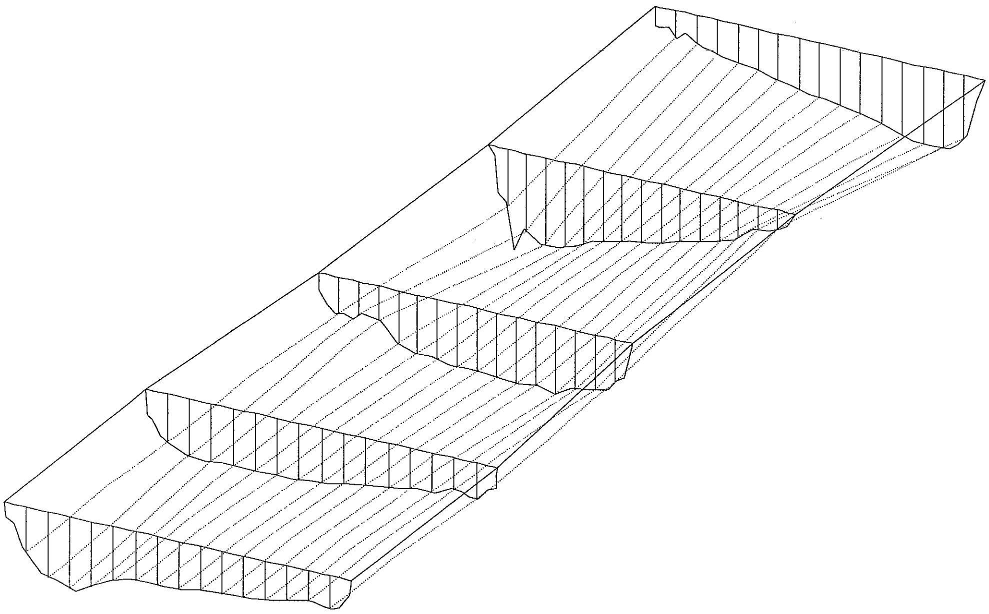
RHYHABSIM

River Hydraulics

and

Habitat Simulation



Computer Manual

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December 1999

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1. INTRODUCTION

1.1 Hydraulic/habitat modelling of rivers

RHYHABSIM was developed to provide hydrologists, engineers and resource managers with an integrated solution to some of the more common hydrometric and hydraulic computations, such as:

- calculation of flow
- stage/discharge rating curves
- hydraulic parameters
- water surface profile analysis
- incremental flow analysis of stream depth, width, velocity, and instream habitat.

The basic stream geometrical unit is a cross-section. A reach of river is a number of cross-sections that represent significant channel characteristics. Each cross-section is related to the reach either by the length or percentage of river length it represents.

A survey is made of the channel and waterway at one or more flows. This forms a model of the stream reach which is then calibrated from field measurements at one of the flows. This flow is the calibration flow. The model can then be used to predict water level, velocity and habitat suitability at other flows.

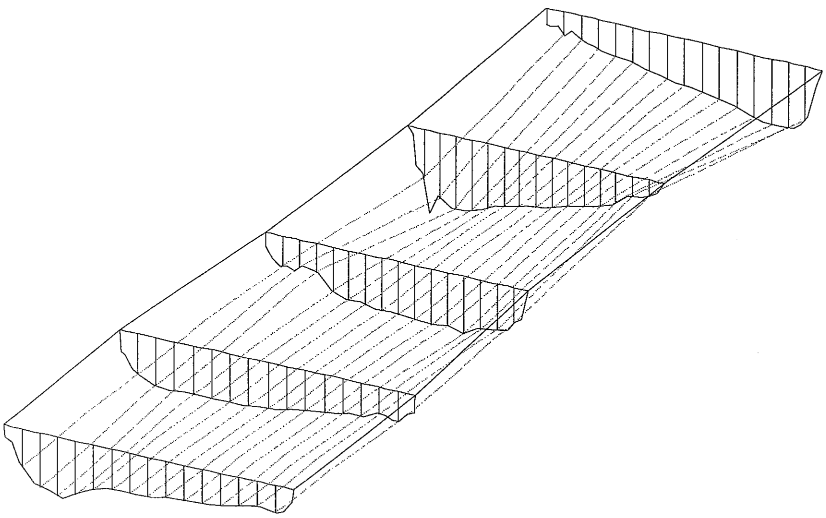


Figure 1. Stream model made up of cross-sections with equi-distant measurements of water depth.

Water depth and velocity is predicted for each measurement point in the model. The steps in this calculation are:

the water level at the new flow is calculated either from a stage/discharge curve or by water surface profile modelling.

the mean velocity is calculated from the cross-section area and flow

$V_m = Q/A$

the depth at each measuring point is calculated from the measured depth and the difference between the measured water level and that calculated for the new flow.

the velocity at each point is calculated from the conveyance at the new flow and the measured velocity.

Calibration procedures allow rating curves to be fitted to actual water levels and measured flows. For water surface modelling, automatic procedures can be used to estimate friction losses between cross-sections.

For instream habitat analysis there is a calibration procedure that relates the conveyance at measurement points to the velocity distribution across the section. This is used to calculate velocities at other flows.

Up to 10 instream characteristics or attributes can be described at each measurement point. Typically, an attribute describes substrate, instream cover or water surface character, but any attribute may be recorded.

Average river characteristics and the way in which these change with flow can be determined. Flows are specified as the minimum flow to be modelled, the maximum, and the flow increment. Water depths and velocities are predicted for each flow at each measurement point and summed over each cross-section and reach. Reaches can be combined. Instream habitat suitability criteria can be applied to the simulated or measured water depths, velocities and recorded attributes to give the weighted usable area (WUA) of instream habitat.

River modelling and habitat simulation is a step-by-step procedure with each step progressing to the next. Each menu item in RHYHABSIM represents one of the steps in a logical modelling procedure - checking data, calibrating the model, simulating for different flows, evaluating and plotting.

This manual is divided into three sections.

The first section describes the types of data, the way in which these are set-out and how to start RHYHABSIM.

The second describes each menu, the steps in that menu, the options available.

The third section describes the requirements of field surveys for some of the applications for which the programme is designed. This includes comments on surveying water levels, locating cross- sections and reaches for hydraulic modelling, fitting and selecting stage/discharge curves, and procedures for calibration and modelling.

1.2 Computer Requirements and Setup

The programme runs under DOS. Graphics are provided for Hercules mono, CGA or EGA (640 x 350 resolution) and VGA. Output can be directed to a computer port or disc file. Printout from graphic displays is possible on printers which emulate the Epson FX80 and HP Laserjet III or higher. Graphics output can be saved on file and imported into Microsoft WORD or similar as HPGL.

No special setup or configuration is required. There is an initialisation programme that can be used to alter some of the default settings within the programme. This configuration applies until changed by re-running the initialisation programme (Section 9).

1.3 Help

Help is available by pressing F1 when an item in the main menu is highlighted. The topics in the menu are described briefly in the help. In the options (F2) sub-menu, the option that is highlighted will be described.

1.4 Keyboard shortcuts

Some keys are used for special purposes. The Escape **Esc** key is used to close menus and to interrupt long sequences of data analysis. Control C **Ctrl C** will interrupt any processing and the user will be asked whether to return to DOS or to continue processing. Menu items can be selected by pressing the number listed with the item description or by moving the highlight down to the item and pressing Enter. When the file list is displayed, you can move quickly to any filename by pressing the first letter of the name, and then using the arrow keys and Enter to select the filename.

Default selections and values are assumed if the Enter key is pressed. Usually, the most appropriate response to a question will be a press of the Enter key. If the prompt is (Y/N) ? : the default answer is Yes if the Enter key is pressed, otherwise the programme responds only to a Y or N. If a number is requested, the default value is displayed in brackets. This value will be used unless a different value is entered.

2. DATA STRUCTURE

2.1 Terminology

All input data files are text (ASCII) which means that they are easily read or constructed by any text editor or word processor.

Each data file represents a reach of the river. The first lines of the file can contain any information, such as a description of the river, name, and date of survey.

The specification of reach data begins with the word "BED" and a description of the attributes (or substrates) that will be specified for each cross-section of the reach.

Data is then entered as cross-sections. A cross-section is a series of pairs of values of offset and level. The offset is the distance from the cross-section origin and the level may be either as a water depth (negative if above water level), or an elevation.

Water levels at cross-sections can be predicted by two methods - water surface profile modelling and stage-discharge curves weighting. Water surface profile modelling requires that height differences between cross-sections be known. To do this water levels at each cross-section are measured to a common datum. Levels in terms of a common datum are termed reduced levels or elevations. Data taken from maps or topographic surveys are usually already in terms of reduced level or elevation.

If the stage-discharge method is used cross-sections need not be contiguous and stage-discharge relationships are developed for each cross-section. In this case, it is not necessary to measure the distance between cross-sections nor establish water levels to the same datum at each cross-section. Each cross-section can use its own local datum, usually the top of the peg or pin marking the location of the cross-section.

Cross-sections are placed at right angles to the direction of flow. Water velocities can be recorded directly or as revolutions and time along with meter constants. The meter constants are the slope and constant in the equation used to convert the measurement of revolutions/second to a velocity, i.e.

velocity = slope x revolutions/second + constant.

Multipoint velocity measurements (e.g. at 0.2 and 0.8 or 0.2, 0.6 and 0.8 depth) are averaged to give the mean velocity in the vertical. Multiple velocity measurements repeat the offset and depth measurements.

Each cross-section represents a portion of the reach, either a proportion of the total length or a percentage of the reach. If the percentage is entered the distance is ignored.

2.2 Units

Data input units must be metric. Decimal points need only be entered where required.
Some output is available in feet units, but not all.

offset, depth, distance - metres

elevation or reduced level - metres

flow - cubic metres/second

velocity - metres/second

current meter revolutions - number

time for revolutions - seconds

substrate attributes - percentage

other attributes - any unit

2.3 File names

The data file may be given any valid DOS name of up to eight characters but must end with the extension *.HAB*. Throughout this manual the symbol *$* is used to represent the filename selected by the user. The drive and directory for datafiles can be specified.
A number of files are generated automatically. Each with the same name as the datafile but a different extension. These files contain calibration information which is used in subsequent processes. Most of these files are ASCII and can be inspected and modified at intermediate processing stages if the fixed format is preserved.

File extensions:

$.HAB - datafile (habitat)

$.CON - hydraulic calibration parameters - calibration flow, rating curve parameters, WSP parameters

$.VDF - calibration of velocity distribution

$.OUT - water surface profile results

$.SUM - habitat evaluation results

$.DAT - detailed output giving details of hydraulic conditions and habitat suitability at each data point

FISH.DAT - Selected habitat suitability curves.

Output files:

RHYHAB.LST - Copy of screen output

RHYHAB.PRN - Printed text output directed to file

RHYHAB.PRT - Printed graphics output directed to file

RHYHAB.TXT - Output from multiple file processing using a command file

RHYHAB.DAT - Detailed output giving details of hydraulic conditions and habitat suitability at each data point when using a command file.

The purpose and form of these files will be described under the appropriate processes.

There may be one or more text (ASCII) files containing habitat suitability criteria. A habitat suitability file may be given any valid DOS name but must have the extension *.PRF*. The selection of suitability curves generates a file *FISH.DAT* which contains those suitability curves in machine code. This file is overwritten if a new set of suitability curves is selected.

2.4 Data Format

Data must be entered into **RHYHABSIM** in a particular order. The order is intended to duplicate that used in the field so that entry can be directly from field sheets.

Numerical data can be separated by one or more blanks or tabs. Fixed format is not required but is useful for visible checking.

Certain word processing programmes can insert non-standard control characterise into the text. While TAB characters are recognised, other may not be. Use text editors in non-document mode (ASCII), and check data by listing on the screen with the DOS command **TYPE**. Stray or unusual characters or unusual screen behaviour will indicate the presence of control characters.

Datasets are identified by filename. Two types of data (water level or elevation) are recognised and are entered with slightly different formats. The data type is identified by a keyword (**BED** or **BED RL**). Any additional comments or description of the data can be on the data file before this keyword.

The following example of the data format is for a reach with cross-sections in pool (23%), run (55.4%), and riffle (21.6%) habitats. In this example the distances are given as 0,14, and 26 metres, but could be specified as any set of increasing numbers. If % habitat is specified distances are not used in any calculation, but are used in some plots (plan and isometric). Note that the stage for zreo flow is specified for the pool but not the run or riffle. If no SZF is specified it is assumed that the stage for zero flow will be the section minimum. Multiple velocity measurements in the vertical have been taken at some points.

```
Wairoa River downstream Tourist Road. Survey dates 19 & 20-3-96   Comment
BED  'r' 'c' 'g' 'f' 's' 'm' 'v'                                   Reach description
0.0  'Pool 1' 0.002 METER 0.676 0.003  %23.0                       Cross-section description
gau -0.017  0.477                                                  Gauging
gau  0.150  1.442
SZF -0.520                                                         Stage for zero flow
 0   -0.40   0    0     0   0  50  50   0   0   0                  Cross-section data
1.7   0      0    0     0   0  80  20   0   0   0
2.3  0.10   -3   20     0   0  80  20   0   0   0
2.6  0.18   -3   20     0   0  80  20   0   0   0
2.9  0.25   -2   20     0   0  75  20   5   0   0
3.2  0.38   -1   20     0   0  75  20   5   0   0
3.6  0.49   -1   20     0   0  75  20   5   0   0
4.0  0.61   -1   20     0   0  75  20   5   0   0
4.3  0.68   -1   20     0   0  75  20   5   0   0
4.4  0.68    0    0     0   0  75  20   5   0   0
4.6  0.73    1   20     0   0  85  15   0   0   0
4.9  0.76    1   20     0   0  85  15   0   0   0
5.0  0.79    1   20     0   0  85  15   0   0   0                  0.2 of the depth
5.0  0.79    1   20                                                0.8 of the depth
5.3  0.80    1   20     0   0  85  15   0   0   0
5.3  0.80    2   40.1
5.7  0.85    4   22.3   0   0  85  15   0   0   0
5.7  0.85    2   21.6
6.0  0.90    1   20.3   0   0  85  15   0   0   0
6.0  0.90    4   21.0
6.3  0.93    4   21.6   0   0  85  15   0   0   0
6.3  0.93    3   28.1
6.7  0.95    2   20.7   0   0  85  15   0   0   0
6.7  0.95    6   20.7
7.1  1.02    7   23.2   0   0  85  15   0   0   0
7.1  1.02    4   20.2
7.6  1.10    5   20.0   0   0  85  15   0   0   0
7.6  1.10    6   20.3
8.0  1.13    5   21.5   0   0  85  15   0   0   0
8.0  1.13    5   22.2
8.5  1.15    4   24.8   0   0  60  40   0   0   0
8.5  1.15    5   23.0
9.0  1.10    3   22.2   0   0  20  40  40   0   0
9.0  1.10    4   20.3
9.5  0.68    4   28.5   0   0   0   0   0 100   0
10   0.25    3   23.3   0   0   0   0   0 100   0
10.3  0      0    0     0   0   0   0   0 100   0
10.6 -0.6    0    0     0   0   0   0   0 100   0
END                                                                End of cross-section data
14.4  'Run 2'  0.001 METER 0.294 0.009 %55.4                       Next Cross-section description
gau -0.019  0.477
gau 0.134  1.442
 0   -0.4    0    0     0   0   0  10  50  40   0
0.1   0      0    0     0   0   0  10  50  40   0
0.4  0.58    0    0     0   0   0  10  50  40   0
0.7  0.66    2   52.6   0   0  10  30  30  30   0
1.0  0.60    0    0     0   0  50  30  20   0   0
1.0  0.60    7   20.2
1.4  0.60    3   20.3   0   0  60  30  10   0   0
1.4  0.60   15   20.0
1.8  0.52   13   21.9   0   0  60  30  10   0   0
```

```
1.8   0.52  10   31.0
2.2   0.54   0    0    0   0 50 30 20   0   0
2.2   0.54   7   21.1
2.6   0.51   7   20.1  0   0 50 30 20   0   0
2.6   0.51  27   20.0
2.9   0.51  32   20.4  0   0 50 30 20   0   0
2.9   0.51  26   20.0
3.2   0.52  28   20.1  0   0 50 30 20   0   0
3.2   0.52  33   20.2
3.5   0.49  31   20.4  0   0 50 30 20   0   0
3.8   0.48  28   20.1  0   0 40 30 30   0   0
4.1   0.44  30   20.5  0   0 40 30 30   0   0
4.4   0.38  28   20.7  0   0 40 30 30   0   0
4.7   0.34  18   20.5  0   0 30 40 30   0   0
5.0   0.33  10   20.7  0   0 30 40 30   0   0
5.3   0.27   1   20    0   0 20 40 40   0   0
5.6   0.16   0    0    0   0 20 40 40   0   0
5.9   0.08  -1   20    0   0 20 40 40   0   0
6.3    0     0    0    0   0 20 40 40   0   0
7.5   -0.3   0    0    0   0 20 40 40   0   0
END
26.0  'Riffle1' 0.000 METER 0.676 0.003 %21.6
gau -0.008  0.477
gau 0.085   1.442
 0   -0.2    0    0     0   0   0   0   0   0 100
0.4   0      0    0     0   0   0   0   0   0 100
1.0   0.31   0    0     0   0   0   0   0   0 100
1.3   0.38  23   20.3   0   0  80  15   5   0   0
1.6   0.35  17   20.6   0   0  70  30   0   0   0
1.9   0.33  16   20.1   0   0  60  40   0   0   0
2.0   0.32  18   20.2   0   0  60  40   0   0   0
2.5   0.28  11   20.5   0   0  60  40   0   0   0
2.5   0.28  19   20.2
2.5   0.28   3   20
3.0   0.13  14   20.0   0   0  90  10   0   0   0
3.5   0.10  17   20.1   0   0  90  10   0   0   0
4.0   0.10  16   21.3   0   0  90  10   0   0   0
4.5   0.11  19   20.8   0   0  90  10   0   0   0
5.0   0.10  16   20.0   0   0  90  10   0   0   0
5.5   0.10  15   20.8   0   0  90  10   0   0   0
6.0   0.09  13   20.4   0   0  90  10   0   0   0
6.5   0.04  13   20     0   0  90  10   0   0   0
7.0   0.02  13   20     0   0  90  10   0   0   0
7.4    0     0    0     0   0  90  10   0   0   0
9.0  -0.1    0    0     0   0  90  10   0   0   0
10   -0.3    0    0     0   0  90  10   0   0   0
END
END
```

End of reach data

Reach description

The lines preceding the keyword **BED** can contain any information.

Data input begins with the keyword **BED** and is followed by up to 10 attribute names enclosed in quotes. The order of attribute names is the order in which the corresponding numeric values appear in the cross-section data.

BED DATA 'BEDROCK' 'BOULDER' 'COBBLE'

If no attributes are recorded the word **BED** is sufficient.

Any attribute name may be specified but the following, in upper or lower case, are recognised as substrate descriptors to which habitat suitability criteria apply. There are eight basic substrate types the keywords for which are:

Preference curve id.	Substrate type	Nominal size (mm)
1	**V**egetation (aquatic macrophytes or instream debris)	
2	**Si**lt (**M**ud)	<0.06
3	**S**and	0.06-2
4	**F**inegravel	2-8
5	**G**ravel	8-64
6	**C**obble	64-264
7	**B**oulder	>264
8	**Be**drock (**R**ock)	

Minimum specifications of keywords are shown bold and alternatives are given in brackets.

Cross-section description

Up to 60 cross-sections can be entered. Each cross-section is described by its distance from the most downstream section, a section name enclosed in quotes (maximum of 10 characters), the level of the water surface and a keyword **METER** if current meter revolutions and times are to be given. If stage-discharge relationships are used and cross-section locations were selected in habitat types rather than as a representative reach, the percentage of the reach that the cross-section represents is specified **after** a percentage sign, and the cross-section distance will be treated as a station identifier and may be consecutive numbers.

The keyword **METER** can be followed by two or five meter constants. If two constants are entered the first is the slope or multiplier and the second the constant. If five are entered a double curve rating is applied the fist pair of slope and constant are applied to the revs/sec and the second pair are applied when the revs/sec exceeds the third value. If the keyword is not followed by meter constants the values for the previous section will be assumed. If the keyword is not specified then data values are assumed to be velocities rather than revolutions and times.

25.0 'xsect 2' 7.632 METER 0.680 0.06 %6.3

Distance 'name' water level meter mult. const. Section percentage

or with two stage meter rating

25.0 'xsect 2' 7.632 METER 0.680 0.006 .032 .725 .002 %6.3

Distance 'name' water level meter mult. const. percentage

or if velocities are to be entered

25.0 'xsect-02' 7.632 %6.3

Distance 'name' water level percentage

Cross-section rating curves

If rating curves are to be derived for a cross-section, their details are given after the cross-section description. The rating curves are derived from pairs of stage and discharge measurements taken at flows other than that of the survey. The discharge is in m^3/s and the stage in metres to the same datum as the water level in the cross-section description. The stage at zero flow can also be entered at this point. The stage at zero flow is the estimated water level at zero flow and forms part of the rating equation:

$Q = a(WL\text{-}SZF)^b$

Riffles and some runs will be dry when the flow drops to zero so that the stage at zero flow is the section minimum and need not be entered specifically. However, pools are not dry when the flow drops to zero and at zero flow the water level will be the minimum level of the downstream riffle or bar.

The format for gaugings and stage of zero flow is the keyword **GAUGING** followed by the stage and discharge:

GAUGING 9.234 1.537

GAUGING 9.234 1.537

GAUGING 9.234 1.537

SZF 8.702

Up to eight gaugings may be entered.

Cross-section measurements

Measurements across the section must be entered in ascending order of offset with one offset per line.

The data items in order are:

4.0	**6.0**	**0.96**	**0**	**10**	**90**
offset	depth	velocity	attributes (up to 10)		

or if revolutions and time is specified.

4.0	**.60**	**40**	**45.6**	**0**	**10**	**90**
offset	depth	revolutions	time	attributes (up to 10)		

There may be up to 100 offset measurements to a cross-section. Values must be entered for every data item at an offset, except for multiple depth velocity measurements, when attributes can be omitted after the first multiple measurement. The same number of attributes must be entered at every section.

Steep banks can have offset values that are very close together but not the same. Overhanging banks cannot be described.

Negative depths represent a height above the water surface. Negative current meter counts indicate water flowing upstream, i.e. eddies.

The keyword **END** indicates the end of a cross-section and repetition of the keyword **END** indicates the end of a reach and the end of the input data.

Multipoint velocity measurements

Multipoint velocity measurements, e.g. at 0.2, 0.6 and 0.8 of the water depth are averaged to give the mean column velocity. To enter a multipoint measurement, repeat the offset and depth measurement with the velocity reading or count at each depth. The order (0.2 or 0.8) does not matter. Attributes must be entered with the first velocity measurement but need not be repeated for the following multipoint measurements.

Elevation data

Elevation or reduced level data are entered like water level data except that the keyword **RL** follows the word **BED**. The main difference is that only pairs of offsets and reduced levels are entered. A reference level or datum level must be entered on each cross-section header. If all levels are to the same datum this can be zero.

2.5 Habitat Preference Criteria

Before instream habitat can be evaluated, a file of habitat suitability criteria must be set up. This file can have any name but must end with the extension *.PRF.* This is a text (ASCII) file with keywords to describe the information contained. Numerical data are separated by one or more blanks. TAB characters are acceptable but beware of other non-standard control characters.

The first line contains a description of the species and life stage to which the habitat suitability criteria apply. Only the first 41 characters are recognised.

The remaining lines contain a keyword specifying whether the numbers which follow are weighting factors, depths, velocities or substrate.

The keywords are **WEIGHT** **DEP**th **VEL**OCITY **SUB**STRATE with the necessary portion of the keywords shown bold. Depth, velocity and substrate values must increase. A maximum of 10 values can be specified. Values of habitat suitability are interpolated linearly from these data. If a depth or velocity is outside the range specified in the criteria, habitat suitability is that of nearest criteria (i.e. horizontal extrapolation).

Eight substrate types must be specified by a code number. The types and their respective code numbers are:

1 Vegetation

2 Silt (Mud)

3 Sand

4 Finegravel

5 Gravel

6 Cobble

7 Boulder

8 Bedrock (Rock)

On the line below that specifying depth, velocity or substrate the keyword **WEI**GHT must be given and be followed by a set of weighting values of between 0 and 1.

The number of weights specified must equal the number of depths velocities or substrates and cannot exceed 10.

Habitat suitability specification ends with **END**.

If the suitability weight of suitable habitat is 1 and the weight of unsuitable habitat is 0, the weighted usable area will be the area of ideal habitat (i.e. where the velocities, depths and substrate meet the criteria specified by the weight of 1). If weights of between and including 0 and 1 are used then the area of habitat is the weighted usable area WUA.

Up to 40 different habitat suitability criteria can be specified in the *$.PRF* file but a maximum of 15 can be selected for evaluation at any one time.

Substrate types are nominal and their definitions can be modified to suit user needs, such as spawning or cover suitability. For example, the attribute types may be reassigned to the different cover attributes used by adult brown trout:

Nominal attribute	Cover attribute	Suitability weight
Vegetation	Debris	.5
Silt	Bank cover	.8
Sand	No cover	0
Finegravel		
Gravel		
Cobble		
Boulder	Boulder	.8
Bedrock	Bedrock crevice	1

The reach specification would read:

BED 'Vege' 'Silt' 'Sand' 'Boulder' 'Bedrock'

but would mean:

BED 'Debris' 'bank cover' 'no cover' 'Boulder' 'Bedrock crevice'.

The presence of cover elements would be recorded at each measurement point under their respective nominal attribute names.

The habitat preference curves would include substrate weightings that reflect cover preferences:

'Brown trout cover'

VELOCITY 0 .05 .5 1 2

WEIGHT .5 1 1 0 0

DEPTH 0 .2 .5 1

WEIGHT 0 .5 1 1

SUBSTRATE 1 2 3 4 5 6 7 8

WEIGHT .5 .8 0 0 0 0 .8 1

Depth and velocity preferences could be specified, as in the example, or set to 1, if depth and velocity does not influence cover.

Habitat evaluation would then determine how cover changes with flow.

A habitat type other than one of the nominal types can be specified, but will not be used in the evaluation of weighted usable area, nor will it be included in the check to see whether substrate attributes sum to 100%. For example, the effect of flow changes on the area of submerged objects can be determined. The object is given the attribute 'Object' and its occurrence is recorded either as a 0 or 100. Habitat evaluation would evaluate the area of 'Objects' that were submerged.

3. Setup menu

3.1 Analysis mode

This option allows the IFG programme code to be used instead of RHYHABSIM. The two options are included so that users can examine the differences between the two methods. Both modes give similar, but not exactly the same, results. Each uses data in the format native to the programme, so that IFG mode requires data in the fixed format of PHABSIM. The basic difference in the two modes is in the calibration and the way in which velocities are predicted across a cross-section. RHYHABSIM distributes velocities according to conveyance and uses the measured velocities as a calibration ratio - the velocity distribution factor. The IFG method uses the measured velocities as a roughness measure and then predicts velocities across the section, then re-adjusting so the section discharge equals the required discharge. The RHYHABSIM method reproduces the calibration data exactly, the IFG method does not. PHABSIM is described in:

Bovee, K. D., and R. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and techniques. U.S. Fish and Wildlife Service Biological Services Program FWS/OBS-78/33.

Milhous, R. T.; Wegner, D. L.; Waddle, T. 1984: User's guide to the physical habitat simulation system. United States Fish and Wildlife Service, Cooperative Instream Flow Group, Instream flow information paper 11. 254 p.

3.2 Convert IFG to RHYHABSIM

This converts an IFG fixed format datafile to a RHYHABSIM free format ASCII file.

3.3 Set drive and directory

This points to the location of all data files, both cross-section data and habitat preference curves. Output files (*RHYHAB.**) and the *RHYHAB* configuration file are stored in the current directory. The message "No files in the current directory" usually indicates that the drive and directory are not set to the correct values.

3.4 Output units

A limited facility exists for output data in feet units.

3.5 Printer and port

Printed output can be directed to an output port (LPT1-3 or COM1-3) or to a file. All text output is also directed to a text file *RHYHAB.LST* and this file can then be edited and printed if required. Direct printing of text to a file (*RHYHAB.PRN*) on the current directory is activated by setting the printer option to ON. The printer should accept either Epson FX80 (80 column dot matrix) or HPIII (Laserjet) style commands.
Graphics printing is not automatic and is activated by pressing Alt P when the graph is displayed on the screen. This can be directed either to a printer port or to a file RHYHAB.PRT. Files can then be imported into other documents such as Microsoft Word. RHYHAB.PRT can be sent directly to the printer. To import the file into Word, import only the HPGL commands, first deleting all commands that begin with an escape character. These are printer commands and are not necessary if the file is imported into a programme that reads HPGL files.

3.6 Graphics font

Presentation quality can be improved by the use of special graphics fonts, although these are a little slower. Helvetica or Times fonts are available and must be installed on the current drive. Their file names are *HELVB.FON* and *TMSRB.FON*.

3.7 Access to DOS

This process allows DOS commands to be issued. When the prompt appears, enter any command as if at a normal DOS prompt. Because the programme occupies some memory only limited operations can be carried out. To exit back to RHYHABSIM press enter then ESC.

4. Data

This menu provides data checking functions that should be used as the first stage of any analysis.

Options (F2) can be specified for this menu and are reset to default values on leaving the programme. Options are:

directing output to the printer or list file or neither - the list file is the default.

echoing data as it is checked. This is useful for determining the location of data errors if the error messages are not sufficiently precise.

plotting cross-section data in terms of elevation rather than water depth.

submitting a list of files (*$.CMD*) to be processed automatically.

4.1 Select file to use

This option brings up a list of files in the directory specified by the drive and pathname specified (Section 3.3). It lists only files with the suffix *HAB* for RHYHABSIM analysis and the suffix *IFG* for IFG analysis (Section 3.1). Once a file is selected it remains the current file until a different file is selected. This is useful if only one file is analysed at a time. However, if more than one file is to be used than it is better not to select any file and the user will be prompted to select a file whenever required.

4.2 Check data

The data file *$.HAB* is read and checked. This checks the syntax to ensure that the reach and section descriptions are entered correctly and then checks that:-

substrate descriptors (if any) are recognised and associated with the correct substrate type

section distances increase in order upstream

cross-section offsets of not decrease across the section

there are not more than 100 points in cross-section

there are less than 60 cross-sections

there are not more than 10 attributes specified

there are not more than 8 gaugings

stage at zero flow is greater than the section minimum

stage for gaugings is greater than the section minimum

An attempt will be made to read the whole file, however errors in the reach or section headers and in the data can cause the error messages to have less meaning as processing proceeds. If the Echo option is set to ON then data will be displayed on the screen as they are read form the file.

Warning messages are issued where data may not be correct. In many instances these warnings can be ignored but they may indicate a mistake in data entry. Warnings include:

unreasonably high velocities

negative velocities

undefined water's edge (no measurement at zero depth)

measurements with the same offset but with different depths or attributes

the substrate values at a point do not add to 100%.

cross-section percentages do not add to 100%. A large number of files can be checked at once and output directed to *RHYHAB.TXT* by listing the file names in a command file, setting the submit command file option (F2) to ON and then pressing the check menu bar.

4.3 Plotting cross-sections

Water depths or elevations are plotted against offset for each cross-section. The default is to plot depths, but elevations can be plotted by setting Plot elevations ON in the options (F2).

If the water level has been recorded the waterway area is shaded and if velocities are recorded they are plotted to a reverse scale above the water level. All sections are plotted to the same scale and the defaults ensure that all data are plotted for all sections. Poor default scaling often results from data errors which cause unreasonably large values of reduced level, velocity or offset. Scales can be specified if required.

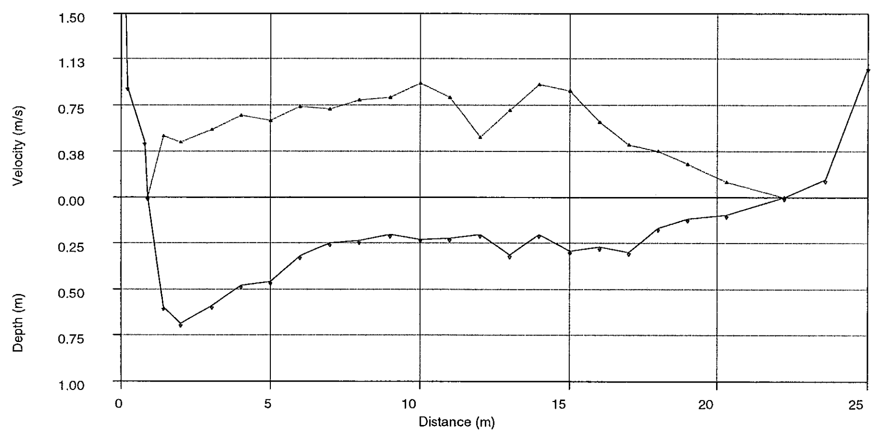


Figure 2. Example of plotted cross-section, showing velocity as dashed line and ground profile as the solid line. Measurement points are indicated by triangles on the ground and velocity lines.

4.4 Reach and cross-section summary

A summary of survey statistics is provided. This includes the total number of cross-sections and measurements, the average spacing of measurements across each cross-section and the average spacing of sections through a reach, if applicable.

The summary can be extended to multiple reaches or files. For a large number of files the file names can be listed in a command file. Each name should be followed by either Y or N indicating whether to continue averaging (Y) or to list results (N) and begin averaging again for the next file or files.

e.g.

File1 Y

File2 Y

File3 N

File4 N

The command file listed above would average measurements for files 1 to 3 and for file4 by itself.

5. Calibration

This menu contains the calibration steps that must be carried out before it is possible to make predictions of hydraulic/habitat at flows other than the calibration flow. In most cases all steps should be carried out whether habitat mapping or representative reach modelling is to used.

Options (F2) can be specified for this menu and are reset to default values on leaving the programme. Options are:

directing output to the printer or list file or neither - the list file is the default.

to vary the calibration flow between cross-sections

print extended details of calculated roughness values at each measurement point (used only in IFG mode).

plotting rating curves in terms of elevation rather than water depth.

submitting a list of files ($.CMD) to be processed automatically.

5.1 Flows and calibration flow

The flow at which the survey was made is known as the calibration flow and is one of the parameters stored in the file of calibration data *$.CON*. The calibration flow is used to develop stage discharge relationships, calibrate the velocity distributions factors (VDFs), and to calibrate friction losses for water surface profile modelling.

The flow at each cross-section is calculated from offsets, depths and either water velocities or revolutions and times. Data entry format is described in Section 2.4.

Flows, hydraulic characteristics, and average flow are tabulated. The average flow is usually the best measure of the calibration flow because most surveys are made at one flow and in a section of river where there are no significant tributary contributions or flow losses. This is the default assumption and the user can usually specify the average flow as the calibration flow. The value of the average flow will sometimes be influenced by large errors in flow measurements at some cross-sections. Users may correct the average by omitting particular sections, and use this value as the calibration flow.

If flows vary between cross-sections, either because the flow varied during the time of the survey or because of significant tributary contribution, then the Vary flows option should be set ON (F2) and the user will be prompted for a calibration flow for every cross-section.

5.2 Rating curves and roughness

Rating curves are used to predict the water level at discharges other than the calibration discharge. These are used either to predict levels at every cross-section in habitat evaluation or to predict the downstream starting level for water surface profile modelling. Rating curves are fitted to the gaugings for each cross-section and are stored in the file of calibration data *$.CON.*

In version 3.0 of the programme, rating curves were fitted to the gaugings and calibration discharge and water level by least squares regression:

*log(water level-SZF) = a*log(discharge) - b.*

This curve was adjusted vertically so that it plotted through the calibration flow and water level, so that the equation predicted the calibration level for the calibration discharge. A similar procedure was followed when finding the SZF of that produced the best fit, with the SZF varied between the minimum section level and then minimum gauging. Version 4.0 uses a slightly different procedure to fit rating curves, so that the derived equation plots through the calibration flow and water level and any vertical adjustment is unnecessary. The procedure is to minimise the sum of the squared departures of data about a line ($y = ax+b$) passing through the calibration stage (y^*) and discharge (x^*).

$$S = \sum (y_i - y^* - a(x_i - x^*))^2$$

where S = sum of squares of deviations from the line through y^* and x^*.

Minimising the sum of the squares:

$$\frac{\partial S}{\partial a} = 0 = \sum (x_i - x^*) y_i - y^* \sum (x_i - x^*) - a \sum (x_i - x^*)^2$$

$$a = \frac{\sum (x_i - x^*) y_i - y^* \sum (x_i - x^*)}{\sum (x_i - x^*)^2}$$

$$b = y^* - ax^*$$

Because the gaugings can contain errors in both stage and discharge, the regression lines were calculated for both x on y and y on x and the geometric mean coefficients calculated. The geometric has been shown to be a robust method of minimising the deviations from a regression line in both the x and y directions. A similar procedure was followed when finding the SZF of that produced the best fit, by allowing the stage for zero flow vary between the minimum gauging level and a point somewhat below the minimum section level (half the distance between the minimum gauging level and the minimum section level). If this rating curve is used, it is possible, for very low flows, to calculate a stage that is lower than the section minimum. Thus, the adjusted SZF will always give a better fit to the gaugings but might give incorrect stages when extrapolated to very low discharges. The plotted curves can be examined to determine if this is likely to occur.

After the curves are fitted to the points, the ratings are plotted for each cross-section on a normal scale. The stage can by plotted either as the height above SZF, the default, or as elevation if the Plot as elevation option is set ON (F2).

The rating curves in riffles and in some runs can be compared to the critical flow rating. The critical flow rating is the stage- discharge relationship that would exist if the section were a critical control i.e. the water level at the section was not influenced by downstream conditions. Critical flow across a whole section of the river is very unusual in natural rivers, so one does not expect a rating curve to cross the critical curve. Any rating curve that crosses the critical flow rating is probably incorrect, at least in the region where it crosses and usually a rating will be parallel to the critical flow rating. The height of the curve above the critical flow rating depends on how close to critical the flow is. For a swift riffle it will be close, for a slow run it may be well above the critical rating, possibly out of sight on the plot.

Rating curves are calculated by 4 methods.

1. Log-log least squares fit through points and SZF (SZF is either the section minimum or a specified value)

$$Flow = a\ (Stage\text{-}SZF)^b$$

2. Log-log least squares fit through points with SZF adjusted so that the correlation coefficient (r) is a maximum. This is the "best-fit" rating curve.

3. Manning's equation - Manning's *N* is calculated for each gauging:

$$Flow = 1/N\ A\ R^{2/3}\ S^{1/2}$$

assuming that the slope is constant. The variation of Manning N with discharge is calculated according to the equation:

$$N = a * Flow^b.$$

Usually Manning's *N* increases as discharge decreases so that *b* is negative.

4. Log-log least squares fit through stage of zero flow and water surface levels calculated by water surface profile modelling. This is fitted only if water surface profiles have been modelled and the results saved in the *$.OUT* file.

When comparing ratings, the exponents of the log-log equations should be close to those of a broad crested weir equation:

Flow = a width (Stage-SZF)$^{1.5}$

but modified slightly because the width changes with flow - usually to the power of about 0.5

hence:

Flow = b (Stage-SZF)^{3}

So the exponent should vary between 1.5 and 3.5.

Stage discharge curves do not necessarily follow a log-log line through the stage at zero flow. Cross-section geometry can be such that the exponent changes when the flow range changes. In some situations the best fit with adjusted SZF might be more appropriate.

The SZF or value of *b* can be altered in the fitting process. However, altered values will be overwritten whenever rating curves are re-calculated. Permanent alterations to the SZF are best made in the *$.HAB* file.

Generally, gaugings tend to be more linear than the curve of log-log fit through the SZF, although the log-log fit through the SZF is often the best choice of rating. Ideally, the ratings by all 4 methods are so close that the choice doesn't matter. The SZF that is used in a rating can be altered either in the original datafile or by pressing F2 and using the keyboard and mouse. The value of *b* in Manning's N ratings can also be altered by pressing F1 to display the variation of N with discharge and then F1 again to alter the value of *b*.

The shape of ratings fitted through the section minimum or SZF can be compared by pressing the F5 key. Generally, ratings within a section of river are similar and parallel to each other. Any rating that crosses other ratings is suspect, but not necessarily wrong.

Rating curves can be fitted to files listed in a command file. The format is the same as in the check command - a list of names, one per line.

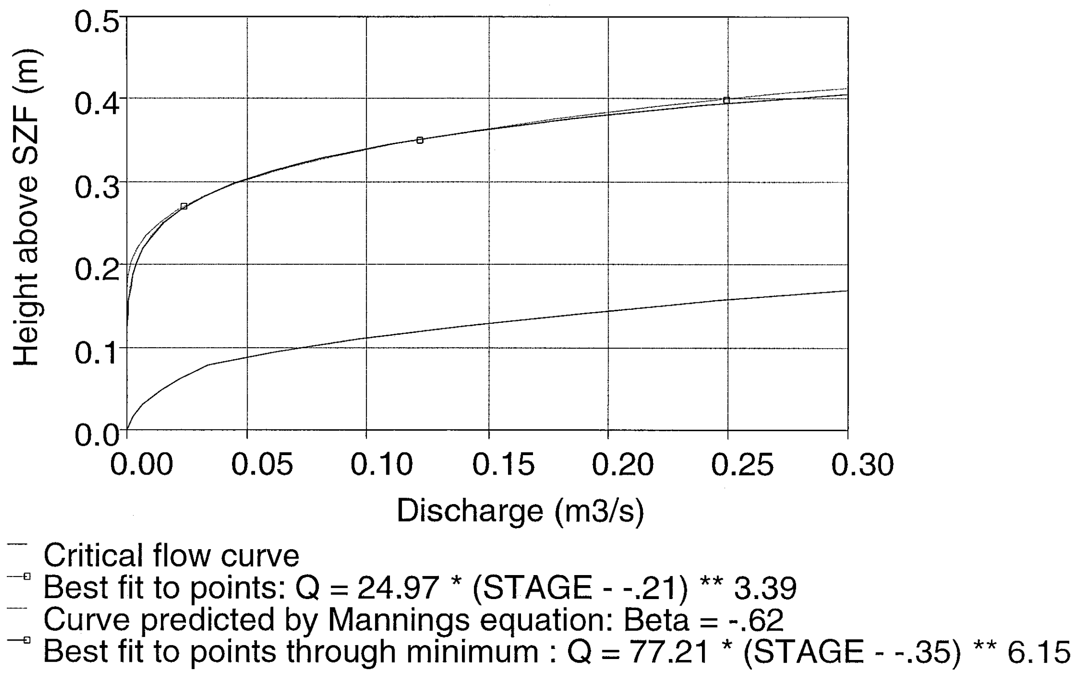


Figure 3. Typical set of rating curves for a run.

The critical flow rating is about 0.2 m lower than ratings. The water level at the calibration flow is 0 m. Manning's N coefficient (beta) is negative indicating that roughness increased as flow decreased. This rating and the rating through the section minimum are indistinguishable. The best fit to the points (dashed line) has a stage of zero flow of -0.21 m, 0.14 m above the section minimum of -0.35m. In this case the best fit to the points is probably the best rating, because its exponent is close to 3.

5.3 Fit velocity distribution factors

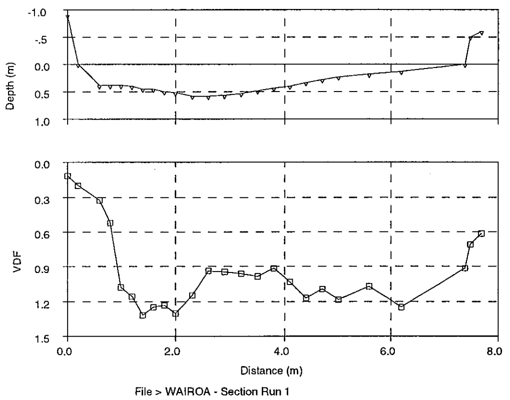
A text file, *$.VDF*, containing velocity distribution factors is created from the velocities that were measured across each cross-section and the calibration flow (Section 5.1). If a file of velocity distribution factors already exists the user is asked whether it is to be overwritten.

Velocity distribution factors can be fitted to files listed in a command file. The format is the same as in the check command - a list of names, one per line.

5.4 Edit velocity distribution factors

After fitting the velocity distribution factors, their values can be examined and altered if required. This is an essential step if predictions of habitat are to be made at flows greater than the calibration flow. In this case values for points at and above the waters edge must be estimated. This is a graphical procedure initiated by pressing F1, then clicking on a point and dragging to the new value.

Velocity distribution factors are usually vary about the value of 1. If the velocity were distributed across the section according to the conveyance of each measurement point then the VDF for each point would be 1. This occurs in situations with uniform flow and cross-section, such as canals. However, in most rivers variations in friction across the section, upstream obstructions such as boulders, and flow patterns caused by bends and eddies cause the VDF to be less than 1 at banks or downstream of obstructions and greater than 1 where flow concentrations occur. Predictions of water velocity at other flows follow the velocity distribution that was measured during the survey and assume that it will not change significantly.



At the end of this editing process the user will be asked if the file *$.VDF* is to be saved with the new values.

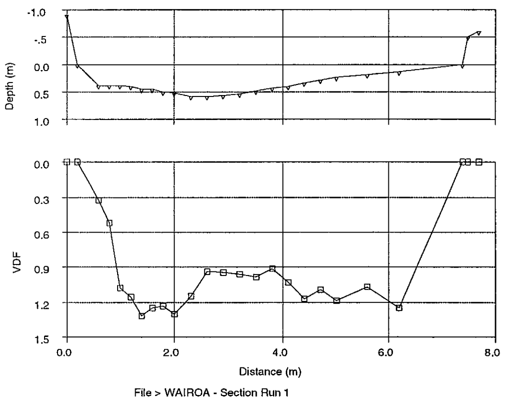


Figure 4. Screen display before (left) and after editing (right) velocity distribution factors (VDF).

To edit press F1 then click on or near one of the hollow squares VDF values. Drag up or down to alter value. VDFs typically vary about 1 except at edges or behind obstructions. VDFs are zero at the stream edges and above the water level. The top half of the screen outlines the cross-section profile, and while editing a bar on this marks the location of the point being edited.

6. WSP - water surface profile modelling

The steps in this menu are only necessary for water surface profile modelling. For this, cross-section data must be entered with the distances between sections specified, in order upstream, and water levels must all in terms of the same datum.

Water surface profile modelling begins with the calibration of the model, primarily values of Manning's N. After calibration, water surface profiles can be calculated for any flow from a starting level at the downstream section.

Options (F2) can be specified for this menu and are reset to default values on leaving the programme. Options are:

directing output to the printer or list file or neither - the list file is the default.

to vary the flow between cross-sections - the user will be prompted for a flow at every cross-section. This can be used to calibrate reaches with tributary inflows or reaches which were surveyed with slightly varying flows.

to apply Manning's N values at a section rather than as a value between sections.

to obtain details of the volume and surface area of the simulated flow profile.

to calculate hydraulic parameters over the full range of the cross-section rather than twice the depth (Section 9.2).

print extended details (used only in IFG mode).

plot rating curves at downstream section in terms of elevation rather than water depth.

6.1 Calculate average values of Manning's N between sections

Values of Manning's N are calculated from the calibration flow and the elevation difference between pairs of cross-sections. With good survey data, the calculated values of Manning's N are all positive (meaning that energy is lost as the river flows downhill) and within a consistent range (from about 0.02 in pools to 0.15 in riffles). This calculation is a stringent check on the water level data, because a small error in level will negative values of N (shown as ***** in the output) usually accompanied by a correspondingly high value of N at the adjacent section. If satisfactory values are obtained, results may be stored on the file *$.CON* and no further adjustment of hydraulic parameters is required. If results are not satisfactory, the user can try calculating values of N with different calibration flows or water levels, but this is usually best done in the fitting process (Section 6.2). Calculated values between sections are useful when values are fitted to the whole reach.

6.2 *Fit Manning's N and loss coefficients*

Adjustments to water levels and loss coefficients can be made so that N is positive and varies smoothly through the reach.

Field measurements of water level can be inaccurate and at times it is appropriate to adjust cross-section elevations to obtain reasonable values of N. Adjustments of less than 1 mm will often achieve this, especially through pools.

Hydraulic loss coefficients for bends, contractions and expansions can also be estimated, but these are probably best used cautiously.

A summary of N and loss coefficients is printed after N has been fitted to the last pair of sections. The user is then asked whether the values of Manning's N and loss coefficients should be stored in the calibration data file *$.CON*.

Friction losses (Manning's N) can be applied either between cross-sections (the default) or at a cross-section (Section 6). In the former case, friction loss is an average between two sections, calculated from the discharge and average cross-section properties.

Measurements of Manning's N are based on the height difference between two sections and average section properties, so logically Manning's N values are an average between sections. However, some water surface profile programmes use values of N applied at a section, rather than between sections. Determining values of N from a measured water surface profile, assuming that N is applied at a section is more difficult than fitting values between sections and is not recommended.

6.3 *Water surface profile*

The water surface profile is calculated using the standard step method. The calculation proceeds in an upstream direction using the level at the downstream section as the starting point. The starting level for the flow to be simulated can be determined from the rating curves at the downstream section - the user is given a choice of ratings to use - or can be specified directly.

Other levels are listed, as well as the level predicted from the rating curve. These are:

Minimum cross-section level

Maximum cross-section level

Water level when surveyed

Water level for critical flow at the section

A zero level for critical flow indicates that the value could not to be calculated.

The user is prompted to enter the number of interpolated sections, with none as the default. The usual procedure is to calculate the profile without interpolated sections. If the profile is parallel to the measured profile then no interpolation is necessary, however if the water levels appear unusually high at the upstream end of a convex slope (the head of a riffle) then the calculation should be retried using 1 or more interpolated sections.

Hydraulic parameters such as hydraulic radius and area are calculated over a range of levels (Section 9.2) starting at the lower level in the section and finishing at a level where the height above the bed is twice the maximum surveyed water depth. Alternatively, the table can be calculated from the maximum and minimum values of the cross-section by specifying the full range option (F2). This is only necessary if flows considerably higher than the calibration flow are to be simulated. If the water level is above the highest point surveyed then linear extrapolation is used to estimate the water's edge if the bank slope is greater than 1 in 10. If the slope is less than this a vertical bank is assumed 0.01 m from the last point surveyed.

After each flow is simulated and water surface profile is plotted. In the plot the mean bed level is the water surface level less the mean water depth (cross-section area divided by width). Usually, a predicted profile should be parallel to the measured profile. However, with convex profiles the predicted water level can be overestimated, because the energy slope is overestimated. Prediction of profiles on convex profiles can be improved by the use of interpolated sections. Average section properties are interpolated between cross-sections and intermediate water levels predicted.

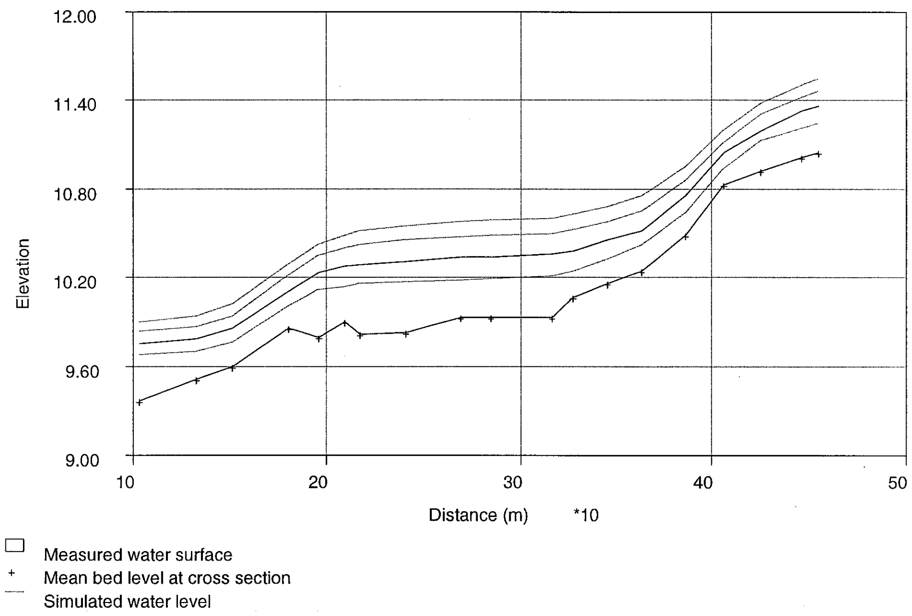


Figure 5. Longitudinal profile through a pool/run/riffle sequence.

The measured profile is shown as a top solid line, the mean bed level is then lower solid line. Tick marks show cross-section locations, with simulated water levels at three flows as the dashed lines.

The user is given the option of filing the results (in *$.OUT*), trying a new flow and/or starting level, or finishing the simulation process. Up to 20 simulations may be stored. When simulating high flows the predicted water level may be above the range of tabulated hydraulic characteristics. If this occurs the user will be asked whether the table should be extended. If an affirmative reply is given the table is recalculated for all cross-sections and the simulation can be repeated.

If flows vary through the reach, the vary flow option (F2) should be specified and the user will be prompted for the flow at each cross-section. This can be used where there are tributary inflows.

7. Habitat evaluation

There are three steps to habitat evaluation for flows other than the calibration flow. First, the user must choose which rating curves are to be used to predict water levels for the required flow range. Secondly, the user must choose the habitat preference curves that are to be used to evaluate the amount of habitat at different flows, and thirdly the user specifies the range of flows and flow increment to be simulated. In addition, water velocities predicted for each of the flows can be compared to measured water velocities, and the amount of habitat at the calibration flow can be evaluated. The latter step does not require ratings to be selected.

Options (F2) can be specified for this menu and are reset to default values on leaving the programme. Options are:

directing output to the printer or list file or neither - the list file is the default.

to print a summary of hydraulic parameters and habitat at each cross-section as well as the summary for the reach. 3. print extended details (used only in IFG mode).

plot rating curves in terms of elevation rather than water depth.

put all data onto a file:- measurements of cell length, width, velocity, depth, and habitat suitability at each measurement point below water level.

submit a list of files to be processed.

evaluate substrate. If this option is OFF (default ON) substrate preferences will be ignored and the stream bed treated as if it were ideal habitat.

use VDFs. If this option is OFF (default ON), velocities will be calculated according to the conveyance of the cell. This can be used to test the sensitivity of calculations to the predicted velocity distribution.

7.1 Selection of rating curves

All available rating curves are displayed and then listed, cross- section by cross-section, so that the user can select a rating to use for prediction of water levels. This is discussed in Section 5.2. Generally, the log-log least squares fit through the section minimum or stage of zero flow is the most appropriate and robust curve. If using water surface profile analysis, log-log equations must be derived for each cross-section (Section 5.2), after calculating and storing water surface profiles in the file *$.OUT* (Section 6.3).

7.2 Simulation of water velocities

Predicted water velocities are displayed for a specified flow range and increment, along with the measured water velocities. This can be used to check that the calibration procedures have been carried out correctly. Simulations of flows higher than the calibration flow should plot at higher velocities than those measured during calibration, simulation of the calibration flow should reproduce the measured velocities, and velocities at flows lower than the calibration flow should be lower than measured flows. In some situations, an increase in water velocity may be predicted at low flows. This occurs when the flow is constrained in a narrow channel, such as between boulders, and is feasible.
If the option to use VDFs (F2) is switched OFF, velocities are predicted according to the conveyance of each cell, and the effect of roughness, obstructions, and flow concentrations on the velocity distribution can be determined.

7.3 Selection of habitat suitability curves

Up to 15 suitability curves can be selected at one time from the suitability curve file *$.PRF* (containing up to 40 sets of criteria). Curves are selected by listing the numbers of the suitability criteria to be used. A file *FISH.DAT* of the criteria is created. These curves are used to evaluate habitat suitability (Sections 7.5, 7.6).

7.4 Removal of habitat suitability curves

This removes all selected suitability curves. It is not necessary to remove curves before selecting a new set.

7.5 Evaluation of measured habitat

The measured water depths, velocities, and substrate are used to evaluate the amount of suitable habitat in each cross-section and over the whole reach. The effect of substrate on habitat assessment can be determined by comparing evaluations with substrate ON and OFF (F2). Data for each cross-section can be obtained with the option transect results ON. A number of reaches from the same river may be processed and the results incorporated into an overall summary. In this way different reaches can represent different habitat types and be averaged to represent a larger section of the river.
Measurements of cell length, width, velocity, depth, and habitat suitability at each measurement point below water level can be saved in a file with the same prefix as the datafile and the suffix *DAT* if the option to put all data is ON.

A list of files can be processed if the submit option (F2) is switched ON. Each filename should be followed by either Y or N indicating whether to list results (Y) and begin averaging again for the next file or files or to continue averaging over the reach (N).

e.g.

File1 N

File2 N

File3 Y

File4 Y

The command file listed above would average measurements for files 1 to 3 and for file4 by itself.

7.6 Habitat simulation

The amount of habitat in the reach (in terms of total area and percentage of stream area or width) is evaluated for between 1 and 20 flows. The effect of substrate on habitat assessment can be determined by comparing evaluations with substrate ON and OFF (F2). Data for each cross-section can be obtained with the option transect results ON. The sensitivity of habitat predictions to velocity distribution can be tested by simulating habitat with VDFs ON and OFF.

Mean water depth and velocity, stream width, reach length or percentage, cross-sectional area, wetted perimeter and maximum velocity and depth are summarised for each flow. The mean depth in a section is calculated as the cross-section area divided by the cross-section width. For a reach, mean depth is averaged over the reach by weighting either by the distances between sections for a representative reach or by the habitat mapping percentages. The mean depth in a reach does not necessarily equal the mean reach area divided by the mean reach width.

The mean velocity is the mean velocity across the section rather than the mean velocity within the section and the two are not necessarily the same. The mean velocity within a section is calculated by dividing the discharge by the cross-section area. The mean velocity across a section is calculated from the velocity weighted by the water surface width over which it occurs. The width/depth ratio is calculated for each flow and the proportion of run, riffle and pool habitat is calculated from the predicted Froude number at each measurement point. Points with Froude numbers in excess of 0.41 are considered to be riffle habitat, and points with Froude numbers of less 0.18 than are considered pool habitat. Intermediate values are run habitat. All attributes or substrates are averaged for each flow and are summarised.

The weighted usable area within a river can be thought of as the area instream where the physical character (water depth, velocity and substrate, if required) meets the criteria specified in the habitat suitability curves. If habitat suitability is specified so that suitable habitat has a weight of 1 and unsuitable habitat a weight of 0, the area is the usable area in m^2.

If habitat suitability curves are specified with weights of between 0 and 1, the area, WUA, is an index of suitability rather than a measure of physical area.

Weighted usable area is evaluated for each of the habitat suitability criteria selected (Section 7.3) for each flow. The weighted usable area is calculated by multiplying the habitat suitability for depth, velocity, and substrate (unless the evaluate substrate option is OFF) at each measurement point and multiplying it by the area represented by that point.

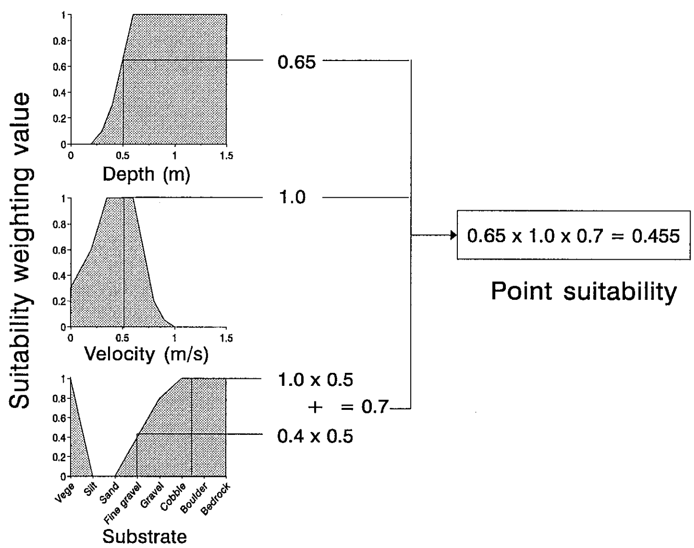


Figure 6. Example of calculation of point habitat suitability by multiplication of habitat suitability for depth, velocity, and substrate.

Weighted usable area can be expressed in two ways:

area or width

percentage of stream area or width.

WUA in terms of area identifies the flow which maximises habitat, whereas WUA in terms of percentage is more useful for comparisons between rivers and for identifying the "most efficient flow" - that is the flow where the highest proportion of the stream is "usable".

A number of reaches from the same river may be processed and the results incorporated into an overall summary. In this way different reaches can represent different habitat types and if necessary flow ranges and can be averaged to represent the effect of flow changes on a larger section of the river.

Measurements of cell length, width, velocity, depth, and habitat suitability at each measurement point below water level can be saved in a file with the same prefix as the datafile and the suffix *DAT* if the option to put all data is ON.

A list of files can be processed if the submit option (F2) is switched ON. Each filename should be followed by either the flows or flow range to be analysed and either Y or N indicating whether to list results (Y) and begin averaging again for the next file or files or to continue averaging over the reach (N). A list of flows to be analysed begins with **F**low and ends with **E**nd. A range of flows to be analysed begins with **R**ange, followed by the minimum flow, the maximum flow, and the increment, then **E**nd.

e.g.

File1 Flows 0.86 19.2 End N

File2 Flows 0.86 19.2 End N

File3 Flows 0.86 19.2 End Y

File4 Flows 0.23 6.7 End Y

The command file listed above would simulate and average habitat for flows of 0.86 and 19.2 cumecs for files 1 to 3 and for flows of 0.23 and 6.7 cumecs for file4.

7.7 Flushing flows

Flushing flows are flows that remove the fine sediments and periphyton accumulations from stream substrates. Flushing flows are necessary in most streams to remove accumulated fine sediments and to restore interstitial space in gravel substrates.

Surface flushing flows remove the fine sediments from the surface layer, leaving the armour layer largely intact. Periphyton will also be removed by the abrasive action of fine sediments moving over the surface.

Bed flushing flows disturb the armour layer, removing the sediments that have deposited within the gravel matrix.

Effect of river slope on bed shear stress

The bed shear stress resists the effect of gravity on water flow so that the sum of the bed shear stresses is equal to the gravitational down slope component of the weight of the water. Thus, bed shear stress is proportional to the product of depth of water and the slope of the river. The slope of the river must be known before flushing flow requirements can be estimated.

The calculation of the amount of disturbance caused by a flow is based on bed shear stress. Sheild's showed that particles were likely to move when the dimensionless bed stress equalled 0.056. Subsequent studies indicate that this value may be slightly high. Milhous used data from a small gravel bed stream to show that surface sediments were flushed when the dimensionless bed stress exceeded 0.021 and that the armour layer was disturbed when the shear stress exceeded 0.035. These values are used to calculate the area of the stream bed that is flushed.

Bed shear stress

The bed shear stress at a point or cell is calculated from the hydraulic radius and slope. The slope can be either the **slope at the cross-section** (slope between the cross-sections upstream and downstream) or the **average slope over the reach**.

$$shear\ stress = sqrt(gRS)$$

where S is the slope, and R the cell hydraulic radius.

Flushing usually occurs at flows higher than the flow that was surveyed. As flows increase, the slope at any cross-section will tend towards the average slope. Thus, an average reach slope should be used if the flushing flows are an order of magnitude higher than the survey flow.

The calculation of bed shear stress from slope and hydraulic radius assumes that the velocity distribution across the section is uniform, i.e., that the velocity at each point is proportional to the depth. At high flows, this will be true in many cases because small obstructions that effect the velocity distribution will be drowned.

Velocity

Bed shear stresses can be calculated from Mannings equation rather than from slope and hydraulic radius.

When using velocity distribution factors the bed shear stress at a point or cell is calculated as:

*shear stress = sqrt(g) * V * VDF * Manning N / R^1/6*

where *Manning N* is the cross-section Manning N, *R* the cell hydraulic radius, *V* the cell velocity calculated from conveyance, and *VDF* the cell velocity distribution factor.

The velocity distribution factors can be applied to reproduce the measured velocity distribution or set to 1 to give a uniform distribution (as is likely at high flows).

Substrate size

The effect of bed shear stress at a point or cell depends on the substrate size. Obviously, large substrate requires higher stresses for movement than small substrate. Substrate size can be specified either as an average value for the reach or can be calculated from the substrate composition at the point. The calculation from the composition multiplies the percentage of each size category by its average size. For example, 60% gravel and 40% cobble is:

gravel 8-64mm, cobble 64-256mm

Average size = 0.6*36mm + 0.4*160mm = 85.6mm.

The average armour size is calculated in a similar way, except that the d85 size is estimated.

The size of suspended and bedload sediments moved by are flow are calculated from formulae presented by Milhous. these are:

*Max. Sus sediment size = Slope * Hydraulic radius/((Specific gravity-1)*0.28)*

*Max. bedload size = Substrate size * (Slope * Hydraulic radius /((Specific gravity-1)*0.018))*$^{2.85}$

Baseflow

As flows increase, a river widens with shallow depths and low velocities along the margins. For this reason, There is rarely 100% flushing of the stream bed.

However, the intention of a flushing flow is to remove fine sediments from the "baseflow" channel. The baseflow is the "normal" flow for a particular time of year.

8. Plotting

The variation of hydraulic parameters, river volume or surface area with elevation, longitudinal water surface profiles, an isometric view of the river, diagrammatic plan of the reach, the variation of weighted usable area (WUA), velocity and width with discharge, and habitat suitability criteria can be displayed graphically. Scales are selected by default but can be specified if required. Any display can be printed by pressing Alt P. This can be directed either to a printer port or to a file RHYHAB.PRT (Section 3.5). Files can then be imported into other documents such as Microsoft Word. To import the file into Word, import only the HPGL command, first deleting all commands that begin with an escape character. These are the commands that setup the printer and are not necessary if the file is imported into a programme that accepts HPGL files.
The only options (F2) for this menu are to:
direct text output to the printer or list file or neither - the list file is the default.

8.1 Hydraulic parameters with elevation

The variation of cross-section area, hydraulic radius and stream width with elevation is displayed for each cross-section. If output is directed to a list file or printer a table of values is produced. The number of values in the table and the range of values to be tabulated can be specified.

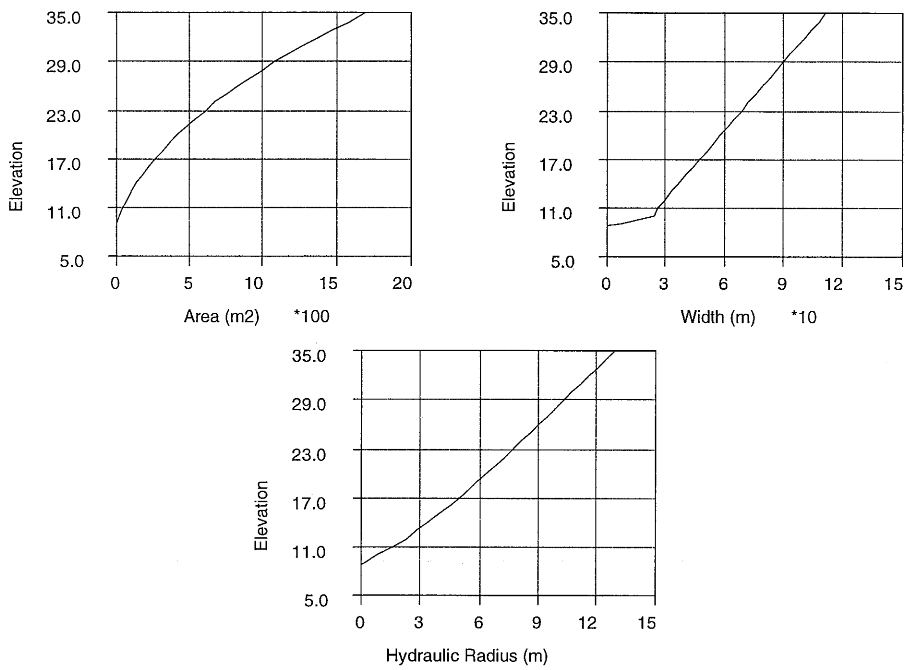


Figure 7. Variation of cross-section area, width, and hydraulic radius with elevation.

8.2 Reservoir/reach volume, area and depth

The variation of total reservoir or reach volume, surface area and mean depth with elevation is displayed.

The calculation of volume assumes that the end cross-sections extend a distance upstream and downstream equivalent to half the distance between them and the adjacent sections. If the end section is a wall or dam face then the produce of the end section cross-section area and half the distance to the next section should be subtracted from the total. Widths and depths should be similarly amended if appropriate.

If output is directed to a list file or printer a table of values is produced. The number of values in the table and the minimum and maximum values can be specified.

8.3 Water surface profile

The longitudinal water surface profile and mean bed level at each cross-section and any calculated water surface profiles are plotted. This plot is the same as that produced for checking water surface profile calculation (Section 6.3). The plot is only a true profile if cross-section water levels are related to the same datum. If habitat weighting percentages are used, each cross-section may be referenced to a different datum and the plot will only display mean bed levels for each section.

8.4 Isometric view of river reach

An isometric view is produced that can be rotated to 30, 60 and 90 degrees. Figure 1 is an example of an isometric plot.

8.5 River plan plots

Displays of the river in plan view are produced. The value of either water depth, water velocity, any of the attributes or habitat suitability is shown graphically on the plot as a bar length or shade intensity. This is useful for determining the location of suitable habitat for comparisons with observed fish use or to see how the location may change with flow.

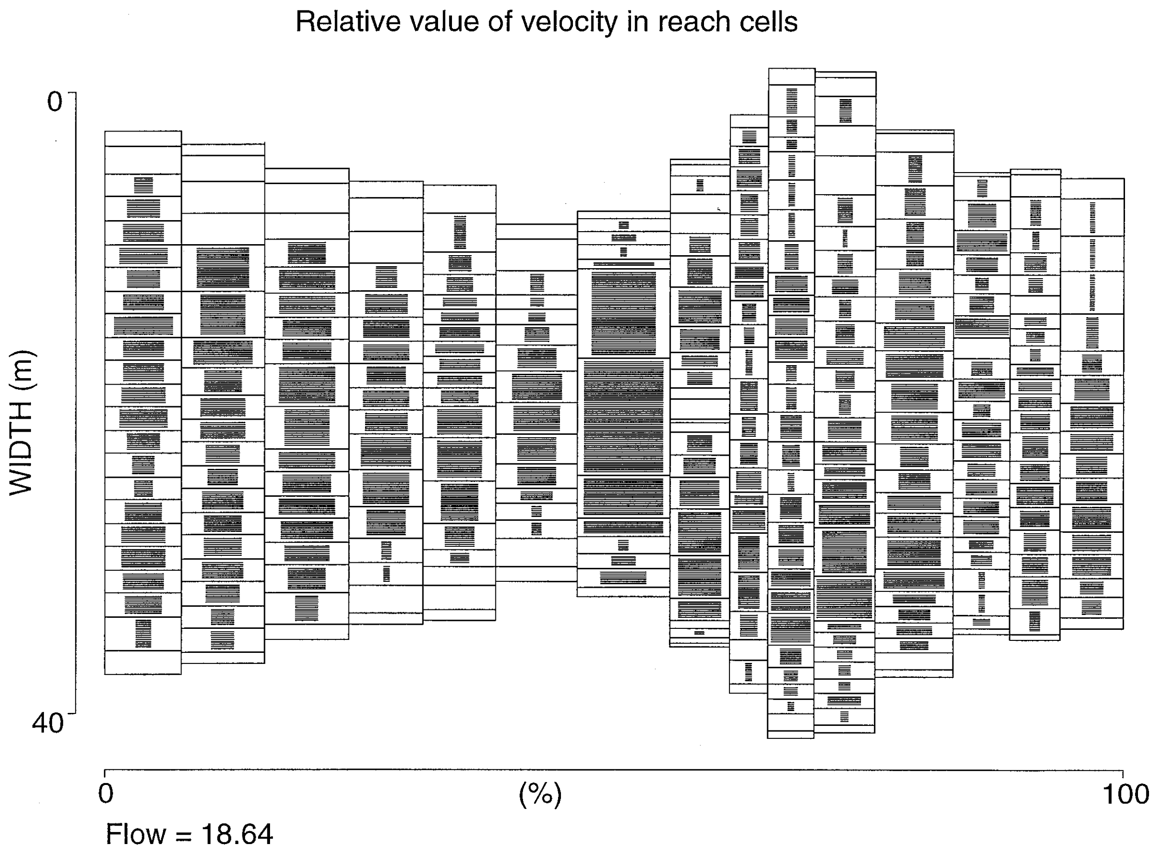


Figure 8. Display of a river reach showing the cells and water velocities that were surveyed.

The width of the solid bar in the cell is proportional to the velocity. The base scale is shown in percentage of reach habitat if habitat weighting percentages are specified, or cross-section distances if representative reaches are surveyed. Sections can be centred, as shown above, or plotted from their offset zeros. If the baseline for offset zeros is a straight line then the plan will display the form of the river channel, i.e. curved, or straight.

8.6 Weighted usable area with discharge

The variation of weighted usable area (WUA) is plotted against discharge for flows simulated as described in Section 7.6. Habitat evaluation (Section 7.6) must be carried out before these plotting WUA against flow. Lines between simulated values are interpolated quadratically. WUA is plotted first as area (m²) for all selected habitat suitability curves and then as a percentage of water surface area.

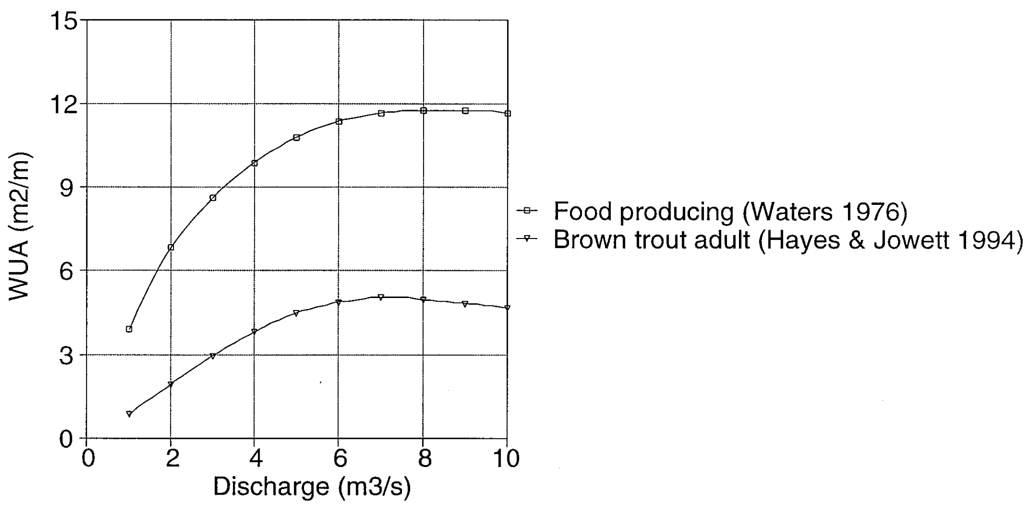


Figure 9. Variation of WUA for brown trout and food producing habitat plotted for a range of flows.

8.7 Width and velocity with discharge

The variation of river width and velocity with discharge is displayed for a specified range of flows. Lines between simulated values are interpolated quadratically. This can be used to determine points of inflection, as in the wetted perimeter method of flow assessment, or to determine flows that provide minimum depth and velocity requirements.

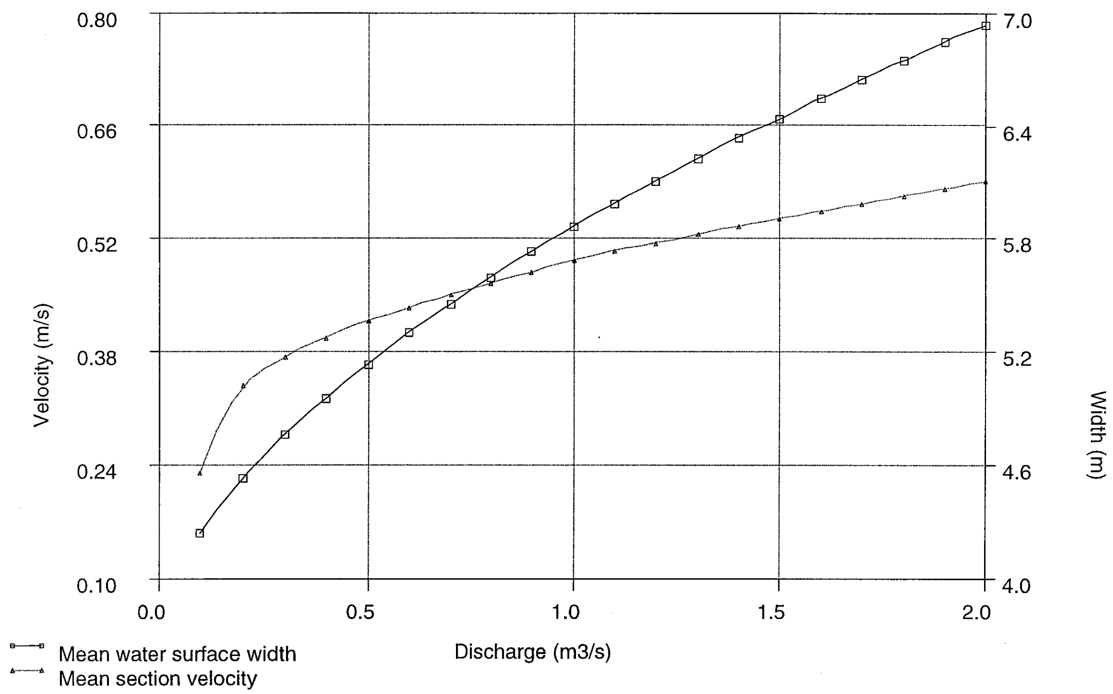


Figure 10. Variation of width and velocity with flow in a reach.

8.8 Habitat suitability criteria

Habitat suitability criteria for depth, velocity and substrate can be displayed. The user chooses the suitability curves to be plotted by listing their numbers. The default RETURN will display all suitability curves.

Substrate codes used are:

V Vegetation

M Silt (Mud)

S Sand

F Finegravel

G Gravel

C Cobble

B Boulder

R Bedrock (Rock)

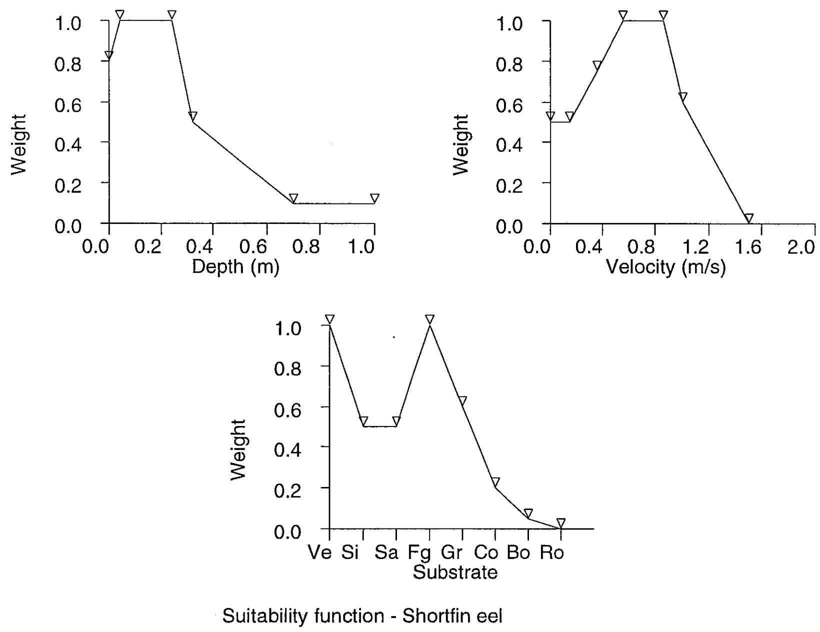


Figure 11. Habitat suitability curves for shortfinned eels.

9. RHYSET - Options

The file *RHYHAB.CFG* contains details of the configuration. If this file is deleted or does not exist, a default configuration is adopted. The default options are recommended.

9.1 Drive for temporary files

It is possible improve speed writing temporary files to RAM. This is known as a virtual disc drive. Reading and writing to RAM is faster than to hard disc. A drive letter can be specified and all temporary files will be written to this drive. With fast computers and hard disc drives this is not usually necessary.

9.2 Numbers of levels

A table of hydraulic parameters for each cross-section is created automatically when water surface profile calculations are made. The number of levels or values in the table can be set in the initialisation process. The programme then calculates parameters such as hydraulic radius and area for that number of levels starting at the lowest level in the section and finishing at a level where the height above the bed is twice the maximum surveyed water depth.

A large number of levels will give better accuracy but computing time is longer. The default value is 32. This will normally simulate levels to within 1 mm of the levels predicted using the maximum resolution of 64.

9.3 Hydraulic options

Hydraulic formulae can be calculated in different ways giving slightly different results. If alternate methods of calculation are used they should be used consistently for a particular reach, the calibration and predictions will not be consistent.

9.4 Calculation of flow

There are a number of ways in which the flow can be calculated for a cross-section. The conventional method of calculating flow is to multiply the area between verticals by the average of the velocity measured at the two verticals.

$Q_{cell} = 1/4(Y_i+Y_{i+1})(X_{i+1}-X_i) * (V_i+V_{i+1})$

where Y is the depth, X the offset and V the velocity at point i.

However, flow can also be calculated from the area between verticals times the average velocity at the vertical (the average of the velocity at the vertical and adjacent mid-points using linear interpolation to estimate mid-point velocities). The difference in the two methods of calculation is rather like the difference between calculating volumes by the end area method and the trapeziodal method.

$Q_{cell} = 1/32(5Y_iV_i + 3\ Y_iV_{i+1} + 3Y_{i+1}V_i + 5Y_{i+1}V_{i+1})(X_{i+1}-X_i)$

9.5 Conveyance

The conveyance is a measure of the capacity of a channel or channel subsection the convey water. The traditional measure of conveyance includes friction (Manning's N) but if friction is constant then conveyance is a measure of the geometry of the channel.

$Conveyance = A\ R^{2/3}$

The conveyance of a section can also be integrated over the whole cross-section as the sum of the cell areas times their hydraulic radii. Integration is the preferred method because when conveyance is calculated in this way its variation with level forms a smooth curve and gives better results in water surface profile modelling.

The velocity head coefficient converts the mean velocity head ($Vm^2/2g$) to the true velocity head. If the velocity does not vary across the section then these two will be the same but normally the true velocity head will 1.5 to 3 times greater. It is calculated by integrating the velocity head across the section:

Velocity head coefficient $\alpha = \Sigma(V^3\ \Delta A)/(Vm^3\ A)$

If the integration method of calculating conveyance is used, the velocity head coefficient (α) is calculated from the section geometry, rather than from measured velocities.

Velocity head coefficient $\alpha = \Sigma(Cell\ conveyance^3/Cell\ area^2) * Area^2/Conveyance^3$

9.6 Water Surface profile calculation

The energy loss between two cross-section is calculated from the average geometrical properties (conveyance) of the sections. This average can be calculated in a number of different ways: an arithmetic average

an arithmetic mean when the friction slope is increasing and the harmonic mean when the slope is decreasing upstream

The latter method helps avoid some of the problems that can occur when calculating a convex profile. Interpolation of extra cross- sections is another way improving the accuracy of profiles over convex slopes.

9.7 *Colours*

Menu and highlight colours can be altered and basic line colours, fill, and background can be specified for graphic displays.

10. Field techniques

10.1 Introduction

The analysis in this programme is similar to that developed by the Co-operative Instream Flow Group (IFG) in Colorado their publications such as "A guide to stream habitat analysis using the instream flow incremental methodology", Instream Flow Information Papers 12 and "Hydraulic simulation in instream flow studies - theory and techniques", Instream Flow Information Papers 4 describe most of the techniques.

The purpose of an instream habitat survey is to compare the range of water velocities and depths that occur in a river, along with their co-occurrence with stationary stream elements such as substrate, bank formations, and cover with the preferred instream conditions. One survey will usually represent a section of river. Cross-sections are located within this section of river so that they represent the range of conditions that occur. There are two ways of doing this. The first is a representative reach, containing a range of habitats, usually one or two pool/run/riffle sequences. Cross-sections are closely spaced through this reach in each of the habitat types and transition zones. The distance between cross-sections is used to calculate the representative length of each cross-section. The second method is stratified random selection of cross-sections based on habitat type. The habitat types are defined and habitat mapping is carried out to determine the percentage composition of each type. Cross-sections are randomly selected in each habitat types. Each cross-section represents the percentage composition of the habitat type divided by the number of sections in that type. For example, if riffles made up 25% of a section of river and 6 cross-sections were surveyed in riffles then each cross- section would represent 25/6 or 4.2% of the river section.

Water surface profile modelling requires that cross-sections describe reach geometry in both longitudinal and cross-sectional profile. This means that a representative reach approach must be used where the elevation of every cross-section is related to the same datum and sections are close enough to represent adequately both the variation in cross-section area and longitudinal profile. If a habitat mapping or stratified random approach is used, the data form a model of the cross-section profile but not of the longitudinal profile and these data cannot be used for water surface profile modelling.

Cross-sections should be clearly identified and field data (offset distances, depths, number of revolutions and times and especially levels) should be accurate and systematic.

10.2 Equipment

The instream habitat surveys are carried out with standard hydrological gauging equipment and can be done by wading, by boat, or raft. In addition, cross-sections need to be marked so that they can be found and identified on return visits and water levels measured.

Current meter and counter

Gauging rod (preferably topsetting) or cable winch in boats

Datasheets (preferably waterproof), pencil, and clipboard

Tagline or tape

Pins for fastening tape or tagline on each bank.

Peg or stake for marking cross-sections.

Marker pen for identifying cross-sections.

Hipchain or similar for habitat mapping.

Reinforcing bars or similar for temporary staff gauges.

Level, levelling sheets, staff, and tripod for levelling water surface or temporary staff gauge.

10.3 Survey procedure

The purpose of a survey will determine cross-section selection and the best flow at which to carry out the survey. The most common purpose is to describe average river conditions under low flows to provide information on how the conditions for a preferred use, aquatic species, or community change with flow. In this case, the survey will encompass all or most existing habitat types and is best carried out at low flow to minimise error in extrapolating beyond the measured conditions. Instream habitat surveys may also be used to determine the effect of flow on spawning grounds or fish passage. Surveys of this nature usually concentrate on known spawning areas or shallow rivers sections.

The habitat types in the section of river to be surveyed are established after examining a reasonable length of river. For habitat mapping, the basic pool/run/riffle subdivision can be used or further sub-divided depending on the river and survey purpose. Once the habitat types are defined, cross-sections are randomly selected in each habitat type. Often a cross-section is chosen in the least common habitat type, with other habitat types represented by adjacent cross-sections. For water surface profile analysis, reaches are selected to represent the range of habitat types in the river.

A tagline or tape is strung across the river at right-angles to the flow. It does not matter whether the tape zero is on the left or right bank, but it is preferable to be consistent. Then when plotted data are viewed, cross-sections will be consistently either looking upstream or downstream.

An initial estimate of offset spacing is made by dividing the river width by 10, and rounding down to the nearest convenient increment. Offset distances, heights above water level, and substrate composition are estimated for the bank and waters edge, either before or while the first instream measurement is made, usually 0.3-0.5 m from the waters edge. Measurements are made at offset increments across the stream, with additional measurements where the depth or velocity change suddenly. This means that boulders, as well as overall bed shape, will be well defined by measurements. After the last instream measurement, the waters edge and the other bank is defined.

The cross-section should be clearly numbered and water level marked by a temporary staff gauge. It can be a reinforcing bar driven into the streambed in a sheltered location on the cross-section in about 10-20 cm of water. The top of this gauge is used as one of the section benchmarks. Two other benchmarks should be established on the bank so that any movement in the temporary gauge can be detected and corrected if necessary. Each benchmark should be levelled and the water level referenced to the top of the gauge (zero if flush with the water surface). A gauge can accurately measure small changes in water level for derivation of the cross-section rating curve. However, for water surface profile analysis, the water level of the main current at two or three points must be levelled in terms of the datum used for the other cross-sections.

Each channel in a braided channel is initially treated as a separate cross-section, with temporary staff gauges in each channel. If it is found that the level variation with flow in each braid is similar, the braids can be treated as one in the analysis, otherwise they are analysed separately.

This procedure is repeated until the required number of cross-section are surveyed. If flows are changing during the survey, stage at one site should be recorded throughout the day so that this can be related to the time and flow of each cross-section survey.

After the initial survey, two or more calibration surveys are required to establish the variation of water level with flow. Stage/discharge calibration should be done as soon as possible to minimise the chance of rating changes occurring between the survey and calibration. On the calibration visit, flow is measured at a good gauging site and the water level at each cross-section (or downstream section for WSP analysis) measured. Bench marks and temporary gauge levels should be checked against the original survey in the field and the source of any discrepancy determined. This could be either survey error or benchmark movement.

10.4 Reach and cross-section location

The reach or section of river surveyed should represent the average characteristics of the river and contain a range of habitat types or attributes. If the number of cross-sections in a reach is small, results can be unduly influenced by unusually wide cross-sections, because the area each cross-section is assumed to represent a proportion of the reach. A number of reaches may be surveyed to represent the different characters of sections of stream. These reaches can be summed to give an average for the river (Section 7.5, 7.6). In some instances critical rather than representative reaches can be selected. An example is the shallowest riffles which can be modelled to determine the flow at which the depth falls below a critical level for the passage of fish.

The number of cross-sections surveyed and the total number of measurements across each section should increase as the variability of the stream geometry increases. At least 5 cross-sections are required in each habitat type. The number of cross-sections for comparison of habitat quality between sections of river or between rivers is greater than the number required to establish the pattern of habitat variation with flow.

10.5 Offset spacing

The offset is the distance across the cross-section from an origin. Usually the origin is the zero of the tape or tagline. Negative values can be used. If the origin is a straight baseline parallel to the general direction of the river the plan can resemble the layout of the river. Measurements are made along each cross-section, usually at fixed intervals (one or two metres depending on the river width), but with additional measurements at the water's edge and abrupt changes in section. Changes in grade across the section should be recorded to obtain the best representation of the section area. Measurements should be taken at the foot, waters edge, top of large boulders or similar bed elements on both the left and right sides.

Offset positions should be such that the measurements describe the bank, as well as the stream. Bank offsets should be located at changes of grade, up to the water level of the highest flow to be simulated. Heights above water level (a negative value of water depth) can be measured form a taut horizontal tagline using a wading rods, can be levelled, or can be estimated.

One offset should be at the actual water's edge. This makes sure that there is no confusion between points measured above the water level and those measured below, if the negative sign for a point above water level is inadvertently omitted.

10.6 Velocity measurements

Velocity measurements should be made at all instream offset points and very small velocities should **not** be ignored. Reverse currents should be recorded as a negative number of revolutions. The movement of silt can be used to assess current direction and magnitude when velocities are too small to measure. Velocity or revolutions and time measurements (at 0.6 depth below water surface or at 0.2 and 0.8 if the depth exceeds 1 m or there is an unusual vertical velocity distribution) are recorded. Water velocities can be measured with 20 second counts rather than the more standard 40 second count. If this is done the actual count and time should be recorded rather than doubling a 20 second count to make it appear as a 40 count.

10.7 Measurement of stream attributes

Attributes (substrate etc.) are recorded for every offset both instream and on bank. Generally, visual assessments are the only practical method of assessing substrate composition. The average substrate composition in the region of the measurement point should be assessed. The area examined will depend on offset spacing, but should not exceed 0.5 m either side of the point and 1 m up- and downstream. Substrate categories used are commonly, bedrock, boulder (>264 mm), cobble (64-264 mm), gravel (8-64 mm), fine gravel (2-8 mm), sand (<2 mm), silt, and vegetation (bank or instream debris). These categories are arbitrary and any subdivision is possible and could be changed depending on the purpose of the survey. For habitat analysis, the only categories used in the survey should match those described in the habitat suitability curves. For example, a spawning suitability survey might only use two substrate categories, suitable for spawning and unsuitable. The suitable category could be called "Gravel" and the unsuitable category "Vegetation". The habitat suitability curves would give "Gravel", substrate index 5, a weight of 1 and all other substrate categories a weight of 0.

10.8 Measurement of water level

The water surface at each cross-section is measured. The most accurate method of measuring water level, or more precisely changes in water level, is to establish a temporary staff gauge in the river. The level can then be measured from the top of this gauge. Reinforcing bars about 50 cm long are ideal for this, and can be driven so they are flush with the water surface at the calibration flow. On subsequent visits it is only necessary to measure the height above or below the top of the pin to determine the change in water level. It is only necessary to establish changes in water level for rating curves so pins can be located where turbulence is minimal and levels can be established accurately. If pins or gauges are to be left for some time they should be levelled into two benchmarks on the bank so that any movement can be detected.

If a rating curve is to be derived for the cross-section, and estimation of the water level at zero flow (SZF) is required. For riffles this will usually be the minimum level and it is not necessary to calculate this. However, for runs and pools the water level at zero flow will be controlled by some downstream feature, usually the minimum level of the downstream bar or head of riffle. This can be estimated by measuring the maximum depth across the bar or riffle head or by levelling to determine the "highest" point on the downstream thalweg. The measurement of stage of zero flow should be in terms of the same datum as the measurement of water level.

For water surface profile modelling the water level should represent the level of the bulk of the flowing water, and should be measured at three positions across the section - left bank, right bank and at a mid point. This usually involves levelling with a staff and level. When levelling the water surface at the banks, the staff should be held clear of any instream obstructions which are likely to influence the water level locally. The flow profile is the level at each cross-section plotted against the distance upstream and should be a smooth curve without anomalies such as water flowing uphill. All levelling should be closed and carefully checked. Errors in levelling water surfaces are difficult to detect retrospectively and there is rarely any opportunity to repeat the levelling run.

10.9 Calculation of flows

Flows calculated at each cross-section should be examined closely as excessive variation could indicate data errors. Usually flows at individual cross-sections should not be more than 10% different from the mean. If they are, and this is not due to data errors, it may be because the flow was not at right angles to the section with the result that the flow is overestimated. If this occurs the offset spacing should be adjusted by multiplying by the cosine of the current angle.

The other explanation for large variations in measured flow is that cross-section locations are not ideal sections for measuring flow. Measurements in pools are often inaccurate, but accuracy can be improved by taking measurements at 0.2 and 0.8 of the depth.

10.10 Velocity distribution factors

Velocity distribution factors, ratios of actual measured velocities to calculated velocities, are fitted automatically (Section 5.3).

When simulating flows, calculated water velocities are multiplied by the velocity distribution factor to give a simulated water velocity. This will reproduce the measured velocity distribution when the measured flow is simulated. Simulated velocities will always be zero at points with zero velocity distribution factors. Thus, distribution factors at the water's edge and banks must be changed from zero to an estimated value if flows higher than measured are to be simulated (Section 5.4).

Usually velocity distribution factors vary across a section in a regular pattern. Adjustments to points should attempt to emulate this pattern. Good field notes can aid the estimation of VDFs at and above stream banks. Obstacles to flow, such as vegetation or large boulders upstream, should be noted and estimated VDFs reduced accordingly.

10.11 Derivation of Velocity Distribution Factors

The conveyance of a cross-section is:

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

where Q is the flow, S the slope, and K the conveyance.

Using Manning's equation, the conveyance K becomes:

$$K = \frac{A \times R^{2/3}}{N}$$

For any cell in the section, the ratio of cell flow Q_i to cell conveyance is equal to the total section flow Q divided by the total section conveyance (Henderson 1966 "Open channel flow" p. 145)

$$\frac{Q_1}{K_1} = \frac{Q_2}{K_2} = \frac{\sum Q}{\sum K}$$

The velocity in a cell can be calculated from the above relationship and $V_1 = Q_1/A_1$:

$$V_1 = \frac{R_1^{2/3}}{N_1} \times \frac{Q}{K}$$

whre Q = total flow, K total conveyance, R_1 cell hydraulic radius, N_1 cell roughness.
If Manning's N is uniform across the section then the velocity across the section varies as $R^{2/3}$, if N is not constant then the velocity varies with cell roughness. The **velocity distribution factor** (VDF) is a measure of how cell roughness varies across a section.

$$V_1 = \frac{R_1^{2/3}}{N_1} \times \frac{Q}{K}$$

becomes

$$V_1 = \frac{R_1^{2/3}}{N_1} \times \frac{QN}{AR^{2/3}}$$

Where N is the section roughness, A section area, and R section hydraulic radius. In terms of a velocity distribution factor:

$$VDF = \frac{N}{N_1}$$

$$V_1 = VDF \times \frac{QR_1^{2/3}}{AR^{2/3}}$$

This formulation is the same as used in **PHABSIM** and **RHABSIM** except they use values of N instead of the N ratio (VDF). In those programs the cross-section N is either entered by the user or assumed to be 0.03. My way avoids the use of the section N.

The assumption, when using this to calculate velocities, is that the velocity distribution does not change with flow. This is the reason that a survey should be carried out at flows near the flows of interest (usually minimum flow) and that you should be cautious when extrapolating too far. If a survey is carried out at low flow the velocity distribution is influenced by local roughness elements. As the flow increases the influence of these elements becomes less and the velocity distribution smoother. I know of no way to predict how the velocity distribution changes with flow. I suggest that it be handled by testing the sensitivity of the results to the VDF. This is done easily by switching VDFs OFF - one of the program options. With the VDFs OFF the velocity distribution is smooth and you can see whether this gives a different area of suitable habitat.

The other and more difficult way is to have a different file of VDFs for each flow simulated. This would mean that you would run each simulated flow one at a time, changing the VDF file (*.VDF) between runs. Very painful and not worthwhile if the VDF's are guessed anyway.

11. Water surface profile modelling

The following section describes some of the techniques used in surveying rivers for water surface profile calculation. This can be difficult, especially in steep or small streams. The alternative procedure is to develop stage discharge curves for each cross-section and to weight each section by the proportion of channel length it represents (habitat weighting percentage). This usually results in more accurate predictions of water levels and a survey that may be more representative of average conditions in the river, because it can encompass all habitat types over a longer section of river.

Hydraulic modelling or simulation uses the Manning equation and the standard step method ("Open Channel Flow", Henderson 1966) to predict the water surface profile for a given flow.

After selecting the channel to be surveyed, a series of cross- sections are marked out and surveyed. The location of cross- sections will be affected by the type of modelling required. For instance low flow modelling, such as in habitat surveys will require more cross-sections than flood flow modelling where the flow is much more uniform and sections can be further apart.

Flows should be constant while water surface profiles are surveyed as varying flows make subsequent analysis of friction losses difficult. If a small fresh occurs during the survey, it is possible to develop an hydraulic model using varying flows throughout the reach.

Cross-section and offset location and spacing determine how accurate the hydraulic model will be. If location and spacing is appropriate to the variability of the gradient and cross-section area there will be little difficulty in calibrating the hydraulic model.

11.1 Reach location

The number, location and length of reaches will depend upon the intended purpose of the hydraulic model. Usually reaches are selected so that they represent the character of a longer section of the river. Changes in river gradient and flow often indicate a change in river character.

11.2 Cross-section spacing and location

Cross-sections should be spaced so that they represent the geometry of the river. The geometry should vary uniformly between cross-sections, so that cross-section spacing will depend on the variability of the stream. Cross-section spacing should decrease where the water surface slope is constant. Large changes in water surface slope between pairs of cross-sections should be avoided.

The water surface across the section should be as near to horizontal as possible. The cross-section need not be in a straight line, and can curve or kink to follow features such as diagonal riffles. This should maintain a constant height difference between all points on the section and the adjacent sections. Usually cross-sections should be a right-angles to the flow but sometimes the requirement to have a horizontal water surface may mean that the flow in all or part of the section is not at right-angles. Minor deviations can be tolerated but if a large part of the flow is not at right-angles, the offset distances can be reduced according to the current angle before processing the data. Failure to do this will result in an excessively large calculated flow for the section and incorrect hydraulic characteristics for the section.

Cross-sections need not be parallel to each other. Ideally, the distance between cross-sections is measured along the thalweg, however for convenience this is usually taken as the distance between cross-sections, or when cross-sections are not parallel, the average of the distance between cross-sections measured along each bank.

11.3 Calibration of downstream section

The relation between water level and discharge at the downstream cross-section give starting levels from which the upstream water surface profile can be calculated. The stage-discharge relationship is best established by recording water levels for a number of flows in the same way as ratings are established for water level recorder staff gauges (see hydrology texts such as "Applied Hydrology" by Linsley, Kohler and Paulhus). A fixed peg or staff should be left at the downstream transect so that the level at other flows can be measured. A temporary staff gauge or pin in the stream is the best method of determining small changes in water level. Methods of determining rating curves are described in Section 5.2.

The rating curve using Manning's equation is calculated from each gauging:

$$Flow = \frac{1}{N} A R^{2/3} S^{1/2}$$

assuming that the slope is constant. The variation of Manning N with discharge for the rating is calculated according to the equation:

$N = a\,Flow^{b}$.

Usually Manning's N increases as discharge decreases so that b is negative. However, this variation of N with discharge is not used in the calculation of water surface profile, other than to determine an appropriate starting level. Potentially, measurements at other flows and levels could be used to calculate the variation of N with discharge between each pair of cross- sections. This would improve the accuracy and utility of water surface profile modelling, but the feature has not been incorporated into this programme.

To assist the user in the selection of the correct level for the flow at the downstream section, some relevant information is listed. This is:

- Minimum cross-section level
- Maximum cross-section level
- Water level when surveyed
- Water level for critical flow at the section
- Water level for the selected rating curve

The first two levels specify the range of acceptable levels. The third, the water level when surveyed, would be the starting level if simulating the flow at which the survey was made. If a flow higher than this is stimulated the starting level should be higher than the surveyed level and if lower the starting level should be lower.

The fourth level is the level at which the flow will be critical. If the downstream section has been located on a control such as the head of a riffle or a narrow constriction then the flow at the section will approach critical. Even if the section is considered to be a control section it is rare to find that the water level as low as the computed critical level. However if the critical level is computed for a number of flows, the general shape of the rating curve can be derived and fitted through the known point - the level and flow at which the survey was made.

11.4 Estimation of friction and other energy losses

The theoretical base of uniform flow hydraulics and the empirical process of fitting or estimating values of N and loss coefficients is one of energy conservation. The theory is described in various hydraulic texts such as Henderson's "Open Channel Flow" and Ven Te Chow's "Open Channel Hydraulics" and is not repeated in great detail here. IFG Group's Instream information paper No. 5 gives many practical hints on techniques used.

When fitting values there are several principles of which the user should be aware:

Between any two sections there is a difference in water level and velocity head ($\propto v^2/2g$).

The total hydraulic losses - friction (Manning's N), bend, expansion and contraction - must equal the difference in level plus change in velocity head.

Values of Manning's N should not alter erratically through the reach. Usually values tend to be between 0.020 and 0.15 and to vary gradually through the reach with higher values in riffles and lower values in pools or runs.

The friction loss is computed from the arithmetic average of the hydraulic properties of the upstream and downstream section. When Manning's N is applied at a section (not recommended) the friction loss is composed of two parts - a friction loss due to the lower cross-section and its value of N and a friction loss due to the upper cross-section and its different value of N.

If the head difference (water level + velocity) between the sections is negative, a value of N cannot be calculated. Such situations should not be possible hydraulically if cross-section locations were placed according to the criteria a set out earlier. The inability to calculate a value for N suggests an error in the measured water levels or poorly located cross- sections.

If a value for N cannot be calculated the user may either assume that the upstream water level was underestimated and enter a new value or assume that the downstream water level was overestimated and go back to the previous pair of sections to adjust its value. This effectively raises or lowers a cross-section and normally this should be within the range of measured left, right and mid- stream water levels.