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Title:
A laboratory and field investigation into the discharge characteristics of an experimental flood alleviation scheme on the River Roding in Essex

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DEPARTMENT OF CIVIL ENGINEERING

A LABORATORY AND FIELD INVESTIGATION INTO THE DISCHARGE CHARACTERISTICS OF AN EXPERIMENTAL FLOOD ALLEVIATION SCHEME ON THE RIVER RODING IN ESSEX

by
D. J. Searle

Thesis Submitted for the degree of Ph.D
in the University of Bristol
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D. J. Searle

Thesis Submitted for the degree of Doctor of Philosophy in the
University of Bristol

September 1986
MEMORANDUM

The accompanying dissertation, entitled "A Laboratory Investigation into the Discharge Characteristics of an Experimental Flood Alleviation Scheme on the River Roding in Essex", is submitted for the degree of Doctor of Philosophy in the Faculty of Engineering at the University of Bristol.

The dissertation is based upon independent work by the author, while funded by Thames Water Authority, between October 1983 and September 1986. The research was carried out in the Department of Civil Engineering and was supervised by Dr R.H.J. Sellin.

The work and ideas recorded are original except where acknowledged in the text or by reference.

This dissertation has not previously been submitted, in part or whole, for a degree or diploma of any other University or examining body.

Signed

D.J. Searle

September 1986
I would like to thank Thames Water Authority for their financial support towards the investigation reported in this thesis and for supplying field data on the River Roding.

I would like to thank my supervisor, Dr. R.H.J. Sellin, for his assistance and advice. My thanks also go to Dr. J. Davis for his willingness to give assistance and continued support throughout the project. Mr. P. Leonard lent a valuable and experienced hand in the technical design and construction of much of the apparatus and my thanks go to him for making my aspirations a reality.
ABSTRACT

An investigation was carried out to determine the stage-discharge characteristics of a meandering compound channel with vegetated floodplains. The fundamental interaction mechanism between a main channel and its floodplain was also investigated.

Field and model studies provided the data for this thesis. A stretch of the River Roding in Essex was monitored for the field study and a scale model of a short reach of the river was reproduced in the laboratory. A Froudian model was constructed with vertical and horizontal scales of 16:1 and 50:1 respectively.

Field data over a two year period were used to match the model to the river. The response of the river to proposed changes was then predicted by varying roughness and shaped parameters within the model. To do this, stage discharge curves were determined for the model and scaled up to prototype conditions. Detailed velocity traverses were carried out across selected sections of the model to determine discharge proportions between floodplain and main channel for different depths of floodplain flow.

A computerised data collection facility was developed to assist the model study.

Vegetation density and distribution on the floodbanks of compound rivers, such as the River Roding investigated here, can have a significant effect on total discharge capacity. Over 40% increase in maximum discharge capacity was realised in the abovementioned scheme between heavily vegetated and cleared floodplains. Sever meanders of the floodplain boundaries produced large form roughness, resulting in flow separation on some bends and a reduction in the effective width of the floodplain. Removal of these, requiring relatively small excavation of the floodbanks, could significantly improve the carrying capacity of the river. The discharge in the main channel was reduced at overbank conditions due to the shear
interaction between floodplain flow and main channel flow. Manning roughness coefficients were calculated for particular vegetative conditions of the river. A proposal was made to incorporate a correction factor into calculations of discharge in compound rivers with meandering main channels. The correction factor would be applied to the discharge calculated for an equivalent compound channel without meander. It depended on the degree of meander, or sinuosity, of the main channel, roughness ratio between main channel and floodplain, and depth of flow.
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9.1 Conclusions

9.1.1 General

9.2 Proposals for future Research

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NOTATION

A - cross-sectional area
Ap - floodplain flow cross-sectional area
Am - main channel cross-sectional area
%ASF - percentage of apparent shear force to total shear force on main channel boundaries
B - half section width in prismatic compound channels with symmetric floodplains or full section width in prismatic compound channels with one floodplain
b - half main channel width for symmetric compound channels or full width in prismatic compound channels with one floodplain
bf - width of wooded floodplain
bfi - width of floodplain
C - Chezy roughness coefficient
d - depth of flow
g - gravitational acceleration
h - main channel depth
H - total depth of water in main channel
k - effective roughness height
[L] - dimension of length
M - scale ratio prototype value/model value
Ma - discharge ratio
Mv - velocity ratio
Ma - depth ratio
Mb - length ratio
Ms - bed slope ratio
[N] - dimension of mass
n - Manning roughness coefficient
P - wetted perimeter
Q - discharge
ΔQ - change in discharge
%ΔQ - percentage change in discharge
Qp - floodplain discharge
Qm - main channel discharge
Q'c - isolated main channel discharge
Q'f - isolated floodplain discharge
R - hydraulic radius
Rf - floodplain hydraulic radius
Rc - main channel hydraulic radius
Re - Reynolds number 4VR/η
Se - friction slope
So - bed slope
s - sinuosity = floodplain bed slope/main channel bed slope
T - equivalent wetted perimeter
[T] - dimension of time
V - mean velocity
Vc - main channel mean velocity
Vfp - floodplain mean velocity
ΔV - (Vc-Vfp)
V* - shear velocity gRSo
V*crit - critical shear velocity
α - B/b dimensionless width ratio
γ - n(fp)/n(mc) roughness ratio floodplain/main channel
\( \frac{(H-h)}{H} \) - dimensionless depth ratio

\( \frac{b}{h} \) - aspect ratio of main channel

\( \frac{n'}{n} \) - bankfull, 'n' calculated by single channel method

\( f \) - correction factor for isolated floodplain discharge

\( f \) - correction factor for isolated main channel discharge

\( \lambda_i \) - ratio of average shear stress across fluid boundary to average channel shear stress

\( \lambda_v \) - for a vertical interface

\( \lambda_d \) - for a diagonal interface

\( \lambda_h \) - for a horizontal interface

\( \tau \) - average bed shear stress \( Q_g R_s \)

\( \tau_a \) - apparent mean shear stress

\( \tau_{av} \) - apparent mean shear stress - vertical interface

\( \tau_{ad} \) - apparent mean shear stress - diagonal interface

\( \tau_{ah} \) - apparent mean shear stress - horizontal interface

\( \tau_o \) - undisturbed floodplain shear stress

\( \tau_f \) - average floodplain boundary shear stress

\( \tau_c \) - average main channel boundary shear stress

\( \theta \) - inclination of division lines from horizontal

\( \nu \) - kinematic viscosity of water

\( \omega \) - unit weight of water

\( \rho \) - density of water
Chapter 1

CHAPTER 1

Introduction

River flooding is a common occurrence in the United Kingdom during the wet winter months and the cost effectiveness of flood prevention measures is beginning to be appreciated. This is especially so in rivers flowing through low lying urban areas where considerable damage to property could occur in a flood situation.

An investigation into the flow characteristics of the River Roding Flood Alleviation Scheme has been funded by Thames Water Authority (TWA), with the assistance of the S.E.R.C.. It is one of two pilot schemes currently in operation in the Thames catchment, designed to alleviate flooding in urban and agricultural areas.

With the introduction of the Water Act 1973 and Land Drainage Act 1976, water authorities have had an increased responsibility to maintain or improve their rivers. Furthermore, they have an obligation to minimise disruption to the environment in discharging their duties. In his paper on the "Conservation Aspects of Two River Improvement Schemes in the River Thames Catchment" (49), Weeks emphasised the responsibilities water authorities have with regard to their rivers. He quotes from section 22 of the Water Act;

"In formulating or considering any proposals... these authorities shall have regard to the desirability of preserving natural beauty, of conserving flora, fauna and geological or physiographical features of special interest... and shall take into account any effect which the proposals would have on any such flora, fauna..."
Chapter 1

Thames Water Authority, therefore, accepts amongst other duties, the management role of maintaining the tributaries of the River Thames. Some of them, unable to contain high flows experienced mainly during the winter months, consequently overtop their banks and flood adjacent land. The River Roding is just such a river and has a long history of flooding. As an indication of the potentially high cost of flood damage, an estimated £1 million worth, at present day prices, was caused after severe flooding in November 1974, according to Wojcik, in his dissertation "An Experimental Scheme on the River Roding" (50).

The long accepted method for solving river flooding has been channelisation. That is, the realignment and reshaping of a river to form a straight channel with a uniform cross-section and an even bed slope. However, as discussed by Wojcik, although channelisation offers a low cost solution and has low land requirements, it has a detrimental effect on the ecology of a river, especially on unspoiled rural rivers. It has been argued by Keller and Brookes (48), that to maintain a balanced morphology, natural features such as meanders, pools and riffles, overhanging banks and riverside vegetation need to be preserved, which is not the case in channelisation.

Therefore, in 1979, Thames Water Authority embarked upon an experimental scheme on the River Roding to investigate a means of reducing the frequency of flooding along a particular stretch of it. This involved the excavation of floodways along a 3 km stretch of the river below the village of Abridge in Essex. The aim of the scheme was to provide a two stage, or compound, channel designed to pass high flows of a specified return period without causing
flooding of low lying fields and village developments adjacent to
the river and minimise the disruption to the environment.

1.1 Experimental Scheme on the River Roding

In the Roding Flood Alleviation Scheme, the lower part of the
natural channel was left, as far as possible, unaltered and extra
flow capacity was obtained by excavating berms above the mean summer
flow on one or both sides of the river to form a wide flood channel
or floodway. The compound channel was to provide protection against
floods of a 1:70 year return period for the village of Abridge,
which was sited at the upstream end of the test section, and a 1:30
year return period for surrounding agricultural land. See figure 1.1
for a plan of the Flood Alleviation Scheme.

To achieve these standards, Wojcik stated that 1200 metres of
channel from Abridge downstream would have to be designed to
withstand a 1:70 year flood and the remaining 2000 metres designed
to a 1:30 year standard.

Wojcik produced the following design discharges:

1:70 year flood = 50 cumecs
1:30 year flood = 40 cumecs

From this, and from other physical factors involved, he calculated
that to contain a 50 cumec discharge, the berm would need to be 30
metres wide and for 40 cumecs, 25 metres wide. In both cases the
maximum depth of flow on the berm was assumed to be 1.35 metres. The
main channel was assumed trapezoidal with 1:1 side slopes, a total
Figure 1.1
Plan of River Roding Flood Alleviation Scheme with Chainages Marked on and Increasing in Downstream Direction
perimeter of 8 metres and average depth of 0.65 metres. Mannings 'n' values of 0.045 and 0.032 for the main channel and floodplain respectively were used.

Excavation works were carried out during 1979 with the reconfigured river ready for the winter flows of 1979/1980.

Late completion of seeding and topsoiling the floodberms resulted in poor grass cover there at the time of the high winter flows. About 80% of the grass and topsoil was washed off the berms and some scouring of the subsoil occurred. The berms were hydraulically reseeded in 1980.

By 1983, however, it had become apparent that the scheme was not operating as designed. Whatever the causes, the vegetation growing on the flood berm had become far too coarse and large to be grazed. The main channel was overbank more often than the expected 70 days per year. So, a densely vegetated and often waterlogged floodplain was becoming a problem in the maintenance of the river as it needed to be cleared every year at not inconsiderable expense to the Water Authority.

It was decided therefore, that a more detailed study of the experimental reach, or at least a part of it, would be beneficial not only in identifying the problems emerging on the River Roding but also in increasing the understanding of compound river reaches with vegetated floodplains.
1.2 Project Aims

A short section has been included here setting out the aims of the research project.

Field Investigation

The stage-discharge characteristics of part of the River Roding Flood Alleviation Scheme would be constructed. Particular attention would be paid to peak flows. These would be gauged at predetermined river cross-sections to determine the distribution of flow velocity across the floodplain and in the main channel.

The effect on total discharge capacity of seasonal vegetation growth on the berms of the river would be assessed.

Model Investigation

It was intended to reproduce in a laboratory model, the known behaviour of the Flood Alleviation Scheme from data recorded in the field studies.

Once the model had been matched to the river, the investigation would proceed by varying conditions within it, simulating changes in the field, and observing their effect on the discharge capacity of the reach.

A final objective was to investigate the more fundamental interaction between a meandering main channel with its adjacent floodplains when in the overbank condition.
Chapter 1

1.3 General Assumptions regarding Uniform Flow

It is relevant at this point to set out a basic assumption that has been made regarding the flow conditions in the river and laboratory model.

It has been assumed that flow in both cases is uniform and steady. Strictly speaking, uniform flow is not possible as river and model sections vary down their length. Model discharges will be steady but river discharges are unlikely to be so. However, river flows, varying at a rate of less than 0.2 cumecs per hour have been taken as steady. To permit an analysis of the river and model flows, these assumptions have had to be made. Steady non-uniform flow is treated as in this thesis as uniform flow.

1.4 Layout of Thesis

In this section, the author has presented a brief description of the contents of the following chapters to assist the reader in establishing the layout of the thesis.

Chapter two introduces, in some detail, past laboratory work on compound open channels of simple geometries. It highlights the lack of work carried out to date on the more natural case of meandering compound channels. Chapters three and four describe the design and construction of the laboratory model. A description of the apparatus and associated computer software which the author developed to collect the model data is included. Chapter five details the field study carried out on the Roding and the methods and problems
Chapter 1

encountered in measuring river discharges and water levels. Field data between 1984 and 1986 are presented and analysed. Stage discharge curves are produced to provide the input for proving the laboratory model which is covered in chapter six. The roughness materials used, problems encountered in modelling the river flows and stage-discharge curves are presented in chapter six. Chapter seven deals with all the different roughness configurations of the model, simulating given field conditions. An analysis of all the data is given in chapter 8 and presents conclusions of the model study and a proposal for calculating discharges in compound rivers with meandering main channels using existing laboratory data to provide the correction factors. Chapter nine summarises the conclusions arrived at in chapter 8 and proposes avenues of future research.
CHAPTER 2

Past Research Into Compound Open Channels

To gain an insight into what laboratory experimentation was needed during the investigation, it was necessary to evaluate earlier related work. Here a survey of relevant past literature is presented and the findings arranged, in most cases, in chronological order.

Formulae to predict open channel resistance have been developed and reworked for nearly 100 years. The results have been the emergence of two widely accepted equations using either a constant roughness coefficient "n" or a variable friction factor $\lambda$ dependent on a variety of parameters.

The first, commonly referred to as the Manning equation states:

$$V = R \frac{S_e^{1/2}}{n}$$

where $V$ = the mean section flow velocity
$R$ = the hydraulic radius $A/P$
$P$ = wetted perimeter of channel
$A$ = cross-section area
$S_e$ = is the friction slope
and $n$ is a roughness value attributed to the bed characteristics.

A more generalised approach used by Chow (5) incorporates a roughness value including major features such as bank waviness and meander of the river, making the total roughness the sum of the individual roughness values.

This method implicitly assumes fully rough flow, i.e. that
the flow is independent of Reynolds number. It requires experience and good judgement in estimating values of 'n' in the field.

The second, the Chezy equation states:

\[ V = C \sqrt{RS_e} \]  \hspace{1cm} (2)

where

\[ C = \sqrt{8g/\lambda} \]  \hspace{1cm} (3)

and \( \lambda \) depends on Reynolds number, hydraulic radius and bed roughness since:

\[ \frac{1}{\sqrt{\lambda}} = -C \log \left[ \frac{k}{aR} + \frac{b}{Re\sqrt{\lambda}} \right] \]  \hspace{1cm} (4)

The latter method is preferred because it is believed that experimental measurements of friction in open channels over a wide range of conditions are better correlated and understood by the use of \( \lambda \).

These formulae were developed for channels of relatively simple section and design engineers, on encountering channels of complex section, traditionally split them up into compartments and calculated the conveyance of each separately. The fluid interfaces between compartments were usually ignored in the determination of the...
wetted perimeter, on the assumption that they would experience no significant shearing forces.

This might be accepted as reasonable when the difference in mean velocities of adjacent compartments was small, but significant interactions occur when the relative submergence of a floodplain to the main channel is small and velocity differences at the interface large.
2.1 Laboratory Evidence of The Kinematic Effect

Since Zheleznyakov discovered the "kinematic effect", various researchers have endeavoured to provide more evidence of the phenomenon and to explain it. Some attempts were made to quantify it but until the latter part of the 1970's, most empirical solutions were unsophisticated and approximate. This section reviews the early investigations into compound channel flow.

Zheleznyakov stated that for depths just above bankfull, the interaction of the channel and the floodplain seriously affected the kinematics of the channel stream. This resulted in decreased channel velocities and discharges which were not sufficiently compensated by the increased floodplain velocities and discharges. Barishnikov (2) later confirmed this and found a reduction in the total discharge capacity of up to 16% for flow just above bankfull when compared to the flow obtained in the absence of a floodplain. Sellin (35) revealed evidence of this "kinematic effect", using a laboratory model, by the visualisation of vertically aligned vortices at the channel/floodplain junction as shown in figure 2.1.

![Photograph of flow showing vortices](Figure 2.1 (Sellin))
The photographs were taken with a camera mounted on a carriage over the flume. The speed of the carriage was matched approximately with the speed of the vortex cores which could be seen with aluminium powder, sprinkled on the surface of the water. He also plotted the mean longitudinal velocity distribution for the central region of the channel cross-section with and without the floodplain flow. Figure 2.2 shows the corresponding pair of isovel diagrams.

![Isovel diagrams with and without floodplains.](image)

*Figure 2.2 (Sellin)*
These clearly indicate the presence of the momentum transfer mechanism by the distortion of the isovels due to the strong secondary circulation to the floodplain. Finally, Sellin found that for low overbank depths the discharge could be increased above the interacting condition by isolating the floodplain from the channel with a floodwall. This confirmed the findings mentioned earlier by Zheleznyakov. In 1967, Delleur, Toebes and Udeozo (8) concluded that an interaction was apparent between the main channel and floodplain and that an important factor on the interaction mechanism was the pattern of secondary currents at the interface. Townsend (38) confirmed Sellin's conclusions about the velocity profiles of the compound channel although he used an asymmetric design with one floodplain. He also used dye injection and hot film anemometry to compare the turbulence levels with and without a floodplain. The results showed a marked increase in turbulence, with overbank flow, at the channel/floodplain junction. This work has more recently been extended by Prinos and Townsend (29) in their paper on "Structure of Turbulence in Compound Channel Flows".
2.2 Quantifying The 'Kinematic Effect' With Modified Friction Factors

A number of attempts were made to predict the stage-discharge curves for overbank flow, either through an artificial variation of the Manning roughness coefficient, or a subdivision of the flow between floodplain and channel with imaginary boundaries and treating the flow for each section separately. Sellin deduced values of Manning's coefficient from his stage-discharge curves. He suggested that with more data, it might be possible to "weight" the roughness factor empirically to allow for the change in flow characteristics.

The trend of research over the years has not generally been in this direction, until very recently. There are, however, a few cases worthy of note from these earlier years. Rice (34) determined the Manning's roughness coefficient for a complex channel at various slopes and roughnesses and demonstrated the errors incurred in the conventional methods of channel analysis, which ignored the presence of the momentum transfer mechanism. A typical textbook analysis like Chow acknowledges the presence of the mechanism and uses both an empirically weighted Manning's roughness coefficient and also the division of flow by imaginary boundaries. Yen and Overton (45) have compared the method of "weighting" the Manning coefficient used by Chow with their own and improved upon it. They analysed the laboratory data produced by Udeozo (39) and were able to locate the planes of approximate zero shear within the compound channel flow (Figure 2.3). They found that with the data available, the plane of zero shear began at the channel/floodplain junction, inclined towards the channel centre-line and the inclination of the plane varied mainly with stage and to a lesser extent on other
variables, e.g. roughness distribution (Figure 2.4).

Velocity Contours For Turbulent Flow
From Udeozo's Data (Yen and Overton)
Figure 2.3

Inclination of Division lines (Yen and Overton)
Figure 2.4
From this, they produced a modified stage-discharge formula based on figures 2.5 and 2.6, which was equivalent to Manning's equation with an effective roughness coefficient. This they compared to the "weighted" Manning equation proposed by Chow (Figure 2.7).

![Graph showing modified stage-discharge curve for floodplain only](image)

*Modified stage-discharge curve for floodplain only (Yen and Overton)*

*Figure 2.5*
Stage-discharge curve for main channel only (Yen and Overton)

Figure 2.6

Comparison of Discharge Calculation Methods (Yen and Overton)

Figure 2.7
James and Brown (15), in research carried out between 1974 and 1976, calculated Manning's $n$ values with the stage-discharge data from their laboratory tests. The $n$ values computed by the single channel method exhibited a decrease just above bankfull stage which compensated for the sudden decrease in hydraulic radius. They produced a set of correction factors, $n = n/bankfull$, with respect to aspect ratio, $\delta$, and relative depth, $\chi$, (see figure 2.8) to calculate discharge by a modified single-channel method. From this it was possible to calculate the stage-discharge curves, Figure 2.9. The improvement in the calculation from the standard methods is apparent.

![Graph showing $\phi$ ratios against aspect ratio for various depth factors (James and Brown).](image)

**Figure 2.8**

\[ \text{$\phi$ Ratios Against Aspect Ratio for Various Depth Factors (James and Brown)} \]
Discharge-Depth Curves using Various Methods (James and Brown)

Figure 2.9

\[ Q_1 = \frac{1}{n} A R^{1.5} s_1^{1.5}, \text{ where } R = A/P, P = \text{ total width of stream/} \]

\[ Q_2 = \left( \frac{1}{n} A R^{1.5} s_1^{1.5} \right)_{fp} + \left( \frac{1}{n} A R^{0.5} s_1^{0.5} \right)_{mc} \]

\[ Q_3 = \frac{1}{2} Q_1 \]

BANKFULL DEPTH
Myers, more recently, (22) investigated the relationship of friction factors to Reynolds number ratios between main channel and floodplain flows. He suggested that the way forward for discharge calculation in compound channels could be to utilise traditional flow formulae whilst incorporating accurate friction factor data.

Apart from the cases mentioned above, research has tended to favour the more traditional method of splitting the flow with an imaginary interface at the floodplain/channel junction and using friction factors based on bed roughness. The method of sub-division and inclusion or otherwise of the interface in the wetted perimeter was generally not the same for the different analyses of the various researchers.

Typical analyses by Chow and Henderson (13) take a vertical interface between channel and floodplain but ignore the interface in calculating the wetted perimeter. This is acceptable for high overbank flows but for the lower cases where interboundary shear is very high, another solution has to be found. Posey (27), in 1967, presented permutations of vertical, diagonal (inclined 45 degrees to the horizontal from the floodplain/channel junction towards the centre-line of the channel) and horizontal interfaces for subdividing the flow. He did not consider very low overbank depths, ranging from \( Q = 0.14 \), to a fairly high overbank condition of \( Q = 0.67 \). He obtained his best agreements with measured discharge values by including the wetted perimeter in the vertical case for the main channel, up to \( Q = 0.24 \). For values of \( Q \) above this he found the single channel method produced the best comparison. The aspect ratio, \( \delta \), of his model was 5. Wright and Carstens (44) in 1970, suggested a more refined solution after laboratory tests on
air flow in a T-shaped closed conduit. They proposed 1) that for the main channel, the interface be included in the wetted perimeter and 2) the mean shear force along the interface be calculated and incorporated as a propulsive force on the floodplain. It is worth mentioning that in carrying out these experiments, Wright and Carstens could measure the boundary skin friction in the conduit and hence calculate quite accurately the shear force across the floodplain/channel interface.
2.3 Development of The Apparent Shear Force

Ghosh and Jena (12) in 1971, published a paper on compound channels which included the measurement of local boundary shear stresses. Measurement of boundary shear had been well established since Preston (28), 1954, published his paper on the determination of turbulent skin friction in air. Little work had been done in water due to the difficulty in measuring accurately the low pressures involved and none on compound channels had been carried out before 1971. The main results of their work were to demonstrate the non-uniformity of boundary shear stresses (Figure 2.10) and point other researchers towards this line of investigation.

![Figure 2.10](image-url)

Boundary Shear Stresses in Compound Channel (Ghosh and Jena)

Figure 2.10
Myers (21), in 1978, investigated the "apparent shear force" between channel and floodplain, a term first coined by Cruff (7) investigating rectangular open channels in 1965. Myers drew attention to the high shear stresses along the channel/floodplain interface. He also tied up the apparent anomaly that existed between the highest turbulence levels recorded by Townsend at the lowest floodplain depths in contrast with the greatest velocity reductions recorded by Sellin and Zheleznyakov at a position noticeably above this. Having measured the boundary shear stresses for various depths of flow, he plotted "apparent shear stress" and "apparent shear force" for the vertical interface against Reynolds number, figures 2.11 and 2.12.

These demonstrated clearly that the vorticity, driving the turbulent momentum transfer or shear stress was a maximum at the lowest depths. As the depth and area of interface increased, the shear stress decreased until a stage was reached where the product of area and shear stress was a maximum. This position corresponded to the maximum drag on the flow and hence resulted in the minimum velocity. Myer's experiments thus led people to realise that the "apparent shear stress" had to be taken into account across interfaces used in subdivision. It was now apparent why the "modified" methods proposed by Posey and Wright and Carstens were too inaccurate for very low overbank depths.
Apparent Shear Force against $Re$ and $Q$ (Myers)

Figure 2.11

Apparent Shear Stress against $Re$ and $Q$ (Myers)

Figure 2.12
Apparent Shear Stress and Velocity Difference for Asymmetric Channels (Ervine and Baird)  
Figure 2.13

\[
\sqrt{r_{av}} = 7.1 \Delta V
\]

Apparent Shear Stress and Velocity Difference for Symmetric Smooth Channels (Ervine and Baird)  
Figure 2.14

\[
\sqrt{r_{av}} = 5 \Delta V
\]
Chapter 2

2.4 Stage Discharge Relationships Using The Apparent Shear Force

Rajaratnam, in 1979 (31), and in 1981 (32) made further steps towards quantifying, $\tau_{av}$, the average apparent shear stress across the vertical channel/floodplain interface. He concluded that it was a function of $Q$, the dimensionless depth ratio.

For the range of geometries,

\[ \alpha = 2.43 \]
\[ Q = 0.15 \text{ to } 0.25 \]
\[ \gamma = 1.0 \]
\[ \delta = 3.65 \]

he produced the equation

\[ \frac{\tau_{av}}{\tau_{0x}} = 0.15 \left( 1 - \frac{Q}{Q_0} \right)^2 \quad (5) \]

where $\tau_{0x}$ is the undisturbed shear stress on the floodplain.

Ervine and Baird (10) also attempted to quantify $\tau_{av}$, in a technical note published in 1982. They used various authors' data (35,12,32) to produce figures 2.13 and 2.14 below for asymmetric and symmetric channels respectively.
They demonstrated that for the range of geometries,

\[ \alpha = 1.75 \text{ to } 4.0 \]
\[ \beta = 0.09 \text{ to } 0.43 \]
\[ \gamma = 0.0 \]
\[ \delta = 1.0 \text{ to } 3.65 \]

\[ \tau_{ov} = \kappa (\Delta V)^2 \] (6)

where \( \Delta V = V_c - V_{fp} \), \( V_c, V_{fp} \) being the isolated mean channel and floodplain velocities respectively, calculated from Manning's equation.

In a subsequent publication (1), Baird and Ervine extended the idea of relating apparent interface shear stress to the relative mean velocity deficit between main channel and floodplain. They produced a relationship of the form

\[ \tau_{ov} = \kappa \Delta V \left( \frac{b}{(B-b)} \right)^{0.5} \cdot \int \left( \delta, \frac{h}{(B-b)} \right) \] (7)

The range of results are plotted in figure 2.15.

Variation of Apparent Shear Stress Parameter with Channel/Floodplain Geometry (Baird and Ervine) (Figure 2.15)
In the same year, Wormleaton, Allen and Hadjipanos (43) provided much more detailed data on the apparent vertical shear stress, $\tau_{av}$, using data obtained from Myers (23), Ghosh and Jena (12), and Elsawy and Crory (9), together with their own. They produced an equation of the form,

$$\tau_{av} = 13.84 \Delta V \cdot \left(1 - \varphi \right) / \varphi \cdot \alpha$$

within the range of geometries

- $\alpha$ = 1.75 to 4.18
- $\varphi$ = 0.05 to 0.75
- $\varphi$ = 1.0 to 1.90
- $\delta$ = 1.0 to 1.25

The correlation of this equation to observed data is shown in figure 2.16.
The authors felt, however, that a simplified method was needed for calculating compound discharge by subdivision of the model section. They defined three sets of division planes within the flow, shown in figure 2.17.

\[ \lambda_i = \frac{\omega A_i S_i}{(P_e + P_w)} \]  

Figure 2.17: Division Lines Between Main Channel and Floodplain  
(Wormleaton et al)

To each of these they attributed an apparent shear stress ratio, \( \lambda_i \), defined as the ratio of the average shear stress across the imaginary boundary to the average channel shear stress, \( \tau_{ci} \), where

- \( \omega \): unit weight of water,
- \( A_i \): channel cross-section area,
- \( S_i \): friction slope,
- \( P \): wetted perimeter, and
- \( i \) denotes the generalised form of the equation - diagonal, d, horizontal, h, or vertical, v.

Figures 2.18, 2.19, 2.20 show \( \lambda_v \), \( \lambda_d \) and \( \lambda_h \) plotted against the depth ratio.
Chapter 2

Figure 2. for the vertical case is very similar to Myers' plot of apparent vertical shear stress against Reynolds number, where the apparent shear is many times the average channel shear. However, it is interesting to note the variation of $\gamma$ and $\mu$ with depth ratio. These are much lower than $\gamma_v$. The authors then simplified the situation further by considering two options only, either including the division planes in the main channel wetted perimeter, $\gamma = 1$, or excluding them, $\gamma = 0$. The discharges were then found by applying Manning's formula for the main channel and floodplain subdivisions individually and then combining them to give the total flow.

In 1984, (42), the authors extended their ideas and introduced parameters $\phi_c$ and $\phi_f$, Radojkovic (30), to characterise the momentum transfer process between the main channel and floodplain where

$$\phi_c = \frac{\gamma_c \omega}{R_c S_c}$$

and

$$\phi_f = \frac{\gamma_f \omega}{R_f S_f}$$

They produced

$$Q_T = Q_c \cdot \phi_c + Q_f \cdot \phi_f$$

where $Q_c, Q_f$ are the isolated main channel and floodplain discharges given by the Manning formula.

From a series of laboratory experiments, they evaluated $\phi_c$ and $\phi_f$
for different interfaces and calculated $Q_\text{net}$ using the equation above. The net transfer of momentum to the floodplain was clearly illustrated in their results for a vertical interface as they found that $\phi_{cv}$ was always less than unity and $\phi_{fv}$ always greater than unity.

Figure 2.21 shows both the earlier method of including the vertical interface in the main channel wetted perimeter, calculating the discharge by the separate channel method, and the $\phi$ method.
\( \lambda_h \) versus Depth Ratio for Horizontal Interface
(Wormleaton et al)
Figure 2.18

\( \lambda_d \) versus Depth Ratio for Diagonal Interface
Figure 2.19

\( \lambda_w \) versus Depth Ratio for Vertical Interface
Figure 2.20
Variation in % Discharge Error with Depth Ratio
(Wormleaton et al)
Figure 2.21
In a subsequent discussion on (43), Buchanan (4) demonstrated that the single channel method with a single n value for the entire cross-section proved as effective as the authors more complex method. In response, the authors pointed out that the single channel method had no theoretical basis and theirs attempted to use the apparent shear stress across the boundary between channel and floodplain. It served to demonstrate, they felt, that the single channel method should feature as a yardstick by which future results and analysis might be measured.

Knight et al (16,17,18,19) have also carried out extensive work on this subject. They have followed a similar line to the other authors by the use of the "apparent shear force" on various interfaces. A graph has been reproduced below in figure 2.22 which plots %ASF, the percentage of apparent shear force across the floodplain /main channel interface to the total shear force on the main channel boundaries, against relative depth, .

![Graph of Variation of Apparent Shear Force on Vertical Interface](image-url)
They proposed a relationship between depth and discharge of the form,

\[ \log_{10} H = C_1 \log_{10} Q + C_2 \]  

(13)

where values of \( C_1, C_2 \) are plotted against \( \lambda \) for a smooth and rough case in figure 2.23.

They also compared the accuracy of various design methods either including or excluding the interface between channel and floodplain in the calculation of hydraulic radius.

![Variation of Constants C1 and C2 with \( \lambda \)](image)
2.5 Vegetatively Roughened Floodplains in Prismatic Compound Channels

Pasche, Rouve, Evers and Indlekofer (12,15,25,26) presented over a period from 1980 to 1985 details of experiments on the more realistic case of heavily roughened floodplains. Pasche and Rouve (26) demonstrated that the width of the vegetation zone on the floodplain was of minor importance only to flow resistance in the main channel. This is demonstrated in figure 2.24, a plot of $\lambda_T$, a friction factor for the imaginary vertical wall between main channel and floodplain against width of wooded floodplain.

They also demonstrated that a flow region occurs on the vegetated floodplain which is not influenced by the main channel flow.

\[ \lambda_T \]

Friction Factor, $\lambda_T$, for vertical interface vs dimensionless width of wooded floodplain (Pasche and Rouve)

Figure 2.24

Nalluri and Judy (24) carried out experiments on prismatic compound channels with heavily roughened floodplains, with $n$ (floodplain) up to .041 and $n$ (main channel) between .02 and .03.
2.6 Field Data

Little field data have been collected or analysed compared with the wealth of laboratory data available. Tingsanchali and Ackermann (36) and Bhowmik and Demissie (3) both showed that floodplains must be considered as conveyance channels as well as storage channels. Figure 2.25 shows how with increasing size of flood the floodplain becomes less of a storage channel and more a conveyance channel.
2.7 Mathematical Models

The topic is not covered here but has been mentioned for completeness. Two references on mathematical modelling are included, (41,20), the latter, Krishnappan and Lau have compared their Turbulent Model of floodplain flows to data produced by Knight et al. Good agreement has been obtained.
2.8 Meandering Compound Channels

As mentioned earlier, very little work has been done on this type of compound channel. The earliest report directly related to the above topic is a publication by the Waterways Experiment Station, Vicksburg, Mississippi, in 1956. (40). Many useful data were presented for a range of \( Q = 0.2, 0.4, 0.6, \) and \( \gamma = 1.0, 2.1, 2.9 \), although very little analysis was carried out on the data.

The conclusion one can draw from the report is that the meandering case of compound flow is far more complex and depends on more parameters than the simpler case considered in the first two chapters. Shown below are a number of graphs selected from the report to highlight the effect that a meander has on the discharge characteristics of a river. In this report, the strength of the meander has been termed the "sinuosity". Figure 2.26 is a schematic plan of the model with details of the different meander configurations. Figures 2.27 and 2.28 are plots of depth discharge relationships for various values of "sinuosity" and roughness ratio, \( \gamma \).

Toebes and Sooky (26), in 1967, published a report titled "Hydraulics of Meandering Rivers with Floodplains". They attempted to analyse their results in more depth than the previous report and concluded that the energy losses in the model depended both on Reynolds number and the Froude number.

They proposed that a method for calculating discharge could be based on the horizontal division of channel and floodplain flow at the junction of the two. They further suggested that an equivalent
Plan of Model With Different Meander Configurations
(Waterways Experiment Station, Vicksburg)
Figure 2.26

Depth Discharge Relationships for Various Sinuosities and Roughness
(Waterways Experiment Station, Vicksburg)
Figure 2.27
Depth Discharge Relationships for Various Sinuosities and Roughness
(Waterways Experiment Station, Vicksburg)

Figure 2.28
wetted perimeter, T, could be used across this interface to correspond to the apparent shear forces across it. Figure 2.29 shows the mathematical solution to the equation below,

$$Q_f = Q_1 \left( 1 + \left( \frac{T - b}{P_1} \right) \right)^{\frac{1}{2}} + \frac{Q_3}{(1 + \frac{T}{P_3})^{\frac{1}{2}}}$$

where the subscripts refer to the geometries detailed in figure 2.30.

The authors carried out detailed velocity traverses of various sections. Some of these have been included in figure 2.31.

Rajaratnam (27), has produced a report recently, titled “Meandering Channels with Floodplains”. In this he has considered two distinct configurations:

- $Q = 0.37$
- $Q = 0.45$

He concluded:

1) that the main channel was not exclusively the location of the highest velocities in the section.
2) The maximum velocity filament (also observed by Toebes and Sooky) tended to roughly follow the inner sidewalls of the main channel.
3) In the floodplain, the velocity varied continuously with distance above the bed whereas the main channel velocity remained almost constant with distance above the floodplain bed level. See Figure 2.32.

Figure 2.33 gives the schematic plan layout of the model with details of the locations of the cross-sections in the curved
(Toebes and Sooky)

Figure 2.29

Model Geometries (Toebes and Sooky)

Figure 2.30
SITUATION OF CROSS-SECTIONS

All sections are plotted looking downstream.
All velocity values are given in feet per second.

-VELOCITY CONTOURS, \( V_x \)

Isocets in Main Channel and Floodplain Cross-Sections
(Toebes and Sooky)

Figure 2.31
Depth Averaged Velocities Across Section of Model
(Rajaratnam and Ahmadi)
Figure 2.32
SCHEMATIC PLAN VIEW OF MEANDERING CHANNEL IN STRAIGHT VALLEY
Geometry of Curved Channel

Model Layout (Rajaratnam and Ahmadi)
Figure 2.33

Velocity Isovels through Horizontal Sections of Model
(Rajaratnam and Ahmadi)
Figure 2.34
channel. Figure 2.34 is an example of the isovels recorded at different levels above the floodplain. It only remains to be said that a definable flow pattern is clear from the various graphs presented in this chapter and a great deal more research needs to be done in this field before we will be able to confidently predict generalised discharge formulae for the meandering channel configuration within a floodplain.
CHAPTER 3

EXPERIMENTAL APPARATUS

This chapter describes the flume and discharge facility designed and constructed for the experimental laboratory programme. New techniques for data measurement and data collection, developed for the project, are described.
3.1 Flume

3.1.1 Design and Construction of Flume

The laboratory model was constructed and operated in a purpose built steel flume. The design criteria for this flume were as follows:

1. High Stiffness under water load
2. Variable tilt
3. Dimensions approximately 300mm deep by 1200mm wide and as long as practicably possible.

Steel was selected as the construction material because of its low cost and high stiffness compared with wood and perspex or glass and steel combinations. The shell of the flume was formed from mild steel sheet pressed to the shape of a shallow U with horizontal flanges at the top. These flanges provided added stiffness and were also intended to act as a base for mounting guide rails on.

The pressed metal sheet was stiffened with 50mm x 50mm x 4mm steel angle and hollow rectangular sections which were welded on to it at the correct spacings. The flume was made up from three lengths, two of 4 metres and one of 1.5 metres. They were bolted together and supported at the joints and at each end of the flume. A computer programme was used to investigate the elastic buckling limits of the steel for a variety of stiffener spacings, steel thickness and overall dimensions. The whole assembly was hinged at the upstream end and simply supported at the two joints and the downstream end. The bed slope of the flume could be altered by raising or lowering the supports with simple screw jacks. Each jacking point comprised of a pair of 25mm diameter, fine pitch,
steel bolts welded to a horizontal box member resting on a brick plinth. A top box member, with locating holes drilled into it for the bolts to pass through, rested on two nuts threaded onto the bolts. In turn, this upper member supported the flume and thus, the rotation of the nuts altered its level. To adjust the bed slope, the six jacks, two at each jacking section, were adjusted in proportion to their distance from the upstream hinge.

The bed level of the flume was checked at each jack point and the level adjusted again until the correct slope had been obtained for the entire length of the flume and the bed horizontal across the flume width. Levelling was carried out using an automatic Kern level set up on a tripod about 5 metres from the flume. A 500mm steel precision rule was used as the measuring staff.

The upstream end of the flume was hinged to a modified braithwaite tank which acted as an inlet stilling basin into which the supply water flowed. The tank was 2 metres wide, 1 metre deep and approximately 1 metre high with one panel cut down to half its height to accommodate the flume inlet. Three baffles dividing the tank, smoothed out the flow discharging into the tank from the constant head supply. A flexible seal between the flume and tank allowed the flume to tilt about its hinges.

Figures 3.1, 3.2 and 3.3 show the overall flume layout, jacking points and stiffener details.
NOTES
ALL DIMENSIONS IN MM
HOLLOW RECTANGULAR SECTIONS, MILD STEEL
A 50 BY 50 BY 6
B 50 BY 50 BY 6
C 127 BY 63 BY 6
JACKING ARRANGEMENT 'D'
2 NO. M24, 1900 LONG BOLTS WITH HEADS WELDED
TO UPPER BOX SECTION
BOLT LOCATED THROUGH HOLE IN LOWER SECTION
WITH HUT TO CONTROL MOVEMENT
BOXES X WELDED TO FLUME

POSITION OF 3 NO CONNECTOR BOLTS

BOLT WELDED TO TOP BOX
MOVEABLE HUT

VIEW AA
Stiffener Details for Central Span of Flume

Figure 3.3
3.1.2 Tail Gate Mechanism

The flume discharged over a broad crested weir gate. The cable and drum winding mechanism of the gate was motorised with the operating switch connected to a travelling overhead cable which could be extended the length of the flume. Thus the operator could be working anywhere along the flume and still have immediate control of the weir gate. It was possible to control the downstream water level to within 1mm with reference to a marked disc on the circumference of the winding drum and thus an absolute gate level could be repeated. Furthermore, the slow winding rate of the drum resulted in minimal wave disturbance travelling up the flume during gate level changes. A 10kg lead weight, attached via a steel cable and running over a pulley to the downstream side of the weir gate, ensured that the gate did not 'stick' whilst being lowered.

Figure 3.4 shows the relationship between tail gate level and gate setting.

3.1.3 Water Supply

To provide controlled discharge with discrete variations, a constant head tank was installed above the stilling basin, discharging water through a series of orifices. A bank of 9 orifices approximately 30mm in diameter, 6 orifices about 10mm in diameter and one orifice 7mm in diameter, were drilled into the underside of the tank, giving a flow range from 0.1 litre/second to 15 litres/second in steps of about 1.5, 0.2 and 0.1 litres/second for each size of orifice.

The orifices were calibrated volumetrically in the cumulative
Tail Gate Setting vs Weir Elevation

Figure 3.4
sequence in which they would be used, as some interference from adjacent holes was apparent.

For discharges below about 3 litres/second, a known volume was collected and the time taken noted. For the higher discharges, the Braithwaite tank was calibrated volumetrically between two marks using a pointer gauge mounted on the tank. The appropriate orifices were opened and discharged into the tank and the time taken to fill a known volume measured. This was repeated until consistent results were obtained for the range of discharges required. Calibrations to within ±2 percent were obtainable in this manner.

The constant head was maintained via a circular decant overflow weir. Once the correct orifices had been opened at the beginning of an experiment, the water level in the constant head tank would be set. This level would subsequently monitored with a variable conductance depth probe, installed in the tank and connected via suitable electronics to an oscilloscope. Thus, immediate warning would be given if the laboratory supply and, as a result, the discharge head changed, whilst an experiment was in progress.

The constant head tank operated at a head of approximately 500mm and this could be confidently maintained to within ±5mm, giving a discharge fluctuation from the orifices of ±0.5 percent. This ensured that series of experiments could be repeated.

Figures 3.5 and 3.6 detail the constant head supply and the mechanised tail gate assembly.
Constant Head Water Supply  
Figure 3.5

Tail Gate Mechanism  
Figure 3.6
3.1.4 Live Loading Test on Commissioning of the Flume

The flume was designed to run full with water i.e. a uniform loading of 3.5 KN/metre, resulting in a maximum vertical deflection of any part of the base of less than 1mm. This was tested once the flume had been constructed and the measured deflections did not exceed this limit. Some distortion of the base of the flume had occurred from spot welding the stiffeners onto the plate but this was not a problem as the model was built into the flume and the only consideration was to eliminate any significant distortion during operation of the model.

The effect of the live loading test has been shown on a plot of bed levels before and after loading, figure 3.7.
3.2 Model Construction

3.2.1 Material

The traditional method of model construction normally uses a sand/cement mortar moulded to templates fitted into the flume. The author felt that a better way could be found and decided to adopt polystyrene as a construction material for its low weight and ability to be cut easily into specific shapes.

3.2.2 Design

The model was constructed in 3 layers of polystyrene blocks, having the same width as the inside of the flume and each layer in two lengths of 4 metres and one length of 1.5 metres. These were cut and glued to form a homogeneous material which fitted snugly into the flume. The edges and joints were sealed with a waterproof silicone rubber sealant.

The high bouyancy of the material constituted a significant danger to the stability of the model when running with water. Any model constructed from this material had to be free from water pressures transmitted to its base from water percolating either through the material or down the joints between sections, thus causing the polystyrene to lift. Therefore, the underside of the model had drainage channels cut into it, running its length. These terminated at a drainage orifice in the flume a short distance upstream of the weir gate. This permitted free drainage from any part of the base to a central drainage hole the leakage from which could be monitored.
Figure 3.8 shows the underdrainage channels and 'sandwich' design of the polystyrene model.

Design Details of Polystyrene Model

Figure 3.8
3.2.3 Construction Details

The shape of the river for the model study lent itself to construction in polystyrene as it consisted of a meandering river contained within what was essentially a flat floodplain. Thus three layers of polystyrene were used, a 100mm base layer and a 50mm layer to form the level of the floodplain with sufficient depth of material to excavate the main channel. The final 100mm layer formed the floodplain banks.

The selected section of the river (choice of reach and selection of model scales covered in Chapters 5 and 6) had been surveyed along its length and the main channel and floodplain boundaries mapped, thus fixing the model in plan. 20 detailed cross-sections had also been surveyed along this reach. The surveying office at Thames Water Authority reproduced their digitised plans to the required model scale and the author cut and stuck the sheets together to form an enlarged plan of the reach. This was used to mark out the main channel on the second layer of polystyrene which was then cut using a hot wire cutter and then glued to the bottom layer. The plan was used again to mark the floodplain boundaries on the third layer which was cut and glued on to the second layer.

The basic shape of the model had now been established and all that remained was to determine the slope of the floodplain boundary and form the cross-section of the main channel. The surveyed cross-sections were digitised and reproduced on plots of the appropriate scale. Negative aluminium templates were made from these and used to determine the final details of the model. The main channel was excavated to a rectangular shape large enough to contain
each cross section. The templates were then fitted on to the model and the main channel filled in to form the correct cross-section using a sand and cement mix. The shape of channel between templates was interpolated.

The model, once complete, was painted with an oil based gloss paint to provide a water resistant surface, minimising the absorption of water and creating a tougher surface.

Finally, the model was sealed to the flume with silicone rubber sealant. During testing, the leakage along the base of the model was monitored at the drainage orifice and found to be less than 0.1 percent of the minimum discharge used.

A photograph of the model nearing completion is shown in figure 3.9.
3.3 Instrument Carriage and Probe Locating Assembly

3.3.1 Guide Rails

25mm x 25mm aluminium angle section rails were mounted on the horizontal flanges of the flume using 6mm diameter adjustable threaded rods fixed to them at 600mm centres and secured to the steel flange of the flume with two nuts. This enabled the rails to be levelled accurately. One guide rail was mounted with one flange horizontal along which the wheels on one side of the instrument carriage would run. The other guide rail was mounted with its flanges at 45 degrees to the vertical and the apex facing upwards. This provided a base along which the sets of wheels on the other side of the carriage, mounted at 45 degrees, would run, thus ensuring precise kinematic location along the flume.

3.3.2 Instrument Carriage

A rectangular frame spanning the flume and about 600mm wide, made from lengths of 25mm square hollow steel section formed the skeleton of the instrument carriage. Horizontal steel plates were bolted on each end of the carriage to support the probe positioning assembly.

Figure 3.10 shows the instrument carriage mounted on the guide rails.
Details of Instrument Carriage
Figure 3.10
3.3.3 Probe Positioning Assembly (PPA)

An automated positioning device, largely designed by the author, (a 3-dimensional version of a 2-dimensional plotter) was built to enable a measuring probe to be automatically positioned within the flume. The mechanical parts of the PPA, consisted of a probe holder (the secondary unit) which was constrained to move vertically within a mobile frame (primary unit). This primary unit could move horizontally, laterally across the flume. Thus, with the instrument carriage free to move along the flume, upon which the PPA was mounted, a probe could be positioned anywhere within the flume.

A horizontal drive rod mounted in the end blocks of the PPA could position the primary unit whilst a vertically aligned drive rod within the primary unit could position the secondary unit with respect to the primary unit.

Precision alignment of the secondary unit, the probe holder, could be maintained throughout this process by two linear bushes mounted within it running on two vertical, parallel, precision ground guide bars fixed into the primary unit. The primary unit was, in turn, constrained by a linear bush fixed into it and running on a horizontal guide bar, fixed on to the end blocks of the PPA.

Figures 3.11 and 3.12 show a block layout and more detailed views of the primary and secondary units of the probe positioning assembly.
Details of Primary and Secondary Units
Figure 3.12
Figure 3.12b
Photograph of Automated Data Collection Carriage
3.3.4 Automated Positioning

A stepper motor, mounted on the instrument carriage and geared to one of the instrument carriage wheels, could position the carriage anywhere along the flume. Positioning of the probe head across a section could be achieved by controlling two stepper motors connected to the horizontal and vertical threaded rods of the positioning assembly.

The motors were controlled from a BBC microcomputer via linear translators which in turn controlled the movements of the motors.

The microcomputer was connected to the control side of the translators with a ribbon cable running 8 lines from the user port of the BBC. Two lines were required for each stepper motor translator, thus 6 of the 8 lines from the BBC were in operation. One provided information on direction and would be set 'high' at 5 volts or 'low' at 0 volts. The second line, when pulsed from 'high' to 'low' or 'low' to 'high', would cause the motor to execute 1 step. Thus successive changes in voltage level on the appropriate line would cause the motor to multiple step. The 'high' or 'low' states of the lines were determined by the value stored at the user port address. Each of the 8 lines represented one bit of a 1 byte value. Thus, storing a 1 byte value at the port address would set the lines according to the binary representation of that number i.e. if 68 in decimal were stored it would represent 01000100 in binary meaning that counting from the right hand digit as zero, lines 2 and 6 would be set 'high' and the remaining lines set 'low'. The means by which this could be utilised to operate the steppers in a more or less continuous mode will be described in chapter three.
The stepper motors and translators used were bought from McLellan Servo Supplies (U.K.). The hardware consisted of three translator cards, together with a power supply, mounted in a rack system, mounted on the instrument carriage. The steppers were:

2No. ID27-101 48 steps/revolution maximum working torque 11Ncm, for the lateral and vertical positioning of the probe positioning assembly.

1No. HR23-101 200 steps/revolution maximum working torque 38Ncm for driving the instrument carriage along the flume.

All three were driven by 3No. EM162 translator modules.

Figure 3.13 shows the block layout of the stepper motors, translators and BBC microcomputer.

Layout of Steppers, Translators and BBC microcomputer
Figure 3.13
3.4 Measuring Instruments

3.4.1 Water Surface Levels

Surface levels, both in the constant head tank and in the model during an experiment, were recorded in two ways. The first, a pointer gauge with a vernier scale reading to 0.1mm, was the conventional method, used together with a more versatile device, a variable conductance depth probe. This second device consisted of a pair of parallel stainless steel wires, partially immersed in the water, about 12mm apart and each 1.5mm diameter, connected to a Churchill Wave Monitor.

The probe works on the principle of measuring the current flowing in the probe which is energised with a high frequency square wave voltage thus avoiding polarisation effects at the wire surfaces. The wires dip into the water and the current that flows between them is proportional to the depth of immersion. The current is sensed by an electronic circuit which produces an output voltage proportional to the instantaneous depth of immersion. In this way, from a reference datum established by use of the pointer gauge, subsequent water levels relative to the start position can be evaluated by the readings received from the probe.

The probe sensitivity, typically between 1 volt/mm and 0.1 volt/mm could be adjusted at the wave monitor. This would give a full scale range on the ADC convertor of between 20mm and 200mm.
3.4.2 Flow Velocities

The author designed a self-aligning pitot-static tube for measuring water velocities in the model. The instrument took the shape of a thin pitot-static tube, 3mm outside diameter, about 100mm in length and bent to accommodate a fin at the bottom of it. The fin was fixed behind the centre-line of the vertical shaft about which the whole assembly rotated.

The layout of the pitot-tube, transducers and electronic components is given in figure 3.15.

Details of the self-aligning pitot tube are shown in figure 3.16. Photograph of primary + secondary units with pitot attached, figure 3.16a. The photograph in figure 3.17 shows the terminals box, Churchill monitor and signal convertor.
Details of Variable Yaw Pitot-Tube

Figure 3.16
Figure 3.16b
Photograph of Primary and Secondary Units with Variable Yaw Pitot Tube Attached
Figure 3.17
Photograph of Terminal Box, Signal Converter and Churchill Wave Monitor
The low dynamic heads generated were measured with a low displacement pressure transducer mounted with the diaphragm horizontal. Velocities between 40mm/s and 600mm/s could be measured depending on the working range of the pressure transducer used.

Three bi-directional pressure sensors were available for use on the rig, having a full scale range of 0.5 mbar, 1.0 mbar and 2.0 mbar. These were purchased through Sandhurst Scientific Instrument Company (U.K.).

Figure 3.18 shows a plot of flow velocity in mm/s vs transducer output in volts for the 1.0mbar and 2.0mbar transducers.

\[ V = 226 \left( \frac{\text{Volts}}{} \right)^{0.5} \]

\[ V = 302 \left( \frac{\text{Volts}}{} \right)^{0.5} \]

20mbar f.s.d. \hspace{1cm} 1.0mbar f.s.d.

Log. Plot of Flow Velocity vs Transducer Output With Pitot-Tube Connected

Figure 3.18
These Elec Torr FA76 series of very low pressure sensors had a maximum volumetric displacement of less than 0.05 millilitres and a line pressure limit of 50 bar. The overpressure limit for the 0.5 and 1.0 mbar units was 100 mbar and 700 mbar for the 2.0 mbar unit. Therefore care had to be taken not to exceed the pressure whilst de-airing them prior to use. A loop supply voltage of between 10 to 30 volts was recommended with a linear output between +5 and -5 volts. De-airing was a quick and simple process and no trouble was encountered with false readings due to trapped air within the transducer unit.

The response curves for the 1.0 mbar unit connected to the pitot-tube and recording dynamic heads in water have been plotted in Figure 3.19.

Response Curve for Pitot-Tube
Figure 3.19
The angular displacement of the probe was measured with a linear angular position sensor mounted axially over it.

A Penny and Giles potentiometer was used, type D3810/300. The required input is a nominal stabilised 10v d.c. from a source impedance of less than 10ohm. The d.c. input is converted to an a.c. waveform by an integral oscillator and then fed to a transformer primary winding. The output from the secondary winding is converted to d.c. by an integral demodulator and filter.

The angular position sensor used provided a linear voltage output over a 300 degree angular range.

The design of the self-aligning probe was such that the probe could not completely align itself with the flow. This was on account of the elasticity of the rubber tubing resisting rotation of the probe head. Therefore, it was necessary to calibrate the error generated for the range of velocities and angles of incidence likely to be encountered.

To do this, the pitot tube was mounted in a parallel sided flume together with a low speed Streamflo Novar propellormeter which had previously been calibrated in a towing tank. The probe was immersed in water with flow velocities ranging from 10-60 cm/s and a range of incident angles from -60 to +60 degrees. From this experiment a correction matrix of true angle/recorded angle for the entire range of speeds was built up. Thus the recorded angle of incidence from the experiment could be corrected to produce a more accurate value.
No velocity corrections were made for the pitot tube for misalignment in the flow direction. Tests demonstrated it was relatively insensitive to deviations of up to 15 degrees from the true direction for measuring the correct magnitude of velocity. Rajaratnam, in his technical note on "The Prandtl Tube as a Preston Tube" (54) found that for a dynamic pressure error of less than 5% (a velocity error of 2.5%) the misalignment of the tube from the flow direction would have to be less than 15 degrees.

Figure 3.20 shows the results of the calibration test and Table 3.1 sets out the correction matrix used in adjusting the results.
Calibration of Variable Yaw Pitot-Tube
Figure 3.20
<table>
<thead>
<tr>
<th>Velocity (mm/s)</th>
<th>recorded angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 [ -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60</td>
<td></td>
</tr>
<tr>
<td>500 [ -60 -50 -40 -30 -20 -10 0 11 20 30 40 50 60</td>
<td></td>
</tr>
<tr>
<td>400 [ -60 -50 -43 -30 -20 -11 0 11 20 30 40 50 60</td>
<td></td>
</tr>
<tr>
<td>300 [ * -57 -47 -35 -25 -11 0 14 25 33 47 56</td>
<td></td>
</tr>
<tr>
<td>200 [ * * -53 -41 -30 -15 0 15 28 38 51</td>
<td></td>
</tr>
<tr>
<td>100 [ * * * -52 -36 -19 0 27 40 54</td>
<td></td>
</tr>
<tr>
<td>0 [ * * * * * * * * *</td>
<td></td>
</tr>
</tbody>
</table>

---

Table 3.1

Table 3.1 Correction Matrix for Variable Yaw Pitot Tube Angular Displacement
Matrix Contains True Angle of Rotation
CHAPTER 4

INSTRUMENTATION

This chapter describes the computer software which was used to control the experiments carried out on the river model. A BBC model B 32k RAM microcomputer fitted with an Aries B-32 32k RAM expansion board and a 3.25 inch disc storage system using cassettes with a storage capacity of 100kbytes/side formed the core of the computer hardware. The BBC User Guide (62), the Advanced User Guide for the BBC Micro (61) and Advanced Disk Users Guide (63) were used extensively in developing the Basic and assembly language programmes.

For the purposes of investigating the characteristics and behaviour of the model, three programme modules were written to assist in the construction of:

1. Depth-Discharge curves.
2. Mean Point Velocities through cross-sections of the river.
3. Isometric views of the free water surface.

These all require the measurement of either velocity of flow, surface levels or both. Recording water surface levels to produce a family of drawdown and backwater profiles for depth-discharge curves, would normally be carried out using a pointer gauge mounted on the instrument carriage, positioned and read manually. The readings and corresponding positions would be entered in a log book. Measuring point velocities is a more complicated task, using either a miniature propellormeter or pitot-static tube. The grid position of the probe within the cross-section would have to be recorded and
together with the output from the probe.

The software developed during the period of experimental work in the laboratory precluded the need for time consuming and tedious manual measurements such as those described above. This has facilitated a more and varied experimental programme which otherwise could not have been considered.

Covered in this chapter is a description of the operating software to investigate the three topics mentioned above.

Listings of all programmes described here can be found in appendix A.4.
Chapter 4

4.1 Stepper Motor Control and Data Collection

The strength of the automated data collection system lies in the ability of the operator through the computer and its software, to control in a predetermined fashion, the position of the probe head with the stepper motors. Chapter three has dealt with the mechanics of the stepper system and here the author will elaborate on how the stepper motors are pulsed from the computer.

There are a number of external sockets on the BBC microcomputer via which the machine can communicate with the outside world or vice versa. The ones of particular interest are:

1. user port
2. analogue to digital convertor input (ADC)
3. RS423 interface

The first and second sockets are used whilst an experiment is running. The user port sends information to the linear translators (described in chapter 3), which in turn pulse the stepper motors by energising the appropriate coils within them. The ADC receives analogue voltage signals from the measuring equipment and converts them into digital values which are then passed on within the computer for storage or processing. The third socket enables the computer to act as a 'dumb' terminal, communicating via a Peripheral Access Device (PAD) line to other computers. This is used for transferring data from the storage disc connected to the microcomputer to a larger computer for more complex processing and analysis.
The user port has 20 lines, 10 of which are earthed, 2 are control lines and 8 are data lines. The user port is connected to the linear translators via a 20 way ribbon cable. The earth lines are connected alternately between the data lines to act as a 'sink' shielding them from stray electric fields which could corrupt the signal travelling down the lines. As previously mentioned in chapter two, 6 of the 8 data lines are used to control the stepper motors. The 8 lines each correspond to 1 bit of an 8 bit byte. The values of each of these bits is determined by a 1 byte value which can range between 0 and 255. This would correspond to 0000 0000 and 1111 1111 in binary, meaning that all the lines would be set to 0 volts or all set to 5 volts. The address at which a value can be stored to control the state of these lines is at location Hexadecimal FE60.

As an example, stepper X is considered. The controlling lines for stepper X are 0 and 4, ***1 ***1 . The least significant bit, the rightmost, is bit 0. This line controls the direction of the stepper, if it is set at 1 the motor will rotate clockwise the next time it is pulsed. If it is set to 0, the motor will rotate anticlockwise. Counting from the right, bit 4 controls the pulsing. The remaining bits, marked as *'s do not affect stepper X. To pulse continuously, the state of bit 4 must switch from 'low' to 'high' continuously. Changing the state of bit 4, in either direction will make the motor execute one pulse.

Included here are some short lengths of assembly language instructions from a working programme to illustrate best how the operation works. PORTB represents the user port location, hexadecimal FE60.
Chapter 4

PortB Description of Operation

<table>
<thead>
<tr>
<th>Description of Operation</th>
<th>PORTB Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) LDA $&amp;01</td>
<td>$*** $**1</td>
</tr>
<tr>
<td>ORA PORTB</td>
<td></td>
</tr>
<tr>
<td>STA PORTB</td>
<td></td>
</tr>
<tr>
<td>b) LDA $&amp;FE</td>
<td>$*** $**0</td>
</tr>
<tr>
<td>AND PORTB</td>
<td></td>
</tr>
<tr>
<td>STA PORTB</td>
<td></td>
</tr>
<tr>
<td>c) LDA $&amp;10</td>
<td>$<strong>1 $</strong></td>
</tr>
<tr>
<td>ORA PORTB</td>
<td></td>
</tr>
<tr>
<td>STA PORTB</td>
<td></td>
</tr>
<tr>
<td>d) LDA $&amp;EF</td>
<td>$<strong>0 $</strong></td>
</tr>
<tr>
<td>AND PORTB</td>
<td></td>
</tr>
<tr>
<td>STA PORTB</td>
<td></td>
</tr>
</tbody>
</table>

The other bits marked * during an operation are unchanged therefore it is possible to execute these instructions in a programme to control the steppers independently of the others. Segments a) or b) would be used at the start of a run to determine the new direction of the stepper motor. Segments c) and d) would be used alternately to multiple step the motor.

Thus, a typical simple sequence would be:
a) or b) to set up direction followed by
c)-delay-d)-delay-c)-delay....until the required operation had been
 carried out. The delay routine would be necessary to control the
 speed of the motor.
4.2 Setting Up

The procedure for setting up the water level and velocity recording instruments is covered in this section. A detailed description of the instruments can be found in chapter 3.

4.2.1 Water Level Probe Calibration

Before use, the depth probe needs to be calibrated to relate the digital reading from the ADC to the degree of submersion of the probe wires. There are two main factors which could change the calibration coefficient of the probe. The first is the drift of the signal amplifiers, which on account of the equipment remaining on all the time, is insignificant. The second could be due to changing the gain of the wave monitor. This would be done if the sensitivity of the probe needed to be adjusted depending on the variation of water level expected down the flume before the start of a run.

The probe can be easily calibrated whilst still in place in the flume. Programme, CALIB, enables the coefficient relating submersion to a digital output to be evaluated. The operator must place a beaker of water beneath the probe before running the programme. Once running, CALIB, immerses the probe automatically into the water whilst recording the depth of immersion, and the output signal from the probe monitor on the ADC. The depth of immersion of the probe is related to the number of angular steps executed by the vertical stepper motor.

The probe is lowered at a constant rate by the stepper motor and a number of readings taken at various stages of immersion. The result
is plotted to check the linearity of the probe output and averaged to give a final calibration coefficient which can be used in the experiment. Resolution to within 0.1mm is easily achieved with this type of probe.

4.2.2 Variable Yaw Pitot-Tube De-airing and Calibration

The variable yaw-pitot tube is used in determining time averaged point velocities across a section of the model. Before commencing a run, it is necessary to ensure the pitot-static tube has been de-aired, that the pressure transducer is operating and to calibrate the Angular Position Sensor (APS), which measures the yaw of the pitot tube.

Programme ADVAL performs these functions by enabling the operator to calibrate the APS and confirm by way of a screen plot and digital displays whether the pitot tube is operating normally.
4.3 Depth-Discharge Curves

Depth discharge curves for the model, for various roughness states have been built up by considering the backwater and drawdown curves over the range of appropriate discharges. From these families of curves, it was possible by inspection to establish the uniform condition and thus find a representative depth of flow for each discharge used.

Two programmes, LONGBAS and LONGMC, the first written in basic and the other in assembly language control the operations which produce the family of M-curves.

The time taken in collecting and plotting data by hand for one profile when attempted in the early days of the research programme took up to half an hour. With the development of this software and the automated instrument carriage, the time taken to collect data for each profile is about 4 minutes. Furthermore, it is always difficult to obtain a mean surface level in a body of highly turbulent fluid using a pointer gauge. In the author's method a large number of instantaneous readings are taken and averaged.

The secondary unit of the Probe Positioning Assembly is fitted with the variable conductance depth probe, see Figure 3.14, and the instrument carriage, driven by the Y-coordinate stepper motor, traverses the length of the flume. During this operation the microcomputer stores depth readings at fixed positions down the flume, measured by the partially submerged depth probe. These readings are taken relative to the level of the instrument carriage guide rails.
It is necessary to produce an averaged water surface level for a longitudinal profile, eliminating the surface fluctuations due to turbulent effects within the body of fluid. The instrument carriage does not stop, however, whilst readings are being recorded from the probe. Thus time averaged values at individual locations cannot be established. However, its slow rate of travel down the flume, about 30mm per second, enables a group of readings to be taken and time averaged over a fairly short distance with a total sampling time of a few seconds.

Up to 200 readings can be taken over a 100mm traverse and time averaged to one reading representing the centre point of the segment. Thus, localised surface disturbances such as small standing waves due to irregularities of the model and surface level fluctuations, varying at a rate greater than about 0.3 Hz, are eliminated.

At the start of a run, there is an option to record averaged readings relative to the floodplain or to a horizontal datum i.e. absolute values. This is possible with correction data stored within the programme. These data have been produced from a detailed levelling exercise on the instrument carriage guide rails and floodplain which was constructed as a plane surface.

Each family of curves are related to each other by measuring the water surface level with a pointer gauge mounted on the instrument carriage at the start position of the depth probe before each traverse. At the end of each traverse the current profile is plotted on the screen then, if acceptable, the levels are stored on
disc together with the discharge, gate setting and spacing between averaged readings. The procedure is repeated for different gate settings until sufficient longitudinal water surface profiles have been produced. The discharge can then be altered and the process repeated. If the operator needs to terminate the run prematurely without crashing the system, an escape facility has been built into the software. Pressing the ESC key whilst a run is in progress will terminate the run and control will return to the operator via the keyboard.

Once an entire set of data have been collected on the storage disc it is ready for further processing and plotting on a main frame computer with advanced graphical routines. A simple Fortran programme using resident plotting packages produces plots of the type in appendix A.6, a sample of which is given in Figure 4.1.

4.3.1 Flow Charts

The operators instructions follow:

1. Calibrate Depth Probe - using programme CALIB
2. Enter Initial Parameters into computer
3. Set Discharge
4. Set Gate
5. Set Instrument Carriage at start of run
6. Adjust depth probe
7. Read Pointer Gauge at probe position
   (At start take floodplain level reading as well)
8. Engage Y-coordinate stepper gear
9. Enter run details into computer
Figure 4.1

Plot of Longitudinal Water Surface Profiles
10. Start run

11. Run finished:
   a) Scrap run GO TO 4
   b) Plot and store run GO TO 12

12. Change Discharge - GO TO 2

13. Change Gate - GO TO 3

14. Stop
Below is a flow diagram for LONGBAS:

The numbered boxes relate to programme sections listings of which can be found in appendix A.4.

Choose Options

Reset probe position to start

Initialise parameters

Input Run parameters

set software parameters given in <PROCparameters>

start run

Y --- rerun?

average and correct data

plot on screen

store on disc

rerun?

Y

STOP

N
The following flow diagram outlines the main operations carried out within the assembled version of LONGASM.

The numbered boxes relate to programme sections listings of which can be found in appendix A.4.

START

pulse motor Y

delay routine

pulse motor Y

delay routine

read probe value

store in memory

escape key pressed?

N

end of traverse?

N

Y

return to main programme
4.4 Velocity Profiles

The most sophisticated software developed during the project has been that written to record time averaged point velocities in a grid pattern across any section of the model, in the main channel as well as the floodplain. The stored data could then be processed to produce contours of constant velocity in the principal direction of flow. This software was developed primarily for the same reasons as for the programmes mentioned above. The time involved in manually traversing a probe across the flume, taking measurements by hand and later entering them into a computer for plotting was prohibitive. Not only would the two coordinates fixing the position of the probe have to be measured together with the appropriate velocity and angle readings but they would all have to be entered manually into a data file. As a rough guide, approximately 300-400 readings were taken across any given section of the model, the number of readings taken dependant on the size of cross-section and depth of flow. The time taken to perform this operation using the automated rig system is between 2 and 5 hours. To carry out the same task manually, an operator would be completely tied up during the measurements and would have to enter the values manually. This could take anything up to an extra 3 or 4 hours. With the automatic system, the operator need not be present during the run and so his time can be spent elsewhere. Some particularly long runs requiring up to 800 readings were left overnight unattended.

As explained in chapter three a self aligning pitot static tube was developed for this project which was fitted to the secondary unit of the Probe Positioning Assembly. A very low head pressure transducer was mounted on the primary unit and the output from this and the
angular position sensor on the pitot tube was directed to the ADC port of the microcomputer via a travelling cable, suspended from an overhead cableway.

The operator could choose to carry out a traverse on one out of 6 available cross-sections and load the appropriate boundary coordinate file into the programme. He would check the pitot tube was de-aired and functioning and calibrate the angular position sensor set-zero (see 4.2 Setting Up). The operator would then position the probe at the start of the traverse and run the programme. At given prompts, the operator would enter various parameters such as spacings between readings and number of readings to average at each position.

Unlike the previous programme, the probe stopped at predetermined settings to take readings. Typically the spacing between readings would be set at about 10mm and the wait time, to allow the pitot static tube reading to reach equilibrium, would be from 15 seconds to 2 minutes depending on the change in flow speed between one position and the next.

The computer would "know" when equilibrium had been reached by using a testing routine incorporating a time delay to check consecutive sets of averaged velocity readings and remain in the 'wait' loop until successive sets of readings were acceptably close in value.

4.4.1 Flow Charts

The operators instructions follow:
1. Set Discharge and Gate
2. De-air pitot static tube and calibrate Angular Position Sensor using programme ADVAL
3. Choose Cross-Section
4. Move Probe to Start Position
5. Run Programme and follow commands on screen
6. Stop

The running programme consists of a suite of programmes. The following flow diagram outlines the basic sequence and operation of the entire suite. The numbered boxes relate to the programmes in appendix A.4.
Flow chart for 3D-SUITE of programmes
Numbered boxes refer to programmes listed in appendix A.4

1. START
   - Use stored programmed coords?
     Y   Use stored coords
     N   New start program
         Y   Input from keyboard
         N   Input from file?
             Y   Load new file
             N   Run without taking rdgs?
                 Y   Input spacing between readings
                 N   Set delays
                     Y   Set rdgs to avge
                     N   Hardcopy of calc'd steps?
                         Y   Printout
                         N   Commence run?
                             Y   Start m/c prog.
                             N   Input series/run,Q,gate,Xsection instrument calibration factors

2. START
   - Input new coords?
     Y   Input from keyboard
     N   New start position?
         Y   Input from file?
         N   Load new file

3. Display pictures
   - Graphical intro?
     Y   Record parameters for run?
     N   Hardcopy of Coords

4. Input series/run,Q,gate,Xsection instrument calibration factors
   - Input spacing between readings
   - Set delays
   - Set rdgs to avge
   - Hardcopy of calc'd steps?
     Y   Printout
     N   Commence run?

Flow Diagrams for 3D.ASM
Numbered boxes refer to programme units within 3D.ASM and listed in appendix A.4.

1. Define, initialise parameters
2. Set pointers
3. Store current traverse data
4. Load total steps in current traverse
5. Set X, Y, Z directions
6. Load no. step blocks between rdgs
7. Load X, Y, Z step blocks
8. Pulse X, Y, Z by step blocks
9. End of traverse?
10. <ESC> pressed?
11. Int. station reached?
12. Correct position error
13. Read ADC channels
14. Increment data pointers
15. Return to main prog.
4.5 Isometric Plotting of Water Surface

This third programme has not been as widely used as the first two but its usefulness in future work justifies its inclusion.

The principle of operation is similar to that used for the longitudinal profiles but instead a number of profiles are taken laterally with a much slower traverse rate and shorter averaging segment. A static water surface level is taken at the beginning of each traverse to tie in successive profiles along the length of the model. The initial level is measured using a pointer gauge with vernier scale accurate to 0.1mm.

A typical isometric plot would be constructed from 20 profiles at 100mm spacings totalling approximately 1000 averaged readings taken at about 10mm spacings.

The data, again stored on floppy disk, could be transferred to a file on the GEC 4090 main frame computer. From there a programme written in Fortran 77 utilising resident plotting packages could produce an isometric view of the water surface. A sample plot is given in Figure 4.2.

4.5.1 Flow Charts

The operators instructions follow:

1. Set Discharge and Gate
2. Read water level at start position with pointer gauge
3. Position depth probe at start position
4. Run programme and follow instructions on screen
5. Choose new start position and GO TO 2 else STOP
Figure 4.2
Isometric Plot of Water Surface Between Y=4500 and Y=6900
CHAPTER 5
River Roding - Field Measurements and Analysis

As part of the investigation into the 1980 River Roding Flood Alleviation Scheme, a field study was planned to run concurrently with the experimental laboratory work.

The study concentrated on a section of the river altered under the Flood Alleviation Scheme. Thames Water Authority and the University of Bristol decided to site three water level recorders between chainages 300m and 1700m below the village of Abridge, (see figure 1.1 in chapter 1). The stretch of river was comprehensively mapped and figure 5.2 shows the mapped river with the surveyed river cross-sections marked in. The canalised section of the river, immediately downstream of recorder 3, was not typical of a natural compound river about which the investigation hinged and, therefore, monitoring of the experimental scheme was confined to the upper part of the river scheme. Permanent discharge recording stations were in operation on the river at the time.

The aims of the field study were to record levels and infer discharges continuously at the three stations over three years, monitor the type and extent of vegetation in the river and on the floodplain, and whenever possible especially during periods of significant overbank flow, carry out velocity traverses at selected sections along the river.

The results would be analysed to produce a number of stage-discharge relationships for the reach, under different conditions. These would be used to implement a model study of a stretch of the river.
between sections 1.029 and 1.036. The location and scales of the modelled reach are discussed in chapter 6. Furthermore, the roughness characteristics of the reach would be evaluated to provide design engineers with photographs of the reach together with typical manning roughness values in varying flow and roughness conditions.
5.1 Instrumentation

Figure 5.1 shows the Roding catchment and general location of the water level recorder stations and the discharge measurement weirs. Figure 5.2, already introduced, gives in more detail, the position of the recorder stations.

5.1.1 Discharge Measurements

Two permanent weirs specifically constructed to measure discharges in the river are sited near the villages of Loughton and Redbridge, 3km and 11 km downstream of the village of Abridge. Of the two gauging stations at Loughton and Redbridge, the latter station only has been operational since 1983. The upstream station at Loughton, damaged in a storm, was not repaired until 1984. The gauge is currently being recalibrated and has been of no use in assessing discharges along the river during the study.

Water levels over the Redbridge gauging weir are automatically logged at 15 minute intervals throughout the year. The record is processed each month by Thames Water Authority to produce data in the form of a computer printout, listing discharges at fifteen minute intervals beginning at 0900 hours every day on a monthly basis.

Figure 5.3 is a copy of a typical daily record at Redbridge.
Figure 5.1
Catchment Area of River Roding down to the Redbridge Gauge
Figure 5.2
Surveyed Plan of River Roding Flood Alleviation Scheme
Between Recorders 1 and 3
**Figure 5.3**

**Typical Daily Record at the Redbridge Gauge**

<table>
<thead>
<tr>
<th>Time</th>
<th>Day 1</th>
<th>Day 2</th>
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Legend:
- **Mean:** Average value
- **Max:** Maximum value
- **Min:** Minimum value
The first objective of the study was to construct a stage-discharge relationship for the reach, based on information from the three level recorders. One possible method of doing this would have been to gauge the sections containing the level recorders over the investigation period, covering as much of the flow range as possible. This would have proved very costly in manpower and TWA were not prepared to do this.

The only other way of calculating discharges at the sections was to use the permanent gauging stations. An ideal gauging site would have been at the downstream end of the reach, at recorder 3. Failing that, the Loughton gauge would have provided the best alternative. Being out of commission, it was of no use and so this left the Redbridge gauge, almost 8 kilometres downstream of recorder 3.

To assume that the discharge values recorded at the Redbridge site would sufficiently describe the discharges at recorder 3 was unreasonable. A number of brooks and outfalls were situated between recorder 3 and Redbridge as well as surface drainage from a section of the M11 motorway. The additional catchment between the two sites would add to the Redbridge flow in times of rain.

The effect of these inflows would be twofold. Firstly, a substantial increase in short term discharges might be expected, such as that caused by a storm passing over the catchment. This would be due to the rapid runoff from the urban catchment and motorway between the two sites. The second effect would be increased base flow. The first effect could not be accounted for easily, an accurate knowledge of the catchment, outfalls and local rainfall patterns being needed to
determine it. The increased base flow between the two locations might be taken into account if the upstream discharge could be measured and compared with the Redbridge discharge for a wide range of flows.

As already mentioned, it was not possible to gauge the river at recorder 3 on a continuous basis, so the only other facility for discharge measurement lay at Loughton, 1.3km farther downstream.

The station at Loughton had been active until 1983 and so it was decided that it might be feasible to use the Redbridge flows and relate them to the Loughton flows, providing reliable correlation could be found between the two. Thames Water Authority supplied the author with 15 minute interval discharge data for both gauges for the first six months of 1982. From this, four periods during which there was significant flow in the river were identified. The data from both stations were digitised and plotted out on a graph of discharge versus real time, to highlight any obvious relationships.

It was apparent that discounting any periods of rapidly varying flow (greater than 0.20 cusecs per hour), two relationships could be developed. Although highly empirical, it was decided that in the absence of any other more accurate information, these relationships would suffice. It was hoped that the validity of these would be checked by comparing the estimated discharge at Loughton, with individual flow gaugings during the study.

A simple translation along both axes was applied to the Loughton data relative to the Redbridge data, which in physical terms equated to the discharge at Redbridge peaking after Loughton and being of
greater magnitude. The results are plotted in figures 5.4 to 5.7. Only Figure 5.4, a plot of consistently high flow, greater than 5 cumecs for over 10 days, showed any reliable correlation. Thus, for flows in excess of 5 cumecs it was decided that a time lag of approximately 3 hours and decrease in discharge of 1 cumec would adequately describe the Loughton flow in terms of the Redbridge gauge. For discharges less than 5 cumecs it was not immediately clear what relationship should apply.

Due to the greater uncertainty in correlating low flows, the author analysed gradually receding flows of which there are 4 examples marked on figures 5.5, 5.6 and 5.7. These data were replotted, this time relating discharges against each other for different relative time lags.

The best fit set of points was obtained with a time lag of

\[(Q(\text{Loughton}))_t \text{ versus } (Q(\text{Redbridge}))_{t+3},\]

\[(Q(\text{name}))\] being the discharge recorded on the gauge, \(t\) being the time in hours. This has been plotted in Figure 5.8.

The discharge relationship between Loughton and Redbridge had now been established, albeit fairly crudely. It must be emphasised here that it was a discharge correction that had been established between the two gauges for all steady flows. It was obvious however, that the most important detail was estimating the correct time lag between the Redbridge discharge data and Loughton for each discharge considered. This had already been found to be approximately three hours but would vary depending on the magnitude of flow down the
Figure 5.4 and Figure 5.5
Redbridge and Loughton Discharge Data
Loughton Data Plotted with 3hr Lag and Reduced by 1 Cumec from Original Values to Compare with Redbridge Data
Figure 5.6 and Figure 5.7
Redbridge and Loughton Discharge Data
Loughton Data Plotted with 3hr Lag and Reduced by 1 Cubic
from Original Values to Compare with Redbridge Data
Figure 5.8
Correlated Discharges Between Loughton and Redbridge Low Flows

- 9th March 1982
- 3rd and 25th June 1982

sections 1 to 4 from previous figures (5.4-5.7) plotted here

Q_R = Q_L
reach. This was achieved by looking for the characteristic flow pattern at a level recorder station and identifying the same pattern from the printout data of the Redbridge station. That is to say, the peaks, troughs or gentle undulations in the level recorders could be easily recognised on the Redbridge data with an approximate three hour time lag. Therefore, establishing the exact time lag from previous data was not essential. Knowing the discharge difference was more important as the actual time lag could be found by inspection. Figure 5.9 shows a typical chart recording at recorder station 3 together with the discharge values recorded at Redbridge.

It was now possible to estimate the discharge at Loughton. As no further information except manual gauging with a propellor meter at the recorder locations would assist in calculating the discharge further up the reach it was decided that the Loughton discharge would be applied to the whole reach.

The only substantial drainage into the river, upstream of the Loughton gauge and below recorder 3 was from the M11 motorway. The runoff from this would be fairly rapid and as only gradually varying flows have been considered, it was reasoned that this would not affect the estimates of discharge in the reach above recorder 3.

5.1.2 Water Level Measurements

Three Ott Horizontal Water Level recorders were used for the field study. Figure 5.10 includes a block diagram of the recorder layout and a photograph of recorder 1 at section 1.039, just below the village of Abridge.
Figure 5.9
Typical Chart Recording at Station 3 with Plot of Discharge Values Recorded at Abridge
Figure 5.10
Diagram of Level Recorder Layout with a Photograph of Recorder 1
These recorders were installed in the summer of 1983 and not calibrated until the autumn. For the first 9 months, the limits of all three recorders were incorrectly set, leading to a loss of data at times of high flow because the recorders reached their upper limits before the water levels peaked. TWA corrected the problem once it had been picked up but not before all significant flows for the 1983/1984 wet season had been lost. Recorder 1 provided the least information over the three years due to a malfunction of the float at high flows. For the 1985/1986 wet season, recorder 3 failed to record all high flows.

Figure 5.11 is a sample of the output from a recorder chart.
Figure 5.11
Sample Output from Recorder 3
5.2 Vegetation

Dense growths of vegetation on the floodplain are considered a major factor in the resistance to flow in the river during flooding. TWA, therefore, carry out a costly annual cutting exercise of the floodplain vegetation to improve the carrying capacity of the river during the wet winter months.

One side effect of lowering the banks of the natural river to form the present artificial floodplains in the Experimental Flood Alleviation Scheme was the increased moisture content of the floodplain surface during the summer months. This is due to the natural water table lying closer to the surface of the floodplains. As a result, large quantities and varied types of vegetation abound, encouraged also by surface runoff rich in fertilisers from the surrounding fields.

5.2.1 Vegetation Type and Density

The river vegetation was photographed throughout its seasonal cycle, to record the type and density, in the main channel and floodplain.

Three types of vegetation abounded.

1. Reed growth adjacent to the main channel, up to 2 metres in height, and forming a dense marginal belt up to 2 metres wide. Stems approx. 5-10mm in diameter, very woody.

2. Dense grasses and other marsh plants up to 1 metre in height, broad leaved, thin stems, uniformly covering the floodplain.
3. Aquatic plants in the main channel extending from channel bed to the surface forming, in places, a dense matting difficult to wade through.

Also scattered on the floodplain were small bushes.

Figure 5.12 shows the floodplain vegetation clearly. Taken in mid-June 1984, the vegetation has almost reached its maximum height. Figure 5.13 shows in detail the type of aquatic growth in the main channel.

In June 1984, a short length of the reach was overflown using a light aircraft as low as 300 feet above the ground. A series of photographs were taken from the plane. The door of the single engined two seater Cessna had been removed to enable the author to lean out of the plane during the flight and take near vertical shots of the river, using an automatic SLR camera with power winder. A high level photograph, figure 5.14, taken at approximately 3000 feet shows the reach between surveyed sections 1.029 to 1.036.

For an analysis of the vegetation, the author pieced together a large scale mosaic of the river between section 1.029 and 1.036. These showed in detail the type and extent of vegetation on the floodplain. The prints were obtained from slides using the Ilford Cibachrome process to maximise the definition. A photograph covering sections 1.029 to 1.032, with lesser detail, is included here, figure 5.15. The aerial photographs were backed up with pictures of the river taken at ground level.
Figure 5.12
Photograph of Floodplain Vegetation (June 1984)

Figure 5.13
Photograph of Weed Growth in Main Channel (June 1984)
Figure 5.14
Aerial Photograph of Modelled Stretch of River (June 1984) 
(Sections 1.029 to 1.036)

Figure 5.15
Aerial Photograph of River Roding Between Sections 1.029 and 1.032
5.2.2 Seasonal Durability of Vegetation

Most of the vegetation growth dies off in winter. A combination of weather and overbank flow knocks the vegetation flat with the exception of the more hardy reed stems.

Figures 5.16 and 5.17 show the same bend in March 1984 and November 1984. The bulk of the vegetation in March 1984 had been cleared the previous Autumn but a considerable amount of marginal vegetation remained. The photograph depicting the same bend in November 1984 shows the vegetation beginning to brown and die off. As part of a controlled exercise, no clearing took place in 1984 and considerable stands of vegetation remaining can be seen in the November 1984 photograph.

Bushes and trees lose their leaves during the winter, leaving stiff branches and stems, providing resistance to flow.
Figure 5.16
Photograph of River Bend between Section 1.035 and 1.036
(March 1984)

Figure 5.17
Photograph of River Bend between Sections 1.035 and 1.036
(November 1984)
5.3 Current Metering

Between January 1985 and June 1986, Thames Water Authority carried out several current metering exercises. Only one traverse was within the bounds of the level recorder stations. Table 5.1 is the record of the traverse, taken at section 1.031. An OTT propellor current meter was used. Gauging was carried out by wading the floodplain and using a temporary bridge to gauge the main channel. One velocity reading was taken at 0.5 x depth of flow at each station. The depth mean velocity was obtained by multiplying the recorded velocity by a correction factor of 0.96. Another traverse was taken at the Loughton gauge, also during a period of high flow. Unfortunately they were carried out whilst the rate of change of discharge was greater than 0.2 cumecs per hour and could not be used to corroborate the previously established discharge calibration of the reach with the Redbridge gauge.
**CURRENT METER FLOW GAUGING RESULTS**

**LOCATION:** RODING AT ABRIDGE  
**SITE:** RIGHT ANGLE FROM TFHP BRIDGE  
**GAGED BY:** 1.8R + 6.8M EAWING  
**DATE:** 4.1.86  
**MEASURES:** UTIL NO 5458 WITH PROP NO 1-157049  
**METHOD OF CALCULATION:** H.E.M. SECTION  
**DEPTH (D):** 0.5 X (VELOCITIES ADJUSTED BY 0.96)  
**ORIGIN:** LEFT BANK  
**SHIFT:** FINISH  
**TIME:** 11.42  
**SPEED:** 0.140 0.000

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**TOTAL DISCHARGE (CUBICS):** 10.1598  
**TOTAL AREA (SQ M):** 20.49  
**MEAN VELOCITY (M/SEC):** 0.4958

Table 5.1  
Current Meter Flow Gauging Results at Section 1.031  
Carried out on 4th January 1986
5.4 River Erosion

With the abundant growth of vegetation on the floodplain, it is unlikely that it would scour. However, it was worth investigating whether scour channels between clumps of vegetation might be forming. As already mentioned in the introduction to this chapter, a ground survey was carried out in 1983 to map accurately the stretch of river and a number of detailed cross-sections were taken across the river during the exercise. A cross-section survey was carried out again between sections 1.029 and 1.037 in June 1986 to determine whether or not significant changes in level had occurred anywhere on the floodplain or in the river channel bed. Figure 5.18 shows the location of the section traverses in 1983 and 1986. The 1983 traverse location numbers have been marked with an asterisk. An exact reproduction of the traverse lines at each section could not be followed as there were no permanent marker stations at each section. Two permanent ground stations nearby provided the base line for the traverses. Despite this difficulty, the 1986 traverse locations were very accurately relocated and followed fairly closely the 1983 traverses. Thus, a comparison between them could be made. Sections 1.029, 1.030 and 1.034 to 1.037 are in appendix A.5. Sections 1.031 and 1.033 are presented in figure 5.19. Two points worth noting are, firstly, in the inside bend of the main channel, on section 1.033, significant scour has occurred indicating a high
Figure 5.18
Location of Sections of River between 1.029 and 1.036
Surveyed in 1983 and 1986
Figure 5.19
Comparisons of Cross-section Surveys of Sections 1.031 and 1.033
velocity gradient there, possibly at times of high flow. On the floodplain in section 1.031, runelling, or longitudinal scour channels appear to have formed, creating an irregular cross-section. A photograph taken in May 1986, of section 1.033, looking upstream towards recorder 1, shows some longitudinal scour of the floodplain with standing water in the low lying areas, figure 5.20.

5.5 Analysis of Field Work

Prototype data is crucial in 'proving' a laboratory model and therefore some of the analysis of the data recorded in the field has been left until chapter 6. In particular, the depth mean velocities recorded at section 1.031 from the velocity traverse. However, stage-discharge curves at the recorder stations are presented here together with associated roughness values calculated from them.

5.5.1 Stage-Discharge Curves

During the 1984/1985 wet season, discharge data greater than 2 cumecs were collected between the last week in November 1984 and the beginning of March 1985. Three lengthy periods of significant flow were recorded from;

16th November 1984 lasting approximately 27 days,

21st January 1985 lasting approximately 10 days and

4th March 1985 lasting approximately 5 days.

A few short duration floods were logged as well. Lower discharges,
Figure 5.20
Photograph of Section 1.033, Looking Upstream towards Recorder 1
(May 1986)
down to about 0.5 cumecs, were much more common in Autumn and Spring and ample points were recorded from October to November 1984 and from April to June of the following year. About 251 discharges were logged during the entire wet season. None of the recorders were fully operational during the period of data collection hence none of the stage discharge curves at the recorder locations were constructed from the maximum no. of data points available. Recorder 1 logged 10 levels out of a maximum 251 recorded discharges, recorder 2 logged 43 and recorder 3 logged 207.

For the 1985/1986 wet season, due to the similarity of water levels at low flows with the previous wet season data, fewer points were recorded for discharges below 10 cumecs. There were also fewer periods of long flow duration for obtaining sets of data points. Data were collected between the middle of December 1985 up to the middle of April 1986. Largest flows were recorded between 10th December 1985 and 6th January 1986. A total of 33 discharges only were logged throughout the season. The peak discharges, however, were much higher in '85/'86 than '84/'85. A much improved recording rate of water levels was obtained, with recorder 1 logging 19 levels out of a maximum 33 recorded discharges, recorder 2 logging 33 and recorder 3 logging 24.

Over the '84/'85 and '85/'86 wet seasons, two controlled experiments were carried out on the river to assess the effect of altering the floodplain roughness on the discharge capacity of the river.

1. In the summer of 1984, the floodplain grasses were left uncut to gauge their effect on the capacity of the river during the winter of 1984/1985.
2. In October 1985, however, the bulk of the grasses were cut on the floodplain with the exception of some marginal vegetation alongside the main channel, comprising tall stands of thick reeds. These were not as accessible being close to the waters edge and therefore in soft mud. As part of the controlled study, it had been intended that all the marginal vegetation be left intact for the 1985/1986 wet season but unfortunately this was not the case. For the analysis then of the discharge characteristics for the river during the 1985/1986 wet season, it has been assumed that normal cutting policy was carried out. That is to say, complete clearance of the floodplain with the exception of some scattered stretches of reeds left intact adjacent to the main channel. In both experiments, the main channel was left untouched and had not been dredged for at least 6 years. It could be assumed, therefore, that the main channel exhibited an established mature roughness state.

The first experiment was to determine the effect of the worst case of river roughness that might occur. The second experiment had been intended to determine the effect of TWA's proposed minimal cutting policy of leaving a fairly wide margin of the more inaccessible reeds adjacent to the main channel. It has still been possible to examine the effect of this policy by use of the laboratory model. Details are included in chapter 7.

The stage discharge curves were constructed from data obtained during the period when the vegetation would have begun to die off. It is noticeable that whereas the flimsier vegetation seemed to die off, the thicker, 'stick' like reeds remained intact during the winter period, thus continuing to provide resistance to flow. Figure 5.21 shows the stage-discharge curves for all three recorders plotted to absolute levels. The loss of data on recorders 1 and 3 can be clearly seen. The recorder sections have been shown in figure 5.22 with water levels just above bankfull included.
Figure 5.21
Plot of Stage-discharge Data for Recorders 1, 2 and 3 for 1984/1985 and 1985/1986 Wet Seasons
Figure 5.22
River Sections at Recorder Stations 1, 2 and 3
Bankfull Levels are Included
5.5.2 Resistance Parameters

Resistance parameters have been calculated for cross-sections 1.010 (recorder 3), 1.028 (recorder 2) and 1.039 (recorder 1) for 1984/1985 and 1985/1986 wet seasons. These have been presented in Tables 5.2, 5.3 and 5.4. They were calculated from tables of discharge, flow cross-section area and wetted perimeter at each cross-section which are included in appendix A.5.

A mean friction slope of the river when above bank was taken as 1/700, a value obtained from a longitudinal profile of the water surface when uniform overbank conditions obtained between recorder 1 and recorder 3. This confirmed the values used by Wojcik (58) who used a mean floodplain slope of 1/700 and mean main channel bed slope of 1/900 in his design of the Flood Alleviation Scheme. In calculating roughness parameters, and assuming uniform flow, a bed slope of 1/900 was taken for below bankfull discharges. Above bankfull, a bed slope of 1/700 was taken for the entire flow.

Manning 'n' values have been plotted against water elevation for the three recorders, figures 5.23 to 5.25. The 'n' values were calculated by the 'single channel method'. The entire cross-section was used in the calculation of a single 'n' value without subdividing the flow at the main channel/floodplain interface. The single channel method was used to determine the roughness coefficient because none of the cross-sections had a sharp transition from main channel to overbank flow and it was difficult to determine the transition region.

As the depth of flow approached the overbank condition and the river
overflowed onto the floodplain, the 'n' value decreased quite sharply. The decrease in calculated roughness just above topbank was to accommodate the rapid decrease in calculated hydraulic radius as the river flooded. James and Brown (15) in their experimental work on prismatic compound channels, calculated 'n' values by this method and produced similar curves where the roughness decreased just overbank and recovered as the depth increased above topbank. However, the decrease in 'n' up to the overbank condition could not be similarly explained. Sargent (65), found that for a number of rivers studied in the U.K, the calculated 'n' value decreased with increasing stage reaching a minimum asymptotic value just below bankfull. As mentioned above, the Roding exhibited the same characteristics below bankfull but without reaching an asymptotic value of 'n'. There is no sharp transition from main channel to floodplain flow due to the irregularity of the river banks and riverside vegetation. Thus, the asymptotic value observed by Sargent near bank full conditions could have been masked by the reduction in 'n' caused by a decrease in hydraulic radius as a result of the transition from in-bank to out-of-bank conditions. In figure 5.24, recorder 2, 'n' value just overbank is considerably smaller than the values at recorders 1 and 3 in a similar state. This could be due to the sharper transition from main channel to overbank flow, causing a greater reduction in 'n' associate with the large reduction in hydraulic radius. Below is a table of bankfull and maximum above-bank 'n' values:

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ANALYSIS OF FLOW
Recorder 1
1984/1985

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Table 5.2
## ANALYSIS OF FLOW

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Table 5.3
## ANALYSIS OF FLOW

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**Table 5.4**
Figure 5.23
Variation of Manning n vs Water Elevation for Recorder 1

Figure 5.24
Variation of Manning n vs Water Elevation for Recorder 2
Figure 5.25
Variation of Manning n vs Water Elevation for Recorder 3
Chapter 5

Maximum 'n' values at recorder 2 were for flows 1.0m and 1.1m above topbank respectively and recorder 3, 0.9m and 0.7m above topbank.

Recorder 3 showed no variation in above-bank roughness value between the two seasons. This suggests that vegetation cutting does not reduce water levels at this station. Immediately downstream of recorder 3 is a 300 metre straight section of two stage channel. This was built as part of the river diversion works for the M11 Motorway. At first inspection, one would assume the capacity of the artificially excavated canal would have a greater discharge capacity than the natural river. The low 'n' value recorded for bankfull conditions at recorder 3 implies that this might be the case for main channel flow but the high values of 'n' at recorder 3 during flooding could be due to a backwater effect of the 'constricted' reach downstream. It is possible that the floodplain of the canalised section is not sufficiently wide to match the high flow characteristics of the monitored river upstream. To further emphasise the effect of the downstream reach on recorder 3, the floodplain of the canalised section has never had substantial growths of vegetation on it, unlike the remainder of the river. It is likely, therefore, that the discharge capacity of the artificial compound channel remained unchanged over the two seasons. This could be the only explanation for the similar 'n' values at recorder 3 for the two wet seasons.

Thus, the results from recorder 3 have been discounted in comparing field data to laboratory model studies and as typical roughness
values of the river. Recorder 2 has been used for typical 'n' values to match photographs of the river.

A range of 'n' values corresponding to bankfull conditions and topbank conditions for the reach, obtained from the roughness plots, have been included together with photographs of the river in the different states. Figure 5.26, is a photograph of the bankfull condition downstream of section 1.035. This condition corresponds to a roughness value of about 0.043. Figures 5.27 and 5.28 show two views depicting floodplain roughness, taken in May 1986. They have a corresponding 'n' value at a submergence of about 1 metre of 'n'=0.031.

Photographs of flooding between sections 1.029 and 1.036, taken in January 1986, are shown in appendix A.5.
Figure 5.26
Photograph of Bankfull Flow Downstream of Section 1.035
(May 1986)

Figure 5.27
View of Floodplain looking Downstream from Section 1.034
(May 1986)
Figure 5.28

View of Floodplain looking Upstream from Section 1.034
(May 1986)
Laboratory Modelling of River Roding

A mathematical treatment of turbulent fluid flow with a free surface without considerable simplifications is not possible. In a real situation containing a problem of this nature, the hydraulic engineer can make use of a physical model as a tool for producing technically and economically optimal solutions to specific engineering problems. Thus, a model could be used to convert given input parameters such as geometry, forces, boundary conditions into output parameters such as flow rates and levels.

In the case of the investigation into the River Roding, the reasons for using a laboratory model were twofold.

1. To reproduce in the laboratory, the behaviour of a stretch of the river from known conditions and then experiment on the 'proved' model to predict the effect of altering certain parameters in the field pertaining to a river management programme. The main objectives of the river management programme are to improve the effectiveness of the reach in carrying peak flood flows and to minimise the cost of annual maintenance.

2. To investigate the more fundamental interaction between the main channel of the river and its floodplain. This was of interest because much work had already been carried out on idealised river floodplain geometries but not on the more natural case of which the Roding was a good example.
6.1 Modelling Theory

Research on scale models is based on the theory of similarity between model and prototype. Novak and Cabelka (55) state that the theory of similarity shows:

1. how the model should be theoretically founded;
2. what requirements the model must fulfil to depict reality on a reduced scale as faithfully as possible;
3. which parameters might be measured during an experiment;
4. to what phenomenon the results may be applied and what is the extent of their validity.

Dimensional analysis is the primary approach to determine the criteria of similarity in the investigation of complex turbulent open channel flow.

Two methods of approach are normally discussed in standard textbooks on the subject (55,56), Rayleigh's method and Buckingham's method. They are well established and will only be mentioned briefly. Rayleigh's method consists essentially of writing down the functional equation which formulates and defines the problem, rewriting the equation in terms of the dimensions involved and then equating the exponents of \([M]\), \([L]\) and \([T]\) to ensure the equation is dimensionally homogeneous. Buckingham in a more theoretical approach, related the number of parameters in a correct functional equation to the number of variables needed to specify the
Two scaling criteria are found to apply to open channel flows. The Reynolds number, \( 4VR/\nu \), and the Froude number, \( V/\sqrt{gd} \), must remain constant between prototype and model to maintain dynamic similarity. \( R \) is a typical dimension of length, such as the hydraulic radius of the river, \( V \) is the mean flow velocity, \( \nu \) is the dynamic viscosity of the fluid, \( g \) is the acceleration due to gravity and \( d \) is the depth of flow.

An inspection of the two numbers will show that the Reynolds number requires \( VR \) to remain constant and the Froude number requires \( V/\sqrt{gd} \) to remain constant, assuming that the same fluid for model and prototype are used and they are subjected to the same gravitational acceleration. Thus, in the case of physical modelling of river flows in an experimental laboratory using water as the fluid, both scaling laws cannot be adhered to.

The Reynolds number is a measure of the importance of the viscous forces and represents the ratio of inertial/viscous forces. The Froude number, however, is a measure of the importance of the gravitational forces and represents the ratio of inertial/gravitational forces.

To model drag effects in rough turbulent flow, it is sufficient to ensure that the model flow is also rough turbulent and the frictional resistance due to form effects is correctly scaled. Sharpe (56), in his textbook
"Hydraulic Modelling", states that the most reliable criteria for determining rough turbulent flow are those in which the Reynolds number is expressed in terms of the shear velocity, $V^*$, and equivalent roughness size, $k_o$, where

$$V^* \frac{k}{\sqrt{\nu}} > 100$$

where the shear velocity is the ratio of bed shear stress/fluid density $V^* = \sqrt{\frac{\tau_w}{\rho}} = \sqrt{\frac{3RS}{g}}$.

This parameter is rarely possible to use as determination of the equivalent roughness size can be very difficult. However, extensive experimentation has shown that above a critical value of Reynolds number, based on mean section flow velocity $V$, and hydraulic radius, $R$, of about 4000 for open channel flow, the viscous forces acting within the fluid are insignificant in comparison with the inertial forces within the body of fluid.

Invariably, river flow is rough turbulent, with Reynolds numbers in the Roding ranging between $10^5$ - $10^6$. It remains then to ensure that when modelling the river flows, the model Reynolds numbers are sufficiently high for viscous effects to remain unimportant.
6.2 River Roding Model

6.2.1 Choice of Model Scales

The length of river monitored in the field study was approximately 1.2 kilometres and the average width of floodplain 30 metres, giving a length to width ratio of 40. The laboratory flume, described in detail in chapter 3, was 9.5 metres long and 1.2 metres wide, having a length to width ratio of about 8. To accommodate the entire reach in the flume was impractical as it would have been an uneconomic fit in terms of available area within the flume. The alternative was to model a reduced length of reach, one that would maximise the use of the flume.

It was now necessary to satisfy two criteria, having decided on modelling a fraction of the reach.

1. The reach must contain a meander pattern to allow more detailed experimentation on a natural river meander/floodplain.

2. The reach must be sufficiently representative of the entire stretch under investigation.

To satisfy the second criterion, the proportion of meander to relatively straight section needed to be about the same proportion between modelled reach and entire reach.

A choice of reach was obtained principally by inspection and superimposing the flume boundaries to different scales until a suitable fit was found. A stretch of river approximately 400 metres
in length and 300 metres downstream of the village of Abridge was chosen, see figure 1.1 and figure 5.2. This has been reproduced in simplified form with the flume boundaries added and with modifications to the ends of the reach to provide transitions at the inlet and outlet of the flume, figure 6.1. The proposed 'fit' within the flume required a horizontal reduction in scale of the prototype of 50:1.

Typical mean velocities and depths on the Roding floodplain during periods of moderate flow, about 10 cumecs, are 0.5 m/s and 0.5 m. Scaled down using a length ratio of 50:1 would give mean model velocities (proportional to \( \sqrt{d} \), approximately 7:1) of 70mm/s and 10mm depth of flow. Aside from the difficulty of measuring such low velocities, the Reynolds number would be sufficiently low for viscous forces to begin to have significant effects within the operating range of the model.

The cross-section of the prototype main channel had an aspect ratio (width/depth) ratio of about 4. Part of the experimental study was aimed at investigating the more specific phenomenon of the turbulent interaction between a natural river channel and that of its floodplain. Past laboratory research on prismatic compound channels (chapter 2), has demonstrated that the interaction phenomenon is maximised for aspect ratios much lower than this.

If the model were to have a distorted scale, to increase the operating flow depths and Reynolds numbers, the following scale ratios for various parameters would apply:

\[ M_x = \frac{\text{prototype value}(x)}{\text{model value}(x)} \]

Where \( x \) represents the ratio of prototype value(x)/model value(x)
Figure 6.1
Plan of laboratory model of River Roding
is a physical parameter. Given $M_d, M_b, M_L$, where $d$ is the normal depth of flow, $b$ width of river model and $l$ the length of model

$$M_Q = \frac{d}{M_L b}$$  \hspace{1cm} \text{(discharge scale)}

$$M_s = M_s = \frac{M_d}{M_L}$$  \hspace{1cm} \text{(bed slope scale)}  \hspace{1cm} S_b - \text{bed slope} \hspace{1cm} S_e - \text{friction slope}

$$M_\lambda = M_s \times \frac{M_R}{M_d} \approx M_s$$ \hspace{1cm} \text{(Friction factor scale from } \lambda = \frac{8gRS}{V^2})

Thus, distortion of the model would not only increase the Reynolds numbers on account of the increased flow depth but also the increased bed slope would raise the section velocities over the undistorted model.

Novak has shown that

$$M_R = \Phi\left[M_d, \left(\frac{M_d}{M_b}\right), d\right]$$

where $M_R$ is the scale of hydraulic radius and, therefore, strictly speaking for a distorted model, similarity with the prototype can only be achieved at a single depth of flow. This is because $M_R$ varies with $d$. However, where the width/depth ratio is large, as is the case for the floodplain which carries the bulk of the flow and $R$ is approximately equal to $d$, little variation in $M_R$ will occur and $M_R$ can be equated to $M_d$.

The calculation below demonstrates the effectiveness of model distortion in increasing the operating Reynolds numbers.
Chapter 6

\[ \text{Re} = \frac{4V_R \gamma}{\nu} \]

\[ M_{\text{Re}} = M_v M_{\text{R}} \] where \( M_v = M_d \) and \( M_{\text{R}} \) is approximately \( M_d \) for a wide channel. Thus,

\[ M_{\text{Re}} = \frac{1}{3} M_d \]

For a model with a vertical exaggeration of 3, which is the same as reducing the vertical scaling factor by 3 would increase the Reynolds number over the undistorted case for equivalent prototype conditions by a factor of 5.

One drawback in using a distorted model is the resultant distortion in velocity profiles compared with the prototype, especially at boundary discontinuities such as the main channel-floodplain interface. For large width to depth ratios, such as on the floodplain, comparisons between depth averaged velocities can be made as the flow is largely 2-dimensional.

It was concluded, therefore, that a vertical exaggeration of the model was a necessary solution. After consideration of the reduced aspect ratio, model Reynolds numbers and the problems of excessive distortion, a vertical model scale of 16:1 was arrived at and the following scale ratios evaluated:

\[ M_Q = 3200 \]
\[ M_v = 4 \]
\[ M_{\lambda} = 16/50 \]
\[ M_{\infty} = 16/50 \]
6.2.2 Construction of the Model

The floodplains of the Roding within the Flood Alleviation Scheme had been artificially excavated and were relatively flat. A slight fall towards the main channel to promote surface drainage had been incorporated but to all intents and purposes, the floodplain could be considered planar with the main channel meandering within it. An aerial photograph showing the modelled stretch is in figure 6.2, demonstrating the uniformity of the floodplain. Figure 6.3, a picture of the laboratory model without any added roughness, provides a comparison between model and prototype.

The floodplain was constructed as a plane (chapter 3), providing a reference datum for water levels when above the main channel top bank. The floodplain was constructed as an idealised version of the prototype floodplain. Figure 6.4 presents a photograph of the completed model fitted with profile plates of each surveyed cross-section. The 'idealisation' of the floodplain is clearly visible between template and floodplain. The undulations which had been eliminated were to be considered as surface roughness.

In chapter 5, the prototype floodplain bed slope was found to be 1/900. The modelled stretch, however, from the longitudinal survey of the modelled reach had a bed slope closer to 1/1000. Thus, for the model, a prototype bed slope of 1/1000 was adopted.
Figure 6.2
Aerial Photograph of Modelled Reach of River Roding
Shortly after Completion of the Flood Alleviation Scheme (1980)

Figure 6.3
Photograph of 'Smooth' Laboratory Model
Figure 6.4
Photograph of Model Fitted with Profile Templates
6.2.3 Stage Discharge Curves

The stage-discharge curves were evaluated from a set of normal flow depths for a range of discharges in the model. Almost all of the data were evaluated for overbank flow and the automatic depth logger (chapters 3 and 4) could be used down the flume. For overbank flows, the datum for measuring depths of flow was the floodplain. A series of M-profiles, drawdown and backwater curves, were established for a particular discharge by altering the downstream water level using the tail gate. Although the longitudinal profiles were not as smooth as would be obtained in a prismatic model of simple cross-section, the uniform condition could be readily inferred. Figure 6.5 is a plan of the river model with the position of the longitudinal water surface profiles marked in. Appendix A6 contains series of these curves for different model roughness configurations. Large surface disturbances were caused by the effect of the upstream bend between Y=1500 and Y=2500 Normal depths of flow were evaluated between Y=4000 and Y=6500.

6.2.4 Stage-Discharge Comparisons with Field Data

The field data, presented in chapter 5, have been used in this chapter to provide a comparison with the model. It is relevant, therefore, to present an assessment of the accuracy of the field material. All discharge measurements were recorded at a permanent weir gauging station. The calibration of this weir has been
Figure 6.5
Plan of Laboratory Model With Location of Longitudinal Water Surface Profiles
determined by numerous discharge gaugings of the river using a propellor type velocity meter. From the flow charts, it can be seen that, assuming an accurate calibration, the gauge can be read to within 1% of the correct discharge. However, TWA have stated that the gaugings are accurate to within 5%. To compound the problem, the discharge at the gauging station has had to be related in a fairly complicated manner to the monitored reach, almost 10km upstream, containing the three recorders. It seemed reasonable that the corrected discharges used, might be in error by as much as 10%. The level measurements could be measured to within 20mm from the charts. At an operating level of 1 metre above the floodplain, the resultant error would be 2%. In view of the relatively high accuracy of the level recorders in comparison to the measured discharges, only a discharge error band of 10% has been marked on the field rating curves presented in this chapter.
6.3 Model Roughness

Once the model had been constructed and the data collection apparatus commissioned, a stage discharge curve for the model in its unroughened state was produced. The unroughened floodplain surface was gloss painted polystyrene and the main channel gloss painted cement render. A comparison of the prototype data indicated that the model, as had been expected, required extra roughening. During the experiments to 'prove' the laboratory model, different roughness types had to be used.

In this section, all the roughness types dealt with in the laboratory study are covered, although some have not been used until chapter 7. A complete list of all the roughness types and configurations is given in Table 6.1 at the end of this chapter.

6.3.1 Flexible Roughness Elements

At the outset, the author intuitively felt that the dense vegetation growth on the floodplain could be effectively modelled by flexible roughness elements, to mimic the real roughness. Much experimental work had been carried out on flexible roughness elements. As a starting point, the author decided to use flexible roughness elements on the floodplain and rigid roughness in the main channel. Two papers on flexible roughness by Kouwen and Unny (60), entitled "Flexible Roughness in Open Channels" and Kouwen and Li (62), entitled "Biomechanics of Vegetative Channel Linings", were referred to. These included detailed experiments with plastic strips of thickness varying from 0.125mm to 0.506mm, a strip width of 5mm, undeflected heights from 100mm to 150mm and roughness elements per
square metre ranging from 741 to 5000. All elements were aligned with their broad side facing the flow. The element layouts and results of different series are presented in appendix A.6.

Wojcik (50), assumed a Manning roughness value for the floodplain of \( n = 0.032 \) when he calculated the floodbank full discharge capacity for the Experimental Flood Alleviation Scheme. Using the Manning equation to describe the discharge-level characteristics of the river:

\[
V = \frac{1}{n} R^{\frac{2}{3}} S^{1.25}
\]

produces scaling ratios for the \( n \) value

\[
M_n = M_r^{\frac{2}{3}} M_s^{\frac{1}{3}} / M_v = M_d^{\frac{2}{3}} M_s^{\frac{1}{3}} / M_d = M_d M_s^{\frac{1}{3}}
\]

gives

\[
M_n = 0.90
\]

Thus, typical model \( n \) values would nearly equal prototype values.

Using the design values taken by Wojcik, mean floodplain velocity of 1.33m/s and hydraulic radius of 1.20m, produces a VR product of about 1.5. Scaled to a model VR value of about 0.025 and corresponding \( n \) of 0.032 and a model bed slope of 0.0033 an estimate of suitable plastic roughness type might be found from Kouwen et al.

An inspection of the series showed that all were too rough but a general indication of spacing and roughness size had been obtained.

The author experimented on flexible roughness in a tilting laboratory flume, 0.3 metres wide and 5 metres long. The roughness strips were punched out of sheets of acetate, using a specially designed punch, in a regular grid. Two thicknesses of sheet were
used, 0.13mm and 0.05mm. The strips were 5mm wide and 37mm in length. Details of the roughness elements and experimental results are given in appendix A.6.

One set of plastic roughness elements, subsequently named FX1, fitted the preliminary design requirements well and a plot of Manning roughness vs Reynolds number and VR is presented in figure 6.6.

In all, six flexible roughness types, FX1 to FX6, were manufactured during the course of the programme. FX3 to FX6 were produced and introduced into the flume without any prior testing in a separate flume to determine their n-VR characteristics. The following table details the FX series characteristics:

<table>
<thead>
<tr>
<th>SERIES</th>
<th>MATERIAL TYPE</th>
<th>LENGTH (MM)</th>
<th>DENSITY (STRIPS/M²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FX1</td>
<td>A</td>
<td>37</td>
<td>1060</td>
</tr>
<tr>
<td>FX3</td>
<td>B</td>
<td>50</td>
<td>970</td>
</tr>
<tr>
<td>FX4</td>
<td>B</td>
<td>50</td>
<td>1900</td>
</tr>
<tr>
<td>FX5</td>
<td>A</td>
<td>50</td>
<td>890</td>
</tr>
<tr>
<td>FX6</td>
<td>A</td>
<td>50</td>
<td>1900</td>
</tr>
</tbody>
</table>

6.3.2 Rigid Roughness

Two types of rigid roughness were used on the floodplain, cylindrical rods and Enkamat matting, type 7200.
Figure 6.6: Manning Roughness 'n' vs Reynolds Number and VR for Plastic Strip Roughness FX1
1. Enkamat Matting

This material was made of a plastic, formed into a wiry mat with substantial voids between the wires and was approximately 20mm thick. Sheets of the matting were cut and laid out uniformly on the floodplain. They were glued to the painted polystyrene surface with blobs of Arbosil silicone sealant. Figure 6.7 is a photograph of Series 4 with flexible roughness (FX3) mounted on Enkamat matting.

2. Cylindrical Rods

Rods of diameter 2.5mm and varying length and separation were used. A photograph of the rods in use is shown in Figure 6.8 depicting the floodplain roughness for series 8.

Various types of materials were used in the main channel. As the main channel was heavily roughened with weed growth in the prototype, the bulk of material used was to provide near 'clogging' roughness with the exception of series 2 where small angular chippings of mean diameter 10mm were glued to the main channel walls. The 'clogging' roughness used was Enkamat matting, hairlok - a type of dense fibrous matting and 20mm dia. glass spheres.
Figure 6.7
Photograph of Roughness F4 (FX3 on top of RR2)
Series 5

Figure 6.8
Photograph of Roughness F17 (Various RR3)
Series 8
6.4 Proving the Laboratory Model

River data for two wet seasons had been analysed, (chapter 5), and stage discharge curves for the reach between recorders 1 and 3 constructed. Reproducing the behaviour of the prototype in the model from known prototype data, otherwise known as 'proving' the model, was necessary before any constructive experimentation could be carried out.

6.4.1 Preliminary Roughening

The first step in proving the model was to verify whether the selected roughness type was sufficient. For Series 2 of the rating curve experiments, Series 1 being the unroughened case, flexible roughness elements (FX1) were used on the floodplain and pebbles glued to the main channel wall in a regular pattern (RR2). Series 3 employed the same floodplain roughness but the main channel being much too smooth, was filled with hairlok or more appropriately named, 'clogging' roughness. Figure 6.7 is a photograph of 'clogging' roughness.

Depth-discharge curves from recorder 2 for 1984/1985 and 1985/1986 wet seasons have been plotted, with flow depths relative to the floodplain, in figure 6.9. Bankfull depth was inferred from the intercept of the two slopes of the stage-discharge curve. Recorder 2 has been used as the prototype comparison with the model because the widest range of data had been obtained on recorder 2, it was closest to the modelled reach and recorder 1 upstream, had yielded very little data. Doubt has been cast on the relevance of recorder 3 to the monitored reach, on account of it being sited so close to a very
Figure 6.9
Figure 6.9b
Plot of Recorder 2 Depth-Discharge Data above Floodplain Level
Scaled to Model Values and Best Fit Curve Superimposed

84/85 wet season
85/86 wet season
different section of river downstream of it, (chapter 5). The data from recorder 2 have been scaled to model values and replotted in figure 6.9b. Superimposed on the data are best-fit 3rd order polynomial curves for each set of points. (These were produced with a numerical analysis software package on a mainframe computer).

Model depth-discharge Series 1,2 and 3 have been plotted in figure 6.10. The fitted curves from figure 6.9b have been superimposed on the model data with the 10% discharge error bands. Series 3 closely matches the 1985/1986 prototype data, with the exception of the peak flows where the model data begins to tail off. It seems, therefore, that the flexible roughness chosen, modelled fairly closely the cut state of the floodplain for almost the entire range of flows.

An explanation for Series 1 flattening off and diverging from the river data at high discharges could have been due to the lack of roughness along the side walls of the floodplain, which, on inspection of the aerial photographs had significant amounts of vegetation growing on them. Due to the exaggeration of scale in the model it is likely that the side walls would have assumed greater significance.

6.4.2 Detailed Roughening

It remained then to increase the model roughness to match the 1984/1985 flows and take the side wall effect into account. Series 4,5 and 6 attempted to do this.
Depth-Discharge Data for River Model Varying the Bed Roughness

Figure 6.10
Model Depth-discharge Series 1, 2 and 3 with Prototype Data Scaled Down and Superimposed
The roughness types for Series 4, 5 and 6 were:

**floodplain**                        **main channel**

Series 4 - Enkamat matting (RR1)         smooth

Series 5 - Flexible roughness (FX3)
          on top of enkamat matting (RR1)
          FX7 up the side walls
          (photo in fig.6.7)

Series 6 - Flexible roughness (FX3)

Enkamat matting was used in Series 4 to try out a different roughness type and Series 5 was an attempt to match the 1984/1985 season by incorporating a dense undergrowth in the form of the matting (RR1), with flexible vegetation on top together with the addition of side wall roughness. The result was a floodplain far too rough. Series 6, in an attempt to reduce the roughness, had no Enkamat on the floodplain but it too was still unsatisfactory. Figure 6.11 is a plot of the rating curves for series 4 to 6 with the prototype data superimposed as for figure 6.10. The lack of fit is clear.

It appeared therefore that although the 1985/1986 prototype data could be successfully compared, it was not possible to extend it to the 1984/1985 data without substantial changes in the roughness.
Figure 6.11
Model Depth-discharge Series 4, 5 and 6 with Prototype Data Scaled Down and Superimposed
At this stage it was decided that another roughness element was required and so RR3 - rigid cylindrical roughness elements were introduced. Series R1 through to R5 and plotted on figure 6.12 were the results of progressively roughening the model with the aim of reducing the level of water at lower flows whilst maintaining sufficient roughness at high overbank levels. For this exercise it was only necessary to produce 2 or 3 critical points on each curve. The R, or roughening, series eventually produced the fully roughened curve equivalent to the 1984/1985 river data, Series 7 (Figure 6.14). The DR, or de-roughening, series, figure 6.13, subsequently led to Series 8, the model equivalent of the 1985/1986 river data.

As can be seen from the curves in figure 6.14, Series 8 matches well the prototype data, although there is some 'tail off' at high discharges. Series 7 although still within the error band could not be altered to fit the curve. Maximum rigid roughness had been applied to the floodplain, non-submerged RR3 in a 25mm by 35mm grid together with a wide main channel roughness margin at twice the density. At low discharges this was sufficient. Vegetation roughness on the side wall was considerable, FX6. Without physically reducing the width of the floodplain to 'push' up the slope of the curve, an option that did not seem justifiable, it was decided to use Series 7 and Series 8, as they stood, as equivalent to the prototype data. The remaining experiments on the model were primarily aimed at the difference between proposed management schemes. It seemed possible that the model could not reproduce the turbulent losses experienced in the reach at high roughness states, which on account of the dense vegetation on the floodplain was very complex.
Depth-Discharge Data for River Model Varying the Bed Roughness

Figure 6.12
Model Series R1, R2, R3, R4, R5
Figure 6.13
Model Series DR1, DR2
Depth-Discharge Data For River Model Varying the Bed Roughness

Figure 6.14
Model Series 7,8 with Prototype Data Scaled Down and Superimposed
Figure 6.14b
Photograph of Fully Roughened Model - Series 7
6.5 Working Model

Series 7 and 8 represent the laboratory equivalent of the available prototype data. All flexible roughness had been abandoned in favour of cylindrical rigid roughness elements, with the exception of side wall roughness in Series 7. The deviation from realistic roughness had to be made as it had become apparent that small scale roughness could not sustain turbulent losses all the way to the fluid surface in the model, a condition which had been observed on the prototype by the evidence of large turbulent eddies erupting to the surface of the river during periods of high flow.

Roughness coefficients for Series 7 and 8 have been evaluated at section Y=4730 by the 'single channel method' and presented in appendix A.6. Manning 'n' values vs overbank depth for both series are plotted in figure 6.15. A bankfull 'n' value of 0.05, and maximum values of 0.055 and 0.04 were recorded for S7 and S8 respectively. Bankfull and maximum 'n' values for '84/'85 and '85/'86 from the prototype data at recorder 2 were, .044, .045, .031 .

In the distorted model, depth averaged velocities were equated to the prototype as discussed in section 6. A depth averaged velocity profile at section 1.031 was produced from the velocity traverse mentioned in chapter 5. This was compared with depth averaged velocity traverses carried out on the model (covered in detail in chapter 7) for approximately equivalent roughness conditions. The predicted model profile, scaled to prototype values agrees fairly well with the actual traverse, figure 6.16.
Figure 6.15
Plot of Manning Roughness 'n' vs Depth of Flow Overbank for Series 7 and 8
Figure 6.16

Depth Averaged Velocity for Model at Y=5200 Scaled and Compared with Prototype

- Curve A: from velocity profile on model 5200/series 2 run 2 scaled to prototype
- Curve B: scaled down from curve A by $(R_c/R_A)^{0.5}$
- Curve C: current meter gauging results at section corresponding to Y=5200 on model, Q=10 cumec

**Note:** $Q(\text{scaled}) = 15$ cumec
NOTES ON ROUGHNESS TYPES

To simplify the presentation of the roughness type table various phrases have been used as shorthand:

FX- - the 'FX' series refers to various types of flexible strips punched out of sheets of acetate. A detailed description of them has been given in Appendix A.5.

RR1 - enkamat matting, type 7720.

RR2 - 10mm dia. pebbles at 20mm centres.

RR3 - wire rods, 2.5 mm diameter of various lengths. Grid spacing is defined as 'lateral spacing' in mm by 'longitudinal spacing' in mm with the orientation along the flume. Given height is the length of wire above the floodplain surface.

marginal roughness - roughness positioned within area of floodplain adjacent to main channel approximately 40mm wide and running the length of the model on both floodplains where applicable.

reduced marginal roughness - as for marginal roughness but reduced to match river conditions for the 1985/1986 season when selective vegetation cropping took place.

side walls - boundary walls of floodplain.

Table 6.1
List of Roughness Types and Configurations used
Now a working model had been obtained, useful experimental work could be carried out on it. This has been dealt with in chapter 7.
### TABLE OF MODEL ROUGHNESS TYPES IN MAIN CHANNEL

<table>
<thead>
<tr>
<th>LABEL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>painted cement render surface</td>
</tr>
<tr>
<td>M2</td>
<td>10mm dia. pebbles at 20mm centres</td>
</tr>
<tr>
<td>M3</td>
<td>horsehair matting filling channel</td>
</tr>
<tr>
<td>M4</td>
<td>RR1 plus glass spheres</td>
</tr>
<tr>
<td>M5</td>
<td>FX3 plus glass spheres</td>
</tr>
<tr>
<td>M6</td>
<td>FX5 plus glass spheres</td>
</tr>
</tbody>
</table>

*Table 6.1 cont'd*
<table>
<thead>
<tr>
<th>LABEL</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>gloss painted polystyrene surface</td>
</tr>
<tr>
<td>F2</td>
<td>FX1</td>
</tr>
<tr>
<td>F3</td>
<td>RR2</td>
</tr>
<tr>
<td>F4</td>
<td>FX3 on top of RR2 marginal FX7</td>
</tr>
<tr>
<td>F5</td>
<td>FX3 marginal FX7</td>
</tr>
<tr>
<td>F6</td>
<td>FX3 up side walls</td>
</tr>
<tr>
<td></td>
<td>FX4 up side walls</td>
</tr>
<tr>
<td>F7</td>
<td>FX3 plus RR3 at 40mm by 100mm grid, non-submerged</td>
</tr>
<tr>
<td></td>
<td>FX4 up side walls</td>
</tr>
<tr>
<td>F8</td>
<td>FX1 plus RR3 at 40mm by 70mm grid, non-submerged</td>
</tr>
<tr>
<td></td>
<td>FX4 up side walls</td>
</tr>
<tr>
<td>F9</td>
<td>FX1 plus RR3 at 40mm by 70mm grid, non-submerged</td>
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<td></td>
<td>FX6 up side walls</td>
</tr>
<tr>
<td>F10</td>
<td>RR3 at 40mm by 35mm grid, non-submerged</td>
</tr>
<tr>
<td></td>
<td>FX6 up side walls</td>
</tr>
<tr>
<td>F11</td>
<td>RR3 at 40mm by 35mm grid, non-submerged</td>
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<td></td>
<td>marginal RR3 at 25mm by 35mm grid, non-submerged</td>
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<tr>
<td></td>
<td>FX6 up side walls</td>
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<tr>
<td>F12</td>
<td>RR3 at 40mm by 35mm grid, 40mm height</td>
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<tr>
<td></td>
<td>marginal RR3, 25mm by 35mm grid, non-submerged</td>
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<td></td>
<td>FX6 up side walls</td>
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<tr>
<td>F13</td>
<td>RR3 at 40mm by 35mm grid, 30mm height</td>
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<td>reduced marginal RR3, 25mm by 35mm grid, non-submerged</td>
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<td></td>
<td>FX6 up side walls</td>
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<tr>
<td>F14</td>
<td>RR3 at 40mm by 35mm grid, 30mm height</td>
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<td></td>
<td>reduced marginal RR3, 25mm by 35mm grid, non-submerged</td>
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<td>reduced marginal roughness RR3, 25mm by 35mm grid, 30mm height</td>
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<tr>
<td>F16</td>
<td>RR3 at 40mm by 35mm grid, 30mm height</td>
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<tr>
<td></td>
<td>marginal roughness RR3, 25mm by 35mm grid, non-submerged</td>
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<tr>
<td>F17</td>
<td>RR3 at 40mm by 35mm grid, 30mm height</td>
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<td></td>
<td>marginal roughness RR3, 25mm by 35mm grid, non-submerged</td>
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<tr>
<td></td>
<td>RR3 at 40mm by 35mm grid, non-submerged at selected bends</td>
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</tbody>
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Table 6.1 cont'd
Chapter 7

Laboratory Experimentation On River Roding Model

Chapter 5 dealt with the preliminary work which had been necessary to prove the model. Constructive experimentation could now be embarked upon and, from the similarity established between model and prototype it would be possible to relate the results from the model studies to the river.

The main aims of the experimental work were to investigate the stage-discharge characteristics and flow patterns in the Flood Alleviation Scheme whilst it was in a flooded state. Various floodplain/main channel roughnesses were used to simulate different vegetative conditions within the river. Minor changes to the floodplain geometry were made to assess the effect of reducing the form roughness of the floodplain. At a more fundamental level, experimentation to investigate the flow interaction between the meandering main channel and floodplain was also carried out.

Stage discharge curves have been established from longitudinal water surface profiles according to the method described in chapter 6. Mean principal flow velocities at points across various sections were measured. Surface flow patterns have been photographed.

Analysis of the model data presented here has been left until chapter 8.
7.1 Stage-Discharge Curves

Knowledge of the water surface level in a reach for a given discharge is of prime importance to the river engineer. In the case of the River Roding Flood Alleviation Scheme, known stage-discharge characteristics were necessary to determine the capacity of the river and hence its ability to accommodate flood flows.

Six alterations were made on the model once similarity had been established. A combination of different roughness states on the floodplain and in the main channel were utilised, together with a physical alteration to the floodplain boundaries.

Two states of the river had been monitored over successive wet seasons. The first represented an extreme state of floodplain roughness, with no cropping of the vegetation on the floodplain and the main channel left untouched. The second case was intended to be the implementation of a minimum cutting policy. Reasons for the proposed introduction of this policy as part of a river management scheme have been fully discussed in chapters 1 and 5. This entailed restricting the clearance of floodplain vegetation to areas away from the banks of the main channel, leaving a substantial margin of dense reedy vegetation. It had been intended that roughly a 2 metre margin of reeds, adjacent to the main channel, be left the entire length of the monitored reach. Unfortunately, when the floodplain clearance exercise was carried out in the autumn of 1985, the usual time of year to clear the river, the vegetation was overcut and a much reduced margin of reeds remained and none at all in some places.
7.1.1 Modelled Schemes - Vegetative Alterations on Floodplain

A first objective of the modelling programme, therefore, was to assess the effect of leaving a two metre margin of reeds adjacent to the main channel to conform to the proposed wildlife conservation aspect of the scheme. The second objective was to determine the capacity of the reach with all the floodplain vegetation cropped, a policy normally followed by TWA but not as of yet monitored in the field.

It has been observed in some of the flow visualisation experiments (described further on in this chapter) that separation of flow occurred at sharp meander bends within the model leaving a portion of the floodplain with a low flow velocity and thus low discharge function. It was decided, therefore, that the third objective in the model study would be to assess the effect of leaving vegetation uncut within these areas.

Depth–discharge curves were produced for the three cases, Series 9, 10 and 11, by a method described in chapter 6. Longitudinal water surface profiles used to construct the stage discharge curves are presented in appendix A.7.

Two types of roughness were selected for the floodplain as a result of the preliminary studies, detailed in chapter 6. Cylindrical rigid rods, 2.5mm in diameter, RR3, varying from 30mm in height to non-submerged. Two grid spacings for the rods were used over the floodplain. On the main portion of the floodplain, the grid spacing was 35mm across the flume and 30mm between rods down the flume. Successive rows were staggered to maximise their drag effect. The
marginal region, corresponding to a two metre band of reeds in the river and approximately a 40mm strip in the model, had been planted with rods at double the density of the predominant floodplain roughness with a grid spacing of 18mm by 30mm.

The marginal roughness in Series 9, simulating a full growth of reeds, on the prototype, along the main channel bank and described above, was non-submerged for all flow depths. The remaining roughness remained at 30mm. For Series 10, in a simulated complete clearance of the floodplain, all the roughness elements were reduced in height to 30mm, with no change in roughness density. The third run, Series 11, simulated the effect, of retaining vegetation within observed low flow areas on the floodplain, together with a fully restored marginal growth of reeds on the main channel banks, as in Series 9. This entailed reproducing the roughness for Series 9, with the additional factor that some floodplain vegetation was increased in length from 30mm to the non-submerged condition described for the marginal roughness above. In the photograph depicting Series 8 roughness, see figure 6.8 of the previous chapter, the tall marginal roughness elements are clearly visible.

The results are presented in figure 7.1. Figure 7.2 shows a plan of the River Roding Model, with the roughened areas referred to in Series 9,10 and 11 marked on it. A roughness key can be found in table 7.3, at the end of this chapter. To provide a comparison, superimposed on the three plots are points for Series 7 and 8. As a reminder, series 7 and 8 correspond to the accepted modelled states of the 1984/1985 and 1985/1986 prototype rating curves.

It is clear from a preliminary inspection of the curves, that
Depth-Discharge Data for River Model Varying the Bed Roughness

**Figure 7.1**
Plot of Depth-Discharge Data for River Model, Series 9, 10 and 11

<table>
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<tr>
<th>SERIES</th>
<th>SYMBOLS</th>
<th>ROUGHNESS KEY</th>
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<td>■</td>
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</tr>
<tr>
<td>10</td>
<td>X</td>
<td>M6 F16</td>
</tr>
<tr>
<td>11</td>
<td>⬤</td>
<td>M6 F17</td>
</tr>
</tbody>
</table>
Figure 7.2
Plan of Model Showing Areas of Different Roughness for Series 9, 10 and 11
Series 9 exhibited a marked improvement, and Series 10 and 11 a marginal reduction, in performance compared with Series 8. Thus, it appears that leaving a 2 metre margin (S10) produces a noticeable reduction in discharge capacity over complete clearance of the floodplain (S9). The negligible difference between S10 and S11 demonstrates the minimal impact of leaving vegetation on the inside of selected bends in the model.

7.1.2 Modelled Schemes - Floodplain Boundary Alteration

Based on observation of flow separation at the floodplain bends in the model (described in section 7.3 at the end of this chapter), it was a logical step to gauge the effect of reducing the severity of floodplain bends for various flows and roughness states. In Series 12, 13 and 14, an alteration was made to the floodplain boundaries, together with variations of the floodplain and main channel roughnesses. Two bend were smoothed out, with maximum local increases in floodplain width of 25% and 43%. The increase in plan area between the floodplain boundaries and limits of the modelled reach was less than 5%. Details of the alterations are given in figure 7.3.

As a proposal for improving the capacity of the river, the cost of removing severe bends within the floodplains had to be offset against the possibility of no subsequent floodplain maintenance at one extreme (S13) and a continued minimal maintenance policy (S12), originally applied in Series 11, at the other. The third configuration to be considered was no floodplain maintenance but with regular maintenance and dredging of the main channel (S14).
Figure 7.3
Plan of Model Showing Altered Floodplain Banks and Roughness Areas for Series 12, 13 and 14
The results are presented in figure 7.4 with Series 7 and 8 superimposed. Series 12 shows a marked improvement over Series 8, a result even more encouraging for the reason that Series 11, in figure 7.1, has the same floodplain roughness and yet showed a reduction in capacity over series 8. This emphasises the significant difference a small alteration to the floodplain boundary can have on the overall form roughness of the reach. Series 13, the return to a fully roughened floodplain, shows a marked improvement over series 7. Clearing the main channel has had some effect at lower discharges but appears to have had little effect on reducing water levels during peak flows.
Depth-Discharge Data for River Model Varying the Bed Roughness

Figure 7.4
Plot of Depth-Discharge Data for River Model, Series 12, 13 and 14
Chapter 7

7.2 Velocity Profiles

The locations of model cross-sections have been defined according to the X,Y coordinate system introduced in chapter 6 and reproduced in figure 7.5. This shows the positions of the velocity traverses carried out and subsequently reported on in this section.

Isovels, lines of constant velocity, plotted through sections of flow within the model, were obtained by measuring mean point velocities within the flow in a grid pattern. The resulting matrices of velocities, resolved in the principal flow direction, were processed on a main frame computer using numerical analysis routines to produce the isovel maps. The measuring probe was a variable yaw pitot tube developed by the author at the University. It was mounted on an automatic tracking frame, all controlled from a microcomputer. Details of this equipment can be found in chapters 3 and 4.

The recorded isovel plots are included in figures 7.6 to 7.20. 32 plots were constructed in all, for 5 roughness series. Most of the plots were produced for Series 2 and the remainder on Series 1 with the exception of 4 plots split between Series 12,13 and 14.

The isovel plots were carried out primarily to investigate the velocity distribution between general meandering main channel and floodplain flow without regard to the similarity criteria between model and prototype. The reason for this was due to the distortion of the isovels in the model, relative to the prototype, which resulted from the geometrical distortion between the two. However, some of the results, such as the proportion of the total flow in the
Figure 7.5
Plan of Model Showing Location of Velocity Traverses
Figure 7.6
Isovel Plots Section 4730-Series
Normal Velocities in m/s
Figure 7.7
Isovel Plots Section 4730-Series 2-Runs 1 and 2
Normal Velocities in mm/s
Figure 7.8
Isovel Plots Section 4730-Series 2-Runs 3 and 4
Normal Velocities in mm/s
Figure 7.9
Isovel Plots Section 4730—Series 2—Runs 5 and 6
Normal Velocities in mm/s
Figure 7.10
Isovel Plots Section 4730-Series 12-Runs 1 and 3
Normal Velocities in mm/s
Figure 7.11
Isovel Plots Section 4730-Series 13-Run 3
Normal Velocities in mm/s
Figure 7.12
Isovel Plots Section 4730-Series 14-Runs 1 and 3
Normal Velocities in mm/s
Figure 7.13

Isovel Plots Section 5200-Series 1-Runs 3, 5, and 6
Normal Velocities in mm/s

MODEL CROSS-SECTION 5200
SERIES NUMBER: RUN NUMBER 1 3
GATE SETTING 205
TOTAL DISCHARGE IN L-S (CALC) 5.22
BANKFULL DISCHARGE IN L-S (CALC) .82
DISCHARGE IN L-S (ACTUAL) 5.51

MODEL CROSS-SECTION 5200
SERIES NUMBER: RUN NUMBER 1 5
GATE SETTING 175
TOTAL DISCHARGE IN L-S (CALC) 2.78
BANKFULL DISCHARGE IN L-S (CALC) .95
DISCHARGE IN L-S (ACTUAL) 2.77

MODEL CROSS-SECTION 5200
SERIES NUMBER: RUN NUMBER 1 6
GATE SETTING 155
TOTAL DISCHARGE IN L-S (CALC) 1.08
BANKFULL DISCHARGE IN L-S (CALC) .69
DISCHARGE IN L-S (ACTUAL) 1.51
Figure 7.14
Isovel Plots Section 5200-Series 2-Runs 2 and 5
Normal Velocities in mm/s
Figure 7.15 Isovel Plots Section 5530-Series 1-Runs 3 and 5 Normal Velocities in mm/s

Model Cross-Section 5530
Series Number: Run Number
Gate Setting
Total Discharge in L-S (Calc) 2.39
Bankfull Discharge in L-S (Calc) .72
Discharge in L-S (Actual) 2.77

Model Cross-Section 5530
Series Number: Run Number
Gate Setting 205
Total Discharge in L-S (Calc) .29
Bankfull Discharge in L-S (Calc) .51
Discharge in L-S (Actual) 5.51
Figure 7.16
Isovel Plots Section 5530-Series 2-Runs 2, 3 and 5
Normal Velocities in mm/s
Figure 7.17

Normal Velocities in mm/s

Figure 6030-Series

Isovel Plots

Section 6030-Series

1-Runs 3 and 5

MODEL CROSS-SECTION 6030

SERIES NUMBER: RUN NUMBER

GATE SETTING 205

TOTAL DISCHARGE IN L-S (CALC) 5.10

BANKFULL DISCHARGE IN L-S (CALC) .36

DISCHARGE IN L-S (ACTUAL) 5.37

MODEL CROSS-SECTION 6030

SERIES NUMBER: RUN NUMBER

GATE SETTING 175

TOTAL DISCHARGE IN L-S (CALC) 2.33

BANKFULL DISCHARGE IN L-S (CALC) .62

DISCHARGE IN L-S (ACTUAL) 2.77

Runs 3 and 5
Figure 7.19
Isovel Plots Section 6350 - Series 1 - Runs 3 and 5

Normal Velocities in m/s

- Model Cross-Section 6350
- Series Number: Run Number
- Gate Setting: 205
- Total Discharge in L-S (Calc) 5.25
- Tank Full Discharge in L-S (Calc) 0.47
- Discharge in L-S (Actual) 5.51

Model Cross-Section 6350
Series Number: Run Number
Gate Setting: 175
Discharge in L-S (Calculated) 2.48
Discharge in L-S (Actual) 2.77
main channel or floodplain, found by integrating the velocities over an area, were useful in gaining an insight to the contribution of the main channel in carrying food flows down the reach. Also floodplain roughness values have been calculated from the discharge it carried at each section.

Total discharges were calculated by integrating the velocities across the entire flow. These were compared with actual discharges in the model. Thus the reliability of the recorded data could be checked. The percentage error of calculated discharge over actual discharge at each section is given in the final column of table 7.1. Section Y=4730 produced the most reliable correlation between measured and calculated discharge, with discrepancies between the two ranging from 0% to 11% with an average error of 4%. Sections 5200, 5530, 6030 and 6350 produced less accurate data with average discrepancies of 7%, 8% 10% and 5% respectively. The reasons for the larger errors with these sections can most likely be attributed to their more complicated geometries. It seems reasonable to explain the discrepancies between the actual and measured discharges as primarily due to errors in boundary measurements and not the measured velocities. As a result, no velocity corrections were made for the isovel plots.

As mentioned above, it was possible to calculate the discharges on the floodplain and in the main channel at each section. The location of the boundaries between which the floodplain and main channel discharges were calculated can be found in figures 7.21 and 7.22., which show the cross-sections at which measurements were made. Roughness element heights on the floodplain for Series 2 and 12 have been included as well. Table 7.1 lists the main channel and
floodplain discharges calculated from the isovel plots within the defined boundaries shown in figures 7.21 and 7.22.

The floodplain Reynolds numbers were calculated and these ranged from 5000 to 41000, demonstrating that fully rough flow had been obtained on the floodplain for all discharges. This confirms the validity of the model based on Froudean similarity as it operated above the minimum established limit of Re=4000. See chapter 6 for details. Floodplain roughness values, for all the velocity profile runs, have also been calculated and are presented together with the Reynolds values, mean floodplain velocities and hydraulic radii in table 7.2.
Figure 7.21
Profiles of Velocity Traverse Sections 4730 and 5200
Floodplain Roughness Heights and Division Lines for Floodplain
and Main Channel Discharge Calculation Included
Figure 7.22
Profiles of Velocity Traverse Sections 5530, 6030 and 6350
Floodplain Roughness Heights and Division Lines for Floodplain and Main Channel Discharge Calculations Included
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Table 7.2
Reynolds Numbers, Roughness Parameters from Velocity Traverses
7.3 Flow Visualisation of Water Surface Velocities

Paths of surface streamlines for various flow conditions were visualised by photographing paper 'confetti' scattered on the water surface. The paper particles were illuminated with a stroboscope and photographed from a camera mounted on an enclosed frame placed over the flume. A 28mm wide-angle lens was used in the camera, mounted about 1.5 metres above the water surface. Time exposures between 4 and 10 seconds were used with a strobe flashing rate of 10 Hertz. Series 1, 7 and 10 were photographed between Y=4700 and Y=6500. An example of the experiments is given in a photograph showing boundary separation at the bend between Y=5500 and 6500. This observed flow separation, shown in figure 7.23, resulted in the decision to retain floodplain vegetation within these low flow zones, Series 11 and cut back the severest floodplain bends, Series 12, 13, and 14. More photographs of surface flow have been left to chapter 8 for a fuller discussion.
Figure 7.23
Photograph of Flow Separation at Floodplain Bend
Between Sections 5500 and 6500
Series 1, Discharge 1.96 l/s
NOTES ON ROUGHNESS TYPES

To simplify the presentation of the roughness type table various phrases have been used as shorthand:

FX- - the 'FX' series refers to various types of flexible strips punched out of sheets of acetate. A detailed description of them has been given in Appendix A.5.

RR1 - enkamat matting, type 7720.

RR2 - 10mm dia. pebbles at 20mm centres.

RR3 - wire rods, 2.5 mm diameter of various lengths. Grid spacing is defined as 'lateral spacing' in mm by 'longitudinal spacing' in mm with the orientation along the flume. Given height is the length of wire above the floodplain surface.

marginal roughness - roughness positioned within area of floodplain adjacent to main channel approximately 40mm wide and running the length of the model on both floodplains where applicable.

reduced marginal roughness - as for marginal roughness but reduced to match river conditions for the 1985/1986 season when selective vegetation cropping took place.

side walls - boundary walls of floodplain.

Table 7.3
Roughness Key for Model Experiments
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<th>LABEL</th>
<th>DESCRIPTION</th>
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<tbody>
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<td>painted cement render surface</td>
</tr>
<tr>
<td>M2</td>
<td>10mm dia. pebbles at 20mm centres</td>
</tr>
<tr>
<td>M3</td>
<td>horsehair matting filling channel</td>
</tr>
<tr>
<td>M4</td>
<td>RKL plus glass spheres</td>
</tr>
<tr>
<td>M5</td>
<td>FX3 plus glass spheres</td>
</tr>
<tr>
<td>M6</td>
<td>FX5 plus glass spheres</td>
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Table 7.3 (Continued)
### List of Model Roughness Types on Floodplain

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<tr>
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<td>FX1</td>
</tr>
<tr>
<td>F3</td>
<td>RR2</td>
</tr>
<tr>
<td>F4</td>
<td>FX3 on top of RR2, marginal FX7</td>
</tr>
<tr>
<td>F5</td>
<td>FX3, marginal FX7</td>
</tr>
<tr>
<td>F6</td>
<td>FX3, FX4 up side walls</td>
</tr>
<tr>
<td>F7</td>
<td>FX3 plus RR3 at 40mm by 100mm grid, non-submerged, FX4 up side walls</td>
</tr>
<tr>
<td>F8</td>
<td>FX1 plus RR3 at 40mm by 70mm grid, non-submerged, FX4 up side walls</td>
</tr>
<tr>
<td>F9</td>
<td>FX1 plus RR3 at 40mm by 70mm grid, non-submerged, FX6 up side walls</td>
</tr>
<tr>
<td>F10</td>
<td>RR3 at 40mm by 35mm grid, non-submerged, FX6 up side walls</td>
</tr>
<tr>
<td>F11</td>
<td>RR3 at 40mm by 35mm grid, non-submerged, marginal RR3 at 25mm by 35mm grid, non-submerged, FX6 up side walls</td>
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<td>RR3 at 40mm by 35mm grid, 40mm height, marginal RR3, 25mm by 35mm grid, non-submerged, FX6 up side walls</td>
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<td>RR3 at 40mm by 35mm grid, 30mm height, reduced marginal roughness RR3, 25mm by 35mm grid, 30mm height</td>
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<tr>
<td>F16</td>
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<tr>
<td>F17</td>
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Table 7.3 (Continued)
CHAPTER 8

Analysis

This chapter tackles the problems listed below using data from chapters 5 and 7. Analysis and discussion have been presented and, where relevant, solutions have been proposed.

1. Maintenance of the River Roding Flood Alleviation Scheme with due regard being given to maximising its discharge capacity whilst minimising annual vegetation clearance, to reduce costs and preserve the ecological environment.

2. The interaction between a meandering main channel and floodplain and its effect on the total carrying capacity of the compound river.

3. Predicting the discharge characteristics of a compound channel consisting of a meandering main channel within a vegetatively roughened floodplain.
8.1 Depth Discharge Curves - Comparisons

Depth-discharge data from the field studies have already been used to prove the laboratory model and further use of them is unnecessary here, except to provide a comparison with Series 7 and Series 8. The analysis of the depth-discharge curves from the model has been aimed at finding practical solutions to the problem of the management of a stretch of compound river such as the River Roding Flood Alleviation Scheme. Data have been drawn from chapters 6 and 7.

8.1.1 Model Data

In this chapter, the model Series will be referred to in an abbreviated form, e.g. S7 will represent Series 7. All model data have been scaled up to the equivalent prototype values to enable the results of any analysis here to be meaningfully assessed.

To assist in a numerical evaluation of the stage-discharge curves, Series 7 to 14 were fitted with 3rd order polynomial functions. Curve fitting was applied using a numerical analysis package incorporated into a Fortran programme written by the author.

The NAG curve fitting routine, using a numerical method of the Tchebycheff approximation, calculates a minimax polynomial fit to a set of data points.

Table 8.3 at the end of the chapter gives the polynomial constants calculated for each set of data points from Series 7 to 14.

Curve fitting was applied to the overbank portions of the
stage-discharge curves to prevent an overall misfit due to the sudden change in curve slope at bankfull level. Good curve fits were obtained for all the data. Figures 8.1, 8.2 and 8.3 are plots of Series 7 to 14 with the best fit curves superimposed. Cross-over of the curves occurs in some instances at low depth values when in reality they should fall on the same line. The effect of this when comparing some sets of data, using the curves, has produced grossly incorrect results at low depths. These have been discounted and as will be seen, have been included in the comparison plots but only as dotted lines.

Comparisons of plots entailed first of all choosing a 'reference' curve against which other curves could be compared. Then the chosen 'reference' curve was subtracted from the curve being considered and the result replotted.
Plot of Scaled Model Depth-Discharge Data with Fitted Curve
Series 7 and 8
Figure 8.2
Plot of Scaled Model Depth-Discharge Data with Fitted Curve
Series 9, 10 and 11
Figure 8.3
Plot of Scaled Model Depth-Discharge Data with Fitted Curve
Series 12, 13 and 14
This method of comparison is explained here:

\begin{align*}
y_i &= a_i + b_i x + c_i x^2 \quad \text{polynomial (1)} \\
y_r &= a_r + b_r x + c_r x^2 \quad \text{reference polynomial}
\end{align*}

\[ \Delta y = y_i - y_r = (a_i - a_r) + (b_i - b_r) x + (c_i - c_r) x^2 \]

\[ y \rightarrow \Delta y \]

y - represents discharge
x - represents depth of flow

Therefore, to plot \( \Delta y \) as a function of \( x \), subtract the polynomial coefficients as shown above and re-plot the new curve with the modified coefficients.

Two types of comparison have been made. The first was the difference in discharge between the two curves, for a given depth above the floodplain, and the second was the percentage change in discharge. Five sets of plots have been produced, the first of which is S8 compared with S7, two plots of which are given in Figures 8.4 and 8.5.

The dotted portion of the line in figure 8.5 is an obviously meaningless result and has been included only for completeness. In figure 8.4, however, the effect of the curve fitting error is not significant. Taking S7 and S8 as equivalent to the prototype data produced in chapter 5, for the '84/'85 and '85/'86 wet seasons on
Figure 8.4
Plot of Discharge Difference Between Series 8 and Series 7
Using the Fitted Curves
Figure 8.5
Plot of Percentage Discharge Difference Between Series 8 and Series 7 Using the Fitted Curves
the river, (see figure 8.6 for a comparison of the best-fit curves between the river data over the two seasons and S7 and S8) the improvement in discharge from clearing the floodplain between the two seasons is very marked. At a flow depth of 1 metre above the floodplain level the increase in discharge, taken from figure 8.4, is about 7.5 cumecs and this represents, from figure 8.5, an increase of almost 40%. Data from the figures cannot be inferred much above an overbank flow depth of 1 metre due to the lack of prototype data for S7 at high discharges.
Figure 8.6
Comparison of River Data with S7 and S8
Using the Fitted Curves for each set of Data Points
Having evaluated the improvement in discharge capacity between S7 and S8, the modelled prototype roughness states, the following presentation deals with the improvements resulting from the schemes outlined in chapter 7, using S7 or S8 as a reference curve. S9, S10 and S11 were similar to S8 and therefore the latter was chosen as a basis for comparison. The following roughness descriptions of S9 to S11 relate to their prototype equivalent:

S9 - completely cleared floodplain, no marginal vegetation and main channel uncleared.

S10 - cleared floodplain with the exception of a 2 metre margin of reeds remaining adjacent to the main channel banks, main channel uncleared.

S11 - as for S10 with the addition of uncleared areas inside the floodplain bends (see figure 7.2)

Figures 8.7 and 8.8 are graphical presentations of the results, S11-S8, S10-S8, S9-S8. As already mentioned, the dotted portions of the curves are meaningless and nothing can be inferred from them. The changes in discharges of all the curves compared with S8 are relatively small. S9 exhibited an increase in discharge over S8 (at a floodplain flow depth of 1 metre) of about 3 cumecs or just over 10%. S10 and S11 differed little from S8.
Figure 8.7
Plots of Discharge Differences for S9, S10 and S11 Compared with S8 Using Fitted Curves
Figure 8.8
Plots of Percentage Discharge Difference for S9, S10 and S11 Compared with S8 Using Fitted Curves
S12, S13 and S14 were grouped together because the boundaries of the floodplain were altered from S12 onwards. As already described in chapter 7, two severe floodplain bends were cut back along the modelled stretch, with maximum localised floodplain widths increased by 25% and 40%. The increase in plan area of the floodplain was less than 5%. (see figure 7.3). S12, S13 and S14 have been compared with the rougher prototype case of S7 and possess the following equivalent prototype surface roughnesses:

S12 - as for S11 - cleared floodplain with the exception of a 2 metre margin of reeds remaining adjacent to the main channel banks, main channel uncleared.

S13 - as for S7 - no vegetation clearance on the floodplain, main channel uncleared

S14 - as for S13, but main channel cleared

Figures 8.9 and 8.10 are graphical presentations of the curves S14-S7, S13-S7, S12-S7. At a floodplain flow depth of 1 metre, S12, as expected, exhibited a significant improvement in discharge capacity over S7, about 10 cumecs or 55% increase. S13, a simulation of no floodplain maintenance, resulted in an increased discharge in the reach of nearly 3 cumecs or 15% and S14, possessing the same surface roughness as S13 but with the main channel cleared, exhibited an increase of 3.5 cumecs or 20% over S7. As the bankfull roughness of the channel, if it were to be dredged, is not known, this figure might not necessarily represent the increase to be found from carrying out such an exercise.
Figure 8.9
Plots of Discharge Differences for S12, S13 and S14 Compared with S7 Using Fitted Curves
PERCENTAGE INCREASE IN DISCHARGE

Figure 8.10
Plots of Percentage Discharge Differences for S12, S13 and S14 Compared with S7 Using Fitted Curves
The two groups of curves provide some comparisons between different surface roughness states in the river but no assessment has been made of the effect of reducing the shape roughness of the floodplain. Two comparisons have been produced from the available data, S12-S11 and S13-S7. Both sets of Series have the same surface roughness but different floodplain form roughness. Figure 8.11 and 8.12 are plots of S12 relative to S11 and figures 8.13 and 8.14, are plots of S13 relative to S7.

At a flow depth of 1 metre, the reduced severity of floodplain meandering has increased the capacity of the reach by 4 cumecs or 16% with the roughness on the floodplain corresponding to that produced from the proposed policy of minimum maintenance, S11. For the same inundation, and maximum vegetative roughness on the floodplain, S13, capacity was increased by 2.5 cumecs or 14%.

8.1.2 Conclusions

It is worth concluding this section with a presentation of the most important facts that the above analysis has revealed.

1. The difference in discharge capacity of the reach between no maintenance of the floodplain, S7, and a policy of minimum clearance, S11, (2 metre margin of reeds and selected vegetation remaining uncut on the outside of floodplain bends) is significant. At a floodplain flow depth of 1 metre, an increase in discharge of 7.5 cumecs, or nearly 40%, was found.

2. The effect of the proposed minimal clearance policy of the floodplain vegetation, S11, leaving substantial stands of vegetation;
INCREASED DISCHARGE IN CUMECS

Figure 8.11
Plot of Discharge Difference Between S12 and S11 Using Fitted Curves
Figure 8.12
Plot of Percentage Discharge Difference Between S12 and S11 Using Fitted Curves
Figure 8.13
Plot of Discharge Difference Between S13 and S7
Using Fitted Curves
Figure 8.14
Plot of Percentage Discharge Difference Between S13 and S7 Using Fitted Curves
for the benefit of the natural wildlife, compared with complete clearance, S9, was to decrease the total discharge by only 10%, or 3 cumecs, at a floodplain flow depth of 1 metre.

3. Reducing the severity of the floodplain bends (localised increase of floodplain widths between 25%-40% - increasing the floodplain area by less than 5%) where gross separation could be seen to occur in the particular reach modelled, produced a significant increase in discharge capacity. At a floodplain flow depth of 1 metre, an increase of approximately 15% was measured. This corresponded to 2.5 cumecs for a heavily roughened floodplain, S13-S7, or 4 cumecs for a lightly roughened floodplain, S12-S11.

4. The effect of clearing the main channel has not been fully established, because the main channel roughness in the prototype when cleared is not known, although it appears, S14-S13, that it might only provide a minimal increase in discharge capacity of around 5%.
8.2 Roughness Coefficients

An analysis of the roughness coefficients on the model and in the field, involved calculating the following parameters:

\[ n = \frac{R^2 S}{V} \]

\[ \lambda = 8gRS/V^2 \]

\[ k = \sqrt{\frac{1}{4\lambda}} = -2.01 \log_{10} \left( \frac{k}{14.83 R} \right), \lambda \text{ from above} \]

The field data have been presented in Tables 5.2, 5.3 and 5.4. The model data have been presented in Appendix A.6 page A.6.27 for Series S7 and S8, calculated at section 4730. More generalised roughness values have been calculated from the velocity profiles and presented in table 7.2.

To provide a comparison between calculated field and model 'n' values, the following table has been constructed.

<table>
<thead>
<tr>
<th>Discharge Curves</th>
<th>model data</th>
<th>field data</th>
</tr>
</thead>
<tbody>
<tr>
<td>bankfull flow</td>
<td>S7</td>
<td>S8</td>
</tr>
<tr>
<td>approx. equivalent</td>
<td>.05</td>
<td>.05</td>
</tr>
<tr>
<td>lm above bank in prototype</td>
<td>.055</td>
<td>.04</td>
</tr>
</tbody>
</table>
From chapter 6 on modelling, it has been shown that the 'n' values for the model should be about 10% larger than the 'n' values for the prototype. From the above table, it appears to be the case for bankfull flow, but for above-bank flow of about 1 metre, the difference in 'n' is about 20%. The model and field 'n' values were calculated for different cross-sections and so some variation in calculated 'n' might be expected.

Figures 8.15 to 8.17 are plots of the roughness coefficients, calculated from the velocity profile data table 7.2, against Reynolds numbers. S2 approximates to S7 (see chapter 5 on proving the model) and in figure 8.15 exhibits a range of Manning 'n' values between 0.028−0.042 for 5 cross-sections of the model, over the entire flow range. In figure 8.16, plotted friction factors, $\lambda$, show a trend of decreasing values with increasing Re. This is at odds with the expected condition of decreasing relative roughness, $K$, with increased flow depth and hence Re which ought to result in an increased $\lambda$ from the Colebrook-White equation. However, the effective roughness height, $k$, increases with increasing Re, from 0.02 − 0.10 metres, figure 8.17.

From the field data for recorder 2, table 5.3, the roughness height, $k$, also increases with depth to a value of 0.6m and 0.2m for the 84/85 and 85/86 wet seasons at a flow depth of about 1 metre.
Figure 8.15
Plot of Manning Roughness Coefficient, $n$, vs Reynolds Number for Velocity Profile Data from Model

$\Re = 4 \sqrt{\frac{H}{Y}}$

Figure 8.16
Plot of Friction Factor, $\lambda$, vs Reynolds Number for Velocity Profile Data from Model

$\Re = 4 \sqrt{\frac{H}{Y}}$
Figure 8.17
Plot of Roughness Height, $k_s$, vs Reynolds Number
for Velocity Profile Data from Model.
above the floodplain.

In utilising effective roughness heights or Manning 'n' values for calculating the roughness of a river reach, it is clear that care must be taken. It seems that neither the roughness height, $k$, or 'n' can be considered constant for large relative roughnesses which prevail in densely vegetated floodplains.

Knight (59), in a paper on resistance coefficients in a tidal channel, found that roughness height, $k$, and Manning 'n' were not constant with varying depth.
8.3 Interaction Between Main Channel and Floodplain

8.3.1 Discharges in Main Channel and Floodplain

Comparisons have been made between bankfull discharge without floodplain flow and discharge in the main channel for various depths of overbank flow.

The ratio of main channel discharge/bankfull discharge for increasing floodplain hydraulic radius has been presented in figure 8.18. It is interesting to note that for all the series covered, the discharge in the main channel increased with overbank flow at section 4730 and decreased for all other sections.

The main channel discharge for section 4730 increased by up to 80% in the case of series 2, whereas the other sections experienced a decrease in discharges to as little as 20% of the original bankfull value. This might be explained as follows.

Firstly, consider the main channel and floodplain to be split at the horizontal interface between the two. Secondly, the highest recorded velocities in the model were always on the floodplain. See figures 7.6 to 7.20. At section 4730, the main channel is approximately parallel to the flood plain. As the overbank flow increases, the main channel flow will experience an apparent shear force across the horizontal interface assisting the flow within the channel and hence increasing the main channel discharge. Furthermore, as can be seen in figure 8.18, the rate of increase of main channel discharge at a low depth of flow is high as the largest differential velocities occur in this region. Figure 7.9, isovel plots at section 4730 for
Figure 8.18
Plot of Main Channel Discharge/Bankfull Discharge vs Hydraulic Radius for Velocity Profile Data from Model
bankfull and just above bankfull discharges in Series 2, demonstrate the significant increase in main channel velocities that occur there as the river floods its banks. At higher depths, the velocities have readjusted and the rate of increase of discharge ratio reduces. The reduction in main channel discharge at sections 5200 to 6350 could be explained in a similar manner. The assisting shear force from the floodplain on the main channel in section 4730, becomes a transverse shear between 4730 and 5200, causing the main channel flow to 'spill' out onto the floodplain, leaving a much reduced discharge at 5200 and 5530. The main channel from there does not recover and the discharge remains below the bankfull value beyond 6350. Figure 8.19 shows a plan of the model with location of the cross-sections marked in.

A practical consideration arising out of these results is what advantage there might be in actually dredging the main channel when at significant meanders, the main channel carries even less flow than when running bank full.

8.3.2 Flow Separation at Bends

As mentioned earlier, flow separation had been observed during the flow visualisation experiments. Marked separation can be seen in figure 8.20 for Series 1 at a discharge of 1.96 l/s. At a similar level of submergence, Series 7, at a discharge of 2.36 l/s, figures 8.21 and 8.22, show a markedly lower degree of separation, although some is evident from figure 8.22.

Figure 8.23 shows Series 10 at a discharge of 6.33 l/s, the separation is quite distinct.
Figure 8.19
Plan of Model Showing Position of Velocity Traverses
Maximum separation of flow at the studied bend occurred in Series 1, where the highest velocities of flow were encountered. The mean velocity of floodplain flow in figure 8.20, was about 0.20 m/s. Reduced separation at a similar depth of flow, figure 8.22, occurred with a mean floodplain velocity of about 0.15 m/s. It seems likely, therefore, that separation at a bend is due partly to the incident flow velocity. Thus, it is reasonable to assume that if separation were observed in the model, it would be likely to occur in the prototype for the same conditions and at the same bend because the mean flow velocities would be 4 times greater (chapter 6 on modelling).

8.3.3 Evidence of Interaction Effect

Two photographs have been included to demonstrate the interaction effect, figures 8.24 and 8.25. They show Series 1, at a discharge of 1.96 l/s between sections Y=4500 and 6000. Figure 8.24 is a 'streak' photograph of a large quantity of small paper particles carried along on the moving water surface. The surface flow, evenly distributed at the left of the picture, is swept to one side by the strong crossflow in the main channel as it passes over it. Marked on the picture is a 'line of interaction' where the surface flow is significantly affected by the lower flow. Figure 8.25, shows individual particles affected by the flow. One path line has been marked on the photograph where the effect is very noticeable.

These pictures serve to show that an interaction exists between the main channel and floodplain flows but it is beyond the scope of this
dissertation to quantify the effect.
Figure 8.20
Surface Flow Between Y=5500 and Y=6500
Series 1, 1.96 l/s

Figure 8.21
Surface Flow Between Y=5500 and Y=6500
Series 7, 2.36 l/s
Figure 8.22
Surface Flow Between Y=5500 and Y=6500
Series 7, 2.36 l/s

Figure 8.23
Surface Flow Between Y=5000 and Y=6000
Series 10, 6.33 l/s
Figure 8.24
Surface Flow Between Y=4500 and Y=5500
Series 1, 1.96 l/s

Figure 8.25
Surface Flow Between Y=4500 and Y=5500
Series 1, 2.36 l/s
8.4 Discharge Evaluation in Meandering Compound Channels - A Proposal

The calculation of discharge for flow in open channels of simple cross-section is well documented. Much research has been carried out on channels consisting of compound cross-section in which straight channels flow within straight parallel floodplains and many proposals for the calculation of discharge have been put forward. Due to the complexity of the problem, little has yet been proposed for discharge calculation in meandering compound channels. In this section, the author has proposed a method by which the discharge in the latter case with vegetatively roughened floodplains could be better estimated than is possible at present.

8.4.1 Evaluation of Roughness Coefficient on Vegetated Floodplain

To calculate the discharge in a river using one of the available methods, a knowledge of the roughness coefficients is required. It is possible to estimate these values using photographs of rivers matched to evaluated roughness coefficients as in Chow (5) or the author's data in chapter 5, figures 5.26 to 5.28. This method is highly empirical and has no physical basis, therefore a great deal of experience is required to use it correctly. For vegetation roughness, the problem is even more complicated as the roughness characteristics of the vegetation, being flexible, will change with different flows and seasons.

Much work has been carried out on the resistance to flow in vegetated channels. The earliest work was produced by the U.S. Department of Agriculture, Soil Conservation Service. This has been reported by Cox and Palmer (57) and Ree and Palmer (64) who
plotted Manning 'n' vs VR (product of hydraulic radius and mean section velocity) for various types of grasses, in channels with bed slopes ranging from 1% to 20%. From these they produced a set of retardance curves, with classifications from A (very high vegetal retardance) to E(very low vegetal retardance). With these were included a description of all the vegetation tested and labelled with a retardance class (A to E). Subsequent research by Eastgate, (58) showed that this data could not be extended to channels with bed slopes of less than 1% as the data, from subsequent research, had proved to be slope dependent. As most natural vegetated open channels had bed slopes smaller than 1%, this posed a problem in using the USDA data. Kouwen et al (60,61,62,63) investigated flow over plastic flexible roughness in an attempt to produce a physically based resistance function. They found that velocity profiles over vegetation in their laboratory investigations were logarithmic and that a logarithmic expression relating the Darcy-Weisbach friction factor, \( \lambda \), to the relative roughness applied.

A method of calculating friction factors for vegetal roughness is presented in "Watershed and Stream Mechanics" from the U.S. Department of Agriculture, Soil Conservation Service (67). In it, the data produced by Kouwen et al, have been used together with data from the "Handbook of Channel Design for Soil and Water Conservation", USDA, 1954 (68), presented here in table 8.1. A work sheet has been included, table 8.2, which begins with identifying the type of grass and producing a stiffness value for it from a similar grass listed in table 8.1. The remaining calculations are based on the equations from Kouwen to calculate the deflected grass height, \( k \), critical shear stress, \( U^{*}\text{crit} \), from which, having
<table>
<thead>
<tr>
<th>Retardance Class</th>
<th>Average Height</th>
<th>Stiffness MEI in Newtons/meters squared</th>
<th>Cover Type</th>
<th>Cover Condition</th>
<th>Calibrated Stiffness MEI in Newtons/meters squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>910</td>
<td>300</td>
<td>Weeping lovegrass..</td>
<td>Excellent stand, tall, (average 760 mm)</td>
<td>200</td>
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<td></td>
<td></td>
<td></td>
<td>Yellow bluestem...</td>
<td>Do</td>
<td>(average 900 mm)</td>
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<td></td>
<td></td>
<td></td>
<td>Ischaemia...</td>
<td>Excellent stand (average 690 mm)</td>
<td>140</td>
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<td></td>
<td></td>
<td></td>
<td>Rhodes Grass (Australian)...</td>
<td>Very dense growth, uncut</td>
<td>47</td>
</tr>
<tr>
<td></td>
<td>610</td>
<td>20</td>
<td>Kikuyu Grass...</td>
<td>Excellent stand (average 420 mm)</td>
<td>47</td>
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<td></td>
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<td></td>
<td>Xaduz...</td>
<td>Good stand, tall, (average 300 mm)</td>
<td>17</td>
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<td></td>
<td></td>
<td></td>
<td>Native grass mixture</td>
<td>Little bluestem, blue grass, and other long</td>
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<td></td>
<td>and short midwest grasses</td>
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<td>Good stand, unabowed</td>
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<td>Good stand, tall, (average 600 mm)</td>
<td>30</td>
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<td>Good stand, not woody, tall</td>
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<td>(average 500 mm)</td>
<td>10</td>
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<td></td>
<td></td>
<td>Dense growth, uncut</td>
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<td></td>
<td>Good stand, uncut, (average 275 mm)</td>
<td>4</td>
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<td></td>
<td>Good stand, uncut, (average 330 mm)</td>
<td>6</td>
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<td></td>
<td></td>
<td>Good stand, uncut, (average 300 mm)</td>
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<td></td>
<td>Good stand, cut to 38 mm height</td>
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<td>Burned stubble</td>
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<td>Very dense growth, uncut</td>
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<td>Good stand, uncut, (average 260 mm)</td>
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<td></td>
<td>Good stand, (average 340 mm)</td>
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<td></td>
<td>Uncut (average 760 mm)</td>
<td>20</td>
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<td>Good stand, uncut</td>
<td></td>
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<td></td>
<td></td>
<td>Good stand, uncut, (average 330 mm)</td>
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<td></td>
<td>Dens growth, uncut</td>
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<td></td>
<td>Good stand, uncut, (average 300 mm)</td>
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<td>Good stand, uncut, (average 215 mm)</td>
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<td></td>
<td>Dense growth, uncut, (average 340 mm)</td>
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<td></td>
<td>Uncut (average 760 mm)</td>
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<td>Good stand, uncut, (average 340 mm)</td>
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<td>Uncut (average 300 mm)</td>
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<td>Uncut (average 125 mm)</td>
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<td></td>
<td>Good stand, uncut, (average 300 mm)</td>
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<td></td>
<td>Good stand, uncut, (average 125 mm)</td>
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<td></td>
<td>Good stand, uncut, (average 215 mm)</td>
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<td></td>
<td>Good stand, uncut, (average 190 mm)</td>
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<td></td>
<td></td>
<td>Good stand, uncut, (average 114 mm)</td>
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<td>Good stand, uncut, (average 150 mm)</td>
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<td>Good stand, uncut, (average 125 mm)</td>
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<td>Good stand, uncut, (average 107 mm)</td>
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<td>Good stand, uncut, (average 75 mm)</td>
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<td>Good stand, uncut, (average 50 mm)</td>
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Note: Covers classified have been tested in experimental channels. Covers were fresh and generally uniform.

Table 8.1
Vegetal Retardance and Stiffness Values for Different Grasses
(U.S.D.A Soil Conservation Service)
Work Sheet: Grassed Channels

INPUTS:

- Height of grass: ft x 0.3048 in x 0.0254
- Stiffness: (from Table 2)
- Channel slope: ft/ft, m/m
- Depth: ft x 0.3048

OUTPUTS:

- Average boundary shear: \( \tau = \sqrt{gdS_o} = \text{Pa} \)
- Shear velocity: \( U_\kappa = \sqrt{gdS_o} = \text{m/s} \)
- Critical shear stress:
  \[ U_{\kappa \text{crit}} = \min \{ 0.28 + 6.33 [\text{MEI}]^2, 0.23 [\text{MEI}]^{0.106} \} = \text{m/s} \]
- Classification:
  \[ \frac{U_\kappa}{U_{\kappa \text{crit}}} = \]
- Deflected grass height:
  \[ k = 0.14h \left( \frac{\text{MEI}}{\tau_0} \right)^{0.25} / h^{1.59} = \text{m} \]
  If \( h \) less than \( k \), set \( k = h \)
- \( U_\kappa / U_{\kappa \text{crit}} \)

\[
\begin{align*}
0 - 1 & \quad \frac{1}{\sqrt{\lambda}} = 0.15 + 1.85 \log_{10}(\frac{d}{k}) \\
1 - 1.5 & \quad \frac{1}{\sqrt{\lambda}} = 0.20 + 2.70 \log_{10}(\frac{d}{k}) \\
1.5 - 2.5 & \quad \frac{1}{\sqrt{\lambda}} = 0.28 + 3.08 \log_{10}(\frac{d}{k}) \\
2.5 - \infty & \quad \frac{1}{\sqrt{\lambda}} = 0.29 + 3.50 \log_{10}(\frac{d}{k})
\end{align*}
\]

Velocity:

\[
V = \frac{1}{\sqrt{\lambda}} \sqrt{gdS_o} = \frac{1}{\sqrt{\lambda}} (2.83) U_\kappa = \text{m/s}
\]

Table 8.2

Work Sheet for Calculating Friction Factors in Grassed Channels ('Watershed and Stream Mechanics', USDA Soil Conservation Service)
calculated the shear velocity, \( U^* = \sqrt{g d \kappa} \), values of \( a \) and \( b \) in the equation

\[
\frac{1}{\sqrt{\kappa}} = a + b (\log_{10} \frac{d}{k})
\]

can be determined

where \( y \) = depth of flow on the floodplain
and the \( \kappa \) value can be directly found from

\[
\kappa = \frac{B_y}{y} \frac{k}{d}
\]

If the type of grass cannot be identified from table 8.1, the descriptions given could be applied to identify similar grasses.

8.4.2 Model Data for Meandering Compound Channel Within Straight Floodplains

The Corps of Engineers (US Army) at the Waterways Experiment Station, Vicksburg, Mississippi in March 1956, produced a Technical Memorandum entitled "The Hydraulic Capacity of Meandering Channels", (40). In it they investigated the various factors which might affect floodway capacity. The specific objectives were to determine the effects on floodway capacity of:

1. radius of curvature of bends
2. sinuosity of channel
3. depth of overbank flow
4. ratio of overbank area to channel area and
5. overbank roughness.

The tests of interest in this analysis were carried out on a floodplain 16ft wide and trapezoidal main channel with top width of 2.5ft and bottom width of 2 ft. Depths of floodplain flow were up to 0.3 ft and the depth of main channel was 0.5 ft. These dimensions produced a floodplain/channel width ratio, $\alpha$, of 8, a depth ratio, $\xi$, between 0.17 - 0.38 and an aspect ratio, $\zeta$, of 4.5. A sinuosity, $s$, defined as the main channel length/floodplain length, varied between 1.0 and 1.57. The ratio of floodplain roughness/main channel roughness, $\chi$, varied between 1 - 3. The floodplain bed slope was .001. These dimensionless parameters, used previously in chapter 2, have been redefined below with the use of a simple diagram.

The author rearranged the 'Vicksburg' raw data and produced a plot of %change in total discharge in the model vs depth ratio for different roughness ratios and sinuosities. Figure 8.26 is a presentation of the rearranged data.

8.4.3 Calculations for Meandering Compound Channel

The previous two sections have outlined:
1. a method of calculating the roughness values for a vegetated floodplain, and
Figure 8.26
Percentage Discharge Decrease over Straight Compound Channel vs Depth Parameter, $Q$, for varying sinuosity, $s$, and Roughness Ratio, $\gamma$
2. a method of correcting the discharge calculated from an idealised prismatic compound channel, using the friction factors found, to the actual case of meandering compound channel.

It is important to stress, before illustrating the method with an example, that the calculation of the main channel bankfull friction factor has not been dealt with. This roughness value must be either found by inspection of known similar reaches or by stream gauging. The correction factors proposed in sub-section 8.4.2 are for very limited geometries only, the ranges of which have been given.

Taking the parameters from Wojcik (50), for designing the Roding Flood Alleviation Scheme (chapter 1),

\[ n_{\text{floodplain}} = 0.032 \]
\[ 2B_{\text{floodplain}} = 30 \text{ metres} \]
\[ 4-h_{\text{floodplain}} = 1.35 \text{ metres} \]

\[ n_{\text{main channel}} = 0.045 \]
\[ 2b_{\text{main channel}} = 6 \text{ metres} \]
\[ H_{\text{total depth}} = 2 \text{ metres} \]

for a designed discharge of 50 cumecs.

These give:

- width ratio, \( \lambda \), \( \frac{B}{b} \) = 5
- maximum depth ratio, \( \varphi \), \( \frac{H-h}{H} \) = 0.325
- aspect ratio, \( \zeta \), \( \frac{b}{h} \) = 4.5
- roughness ratio, \( \chi \), \( \frac{n_{\text{floodplain}}}{n_{\text{main channel}}} \) = 0.7
sinuosity, approximately the ratio of bed slopes, $s = \frac{9}{7} = 1.3$
floodplain bed slope $S_0 = \frac{1}{900}$

Some of these parameters fall outside the bounds of the "Vicksburg" model;

width ratio $\alpha = 6.4$
aspect ratio $g = 5$
minimum roughness ratio $\gamma = 1$
floodplain bed slope $S_0 = \frac{1}{1000}$

It will be a useful exercise, however, to demonstrate the practicality of introducing a correction factor for river meander, given sufficient laboratory data. Figure 8.27, is a reproduction of figure 8.26, with the calculations for discharge correction included. No correction could be made for the different width ratios, or floodplain bed slopes but an approximate correction has been made for the 'out of range' roughness ratio. The assumptions made, therefore, are that the small difference in width ratios and bed slopes between the "Vicksburg" model and River Roding Flood Alleviation Scheme, can be ignored. Without any further knowledge of the effect of a roughness ratio of less than unity, the conservative value of reduction in discharge for $\gamma = 1$ has been used. From figure 8.27, this gives a reduction in discharge of 25%, for a floodplain depth of flow of 1 metre, $Q = 0.3$.

Therefore, the calculated discharges for the design of the Flood Alleviation Scheme, based on the given design parameters, would have been overestimated by about 25%. Or, presented another way, the reach between chainages 0m to 1200m, designed to carry a flow of 50
Figure 8.27
Reproduction of Figure 8.26 with Calculations for River Roding Marked on
cumecs at a flow depth of 1.35 metres on the floodplain, would reach this maximum designed flow depth, at a discharge of around 35 to 40 cumecs. Wojcik reported, that the River Roding experienced a major flood of 25 cumecs in December 1979. The estimated depths of flow between chainages 0 m to 1200 m were 18% greater than expected although the depths of flow recorded between chainages 1200 m and 3200 m were approximately the designed values.

Given the simple design parameters used by engineers in calculating expected discharges and levels for rivers, it is worth applying an empirical factor, similar to one described above, for the fairly common case of a meandering river within vegetatively roughened floodplains. Limited geometries have been considered in the analysis and it would be worthwhile extending the range of information for different roughness ratios between main channel and floodplain and depth of flow. Experimentation using model geometries based on natural river dimension ratios would be valuable.
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<td>1.84</td>
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<tr>
<td>S14</td>
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<td>15.58</td>
<td>4.88</td>
</tr>
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</table>

\[ y = a + bx + cx^2 \]

\[ y = \text{discharge} \]

\[ x = \text{defm} \]

**Table 8.3**  
Polynomial Constants for Best Fit Curves S7 to S14
Conclusions and Proposals for Future Research

Chapter one laid out the general aims for the research programme. In this final chapter, the author summarises the conclusions arrived at and to what degree the aims of the project have been achieved.

Briefly, the aims of the project had been to;

1. determine the effect of vegetated floodplains on the discharge capacity of the River Roding Flood Alleviation Scheme and
2. investigate the turbulent interaction mechanism between the main channel and its adjacent floodplains.

9.1 Conclusions

The conclusions can be best stated in note form.

The study of past research on compound channel flow in chapter two has shown the following.

1. Standard resistance formulae do not take into account the turbulent energy losses which occur across the fluid interface between main channel and floodplain.

2. The turbulent interaction between main channel and floodplain is extremely complex.

3. Very little research has been carried out on 'real rivers' but
mainly on laboratory models with prismatic cross-sections.

The field study has shown:

1. that the presence of vegetation growth on the floodplains of the Roding Scheme has a significant effect on its discharge capacity. Chapter 5 shows the effect of varying the roughness of the floodplain over two successive wet seasons on the river. For no river maintenance on one hand and almost complete floodplain clearance on the other, at a flow depth of 1 metre on the floodplain, over 40% increase in discharge capacity was observed.

The model Study has shown the following.

1. Turbulent losses in the river could only be reproduced in the model with use of non-submerged rigid roughness elements as large scale turbulent eddies, observed in the river, did not reach to the surface in the model when using small scale roughness elements.

2. Leaving a 2 metre margin of reeds adjacent to the floodplain in line with wildlife conservation policy only reduces the capacity of the reach compared with a policy of complete clearance, by about 10%.

3. Flow separation at severe floodplain bends results in 'dead water' zones on the floodplain and leaving these areas uncut has minimal effect on flow capacity.

4. Reducing the severity of selected floodplain bends could significantly increase discharge capacity. In the modelled reach, an
increase of 15% was obtained in this manner for an overbank flow depth of 1 metre and increased floodplain plan area of less than 5%.

5. The main channel in a meandering river, such as the Roding, might contribute less to the total flow at increasing overbank depths due to the shear interaction at the interface between the main channel and floodplain. This has been demonstrated in the model in chapter 8. This indicates the possible lack of importance of clearing the main channel in an attempt to increase the capacity of the reach.

9.1.1 General

6. Roughness coefficients for the model and prototype were not constant with increasing depth of flow for a particular surface roughness. It is important, therefore, to use any evaluated roughness coefficients, $\alpha$, effective roughness heights, $h$, or friction factors with care in calculating river discharge capacities. For example, the Manning roughness values calculated in chapter 5 and linked with photographs of floodplain vegetation can only be used for the stated depths of flow on the floodplain.

7. A proposal was made, chapter 8, for including a correction for the meander in discharge calculations for a compound reach. In brief, this entailed first of all calculating the discharge in the compound reach assuming a straight main channel bounded by a straight floodplain by the normal method. Then a correction factor, percentage reduction in discharge, could be calculated from a graph relating the discharge reduction to depth of flow, sinuosity, roughness ratio between floodplain and main channel for particular river geometries. A very limited range of geometries was available.
9.2 Proposals for Future Research

In the light of so little field data being available on compound rivers, it would be valuable to extend the data measurement programme on the River Roding Alleviation Scheme. Velocity traverses could be taken to measure the distribution of flow in the main channel and on the floodplain to confirm the contribution of the main channel to the total flow.

Much research has been carried out in the past aimed at gaining a better understanding of the interaction phenomenon particularly in straight channels between the main channel and the floodplain. In this thesis, the author has pursued the argument that whilst research in this area is very valuable and of long term significance, there is a real need for the development of empirical solutions to the problems of designing compound reaches containing a meandering main channel.

It was proposed in chapter eight that model data incorporating all the variable features which affect the total discharge in a meandering compound channel might be used to determine a correction factor to take the main channel meander into account. The use of the "Vicksburg" model data was an attempt to demonstrate this point.

Simple empirical design formulae are still very useful and relevant. The River Roding Flood Alleviation Scheme was designed in such a manner and has been used in this thesis as an example of applying a correction factor to the design discharges obtained to take into account the river meander.

It is felt, therefore, that much useful knowledge might be gained in pursuing an empirical approach to the compound channel.
problem by extending investigations on the same lines as the "Vicksburg" experiments. Channel sinuosity, main channel-floodplain roughness ratio and relative width could be three parameters that might be varied in gaining a better working knowledge to cope with the problem.

9.3 Prospects for Numerical Modelling in Compound Channel Flows

Although not pursued in this dissertation, the author appreciates that a numerical modelling of compound flows in rivers is highly desirable. The calculations required can now be carried out on very powerful computer systems. Many numerical models utilise empirical equations for flow. It might be feasible therefore to use any empirical correction factors found as a result of the proposals suggested in 9.2 for meandering main channels within floodplains into these numerical models.
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APPENDIX TO:

A LABORATORY AND FIELD INVESTIGATION INTO THE DISCHARGE CHARACTERISTICS OF AN EXPERIMENTAL FLOOD ALLEVIATION SCHEME ON THE RIVER RODING IN ESSEX

D.J Searle

Thesis Submitted for the degree of Ph.D in the University of Bristol
APPENDIX

Appendix references are referred to by chapter number from the thesis. Appendices were required for chapters 4, 5, 6 and 7 only.

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### APPENDIX A.4

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APPENDIX A. 4

PROGRAMME LISTING FOR - LONGBAS

10 REM**************************************************
20 REM PROG LONGBAS OCTOBER 1985 WRITTEN BY D.J. SEARLE
30 REM RUNS IN CONJUNCTION WITH LONGMC
40 REM PAGE IS SET AT &1C00
50 REM HIMEM IS SET AT &4000 LEAVING DATA STORE FROM &4000 TO &5800
60 @%=131594
70 MODE 7
80 PORTB = &FE60
90 DDRB = &FE62
100 ADPTR= &70
110 OSFIND= &FFCE
120 OSBYTE= &FFF4
130 PT= &4000
140 HIMEM= PT
150 DTASTR= PT + 50
160 delay = PT
170 steps= PT + 9
180 filename= PT + 10
190 fchan= PT + 20
200 eflag= PT + 21
210 dist= PT + 22
220 REM**************************************************
230 AA$= ""
240 AB$ = ""
250 AC$ = ""
260 AD$ = ""
270 S= 0
280 DISC= 5
290 AO%= 100
300 DIM Y%(12)
310 CLOSEEO
320 REM**************************************************
330 *LOAD LONGMC 1A00
340 start= &1A00
350 pulse11= &1A37
360 pulse22= &1A61
370 on1= &1A13
380 on2= &1A25
390 off1= &1A2C
400 off2= &1A2E
410 blinkfile= &1B1E
420 openfile= &1B2B
430 closefile= &1B38
440 REM**************************************************
450 PROC intro
460 PROC options
470 PROC probeset
480 PROC set
490 PROC parameter
500 PROC run
510 IF ADS = "S" THEN 470
520 REM**************************************************
530 MODE 4
540 IF PLT$= "R" THEN RESTORE 590
550 IF PLT$= "A" THEN RESTORE 600
560 FOR X= 1 TO 11

) read in
) appropriate
) correction
Appendix A. 4

1040 PROC file2
1050 PRINT "Data filed"

A. 4.1
Appendix A.4

1140 NEXT I: T=T/500
1141 PRINT T, CHK
1150 IF ABS(T-CHK)<2 THEN VDU7
1160 CHK=T
1170 GOTO 1090
1180 REM subroutines for disk filing
1190 REM*****************************************************************************
1200 DEF PROC write
1210 L1=LEN(D$)
1220 FOR I=1 TO L1
1230 E=ASC(MID$(D$, I, 1))
1240 BPUT$chan,E
1250 NEXT
1260 BPUT$chan,10
1270 BPUT$chan,10
1280 BPUT$chan,13
1290 ENDPROC
1300 REM*****************************************************************************
1310 DEF PROC file1
1320 PROC openfile
1330 LET D$="f."
1340 PROC write
1350 LET D$="DATE OF RUN "+DATE$
1360 PROC write
1370 LET D$="DISCHARGE IN L/S "+STR$(DISC)
1380 PROC write
1390 LET D$="CALIBRATION COEFFICIENT IS "+STR$(AO%)
1400 PROC write
1410 LET D$=" POSO DEPTHO GATE DISCHARGE"
1420 PROC write
1430 PROC closefile
1440 ENDPROC
1450 REM*****************************************************************************
1460 DEF PROC file2
1470 PROC openfile
1480 D$=STR$(POS0%)+" "+STR$(DEPTHO)+" "+STR$(GATE)+" "+STR$(DISC)
1490 PROC write
1500 FOR I=1 TO L STEP 20
1510 FOR K=I TO 19+I STEP 2
1520 Z=DATSTR$(K-1)+256*DATSTR$(K)
1530 FOR J=1 TO LEN(STR$(Z))
1540 Z=ASC(MID$(STR$(Z), J, 1))
1550 BPUT$chan,Z
1560 NEXT J
1570 BPUT$chan,32
1580 BPUT$chan,10
1590 BPUT$chan,13
1600 NEXT I
1610 D$="999 999 999 999"
1620 PROC write
1630 PROC closefile
PROCEDURE TO CREATE NEW DISC FILE

1690 INPUT TAB(0,3) "ENTER FILENAME " $N$
1700 IF LEN($N$) > 7 THEN 1690
1710 $filename = N$
1720 CALL binkfile
1730 chan = ? fchan
1740 fptr = PTR & chan
1750 PRINT $chan, fptr
1760 fptr = PTR & chan
1770 PTR & chan = 0
1780 PRINT $chan, fptr
1790 FOR X = 1 TO 20000
1800 BPUT $chan, 255
1810 NEXT
1820 CALL closefile
1830 ENDPROC

PROCEDURE TO OPEN DISC FILE

1860 PRINT
1870 INPUT TAB(0,1) "ENTER FILENAME " $N$
1880 IF LEN($N$) > 7 THEN 1870
1890 $filename = N$
1900 CALL openfile
1910 chan = ? fchan
1920 IF chan = 0 THEN PROC closefile
1930 PTR & chan = 0
1940 INPUT $chan, fptr
1950 PTR & chan = fptr
1960 ENDPROC

PROCEDURE TO CLOSE DISC FILE

1990 fptr = PTR & chan
2000 PTR & chan = 0
2010 PRINT $chan, fptr
2020 CALL closefile
2030 ENDPROC

PROCEDURE TO OPEN DISC FILE

2060 CLS
2070 IF NOT(AA$ = "") THEN 2220
2080 PRINT TAB(0,0) "Plot curves rel. to floodplain(R)" ; "or absolute(A)"
2090 REPEAT: PLT$ = INKEY$(0): UNTIL PLT$ = "R" OR PLT$ = "A"
2100 PRINT TAB(0,0) "Store data on disk today?, y/n"
2110 AA$ = INKEY$(0)
2120 IF AA$ = "Y" THEN 2150
2130 IF AA$ = "N" THEN CLS: GOTO 2300
2140 GOTO 2110
2150 PRINT TAB(0,1) "Open new file, y/n"
2160 AB$ = INKEY$(0)
2170 IF AB$ = "Y" THEN 2200

A.4.3
Appendix A.4

2180 IF AB$="N" THEN 2210
2190 GOTO2160
2200 PROCnewfile
2210CLS
2220 IF AD$="S" THEN 2260
2230 IF AC$="Q" THEN 2270
2240 IF AC$="G" THEN 2300
2250 INPUT TAB(0,4)"DATE e.g. 3/1/85 ";DATE$
2260 INPUT TAB(0,5)"CALIBRATION COEFFICIENT (UNITS/MM) ";AO%
2270 INPUT TAB(0,6)"DISCHARGE (L/S) ";DISC
2280 IF AD$="S" OR AC$="Q" THEN2300
2290 PROCfilel
2300 INPUT TAB(0,7)"GATE SETTING ";GATE
2310 INPUT TAB(0,8)"POSITION OF STATION AT START(MM) ";(Y=1500,PREFERRED) ";POSO%
2320 INPUT TAB(0,10)"DEPTH AT START POSITION(MM) ";DEPTHO
2330 PRINT TAB(0,12)"Correct values? 
2340A$=INKEY$(0)
2350IF A$=CHR$(&OD) THEN2400
2360IF A$="N" AND AC$="Q" THEN CLS: GOTO2270
2370IF A$="N" AND AC$="G" THEN CLS: GOTO2300
2380IF A$="S" AND AC$="" THEN CLS: GOTO2250
2390GOTO2340
2400 AD$=""
2410ENDPROC
2420REM*****************************************************************************

2430 DEF PROCprobeset
2440dist?200:dist?1=200:dist200
2450steps255
2460CALL start
2470CLS
2480PRINT TAB(0,15)"SETTING CARRIAGE TO START POSITION"
2490PRINT TAB(6,2)"Horizontal-X or -Y stepper? 
2500PRINT TAB(10,3)"Return to Continue"
2510REPEAT
2520L=GET
2530UNTIL L=88 OR L=89 OR L=&OD
2540IF L=89 THEN2630 ELSE IF L=&OD THEN2830
2550PRINT TAB(0,5)"For motor direction""Enter L-left or R-right"
2560?delay=150
2570delay?1=01
2580REPEAT
2590K=GET
2600IF K=76 THEN CALL on1:GOTO2710
2610IF K=62 THEN CALL off1:GOTO2710
2620UNTIL K=76 OR K=82
2630PRINT TAB(0,5)"For motor direction""Enter U-up or D-down"
2640?delay=150
2650delay?1=0
2660REPEAT
2670K=GET
2680IF K=85 THEN CALL on2:GOTO2710
2690IF K=68 THEN CALL off2:GOTO2710
2700UNTIL K=68 OR K=85
2710PRINT TAB(0,7)"Motor "CHR$(L)" called in ";CHR$(K);" Direction."
2720PRINT TAB(0,8)"Start?"
2730REPEAT UNTIL GET=&OD
2740PRINT TAB(0,11)"RESETTING PROBE TO START POSITION"
Appendix A. 4

2750 PRINT TAB(0,9)"To stop press space bar"
2760 IF L=88 THEN CALL pulse1
2770 IF L=89 THEN CALL pulse22
2780 PRINT TAB(0,11)"Restart same motor? Otherwise Quit"
2790 REPEAT V$=INKEY$(0)
2800 IF V$=CHR$(65) THEN 2460
2810 IF V$="Q" THEN 2830
2820 UNTIL FALSE
2830 ENDPROC
2840 REM******************************
2850 DEF PROC run UNIT 5- PROC run
2860 DIST=(6500-POSO%)*25.65
2870 ? dist=DIST MOD 256
2880 AA-DIST DIV 256
2890 ? dist? 1=AA MOD 256
2900 ? dist? 2=AA DIV 256
2910 CALL start
2920 CALL off2
2930 PRINT TAB(0,5)"To stop press space bar"
2940 CALL pulse22
2950 PRINT TAB(10,8)"Store data? To scrap and re-run 'S'"
2960 REPEAT AD$=INKEY$(0)
2970 UNTIL NOT(AD$="")
2980 ENDPROC
2990 REM******************************
3000 DEF PROC set UNIT 3- PROC set
3010 PRINT TAB(0,0)"SETTING UP INITIAL PARAMETERS FOR RUN"
3020 PRINT TAB(0,2)"Steps between unaveraged reading x"
3030 PRINT TAB(O. 3)"Default is 150"
3040 INPUT TAB(0,4); RD
3050 IF RD=0 THEN RD=150
3060 ? steps=RD
3070 IF RD=0 THEN RD=150
3080 CALL start
3090 CALL off2
3100 PRINT TAB(0,5)"To stop press space bar"
3110 CALL pulse22
3120 PRINT TAB(10,8)"Store data? To scrap and re-run 'S'"
3130 REPEAT AD$=INKEY$(0)
3140 UNTIL NOT(AD$="")
3150 ENDPROC
3160 REM******************************
3170 DEF PROC intro
3180 PRINT TAB(12,10)"PROGRAMME DPBAS"
3190 PRINT TAB(7,14)"OCTOBER 1985 D. J. SEARLE"
3200 IF A$=CHR$(65) THEN 3310
3210 ENDPROC
3220 REM******************************
3230 DEF PROC intro
3240 PRINT TAB(12,10)"PROGRAMME DPBAS"
3250 PRINT TAB(7,14)"OCTOBER 1985 D. J. SEARLE"
3260 IF A$=CHR$(65) THEN 3310
3270 ENDPROC
3300 UNTIL TIME = TIME + 1500
3310 CLS
3320 PRINT TAB(0, 4) "Programme to run an automatic data collection facility."
3330 PRINT TAB(10, 16) "Return to continue"
3340 REPEAT
3350 A$ = INKEY$(0)
3360 IF A$ = CHR$(&OD) THEN 3380
3370 UNTIL TIME = TIME + 1500
3380 CLS
3390 ENDPROC
3400 REM
3410 DEF PROC options
3420 REM***************************
3430 PRINT TAB(1, 2); CHR$(141) " Choose options to continue"
3440 PRINT TAB(1, 3); CHR$(141) " Choose options to continue"
3450 PRINT TAB(5, 8) "Begin new set of runs - 1"
3460 PRINT TAB(5, 11) "Continue runs from break : "
3470 PRINT TAB(5, 12) "Collecting data on disk - 2"
3480 PRINT TAB(5, 13) "VDU runs only - 3"
3490 PRINT TAB(5, 16) "Terminate programme - 4"
3500 K = GET
3510 IF K = 49 THEN 3600
3520 IF K = 50 THEN AA$ = "Y"; AD$ = "S"; GOTO 3550
3530 IF K = 51 THEN AA$ = "N"; AD$ = "S"; GOTO 3550
3540 IF K = 52 THEN STOP
3550 GOTO 3490
3560 CLS
3570 IF PLT$ = "A" OR PLT$ = "R" THEN 3600
3580 PRINT TAB(0, 0) "Plotting relative to floodplain(R)"; "or absolute(A)"
3590 CLS
3600 ENDPROC
PROGRAMME LISTING FOR - LONGASM

10REM******************************
20REM LONGASM OCTOBER 1985 D. J. SEARLE
30REM MACHINE CODE PROGRAMME ASSEMBLED INTO LONGMC
40REM IN CONJUNCTION WITH LONGBAS
50REM******************************

60 MODE7 )
70 PROG=&1A00 )
80 Workspace=&7800 )
90 PORTB=&FE60 )
100 DDRB=&FE62 )
110 OSFIND=&FFCE )
120 OSBYTE=&FFF4 )
130 ADPTR=&70 )
140 PT=&4000 )
150 HIMEM=PT )
160 DTASTR=PT+50 )
170 delay=PT )
180 ctr=PT+2 )
190 Ref=PT+4 )
200 Check=PT+6 )
210 cntr=PT+8 )
220 steps=PT+9 )
230 filename=PT+10 )
240 fchan=PT+20 )
250 eflag=PT+21 )
251 dist=PT+22 )

60REM******************************
70 FOR I%=4 TO 6 STEP 2
80 PX=PROG
90 O%=Workspace
100 0%=Workspace

310 .start LDA £&FF ) set user port to output
type port
320 STA DDRB ) mode
330 LDA £DTASTR MOD 256 ) set memory location
340 STA ADPTR ) pointer to base
350 LDA £DTASTR DIV 256 ) address
360 STA ADPTR+1
370 LDA £&01 )
380 STA cntr )
390 RTS )

4000 routines, off/on-direction of
4100 motor drives

4200
430 .on1 LDA £&01 )
440 ORA PORTB )
450 STA PORTB )
460 RTS )
470 .off1 LDA £&0E )
480 AND PORTB )
490 STA PORTB )
500 RTS )
510 .on2 LDA £&02 )
520 ORA PORTB )
530 STA PORTB )
540 RTS )
550 .off2 LDA £&FD )
Appendix A.4

560 AND PORTB
570 STA PORTB
580 RTS
590****************************

600 pulsing motor X
610.pulse11
620 LDA $&10
630 ORA PORTB
640 STA PORTB
650 JSR delaysub
660 LDA $&EF
670 AND PORTB
680 STA PORTB
690 JSR delaysub
700 JSR readadc
710 JSR inkey
720 CMP $&20
730 BEQ endpulse
7400 check datastore is full
750 LDA ADPTR+1
760 CMP $&55
770 BEQ endpulse
780 JMP pulse11
790.endpulse RTS
800****************************

UNIT 1

820 pulse22
830 LDA $&20
840 ORA PORTB
850 STA PORTB
860 JSR delaysub
870 LDA $&DF
880 AND PORTB
890 STA PORTB
900 JSR delaysub
910 JSR readadc
920 JSR inkey
930 CMP $&20
940 BEQ endpulse22

UNIT 4

941 DEC dist:BNE pulse22
942 LDA $0:CMP dist+1:BEQ next
943 DEC dist+1:LDA $&FF:STA dist:JMP pulse22
944.next LDA $0:CMP dist+2:BEQ endpulse22
945 DEC dist+2:LDA $&FF:STA dist+1:STA dist

946 JMP pulse22
960.endpulse22 LDY $10
961.end LDA $7:JSR $&FEE:DEY:BNE end
962 RTS
970****************************

990.delaysub

DELAY ROUTINE - delaysub

A.4.8
UNIT 3
ESCAPE PRESSED ROUTINE
- inkey

1000 LDA delay
1010 STA ctr
1020 LDA delay+1
1030 STA ctr+1
1040 LDA $600
1050.loop
1060 DEC ctr
1070 BNE loop
1080 CMP ctr+1
1090 BEQ enddly
1100 DEC ctr+1
1110 JMP loop
1120.enddly RTS
1130***********

1150.inkey

1160 LDX $600
1170 LDY $600
1180 LDA $681
1190 JSR OBYTE
1200 CPY $1B
1210 BEQ escape
1220 CPY $600
1230 BNE nokey
1240 TXA
1250 RTS
1260.escape
1270 LDA $67E
1280 JSR OBYTE
1290 LDA $61B
1300 RTS
1310.nokey
1320 LDA $600
1330 RTS
1340***********

UNIT 2
READ ADC ROUTINE - readadc

1360.readadc

1370 DEC cntr
1380 BNE endread
1390 LDA steps
1400 STA cntr
1410 LDA $680
1420 LDX $602
1430 JSR OBYTE
1440 TYA
1450 LDY $601
1460 STA (ADPTR),Y
1470 DEY
1480 TXA
1490 STA (ADPTR),Y
1500.incptr
1510 CLC
1520 LDA $602
1530 ADC ADPTR
1540 STA ADPTR
1550 LDA $600
1560 ADC ADPTR+1
Appendix A.4

1570   STA ADPTR+1
1580 .endread RTS
1590$
1600 .blnkfile LDA $&80$
1610 LDX $filename$ MOD 256$
1620 LDY $filename$ DIV 256$
1630 JSR OSFIND$
1640 STA fchan$
1650 RTS$
1660$
1670 .openfile LDA $&C0$
1680 LDX $filename$ MOD 256$
1690 LDY $filename$ DIV 256$
1700 JSR OSFIND$
1710 STA fchan$
1720 RTS$
1730$
1740 .closefile LDA $&00$
1750 LDY fchan$
1760 JSR OSFIND$
1770 RTS$
1780$
1790 NEXT I$
1800 REM*******************************
1810 *SAVE LONGMC 7800 7A00 1A00 1C00
1820 PRINT"start=&";start
1830 PRINT"pulsell=&";pulsell
1840 PRINT"pulse22=&";pulse22
1850 PRINT"on1=&";on1
1860 PRINT"on2=&";on2
1870 PRINT"blnkfile=&";blnkfile
1880 PRINT"openfile=&";openfile
1890 PRINT"closefile=&";closefile
1900 PRINT"off1=&";off1
1910 PRINT"off2=&";off2

file handling routines
called as required
from LONGBAS

save assembled programme
in LONGMC

LONGMC variable locations
required for
linking to LONGBAS

A.4.10
3D-SUITE
UNIT 1

PROGRAMME LISTING - INIT

10 REM PROGRAMME TO START 3D-SUITE
20 REM *******************************
30 REM ********** INIT *************
40 REM *** DJ SEARLE* UOB ***********
50 REM ***** OCTOBER 1985 ***********
60 * FX21, 0
70 MODE 7
80 PROC intro
90 CLS
100 PRINT CHR$(141)" Choose options to continue"
110 PRINT CHR$(141)" Choose options to continue"
120 PRINT TAB(3, 8)" New coords or alter coords - 1"
130 PRINT TAB(3, 10)" Continue with preset coords - 2"
140 PRINT TAB(3, 12)" Terminate programme - 3"
150 K = GET
160 IF K = 49 THEN CHAIN" 3D. DATA"
170 IF K = 50 THEN 200
180 IF K = 51 THEN STOP
190 GOT0 150
200 CLS: PRINT TAB(5, 0)" Graphical Description? 
210 K = GET: IF K = 89 OR K = & OD THEN CHAIN" 3D. GRPH"
220 ELSEIF K = 78 THEN CHAIN" 3D. INT"
230 GOT0 210
240 END
250 DEF PROC intro
260 PRINT TAB(8, 10); CHR$(141); " PROGRAMME SUITE-3D"
270 PRINT TAB(8, 11); CHR$(141); " PROGRAMME SUITE-3D"
280 PRINT TAB(5, 12)" GENERALISED STEPPER MOVEMENT"
290 PRINT TAB(10, 13)" AND DATA COLLECTION"
300 PRINT TAB(7, 15)" OCTOBER 1985 D. J. SEARLE"
310 PRINT TAB(10, 17)" Return to continue"
320 TIME = 0
330 REPEAT
340 A$ = INKEY$(0)
350 IF A$ = CHR$(& OD) THEN 370
360 UNTIL TIME = 1500
370 CLS
380 PRINT TAB(0, 4)" Programme to move instrument probe in"
390 PRINT TAB(0, 4)" any directions and collect data"
390 PRINT TAB(0, 9)" Either enter new coord data or use"
390 PRINT TAB(0, 9)" existing file DAT. IN"
390 PRINT TAB(10, 16)" Return to continue"
400 TIME = 0
410 REPEAT
430 A$ = INKEY$(0): IF A$ = CHR$(& OD) THEN 450
440 UNTIL TIME = 1500
450 END PROC
3D-SERIES
UNIT 2
PROGRAMME LISTING - 3D.DAT

10REM*****************************************************************************;
20REM PROGRAMME 3D.DAT LATEST ED 1.86
30REM*****************************************************************************
40MODE7
50HIMEM=63000
60*LOAD DAT.IN 3000
70A=640000
80B=63000
90xx=B
100yy=B+100
110zz=B+200
120PRINT CHR$(141)" MENU"
130PRINT CHR$(141)" MENU"
140PRINT TAB(5,8)"New Set of Coords"
150PRINT TAB(5,10)"New Start Position"
160PRINT TAB(5,12)"Continue With Programme"
170PRINT TAB(5,14)"Load New File"
180K=GET
190K=K-48
200N K GOTO 820,210,1200,330
210CLS
220PRINT TAB(10,6)"New XY Z"
230INPUT TAB(14,8)X,Y,Z
2401-1
250xx? (I-1)-X MOD 256
260xx? (I)-X DIV 256
270yy? (I-1)-Y MOD 256
280yy? (I)-Y DIV 256
290zz? (I-1)-Z MOD 256
300zz? (I)-Z DIV 256
310GOTO1060
320REM*****************************************************************************
330CLS
340REM Initialise block of data
350FOR I=1 TO 300
360xx? I=0
370NEXT
380PRINT TAB(0,0);CHR$(141);CHR$(136);"Load Disc containing coordinate data"
390PRINT TAB(0,1);CHR$(141);CHR$(136);"Load Disc containing coordinate data"
400PRINT TAB(13,3);CHR$(141);CHR$(136);"Marked 'BB'"
410PRINT TAB(13,4);CHR$(141);CHR$(136);"Marked 'BB'"
420PRINT TAB(0,10);"Enter view file for conversion"
430PRINT "or return to exit"
440PRINT
450INPUT TAB(0,15)"File to convert ";FIL$
460IF FIL$="" THEN CLS:GOTO1210
470CLS"LOAD "+FIL$+" 40000"
480CLS
490PRINT TAB(0,0);CHR$(141);CHR$(136);"Replace Original Drive Disc Marked"
500PRINT TAB(0,1);CHR$(141);CHR$(136);"Replace Original Drive Disc Marked"
510PRINT TAB(13,3);CHR$(141);CHR$(136);"3D-SERIES"

A.4.12
520PRINT TAB(13,4);CHR$(141);CHR$(136);"3D-SERIES"
550REM*****************************************************************************
560 K=0
570 T=1
580 dataptr=0
590 DS=":chr$="
600REPEAT
610 DS=DS+chr$
620 chr$=dataptr?A
630 chr$=CHR$(chr$)
640 dataptr=dataptr+1 "data in ASCII format"
650 UNTIL chr<&21 "read and convert"
660 X=VAL(D$)
670 IF X>999 THEN 1051 "store in memory"
680 K=K+1
690 IF K>1 THEN 720
700 IF K=2 THEN 740
710 IF K=3 THEN 760
720 xx? (I-1)=X MOD256
730 xx? (I)=X DIV256:GOTO780
740 yy? (I-1)=X MOD256
750 yy? (I)=X DIV256:GOTO780
760 zz? (I-1)=X MOD256
770 zz? (I)=X DIV256
780 IF K=3 THEN 790 ELSE 800
790 K=0: I=I+2
800 GOTO590
810REM*****************************************************************************
820CLS
830REM Initialise block of data
840 FOR I=1 TO 300
850 xx? I=0
860 NEXT I
870REM*****************************************************************************
880PRINT TAB(6,6)"Enter X,Y,Z coords in mm"
890PRINT TAB(4,7)"Return for new line, Q to quit"
900PRINT TAB(6,9)" X Y Z"
910 I=1
920 T=(I+1)/2+9
930 INPUT TAB(12,T);X,Y,Z
940 xx? (I-1)=X MOD 256
950 xx? (I)=X DIV 256
960 yy? (I-1)=Y MOD 256 "input new coords"
970 yy? (I)=Y DIV 256
980 zz? (I-1)=Z MOD 256
990 zz? (I)=Z DIV 256
1000 I=I+2
1010A$=INKEY$(0)
1020 IF A$="Q" THEN 1060
1030 IF A$=CHR$(60) THEN 920
1040 GOTO1010
1050REM*****************************************************************************
1051PRINT TAB(10,15)"Return To Continue"
1052REPEAT: UNTIL GET=60D
1060CLS
1070PRINT TAB(5,0)"Save To Backup File?"
1080 K=GET
1090 IF K=78 THEN 1130 ELSE IF K=89 OR K=60D THEN 1090
1092 GOTO1080

A.4.13
1090 INPUT TAB(5,0)"DATA FILE NAME ";FIL$  
1100 PRINT TAB(5,0)"Saving Data To ";FIL$  
1110 SCLI "SAVE "+FIL$+" 3000 312C"  
1120 PRINT TAB(5,0)"Saving Data To DAT.IN"  
1130 SCLI "SAVE DAT.IN 3000 312C"  
1140 GOTO1200  
1150 CLS  
1160 INPUT TAB(5,0)"DATA FILE NAME ";FIL$  
1170 SCLI "LOAD "+FIL$+" 3000"  
1180 PRINT TAB(5,0)"Saving Data To ";FIL$  
1190 SCLI "SAVE DAT.IN 3000 312C"  
1200 CLS  
1210 PRINT TAB(5,0);" Run stepper programme?"  
1220 K-GET: IF K=78 THEN STOP ELSEIF K=89 THEN 1230: GOTO1220  
1230 PRINT TAB(7,0);" Graphics Description?"  
1240 K-GET: IF K=78 THEN CHAIN"3D.INT" ELSEIF K=89 THEN CHAIN"3D.GRPH"  
1250 GOTO1240  
1260 STOP
UNIT 3
PROGRAMME LISTING - 3D.GRPH

******************************************************************************
REM 3D.GRPH DJ SEARLE 1986
******************************************************************************
10MODEO
20*LOAD PP1 3000  ) load graphics screens
30*LOAD PP2 440A  ) into shadow RAM
40*LOAD PP3 65F6  )
50PRINT TAB(20,5)"LINE DRAWING OF FLUME AND INST CARRIAGE"
60PRINT TAB(20,6)" X Y Z ORDINATES INCLUDED"
70*XSWAP V.65F6 8000 P.3000  ) swap PP1 onto screen
80PROCchge
90*LOAD PP4 3000  ) load PP4 into shadow RAM
100PRINT TAB(17,5)"ISOMETRIC PLOT OF WATER SURFACE BETWEEN"
110PRINT TAB(17,6)" 4500 < Y < 6500"
120PRINT TAB(22,8)" OVERALL VIEW - PICTURE ONE"
130*XSWAP V.65F6 8000  ) swap PP2 onto screen
140PROCchge
150PRINT TAB(22,8)" INITIAL ZOOM - PICTURE TWO"
160*XSWAP V.65F6 8000  ) swap PP3 onto screen
170PROCchge
180PRINT TAB(17,5)"CROSS-SECTION PROFILE OF FLOW AT STATION"
190PRINT TAB(20,6)" Y=6000"
200PRINT TAB(22,8)"
210*XSWAP V.65F6 8000 P.3000  ) swap PP4 onto screen
220PROCchge
230*XSWAP P.3000 4A09 P.4A0A  ) switch graphics in
240*XSWAP P.4A0A 65F5 P.65F6  ) shadow RAM to repeat
250PRINT TAB(17,5)"LINE DRAWING OF FLUME AND INST CARRIAGE"
260PRINT TAB(17,6)" X Y Z ORDINATES INCLUDED"
270PRINT TAB(22,8)"
280*XSWAP V.65F6 8000 P.3000  ) swap PP1 onto screen
290PROCchge
300GOTO100
310DEF PROCchge
320PRINT TAB(26,0)"Return to change picture"
330PRINT TAB(22,1)"Q to quit graphics and continue"
340K=GET
350IF K=81 THEN PAGE=62A00:CHAIN "3D.BAS"
360IF K=60D THEN ENDPRECOMMEND
3D-SUITE
UNIT 4

PROGRAMME LISTING - 3D.INT

10REM PROGRAMME TO INPUT PARAMETERS
20REM FOR 3D PROGRAMME
30REM ********** 3D.INT **************
40REM *** DJ SEARLE *** OCTOBER 1985 ***
50REM ********** 3D.INT **************
60* FX21,0
70 MODE 7
80 HIMEM $ & 7700
90 REM aread placed above any
overwriting from subsequent programmes
100 REM relocated to & 3500 during execution of 3D.RUN
110 aread & 7 B50
120 PRINT TAB(5,0); "Enter Parameters for Run?"
130 K-GET
140 IF K-89 OR K=& OD THEN 170
150 IF K-78 THEN 710
160 GOT0 130
170 FOR I=1 TO 150
180 aread? I° & 20
190 NEXT
200 CLS
210 PRINT TAB(4, U); CHR$(141); "Series/Run Parameters"
220 PRINT TAB(4,1); CHR$(141); "Series/Run Parameters"
230 PRINT TAB(0,3)"DISC - discharge in litres per second"
240 PRINT TAB(0,5)"GATE - weir gate setting"
250 PRINT TAB(0,7)"SERIES - series number"
260 PRINT TAB(0,9)"RUN - run number"
270 PRINT TAB(0,11)"CROSS-SECTION - position along y-axis"
280 PRINT TAB(7,13)"Enter parameters for run"
290 INPUT TAB(0,17)"DISCHARGE ° " DISC
291 DISC=INT(DISC*100)
300 INPUT TAB(0,18)"GATE; ° " GATE
310 INPUT TAB(0,19)"SERIES = " SERIES
320 INPUT TAB(0,20)"RUN = " RN
330 INPUT TAB(0,21)"CROSS-SECTION = " XSECT
340 PRINT TAB(8,23)"Are these correct?"
350 K-GET; IF K-89 OR K=& OD THEN 360 ELSE IF K=78 THEN 200: GOT0 350
360 CLS
370 PRINT TAB(4,0); CHR$(141); "Calibration parameters"
380 PRINT TAB(4,1); CHR$(141); "Calibration parameters"
390 PRINT TAB(0,3)"ADTO, ADTCAL -
from programme ADVAL"; "giving operational
parameters for the "; "angular displacement transducer."
400 PRINT TAB(0,7)"RATEPT -
maximum working range"; "of the pressure transducer."
410 PRINT TAB(0,10)"PTCALIB - ADC reading for 5volt PT input"
420 PRINT TAB(0,12)"DISTBM, DSTDTP -
dist. hi/lo probe range"; "from bed and surface of f/p"
430 PRINT TAB(0,15)"Enter parameters for instruments"
440 PRINT TAB(0,16)"Default in brackets:"
450 INPUT TAB(0,17)"ADTO(500) units = " ADTO
460 INPUT TAB(0,18)"ADTCAL1(800) units/180deg = " ADCL1
470 INPUT TAB(0,19)"RATEPT(20) mm.H20 = " RATPT
480 INPUT TAB(0,20)"PTCALIB5(1118) = " PTCL1
490 INPUT TAB(0,21)"DSTBTM(1)= " ; PTCL2
500 INPUT TAB(0,22)"DSTTP(5)= " ; PTCL3
510 PRINT TAB(8,23)"Are these correct?"
520 K = GET; IF K = 89 OR K = &OD THEN GOTO 530 ELSE IF K = 78 THEN GOTO 520
530 IF ADTO = 0 THEN ADTO = 500
540 IF ADCL1 = 0 THEN ADCL1 = 800
550 ADCL2 = 1
560 IF RATPT = 0 THEN RATPT = 20
570 IF PTCL1 = 0 THEN PTCL1 = 1118
580 PTCL2 = 2
590 A$ = "DISCHARGE: GATE: SERIES: RUN: CROSS SECTION"
600 PROC convert
610 A$ = STR$(DISC) + " +STR$(GATE) + " +STR$(SERIES) + " +STR$(RN) + " +STR$(XSECT)
620 PROC convert
640 PROC convert
650 A$ = STR$(ADTO) + " +STR$(ADCL1) + " +STR$(RATPT) + " +STR$(PTCL1) + " +STR$(PTCL2) + " +STR$(PTCL3)
660 L = LEN(A$)
670 FOR I = 1 TO L
680 aread? (I - 1) = ASC(MID$(A$, I, 1))
690 NEXT I
700 aread = aread + L
710PAGE = &A00
720CHAIN "3D.BAS"
730 REM****************************
740 DEF PROC convert
750 L = LEN(A$)
760 FOR I = 1 TO L
770 aread? (I - 1) = ASC(MID$(A$, I, 1))
780 NEXT I
790 aread = aread + L
800 aread? 0 = &A
810 aread? 1 = &D
820 aread = aread + 2
830 END PROC
[verbatim]
3D-SUITE
UNIT 5
PROGRAMME LISTING - 3D.BAS

10REM PROGRAMME FOR 3D STEPPER PROGRAMME
20REM RUNS WITH 3D.MC
30REM ******************3D.BAS******************
40REM **** DJ SEARLE *** OCTOBER 1985 ********
50REM ****************************
60MODEO
70VDU 28,0,31,0,79 )
80A=62500 )
90B=67700 )
100HIMEM=B )
110* LOAD 3D.MC 1A00 ) * load m/code prog.
120* LOAD DAT.IN 2500 ) load data file
130C=61A17 )
140xx=A )
150yy=A+100 )
160zz=A+200 )
170ddx=A+300 )
180stpx=B )
190stpy=B+100 )
200stpz=B+200 )
210minj=B+300 )
220derx=B+400 )
230dery=B+500 )
240derz=B+600 )
250signx=B+700 )
260signy=B+750 )
270signz=B+800 )
280sindx=B+850 )
290sindy=B+900 )
300sindz=B+950 )
310cycles=B+1000 )
320moves=C )
330delay=C+1 )
340delayrd=C+3 )
350average=C+16 )
360AD=0
370HH=0
380KK=0
390REM ****************************
400REM Initialise data to zero
410FORI=1TO1000: stpx? I=0:NEXT
411FORI=1TO300: ddx? I=0:NEXT
420REM ****************************
430DIM PS%(3,50), DIFF%(3,50), MIN%(50), STP%(3,50), TT%(3,50)
440DIM ERX%(50), ERY%(50), ERZ%(50)
450DIM SIGNDX(50), SIGNDY(50), SIGNDZ(50), CYCLES(50)
460REM ****************************
470PRINT TAB(28,4); "COORDS (MM)"
480PRINT TAB(28,5); "X Y Z"
490PRINT TAB(28,6); "----------"
500J=0
510FORI=1TO100STEP2
520J=J+1
530PS%(1,J)=xx?(I-1)+xx?I*256 )

[/verbatim]
Appendix A.4

540PSZ(2,J)=yy?(I-1)+yy*I*256 ) read coord data into arrays
550PSZ(3,J)=zz?(I-1)+zz*I*256 )

560IF PS%(1,J)=0 AND PS%(3,J)=0 AND PS%(2,J)=0 THEN N=J-1:GOTO610
570IF J<25 THEN 580 ELSEIF J>=25 THEN 590
580PRINT TAB(0,J+6),PS%(1,J),PS%(2,J),PS%(3,J):GOTO600
590PRINT TAB(40,J+6-24),PS%(1,J),PS%(2,J),PS%(3,J):GOTO600
600NEXT

610PRINT TAB(0,0)"Hardcopy of X,Y,Z coordinates?"
620K=GET
630IF K=78 THEN750
640IF K=89 OR K=60D THEN660
650GOTO620
660VDU2
670VDU21
680PRINT " COORDS(MM)"
690PRINT" X Y Z"
700PRINT
710FORI=1TO N
720PRINTPS%(1, I), PS%(2, I)PS%(3, I): NEXT
730VDU6
740VDU3
750REM convert coords to step values
760FORJ=1TON: FORI=1TO3STEP2 )
770PS%(I,J)=PS%(I,J)*48/1.25: NEXTI ) convert coords to
780PS%(2, J)=PS%(2, J)*24.88 ) step values in X,Y,Z
790NEXTJ ) directions
800REM*******************************

810REM Obtain difference between values
820FORJ=1TON: FORI=1TO3 )
830DIFF%(I, J)=PS%(I, J+1)-PS%(I, J) ) calculate steps in X,Y,Z
840NEXT: NEXT ) between coordinates
850REM*******************************

860REM find least steps in X,Y or Z
870FORJ=1TON-1
880D1%=ABS(DIFF%(1, J)): D2%=ABS(DIFF%(2, J)): D3%=ABS(DIFF%(3, J))
890IF D1%=0 AND D2%=0 AND D3%=0 THEN CHAIN "3D. DATA"
900 IF D1%=0 AND D2%=0 AND D3%=0 THEN MIN%(J)=D3%=GOTO970
910 IF D1%=0 AND D3%=0 AND D2%=0 THEN MIN%(J)=D2%=GOTO970
920 IF D2%=0 AND D3%=0 AND D1%=0 THEN MIN%(J)=D1%=GOTO970
930 IF D1%>0 AND D2%>0 AND D3%>0 THEN MIN%(J)=D2%ELSE MIN%(J)=%D2% ) Y or Z
940 IF D1%<D2 AND D1%<D3 AND D1%>0 THEN MIN%(J)=D1%=GOTO970
950 IF D2%<D3 AND D2%<D1 AND D2%>0 THEN MIN%(J)=D2%=GOTO970
960 IF D1%<D3 AND D1%<D2 AND D3%>0 THEN MIN%(J)=D3%=GOTO970
970NEXT

980REM*******************************
990REM find integer ratios between X,Y,Z steps
1000INPUT TAB(0,1)"Enter K to change step ratio(default=50)"; K
1010IF K=0 THEN K=50 ) find
1020FORJ=1TON-1: MIN%(J)=MIN%(J)/K: FORI=1TO3 ) approximate
1030IF MIN%(J)=0 THENMIN%(J)=1 ) integer
1040STP%(I, J)=DIFF%(I, J)/MIN%(J)+0.5 ) ratios
1050NEXTI )
1060NEXTJ )
1070REM*******************************
1080REM reduce steps to smallest factor
1090FORK=1TO2: FORJ=1TON-1: FORNUM=1TO1STEP-1 )
1100IF STP%(I, J)MODNUM=0 AND STP%(2, J)MODNUM=0
AND STP%(3, J)MODNUM=0 THEN 1120 ) reduce to smallest
1110NEXTNUM ) common denominator

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1120 FOR I=1 TO N:
1130 STP%(I,J)=STP%(I,J)/NUM:
1140 NEXT I:
1150 FOR J=1 TO N:
1160 IF STP%(1,J)<0 THEN signx%(J)=&FE
1170 IF STP%(1,J)>0 THEN signx%(J)=&01
1180 IF STP%(2,J)<0 THEN signy%(J)=&FD
1190 IF STP%(2,J)>0 THEN signy%(J)=&02
1200 IF STP%(3,J)<0 THEN signz%(J)=&FB
1210 IF STP%(3,J)>0 THEN signz%(J)=&04
1220 NEXT J:
1230 REM**********************************************************
1240 REM Calculate cycles and dx dy dz
1250 REM**********************************************************
1260 PRINT TAB(0,2); "Run motor only?"
1270 B$=INKEY$(0)
1280 IF B$="Y" THEN 1310
1290 IF B$="N" THEN 1350
1300 GOTO 1270
1310 J=0:
1320 FOR I=1 TO N-1:
1330 cycles%(I)=MIN%(I) MOD 256
1340 cycles%(I+1)=MIN%(I) DIV 256:
1350 FOR I=1 TO N-1:
1360 CYCLES(I)=MIN%(I):
1370 H=0:
1380 L=1:
1390 AVGE=1:
1400 GOTO 2180
1410 REM**********************************************************
1420 SC=1.25/48
1430 PRINT TAB(0,0)
1440 PRINT TAB(0,1)
1450 PRINT TAB(0,2)
1460 M=0:
1470 I=0
1480 PRINT TAB(0,0); "Enter parameters for leg"
1490 FOR J=1 TO N:
1500 IF J<24 THEN 1510 ELSE 1520
1510 PRINT TAB(0,6+J) ">
1520 PRINT TAB(0,7+J) ">
1530 PRINT TAB(0,5+J) ""
1540 NEXT J:
1550 D1%=ABS(DIFF%(1,J)): D2%=ABS(DIFF%(2,J)): D3%=ABS(DIFF%(3,J))
1560 PRINT "Axis (X,Y,Z)"
1570 K=GET
1580 IF K=88 THEN D1%=GOTO1600
1590 IF K=89 THEN D2%=GOTO1600
1600 IF K=90 THEN D3%=GOTO1600
1610 GOTO1550
1620 IF D=0 THEN PRINT "Illegal axis": GOTO 1540
1630 IF D>0.5 THEN AD=1 ELSE AD=0
1690NN%=NN+AD
1700IF NN%=0 THEN NN%=1
1710DX=D1%*SC*10/NN%
1720DY=D2%*SC*10/NN%
1730DZ=D3%*SC*10/NN%
1740IF K=88 THEN SP-DX/10
1750IF K=89 THEN SP-DY/10
1760IF K=90 THEN SP-DZ/10
1770CYCLES(J)=INT((SP*MIN%(J))/(SC*D))
1780NN%=MIN%(J)/CYCLES(J)
1790R=NN MOD 1 - NN
1800IF R=0 THEN CYCLES(J)*1.01
1810ELSE CYCLES(J)
1820NN%=MIN%(J)/CYCLES(J)
1830IF NN%=0 THEN NN%=1
1840DXsD1%*SC*10/NN%
1850DY-D2%*SC*10/NN%
1860DZ=D3%*SC*10/NN%
1870DX%-DX: DY%=DY: DZ%=DZ
1880PRINT TAB(40,2), DX%/10, DY%/10, DZ%/10
1890ONN%=NN%+1
1900IF NN%=0 THEN NN%=1
1910PRINT TAB(0,0);"No. of readings =";NN%;" cycles=";CYCLES(J)
1920CLS
1930PRINT TAB(20,0)" STPX STPY STPZ MIN%(J)"
1940FOR J=1 TO N-1
1950input TAB(16,10); "Delay between readings (0.1-. . 255secs:default=1)" DELAY
1960IF DELAY=0 THEN DELAY=1
1970ELSE DELAY=1
1980IF DELAY>1 THEN H=DELAY-I: L=70
1990IF DELAY<1 THEN H=0: L=DELAY/0.01
2000PRINT TAB(11,12); "Readings to sample 2,4,8,16,32,64,128 only (default=4) " AVGE
2010CLS
2020INPUT TAB(16,10); "Delay between readings (0.1-. . 255secs:default=1)" DELAY
2030GOTO2150
2040REM*******************************
2050REM print step values
2060REM******************************
2230 IF J<25 THEN 2240 ELSE 2250
2240 PRINT TAB(0,J+2)STP%(1,J),STP%(2,J),STP%(3,J),MIN%(J):GOTO2260
2250 PRINT TAB(40,J-23)STP%(1,J),STP%(2,J),STP%(3,J),MIN%(J)
2260 NEXT
2270 PROCcontinue
2280 REM********************
2290 REM calculate and print stepped positions
2300 PRINT TAB(15,0)" STEPPED POSITIONS"
2310 PRINT TAB(15,1)" X Y Z"
2320 FOR J=1 TON
2330 FOR I'=1 TO 3
2340 TT%(I, J)=PS%(I, J)
2350 TT%(I, J+1)=TT%(I, J)+STP%(I, J)*MIN%(J)
2360 NEXT
2370 IF J<25 THEN 2380 ELSE 2390
2380 PRINT TAB(0, J+4)TT%(1, J), TT%(2, J), TT%(3, J): GOT02400
2390 PRINT TAB(40, J+2-22)TT%(1, J), TT%(2, J), TT%(3, J)
2400 NEXT
2410 PROCcontinue
2420 REM************************
2430 FOR J=1 TO N-1
2440 FOR I=1 TO 3
2450 ERX%(J)'TT%(1, J)-PS%(1, J)
2460 ERY%(J)'TT%(2, J)-PS%(2, J)
2470 ERZ%(J)'TT%(3, J)-PS%(3, J)
2480 NEXT: NEXT
2490 REM calculate d. errors and signs
2500 PRINT TAB(15,0)" Corr. factors between legs"
2510 PRINT TAB(15,1)" DERX DERY DERZ"
2520 PRINT
2530 )
2540 FOR I=1 TO N-1
2550 DERX% CYCLES(I)*(ERX%(I+1)-ERX%(I))/MIN%(I)+0.5
2560 DERY% CYCLES(I)*(ERY%(I+1)-ERY%(I))/MIN%(I)+0.5
2570 DERZ% CYCLES(I)*(ERZ%(I+1)-ERZ%(I))/MIN%(I)+0.5
2580 IF DERX%<0 THEN signdx?(I-1)=&01
2590 IF DERX%>0 THEN signdx?(I-1)=&FE
2600 IF DERY%<0 THEN signdy?(I-1)=&02
2610 IF DERY%>0 THEN signdy?(I-1)=&FD
2620 IF DERZ%<0 THEN signdz?(I-1)=&04
2630 IF DERZ%>0 THEN signdz?(I-1)=&FB
2640 IF J<25 THEN 2650 ELSE 2660
2650 PRINT TAB(0, I+2) DERX%, DERY%, DERZ%: GOT02670
2660 PRINT TAB(40, I+2-22) DERX%, DERY%, DERZ%
2670 DERX%=ABS(DERX%)
2680 DERY%=ABS(DERY%)
2690 DERZ%=ABS(DERZ%)
2700 Dery?(J-1)=DERY% MOD 256
2710 Dery?(J-1)=DERY% DIV 256
2720 Dery?(J-1)=DERY% MOD 256
2730 Dery?(J-1)=DERY% DIV 256
2740 Dery?(J-1)=DERY% MOD 256
2750 Dery?(J-1)=DERY% DIV 256
2760 J=J+2
2770 NEXTI
2780 PRINT TAB(20,30)"Hardcopy of calculated step values?"
2790 K=GET
2800 IF K=78 THEN 2920
2810 IF K=89 OR K=&0D THEN VDU2: VDU2: GOT02830
REM PROGRAMME 3D.RUN  LATEST ED. 1.86
30REM********D J SEARLE********************
40REM*****UNIVERSITY OF BRISTOL**********
50MODE7
60CLS
70HIMEM=&3500
80C=&1A17
90Setup=C+18
100REM move data stored from 3D.INT at 7B50 to 3500
110*XMOVE P.7B50 +83 P.3500
120AREAD=&3583
130TMP=7C
140AREAD?1=(TMP MOD 10)+&30
150TMP=TMP DIV 10
160AREAD?2=(TMP MOD 10)+&30
170AREAD=7B50+1-(TMP MOD 10)+&30
180AREAD=7B50+1-(TMP DIV 100)+&30
190 AREAD?3=20
190 AREAD?4=60A
200AREAD?5=60D
210PRINT TAB(5,2);CHR$(141)"Choose option to continue"
220PRINT TAB(5,3);CHR$(141)"Choose option to continue"
230PRINT TAB(5,6)"Commence programme run - 1"
240PRINT TAB(5,8)"Terminate programme - 2"
250PRINT TAB(5,10)"Return to original menu - 3"
260K=GET
270IF K<47 OR K>51 THEN 260
280K=K-48
290PAGEs&1A00: CHAIN"INIT"
300REM Initialise //ram
310PRINT TAB(U, 9)
320BASE=&3500
330US$="parallel ram"
340FOR I=0 TO 99: S$=S$+CHR$(BASE?I): NEXT
350FOR I=107 TO 140: S$=S$+CHR$(BASE?I): NEXT
360PRINT S$+CHR$(136);"Initialising parallel ram"
370PRINT TAB(6,15);CHR$(136);"Initialising parallel ram"
380PRINT TAB(6,15);CHR$(136);"Initialising parallel ram"
390BASE=&3500
400S$=""
410FOR I=0 TO 99: S$=S$+CHR$(BASE?I): NEXT
420PRINT S$+CHR$(136);"Initialising parallel ram"
430S$=""
440FOR I=107 TO 140: S$=S$+CHR$(BASE?I): NEXT
450PRINT S$+CHR$(136);"Initialising parallel ram"
460PRINT TAB(6,1)"MACHINE PROGRAMME RUNNING"
470PRINT TAB(12,2)"DO NOT TOUCH"
480PRINT TAB(12,2)"Averaged Velocity and Angles at probe"
490PRINT TAB(5,21)"VELOCITY ANGLE"
500CALL Setup
510CLS
520PRINT TAB(6,1);CHR$(141)"Run finished"
530PRINT TAB(6,1);CHR$(141)"Run finished"
540PRINT TAB(6,1);CHR$(141)"Choose option to continue"
Appendix A.4

550 PRINT TAB(6,5); CHR$(141) "Choose option to continue"
560 PRINT TAB(3,8) "Save and process data - 1"
570 PRINT TAB(3,10) "Rerun programme-same coords - 2"
580 PRINT TAB(3,12) "Return to original Menu - 3"
590 K = GET
600 IF K < 49 OR K > 51 THEN 590
610 IF K = 49 THEN 660
620 IF K = 50 THEN CHAIN "3D.BAS"
630 IF K = 51 THEN PAGE = &1A00: CHAIN "INIT"
640 IF K = 52 THEN
650 GOTO 590
660 CLS
680 *SAVE DAT.OUT 3500 5500
700 PRINT TAB(0,0) "Convert data to ASCII format?"
710 K = GET: IF K = 78 THEN 720 ELSE 730
720 STOP
730 PAGE = &1A00
740 CHAIN "TFR"
3D-SUITE
PROGRAMME LISTING - 3D-ASM

10REM PROGRAMME 3D.ASM LATEST ED. 25/7/86
20REM**************************************
30MODE7
40aread=&3589 )
50A=&2500 )
60xx=A )
70yy=A+100 )
80zz=A+200 )
90ddx=A+300 )
100B=&7700 )
110stpx=B )
120stpy=B+100 )
130stpz=B+200 )
140minj=B+300 )
150derx=B+400 )
160dery=B+500 )
170derz=B+600 )
180signx=B+700 )
190signdx=B+850 )
200cycles=B+1000 )
210STPX=&70 )
220STPY=&72 )
230STPZ=&74 )
240MINJ=&76 )
250DERRX=&78 )
260DERRY=&7A )
270DERRZ=&7C )
280AREAD=&7E )
290SIGN=&80 )
300SIGND=&82 )
310XX=&84 )
320YY=&86 )
330ZZ=&88 )
340DX=&8A )
350CYCLES=&8C )
360PORTB=&FE60 )
370DDRB=&FE62 )
380OSBYTE=&FFF4 )
390FOR OPT%=O TO 3 STEP 3
400P%=&1A00
410OPT%=&7300
420(OPT OPT% )
430.x EQUW 0 ) UNIT 7
440.y EQUW 0 )
450.z EQUW 0 )
460.dx EQUW 0 )
470.dy EQUW 0 )
480.dz EQUW 0 )
490.cnt EQUW 0 )
500.cycl EQUB 0 )
510.cyh EQUB 0 )
520.offal EQUB 0 )
530.offh EQUB 1 )
540.offabl EQUB 0 )
550.offab2 EQUB 50 )

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Appendix A. 4

560. offsb3  EQUB 100  
570. offsb4  EQUB 0  
580. inkey   EQUB 0  
590. moves   EQUB 0  
600. delay   EQUW 0  
610. delayrd EQUW 0  
620. ctr     EQUW 0  
630. ctrl    EQUW 0  
640. store   EQUW 0  
650. temp    EQUW 0  
660. templ   EQUW 0  
670. channel EQUB 0  
680. average EQUB 0  
690. reading EQUB 0  

700. Setup  
710  LDA £stpx MOD 256: STA STPX  
720  LDA £stpx DIV 256: STA STPX+1  
730  LDA £stpy MOD 256: STA STPY  
740  LDA £stpy DIV 256: STA STPY+1  
750  LDA £stpz MOD 256: STA STPZ  
760  LDA £stpz DIV 256: STA STPZ+1  
770  LDA £minj MOD 256: STA MINJ  
780  LDA £minj DIV 256: STA MINJ+1  
790  LDA £derx MOD 256: STA DERX  
800  LDA £derx DIV 256: STA DERX+1  
810  LDA £derx MOD 256: STA DERY  
820  LDA £derx DIV 256: STA DERY+1  
830  LDA £derz MOD 256: STA DERZ  
840  LDA £derz DIV 256: STA DERZ+1  
850  LDA £signx MOD 256: STA SIGN  
860  LDA £signx DIV 256: STA SIGN+1  
870  LDA £signdx MOD 256: STA SIGND  
880  LDA £signdx DIV 256: STA SIGND+1  
890  LDA £aread MOD 256: STA AREAD  
900  LDA £aread DIV 256: STA AREAD+1  
910  LDA £xx MOD 256: STA XX  
920  LDA £xx DIV 256: STA XX+1  
930  LDA £yy MOD 256: STA YY  
940  LDA £yy DIV 256: STA YY+1  
950  LDA £zz MOD 256: STA ZZ  
960  LDA £zz DIV 256: STA ZZ+1  
970  LDA £ddx MOD 256: STA DX  
980  LDA £ddx DIV 256: STA DX+1  
990  LDA £cycles MOD 256: STA CYCLES 
1000 LDA £cycles DIV 256: STA CYCLES+1  
1010 LDA £&FF: STA DDRB  

10200 Start  
10400 Store new data in parallel ram from &3000  
10500 UNIT 8  
1060  LDA £&6F:LDX £&81: JSR OSBYTE  
1070  LDY £0  
1080  LDA £&FF:STA (AREAD),Y  
1090  INY: LDA £&FF: STA (AREAD),Y  
1100 LDA £2:CLC:ADC AREAD:STA AREAD  
1110 LDA £0  
1120 ADC AREAD+1:STA AREAD+1  
1130 DEY  
1140. Lpl LDA (XX),Y:STA (AREAD),Y  

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Appendix A.4

1150 INY: CPY £2: BEQ Lp2: JMP Lp1 )
1160. Lp2 LDA £2: CLC: ADC AREAD: STA AREAD )
1170 LDA £0 )
1180 ADC AREAD+1: STA AREAD+1 )
1190 LDA £2: CLC: ADC XX: STA XX )
1200 LDA £0 )
1210 ADC XX+1: STA XX+1 )
1220 LDY £0 )
1230. Lp3 LDA(YY), Y: STA (AREAD), Y )
1240 INY: CPY £2: BEQ Lp4: JMP Lp3 )
1250. Lp4 LDA £2: CLC: ADC AREAD: STA AREAD )
1260 LDA £0 )
1270 ADC AREAD+1: STA AREAD+1 )
1280 LDA £2: CLC: ADC YY: STA YY )
1290 LDA £0 )
1300 ADC YY+1: STA YY+1 ) store current traverse
1310 LDY £0 ) data -X,Y,Zcoord
1320. Lp5 LDA(ZZ), Y: STA (AREAD), Y ) at start
1330 INY: CPY £2: BEQ Lp6: JMP Lp5 )
1340. Lp6 LDA £2: CLC: ADC AREAD: STA AREAD ) dist between rdgs
1350 LDA £0 ) directions
1360 ADC AREAD+1: STA AREAD+1 ) no of rdgs per traverse
1370 LDA £2: CLC: ADC ZZ: STA ZZ )
1380 LDA £0 ) traverse
1390 ADC ZZ+1: STA ZZ+1 )
1400 LDY £0 )
1410. Lp7 LDA(DX), Y: STA (AREAD), Y )
1420 INY: CPY £6: BEQ Lp8: JMP Lp7 )
1430. Lp8 LDA(DX), Y: STA (AREAD), Y: STA reading )
1440 INY )
1450 LDA(DX), Y: STA (AREAD), Y )
1460 LDA £8: CLC: ADC AREAD: STA AREAD )
1470 LDA £0 )
1480 ADC AREAD+1: STA AREAD+1 )
1490 LDA £8: CLC: ADC DX: STA DX )
1500 LDA £0 )
1510 ADC DX+1: STA DX+1 )
1520 LDY £0 )
1530 LDA £&FF: STA (AREAD), Y )
1540 INY: LDA £&FF: STA (AREAD), Y )
1550 LDA £2: CLC: ADC AREAD: STA AREAD )
1560 LDA £0 )
1570 ADC AREAD+1: STA AREAD+1 )
1580 LDA £&6F: LDX £&CO: JSR OSBYTE ) switch out shadow RAM
1590\ )
1600 DEC moves: BNE Cnt: JMP End ) check end of run
1610\ )

1620 Set minj to next value\)
1630. Cnt LDA reading: BEQ Cnt1: JSR Procadc ) UNIT 9
1640. Cnt1 LDY offsl: LDA (MINJ), Y: STA cnt )
1650 LDY offsh: LDA (MINJ), Y: STA cnt+1 ) load total steps in
1660 BNE Reset ) traverse
1670 LDA cnt )
1680 BNE Reset )
1690 LDA £01: STA cnt )
1700\ )

1710 Reset\)
1720 Reset directions of stepper motors\) UNIT 10
1730 LDY offsb1: LDA (SIGN), Y )
1740 BMI R1
1750 ORA PORTB:STA PORTB:JMP R2
1760.R1 AND PORTB:STA PORTB
1770.R2 LDY offsb2:LDA (SIGN),Y set current dir of
1780 BMI R3 stepper motors
1790 ORA PORTB:STA PORTB:JMP R4
1800.R3 AND PORTB:STA PORTB
1810.R4 LDY offsb3:LDA (SIGN),Y
1820 BMI R5
1830 ORA PORTB:STA PORTB:JMP R6
1840.R5 AND PORTB:STA PORTB
1850
1860 Reset value for cycles0
1870.R6 LDY offsl:LDA (CYCLES),Y:STA cyc1 load no. stepblocks
1880 LDY offsh:LDA (CYCLES),Y:STA cyc2 between readings
1890Ω
1900 Pulse
1910Ω Reset x,y,z values for pulsing0
1920 LDY offsl
1930 LDA (STPX),Y:STA x
1940 LDA (STPY),Y:STA y
1950 LDA (STPZ),Y:STA z load X,Y,Z stepblocks
1960 LDY offsh equal val. of steps
1970 LDA (STPX),Y:STA x+1 in X,Y,Z directions
1980 LDA (STPY),Y:STA y+1 to move probe in
1990 LDA (STPZ),Y:STA z+1 computed direction
2000Ω
2010Ω Beginning of pulsing routine0
2020Ω
2030Ω
2040Ω Pulsing motor X
2050.P1s1 UNIT 13
2060 LDA £0:CMP x:BEQ P2
2070.P1
2080 LDA £10:ORA PORTB:STA PORTB
2090 JSR Delay
2100 LDA £&EF:AND PORTB:STA PORTB pulse X by stepblock
2110 JSR Delay
2120 DEC x:BNE P1
2130.P2 LDA £0:CMP x+1:BEQ P1s2
2140 DEC x+1:LDA £&FF:STA x
2150 JMP P1
2160Ω
2170Ω Pulsing motor Y
2180.P1s2 LDA £0:CMP y:BEQ P4
2190.P3 LDA £&20:ORA PORTB:STA PORTB
2200 JSR Delay
2210 LDA £&DF:AND PORTB:STA PORTB
2220 JSR Delay pulse Y by stepblock
2230 DEC y:BNE P3
2240.P4 LDA £0:CMP y+1:BEQ P1s3
2250 DEC y+1:LDA £&FF:STA y
2260 JMP P3
2270Ω
2280Ω Pulsing motor Z
2290.P1s3 LDA £0:CMP z:BEQ P6
2300.P5 LDA £&40:ORA PORTB:STA PORTB
2310 JSR Delay
2320 LDA £&BF:AND PORTB:STA PORTB

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2330 JSR Delay  
2340 DEC z:BNE P5  
2350 .P6 LDA $0:COMP z+1:BEQ Endpulse  
2360 DEC z+1:LDA &FF:STA z  
2370 JMP P5  
2380
2390 Check values of cycles, minj to continue pulsing
2400
2410 .Endpulse
2420 DEC cnt:BEQ Cl:JMP C2  
2430 .C1 LDA cnt+1:BEQ Nextj:DEC cnt+1  
2440
2450 .C2 JSR Inkey:CMP $&1B:BNE C3:JMP End  
2460
2470 .C3 DEC cycl:BEQ C4:JMP Pulse  
2480 .C4 LDA cycl:BEQ Endcycle:DEC cycl:  
2481 JMP Pulse  
2490
2500 .Endcycle
2510 JSR Procint  
2520 DEC reading:BMI El  
2530 JSR Procadc  
2540 .El JMP Reset  
2550 .Nextj
2560 LDY offsh:LDA (CYCLES),Y:CLC:LSR A  
2570 STA temp+1  
2580 LDY offsl:LDA (CYCLES),Y::ROR A  
2590 STA temp  
2600 LDA temp+l:CMP cycl:BMI Nextjj  
2610 LDA temp:CMP cycl:BMI Nextjj  
2620 JSR Procint  
2630 .Nextjj
2640 Increment offset values
2650 LDY offsl:INY:INY:STY offsl  
2660 LDY offsh:INY:INY:STY offsh  
2670 LDY offsb1:INY:STY offsb1  
2680 LDY offsb2:INY:STY offsb2  
2690 LDY offsb3:INY:STY offsb3  
2700 LDY offsb4:INY:INY:STY offsb4  
2710
2720 JMP Start  
2730 .End
2740 LDA $&6F:LDX $&81:JSR OSBYTE  
2750 LDY $0  
2760 LDA $&FE:STA (AREAD),Y  
2770 INY:LDX $&FE:STA (AREAD),Y  
2780 LDA $2:CLC:ADC AREAD:STA AREAD  
2790 LDA $0  
2800 ADC AREAD+1:STA AREAD+1  
2810 LDA $&6F:LDX $&CO:JSR OSBYTE  
2820 .Envelope
2830 EQUI &FC040101  
2840 EQUI &0A140A04  
2850 EQUI &FB00007F  
2860 EQUI &7E7E  
2870 LDX &Envelope MOD 256  
2880 LDY &Envelope DIV 256  

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Appendix A.4

2890  LDA £8:JSR &FFF1 ) operator at  
2900.Beepl EQUD &00010001 ) end of run  
2910 EQUD &000640064 )  
2920.Beepl2 EQUD &00010002 )  
2930 &FFF1 EQUD &000640032 )  
2940.Sound LDX &Beepl MOD 256 )  
2950 LDY &Beepl DIV 256 )  
2960 LDA £7:JSR &FFF1 )  
2970 . Beepl2 EQUD &00010002 )  
2980 LDY &Beepl2 DIV 256 )  
2990 LDA £7:JSR &FFF1 )  
3000 RTS  
3010  
3020  
3030 Subroutines  
3040  
3050 Corrections between cycles  
3060 Procin  
3070.Derx LDY offsb1:LDA (SIGND),Y ) set X direction  
3080 BMI I1 )  
3090 ORA PORTB:STA PORTB:JMP I2 )  
3100.I1 AND PORTB:STA PORTB )  
3110.D12 LDY offsb4:LDA (DERX),Y:STA dx )  
3120 INY:LDA (DERX),Y:STA dx+1:BNE I3 )  
3130 LDA dx:BNE I3 )  
3140 JMP Dery )  
3150.I3 LDA £&10:ORA PORTB:STA PORTB ) pulse X motor  
3160 JSR Delay ) by total steps  
3170 LDA £&EF:AND PORTB:STA PORTB ) for correction  
3180 JSR Delay )  
3190 DEC dx:BNE I3 )  
3200 LDA dx+1:BEQ Dery )  
3210 DEC dx+1:LDA £&FF:STA dx:JMP I3 )  
3220.Dery LDY offsb2:LDA (SIGND),Y ) set Y direction  
3230 BMI I4 )  
3240 ORA PORTB:STA PORTB:JMP I5 )  
3250.I4 AND PORTB:STA PORTB )  
3260.D55 LDY offsb4:LDA (DERY),Y:STA dy )  
3270 INY:LDA (DERY),Y:STA dy+1:BNE I6 )  
3280 LDA dy:BNE I6 )  
3290 JMP Derz )  
3300.I6 LDA £&20:ORA PORTB:STA PORTB ) pulse Y motor  
3310 JSR Delay )  
3320 LDA £&DF:AND PORTB:STA PORTB )  
3330 JSR Delay )  
3340 DEC dy:BNE I6 )  
3350 LDA dy+1:BEQ Derz )  
3360 DEC dy+1:LDA £&FF:STA dy:JMP I6 )  
3370.Derz LDY offsb3:LDA (SIGND),Y ) set Z direction  
3380 BMI I7 )  
3390 ORA PORTB:STA PORTB:JMP I8 )  
3400.I7 AND PORTB:STA PORTB )  
3410.D18 LDY offsb4:LDA (DERZ),Y:STA dz )  
3420 INY:LDA (DERZ),Y:STA dz+1:BNE I9 )  
3430 LDA dz:BNE I9 )  
3440 JMP Endint )  
3450.I9 LDA £&40:ORA PORTB:STA PORTB ) pulse Z motor  

UNIT 15

POSITION CORRECTION ROUTINE
Appendix A.4

3460    JSR Delay
3470    LDA &BF:AND PORTB:STA PORTB
3480    JSR Delay
3490    DEC $z:BNE I9
3500    LDA $z+1:BEQ Endint
3510    DEC $z+1:LDA &FF:STA $z:JMP I9
3520.Endint
3530    RTS
3540
35500Read adc channels
3560.Procadc LDA $7:JSR &FFEE
3570.Trans
3580    LDA temp:STA channel
3590    LDA $0:STA temp:STA temp+1
3600    LDA $4:STA ctr
3610.Rpt1 JSR Delayrd
3620    LDA $&80:LDX $4:JSR OSBYTE
3630    STX templ:STY templ+1:LDX $6
3640.Div0 CLC:LSR templ+1:ROR templ:DEX
3641    BNE Div0
3650    LDA temp:CLC:ADC temp:STA temp ) delay loop to
3660    LDA temp+1:ADC temp+1:STA temp+1 ) allow pressure
3670    DEC ctr:BNE Rpt1 ) reading to stabilise
3680    LDA $2 ) before recording
3690.Div1 CLC:LSR temp+1:ROR temp:LSR A
3691    BNE Div1
3700    SEC:LDA temp:SBC channel:CMP $0
3701    BNE Trans
3710    LDA average:STA ctr ) load rdgs to avge
3720    LDA $4:STA channel ) read on ADC ch. 4
3730    LDA $0:STA temp:STA temp+1
3740.Convert
3750    JSR Delayrd
3760    LDA $&80:LDX channel:JSR OSBYTE
3770    STX templ:STY templ+1
37800Reduce ADC value to 10 bits
3790    LDX $6
3800.Div CLC:LSR templ+1:ROR templ:DEX ) read ADC values
3801    BNE Div ) reduce to 10 bits
3810    LDA temp:CLC:ADC temp:STA temp ) and average
3820    LDA temp+1:ADC temp+1:STA temp+1 )
3830    DEC ctr:BNE Convert
3840    LDA average
3850.Avge
3860    CLC
3870    LSR temp+1
3880    ROR temp
3890    LSR A:CMP $1:BNE Avge
39000
3910.Store LDA $&6F:LDX $&81:JSR OSBYTE
3920    LDY $0
3930    LDA temp:STA (AREAD),Y ) store data
3940    INY ) in shadow RAM
3950    LDA temp+1:STA (AREAD),Y )
3960    LDA $&6F:LDX $&C0:JSR OSBYTE
40200
40300 Print out value
4040    LDA temp:STA Lobyte ) print data on screen
4050    LDA temp+1:STA Hibyte
Appendix A.4

4060  JSR Print:JSR Fwdspce

40700

4080.Incptr

4090  CLC:LDA £2:ADC AREAD:STA AREAD

4100  LDA £0:ADC AREAD+1:STA AREAD+1

4110  LDX channel:CPX £3:BEQ Endrd

4120  DEX:STX channel

4130  LDA average:STA ctr

4140  LDA £0:STA temp:STA temp+1

4150  JMP Convert

4160.Endrd RTS

41700

41800 Delay loop between adc readings

4190.Delayrd

4200  LDA delayrd+l

4210  STA ctrl+l

4220.DR1  LDA delayrd

4230  STA ctrl

4240.DR2  LDY £10

4250.DR3  LDX £255

4260.DR4  DEX:CPX £0:BNE DR4

4270  DEY:CPY £0:BNE DR3

4280  DEC ctrl

4290  BNE DR2

4300  LDA £0

4310  CMP ctrl+l

4320  BEQ Endlyrd

4330  DEC ctrl+l

4340  JMP DR1

4350.Endlyrd

4360  RTS

43700

43800 Delay loop between pulses

4390.Delay

4400  LDA delay+l

4410  STA ctrl+l

4420.D1  LDA delay

4430  STA ctrl

4440  LDA £0

4450.D2  DEC ctrl

4460  BNE D2

4470  CMP ctrl+l

4480  BEQ endly

4490  DEC ctrl+l

4500  JMP D1

4510.endly RTS

4520.Inkey

4530  LDX £0:LDY £0:LDA £&81:JSR OSBYTE

4540  CPY £&1B:BEQ Escape

4550  CPY £0:BNE Nokey

4560  STX inkey

4570  RTS

4580.Escape

4590  LDA £&7E:JSR OSBYTE:LDA £&1B:RTS

4600.Nokey

4610  LDA £0:RTS

46200Routine to output ang and vely to screen

4630.Locheck EQUB 0

4640.Hicheck EQUB 0
Appendix A.4

4650. Lobyte EQUB 0
4660. Hibyte EQUB 0
4670. TTHOU EQUW 10000
4680. THOU EQUW 1000
4690. HUN EQUW 100
4700. TEN EQUW 10

DATA ON SCREEN ROUTINE

4710. Print

4720    LDY £0
4730    LDA TTHOU: STA Locheck
4740    LDA TTHOU+1: STA Hicheck
4750    JSR LOOP
4760    LDA THOU: STA Locheck
4770    LDA THOU+1: STA Hicheck
4780    JSR LOOP
4790    LDA HUN: STA Locheck
4800    LDA HUN+1: STA Hicheck
4810    JSR LOOP
4820    LDA TEN: STA Locheck
4830    LDA TEN+1: STA Hicheck
4840    JSR LOOP
4850    LDA £1: STA Locheck
4860    LDA £0: STA Hicheck
4870    JSR LOOP
4880    RTS
4890
4900
4910. LOOP  LDA Lobyte: STA ctrl
4920  LDA Hibyte: STA ctrl+1
4930. LOOP1  LDA ctrl: SEC: SBC Locheck: STA ctrl
4940  LDA ctrl+1: SBC Hicheck: STA ctrl+1
4950  BMI NXT
4960  INY: JMP LOOP1
4970 iny: jmp loop1
4980. NXT JSR PRNT  LDA ctrl: CLC: ADC Locheck: STA Lobyte
4990  LDA ctrl+1: CLC: ADC Hicheck: STA Hibyte
5000  LDY £0
5010  RTS
5020
5030
5040
5050. PRNT  TYA: CLC: ADC £&30: JSR OSASCI: RTS
5060  Tab: LDA £&1F: JSR OSWRCH: LDA £7: JSR OSWRCH: LDA £22: JSR OSWRCH
5070  RTS
5080
5090
5100. Fwdspce
5110  LDY £13
5120. Fwdlp  LDA £&09: JSR OSWRCH
5130  DEY: BNE Fwdlp
5140  RTS
5150
5160. NEXT OPT%
5170*SAVE 3D.MC 1A00 2500
5180 PRINT"C=\";\"moves
PROGRAMME LISTING FOR - SURFBAS

10REM***************************************************************************
20REMPROG SURFBAS OCTOBER 1985 WRITTEN BY D.J. SEARLE
30REM RUNS IN CONJUNCTION WITH LONGMC
40REMPAGE MUST BE SET AT 1C00
50REM HIMEM=&4000 AVAILABLE SPACE TO &5800: 6K OF MEMORY
60PT=&4000
70HIMEM=PT
80 @%=131594
90 PORTB = &FE60
100 DDRB = &FE62
110 ADPTR=&70
120 OSFIND=&FFCE
130 OSBYTE=&FFF4
140 DTASTR=PT+50
150 delay=PT
160 steps=PT+9
170 filename=PT+10
180 fchan=PT+20
190 eflag=PT+21
200REM***************************************************************************
210 AA$=""
220 AB$=""
230 AC$=""
240 AD$=""
250 BR$=""
260 S=0
270T=0
280 DISC=5
290 AO%=50
300REM***************************************************************************
310 *LOAD SURFMC 1A00
320 start=&1A00
330 pulsell=&1A37
340 pulse22=&1A61
350 onl=&1A13
360 on2=&1A25
370 offl=&1A1C
380 off2=&1A2E
390 binkfile=&1AEB
400 openfile=&1AF8
410 closefile=&1B05
420 REM***************************************************************************
430MODE7
440PROCintro
450PROCoptions
460MODE4
470PROCprobeset
480PROCset
490IF AD$="S" THEN 510
500PROCparameter
510PROCrun
520IF AD$="S" THEN 470
530REM***************************************************************************
540SCROLL=0
550CLS
560SCROLL=SCROLL+150

Appendix A.4
570 IF SCROLL=600 THEN CLS: SCROLL=0
580 PRINT TAB(0,2) "Data points to average?"
590 PRINT TAB(0,1) "Default is 30"
600 INPUT TAB(0,2); R
610 IF R=0 THEN R=30
620 L=0
630 D1=DESTR
640 hiaddr=? ADPTR+256*(ADPTR?1)
650 readings=INT((hiaddr-DESTR)/2)
660 FOR MM=0 TO 2*(R-1) STEP 2
670 tot=tot+(N1? MM+256*(N1? (MM+1)))/64
680 NEXT MM
690 Z1=INT(tot*10/(AO%*R))
700 MOVE 0,Z1%*2+SCROLL
710 FOR N=N1 TO hiaddr-2*R STEP 2*R
720 tot=0
730 FOR M=0 TO 2*(R-1) STEP 2
740 tot=tot+(N? M+256*(N? (M+1)))/64
750 NEXT M
760 Z%=INT(tot*10/(AO%*R))
770 DRAW 600*L*R/readings,Z%*2+SCROLL
780 L=L+2
790 NEXT N
800 PRINT TAB(0,2) "Averaged plot O.K.?"
810 A$=INKEY$(0)
820 IF A$=CHR$(&OD) AND AA$="N" THEN1060
830 IF A$=CHR$(&OD) THEN880
840 IF A$="N" THEN560
850 GOTO0830
860 PRINT TAB(0,2) "Data being processed"
870 L=0
880 FOR N=N1 TO hiaddr-2*R STEP 2*R
890 tot=0
900 FOR M=0 TO 2*(R-1) STEP 2
910 tot=tot+(N? M+256*(N? (M+1)))/64
920 NEXT M
930 Z%=INT(tot*10/(AO%*R))
940 D1ASTR?L=Z% MOD 256
950 D1ASTR? (L+1)=Z% DIV 256
960 L=L+2
970 NEXT N
980 FOR I=L TO L+40 STEP 2
990 D1ASTR? I=999 MOD 256
1000 D1ASTR? (I+1)=999 DIV 256
1010 NEXT I
1020 PROCfile2
1030 PRINT TAB(0,2) "Data filed"
1040 PRINT TAB(0,3) "Return to continue else Stop"
1050 A$=INKEY$(0)
1060 IF A$=CHR$(&OD) THEN460
1070 IF A$="S" THEN STOP
1080 GOTO01070
1090 REM*****************************
1100 REM subroutines for disk filing
1110 REM*****************************
1120 DEF PROCwrite
1130 LEN(D$)
1160 FOR I=1 TO L1
1170 E=ASC(MID$(D$, I, 1))
1180 BPUT£chan, E
1190 NEXT
1200 BPUT£chan, 10
1210 BPUT£chan, 10
1220 BPUT£chan, 13
1230 ENDPROC
1240 REM***************************
1250 DEF PROCfile1
1260 PROCPopenfile
1270 LET D$="DATE OF RUN " +DATE$
1280 PROCPwrite
1290 LET D$="DISCHARGE IN L/S " +STR$(DISC) + " GATE SETTING " +STR$(GATE)
1300 PROCPwrite
1310 D$=" X Y DIST Q LEVEL"
1320 PROCPwrite
1330 PROCPclosefile
1340 ENDPROC
1350REM***************************
1360 DEF PROCfile2
1370 DIST=1.25*R*SR/48
1380 LAT0%=INT(1ATO%-DIST/2+0.5)
1390 PROCPopenfile
1400 D$=STR$(LAT0%) + " " +STR$(LONG0%) + " " +STR$(DISC) + " " +STR$(LEVEL)
1410 PROCPwrite
1420 FOR I=1 TO L+20 STEP 20
1430 FOR K=I TO 19+1 STEP 2
1440 Z%=DTASTR? (K-1)+256*DTASTR? K
1450 IF NOT(Z%=999) THEN 1460 ELSE 1470
1460 Z%=Z%-Z1% + LEVEL*10
1470 FOR J=1 TO LEN(STR$(Z%))
1480 Z=ASC(MID$(STR$(Z%), J, 1))
1490 BPUT£chan, Z
1500 NEXT J
1510 BPUT£chan, 32
1520 NEXT K
1530 BPUT£chan, 10
1540 BPUT£chan, 13
1550 NEXT I
1560 PROCPclosefile
1570 ENDPROC
1580REM***************************
1590DEF PROCnewfile
1600 PRINT "Procedure to open new file"
1610 INPUT "ENTER FILENAME " N$
1620 IF LEN(N$)>7 OR N$="" THEN 1610
1630 $filename=N$
1640 CALL binkfile
1650 chan=? fchan
1660 fptr=PTR£chan
1670 PRINT£chan, fptr
1680 fptr=PTR£chan
1690 PTR£chan=0
1700 PRINT£chan, fptr
1710 FOR X=1 TO 12000
1720 BPUT£chan, 255
1730 NEXT
1740 CALL closeflie
Appendix A.4

2820 GOTO 2790
2830 PRINT "STPX STPY STPZ MIN%(J)"
2840 FOR J = 1 TO N-1
2850 PRINT STP%(1, J), STP%(2, J), STP%(3, J), MIN%(J): NEXT
2860 PRINT
2870 PRINT "STEPED POSITIONS"
2880 PRINT "XY Z"
2890 FOR J = 1 TO N-1
2900 PRINT TTZ(1, J), TT%(2, J), TT%(3, J): NEXT
2910 OVDU6: VDU3
2920 PRINT TAB(28) "Return to continue"
2930 REPEAT: UNTIL GET = &OD
2940 CLS
2950 REM***************************
2960 REM Section to input data to m/c programme
2970 REM***************************
2980 J = 0
2990 FOR I = 0 TO 2*(N-1) STEP 2
3000 J = J + 1
3010 STP%(1, J) = ABS(STP%(1, J))
3020 STP%(2, J) = ABS(STP%(2, J))
3030 STP%(3, J) = ABS(STP%(3, J))
3040 stpx? I = STP%(1, J) MOD 256
3050 stpx? (I + 1) = STP%(1, J) DIV 256
3060 stpy? I = STP%(2, J) MOD 256
3070 stpy? (I + 1) = STP%(2, J) DIV 256
3080 stpz? I = STP%(3, J) MOD 256
3090 stpz? (I + 1) = STP%(3, J) DIV 256
3100 minj? I = MIN%(J) MOD 256
3110 minj? (I + 1) = MIN%(J) DIV 256
3120 NEXT I
3130 REM***************************
3140 PRINT TAB(29, 2) "Alter stepping rate?"
3150 K = GET: IF K = 89 THEN 3160 ELSE IF K = 78 THEN 3230: GOTO 3150
3160 INPUT TAB(22, 3) "DELAY (1-20) - DEFAULT=10" ; DLY
3170 IF DLY = 0 THEN DLY = 10
3180 DLY = DLY + 90
3190 ? delays DLY*5 MOD 256
3200 delay? 1 = DLY*5 DIV 256
3210 GOTO 30250
3220 REM*******************
3230 ? delay = 244
3240 delay? 1 = 1
3250 ? moves = N
3260 ? delayrd = L
3270 delayrd? 1 = H
3280 ? average = AVGE
3290 ? CHAIN "3D.RUN"
3300 REM*******************
3310 DEF PROC continue
3320 PRINT TAB(25, 30) "Return to Continue"
3330 K = GET: IF K = &OD THEN 3340: GOTO 3330
3340 CLS
3350 ENDPROC
Appendix A. 4

1750ENDPROC
1760REM******************************************************************************
1770DEF PROC openfile
1780 PRINT
1790 IF LEN(N$) < 8 THEN 1790
1800 $filename = N$
1810 CALL openfile
1820chan = ? fchan
1830chan = 0 THEN PROC closefile
1840PTR£chan = 0
1850CALL closefile
1860ENDPROC
1870REM******************************************************************************
1880DEF PROC closefile
1890fptr = PTRichan
1900PTREchan = 0
1910PRINT£chan, fptr
1920CALL closefile
1930ENDPROC
1940REM******************************************************************************
1950DEF PROC parameter
1960T = T + 1
1970CLS
1980IF NOT(BR$ = "") THEN 2140
1990 IF NOT(AA$ = "") THEN 2180
2000 PRINT TAB(0,0) "Do you wish to store data on disk today?, y/n"
2010 AA$ = INKEY$(0)
2020 IF AA$ = "Y" THEN 2070
2030 IF AA$ = "N" THEN 2180
2040GOT02030
2050 PRINT TAB(0,2) "Do you need to open a new file, y/n"
2060 AB$ = INKEY$(0)
2070 IF AB$ = "Y" THEN 2120
2080 IF AB$ = "N" THEN 2130
2090GOT02080
2100 PROC newfile
2110INPUT TAB(0,5) "DATE e.g. 3/1/85"; DATE$
2120 INPUT TAB(0,7) "CALIBRATION COEFFICIENT (UNITS/MM)"; AO%
2130 IF NOT(BR$ = "") THEN 2180
2140 INPUT TAB(0,9) "DISCHARGE (L/S)"; DISC
2150 INPUT TAB(0,11) "GATE SETTING"; GATE
2160 INPUT TAB(0,13) "X-COORD Y-COORD AT START"; LAT%, LONG%
2170 INPUT TAB(0,15) "SURFACE LEVEL AT START"; LEVEL
2180 PRINT TAB(0,16) "Correct values?"
2190 A$ = INKEY$(0)
2200 IF A$ = CHR$(60D) THEN 2260
2210 IF A$ = "N" AND AA$ = "N" THEN CLS: GOTO 2080
2220 IF A$ = "Y" AND AA$ = "Y" THEN CLS: GOTO 2130
2230GOTO210
2240IF AA$ = "N" OR T = 1 OR NOT (BR$ = "") THEN 2290
2250CLS
2260PROC filel
2270PROC closefile
2280PROC probeset
2290BR$ = ""
2300ENDPROC
2310REM******************************************************************************
2320DEF PROC probeset
2330CALL start
2340 ?steps=255
2350 ?delay=150
2360 delay=1
2370 CLS
2380 PRINT TAB(0,0)"Horizontal-X or Vertical-Z stepper?"
2390 PRINT TAB(9,2)"Return to Miss"
2400 REPEAT
2410 L=GET
2420 UNTIL L=88 OR L=90 OR L=&OD
2430 IF L=90 THEN2510
2440 IF L=&OD THEN2690
2450 PRINT TAB(0,2)"For motor direction"
2460 REPEAT
2470 K=GET
2480 IF K=82 THEN CALL off1: G0T02570
2490 IF K=76 THEN CALL on1: G0T02570
2500 UNTIL K=76 OR K=82
2510 PRINT TAB(0,2)"For motor direction"
2520 REPEAT
2530 K=GET
2540 IF K=68 THEN CALL off2: G0T02570
2550 IF K=85 THEN CALL on2: G0T02570
2560 UNTIL K=68 OR K=85
2570 PRINT TAB(0,4)"Motor "CHR$(L)" called in ";CHR$(K);" Direction."
2580 PRINT TAB(0,5)"Start?"
2590 K=GET: IF K=&OD THEN 2600: G0T02590
2600 PRINT TAB(0,6)"RESETTING PROBE TO START POSITION"
2610 PRINT TAB(0,6)"To stop press space bar"
2620 IF L=88 THEN CALL pulse11
2630 IF L=90 THEN CALL pulse22
2640 PRINT TAB(0,8)"Restart motors? Otherwise Quit"
2650 REPEAT V$=INKEY$(O)
2660 IF V$=CHR$(&OD) THEN 2370
2670 IF V$="Q" THEN 2690
2680 UNTIL FALSE
2690 ENDPROC
2700 REM***************************
2710 DEF PROCrun
2720 CALL start
2730 CLS
2740 PRINT TAB(0,0)"For motor direction"
2750 PRINT TAB(9,2)"Enter L-left or R-right"
2760 REPEAT
2770 K=GET
2780 IF K=82 THEN CALL off1: G0T02800
2790 IF K=76 THEN CALL on1: G0T02800
2800 UNTIL K=76 OR K=82
2810 PRINT TAB(0,3)"Motor X called in ";CHR$(K);" Direction."
2820 IF K=68 THEN2830: G0T02820
2830 PRINT TAB(0,6)"RUN STARTED TOWARDS ";CHR$(K);" EDGE"
2840 PRINT TAB(0,3)"To stop press space bar"
2850 CALL pulse11
2860 PRINT TAB(0,6)"To scrap and re-run 'S'"
2870 IF K=68 THEN2880: G0T02870
2880 ENDPROC
2890 REM***************************
2900 DEF PROCset
2910 CLS
2920 PRINT TAB(0,0)"SETTING UP INITIAL PARAMETERS FOR RUN"
2930 PRINT TAB(0,2)"Steps between unaveraged readings"
2940 PRINT TAB(0,3)"Default is 12"
2950 INPUT TAB(0,4); SR
2960 IF SR=0 THEN SR=12
2970 PRINT TAB(0,6)"Stepping rate? (1-10)"
2980 INPUT TAB(0,8); DL
2990 ODL=DL*200
3000 IF DL=0 THEN DL=1025
3010 PRINT TAB(0,10)"Delay? (1-1025)"
3020 ENDPROC
3030 REM******************************
3040 DEF PROCintro
3050 PRINT TAB(10,10); CHR$(141)"Programme Surfbas"
3060 PRINT TAB(10,11); CHR$(141)"Programme Surfbas"
3070 PRINT TAB(3,12)"AUTOMATIC SURFACE DATA COLLECTION"
3080 PRINT TAB(7,14)"OCTOBER 1985 D. J. SEARLE"
3090 PRINT TAB(10,16)"Return to continue"
3100 TIME=0
3110 REPEAT
3120 A$=INKEY$(0)
3130 IF A$=CHR$(&OD) THEN 3150
3140 UNTIL TIME=500
3150 CLS
3160 PRINT TAB(0,4)"Programme to run an automatic data collection facility."
3170 PRINT TAB(10,16)"Return to continue"
3180 ENDPROC
3190 DEF PROCoptions
3200 CLS
3210 PRINT TAB(1,2); CHR$(141)" Choose options to continue"
3220 PRINT TAB(1,3); CHR$(141)" Choose options to continue"
3230 PRINT TAB(5,8)"Begin new set of runs - 1"
3240 PRINT TAB(5,11)"Continue runs from break :"
3250 PRINT TAB(5,12)"Collecting data on disk - 2"
3260 PRINT TAB(5,13)"VDU runs only - 3"
3270 PRINT TAB(5,16)"Terminate programme - 4"
3280 K=GET
3290 IF K=49 THEN 3420
3300 IF K=50 THEN A$="Y"; BR$="B": GOTO3420
3310 IF K=51 THEN A$="N" AND BR$="B": GOTO3420
3320 IF K=52 THEN STOP
3330 CLOSE 0
3340 ENDPROC
PROGRAMME LISTING - ADVAL

10REMPROGRAME TO READ ADC CHANNELS
20REMAPPRODUCED FOR VELOCITY AND ANG
30REMRENREADINGS
40REMR************ADVAL************
50REMR**********ADVAL************
60REMDJ SEARLE**UOB************
70REMOCTOBER 1985************
80MODE7
90PROCintro

100CLS
110PRINT TAB(0,0)"Calibrate Angular Displacement Inst."
120PRINT TAB(0,2)"ANG0%=ADC readout at zero displacement"
130PRINT TAB(0,3)"CAL%=rotation in degrees/unit"
140PRINT TAB(0,5)"ENTER TRANSDUCER RATING MBAR"
150INPUT TAB(30,5);RAT%
160PRINT TAB(0,6)"Set probe to zero position"
170PRINT TAB(0,7)"Return to enter value currently read"
180REPEAT:A$=INKEY$(0):ANG0%=ADVAL(3)/64:PRINT TAB(5,9)"ANG0%=
190PRINT TAB(0,6)"Set probe to 90 degrees"
200PRINT TAB(0,7)"Return to enter value currently read"
210REPEAT:A$=INKEY$(0):MAX%=ADVAL(3)/64:PRINT TAB(5,10)"MAX%=
220PRINT TAB(0,6)"Set probe to -90 degrees"
230PRINT TAB(0,7)"Return to enter value currently read"
240REPEAT:A$=INKEY$(0):MIN%=ADVAL(3)/64:PRINT TAB(5,11)"MIN%=
250MODE0
260PRINT TAB(6,0)" CH1 CH2 ANG VELY"
270PRINT TAB(0,3)"ANG0%=
280PRINT TAB(0,4)"MAX%-MIN%= 
290PRINT TAB(0,7)"ANGULAR DISP= DEGREES"
300PRINT TAB(0,6)"VELOCITY= MM/S"
310IF RAT%=0 THEN RAT%=2
320CAL%=MAX%-MIN%
330IF CAL%<10 THEN CAL%=600
340PRINT TAB(11,8)"Return to Stop"
350REPEAT
360VDU24,0;0;1279;500;
370MOVE 0,0
380DRAW 1200,0
390DRAW1200,500
400DRAW 0,500
410DRAW 0,0
420TIME=0
430PRINT TAB(0,30)"0 10 20 seconds 40"
440REPEAT
450PRINT TAB(0,1)INT(ADVAL(1)/64),INT(ADVAL(2)/64),INT(ADVAL(3)/64),INT(ADVAL(4)/64),VELY=
460VELY%=VELY
470VELY%=VELY
480PRINT TAB(13,6)"
490PRINT TAB(13,6);VELY%
500ANG%=ADVAL(3)/64-ANG0%*(180/ABS(CAL%))
510ANG%=ANG*10
520ANG%=ANG%/10
530PRINT TAB(17,7)"
540PRINT TAB(17,7);ANG%
550PLOT 5,TIME/5,VELY%
Appendix A. 4

551 SOUND1, -5, VELY%3,5
560 UNTIL TIME>6000
570 MOVEO, 0
580 CLG
590 A$=INKEY$(0)
600 UNTIL A$=CHR$(&OD)
610 STOP
620 END

630 REM******************************
640 DEF PROC intro
650 PRINT TAB(10,10) "PROGRAMME ADVAL"
660 PRINT TAB(5,12) "ANALOGUE/DIGITAL READ PROGRAMME"
670 PRINT TAB(7,14) "OCTOBER 1985 D. J. SEARLE"
680 PRINT TAB(10,16) "Return to continue"
690 TIME=0
700 REPEAT
710 A$=INKEY$(0)
720 IF A$=CHR$(&OD) THEN 740
730 UNTIL TIME=500
740 CLS
750 PRINT TAB(0,4) "Programme to read ADC convertors" "Adapted to read angular di
760 PRINT TAB(0,11) "Setup apparatus-you are ready to start"
770 PRINT TAB(10,16) "Return to continue"
780 TIME=0
790 REPEAT
800 A$=INKEY$(0): IF A$=CHR$(&OD) THEN 820
810 UNTIL TIME=500
820 END PROC

A.4.42
PROGRAMME LISTING - CALIB

20REMCALIBRATION PROGRAMME FOR DEPTH PROBE
30REMCALIB***************
40REM**********DJSEARLE*OACTOBER1985**
50 PT=&5000
60 OSBYTE=&FFF4
70 MODE4
80 HIMEM=PT-1
90 DTASTR=PT+256
100 ctr=PT+1
110 cntr=PT+3
120 steps=PT+5
130 cntr2=PT+6
140 PORTB = &FE60
150 DDRB = &FE62
160 ADPTR=&70
170 DIM Z(1000)
180 DIM CODE% 520
190 FOR I%=0 TO 2 STEP 2
200 P%=CODE%
210 OPT I%
220 .START LDA £&FF
230 STA DDRB
240 LDA £DTASTR MOD 256
250 STA ADPTR
260 LDA £DTASTR DIV 256
270 STA ADPTR+1
280 LDA £&01
290 STA cntr
300 RTS
3100 routines, off/on-direction of
3200 motor drives
3300
340.on2 LDA £&04
350 ORA PORTB
360 STA PORTB
370 RTS
380.off2 LDA £&FB
390 AND PORTB
400 STA PORTB
410 RTS
4200****************************
4300 pulsing motor two
440.pulse22
450 LDA £&40
460 ORA PORTB
470 STA PORTB
480 JSR delaysub
490 LDA £&BF
500 AND PORTB
510 STA PORTB
520 JSR delaysub
530 JSR readadc
540 LDA £&00
550 DEC cntr2
560 BNE pulse22
Appendix A.4

570        CMP cntr2+1
580        BEQ endpls22
590        DEC cntr2+1
600        JMP pulse22
610.endpls22    RTS
6200*****************************
6300 delay routine for pulse
640.delaysub
650        LDA £&05
660        STA ctrl
670        LDA £&03
680        STA ctrl+1
690        LDA £00
700.loop
710        DEC ctrl
720        BNE loop
730        CMP ctrl+1
740        BEQ enddly
750        DEC ctrl+1
760        JMP loop
770.enddly    RTS
7800sub to read ad convertor
790.readadc  DEC cntr
800        BNE endread
810        LDA steps
820        STA cntr
830        LDA £&80
840        LDX £&02
850        JSR OSBYTE
860        TYA
870        LDY £&01
880        STA (ADPTR),Y
890        DEY
900        TXA
910        STA (ADPTR),Y
920.incptr    CLC
930        LDA £&02
940        ADC ADPTR
950        STA ADPTR
960        LDA £&00
970        ADC ADPTR+1
980        STA ADPTR+1
990.endread    RTS
1000]NEXT 1%
1010PROCintro
1020CLS
1030PRINT TAB(0,4)"ADJUST SENSITIVITY OF PROBE"
1040PRINT TAB(0,6)"RAISE PROBE UNTIL JUST IMMERSED"
1050PROCspace
1060PRINT TAB(0,8)"ADJUST WAVE MONITOR CONTROLS"
1070FOR I=1 TO 10000
1080PRINT TAB(25,11)"MINIMUM VALUE ";ADVAL(2)/64
1090PRINT TAB(0,13)"Return to continue"
1100A$=INKEY$(50)
1120IF A$=CHR$(60D) THEN 1150
1130NEXT
1140GOTO1070
1150PRINT TAB(0,13)""
1160 PRINT TAB(0,14)"IMMERSE PROBES TO MAXIMUM DEPTH"
1170 FOR I=1 TO 10000
1180 PRINT TAB(25,16)"
1190 PRINT TAB(7,16)"MAXIMUM VALUE ";ADVAL(2)/64
1200 PRINT TAB(0,18)"Return to continue"
1210 A$=INKEY$(50): IF A$=CHR$(6O) THEN 1240
1220 NEXT
1230 GOTO1170
1240 PRINT TAB(0,18)"
1250 PRINT TAB(0,20)"Return to 
1260 A$=INKEY$(0)
1270 IF A$=" " THEN 1020 ELSE
1280 GOTO1260
1290 PRINT
1300 CLS
1310 CALL START
1320 MODE4
1330 PRINT TAB(0,0)"Enter starting parameters"
1340 PRINT TAB(0,2)"Up or Down?"
1350 K=GET
1360 IF K=68 THEN CALL off2: GOTO1390
1370 IF K=85 THEN CALL on2 : GOTO1390
1380 GOTO1350
1390 INPUT TAB(0,4)"TRAVERSE IN MM ";SC
1400 INPUT TAB(0,5)"READINGS PER MM ";SR
1410 PRINT TAB(0,6)"Entries correct?"
1420 A$=INKEY$(0)
1430 IF A$="N" THEN CLS: GOTO1330
1440 IF A$=CHR$(6O) THEN1460
1450 GOTO1350
1460 SC=INT(SC*48/1.25)
1470 SR=INT(48/(1.25*SR))
1480 PRINT TAB(0,8)"Total steps= ";SC;"and steps/rdg= ";SR
1490 cntr2=SC MOD 256
1500 cntr2? 1-SC DIV 256
1510 steps=SR
1520 IF SC MOD 256=0 THEN ?cntr2=1
1530 PRINT TAB(0,9)"Return to start else Quit"
1540 A$=INKEY$(0)
1550 IF A$=CHR$(6O) THEN 1580
1560 IF A$="Q" THEN 2030
1570 GOTO1540
1580 CLS
1590 PRINT TAB(14,10); "RUN STARTED"
1600 CALL pulse22
1610 CALL hiaddr =ADPTR+256*ADPTR+1
1630 readings=(hiaddr-DTASTR)
1640 MOVE 0,0
1650 DRAW 1200,0
1660 DRAW 1200,511
1670 DRAW 0,511
1680 DRAW 0,0
1690 L=1
1700 Z%=INT((DTASTR?0+256*DTASTR?1)/64)
1710 MOVE 2400*L/readings,Z%/2
1720 FOR I=2 TO readings-2 STEP 2
1730 L=L+1
1740 Z%=INT((DTASTR?I+256*DTASTR?I+1)/64)
Appendix A.4

1750 \text{DRAW} 2400*1/\text{readings, Z}/2
1760 \text{DIST}=(1.25/48)*\text{SR}
1770 \text{Z(L)}=\text{Z}
1780 \text{NEXT}
1790 \text{A1}=0
1800 \text{A2}=0
1810 \text{FOR J}=1 \text{ TO L}
1820 \text{IF Z(J)}>1000 \text{ OR Z(J)}<24 \text{ THEN} 1830 \text{ ELSE} 1840
1830 \text{NEXT J}
1840 \text{IF Z(J)}>500 \text{ THEN} \text{A2}=J+1 \text{ ELSE} \text{A1}=J+1
1850 \text{FOR K}=J+1 \text{ TO L}
1860 \text{IF Z(K)}>1010 \text{ THEN} 1870 \text{ ELSE} 1880
1870 \text{NEXT K}
1880 \text{IF A2}=(J+1) \text{ THEN} \text{A1}=K \text{ ELSE} \text{A2}=K
1890
1900 \text{IF A1}=(J+1) \text{ THEN} \text{X}=1 \text{ ELSE} \text{X}=-1
1910 \text{N}=0
1920 \text{M}=0
1930 \text{PRINT TAB(32,0)}\text{INT. VALS}
1940 \text{FOR I}=2 \text{ TO ABS(A2-A1)/20-1} \text{ \text{STEP 1}}
1950 \text{N}=N+1
1960 \text{TEMP}=(\text{Z(A1+20*I*X)}-\text{Z(A1+10*I*X)})/(\text{DIST*10*I})
1970 \text{TEMP$}\text{=TEMP}
1980 \text{PRINT TAB(35,I+1)};\text{TEMP$}
1990 \text{A$}=\text{INKEY$(10)}
2000 \text{M$}=\text{INT(M$+TEMP0.5)}
2010 \text{NEXT I}
2020 \text{M$}=	ext{INT(M$/N+0.5)}
2030 \text{PRINT TAB(0,0)}\text{CALIB. IS };\text{M$}; \text{UNITS/MM}
2040 \text{PRINT TAB(0,2)}\text{RERUN?}
2050 \text{K}=GET
2060 \text{IF K}=89 \text{ THEN} \text{CLS} \text{: GOTO}1300
2070 \text{IF K}=78 \text{ THEN} \text{PRINT TAB(8,2)}\text{CALIBRATION FINISHED}: \text{STOP}
2080 \text{GOTO}2050
2090 \text{REM} \text{******************************************************}
2100 \text{DEF PROCSpace}
2110 \text{PRINT TAB(0,0)}\text{PRESS SPACE BAR TO CONTINUE}
2120 \text{REPEAT}
2130 \text{K}=GET
2140 \text{UNTIL K}\%20
2150 \text{PRINT TAB(0,0)}\text{

\text{ENDPROC}
2160 \text{REPEAT}
2170 \text{REM} \text{*******************************************************************************}
2180 \text{DEF PROCMintro}
2190 \text{PRINT TAB(10,10)}\text{PROGRAMME CALIB}
2200 \text{PRINT TAB(5,12)}\text{AUTOMATIC PROBE CALIBRATION}
2210 \text{PRINT TAB(7,14)}\text{OCTOBER 1985 D.J. SEARLE}
2220 \text{PRINT TAB(10,16)}\text{Return to continue}
2230 \text{TIME}=0
2240 \text{REPEAT}
2250 \text{A$}=\text{INKEY$(0)}
2260 \text{IF A$}\text{=CHR$(60D)} \text{THEN}2280
2270 \text{UNTIL TIME}=500
2280 \text{CLS}
2290 \text{PRINT TAB(0,4)}\text{Programme to calibrate depth probe used in measuring water}
2300 \text{PRINT TAB(10,16)}\text{Return to continue}
2310 \text{TIME}=0
2320 \text{REPEAT}
2330 \text{A$}=\text{INKEY$(0)}
2340IF A$=CHR$(60D) THEN
2350UNTIL TIME=500
2360ENDPROC
APPENDIX A.5

1983/1986 Surveyed Sections - 1.029-1.036 A.5.0-A.5.2

Stage-discharge data at recorders 1, 2 and 3 for 1984/1985 and 1985/1986 A.5.3-A.5.4

Photographs of River Roding in flood A.5.5-A.5.6
### Appendix A.5

**Recorder No. 1 - Section 1.039**  
1984/1985

<table>
<thead>
<tr>
<th>LEVEL (M)</th>
<th>DISCHARGE (M /S)</th>
<th>CROSS-SECTION AREA (M )</th>
<th>WETTED PERIMETER (M)</th>
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<td>1.5</td>
<td>6.0</td>
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<tr>
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<td>0.5</td>
<td>2.1</td>
<td>6.2</td>
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<td>0.8</td>
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<td>1.0</td>
<td>3.6</td>
<td>15.3</td>
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<td>1.5</td>
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<td>25.3</td>
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**Recorder No. 1 - Section 1.039**  
1985/1986

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<th>CROSS-SECTION AREA (M )</th>
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<td>28.6</td>
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<td>8.5</td>
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**Recorder No. 2 - Section 1.028**  
1984/1985

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Appendix A.5

At Section 1.029 Looking Upstream

Between Sections 1.030 and 1.031 Looking Upstream
At Section 1.036 Looking Downstream

Between Section 1.034 and 1.035 Looking Downstream
APPENDIX A.6

Longitudinal water surface profiles
S1 to S8 \hspace{1cm} A.6.0-A.6.21

Stage-discharge data points
S1 to S8 \hspace{1cm} A.6.22

Plastic flexible roughness data
by Kouwen et al \hspace{1cm} A.6.23-A.6.24

Plastic flexible roughness data
author's data \hspace{1cm} A.6.25-A.6.26

Stage discharge data and roughness
values for Series 7 and Series 8 \hspace{1cm} A.6.27
Distance along Y axis in mm (x1000)
Distance along Y axis in mm (x1000)
Distance above floodplain in mm

Distance along Y axis in mm (x1000)
Appendix A.6

SERIES 2

Distance above floodplain in mm

Distance along Y axis in mm (×1000)
Appendix A.6

Series 2

Distance along Y axis in mm (x1000)
Distance along Y axis in mm (×1000)
Distance along Y axis in mm (x1000)
Appendix A.6

Distance above floodplain in mm

Distance along Y axis in mm (x1000)
Appendix A.6

SERIES 4

Distance above floodplain in mm

Distance along Y axis in mm (×1000)
SERIES 5

Distance above floodplain in mm

Distance along Y axis in mm (x1000)
Distance above floodplain in mm

Distance along Y axis in mm (x1000)
Distance above floodplain in mm

Distance along Y axis in mm (×1000)
Appendix A.6

Distance along Y axis in mm (×1000)
Distance along Y axis in mm (x1000)
Distance above floodplain in mm

Distance along Y axis in mm (×1000)
Distance along Y axis in mm (x1000)
Distance above floodplain in mm

Distance along Y axis in mm (x1000)
Distance along Y axis in mm (×1000)

Distance above floodplain in mm

Appendix A.6
Distance above floodplain in mm

Distance along Y axis in mm (x1000)
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Appendix A

Effect of Spacing on Retardance Curves
Effect of Stiffness on Retardance Curves
Illustrations of Different Roughness Configurations Used

(FX1) Roughness type 1 - 40/45/45/5 length 40mm
sheet thickness 0.13 mm

(Roughness type 2 - 40/53/53/5-D length 40mm
sheet thickness 0.13 mm
configuration as above

Roughness type 3 - 40/53/53/5-D@ length 40mm
sheet thickness 0.05 mm
Appendix A.6

dotted lines represent 'trend' of data points for each series to highlight difference in roughness.

Roughness type 1
data bed slope = 0.0040

Roughness type 2
data bed slope = 0.0043

Roughness type 3
data bed slope = 0.0032

$VR (m/\text{s})$
### SERIES 7

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### SERIES 7

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APPENDIX A.7

Longitudinal water surface profiles
S9 to S14

A.7.0-A.7.6
Distance along Y axis in mm (x1000)
Appendix A.7

Distance above floodplain in mm

Distance along Y axis in mm (x1000)
Distance along Y axis in mm (x1000)
Appendix A.1

- SERIES 12

Distance above floodplain in mm

Distance along Y axis in mm (x1000)
Distance along Y axis in mm (x1000)
Distance above floodplain in mm

Distance along Y axis in mm (×1000)
### Series 9
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