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Assessment of Flows in Meandering Compound Channels

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NRA

National Rivers Authority

Assessment of Flows in Meandering Compound Channels

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EXECUTIVE SUMMARY

In October 1991 the National Rivers Authority (NRA) commissioned HR Wallingford to produce a hydraulic manual, giving NRA engineers a more accurate method of estimating stage-discharge relationships in meandering compound channels. The development of the assessment procedure was to be based on the SERC Flood Channel Facility (FCF) Phase B tests and other suitable data sources, from both experimental and field information. This report summarizes the development of the procedure, gives a worked example and discusses further work.

The analysis considered both inbank and overbank flows. For inbank conditions, there are a number of existing methods and these were reviewed in the light of the Phase B data. Modification of an existing method (SCS, 1963) was found to give satisfactory results over a wide range of test conditions and this has been recommended for use with inbank conditions. For the overbank case, a new approach was adopted which quantified the loss mechanisms which occur in meandering compound channels. The main loss mechanisms are friction losses, losses due to secondary circulations driven by shear imposed by the flood plain flow, and expansion and contraction of the flow as it passes from main channel into flood plain and vice versa. The new procedure splits the flow into four flow zones: the main channel below bankfull level, the flood plain within the meander belt and the flood plains either side of the main channel beyond the meander belt. For a given stage, the discharge is calculated as the sum of the zonal discharges. The new procedure was found to give substantially better results than existing methods.

From the available Phase B data some guidelines on shear stress predictions were made. Conventional boundary shear stress methods can be used to determine those for the main channel and banks for the full range of inbank stages. In addition the level of bank shear stress protection which would be required on the upstream and downstream sides of a meandering channel under overbank conditions has been recommended. Observed shear stress distributions suggested that the sediment transport capacity will be lower for overbank flows than inbank flows. Net deposition of sediment may therefore occur in the main channel during prolonged flood events.

The new procedure has been developed based on laboratory data. At present, insufficient data for natural rivers means that the generality of the procedure has not been fully verified. Future research needs have been identified, which would enhance the data used in the development of the method. These include extensions of the laboratory data sets, further laboratory studies of loss mechanisms, and field data collection. In addition, computational modelling techniques using turbulence and 2-D modelling techniques have been identified as promising methods by which to help further develop our understanding of the complex mechanics of flow in meandering compound channels.

A summary of the procedure is presented together with guidelines on its use and a worked example. This gives a step-by-step guide for applying the procedure. However, it is strongly recommended that the report be read as a whole by any user so that they fully understand the methodology behind the development of the procedure and its possible limitations.

The new procedure should not be used in the case of straight compound channels. Guidelines are given to indicate when a straight channel method should be applied.

One of the aims of the study was to consider the use of the new procedure in 1-D river models currently in use within the NRA. The implications of this are discussed and recommendations made as to the means of development required to achieve this aim. A specification for a software package intended to assist engineers in applying the method by hand has been drawn up and is included.

KEY WORDS

Hydraulic, capacity, design, compound channels, meanders, flood plains, stage-discharge, National Rivers Authority, HR Wallingford.

NOTATION

		Units
A	cross-sectional area	m^2
A	unsubscripted, cross-sectional area of main channel	m^2
B	top width of main channel	m
C_{sl}	length coefficient for expansion and contraction losses, zone 2	m
C_{ssc}	side slope coefficient for contraction loss, zone 2	
C_{sse}	side slope coefficient for expansion loss, zone 2	
C_{wd}	shape coefficient for expansion and contraction losses, zone 2	
c	coefficient in equation for zone 1 adjustment factor	
F_1	factor for non-friction losses in zone 2 associated with main channel geometry	
F_2	factor for additional non-friction losses in zone 2 associated with main channel sinuosity	
f	Darcy-Weisbach friction factor	
f'	ratio of flood plain and main channel Darcy-Weisbach friction factors	
g	gravitational acceleration	m/s^2
h	hydraulic mean depth of main channel, = A/B	m
K	coefficient in equation for zone 1 adjustment factor	
K_e	factor for expansion and contraction losses in zone 2	
K_c	contraction coefficient	
L	meander wavelength	m
m	coefficient in equation for zone 1 adjustment factor	
n	coefficient in Manning's equation	$m^{1/3}/s$
n'	coefficient in Manning's equation, including bend losses	$m^{1/3}/s$
P	wetted perimeter	m
P	unsubscripted, wetted perimeter of main channel at bankfull	m
Q	zonal discharge	m^3/s
Q_{bf}	main channel bankfull discharge	m^3/s
Q_{calc}	calculated discharge	m^3/s
Q_{meas}	measured discharge	m^3/s
Q_T	total discharge	m^3/s
Q_1'	adjustment factor for zone 1 discharge	
R	hydraulic radius	m
R	unsubscripted, hydraulic radius of main channel at bankfull	m
S	main channel gradient	
S_o	flood plain gradient	
S_s	cotangent of main channel side slope (Horizontal / Vertical)	
s	channel sinuosity	
V	mean flow velocity	m/s
V	unsubscripted, mean flow velocity in main channel at bankfull	m/s
W_2	width of zone 2	m
y_2	flow depth on flood plain at main channel bank	m
y'	dimensionless flow depth on flood plain = $y_2/(A/B)$	
ρ	density of water (approximately 1000 kg/m^3)	Kg/m^3
γ	unit weight of water (approximately 9.81 x 10^3 N/m^2)	N/m^3
τ	boundary shear stress	N/m^2

Subscripts

1-4 zones 1 to 4

PART 1

DEVELOPMENT OF THE PROCEDURE

1. INTRODUCTION

1.1 Background

Sinuous and meandering river channels are frequently encountered in engineering practice. The behaviour of flow in such channels is considerably more complex than in straight channels, particularly when overbank flows occur, and different methods must be used for estimating conveyance, boundary shear stresses and sediment transport capacity. This manual presents methods for estimating stage-discharge relationships and for obtaining provisional estimates of maximum bank shear stresses under overbank flow conditions.

Estimation of channel conveyance requires accounting for the energy dissipated or "lost" by the flow. Energy can be lost by a variety of different mechanisms which depend on the physical characteristics of the channel and the flow conditions. In a straight, prismatic channel the energy loss can be ascribed wholly to friction. Bends in a channel induce secondary currents in the flow, which effectively add to the energy loss by reducing the energy available for the primary flow. For overbank flow in a straight channel, further energy is lost through the interaction between the main channel and flood plain flows. In the case of overbank flow in a channel with bends, the mechanisms are yet more complex and the energy loss still greater.

Even in the more complex flow situations, friction is usually the most important loss mechanism and, although it is the best understood, estimation of the friction factor for natural rivers is largely subjective and remains a potential source of significant error in conveyance predictions. This manual focuses on quantification of the other loss mechanisms, but due consideration of bed friction must not be neglected.

The Science and Engineering Research Council Flood Channel Facility (SERC FCF) at HR Wallingford was designed to study the mechanisms associated with overbank flows in straight and meandering compound channels. Phase A dealt with straight channels and the conveyance results were analyzed and presented by Ackers (1991). This analysis stemmed from a need to make the results of the research being carried out on the SERC FCF available to practising engineers in a useful form. Ackers' work was funded by the former Regional Water Authorities of England and Wales, later the National Rivers Authority (NRA), and HR Wallingford. Phase B dealt with meandering channels and provided most of the information on which the methods presented in this report are based. Full details of the development of these methods will be published in a technical report by HR Wallingford with funding provided by the Ministry of Agriculture Food and Fisheries (MAFF). Early stages of the project involved re-presenting and evaluating the Ackers method, this is reported elsewhere see NRA R&D Note 44 (1992) (document 252/1/T) and HR Wallingford (1991) and (1992).

1.2 Objectives

Following the development of a method suitable for estimating conveyance in straight compound channels it was seen to be important to carry out a similar exercise for meandering channels, using the results available from the Phase B experiments of the SERC FCF programme. With this in mind the NRA commissioned HR Wallingford in 1991 to analyze the Phase B results. The main objects of the analysis were detailed in the HR proposal and were:

- summarize the tests and conclusions of the analysis of the Phase B tests;
- Review the Phase B data and devise a suitable form of analysis;
- Identify key sources of external data;
- Carry out an analysis of Phase B data in order to quantify the factors that influence the stage-discharge relationship, spatial distribution of flow and shear stress;
- Verify and extend the methods by application to data available from other laboratory and field experiments;
- Examine implications of the method for 1-D river modelling and
- Present a hand calculation method that can be implemented by NRA engineers.

1.3 Layout

This report addresses these objectives. For convenience Part 1 summarizes the data and analysis undertaken with detailed recommendations and guidelines. Part 2 presents a summary of the methods and gives a step by step worked example. The report is intended to be read as a whole and it is strongly recommended that users be familiar with the contents of Part 1 before proceeding to use the summary in Part 2. The final portion (Part 3) addresses issues which arise if the method is to be included in a 1-D river modelling package and gives a specification for software intended to assist in applying the method by hand.

2. STAGE-DISCHARGE PREDICTION

2.1 Available Data

The SERC FCF Phase B experiments were limited to two sinuosities (1.37 and 2.04) and two main channel geometries (trapezoidal and pseudo-natural). Stage-discharge and boundary shear measurements were taken for inbank and overbank flows with smooth and rod-roughened flood plains. Details of the Phase B experiments are described by James and Wark (1992).

Data from a series of experiments performed at the University of Aberdeen (Willetts et al 1990 and Willetts, personal communication) were also used in the development and evaluation of the methods. These experiments covered a wider range of sinuosities (1.2, 1.4 and 2.04) than the Phase B experiments, and the main channel had a considerably smaller width-depth ratio.

Several other data sets were used for evaluation of the proposed methods. These were obtained from the experimental work of Kiely (1990), Toebes and Sooky (1967) and the US Army Corps of Engineers (Vicksburg) (1956), and also the field and model test data for the River Roding presented by Sellin and Giles (1988) and Sellin et al (1990).

2.2 Inbank Flows

Various methods were identified in the literature for accounting for the additional resistance to flow induced by channel curvature. The methods proposed by the following authors were selected as being potentially suitable for practical application.

- Soil Conservation Service (SCS) (1963)
- Toebes and Sooky (1967)
- Leopold et al (1960)
- Mockmore (1944)
- Agarwal et al (1984)
- Chang (1983)

In addition, modifications to two of these methods were formulated.

The SCS Method involves increasing the basic value of Manning's n to account for meander losses. An adjustment factor is defined for each of three ranges of sinuosity. The step nature of this recommendation introduces discontinuities at the limits of the sinuosity ranges, with consequent ambiguity and uncertainty. To overcome this problem the relationship was linearized and can be expressed as

$$n'/n = 0.43\,s + 0.57 \qquad \text{for} \quad s < 1.7$$

$$n'/n = 1.30 \qquad \text{for} \quad s \geq 1.7 \qquad (1)$$

in which n' is the value of Manning's n including bend loss effects, n is the basic value as determined by surface roughness, and s is sinuosity. This extension will be referred to as the Linearized SCS (LSCS) Method.

Chang's (1983) method predicts the energy gradient associated with secondary circulation assuming that the circulation is fully developed. In fact, the circulation takes considerable distance to develop through a bend and begins to decay once the channel straightens out. For meanders, the circulation must reverse between successive bends and the associated energy gradient must drop to zero at two points over each wavelength. The average energy gradient associated with secondary circulation along the channel must therefore be substantially less than predicted assuming full development. Chang's (1984) approach for nonuniform flow through bends accounts for this and was simplified to apply to uniform flow. This enabled a correction factor to be computed which could be applied to the energy gradient predicted by his 1983 method, to account for growth and decay of circulation. Application of this correction is referred to here as the Modified Chang Method.

The selected prediction methods were applied to the SERC FCF trapezoidal channel data, the Aberdeen trapezoidal channel data, and the Vicksburg data. The average errors and standard deviations in estimating discharge by each method, for all the in bank data (62 measurements), are listed in Table 2.1. The upper value in each column is the average error in per cent; the lower value is the standard deviation. Two sets of results are presented for the SCS Method. In the first the adjustment factor was assumed to be on the higher side of the discontinuity where there was ambiguity, and in the second (marked *) the lower value was used. %Error as defined here is a skewed function and this biases the definition of Standard Deviation to positive %Error values.

Table 2.1 Errors (%) in bend loss predictions

Method	Friction Loss Only	SCS Method (1963)	Toebes Sooky (1967)	Leopold et al (1960)	Agarwal et al (1983)	Mock-more (1944)	Chang Rect. (1983)	Mod. Chang	LSCS Method
Mean	16.14	-3.46	-1.02	-7.68	-22.80	-39.40	19.03	-1.76	-1.45
S - D	9.86	7.74	12.06	9.36	11.48	11.12	12.33	7.35	9.84
Mean		-2.76*							
S - D		8.48*							

Notes %Error = 100 $(Q_{calc} - Q_{meas})/Q_{meas}$

S - D Standard Deviation of the % error

* Denotes Mean % error and Standard deviation in the mean for the SCS method assuming the low side of the discontinuity in choice of correction factor values.

Clearly, ignoring the energy loss induced by meandering introduces fairly large errors in the prediction of discharge for inbank flows. On the basis of simplicity and overall performance, it is recommended that the Linearized SCS method (equation 1) be used for inbank discharge prediction in meandering channels. If the resistance is to be described by the Darcy-Weisbach f, the adjustment factor should be squared before it is applied to the basic value.

The resistance coefficient should be adjusted only if the basic value does not already account for meander losses. This would be the case if recommendations based on surface roughness characteristics are followed. If a value is determined from flow data measured at the site in question by slope-area calculation, it will already incorporate meander effects and should not be adjusted further.

2.3 Overbank Flows

Various methods have been proposed in the past for estimating discharges in straight compound channels (Wark et al, 1991). Application of these to meandering channels results in unacceptable errors because they do not account for all of the important energy loss mechanisms present in meandering flows. This was demonstrated by applying the following widely used methods to the stage-discharge data obtained in the SERC FCF Phase B experiments.

The Divided Channel Method (DCM) separates the main channel and flood plain flows by vertical divisions. Discharges are calculated separately for the main channel and flood plain zones and then added. Zonal discharges are calculated using a friction equation with the vertical division lines included in the wetted perimeter for the main channel, but not for the flood plains. A variation of this method (DCM2) omits the vertical division lines from the main channel wetted perimeter as well.

In the Sum of Segments Method (SSGM) a vertical division line is located at each surveyed point defining the cross-section. Discharges are calculated in each of the resulting segments separately, using a friction equation and excluding the division lines from the wetted perimeters. The component discharges are then added.

In the Ackers Method (ACKM) the basic zonal discharges as calculated by DCM2 are adjusted using empirical factors based on the SERC FCF Phase A data. The factors and their derivation are described by Ackers (1991) and summarized in R&D Note 44, NRA (1992).

Because a hand calculation method was being sought, no computational methods were considered in this analysis although some are known to give good results for straight channels (for example, the Lateral Distribution Method, Wark et al, 1991).

The mean errors produced by these methods when applied to the SERC FCF Phase B stage-discharge data are presented in Table 2.2.

Table 2.2 Errors in discharge estimation by straight compound channel methods

Method	Mean Error (%)	Standard Deviation (%)
DCM	38.5	17.8
DCM2	41.6	16.8
SSGM	70.1	30.6
ACKM	24.8	26.0

Note %Error = $100\,(Q_{calc} - Q_{meas})/Q_{meas}$

The errors produced by straight channel methods when applied to meandering channels are clearly unacceptably large. The large standard deviations result mainly from trends in the predicted errors, which either increase or decrease strongly with increasing stage. These trends indicate that the methods do not account for all of the flow processes correctly.

A new method for predicting discharges in compound meandering channels was developed using a divided channel approach. The compound cross-section is divided into four zones, as shown in Figure 2.1. Zone 1 is the main channel below bankfull level, Zone 2 is the flood plain within the meander belt, and Zones 3 and 4 are the flood plains on either side of the main channel beyond the meander belt. For a given stage the discharge is calculated as the sum of the zonal discharges, calculated separately, i.e.

$$Q_T = Q_1 + Q_2 + Q_3 + Q_4 \tag{2}$$

The SERC FCF Phase B data were used to derive procedures for calculating the zonal discharges. The development of the procedures for each zone is described in the following paragraphs.

2.3.1 Zone 1 : main channel

The flow mechanisms in this zone are complex and not well understood. In addition to friction, energy is lost through secondary circulation driven by the shear imposed by the flood plain flow, which is radically different in character from the inbank secondary circulation. There is also considerable bulk exchange of water between the main channel and flood plain and so the discharge in this zone will vary over a wavelength, being maximum at a bend apex and minimum at some point between bends.

Because of the poor current understanding of the flow mechanisms, an empirical approach has been followed for predicting discharge. The variation of discharge along the channel is ignored. Hence for the purposes of stage-discharge estimation the flow in Zone 1 is assumed to be constant along the reach considered. The procedure is to calculate the bankfull discharge (Q_{bf}), and then to adjust this to account for the effects of overbank flow. The bankfull discharge can be estimated using inbank flow methods or obtained by measurement, if possible. The hydraulic slope which controls the flow in the main channel zone (S) is related to the flood plain or valley hydraulic slope by the channel sinuosity, (ie $S = S_o / s$). It should be noted that S_o can either be a ground slope if uniform flow is assumed or a water surface slope.

The adjustment factor was determined from the SERC FCF Phase B data. Actual discharges in this zone were obtained by integrating the velocity magnitude and direction measurements taken in some of the experiments. Bankfull discharges were estimated using the Modified Chang Method for the trapezoidal channel, and by extrapolating the inbank stage-discharge curves for the pseudo-natural channels. The ratio of actual to bankfull discharge defines the adjustment factor, Q_1'.

Q_1' was found to depend on:

- the flood plain flow depth at the edge of the main channel (y_2);
- the channel sinuosity (s);
- the cross-section geometry and
- flood plain roughness.

These characteristics are represented by dimensionless parameters which were chosen as being both meaningful and easy to measure. The flow depth is normalized by the hydraulic depth of the main channel at bankfull, equation 3, where A is the cross-sectional area and B the surface width of the main channel at bankfull.

$$y' = y_2 / (A/B) \tag{3}$$

The cross-section geometry is characterized by B^2/A. The flood plain roughness is expressed as the ratio of flood plain and main channel Darcy-Weisbach friction factors, i.e.

$$f' = f_2 / f_1 \tag{4}$$

The Darcy-Weisbach friction factor can be calculated using the Colebrook-White equation. If Manning's n is used then f is related to n by

$$f = \frac{8 \, g \, n^2}{R^{1/3}} \tag{5}$$

The ratio f' can therefore also be expressed in terms of Manning's n

$$f' = (n_2/n_1)^2 \, (R_1/R_2)^{1/3} \tag{6}$$

The relationship between the adjustment factor and these variables is shown schematically in Figure 2.2. This shows that the main channel discharge is initially reduced as stage rises above bankfull, and that this reduction is independent of channel characteristics. At higher stages the discharge increases with stage at a rate which depends strongly on B^2/A, s and f'. This variation can be accounted for by choosing the adjustment factor to be the **greater** of :

$$Q_1' = 1.0 - 1.69 \, y' \tag{7}$$

or

$$Q_1' = m \, y' + K \, c$$

with

$$m = 0.0147 \, B^2/A + 0.032 \, f' + 0.169$$

$$c = 0.0132 \, B^2/A - 0.302 \, s + 0.851$$

$$K = 1.14 - 0.136 \, f' \tag{8}$$

Hence the correct flow in Zone 1 is given by

$$Q_1 = Q_{bf} \, Q_1' \tag{9}$$

2.3.2 Zone 2 : inner flood plain

The method for predicting the inner flood plain discharge is based on quantitative descriptions of major loss mechanisms identified by other researchers (for example, Ervine and Ellis, 1987). These are

- friction on the wetted perimeter,
- expansion of the flow as it enters the main channel, and
- contraction of the flow as it re-enters the flood plain.

Additional losses associated with the bulk exchange of water between the main channel and flood plains are also likely to occur. However, due to the lack of any theoretical model which would account for this, for the purposes of stage-discharge estimation it is assumed that the discharge in Zone 2 is constant along the reach of valley considered.

Friction losses can be estimated using the Darcy-Weisbach equation. In this case the wetted perimeter does not include the vertical planes separating Zone 2 from Zones 3 and 4, or the horizontal plane separating Zones 1 and 2. It should be estimated as the total length of the flood plain surfaces across the section less B(s - 1). This approximation is arrived at by considering that the total area over which bed friction acts is given by Total area of flood plain (including the main channel) minus the top area of the main channel. The relative length of the main channel is the sinuosity. If Zones 3 and 4 do not exist, ie the main channel meanders across the full valley width, the flood plain surfaces up to the water surface should be included.

A basic description of the expansion and contraction losses was derived by analyzing the flow over a simple slot. The expansion loss was estimated by application of the energy and momentum equations, and the contraction loss using an empirical loss coefficient, as suggested by Yen and Yen (1983). An adjustment for width to depth ratio of the main channel was derived from data presented by Jasem (1990), and adjustments to account for the effect of main channel side slopes were derived from the results of Formica (1955), as presented by Chow (1959). The total loss over a meander wavelength was assumed to be proportional to the width over which expansion and contraction take place.

The SERC FCF Phase B and Aberdeen data showed that the non-friction losses were not wholly accounted for by the expansion-contraction model, and that there were additional effects associated with the main channel sinuosity and cross-sectional geometry. Empirical correction factors were introduced to account for these effects.

According to this model, the discharge for Zone 2 is given by

$$Q_2 = A_2 V_2 \tag{10}$$

in which

A_2 is the cross-sectional area of Zone 2, and

V_2 is the flow velocity in Zone 2, given by

$$V_2 = \left(\frac{2 g S_o L}{(f_2 L) / (4 R_2) + F_1 F_2 K_e} \right)^{1/2} \tag{11}$$

in which

g is the acceleration due to gravity.

S_o is the flood plain or valley hydraulic gradient and may be either the ground slope if uniform flow is assumed or the water surface slope.

L is the meander wavelength, (Figure 2.1).

f_2 is the Darcy-Weisbach friction factor for the inner flood plain.

P_2 is the wetted perimeter for the inner flood plain. It is defined as the total wetted surface of the inner flood plain minus the term B(s-1). (Figure 2.1)

R_2 is the inner flood plain hydraulic radius (A_2/P_2), with the area and wetted perimeter as defined above.

F_1 is a factor to account for variations of non-friction energy loss associated with the main channel cross-section geometry, given by

$$F_1 = 0.1\ B^2/A \qquad \text{for } B^2/A < 10$$

$$F_1 = 1.0 \qquad \text{for } B^2/A \geq 10 \qquad (12)$$

F_2 is a factor to account for variations of non-friction energy loss associated with the main channel sinuosity, given by

$$F_2 = s/1.4 \qquad (13)$$

K_e is a factor to account for expansion and contraction losses, given by

$$K_e = C_{sl}\ C_{wd}\ (\ C_{sse}\ (1 - y_2/(y_2 + h))^2 + C_{ssc}\ K_c) \qquad (14)$$

y_2 is the flow depth on the flood plain, measured at the edge of the main channel, (Figure 2.1).

h is the step height for expansion and contraction, and can be approximated by the hydraulic mean depth of the main channel, (A/B).

C_{sl} defines the length over which expansion and contraction occur in one meander wavelength, and is given by

$$C_{sl} = 2(W_2 - B)/W_2 \qquad (15)$$

W_2 is the total width of the inner flood plain.

C_{wd} accounts for the effect of cross-section shape on expansion and contraction loss, and is given by

$$C_{wd} = 0.02\ (B^2/A) + 0.69 \qquad (16)$$

C_{sse} accounts for the effect of the main channel side slope on expansion loss, and is given by

$$C_{sse} = 1.0 - S_s/5.7$$
(but C_{sse} not less than 0.1) (17)

C_{ssc} accounts for the effect of the main channel side slope on contraction loss, and is given by

$$C_{ssc} = 1.0 - S_s/2.5$$
(but C_{ssc} not less than 0.1) (18)

S_s is the cotangent of the main channel side slope, (Figure 2.1).

K_c is the basic contraction coefficient, as given in Table 2.3, and by Figure 2.3.

Table 2.3 Contraction loss coefficients (Rouse, 1950)

$y_2/(y_2+h)$	:	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
K_c	:	0.50	0.48	0.45	0.41	0.36	0.29	0.21	0.13	0.07	0.01	0.00

2.3.3 Zones 3 and 4 : outer flood plains

Flow in the outer flood plain zones is assumed to be solely controlled by friction. The zonal discharges are calculated using an appropriate friction equation with the division lines separating these zones from Zone 2 excluded from the wetted perimeter, ie.

$$Q_3 = A_3 V_3$$

$$Q_4 = A_4 V_4 \qquad (19)$$

where

$$V_3 = \left(\frac{8 g R_3 S_o}{f_3} \right)^{1/2}$$

$$V_4 = \left(\frac{8 g R_4 S_o}{f_4} \right)^{1/2} \qquad (20)$$

2.4 Evaluation of Overbank Flow Models

2.4.1 Laboratory data

The methods proposed for calculating discharge for overbank flows in meandering channels have been evaluated by applying them to stage-discharge data measured in laboratory channels. Data were used from the SERC FCF Phase B experiments, the Aberdeen experiments, the Vicksburg experiments, and experiments performed by Kiely (1990) and Sooky (1964). The method proposed by Ervine and Ellis (1987) and two methods proposed by Greenhill (1992) were also evaluated. Calculations were also done with the same zonal subdivision as proposed here, but ignoring non-friction losses in all zones, (Friction only). The errors in reproducing the stage-discharge data by the different methods are summarized in Table 2.4. In this table James and Wark refers to the method presented in this report.

Table 2.4 Errors in predicting overbank discharges: laboratory data

Method	Mean Error (%)	Standard Deviation (%)
Friction only	34.1	23.2
James and Wark	-2.1	9.7
Ervine and Ellis	5.3	18.3
Greenhill 4	11.5	19.3
Greenhill 5	7.6	14.7

Note %Error = 100 $(Q_{calc} - Q_{meas})/Q_{meas}$

The results presented in Table 2.4 are the mean errors in predicted discharge calculated over 279 data points from all of the above sources. They show that considerable errors can be expected if non-friction losses are omitted. The method presented in this report performs the best and is therefore recommended. This method has the advantage over the others that it is based on measured discharges for Zone 1, and should be more reliable if zonal conveyances are required separately. It is worth noting that the large standard deviations shown in Table 2.4 are caused by strong trends, over the ranges of stage considered, in the calculated errors and not random scatter.

Distribution of discharge

The results above demonstrate the overall accuracy of the new method. The procedure is to calculate the discharges in the various parts or zones of the channel separately and to sum them together to obtain the total discharge. Hence the method gives the distribution of flow between the zones in addition to the total discharge.

There is very little independent information available on the distribution of discharge in meandering overbank flow. Sooky (1966) carried out detailed velocity measurements in shallow (Geometry 1) and deep (Geometry 2) meandering channels which were otherwise identical. These experiments were carried out in a channel which was built at a scale approximately 8-9 times smaller than the SERC FCF Phase B geometries. Sooky integrated these velocity measurements to obtain the proportion of the total discharge within each zone. Table 2.5 shows comparisons between the measured and calculated discharges in the main channel (Zone 1) for the two cases Sooky considered. The method presented in this report has given the main channel discharges to an accuracy of about 5% to 7%, which is of the same order as the error in the measured values.

Table 2.5 Comparison between discharges in zone 1 (Sooky, 1966)

Case	$\%(Q_1/Q_T)$ Measured (Sooky, 1966)	Calculated (James and Wark)
Geometry 1	26.5	19.0
Geometry 2	38.2	33.5

Note : The values above are the zone 1 discharges expressed as a percentage of the total discharge.

Sensitivity analysis

Meander wavelength and main channel side slopes (required for the Zone 2 model) are not well defined in natural channels. However, sensitivity analyses have shown that predicted discharges are quite insensitive to these parameters and great accuracy in their estimation is not necessary. For example, for all of the laboratory data used above errors of ±50% in the wavelength gave mean errors of less than ±10% in the calculated discharge, similarly changes of ±100% in the main channel side slope gave mean errors of less than ±5% in the discharges.

2.4.2 Field data

The method presented in this report was developed and verified using laboratory model data. There is very little field information available regarding the performance of full scale meandering channels with flood plains. The only detailed field investigation known at present was carried out on the River Roding in Essex, see Sellin and Giles (1989) or Sellin et al (1990).

A combined laboratory and field monitoring research programme to study the behaviour of a stretch of the River Blackwater in Hampshire has recently been initiated. Laboratory work is currently under way on a large model (at 1:5 scale) of a 250 metre length of the proposed channel, which has been constructed in the SERC FCF at HR Wallingford. The prototype channel will be constructed in the field to match the laboratory channel and a programme of field measurements will be under taken. Unfortunately the Blackwater project has not produced enough information to date for verification of the methods proposed in this report. However it is expected that eventually the laboratory and field information will form the basis of a verification. In the absence of the Blackwater data, the method has been applied to a selection of the information available from the Roding study.

The Roding study

Full details of the field and laboratory measurements carried out on this site are available in Sellin and Giles (1988) and Sellin et al (1990). The study reach lies downstream of Abridge and as part of a flood alleviation scheme a two stage channel was formed by excavating berms on either side of the main channel (Figure 2.4). The original channel was untouched and remained in the natural state with a bankfull capacity of approximately 3 cumecs. The resulting flood channel has a low flow channel which meanders within the berm limits with a sinuosity of 1.38.

The project investigated the effects of different maintenance policies on the channel capacity. Most of the conditions investigated in the field and laboratory were with the flood berms covered, totally or partially, with extremely dense vegetation and verification of calibrated bed roughness values was not possible. The method was applied to the stage-discharge data from the following two cases.

P2 The berm growth was cut immediately after the summer growing season and so the berms were covered in short grass.

M2 The laboratory model data corresponding to the smooth berm case (P2 on the prototype).

In order to apply the method to these stage-discharge measurements the seven available sections were used to provided reach averaged areas, widths etc for all four flow zones at stages up to 1.0m above the berm level. The information provided by Sellin and Giles (1988) and Sellin et al (1990) combined with widely accepted guidelines, Chow(1959) and Henderson (1966) allowed the berm Manning's n values for the two cases, P2 and M2 to be estimated as 0.050.

The measured and predicted stage-discharge curves for these two cases are shown in Figure 2.5 and the mean errors in Table 2.6. It is obvious from Table 2.6 that the present method improves the overall accuracy of the predicted discharges and that by ignoring the non-friction head losses the discharge will be over predicted by about 10%.

Some sensitivity tests were carried out and they showed that as the flood plain was allowed to become smoother the two methods diverged more. Thus the effect of increased flood plain roughness is to make the non-friction head losses less important. It is not possible yet to give general guidelines as site specific aspects are likely to govern the relative importance of the various loss mechanisms. Sensitivity tests should be carried out for each application.

Table 2.6 Errors in predicting overbank discharges: Roding study

Case	P2		M2	
Method	Mean Error (%)	Standard Deviation (%)	Mean Error (%)	Standard Deviation (%)
Friction only	9.5	9.0	7.3	8.6
James and Wark	-2.0	1.7	-2.2	3.2

Note %Error = $100*(Q_{calc} - Q_{meas})/Q_{meas}$

3. BOUNDARY SHEAR STRESS PREDICTION

Very little information is available on which to base methods for predicting boundary shear stresses in meandering compound channels. The data obtained from the SERC FCF Phase B experiments have been analyzed by Knight et al (1992) and Lorena (personal communication) and form the basis of the provisional recommendations presented here.

There is no simple, general method for predicting boundary shear for inbank flows in meandering channels, but several simulation models have been developed which can be used for this purpose (for example, by Bridge, 1992, and Nelson and Smith, 1989).

For overbank flows, Knight et al have shown that the sectional average boundary shear stress in the main channel is less than would occur at bankfull stage at all cross-sections through a meander wavelength. Sectional average values are insufficient for designing scour protection, however, because the distributions of boundary shear across the sections are not uniform and vary with flow condition. The measured distributions suggest that during overbank flows the shear stress on the main channel banks may be higher than for inbank flows at some locations through the meander. The shear stress on the bed, however, is less than for inbank flows. Design shear stresses for scour protection should therefore be based on inbank flows for the bed and on overbank flows for the banks.

Under overbank flow conditions the bank shear stress on the upstream bank does not exceed $1.6\ \gamma\ y_2\ S_o$ in any of the measured distributions, where γ is the unit weight of water defined by ρg (9.81×10^3 N/m^3). On the downstream bank a high, localised stress concentration was observed downstream of each bend apex, associated with the expulsion of water from the main channel to the flood plain (see Figure 1.1). This concentration is shown in Figure 3.1, which presents Lorena's plot of contours of shear stress for the 2.04 sinuosity channel with a flow depth on the flood plain of 50 mm. The concentrations were centred at points between 60° and 70° downstream of the apex section for all the experimental conditions. The maximum observed shear stresses in the concentrations approached $5\ \gamma\ y_2\ S_o$. The stress concentrations are very localised and decrease rapidly with distance but, because of the limited experimental conditions and consequent uncertainty regarding locations, they should be assumed to be more extensive when designing scour protection. The enhanced shear stresses also extend for some distance over the flood plain on the downstream side of the channel.

For the design of scour protection, it is recommended that boundary shear stresses be determined for the main channel bed and banks for the full range of inbank stages, using currently available methods. In addition, the banks should be able to resist stresses of

$$\tau = 1.6\ \gamma\ y_2\ S_o \qquad (19)$$

on the upstream side, and

$$\tau = 5\ \gamma\ y_2\ S_o \qquad (20)$$

on the downstream side.

The observed shear stress distributions suggest that the sediment transport capacity in the main channel will be lower for overbank flows than for inbank flows. Net deposition of sediment may therefore occur in the main channel during prolonged flood events. The shear concentrations on the downstream banks during overbank flows suggest enhancement of meander migration in the valley direction during prolonged flood flows, and also corroborate the mechanism of meander cutoff by opening chutes across point bars.

4. GUIDELINES

4.1 General

The methods presented here are based on laboratory data. There are at present insufficient data for real rivers to verify their generality. Natural rivers obviously have irregularities and features which have not been accounted for, and it is not possible to make specific recommendations for all possible situations. The methods should not, therefore, be treated as rigorous, universal procedures; additional, unspecified decisions based on professional experience and judgement will be required in most applications. The following discussion has two natural elements: section 4.2 deals with the problem of the transition from straight to meandering conditions and section 4.3 deals with examples of the type of judgement the user will be required to make in practice. It is again emphasised that both parts of this report should be viewed as complementary. The description of the development process given in Part 1 is intended to provide the user with an insight into the conditions covered by the data available so that sensible decisions about how the methods should be generalized.

4.2 Straight and Meandering Channels

The method presented in this report was developed and verified against laboratory data with main channel sinuosities in the range 1.09 to 2.04 and was shown to perform well for all of this data (section 2.4.1). The method has also been applied to the limited amount of field data available and performed reasonably well (section 2.4.2). However, applications to straight compound channel laboratory and field data show that the method developed for meandering compound channels under-predicts discharges by about 20% on average, with extreme cases being under-predicted by as much as 40%. It was shown above (section 2.3) that straight channel methods will over-predict discharges in meandering compound channels by as much as 50% to 60%.

The method presented in this report for meandering compound channels has been verified successfully at sinuosities as low as 1.09 but does not accurately predict discharges in straight compound channels (sinuosity 1.00). The Ackers method (Ackers 1991) has been extended to cope with channels which are skewed to the flood plain by angles smaller than 10° which corresponds to a sinuosity of 1.02. Unfortunately there is no available information on the behaviour of flow in channels with sinuosities between 1.09 and 1.02 on which to base recommendations as to when to switch from the meandering to a straight channel method. The recommendations given below are therefore not well documented and must be regarded as tentative.

When the main channel sinuosity is less than 1.02 use a straight channel method, with appropriate corrections for sinuosity and for cases with main channel sinuosity greater than or equal to 1.02 use the James and Wark (1992) method.

A straight channel method may also be appropriate if the lateral slopes of the flood plains are steep enough to constrain the flow to being parallel to the main channel. There is an intuitive argument that in this case the interaction between channel and flood plain is similar to the straight channel situation. The nature of the energy losses depends on whether the flows are parallel and not on the channel and flood plains being straight. There is no evidence to verify this argument and this aspect is still open to conjecture.

4.3 Generalization of the Method to Field Conditions

The method was developed using laboratory data. Typical laboratory geometries are idealized and the data available were collected in channels with the following geometric conditions.

- Horizontal flood plains at the same level on both sides of the main channel.

- Flood plains which are a fixed uniform width along the length of the channel.

It is obvious that typical applications will involve real geometries which differ from the situations which have been studied to date. Some examples of differences to be expected, along with suggested approaches for dealing with these differences are given below. It should be noted that the cases given below do not represent an exhaustive treatment and other differences between laboratory and field conditions may exist in particular situations.

- Flood plains on different levels: Use judgement to define a reach averaged value of bankfull stage (to ordinance datum) or depth (to channel bed) and define y_2 relative to this.

- Flood plains of different roughness or flood plain roughness which varies along a reach: Apply judgement in determining reach averaged values of friction values.

- Flood plains vary in width along a reach: Use judgement to define reach average values of area, width and wetted perimeters for zones 2, 3 and 4.

In many engineering applications the methods will be applied to successive sections along a channel. Obviously, the channel characteristics will vary between sections, and the parameters used in the methods must be specified to represent average conditions over the reach represented by the particular section. The guidelines given above are also applicable to these applications.

It is recommended that the user should carry out sensitivity tests in order to assess the relative importance of any uncertainties that arise from the application of professional judgement.

5. FUTURE RESEARCH NEEDS

5.1 Laboratory Studies

5.1.1 Extension of existing data sets

Existing laboratory studies cover a relatively narrow range of conditions. Further laboratory work would be required either to verify or extend the present method for conditions other than those covered by the existing data. In particular the following list of experiments would fill gaps in the available laboratory data. It should be noted that this list is not in any particular order.

- Undertake experiments to measure stage-discharge, velocity and bed shear stresses for meandering channels with sinuosities between 1.0 and 1.09. This is important because there is a need to establish at what sinuosity a compound channel analysis treatment should switch from straight to meandering.

- Undertake experiments to measure stage-discharge, velocity and bed shear stresses for low overbank stages, ie (y_2/h) values between 0.0 and 0.1. There are few data points in this region and it is probably the most common range of overbank flow conditions which occur in nature.

- Undertake experiments to measure stage-discharge, velocity and bed shear stresses for flood plains with transverse slope away from the main channel. There are few laboratory data for this condition and natural flood plains tend to slope laterally in this manner. There is some conjecture that it may be more realistic to analyze overbank flow in these geometries using straight channel techniques, as the flow will be constrained parallel to the main channel.

- Undertake experiments to measure stage-discharge, velocity and bed shear stresses for sinuosities between 1.09 and 1.20; 1.20 and 1.40; 1.40 and 2.01 and for sinuosities greater than 2.01. All known laboratory experiments have been carried out at or very close to sinuosities of 1.09, 1.20, 1.40 and 2.01 and this is obviously leaves gaps in the available information.

- Undertake experiments to measure stage-discharge, velocity and bed shear stresses in meandering channels for a range of channel to flood plain widths and for cases with asymmetric flood plains on either side of the main channel. All existing data have been collected for a limited range of channel to flood plain width ratios and with symmetric flood plains.

- In order to confirm the SERC Phase B data it would be useful to conduct experiments in small scale flumes with geometries which are exact scale models of the phase B tests. If such experiments were carried out and proved to be positive then the gaps in the Phase B results could be filled using data collected in much smaller laboratory facilities.

Laboratory work intended to extend existing information should be carried out in channels with idealized geometries similar to those from which the existing laboratory data were obtained. For example the flood plains should be uniform in width along the length of the channel and the meandering main channel plan geometry should be a simple repeating geometric shape.

5.1.2 Laboratory studies of loss mechanisms

The formulation of models of loss mechanisms has exposed some surprising gaps in experimental results. Some useful information could be obtained from relatively simple and inexpensive laboratory studies. The following studies would contribute to the descriptions of losses in the identified flow zones :

- A quantification of contraction loss over an upward step.
- A study of the effect of slot alignment on expansion and contraction losses.

5.2 Field Data Collection

5.2.1 General remarks

The lack of adequate and reliable field data has been a major constraint in the verification of analysis method for meandering compound channels. The method presented is based on results from laboratory experiments and while this is appropriate because of the high degree of control of the relevant variables required, the correspondence between laboratory and field conditions is not firmly established. The relative importance of different energy loss mechanisms may change with scale. Some information was available from the River Roding study (Sellin and Giles, 1988) and provided good initial verification of the findings reported above. However further field data should be sought to fully verify methods of estimating conveyance in meandering channels.

The River Blackwater study which combines laboratory and detailed field measurements will provide a useful data set to compare many of the details of the method. It is proposed to make measurements of stage discharge and point velocity distributions, both in the laboratory and the field. This research programme is planned to take place over three to four years and will provide a good deal of detailed information on flow distributions between the various zones in particular cases.

5.2.2 Strategy for field data collection

It is apparent that the analysis method has not yet been fully verified against field data because very few relevant field measurements have been made. Given that it is desirable to collect more field data it is important that the correct types of information are obtained in order to make the most efficient use of resources.

In general there are two levels of validation possible and these differ in the amount of hydraulic information to be measured at each site.

1) Collect only stage-discharge information at each site.

2) Collect stage-discharges, point velocities, and water levels both along and across the study reach.

Obviously it will be possible to carry out measurements at a larger number of sites if only total discharges are to be measured. This would provide a wide range of data for the validation of the overall method but would not provide information to validate the calculated flow distributions. If the more detailed validation is required then it is likely that fewer sites would be considered due to the increased costs.

It will either be possible to partially validate the overall method on a relatively large number of sites, or carry out more detailed validation on a limited number of sites. The detailed validation would require that at least three or four other projects similar to the Blackwater project be set up and the costs of running these projects over three of four years are likely to be considerable.

Partial validation of the method using stage-discharge data from a wider set of sites would probably be sufficient in the short term combined with the long term aim of collecting sufficient information to carry out full validation over a number of sites.

5.2.3 Suitable sites

Since this document is concerned with meandering compound channels any field data should also relate to meandering channels. The type of reach to be considered for field data collection should conform to the following guidelines.

1) Sites should have significant meanders or bends. The meander zone should form a significant part of the floodplain and the meanders should be distinct and well developed.

2) Sites should preferably have a fairly regular meander pattern. The meander wave length and amplitude should not vary significantly within each site.

3) Land usage, (vegetation etc) on each floodplain should be reasonably uniform.

4) The presence of buildings or other obstructions on the floodplain should not disqualify a site provided that the obstruction has a minor effect of the flow pattern through the site.

In order to carry out any hydraulic calculations relating to a chosen site certain information is required detailing both the plan and cross section geometries.

5) Enough survey data should be available from maps and channel cross sections to estimate both the main channel and floodplain longitudinal slopes. Where the local bed slopes at the site differ from the overall reach slopes both should be given.

5.2.4 Hydraulic data

In order to provide enough validation data for either a partial or a full validation then the following hydraulic data should be measured.

Water surface slopes. The important hydraulic slope which controls flow in open channels is the water surface slope. In uniform flow this slope will be equal to the valley or floodplain slope. Water surface slopes should be measured over the reaches of interest. It may be possible to do this relatively easily and cheaply using maximum water level recorders set at intervals along the reach.

Pairs of measured stage and corresponding discharge. These should be provided at both inbank and out of bank stages. It may be possible to identify suitable sites which are close to existing inbank gauging stations. Maximum water level recorders would provide stage values with discharges being obtained from the nearby gauging sites. This would probably be the most efficient method of collecting stage discharge data in meandering overbank reaches. In suitable reaches not close to existing gauging stations special arrangements would be required to measure discharge.

Velocity profiles. These may be either just in the main channel regions or across the whole channel and floodplain. This would require a cableway to be set up at selected sites in the reach.

To provide information for a partial validation items 1 and 2 above should be measured at as many sites as possible. If a more complete validation is required then item 3 above should also be measured at each site. In the immediate future it is recommended that suitable sites should be identified and, if possible, a partial validation carried out. In the longer term detailed measurements should be sought to add to the data set provided by the Blackwater project.

5.3 Computational Modelling

5.3.1 Turbulence modelling

Three dimensional turbulence modelling is the most promising approach for developing methods to describe the complex mechanics of flow in meandering compound channels. It is not envisaged that turbulence models will be used directly for routine design applications, but rather that they could be used in parametric studies to generate general results for incorporation in standard design methods. By following such an approach the results of experimental work (such as the SERC FCF Phase A and B studies) and field studies could be extended and generalized. The procedure would be to calibrate the model on the existing laboratory data and then to use the computational model rather than the laboratory to generate information about a wider range of conditions. Turbulence modelling should be used to complement laboratory studies rather than replace them.

5.3.2 One and two dimensional modelling

Some implications for 1-D river modelling of the method have been identified in chapter 9. Other important considerations will become obvious in the future. It is likely that several possible procedures exist for incorporating the method into existing 1-D river models. Some research should be carried out to identify the possibilities and implement them in a simple backwater model. The resulting models should be evaluated against each other, and against laboratory and field data.

In design applications use of a 3-D flow and turbulence model is unlikely to be practical for the foreseeable future. However useful information may be obtained from a two dimensional, depth integrated model. This type of approach has proved to be useful in the simpler straight channel case, (Wark et al, 1990). Development of suitable 2-D models should be encouraged.

5.4 Stage-Discharge Prediction For Inbank Flows

The current project has put a low priority on inbank flows. It is clear, section 2.2, that the effect of meandering on inbank channel conveyance is considerable, and the importance of main channel capacity in a two-stage channel design is obvious.

The SCS method of adjusting the friction factor to account for meander effects has been shown to be reasonable. It has no theoretical basis, however, and suffers from the main limitation of relating bend energy losses to only one parameter. In order to circumvent these limitations it is recommended that Chang's (1984) approach be further developed to provide simple guidelines for estimating losses that account for a wide range of all the relevant parameters, see section 2.2. The guidelines should allow losses to be evaluated for individual bends as well as for a meander train. The effect of variation of cross-section along the channel should also be investigated, but this would require a more complete description of flow in bends.

6. CONCLUSIONS AND RECOMMENDATIONS

- Existing methods for estimating conveyance in meandering compound channels were applied to the Phase B data and gave errors in the region of 20% to 30%, which are unacceptably high. The need for a new method has been clearly identified for both inbank and overbank flows.

- Analyzing the SERC FCF Phase B data, and other available data sources, a new method has been developed for both inbank and overbank flow cases and these were found to give a marked improvement in the accuracy of predictions, with an average error of under 5%.

- It is recommended that the method should be used for compound channels with sinuosities greater than 1.02. For sinuosities less than or equal to 1.02 it is recommended that a suitable straight channel method should be used with an appropriate correction for sinuosity.

- For convenience Part 2 of this report gives a summary of the method and guidelines for its use and these are presented as a hand calculation procedures which are suitable for application by NRA engineers. Nevertheless, it is strongly recommended that the document is read in its entirety by any potential user.

- In any application of the method to natural rivers the user will be required to make choices or decisions on the basis of professional experience and judgement. In such cases it is recommended that the user should carry out tests to gauge the sensitivity of the solution to these choices. For example bed friction is the most important source of energy loss in open channel flows and uncertainties in estimating friction factors remain potentially the most significant source of error in determining conveyance.

- The new method has been developed based on laboratory data. At present, insufficient data for real rivers means that the generality of the method has not been fully verified.

- With the currently available data, no further significant improvements of the new method could be achieved. New information must be obtained before any substantial further development of the method is undertaken.

- Additional research needs have been identified which would enhance the data used in the development of the method. These include extensions of the laboratory data sets, further laboratory studies of loss mechanisms, and field data collection.

- Computational modelling including 3-D turbulence and 2-D modelling techniques have been identified as promising methods to use in further development of the understanding of the complex mechanics of flow in meandering compound channels.

- Before including the new method in general 1-D river models it is recommended that the method is incorporated in a 'trial' modelling package so that a full assessment and evaluation of its performance can be made.

FIGURES FOR PART 1

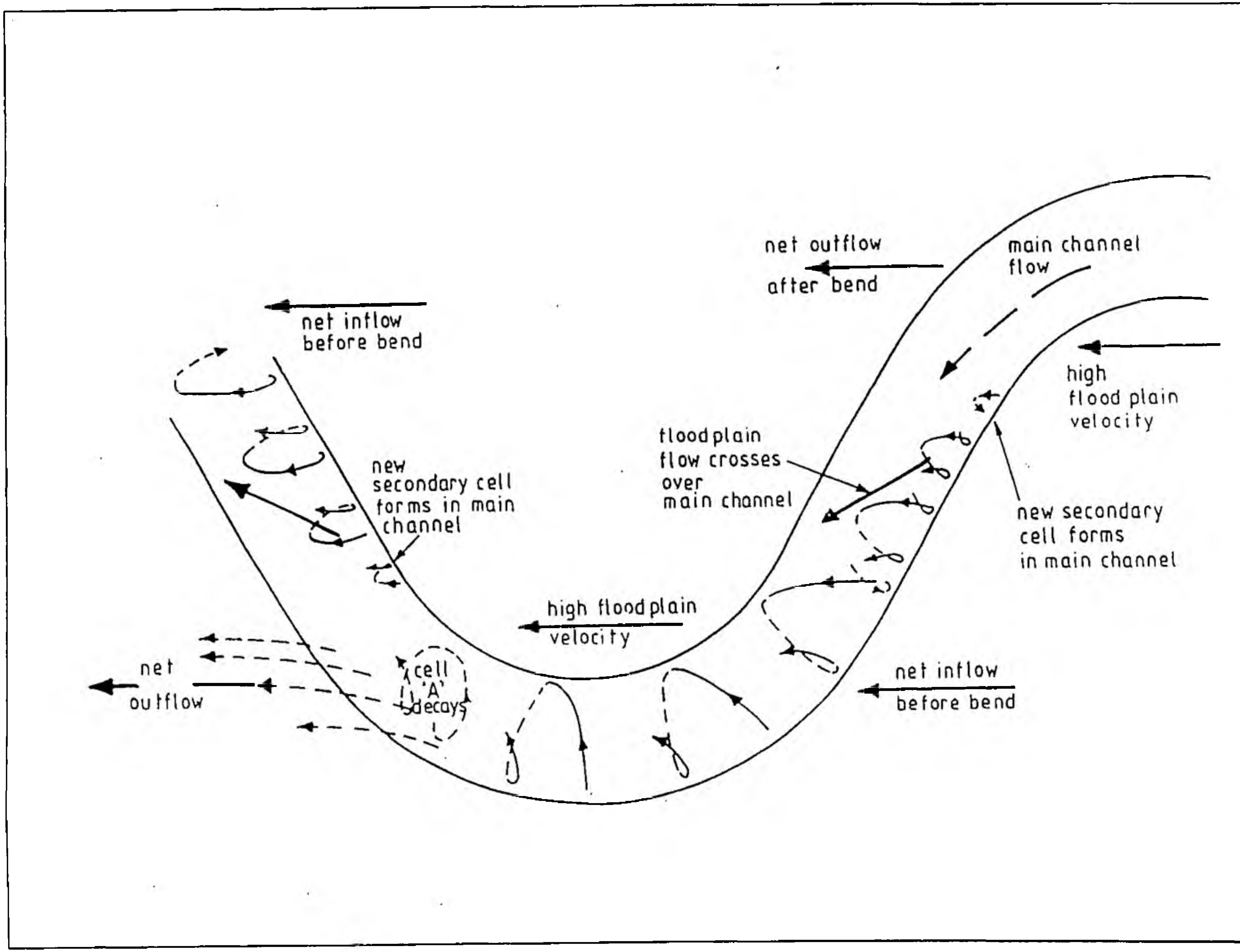


Figure 1.1 Flow processes in a meandering compound channel (after Ervine and Jasem)

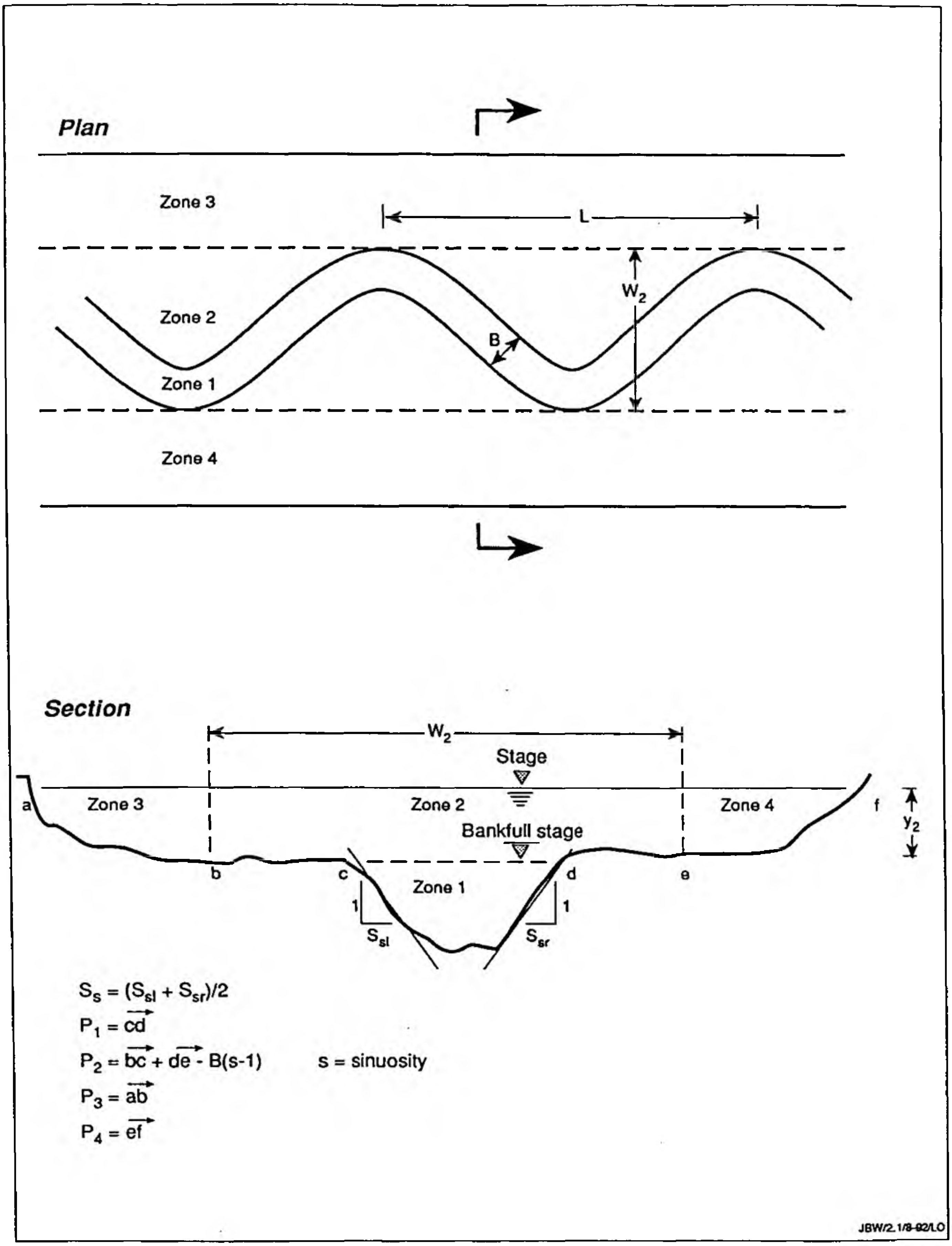
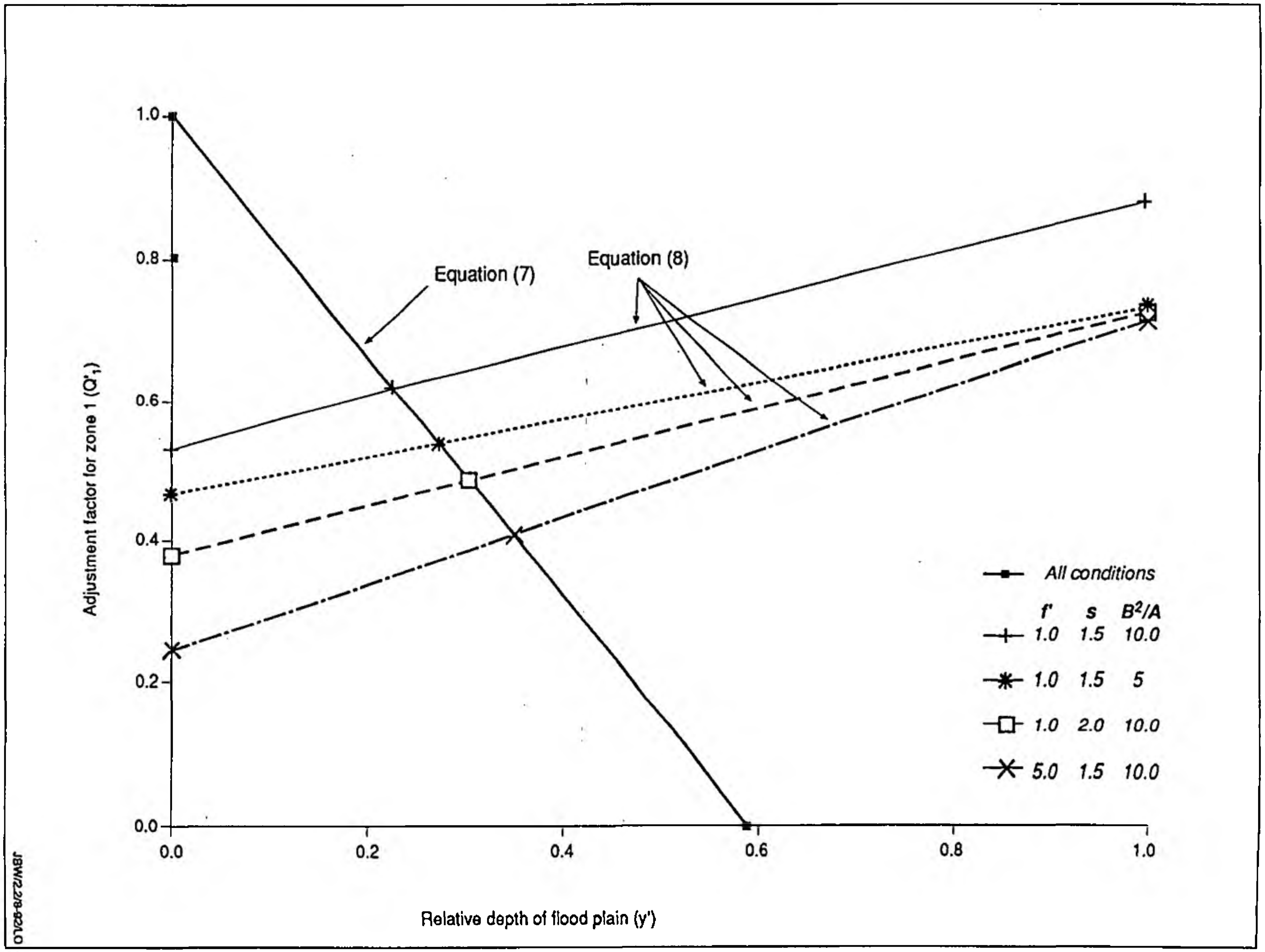


Figure 2.1 Cross-section subdivision of overbank flows

Figure 2.2 Adjustment factor for Zone 1 discharge



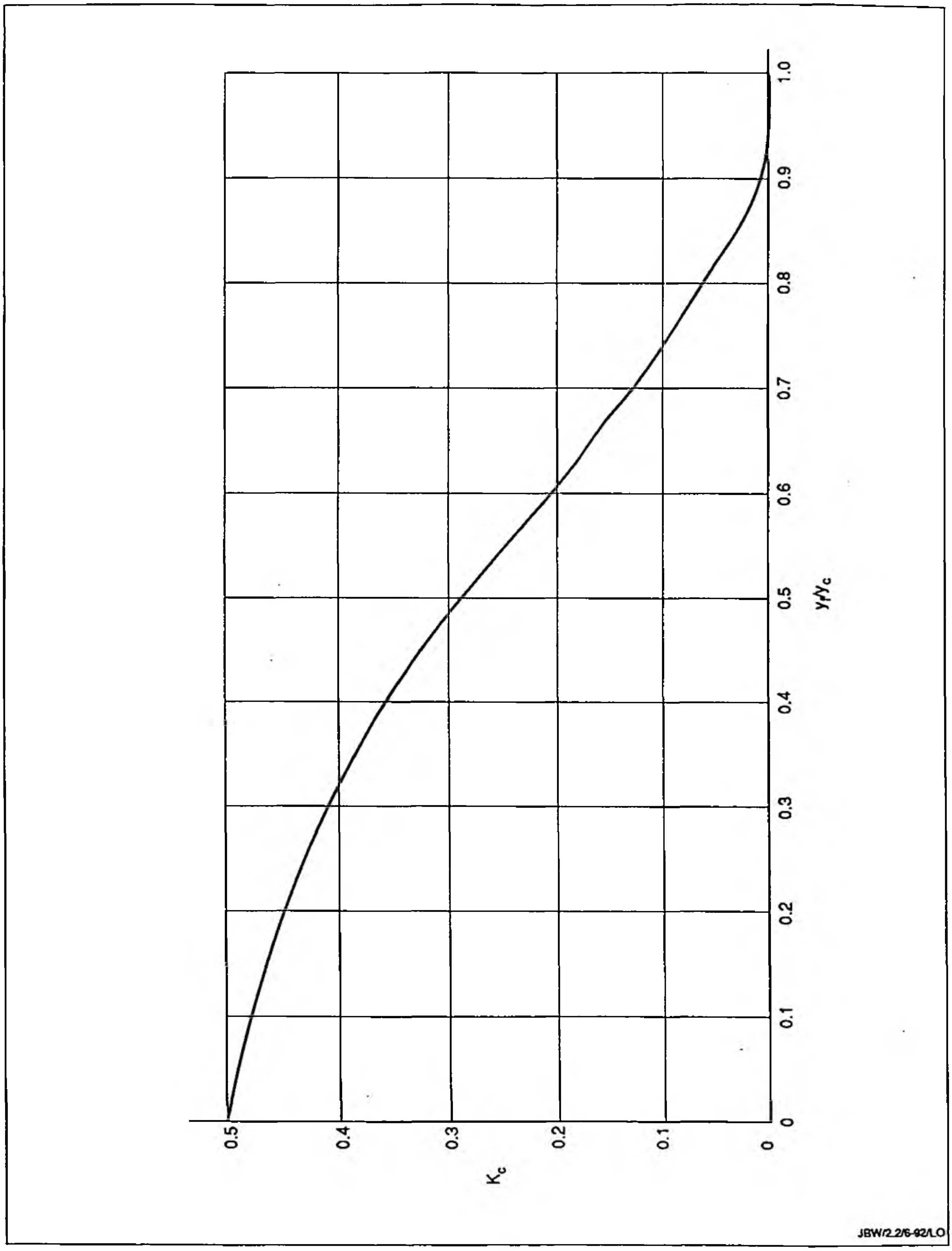


Figure 2.3 Contraction loss coefficient

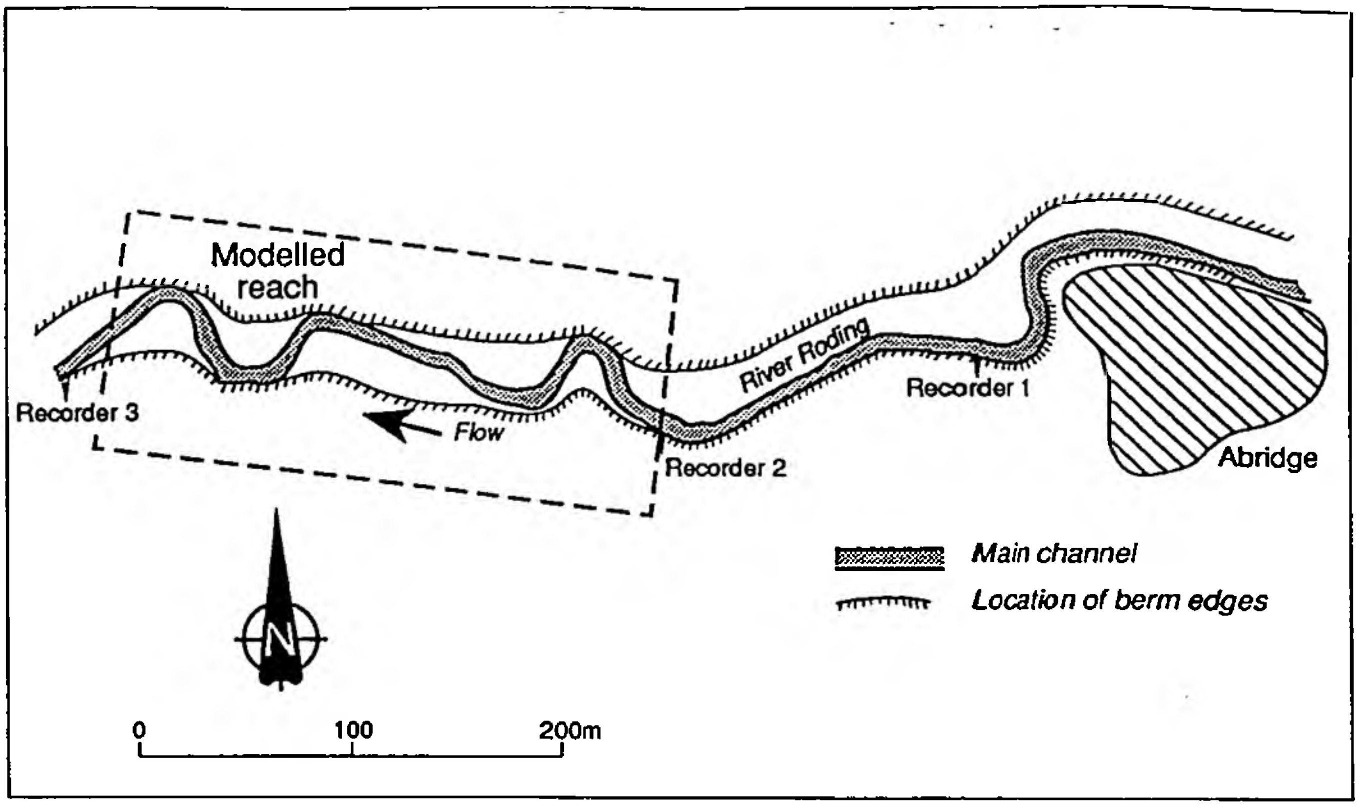


Figure 2.4 Location plan of study area on River Roding (after Sellin et al)

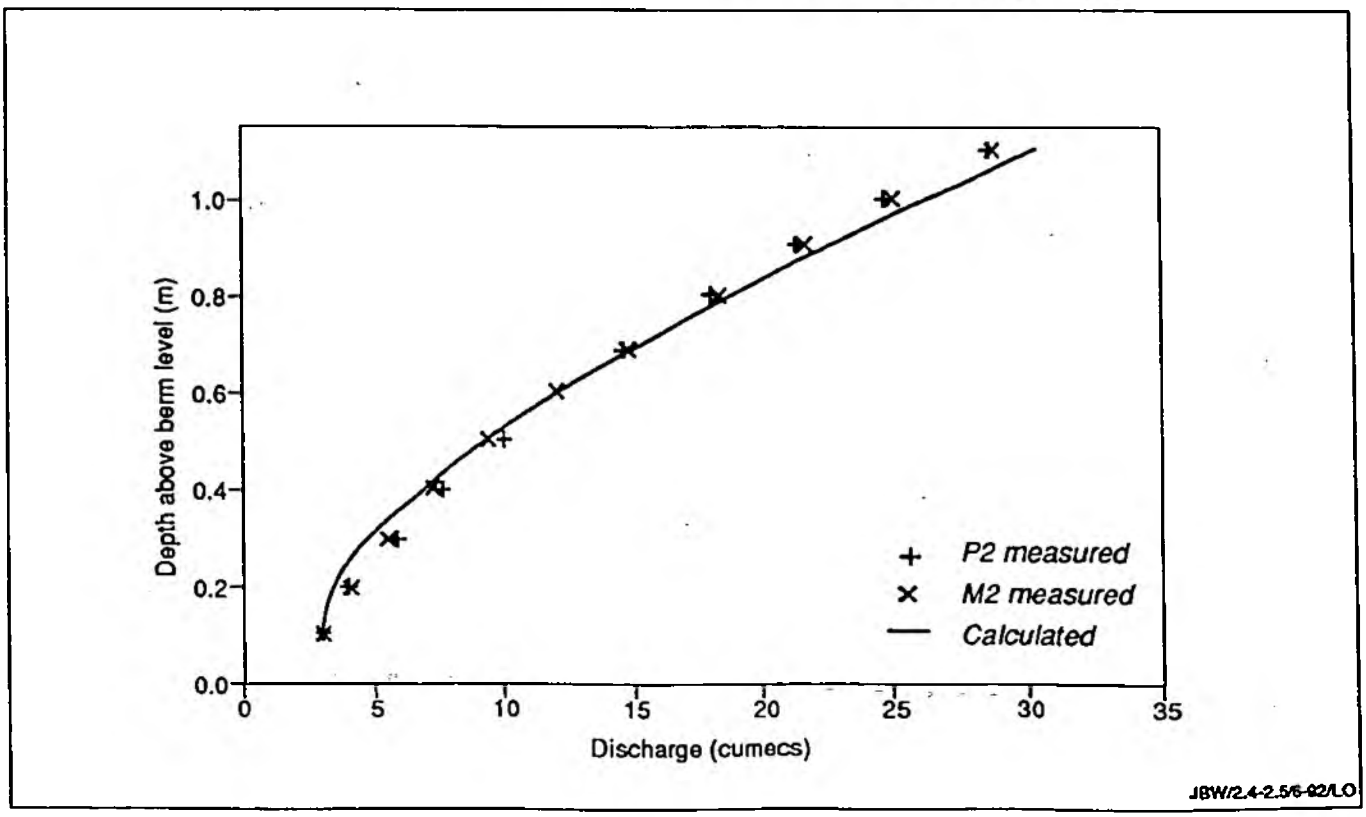


Figure 2.5 Stage discharges for the River Roding

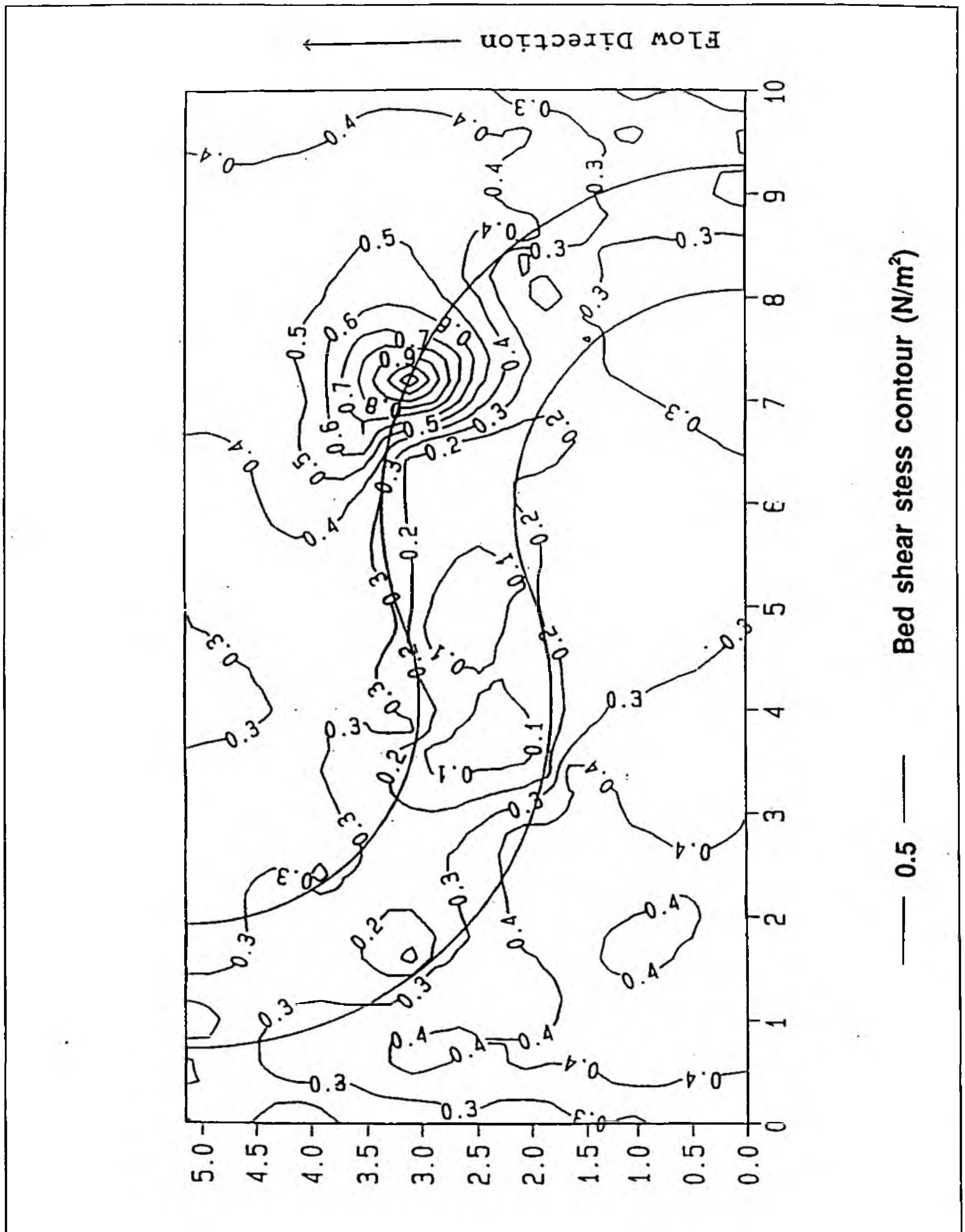


Figure 3.1 Example of boundary shear stress distribution in a meandering compound channel (after Lorena)

PART 2

SUMMARY AND WORKED EXAMPLE

7. SUMMARY OF EQUATIONS

7.1 The Zonal Discharge Equations

For a given stage the discharge is calculated as the sum of the zonal discharges, ie.

$$Q_T = Q_1 + Q_2 + Q_3 + Q_4 \qquad (2)$$

Zone 1 : Main Channel

The correct flow in Zone 1 is given by

$$Q_1 = Q_{bf} \, Q_1' \qquad (9)$$

The adjustment factor (Q_1') is the greater of :

$$Q_1' = 1.0 - 1.69 \, y' \qquad (7)$$

or

$$Q_1' = m \, y' + K \, c$$

with

$$m = 0.0147 \, B^2/A + 0.032 \, f' + 0.169$$

$$c = 0.0132 \, B^2/A - 0.302 \, s + 0.851$$

$$K = 1.14 - 0.136 \, f' \qquad (8)$$

$$y' = y_2 / (A/B) \qquad (3)$$

$$f' = f_2 / f_1 \qquad (4)$$

Zone 2 : Inner Flood Plain

According to this model, the discharge for Zone 2 is given by

$$Q_2 = A_2 \, V_2 \qquad (10)$$

in which

$$V_2 = \left(\frac{2 \, g \, S_o \, L}{(f_2 \, L) / (4 \, R_2) + F_1 \, F_2 \, K_e} \right)^{1/2} \qquad (11)$$

with

$$F_1 = 0.1 \, B^2/A \qquad \text{for } B^2/A < 10$$

$$F_1 = 1.0 \qquad \text{for } B^2/A \geq 10 \qquad (12)$$

$$F_2 = s/1.4 \qquad (13)$$

$$K_e = C_{sl} \, C_{wd} \, (C_{ssc} \, (1 - y_2/(y_2 + h))^2 + C_{ssc} \, K_c) \qquad (14)$$

$$C_{sl} = 2(W_2 - B)/W_2 \qquad (15)$$

$$C_{wd} = 0.02\ (B^2/A) + 0.69 \qquad (16)$$

$$C_{ssc} = 1.0 - S_r/5.7$$
(but C_{ssc} not less than 0.1) (17)

$$C_{ssc} = 1.0 - S_r/2.5$$
(but C_{ssc} not less than 0.1) (18)

Zones 3 and 4 : Outer Flood Plains

Flow in the outer flood plain zones is assumed to be solely controlled by friction. The zonal discharges are calculated using an appropriate friction equation with the division lines separating these zones from Zone 2 excluded from the wetted perimeter.

$$Q_3 = A_3\ V_3$$

$$Q_4 = A_4\ V_4 \qquad (19)$$

where

$$V_3 = \left(\frac{8\ g\ R_3\ S_o}{f_3} \right)^{1/2}$$

$$V_4 = \left(\frac{8\ g\ R_4\ S_o}{f_4} \right)^{1/2} \qquad (20)$$

7.2 <u>Bed Shear Stresses</u>

For the design of scour protection, it is recommended that boundary shear stresses be determined for the main channel bed and banks for the full range of inbank stages, using currently available methods. In addition, the banks should be able to resist stresses of

$$\tau = 1.6\ \gamma\ y_2\ S_o \qquad (19)$$

on the upstream side, and

$$\tau = 5\ \gamma\ y_2\ S_o \qquad (20)$$

on the downstream side.

7.3 Notation

Symbol	Description	Units
A	cross-sectional area	m^2
A	unsubscripted, cross-sectional area of main channel	m^2
B	top width of main channel	m
C_{sl}	length coefficient for expansion and contraction losses, zone 2	m
C_{ssc}	side slope coefficient for contraction loss, zone 2	
C_{sse}	side slope coefficient for expansion loss, zone 2	
C_{wd}	shape coefficient for expansion and contraction losses, zone 2	
c	coefficient in equation for zone 1 adjustment factor	
F_1	factor for non-friction losses in zone 2 associated with main channel geometry	
F_2	factor for additional non-friction losses in zone 2 associated with main channel sinuosity	
f	Darcy-Weisbach friction factor	
f'	ratio of flood plain and main channel Darcy-Weisbach friction factors	
g	gravitational acceleration	m/s^2
h	hydraulic mean depth of main channel, = A/B	m
K	coefficient in equation for zone 1 adjustment factor	
K_e	factor for expansion and contraction losses in zone 2	
K_c	contraction coefficient	
L	meander wavelength	m
m	coefficient in equation for zone 1 adjustment factor	
n	coefficient in Manning's equation	$m^{1/3}/s$
n'	coefficient in Manning's equation, including bend losses	$m^{1/3}/s$
P	wetted perimeter	m
P	unsubscripted, wetted perimeter of main channel at bankfull	m
Q	zonal discharge	m^3/s
Q_{bf}	main channel bankfull discharge	m^3/s
Q_{calc}	calculated discharge	m^3/s
Q_{meas}	measured discharge	m^3/s
Q_T	total discharge	m^3/s
Q_1'	adjustment factor for zone 1 discharge	
R	hydraulic radius	m
R	unsubscripted, hydraulic radius of main channel at bankfull	m
S	main channel gradient	
S_o	flood plain gradient	
S_s	cotangent of main channel side slope (Horizontal / Vertical)	
s	channel sinuosity	
V	mean flow velocity	m/s
V	unsubscripted, mean flow velocity in main channel at bankfull	m/s
W_2	width of zone 2	m
y_2	flow depth on flood plain at main channel bank	m
y'	dimensionless flow depth on flood plain = $y_2/(A/B)$	
ρ	density of water (approximately 1000 kg/m^3)	Kg/m^3
γ	unit weight of water (approximately 9.81×10^3 N/m^3)	N/m^3
τ	boundary shear stress	N/m^2

Subscripts

1-4 zones 1 to 4

8. WORKED EXAMPLE

8.1 Problem Definition

The conveyance of a two-stage river channel is to be determined. The reach under consideration is shown in Figure 8.1 and is represented by the surveyed cross-section at the location indicated, which is presented in Figure 8.2. The slope of the flood plain is estimated as 0.0014.

Manning's n values for the main channel and flood plains are estimated as 0.025 and 0.045 respectively, based on the observed surface roughnesses.

The following are required.

- The capacity of the main channel at bankfull.
- The zonal and total discharges when the water level is 1.2 m above bankfull level.
- Values of boundary shear stress for designing scour protection of the main channel banks when the water surface is 1.2 m above bankfull level.

8.2 Solution

1. Define cross-section zones and calculate the necessary geometric parameters.

The zone subdivisions are shown in Figures 8.3 and 8.4. Because the geometry varies along the reach the positions of the subdivision planes are selected by judgement to represent average conditions over the reach.

From the geometries defined by this subdivision, the following geometric characteristics are calculated for the water surface 1.2 m above bankfull.

Zone 1 : Main Channel

A = 5.07 m^2

P = 6.40 m

B = 6.10 m *from survey*

The main channel sinuosity is found from the plan of the reach. It is defined as the ratio of the length along the channel centre line (between two points) to the straight line distance between the points. Using points x and y on Figure 8.3, this gives a sinuosity of

s = 376 m / 275 m

= 1.37

Note: Since $s > 1.02$ we should use the method for meandering compound channels.

If s had been: $1.0 \leq s \leq 1.02$ then we should use a straight channel method, with appropriate corrections for sinuosity.

The main channel slope is obtained by dividing the flood plain slope by the sinuosity, i.e.

$$S = 0.0014 / 1.37$$

$$= 0.00102$$

The main channel side slopes are measured on the cross-section reproduced in Figure 8.4. The average of the values for the right and left banks will be used in the calculations, i.e.

$$S_s = (1.43 + 1.64) / 2$$

$$= 1.54$$

Note : The final solution is likely to be relatively insensitive to side slope, so great accuracy is unnecessary in estimating the value.

Zone 2 : Inner Flood Plain

$A_2 = 47.77\ m^2$ *from survey*

The wetted perimeter is calculated excluding the division planes, i.e.

P_2 = Wetted surface to left of main channel + Wetted surface to right of main channel - Channel top width (sinuosity - 1.0)

$$P_2 = 22.48 + 17.72 - 6.10 \times (1.37 - 1.00)$$

$$= 37.94\ m$$

$W_2 = 49.40\ m$ *from survey*

Zone 3 : Left Bank Outer Flood Plain

$A_3 = 16.28\ m^2$

$P_3 = 18.90\ m$ *from survey*

Zone 4 : Right Bank Outer Flood Plain

$A_4 = 8.00\ m^2$

$P_4 = 21.00\ m$ *from survey*

2. Calculate the capacity of the main channel at bankfull.

$$Q_{bf} = A\ V$$

$A = 5.07\ m^2$ *from Step 1*

V is calculated using Manning's equation,

$V = 1 / n\ R^{2/3}\ S^{1/2}$

The coefficient n is given as 0.025, based on surface roughness. This must be adjusted to account for meander losses, which can be done using the Linearized SCS Method, given by equation 1, i.e.

$n' = n\ (0.43\ s + 0.57)$

$= 0.025 \times (0.43 \times 1.37 + 0.57)$

$= 0.029$

Note : If the given value of 0.025 had been obtained from a back calculation on measured discharges then this would already account for the influence of the meandering channel on inbank flow resistance and the adjustment above would be unnecessary.

The hydraulic radius is given by

$R = A / P$

$= 5.07 / 6.40$

$= 0.792\ m$

Therefore $V = (1 / 0.029) \times 0.792^{2/3} \times 0.00102^{1/2}$

$= 0.943\ m/s$

Therefore the bankfull discharge is

$Q_{bf} = 5.07 \times 0.943$

$= 4.78\ m^3/s$

3. Calculate the discharge for water level 1.2 m above bankfull

3.1 Calculate Zone 1 discharge

$Q_1 = Q_1'\ Q_{bf}$ *(equation 9)*

$Q_{bf} = 4.78\ m^3/s$ *from Step 2*

The Zone 1 adjustment factor, Q_1', is the greater of the values given by equations 7 and 8

$Q_1' = 1.0 - 1.69\ y'$ *(equation 7)*

$y' = y_2 / (A / B)$

$= 1.20 / (5.07 / 6.10)$

$= 1.44$

$= 1.0 - 1.69 \times 1.44$

$= -1.44$

$Q_1' = m\, y' + K\, c$ *(equation 8)*

$m = 0.0147\, B^2/A + 0.032\, f' + 0.169$

$B^2/A = 6.10^2 / 5.07$

$= 7.34$

$f' = (n_2 / n_1)^2 (R / R_2)^{1/3}$ *(equation 6)*

$R = 0.792$ m *from Step 2*

$R_2 = A_2 / P_2$

$= 47.77 / 37.94$

$= 1.259$ m

$= (0.045 / 0.025)^2 \times (0.792 / 1.259)^{1/3}$

$= 2.78$

Therefore $m = 0.0147 \times 7.34 + 0.032 \times 2.78 + 0.169$

$= 0.366$

$K = 1.14 - 0.136\, f'$

$= 1.14 - 0.136 \times 2.78$

$= 0.762$

$c = 0.0132\, B^2/A - 0.302\, s + 0.851$

$= 0.0132 \times 7.34 - 0.302 \times 1.36 + 0.851$

$= 0.534$

Therefore $Q_1' = 0.366 \times 1.44 + 0.762 \times 0.534$

$= 0.934$

which is greater than the value given by equation 7

Therefore the discharge in Zone 1 is

$Q_1 = 0.934 \times 4.78$

$= 4.46\ m^3/s$

In engineering applications the level of accuracy will be less than implied by quoting the answer to this precision hence Q_1 should be given as:

$Q_1 = 4.5\ m^3/s$

3.2 Calculate Zone 2 discharge

$Q_2 = A_2 V_2$ *(equation 10)*

$A_2 = 47.77\ m^2$ *from Step 1*

$$V_2 = \left(\frac{2\ g\ S_o\ L}{(f_2\ L) / (4\ R_2) + F_1\ F_2\ K_c} \right)^{1/2}$$ *(equation 11)*

The average meander wavelength is estimated from Figure 8.3 by dividing the flood plain length by the number of wavelengths over the reach, i.e.

$L = 275 / 3$

$= 91.7\ m$

$R_2 = 1.259\ m$ *from Step 3.1*

$f_2 = (8\ g\ n_2^2) / R_2^{1/3}$ *(equation 5)*

$= (8 \times 9.81 \times 0.045^2) / 1.259^{1/3}$

$= 0.147$

$F_1 = 0.1\ B^2/A$ *(equation 12)*

$B^2/A = 7.34$ *from Step 3.1*

$= 0.1 \times 7.34$

$= 0.734$

$F_2 = s / 1.4$ *(equation 13)*

$= 1.37 / 1.4$

$= 0.979$

$K_e = C_{sl}\ C_{wd}\ (C_{ssc}(1 - y_2/(y_2 + h))^2 + C_{ssc}\ K_c)$ *(equation 14)*

$C_{sl} = 2\ (W_2 - B)/W_2$ *(equation 15)*

$= 2 \times (49.4 - 6.10)/49.4$

$= 1.753$

$C_{wd} = 0.02\ B^2/A + 0.69$ *(equation 16)*

$B^2/A = 7.34$ *from Step 3.1*

$= 0.02 \times 7.34 + 0.69$

$= 0.837$

$C_{ssc} = 1.0 - S_s / 5.7$ *(equation 17)*

$= 1.0 - 1.54 / 5.7$

$= 0.730$

$C_{ssc} = 1.0 - S_s / 2.5$ *(equation 18)*

$= 1.0 - 1.54 / 2.5$

$= 0.384$

$h = A / B$

$= 5.07 / 6.10$

$= 0.831$ m

$y_2/(y_2 + h) = 1.2 / (1.2 + 0.831)$

$= 0.591$

$K_c = 0.217$ *from Figure 23*

Therefore $K_e = 1.753 \times 0.837 \times (0.730 \times (1 - 0.591)^2 + 0.384 \times 0.217)$

$= 0.301$

Therefore

$$V_2 = \left(\frac{(2 \times 9.81 \times 0.0014 \times 91.7)}{((0.147 \times 91.7) / (4 \times 1.259) + 0.734 \times 0.979 \times 0.301)} \right)^{1/2}$$

$= 0.933$ m/s

Therefore the discharge in Zone 2 is

$Q_2 = 47.77 \times 0.933$

$= 44.57$ m³/s

$= 44.6$ m³/s

3.3 Calculate Zone 3 discharge

$Q_3 = A_3 V_3$

$A_3 = 16.28$ m² *from Step 1*

V_3 is calculated using Manning's equation,

$V_3 = (1 / n_3) R_3^{2/3} S_o^{1/2}$

$n_3 = 0.045$

$R_3 = A_3 / P_3$

$= 16.28 / 18.90$

$= 0.861$ m

Therefore $V_3 = (1 / 0.045) \times 0.861^{2/3} \times 0.0014^{1/2}$

$= 0.753$ m/s

Therefore the discharge in Zone 3 is

$Q_3 = 16.28 \times 0.753$

$= 12.26$ m³/s

$= 12.3$ m³/s

3.4 Calculate Zone 4 discharge

$Q_4 = A_4 V_4$

$A_4 = 8.00\ m^2$ *from Step 1*

V_4 is calculated using Manning's equation,

$V_4 = (1 / n_4)\ R_4^{2/3}\ S_o^{1/2}$

$n_4 = 0.045$

$R_4 = A_4 / P_4$

$= 8.00 / 21.00$

$= 0.381\ m$

Therefore $V_4 = (1 / 0.045) \times 0.381^{2/3} \times 0.0014^{1/2}$

$= 0.438\ m/s$

Therefore the discharge in Zone 4 is

$Q_4 = 8.00 \times 0.438$

$= 3.5\ m^3/s$

3.5 Calculate total discharge

$Q_T = Q_1 + Q_2 + Q_3 + Q_4$ *Equation 2*

$= 4.5 + 44.6 + 12.3 + 3.5$

$= 64.9\ m^3/s$

Hence the total discharge in the channel is 65 m^3/s

4. **Calculate maximum bank shear stresses**

The distribution of boundary shear should be determined by simulation (or other appropriate methods) for all stages below bankfull to establish values for the design of bank protection. In addition, local concentrations during overbank flow events must be allowed for.

Upstream banks must be able to resist

$$\tau = 1.6\,\gamma\,y_2\,S_o \qquad \textit{Equation 19}$$

$$= 1.6 \times 9.81 \times 10^3 \times 1.20 \times 0.0014$$

$$= 26.4\ \text{N/m}^2$$

Downstream banks must be able to resist

$$\tau = 5\,\gamma\,y_2\,S_o \qquad \textit{Equation 20}$$

$$= 5 \times 9.81 \times 10^3 \times 1.20 \times 0.0014$$

$$= 82.4\ \text{N/m}^2$$

For engineering purposes these values should be rounded up to say 30 N/m^2 and 85 N/m^2. Because of the uncertainty of the locations of the shear stress concentrations, protection should extend over the regions shown on Figure 8.5.

8.3 General Comments

1) The above example involved the estimation of some geometric parameters (L and S_v). The final solution is expected to be relatively insensitive to small variations in these parameters and great accuracy in their determination is not necessary.

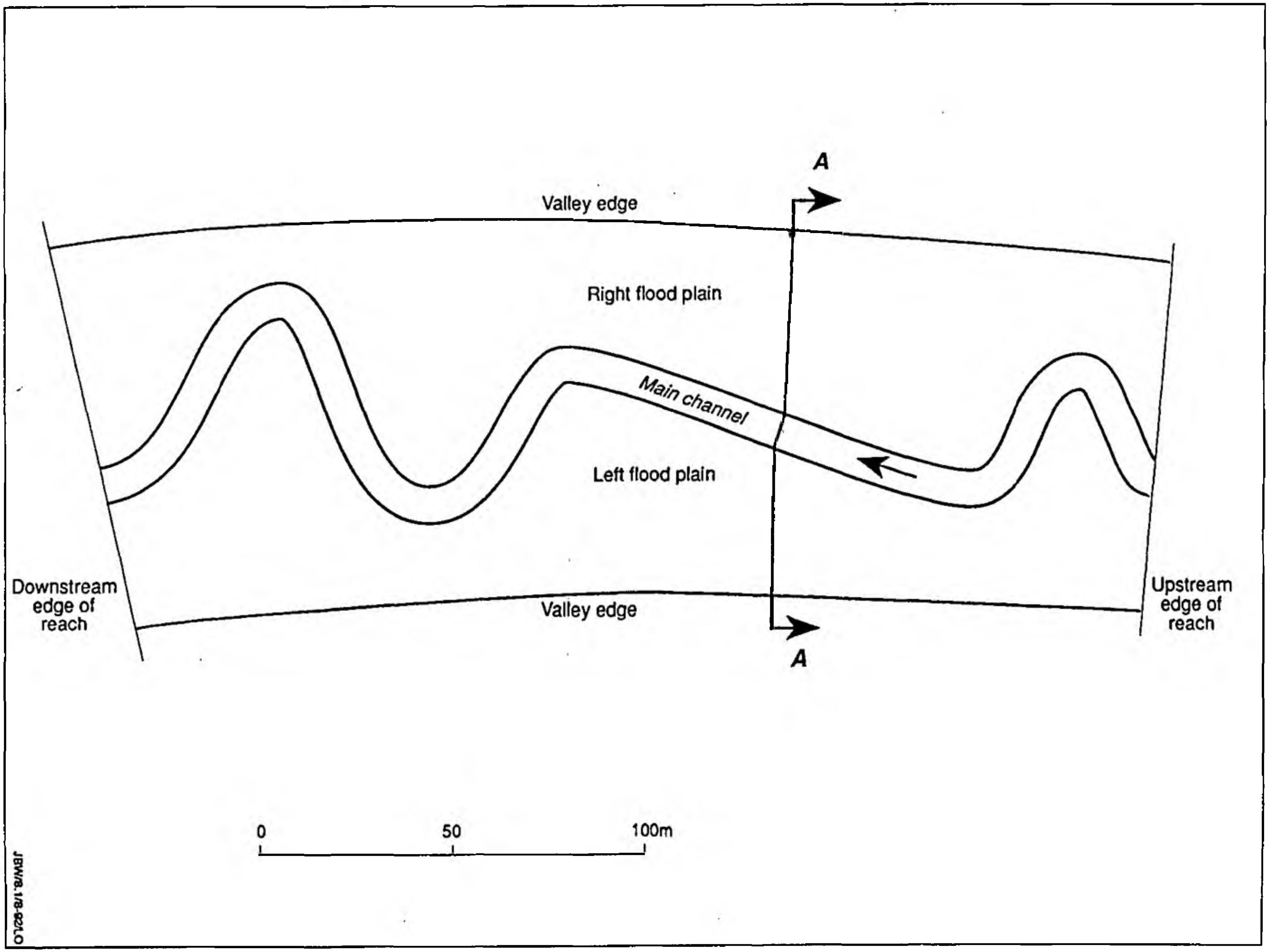
2) For this example the bed roughness (Manning's n) values were given. In practice the engineer will have to estimate these values. Users should be aware that the estimation of bed roughness is not exact and represents a significant potential source of error when carrying out any hydraulic calculations.

3) The method was developed using laboratory data. These laboratory channels were designed to have well defined meandering geometries, which were well suited to the method. Natural or man-made channels in the field are unlikely to match simplified laboratory channels in all respects. This means that the engineer will have to apply his own judgement in determining some of the geometric parameters such as: side slopes, width of Zone 2, bankfull stage etc. The guideline given in section 4 are intended to assist the user in these sorts of decisions.

4) Although the calculations above have been quoted to two or three decimal places the user should be aware that the true level of accuracy of the calculations is much less and the final solution should be rounded off.

FIGURES FOR PART 2

Figure 8.1 Plan of problem reach



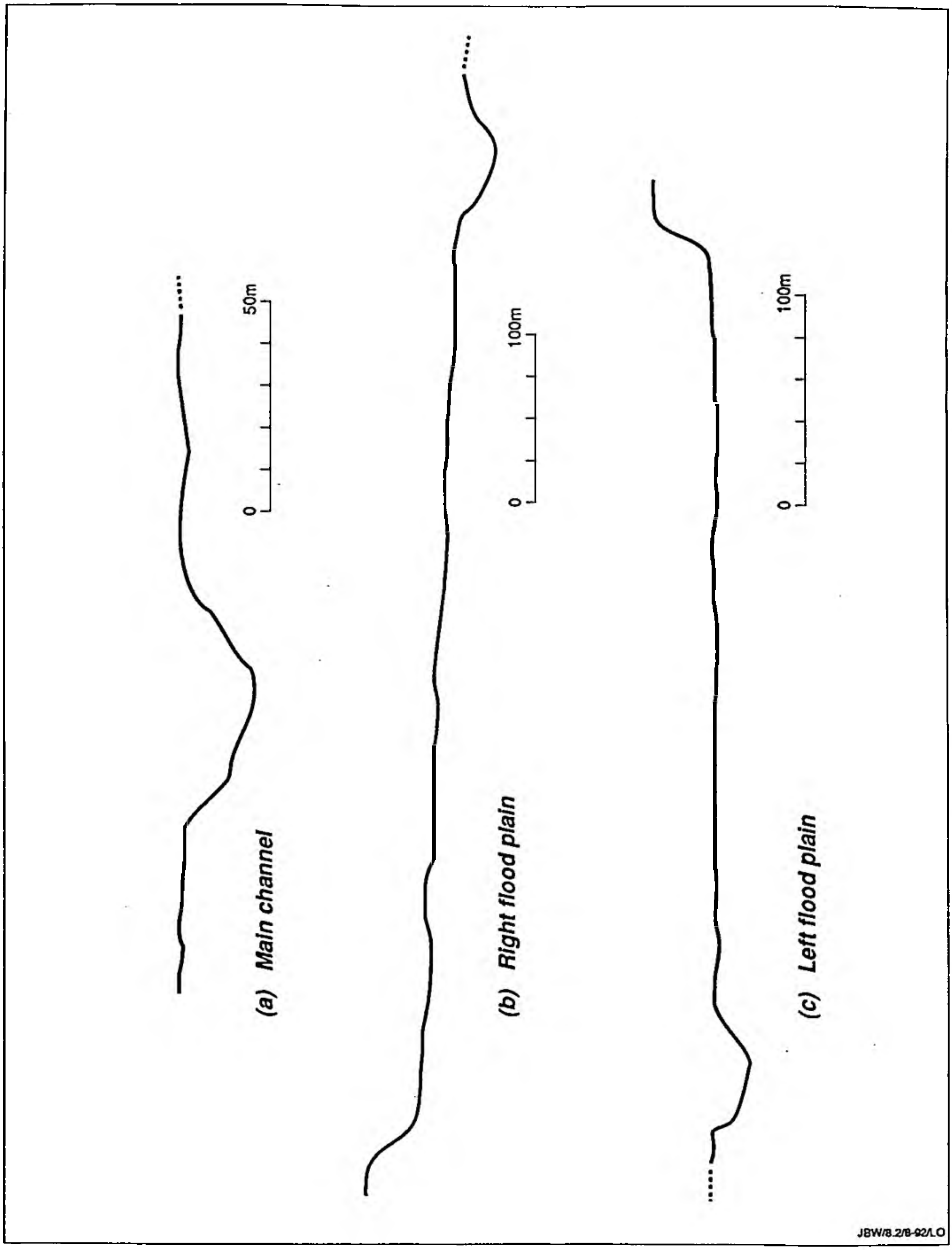


Figure 8.2 Cross-section (A-A) through problem reach (looking upstream)

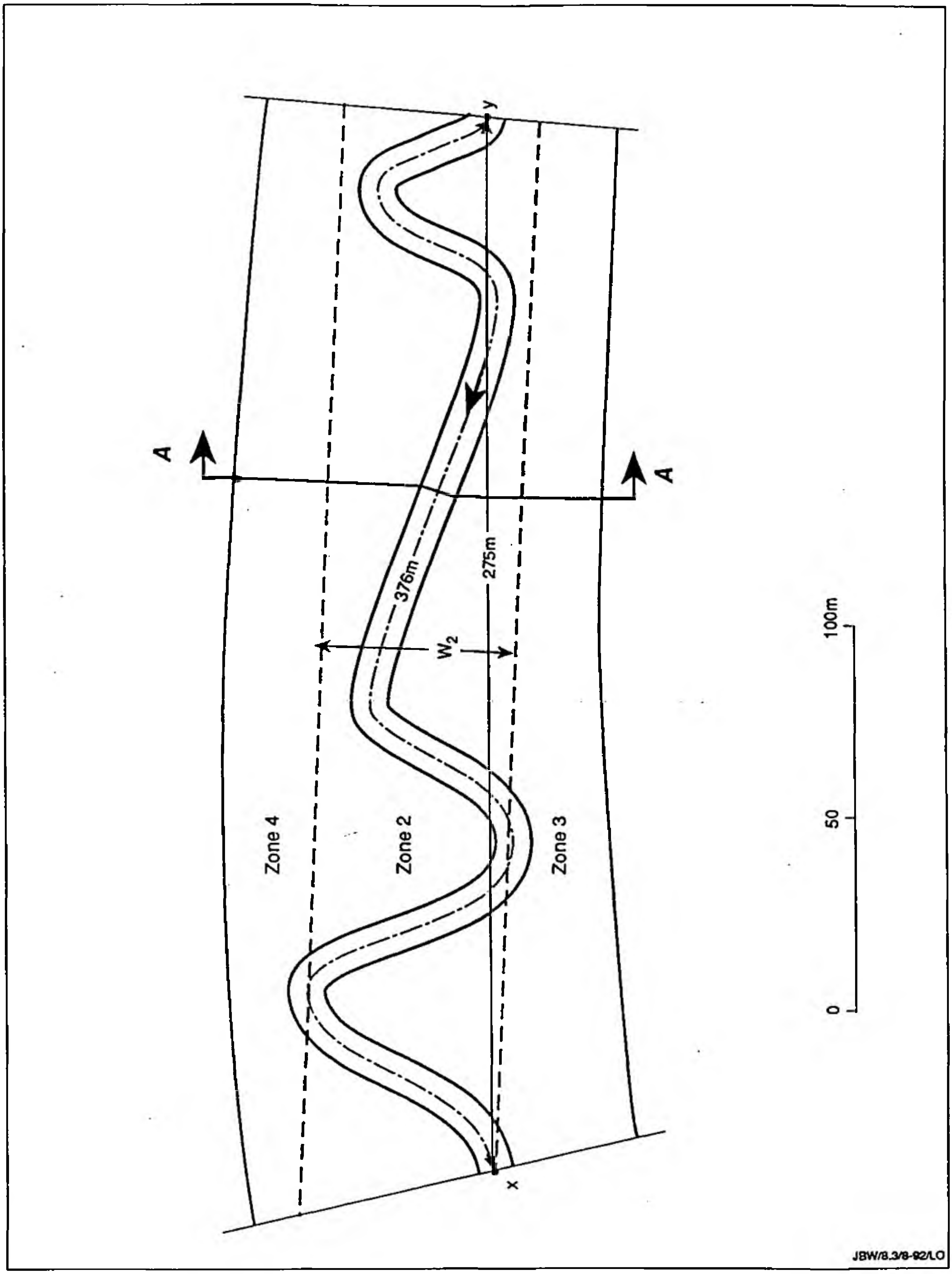


Figure 8.3 Plan of problem reach with zones shown

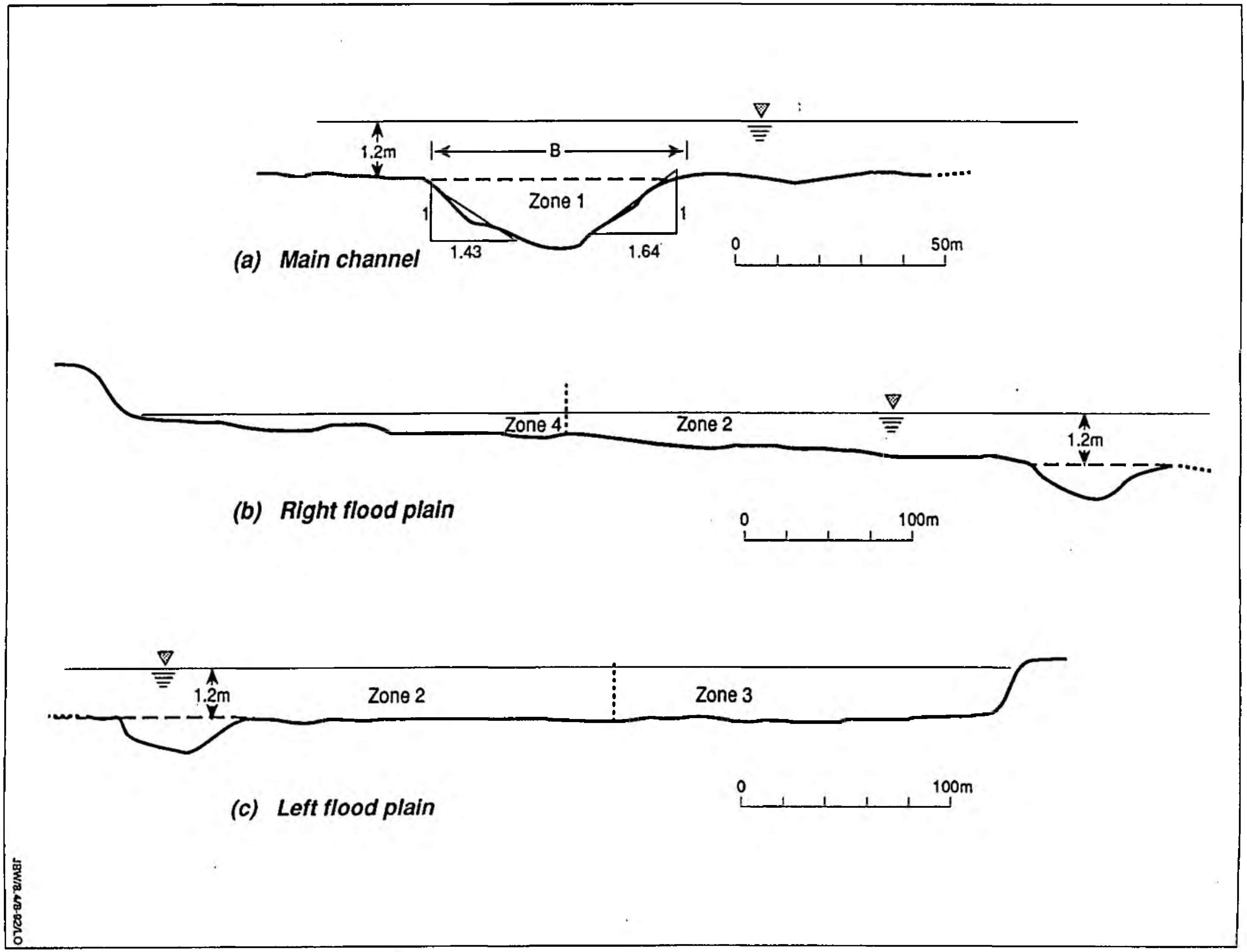


Figure 8.4 Cross-section through problem reach (looking upstream)

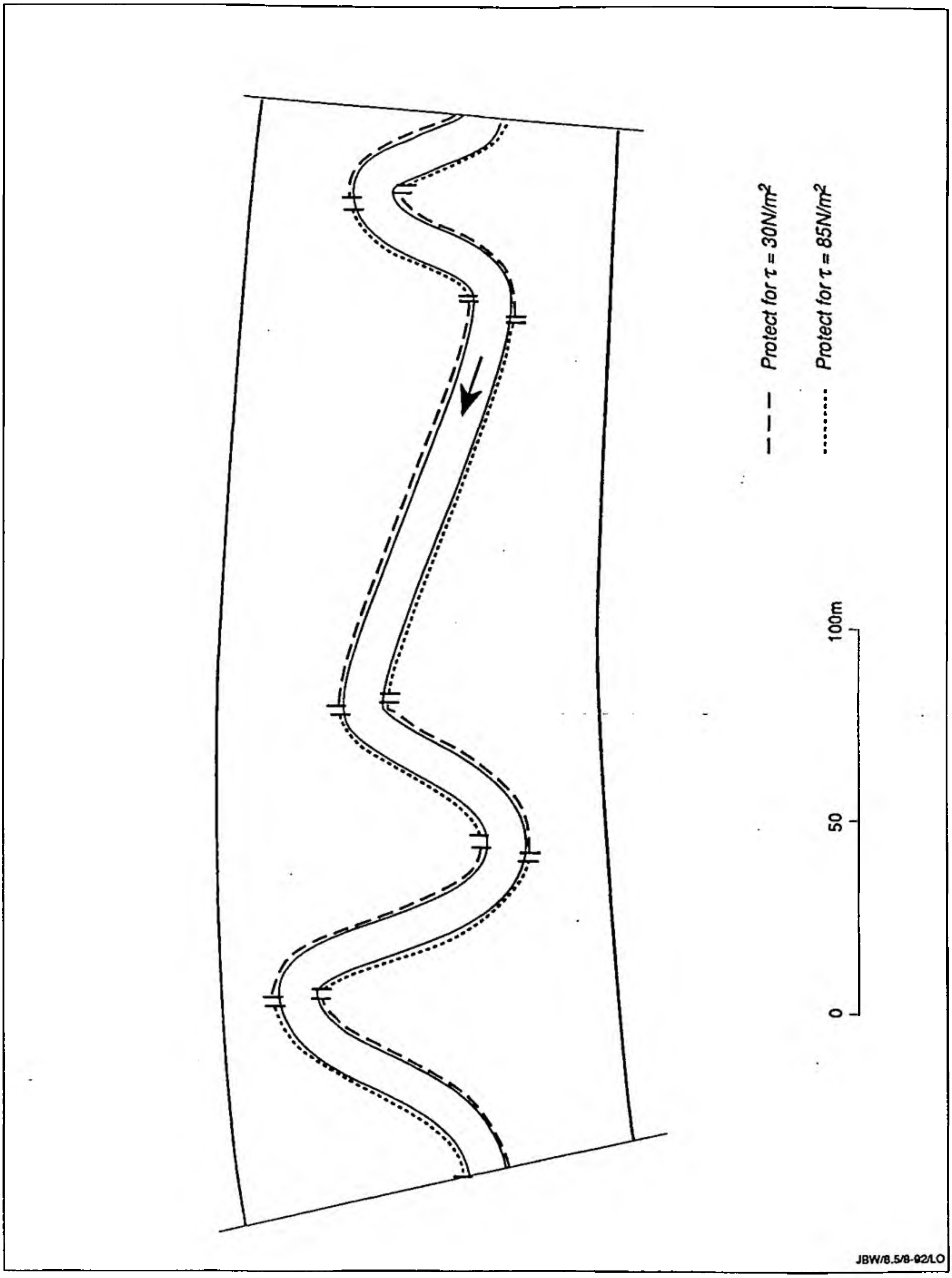


Figure 8.5 Bank scour protection

PART 3

IMPLICATIONS FOR 1 - D MODELLING AND SOFTWARE SPECIFICATION

9. IMPLICATIONS FOR 1-D RIVER MODELLING

9.1 1-D River Models In Use Within The NRA

Within the NRA a number of standard river modelling packages are used for undertaking both steady and unsteady modelling of rivers. The more widespread packages in use have been identified as:

	Package	Originator
•	FLUCOMP	(HR Wallingford)
•	SALMON-F	(HR Wallingford)
•	ONDA	(Halcrow)
•	HYDRO	(Mott MacDonald)
•	MIKE11	(DHI)
•	HEC2	(US Army Corps of Engineers)
•	FLOODTIDE	(Babtie-Dobbie)
•	Backwater	(NRA - Thames)

Each of the modelling software packages above have different originators and while they vary in detail, they do have a common purpose in that they are intended to approximate the St Venant equations of 1-D flow. They all use the computational technique of finite differences to solve the St Venant equations and so display some basic similarities to each other.

9.2 Existing Methods Used to Calculate Conveyance

All of the packages above require channel cross-sections to be supplied at locations along the river. These cross-sections and other data describing the bed roughness of the channel are then used to calculate the conveyance of each cross-section within the model. Conveyance is a convenient measure of a rivers' capacity to pass discharge. The various 1-D models above all use slightly different methods of calculating conveyance. Typically the methods are based on variants of the divided channel or sum of segment methods. In summary, the following approach to conveyance calculations used in the some of the models are as follows :

FLUCOMP	-	sum of segments method with option for variable roughness in segments, plus a toggle to the divided channel method if required
SALMON-F	-	sum of segments method with option for variable roughness in segments
ONDA	-	large sum of segments/divided channel (or 'panels') method
HYDRO	-	horizontal/vertical subdivision of the section, treated as a single unit
MIKE11	-	uses a modified hydraulic radius based on Engelund's method and allows variable roughness with depth
HEC2	-	sum of segments method with option for variable roughness in segments

9.3 Inclusion of the New Method in 1-D Models

The new method for calculating stage-discharges in meandering compound channels has a number of implications regarding its use in 1-D river models. Primarily these are changes in the data specification for the cross-sectional data (ie additional data items) and changes to the conveyance calculation procedures.

Data requirements

The data requirements for the new method are slightly greater than those that would currently be specified in existing packages. Modifications to the cross-sectional data inputs would be required to account for additional items such as :

- sinuosity of the channel
- meander wavelength
- main channel side slope
- pointers to indicate the limits of the inner flood plain meander belt

Where possible reach average values, based on sub-reaches of the model, should be used to specify these additional data items. The sub-reaches are likely to cover a number of cross-section locations in the model and should be selected such that the geometric parameters (main channel side slope, sinuosity and width of meander belt) remain approximately constant throughout the sub-reach. These data items are readily available from a combination of cross-section and plan surveys of the river reach and would not require any additional resources when undertaking a model study.

Conveyance calculations

In general, 1-D models pre-calculate conveyance values at a range of depths and store them in tabular form prior to the backwater or time stepping calculations. In principle, therefore, the major changes to be incorporated into the models are for the existing conveyance calculations to be replaced by the new method for meandering compound channels.

In unsteady flood modelling, storage on the flood plains can play an important role in the attenuation of flood peaks. In a highly meandering river specifying the flood plain length equivalent to the river length between adjacent cross-section locations may have a tendency to over-estimate the storage area available on the flood plains. This may then lead to errors in the attenuation of a flood wave. It is important therefore to specify the river length and flood plain lengths separately, as some of the above models do.

9.4 Implications For 1-D River Models

There are a number of other issues to be considered when using a package with the new method of calculating conveyances. The usual procedure when modelling compound channels is to calibrate firstly for the inbank roughness and then proceed to calibrate the overbank roughness. Analysis of the Phase B data has shown that the inbank discharge falls as the water level moves from inbank to overbank conditions. In existing methods this may lead to large errors in the flood plain roughness as the calibration procedure implicitly assumes that the main channel discharge remains constant at overbank stages. This implies that the calculated main channel flows and velocities will be too high at overbank stages and those on the flood plain will be too low. This results in incorrect values for the energy and momentum coefficients, which in turn leads to errors in :

- afflux calculations at structures,
- shear stress and sediment transport properties and
- the effective flood wave speed.

A major factor to be considered, should the new hydraulic method for meandering compound channels be incorporated in existing modelling packages, is that the calibration coefficients obtained from earlier model studies may no longer be applicable in the revised versions of the modelling software. The calibrated roughness coefficients (Manning's n, Colebrook-White k_s or Chezy C) would be effectively compound roughness coefficients which take account of surface and form roughness, vegetation, and resistance losses due to meandering. The latter of these is included explicitly in the new hydraulic method and should therefore not be included in the roughness estimates for the channel or flood plain in any revised model. Considerable effort may therefore be required in re-calibrating existing models if further studies were to be undertaken using a revised modelling package.

9.5 Recommendations

Due to the lack of field data for meandering compound channels it has been impossible to verify fully the new hydraulic method and it is suggested that the method only be included in 1-D modelling packages for development purposes at this point in time. The most appropriate development path to follow would be to include the method in a single 'trial' package so that an assessment and evaluation of the method could be made. For ease of application and interpretation of results, it would be desirable for this to be a steady-state backwater package (or steady-state module of an unsteady modelling package) with a switch to enable the method of conveyance calculation to be selected using a number of alternative calculation procedures including the newly proposed hydraulic method. Tests could then be carried out to find the most appropriate method of specifying the data requirements and to make comparisons with measured field data over river reaches with known or observed stage and discharge information.

10. OUTLINE SOFTWARE SPECIFICATION

10.1 Objectives

To provide the outline specification for a professional software package intended to assist engineers in the analysis of meandering compound channels. The software will predict stage discharge relationships for given meandering geometries and also analyze available data in order to provide a sound basis for the extrapolation of the method to higher stages. This outline will form the basis of the more detailed specification which will be required to adequately define the software for a programmer.

10.2 Background

This specification includes details of:

1) Minimum Hardware
2) Method of use (batch driven, Menu driven, Graphical interface)
3) Identification of appropriate source coding.
4) Data requirements
5) Calculation procedures
6) Format of presentation of results
7) Proposed Menu structure.

The detailed specification presented below addresses each of these issues.

10.3 Detailed Specification

10.3.1 Hardware

The calculations which make up the method presented in section 2 above are comparatively straight-forward and relatively small computers will be sufficient to carry them out. From other software projects involving the NRA it is clear that IBM compatible PCs are almost universal in NRA offices. It is recommended that the software should be designed to operate on IBM compatible PCs. If the package is to be used through a combination of Menus and Graphics then the PC should have the following minimum specification.

Type	IBM PC (or Compatible)
Processor	80286
RAM	640K
VDU	VGA

10.3.2 Style of interface

There are three possible methods of using the type of software considered :

1) In Batch mode. Data files containing all the relevant information are pre-prepared and supplied to the software, which produces an output file.

2) Menu driven. The software supplies the user with lists of options at each stage. The user chooses the appropriate option and proceeds through lists of tasks and options.

3) Through a graphical interface. The software supplies the options to the user in graphical form, rather than in menus. The graphics are used where necessary to make the software easy to use and understand.

It is understood that the software is intended to be used as an interactive design tool. This requirement means that it will probably be most appropriate to design software which is accessed through a combination of menus and graphics, rather than through a full graphical interface. This allows the engineer to change variables quickly and easily when assessing various design options. In this case the option to save and load data from file should also be retained. It may be useful to design the software to operate with a mouse, in this case it should also be possible to use the software from the keyboard alone.

10.3.3 Choice of source code

The most efficient method of developing software involves the use of existing libraries of routines. The actual hydraulic calculations are relatively simple and would not limit the choice of programming language or environment. It is recommended that the software should be written in FORTRAN and that a commercially available library should be used to provide menu handling and graphics facilities.

10.3.4 Data requirements

The information required in carrying out the hydraulic calculations is :

1) Cross-section data for both main channel and flood plains.

This information is required to enable areas and wetted perimeters of the various zones to be calculated. This data will be made up of the following items.

a) Pairs of offsets and levels defining the cross-section
b) Offsets defining the edges of:

Main channel (Zone 1)
Inner floodplain (Zone 2)

c) Bankfull stage
d) Main channel side slopes

2) Information describing the plan geometry of the reach :

a) Meander wave length
b) Main channel sinuosity
c) Floodplain hydraulic gradient. This may be either the longitudinal valley slope or a measured water surface slope.

3) A list of stage values at which discharges are to be calculated.

4) Bed roughness information.

This should include the following:

a) Choice of resistance formula :

Manning (n)
Chezy (C)
Colebrook White (k_s)
Wide channel Colebrook White (k_s)
Darcy friction factor (f)

b) Values of the required resistance parameters for the four Zones. Since these may vary with stage the option to assign separate values for the chosen stages should be included.

If existing stage discharge information is available for the site then it should be used to calibrate the resistance parameters. The required information is pairs of measured stage and discharge.

Guidelines to assist in the choice of resistance parameter may also be included. It is envisaged that these would be based, in the first instance, on the well known guidelines given in Tables 5.5 and 5.6 of Chow.

10.3.5 Calculation procedures

The calculations to be carried out fall into three types :

1) Calculation of areas, wetted perimeters etc from the supplied survey information. These types of calculation are straight-forward and obvious.

2) Analysis of supplied stage discharge data to provide calibrated bed roughness parameters for the main channel. The supplied discharge and calculated areas etc are used to back-calculate appropriate resistance parameters, from the basic definitions.

3) Calculation of the various zonal and total discharges for specified stages. These calculations are defined by Chapters 2 and 8 of this report.

10.3.6 Presentation of results

Detailed calculations at each step should be displayed on the screen for each water level, these calculations should follow the order of the worked example in chapter 8. Wherever necessary relevant guidelines and limitations for the use of the method should be highlighted. The final results of all calculations should be tabulated against stage and for ease of interpretation it may also be appropriate to display some of these results in graphical form. The following parameters should be considered.

Parameter	Tabulated	Graphed
Areas of all zones	yes	no
Total area	yes	no
Hydraulic radii of all zones	yes	no
Calculated discharges for all Zones	yes	yes
Calculated and measured total discharges	yes	yes
Calibrated bed roughness parameters	yes	yes

10.3.7 Proposed menu structure

It is recommended that the software should be used through a combination of a hierarchy of menus and graphics. The menu structure proposed below is a starting point and should form the basis of a more detailed specification.

On accessing the software the user will be presented with one or two pages of details such as program name, sponsor / developer and copyright declaration etc. After these pages a screen showing the options available from the first menu will be displayed. The user will then choose the required option.

MENU LEVEL 1

The available options from this menu should be :

1.1 Data handling / File management
1.2 Data analysis and calculation
1.3 Exit from program

The user must enter the Data handling option before proceeding to the analysis and calculation stage.

MENU LEVEL 2

1.1 Data handling / File management

The options available from choice 1.1 should be :

1.1.1 Delete file
1.1.2 Input all data from file
1.1.3 Save all data in file

1.1.4 Input / Edit cross section and plan geometry data from keyboard
1.1.5 View / Edit / Print cross-section data graphically

> It may be possible to edit the cross-section data while it is displayed graphically on the screen. This could be achieved using a cursor which is directable either with arrow keys or a mouse with a split screen showing the plotted cross-section and data in separate windows.

1.1.6 Input / Edit measured stage discharge data from keyboard
1.1.7 View / Edit stage discharge data graphically
1.1.8 Exit to menu level 1

1.2 Data analysis and calculation

The user should have completed 1.1.2 or 1.1.4 and possibly 1.1.6 before entering this option of menu 1.

The options available from this choice of menu level 1 should be :

1.2.1 Input / Edit stages at which calculations to proceed.
1.2.2 Input / Edit resistance function choice :

> Manning (n)
> Chezy (C)
> Colebrook White (k_s)
> Wide channel Colebrook White (k_s)
> Darcy friction factor (f)

1.2.3 Analyze measured stage discharges to give zone 1 roughness values

> This option should be entered if measured stage discharge values have been supplied (1.1.6) and after the user has chosen the resistance function to use (1.2.2). The user should still be allowed to adjust the derived roughness values manually (1.2.4).

1.2.4 Input / Edit values of resistance factor for all zones
1.2.5 Calculate stage discharges :

> All stages
> Step through calculations for single stage, highlighting relevant guidelines and limitations.

Print detailed calculations for single stage, highlighting relevant guidelines and limitations.

1.2.6 View / Print tabulated geometric and hydraulic information :

Areas
Wetted perimeters
Hydraulic radii
Bed friction values for all zones
Calculated discharges for all zones
Calculated and measured total discharges

1.2.7 View / Print graphs of geometric and hydraulic information.

Bed friction values for all zones
Calculated discharges for all zones
Calculated and measured total discharges

1.2.8 Save all data in file
1.2.9 Exit to menu level 1

1.3 Exit from program

The available choices within this option of level 1 should be:

1.3.1 Return to menu level 1
1.3.2 Really exit from program

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