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Ecologically Acceptable Flows

Project Report

Institute of Hydrology
Institute of Freshwater Ecology

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Foreword

This report describes the application of the Instream Flow Incremental Methodology using the PHABSIM system to rivers in the UK. The Instream Flow Incremental Methodology (IFIM) allows the quantification of a weighted measure of physical habitat available to aquatic species for the range of discharges experienced in a river. This information, when combined with hydrological data describing the flow regime may be used as a tool in the setting of flow regimes optimal for ecological management.

The contents of this report are based on documented material from application in the USA and from experience gained from application of the method in the UK by staff from the Institute of Hydrology, Institute of Freshwater Ecology, Institute of Terrestrial Ecology and Loughborough University. Previous PHABSIM studies conducted by the above organisations have been commissioned as follows:

Department of The Environment
Instream flow Requirements of Aquatic Ecology In Two British Rivers - Application and Assessment of the Instream Flow Incremental Methodology Using The PHABSIM System. (Bullock, Gustard and Grainger, 1991).

Ministry of Agriculture Fisheries and Food
Quantitative Environmental Assessment of River Flood Defence Schemes. (Johnson, Elliott, Gustard *et al*, 1993(1)).

NERC Science Vote
Modelling Faunal and Floral Response to Reduced Flows and Habitat Loss In a River. An Experimental Approach - The Millstream Project (Armitage *et al*, 1992).

NRA Wessex Region
River Allen Instream Flow Requirements (Johnson, Elliott, Gustard & Clausen, 1993(2)).

Work under R&D Commission B2.1 Ecologically Acceptable Flows commenced in October 1990. For this commission the IFIM is being assessed through application on ten different rivers in England and Wales, chosen to lie in ten different ecological groups identified by analysis of data from the RIVPACS database.

The authors would like to acknowledge the Aquatic Systems Branch of the US Fish & Wildlife Service who developed the Instream Flow Incremental Methodology, in particular Dr Robert Milhous for his contribution to UK application of the methodology. We acknowledge the assistance of NRA staff and landowners at the study sites. We acknowledge Bente Clausen from the University of Aarhus, Denmark for her assistance in running model simulations. We acknowledge the encouragement and support given by National Rivers Authority Project Leader Dr Terry Newman (NRA Wessex Region).

Executive summary

A national assessment by the NRA (1990) of low river flows identified 20 sites demanding urgent consideration. The current high profile of low flow conditions existing in UK rivers after two years of severe drought, coupled with the requirement under 1989 Water Act for the NRA to set Minimum Acceptable Flows when requested by the Secretary of State has prompted the need to develop operational tools for managing aquatic communities in British Rivers on a national scale. The Instream Flow Incremental Methodology (IFIM) developed by the Aquatic Systems Branch of the U.S. Fish & Wildlife Service has been used widely for this purpose. The IFIM gives a quantitative measure of the ecological value of river flows to target aquatic species; on the basis of limited field observations the model may be calibrated to give predictive estimates for the complete range of discharges experienced. The IFIM is implemented using the Physical Habitat Simulation System (PHABSIM), a suite of computer programs supplied by the U.S. Fish & Wildlife Service.

In addition to its routine application in the United States IFIM is the subject of previous studies and ongoing research in several countries world wide including Canada (Shirvell, C.S., Morantz, D.L., 1983), New Zealand (Scott, D., Shirvell, C.S., 1987), Norway (Heggenes, J., 1990) and France (Souchon, Y., Trocherie, F., Fragnoud, E., Lacombe, C., 1989). An initial assessment of the application of the IFIM to UK rivers was carried out at five sites on the rivers Gwash and Blithe (Bullock, A., Gustard, A. and Grainger, E. S., 1991). Under a commission to MAFF (Johnson *et al*, 1993) the IFIM was used for assessing the environmental impact of a typical river flood defence scheme (Poyle Channel regrading, Thames NRA region). The IFIM has recently been applied at two sites on the River Allen (Wessex NRA region) to assess the impact of the historical groundwater abstraction regime on habitat available to trout and salmon (Johnson, Elliott, Gustard & Clausen, 1993). The Institute of Hydrology have recently been commissioned to conduct IFIM studies to investigate low flow problems on the rivers Bray and Barle in NRA South West region.

For this project the NRA have commissioned the Institute of Hydrology and Institute of Freshwater Ecology to assess the method on selected study reaches on ten different rivers in England and Wales. Study rivers were selected from ten different ecological groups identified by analysis of data from the RIVPACS database. At each of the study sites hydraulic data have been collected at a number of calibration flows. Hydraulic models have been calibrated to simulate a wide range of discharges for nine of the eleven study sites. To assist in the choice of target species and in habitat suitability curve construction, the study sites have been electrofished on one occasion and invertebrates have been collected from selected microhabitats.

Habitat suitability curves have been constructed for three fish species (trout,roach and dace). Two macrophyte species (*Ranunculus* and *Nasturtium*) and ten invertebrate species. Curves are based on expert opinion, existing data and information from the literature. These curves have been combined with habitat suitability data to give habitat vs discharge relationships for selected target species. An example of the construction of habitat time series and habitat duration curves is given using data from the East Stoke Mill Stream.

In order to illustrate the application of the IFIM to the assessment of an ecologically acceptable flow we have used data from the River Allen study mentioned above. Based on model predictions we have focused on the most sensitive target species life-stage and conducted an analysis of the sensitivity to different levels of abstraction. Results are presented separately for summer and winter periods illustrating how seasonality may be incorporated

into an IFIM analysis.

The wide range of study rivers selected for this assessment has provided a comprehensive test of the practical applicability of the model in a variety of different situations. Fieldwork techniques, data collection procedures and equipment requirements have been identified and refined to facilitate rapid and efficient application of the model. For wadeable rivers an initial PHABSIM survey can be completed in four days by a four-person fieldwork team; a further two days input to measure repeat calibration flows would complete the data collection exercise. In this study we have demonstrated that PHABSIM hydraulic models can be successfully calibrated to simulate hydraulic conditions in a wide range of river types. At the two sites where model calibration was not possible (Great Ouse and Lees Brook) velocities and depths are artificially regulated on a time scale that is incompatible with the hydraulic modelling approach used in PHABSIM. Aside from the need to improve modelling of the hydraulic effects of weed growth PHABSIM hydraulic models seem to perform satisfactorily for UK applications. A detailed study of the hydraulic effects of weed growth forms part a detailed study 'Modelling Faunal and Floral Response', an NERC Science Vote Commission involving the Institute of Hydrology and Institute of Freshwater Ecology. For this project PHABSIM hydraulic model outputs will be compared with continuous stage-discharge relationships. Results of repeated biological sampling will be compared with PHABSIM habitat model outputs.

Although we have not changed the source code of PHABSIM hydraulic models we have significantly improved model input/output, most noticeably with the introduction and testing of the RPM program menu. The menu provides on-line help facilities to accompany each program and allows execution of programs with single keystrokes. Using the RPM menu in a Windows environment, in conjunction with a spreadsheet such as Microsoft EXCEL, allows rapid graphical review of model input/outputs. Software improvements made in the course of this commission have significantly reduced the time required to complete model calibration and simulation. A number of new utility programs have been developed and from the original suite of over 250 programs in PHABSIM we have selected around 30 we consider worth retaining for UK application. The version of PHABSIM software used to complete simulations for this assessment will now be available on two diskettes. This version includes programs developed to transform time series of gauged flows to corresponding habitat time series which may be analysed using conventional duration curve programs.

It is clearly difficult to assess the accuracy of individual model outputs given the limited amount of observed ecological data available for comparison. Despite some anomalies model outputs appear to be on the whole fairly realistic and results for fish and macrophyte species show a fairly high level of sensitivity of habitat to change in discharge. The much reduced sensitivity predicted for invertebrate habitat to changing discharge suggests that invertebrates may be a less appropriate choice of target species for IFIM studies. A wide range of applications have been covered in the course of this assessment; for individual applications the framework provided by IFIM may be retained whilst elements of the modelling procedure are refined to focus on key project objectives.

In the development of objective methods for the assessment of ecologically acceptable flows it is clear that a balance must be struck between providing as realistic a description as possible of complex aquatic ecosystems and maintaining ease and generality of application. In the arena of operational water resources decision-making such methods must have the capability of quantifying ecological demands in a form which may be conveyed concisely to those concerned. Whilst PHABSIM may face criticism for limitations in the reality of its description of aquatic ecosystems we have demonstrated that it is versatile and may be applied with a reasonable level of resource input. Whilst there are clearly areas of the modelling procedure which could be developed to improve the biological reality of model outputs the version of PHABSIM developed in the course of this assessment is, as it stands, capable of providing valuable predictive estimates of the ecological impact of river flow regimes unavailable from any other sources.

A key area demanding future research effort is in the improvement of habitat suitability data to produce curves specific to species and particular ecological categories of river. The best results will be obtained by direct sampling techniques involving large levels of resource input. The first fish habitat suitability curves based on direct observations in the UK have been developed by Dr.Graham Lightfoot and staff from the fisheries section of NRA Wessex Region. Curves for salmon and trout have been constructed from observations made by snorkelling and counting of redds in a number of southern chalk streams. Similar sampling programs for different river types and species would be of great value in improving the accuracy of PHABSIM predictions for general application in the UK.

In conclusion the main acievements of this project are:

- To demonstrate that the IFIM procedure can be applied to rivers in England and Wales to give quantitative relationships between stream discharge and available habitat for key aquatic life forms.

- To demonstrate that conventional statistical analysis of river flow hydrographs can be transformed into equivalent analysis of available habitat.

- To provide, using the IFIM, a framework for an objective method for the evaluation of seasonal prescribed minimum flows.

- To conduct literature searches and produce habitat suitability curves for life-stages of selected target species.

- To establish that the resource input required for PHABSIM model calibration is not prohibitively large in the context of the important task of setting ecologically acceptable flows.

- To identify from the 250 PHABSIM programs supplied by the U.S.Fish & Wildlife service a subset of programs required for current UK application of the model.

- To improve model software with respect to menu structure, input/output facilities and to provide new software for production of habitat time series.

Key words

Cover
Current Metering
Depth
Discharge
Ecology
Ecologically Acceptable Flows
Electrofishing
Fish
Habitat
Habitat Suitability Indices (Preference Curves)
Hydraulics
Hydrology
IFIM
Kick Sampling
Macroinvertebrate
Macrophyte
PHABSIM
RIVPACS
Substrate
Velocity
Weighted Usable Area

1. Introduction

1.1 HISTORICAL BACKGROUND

One recent development of water resources management in the United Kingdom is the use of the computer model PHABSIM (Physical Habitat Simulation System) which is used to implement the Instream Flow Incremental Methodology (IFIM). The IFIM relates the requirements of freshwater ecology to river flow regimes. The IFIM is a concept developed by the United States Fish and Wildlife Service to fill a particular need for decision makers in the water resources arena. The methodology provides a quantitative method to assess species habitat trade-offs against other uses of water, particularly surface water abstractions for irrigation, domestic and industrial water use which can threaten the integrity of running water ecosystems. The goal of the method is to relate ecological values to stream discharge in a manner generally consistent with methods for quantifying other beneficial uses of water.

An initial assessment of the application of the IFIM using PHABSIM to UK rivers was conducted by a multidisciplinary team headed by the Institute of Hydrology (Bullock, Gustard & Grainger 1991), involving the Institute of Freshwater Ecology, Institute of Terrestrial Ecology and Loughborough University (Petts, 1990). This study, funded by the Department of The Environment, used data collected from the Rivers Gwash and Blithe. Subsequently the method was applied, under a commission from MAFF to the assessment of environmental impact of a typical river flood defence scheme, using data from the Poyle Channel and Colnebrook (Middlesex), pre and post regrading works undertaken in 1991 (Johnson *et al*, 1993), (Armitage and Blackburn, 1992). An NERC Science Vote funded research project' Modelling Floral and Faunal Response', involving collaboration between IH and IFE has been ongoing since 1991. This project involves detailed studies on the experimental reach of the Mill Stream at the IFE Riverlab, which are aimed at assessing and improving the capabilities of the PHABSIM model. Repeated fauna sampling, and measurement of hydraulic parameters will yield data to test the accuracy of PHABSIM model outputs. Enhancement of hydraulic models to incorporate the hydraulic effects of weed growth (Hearne and Armitage, 1993) is an important feature of this work. The first application of the IFIM using PHABSIM to a current operational water resources problem has recently been completed by the Institute of Hydrology (Johnson, Elliott, Gustard, & Clausen 1993) for NRA Wessex Region. The model was used to assess the impact of the historical groundwater pumping regime on the River Allen (Dorset) on the habitat available to Trout and Salmon.

Water management in the United Kingdom has historically adhered to discharge-based methods in the setting of prescribed flows. Typically Dry Weather Flows have been indexed by a low flow discharge statistic, for example either the 95 percentile flow duration statistic, or the mean annual minimum seven day flow frequency statistic. It is only a recent phenomenon in the United Kingdom that consideration is given by resource planners to the ecological value of low river flows; for example, the Yorkshire National Rivers Authority region now employ an environmental weighting scheme, which sets prescribed flows as a proportion of the Dry Weather Flow (DWF), weighted according to a range of environmental characteristics (Drake and Sheriff, 1987). An Environmental Prescribed Flow is set at 1.0 x DWF for the most sensitive rivers and at 0.5 x DWF for the least sensitive, determining the amount of water available for offstream uses, pollution dilution and environmental protection.

Recommendations from a review of compensation flows below impounding reservoirs in the

United Kingdom (Gustard *et al*, 1987) suggest that a reevaluation of awards is warranted but that any negotiation of new awards should move away from simply setting prescribed flows as a fixed percentage of the mean flow. The review establishes that many reservoirs provide compensation flows which were determined by industrial and political constraints which no longer apply. Furthermore, the majority of compensation flows were awarded when there were little or no hydrometric data to describe differences in catchment hydrology and little knowledge of the impact of impoundments on downstream aquatic ecology. It is the inheritance of this historical legacy that prompts a reassessment of current compensation flows. Equally, the recognition that aquatic ecosystems have specific flow requirements, which perhaps bear little relation to existing compensation awards, is a strong argument towards the reassessment of prescribed flows, moving away from discharge-based methods alone towards habitat methods.

While quantitative models and design techniques are available for estimating discharge statistics in rivers, for example Low Flow Studies (Institute of Hydrology 1993), there is a paucity of operational tools for managing aquatic communities in British rivers at a national scale. A notable exception is the development of the RIVPACS (River Invertebrate Prediction And Classification System) technique, appropriate for modelling invertebrates. Fish management models tend to be more scheme-specific in nature, for example the fisheries study downstream of Roadford Reservoir which commenced in 1984 aimed at developing operating rules to minimise detrimental impacts upon salmonids in the Tamar and Torridge rivers. The recent development of the HABSCORE technique by the Environmental Appraisal Unit of the National Rivers Authority, Welsh Region establishes an operational tool for the management of salmonid populations in Welsh rivers. Essentially, both RIVPACS and HABSCORE adopt the same rationale - that the carrying capacities of streams are to a large extent dependent on channel structure and the environmental regime (hydrological, chemical, temperature) experienced within the stream. These characteristics can be measured by a combination of site features (width, depth, substrate, cover etc.) and catchment features (altitude, gradient, conductivity etc.). By measuring these features and species populations at a number of pristine sites which have variable habitat, multivariate models can be calibrated which predict species presence and abundance from the environmental variables. The predicted population sets an objective for the river reach based on the habitat which it provides. This type of model may be used to detect anomalies in observed ecological data in relation to the objective population, anomalies which may be attributable to impacting factors. However, this type of model does not enable the impact of different flow (regimes or prescribed flows) regimes to be explicitly simulated.

Water management in Britain lags a considerable way behind the United States as regards the development of models for recommending flow regimes which consider ecological demands. In the United States procedures for evaluating impacts of streamflow changes have advanced considerably in the period 1974-1989. Central to these advances has been the concept of instream flow requirements which recognises that aquatic species have preferred habitat preferences, with habitat defined by physical properties (flow velocity, water depth, substrate and vegetal/channel cover). Because some of these physical properties which determine habitat vary with discharge, so species have different preferences for different discharges. Development of the Instream Flow Incremental Methodology (IFIM) by the Aquatic Systems Branch of the U.S. Fish and Wildlife Service has allowed the quantification of species preferences for the full range of discharges that may be experienced within a river. This quantification of habitat preferences and the relationship with river flow permits the negotiation and setting of flows optimal for ecological management. Setting instream flows in this manner complements purely water-quantity or cost-management objectives by paying due consideration to the physical habitat requirements.

In the period since 1960 in the United States the importance of instream flows have become regarded more widely as essential to maintain and restore values and uses of water for fish, wildlife, ecological processes, and other environmental, recreational and aesthetic purposes (Jahn 1990). By the mid-1980's, at least 20 states provided legislative recognition of instream flows for fish aquatic resources. Data from Lamb and Doerksen (1987) show that the IFIM is now the most widely applied method for determining instream flow requirements for major resource schemes in the United States, being used in 38 states. The US equivalent of the Dry Weather Flow, the 7-Day, 10 Year (7Q10) Low Flow is used in just 5 states. Along with other simpler methods, such as the Tennant Method, 7Q10 would tend to be applied to minor schemes and basin-wide planning purposes.

The essence of the Instream Flow Incremental Methodology is stated concisely by Bartholomew and Waddle (1986):

"The Instream Flow Incremental Methodology is a reasoned approach to solving complex streamflow allocation problems that are often characterised by uncertainty. Application of the IFIM requires an open and explicit statement of management goals, study objectives, technical assumptions, and alternative courses of action. IFIM provides a framework for presenting decision makers with a series of management options, and their expected consequences, in order that decisions can be made, or negotiations begun, from an informed position. IFIM exposes for the decision makers those areas where their judgement is necessary and presents the potential significance of the alternatives they might choose."

By relating ecological demands to discharge, the merit of IFIM lies in providing a quantitative basis which allows river ecologists to negotiate prescribed flows or flow regimes in equivalent terminology to other water resource demands.

1.2 JUSTIFICATION FOR SELECTION OF INSTREAM FLOW INCREMENTAL METHODOLOGY

The demand for a scientifically defensible method for both resource allocation and environmental impact assessment in the United Kingdom (Petts 1989) may be satisfied by IFIM when it is considered that the scientific rationale of IFIM has been successfully defended against legal challenges in the U.S.. There is therefore scope for the application of IFIM in the United Kingdom to yield long-term benefits to instream flow management. By relating ecological requirements to discharge IFIM allows prescribed flows to be determined and set using values which complement quantity-based statistics. The method has received wide international recognition and has been extensively applied to real water resource problems in the U.S. The validity of IFIM and PHABSIM for assessing ecologically acceptable flows may be summarised as follows:

a. No other model can predict the impact of changing flows upon fish, invertebrates and macrophytes. Existing habitat models such as Habscore and Rivpacs are not designed for the recommendation of the hydrological regime or prescribed flow.

b. The primary impact of changing flow is upon changing water depth and velocities, both of which are considered as primary variables by IFIM.

c. IFIM predicts physical habitat losses/gains and quantifies this in respect of their ecological value.

d. Relative values of physical habitat are more important than absolute values.

e. Experience of model elsewhere: US, France, Norway, New Zealand, Australia. Successful defence of the underlying methodology against legal challenges in US.

f. IFIM, by relating habitat to discharge, provides a quantitative basis allowing river ecologists to negotiate prescribed flows in equivalent terminology to other water resource demands.

To question the validity of the IFIM rational is to question whether physical habitat is an important variable to model in the prediction of instream flow requirements for aquatic species. For this reason the onus must lie with critics of the methodology to show that physical habitat is not important in this context.

1.3 IFIM RATIONALE AND CONCEPT

The IFIM procedure provides an estimate of habitat loss/gain with changes in discharge. The IFIM itself is a concept or at least a set of ideas and PHABSIM is software (Gore and Nestler, 1988). The underlying concepts of the Instream Flow Incremental Methodology are that:

- IFIM is habitat based, with potential usable habitat being simulated for unobserved flow or channel conditions.

- Evaluation species exhibit a describable preference/avoidance behaviour to one or more of the physical microhabitat variables; velocity, depth, cover or substrate.

- Individuals select the most preferred conditions within a stream, but will use less favourable areas with decreasing frequency/preference.

- Species populations respond to changes in environmental conditions that constitute habitat for the species.

- Preferred conditions can be represented by a suitability index which has been developed in an unbiased manner.

The purpose of the PHABSIM system is the simulation of the relationship between streamflow and available physical habitat where physical habitat is defined by the microhabitat variables depth, velocity and substrate/cover. The two basic components of PHABSIM are the hydraulic and habitat simulations within a stream reach using defined hydraulic parameters and habitat suitability criteria, as displayed in Figure 1.1 below.

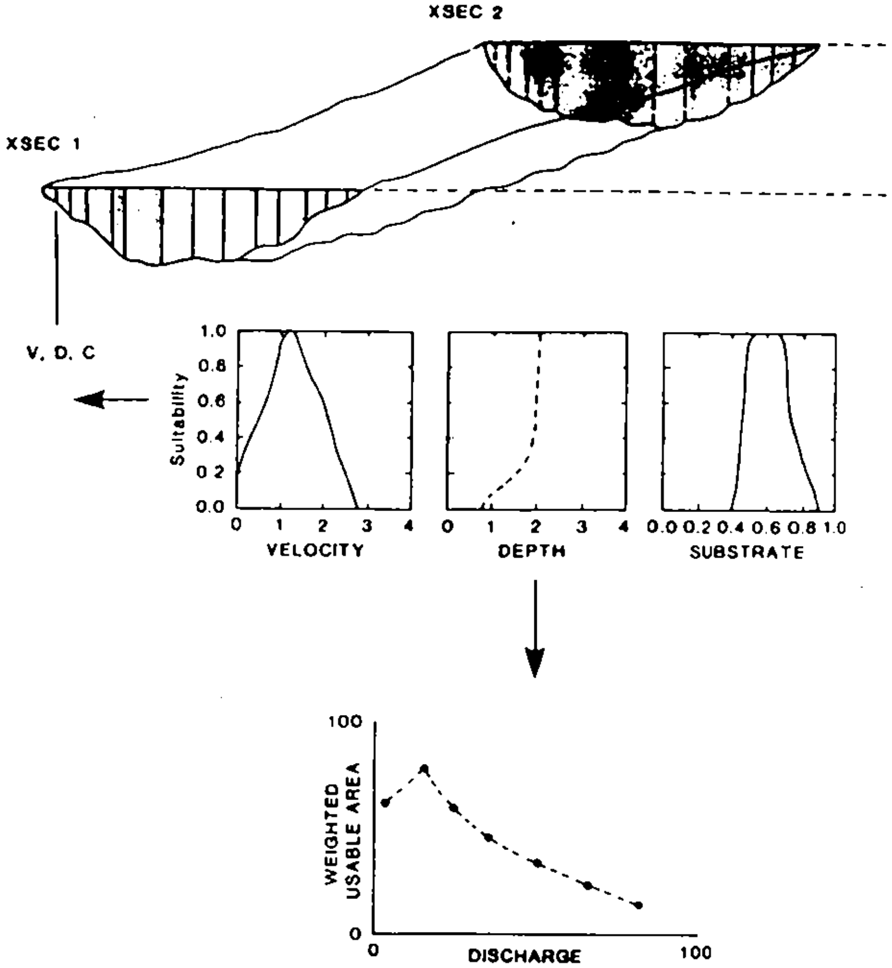


Figure 1.1 *Structure of PHABSIM model data*

Hydraulic simulation is used to describe the area of a stream having various combinations of depth, velocity and channel index (cover or substrate) as a function of flow. Habitat suitability is based on the preference of species for certain combinations of physical parameters above others.

Hydraulic and habitat data are combined to calculate the weighted usable area (WUA) of a stream segment at different discharges based on the preference of selected target species for the simulated combinations of hydraulic parameters.

Physical habitat suitability information for target species, and distinct life stages of those species, can be derived from existing empirical data (including the US Fish and Wildlife Service Curve Library), scientific literature, or direct field sampling.

It is important to realise that the IFIM is a concept, or at least a set of ideas whereas PHABSIM is a computer model comprising a suite of programs. For some IFIM studies PHABSIM may be one of a number of different models used to provide information to assist in the decision making process. In some situations output from water quality models or temperature models may augment that from PHABSIM. In scoping an IFIM study it is important to identify at the outset those factors which are likely to have significant impact on aquatic ecology and which may be limiting to aquatic populations. If, for example, a change of water temperature was identified as the principle result of some proposed development (eg. afforestation or deforestation) then a water temperature model would be the most appropriate model to employ in the IFIM study and PHABSIM would be inappropriate. If, conversely, the chief impact of a resources development was to alter the flow regime (and consequently local velocities, depth, substrate type and available cover) without significantly altering other factors such as temperature and water quality, then PHABSIM could be the sole model employed in the IFIM study.

It is clear that in conducting an IFIM study an ideal goal would be to relate changes in aquatic populations to change in the flow regime. Although some studies have successfully demonstrated that PHABSIM may be capable of achieving this goal it must be appreciated that PHABSIM is not in general capable of this task since it predicts change in a weighted measure of physical habitat area (WUA) available to aquatic species and does not predict change in biomass. In some instances a linear relationship between biomass and WUA has been demonstrated (Milhous, R.T., 1988) but it is clear that this is not generally the case since factors other than change in WUA may be limiting to populations. It is essential that, in the absence of equivalent population models, one accepts the limitation of using WUA as the key variable and attempts to take into account as best as is possible factors which are likely to influence the relationship between WUA and populations. Gore and Nestler (1988) make the following statement with regard to this issue:

"PHABSIM is a vehicle for presenting biological information in a format suitable for entry into the water resources planning process. It is not, nor was it ever intended to be, a replacement for population studies, a replacement for basic research into the subtleties of fish or benthic ecology, nor a replacement for biological innovation or common sense. As such, PHABSIM has been found to be a defensible technique for adjudicating flow reservations".

2. PHABSIM model

2.1 INTRODUCTION

In this section we will briefly describe the structure and flow of information through the PHABSIM model (see Figure 2.1). For details of the basic concepts and assumptions underlying the model please refer to Section 1.3, and for rigorous mathematical details to the Project Inception Report, to Bullock, Gustard & Grainger (1991) or to Bovee (1982).

A representation of the basic structure of the PHABSIM model is shown in Fig 2.1 below:

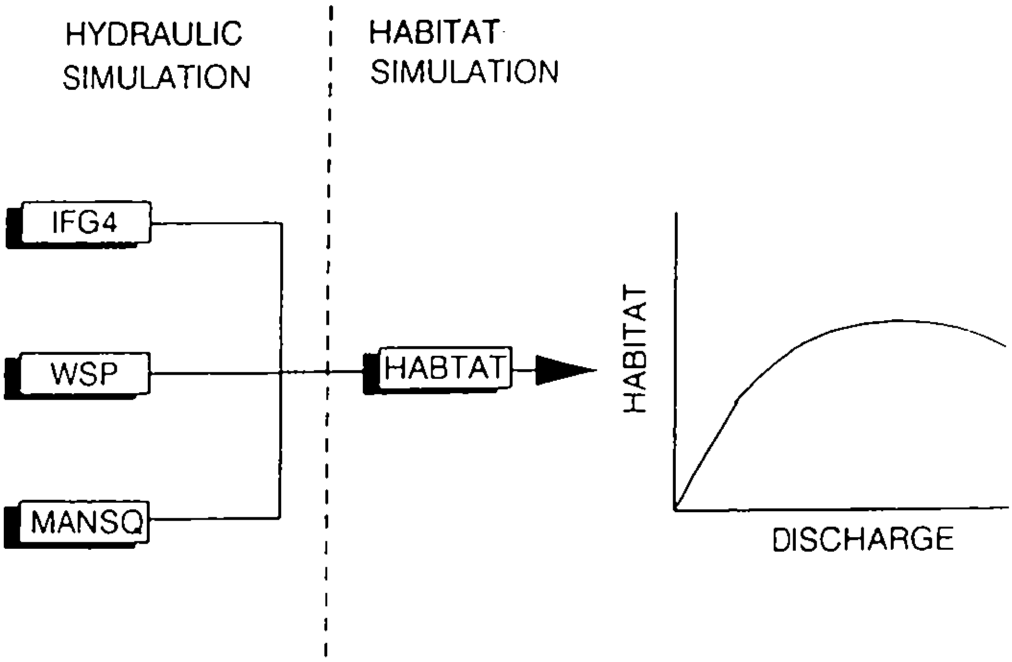


Figure 2.1   *Flow of Information Through PHABSIM model*

There are two distinct stages in the simulation process, hydraulic simulation, followed by habitat simulation. In the hydraulic simulation phase one (or a combination) of the hydraulic models is calibrated using observed values of depth, and velocity for at least one calibration discharge. Once calibration is complete the calibrated model is used to predict depths and velocities at all simulation discharges of interest.

Observations of substrate and cover values do not enter into calculations performed in the hydraulic simulation phase. Values may be entered into the data file but they are not required or used until the habitat simulation phase. Values are assumed to remain constant as discharge varies.

Once predicted values of depth and velocity are available for all simulation discharges and values of cover/substrate have been added to the habitat model input file the habitat modelling stage begins. The basic habitat model contained in PHABSIM is HABTAT. There are other models but these all perform the same basic methodology. For each of the simulation discharges of interest then modelling process is as follows:

Through the assignment of weights (see Johnson, Elliott *et al*, 1991) and reach lengths (see 4.2) a cell area is defined for each data point used in the hydraulic simulation phase. A plan view of the reach is made up of a grid of these cells. For edge cells this area is clearly dependent upon discharge-predicted depths from the simulation phase are used in the area calculation .Associated with a point X_i on any given transect we thus have values of depth (d_i), velocity (V_i), a substrate/cover value (SC_i), and an associated cell area A_i. For this point the basic habitat calculation is:

$$WUA_i = A_i \ x \ CSI \ (d_i, V_i, SC_i)$$

giving the weighted measure of available physical habitat associated with the given data point for this particular simulation discharge. The function CSI is known as the Composite

Suitability Index. This function combines information from suitability indices (preference curves) which describe the relative suitability to the target species of the predicted cell variables d_i, V_i and SC_i. Typically the CSI is a simple multiplicative index.

For the given simulation discharge this process is repeated at each data point and the results of these calculations are summed to give a total Weighted Usable Area. Repeating this process for a number of different simulation produces the required WUA vs Q relationship for use in the IFIM decision making process.

2.2 HYDROLOGICAL MODELLING

The basic output from PHABSIM simulations is the Weighted Usable Area vs discharge relationship. This relationship allows the user to identify an "optimal" discharge by locating the peak of the weighted usable area curve, and gives a measure of the relative reduction in weighted usable area for non-optimal discharges. In an IFIM study, we are generally interested in how the availability of physical habitat varies over the whole flow regime experienced, or perhaps over the range of flows experienced within a particular season. This is certainly the case when we are considering the setting of Ecologically Acceptable Flows. In order to conduct analyses of this type it is clear that we must also have available as input to the modelling process a description of the flow regime. Hence, in the choice for a study site for application of IFIM an important consideration is the availability of historical flow data.

In the current R&D study we have selected study sites so that they are within approximately 10km of a gauging station. It is preferable that the gauging station should have a continuous record of flow data for five years or more. Details of gauged flow data available at each of the study sites is given in Chapter 3.

The availability of gauged flow data is also very useful in the modelling process as it may be used in the verification of discharge estimates made in the field by current metering.

It is important to recognise the necessity to approximate any inflows between the study site and the nearest gauging station.

2.3 HYDRAULIC MODELLING

The hydraulic models contained within PHABSIM are calibrated with observed field data and used to simulate depths and velocities at different discharges selected by the user.

Along the study reach a number of transects T_j are placed perpendicular to the direction of flow. Across each of these transects a number of data points $X_{i,j}$ are defined, as shown in Figure 2.2. The points at the left and right hand extremes of each transect are marked with permanent survey markers and their elevations are surveyed relative to some fixed datum level. The bed elevations $e_{i,j}$ are then surveyed at the data points across each transect. In the PHABSIM hydraulic models the water surface elevation is assumed to remain constant across each transect as shown in Figure 2.2.

The hydraulic simulation is composed of two independent stages; water surface level simulation and velocity simulation.

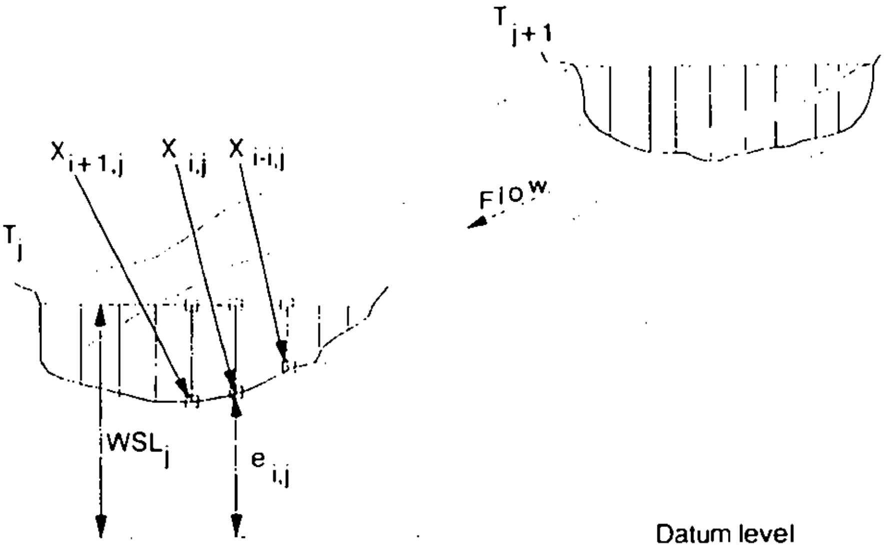


Figure 2.2 Data points placed across two neighbouring transects in the study reach.

Water Surface Level Simulation

As mentioned above the hydraulic models in PHABSIM assume that the water surface level is constant across each transect. In order to calibrate hydraulic models to simulate water surface levels the water surface levels are measured at three or more calibration discharges (in practice measurements are made at the left, centre and right of the stream and averaged to give a single value). An example of three sets of observed water surface levels is given in Figure 2.3 below.

There are three different models within PHABSIM which can simulate water surface profiles. The IFG4 model treats each transect independently of its neighbours and uses a standard stage-discharge regression, calibrated using the three (or more) pairs of stage and discharge values observed in the field. The MANSQ model also treats transects independently, but it uses a technique based on the solution of Manning's equation.

The WSP model is the only model in which the water surface level at each transect is assumed to depend on the levels at the neighbouring transects. The WSP model uses an energy balance equation together with Manning's equation. The model is calibrated by assigning values of Manning's n to each transect so as to fit predicted water surface levels as closely as possible to observed values.

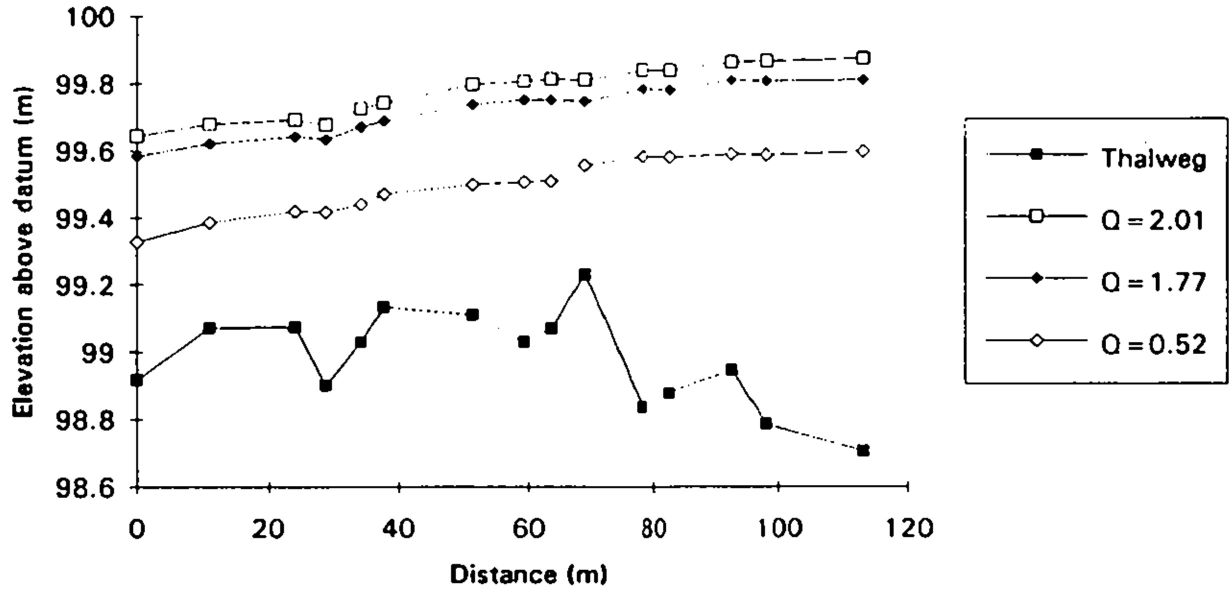


Figure 2.3 Observed calibration water surface levels : East Stoke Mill Stream

Whichever model is used the output of the water surface level simulation phase for a given simulation discharge QSIM is a set of water surface levels WSL_j (QSIM) associated with each of the transects T_j, one per transect. Since the bed elevations are known at the data points across each transect (see Figure 2.2) the depth $d_{i,j}$ associated with a point $X_{i,j}$ on a given transect T_j for a given simulation discharge QSIM may be calculated by subtracting the known bed elevation $e_{i,j}$ from the predicted water surface level (see Figure 2.4). This process is repeated at each transect to give a predicted depth for each data point at the given simulation discharge.

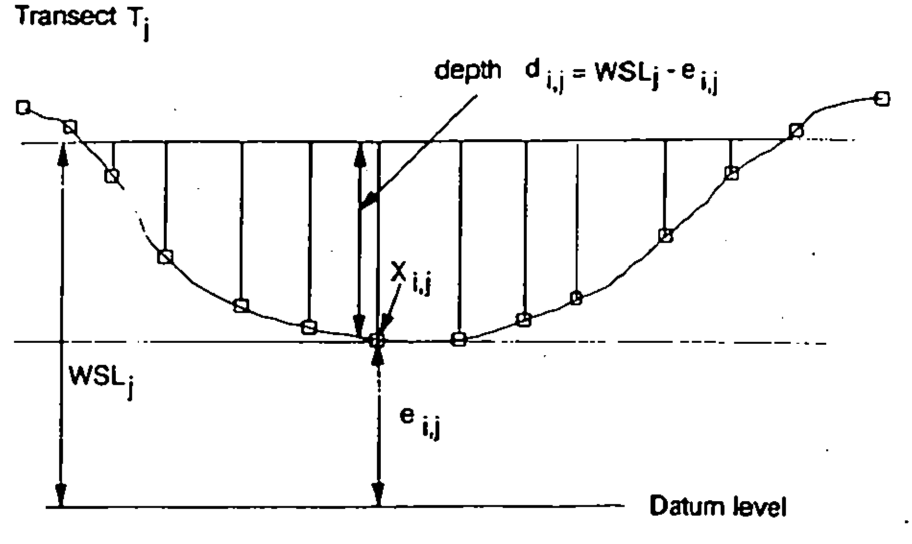


Figure 2.4 Calculation of simulated depths at points across transect T_j

Velocity Simulation

The simulation of velocities uses output from the water surface level simulation to predict values of mean column velocity for the data points across each transect. For the simulation of velocities the IFG4 model is used. For each data point $X_{i,j}$ on a given transect T_j (see Figures 2.2, 2.4) a calibration value of Manning's n, $ncal_{i,j}$ is computed by solving Manning's equation using the observed values of velocity, $vcal_{i,j}$, depth, $dcal_{i,j}$, and average water surface slope S_j at one of the calibration discharges (usually the highest):

$$ncal_{i,j} = 1.49 \frac{dcal_{i,j}^{2/3} S_j^{1/2}}{vcal_{i,j}}$$

At a given simulation discharge QSIM the velocity $v_{i,j}$ at the point $X_{i,j}$ is predicted by solving Manning's equation using this calibration value of Manning's n, $ncal_{i,j}$ and the depth $d_{i,j}$ and average water surface slope S_j available as output from the water surface level simulation:

$$v_{i,j} = 1.49 \frac{d_{i,j}^{2/3} S_j^{1/2}}{ncal_{i,j}}$$

For the given simulation discharge this process is repeated at each data point across the transect. On the basis of these predicted velocities and the depths available from the water surface level simulation the model then computes an estimate of the discharge for the transect using a standard velocity x area calculation. Since there are errors in the modelling procedure the discharge computed in this way will not equal the given simulation discharge. In order to rectify this position and achieve a mass-balance the predicted velocities $v_{i,j}$ at all data points across the transect T_j are adjusted by multiplying by a single correction factor known as the Velocity Adjustment Factor (VAF). This process is repeated for each transect independently.

2.4 HABITAT MODELLING

The outputs from the hydraulic simulation phase are matrices of predicted depths, $d_{i,j}$, and velocities $v_{i,j}$, associated with each data point $X_{i,j}$ on the various transects T_j (see Figure 2.2) at each of the simulation discharges. Associated with each of the data points we also have an observed value of substrate/cover, $SC_{i,j}$. In the habitat simulation program HABTAT these hydraulic parameters are transformed into a measure of suitability to the target species known as the Composite Suitability Index (CSI). Associated with the matrices $d_{i,j}$, $v_{i,j}$ and $SC_{i,j}$ a matrix of CSI values $CSI_{i,j}$ is computed using a specified functional relationship. The definitions of CSI available for use in the HABTAT program are as follows:

(1) Multiplicative CSI

Here

$$CSI_{i,j} = (SIV(v_{i,j})\ x\ SID(d_{i,j})\ x\ SISC(SC_{i,j})$$

where SIV, SID, SISC are the univariate habitat suitability indices for the microhabitat variables velocity, depth and substrate/cover respectively

(2) Geometric Mean CSI

Here

$$CSI_{i,j} = (SIV(v_{i,j}) \times SID(d_{i,j}) \times SISC(SC_{i,j}))^{1/3}$$

(3) Minimum CSI

Here

$$CSI_{i,j} = Min(SIV(v_{i,j}),\ SID(d_{i,j}),\ SISC(SC_{i,j}))$$

Whichever definition of the CSI is chosen (see end of this section) the result of this computation gives a suitability value $CSI_{i,j}$ at each data point $X_{i,j}$ on a given transect T_j. The final stage in the habitat calculation is the computation of Weighted Usable Area (WUA) for the reach at the given simulation discharge. The fundamental principal in the computation of the WUA is to multiply the point values of the Composite Suitability Index $CSI_{i,j}$ by 'cell areas' $A_{i,j}$ defined around each data point $X_{i,j}$ to give 'cell Weighted Usable Areas':

$$WUA_{i,j} = A_{i,j} \times CSI_{i,j}$$

The WUA for the whole reach is then computed as the summation of the individual cell Weighted Usable Areas $WUA_{i,j}$ over all of the data points.

The width of the cell $A_{i,j}$ associated with the data point $X_{i,j}$ is defined by the mid-points of the distances to neighbouring points $X_{i-1,j}$, $X_{i+1,j}$ across the transect T_j. The length of the cell is determined by two factors; the distances to the next up and downstream transects, and user-defined parameters known as 'upstream weighting factors', W_j (taking values between 0 and 1) which must be assigned one per transect. The values of these weighting factors determine in which proportions the area between two transects are represented by the conditions at each transect. The weight W_j associated with transect T_j determines how much of the area between T_j and the next transect upstream, T_{j+1}, is represented by the conditions at the data points across T_j. For a given data point $X_{i,j}$ the total length $L_{i,j}$ in the calculation of the associated cell area $A_{i,j}$ used in the habitat calculation is defined as (see Figure 2.5).

$$L_{i,j} = L_{up} + L_{down} = (1 - W_{j-1}) \times R_{j-1} + W_j \times R_j$$

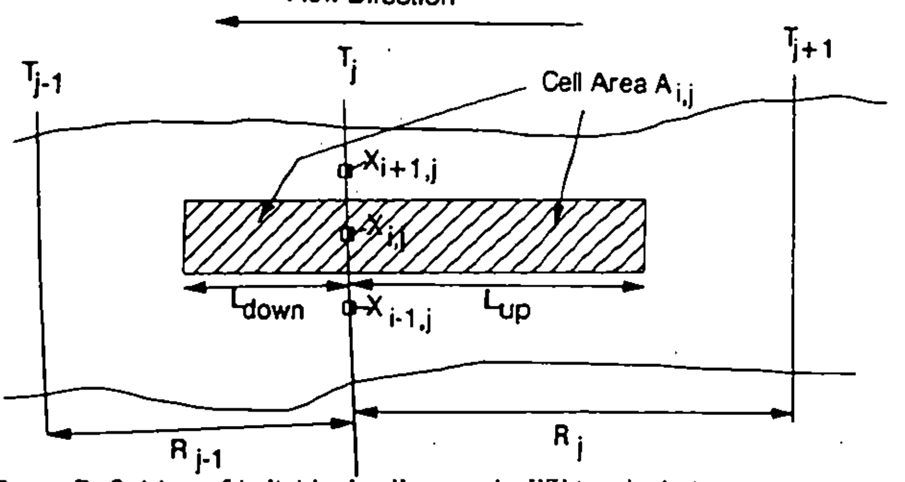


Figure 2.5 *Definition of individual cell areas in WUA calculation*

where R_j is defined as the distance between transects T_{j-1} and T_j (averaged between measurements made at the left and right hand sides of the stream).

The total area A of the study reach is the sum of the individual cell areas $A_{i,j}$. The default value of the W_j used by the HABTAT program is 0.5; if this value is used then the individual cell areas $A_{i,j}$ associated with points $X_{i,j}$ on transect T_j extend exactly half-way to the next up and downstream transects T_{j-1}, T_{j+1}. By choosing values of W_j between 0 and 1 it is possible to control the cell areas $A_{i,j}$ to reflect visual field observation of the way in which hydraulic parameters and habitat features change between neighbouring transects. For this study we have chosen the values of these weighting factors as the default value of 0.5. Having computed the individual cell values $WUA_{i,j}$ the total WUA is computed by summing over all of the data points and scaling the total by the length (L) of the study reach:

$$WUA = \frac{1}{L} x \sum_{\substack{i=1,NI_j \\ j=1,NJ}} WUA_{i,j}$$

where NJ is the total number of transects and NI_j the number of data points $X_{i,j}$ across transect T_j (excluding those at the left and right boundaries of the transect).

Effect of Choice of CSI on WUA

As mentioned above the PHABSIM HABTAT habitat simulation program allows the user to choose between three definitions of the Compsite Suitability Index (CSI); a multiplicative index, a geometric mean, and a minimum function. It is suggested from experience of model application in the USA that the predicted values of WUA are not particularly sensitive to this choice and that the overall shape of the WUA vs Discharge relationship will be similar for each choice. As an example we have computed the WUA for Adult Dace using data from the Mill Stream using all three choices of the CSI. The result shown in Figure 2.6 shows very little difference in the results of the three computions.

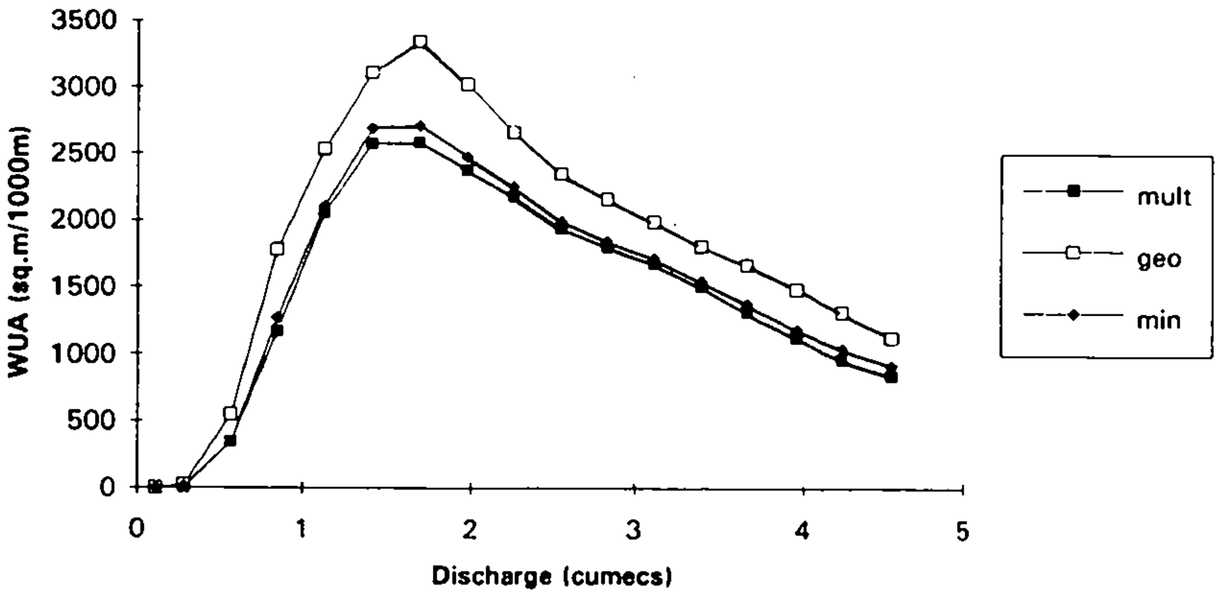


Figure 2.6 Effect of choice of CSI on WUA vs Discharge : Adult Dace, Mill Stream

2.5 ECOLOGICAL MODELLING

2.5.1 Invertebrates

Gore (1989) has reviewed models available for predicting habitat suitability for macroinvertebrates under regulated flow. A major obstacle to this objective is that benthic species are plastic in their niche requirements. While lacking the mobility to make large scale responses to rapid changes in flow they can adapt quickly to changing resource availability and habitat requirements and their responses will vary from system to syste. Evaluation of macroinvertebrate habitat requirements should ideally be made on a site-specific basis.

In this investigation habitat preference data were obtained from a large number of sites but without the degree necessary to define sharply species' requirements, which may differ with age, river type or biological interactions with other species. Ecological modeling of benthic populations is at an early stage and finely focused data for a range of species is not available. Until then broader descriptions of habitat preference have to be used.

Ecological modelling of macrophytes poses similar problems due to niche plasticity, seasonality and river specific factors such as geology, topography and discharge regime. In addition the concept of cover can be misleading and the estimates of % cover and biomass may be adrift by a factor of four due to high cover/low biomaas and low cover/high biomass stands. The structure of stands in relation to depth and flow factors are also important considerations and need to be taken into account when assessing habitat preferences.

2.5.2 Fish

Fish present a range of problems in relation to the construction of habitat models. The major difference to other groups of organisms is that fish are extremely mobile. The sampling of short reaches can not cover available habitats for all life stages because migrations (often over great distances) between spawning and feeding areas are the norm.

In terms of seasonal variation the exploitation of specific habitat features is often for very short periods of time. Thus the young stages of many coarse fish (cyprinids) change their habitat week by week as they grow rapidly from yolk-sac fry to miniatures of the adults.

It can be quite difficult to assess many of the relevant habitat features for fish. Cover for a small specimen may be merely substrate for a larger one. In addition there is no account taken of biotic interactions. For example the presence or absence of predator or competitor species could shift the apparent level of habitat suitability. Interactions with plants and invertebrates are also likely to occur and most of the comments on site specificity and niche plasticity are also applicable to these animals.

2.6 PHABSIM DATA REQUIREMENTS

In this section we define the minimum data requirements for the hydraulic and habitat models contained within PHABSIM. Detailed description of the data collection procedure is given in Johnson, Elliott *et al* (1991).

a) Hydraulic Data Requirements

Hydraulic Simulation Programs: Minimum Data Requirements

IFG4

(i) Survey of x, y coordinates of the bed elevation for each transect (maximum 100 points per transect). The x, y coordinates represent the horizontal distance and the vertical elevation difference from the headpin representing the start of the transect. Within PHABSIM these are converted to a cross-sectional profile of channel bed elevations. It is a convention within PHABSIM that the most downstream transect be labelled transect number 1 and that x distances across the transect be measured moving from left to right looking upstream. Coded observations of cover and substrate must be recorded for each surveyed point. The transect which represents the most downstream end of the study reach should be located at a hydraulic control, upstream of which there is a unique stage-discharge relationship.

(ii) Measurement of inter-transect distances and assigned upstream weighting factor (see sections 4.4, 4.9 for details).

(iii) Measurement of water surface elevation and discharge at a minimum of three calibration flows. The measurement of velocity at each surveyed point across the transect during at least one of the calibration flows, preferably at the highest of the three calibration discharges.

MANSQ

(i) As (i) above.

(ii) As (ii) above.

(iii) Measurement of discharge and water surface elevation at a minimum of one calibration flow.

WSP

(i) As (i) above.

(ii) As (ii) above.

(iii) Measurement of discharge at all transects for one calibration flow and at the most downstream section only for a minimum of three calibration flows.

b) Habitat Data Requirements

Habitat simulation program: minimum data requirements

HABTAT

For each target species life stage HABTAT requires the following data:

(i) Set of suitability indices for one or more of the following:

depth
velocity
substrate
cover

(ii) Set of hydraulic information describing the depth and velocity characteristics for each cell as a function of discharge. This information is supplied as output from the hydraulic simulation programs.

(iii) Coded observation of cover and substrate at every survey point. These values are supplied by field observation and are assumed to be independent of discharge. In order to account for seasonal variability separate seasonal observations of substrate and cover may be made and corresponding simulations run.

c) Hydrological Data Requirements

Hydrological data is required if one is to interpret the weighted usable area vs discharge relationship in the context of the historical flow regime. we recommend the following as sufficient data for such an exercise:

(i) Record of daily flows of at least five years duration.
(ii) Record of daily stage of at least five years duration.

The stage record is not necessary for the interpretation of output but is useful for verifying stage-discharge relationships predicted by the hydraulic simulation programs.

Although it is clearly beneficial that data be available from a gauging station close to the study site this will clearly not be possible in all cases. In the absence of gauged flow data an appropriate technique for estimating flows at an ungauged site may be employed.

3. River/Reach selection

3.1 SELECTION CRITERIA

A selection of study reaches on rivers throughout England and Wales was identified for assessment of the IFIM (see Figure 3.1 overleaf). This sample of rivers was chosen to be representative of the range of river types present in England and Wales.

River and site selection was initially guided by ecological criteria, using ten ecological groups defined using data from the RIVPACS database (Wright, J. F., *et al.* 1988.). RIVPACS data on macroinvertebrate fauna were collected at a large number of sites throughout the U.K. each site being sampled in the spring, summer and autumn, the species lists for each season being combined to produce a complete, yearly, list. These data were then analysed using the

TWINSPAN classification to divide the sites into groups according to the fauna found. This process produced the ten ecological groupss used for river selection.

For each of the ten RIVPACS groups a list of rivers and sites was produced to ensure that the full range of and habitat types will be examined. These habitat types and the initial site list are summarised in appendix A. It is also important to be able to obtain up to date flow data for the sites in question, so that the data obtained during field visits can be checked for accuracy and also as an aid to hydrological modelling. Thus any rivers that do not have an operating gauging station were eliminated. It must also be possible to relate the hydrological data to the site involved, therefore sites that do not have a gauging station within a distance of ten kilometres of the sample area have been removed from the lists, (unless there are no alternative rivers). Sites may also have been excluded if, for example, the quality of the gauging station data was low of if there were problems of high artificial influences on the flows.

The problem of the increase in the amount of fieldwork required when studying large rivers was also taken into account, thus, where possible, rivers that have a catchment area in excess of 150 km^2 were excluded in favour of sites with smaller catchments. However, this was only done where smaller alternative sites existed and without reducing the range of river types sampled. Consequently some of the rivers have much larger catchments than the critical size outlined above.

Aside from the need to cover the full range of hydrological and ecological river types there was also a need to examine sites were problems occur that are relevant to other sites in the U.K.. For instance, a river where the flow is regulated by sluice gates, such as the Gt. Ouse; a river that is influenced by a reservoir such as the Blithe; a chalk stream with or without nearby water abstractions, and so on. Conversely, it was also important to ensure that natural rivers were sampled so that the sample was representative and so that data are obtained on sites that may undergo future resource development. Finally, some sites were selected that did not fulfil all of the above criteria fully. This was because of the availability of existing data from other work which would produce benefits outweighing any potential problems that may occur.

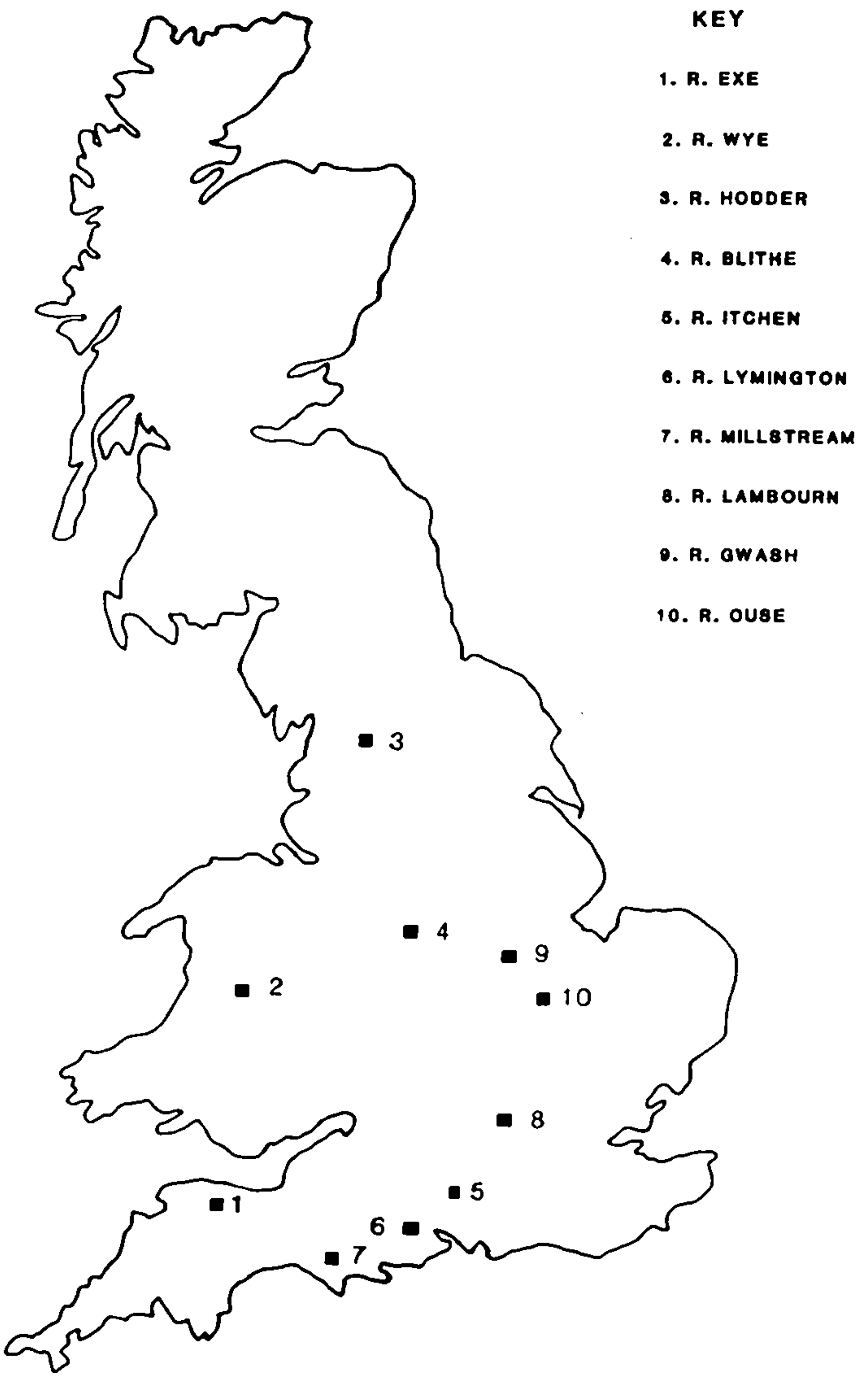


Figure 3.1 *Location of study sites*

3.2 SELECTED STUDY SITES

The study sites selected for this assessment are given in Table 3.1 below, with RIVPACS group number and grid reference. Further details and location maps for each site are given in Appendix A.

Table 3.1 *Selected Study Sites*

RIVPACS Group No.	Site Grid Reference	Site Name
Group 1	SS 792406	R. Exe at Warren Farm
Group 2	SN 847823	R. Wye at Pant Mawr
Group 3	SD 655487	R. Hodder at Hodder Bank
Group 4	SK 109189	R. Blithe at Hamstall Ridware
Group 5	SU 467213	R. Itchen U/S of Highbridge
Group 6	SU 302033	R. Lymington U/S of Balmerlawn
Group 7	SY 873866	R. Frome at I.F.E. East Stoke
Group 8	SU 435701	R. Lambourn at Hunt's Green
Group 9	TF 041105	R. Gwash at Belmesthorpe
Group 10	TL 220697 and TL 233702	Gt. Ouse S.E of Brampton and Lee's Brook W of Godmanchester

4. Data collection procedure for application of phabsim

4.1 INTRODUCTION

In this section we will describe briefly the various elements in the data collection procedure required for application of the IFIM using PHABSIM. For a more detailed guide to the techniques involved and equipment required please refer to Johnson, Elliott *et al* (1991).

4.2 INITIAL SURVEY

The first step in the application of PHABSIM is the choice of a suitable reach of river for the study. In some applications this choice may be directly associated with a certain problem - for example in a study of the effects of an abstraction we may choose reaches immediately up and downstream of the abstraction point. In a more general study we may choose a reach on the basis that it adequately represents the habitat types present in a longer stretch of river. In this assessment we have chosen study reaches after visually surveying some 20-30 km of the river. If we wish to extrapolate results from the study reach to other sites up and downstream it is important that the study reach contains a representative sample of the habitat types present for some distance up and downstream.

Transect Placement
Having selected a reach of river for the study the next step is the placement of a number of transects within the reach. Sufficient transects should be placed to sample the range of different habitat types (eg. pool, riffle, run etc) present in the reach. Hydraulic models require transects to be placed at hydraulic controls (located by looking for breaks in the water surface elevation) occurring in the reach. At least some of the transects should be placed in positions considered to be favourable for accurate measurement of discharge (free of weed-

growth/obstructions with a fairly uniform depth). The most downstream transect must always be placed at a hydraulic control so that the water surface within the reach is not influenced by a control downstream of the reach. (In practice it is worth placing extra transects up and downstream of the first choice for the position of the downstream transect as it is sometimes difficult to spot the exact position of a control).

Once positions of transects have been selected their positions must be marked with survey markers - we have found Permamark permanent survey markers to be very resistant to movement and recommend their use. It is important to make a good record of the positions of the markers to allow them to be relocated easily. In some locations it is preferable to bury the markers to minimise the risk of disturbance. They may be relocated using a metal detector. Even if markers are not buried we strongly recommend the use of a metal detector as natural vegetation growth is often sufficient to obscure the markers.

Headpin Elevation Survey

Once the headpins marking the position of each transect have been placed their elevations must be surveyed. If at all possible at least one headpin should be surveyed relative to some fixed datum level, eg. a point on a bridge. The headpin elevation survey can be conducted on either bank - for ease of surveying it is sensible to choose the bank which is most free of visual obstructions (trees etc.). Distances between the headpins (reach lengths) must be measured on both banks if possible. Reach lengths are used as input data to the hydraulic and habitat models but also serve a useful purpose in helping to relocate the headpins.

Cross-Sectional Survey

Across each transect we must select a number of points which will be the data points for measurement of depths, velocities and cover/substrate characteristics. Around 20-30 points should be adequate to describe the shape of the cross-section and to give a sufficiently accurate measurement of discharge at high and low flows. Points should be spaced evenly and additional points inserted where there are distinct breaks in the slope of the bed (typically at the sides of the bank). The elevation of each data point is then surveyed relative to the headpins on either bank.

Observation of Cover and Substrate

Whilst it is not at present possible to incorporate both cover and substrate simultaneously in the modelling procedure we recommend observation of both. To economise on effort it is possible to observe whichever is thought to be the most significant in terms of its effect on habitat availability to the target species chosen for the study. In the course of this assessment we have designed a new substrate and cover coding system with Dr Bob Milhous of the US Fish & Wildlife Service (see Johnson, Elliott *et al.*, 1991). At present habitat suitability index information cannot incorporate all of the observations made using this system - we still recommend its use as it is possible that future development of habitat suitability indices will allow further use of these data. The current version of PHABSIM requires substrate to be described for each data-point using the particle-size classification given in Table 4.1 below.

Table 4.1 *Substrate classification scheme*

1	Plant
2	Mud
3	Silt (<0.062mm)
4	Sand (0.062 - 2mm)
5	Gravel (2 - 64mm)
6	Rubble (64mm - 250mm
7	Boulder (250mm - 4000mm)
8	Bedrock (solid rock)

SOURCE: Trihey E.W and Wegner D.L. 1981

Likewise cover is described using the conditional cover classification code given in Table 4.2 below.

Table 4.2 *Conditional cover classification scheme*

Cover	Description
0	No physical cover
1	0 - 25% of the cell affected by object cover
2	25 - 50% of the cell affected by object cover
3	50 - 75% of the cell affected by object cover
4	75 - 100% of the cell affected by object cover
5	0 - 25% of the cell has overhanging vegetation
6	25 - 50% of the cell has overhanging vegetation
7	50 - 75% of the cell has overhanging vegetation
8	75 - 100% of the cell has overhanging vegetation
9	0 - 25% of the cell has undercut bank
10	25 - 50% of the cell has undercut bank
11	50 - 75% of the cell has undercut bank
12	75 - 100% of the cell has undercut bank
13	0 - 25% of the cell affected by object cover combined with overhanging vegetation
14	25 - 50% of the cell affected by object cover combined with overhanging vegetation
15	50 - 75% of the cell affected by object cover combined with overhanging vegetation
16	75 - 100% of the cell affected by object cover combined with overhanging vegetation
17	0 - 25% of the cell affected by object cover combined with undercut bank
18	25 - 50% of the cell affected by object cover combined with undercut bank
19	50 - 75% of the cell affected by object cover combined with undercut bank
20	75 - 100% of the cell affected by object cover combined with undercut bank
21	0 - 25% of the cell has a combination of undercut bank and overhanging vegetation
22	25 - 50% of the cell has a combination of undercut bank and overhanging vegetation
23	50 - 75% of the cell has a combination of undercut bank and overhanging vegetation
24	75 - 100% of the cell has a combination of undercut bank and overhanging vegetation
25	0 - 25% of the cell has a combination of object cover, undercut bank and overhanging vegetation
26	25 - 50% of the cell has a combination of object cover, undercut bank and overhanging vegetation
27	50 - 75% of the cell has a combination of object cover, undercut bank and overhanging vegetation
28	75 - 100% of the cell has a combination of object cover, undercut bank and overhanging vegetation

SOURCE: Trihey E.W. and Wegner D.L. 1981

Values recorded using the new substrate/cover code mentioned above can be transformed automatically to equivalent values of the codes given in Tables 4.1, 4.2 using a computer program written by Dr Milhous. The program allows the user a number of alternative descriptions of cover and substrate. When substrate and cover are observed at a given data point we must specify an area over which to base our observations. In practice consideration of resources have led us to restrict observations to an area of about 1 metre around the data point. 'Average' conditions within this area are estimated visually.

Point Velocity and Stage-Discharge Measurement

For calibration of point velocities in the hydraulic models we require mean column velocity to be measured at data points across all of the transects for at least one calibration flow. It is recommended that these measurements are made at the highest calibration flow, since there are more wetted points. Experience of applying the hydraulic models suggest that the best results are obtained by calibrating velocities using data from the highest calibration flow. Measuring velocities for all points at the remaining calibration flows may improve the accuracy of simulations but can be avoided to reduce resource input.

For each calibration flow the stage-discharge relationship must be measured for all transects in the reach. This requires the water surface level to be surveyed relative to the headpins for all of the transects in the reach. If possible the water surface level should be measured at the left, centre and right of the stream. Care should be taken in ensuring that these measurements are made as accurately as possible as errors in the water surface profile are the greatest source of problems encountered in model calibration. When the water surface level is surveyed at a given transect the relative heights to both headpins should be noted - this affords a double-check of the water surface elevation if an error is suspected.

An estimate of the discharge can be based on an average of measurements made at only some of the transects in the reach; those most suited to discharge measurement should be chosen. It is advisable to measure the discharge at the most downstream cross-section for all of the calibration flows. If data is available from a nearby gauging station, discharge measurement can be avoided completely.

4.3 REPEAT CALIBRATION MEASUREMENTS

In order that hydraulic models can be calibrated to simulate a wide range of discharge conditions a number of repeat stage-discharge measurements are required. It is preferable that these cover as wide a range of discharge as possible. We recommend (as a minimum) measurement of stage -discharge at a low, medium and high flow. Water surface levels must be measured at each transect in the reach, but as mentioned above discharge need only be measured at some (including the most downstream) of the transects, or a gauged estimate may be used.

In practice it is likely that the initial survey may be conducted at a fairly low flow, since practical problems are reduced. If this is the case it is recommended that the measurement of point velocities for all transects in the reach be left until the high calibration flow is measured.

Substrate and cover are considered by the model to be independent of discharge, hence there is little value in repeating these observations after the initial survey. In reaches where the hydraulic effects of weed growth are very significant it is useful to map and attempt to quantify the extent of weed growth. This information can be of value in interpreting model calibration data. The cover coding system developed in the course of this assessment (Johnson, Elliott *et al.*, 1991) can be used for this purpose. Where seasonal aspects such as weed growth are significant model accuracy can be increased by carrying out separate seasonal sets of calibration measurements.

4.4 ESTIMATE OF COST OF DATA COLLECTION FOR IFIM STUDIES

Below is an estimate of the cost of data collection expressed in man hours. As a guide to the effect of river size on necessary expenditure the cost has been estimated for both a small river and a large river. It must be stressed that this is only an approximate guide based on the authors experience. Unless otherwise stated each time is calculated for a site with 10 transects in it, each transect having 15 points.

	Small River	Large River	No. of staff
Initial site visit and reach selection	7 hrs	7 hrs	2
Transect placement and installation of markers	4 hrs	4 hrs	2
Headpin elevation survey inc. reach length survey	3 hrs	4 hrs	2
Bed elevation survey (per transect)	½ hr	1 hr	2
Measurement of velocities and water surface elevations (per transect)	1 hr	2 hrs	3
Observation of cover and substrate (per transect)	½ hr	1 hr	2
Site record note taking, photos etc.	3 hrs	3 hrs	2

Note that some of the measurements may be combined thus saving some time. For example the bed elevation survey could be done simultaneously with the observation of cover and substrate requiring 3 people for approximately 1 or 2 hours for small and large rivers respectively.

5. Construction of habitat suitability indices

5.1 INVERTEBRATES

5.1.1 Methods

The most accurate estimates of habitat preferences are derived from detailed analyses of distribution patterns of species with respect to specific variables measured at the point at which a faunal sample is taken (Gore & Judy 1988). Such techniques are time-consuming and costly but are ultimately necessary for developing the model. In the absence of such data cruder estimates have to be used.

Large data bases which record both the occurrence of fauna and the physical features of the sites provide the raw material for preliminary assessments of habitat preferences. The Institute of Ecology has over the last 12 years identified about 600 species from more than 400 substantially unpolluted sites throughout Great Britain (Wright *et al.*, 1988). The physical and chemical characteristics of these sites have also been recorded. Together these two blocks of data (distributional information and physico-chemical features) have been used to assess the habitat preferences of selected species.

At a site, benthic fauna is taken from all available habitats usually in proportion to their occurrence, and a sample consists of all the material collected in a three minute period. This method therefore does not take account of distribution patterns within the site and the results express occurrence with respect to mean values of variables such as substratum, velocity, and depth. This reduced precision is offset to a certain extent by the large number of records for the selected species.

In addition to the presence absence data for individual species, information on the relative abundance of families is also available. In some cases a family may only contain one dominant species and here it is possible to use these abundance data to show preferred conditions for maximum abundance.

In a previous study for the Department of the Environment, habitat preferences of five species of invertebrate were calculated from the I.F.E. data base (Armitage & Ladle 1989). The selections excluded catholic species and included animals with narrower ecological limits because these are more likely to respond to changes in habitat. The species examined in this study were:- the stoneflies Leuctra fusca and Isoperla grammatical, two caddis-flies Polycentropus flavomaculatus and Rhyacophila dorsalis and the pea-mussel Sphaerium corneum.

The present study has added to this list by including a further ten species. These have been chosen according to the following criteria:- occurrence in at least 15% of the sites in the data base, representative of a range of habitats, and at least some selections should provide abundance data. The species are listed below together with available data (occurrence=O, abundance=A).

Crustacea	*Gammarus pulex*	(O)
	Crangonyx pseudogracilis	(O)
	Gammaridae[1]	(O),(A)
Stoneflies	*Leuctra inermis*	(O)
	Leuctridae[2]	(A)
	Chloroperlidae[3]	(O),(A)
Mayflies	*Heptagenia sulphurea*	(O)
	Heptagenia lateralis	(O)
	Rhithrogena semicolorata	(O)
	Ephemeridae[4]	(O),(A)
	Habrophlebia fusca	(O)
Caddis-fly	Sericostomatidae[5]	(O),(A)

[1 includes two species; 2 includes all other Leuctra species found with *L.inermis*; 3 includes *Chloroperla torrentium* and *C. tripunctata*; 4 includes four species with *Ephemera danica* dominant; 5 includes 2 species with *Sericostoma personatum* dominant.]

5.1.2 Discussion of Results

Results of habitat preference curve calculations for the taxa under investigation appear in Appendix B, as tables and curves. The occurrence, and abundance data (when available) are presented for three habitat variables, substratum (as PHABSIM codes), velocity (cm per second), and depth (cm). The distribution of categories of these variables in the data set is illustrated in Figure 5.1. Observations on the results for the various taxa are as follows :

Crustacea
Gammarus pulex is common and widespread in Great Britain. *Crangonyx pseudogracilis* is an introduced species which inhabits rivers, canals, ponds lakes and reservoirs and tolerates saline and polluted water. Both species have similar habitat requirements but *C. pseudogracilis* has a slightly greater preference than *G. pulex* for slow velocity, deep water and fine substratum. Gammaridae abundance shows slightly more focused preference curves than does occurrence.

Stoneflies
Leuctra inermis is a common and widespread species with a preference for fast flows, shallow depths and coarse substrates. The velocity curve is not focused and suggests a wide range of tolerance. In contrast, optimum depth and most particularly substrate lie within fairly narrow bands. In an effort to determine if abundance values tended to narrow the optimum ranges of the physical parameters; abundance data for the family Leuctridae were plotted. The family contains five species in all and although two of these *L. nigra* and *L. geniculata* favour less torrential habitats Leuctridae occurrences are dominated numerically by *L. inermis* which is why the family curve reflects the species curve so closely. No increases in focusing of the curves were noted with abundance data.

Chloroperlidae is another family of stonefly with a preference for fast shallow coarse bottomed streams. However it has a broad range of occurrence and the curves are not finely focused. Even the use of abundance data fails to reduce this lack of focusing.

Mayflies
Five species of mayfly were examined. Two, *Rhithrogena semicolorata* and *Heptagenia lateralis* show preference for torrential type streams. Both species have rather focused curves for depth and substrate preferences but velocity curves are not appreciably focused. *Heptagenia lateralis* shows the most rigorous habitat requirements of the two species. A third species also in the family Heptageniidae - *H. sulphurea* - is generally found in larger streams but the species shows a wide range of occurrence.

Habrophlebia fusca is a species of small streams. The habitat preference curves show moderately focused curves for velocity and depth but tolerance to a wide range of substrate conditions.

Ephemeridae are burrowing mayflies. The family contains four species in our data set with *Ephemera danica* the most widespread and abundant species. Velocity and depth are very unfocused and it would be difficult to identify a single peak. Depth shows a bimodal distribution in preference which reflects the species widespread occurrence in deep water sites. The chief control over distribution appears to be substrate which is shown in the focused habitat preference curve. The use of abundance data reduced the bimodality of the depth curve and focuses the substrate curve even more.

Caddis flies

Sericostomatidae contains two species *Sericostoma personatum* and *Odontocerum albicorne* with *S. personatum* as the most widely occurring and abundant form. Velocity and substrate curves are non focused but there does appear to be a closer relation of occurrence and abundance with depth.

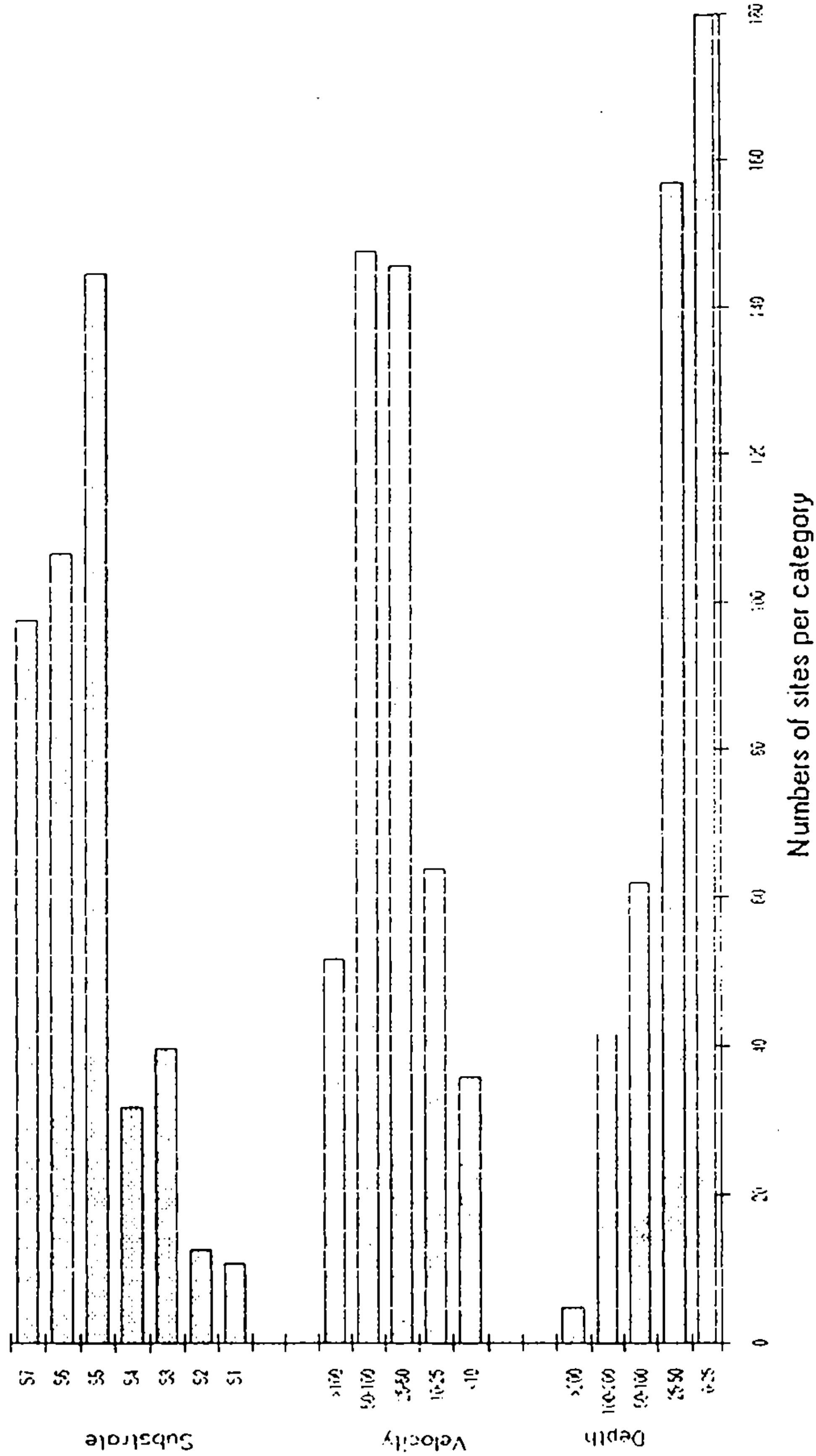


Figure 5.1 *The distribution of the 446 sites in categories of velocity, depth, and substrate*

5.1.3 Overview

The taxa tested occurred over a relatively wide range of conditions and this may reflect the composite nature of the samples which were not microhabitat specific. This suggests again that occurrence data collected from such samples is not the best way to obtain detailed information on habitat preference. However the results conform to the generally accepted (from the literature) view of the habitat requirements of the tested species and are the most cost effective way of obtaining data on physical habitat requirements of species and families.

The lack of finely focused curves for velocity, depth and substrate for the majority of species tested may also reflect the very heterogeneous nature of most river beds which allows species to occupy small niches which although differing greatly in velocity, shear stress and particle size may be in very close proximity to one another. Examples are the surface of a boulder and the downstream side of that boulder. Two niches close to one another but experiencing quite different velocity and shear stress. In addition the biofilm which develops on the boulder surface will vary with locus with respect to current flow.

Another factor which may contribute to the lack of focused curves is the nature of the river. This relates directly with the niche aspect above in that some streams will have a wider range of niches than others. This point was raised in a previous report to the Institute of Hydrology for the Department of the Environment (Armitage & Ladle 1989) where it was suggested that the fauna of some rivers will react less to environmental change than will that of more 'susceptible' rivers. A susceptible river may be one that has less niches/habitat variability and less fluctuations in natural discharge which could act as re-setting mechanisms to recreate habitat diversity.

Another point raised in the 1989 report cited above must be made again. The invertebrate community at a site is a dynamic complex of interactions and the attempt to describe habitat preference only with reference to three or four variables is unlikely to be wholly successful. The concept of cover although a useful one for fish is not particularly so for invertebrates. Here the substrate descriptors are in effect measures of cover. With respect to substrate a feature of major importance to the benthic community is the settlement of fine particulate material. This material which is partly biological in origin can determine the nature and abundance of invertebrates in rivers. It is important that attempts are made to establish the relationship between flow characteristics and channel morphometry and the dynamics of fines. The situation is complicated by the fact that managed flow changes may not be sufficiently great to alter the basic substrate type but would allow the deposition of a thin layer of fines. This would result in faunal change.

The combination of niche specific distribution, quick response to changing conditions, and recolonization from upstream sources or via tributaries, means that the response of invertebrate communities to for example, reduced flows may not be clear in all but the most extreme cases. Habitat loss in relation to reduced discharge may not be accompanied by changes in the invertebrate community as measured by occurrence of species. Instead it will be necessary to relate communities with specific microhabitats and determine the effects of discharge changes on these microhabitats in order to assess possible changes in the benthos. Emphasis on the use of habitat classifications has recently been made by Kershner & Snider (1991) and Harper *et al.* (1991) and the uniformity of microhabitat communities in eight rivers throughout the country is investigated in another section of this report.

5.1.4 Supplementary Invertebrate Studies

Microhabitat Sampling
Habitat preference curves for this study are based largely on information held on the IFE data base which has been used to develop the predictive model RIVPACS. However these data do not include information from specific microhabitats. In order to investigate the distribution of invertebrates within these areas a series of samples were taken in microhabitats within the reaches selected for the fishing programme which includes a wide range of river types from chalk streams to upland spatey rivers.

The objectives were to determine a) whether 'microhabitats' selected from the bankside would contain different communities of invertebrates; b) whether these communities were stable across a range of river types and c) to use any appropriate data to supplement the habitat preference information obtained from the RIVPACS data base. Methods and results are given in Appendix

Distribution of Invertebrates Along River Reaches - The Rivers Gwash and Blithe
In a previous study which examined the feasibility of using the PHABSIM model in the UK, invertebrate samples were collected from three reaches on the River Blithe and from one reach on the Gwash (Armitage & Ladle 1989). These samples were collected at the same time as physical and hydraulic variables were measured along transects for input into the model. There were insufficient funds available for processing the samples at that time and the entire collection was stored by the Institute of Freshwater Ecology until such time and funds became available for further examination. This current project allows for these data to be processed in order to examine in more detail the distribution of invertebrate groups across and along a broad area of river.

Most invertebrate surveys are confined to a single sample within a given reach. This sample may include all microhabitats within the site area (usually rather loosely defined) which may consist of a section 5-10m along the stream. In this type of sample the catches from different microhabitats within the area are usually bulked together and no microhabitat-specific distributional data can be extracted. Other techniques involve sampling a single habitat usually a riffle and again no picture of distribution patterns for the reach can be obtained from the results.

It is important to know whether invertebrates have a patchy distribution and this has been the subject of much investigation by theoretical ecologists (see Pringle *et al.* 1988, JNABS 7, 503-524). However to date there has been little attempt to obtain such data for studies of applied problems. Detailed distributional data has practical application particularly in the field of flow changes. Such changes are accompanied by shifts in the proportions and absolute amounts of habitat types which in turn can have major effects on the benthic community. It is the object of this investigation to determine the distribution of benthic invertebrates along river reaches and relate them initially to substrate features with the ultimate aim of defining zones/reaches which would be particularly sensitive to flow changes and their associated hydraulic characteristics. Methods used and results of this study are given in Appendix E.

5.2 FISH

5.2.1 Selection of Target Species : Rationale

Selection of target fish species for preference curve construction presents a number of problems. In Britain there are three cyclostomes (lampreys) and more than thirty bony fishes which occur in fresh waters, of the latter only about twenty occur in running waters for substantial parts of their lives. Only the trout (which may be anadromous feeding in the sea and spawning in rivers), the eel (catadromous feeding in rivers and spawning in the sea), grayling, barbel, chub, dace, stone loach and bullhead are truly running water species. Pike, gudgeon, silver bream, bleak, bronze bream, minnow, roach, rudd, perch, ruffe, zander, and three spined stickleback occur in both still and running waters.

Stone loach, bullhead, gudgeon, bleak, minnow, ruffe and three spined stickleback are small and of little angling interest. Barbel, silver bream and zander are of fairly restricted distribution and, together with rudd are unlikely to occur in many of the PHABSIM test rivers. The remaining species are all worthy of consideration as target species.

Brown trout - Trout is probably the best documented river fish species and must really be included because of its territorial behaviour, wide distribution, high level of angling interest and strong data base. Having said this it is unfortunate that trout are widely and indiscriminately stocked so that distributions could in some instances be very misleading.***

Eel - Eel is possibly the most widespread and abundant species in the list. Because eels are catadromous in nature breeding and the first three years of larval life take place in salt water so that only the immature and early adult stages would provide information applicable to PHABSIM, probably not a satisfactory situation.*

Grayling - Grayling is a shoaling fish with much in its favour from the point of view of the present study. However, the distribution of the fish is patchy and it may be absent from many of the study sites. In addition grayling, like trout, is subject to management (usually intensive removal) and may thus be unsatisfactory.**

Chub - Chub is a river fish with a tendency to form shoals and has a wide distribution. Documentation of immature and adult stages is quite good but there may be little information about spawning and fry stages.**

Dace - Dace has much in common with chub, to which it is quite closely related. Dace is also a shoaling species and being smaller tends to be rather more numerous and possibly to penetrate into rather smaller watercourses. Documentation of the spawning requirements for dace is good. Probably a good choice of target species.***

Pike - Pike is a predator with a wide distribution and a good basis of knowledge regarding habits and habitat. The fish are relatively large and easy to catch by electro-fishing. Pike are heavily managed in many waters by intensive culling and removal, in others they are popular with coarse anglers and because of this it may not be the best choice for the present study.**

Bronze bream - Bronze bream is a fish strongly favoured by slow flows and is widespread in still waters. There is information regarding the various life stages of the fish because in Europe bream is farmed as food. Bream will certainly be present in some of the study rivers but may not be sufficiently widespread to be a useful target species.*

Roach - Roach is the most sought after angling species and is present in the majority of still and running waters. It is a shoaling species and is likely to provide a good contrast to trout and dace (which it resembles in some respects) with regard to its habitat preferences in some life stages. The various life stages of roach have been studied to differing degrees but there is likely to be adequate information for this study.***

Perch - Perch is a species which has been studied in great detail and in fact has provided the basis for major models of fish population dynamics, it is a popular angling fish and is widespread but, although perch live in many rivers they are most abundant in still waters and may be scarce in many running water situations. Probably not a suitable target species.**

On the basis of the above criteria together with the known and anticipated probabilities of occurrence of the species in the sites selected for the present study trout, dace and roach have been chosen as the target fish.

In addition to the factors outlined consideration has been given to the contrasting characteristics of the species in relation to their spatial and temporal requirements. For example, the brown trout differs from the others in being a salmonid which is territorial and frequently non-shoaling in its behaviour whereas both dace and roach are normally found in shoals of various sizes. The life stages will be considered in turn, with particular reference to features of the physical habitat which are known to influence behaviour or "ecological fitness" of life stages.

5.2.2 Construction of Habitat Suitability Indices for Species Life-Stages

Spawning

It is probable that the spawning strategies of some fish species are flexible in terms of the relationship between egg numbers and egg size. This should be borne in mind when attempting to generalise about factors influencing survival of the early stages.

The eggs of the trout are relatively large, few in number and are deposited, in early winter, within shallow redds formed in gravel having an interstitial throughflow of water. The eggs develop slowly over a period of one to three months, this makes their development particularly susceptible to clogging of gravel interstices by fine sediment in the event of catchment erosion or reduced winter flows.

The dace also spawns on gravels in shallow water but the small eggs adhere to the surface of stones and are laid in springtime. The eggs develop quickly but may suffer heavy mortalities, during their development, in the event of redistribution of fine sediment (onto the spawning gravels) by spates. Presumably mortality would also occur if flash floods disturbed the spawning areas.

Roach spawn in late spring to early summer and the eggs are normally laid on macrophytes, including mosses and macrophytic algae. This species appears to be capable of successful spawning in either still water conditions or in very fast flowing water, the latter normally being selected in stream and river situations. The eggs adhere to plants and, as in the dace, develop over a few days (the period is, of course, strongly temperature dependent). It has been noted that sudden reductions in water level, such as may occur after weed cutting or flow diversion, can result in heavy mortality.

Fry

Trout fry live (at first) within the river bed in shallow, well aerated, flowing water. The behaviour patterns and colouration are cryptic and the young fish depend on supplies of yolk for two to three weeks. Subsequently the fish (2.5 - 3.0 cm in length) establish small territories in shallow, flowing water. In general faster growing fry show better survival. At this stage in the life cycle, in the absence of catastrophic events, survival is probably mainly density dependent.

Hatched dace fry probably migrate passively, with the flow, from the shallow spawning regions to slower flowing marginal areas. Large numbers of dace fry have been found to occur, in May, in deep marginal slacks with masses of floating weed present. In June fry still occur in marginal areas but in slightly faster flowing areas devoid of weed. In early summer the fry may be vulnerable to rapid changes in discharge conditions and in cool water growth will be relatively slow and susceptibility to physical damage and/or predation consequently prolonged.

Being later to hatch than dace, roach fry, which tend to occur in similar marginal conditions, are generally smaller than the dace. Although the fry will be susceptible to similar factors the timing of events may be critical in selectively influencing the different species.

In general it may be that inter- and intra-specific competition for resources is of importance to success of a species in a given situation. Similarly predation by fish may result in interactions which exclude one species in the presence of another. In any analysis of physical habitat conditions such possibilities should never be ignored.

Juveniles/Mature Fish

It can be quite difficult to define the cut off points between juvenile fish and fry or mature fish. In general it is easiest to regard 0+ specimens as fry, although it is probable that critical changes in form and behaviour take place before the "first birthday". At the other extreme, although the transition from juvenile to mature fish is relatively clearly defined in terms of physiology, the criterion of maturity being reached at a certain size, which is often applied, does not take account of differences between the sexes.

Brown trout grow rapidly and mature quite quickly. In practice the mature fish are extremely tolerant and various phenotypes use a range of habitats from marine coastal waters through lakes, reservoirs and small still waters to rivers and small stony streams. The behaviour of the fish differs in these situations from small active shoals in the sea to strictly territorial individuals in running waters where the feeding stations may be defined by flow patterns and topographic details of the stream bed (lies) and there is a requirement for overhead cover (which may be utilised by more than one fish) in times of disturbance. It may be that the presence of shear zones is more important than velocity sensu-stricto for the establishment of feeding territories. Summer droughts have been demonstrated to have severe effects on 1+ parr but other factors exerted no significant influence.

Dace form feeding shoals in shallow, relatively fast flowing water over stony or gravelly river beds. They are strictly river fish at all stages of their lives although the juveniles and adults may survive for long periods in still water. The larger mature fish probably make use of a wider range of depths, velocities and substrata than the immatures and expert opinion suggests that overhead cover may be relevant to their distribution. The fish migrate actively to suitable spawning localities in the early part of the year.

As mentioned previously roach are able to sustain large populations in both still and running waters. In the latter they tend to favour deep, slow flowing, weedy situations except during the spawning period. There appears to be little published information regarding the importance of overhead cover but personal observations suggest that object cover in the form of submerged branches, roots or aquatic vegetation may be significant.

5.2.3 Discussion of Results and Recommendations

If the NRA are to use the PHABSIM model and wish to collect compatible IFIM data the procedures applied by IH and IFE in the present study will be required. For territorial species, such as the brown trout, spot measurements of velocities, depths, substrata and cover characteristics of individual lies may provide useful supplementary information. However, it should be borne in mind that, as it stands, PHABSIM simply provides a measure of the weighted usable area of suitable habitat for a given species in a surveyed reach and is NOT a method for assessing the stock of a species present. For stock generation/support potential, models such as HABSCORE, which correlate stock with habitat features over a limited range of stream types, will be required.

In view of the above it would seem to be important that a longitudinal survey of any catchment under consideration should be carried out, with assessment of the occurrence of essential features for all life stages AT THE APPROPRIATE SEASONS. Also, since no account is taken of biotic characteristics (presence of competitors or predators) or of water quality information, these should be incorporated in any study together with the known or supposed tolerances of target species. It should also be appreciated that habitat preference curves are invariably constructed on inadequate data, notably in relation to the diel variations in species habitat requirements. Lastly there will always be a risk of an unforseen factor (e.g. an impassable obstruction preventing upstream access) which is not incorporated in the model influencing the suitability of the system.

The present study is designed to test the feasibility of applying PHABSIM technology to British rivers. In order to do this the habitat preferences of selected target fish species will be described in the form of habitat suitability curves, the information required to construct these curves is derived mostly from published studies and reports (references appended). Understandably, the availability of data for curve construction is very limited. In many cases the details were collected as information which was incidental to the study in question and were published as background. Because of this it is quite rare to find adequate descriptions of velocity, depth or substrate. Correlations of the above factors with life stages are scarce and worthwhile information on the diverse, complex and controversial aspect of "cover" is virtually non existent.

It is clear that there are a number of problems which are general to all fish habitat studies in rivers. In general the total absence of suitable habitat with reference to any feature (depth, flow, sediment, cover) for any life stage should, in theory, eliminate that species but the following aspects must be taken into account.

Firstly, the distribution of species and of the different life stages of those species in rivers is rather poorly known and differs between river types and probably also in relation to interactions with other species. For example, fishes in chalk streams do not show the "classical" zonation of dominant species, (Minnows-trout-grayling-barbel-bream) (Mann, R., Pers. Com.). This lack of longitudinal partitioning is presumably related to blurring of habitat boundaries, intercalation of habitat features at any given site and biotic interactions.

Ultimately it will be necessary to group data into a number of river types. Within these groups different sub-models of PHABSIM or a derivative may be necessary to take account of varying levels of habitat factor predominance.

Secondly, fish are very mobile animals and may migrate large distances, often on a seasonal basis, in order to fulfil particular life history requirements. Mature brown trout, for example, shift upstream in late Autumn to locate suitable spawning areas. Because of such a shift it may well be that a section of river which, ostensibly, has no trout spawning gravels when surveyed supports a large population of juvenile and mature trout derived from breeding elsewhere in the catchment; possibly in some unsurveyed reaches.

A walk-over survey of the entire river system should therefore be a prerequisite. In considering the mobility of fish the presence of impassable barriers must be taken into account.

Thirdly, rivers, being dynamic systems, show strong seasonal variations in depth, velocity, substrate and cover characteristics. Again, taking the brown trout as an example, it is quite possible that a particular reach may only have extensive areas of spawning depth/velocity/substratum/cover in winter, when increases in discharge have flushed out the detritus, silt and plant growths accumulated over the summer.

Adequate seasonal coverage of study reaches is essential. It will usually be necessary to consider seasonal requirements in terms of the fish species which are known to be present or which are desired.

Fourthly, it is probable that strong interactions take place between (particularly) the young stages of larger fish and small species of fish (or even large invertebrates) such as minnow, bullhead, stone loach, sticklebacks and ruffe etc. (Winfield 1991).

Many of these latter species can not be sampled adequately by existing techniques but should be assessed by observation if possible. Four or five levels of abundance should be adequate for this purpose.

Fifthly, habitat characteristics interact strongly in such a manner that it may be impossible to dissociate the effects of factors considered as distinct. For example, Current velocity which is generally, and realistically, measured at some mean point on the depth/velocity profile, may have little relevance to fish which spend much of their time in positions of shelter behind large stones or other obstructions. Evidence is available which suggests that velocity shear zones may be the essential factors governing habitat suitability in some species: thus, in slow flows trout may choose the margins of faster flow in sections and in fast flows they may select lies peripheral to the slower flowing areas.

This particular constraint may, in some instances, reduce the value of spot measurements made in relation to the observed locations of individual fish (one of the cornerstones of traditional PHABSIM habitat preference curve development. It emphasises the fact that the "community approach" to preference assessment is essential and that the finer detail of habitat measurement could prove valuable.

Similar constraints to those outlined above are applicable to all species considered.

The Instream Flow Incremental Methodology required for the PHABSIM model operates on a relatively simple principle. Estimates of AVAILABLE USABLE AREA for discrete SPECIES LIFE STAGES under a range of DISCHARGE VALUES are established.

Currently, data is being collected from a selection of rivers in England and Wales, by IFE and IH, using the conventional PHABSIM approach developed in the USA with the objective of evaluating the technique. It would, of course, be possible for the NRA to simply increase the data set indiscriminately by precisely repeating the methodology presently in operation. However, a more efficient use of time and effort would seem to be to select those features which could be "guaranteed" to be useful. It may also be cost effective to record information on features which are not currently included in the model if this seems appropriate.

With regard to the "problems" mentioned above:
It will be necessary to group data into a number of river types. Within these groups different sub-models of PHABSIM or a derivative may be necessary to take account of varying levels of habitat factor predominance.

A walk-over survey of each entire river system should therefore be a prerequisite. In considering the mobility of fish the presence of impassable barriers must be taken into account.

Adequate seasonal coverage of study reaches is essential. It will usually be necessary to consider seasonal requirements in terms of the seasonal life history requirements of fish species which are known to be present or which it is desired to encourage/enhance.

Many of the small fish species can not be sampled adequately by existing techniques but should be assessed by observation if possible. Estimates at four or five arbitrary levels of abundance should be adequate for this purpose.

The constraint of habitat feature interaction may, in some instances, reduce the value of spot measurements made in relation to the observed locations of individual fish (one of the cornerstones of traditional PHABSIM habitat preference curve development). The "community approach" to assessment of "preference" is essential and determination of the finer detail of habitat measurement could prove valuable. A similar aspect worthy of full consideration is the impact of variability in time and space, of habitat characteristics.

In conclusion it would seem that the best habitat model for each species will take into account the annual sequence of life stages and their habitat requirements. A river could be partitioned at the appropriate seasons to determine whether there is a proportion of usable area for all stages of the given species present at that time and a descriptive model generated to test the apparent suitability of the river in question.

5.2.4 Fish field data

Habitat preference curves of selected target species have been developed mainly from information in published papers and unpublished reports. These curves will be applied in the PHABSIM program to examine the effects of habitat loss at reduced discharges on the selected target species. In order to test whether the results from the PHABSIM program are accurate it is useful to have information about the fish population in the river.

The results of the fishing programme show how fish in differing river types are distributed with respect to habitat. (River and site selection procedure are outlined in chapter 3). In addition, repeat fishings and scale analysis and length/weight relationships provide data on the age structure and density of the population. These data can be used to assess the accuracy of the PHABSIM predictions and in addition will supplement information on habitat requirements of particular fish species.

During the electrofishing it is possible for an operator to record the position of fish caught and to relate this to reference markers on the bank and instream. The procedure carried out in the millstream involved preparing a sketch map of each reach and relating this to reference points such as trees and bushes and the IH markers. When the fishing team catch a fish its identity is communicated to the operator on the bank who records the capture locus on the sketch map. The location of fish can then be directly linked to the physical characteristics of the reach as determined by the IH transects.

The consensus view of several fish workers suggests that the proposed methodology will provide useful information on the association of fish species with particular habitat characteristics. More detailed field assessment of habitat requirements of fish would require a considerable amount of effort and may need to consider seasonal aspects, longitudinal movements (out of the reach or tributary) and life-history data. Such effort is beyond the scope of this project and it is hoped that the proposed methodology offers a compromise whereby a good deal of information is obtained with an economy of effort. Methods of data analysis and results are presented in Appendix F.

5.3 MACROPHYTES

5.3.1 Methods and Data Sources

There have been several attempts at choosing typical species and some attempts at defining their environmental range or requirements.

Such groups typically include:

Submerged - with bulk of plant in water but with access for fish

Ranunculus (aquatilis)/fluitans/penicillatus
Potamogeton pectinatus
Myriophyllum spicatum
Elodea spp
Callitriche spp (*stagnalis/obtusangula/platycarpa*)
(large algae - filamentous)

Emergent - with plant above and below water with reduced or difficult habitat for fish

Nasturtium/Apium/(Veronica)
Glyceria maxima
Phragmites australis
Scirpus lacustris
Sparganium spp

Floating *Lemna* spp
Azolla spp

Surfacing - submerged attaching stems but with surfacing and shading leaves

Nuphar spp
Potamogeton natans

Choice of aquatic plant genera to typify fish habitats

The selection of the typical aquatic plant species of most relevance to fish habitat is difficult although a recent assessment of weed control in flowing watercourses for WRc, indicates that emergent reed species are the most frequently controlled, after which the submerged species *Potamogetons* and *Ranunculus* are the most abundant in flowing waters, followed by species of *Elodea* and *Callitriche*. The former, *Elodea* spp, develop later in the growing season and are generally considered to be a poorer fish habitat but they also prefer to grow in slower non-salmonid watercourses. *Callitriche* spp, typical of lowland and often calcareous streams, grow slowly and are managed more often on a cycle exceeding a year. Thus the choice of *Ranunculus* as typifying submerged aquatic plants, is particularly acceptable if the link between weed-cutting and fisheries is accepted in preference to the supposed legal basis of weed removal ie. for land drainage purposes. If reed or grass-like species are excluded, the choice of emergent species ie the *Nasturtium-Apium-Veronica* group, is less complex as they often grow together in a similar manner in overlapping habitats. Of the genera available for selection above, there is a considerable knowledge base on both *Ranunculus* and *Nasturtium*; little is known about the colonisation, seasonal growth cycles or general requirements of other flowing water species.

Information on particular species of *Ranunculus* is complicated by the similarity in form, absence of confirmation in some distributional and taxonomic difficulties of several species. Thus it is proposed to use a composite of three species as mentioned above; this will be called *Ranunculus* afp to emphasise both the combination, the above complications but in addition the general quality or variation of result available even from clonal material under controlled environmental conditions.

Data sources

Ranunculus afp

The basic data are derived from a intensive 4-year study of *Ranunculus penicillatus ssp pseudofluitans* (formerly *R. p.* var *calcareus*) from the upper catchment of the River Piddle in Dorset. These and other species from the adjacent River Frome were introduced to an experimental stream system for growth and taxonomic studies; these results are also incorporated. Overlying these data are a series of other data including:

1. A previous field study for this project on the river Gwash and Blithe (Mountford and Gomes, 1990);

2. Data from hydraulic, production and light studies on the Rivers Piddle and Frome.

3. Data from other IFE surveys particularly from EIA and RIVPACS.

Rorippa

Data on the habitat of this plant is derived from:

1. Detailed studies of sediment accumulation on sections on the Rivers Piddle, Frome and Lambourn;

2. Detailed studies of the seasonal interactions of growth of *Ranunculus* and *Rorippa* on the R. Piddle.

Habitat suitability curves

The occurrence of water plants poses a fundamental problem to aquatic botanists. For example, Haslam considers that the presence of a plant is related to many factors whereas its absence may be caused by a single factor.

The extent to which a plant grows is determined by environmental factors but particularly light, carbon supply and nutrients. The biomass achieved must therefore be an assessment of the suitability of a habitat however this seems to contrast with that for fauna.

Plant growth in flowing water, however, modifies its environment particularly water flow, and thus water velocity may decrease progressively during the growing season resulting in significantly raised water levels of up to 0.5 m at the time of maximum biomass. Water velocity during these periods is both difficult to measure and the results are difficult to interpret. Experimental data shows that whilst the mean velocity of a cross section falls the velocity range is extended considerably. Thus, the water velocity within the plant stand may be <0.1 m s^{-1}, but the flow between stands may be 1 m s^{-1} however the mean may be 0.25 m s^{-1}.

Growth habit

Ranunculus afp

This plant complex is normally found growing rooted in stable gravels in streams and river which are not subjected to large extremes of flow ie where the maximum to minimum is less than 1:10-20, or in areas of such where the effects of winter flows are locally moderated by, for example, the effects of barrages, etc. Suitable gravels are likely to be cemented together by sand or silt grains to form a hard pavement ('pseudo-armoured') and they not worked over during winter flows.

Nasturtium

This emergent plant is normally found growing as an annual in shallow water to 0.7 m or in late summer in the margins of larger rivers. Although seedling development is important, backwaters and marginal areas protected from scouring or direct effects of winter flows act as overwinter refugia and as seasonal growth starts in the late spring, many fragments or propagules are continually broken off to pass downstream to colonise suitable areas by early summer. Frost may however limit overwintering and thus this select for presence of this plant in warmer water streams ie. those fed from springs.

Velocity
Preference curves were made from mean velocity data for the cross sectional area of the watercourse either at a discrete sample site or as a mean of a 100 m section.

Depth
A wide range of water depths were incorporated. Mean depth of the section of stream was used although it is often likely with *Nasturtium* in depths over approx. 1 m, that growth will be from the margins.

Substrate
Data collection for sites with high plant cover of the stream bed differs from that of sites with low cover, in that the progressive seasonal growth yielding high biomasses enhance sediment accumulation of that type of material available upstream for deposition, within the plant stands but substrates of larger size remain exposed between plant stands for easier observation. If excessively large plant stands develop because of slightly lower flow then sedimentation over the entire stream bed may occur and the true stream bed may only be visible following the winter washout period. However, for *Ranunculus*, although rooting may occur within such soft sediments only those plants or parts of rooted in the firmer base substrate will survive winter flooding.

Cover
Cover was equated to shade and preference curves were made from data from both large-scale experiments and detailed continuously-recorded observations from several river sites in Britain and Denmark. A model derived from data obtained light measurements from artificial vertical shade was also included.

Other Factors

Nutrient levels
The minimum and maximum levels of nitrate-nitrogen, phosphate-phosphorus and potassium were in milligrams per litre respectively:

	Nitrate-N	Phosphate-P	Potassium
Ranunculus	0.28-5.1	n.d.-0.37	0.36-6.1
Nasturtium	0.25-4.7	n.d.-0.46	0.60-5.8
Apium	1.10-9.5	n.d.-0.55	n.d.-1.6
Veronica spp.	0.05-1.8	n.d.-0.34	0.26-6.3

These we all within the normal limits expected for an acceptable level of plant growth and would not be expected to limit plant growth; they are not near those levels considered suitable for the encouragement and overgrowth by epiphytic algae.

Water temperature
Experimental data in growth chambers indicates that the growth of *Ranunculus penicillatus ssp pseudofluitans* (formerly *R. p.* var *calcareus*) may be severely limited when below 5°C. Net photosynthesis is at its maximum around 10° but progressively reduces to 25-30°C above which temperature death may occur (for strains of plant acclimatized or adapted to the UK). The growth relationship is complicated by the association of high light and high temperatures

during the late summer which gives better increases in biomass and the seasonal cycle but the plants function at lower overall efficiencies.

5.3.2 DISCUSSION

Water velocity effects are the most significant effect for both Ranunculus afp and Nasturtium officinal. In the former, for example, where the seasonal range of flow is small eg 3:1 there is little winter washout and often a high overwinter biomass with a high maximum biomass in the successive season whereas in rivers with a seasonal flow range of 10-20:1, a similar seasonal maximum biomass may not be achieved. This reduction in biomass may be further reduced by the effect of deeper water such that at mean depths of 2-3 m only a small biomass may be achieved; this leaves the plants susceptible to overgrowth by algae at relatively low nutrient levels and their elimination from this part of the system.

The seasonality effects of plant growth and the consequential effects on water flow have been discussed with R.T Milhous. Habitats have not been satisfactorily coded from Cover groups and their combinations.

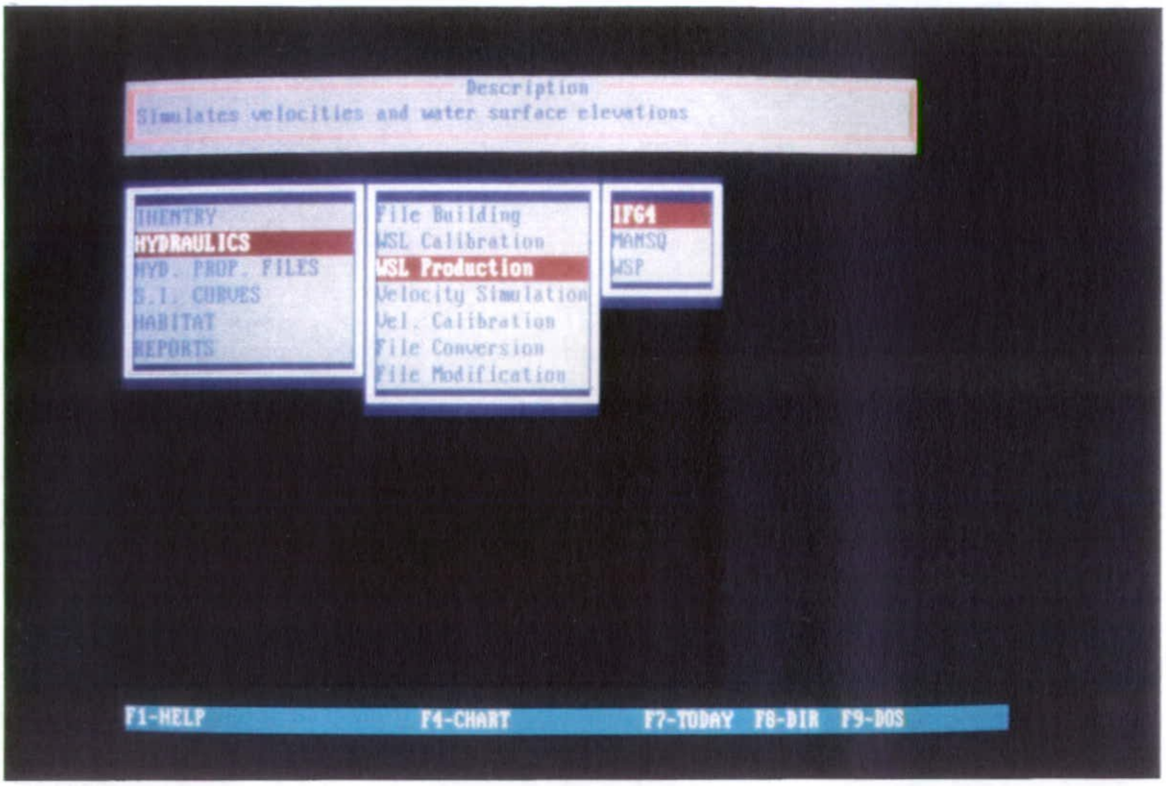
6. PHABSIM model calibration

6.1 INTRODUCTION

Calibration of the hydraulic models within PHABSIM is not a fully automated procedure: the user must have an understanding of the basic principals of the different models available in order to make subjective judgements in the choice of calibration parameters based on model error estimates and values of output variables. Nevertheless the procedure can be broken down into a number of simple, well-defined steps. Manipulation of data files is straightforward as there are utility programs available for all but the most simple file conversions required.

The PHABSIM system as supplied by the US Fish & Wildlife Service comprises some 250 or more programs - we have found in practice that we use around 30 of these. In addition we use 15 new programs for inputting data, building and reviewing data files. All programs are written in Microsoft PC FORTRAN. The original version of PHABSIM occupied some eleven diskettes; the version we now use in practice is available on two diskettes.

The most significant improvement in PHABSIM software is the introduction of the RPM program menu (see Figure 6.1 below). This allows programs to be executed using simple keystrokes and provides on-line help facilities for all programs in the menu. On-line graphics provided by PHABSIM are of a very poor quality and are practically unusable. Similarly text output files are unnecessarily lengthy making it very difficult for the user to find the most relevant information. In the course of this assessment we have worked to overcome this problem by writing utility programs which extract relevant data from PHABSIM output files in a concise, well-formatted form. Files in this form can be readily analysed in a spread-sheet. We have used the RPM menu interface to run PHABSIM programs and to extract relevant output data We then import these data into the Microsoft EXCEL spread-sheet to analyse and plot output data. Since both RPM and EXCEL can be run in a Windows environment this approach is almost as effective as re-writing on-line graphics procedures in the PHABSIM source code. An additional benefit of importing data to the spread-sheet for analysis and plotting is that a complete record of the calibration and simulation procedure can be stored in the spread-sheet.



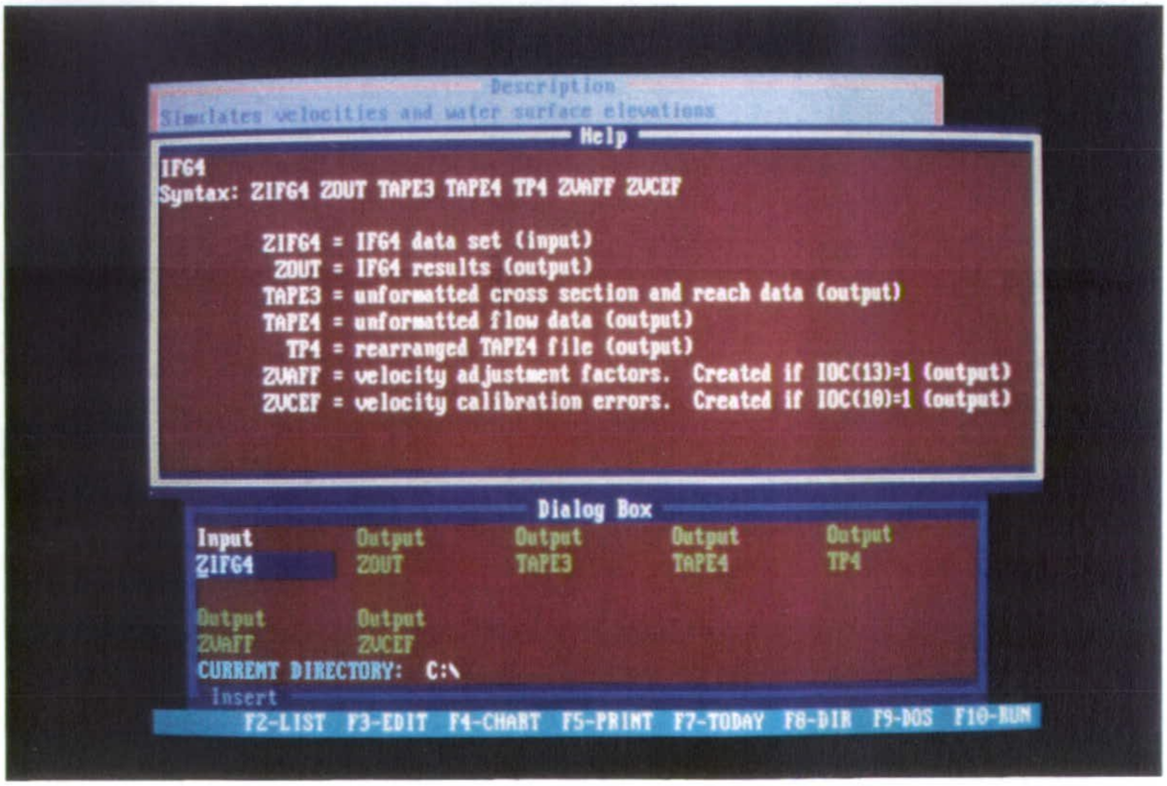


Figure 6.1 *RPM Program Menu*

6.2 HYDRAULIC MODELS : CALIBRATION AND SIMULATION

6.2.1 Introduction

PHABSIM contains three hydraulic models, IFG4, MANSQ, and WSP. One or more of these models must be calibrated to fit observed values of water surface profiles, discharge and point velocities. In practice model calibration is composed of two distinct steps; water surface level calibration and velocity calibration. For mathematical details please refer to the Project Inception Report or to Bullock, Gustard & Grainger, 1990.

6.2.2 Water Surface Level Calibration and Simulation

The hydraulic models IFG4, MANSQ and WSP may all be used to simulate water surface profiles. All three are one-dimensional models, viewing the water surface along the reach as a single profile. Across each cross-section in the reach the water surface level is assumed to remain constant. Calibration data are based on observed values measured at the left, right and centre of each cross-section. These are averaged to give a single value for each cross-section at the calibration discharge.

For effective calibration of water surface profiles at least three water surface profiles must be measured in the field. Unless gauged discharge data is available water surface profile measurements must be accompanied by a measurement of discharge. For water surface level calibration it is not necessary that discharge be measured at each cross-section in the reach - clearly an estimate based on an average of discharges measured at a number of cross-sections may be more accurate than a single measurement.

In order to simulate water surface profiles over a wide range of discharges, field observations should cover as wide a range of discharges as possible, preferably a low, medium and high discharge.

Before water surface level calibration is commenced the observed water surface profiles should be plotted with the thalweg profile and reviewed for obvious survey error, as shown in Figure 6.2. We have found in practice that measurement of water surface profiles is the most common source of survey error. Errors may be minimised by repeated observation in the field and by sighting to more than one survey peg when the water surface level is surveyed. Increasing accuracy in water surface profile measurement can greatly reduce resource effort in the calibration procedure and provide more accurate results.

As mentioned above we have a choice of three models, IFG4, MANSQ and WSP for simulating water surface profiles. In some cases we may use a combination of two or all three models. Models used for calibration of the data used in this assessment are given in Table 6.1 below

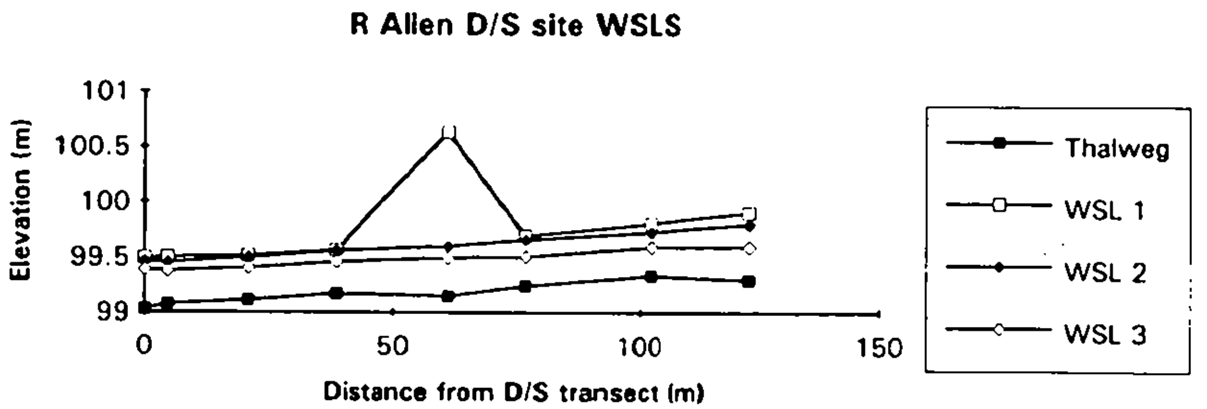


Figure 6.2 *Survey Error In Water Surface Profile Measurement*

Table 6.1 *Hydraulic Models Used for Water Surface Profile Simulation*

Model used fo calibration			
River	**IFG4**	**WSP**	**MANSQ**
Exe	X		
Wye	X		
Hodder	X		X
Blithe	X	X	
Itchen	X		
Lymington	X		X
Frome (Millstream)	X		
Lambourn	X	X	
Gwash	X		
Gt. Ouse & Lees Brook			

It may be noted from Table 6.1 that simulation never uses the WSP model alone. This is because the WSP model is a step-backwater model and requires starting values of the water surface profile at the most downstream cross-section in the reach to be supplied as input data. For this reason the stage-discharge relationship at the most downstream cross-section must be simulated using IFG4 or MANSQ.

The different hydraulic models require different levels of user effort in the calibration process:

IFG4 is relatively straightforward and the user has little control over the output. MANSQ is somewhat more time-consuming to calibrate than IFG4. At each cross-section a calibration parameter must be selected on the basis of guessing iteratively to fit observed values.

WSP is definitely the most time-consuming model to calibrate. The WSP model is the only model in which water surface levels at neighbouring cross-sections are dependent; changing calibration parameters selected for a single cross-section can change simulation results for the whole reach. To calibrate WSP values of Manning's n are chosen to fit one of the observed water surface profiles. Dependency of the cross-sections can make this time-consuming. (An automated program to carry out this step has been made available by Dr Thomas Hardy of the US Fish & Wildlife Service but has yet to be tested). After calibrating Manning's n values to the single water surface profile, further calibration parameters must be assigned. These parameters are known as 'roughness modifiers' and are chosen to mimic the anticipated change in Manning's n with discharge. Within PHABSIM this step is not automated nut may be achieved rapidly using a spread-sheet to analyse model outputs. Although WSP is the most time-consuming model to calibrate it is in some instances the only model which will give sensible output, and it is the only model which can simulate backwater effects.

The approach recommended to minimise effort in water surface profile calibration is as follows :

(i) Run IFG4 Program over full range of simulation discharges and review outputs. If output error statistics and plotted profiles are acceptable this step is complete. If for certain cross-sections errors are too large and water surface levels look unacceptable then:

(ii) Run MANSQ over the same range of simulation discharges. Calibrate the model for the unacceptable cross-sections from (i) and review outputs. If they are still unsatisfactory then

(iii) Calibrate the WSP model and simulate for the full range of simulation discharges (using output from (i) or (ii) to provide starting values of the water surface level at the most downstream cross-section.)

6.2.3 Velocity Calibration and Simulation

The next phase is the calibration and simulation of velocities at points across each transect using the water surface profiles predicted as output from the water surface profile simulations. For velocity simulation we use the IFG4 model (WSP can simulate velocities but is extremely difficult and time-consuming to calibrate). The approach we have found most successful is that recommended by the US Fish & Wildlife Service. IFG4 is calibrated using a single set of velocity measurements made at each point across all of the cross-sections at a single calibration flow. The best results are obtained if these measurements are made at the highest calibration flow. In the calibration of velocities there are no calibration parameters to choose, hence this step requires little effort.

The IFG4 model is automatically calibrated by solving Manning's equation using observed values from the single calibration flow and assigning a calibration value of Manning's n to each velocity data point. At the simulation discharges velocities are predicted by solving Manning's equation using the water surface levels predicted as described in 6.2.1, and the calibration value of Manning's n. These predicted velocities are then scaled by a parameter called the Velocity Adjustment Factor (VAF) so that a discharge balance is achieved. The theoretical shape of the Manning's n versus Discharge (Q) and consequent VAF vs Discharge relationship are shown in Fig 6.3 below.

Having run the IFG4 program to simulate velocities the VAF vs Q relationship at each cross-section should be plotted and reviewed. If the relationship for certain cross-sections does not conform to the expected shape the water-surface level simulation should be reviewed, together with the velocity calibration data. A different choice of water surface level model at the offending cross-sections may yield a more realistic velocity simulation. Once again, the VAFs are best reviewed using a spread-sheet.

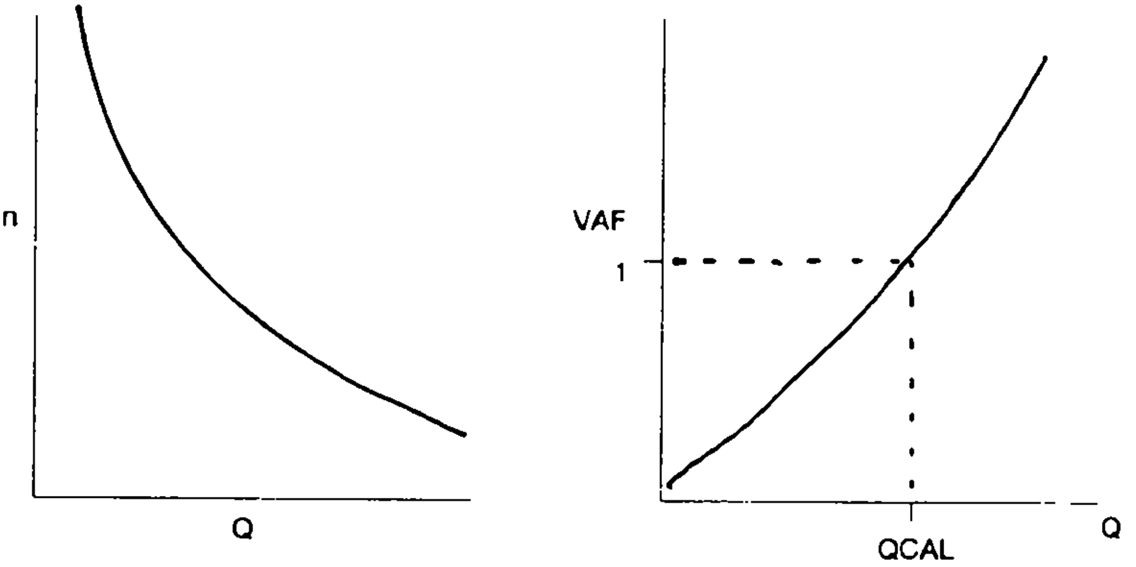


Figure 6.3 *Theoretical Shape of n vs Q and VAF vs Q*

6.3 HABITAT MODEL CALIBRATION AND SIMULATION

A number of different habitat models are available within PHABSIM. We have used only one model - the HABTAT model. The user must specify the type of Composite Suitability Index used in the calculation of Weighted Usable Areas (see Section 2.1): we have chosen the multiplicative index throughout. Upstream Weighting Factors (see Section 2.1) which control the dimensions of cell areas in the habitat calculations have been set to the default value of 0.5. Assessment of the sensitivity of output to the choice of these parameters is being undertaken under the NERC Science Vote Project 'Modelling Floral and Faunal Response'.

Habitat Simulations can be run simultaneously for all target species, hence the habitat calibration and simulation phase can be completed in a single keystroke (assuming all habitat suitability data and hydraulic simulation outputs are loaded). The HABTAT output file is well formatted and easily imported to a spread-sheet for plotting data.

7. Results of PHABSIM simulations

7.1 TARGET SPECIES SELECTED FOR EACH SITE

In order to limit the number of model simulations and outputs to a practical level it was decided that the most appropriate two fish, invertebrate and macrophyte species be selected as target species for simulations using data from each study site. For some sites only a single fish and macrophyte species were chosen if no other possible choice of species were present in significant numbers in recorded occurrence data. Target species selected for model simulations at each site are listed in Table 7.1 below.

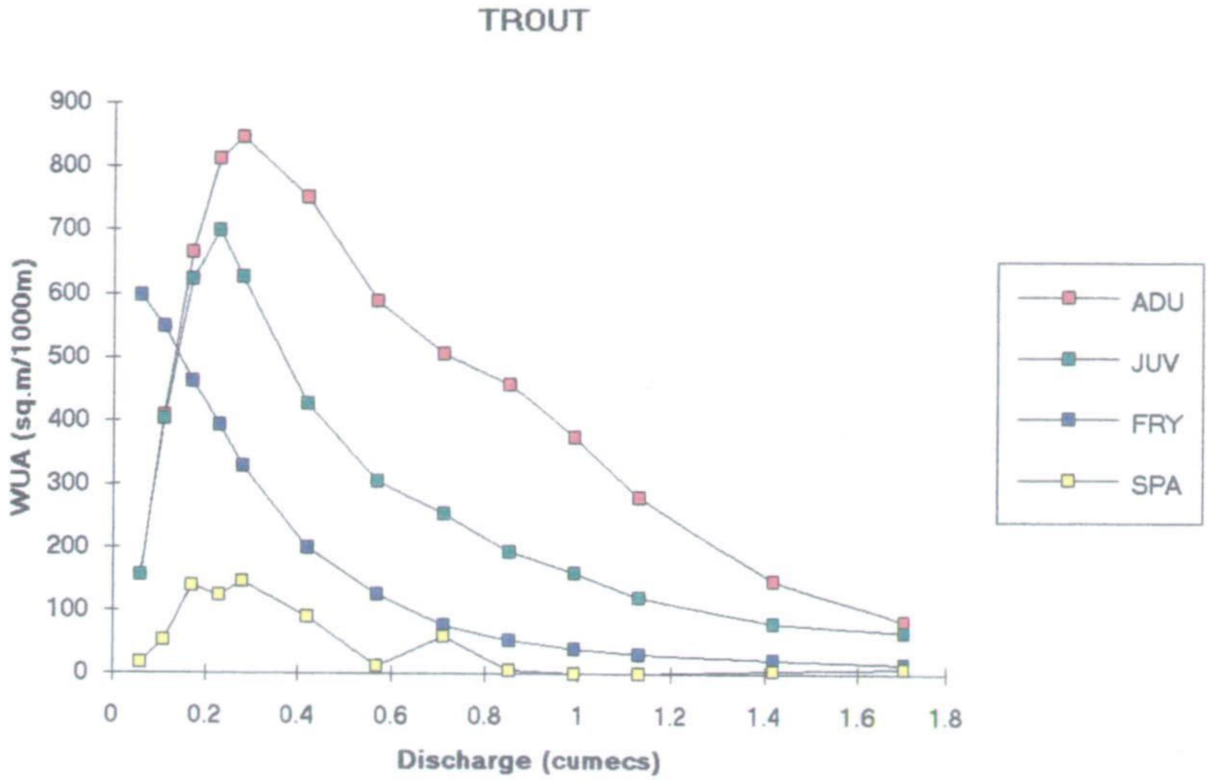
Table 7.1 *Target Species Selected for Each Study Site*

	Fish	**Invertebrate**	**Macrophytes**
Exe	Trout	Chloroperlidae *(A)* Leuctridae *(A)*	
Wye	Trout	Leuctridae *(A)* *Polycentropus Flavomaculatus*	*Ranunculus*
Hodder	Trout	Leuctridae *(A)* *Rhithrogenia Semicolorata*	.
Blithe	Dace Roach	*Gammaridae* (A) Polycentropus Flavomaculatus	*Nasturtium*
Itchen	Trout	*Gammarus Pulex (A)* Ephemeridae (A)	*Ranunculus* *Nasturtium*
Lymington	Trout	Gammaridae *(A)* Leuctridae *(A)*	*Ranunculus* *Nasturtium*
Millstream	Dace Roach	Gammaridae *(A)* Leuctridae *(A)*	*Ranunculus*
Lambourn	Trout	Gammaridae *(A)* *Rhyacophilia Dorsalis*	*Ranunculus* *Nasturtium*
Gwash	Trout	Gammaridae *(A)* *Sericostomatidae (A)*	*Nasturtium*
Gt. Ouse	Dace Roach	*Sphaerium Corneum* *Cragonyx Pseudogracilis*	*Nasturtium*
Lees-Brook	Dace Roach	*Sphaerium Corneum* *Cragonyx Pseudogracilis*	

7.2 HABITAT VS DISCHARGE RELATIONSHIPS

Using data from each study site the hydraulic models in PHABSIM were calibrated to predict water surface levels (and thus depths) and velocities for a range of simulation discharges. In order to retain consistency in the presentation of results the simulation discharges were chosen to cover the range from the 95 percentile to the 10 percentile exceedance flow (Using gauged records, adjusted by estimation where necessary). Details of hydraulic model outputs are given in Appendix C.

Simulated depths and velocities over the range of simulation discharges were coupled with Habitat Suitability Index data for the chosen target species in the PHABSIM HABTAT model. The HABTAT outputs give Total Available Habitat Area and Weighted Usable Area at the simulation discharges for each target species life-stage. HABTAT outputs for each study site are given in Figures 7.1 to 7.9 below. In figure 7.10 we give the corresponding total area vs discharge relationships. Results are not included for the Great Ouse and Lees Brook as it was not possible to achieve satisfactory calibration of the hydraulic model.



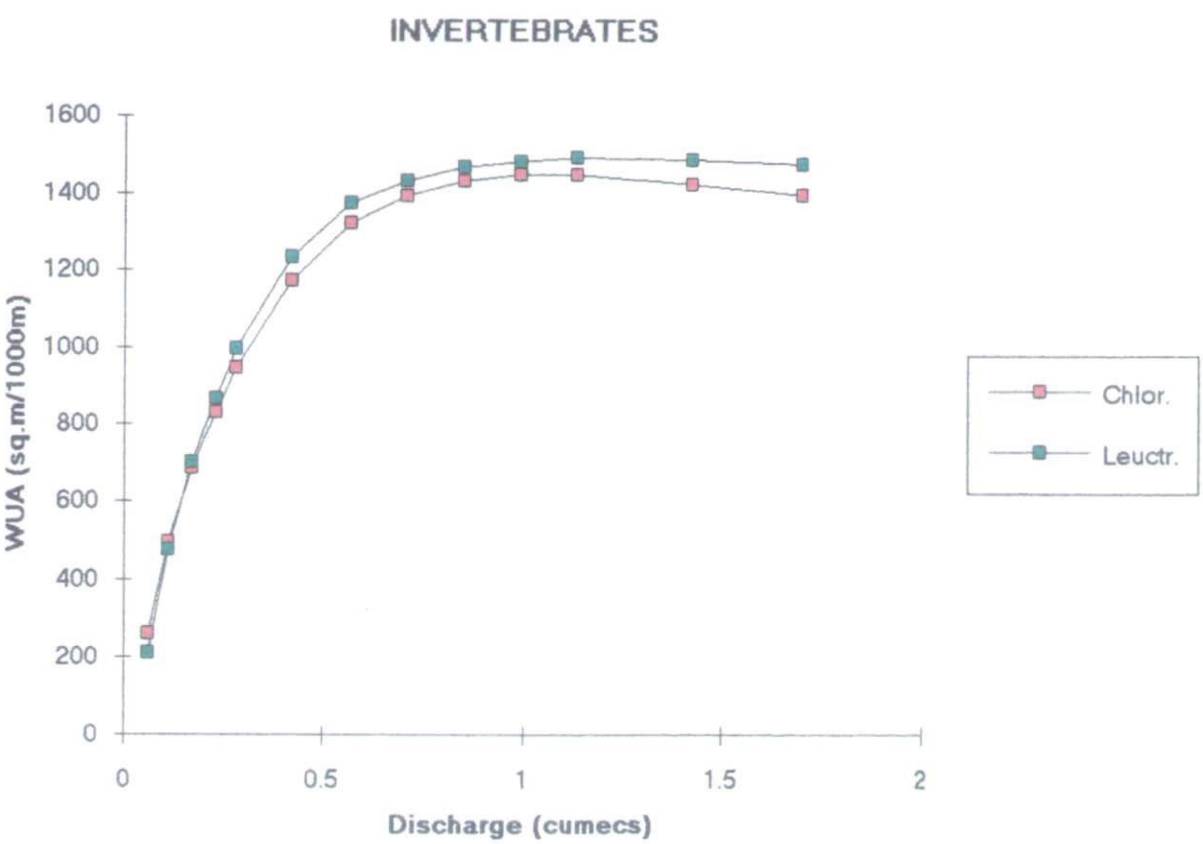
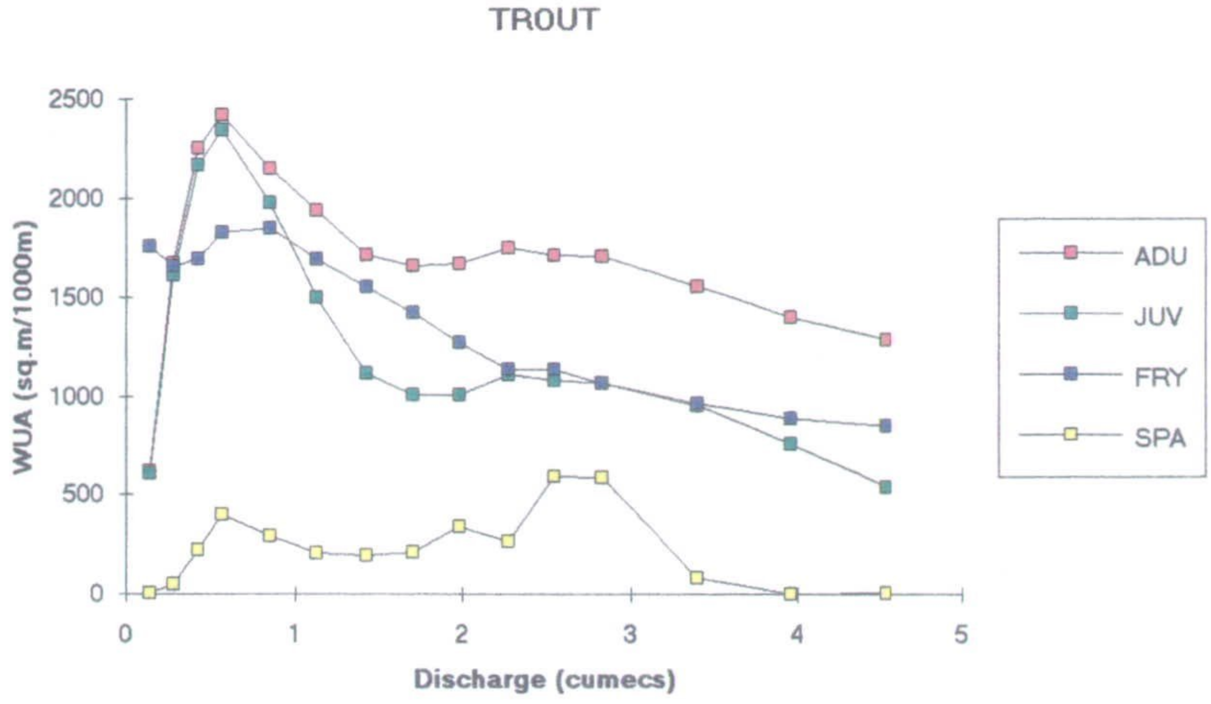


Figure 7.1 *Habitat vs Discharge Relationships : River Exe*



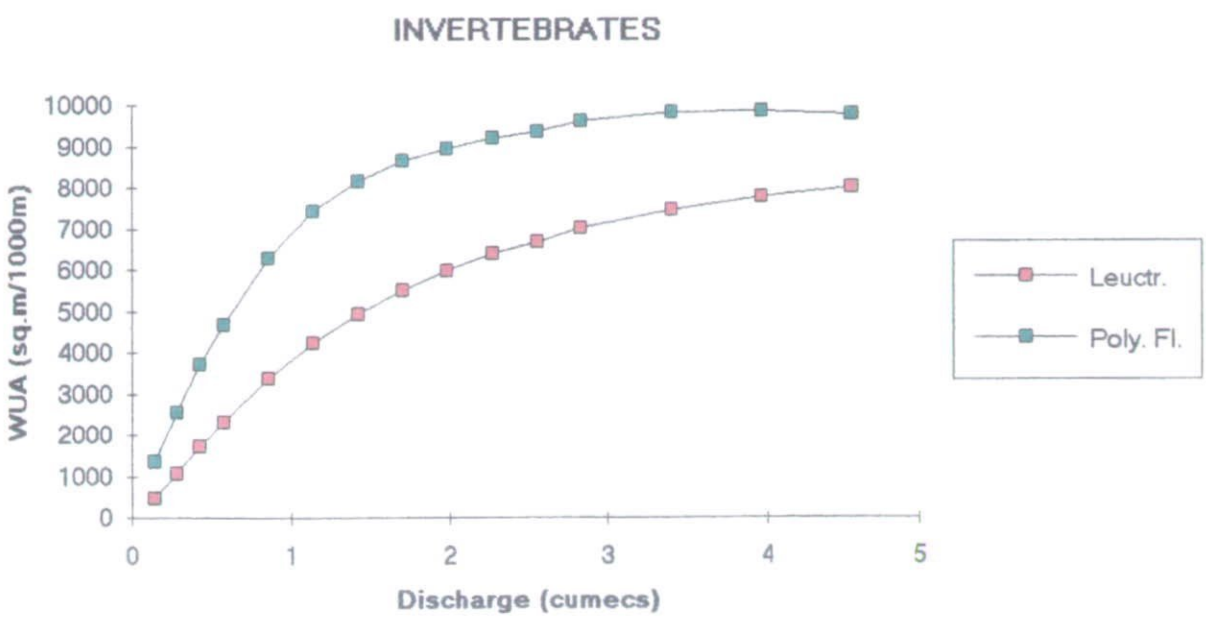


Figure 7.2 *Habitat vs Discharge Relationships : River Wye*

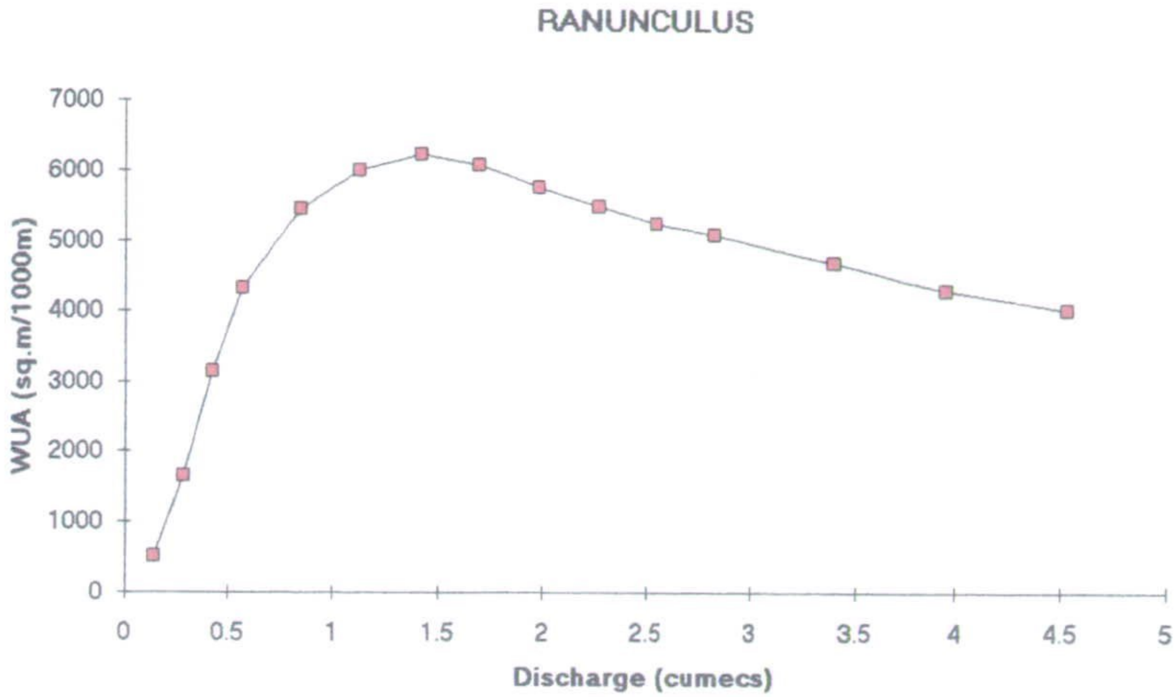
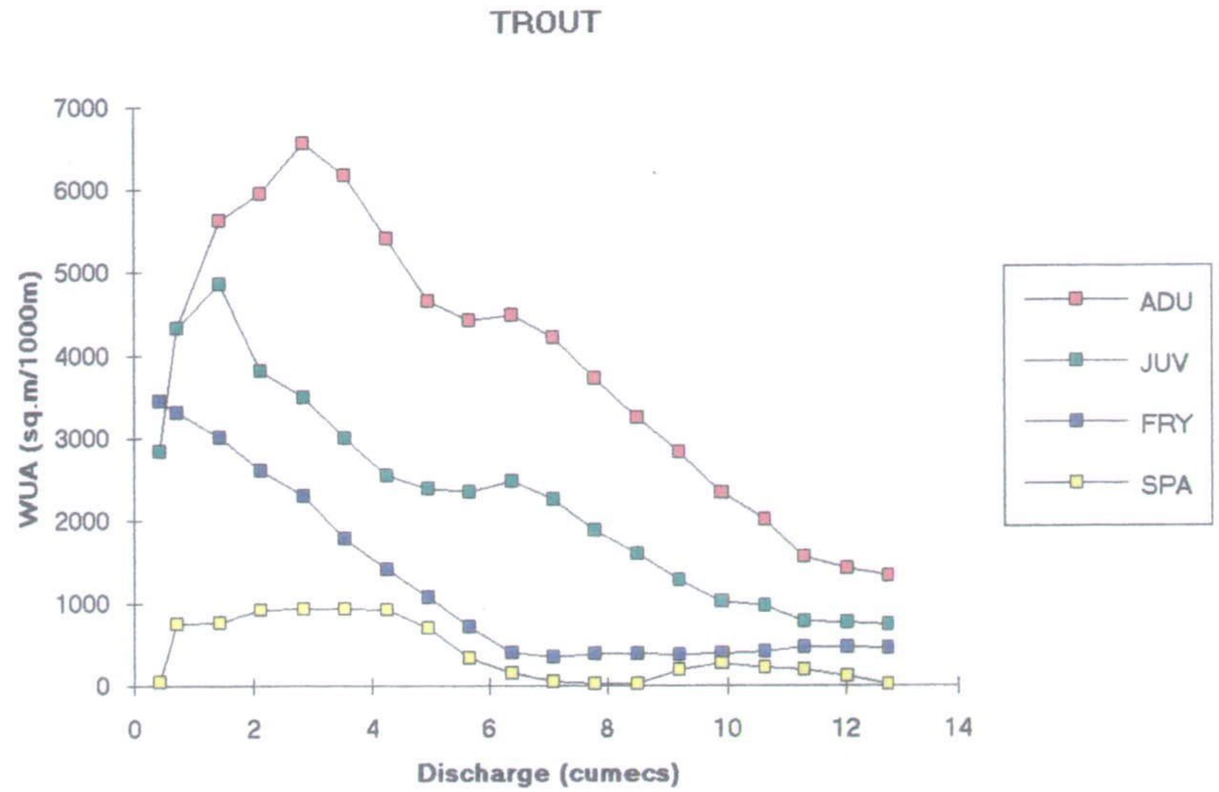


Figure 7.2 *Habitat vs Discharge Relationships : River Wye (contd.)*



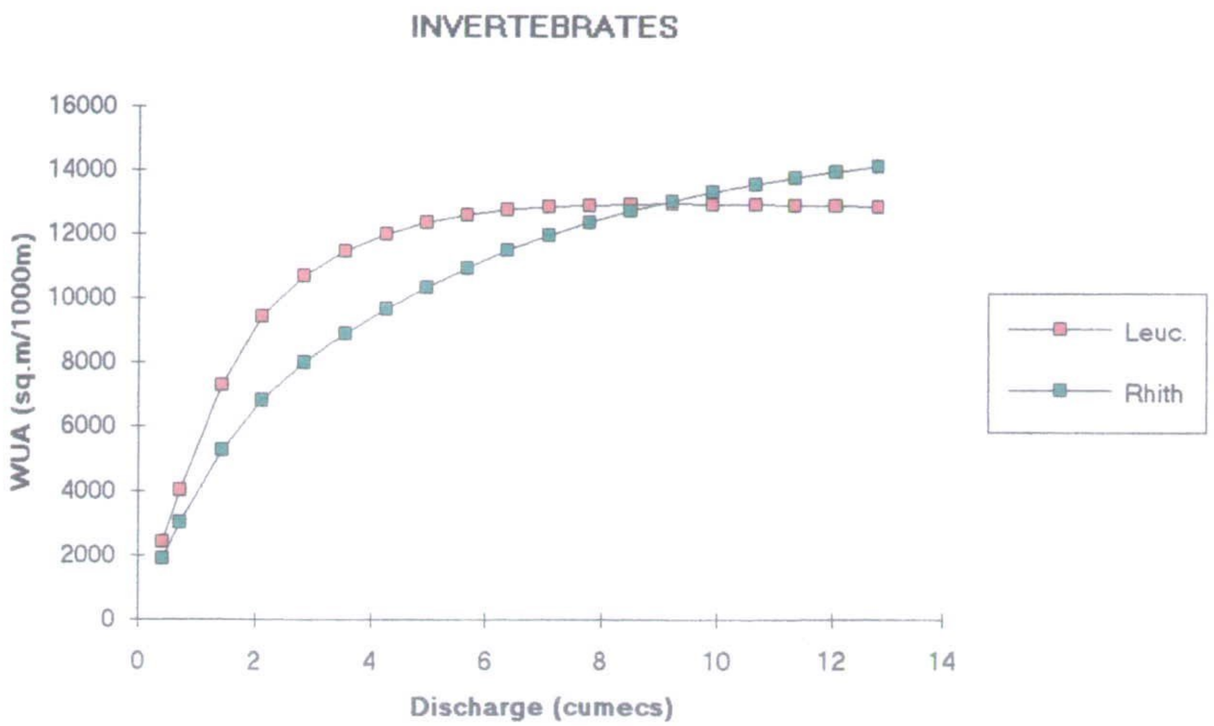
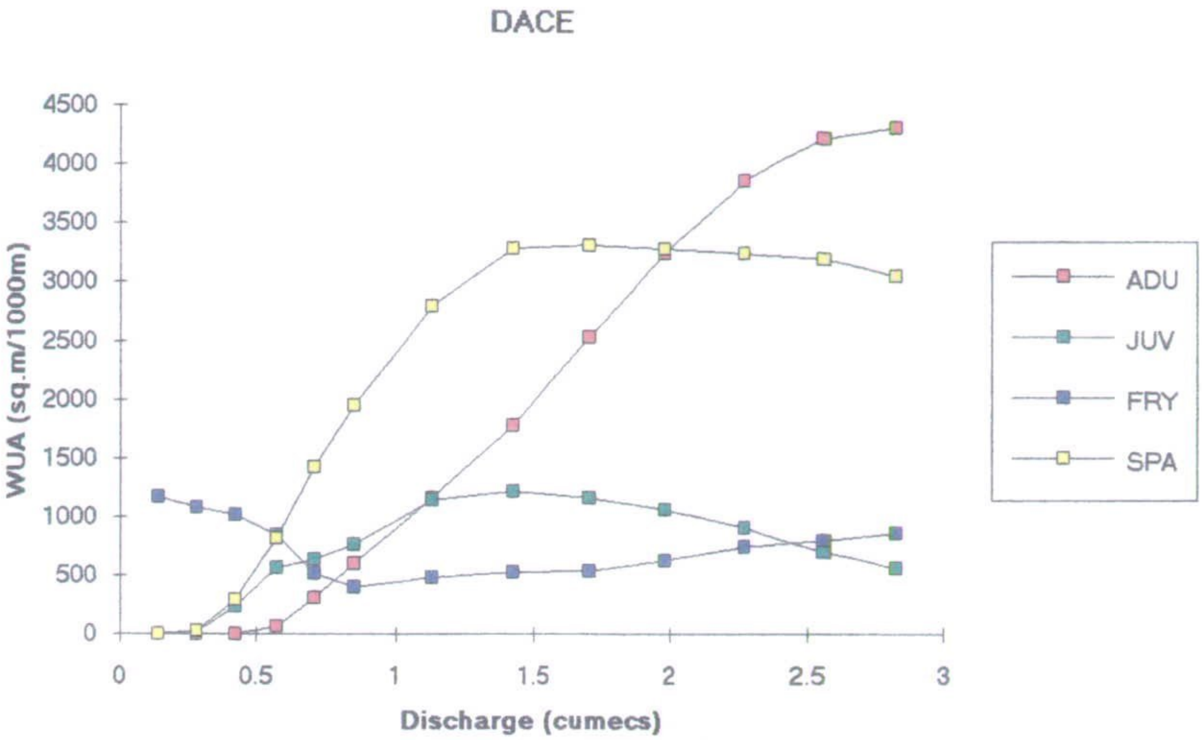


Figure 7.3 *Habitat vs Discharge Relationships : River Hodder*



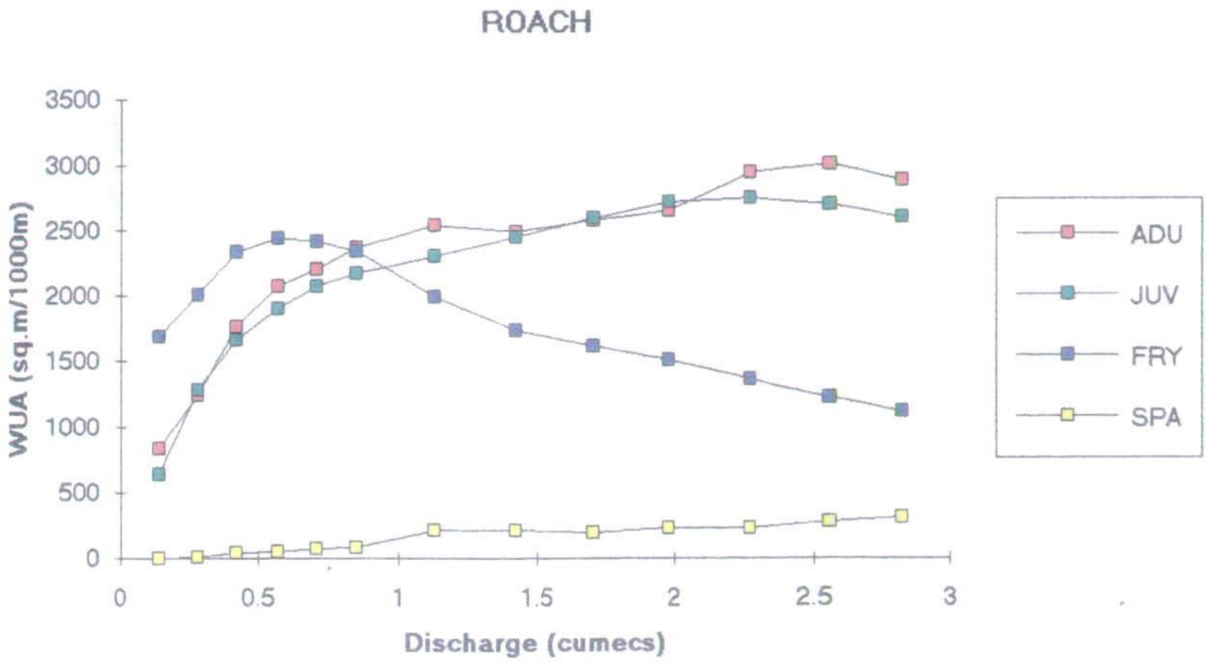
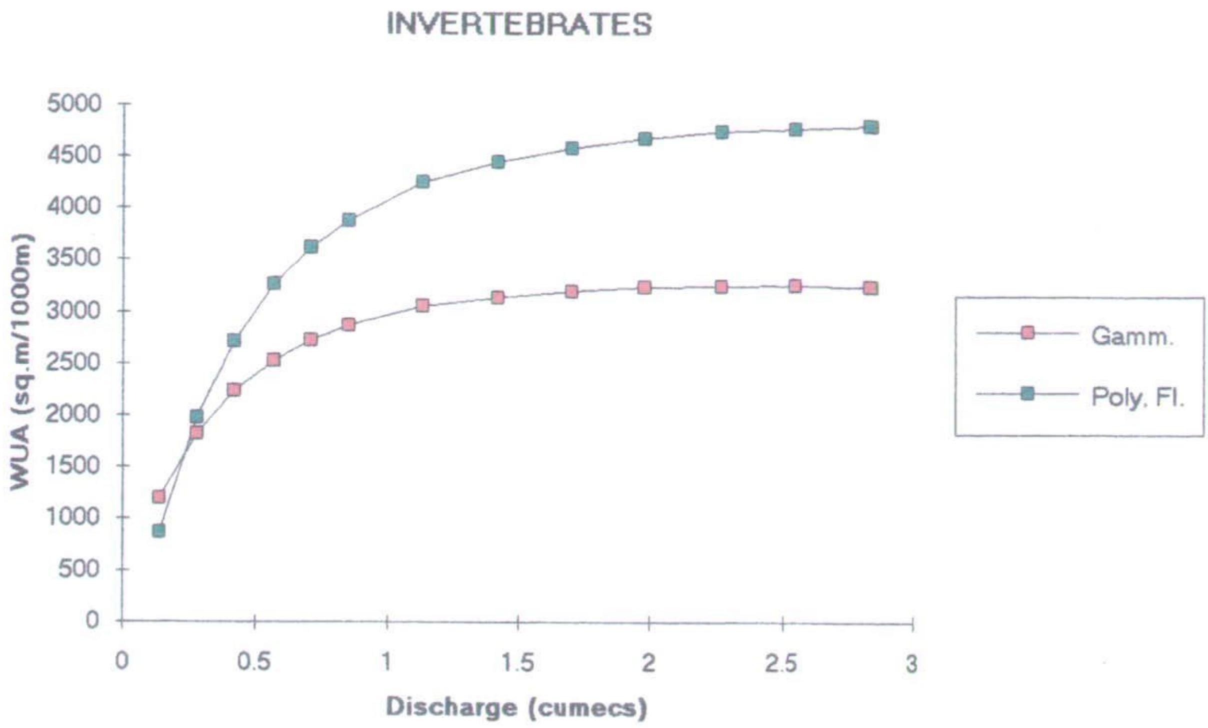


Figure 7.4 *Habitat vs Discharge Relationships : River Blithe*



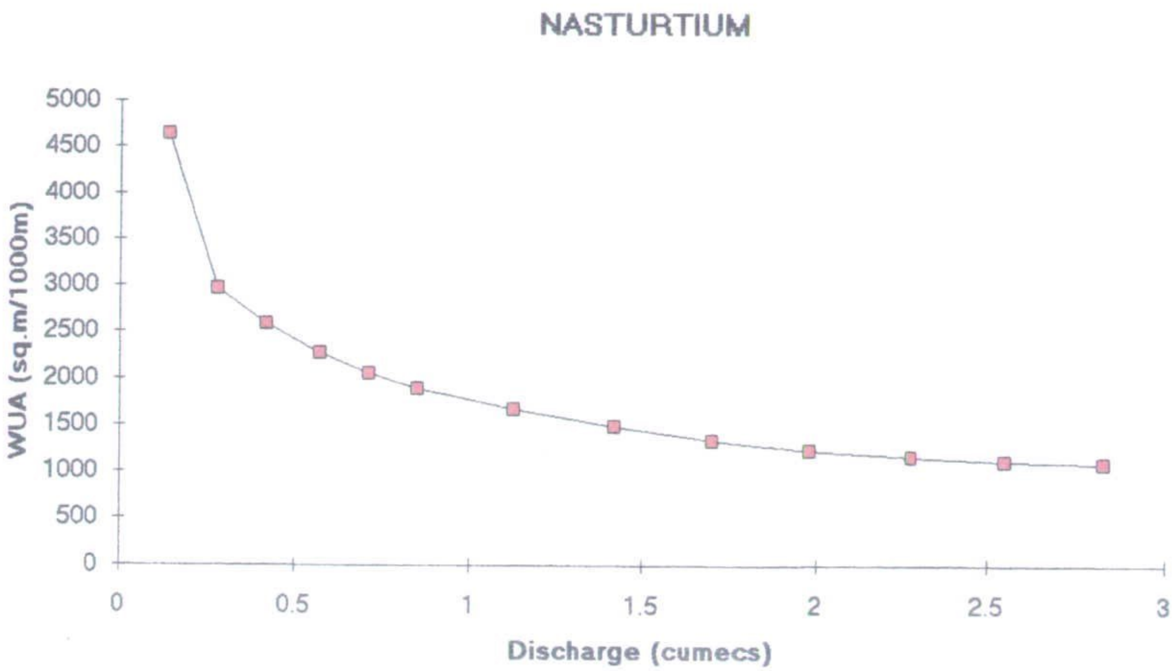
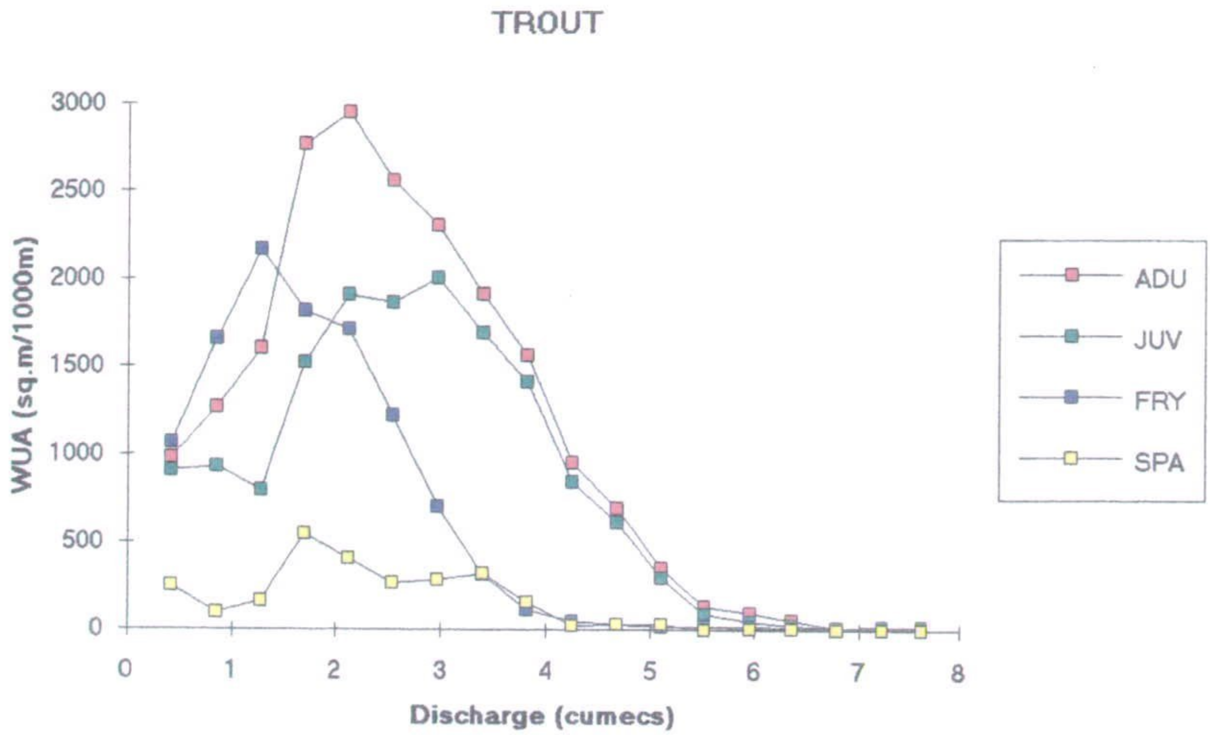


Figure 7.4 *Habitat vs Discharge Relationships : River Blithe (contd.)*



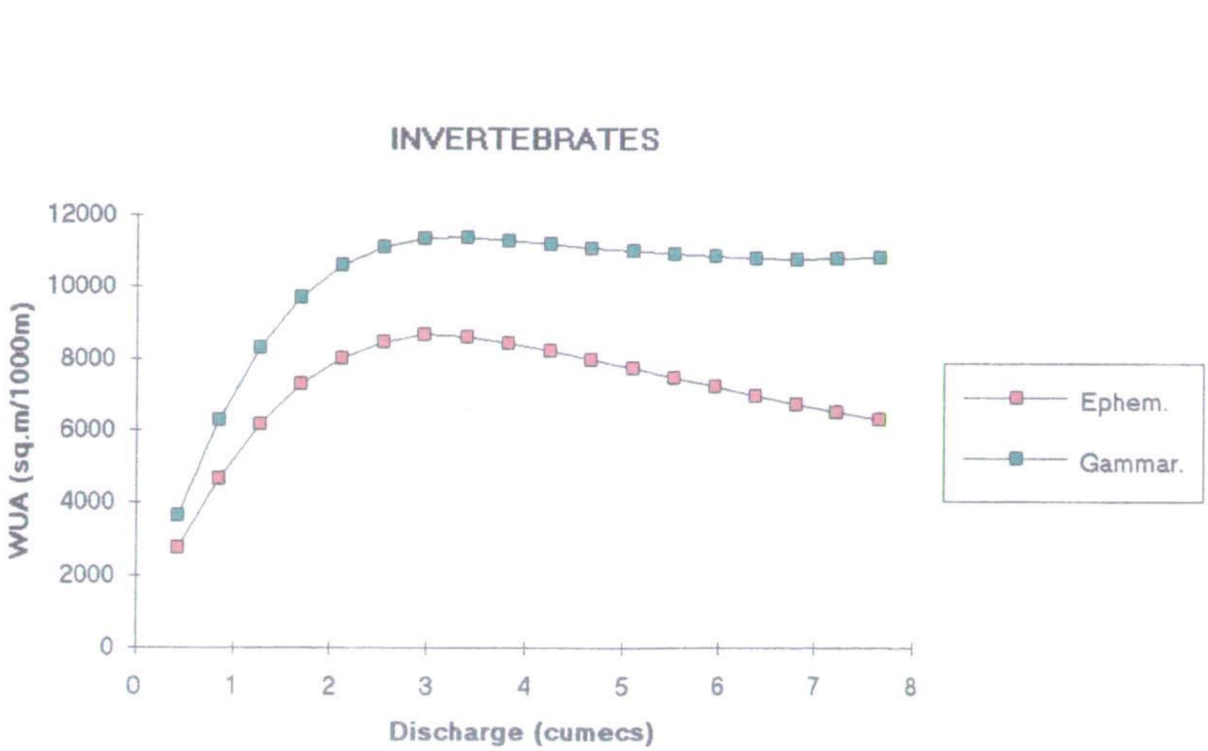


Figure 7.5 *Habitat vs Discharge Relationships : River Itchen*

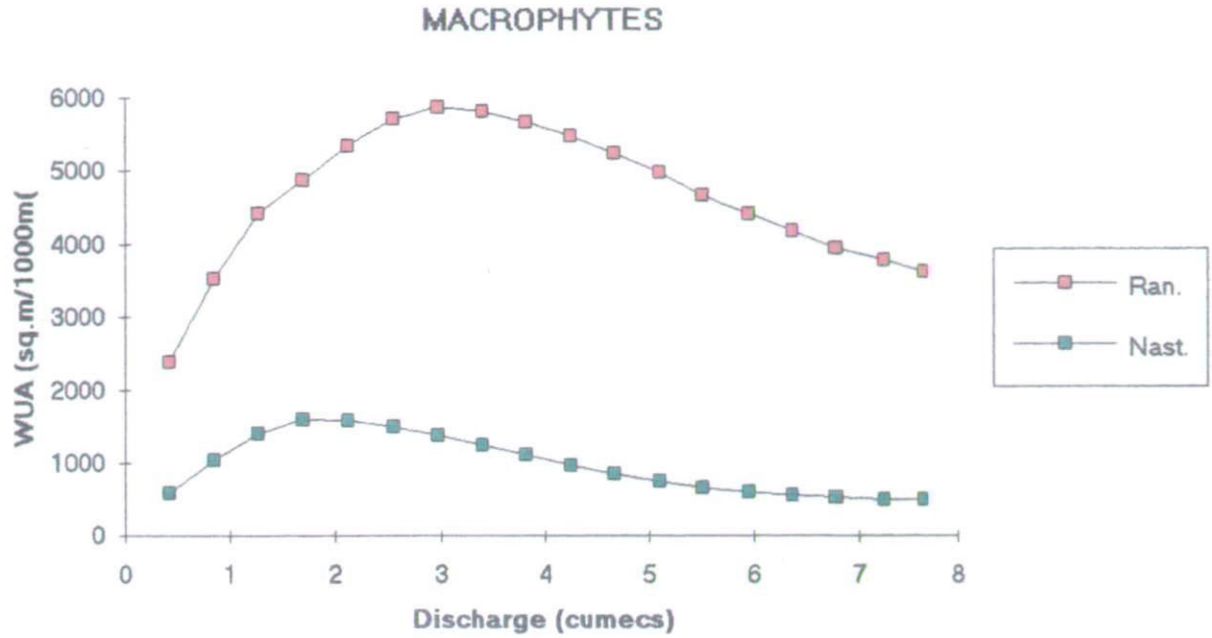
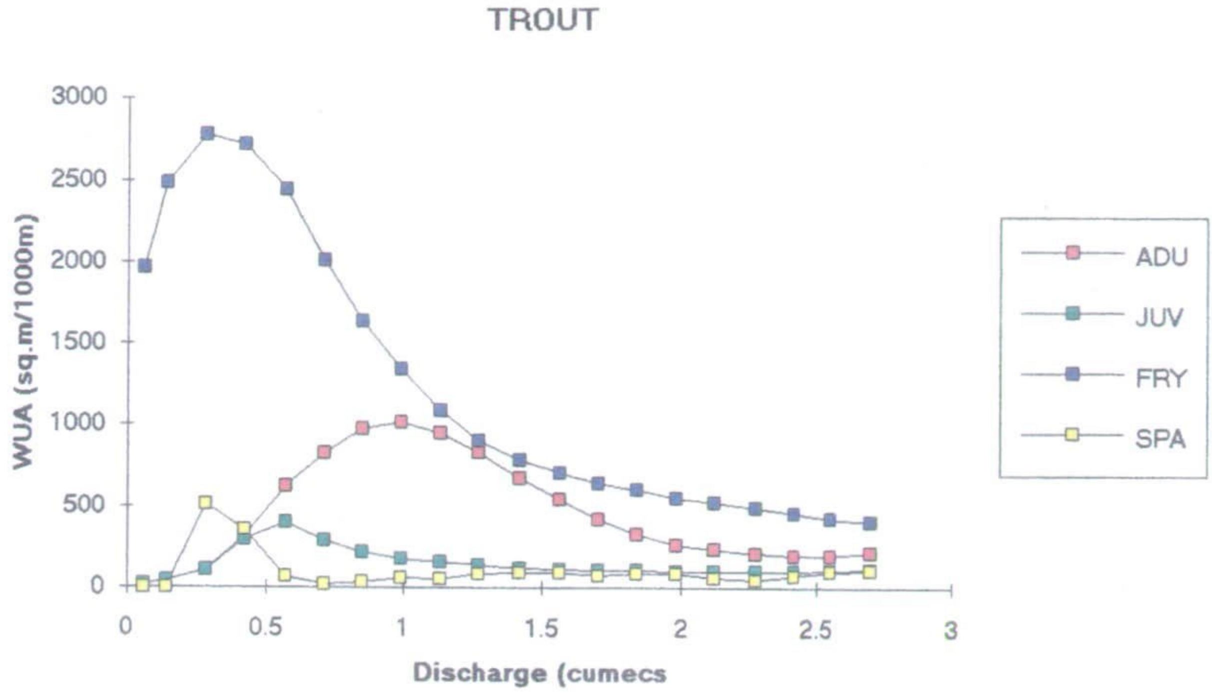


Figure 7.5 *Habitat vs Discharge Relationships : River Itchen (contd.)*



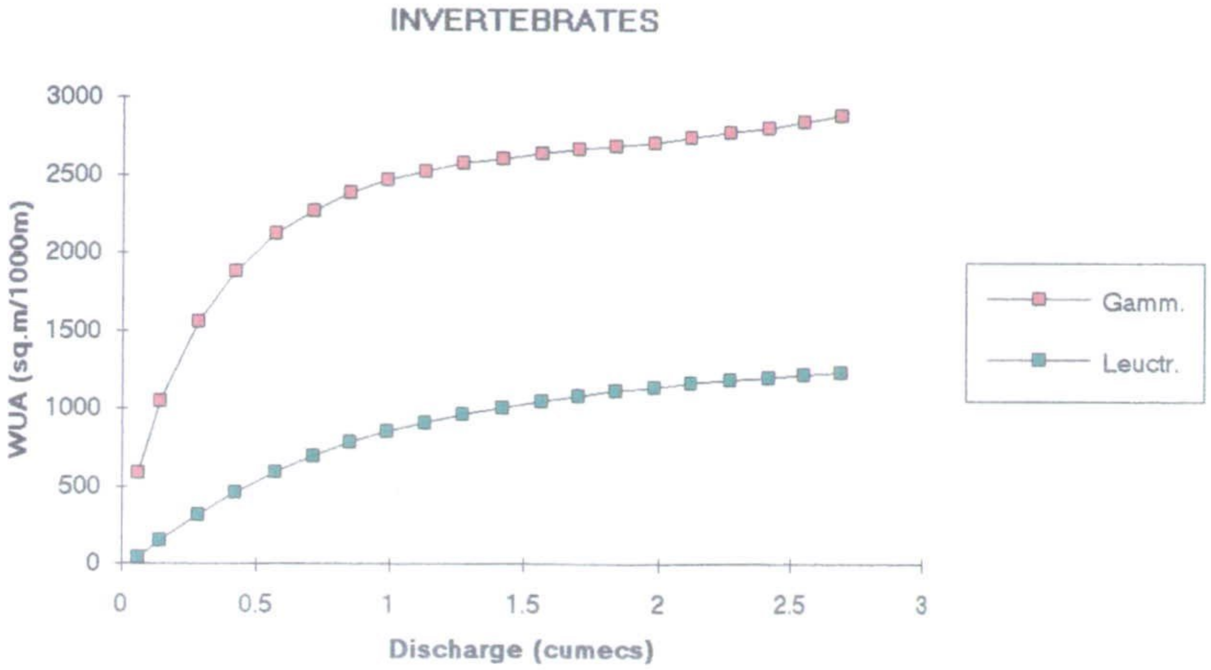


Figure 7.6 *Habitat vs Discharge Relationships : River Lymington*

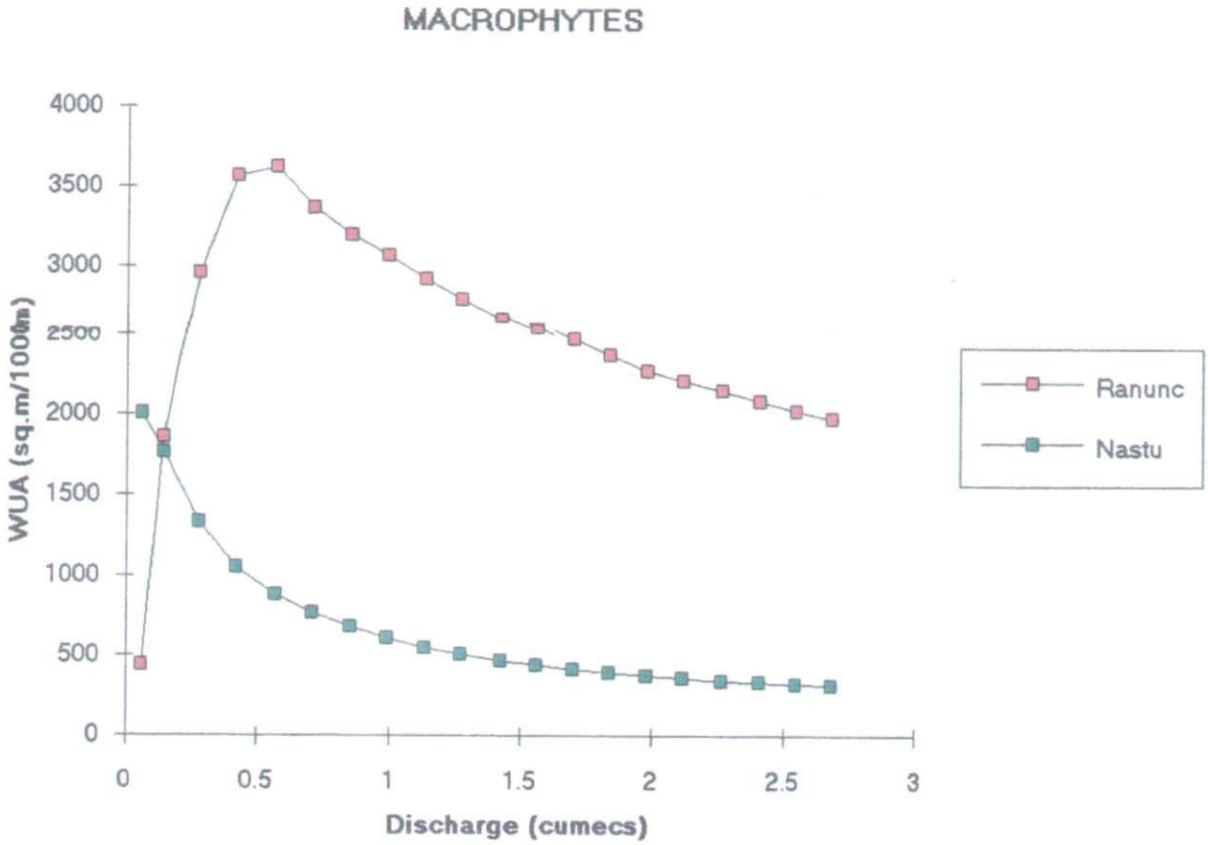
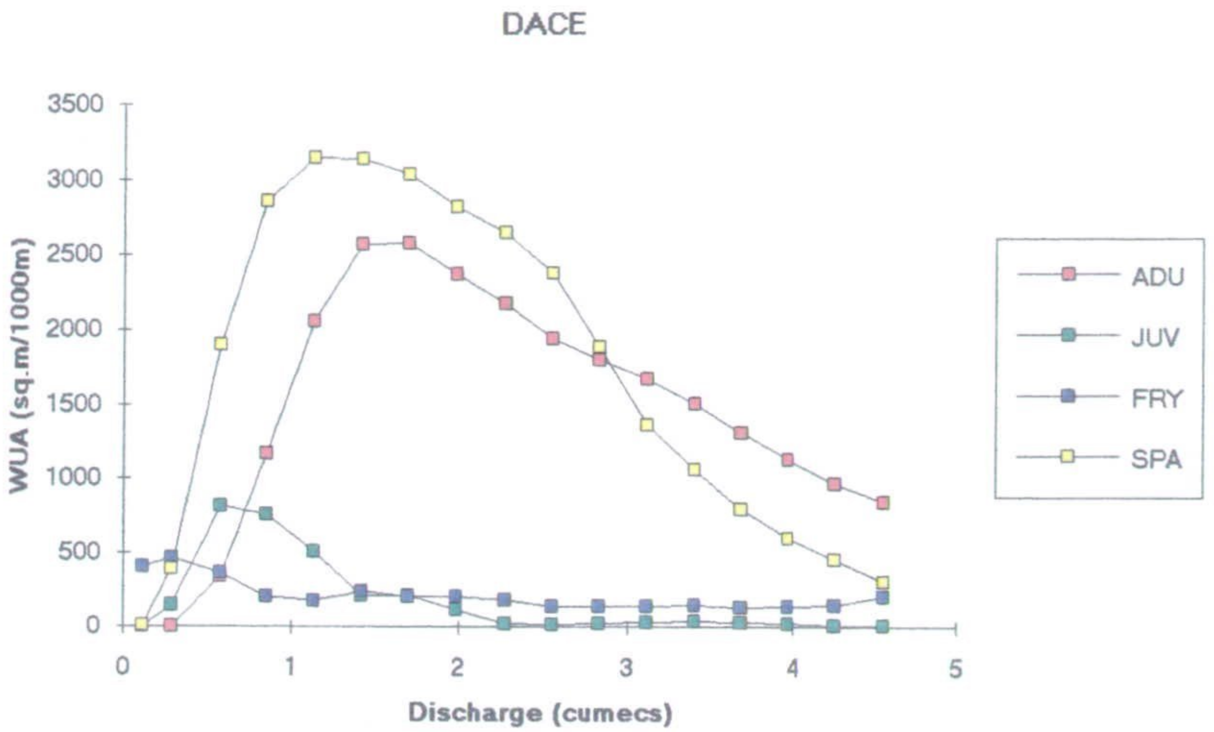


Figure 7.6 *Habitat vs Discharge Relationships : River Lymington (contd.)*



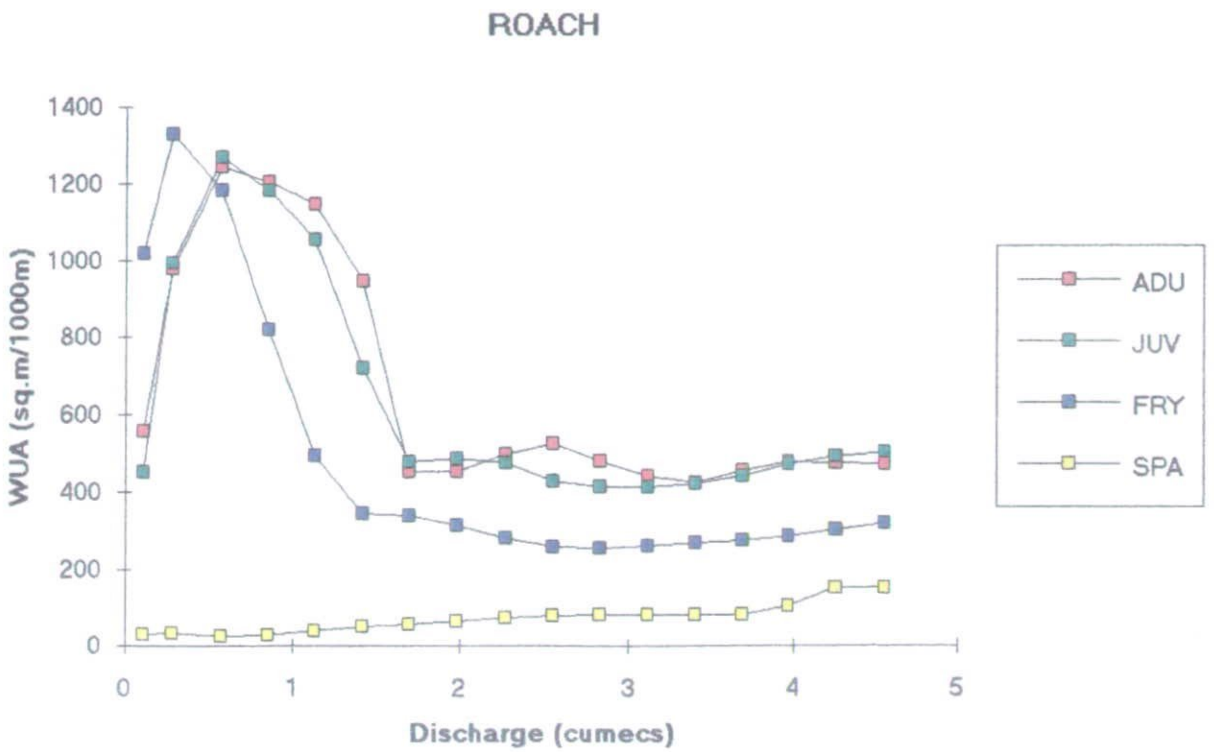
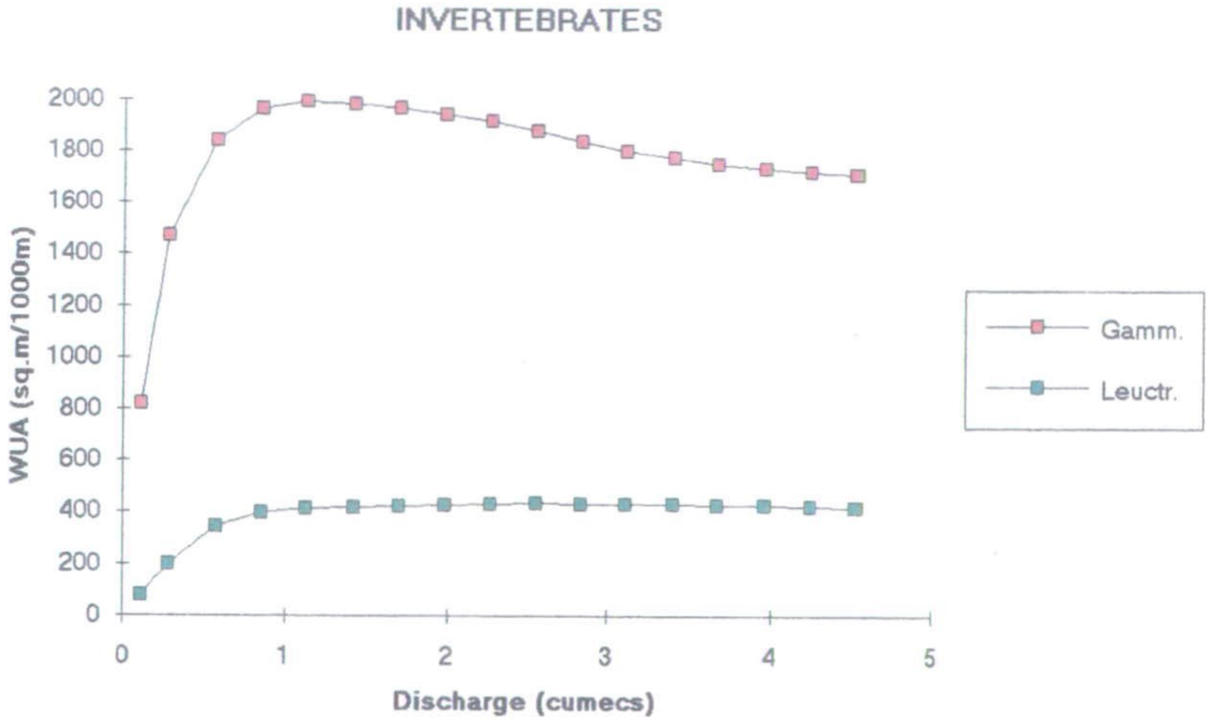


Figure 7.7 *Habitat vs Discharge Relationships : Mill Stream*



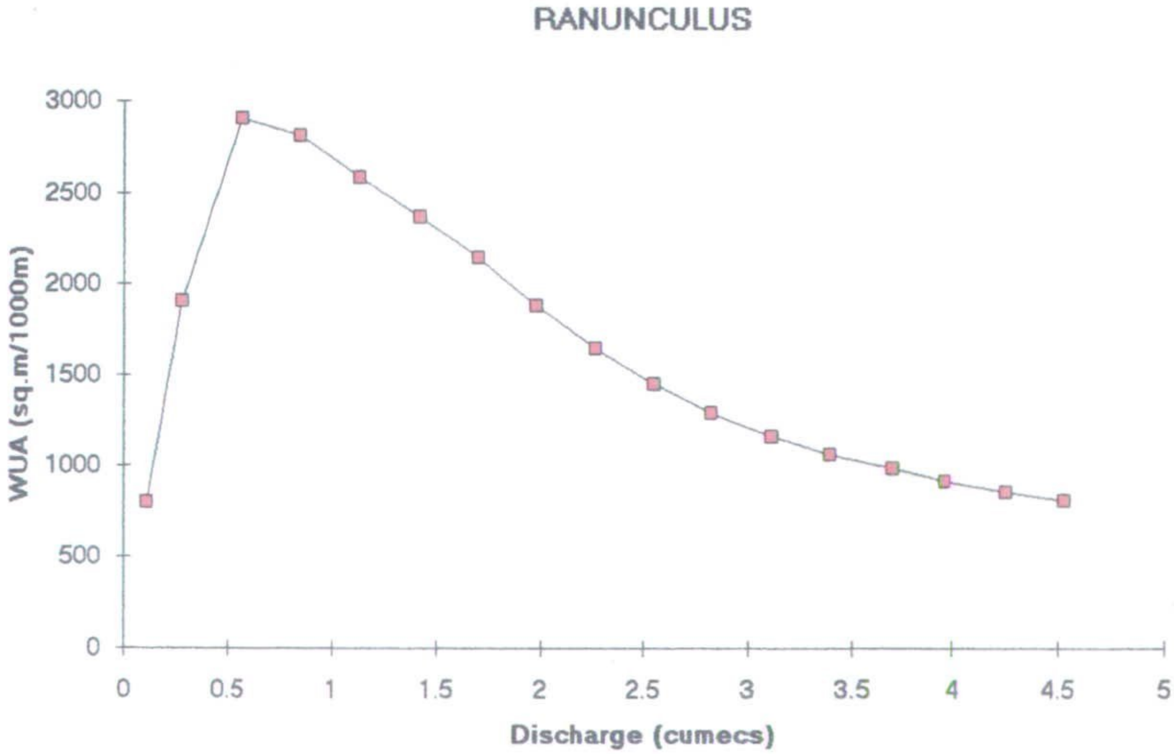
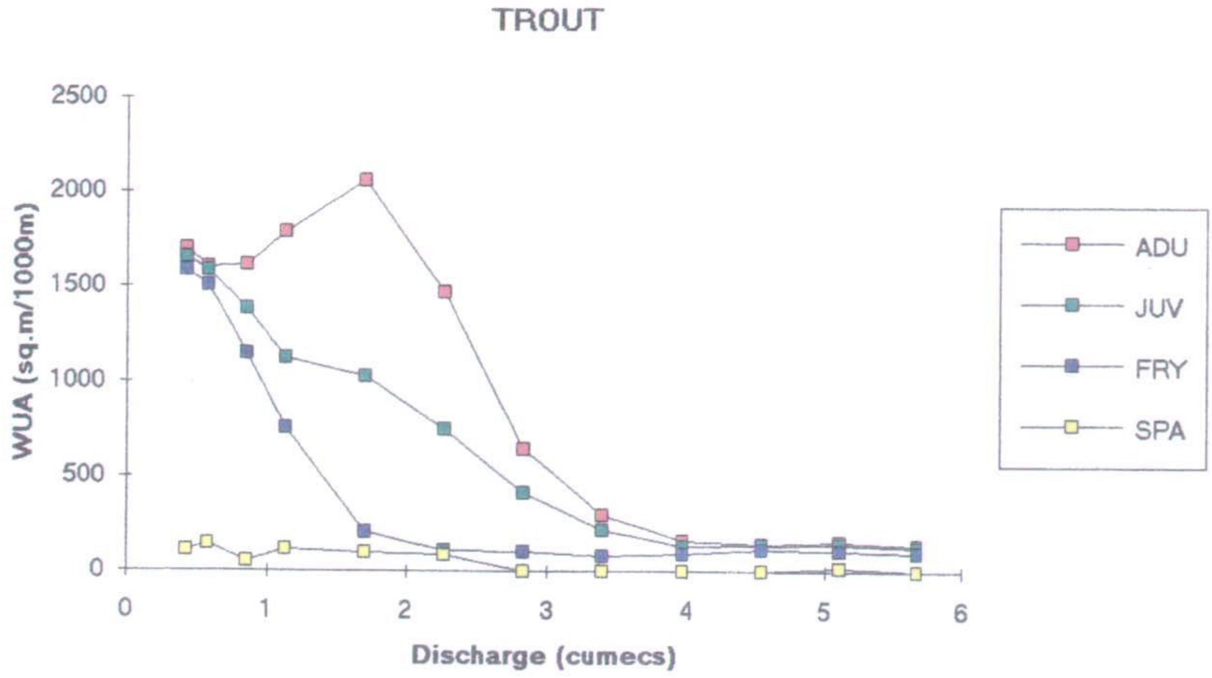


Figure 7.7 *Habitat vs Discharge Relationships : Mill Stream (contd.)*



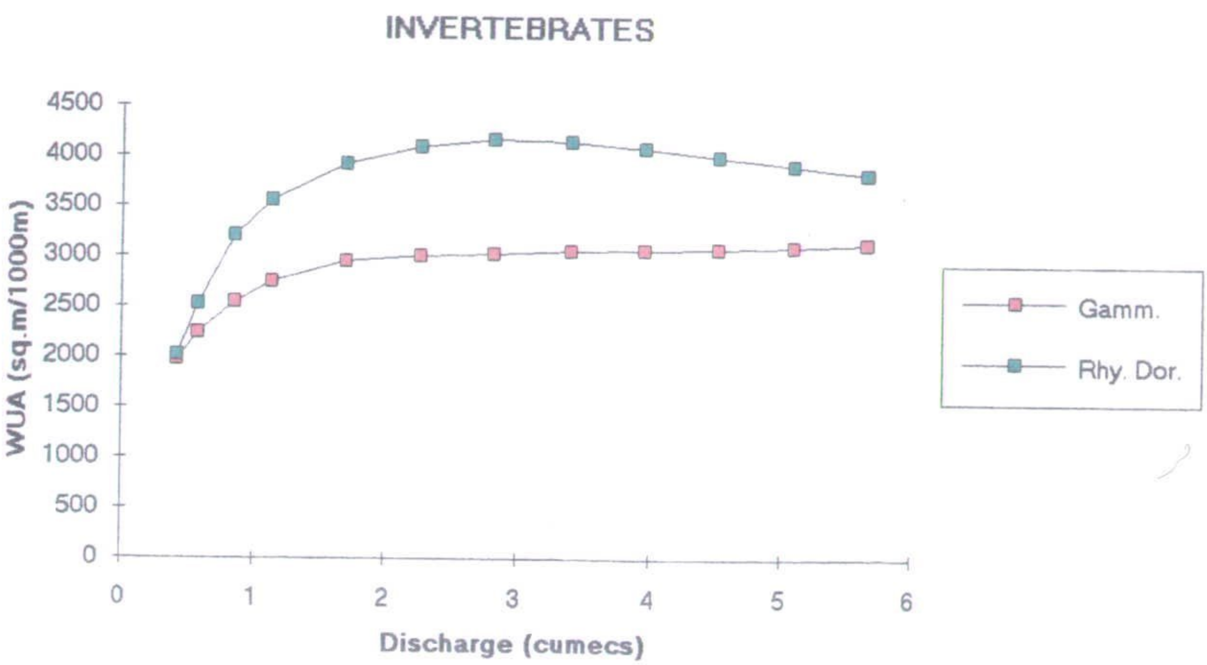


Figure 7.8 *Habitat vs Discharge Relationships : River Lambourn*

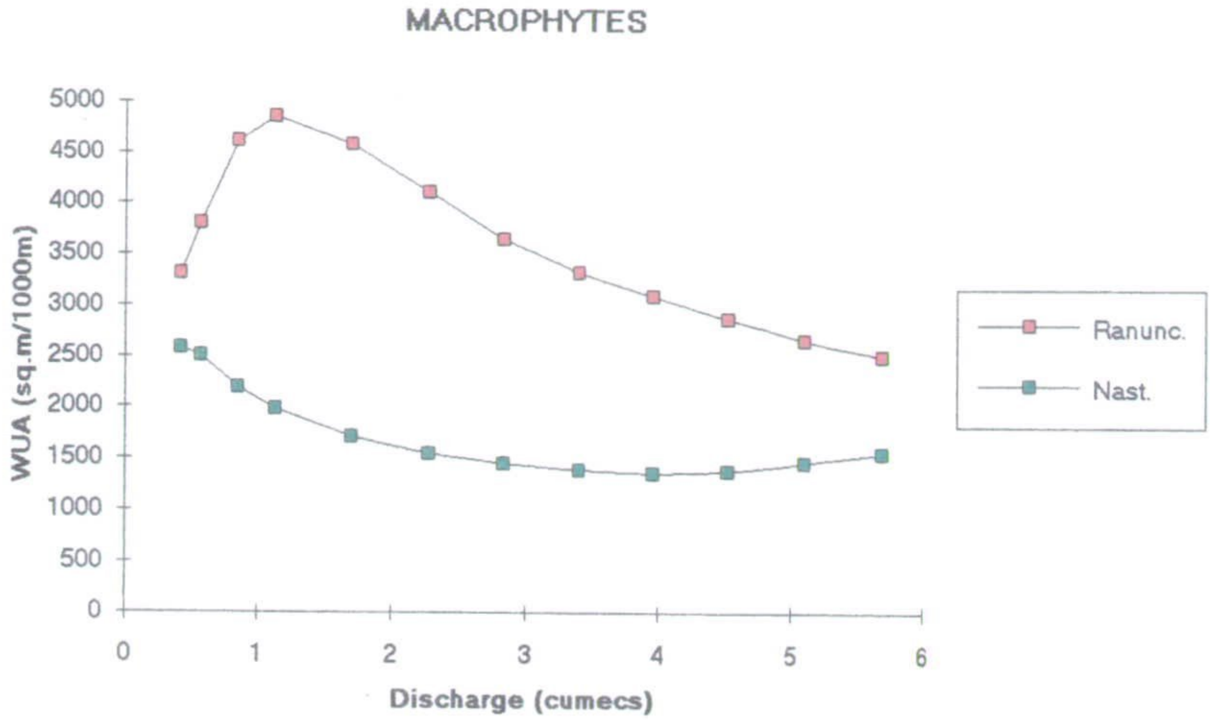
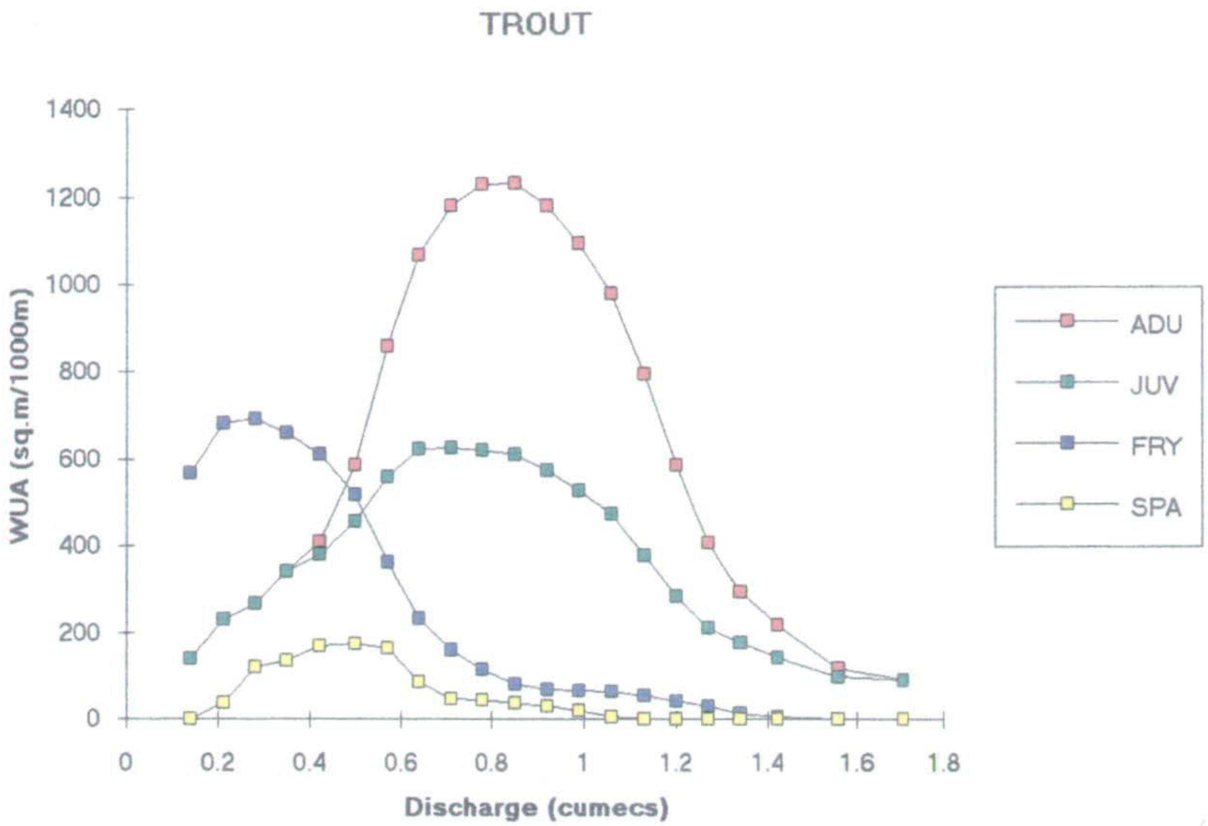


Figure 7.8 *Habitat vs Discharge Relationships : River Lambourn (contd.)*



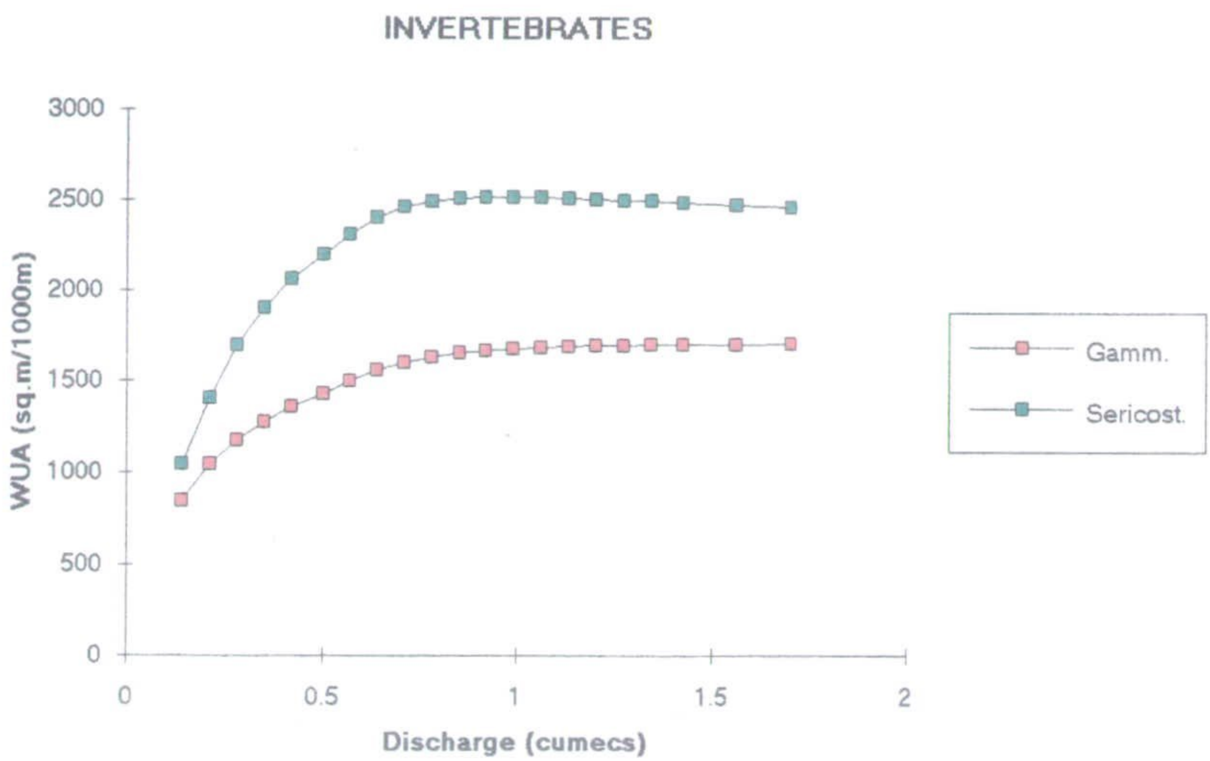


Figure 7.9 *Habitat vs Discharge Relationships : River Gwash*

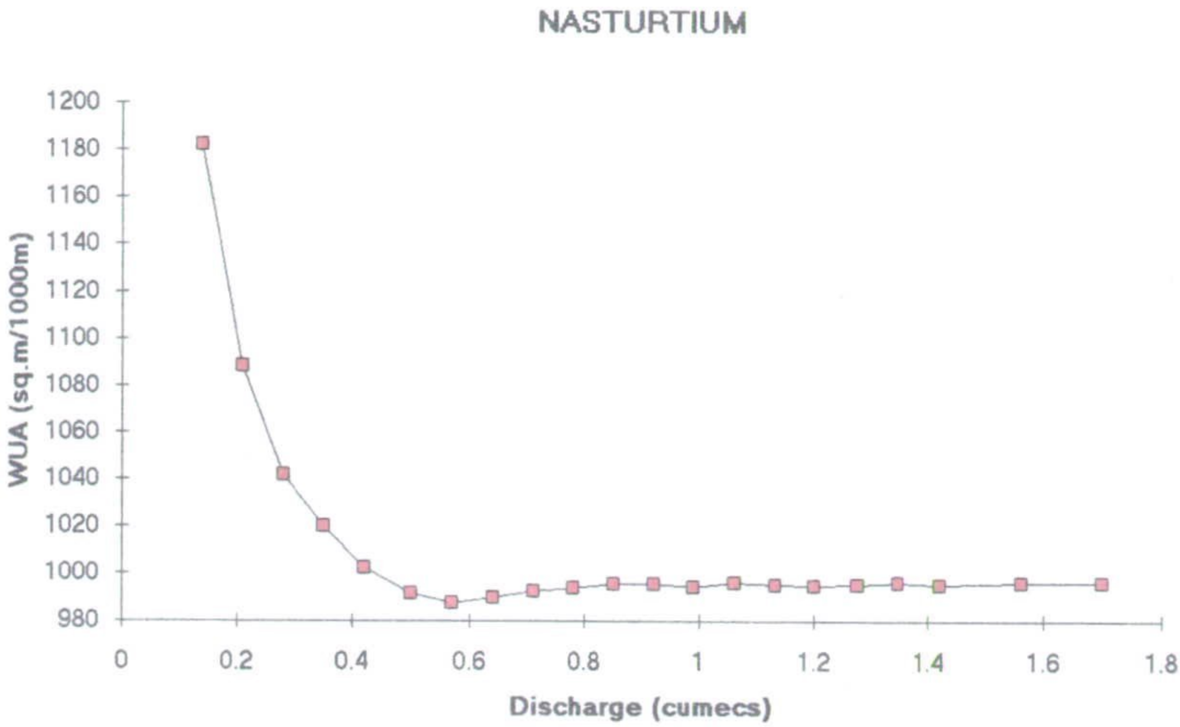


Figure 7.9 *Habitat vs Discharge Relationships : River Gwash (contd.)*

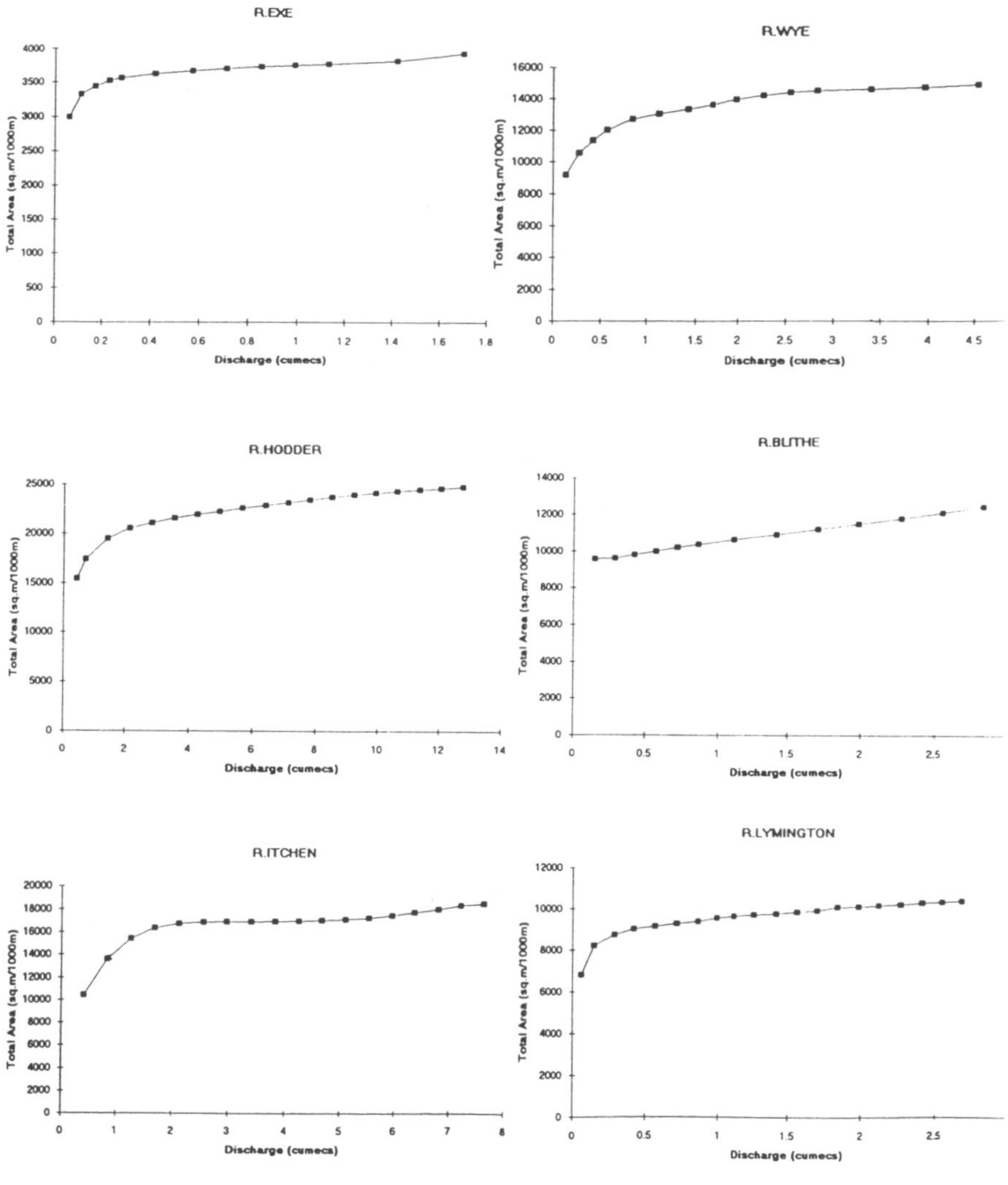
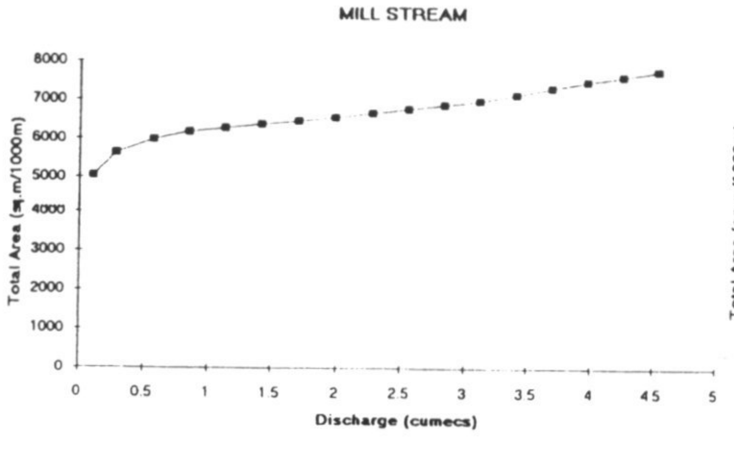
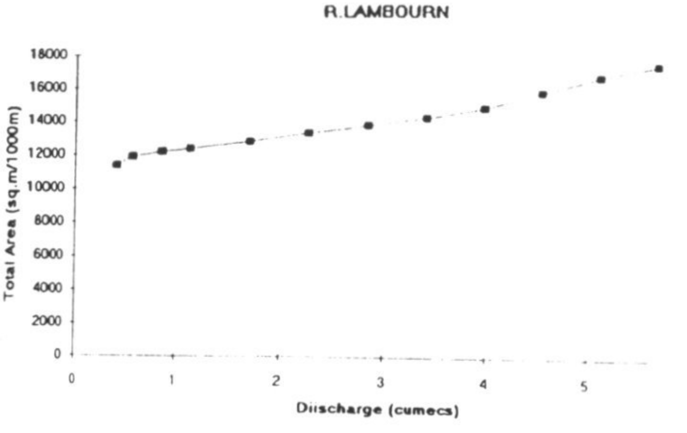


Figure 7.10: *Total Area vs Discharge Relationships*





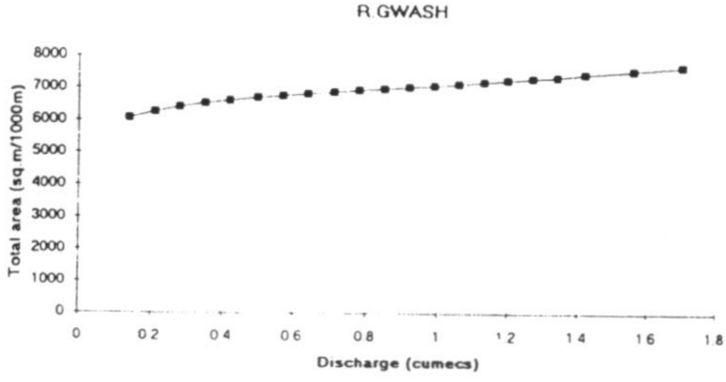


Figure 7.10: Total Area vs Discharge Relationships (contd.)

7.3 HABITAT DURATION CURVES : EXAMPLES - MILL STREAM

The results presented in the previous sub-section show the response of different target species life-stages to change in discharge over a wide range of discharges (10 percentile to 90 percentile exceedance discharges). In assessing the ecological flow requirements of a river we are interested in analysing the time variation of habitat availability in the context of the flow regime. Such analysis can be of great value in determining periods critical to habitat availability and in assessing the sensitivity of habitat availability to periods of unusually low (or high) flows.

In this section we shall present the results of such an analysis in the form of habitat duration curves for selected target species life-stages, using data from the Mill Stream The habitat discharge relationships shown in Figure 7.7 were coupled with a record of daily mean gauged flows over the period 1986-1991 to give time series of mean daily Weighted Usable Area for target species life-stages. These time series were analysed using a duration curve program.

For the sake of brevity output included here has been limited to the analysis of habitat availability for life-stages of dace. In Figure 7.10 we give the flow duration curve for the flow record used in this analysis. Corresponding habitat duration curves for Total Available Habitat Area and Weighted Usable Area for each life-stage of dace are given in Figure 7.11.

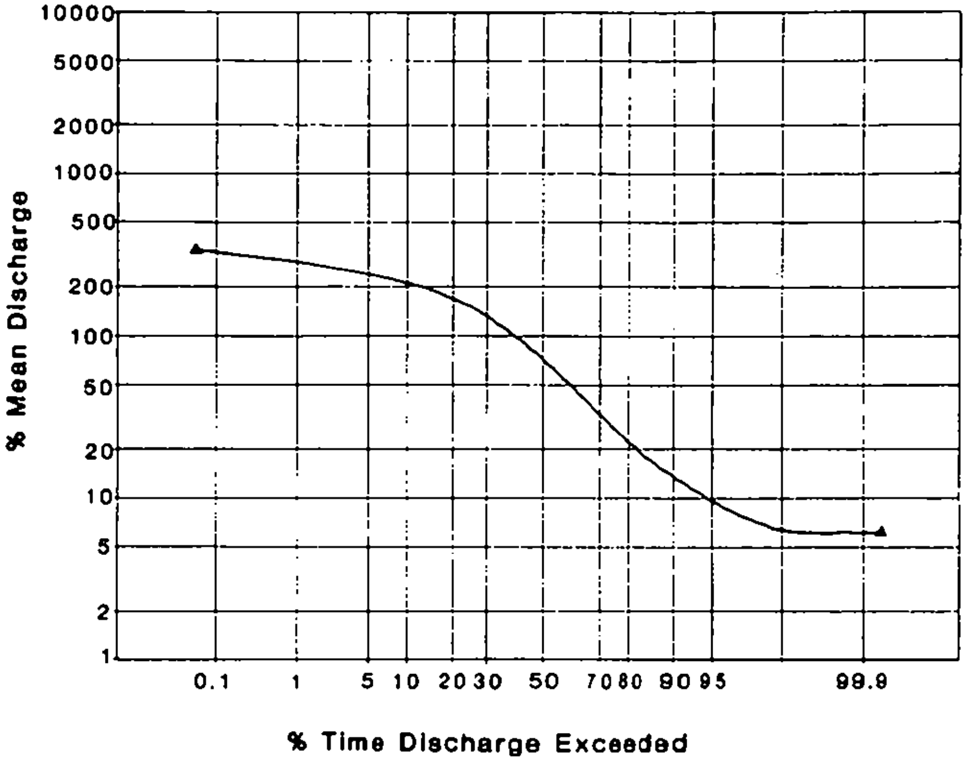


Figure 7.11 *Flow Duration Curve : Mill Stream (1986-1991)*

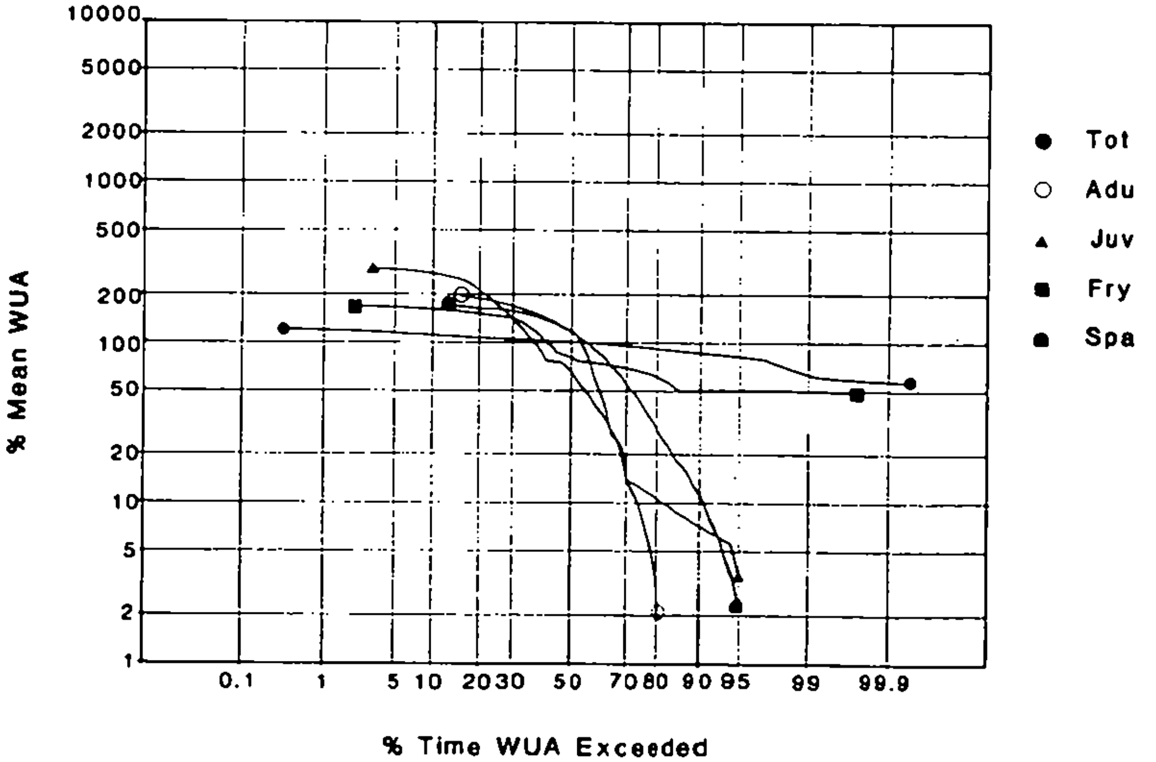


Figure 7.12 *Weighted Usable Duration Curves : Dace, Mill Stream*

7.4 DISCUSSION AND ANALYSIS

7.4.1 Hydraulic Model Simulations

Predicted water surface profiles from PHABSIM hydraulic simulations are given Appendix C. Hydraulic models were calibrated for nine of the eleven data sets collected. It was not possible to calibrate hydraulic models using data sets from the Great Ouse and Lees Brook.

As shown in Table 6.1 a combination of the three hydraulic models IFG4, MANSQ and WSP were used for the various hydraulic simulations. In the majority of cases satisfactory results were achieved using the IFG4 model, with MANSQ at a few cross-sections where IFG4 results seemed unrealistic. WSP was used only when a combination of IFG4/MANSQ failed. This tends to be the case where backwater effects are present; in lower gradient streams, particularly those affected to a large extent by weed growth.

The effects of weed growth were not adequately modelled in the hydraulic simulations. Depending on the dates when flows were measured the effects of weed growth tend to be either over or under-estimated. Further research effort is required to tackle this problem.

It is difficult to judge the quality of hydraulic simulation outputs in the absence of data to verify them. Model outputs give estimates of the error in stage-discharge regressions. The shape of the water surface profiles and the Velocity Adjustment Factor vs Discharge relationships also give an indication as to whether results seem realistic. Simulation results on the whole seem fairly realistic - given the uncertainty involved in the habitat modelling phase it would appear that the PHABSIM hydraulic models can provide estimates of depths and velocities to an acceptable level of realism in a variety of different types of rivers.

In the case of the Great Ouse and Lees Brook only two flow calibration data sets were collected. This was in part owing to practical problems encountered, such as navigation. On the Great Ouse velocities were so low that a current meter suspended from a boom would not even stay pointing upstream. At both sites discharge could be seen to change suddenly as sluice gates up or downstream were operated: discharges collected at separate transects over a single day vary by as much as seventy per cent. For this type of river, regulated automatically over short time scales and with an extremely low gradient the hydraulic models within PHABSIM are completely inappropriate.

More detailed studies to assess the accuracy of hydraulic model predictions (particularly in the presence of weed growth) are currently in progress on the Mill Stream at East Stoke under the NERC Science Vote Commission 'Modelling Faunal and Floral Response'.

7.4.2 Habitat Simulations : Invertebrates

The predictions are compared with the results of a survey of the invertebrate fauna of the sites carried out in the summer of 1991 and with known information on the distribution and ecology of the taxa. Predictions were run for pairs of taxa which were known to occur in the rivers.

River Hodder
Leuctridae and *Rhithrogena semicolorata* occurred at relatively high densities (28 and 47 per 15s pond net sweep) in riffle sites in samples taken in the summer.

According to the predictions WUA for these species is high at discharges greater than 4 cumecs. Rapid reduction in WUA is predicted at discharges <2 cumecs. Although this is probably a correct scenario it does not follow that reductions in WUA will necessarily be accompanied by drops in density. To establish this fact it would be necessary to obtain detailed data on abundance fluctuations.

River Lambourn
Rhyacophila dorsalis occurred infrequently at the site at densities of 1 to 2 per sample whereas Gammaridae were abundant (91 per 15s sweep). The predicted WUA for both taxa is high at discharges >2 cumecs although this represents only about a third of the total area of the reach. The anomalous predictions of R. dorsalis could be related to the presence of dense weed growth which may have reduced areas of high flow which are favoured by this species.

River Itchen
Gammaridae are abundant in the Itchen (RIVPACS data) whereas Ephemeridae are relatively uncommon. The predictions of weighted useable area for these taxa indicate a steep reduction below a discharge of 2 cumecs. Gammaridae reach an asymptote at this discharge but for Ephemeridae there is a gradual decline in WUA as discharge increases. About half of the total available area is predicted to be suitable for Ephemeridae at 2 cumecs but the results of on site surveys do not support this. It is probable that the suitability curves are not finely focused.

River Lymington
Gammaridae and Leuctridae occurred at relatively high densities in the samples from this river (37 and 25 per 15s sweep) but Leuctridae were abundant only in riffle areas. According to the predictions only about one quarter of the total area is suitable for Gammaridae when the discharge is > 1 cumec and the figure for Leuctridae is even lower at one eighth. Below this discharge WUA decreases very rapidly as riffle habitat is lost and the river occupies a series of deep pools.

Millstream
Gammaridae are common at this site (35 per 15s sweep) especially in marginal habitat. Leuctridae occur at low densities (10 per 15s sweep) and are confined to riffle areas. About one third of the total available area is suitable for Gammaridae at discharges over 1 cumec. For Leuctridae the WUA is only about one fifteenth of the total available at discharges > 1 cumec. Discharge in this stream during the summer and autumn is well below 1 cumec and in 1992 fell below 0.2 cumecs. According to the predictions discharges as low as these would reduce the WUA to its minimum level and yet both taxa are relatively common. It is possible that the growth of macrophytes is creating a diversity of conditions which allow these taxa to maintain populations in an otherwise unsuitable flow environment.

River Wye
Leuctridae were very rare in samples from this river with a maximum abundance of 4 per 15 s sweep and yet the predicted useable area for this taxon is about half of the total available. It is possible that in the rigorous environment of upland streams densities may in reality be low but the habitat suitability curves are built from average values and would mask river-specific variations in habitat preference.

Polycentropus flavomaculatus occurred at low densities (7 per 15s sweep) at this site in slack water and marginal areas. The WUA is however predicted to increase with increasing discharge. This is surprising and indicates that the habitat suitability curves are incorrect. Polycentropus flavomaculatus is reported in the literature as favouring areas of low velocity (Edington 1968). Such areas in upland streams are frequently found in marginal zones. The RIVPACS environmental data averages out physical parameters and, as for Leuctridae above, masks out the real preferences of the species.

River Exe
Chloroperlidae and Leuctridae occur at low densities of 1-4 specimens per 15s sweep. This is a boulder/cobble substratum which is difficult to sample so the estimates of numbers may be low. Both taxa have similar habitat requirements and nearly half of the total area is predicted to be suitable at discharges greater than 0.6 cumecs. There is a major reduction in WUA when discharge is lower than 0.25 cumecs.

River Blithe
Gammaridae were abundant in the Blithe (32 specimens per 15s sweep). Polycentropus flavomaculatus in contrast occurred only rarely with a maximum density of 6 per 15s sweep. The predictions indicate increasing WUA for both taxa with increasing discharge. This seems unlikely but without a knowledge of velocity distribution at different discharges it is difficult to judge the accuracy of the prediction. The point made previously concerning the lack of focussed curves may also apply here.

Conclusions
This preliminary comparison of observed and predicted distribution has revealed both weakness's and strengths in the application of the IFIM methodology. In general the predictions work and show clear trends in the response of invertebrates to changing discharge. What is clearly missing is, quantitative microhabitat-specific data. Most changes in benthic populations in response to altered flow patterns are shifts in the relative abundance of components of the faunal community and quantitative data from areas of known physical characteristics is essential for the future construction of habitat preference curves. In addition, responses of invertebrates will vary with river type and it would be useful in further development of this work to derive curves which are based on data from different types of water course. For example the responses of a target taxon may differ in a weeded chalk stream and an upland coarse-bottomed river. The growth of weed is a further complicating factor which may render the predictions inaccurate. The inclusion of a macrophyte component to the model is essential for its use in lowland and weed rich stream.

7.4.3 Habitat Simulations : Fish

River Hodder
A medium sized river which was difficult to fish effectively, the Hodder was inhabited by both brown trout (resident) and sea trout (migratory). The two "forms" of trout both spend their spawning, fry and juvenile stages in the river but sea trout do not require adult feeding territories, within the river, in order to survive. It is possible, however, that (relatively) large sea trout may displace resident adult brown trout (which do require feeding territories) from suitable habitat during summer and autumn. The migratory form may monopolise potential brown trout spawning/fry/juvenile habitat, as may the many salmon which were also present as juveniles in large numbers.

Despite predictions of substantial areas of suitable juvenile and adult trout habitat, at most discharge levels, relatively few trout were present. It would appear that the reason could lie in lack of instream/outstream cover. It is suspected that the importance of these factors has been understressed in the suitability curves constructed for juvenile/adult trout and that these should now be redrawn to give more emphasis to "cover" as a factor influencing the variations in trout habitat suitability.

Other reasons for the discrepancies between predicted and actual situations could include - poor spawning conditions in the river as a whole (unlikely in view of spawning success of salmon, a fish with similar requirements) or poor fry survival. It should always be borne in mind that numbers are likely to be set by extreme events (eg peak discharge conditions). The Hodder may be a flashy river(?) and the populations of trout thus subject to density independent (mainly climatic) factors (Elliott 1992).

River Lambourn
This site is a chalk stream with small amounts only of macrophyte cover but some outstream cover in the form of trees and marginal *Carex*. At high discharges there would seem to be little juvenile/adult habitat, however, samples showed that there were substantial numbers of these fish present. It is suspected that more attention should be paid to river type, water quality etc. Perhaps a broad classification on which habitat preference curves could be superimposed would be appropriate. It is also apparent that an indication of mean discharge and coefficient of discharge variation could be a significant help in interpreting Weighted Usable Areas. It is not clear why, when total area is so constant with discharge, WUA should fall off so dramatically above 3 cumec. Presumably, due to the high banks and rectangular channel-cross-sections of the chalk stream, depth increases beyond the limits of the preference curve . This suggests that higher upper depth limits are required.

In some rivers biological factors may exert the major controls on population (see also Hodder).

River Lymington
Again this is a smallish, shallow river with little instream or macrophyte cover. There appears to be a relative deficiency of juvenile habitat which, at first consideration is inconsistent with the large number of juvenile trout found. However, it seems plausible that the very high values for fry habitat, which occur, could generate major levels of recruitment to the juvenile population and that subsequent heavy mortalities of these fish could then produce the observed low numbers of adult fish.

Mill Stream
In this small stream there was a much more diverse community of fishes than in the two preceding rivers. Three reaches having different characteristics were investigated but are combined for the present analysis. Cover levels are very variable but both instream and outstream cover is present.

The dace data indicate the presence of large areas of adult and juvenile habitat over a wide range of flows with adult habitat rapidly diminishing below discharges of 1 cumec but juvenile habitat present down to 0.5 cumec. During the sampling period (May to September) the discharge was) 0.5 cumec or less predicting only juvenile dace habitat with few adult fish. This was in reasonable agreement with the observed populations.

River Wye
Predictions suggest extensive habitat availability at all levels of discharge in this river. There was no cover of any description and as in the case of the Hodder, adult trout were virtually

absent.

River Exe
A small stream of flashy character with some depth variation and overhanging banks to provide cover. The presence of both juvenile and adult trout is in good agreement with predictions of habitat availability.

7.4.4 Habitat simulations : macrophytes

Discussion
Water velocity effects are the most significant factor for both *Ranunculus* afp and *Nasturtium officinale*. Species interaction can be very important, for example in *Ranunculus* afp when the seasonal range of flow is small eg 3:1 there is little winter washout resulting in possible colonisation or overgrowth by *Nasturtium officinale* resulting in suppression of *Ranunculus* afp. This can follow through to a high overwinter biomass with a high maximum biomass of *Nasturtium officinale* in the successive seasons. In rivers with a seasonal flow range of 5-10 (-20):1, a similar seasonal maximum biomass may not be achieved and the plant is restricted to the margins of rivers at low altitudes (areas of low winter frosts). This reduction in biomass of emergent species may be further reduced by the effect of deeper water such that at mean depths of 2-3 m only a small biomass may be achieved. Conversely the effects of reduced flows on submerged plants as typified by *Ranunculus* afp but without the overgrowth by an emergent plant can leave the plant susceptible to overgrowth by algae at relatively low nutrient levels and their eventual elimination from this part of the system in regimes of extended low flows or regimes without regular or seasonal flushing of the stream systems.

Trial simulations all show some realism in predicting the possibility for the presence of type plants but lack seasonality and the effects of stability of substrate.

The Millstream site simulation indicates broadly a 50% cover of the stream bed by submerged macrophytes in this partly shaded stream but does not enable the effects of seasonality to be shown in terms of plant growth and enhanced cover in the falling spring and summer discharges prior to the autumn washout. Flow statistics indicate a 8:1 daily maximum to annual mean flow. The overemphasised cover to discharge relationship is however included in the term WUA; some fine tuning or alternative line could emphasise this seasonal relationship.

The Lymington River simulation indicate the potential presence of higher than normally expected populations of submerged plant although the emergent species could be expected to occupy the projected 5% of the full stream area. (Flow statistics show a 11:1 daily maximum to annual mean flow).

Simulations of the Rivers Lambourn and Itchen (both about 2.5:1) provide a lower than expected cover of submerged macrophyte (45%) although submerged forms of other species frequently occur in this river system; the emergent species is anomalous towards the higher discharges but this could relate to differences in the observed and effective sediments and their stability as mentioned above ('pseudo-armouring' effects).

The River Wye simulation indicates a 40-50% cover of submerged macrophyte but which whilst it may be typical of the lower reaches and the River Lugg, few plants are said to be found in the uppers reaches as chosen and shown in the simulation; plant would be unlikely in such a spatey river as indicated by the flow statistics (with a 25:1 daily maximum to annual mean flow).

The River Blythe simulation with its 30:1 daily maximum to annual mean flow is unlikely to have. The seasonality effects of plant growth and the consequential effects on water flow have been discussed with R.T. Milhous. Habitats have not been satisfactorily coded for Cover groups and their combinations.

In general, some input of the probabilities of particular plant species or groups being present needs to be incorporated in simulation or on-site checks prior to simulation other wise erroneous predictions will undoubtedly occur. Such a data base or predictive system could be linked with the related river corridor classification also being undertaken by NRA.

8. Setting of ecologically acceptable flows

8.1 EXAMPLE : RIVER ALLEN ABSTRACTION REGIME

In this section we shall give an example of an application of the IFIM using PHABSIM to the setting of an ecologically acceptable flow. The results presented in this section are based on data collected from the River Allen (Dorset), (Johnson, Elliott, Gustard and Clausen, 1993) as part of a commission from NRA Wessex Region.

A national assessment by the NRA (1990) of low river flows identified the Allen as one of 20 sites demanding urgent consideration. Concerns for the effects of groundwater pumping on the ecology of the Allen have been voiced for some twenty years. Newman and Symonds (1991) state that "The River Allen by reputation was once an exemplary Chalk Stream: a classic habitat for trout. Its character is believed to have been eroded by the groundwater planning techniques of the 1960s and 1970s". Relevant features of the Allen catchment are shown in Figure 8.1 below

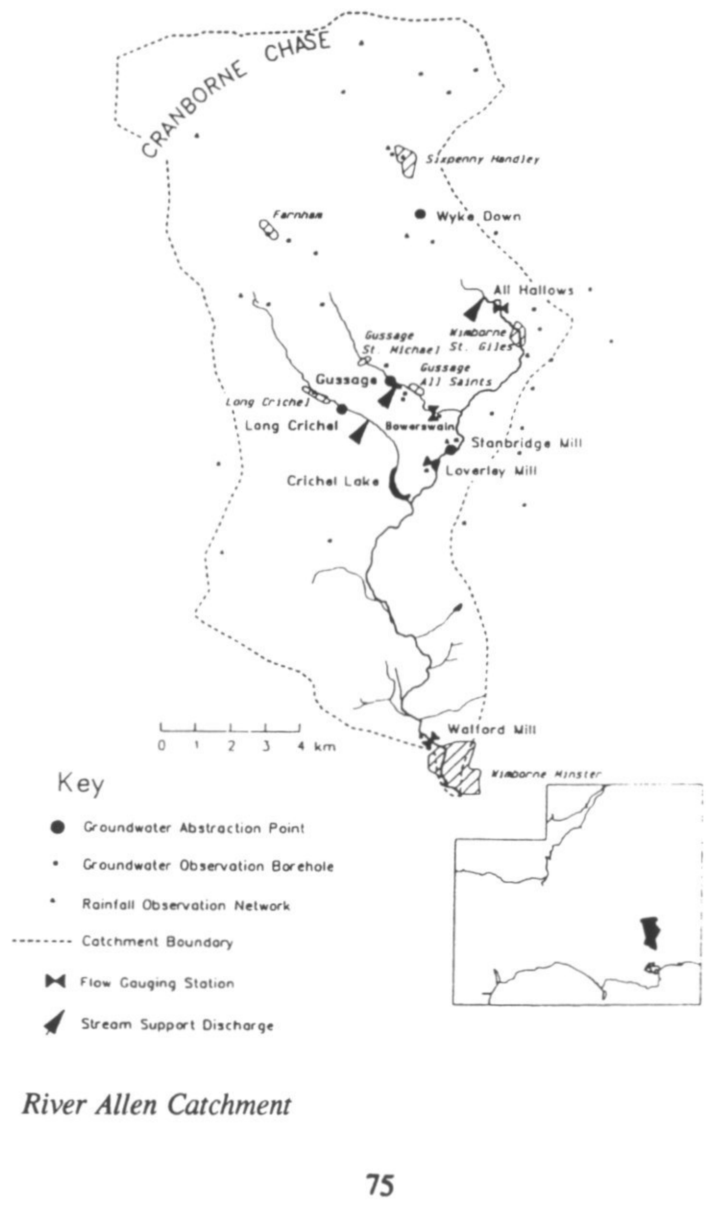


Figure 8.1 *River Allen Catchment*

As part of a detailed catchment study of the Allen a groundwater model was developed by Groundwater Development Consultants (GDC) of Cambridge. Outputs from this model give time series of "naturalised flows" where the predicted effect of the historical abstraction has been removed. By applying the IFIM using PHABSIM at representative study sites on the Allen and coupling Weighted Usable Area vs Discharge results for chosen target species with time series of historical and "naturalised" flows it is possible to assess the impact of the historical abstraction regime upon seasonal habitat availability.

Two study sites were chosen for this assessment; upstream of Didlington Mill (grid ref. SU007080) and some 400m downstream of Didlington Mill (grid ref. SU003075) as shown in Figure 8.2 below. At each site PHABSIM data were collected as described in Section 4. After the initial surveys calibration flow measurements were made by NRA Wessex Region staff at a further two flows.

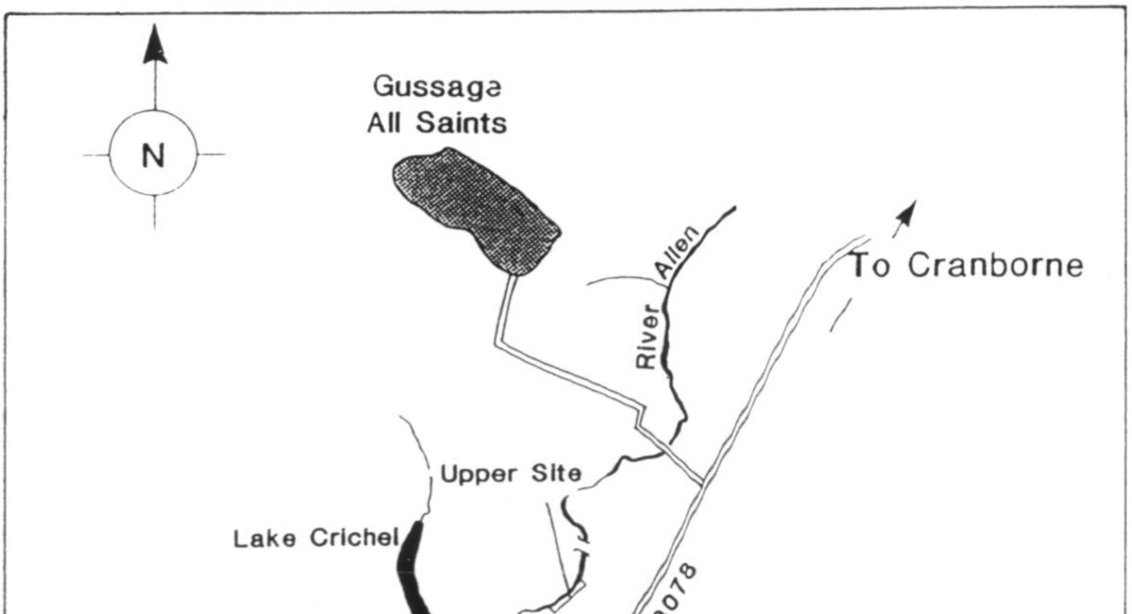


Figure 8.2 *Location of PHABSIM Study Sites*

In liaison with NRA Wessex Region Fisheries Section the target species for the assessment were chosen to be trout and salmon. Habitat suitability index data for life-stages of trout and salmon were developed by NRA Wessex Region. These data are based on observations made by snorkelling and surveys of redds in chalk streams similar in character to the Allen. Examples of the habitat suitability indices developed for fry/juvenile trout from these data are given in Figures 8.3-8.5 for the microhabitat variables depth, velocity and substrate respectively.

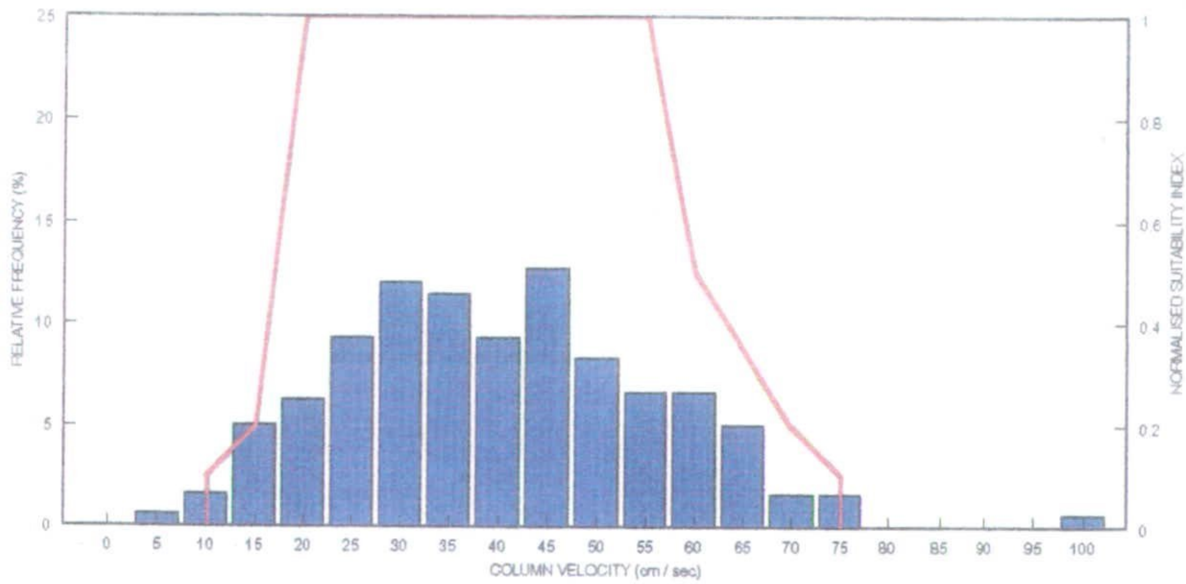


Figure 8.3 *Suitability Index for Velocity : Juvenile/Fry Trout*

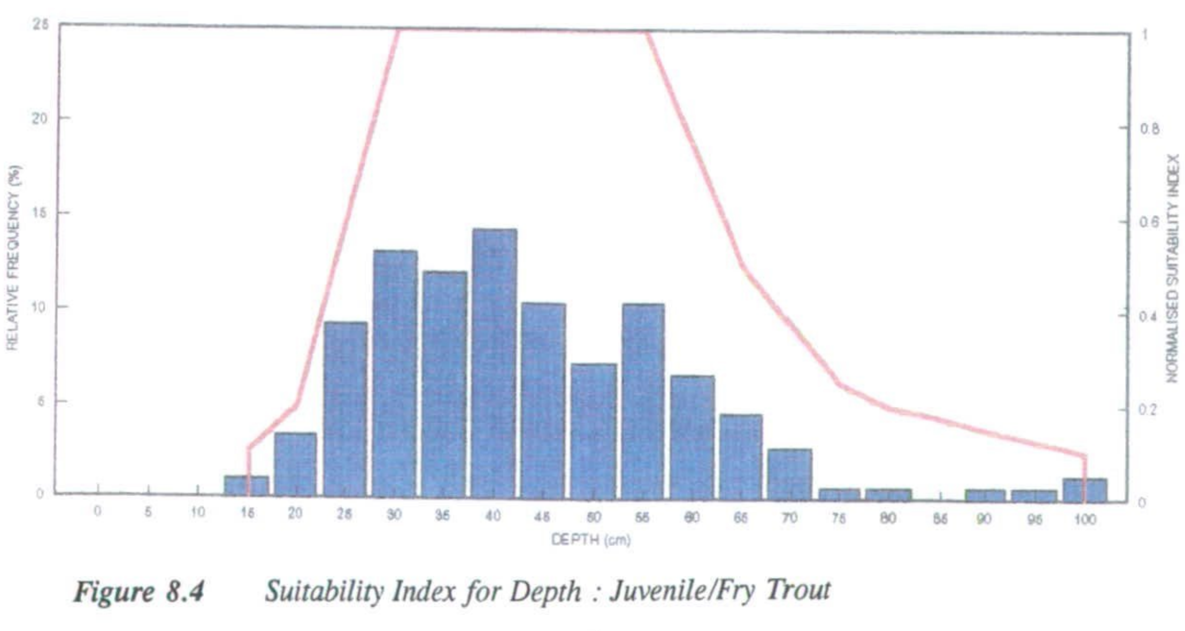


Figure 8.4 *Suitability Index for Depth : Juvenile/Fry Trout*

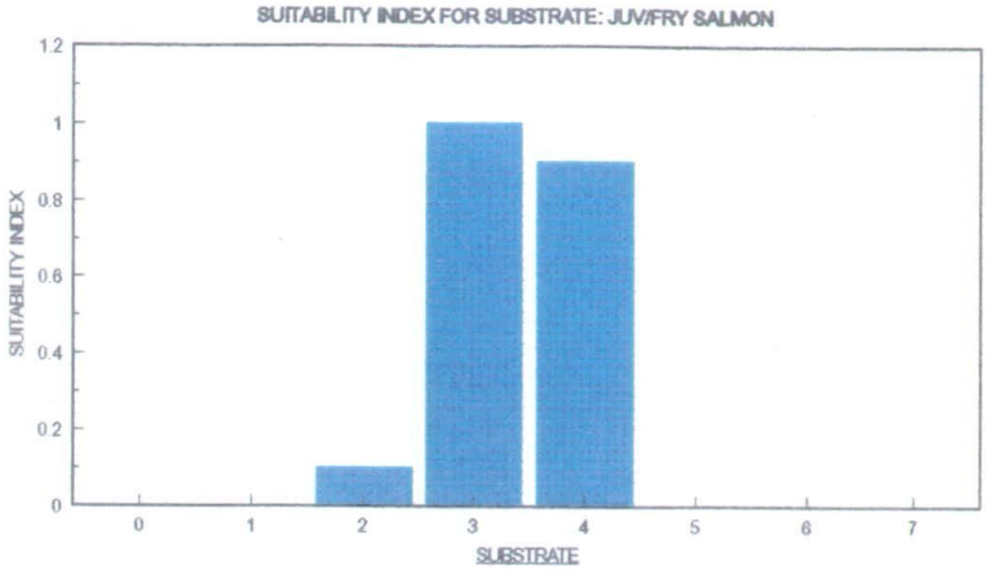


Figure 8.5 *Suitability Index for Substrate : Juvenile/Fry Trout*

PHABSIM Weighted Usable Area (WUA) vs Discharge relationships were produced for adult, fry/juvenile and spawning trout, fry/juvenile and spawning salmon using model calibration data from the two study sites. An example of the output giving Total Habitat Area and WUA vs Discharge for life-stages of trout at the downstream study site is given in Figure 8.6 below. (Fry and juvenile are considered here as a single life-stage).

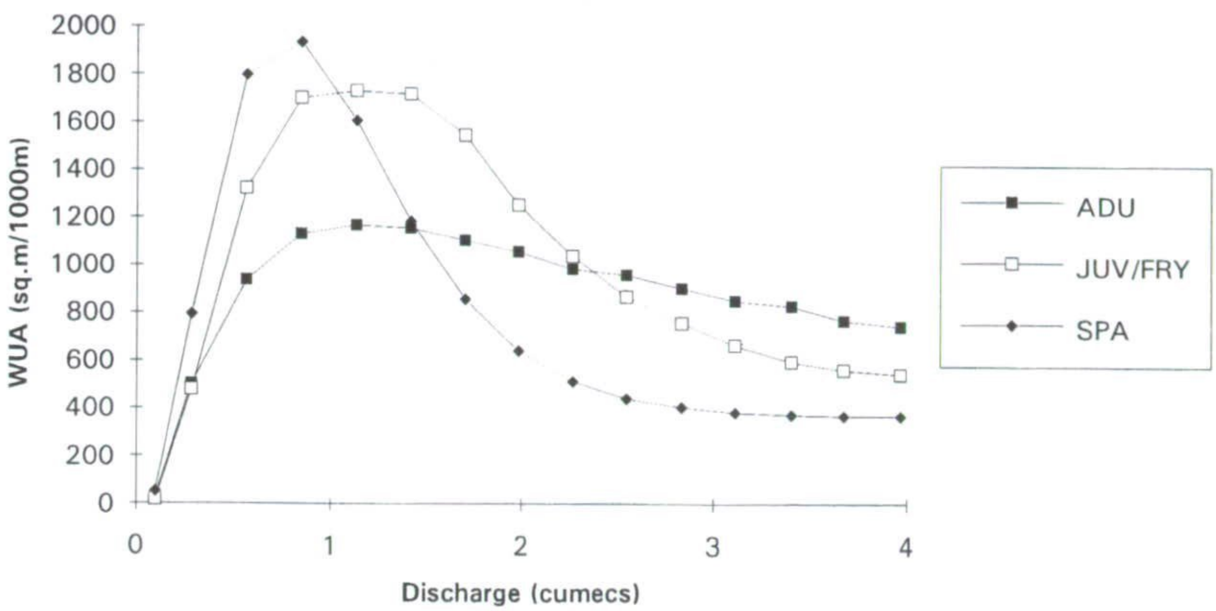


Figure 8.6 *WUA vs Discharge : Trout, Allen Downstream Site*

WUA vs Discharge relationships for target species life-stages were coupled with time series of mean monthly historical and simulated "naturalised" flows to give corresponding time series of WUAs. These were analysed using a duration curve program to give corresponding duration curves for mean monthly WUA for each target species life-stage. Results predicted that the impact of abstraction was greatest at the downstream site. Of the species life-stages considered impact was predicted to be greatest for fry/juvenile trout. Duration curves for mean monthly historical and "naturalised" flows over the period 1970-1991 at the downstream site are given in Figure 8.7 below. The corresponding duration curves for the availability of WUA for fry/juvenile trout are given in Figure 8.8.

It is clear from Figure 8.8 that a significant impact upon the availability of WUA for fry/juvenile trout is predicted for exceedance percentiles of 50 per cent or more. In order to investigate the sensitivity of this impact to reduction in the level of abstraction we have modelled three hypothetical scenarios where the effect of abstraction on the mean monthly flow is reduced by 25, 50 and 75 per cent. As the greatest impact of abstraction on WUA availability is felt in the summer months we have run separate simulations for the summer (April-Sept) and winter (March-Oct) periods. Results are shown in Figures 8.9, 8.10 for the summer and winter periods respectively.

The results in Figures 8.9, 8.10 are strikingly different and serve to illustrate the importance of considering habitat availability on a seasonal basis. For the summer months the abstraction has a significant effect in reducing available WUA at all exceedance percentiles of 5 per cent or more. The sensitivity analysis indicates that this reduction is in direct proportion to the level of abstraction. For the winter months reduction in available WUA is only significant at exceedance percentiles of 90 per cent and above.

In the interpretation of habitat duration curves we must be mindful that a single value of WUA may occur at two quite different discharges. This is a consequence of the shape of the WUA vs discharge relationship (Figure 8.6). In general we cannot therefore conclude that low values of WUA (corresponding to high exceedance percentiles) correspond to low flows. Results in Figure 8.9 suggest that in this particular example low summer WUA values correspond to low flows, and are reduced by the effect of abstraction. In order to test this hypothesis we have plotted (in Figure 8.11) the duration curve for WUA for the period 1970-1991 (all months) and marked the mean monthly discharge corresponding to points on the duration curve. From Figure 8.11 it can be seen that WUA values exceeded for 70 per cent or more of the time of record <u>do</u> correspond to low discharges.

In conclusion it would appear that in this example the historical abstraction regime has had significant effect in reducing the availability of habitat for fry trout. The extent of this impact would appear to be directly proportional to the level of abstraction and confined almost entirely to the summer period.

8.2 DISCUSSION

In the example above we have demonstrated that the IFIM using PHABSIM can be an effective tool in the analysis of the relative ecological merits of different flow regime scenarios. Although we have not defined a specific ecologically acceptable flow we have demonstrated how <u>real</u> proposals to alter the regime of abstraction could be assessed in terms of their relative ecological benefits. It is possible from the results and analysis presented above to choose a prescribed minimum summer discharge corresponding to any given (high)

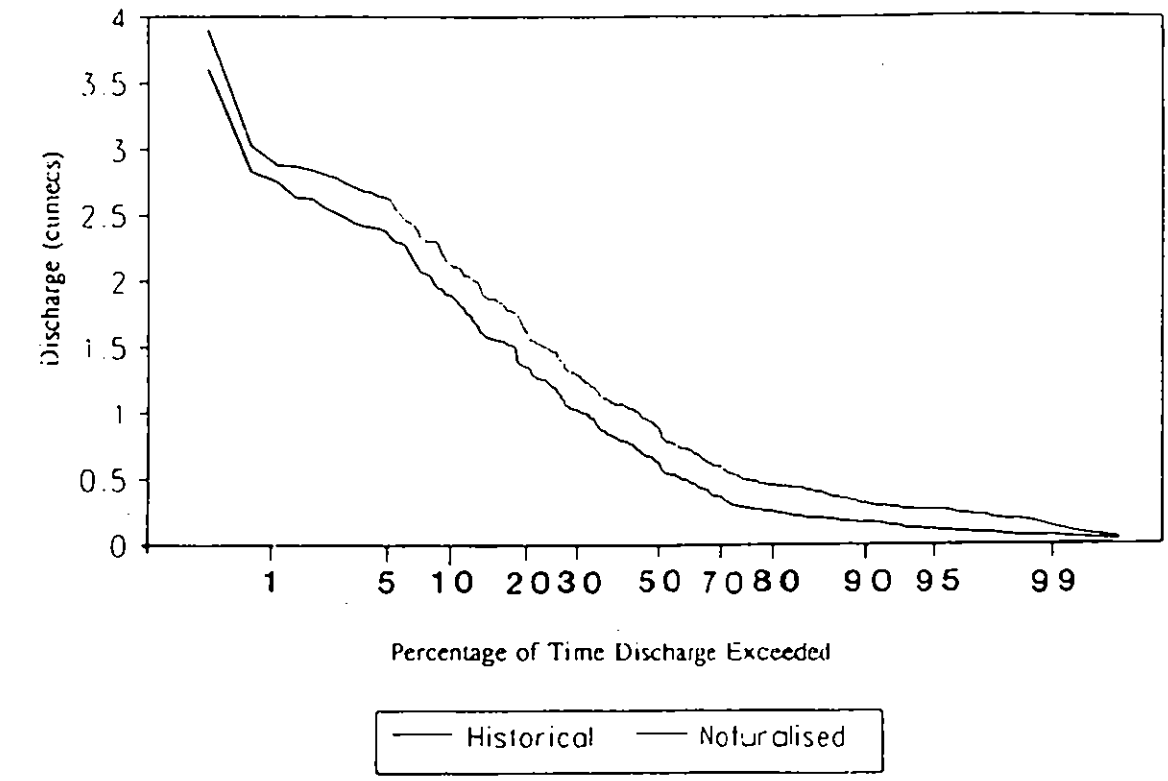


Figure 8.7 *Duration Curves for mean monthly historical and naturalised flows, River Allen downstream site. 1970-1991 (all months)*

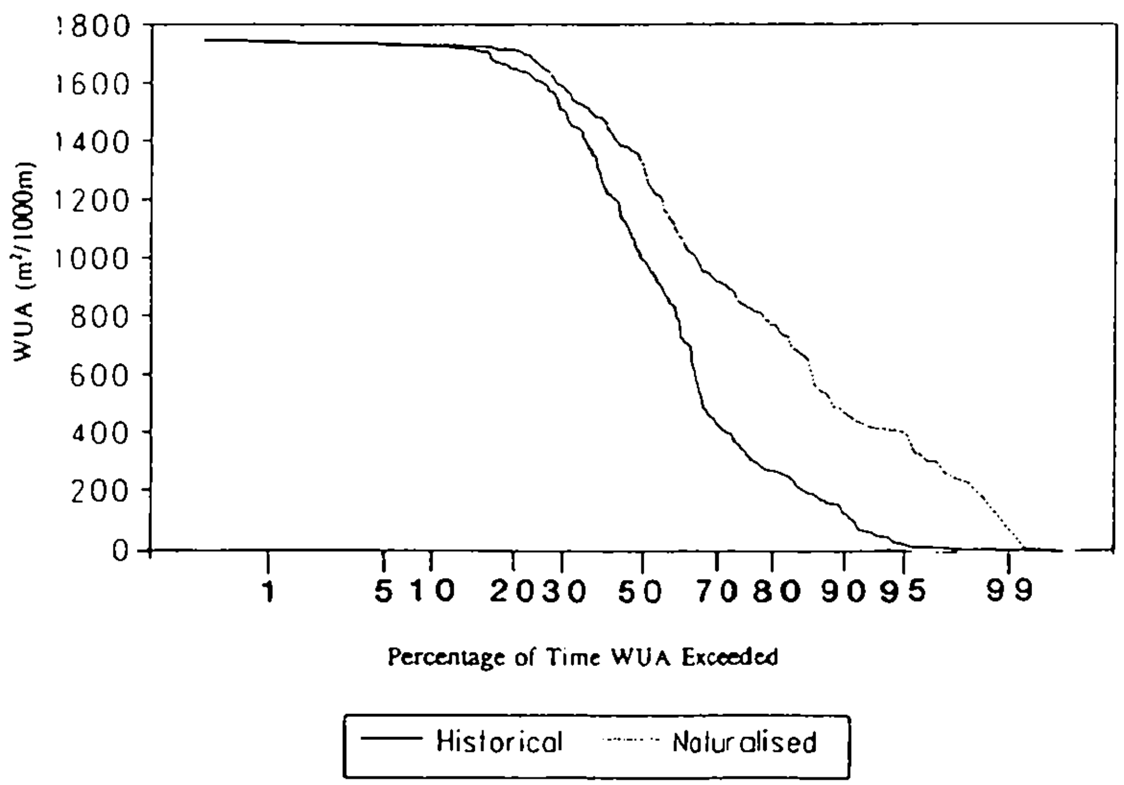


Figure 8.8 *Duration curves for WUA for juvenile/fry trout, River Allen downstream site, 1970-1991 (all months)*

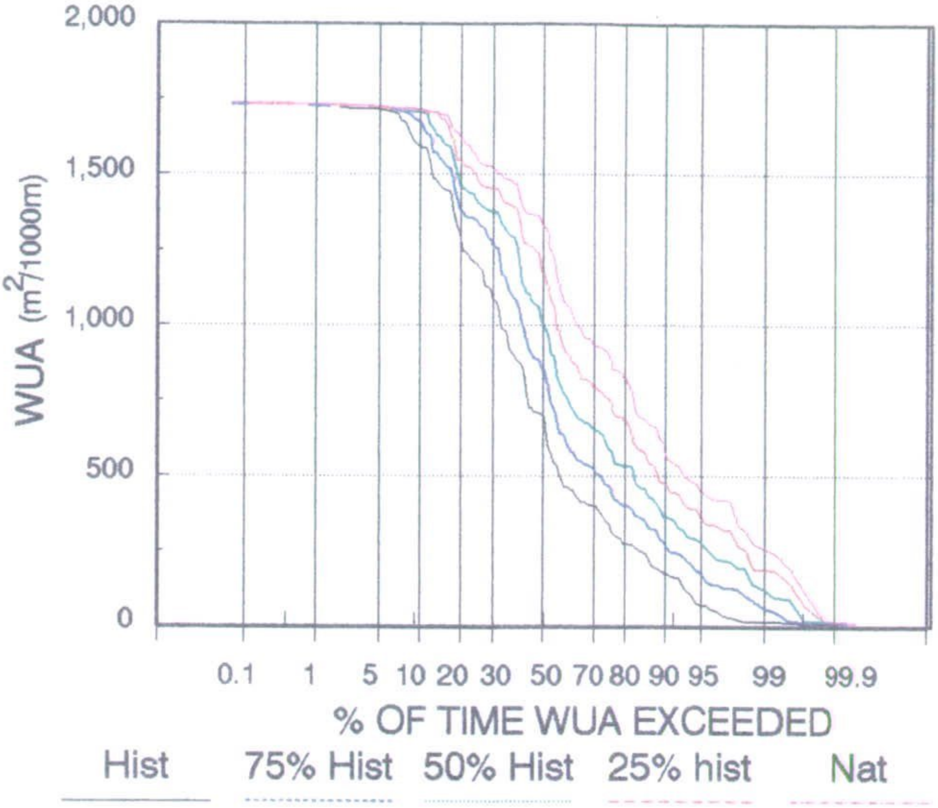


Figure 8.9 *Duration Curves for WUA for juvenile/fry trout under alternative abstraction regimes, R.Allen downstream site. 1970-1991, summer months*

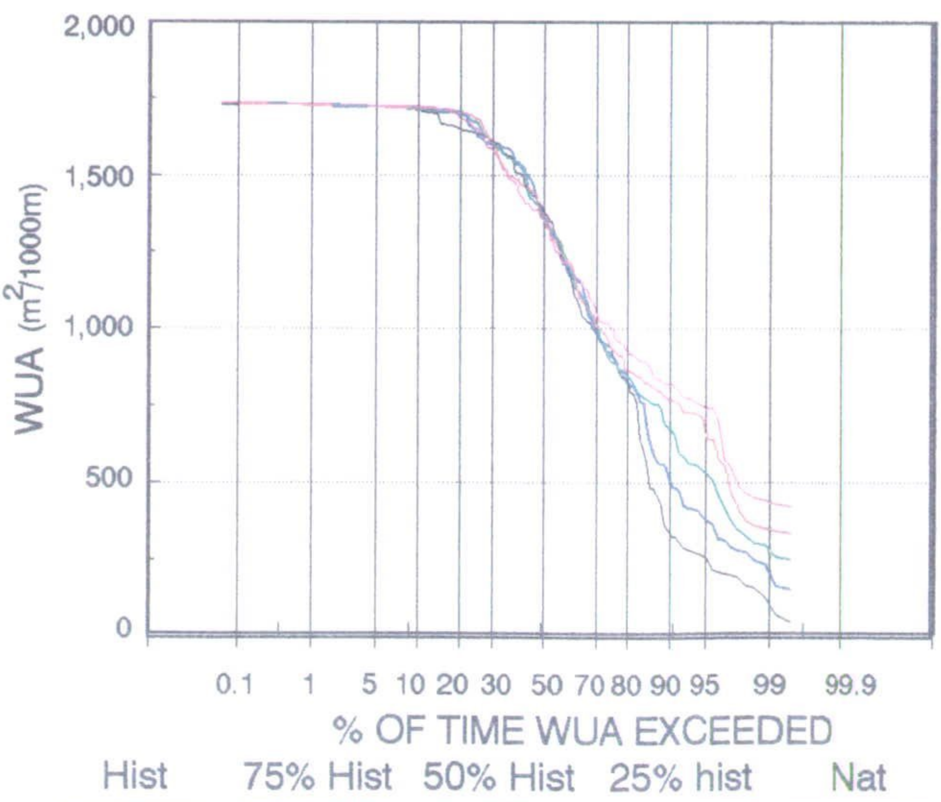


Figure 8.10 *Duration Curves for WUA for juvenile/fry trout under alternative abstraction regimes, R.Allen downstream site. 1970-1991, winter months*

exceedance percentile of WUA for the most sensitive of the target species, trout fry. For example, to ensure that WUA for trout fry remains always above its historical 50 per cent exceedance value of around 650m^2/1000m would require a minimum discharge of 0.35 cumecs to be maintained. There is clearly an outstanding issue in deciding exactly which percentile exceedance of WUA we can define as being 'ecologically acceptable'. Further model applications may give us a clearer picture of the level at which sustained periods of low WUA values become critical to species success.

If an ecologically acceptable flow were to be defined in practice for the Allen it would be necessary to transfer results from the study site to the point at which the minimum flow were to be prescribed and gauged. If we assume that this were close enough to the study site for the habitat at the two points to remain broadly similar we could transfer an estimate of an ecologically acceptable minimum flow at the study site to the point of gauging using standard techniques for extrapolating discharges. Clearly it is not justifiable to do this if there is a significant change in the ecological character of the stream between the study site and point of minimum flow prescription.

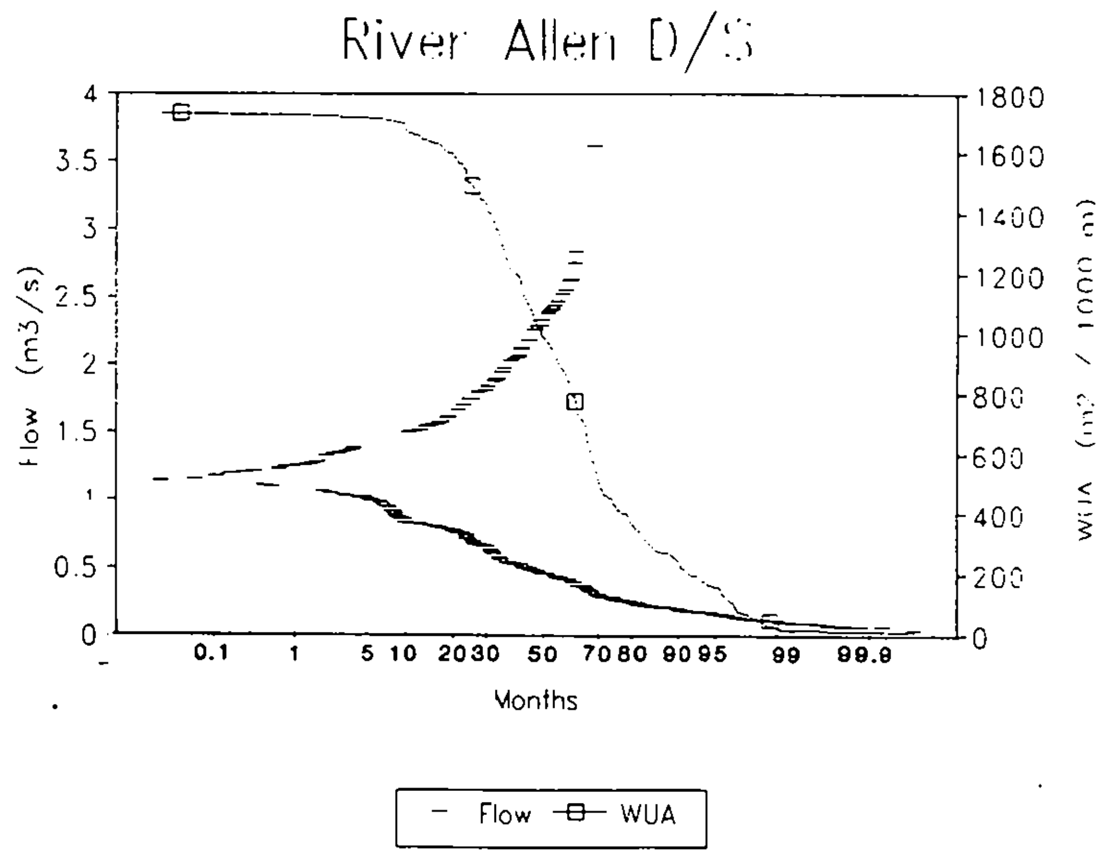


Figure 8.11 *Flows corresponding to WUA values in the duration curve*

9. Conclusions and Recommendations

9.1 DISCUSSION AND CONCLUSIONS

This assessment has demonstrated the potential of the IFIM using PHABSIM as a powerful tool in the assessment of the flow requirements of aquatic species. Calibration of hydraulic models on the basis of modest levels of fieldwork resource input has been achieved for a wide range of different river types. Hydraulic model outputs have demonstrated that realistic simulations over wide ranges of discharges can be achieved using calibrated hydraulic models. On the basis of extensive literature searches and data from the RIVPACS database, habitat suitability curves have been constructed for life-stages of selected fish, invertebrate and macrophyte species. These data have been combined with PHABSIM hydraulic model outputs to give quantitative measures of available physical habitat over the range of simulation discharges. We have given examples of the transformation of river flow hydrographs to corresponding time series of habitat values by coupling PHABSIM habitat vs discharge outputs with gauged flow records. These time series have been analysed using a conventional statistical duration curve technique. Using an example from a current operational problem we have demonstrated how the IFIM may be applied to analyse the seasonal variability of available habitat and how a low threshold value of WUA could be used to define a minimum discharge which would guarantee availability of a minimum acceptable level of habitat area.

In this assessment the PHABSIM model has been applied in a wide variety of situations using the same, generalised approach in the data collection and modelling procedure. It is important to realise that the framework provided by the IFIM using PHABSIM is fairly flexible and that for specific operational applications improved outputs could be obtained by simple modifications in the description of physical habitat used by the model. An example is in the modelling of substrate and cover characteristics, where it is possible to refine the definition of habitat suitability data and the collection of observed data at the study site to reflect those aspects of substrate/cover considered to be most important to the particular target species life-stage being considered. Careful consideration of such aspects at the project planning stage may assist in utilising the IFIM methodology most effectively.

It is clearly difficult to validate the WUA vs Discharge relationships produced for target species at the study sites, as the amount of observed data on species populations has been limited to sampling on a one off basis. On the whole the results concur with intuitive expectations despite some anomalies. In some instances the generality of the modelling approach used may account for such anomalies; an example is the low population estimate of adult trout for the River Hodder where fairly high WUA values are predicted. In this instance it is thought that the population of trout is limited by lack of cover at the site - this has not been properly accounted for in the modelling process since the definition of channel index used in the PHABSIM simulations was as substrate. Choosing the channel index as the component of cover thought to be most important to adult trout would be likely to yield much reduced WUA values which would concur more closely with population estimates from direct observations at the site.

In the setting of ecologically acceptable flows the choice of target species is a critical issue. In some instances, as in the case of the Allen, this choice may be driven by perception of a given problem, such as diminished angling success for a given species. In general we face the problem of selecting a target species that is sensitive enough to respond to changes in the flow regime, but at the same time occurs in sufficiently high numbers to allow the gathering of adequate habitat suitability data. For the target species considered in this assessment results for fish and macrophyte species show much greater focus in habitat suitability requirements and consequently much greater sensitivity of Weighted Usable Area to discharge than the corresponding results for invertebrate species .Habitat suitability data and subsequent WUA vs Discharge outputs for invertebrate species suggest that, in general, invertebrates are not sufficiently responsive to make a good choice of target species for IFIM studies.

For future application of the IFIM procedure it would clearly be of great value to extrapolate existing model outputs from sampled to non-sampled river reaches. In the assessment of the effects of small abstractions the resource demands of a full model calibration may not be justifiable. For this project the method has been applied at study sites chosen to lie in different ecological groups, hence there is little data to use in the assessment of the transferability and extrapolation of model outputs within individual groups. Further assessment of the IFIM methodology by application at a number of study sites within a single ecological group would be of great value in assessing the potential for extrapolation of model outputs. A basis for this type of extrapolation which has been used in US applications is a technique known as 'habitat mapping' in which PHABSIM outputs from one river reach are mapped to an unsampled reach on the basis of a simple description of the distribution of habitat types at the two locations.

For this project the same habitat suitability data has been used for model simulations at each of the study sites. In an IFIM application it is clearly beneficial that suitability data for target species is based on direct observations from ecologically "similar" reaches to the study reach. Bovee (1982) emphasises this fact on the basis of US application of the IFIM. The example we have used from the River Allen is the first UK application of the IFIM using habitat suitability data derived from direct observations made in habitats ecologically similar to those present at the study area. Clearly we cannot expect one set of habitat suitability data for a species to apply equally well to streams of different ecological types in which the species is present. Development of habitat suitability data specific to classes of target species and types of rivers is clearly of great value in maximising the accuracy of model outputs.

The IFIM methodology using PHABSIM is unique in its ability to provide a predictive, quantitative measure of available physical habitat which may be used in the assessment of ecologically acceptable flows. Since the IFIM predicts physical habitat area and does not directly predict species populations, operational decisions based on the output of IFIM simulations must inevitably make the assumption that acceptable levels of target species populations can be maintained by ensuring the availability of sufficient physical habitat area. In the short term this approach seems justifiable in the absence of predictive population models. In the longer term it would be beneficial to investigate in detail the relationship between the IFIM measure of physical habitat, Weighted Usable Area, and estimates of species populations based on direct sampling. This would be of great value in assessing levels of Weighted Usable Area which are sufficient to ensure acceptable levels of species populations. A study of the relationship between Weighted Usable Area and species populations would be most likely to succeed if it were clearly focused on a specific ecological class of streams and used habitat suitability data based on direct observations from ecologically "similar" streams. In view of the high profile of low flow problems affecting chalk streams in southern England and the availability of high quality habitat suitability data from NRA Wessex Region studies this would seem an appropriate area for a more focused assessment.

An important issue which has not been fully addressed in this project is the development of hydraulic models to realistically incorporate the hydraulic effects of weed growth. The existing PHABSIM hydraulic models take no explicit account of such effects. It is, however, possible to incorporate such effects in an implicit manner by calibrating the model using data sets collected at different stages of weed growth and running separate model simulations based on these calibration data sets. The development of a macrophyte growth model which could be interfaced with an existing hydraulic model would clearly be beneficial in improving the accuracy of hydraulic model simulations. Such a model may have application in many other areas in addition to IFIM studies. A simple model developed by Hearne and Armitage (1993) could be developed for use in conjunction with PHABSIM hydraulic models.

We have summarised our recommendations for further development and assessment of the IFIM using PHABSIM as follows:

9.2 RECOMMENDATIONS FOR FUTURE DEVELOPMENT AND ASSESSMENT OF IFIM

1. Time Series Analysis

This analysis would combine calibrated model outputs from the current R&D commission with time series of historical flows. Study sites were chosen to be sufficiently close to operational gauging stations to facilitate this analysis. The work would extend commission B2.1 by analysing more species life-stages and by producing both annual and critical seasonal habitat duration curves. Primary outputs would be in the form of habitat duration curves for target species life stages. Secondary outputs would be in the form of critical/seasonal habitat indicators. Methodology for this analysis would be as follows:

a) Select appropriate target species life-stages and identify availability of flow data.

b) For selected target species life-stages combine PHABSIM WUA vs Discharge outputs with time series of daily flows.

c) Produce habitat duration curves

d) Compute selected seasonal habitat indicators.

2. Ecological Validation of WUA Predictions

Since factors other than the availability of physical habitat (eg. water quality or temperature) will undoubtedly affect populations of target species, a linear relationship between biomass and WUA can only be expected for different river reaches which are in the same or "similar" hydrological/ecological category. For this reason it is appropriate that separate validation studies be conducted for different types of river. Each validation study would involve field sampling at a number of different reaches. Given the current operational problems facing the NRA a validation study based on sampling from different reaches of chalk streams in the south of England would be most appropriate as an initial study. Selection of a number of reaches on one particular stream, and single reaches on a number of "similar" streams would provide valuable data for assessing transferability of model outputs both between different reaches within a stream and between different streams. The basic methodology for such a study would be as follows:

a) Select a number of study reaches

b) At approximately the same time of year (repeating at different seasons if possible)

(i) Survey each reach to provide depth,velocity and cover/substrate data for input to PHABSIM

(ii) Electro-fish each reach to provide population estimates of selected target species.

c) Combine PHABSIM hydraulic data with habitat suitability data to give an estimate of Weighted Usable Area. No model calibration is necessary since the WUA is only required for the single discharge when the sampling is conducted.

d) Analyse biomass vs WUA relationship

3. Local Extrapolation Techniques

Data collected under item 2 above could be exploited further to investigate extrapolation using habitat mapping techniques. The investigation could be limited to studying reaches within the same stream, or be extended to reaches in "similar streams". In either case the study sites would be those used under item 2. The proposed methodology is as follows:

a) Survey each reach at a minimum of two additional calibration discharges.

b) Make visual estimates and measurements of frequency of occurrence of different habitat types.

c) Calibrate the hydraulic models within PHABSIM.

d) Run simulations over a full range of discharges and combine with habitat suitability data to give WUA vs discharge relationships for target species

e) For each reach estimate WUA using a habitat mapping approach with data from b)

f) Compare outputs from d) and e)

g) Consider refinement of the extrapolation procedure by supplementing with limited amounts of hydraulic data (eg mean/min/max depths and velocities.)

4. Regional Extrapolation of PHABSIM Output

For major water resource developments or changes to operational procedures it will be important to calibrate the PHABSIM model at one or more reaches close to the site of interest. There will however be a requirement in some instances for a more rapid assessment of ecologically acceptable flows. One approach to meeting this requirement will be to transfer habitat duration curves from modelled sites. The validity of this approach will depend on the variability of habitat duration curves between rivers and between sites. This could be tested by further model calibration on different rivers and reaches on, for example, chalk streams.

Data collected under Item 3 could be combined with time series of daily flows and used in this analysis. These data would be supplemented by the output from item 1. Development of a simple classification of river habitat types into 10-15 groups covering the UK would enable the results of a PHABSIM model calibration to be transferred to unsampled rivers/reaches. Basic methodology would be as follows:

a) Identify availability of flow data at study sites used under item 3.

b) Construct time series of mean daily flows for each site, using estimation techniques if required.

c) For selected target species combine WUA vs Discharge relationships available as output from Item 3 with flow data to produce habitat time series.

d) Compute habitat duration curves for selected target species.

e) Analyse output together with outputs from Item 1.

5. Incorporation of Macrophyte Growth Model

This work would involve the development of a macrophyte growth model to be interfaced with existing PHABSIM hydraulic models. Methodology would be:

a) Identify an appropriate structure for the macrophyte growth model

b) Write a FORTRAN subroutine to carry out computations required for macrophyte growth modelling.

c) Interface this subroutine with PHABSIM hydraulic models.

d) Produce example output using an existing PHABSIM data set.

6. Testing of Macrophyte Growth Model

Testing of a hydraulic model incorporating the effects of macrophyte growth on a microhabitat scale would involve detailed studies best confined to a single site. The Mill Stream at IFE would be highly suitable, particularly as data from the current NRA R&D commission and a separate NERC Science Budget project could be exploited. The methodology would be as follows

a) Select a portion of the existing study reach as a test reach.

b) Install stage recorders at each transect in the test reach

c) Quantify macrophyte growth at regular intervals during its growth and recession.

d) Measure velocities at points across each transect when observations under c) are made.

e) Compare predicted and simulated depths and velocities.

7. Assessment of Sensitivity of Model Output to Data Collection Program

Existing data sets may be used to assess the sensitivity of model output to different levels of data input. Analysis of basic PHABSIM Weighted Usable Area vs Discharge output and habitat duration outputs from time series analysis would be included in the assessment. Sensitivity of model output to the following variations in input data would be assessed

a) The number of calibration flows measured

b) The number of transects/ number of verticals per transect

c) The number of reaches sampled

d) The length of flow record,eg. 1 year, 5 years, 10 years.

8. Feasibility Assessment of Inclusion of Water Quality Parameters

The current PHABSIM software does not enable water quality parameters to be modelled. It is proposed that for a single target species water quality suitability curves are developed for which time series are available. A time series of water quality suitability values would be derived and combined with physical habitat analysis. Output would be in the form of habitat duration curves modified by the water quality suitability index.

a) Identify appropriate water quality parameters for inclusion in the modelling procedure.

b) Identify availability of time series of these parameters.

c) Develop water quality suitability curves for selected target species life-stages.

d) Using an existing PHABSIM data set produce modified habitat duration curves incorporating water quality suitability data.

9.3 OVERVIEW

We have demonstrated that the IFIM using PHABSIM is a powerful practical tool with potential for widespread application to the assessment of ecologically acceptable flows. We have demonstrated, using an example from a current operational problem, how IFIM outputs may be used in a seasonal analysis of habitat availability which can provide a framework for the setting of prescribed minimum flows.

The PHABSIM menu-driven software can now be provided on two diskettes. It is anticipated that a limited amount of training will be required to familiarise potential users with the procedures of data entry, data file construction, hydraulic model calibration and simulation.

We have identified a number of areas in which it is felt that the accuracy of model outputs could be enhanced by further development and outlined strategies for further research which could improve understanding, and increase the potential for extrapolation, of model outputs. Future applications of the existing model will help to expand the database available for such studies but some aspects of further assessment and development may require further, clearly focused R&D studies.

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Appendix A

Study site selection details

1: Summary of the characteristics of groups 1 to 10 derived from the 370 site RIVPACS data set:

Groups 1 and 2:	Predominantly headwater sites in the N and W of England and Wales.
Group 3:	Mid to upper sites in N. and S.W. England.
Group 4:	Mid to lower sites in W. Great Britain plus mid to low sites in 2 chalk streams in Southern England and one upper site in Kent.
Groups 5 and 6:	Upper sites mainly in C. S. and E. England.
Group 7:	Mid to lower sites in S. England and S. Wales.
Group 8:	Mid-Upper-Low sites in C. S. and E. England.
Group 9:	Upper to lower sites in C. S. and E. England.
Group 10:	Lower sites in S. and E. England.

Grp	Alt	Slope	Substrate	TON	Alk	Chlor
1, 2	56-203	5-11	-6.21–4.46	0.4-1.2	15-85	10-19.5
3	45-127	2-6	-5.88–5.24	0.5-2.4	45-137	9-26
4	16-45	1-3	-4.62–1.43	1.5-3.9	55-180	17-23
5, 6	36-46	3-5	-2.81–0.54	1.4-3.8	47-223	22-31
7	17-24	0.6-1	-2.83-+3.08	4.6-4.8	159-206	27-335
8	7-22	1-2	-1.25-+0.23	6.2-6.9	193-227	39-74
9	3-45	0.5-2	+0.91-+7.11	2.6-5.9	95-199	37-51
10	3-13	0.4-7	+2.58-+6.20	7.2-7.5	223-239	53-101

Key:

Grp	=	RIVPACS group number
Alt	=	Altitude (m) of sites
Slope	=	Slope of river at site in degrees
Substrate	=	Grain size range in phi
TON	=	Total oxidised nitrates (mg/l)
Alk	=	Calcium carbonate levels (mg/l)
Chlor	=	Chlorides (mg/l)

2: List of first and second choice rivers:

The data below is set out as follows:

R. name	Ecological site and grid ref.	Gauging stn. site and grid ref	W.A. Catchment area	Stn. no. Length of rec.
	Distance between station and site.		Hydrometric data + Art. influence	
GROUP 1:				
FIRST CHOICES				
EXE	SS791407	SS935260	S.W.	045009
	Warren Farm	Pixton	147.6	81-
	distance=20.5km		B C	
HODDER	ST702590	SD718546	N.W.	071002*
	Cross Gt.Bdg.	Stocks Res.	37.0	36-80
	distance=4.7km		A C	
		SD704399	N.W.	071008
		Hodder Pl.	261.0	77..
	distance=10.1km		A C	
SECOND CHOICES				
ESK	NZ663062	NZ865081	Yorks.	027050
	Westerdale	Sleights	308.0	70..
	DISTANCE=20.2km		A A	
RYE	Broadway		Yorks.	
SEVERN	Plynlimon		S.T.	
GROUP 2:				
FIRST CHOICE				
HABSCORE RIVER IN WALES (to be decided)				
SECOND CHOICES				
TEES	NY814288	NY813288	N.umbrian	025023
	Cauldron Snout	Cowgreen Res.	58.2	71..
	DISTANCE=0.1km		A C	
TEES	NY762338	NY813288	N.umbrian	925023
	Moorhouse	Cowgreen Res.	58.2	71..
	DISTANCE=7.14km		A C	
DWYFACH	SH468472	SH499421	Welsh	065007
(dwyfawr)	Pant Glas	Garndolbenmaen	52.4	75-
	DISTANCE=5.3km		B A 1975	B B 1986
S.TYNE	NY683554	NY672611	N.umbrian	023006
	d/s Knaresdale	Featherstone	321.9	66-
	DISTANCE=5.8km	A A		

GROUP 3:				
FIRST CHOICES				
EHEN	NY068159 Ennerdale Bdg. DISTANCE=1.6km	NY084154 Ennerdale Bdg.	N.W. 44.2 A B	074003 73..
EHEN	NY014130 u/s Keekle DISTANCE=6.9km	NY009061 Braystones	N.W. 125.5 B B	074005 74..
EHEN	NY012125 d/s Keekle DISTANCE=6.4km	NY009061 Braystones	N.W. 125.5 B B	074005 74..
EHEN	NY007061 Braystones DISTANCE=0.2km	NY009061 Braystones	N.W. 125.5 B B	074005 74-
DOVE	SK121598 Hartingdon DISTANCE=9.2km	SK146509 Isaak Walton	S.T. 83.0 A A	028046 69-
DOVE	SK146504 Hartingdon DISTANCE=0.5km	SK146509 Isaak Walton	S.T. 83.0 A A	028046 69-
SECOND CHOICE				
EXE	SS912342 Edbrooke DISTANCE=8.5km	SS935260 Pixton	S.W. 147.6 B C	045009 81-
EXE	SS930245 Exbridge DISTANCE=1.5km	SS935260 Pixton	S.W. 147.6 B C	045009 81-
GROUP 4:				
FIRST CHOICE				
BLITHE	SK109190 Hamstall Rid. DISTANCE=0.2km	SK109192 Hamstall Rid.	S.T. 163.0 B C	028002 37..
SECOND CHOICE				
OTTER	ST184030 Monkton DISTANCE=8.1km	SY115986 Fenny Bridges	S.W. 104.2 B A	045008 74-
OTTER	SY123993 Colhayes Farm DISTANCE=1.1km	SY115986 Fenny Bridges	S.W. 104.2 B A	045008 74-

GROUP 5:				
FIRST CHOICE				
ROTHER	SU749307 U/S Liss Stn. DISTANCE=0.3km	SU772270 Princes Marsh	S. 37.2 A B	041027 72-
ROTHER	SU769260 Stodham Park DISTANCE=1.0km	SU772270 Princess Marsh	S. 37.2 A B	041027 72-
ROTHER	SU783234 Durford Bridge DISTANCE=6.9km	SU852229 Iping Mill	S. 154.0 A A	041011 66..
SECOND CHOICES				
DUDWELL	TQ655224 Burwash Weald DISTANCE=2.8km	TQ679240 Burwash Weald	S. 27.5 B A	040017 71..
Gt. EAU	TF370768 Swaby DISTANCE=5.2km	TF416793 Claythorpe Mill	Ang. 77.4 C A	029002 62..
WENSUM	TF885240 S.Raynham DISTANCE=6.3km	TF919294 Fakenham	Ang. 127.1 A A	034011 67..
TILLINGBOURNE	TQ053479 u/s Albury DISTANCE=5.3km	TQ000478 Shalford	Thames 59.0 A A	039029 68-
GROUP 6:				
FIRST CHOICE				
LYMINGTON	SU297036 Balmorlawn DISTANCE=2.7km	SU318019 Brockenhurst	S. 98.9 A A	042003 60..
SECOND CHOICES				
ROTHER	SU747307 Hawkley Mill DISTANCE=4.3km	SU772270 Princes Marsh	S. 37.2 A B	041027 72-
Gt. EAU	TF332779 Ruckland DISTANCE=5.2km	TF416793 Claythorpe Mill	Anglian 77.4 C A	029002 62..

GROUP 7:				
FIRST CHOICES				
FROME	SY866867 E.Stoke DISTANCE=0km	SY866867 E.Stoke	Wessex 414.4 B B	044001 66-
SECOND CHOICES				
W. AVON	SU132558 Rushall DISTANCE=0.14km	SU133559 Upavon	WESSEX 76.0 A B	043017 71-
CANDOVER BROOK	SU565345 Abbotstone DISTANCE=2.2km	SU568323 Borough Bridge	S. 71.2 A B	042009 70-
LYMINGTON	SZ320984 Boldre Bg DISTANCE=3.5km	SU318019 Brockenhurst Pk.	S. 98.9 A A	042003 60..
GROUP 8:				
FIRST CHOICE				
MIMRAM	TL193207 Whitwell DISTANCE=0.1km	TL184212 Whitwell	Thames 39.1 B C	038017 70-
MIMRAM	TL282134 Panshanger DISTANCE=0.1km	TL282133 Panshanger Pk.	Thames 133.9 A B	038003 52-
SECOND CHOICES				
WENSUM	TF881282 South Mill Fm. DISTANCE=3.9km	TF919294 Fakenham	Ang. 127.1 A A	034011 67..
WENSUM	TF964273 Gt Ryburgh DISTANCE=4.9km	TF919294 Fakenham	Ang. 127.1 A A	034011 67..
COLNE	TL798323 d/s Headingham DISTANCE=4.9	TL771364 Poolstreet	Ang. 65.1 A B	037012 63-
W.AVON	SU071585 Putney DISTANCE=6.7km	SU133559 Upavon	Wessex 76.0 A B	043017 71-
THET	TL996924 Red Bridge DISTANCE=0.1km	TL996923 Red Bridge	Ang. 145.3 A A	033046 67-
Gt. EAU	TF403777 Bellam DISTANCE=2.0km	TF416793 Claythorpe Mill	Ang. 77.4 C A 1962 A A 1974	029002 62..
Gt. EAU	TF425826 Withem DISTANCE=3.4km	TF416793 Claythorpe Mill	Ang. 77.4 C A 1962 A A 1974	029002 62..

GROUP 9:				
FIRST CHOICE				
GWASH				
SECOND CHOICE				
Gt. EAU	TF452867 Theddlethorpe. DISTANCE=8.2km	TF416793 Claythorpe Hill	Ang. 77.4 C A 1962 A A 1974	029002 63-85
GROUP 10:				
FIRST CHOICE				
Gt. OUSE	TL010590 Shornbrook DISTANCE=10.5km	TL055495 (Bed.Ouse) Bedford	Ang. 1460.0 B B	033002 33-
Gt. OUSE	TL160535 Roxton Lock DISTANCE=10.0km	TL216619 Offord	Ang. 2570.0 A C	033026 70-
SECOND CHOICE				
THAMES	SU225984 Malthouse DISTANCE=0.5km	SU230981 Buscot	Thames 997.0 B B	039097 80-
THAMES	SU590932 Shillingford DISTANCE=2.2km	SU568935 Days Weir	Thames 3444.7 B B 1938 A B 1969	039002 38-

3. Site Location Maps

In figures A1 to A11 below we give location maps for the eleven study sites.

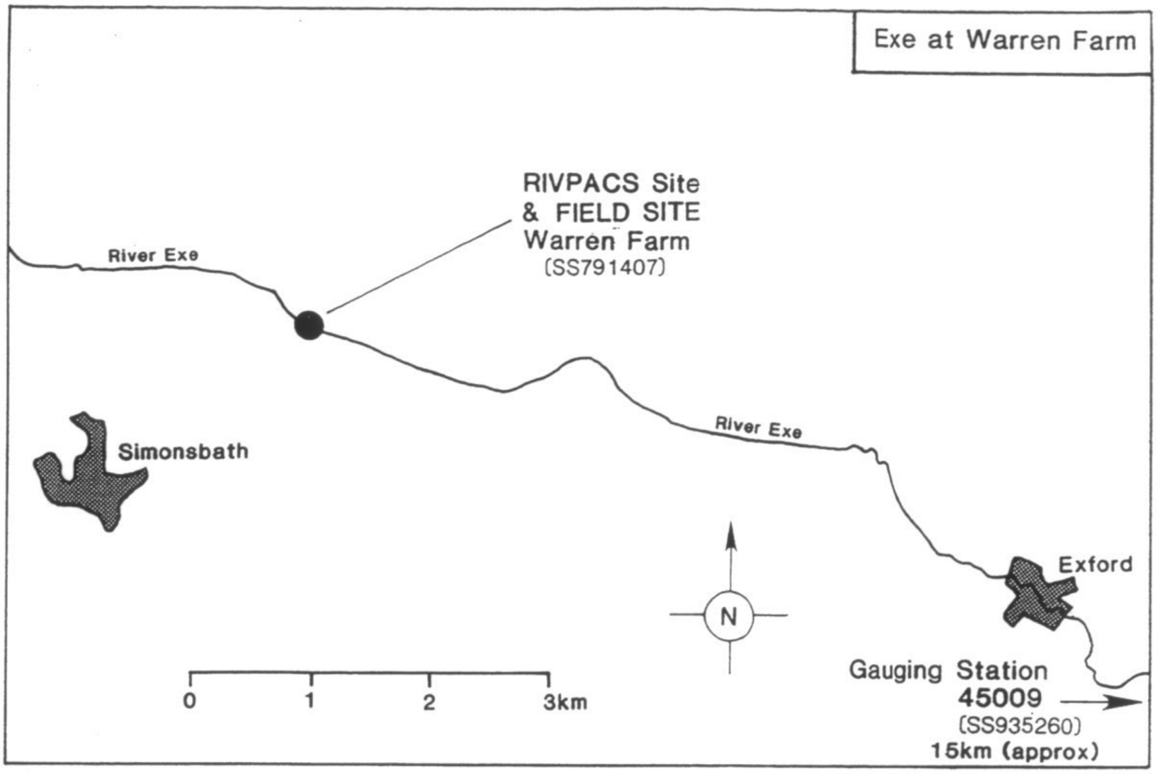


Figure A1 *River Exe study site*

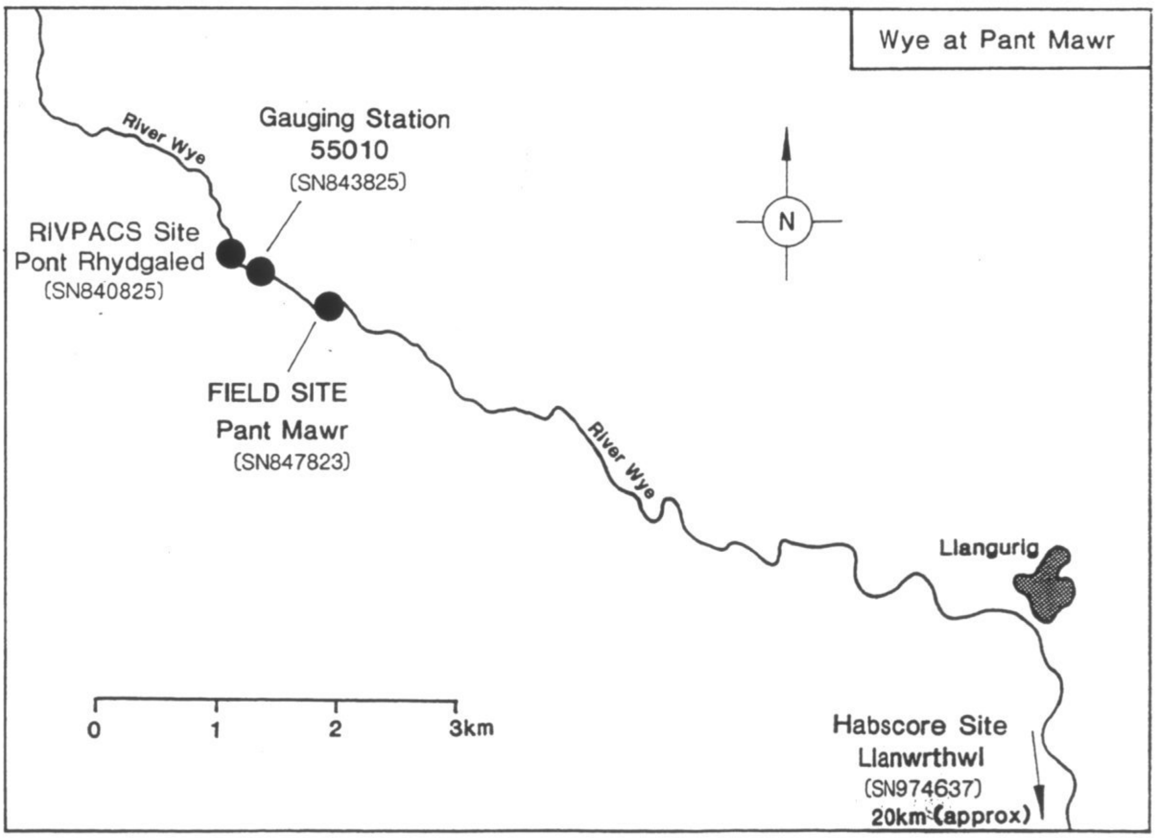


Figure A2 *River Wye Study site*

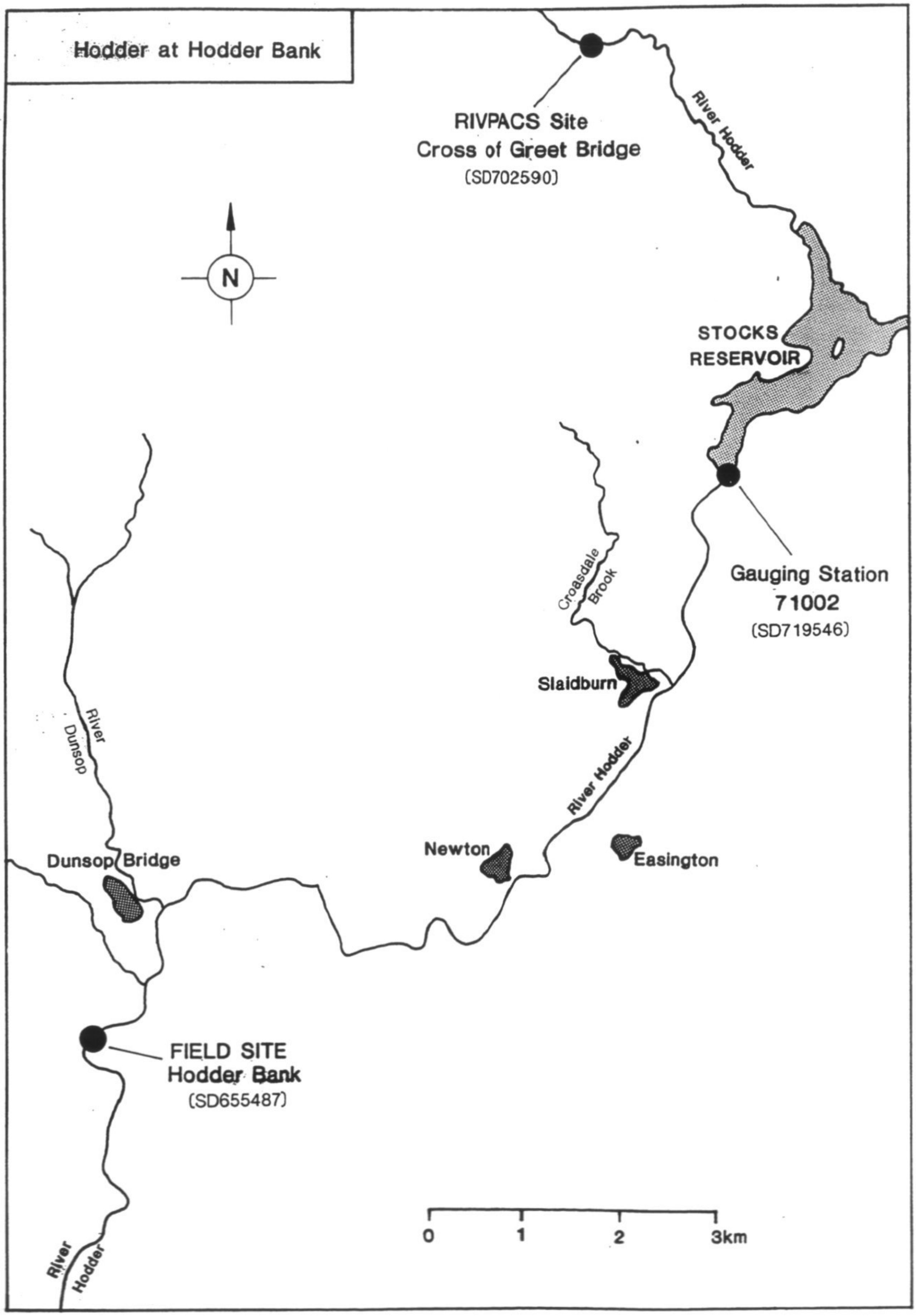


Figure A3 *River Hodder study site*

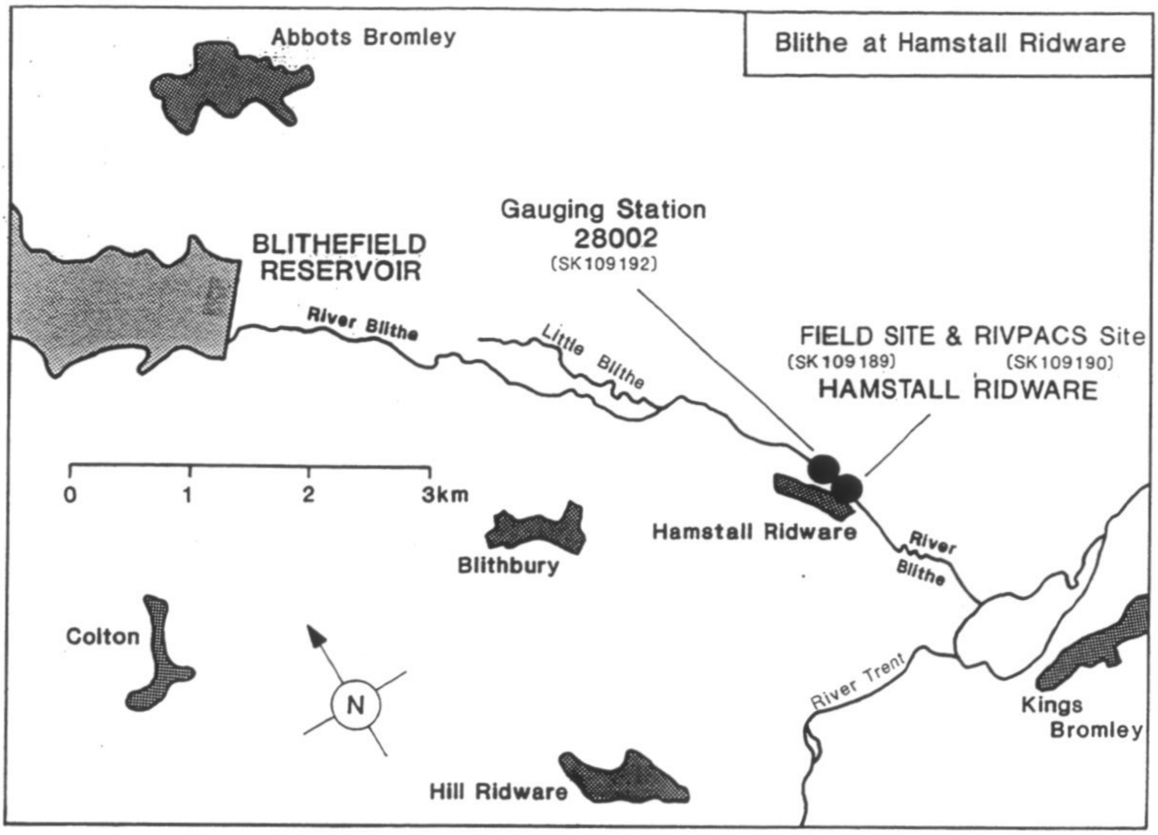


Figure A4 *River Blithe study site*

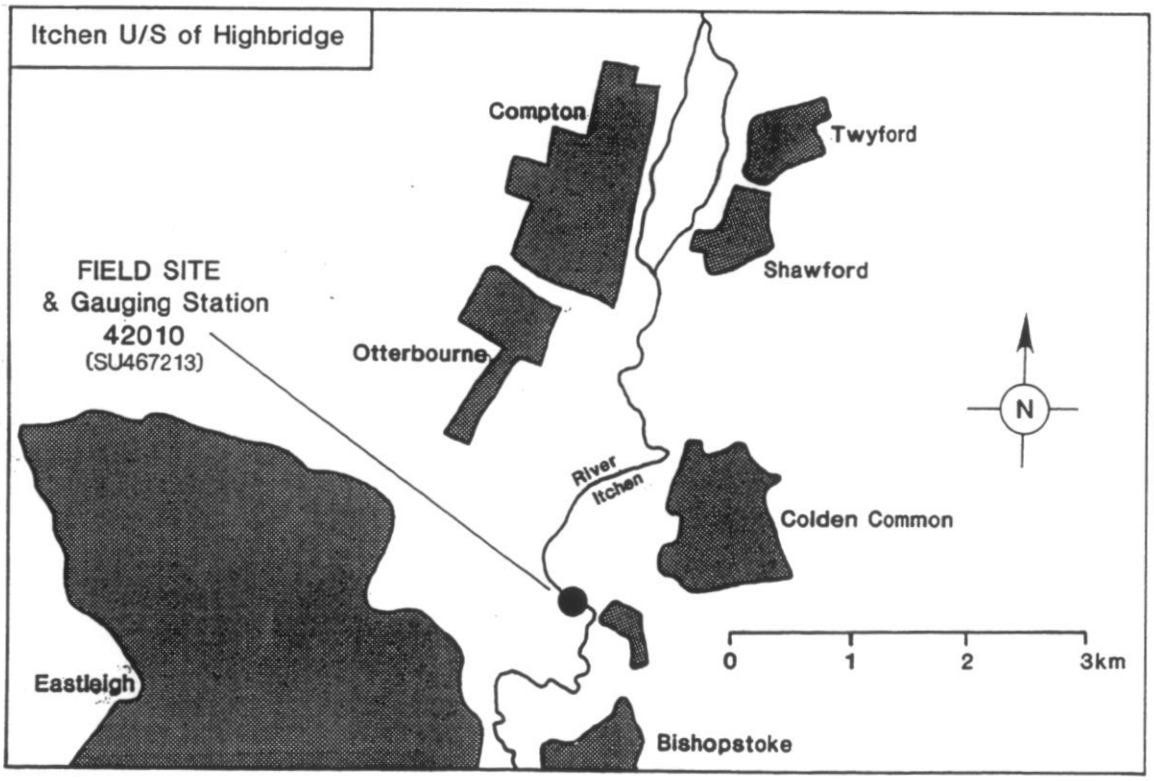


Figure A5 *River Itchen study site*

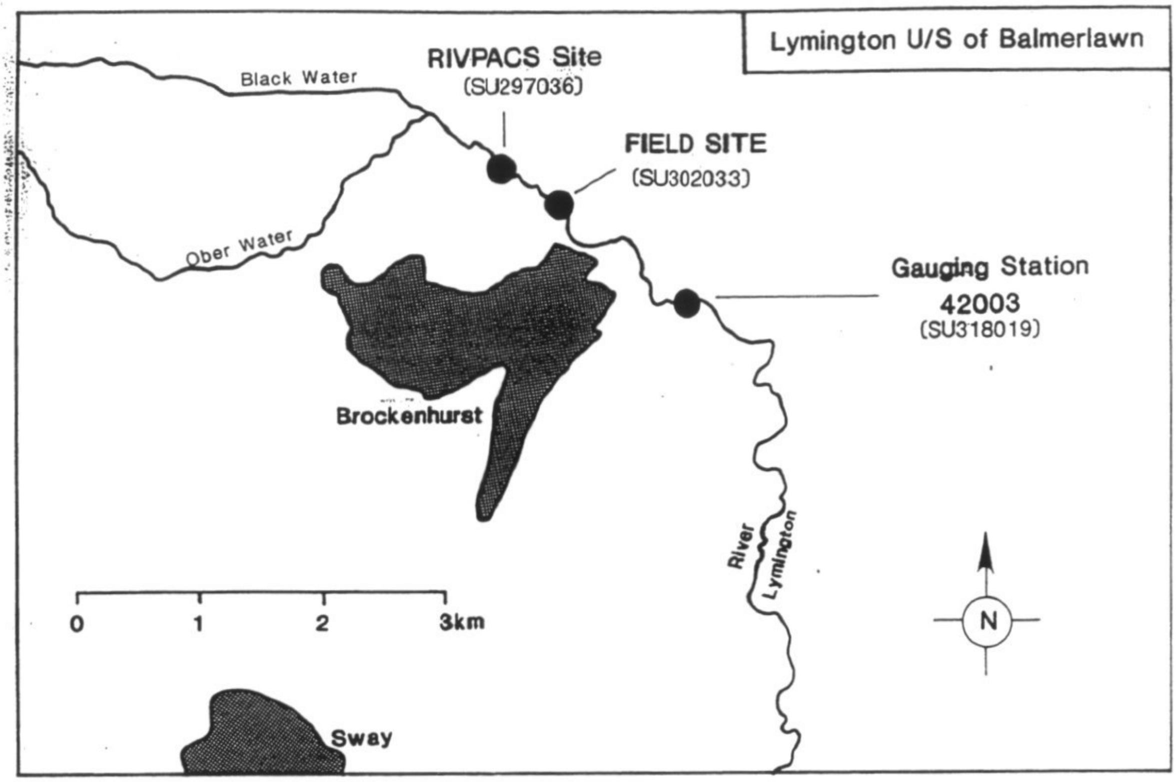


Figure A6 *River Lymington study site*

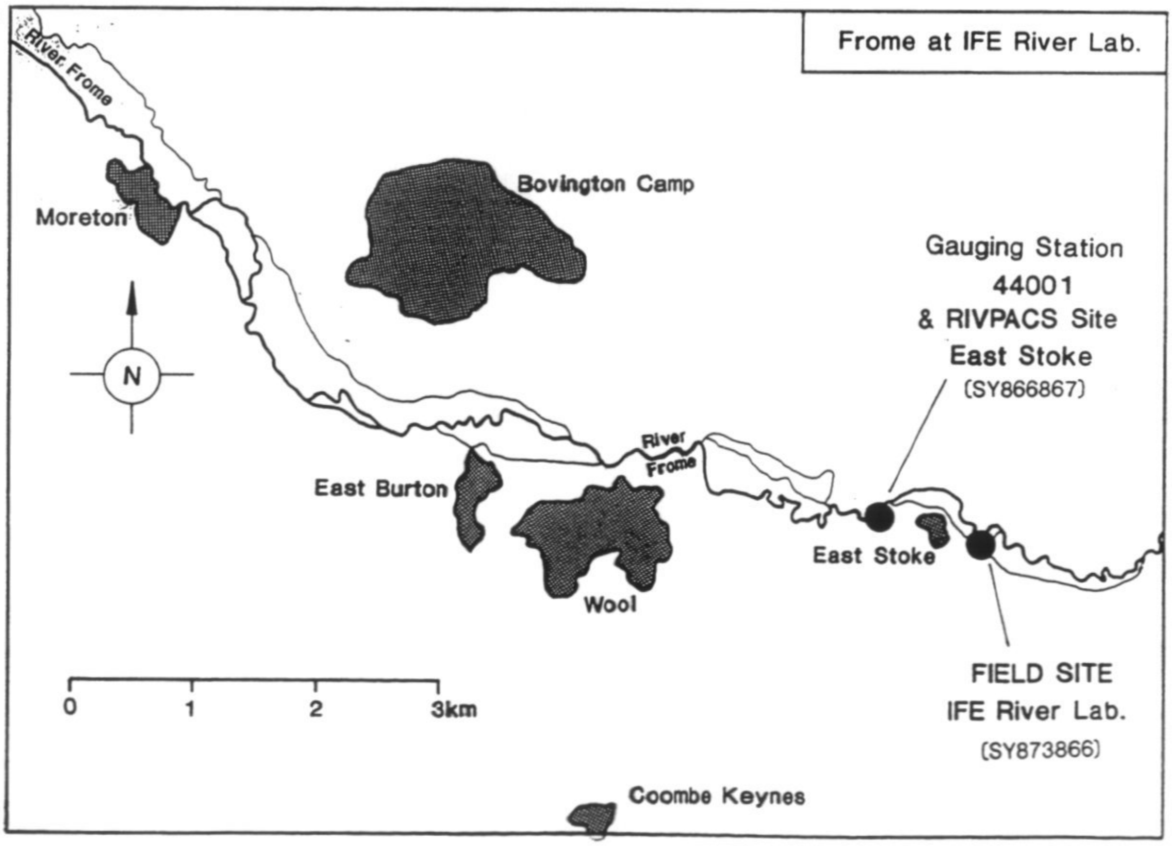


Figure A7 *River Frome (Mill Stream) study site*

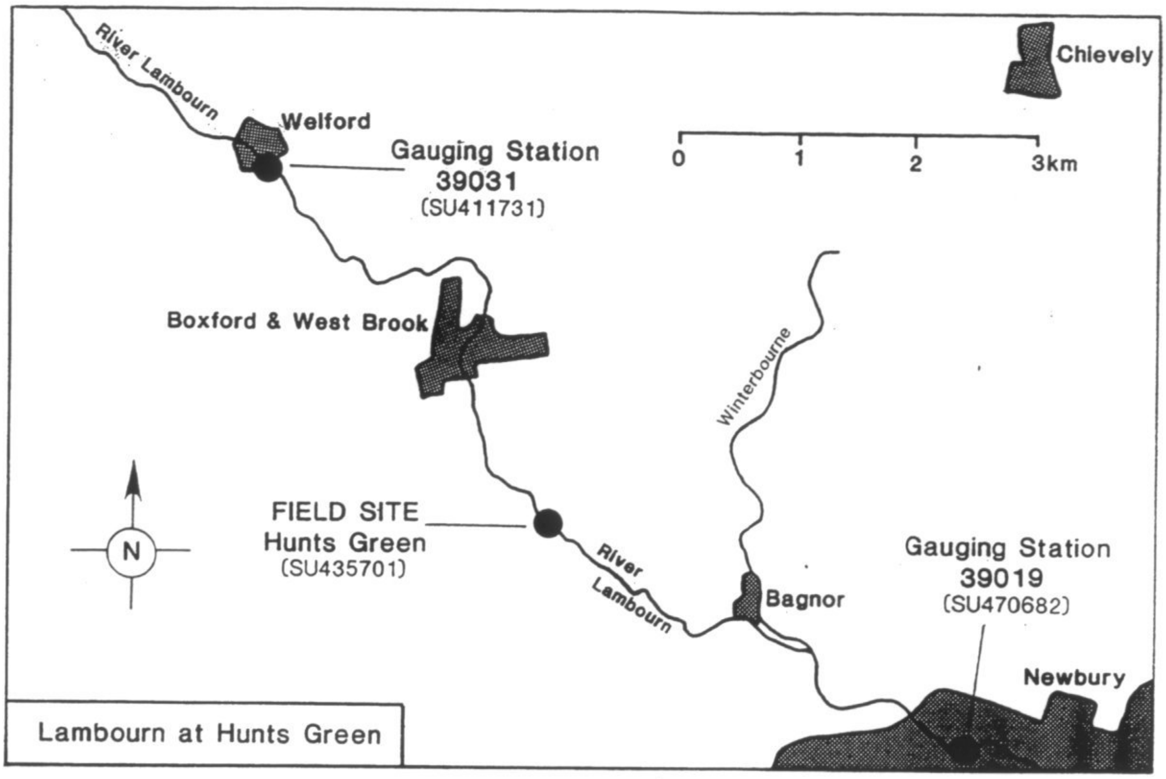


Figure A8 *River Lambourn study site*

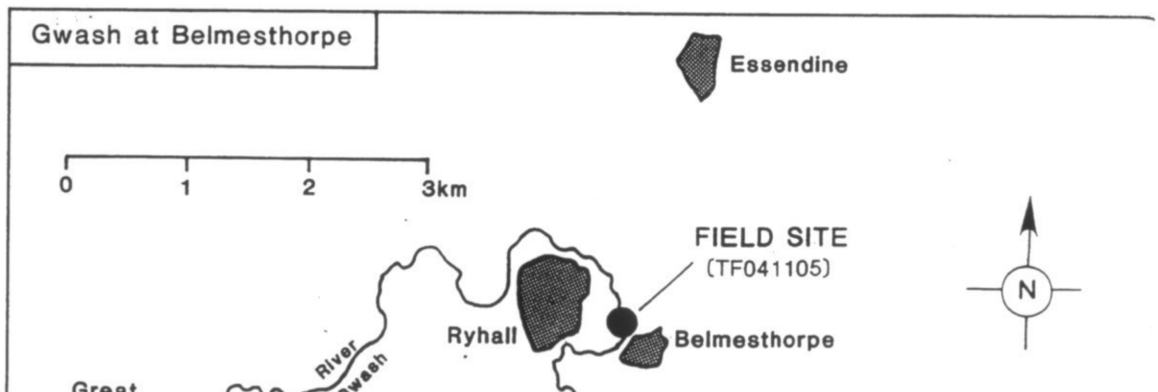


Figure A9 *River Gwash study site*

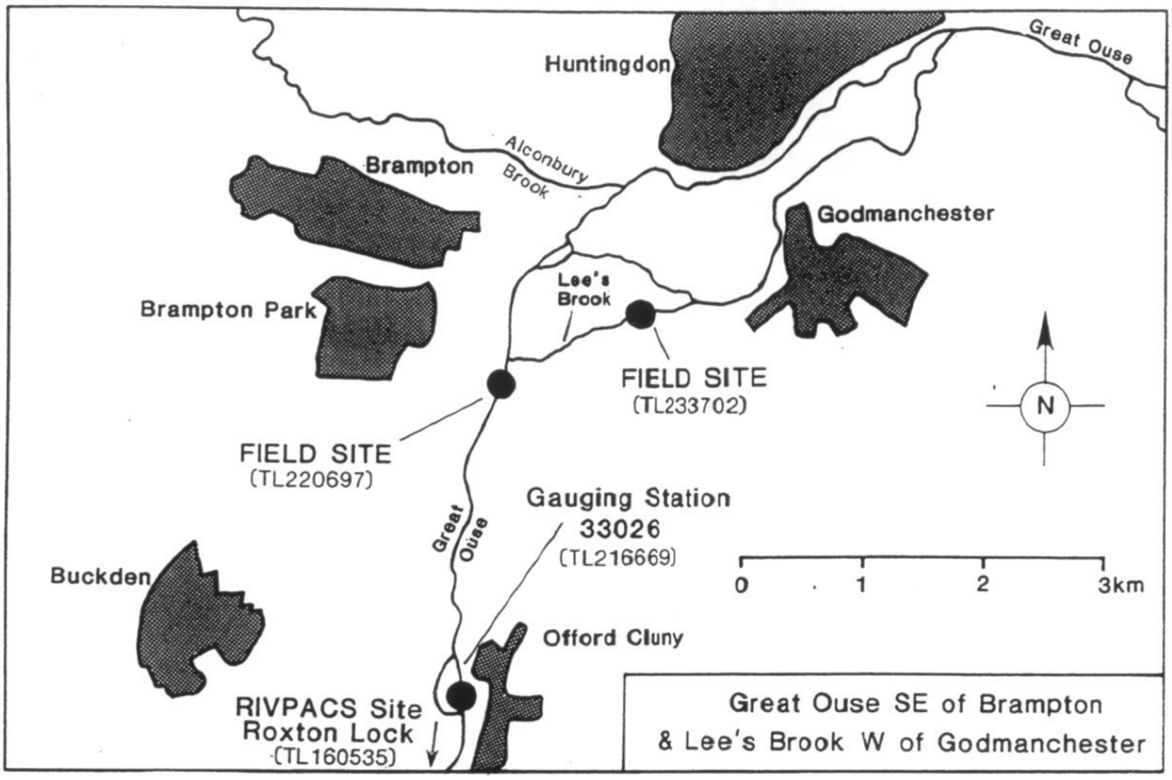


Figure A10 *Great Ouse and Lee's Brook study sites*

Appendix B

Habitat Suitability Data For Target Species

Invertebrate Suitability Data and Curves

Habitat suitability data from the RIVPACS database are given in Tables B1-B8 for each of the target species discussed in Section 5.1. The corresponding habitat suitability curves are given in Figures B1-B16.

Table B1 *Habitat suitability data:* Ephemeridae

Taxon	Ephemeridae				Ephemeridae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	7	0.19	0.52	18	0.50	0.44
10-25	64	23	0.36	0.97	72	1.13	1.00
25-50	146	54	0.37	1.00	149	1.02	0.90
50-100	148	39	0.26	0.71	105	0.71	0.63
>100	52	19	0.37	0.99	56	1.08	0.96
	446	142			400		
Depth							
0-25	180	74	0.39	1.00	196	1.09	1.00
25-50	157	52	0.33	0.84	156	0.99	0.91
50-100	62	9	0.15	0.37	35	0.56	0.52
100-200	42	5	0.11	0.28	10	0.24	0.22
200-300	5	2	0.15	0.39	3	0.60	0.55
	446	142			400		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	21	0.21	0.46	38	0.39	0.24
6	107	23	0.21	0.44	58	0.54	0.33
5	145	64	0.44	0.94	187	1.28	0.77
4	32	15	0.47	1.00	68	1.66	1.00
3	40	17	0.43	0.91	45	1.13	0.68
2	13	2	0.13	0.28	4	0.27	0.16
1	11	0	0.00	0.00	0	0.00	0.00
	446	142			400		

Table B2 *Habitat suitability data: Heptagenia*

Taxon	*Heptagenia sulphurea*				*Heptagenia lateralis*		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	0	0.00	0.00	0	0.00	0.00
10-25	64	8	0.13	0.26	3	0.05	0.38
25-50	146	29	0.20	0.40	19	0.13	1.00
50-100	148	43	0.29	0.58	16	0.11	0.85
>100	52	26	0.50	1.00	4	0.08	0.62
	446	106			42		
Depth							
0-25	180	30	0.16	0.41	22	0.12	1.00
25-50	157	44	0.28	0.72	14	0.09	0.75
50-100	62	24	0.39	1.00	5	0.08	0.67
100-200	42	7	0.17	0.44	1	0.02	0.17
200-300	5	1	0.20	0.51	0	0.00	0.00
	446	106			42		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	29	0.30	0.91	6	0.06	0.21
6	107	35	0.33	1.00	30	0.28	1.00
5	145	30	0.21	0.63	6	0.04	0.14
4	32	5	0.16	0.48	0	0.00	0.00
3	40	7	0.18	0.55	0	0.00	0.00
2	13	0	0.00	0.00	0	0.00	0.00
1	11	0	0.00	0.00	0	0.00	0.00
	446	106			42		

Table B3 *Habitat suitability data: Rhithrogena semicolorata, Habrophlebia fusca*

Taxon	*Rhithrogena semicolorata*				*Habrophlebia fusca*		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	3	0.08	0.11	7	0.19	0.61
10-25	64	22	0.34	0.45	20	0.31	1.00
25-50	146	67	0.46	0.61	32	0.22	0.71
50-100	148	104	0.70	0.93	18	0.12	0.39
>100	52	39	0.75	1.00	6	0.12	0.39
	446				83		
Depth							
0-25	180	102	0.57	0.95	57	0.32	1.00
25-50	157	94	0.60	1.00	17	0.11	0.34
50-100	62	33	0.53	0.88	6	0.10	0.32
100-200	42	6	0.14	0.23	3	0.07	0.22
200-300	5	0	0.00	0.00	0	0.00	0.00
	446	235			83		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	86	0.88	1.00	11	0.11	0.41
6	107	82	0.77	0.88	13	0.12	0.44
5	145	53	0.37	0.42	39	0.27	1.00
4	32	9	0.28	0.32	7	0.22	0.81
3	40	5	0.13	0.15	8	0.20	0.74
2	13	0	0.00	0.00	3	0.23	0.85
1	11	0	0.00	0.00	2	0.18	0.67
	446	235			83		

Table B4 *Habitat suitability data: Leuctra inermis,* Leuctridae

Taxon	*Leuctra inermis*				Leuctridae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	1	0.03	0.08	5	0.14	0.08
10-25	64	9	0.14	0.38	56	0.88	0.53
25-50	146	44	0.30	0.81	219	1.50	0.90
50-100	148	50	0.35	0.95	245	1.66	1.00
>100	52	19	0.37	1.00	83	1.60	0.96
	446	123			608		
Depth							
0-25	180	61	0.34	1.00	313	1.74	1.00
25-50	157	45	0.29	0.71	214	1.36	0.78
50-100	62	15	0.24	0.71	71	1.15	0.66
100-200	42	2	0.04	0.12	10	0.24	0.14
200-300	5	0	0.00	0.00	0	0.00	0.00
	446	123			608		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	55	0.56	1.00	257	2.62	1.00
6	107	55	0.51	0.91	277	2.59	0.99
5	145	13	0.09	0.16	74	0.51	0.20
4	32	0	0.00	0.00	0	0.00	0.00
3	40	0	0.00	0.00	0	0.00	0.00
2	13	0	0.00	0.00	0	0.00	0.00
1	11	0	0.00	0.00	0	0.00	0.00
	446	123			608		

Table B5 *Habitat suitability data:* Chloroperlidae

Taxon	Chloroperlidae				Chloroperlidae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	3	0.08	0.17	6	0.17	0.18
10-25	64	17	0.27	0.59	31	0.48	0.52
25-50	146	48	0.33	0.72	111	0.76	0.82
50-100	148	68	0.46	1.00	137	0.93	1.00
>100	52	21	0.40	0.87	40	0.78	0.84
	446	157			325		
Depth							
0-25	180	72	0.40	1.00	162	0.90	1.00
25-50	157	59	0.37	0.93	119	0.76	0.84
50-100	62	21	0.34	0.83	36	0.58	0.64
100-200	42	5	0.12	0.30	8	0.19	0.20
200-300	5	0	0.00	0.00	0	0.00	0.00
	446	157			325		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	52	0.53	0.84	101	1.03	0.72
6	107	67	0.63	1.00	154	1.44	1.00
5	145	32	0.22	0.35	61	42.00	0.29
4	32	4	0.13	0.21	5	16.00	0.11
3	40	1	0.03	0.05	2	0.05	0.03
2	13	1	0.08	0.13	2	0.15	0.10
1	11	0	0.00	0.00	0	0.00	0.00
	446	157			325		

Table B6 *Habitat suitability data:* Sericostomatidae

Taxon	Sericostomatidae				Sericostomatidae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	7	0.19	0.33	24	0.67	0.44
10-25	64	28	0.44	0.76	87	1.36	0.89
25-50	146	58	0.40	0.69	184	1.26	0.83
50-100	148	76	0.51	0.88	225	1.52	1.00
>100	52	30	0.58	1.00	75	1.44	0.95
	446	199			595		
Depth							
0-25	180	97	0.54	1.00	304	1.69	1.00
25-50	157	81	0.51	0.94	238	1.51	0.89
50-100	62	17	0.27	0.50	36	0.58	0.34
100-200	42	4	0.09	0.17	17	0.37	0.22
200-300	5	0	0.00	0.00	0	0.00	0.00
	446	199			595		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	50	0.51	0.93	109	1.11	0.67
6	107	59	0.55	1.00	178	1.66	1.00
5	145	63	0.44	0.83	217	1.50	0.90
4	32	17	0.53	0.96	53	1.66	1.00
3	40	9	0.23	0.42	37	0.93	0.56
2	13	1	0.08	0.13	1	0.08	0.05
1	11	0	0.00	0.00	0	0.00	0.00
	446	199			595		

Table B7 *Habitat suitability data: Crangonyx pseudogracilis, Gammarus pulex*

Taxon	*Crangonyx pseudogracilis*				*Gammarus pulex*		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	24	0.67	1.00	26	0.72	0.82
10-25	64	20	0.31	0.46	56	0.88	1.00
25-50	146	21	0.14	0.21	115	0.79	0.90
50-100	148	21	0.14	0.21	104	0.71	0.81
>100	52	14	0.27	0.40	37	0.71	0.81
	446	100			338		
Depth							
0-25	180	24	0.13	0.16	150	0.83	1.00
25-50	157	32	0.20	0.25	116	0.73	0.88
50-100	62	13	0.21	0.80	40	0.65	0.78
100-200	42	27	0.64	1.00	28	0.67	0.81
200-300	5	4	0.80		4	0.80	0.96
	446	100			338		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	7	0.07	0.09	54	0.55	0.55
6	107	9	0.08	0.10	71	0.66	0.66
5	145	41	0.28	0.36	127	0.88	0.88
4	32	10	0.31	0.40	28	0.88	0.88
3	40	15	0.38	0.49	40	1.00	1.00
2	13	10	0.77	1.00	12	0.92	0.92
1	11	8	0.73	0.95	6	0.55	0.55
	446	100			338		

Table B8 *Habitat suitability data:* Gammaridae

Taxon	Gammaridae				Gammaridae		
Variable velocity	T	O	MO	S	A	MA	S
<10	36	32	0.88	0.96	184	5.10	0.93
10-25	64	59	0.92	1.00	340	5.30	0.96
25-50	146	116	0.79	0.86	803	5.50	1.00
50-100	148	107	0.73	0.79	612	4.10	0.75
>100	52	43	0.83	0.90	247	4.80	0.87
	446	357			2186		
Depth							
0-25	180	154	0.86	0.86	928	5.20	0.44
25-50	157	120	0.76	0.76	811	5.20	0.44
50-100	62	46	0.74	0.74	238	3.90	0.33
100-200	42	32	0.76	0.76	150	3.30	0.28
200-300	5	5	1.00	1.00	59	11.80	1.00
	446	357			2186		
Substrate							
8	0	0	0.00	0.00	0	0.00	0.00
7	98	58	0.59	0.59	210	0.55	0.55
6	107	73	0.68	0.68	331	3.09	0.40
5	145	133	0.92	0.92	1130	7.79	1.00
4	32	31	0.97	0.97	165	5.16	0.66
3	40	40	1.00	1.00	226	5.65	0.75
2	13	13	1.00	1.00	82	6.30	0.85
1	11	9	0.82	0.82	42	3.82	0.49
	446	357			2186		

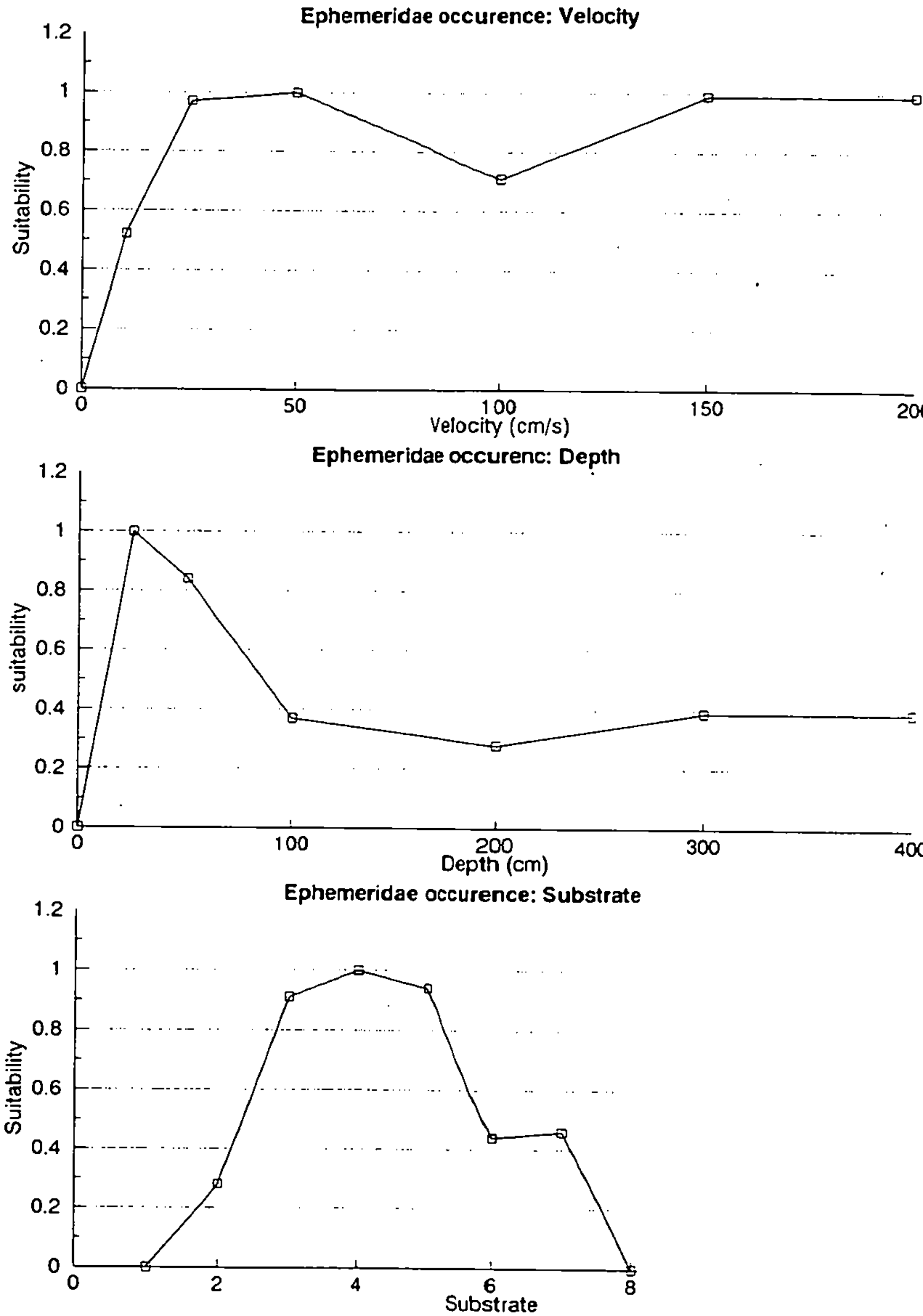


Figure B1 *Habitat suitability curves:* Ephemeridae *occurrence*

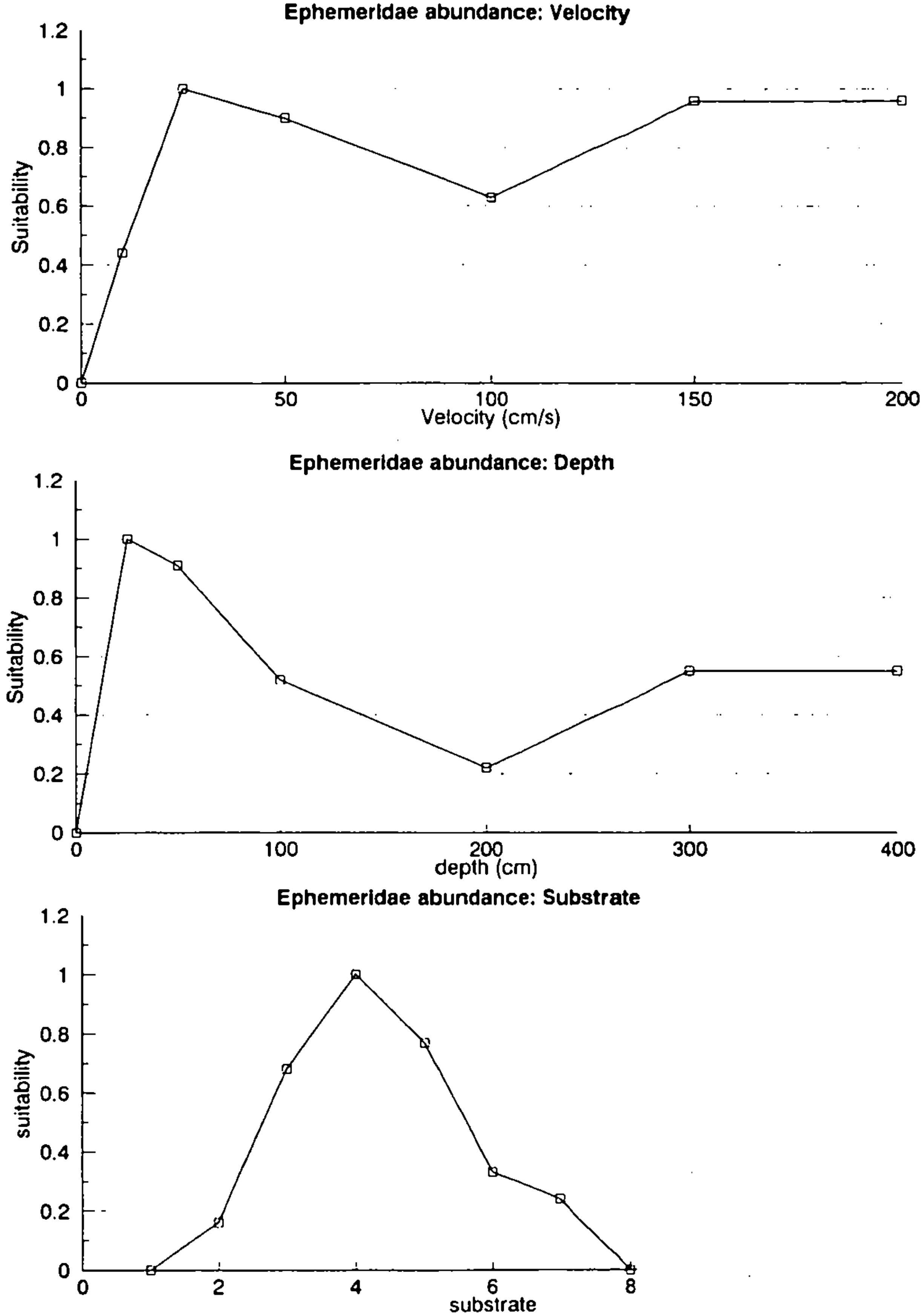


Figure B2 *Habitat suitability curves:* Ephemeridae *abundance*

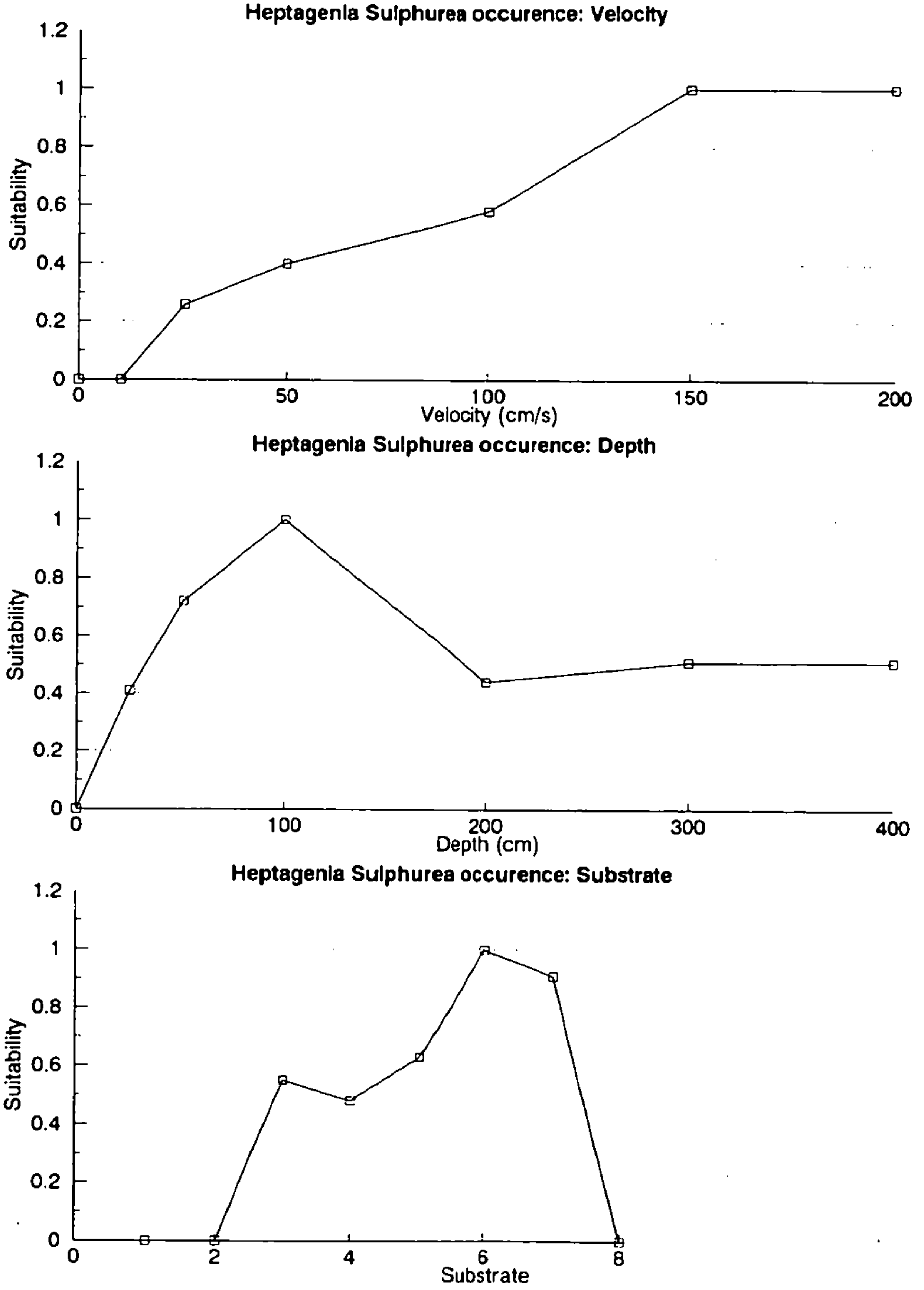
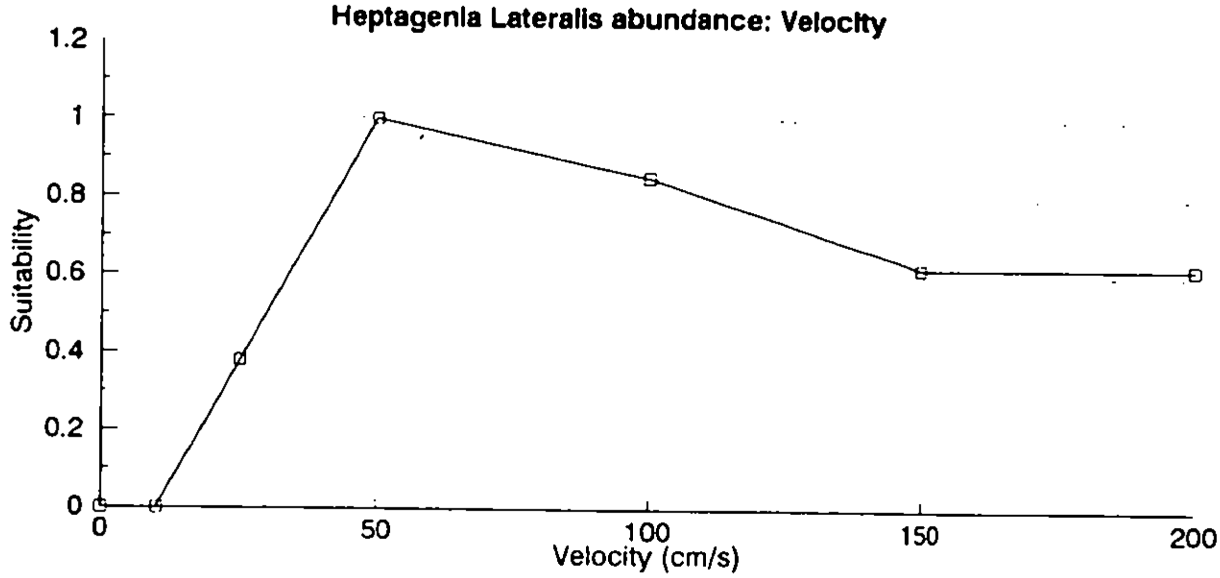
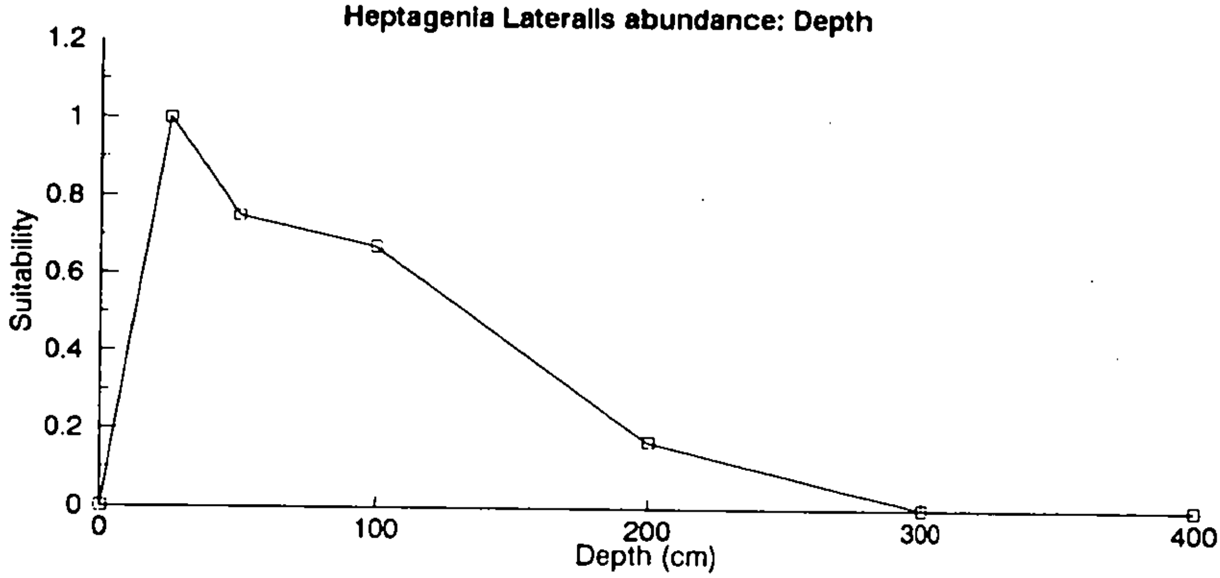


Figure B3 *Habitat suitability curves: Heptagenia sulphurea occurrence*





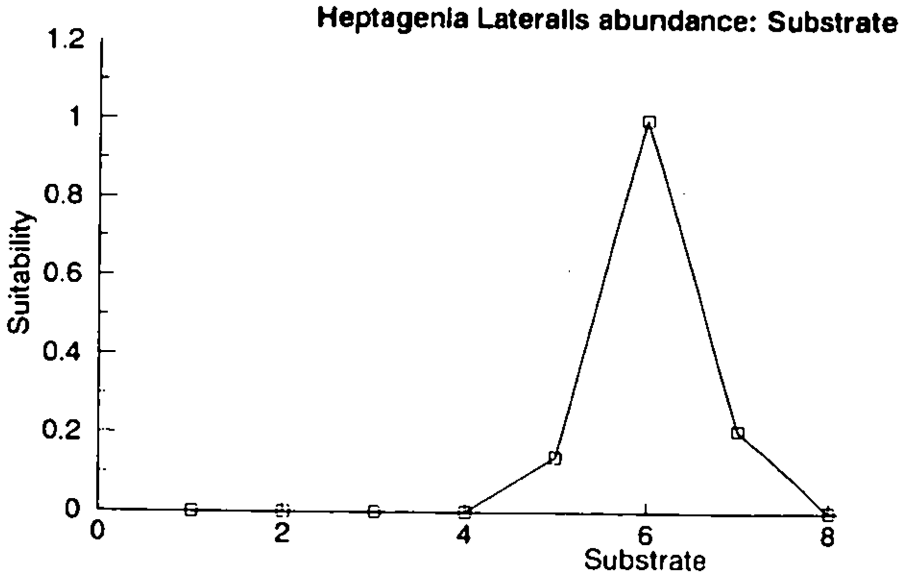


Figure B4 *Habitat suitability curves: Heptagenia lateralis occurence*

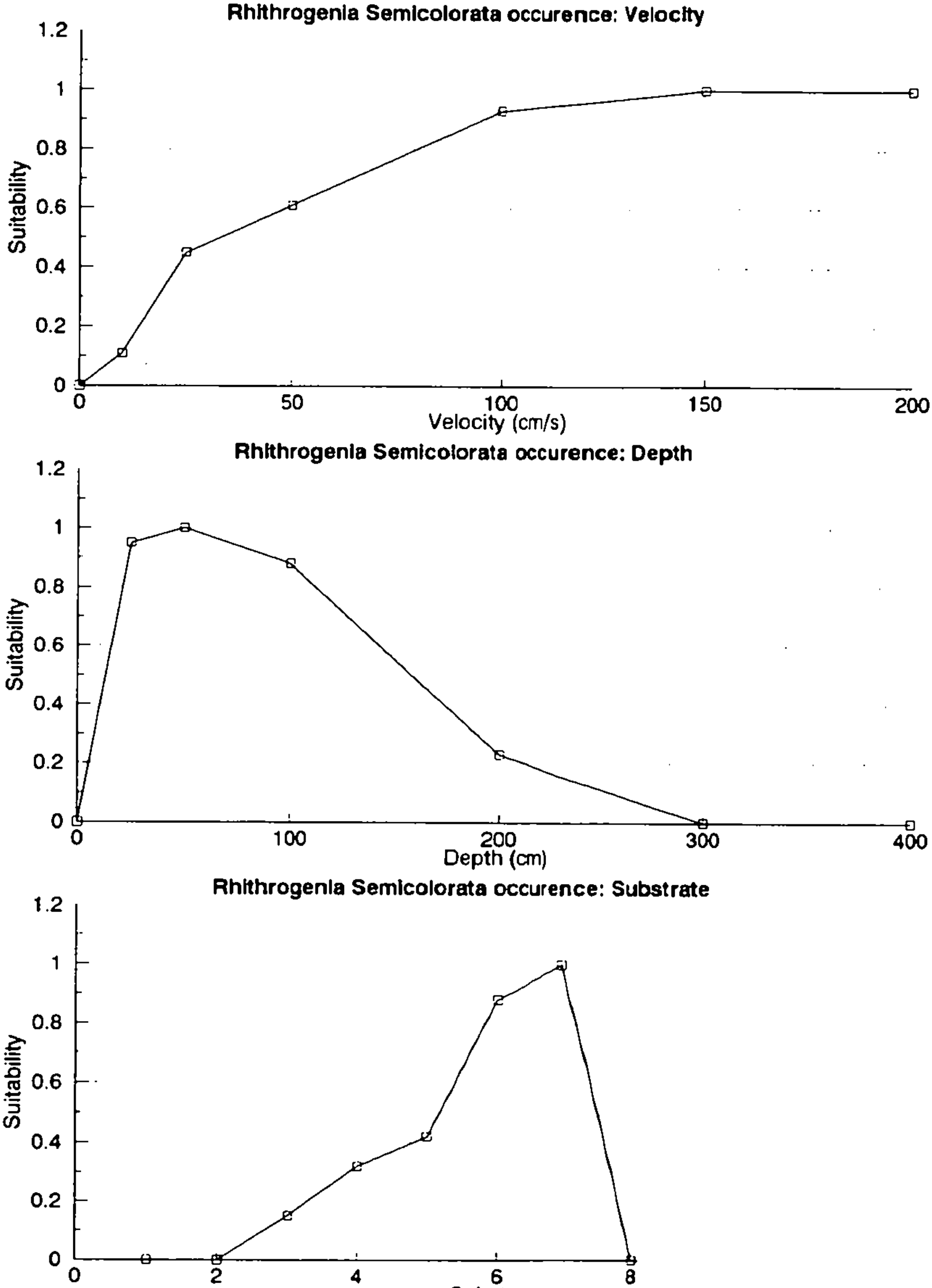


Figure B5 *Habitat suitability curves: Rhithrogena semicolorata occurrence*

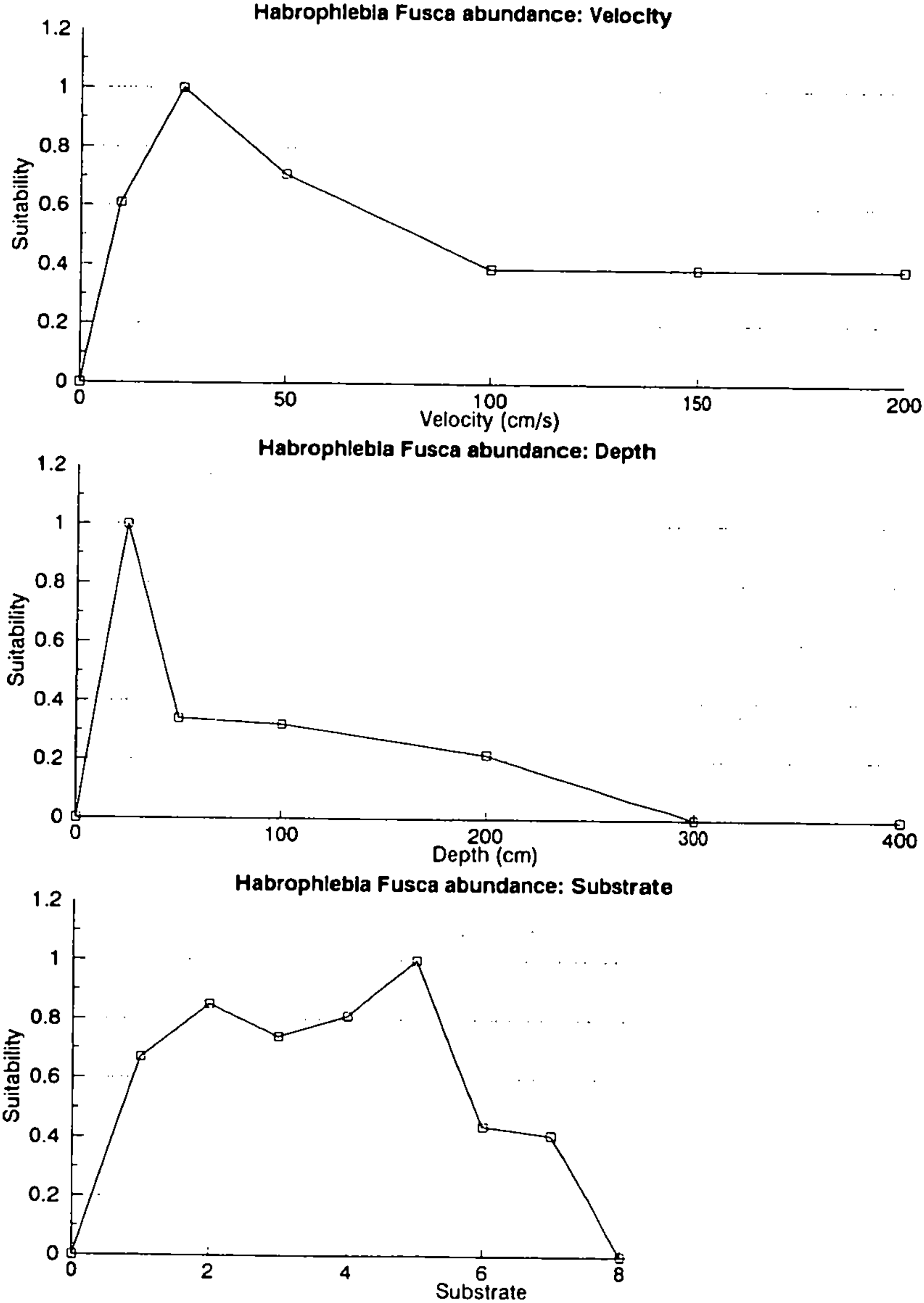


Figure B6 *Habitat suitability curves: Haberophlebia Fusca abundance*

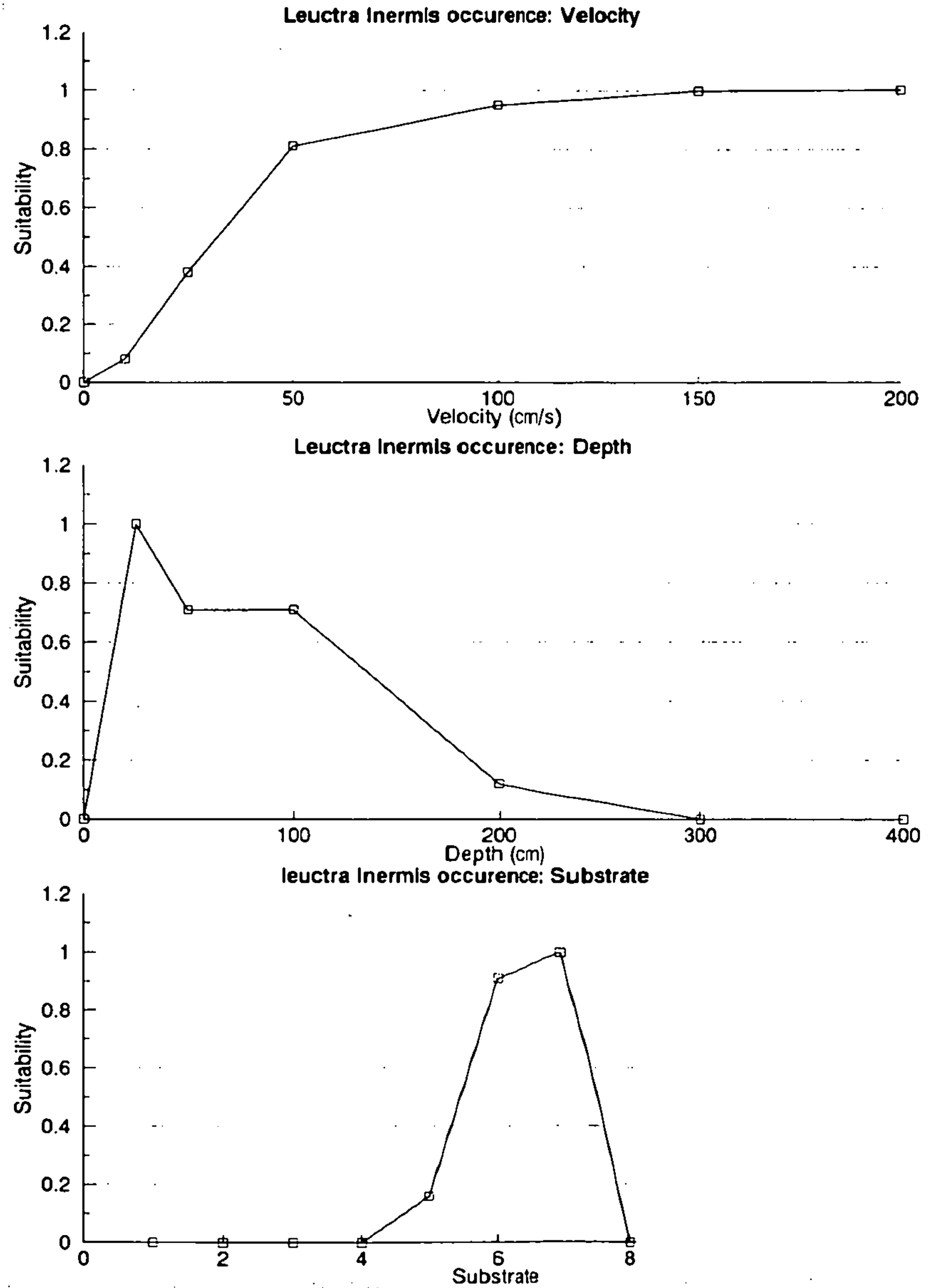


Figure B7 *Habitat suitability curves: Leuctra inermis occurrence*

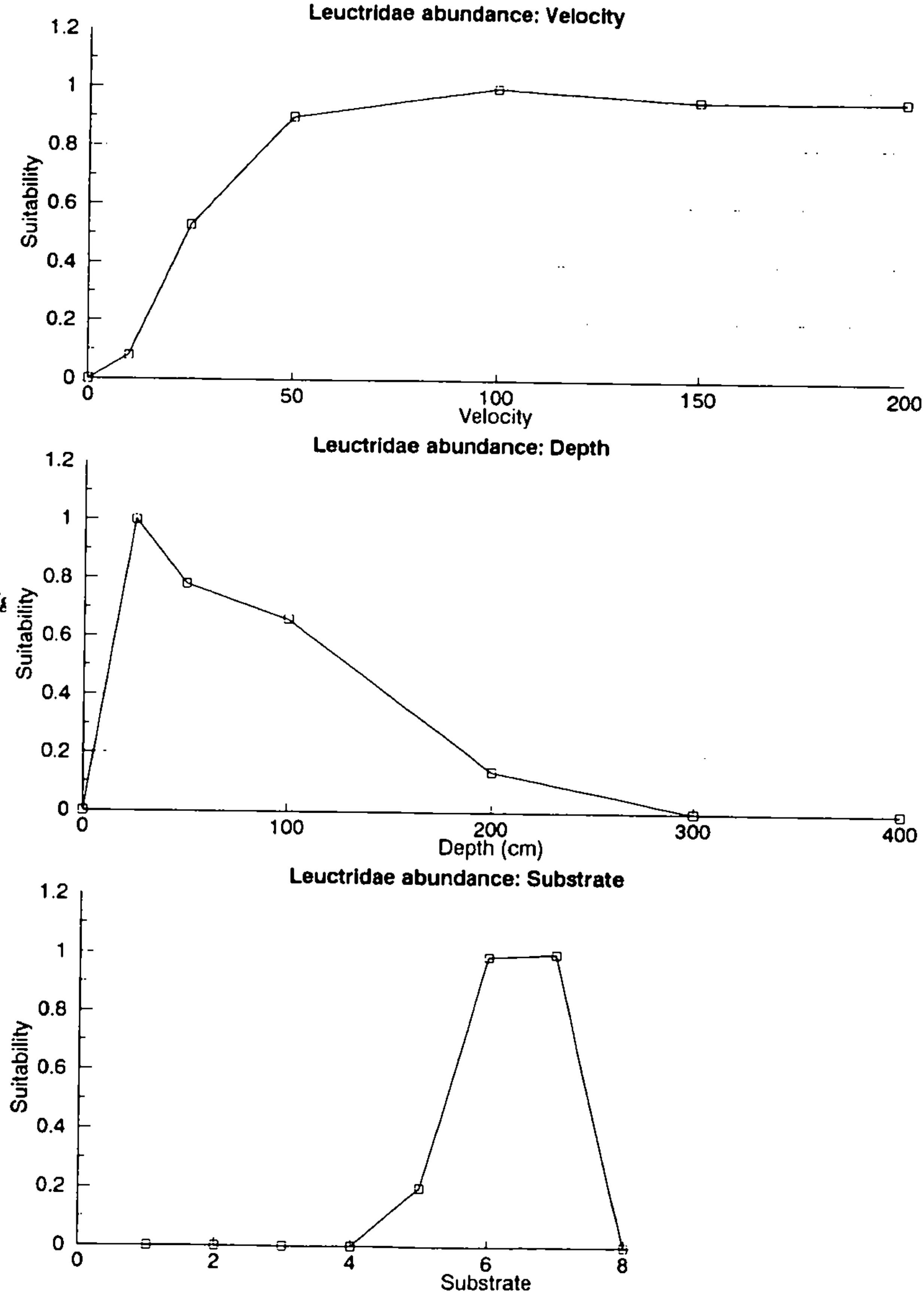


Figure B8 *Habitat suitability curves:* Leuctridae *abundance*

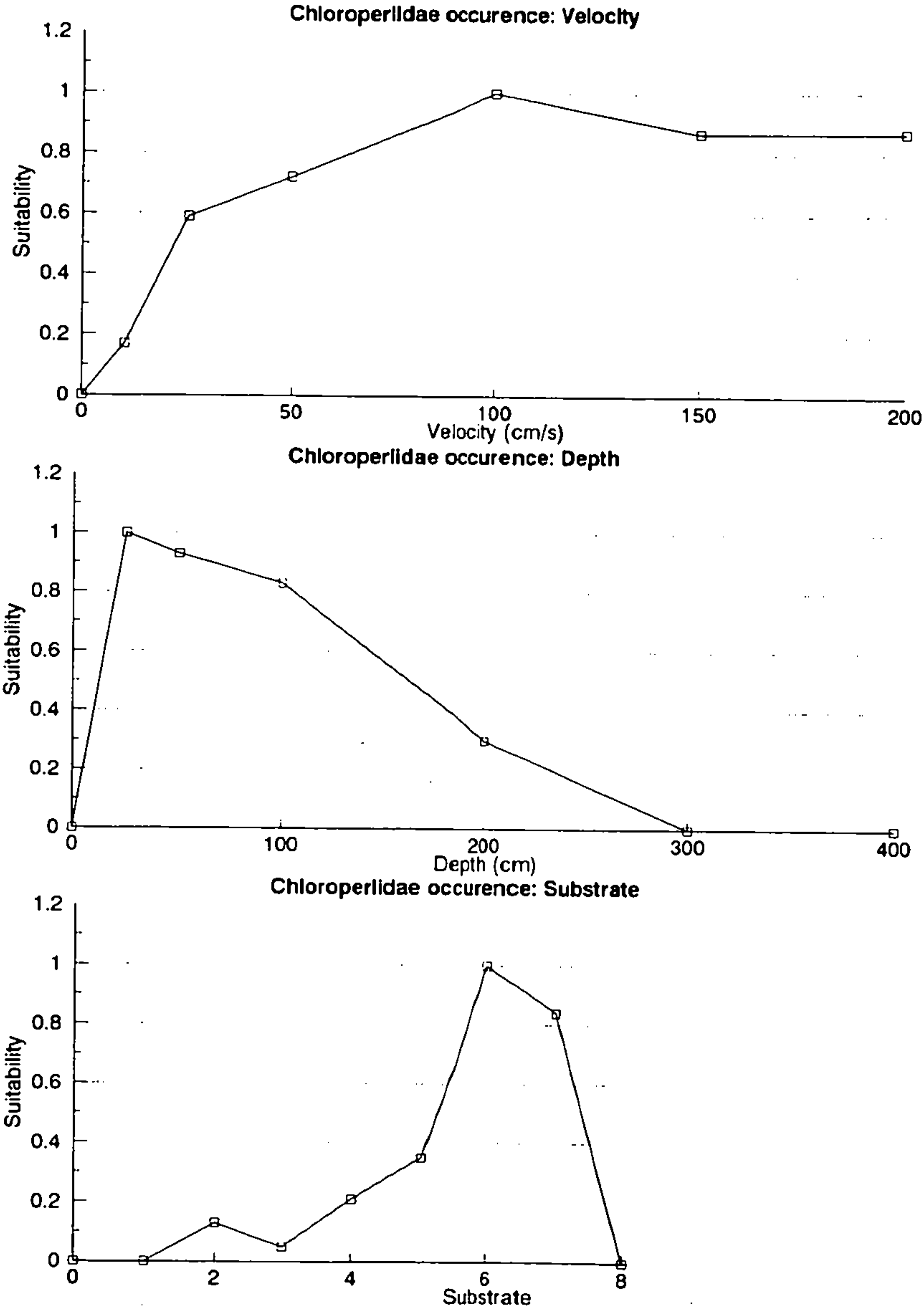


Figure B9 *Habitat suitability curves:* Chloroperlidae *occurrence*

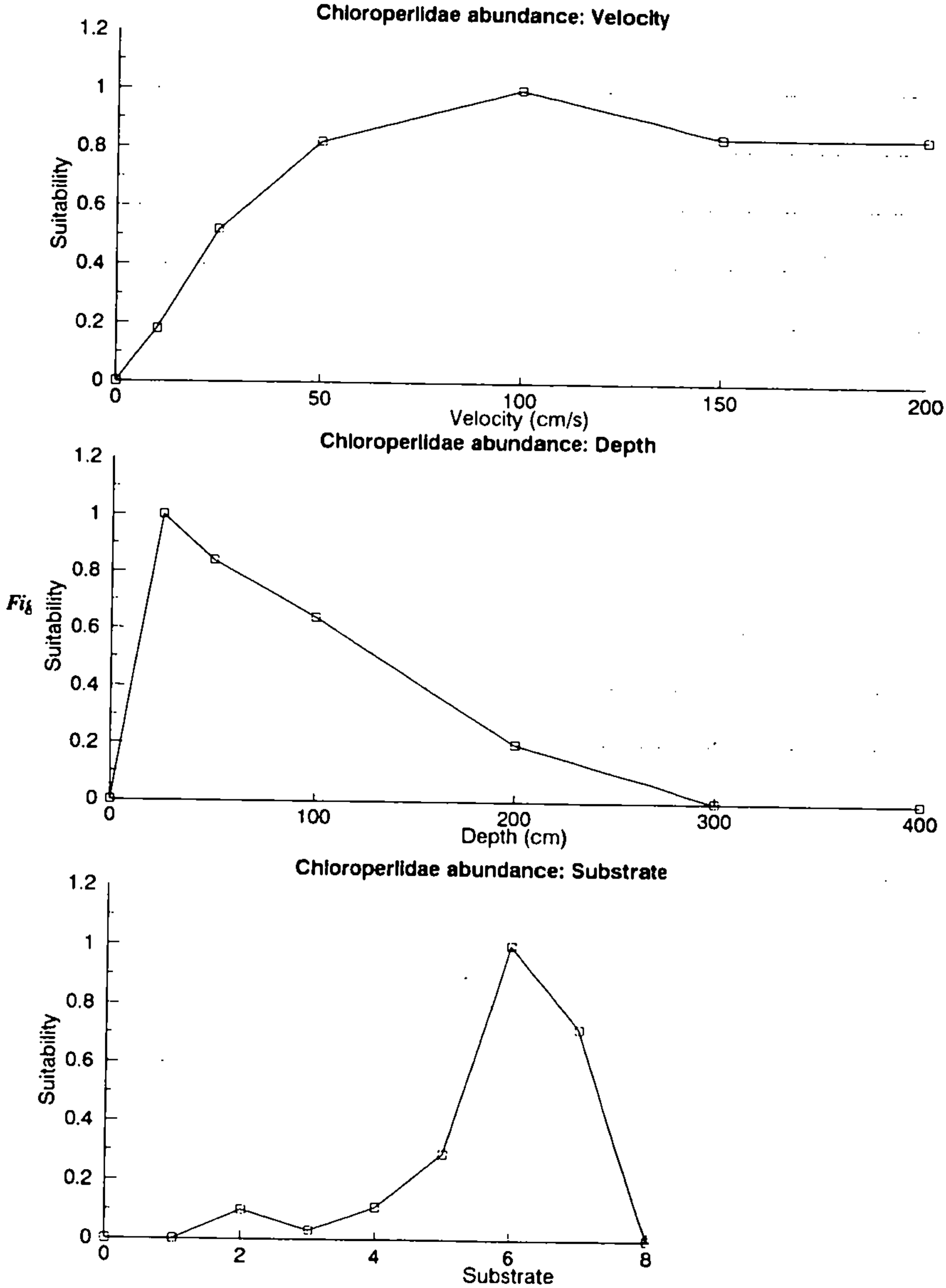


Figure B10 *Habitat suitability curves:* Chloroperlidae *abundance*

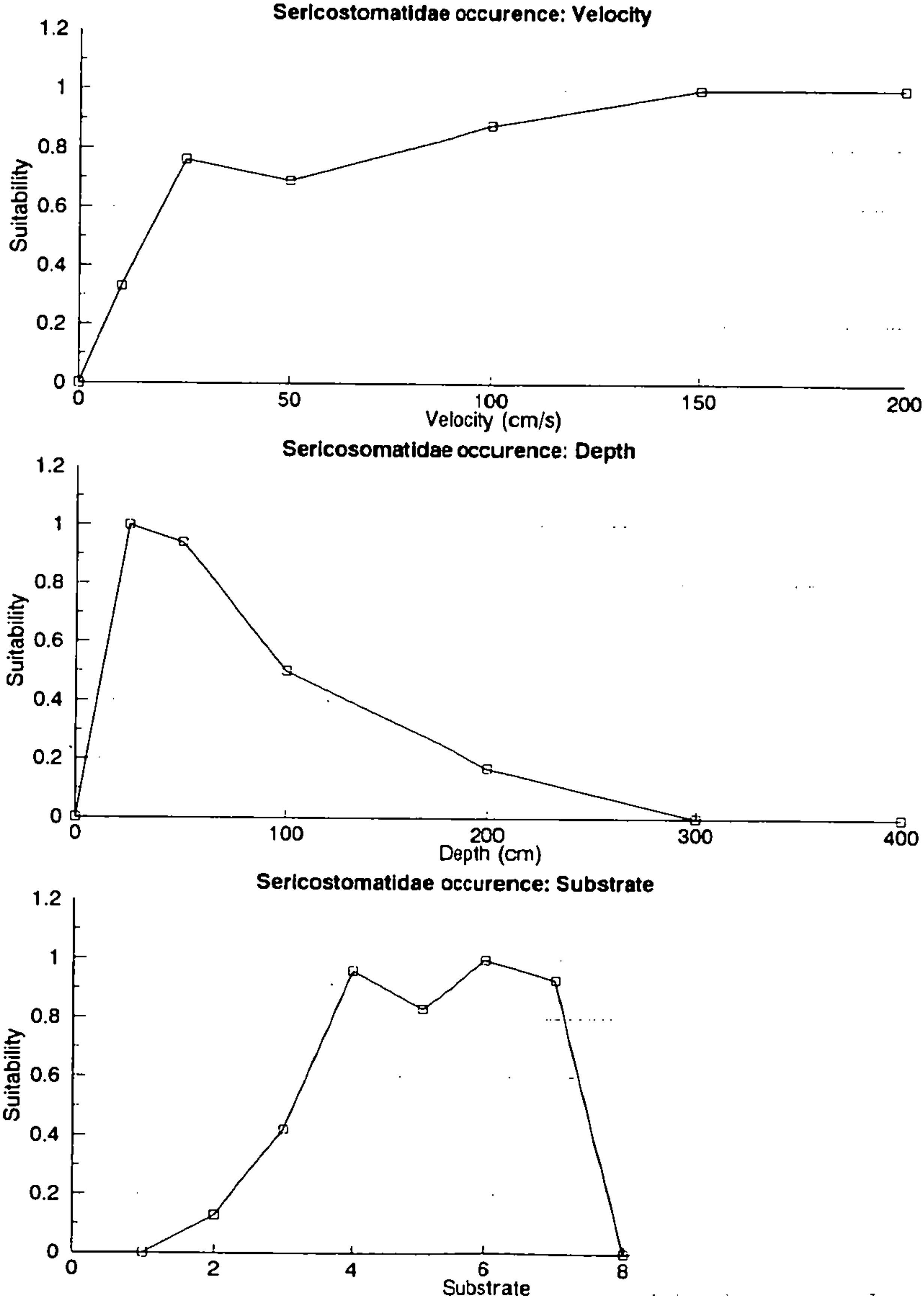


Figure B11 *Habitat suitability curves:* Sericostomatidae *occurrence*

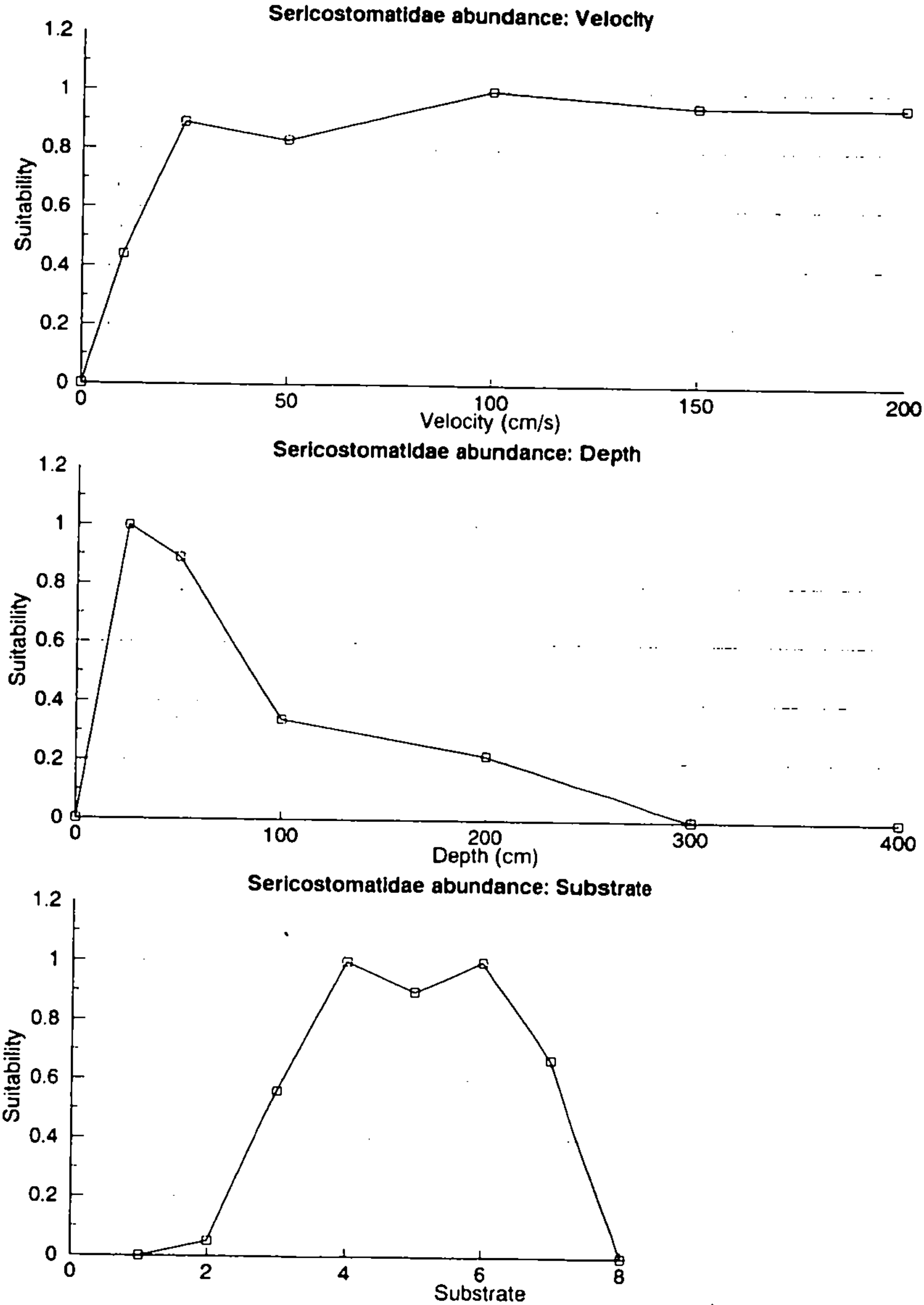


Figure B12 *Habitat suitability curves:* Sericostomatidae *abundance*

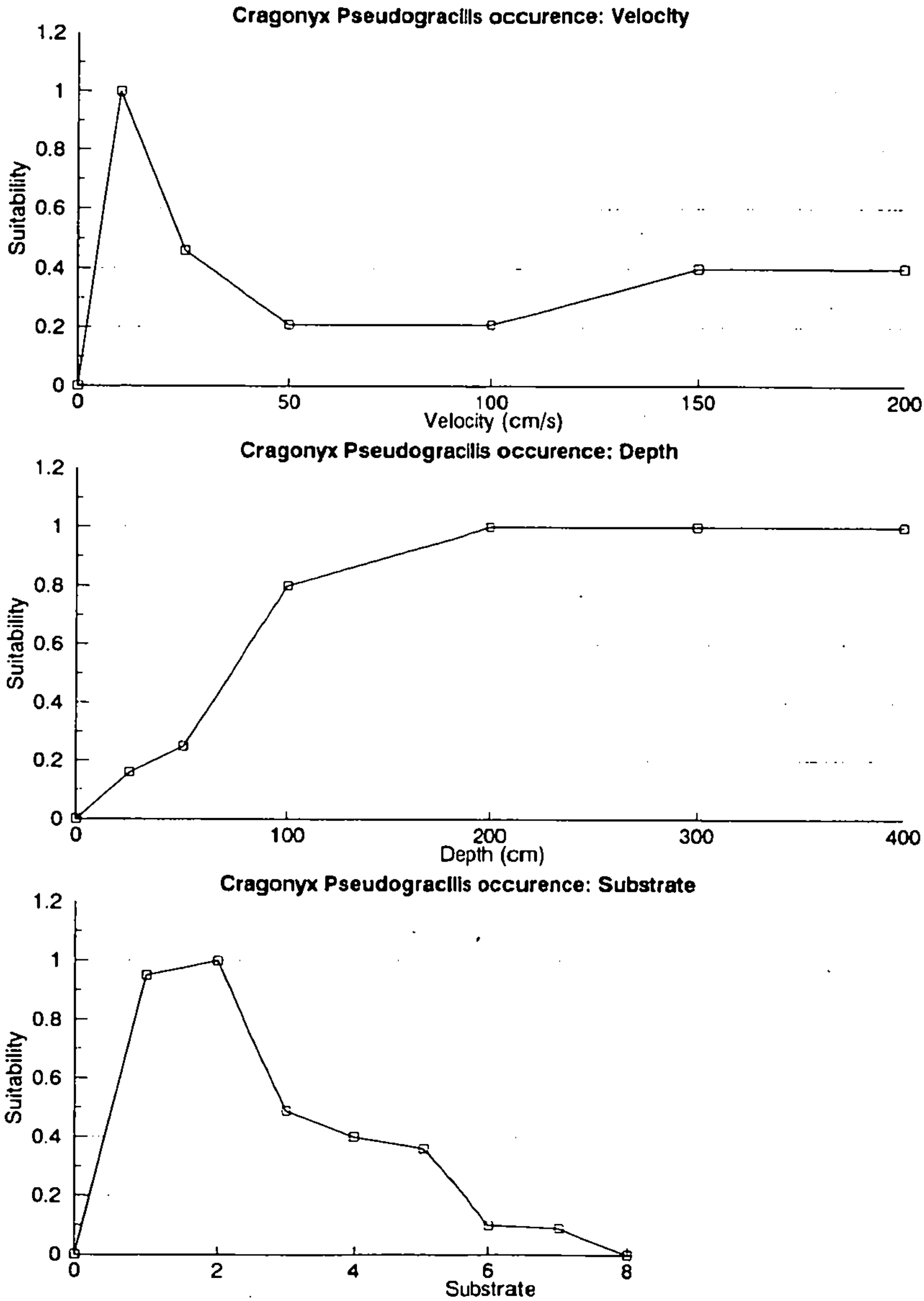


Figure B13 *Habitat suitability curves: Crangonyx Pseudogracilis occurrence*

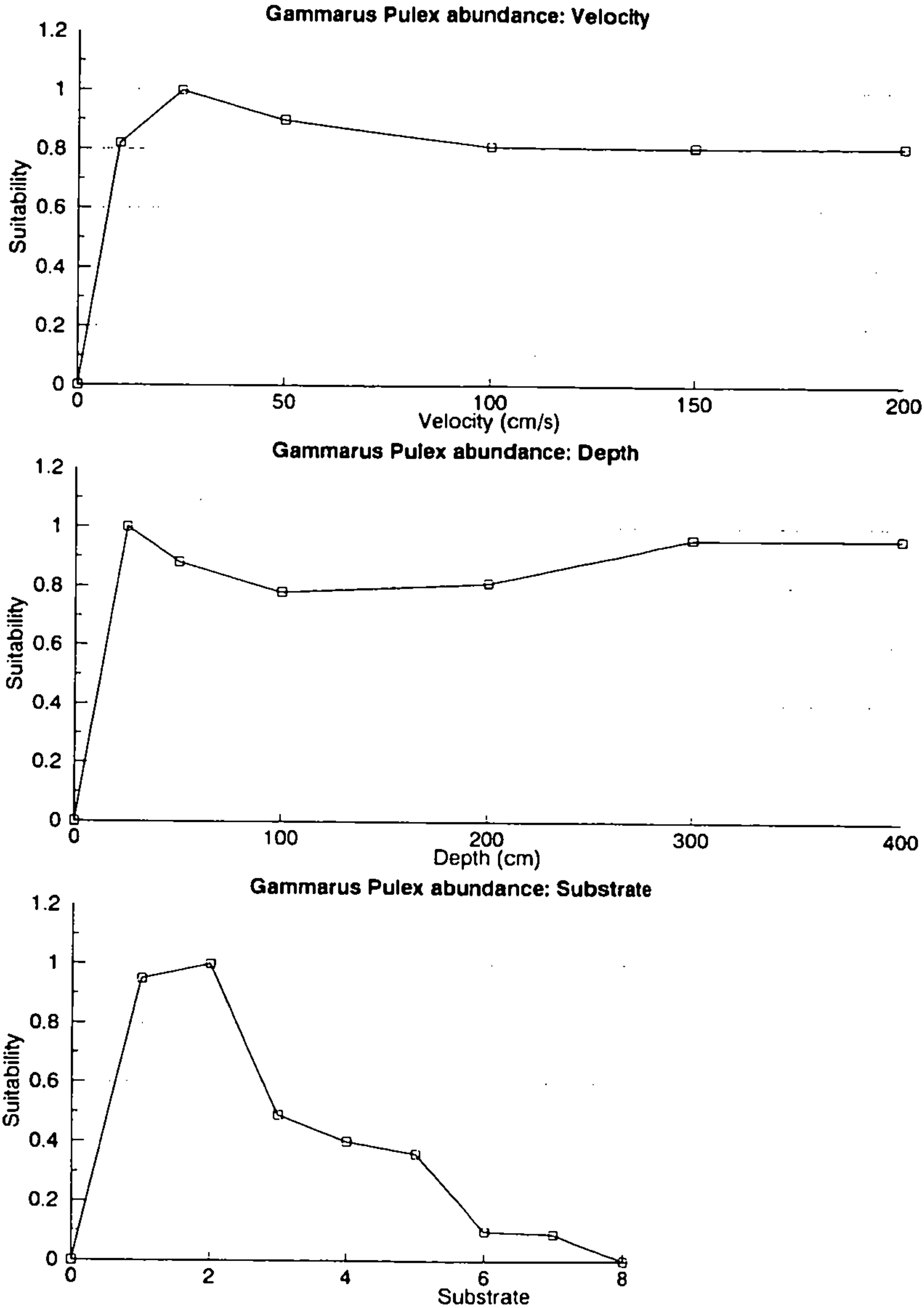


Figure B14 *Habitat suitability curves: Gammarus pulex occurrence*

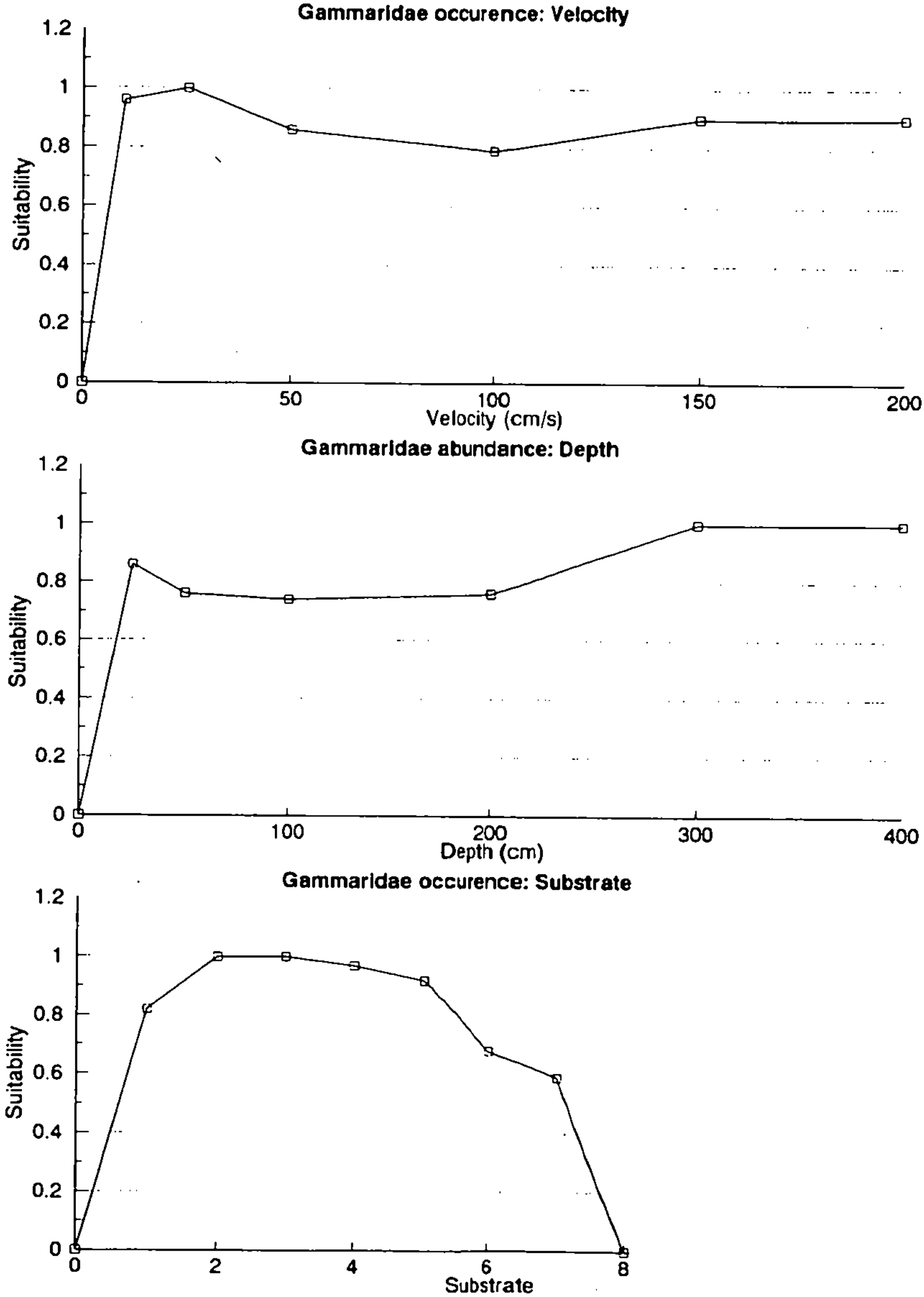


Figure B15 *Habitat suitability curves:* Gammaridae *occurrence*

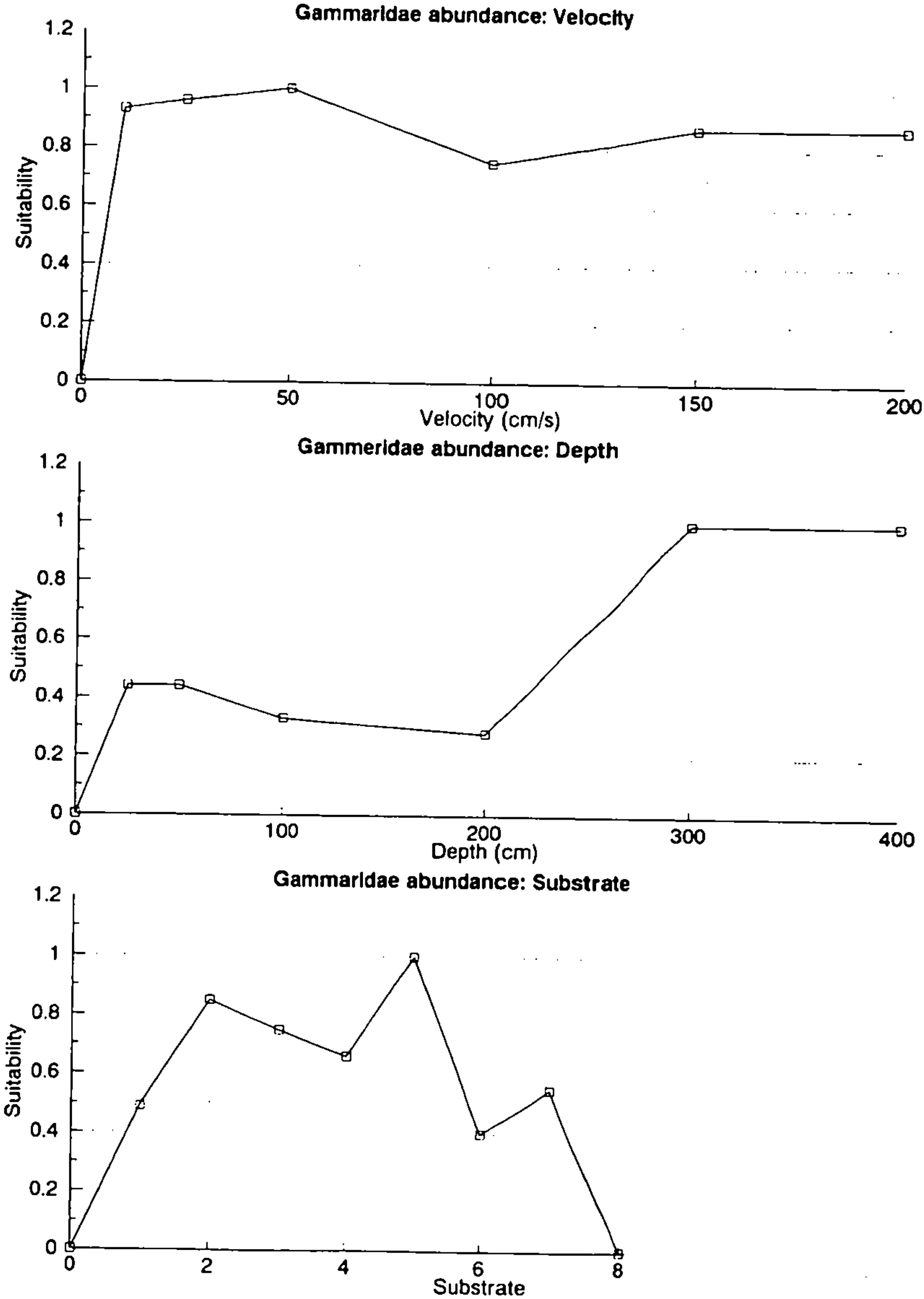


Figure B16 *Habitat suitability curves:* Gammaridae *abundance*

Fish Habitat Suitability Curves

As discussed in Section 5.2 the target fish species chosen for this assessment were dace, roach and brown trout. Habitat suitability curves have been developed for the adult, juvenile, fry and spawning life-stages of all three species. These curves describe the relative suitability to the target species life-stage of different values of the microhabitat variables, depth, mean column velocity and substrate. Substrate classification is based on the particle size coding system defined in Table 2.2. The habitat suitability curves for depth, velocity and substrate developed under this commission, and used as input data to PHABSIM habitat simulations, are given in Figures B17-B19 below for life-stages of dace, :rout and roach respectively.

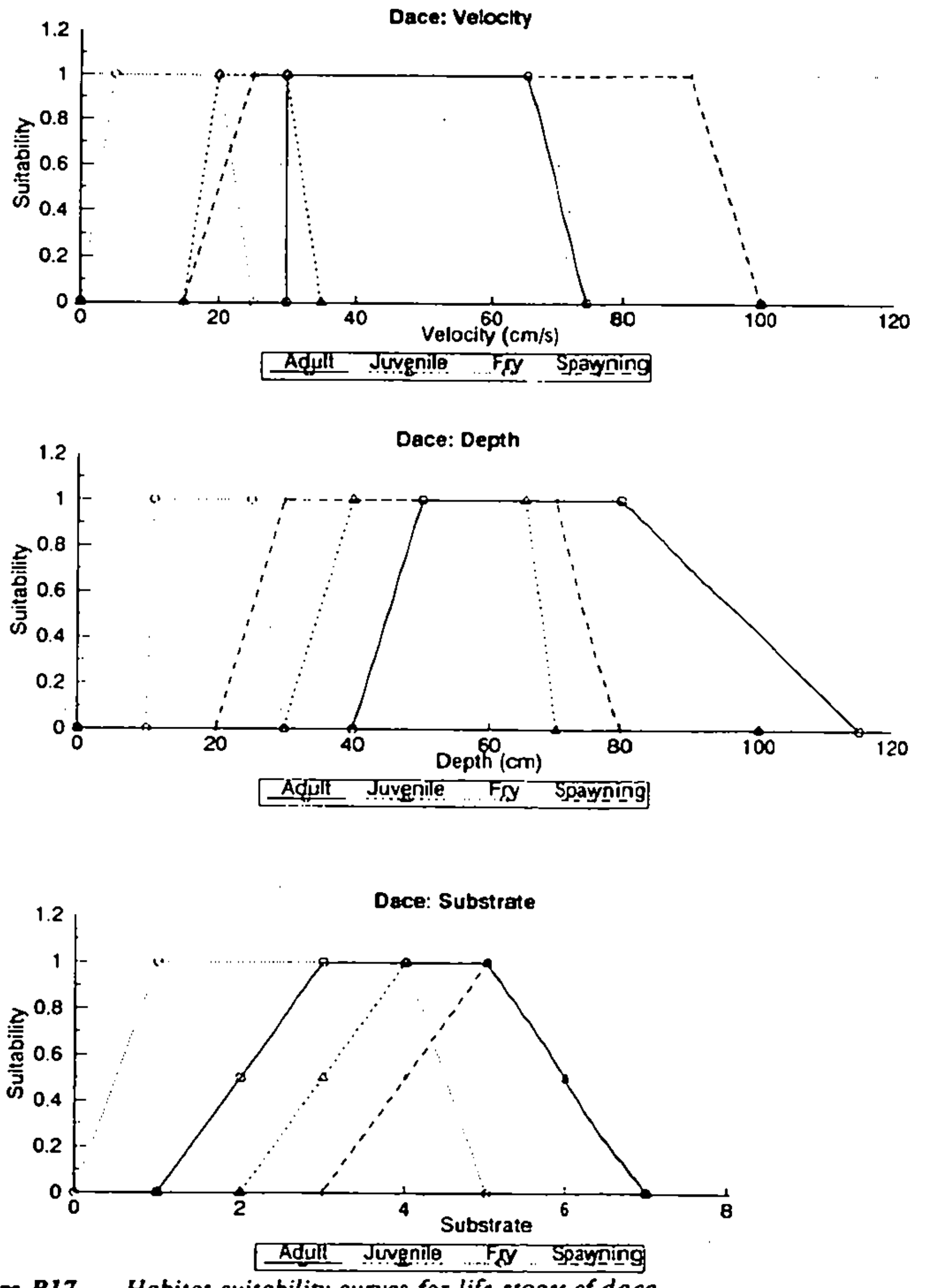
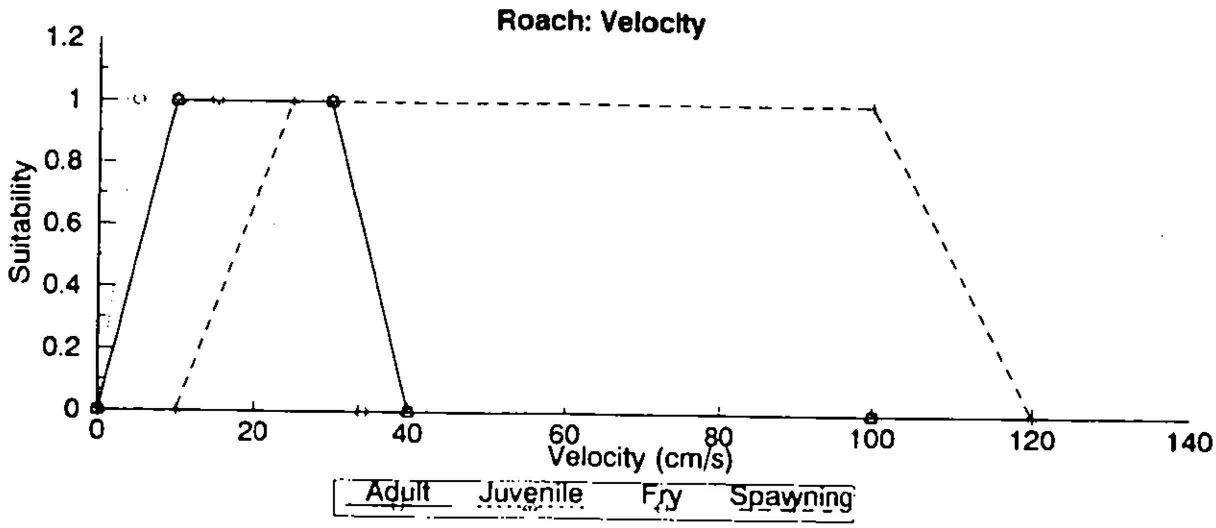
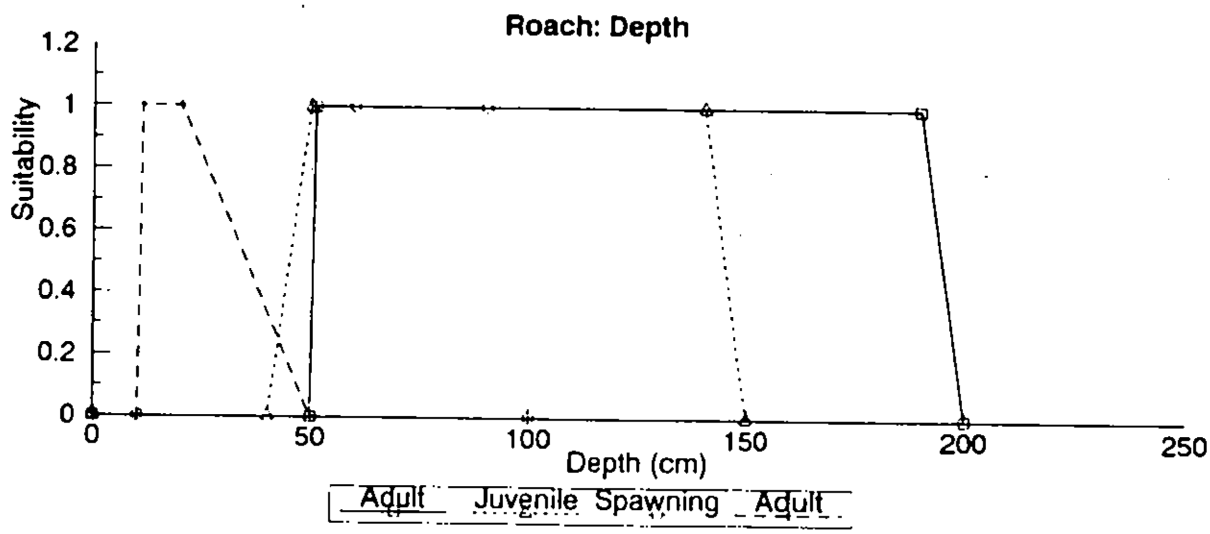


Figure B17 Habitat suitability curves for life-stages of dace





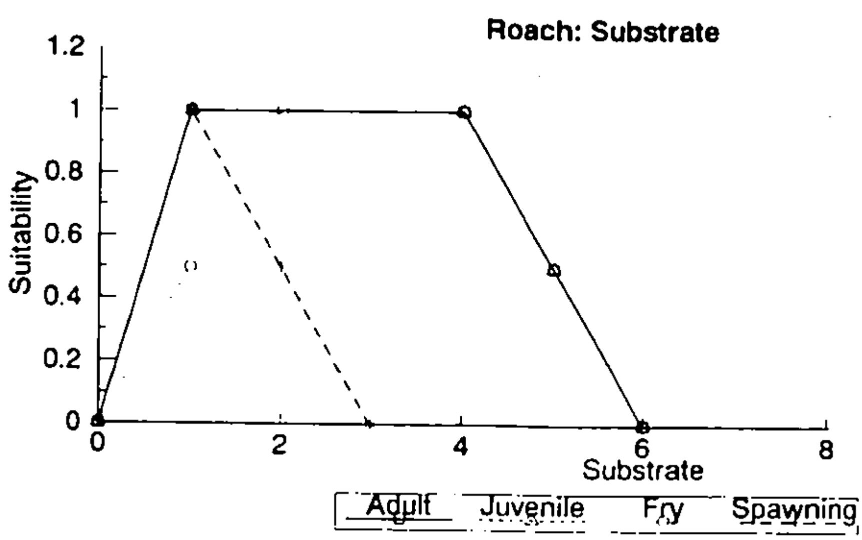
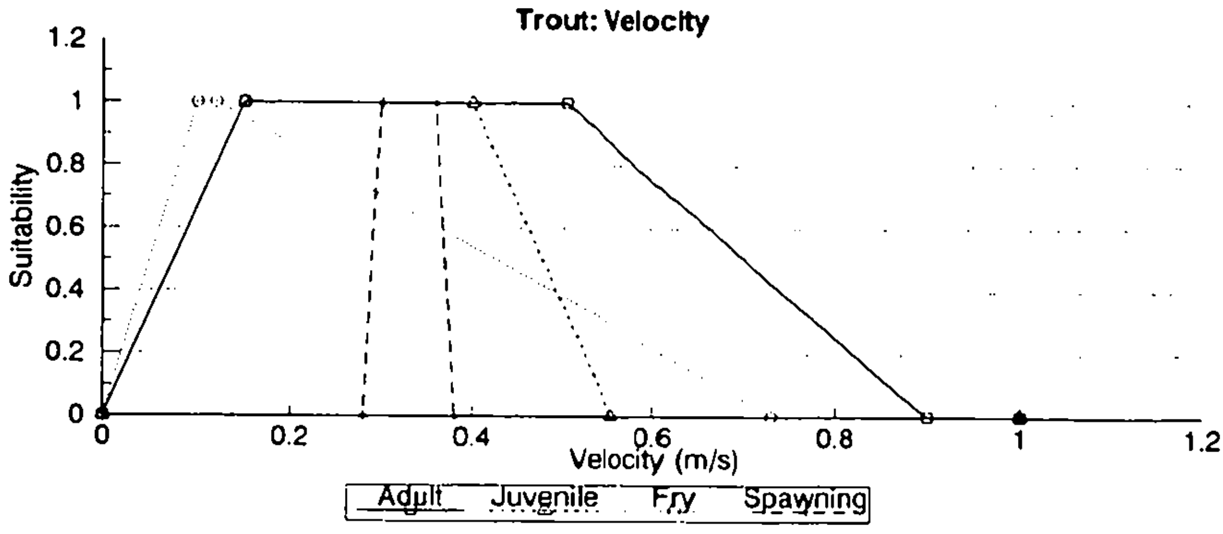
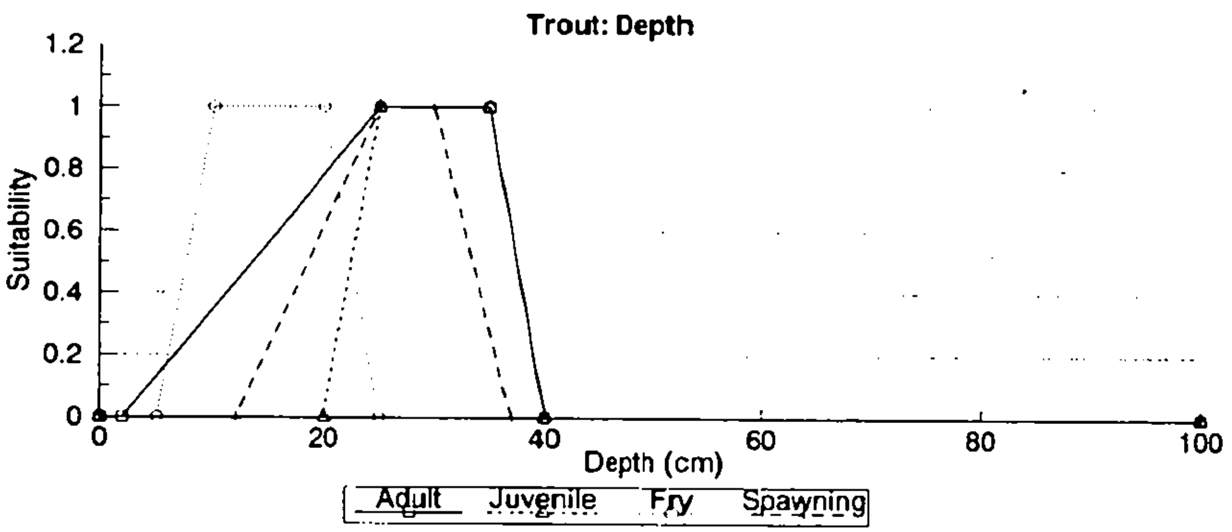


Figure B18 *Habitat suitability curves for life-stages of roach*





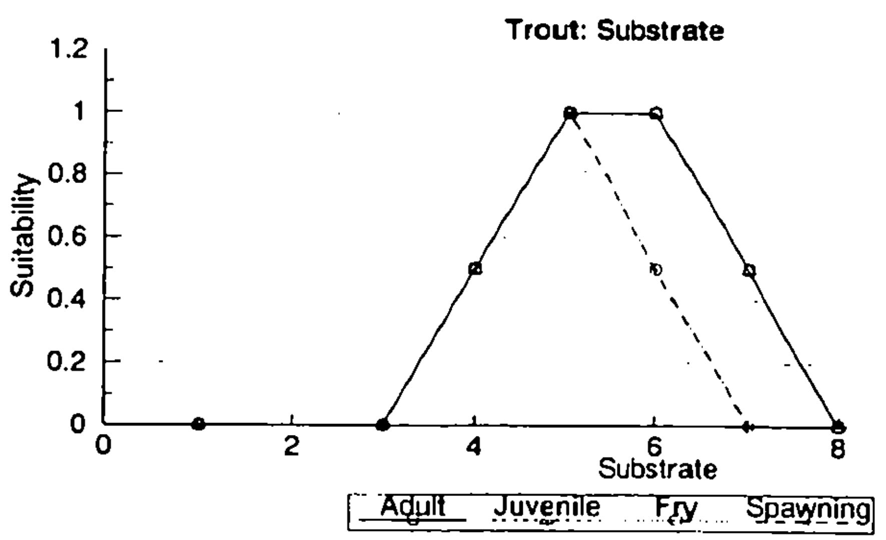


Figure B19 Habitat suitability curves for life-stages of brown trout

Macrophyte Habitat Suitability Curves

As discussed in Section 5.3 Habitat suitability curves have been developed for two macrophyte species, *Ranunculus* and *Nasturtium*. The data on *Ranunculus* is based on a composite of the three species *Ranunculus fluitans/pencillatus(/aquatilis)* which is referred to as *Ranunculus afp*. Habitat suitability curves for depth, mean column velocity and substrate are given in Figures B20 and B21 for *Ranunculus afp* and *Nasturtium* respectively.

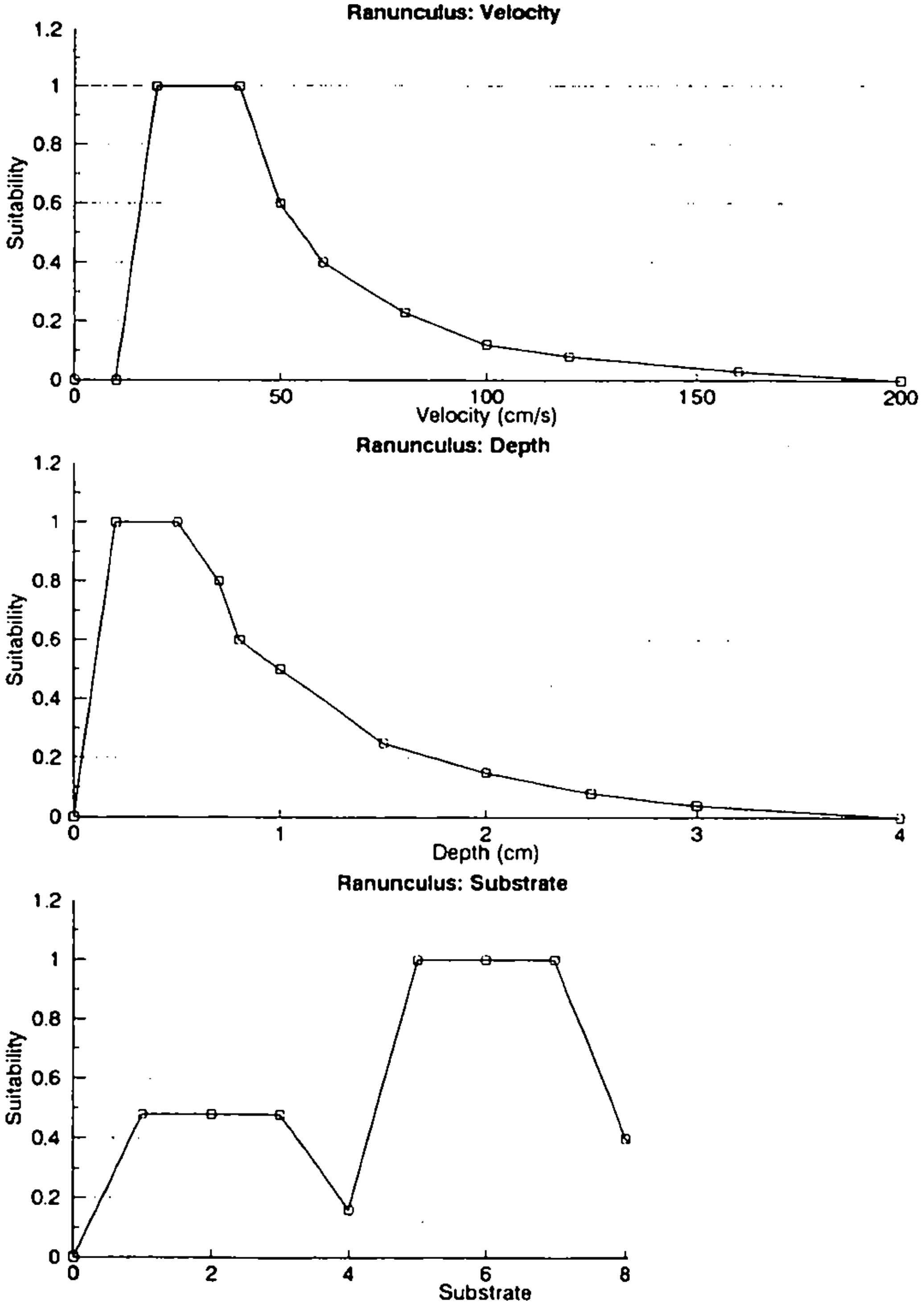


Figure B20 *Habitat suitability curves : Ranunculus afp*

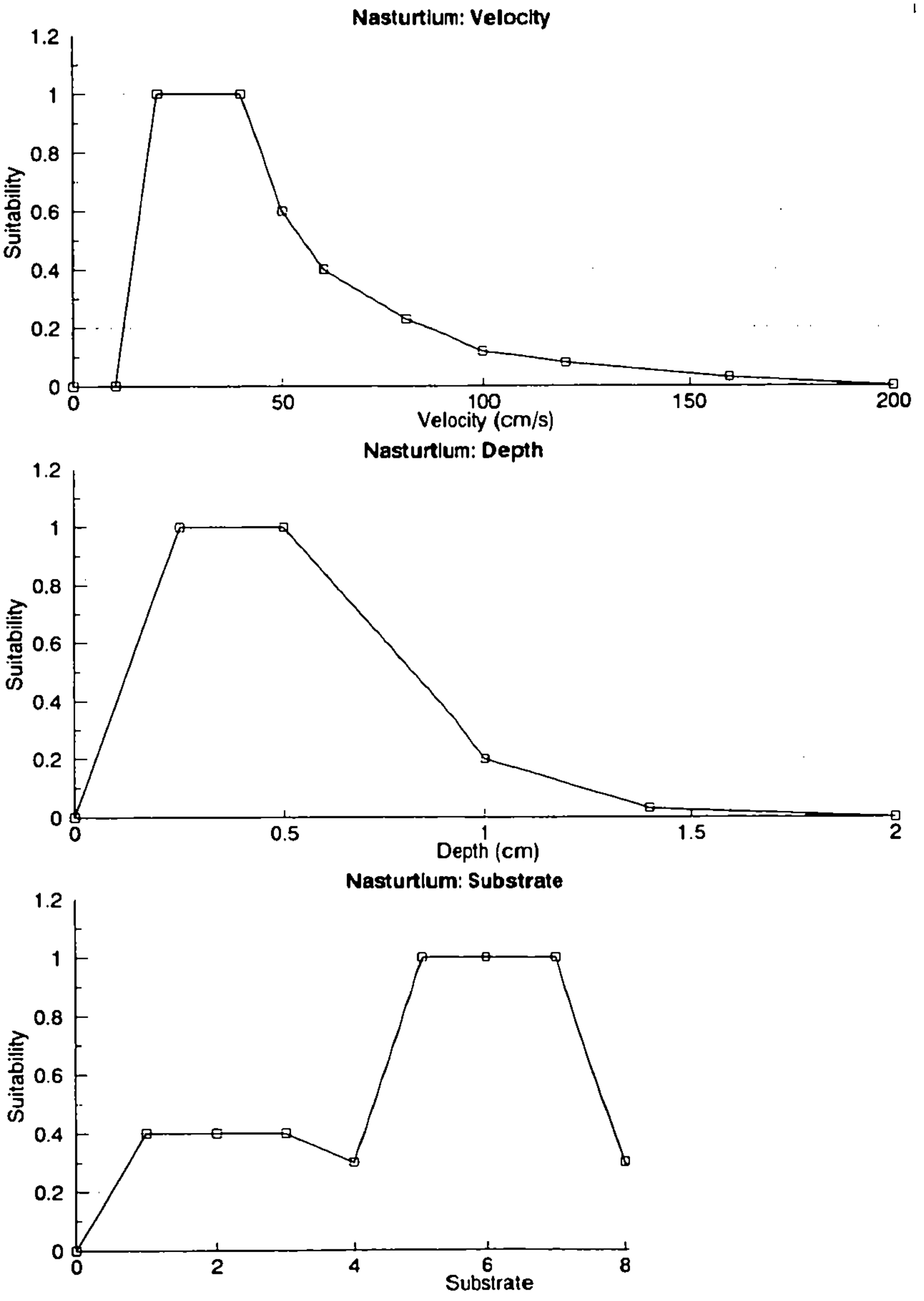


Figure B21 *Habitat suitability curves : Nasturtium*

Appendix C

Hydraulic Modelling : Calibration Data and Model Simulation Outputs

For each of the study rivers listed in Section 3 water surface elevations and discharge were measured at a number of calibration discharges (2 or 3). PHABSIM hydraulic models were calibrated on the basis of these data. The calibrated model(s) were then run for a range of simulation discharges. The range for simulation was chosen to be from the 95 percentile to the 10 percentile exceedance discharges (where data allowed estimation of these parameters). In Figures C1-C22 we give the water surface profiles at the calibration flows and the water surface profiles predicted by the hydraulic model(s) for the simulation discharges. For the sake of clarity we have only plotted simulation outputs for selected discharges (including the highest and lowest). The longitudinal thalweg profile (computed as the lowest point on each transect) is plotted for comparison. Distances are measured in an upstream direction from the benchmark marking the most downstream transect. Elevations are measured relative to an arbitrary datum level of 100.0m which is assigned to one of the headpins or some other fixed point.

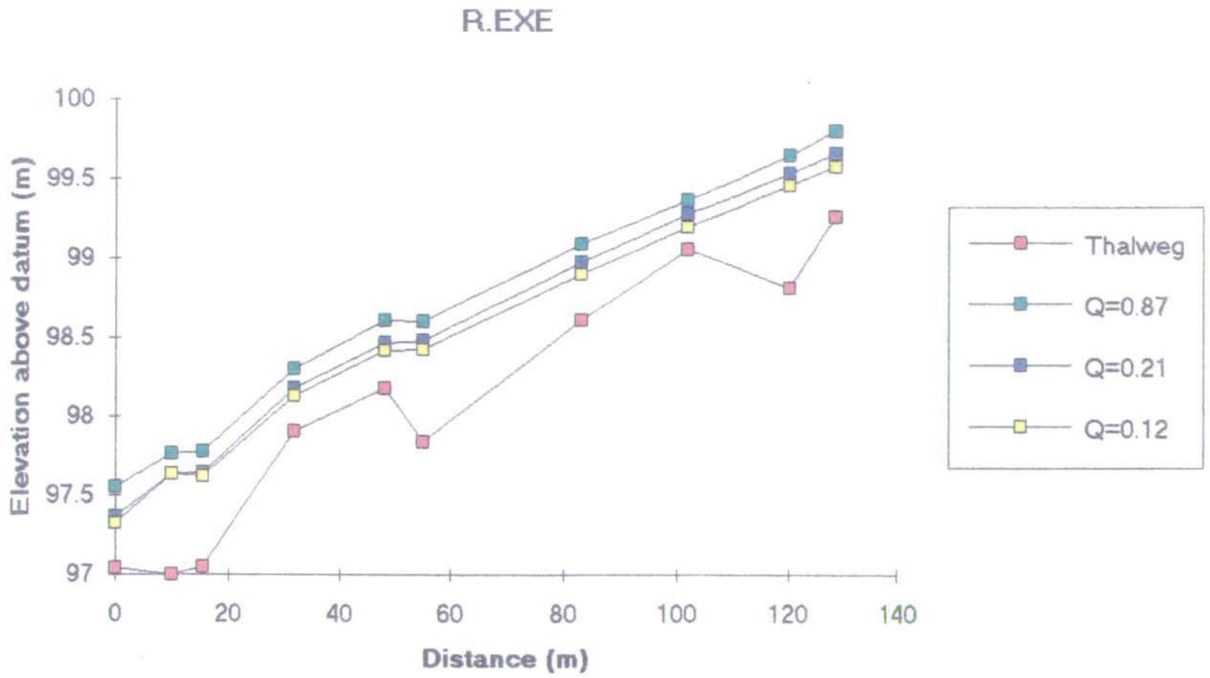


Figure C1 *Observed Water Surface Profiles at Calibration Discharges: River Exe*

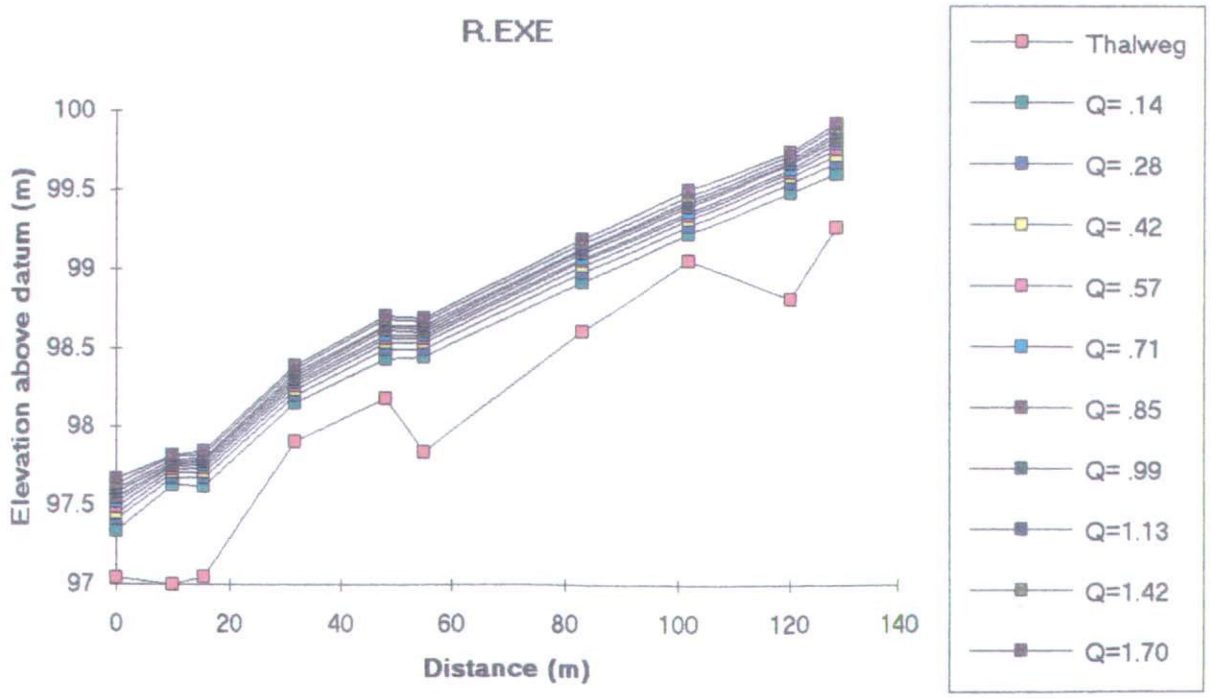


Figure C2 *Predicted Water Surface Profiles at Simulation Discharges: River Exe*

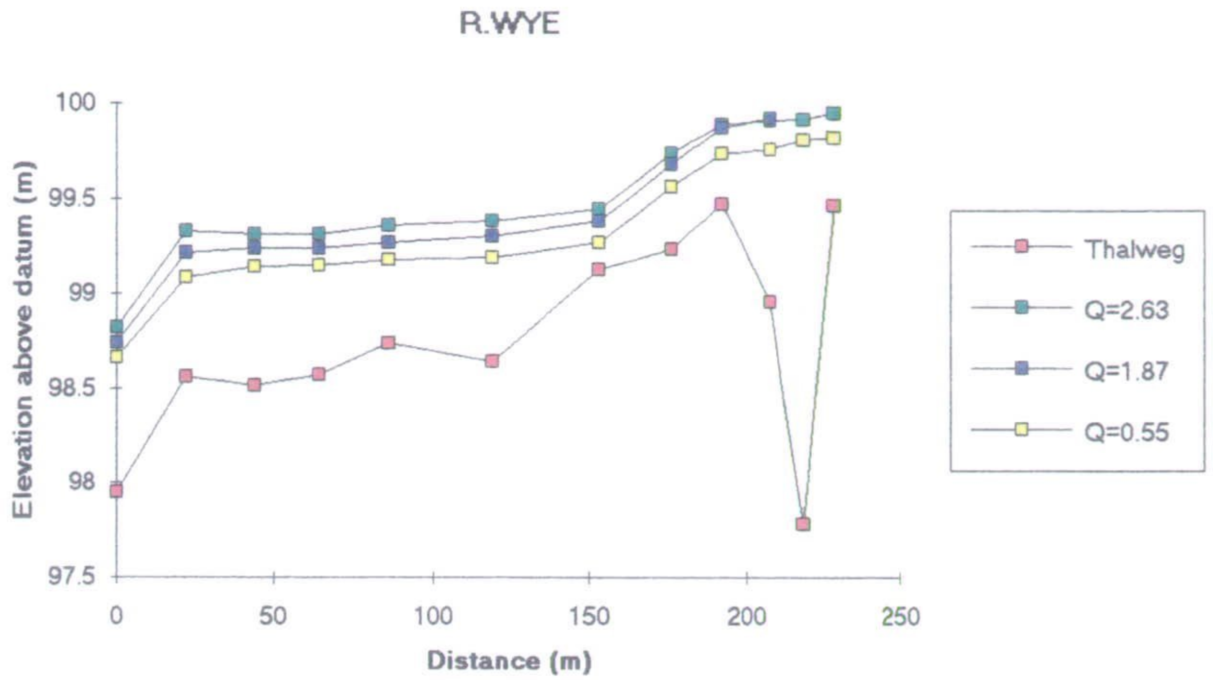


Figure C3 *Observed Water Surface Profiles at Calibration Discharges: River Wye*

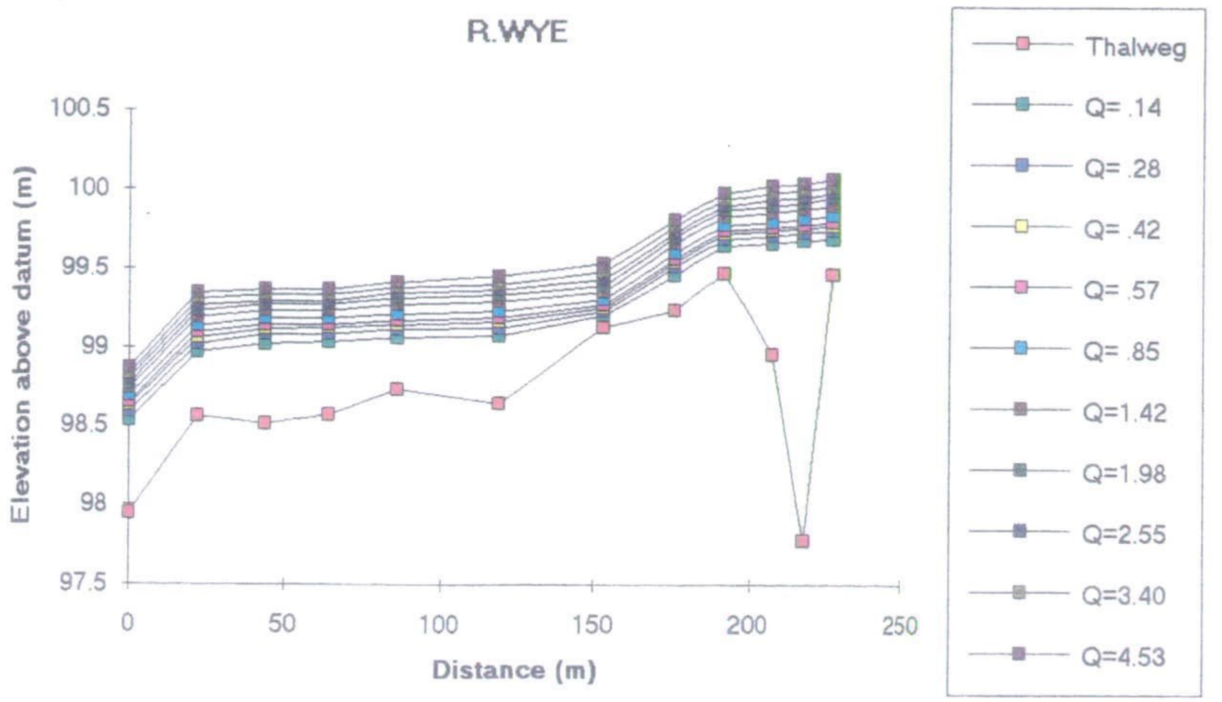


Figure C4 *Predicted Water Surface Profiles at Simulation Discharges: River Wye*

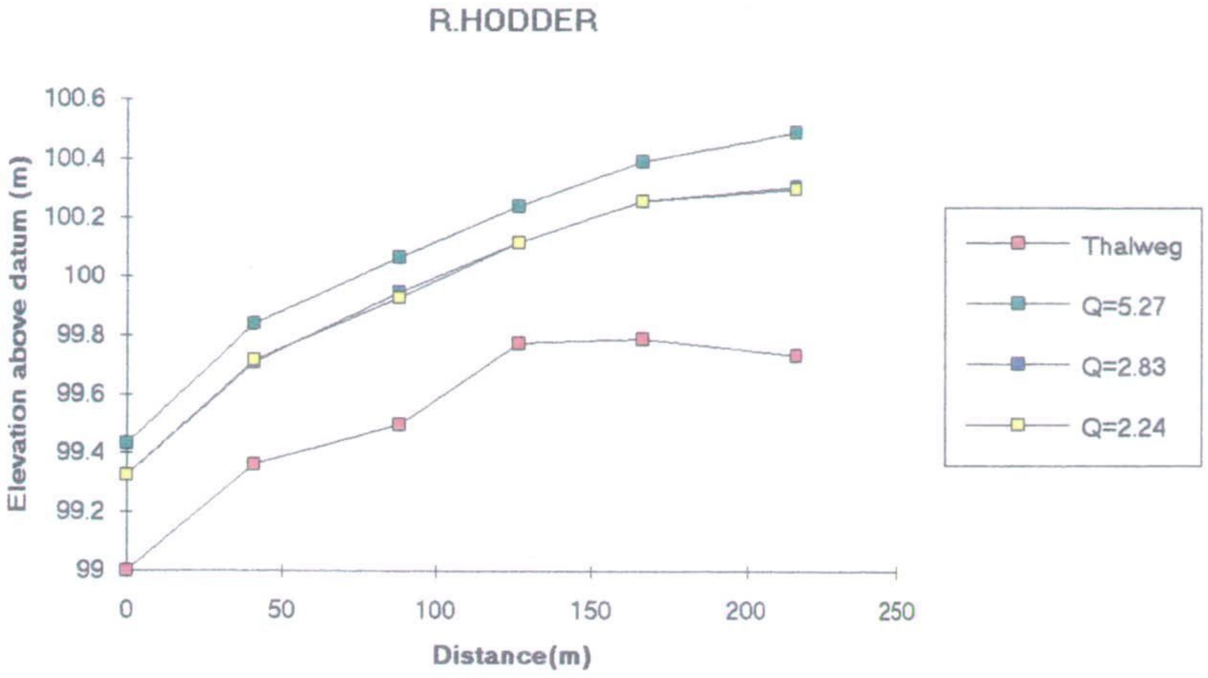


Figure C5 *Observed Water Surface Profiles at Calibration Discharges: River Hodder*

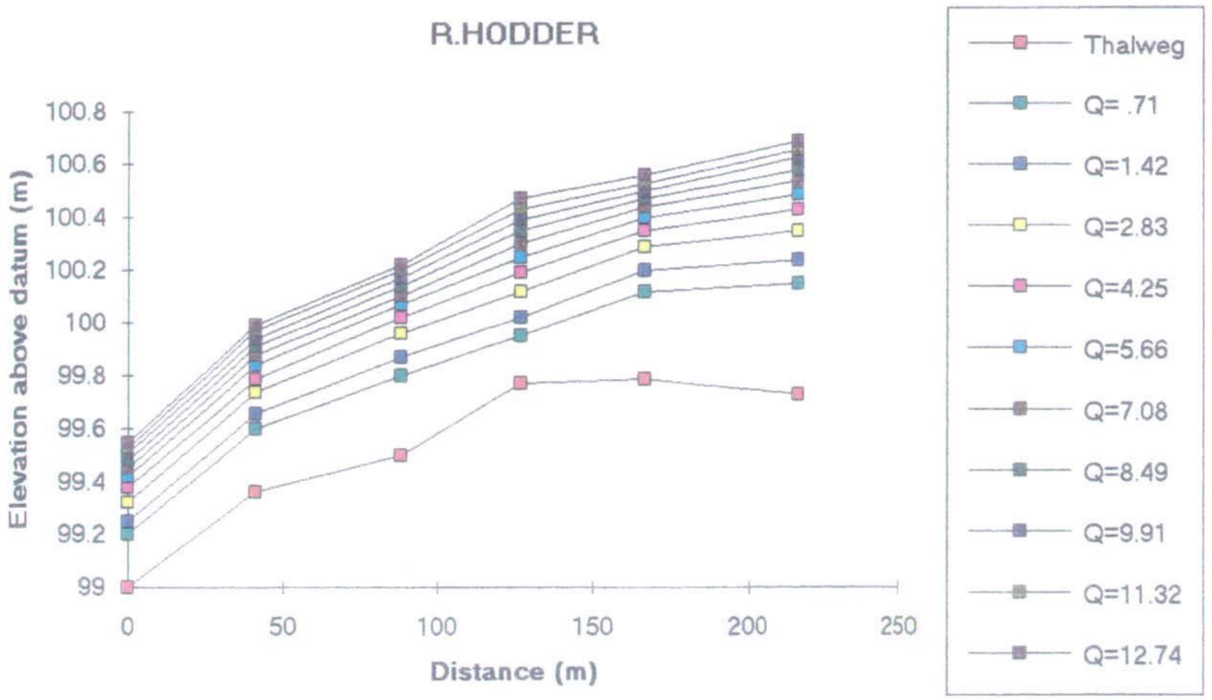


Figure C6 *Predicted Water Surface Profiles at Simulation Discharges: River Hodder*

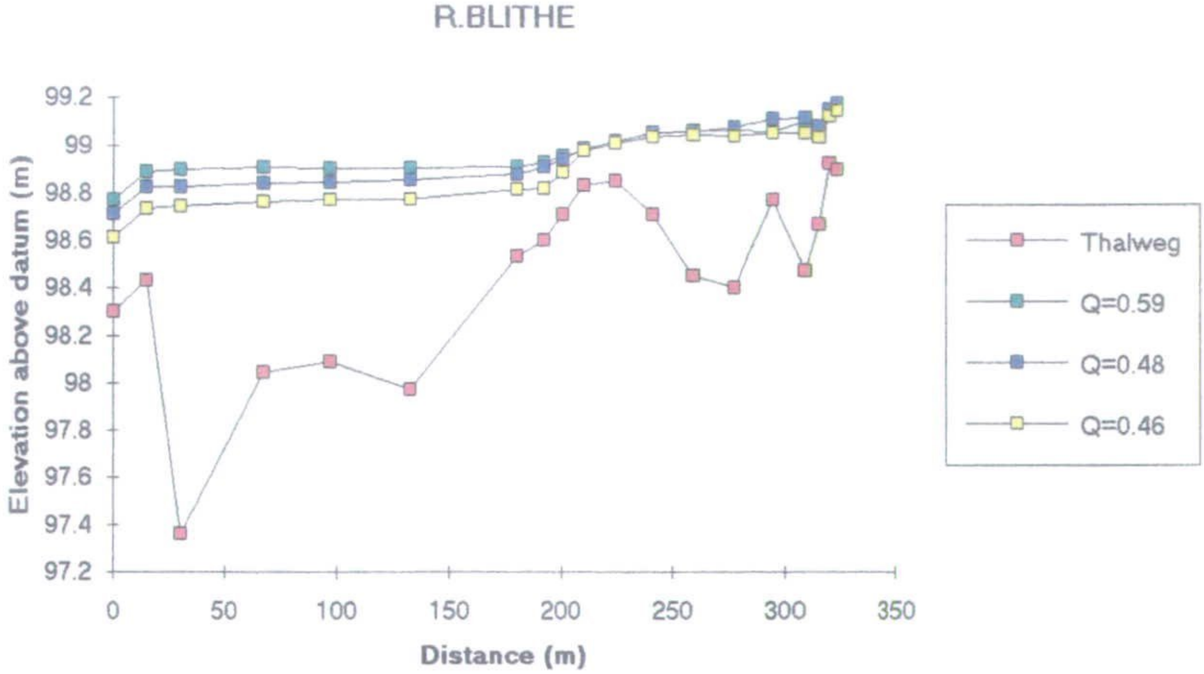


Figure C7 *Observed Water Surface Profiles at Calibration Discharges: River Blithe*

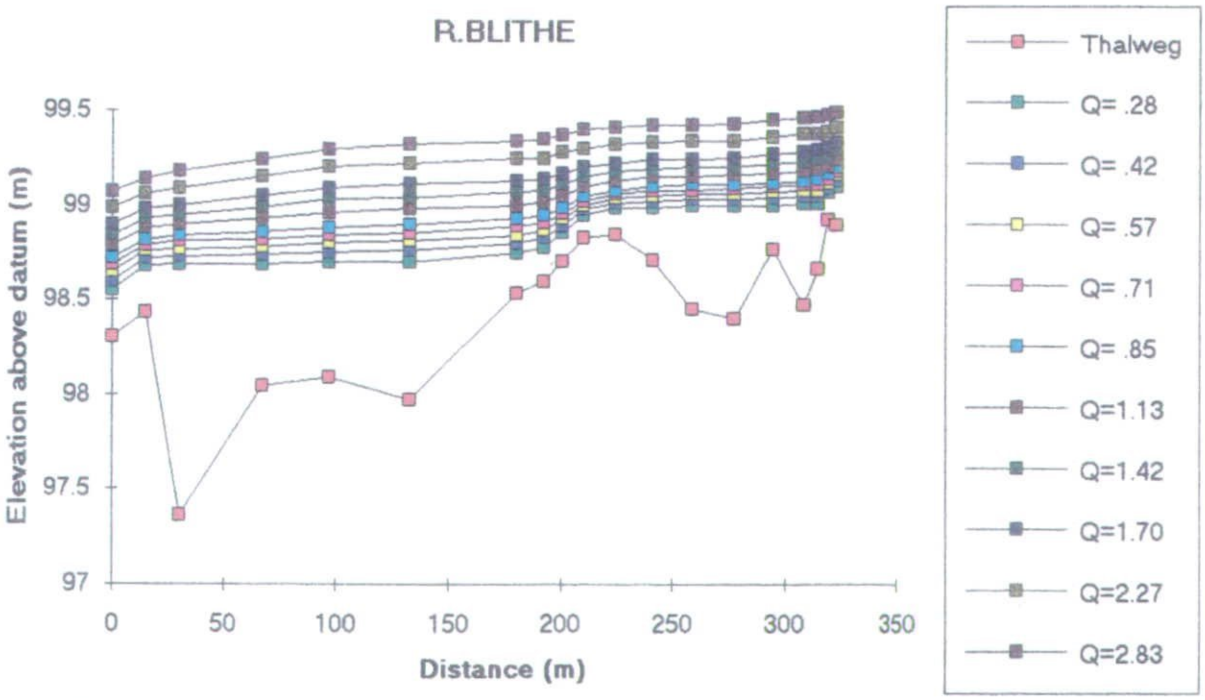


Figure C8 *Predicted Water Surface Profiles at Simulation Discharges: River Blithe*

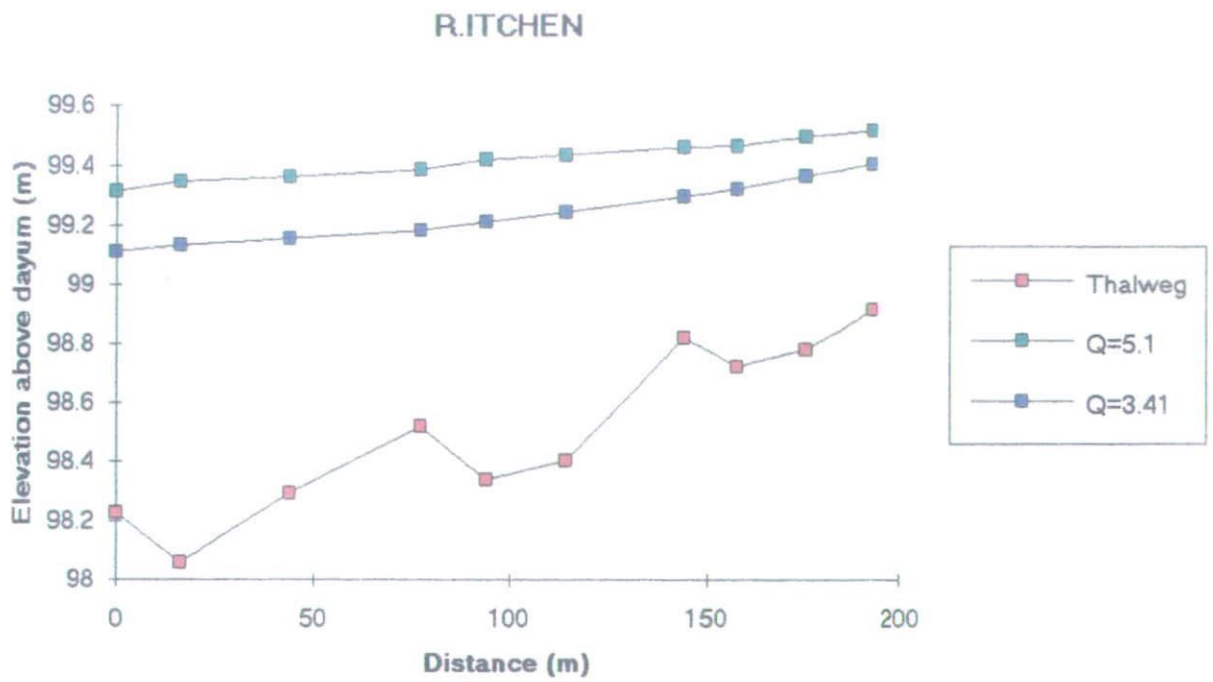


Figure C9 *Observed Water Surface Profiles at Calibration Discharges: River Itchen*

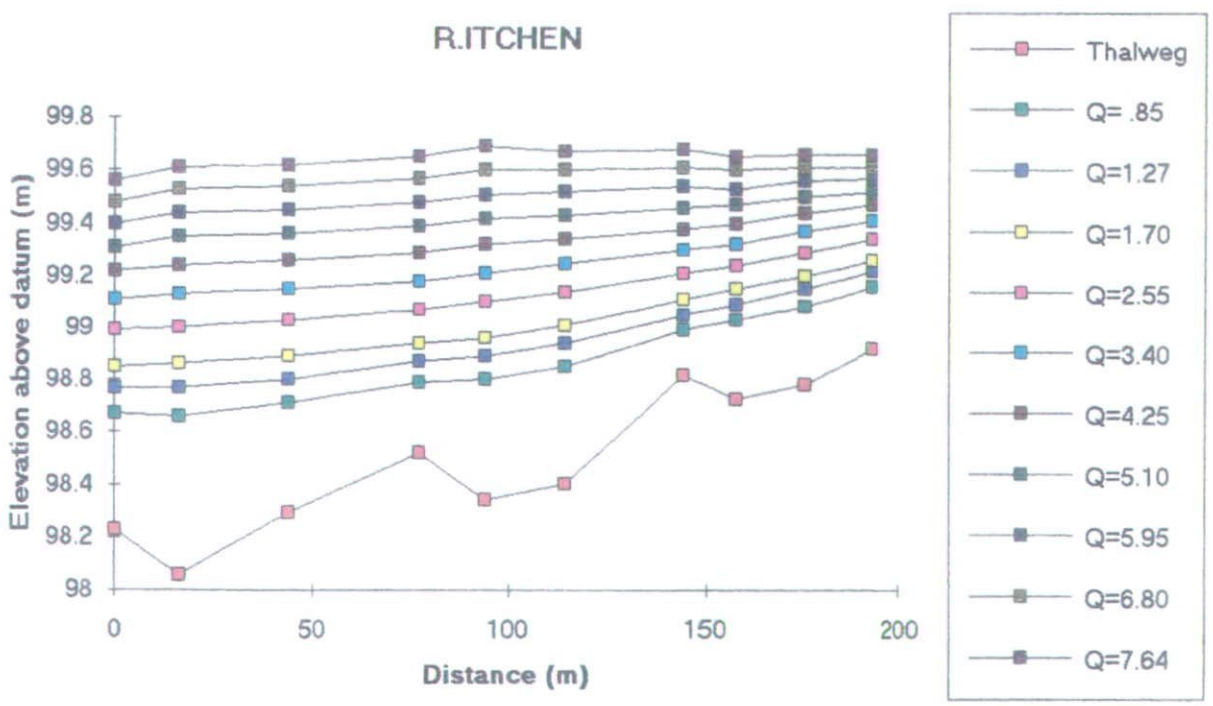


Figure C10 *Predicted Water Surface Profiles at Simulation Discharges: River Itchen*

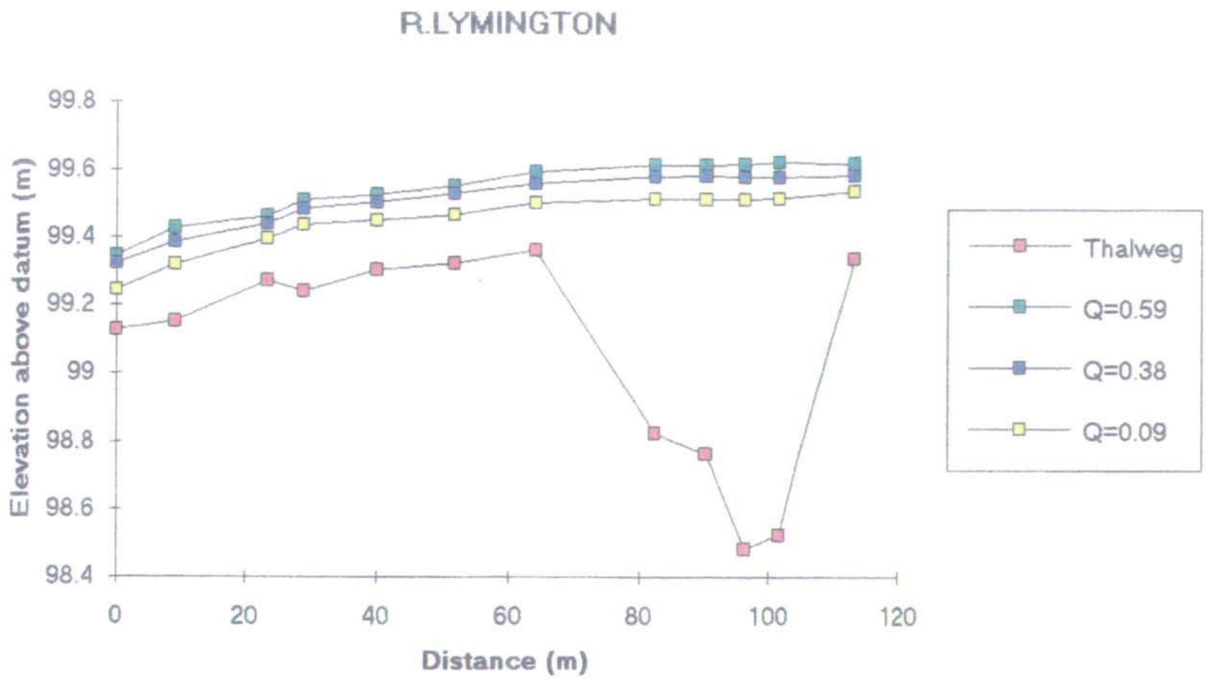


Figure C11 *Observed Water Surface Profiles at Calibration Discharges: River Lymington*

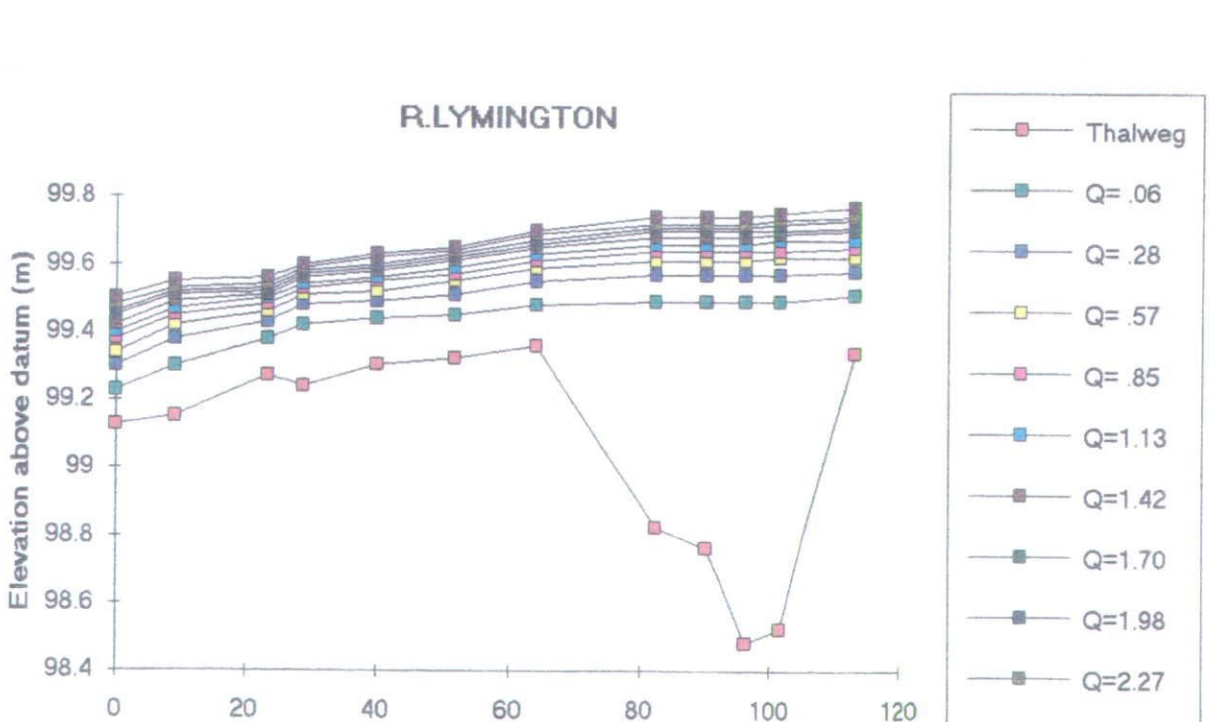


Figure C12 *Predicted Water Surface Profiles at Simulation Discharges: River Lymington*

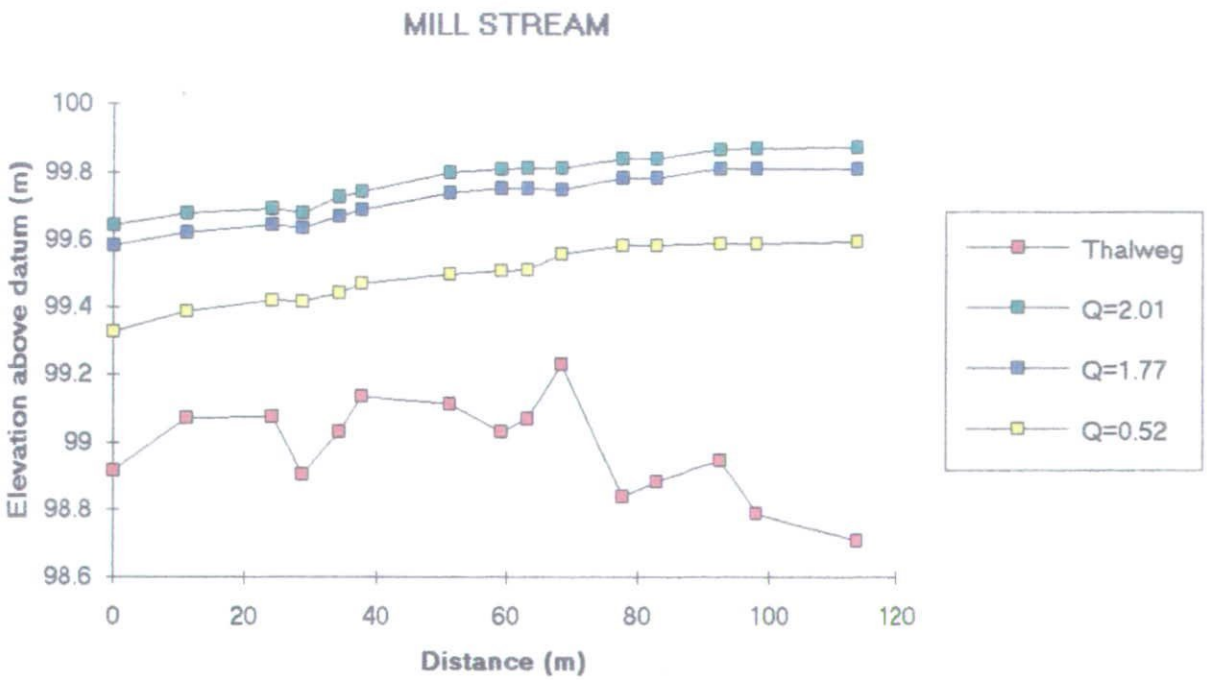


Figure C13 *Observed Water Surface Profiles at Calibration Discharges: Mill Stream*

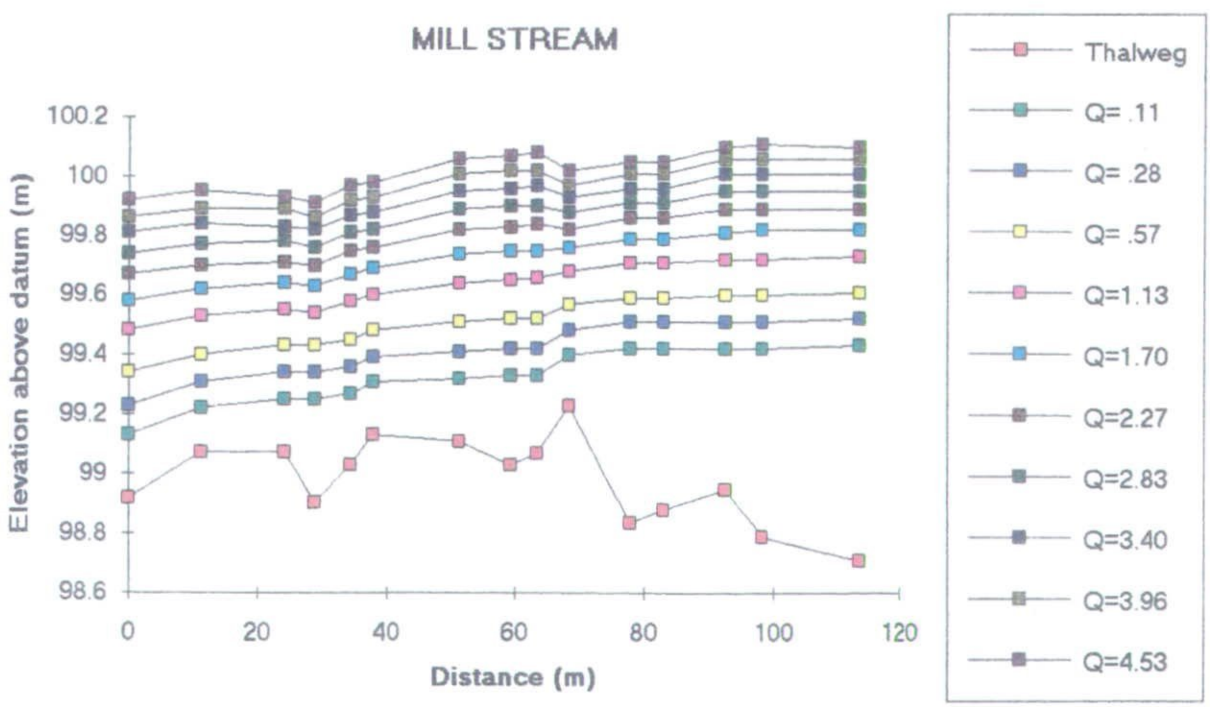


Figure C14 *Predicted Water Surface Profiles at Simulation Discharges: Mill Stream*

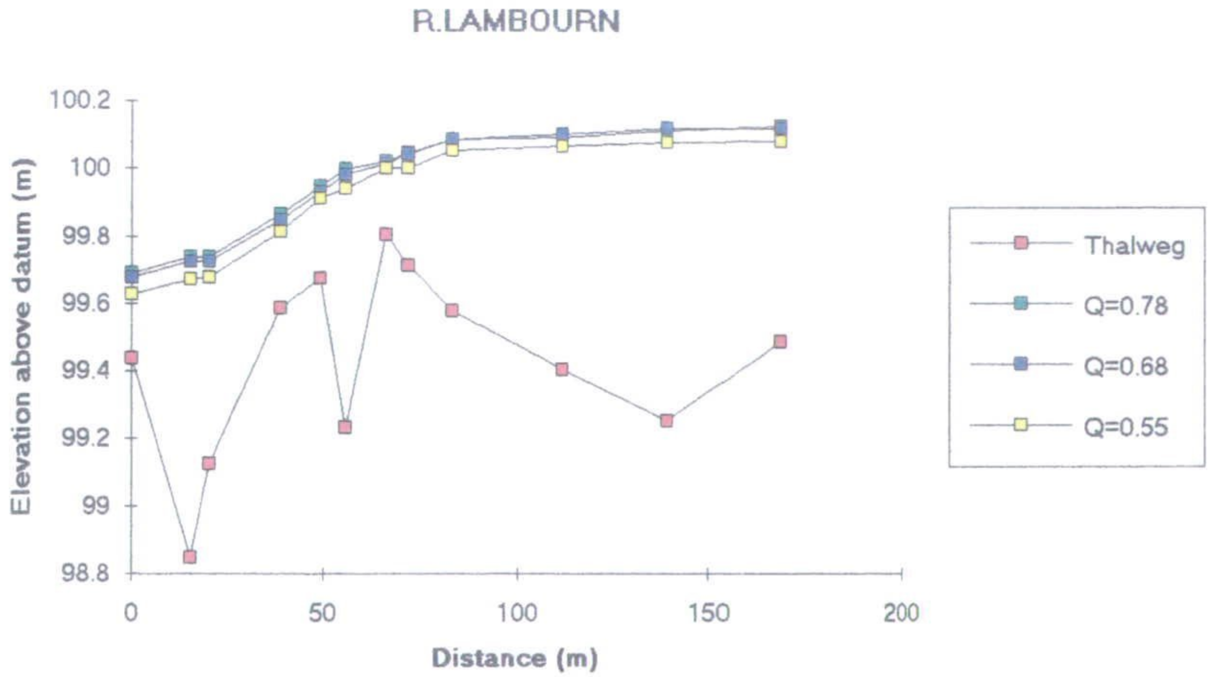


Figure C15 *Observed Water Surface Profiles at Calibration Discharges: River Lambourn*

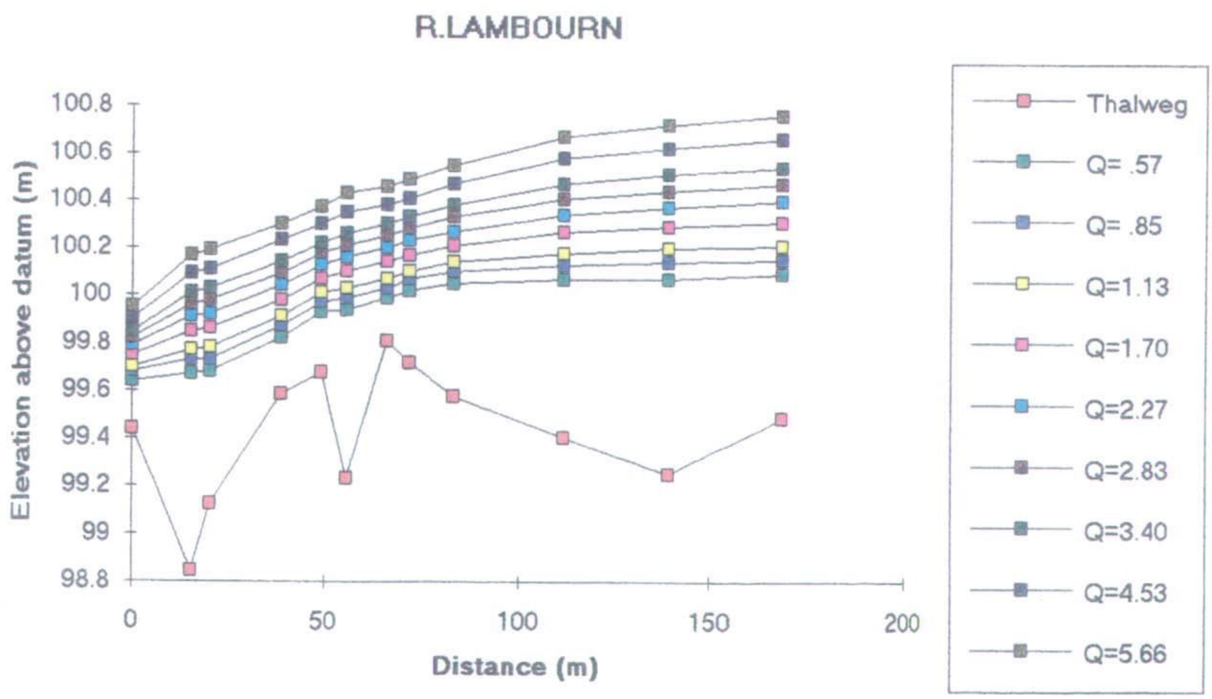


Figure C16 *Predicted Water Surface Profiles at Simulation Discharges: River Lambourn*

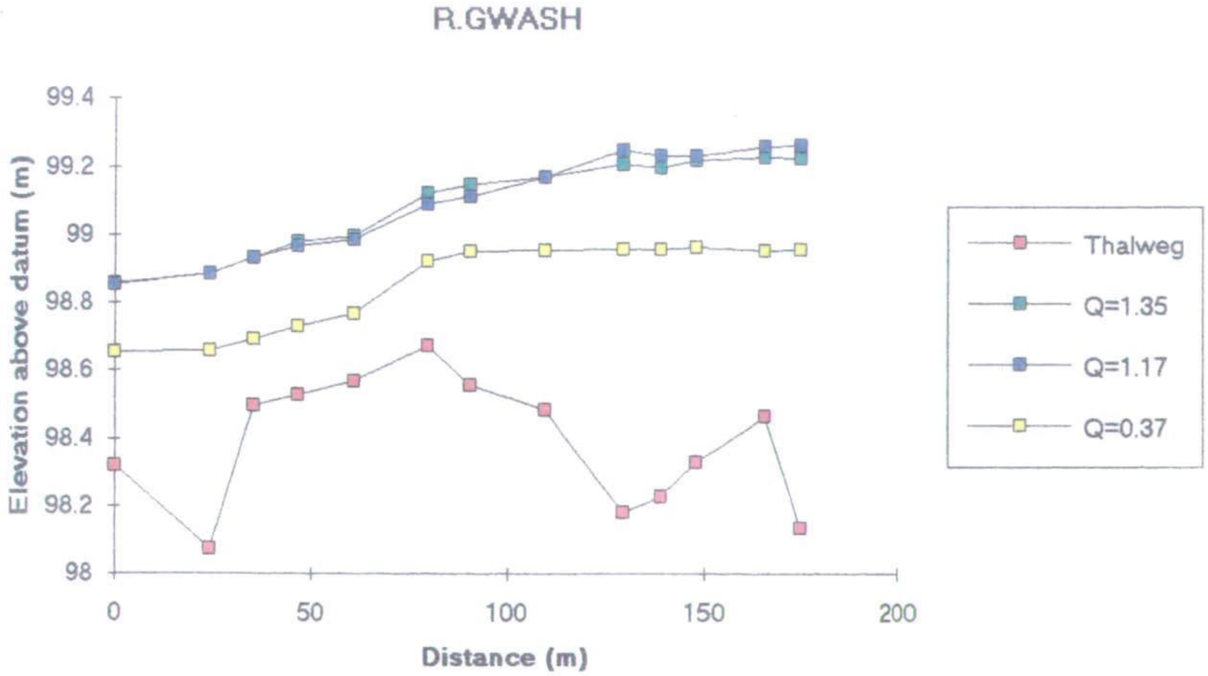


Figure C17 *Observed Water Surface Profiles at Calibration Discharges: River Gwash*

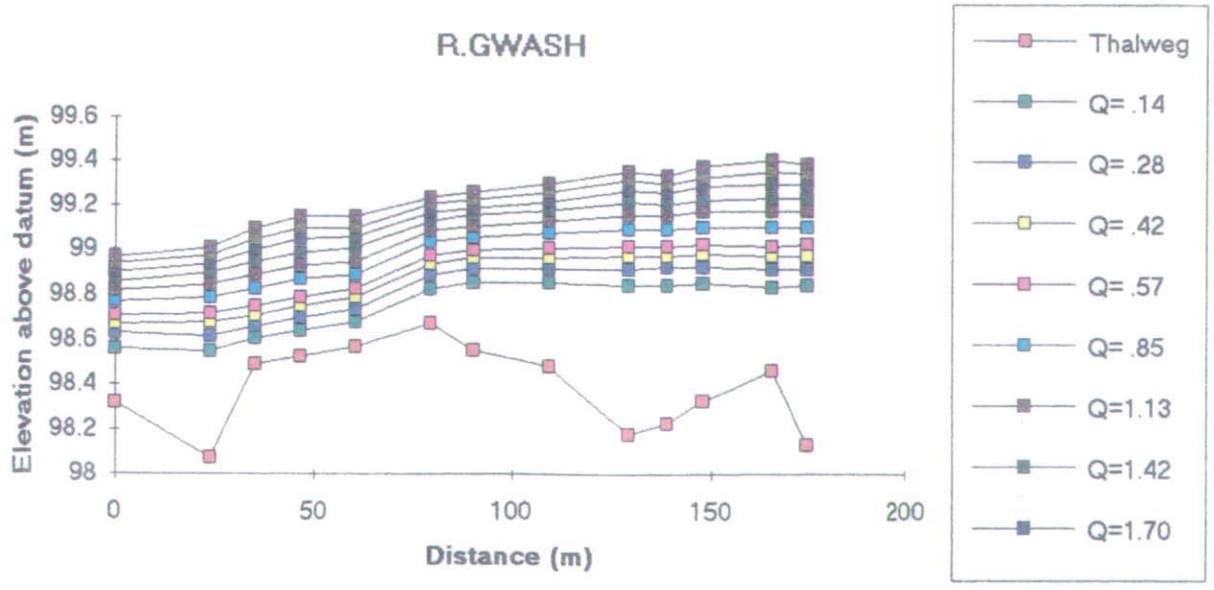


Figure C18 *Predicted Water Surface Profiles at Simulation Discharges: River Gwash*

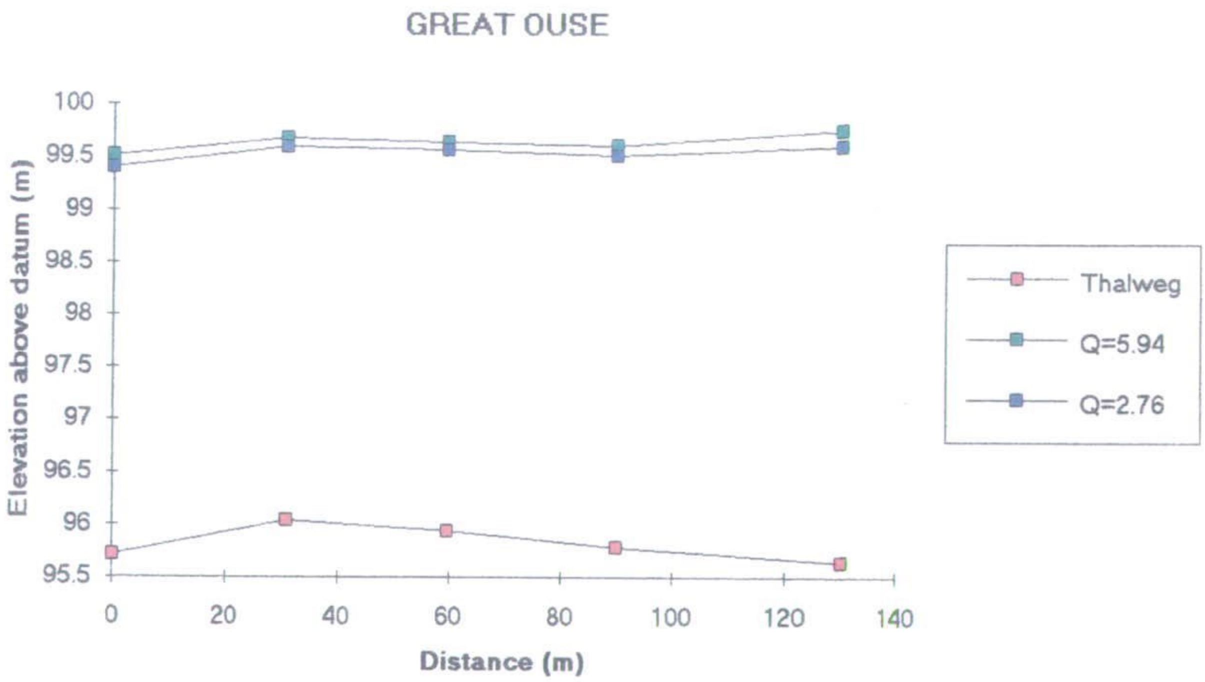


Figure C19 *Observed Water Surface Profiles at Calibration Discharges: Great Ouse*

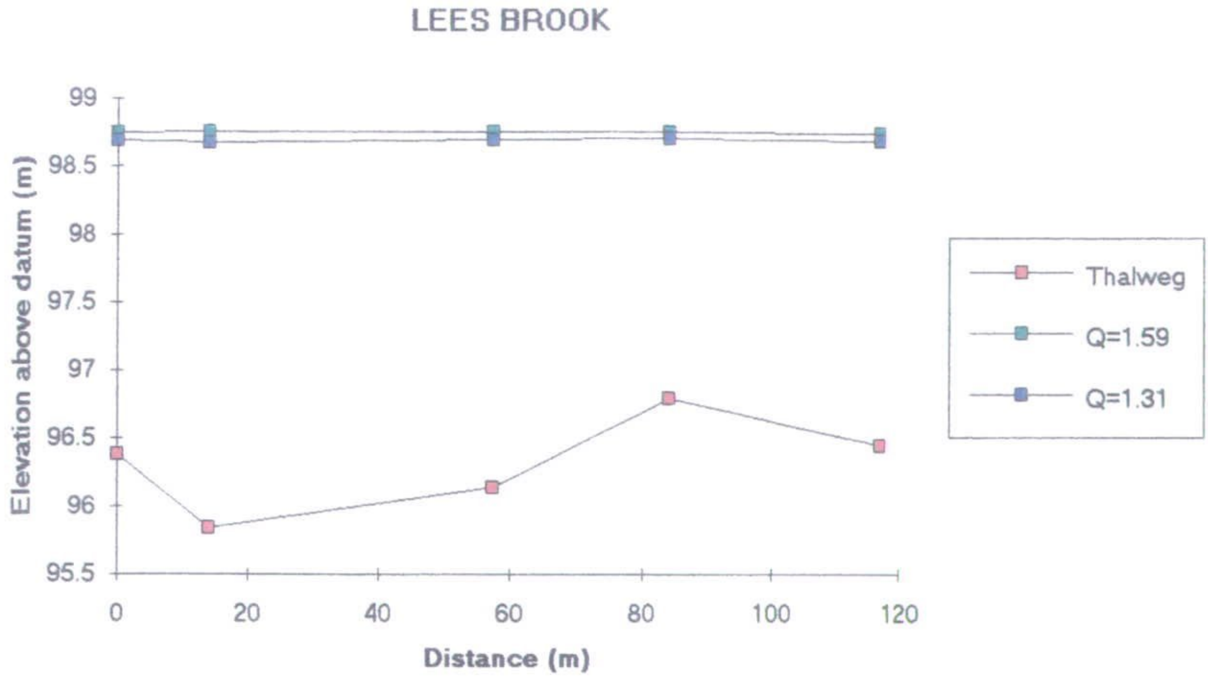


Figure C20 *Observed Water Surface Profiles at Calibration Discharges: Lees Brook*

Appendix D

Supplementary Study : Modelling faunal and floral response to reduced flows and habitat loss in a river : An experimental approach. [The Mill stream project - biological studies]

Introduction

Modifications of the environment are frequently accompanied by changes in the composition, distribution, and abundance of the resident flora and fauna. In rivers, resident biological communities are adapted to basic river characteristics with flow (discharge-velocity) a major controlling factor.

Basic information on the distribution and movements of fish and invertebrates in response to flow changes is needed to increase our understanding of how such modifications affect the resident populations. The East Stoke Mill stream, with its controllable flow, provides an ideal opportunity to carry out a series of large-scale experiments designed to elucidate the responses of biological components of the ecosystem to reduced flows.

This project is science budgeted by NERC to support biological (Institute of Freshwater Ecology) and hydrological (Institute of Hydrology) studies. The NRA, for the 'Ecologically acceptable flows project', contributed funds for the first two months.

Objectives

1. To describe habitat availability at 'normal' flows for fish, invertebrates and plants.
2. To determine the effects of reduced flows on habitat availability for the biota above.
3. To examine the response of fish and invertebrate populations, in terms of composition, distribution, and abundance, to loss of habitat.
4. To measure physical and chemical changes resulting from low flows.
5. To use data obtained in 1-4 to determine the overall responses of component parts of the ecosystem to reduced flows.
6. To repeat flow reductions to provide replicate data and to examine seasonal effects.
7. Using the PHABSIM model (Physical Habitat Simulation System) evaluate the relationship between observed and predicted response of physical habitat to modified flows.
8. Using the PHABSIM model evaluate the relationship between predicted change and observed change in faunal and floral response. This will be carried out by relating weighted habitat area to changes in species and abundance of invertebrates, fish and macrophytes.

9. Objectives 1-4 will provide basic information on the distribution, community composition, population structure and food preferences of fish in different habitat types in relation to flow changes. Ultimately studies on diel and seasonal changes of fish distribution related to spawning, life-stage and feeding will provide the information necessary to model detailed habitat requirements of fish species and associated invertebrate and macrophyte communities.

The objectives above can only be achieved with full staffing and resources. Contractual obligations have resulted in a shortage of staff such that certain aspects of the project have not been started in this first year of study. This situation has resulted in a reduced effort and invertebrate work has not been instigated because of lack of staff availability. Most effort in this first year has been placed on investigating the response of fish populations to flow changes and developing a method for recording the distribution of fish. Macrophyte populations were mapped and the distribution of plant stands was followed throughout the period May to September. Chemical data has been collected from six sites from May to the present.

Study area
The Mill stream is a branch of the River Frome which flows for about 1.2 km before rejoining the main river. The channel morphometry comprises an upstream section about 500 m in length which is divided from the lower section by the 'Fluvarium' which can be used to control the flow downstream by closing hatches. The upstream section is characteristically deeper and slower flowing than the downstream section. The experimental reach is located in the downstream stretch and comprises three sub-sections (Upper, Middle and Lower).
A sketch map of the Mill Stream showing the location of the experimental reach and chemical sampling points is given in Figure D1 below.

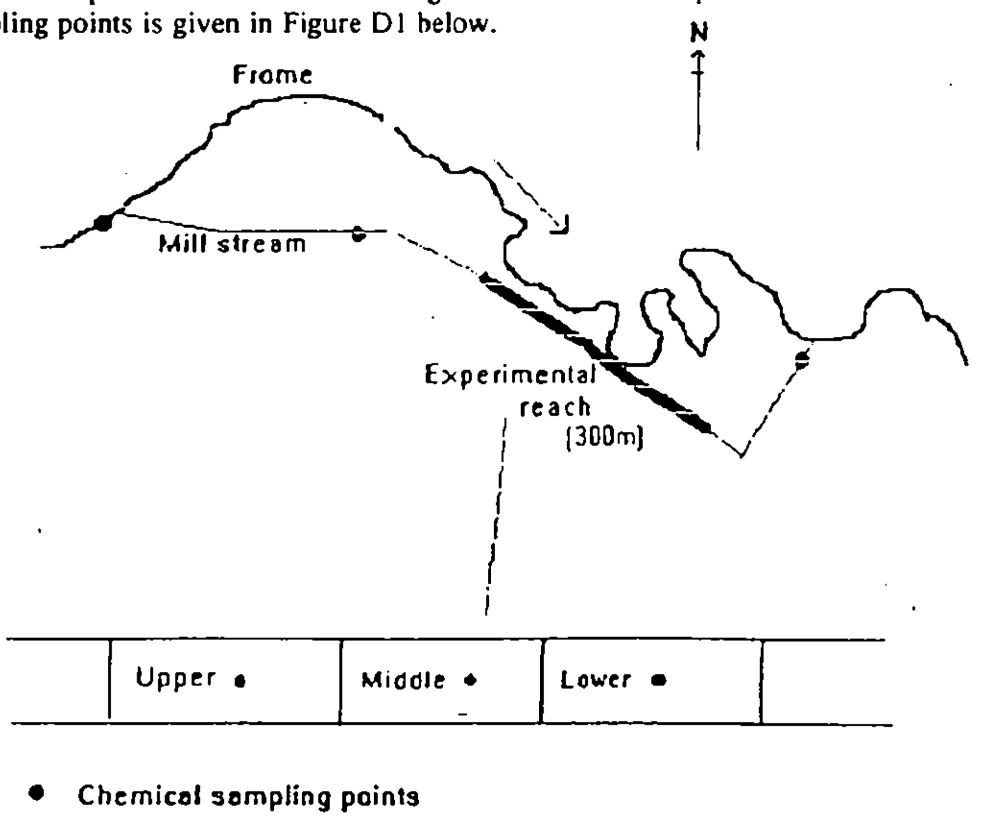


Figure D1 *A sketch map of the Mill Stream showing the location of the experimental reach and chemical sampling points.*

The three experimental sections were selected prior to detailed hydrological analysis to reflect the range of available habitat.

The upper reach is 120m long, unshaded and moderately deep, the middle reach is 80 m long, shaded, and deep, and the lower reach is 110 m long, largely unshaded, and is the shallowest and fastest flowing of the three sections.

Discharge data will be collated for both Frome and Mill stream but detailed information was not available for inclusion in this interim report. The observed range of discharge throughout the period May to November was 0.25-2.1cumecs.

Methods

The effort to date has been put into a study of fish responses to changes in flow. At 'normal' flow the three experimental zones were demarcated with nets across the stream. The flow was reduced by closing hatches in the fluvarium to facilitate electrofishing. Each zone was then fished (see Appendix F for details) to determine distribution, composition and population structure. The nets were then removed and the flow maintained at a 'lower than normal' level' for a period of forty-five days. After this time the nets were replaced, the flow reduced and the whole experimental reach was electrofished. This procedure was repeated every month to date. However the maintained flows were not necessarily much lower than the normal unregulated flow. Details of conditions are presented in Table D1 below. All mean discharge measurements are given in stage board heights together with maximum and minimum values and the standard deviation of the mean. The values pre- and post are those discharges recorded just prior to fishing and one day after.

Table D1 *Stage and Discharge in the Mill Stream On Dates of Electro-Fishings*

Date	15/05	27/06	24/07	08/08	13/09	24/10	27/11
Stage pre-	2.70	1.55	1.80	1.20	1.40	1.7	2.8
Stage post-	1.75	1.40	1.75	1.10	1.60	1.65	2.6
Mean	-	1.60	1.63	1.38	1.21	2.15	2.89
Max	-	1.80	2.60	1.80	1.45	3.50	4.40
Min	-	1.55	1.00	1.18	0.80	1.60	1.60
SD	-	0.178	0.388	0.210	0.229	0.579	0.763
Days	0	43	27	15	36	41	34

A technique was developed to record the position of fish at the time of capture. This provides data on the preferred distribution of stressed fish and may help to show the relative importance and variation in cover requirements for different species of fish. In addition it probably accurately reflects distribution of species along the reach for all but shoaling species, but this latter requires testing. Details of the method are described in Chapter 5 and some examples of the results are also included.

Hydrological data were collected at a range of flows. A sketch of the experimental reach showing the relationship between hydrological survey pegs and botanical zones is given in Figure D2 which is included together with the results at the end of this appendix.

Macrophyte vegetation was mapped throughout the experimental reach on 20th July and again on the 7th of August.

Results
Results are presented together at the end of this appendix.

Chemistry
Major anions and cations have been analyzed every week since the start of May 1991. The objectives of this monitoring work are to establish the within reach variability and determine whether the selected experimental discharges result in changes in concentration of the major ions. For each date there are six points which correspond to locations on the Frome/Mill stream system. Data on nitrate, phosphate and pH levels are presented in Fig. D3 for the first two months.

The results in general agree with those reported by Casey & Clarke (1979) for nitrate and Casey & Clarke (1986) for phosphate, and their were no distinct and consistent longitudinal trends in concentrations along the Mill stream. The values of pH did however show a tendency to increase with distance down the Mill stream. These results must be considered in relation to the full set and await further analysis.

Fish
The fish community in the millstream comprised a total of 10 species on the first fish survey and 12 on the second, the additional two species being pike and grayling. Densities together with 2* standard error values (fish/100m^2) for all fish caught are given in Table D2. Where possible, estimates of population density have been made for all species. Where an * is shown in Table D2 population estimates were not possible for that species, either because of low numbers or a variable catch efficiency which renders the population estimate invalid. Where possible in these cases a minimum population density based upon actual catch is shown. A cross (X) in the table indicates that species was not present in that reach. Histograms of the densities (100m2) for trout, salmon, dace and gudgeon are shown in Figs D4 and D5. The distribution of Dace in May and June throughout the experimental reach is shown in Figs D6 and D7.

Trout densities showed the same pattern for each of the sampling dates, with the highest density being found in reach 1 (the lower section). Smaller densities or no fish were recorded in reach 2 (middle) and reach 3 (upper).

Salmon were found only in reach 1 on both fishing dates but densities were markedly higher on the June fishing.

Dace densities showed a similar pattern of density for each reach at each date and no differences between dates can be seen when looking at the results from the whole of each reach. However the distribution of captured fish was more even in the June fishing compared with the situation in May, see Figs D6 and D7.

Gudgeon densities show a marked difference between both reaches and dates. Densities on the first fishing increased from reach 1 (lower), 9.5 fish/100m^2, to reach 3 (upper), 23 fish/

100m^2. Densities for the second fishing were much lower and whilst the highest density was again found in reach 3 it was at the much lower value of 5.8 fish/100m^2.

Data on fish distribution and abundance continues to be collated from the millstream fishings.

Macrophyte and habitat changes - June-November 1991

The relation between botanical map zone and the position of survey pegs is illustrated in Fig. D2.

A significant increase in the cover of many riparian plants was noted between June and August, including *Phragmites australis (Cav.) Trin. ex Steudel* (Common Reed), *Carex L. spp.* (Sedges), *Solanum dulcamara L.* (Woody Nightshade or Bittersweet), *Glyceria maxima (Hartm.) Holmberg* (Reed Sweet-grass) and *Sparganium erectum L.* (Branched Bur-reed). The most significant growth observed, however, were the stands of *Nasturtium officinale R. Br.* (Water-cress), which grew mostly in zone 5.

The growth of many of these plants altered the range of aquatic habitats by increasing areas of shading and affecting flow rates. The density of the *Phragmites australis* stand in zone 5, for example, reduced the velocity of the water on the south side of the stream, which was presumably compensated for by an increase in the velocity along the north side.

One of the most dominant aquatic plants observed during the surveys in June was *Ranunculus penicillatus (Dumort.) Bab. var. calcareus* (R.W. Butcher) C.D.K. Cook (Water crowfoot). This species was almost absent in the November surveys, however, with only remnants of the large stands formerly observed in zone 6. This loss of water crowfoot was apparently due to damage incurred by swans.

Consonant with this reduction was the loss of a large expanse of *Lemna minor L.* (Common Duckweed) that was trapped in a stand of *R. penicillatus* mid-stream in zone 6. This loss was also possibly due to the water spates that occurred periodically between June and August following heavy rain. In many other stretches of the river, however, L. minor was observed to have increased in extent.

Most of the riparian plants have died back since the surveys were conducted in August; this has resulted in greater habitat uniformity along the river bank. Although the stands of *Phragmites australis* (most notably in zone 5) have died back, they have further reduced water flow by collapsing into the water. The large *Nasturtium officinale* stand (zone 5) has not died back.

Invertebrates

Work was confined to sampling 'microhabitats' as part of a general invertebrate sampling programme in rivers nationwide. These results are described separately under the section 'supplementary invertebrate studies'.

Discussion

It is too early to review the findings from this study in detail. However it is clear that the experimental facility is providing much data on the distribution of fish and seasonal changes in macrophytes. The chemical data are also showing the relative small effects of discharge (within the range available). Most chemical changes are associated with high rainfall/flood events and in general there does not seem to be a difference between reaches. However this may simply be because the discharges were not maintained at a low enough level for a long period.

Perhaps the most significant feature to emerge from this work to date has been the role of macrophytes in controlling flows. Despite low discharges in the Frome in the summer weed growth caused the main river to overtop its banks and riffles in the experimental reach were 'drowned-out' by the rise in water level. The implications for the application of the PHABSIM model, which was developed in generally weed-free rivers, are important and data from the Millstream work will provide information which can be used to modify the model to take account of this feature of British lowland rivers.

It is hoped that a start will be made on other aspects of the project in the coming year. Most particularly invertebrate communities will be investigated in more detail, if staff are available. In addition more work will be carried out on the effect of weed growth on flow retention and habitat availability.

Table D2 *Fish density estimates for the East Stoke Mill stream ESMS in May and June 1991. See text for details.*

ESMS I = 15.5.91 ESMS II = 27.6.91

Fish density /100 m²

	Trout	Salmon	Dace	Gudgeon	Roach	Minnow	Pike	Flounder	Grayling	Eel
ESMS I										
R1	0.8±0.0	0.3±0.0	14.2±0.0	9.5±1.9	x	24.1±7.0	x	2.2±0.0	x	• 20.6
R2	• 0.2	x	15.5±1.4	• 13.4	• 2.1	• 6.6	x	4.7±0.6	x	• 19.5
R3	• 0.6	x	7.6±2.3	23.0±11.0	x	16.0±3.6	x	5.5±0.5	x	37.8±7.6
ΣR	• 0.5	• 0.1	12.4±0.9	• 15.3	• 0.7	• 15.6	x	4.1±0.3	x	• 26.0
ESMS II										
R1	0.8±0.0	3.0±0.8	14.7±2.2	• 4.0	x	• 17.1	x	• 2.5	x	5.8±3.1
R2	x	x	16.9±11.6	1.6±0.0	2.1±0.7	8.9±1.3	• 0.5	x	x	5.2±1.0
R3	• 0.4	x	9.2±0.7	5.8±0.8	x	• 12.5	• 0.2	• 0.6	5.1±0.8	x
ΣR	• 0.4	• 1.0	13.6±3.9	• 3.8	• 0.7	• 12.8	• 0.2	• 1.0	• 1.7	• 3.7

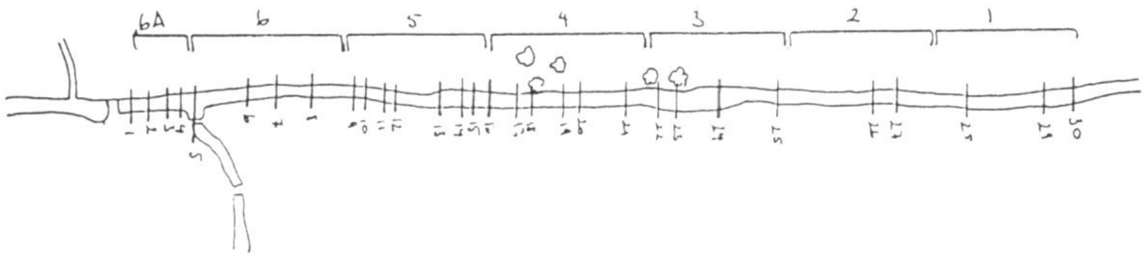


Figure D2 *Sketch of Mill stream experimental zone showing the relationship between hydrological survey pegs and botanical zones.*

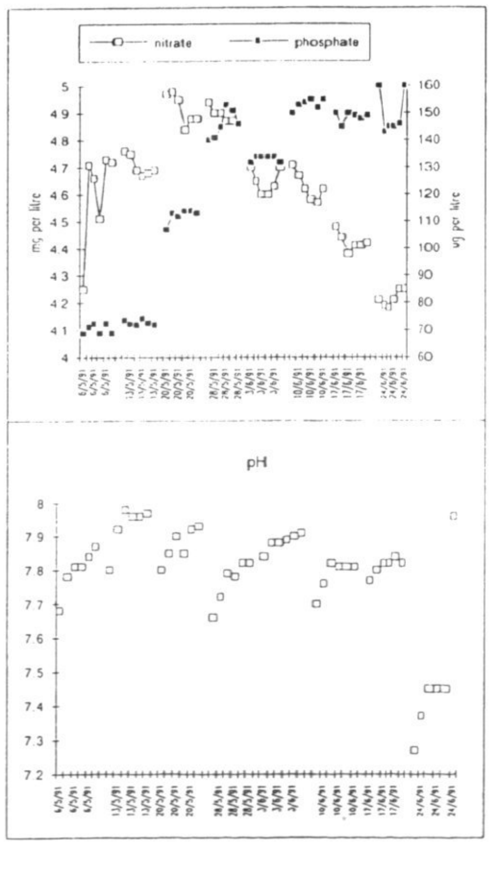


Figure D3 *The variation in values of nitrate and phosphate, and pH in the first two months of the study. Each grouping of six points per date represent the sample locations noted in Fig.* ***A*** *-working from left to right Frome, upstream of fluvarium, upper reach, middle reach, lower reach and 50m downstream from confluence with Frome.*

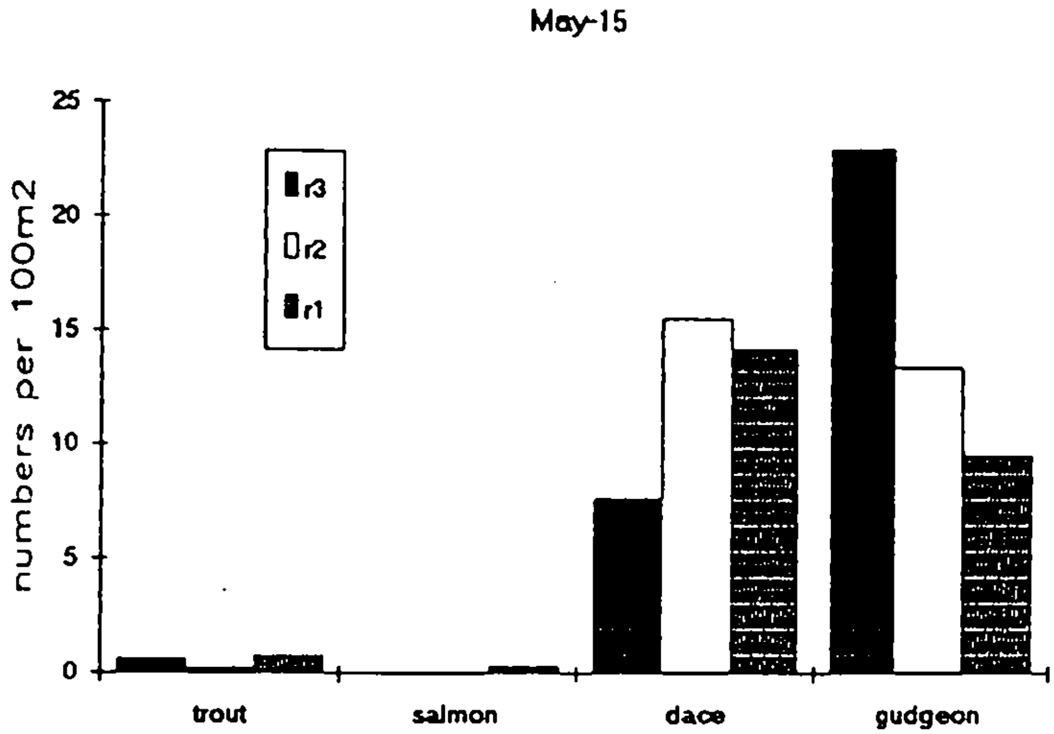


Figure D4 *The densities (N= number per 100m²) of trout, salmon, dace and gudgeon in lower (1), middle (2) and upper (1) reaches of the experimental section of the Mill stream for May, 1991 fishing.*

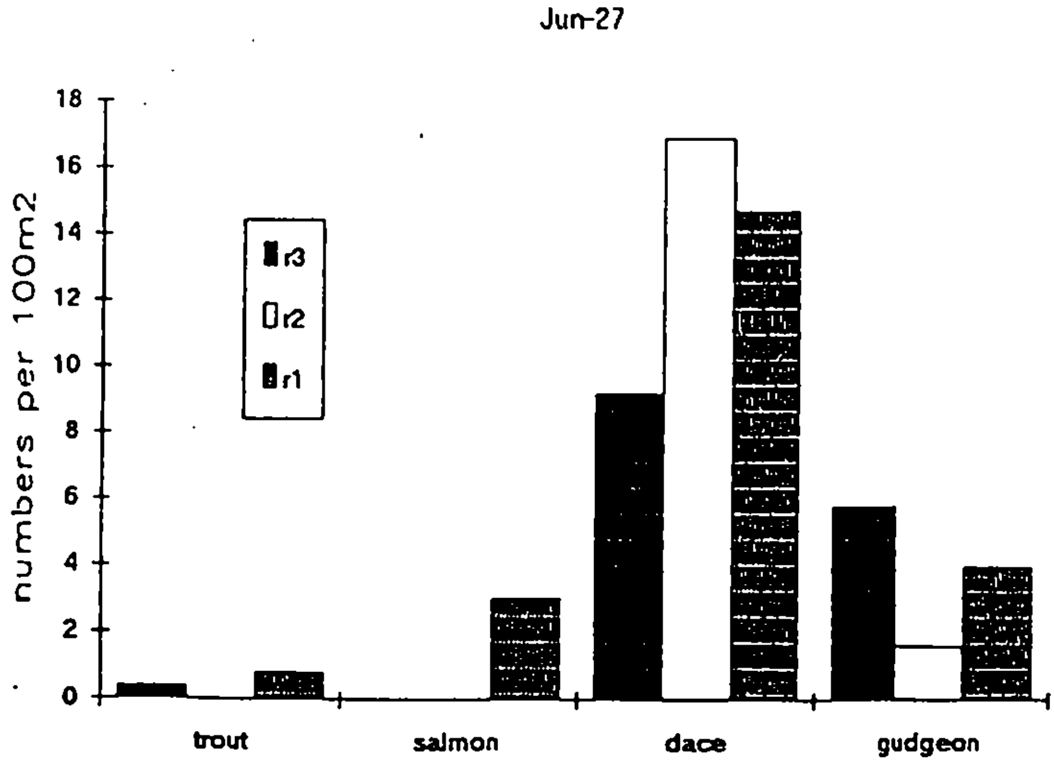


Figure D5 *The densities (N= number per 100m²) of trout, salmon, dace and gudgeon in lower (1), middle (2) and upper (1) reaches of the experimental section of the Mill stream for June, 1991 fishing.*

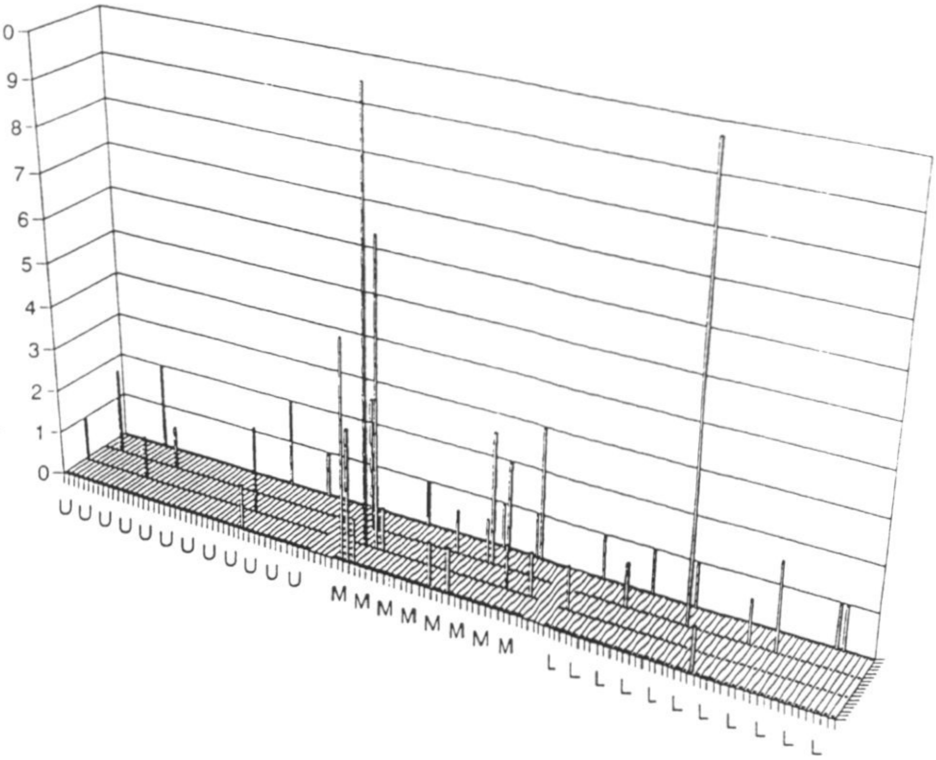


Figure D6 *The distribution of Dace in the experimental section of the Mill stream, May 1991. (U upper, M middle, L lower).*

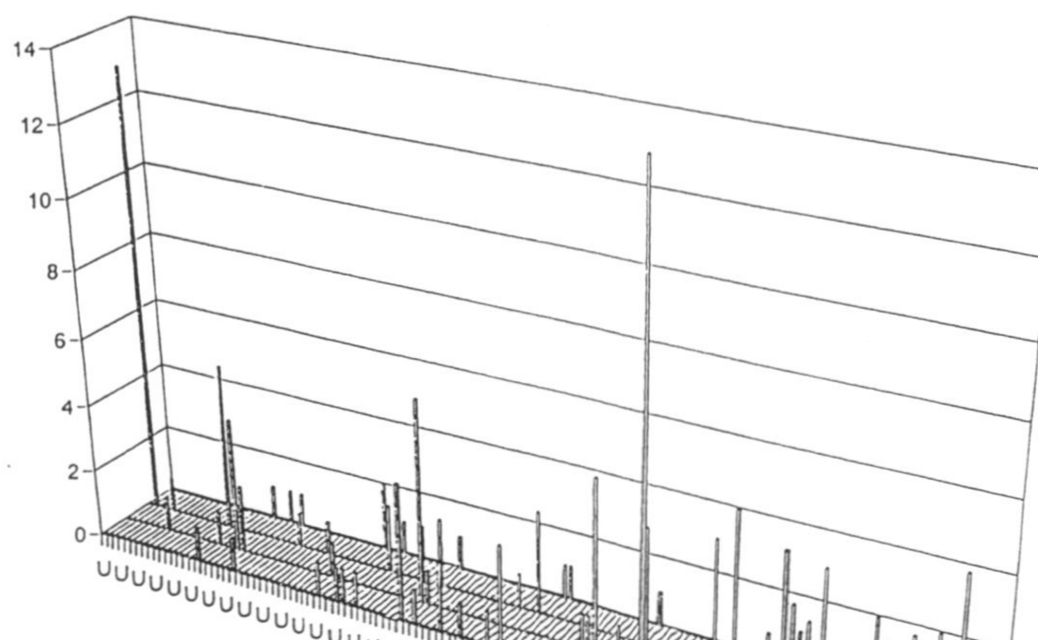


Figure D7 *The distribution of Dace in the experimental section of the Mill stream, June 1991. (U upper, M middle, L lower).*

Appendix E

Supplementary Study : Distribution of Invertebrates Along River Reaches - The Rivers Gwash and Blithe.

Introduction

In a previous study which examined the feasibility of using the PHABSIM model in the UK, invertebrate samples were collected from three reaches on the River Blithe and from one reach on the Gwash (Armitage & Ladle 1989). These samples were collected at the same time as physical and hydraulic variables were measured along transects for input into the model. There were insufficient funds available for processing the samples at that time and the entire collection was stored by the Institute of Freshwater Ecology until such time and funds became available for further examination.

This current project allows for these data to be processed in order to examine in more detail the distribution of invertebrate groups across and along a broad area of river.

Most invertebrate surveys are confined to a single sample within a given reach. This sample may include all microhabitats within the site area (usually rather loosely defined) which may consist of a section 5-10m along the stream. In this type of sample the catches from different microhabitats within the area are usually bulked together and no microhabitat-specific distributional data can be extracted. Other techniques involve sampling a single habitat usually a riffle and again no picture of distribution patterns for the reach can be obtained from the results.

It is important to know whether invertebrates have a patchy distribution and this has been the subject of much investigation by theoretical ecologists (see Pringle *et al.* 1988, JNABS 7,503-524). However to date there has been little attempt to obtain such data for studies of applied problems. Detailed distributional data has practical application particularly in the field of flow changes. Such changes are accompanied by shifts in the proportions and absolute amounts of habitat types which in turn can have major effects on the benthic community. It is the object of this investigation to determine the distribution of benthic invertebrates along river reaches and relate them initially to substrate features with the ultimate aim of defining zones/reaches which would be particularly sensitive to flow changes and their associated hydraulic characteristics.

Methods

Six samples were collected along every other transect (see Fig. E1 for details of the grid system). Each sample consisted of one 60s kick within a defined area in a cell. Such a sample can provide quantitative data (Armitage *et al.* 1974). Water flow carries the fauna from the disturbed area of river bottom into a net held downstream. Where flow is too slow the net is moved to and fro over the area of disturbance.

Each sample was preserved in formalin solution, and sorted into alcohol. The cost both in time and money precluded the identification of the fauna to species level in all reaches, and analysis is confined to family level. Data are available on the substrate characteristics at each sample point and velocity and depth data were collected along each transect. In this study substrate type is considered to be the consequence of velocity and depth variations over a period of time. Seven categories of substrate were recognized and coded as follows:- silt=1, silty sand=4, sand=9, sandy gravel=16, gravel=25, pebbly gravel=36, and cobbles=49. This allowed substrate type to be plotted for the whole reach.

Results and Discussion
The results are presented as a series of three-dimensional plots which show the distribution and abundance of selected families across and along the whole of each experimental reach.

Substrate
Substrate variation in the three reaches on the river Blithe are indicated in Fig E2. Gravel is the dominant particle size in every reach but there are variations between Blithe 1-3. Silt and silty sand is largely confined to the downstream end of Blithe 1. Blithe 2 has a relatively homogenous gravel substrate but heavily overlain with silt. Blithe 3 shows more variability than the other two sites with a higher proportion of larger particle sizes.

In Gwash 3 the substrate is heterogeneous with silty margins, slightly coarser gravel in the middle of the reach with most of the largest particles at the downstream end (see Fig E3).

These categorisations of substrate conditions are oversimplified but present an overall picture of conditions in each reach. Data which are not included in the plots concern information on the occurrence of vegetation (algae or macrophytes) or coarse organic detritus. The River Blithe was relatively free of vegetation with only isolated patches of vegetation in contrast to the Gwash reach in which most samples contained either macrophyte or algal material.

Fauna
Faunal analyses are not complete for all reaches. Data for this report are presented only for Gwash 3 and Blithe 3. The distribution of total numbers per sample per reach is illustrated in Fig E4 for Blithe 3. There is considerable variation in numbers per sample in the reach as a whole. The most obvious trend is the generally higher numbers in the midstream section compared with the stream margins. Major trends in distribution are more clearly seen when individual families are plotted. Fig E5 presents distributions of 9 commonly occurring families. The patchiness of the distributions is clear but association with particular substrate conditions is not marked. This may be a consequence of the relatively heterogeneous substrate which offers a wide range of niches for the benthic fauna.

In the Gwash (see Fig E6) total numbers are more evenly spread over the reach than at Blithe 3 despite a substrate distribution which is much patchier. Coarse particles are almost restricted to the downstream end of the reach and silt is common at the top and along most of the margins. This substrate patchiness is reflected in the distribution of certain invertebrate families. For example, Hydropsychidae and Rhyacophilidae are restricted to the downstream end of the reach where the substrate is coarser. Simuliidae are more abundant towards the upstream weedier section as are Baetidae. Gammaridae although widespread are more common in the downstream section as are the riffle beetles Elmidae (see Fig E7).

The observed distributions point up the need for site specific rulings for water abstractions. Invertebrates clearly require specific conditions to flourish. Any changes in flow will alter hydraulic conditions and available habitat which will have repercussions on the distribution of the faunal community. The impact on the benthos will vary according to the river type.

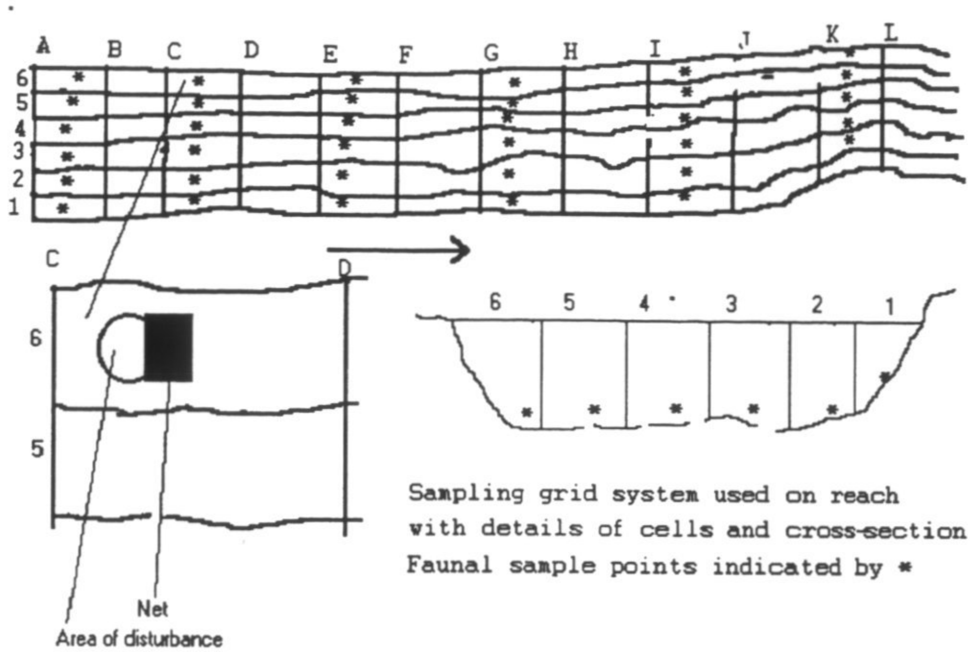


Figure E1 *The sampling grid system employed in the Rivers Gwash and Blithe.*

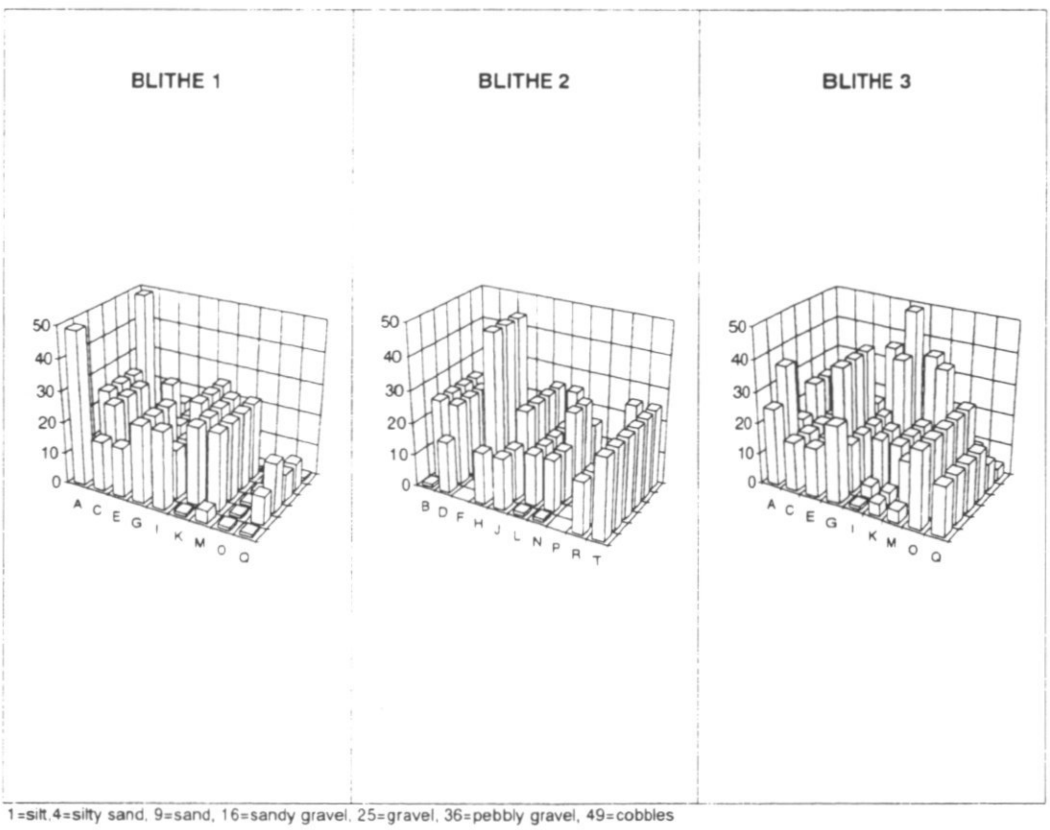


Figure E2 *The distribution of dominant substrate particle size in each of the three reaches sampled on the River Blithe.*

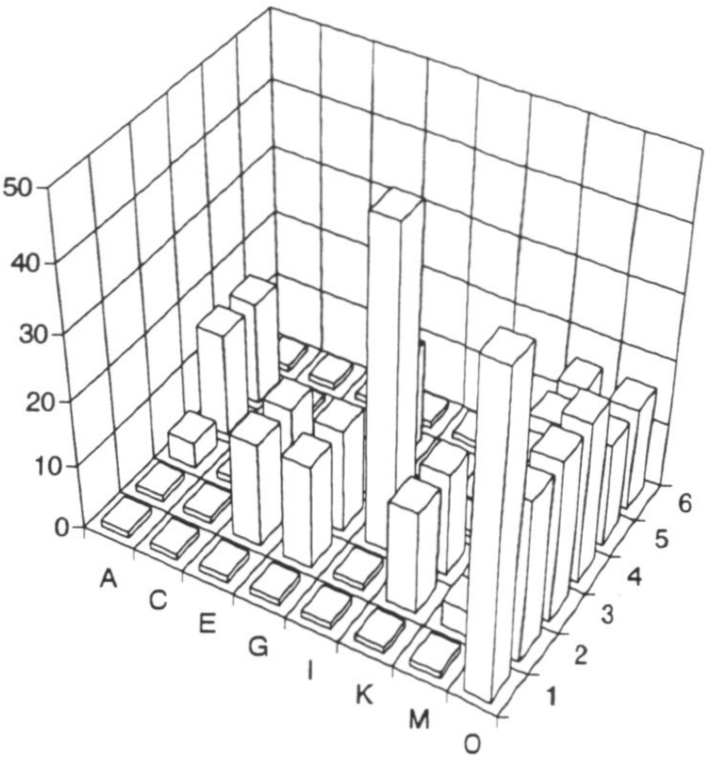


Figure E3 *The distribution of dominant substrate particle size at site 3 on the River Gwash.*

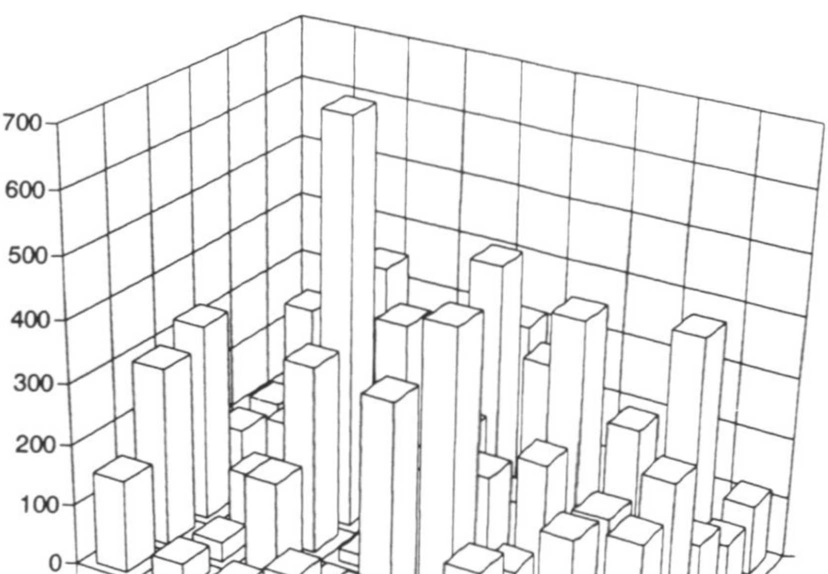


Figure E4 *The distribution of total fauna (numbers per sample) at site 3 on the River Blithe.*

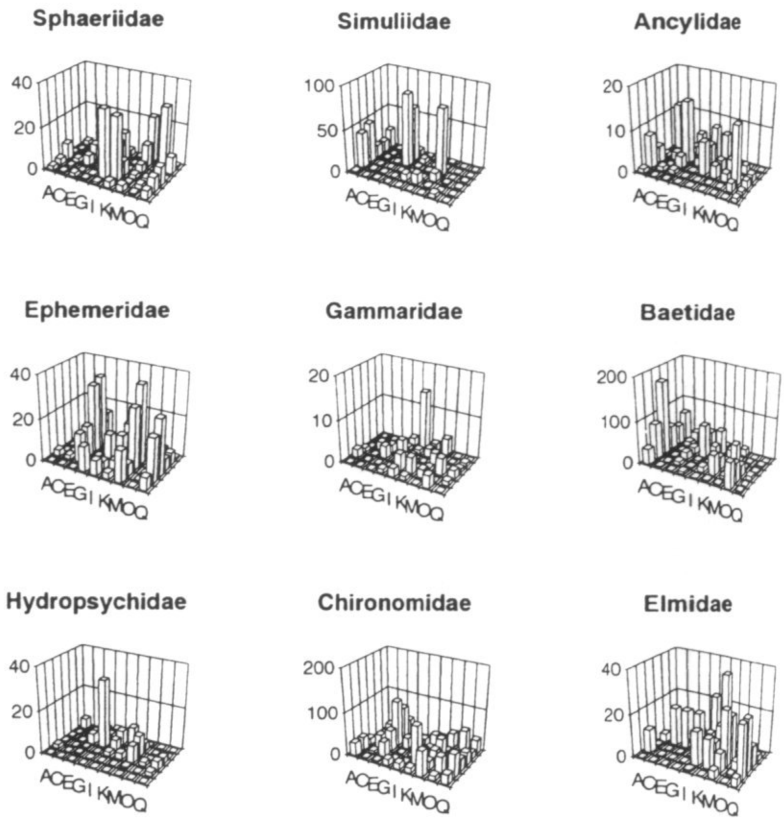


Figure E5 *The distribution of selected families (numbers per sample) at Blithe 3.*

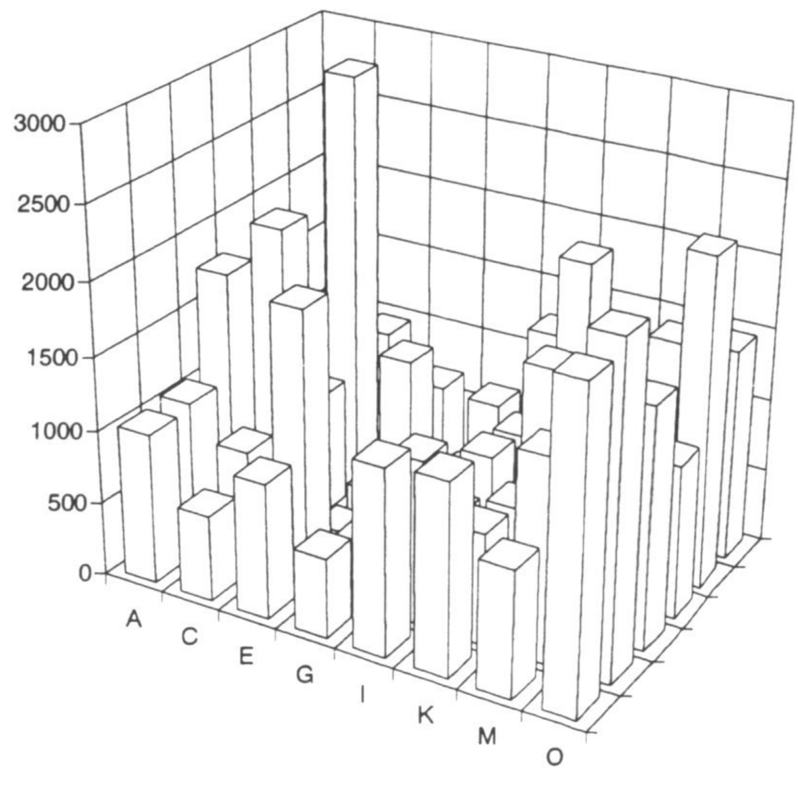


Figure E6 *The distribution of total fauna (numbers per sample) at site 3 on the River Gwash.*

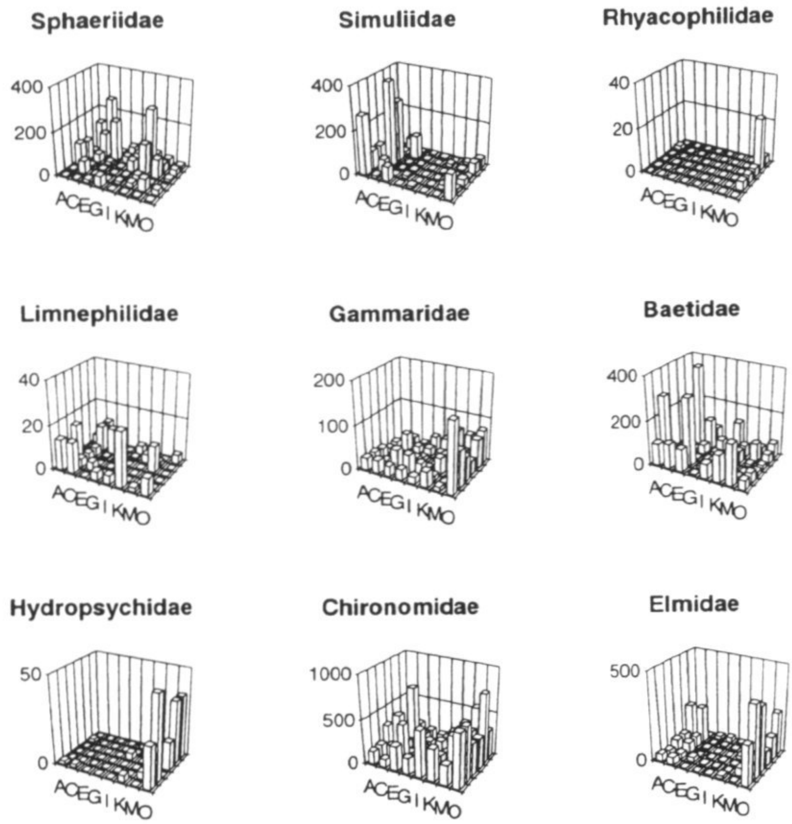


Figure E7 *The distribution of selected families (numbers per sample) at site 3 on the River Gwash.*

Appendix F

Supplementary invertebrate study : Sampling from Microhabitats

Introduction

Habitat preference curves for this study are based largely on information held on the IFE data base which has been used to develop the predictive model RIVPACS. However these data do not include information from specific microhabitats. In order to investigate the distribution of invertebrates within these areas a series of samples were taken in microhabitats within the reaches selected for the fishing programme which includes a wide range of river types from chalk streams to upland spatey rivers.

The objectives were to determine a) whether 'microhabitats' selected from the bankside would contain different communities of invertebrates; b) whether these communities were stable across a range of river types and c) to use any appropriate data to supplement the habitat preference information obtained from the RIVPACS data base.

Study Area and Methods
Details of the river selection programme are given in Chapter 3 and need not be repeated here. At each river five microhabitats were identified which fitted as closely as possible into the following categories:-

A - SLACK, an area with no flow, often immediately downstream of an obstacle such as a submerged log or large boulder.

B - MARGINAL, an area of low or minimal flow in marginal vegetation or its roots.

C - RIFFLE, shallower part of study reach where the water flows with broken or rippling surface.

D - WEED, submerged aquatic vegetation. In the absence of macrophytic vegetation algae was sampled. In all cases sampling was confined to the vegetation, not the underlying substrate.

E - DEEPER, a deeper and more slowly flowing part of the reach where the substrate is usually finer due to increased deposition of particulate material.

Each sample consisted of a 15 second kick sample, taken in either the weed or substrate with a standard pond net. The area of disturbance was approximately one tenth of a square metre (Armitage *et al.* 1974). The fauna in each sample was sorted counted and identified to family level.

Results
Although the biological data have been processed the collation and analytical phases are not complete. The exception is habitat preference data which have been worked up to supplement the RIVPACS based preferences.

The preferences for depth, substrate and velocity were calculated for seven families of invertebrate for which data are available from the RIVPACS data base. The results are presented in Table F1 and Figs F1 and F2. In general despite the relatively low numbers of samples (40) on which the curves are based there is a good agreement between the findings from the microhabitat study and those based on the RIVPACS data. These results await further analyses.

Discussion

Analysis of the complete set of results is likely to suggest modification to the invertebrate sampling programme. Preliminary indications are that microhabitats as identified in this project are not sufficiently discrete to obtain the fine focusing needed to identify precise conditions required by the benthos.

Table F1 *Frequency of occurrence and abundance of selected families together with weighted % and habitat suitability (suit) for substrate (bc, boulders/cobbles, pg, pebbles/gravel, sa, sand, si, silt); depth (categories as indicated based on depths in cm); and velocity (categories as indicated (cm per second) in a data set of 40 samples obtained from 5 'microhabitats' on each of 8 rivers (Blithe, Exe, Gwash, Hodder, Lambourn, Lymington, Millstream, and Wye).*

Gammaridae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	1	0.11	4.71	13.89	1	0.11	0.31
pg	19	14	0.74	31.22	92.11	428	22.53	62.82
sa	7	5	0.71	30.27	89.29	251	35.86	100.00
si	5	4	0.80	33.90	100.00	36	7.20	20.08
	40	24	2.36			716	65.69	
Heptageniidae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	4	0.44	74.07	100.00	69	7.67	100.00
pg	19	3	0.16	26.32	35.53	45	2.37	30.89
sa	7	0	0.00	0.00	0.00	0	0.00	0.00
si	5	0	0.00	0.00	0.00	0	0.00	0.00
	40	7	0.60			114	10.04	
Leptophlebiidae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	1	0.11	17.09	38.89	1	0.11	6.94
pg	19	1	0.05	8.10	18.42	4	0.21	13.16
sa	7	2	0.29	43.96	100.00	10	1.43	89.29
si	5	1	0.20	30.77	70.00	8	1.60	100.00
	40	5	0.65			23	3.35	
Ephemeridae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	2	0.22	38.31	100.00	10	1.11	100.00
pg	19	4	0.21	36.30	94.74	13	0.68	61.58
sa	7	1	0.14	24.63	64.29	4	0.57	51.43
si	5	0	0.00	0.00	0.00	0	0.00	0.00
	40	7	0.58			27	2.37	
Chloroperlidae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	2	0.22	58.48	100.00	5	0.56	100.00
pg	19	3	0.16	41.55	71.05	9	0.47	85.26
sa	7	0	0.00	0.00	0.00	0	0.00	0.00
si	5	0	0.00	0.00	0.00	0	0.00	0.00
	40	5	0.38			14	1.03	
Leuctridae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	6	0.67	38.76	100.00	70	7.78	100.00
pg	19	8	0.42	24.48	63.16	110	5.79	74.44
sa	7	3	0.43	24.92	64.29	18	2.57	33.06
si	5	1	0.20	11.63	30.00	2	0.40	5.14
	40	18	1.72			200	16.54	
Sericostomatidae								
substrate	total	occ	x occ	w%	suit	nos	x nos	suit
bc	9	1	0.11	10.48	25.93	1	0.11	4.86
pg	19	6	0.32	29.79	73.68	11	0.58	25.33
sa	7	3	0.43	40.43	100.00	16	2.29	100.00
si	5	1	0.20	18.87	46.67	3	0.60	26.25
	40	11	1.06			31	3.58	

Table F1 *contd.*

Gammaridae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	11	0.55	31.25	77.00	207	10.35	33.16
2 (>25-50)	14	10	0.71	40.58	100.00	437	31.21	100.00
3 (>50-100)	6	3	0.50	28.41	70.00	72	12.00	38.44
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	24	1.76			716	53.56	
Heptageniidae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	6	0.30	81.08	100.00	112	5.60	100.00
2 (>25-50)	14	1	0.07	19.31	23.81	2	0.14	2.55
3 (>50-100)	6	0	0.00	0.00	0.00	0	0.00	0.00
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	7	0.37			114	5.74	
Leptophlebiidae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	3	0.15	51.72	100.00	13	0.65	91.00
2 (>25-50)	14	2	0.14	49.26	95.24	10	0.71	100.00
3 (>50-100)	6	0	0.00	0.00	0.00	0	0.00	0.00
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	5	0.29			23	1.36	
Ephemeridae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	4	0.20	39.22	100.00	15	0.75	75.00
2 (>25-50)	14	2	0.14	26.01	71.43	6	0.43	42.86
3 (>50-100)	6	1	0.17	32.68	83.33	6	1.00	100.00
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	7	0.51			27	2.18	
Chloroperlidae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	4	0.20	54.05	100.00	11	0.55	100.00
2 (>25-50)	14	0	0.00	0.00	0.00	0	0.00	0.00
3 (>50-100)	6	1	0.17	45.05	83.33	3	0.50	90.91
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	5	0.37			14	1.05	
Leuctridae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	13	0.65	50.39	100.00	180	9.00	100.00
2 (>25-50)	14	2	0.14	11.07	21.98	15	1.07	11.90
3 (>50-100)	6	3	0.50	38.76	76.92	5	0.83	9.26
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	18	1.29			200	10.90	
Sericostomatidae								
Depth	total	occ	x occ	w%	suit	nos	x nos	suit
1 (0-25)	20	7	0.35	42.17	100.00	12	0.60	56.00
2 (>25-50)	14	2	0.14	17.21	40.82	15	1.07	100.00
3 (>50-100)	6	2	0.33	40.16	95.24	4	0.67	62.22
4 (>100)	0	0	0.00	0.00	0.00	0	0.00	0.00
	40	11	0.83			31	2.34	

Table F1 *contd.*

Gammaridae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	10	0.77	27.47	100.00	234	18.00	41.47
1-25 1	5	2	0.4	14.29	52.00	217	43.40	100.00
>25-50 2	10	5	0.5	17.86	65.00	38	3.80	8.76
>50-100 3	4	2	0.5	17.86	65.00	90	22.50	51.84
>100 4	8	5	0.63	22.32	81.25	137	17.13	39.46
	40	24	2.79			716	105	
Heptageniidae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	3	0.23	28.85	92.31	51	3.92	64.05
1-25 1	5	1	0.2	25.00	80.00	12	2.40	39.18
>25-50 2	10	1	0.1	12.50	40.00	2	0.20	3.27
>50-100 3	4	0	0	0.00	0.00	0	0.00	0.00
>100 4	8	2	0.25	31.25	100.00	49	6.13	100.00
	40	7	0.78			114	12.6	
Leptophlebiidae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	4	0.31	61.54	100.00	15	1.15	100.00
1-25 1	5	0	0	0.00	0.00	0	0.00	0.00
>25-50 2	10	2	0.2	40.00	65.00	8	0.80	69.33
>50-100 3	4	0	0	0.00	0.00	0	0.00	0.00
>100 4	8	0	0	0.00	0.00	0	0.00	0.00
	40	6	0.51			23	1.95	
Ephemeridae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	4	0.31	34.19	100.00	14	1.08	71.79
1-25 1	5	1	0.2	22.22	65.00	6	1.20	80.00
>25-50 2	10	0	0	0.00	0.00	0	0.00	0.00
>50-100 3	4	1	0.25	27.78	81.25	6	1.50	100.00
>100 4	8	1	0.13	13.89	40.63	1	0.13	8.33
	40	7	0.88			27	3.9	
Chloroperlidae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	0	0	0.00	0.00	0	0.00	0.00
1-25 1	5	1	0.2	25.00	80.00	2	0.40	57.14
>25-50 2	10	2	0.2	25.00	80.00	7	0.70	100.00
>50-100 3	4	1	0.25	31.25	100.00	1	0.25	35.71
>100 4	8	1	0.13	15.63	50.00	4	0.50	71.43
	40	5	0.78			14	1.85	
Leuctridae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	5	0.38	16.72	61.54	93	7.15	86.71
1-25 1	5	3	0.6	26.09	96.00	16	3.20	38.79
>25-50 2	10	4	0.4	17.39	64.00	15	1.50	18.18
>50-100 3	4	1	0.25	10.87	40.00	10	2.50	30.30
>100 4	8	5	0.63	27.17	100.00	66	8.25	100.00
	40	18	2.26			200	22.6	
Sericostomatidae								
Velocity	total	occ	x occ	w%	suit	nos	x nos	suit
0	13	4	0.31	23.67	82.05	5	0.38	13.74
1-25 1	5	1	0.2	15.38	53.33	14	2.80	100.00
>25-50 2	10	2	0.2	15.38	53.33	4	0.40	14.29
>50-100 3	4	1	0.25	19.23	66.67	4	1.00	35.71
>100 4	8	3	0.38	28.85	100.00	4	0.50	17.86
	27	7	1.33			26	5.08	

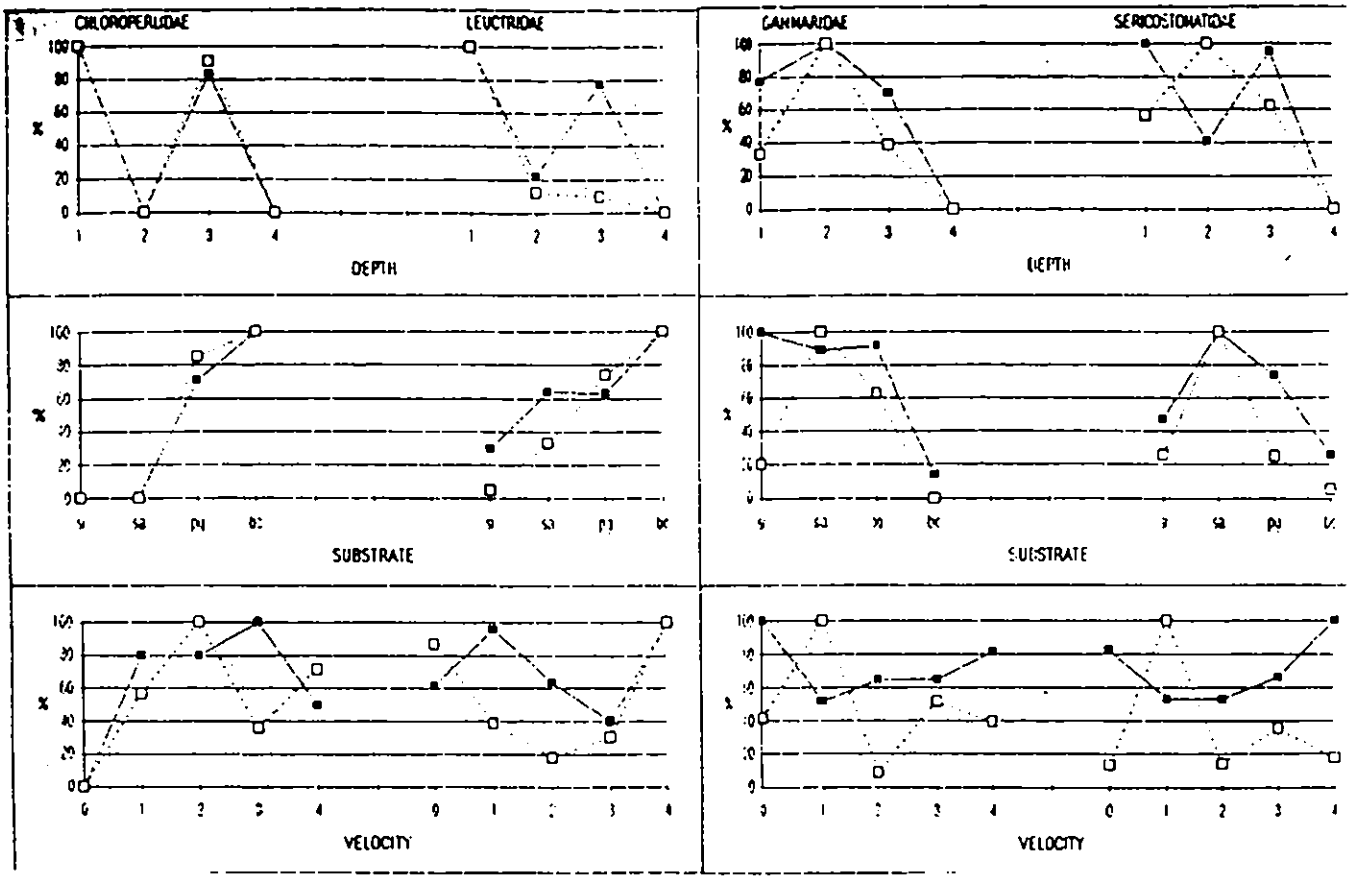


Figure F1 *Habitat suitability curves for* Chloroperlidae, Leuctridae, Gammaridae, and Sericostomatidae *based on data in Table F1.*

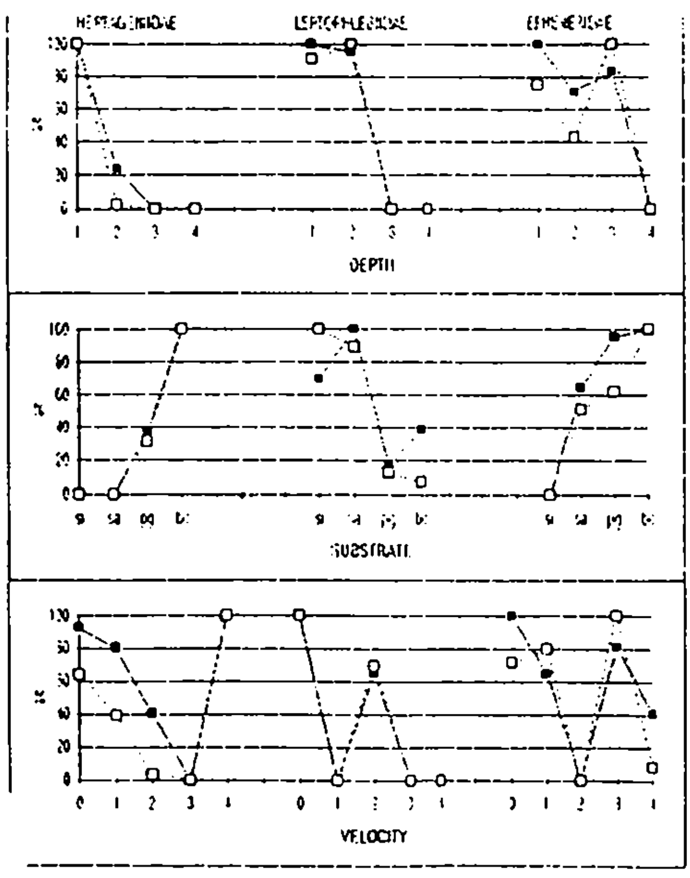


Figure F2 *Habitat suitability curves for* Heptageniidae, Leptophlebiidae *and* Ephemeridae *based on data in Table F1.*

Appendix G

Fish Survey Report

Introduction

Whilst habitat preference curves for the selected target fish species (dace, roach and brown trout) have been developed primarily from published information and expert opinion, it is necessary to have information about the fish populations present in the study reaches in order to test and verify the PHABSIM model.

The fishing programme has been designed to show how fish in different river types are distributed with respect to habitat characteristics. Age structure and population densities have also been assessed and these data may be used to test the accuracy of the PHABSIM predictions. The data will also supplement existing information on habitat requirements of different fish species.

To this end the fish populations in ten of the eleven selected PHABSIM study reaches, located throughout England and Wales, have been surveyed, (Fig. 1, Tab. I). Species composition and length frequency distributions have been ascertained and where possible population number and densities of juveniles and adults of the three target species, dace, roach and trout have been calculated.

The River Itchen has not been surveyed as it was not possible to obtain satisfactory permission to electrofish.

On the smaller rivers it was possible to obtain all required information (species composition, length-frequency distribution, species population number and species population density estimates) for nearly all the species present. On larger rivers or where non-target species were numerous this was often not possible and effort was concentrated on obtaining information relating to the target species.

As previously stated the sites for this study were chosen in order to encompass a wide range of habitat types ranging from chalk streams to upland rivers. Many of the sites were, however, not ideal for obtaining fish population estimates and it has often been difficult to make an accurate population assessment having a low measure of error.

Methods
Methodology used to sample each site was decided on an individual basis according to the river type and topography. Ideally the whole site would have been isolated with stop nets, electro-fished three times and a triple catch depletion estimate made to obtain the population estimate. This was not possible, however, on many of the sites fished. Variations from this ideal are reported in table I together with details of sites, locations and RIVPACS group classification.

Where sites were divided up into smaller reaches the reach population estimates and standard error estimates were then added to one another to obtain total site estimates. Standard error estimates were added according to the formula:

$$\sum SE = \sqrt{\sum (SE^2)}$$

This process made estimation of the validity of the population estimated difficult as a single invalid reach estimate would bias the site estimate.

Target fish species were stratified into juvenile and adult categories. It was however, quite difficult to define the cut off points between these categories. Whilst the transition from juvenile to mature fish is relatively clearly defined in terms of physiology it is less easily determined ny age or length criteria. Problems were exacerbated by such factors as; differences between age at maturity between males and females, fish in less productive systems (e.g. the River Wye) having slower growth-rates than more productive systems (e.g. the River Lambourn), differences in geographic location of the sites and the variation in the time of year of the fishing surveys. In the absence of an extensive research programme to determine absolute age and length at maturity on each river a best guess estimate, based upon fish length and age, has been made for each site. Figures 2, 3 & 4 show the length-frequency distributions of the three target species at each site and also show the cut off length used to discriminate between juvenile and adult fish. For the sake of consistency a cut-off point of 200mm has been used for trout stratification, whilst this cut-off is probably valid for most of the sites surveyed, it may be less so for the faster growing and later sampled trout in the Rivers Gwash and Lambourn.

Roach were stratified on the basis of length/age/maturity criteria found in the River Frome (Mann 1973). However, the age stucture of roach from the Ouse and Lee's Brook showed wide variation (e,g, a 184mm fish aged 3+ and a 125mm fish aged 5+). As scales were not taken from all fish it was not possible to accurately stratify between juveniles and adults for these two rivers. Instead an arbitrary length criterion of 140mm was used, however some fish smaller than this may well have been adults.

Dace were also stratified based upon data on length/age/maturity criteria found in the River Frome (Mann 1974).

Site Descriptions
River Exe
Sample date: 12.8.91
Length 127m: Width, max 6.10m, min 2.35m: Area 441.15m^2.

This small shallow river is situated in a steep valley. There were signs indicating the flashy nature of the river and most fish habitat consisted of overhanging river banks, large stones and one or two deep pools. There was no instream macrophyte cover. The whole reach was fished three times by use of a single anode (0.9KVA). Only 3 species were found to be present.

River Wye (Afon Gwy)
Sample date: 18.9.91
Length 226m: Width, max 18.9m, Min 7.6m: Area 2756.86 m^2.

The reach of this river chosen was quite wide with a depth varying between 5cm and c2.5m. The lower end of the reach was an are of rapids which, together with the slippery nature of the rock, made fish capture difficult. In the middle half of the site the river was divided into two shallow channels and the upper end of the reach was a very deep pool (c2.5m deep) across the whole width of the river. With the exception of the deep pool at the top of the reach the river was fished by wading using two anodes powered by a 1.9KVA generator. The pool was fished by towing a boat through it with the anode operators fishing from the boat. The depth and low conductivity of the water, however, meant that capture efficiency was very poor in this section. Because of the low capture efficiency for the reach as a whole the reach was fished four times. There was no instream macropyhte cover.

River Hodder
Sample date: 14.8.91
Length 245m: Width, max 23.91, min 16.6: Area 4821.58m^2.

This site was a very wide reasonably shallow river. The site was split into two reaches and was fished by wading using twin anodes powered by a 1.9KVA generator. Site one was shallower and wider than site two. There was no instream macrophyte cover in either reach. All of the large sea trout and most of the large brown trout caught in this site were caught in reach one in a deep area of river where a fallen tree had caused a scour hole and an overhanging tree provided cover. In view of the width of the river it was impossible to fish the entire area of the river in a systematic fashion, instead an attempt was made to fish a constant amount of effort at each fishing. Lack of time caused by the size of the site to be fished meant that only two fishings per reach were possible at this site.

River Blithe
Sample date: 13:8:91
Length**m: Width, max**m, min**m: Area 2946.00m^2

This river is moderately deep and wide. It was fished by using twin anodes powered by a 1.9KVA generator. The site was split into two reaches, reach one was deep and had cover provided by bank vegetation. The lower end of this reach had extensive macrophyte cover but most of the reach was without this cover. Reach two was shallower and bank vegetation was more sparse. A large proportion of the fish caught in reach two came from a small area of overhanging shrubs on the west bank. Though not extensive there was a reasonable amount of macrophyte cover in the shallow ares of the reach. Large numbers of fish were caught comprising twelve different species.

River Lymington
Sample date: 20.1.92
Length 103m: Width, max 12.6m, min 5.6m: Area 1002.51m^2

At this site the river was primarily gravel shallows apart from the top 10m where it deepened into a 2m deep pool. The site was fished using single anode wading for the shallows and single anode from a boat for the deeper pool. There was little instream macrophyte cover.

East Stoke Mill Stream (ESMS)
Sample date 8.8.91
Total length 310m: Width, max 6m, min 4m: Area 1500.00m^2

This site was divided into three reaches each of which had the differing features.
Downstream reach (ESMS 1): 110m long, reasonably shallow (0.5m), largely unshaded, pasture on one bank and open shrub and alder cover on the other there was extensive instream cover provided by beds of ranunculus.

Middle reach (ESMS 2): 80m long, it had similar land use but was considerably deeper (1.5m) and somewhat more shaded. It had an area of good tree cover at its upstream end and very little instream cover.

Upstream reach (ESMS 3): 120m long, it had pasture on one bank and reed beds on the other. In depth it was midway between ESMS 1 and ESMS 2 it had little instream cover. All three reaches were fished by a single anode powered by a 0.9 KVA generator. Results have been tabulated both for each reach separately and for the reach as a whole.

River Lambourn
Sample date: 6.4.92
Length 203m: Width, max 17.25m, min 6.7m: Area 2083.89m^2.

Depth of this site varied between 0.5m and 1.5m. The deeper areas being sites of dredging activity. The site was fished using twin anodes powered by a 1.9KVA generator. Large numbers of target fish were caught at this site and in order to prevent mortality (by overcrowding in the retaining bins) only two fishings were carried out. The time of year of the survey meant that there was very little macrophyte cover present, the exception being an area of marginal Sparganium in the upper part of the site. Substrate was fine chalky gravel.

River Gwash
Sample date: 17.1.92
Length 175m: Width: max 8.0m, min 5.4m: Area 1119.57m^2.

This site was fished using twin anodes powered by a 1.9 KVA generator. The site was reasonably uniform in width (max 6m). Depth varied between c1.5m and 0.1m. The site had apparently been dredged in September and fish were aggregated under overhanging cover, there being little instream cover available.

River Gt. Ouse
Sample date 19.5.92
Length c400m: Width c50m: Area C20,000m^2.

The size of the river at this site, the turbidity of the water and the presence of boat traffic navigating the river made a quantitative survey of the fish at this site impossible. Instead a qualitative survey was carried out by fishing close to and parallel to each bank. This process was repeated twice. This enabled species composition and species length frequency to be determined. A minimum population estimate was calculated for dace, roach and bleak based upon actual catch. The reach was fished using a twin boom electrofishing boat, (two 1m diameter anodes powered by a 7.5KVA generator).

Lee's Brook
Sample date 19.5.92
Length**m: Width, max**m, min**m: Area c800m^2

Although smaller than the River Ouse this site also proved difficult to electrofish due to the turbidity of the water and obstructions in the river. The site was fished twice using the boom electrofishing boat.

Results
Within the limitations described earlier, estimates of population density (plus standard

have been made for as many species as possible in all the rivers fished (Table II). Results are coded as follows: v = valid population density estimate; IV = invalid population density estimate; LC = low catch (<30) may render the population density estimate invalid; ME = minimum population estimate based upon actual catch; Y = species present but no assessment of population carried out; X = species not present.

A total of 19 species were caught at the sites with one or more of the target species present at all sites. Dace were found at 4 sites, roach at 4 sites and trout at 8 sites. Fig 5 shows the variation in adult and juvenile target species density (per m^2)at each site. Broad differences in target species community structure in the different rivers are apparent.

Dace were absent from the lower RIVPACS group rivers (Exe, Wye and Hodder) these sites being characterised by low species abundance but high salmonid density. They were also absent from the 6th and 8th RIVPACS group sites (Lymington and Lambourn). High densities were found in both the 4th and 7th RIVPACS group sites (Blithe and East Stoke Mill Stream).

Roach showed a similar pattern of distribution but with the highest densities occurring in the 10th RIVPACS group sites.

Trout showed a variable pattern of occurrence. The most noticeable feature being their absence from the 10th RIVPACS group sites. Sites 3 and 4 also stand out as having low densities of trout, however, site 3 had a high density of salmon and it is possible that whilst higher populations of trout occurred nearby the shallow depth of water at this site was unsuitable for them. It is important to note that sites 8 & 9 are known to be stocked with trout and densities of adults at these two sites are almost certainly above natural levels, this is supported by the greater density of adults than juveniles (the reverse is true of naturally occurring populations). If only the juvenile densities are considered and sites 3 & 4 excluded there appears to be a trend of decreasing trout density with increasing site RIVPACS group. Figure 6 shows the densities of fish grouped into salmonids (brown trout & salmon) and cyprinids (dace, roach, chub, bleak, tench, gudgeon & bream) for the different sites. This enables the trend of decreasing salmonid density and increasing cyprinid density with increasing RIVPACS group number to be seen more clearly.

In general terms site 4 (River Blithe) does not conform with the pattern of target species occurrence. It is the lowest RIVPACS group site to have dace and roach present and with the exception of site 3 (see above) the lowest RIVPACS group site to have a low trout density.

Site 8 (River Lambourn) also appears to have a lower cyprinid density than that which may be expected. Some trout fisheries however operate a coarse fish removal program and the lower cyprinid densities may be a result of this factor.

Figure 7 shows total fish species number per site, this also shows increasing values in the low RIVPACS group sites before levelling off after site 6.

Table G1 *Sampling sites, locations, dates and comments*

NAME	LOCATION	NGR	RIVPACS GROUP	COMMENTS
R.EXE	WARREN FARM	SS792406	1	3 FISHINGS
R.WYE (AFON GWY)	PANT MAWR	SN847823	2	DEEP POOL AT TOP OF REACH. 4 FISHINGS
R.HODDER	HODDER BANK	SD655487	3	REACH DIVIDED INTO TWO. 2FISHINGS PER REACH
R.BLITHE	HAMSTALL RIDWARE	SK109189	4	REACH DIVIDED INTO TWO. 3FISHINGS PER REACH
R.ITCHEN	HIGHBRIDGE	SU467213	5	NOT FISHED
R.LYMINGTON	BALMERLAWN	SU302033	6	3 FISHINGS
R.FROME (ESMS)	EAST STOKE	SY873866	7	3 REACHES EACH FISHED 3 TIMES
R.LAMBOURNE	HUNTS GREEN	SU435701	8	2 FISHINGS
R.GWASH	BELEMSTHORPE	TF041105	9	3 FISHINGS
GREAT OUSE	BRAMPTON	TL220697	10	LARGE REACH, QUALITATIVE SURVEY, BOOM BOAT
LEE'S BROOK	GODMANCHESTER	TL233702	10	2 FISHINGS. WATER TURBID + OBSTRUCTIONS

Table G2 Fish Population Estimates

	EXE 12/08/91			GWY 18/09/91			HOODER14/08/91			BLITHE 13/08/91			LYMINGTON 20/01/92		
RIVPACS NO	1			2			3			4			6		
	D	'2*SE'	COMM	D	'2*SE'	COMM	D	'2*SE'	COMM	D	'2*SE'	COMM	D	'2*SE'	COMM
DACE JUVENILE										0.033	0	V			
ADULT										0.113	0	V			
TOTAL	X			X			X			0.063	0.001	V	X		
ROACH JUVENILE										0.012	.	IV LC			
ADULT										0.008	.	IV LC			
TOTAL	X			X			X			0.021	0.005	LC	X		
TROUT JUVENILE	0.088	0.008	V	0.036	0.012	V	0.001	.	LC ME	0.001	0	LC	0.035	0	V
ADULT	0.009	0	LC							0.001	.	LC	0.005	0	V
TOTAL	0.1	0.009	V	0.036	0.012	V	0.001	.	LC ME	0.002	0	LC	0.04	0	V
SALMON	0.172	0.008	V	0.089	0.06	V	0.056	.	ME IV	X			X		
SEA TROUT	X			X			0.001	.	LC ME	X			0.001	.	LC ME
RAINBOW TROUT	X			X			X			X			X		
GRAYLING	X			X			X			X			X		
CHUB	X			X			X			0.028	0.003	V	0.002	0	LC
GUDGEON	X		.	X			X			0.059	X	IV	X		
TENCH	X			X			X			Y			X		
BLEAK	X			X			X			Y			X		
BREAM	X			X			X			X			X		
PERCH	X			X			X			0.018	0.002	V	X		
PIKE	X			X			X			X			0.003	.	LC ME
EEL	0.002	.	LC ME	0.001	0	LC	Y			Y			0.106	0.043	V
FLOUNDER	X			X			X			X			X		
MINNOW	X			0.143	0.066	IV	Y			Y			0.074	0.019	V
LOACH	X			X			Y			Y			0.039	0.028	LC
BULLHEAD	X			X			Y			Y			3.967	0.361	V

LC = Low Catch ME= Minimum Density Estimate IV= Invalid Estimate EIV = Error Values may be Invalid Y=Species Present X=Species not present

Table G2 *Fish Population Estimates contd.*

	ESMS 1 8/08/91			ESMS 2 8/08/91			ESMS 3 8/08/91			ESMS TOTAL 8/08/91			LAMBOURNE 6/04/92		
RIVPACS NO.	7			7			7			7			8		
	D	'2*SE'	COMM	D	'2*SE'	COMM	D	'2*SE'	COMM	D	'2*SE'	COMM	D	'2*SE'	COMM
DACE JUVENILE	0.132	0	V	0.127	0.006	V	0.492	0.022	IV	0.25	0.022	V			
ADULT	.		LC	.			0.01	0	LC	0.004	.	LC			
TOTAL	0.132	0	V	0.127	0.006	V	0.504	0.022	IV	0.254	0.022	V	X		
ROACH JUVENILE				0.012	0	LC				0.004	.	LC			
ADULT				.						.					
TOTAL	X			0.012	0	LC	X			0.004	.	LC	X		
TROUT JUVENILE	0.042	0	V	0.002	.	LC	0.008	0	LC	0.017	0	V	0.016	0.004	V
ADULT	0.002		LC	0.005	.	LC	.			0.002	.	LC	0.047	0.001	V
TOTAL	0.043	0	V	0.007	0	LC	0.008	0	LC	0.019	0	V	0.062	0.002	V
SALMON	0.016	0	LC	0.005	.	LC ME	0.022	0.006	LC	0.014	.	LC	0.005		ME
SEA TROUT	X			X			X			X			X		
RAINBOW TROUT	X	.		X			X			X			0.005	.	LC ME
GRAYLING	0.029	0	LC	X			0.032	0.009	LC	0.02	0.009	LC	0.015	0.001	V
CHUB	X			X			X			X			X		
GUDGEON	0.061	0.01	V	0.094	0.031	V	0.289	0.101	V	0.148	0.138	V	X		
TENCH	X			X			X			X			X		
BLEAK	X			X			X			X			X		
BREAM	X			X			X			X			X		
PERCH	X			X			X			X			X		
PIKE	0.007	0	LC	X			X			0.002	.	LC	X		
EEL	0.122	0.008	V	0.101	0.016	V	0.117	0.015	V	0.113	0.023	V	Y		
FLOUNDER	0.024	0	LC	0.028	0.007	LC	0.036	0	LC	0.029	.	LC	X		
MINNOW	Y			Y			Y			Y			Y		
LOACH	Y			Y			Y			Y			Y		
BULLHEAD	Y			Y			Y			Y			Y		

LC = Low Catch ME= Minimum Density Estimate IV= Invalid Estimate EIV = Error Values may be Invalid Y=Species Present X=Species not present

Table G2 *Fish Population Estimates contd.*

	GWASH 17/01/92			OUSE 19/05/92			LEES BROOK 19/05/92		
RIVPACS NO.	9			10			10		
	D	"2*SE"	COMM	D	"2*SE"	COMM	D	"2*SE"	COMM
DACE JUVENILE	0.009	0	LC	Y					
ADULT				X					
TOTAL	0.009	0	LC	0.003	0.002	LC EIV	X		
ROACH JUVENILE				0.027		ME	0.116	0.103	EIV
ADULT				0.001		ME	0.013	0	
TOTAL	X			0.028		ME	0.114	0.061	EIV
TROUT JUVENILE	0.004	0	LC						
ADULT	0.045	0	V						
TOTAL	0.048	0	V	X			X		
SALMON	X			X			X		
SEA TROUT	X			X			X		
RAINBOW TROUT	X			X			X		
GRAYLING	0.004	0	LC	X			X		
CHUB	X			Y			0.019	0	LC
GUDGEON	0.002	-	LC	Y			X		
TENCH	X			Y			X		
BLEAK	X			0.031	-	ME	0.096	0.046	EIV
BREAM	X			Y			X		
PERCH	X			X			X		
PIKE	X			Y			0.01	0.004	EIV LC
EEL	0.077	0.032	V	Y			Y		
FLOUNDER	X			X			X		
MINNOW	Y			Y			X		
LOACH	Y			X			X		
BULLHEAD	Y			X			X		

LC = Low Catch ME= Minimum Density Estimate IV= Invalid Estimate EIV = Error Values may be Invalid Y=Species Present X=Species not present

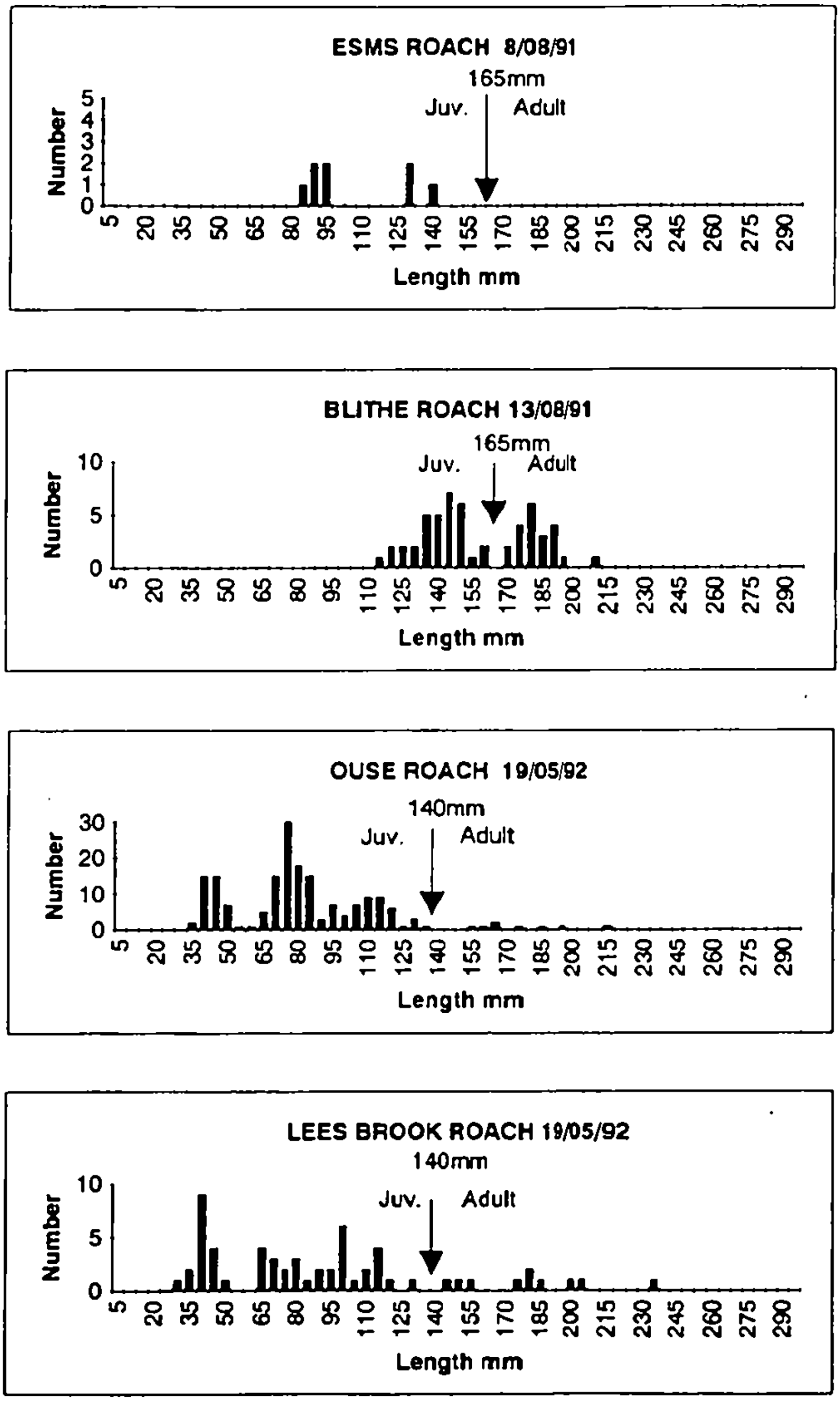


Figure G1 *Roach length frequency histogram*

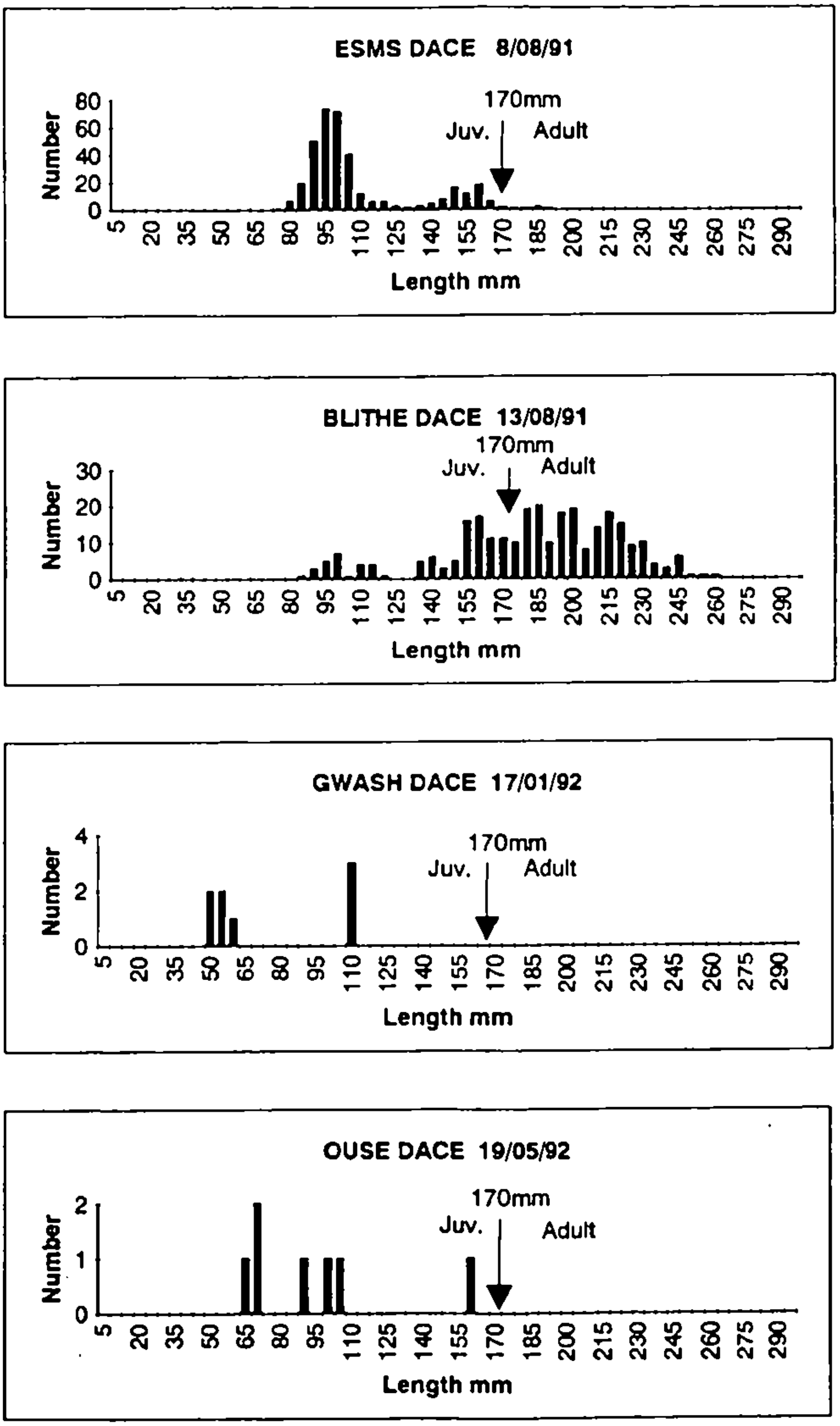


Figure G2 *Dace length frequency histogram*

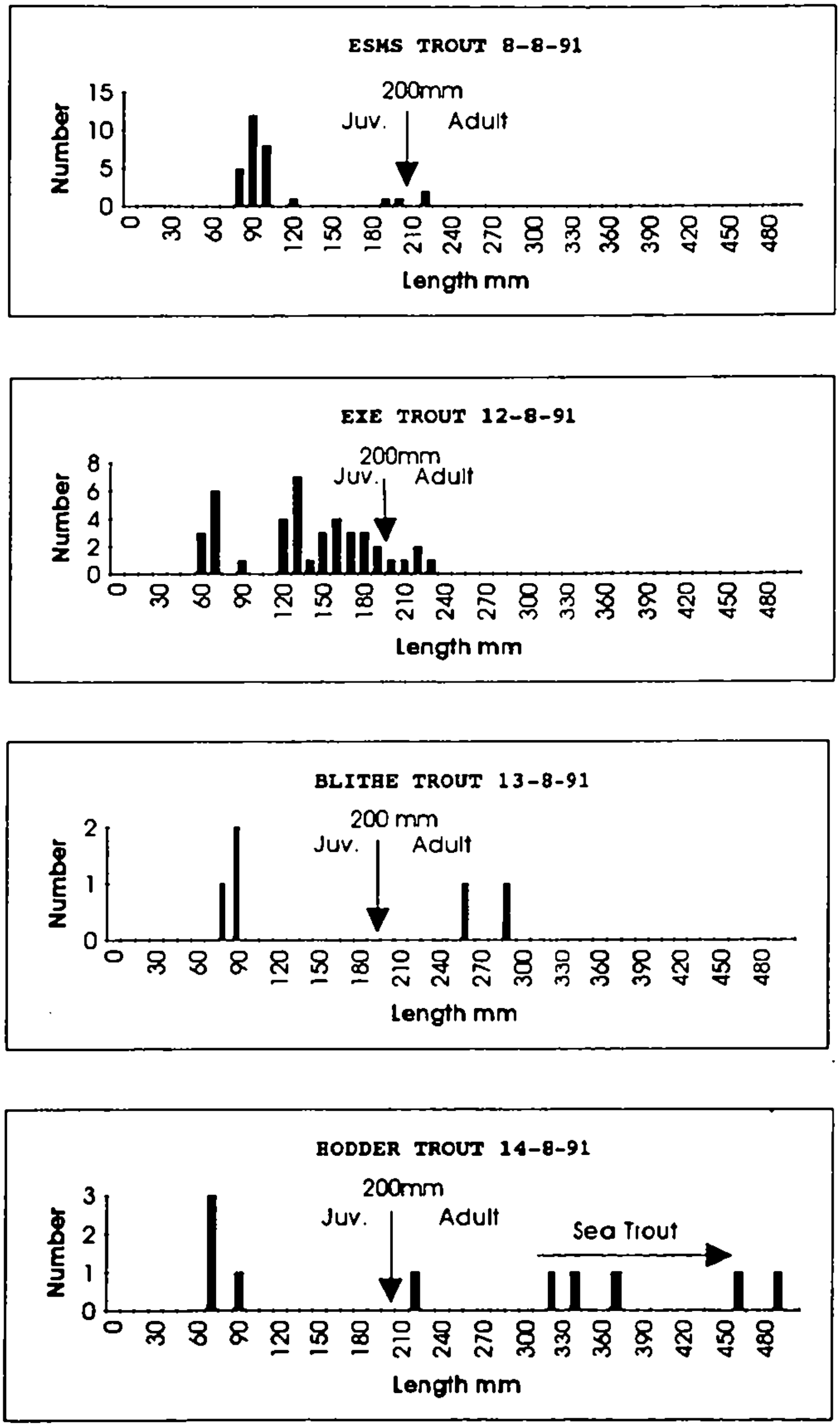
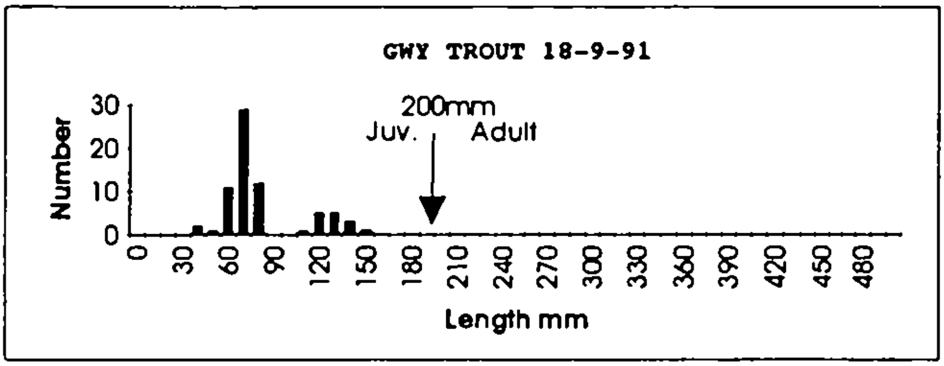
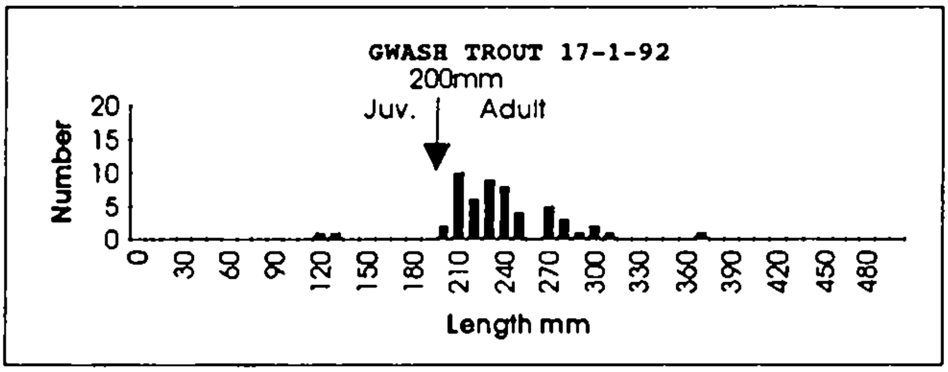
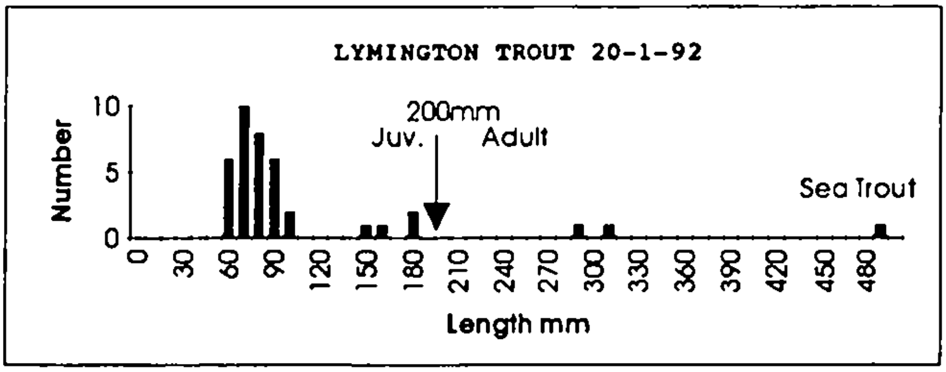


Figure G3 *Trout Length frequency histogram*







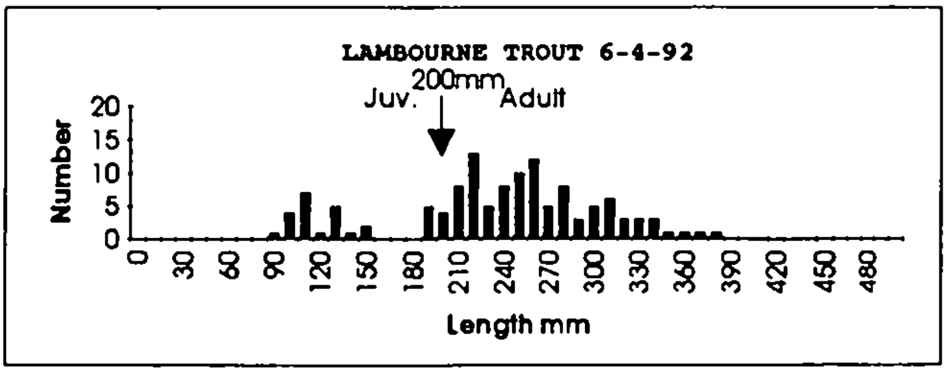


Figure G3 *Trout Length frequency histogram contd.*

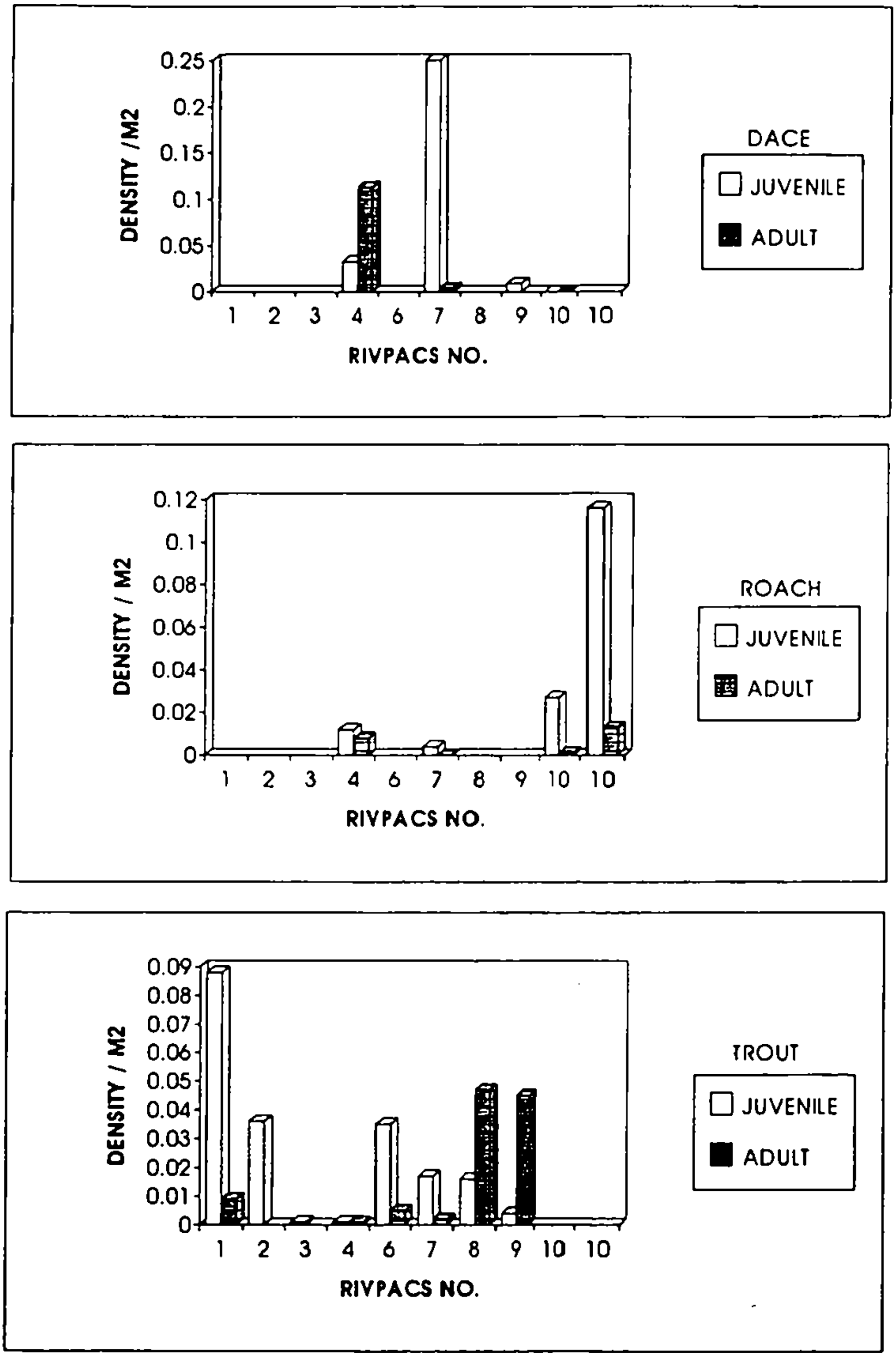


Figure G4 Densities of target fish species

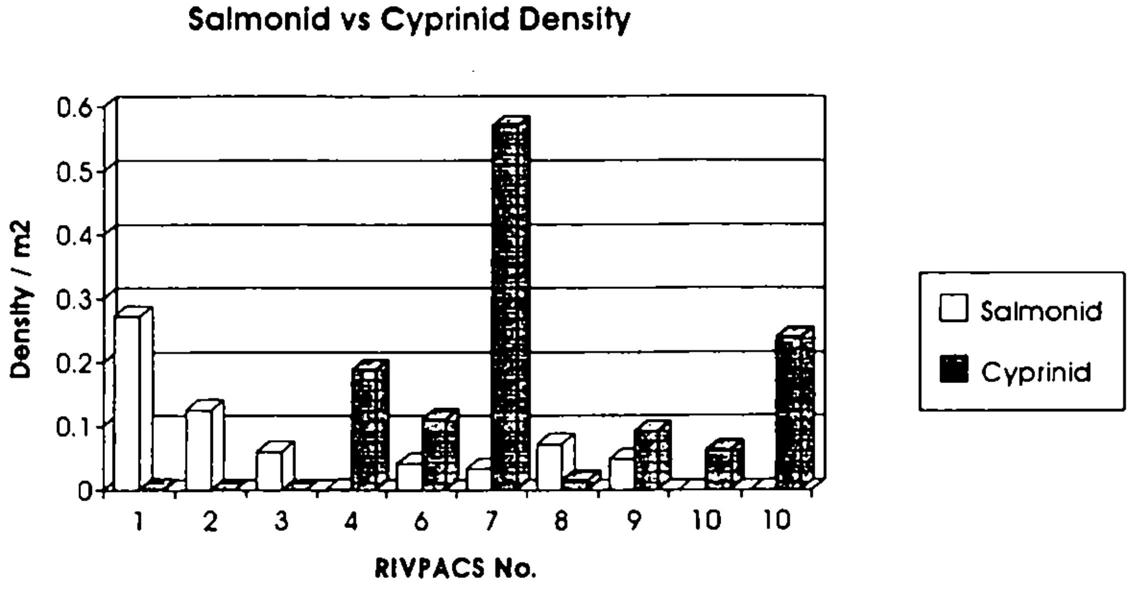


Figure G5 *Salmonid vs Cyprinid densities*

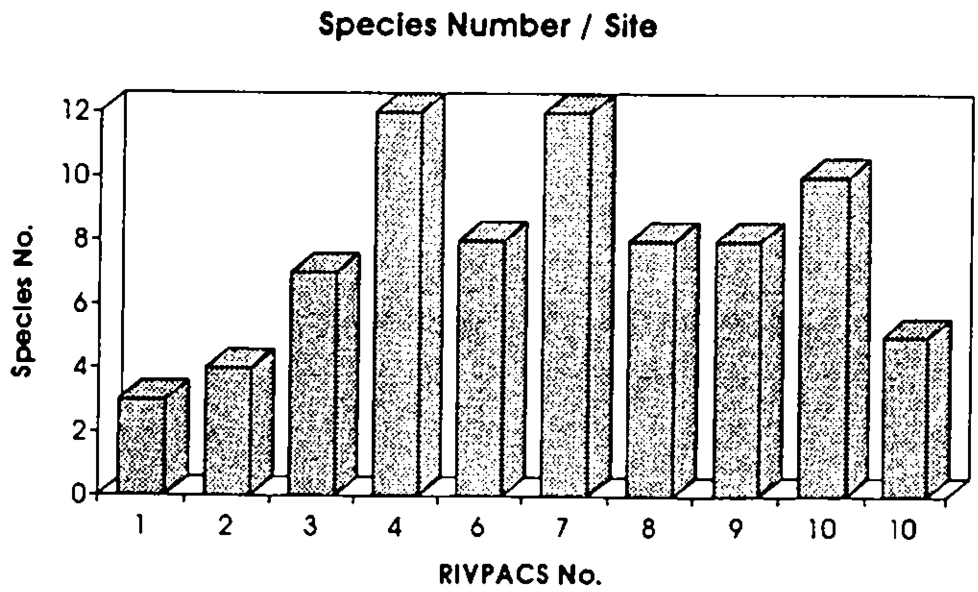


Figure G6 *Number of fish species per site*