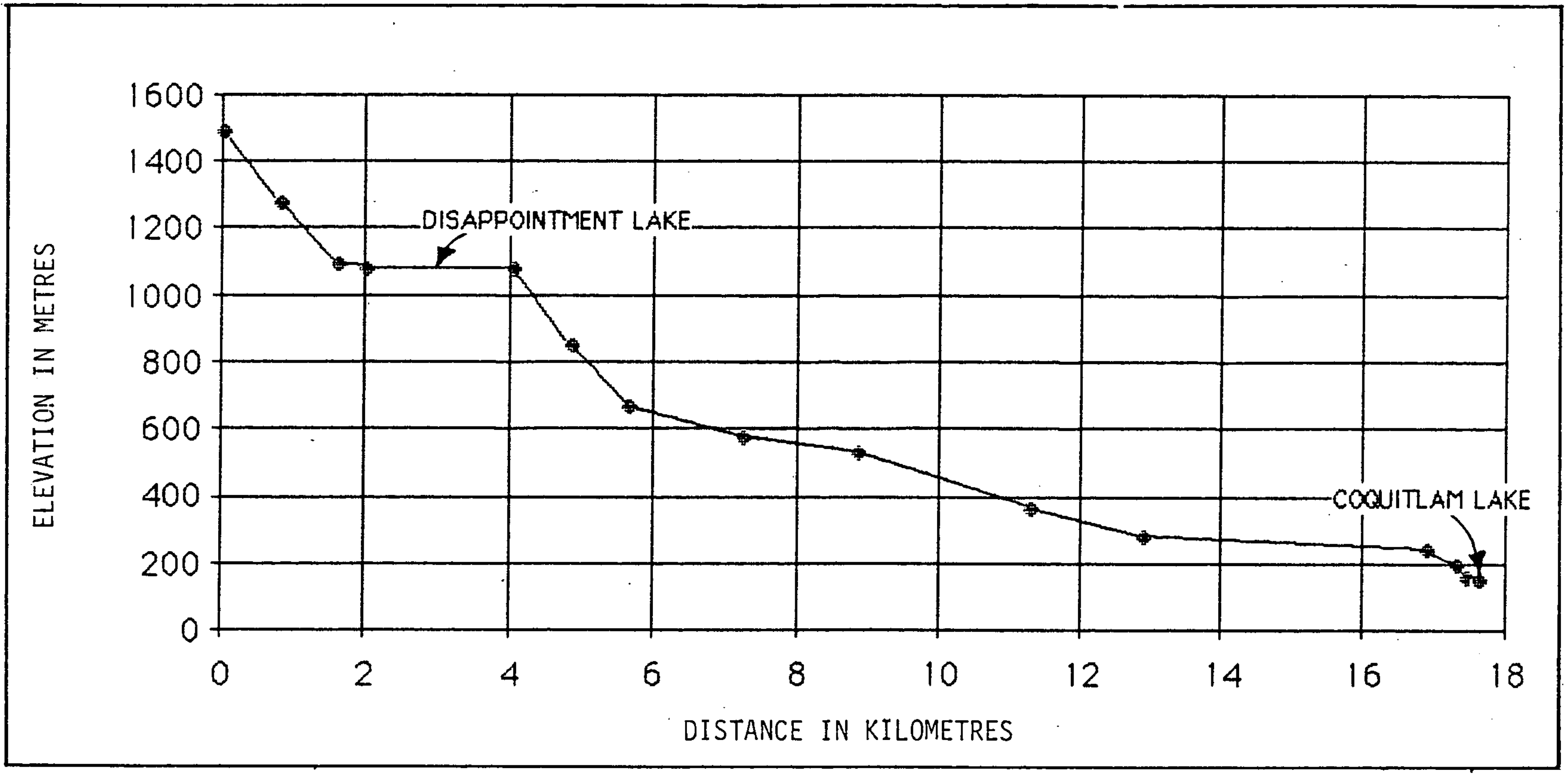


Figure 3 Profile of Coquitlam River

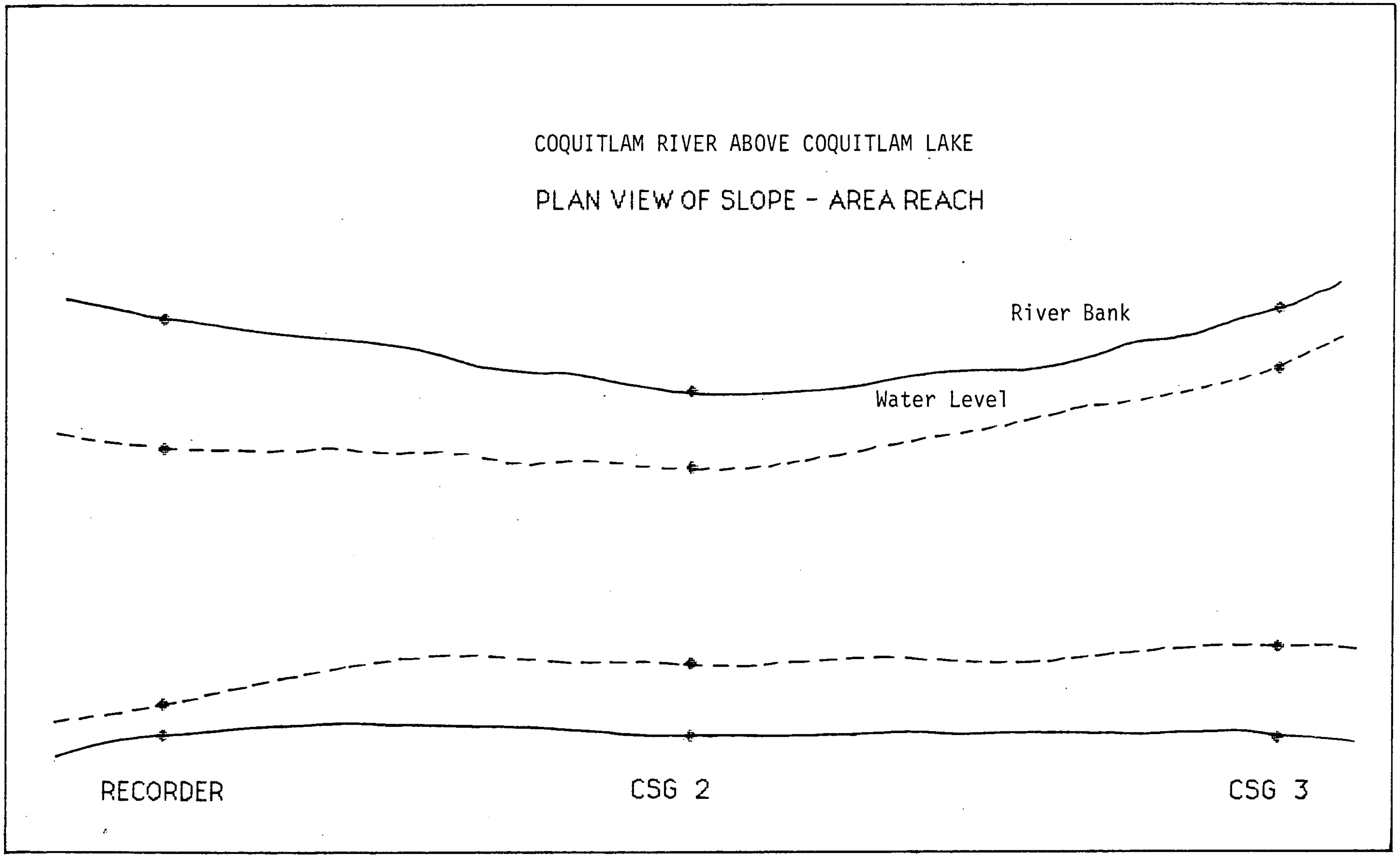


Figure 4 Plan View of Slope-Area Reach

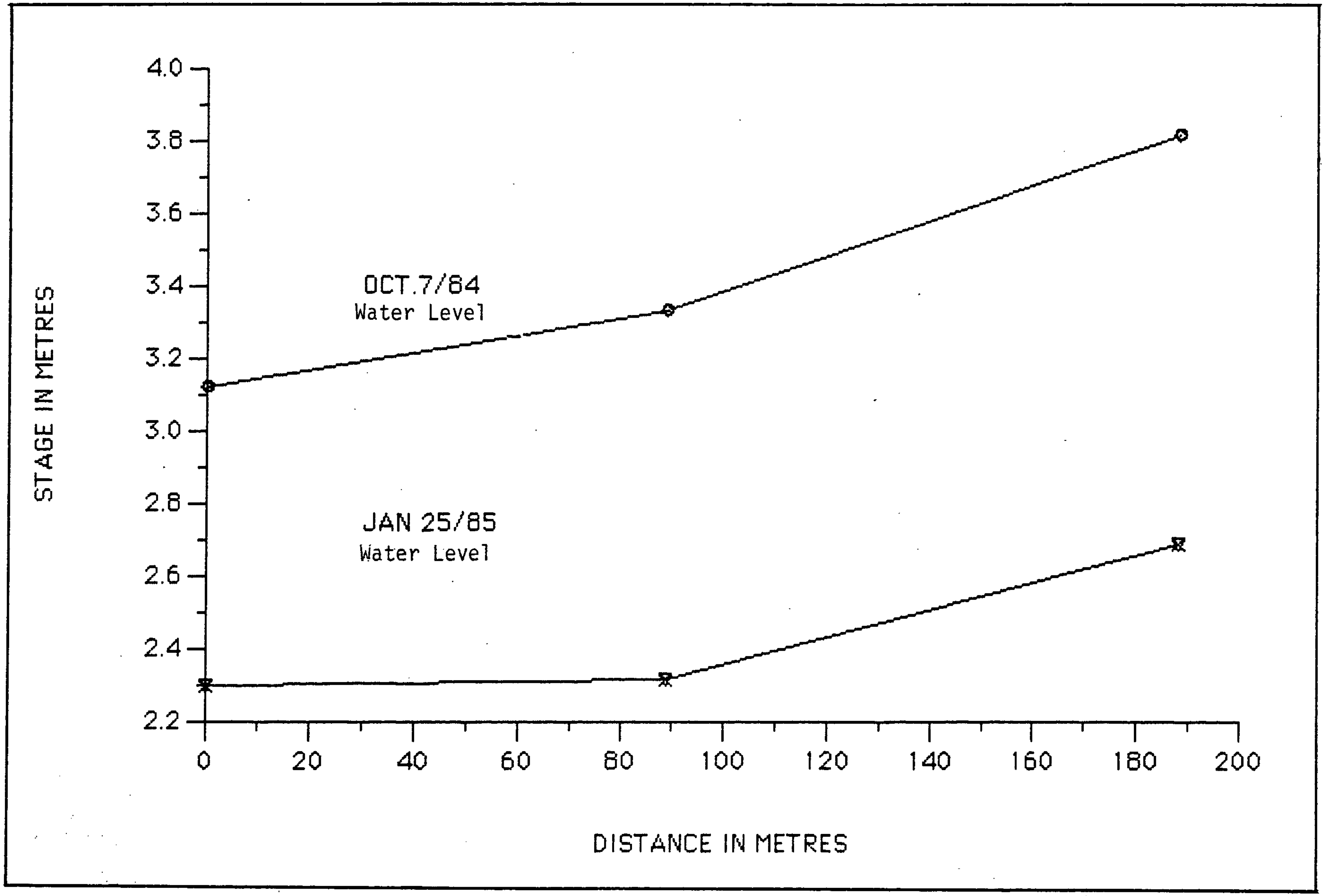


Figure 5 Profile of Slope-Area Reach

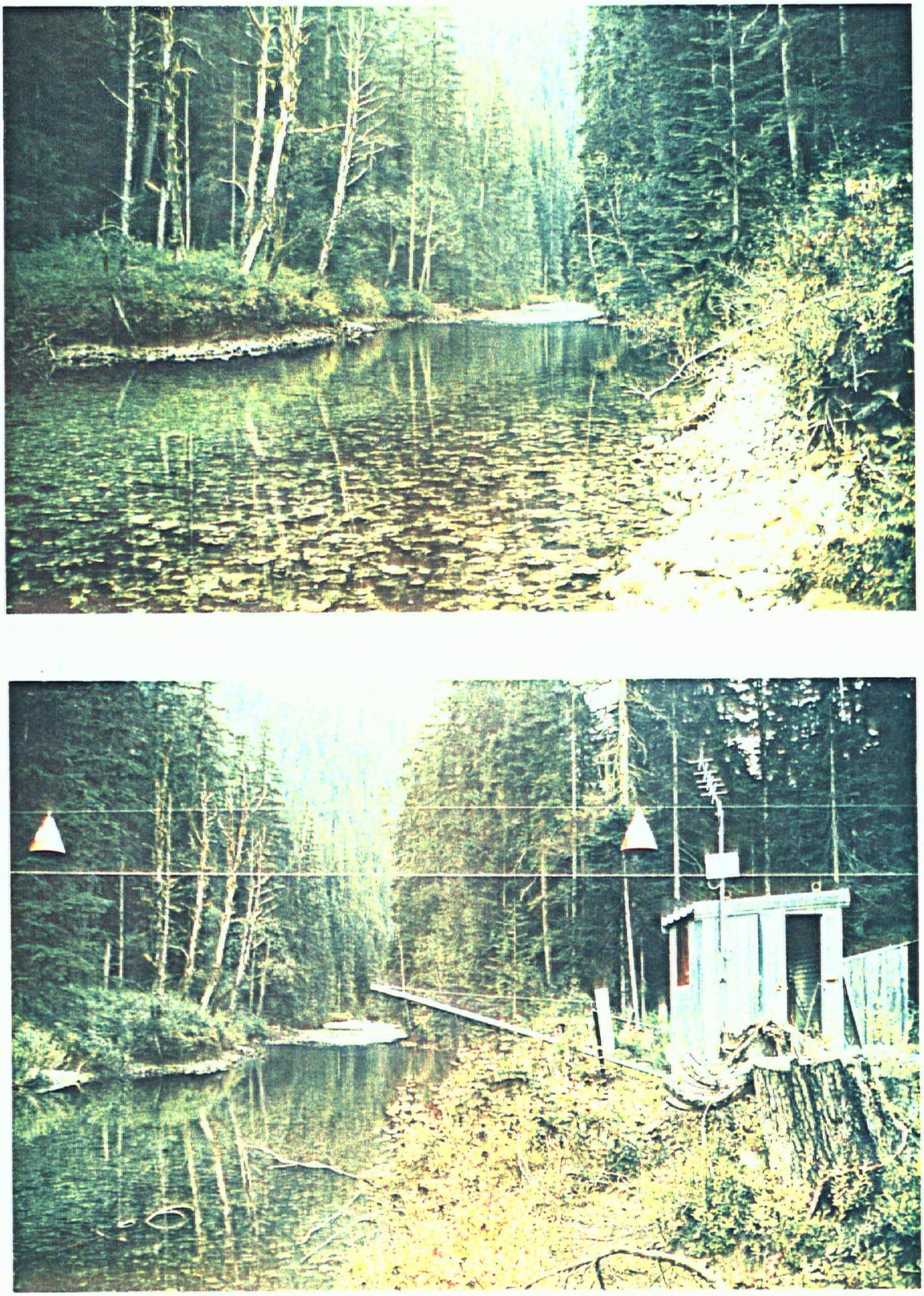


Figure 6 Coquitlam River above Coquitlam Lake
Slope-Area Reach Looking Upstream

Figure 6a Coquitlam River above Coquitlam Lake
Slope-Area Reach Looking Downstream

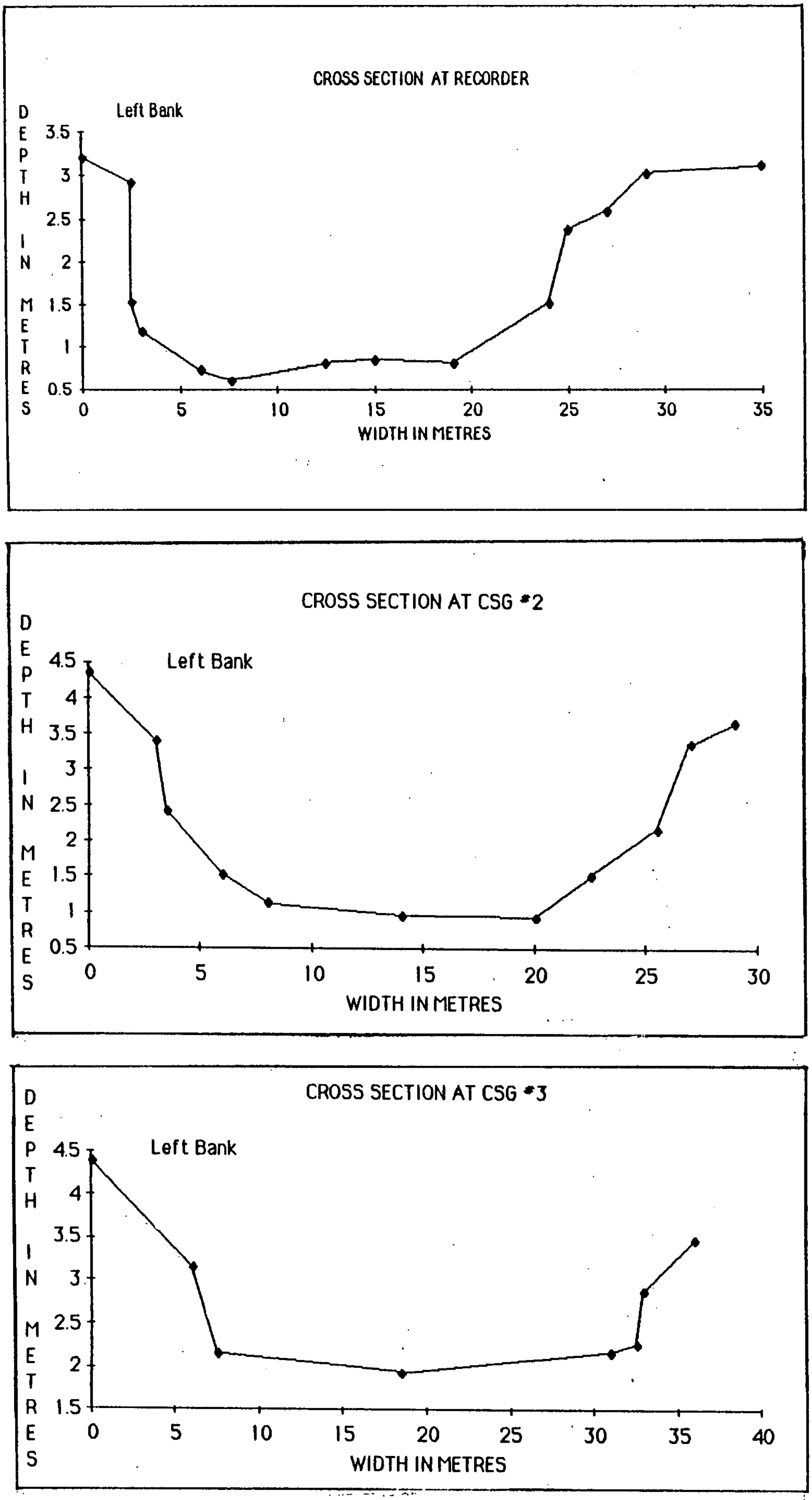


Figure 7 . Cross Sections at the Recorder and Crest Stage Gauge One and Two

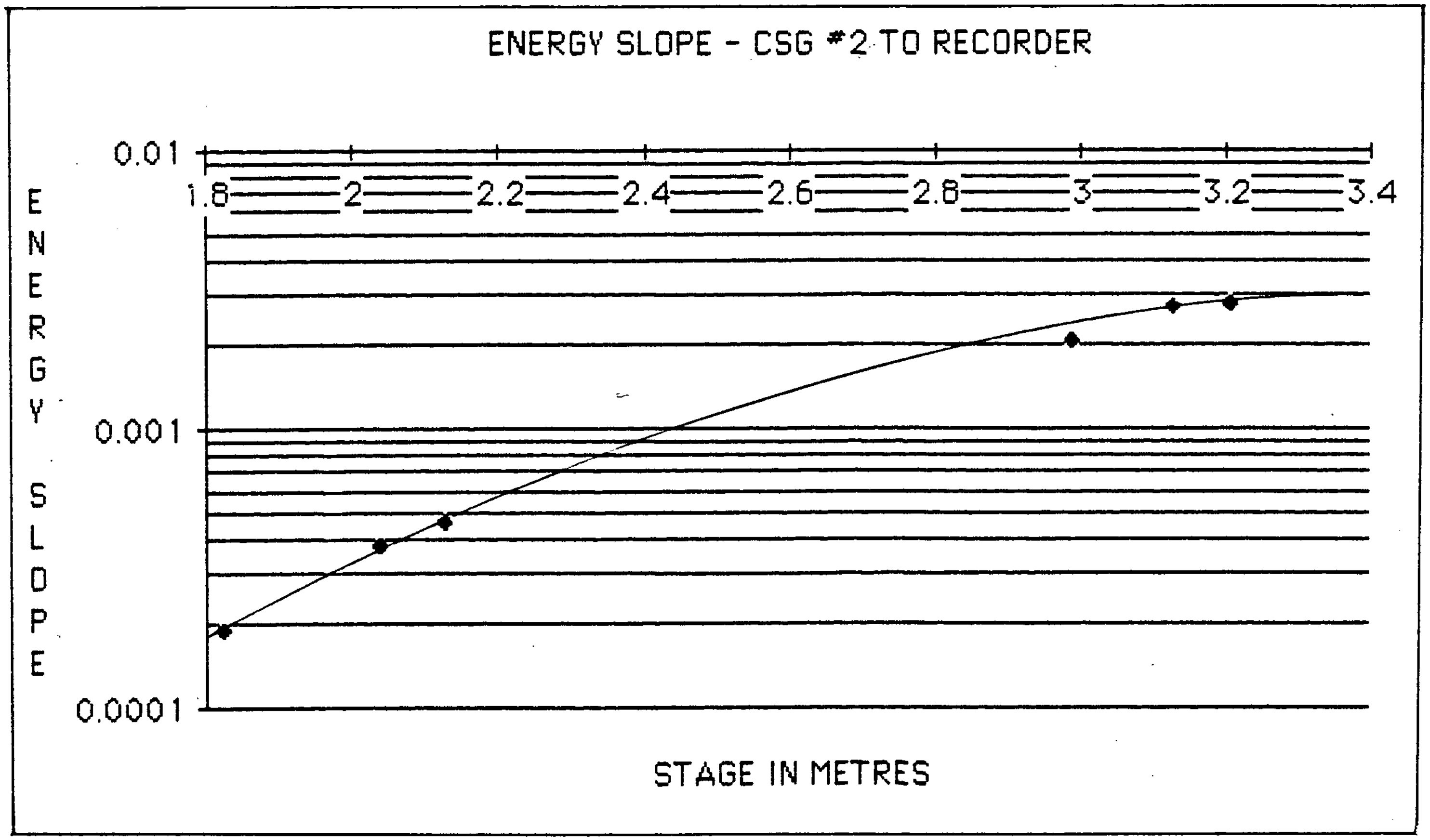


Figure 8 Energy-Slope Curve for Lower Reach

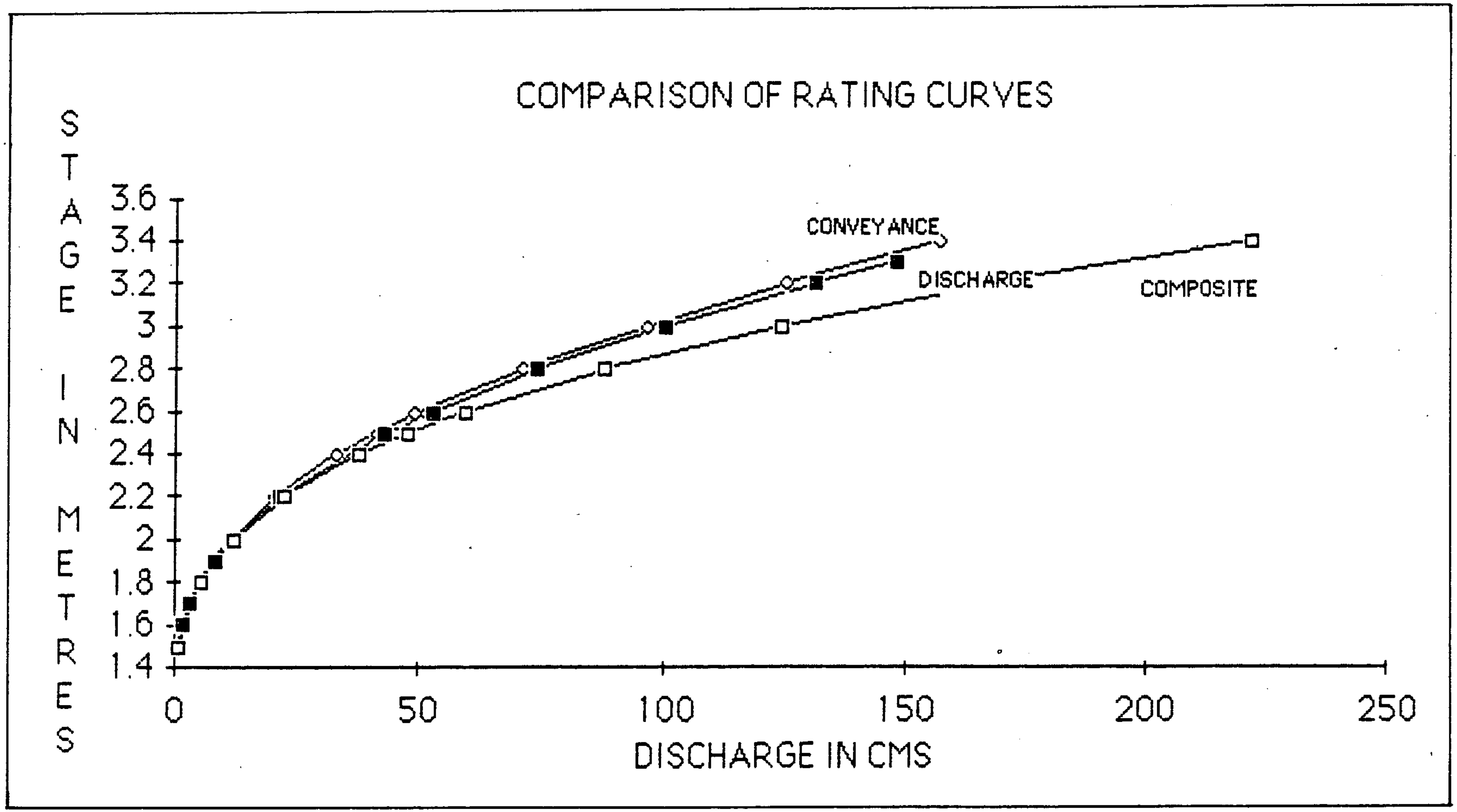


Figure 9 Comparison of Rating Curves

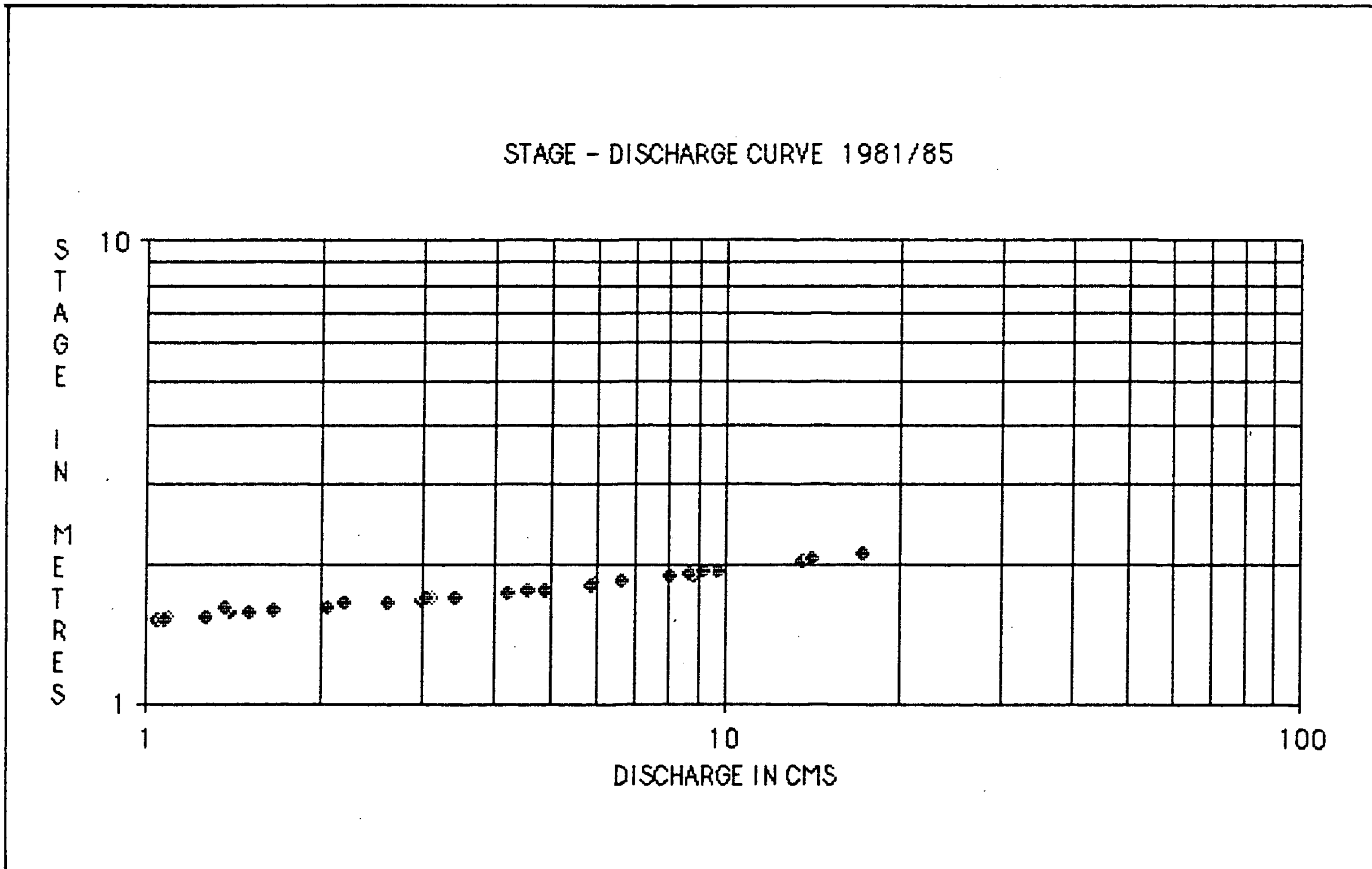
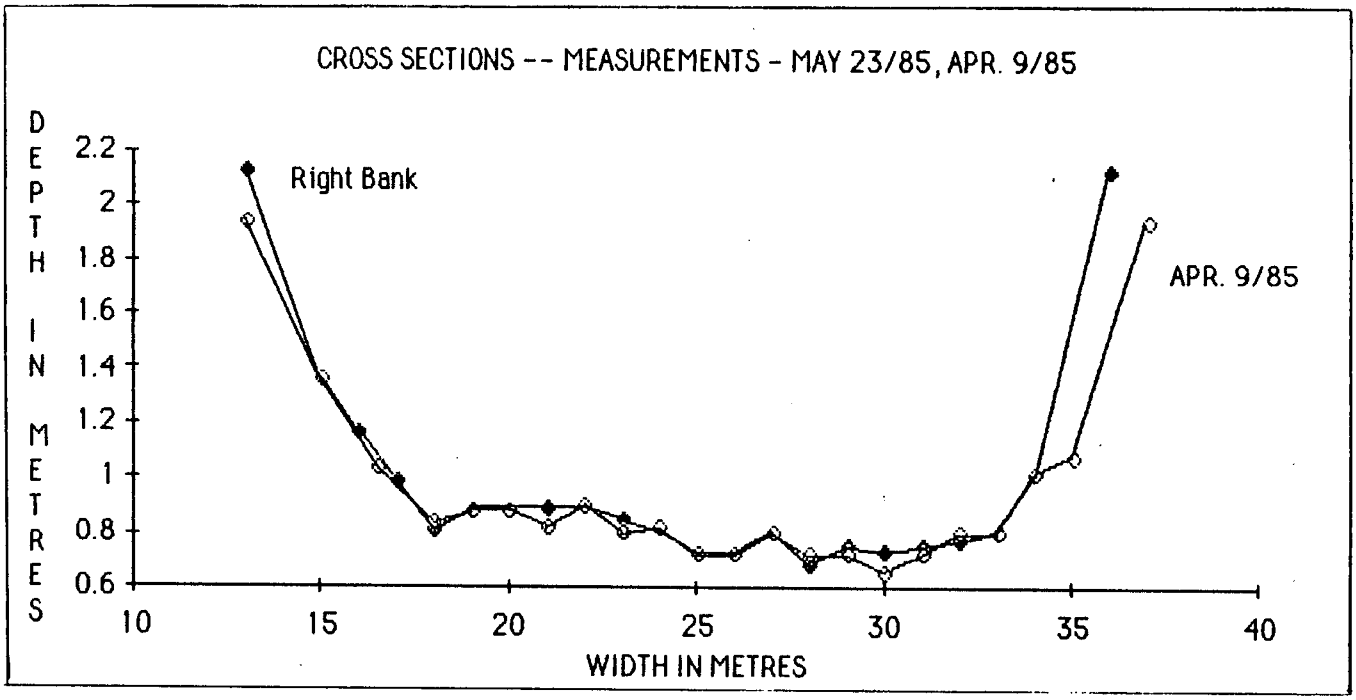


Figure 10 Log-Log Graph of Stage-Discharge Measurement Relationship (1981-1985)



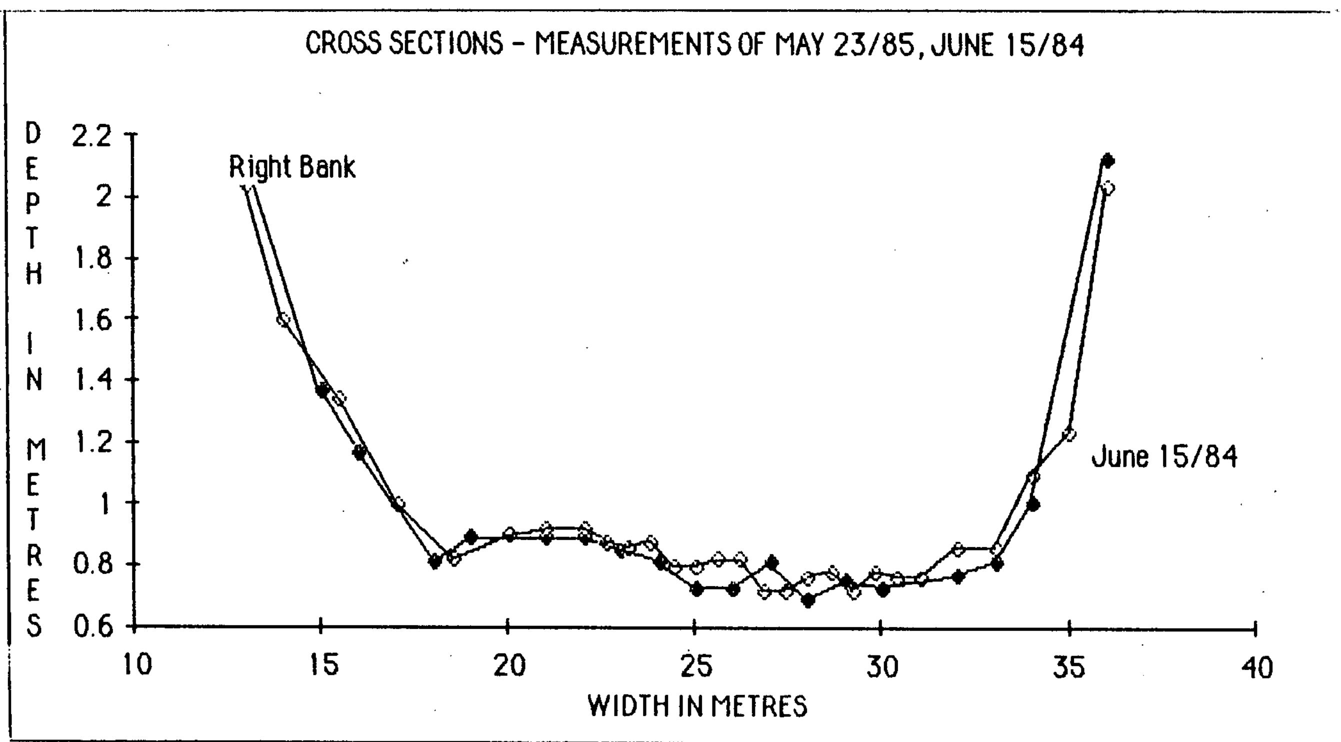


Figure 11 Cross Sections at Metering Cableway Obtained From Selected Measurements