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Natural Environment Research Council

National Rivers Authority Project
B2.1 Ecologically Acceptable Flows

INCEPTION REPORT

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Ecologically Acceptable Flows
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Executive Summary

The present high commitment of the NRA to resolving the problem of unacceptable low river flows make it imperative that an objective method of assessing ecological impacts of abstraction and setting ecologically acceptable flows is developed as a matter of high priority. The chief aim of this project is to provide the framework for an objective method based on the recognition of ecologically acceptable flows apposite to the particular seasonal requirements of aquatic species.

Since 1974 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 has permitted the negotiation and setting of flow regimes optimal for ecological management, paying specific regard to the physical habitat requirements of selected target species.

Essentially, IFIM provides an estimate of habitat loss/gain with changes in discharge. IFIM is a concept which is based on the fundamental assumption that aquatic species exhibit a describable and quantifiable preference for one or more of the physical habitat variables; velocity, depth, channel substrate and cover. Preferences for each variable by a species is represented by an index of suitability which may take the from of a binary function or univariate curve. A major component of IFIM is the Physical HABitat SIMulation (PHABSIM) system, a suite of computer programs which combines simulated values of velocity and depth in a channel reach with the habitat suitability indices (preference curves). Simulation of the physical variables is achieved by using one of the three hydraulic simulation routines available within PHABSIM. Calibration of the hydraulic model is on a transect defined cell-by-cell basis requiring field observation of channel cross-sectional profiles, water surface elevation, mean column velocity and application of appropriate substrate and cover classification schemes. Cell values of each of the physical variables predicted by the calibrated hydraulic model are combined with preference curve information for a given species and life stage. This is achieved by using a selected functional relationship to weight the total usable available habitat by its suitability for the specific species life-stage. Simulations over a range of discharges generate a Weighted Usable Area against discharge relationship. Optimal discharges for specific species life-stages may be identified from these habitat versus flow relationships providing an estimate of habitat loss/gain with changes in discharge.

A preliminary assessment of the application of PHABSIM to UK rivers has already been explored by IH as a suitable technique for achieving the objectives of this project. PHABSIM potentially offers a readily available basis for the generation of hydrological models which incorporate the essential features of ecological protective flows in order to define the primary objectives of environmental protection. Assessment of the suitability of PHABSIM in UK conditions requires further extensive trials to assess the range of rivers and resource problems which are appropriate for application of the model.

Criticisms of IFIM have been focussed on the fact that it predicts available

physical habitat rather than biomass. The relationship between habitat and biomass is complex and may vary between different locations - in some instances variables such as water quality or temperature which are not modelled within PHABSIM may have a limiting effect on biomass hence it is important to consider each application of the IFIM separately and pay cognisance to other possible influences on the relationship between biomass of aquatic species and discharge. At present no model is available which can provide predictive biomass versus discharge relationships and PHABSIM is the only model available which can predict habitat versus discharge relationships. In the setting of ecologically acceptable flows PHABSIM should be viewed as a potentially very useful tool but it must equally be recognised that in a particular situation the effects of other factors not accounted for in the PHABSIM model must also be considered.

In order to best facilitate communication with end users not familiar with using computer models the language used in the final report from the project should reflect this level of scientific knowledge and should be user orientated.

1. INTRODUCTION

1.1 Historical background

One recent development of water resources management in the United Kingdom is the use of computer models which relate the requirements of freshwater ecology to low river flows. A multidisciplinary team funded by the Department of the Environment and headed by the Institute of Hydrology, involving the Institute of Freshwater Ecology, Institute of Terrestrial Ecology and Loughborough University (Petts, 1990) has gained experience in the use of one such technique, the Instream Flow Incremental Methodology (IFIM).

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 tradeoffs 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.

Water management in the United Kingdom has historically adhered to discharge-based methods in the setting of prescribed flows, being set according to the Dry Weather Flow. The Dry Weather Flow is itself an undefined discharge, but which is indexed by a low flow discharge, typically either the 95 percentile flow duration statistic, or the mean annual minmum seven day flow frequency statistic. It is only a recent phenomenon in the United Kingdom that cognisance 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 and uses (Drake and Sherriff, 1987). Thus the 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, which will determine 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 and 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.

However, while quantitative models and design techniques are available for estimating discharge statistics in rivers, for example Low Flow Studies (Institute of Hydrology 1980), 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 - Wales 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 appropriate management models for recommending flow regime measures which consider ecological demands. In the United States procedures for evaluating impacts of streamflow changes were first developed and 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 optimal flows for ecological management. Setting instream flows in this manner complements purely water-quantity or cost-management objectives by paying cognisance to the physical habitat requirements.

In the period since 1960 within the United States the importance of instream flows has 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 Doersken (1987) in

Table 1.1 illustrates that IFIM is now the most widely applied method for determining instream flow requirements for major resource schemes in the United 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 basinwide planning purposes.

Table 1.1 Methods for determining instream flow requirements in the United States and number of States using method

METHOD	NUMBER OF STATES USING METHOD
Instream Flow Incremental Methodology (IFIM)	38
Tennant method	16
Wetted perimeter	6
Aquatic Base Flow	5
7-Day, 10-Year Low Flow (7Q10)	5
Professional judgement	4
Single Cross-Section (R-2 CROSS)	3
USGS Toe-Width	2
Flow records/duration	2
Water quality	2
Average Depth Predictor (AVDEPTH)	1
Arkansas	1
Habitat quality index	1
Oregon fish-flow	1
US Army Corps of Engineers	1
Hydraulic Modelling (HEC-2)	1

Source: Lamb and Doersken (1987)

The essence of the Instream Flow Incremental Methodology is concisely stated by Bartholow 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 decisionmakers 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 decisionmakers 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 Methodolgy

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 change, and quantifies this in respect of the ecological value of those habitat loss/gains

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 essentially to question whether physical habiat 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.

2. IFIM RATIONALE AND PHABSIM DATA REQUIREMENTS

2.1 IFIM rationale and concepts

The IFIM procedure provides an estimate of habitat loss/gain with changes in discharge. 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

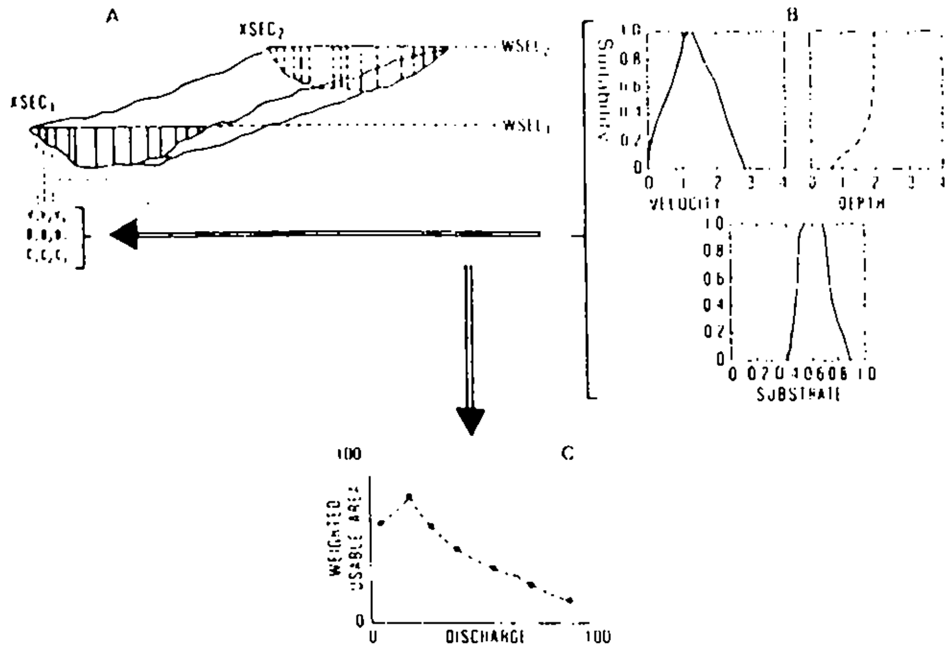
- individuals select the most preferred conditions within a stream, but will use less favorable areas with decreasing frequency/preference

- 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. 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 2.1. 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.



A schematic representation of the IFIM process. Velocity (V), depth (D), and cover/substrate (C) values from various cross sections (XSEC) are combined with water surface elevations (WSEL) at a steady discharge to drive the hydraulic model (steady or dynamic flow) which provides stage discharge information to PHABSIM [A]. The habitat suitability information [B] is linked to the simulation of cell-by-cell hydraulics to predict (via HABITAT) the amount of weighted usable area at any proposed discharge [C].

Source: Gore and Nestler (1988)

Figure 2.1 PHABSIM scientific rationale

sampling.

Calibration of the hydraulic model components is achieved on a transect-defined cell-by-cell basis requiring field observation of channel bed cross-sectional profiles, water surface elevation, mean column velocity, and application of substrate and cover classification schemes. Cells are defined as the boundaries of the data represented by a single survey point, and are most commonly defined in the cross-channel directions as the mid-point between survey points, and in the downstream direction by the inter-transect midpoint.

Observations of these data at calibration flows are necessary to create the dataset from which the depth and velocity within cells is simulated at different discharges using the hydraulic programs. Observed channel index values are assumed to be independent of flow.

Cell values of each of the physical parameters are combined with species preference curve information through a selected functional relationship, termed the Composite Suitability Index (CSI), to develop the composite habitat index, termed weighted usable area. Typical CSI functional relationships are multiplicative, but any alternative can be devised. Weighted usable area, indexed by total surface area of the cell weighted by its relative suitability for a given species, simulates the amount of physical habitat within that cell at different discharges.

Summation of individual cell values within the river reach of interest can be achieved either by a representative reach approach or by habitat mapping and selective identification of field sites. In the representative reach approach, individual transects are assigned a weighting which represents a fraction of the distance to the next-downstream transect, according to the distance to the change in habitat type. In the habitat mapping approach, transects are assigned a distance weighting according to the frequency of occurrence of that habitat which the transect represents within the study river as a whole.

Once achieved, output comprises a graphical weighted usable area against discharge function for the particular target species under study. Optimal discharges for specific species can be identified from the WUA-discharge functions, but must be considered in the context of water availability, water management constraints and ecological objectives.

2.2 HYDRAULIC AND HABITAT DATA REQUIREMENTS OF PHABSIM

The Physical HABitat SIMulation (PHABSIM) system comprises a large number of separate programs which fall into two main categories; hydraulic simulation and habitat simulation. The hydraulic simulation programs when calibrated with observed field data, are used to simulate depths and velocities at different discharges selected by the user at transects along a reach of river. To calibrate the hydraulic programs it is necessary to survey the bed profile of the river reach on a transect basis, to measure the distances between transects, and to observe water surface elevation and velocity on a cell-by-cell basis across each transect at a range of different flows. The flows at which the water surface elevation and velocities are measured are termed calibration flows. The discharge for each calibration flow (Q_{CAL}) must be calculated from the observed data. The flows selected by the user when running PHABSIM are termed simulation discharges, (Q_{SIM}).

There are three basic hydraulic simulation programs; IFG4, MANSQ and WSP. For the simulation discharges, IFG4 predicts the water surface elevation using a simple stage/discharge relationship and predicts velocities on a cell-by-cell basis using Mannings n and a simple mass balance adjustment. In IFG4 and MANSQ each transect is modelled independently. When IFG4 fails to sensibly predict water surface elevations due to the poor calibration of the stage-discharge relationship then water surface elevations can be predicted by MANSQ using the solution of Mannings equation. WSP is a standard stepbackwater model for the prediction of water surface elevations which considers transects as dependent and uses an energy balance model to project water levels from one known stage/discharge relationship to all transects upstream. Neither MANSQ nor WSP can predict velocities so once a sensible downstream water surface elevation profile has been predicted for the simulation discharges, then IFG4 is used to predict velocities.

The output from the hydraulic simulation programs is predictions of depth and velocity for each cell for each simulation discharge. Cell values of the channel index (cover or substrate) remain independent of discharge.

Table 2.1 Minimum data requirements of PHABSIM

HYDRAULIC PROGRAMS

IFG4

1. Survey of x,y coordinates of the bed elevation (maximum of 100 data points) for channel cross-section transects. The x,y coordinates represent the horizontal distance and the elevation difference respectively from the headpin representing the start of the transects. These are converted by PHABSIM to a cross-sectional profile of channel bed elevations (BE). Substrate code or cover code value for each surveyed point. The transect which represents the downstream end of the study reach should be located at a hydraulic control, upstream of which there is a unique stage-discharge relationship.

2. Measurement of inter-transect distances and assigned upstream weighting factor

3. A minimum of 3 calibration flows at which water surface elevation and discharge through the transects are measured. The measurement of velocity at each survey point across the transect is essential during at least one calibration flow, preferably the highest of the three discharges. The three calibration flows should sample flows with differences of an order of magnitude. Data from a maximum of 9 calibration flows can be accepted.

MANSQ

1. As (1) above

2. As (2) above

3. Minimum of one calibration discharge and water surface elevation

WSP

1. As (1) above

2. As (2) above

3. Minimum of one calibration discharge at all transects and a minimum of three calibration flows at the transect furthest downstream

continued.....

Table 2.1 continued

ECOLOGICAL PROGRAMS
HABTAT 1. Set of suitability index curves for one or more of the following: depth velocity substrate cover 2. Set of hydraulic information describing the depth and velocity characteristics for each cell as a function of flow derived from the hydraulic programs.

The second category is the suite of programs for the simulation of physical habitat space. The input to this suite of programs are habitat suitability curves, which quantify the relative preference of a selected life stage of a target species for depth, velocity and channel index independently. Preference ranges from 0 to 1, with 1 being optimal and 0 being the most unsuitable. The programs, of which the principal is HABTAT, combine the habitat preference values for depth, velocity and channel index for life stages of target species with the predictions of the physical variables from the hydraulic simulations.

The minimum data requirements for the three hydraulic simulation routines and HABTAT are summarised in Table 2.1.

2.3 THEORY OF HYDRAULIC SIMULATION ROUTINES

2.3.1 IFG4

IFG4 simulates water surface levels and predicts velocities for any simulation discharges selected by the user, treating each cross-section independently. Water surface elevations are simulated by a stage-discharge relationship from which water depths in each cell and cell widths are calculated. Velocities are predicted by solving Mannings equation. A velocity adjustment factor is used to ensure that the discharges calculated from the predicted values of depth, width and velocity equal the simulation discharge. Because IFG4 uses a constant Mannings n at any simulation discharge, the theoretical relationship of decreasing n with increasing discharge at a point is contravened. Instead, IFG4 uses a variable velocity adjustment factor to account for variable Mannings n. The IFG4 routine is explained in more detail below.

DEPTH PREDICTION

A stage/discharge relationship is calculated from the water surface elevation and discharge data measured at the three or more calibration discharges. The stage/discharge relationship allows water surface elevations to be predicted at any simulation discharge.

Once the water surface elevation has been predicted for a simulation discharge then the depths for all cells across the transect are calculated as the difference between the predicted water surface elevation and the surveyed channel bed elevation. This is illustrated in Figure 2.2 where for a single cell

$$\hat{d}_i = \hat{WSL} - BE_i$$

where $\hat{d}_i$ = predicted depth at point i
$\hat{WSL}$ = predicted water surface elevation
BE_i = bed elevation

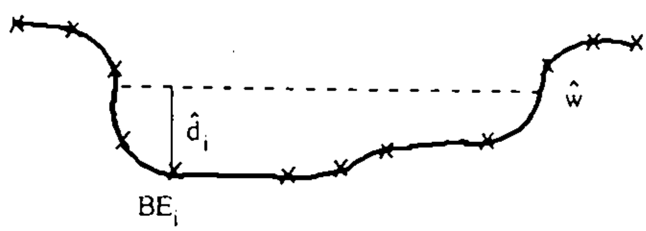


Figure 2.2 Prediction of water depth using IFG4

VELOCITY PREDICTION - ASSUMING CONSTANT MANNINGS N

To enable predictions of velocities at simulation flows to be made, data from one of the calibration flows are used to derive the value of Mannings n. If velocities have been measured at more than one calibration flow, then the user is free to select any one of the flows. Given a choice, it is preferable to select the highest calibration flow because more cells in the transect are likely to contain water. The parameters v_i, d_i and S are known (Figure 2.3), where

v_i = measured mean column velocity at vertical i
S = measured average slope through transect
d_i = WSL - BE_i, where WSL is the measured water surface elevation

allowing the solution of n_i where

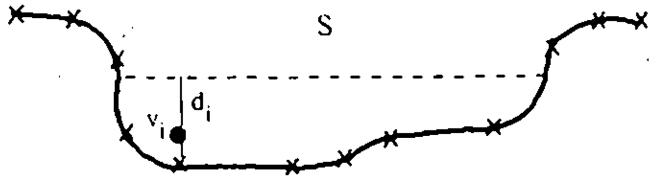


Figure 2.3 Calibration data necessary for velocity predictions in IFG4

$$n_i = \frac{1.49}{v_i} d_i^{2/3} S^{1/2}$$

It should be noted that the calculated values of n are not constrained to equal published n values (for example Gregory and Walling, 1973) for the streambed types in the river reach when predicting velocity distributions, because n is being used in IFG4 as a velocity calibration coefficient rather than an index of energy dissipation. It would, however, give added confidence to the modeller if calculated n values were found to be close to typical n values for the river type being modelled.

$$\hat{v}_i = \frac{1.49}{n_i} \hat{d}_i^{2/3} S^{1/2}$$

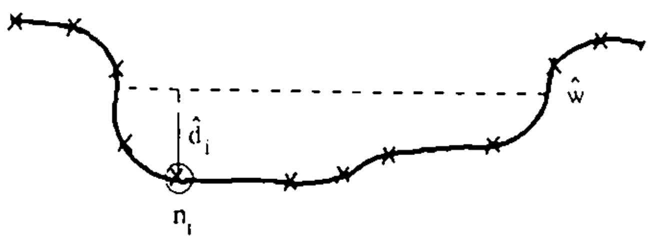


Figure 2.4 Prediction of velocity distributions at simulation discharges in IFG4

For the prediction of velocity in cells at simulation flows $\hat{v}_i$ is predicted using predicted depth, $\hat{d}_i$, calculated n_i and constant S (Figure 2.4) as follows

VELOCITY ADJUSTMENT FACTOR

Once $\hat{v}$ has been predicted then a velocity adjustment factor based on a simple mass balance is applied to ensure that the sum of the discharges calculated at all cells from the predicted values of n, $\hat{d}$ and $\hat{v}$ equals the simulation discharge initially selected by the user. Because in general terms discharge, Q, equals velocity times cross-sectional area, so for each cell the predicted discharge, $\hat{q}_i$, is calculated from

$$\hat{q}_i = \left[\hat{width}_i \times \hat{d}_i\right] \hat{v}_i$$

where $\hat{width}_i$ is the predicted width of the $cell_i$.

The predicted discharge through the whole transect, $\hat{Q}$, is the sum of all the individual cell discharges

$$\hat{Q} = \Sigma\hat{q}_{i...z}$$

$\hat{Q}$ must equal Q_{SIM}, but may not when calculated as the sum of $\hat{q}_i...\hat{q}_z$ because of errors introduced by poor predictions of water surface elevations, water depth, cell widths or velocities within one, some or all of the cells. IFG4 uses a velocity adjustment factor, VAF, where

$$VAF = \frac{Q_{SIM}}{\hat{Q}}$$

to ensure that $\hat{Q} = Q_{SIM}$.

The VAF adjusts the predicted velocity in each cell, $\hat{v}_i$, such that

$$\hat{v}_i' = \hat{v}_i \times VAF$$

thereby ensuring that

$$\left[\hat{width}_i \times \hat{d}_i\right] \hat{v}_i' = \hat{Q} = Q_{SIM}.$$

It must be recognised that it is the predicted velocities alone which are adjusted and not predicted depths or predicted cell widths. However, poor measurement of water surface elevations at the calibration flows and subsequently prediction of erroneous water depth by an incorrect stage/discharge relationship can introduce a major source of error into IFG4 simulations, which can be partly overcome by ensuring that the calibration flows represent wide stage/discharge relationship.

VELOCITY PREDICTION - VARIABLE MANNINGS N

So far Mannings n has been assumed to be constant and independent of discharge. In reality Mannings n at a point would be expected to decrease with increasing discharge, the relationship having form displayed in Figure 2.5.

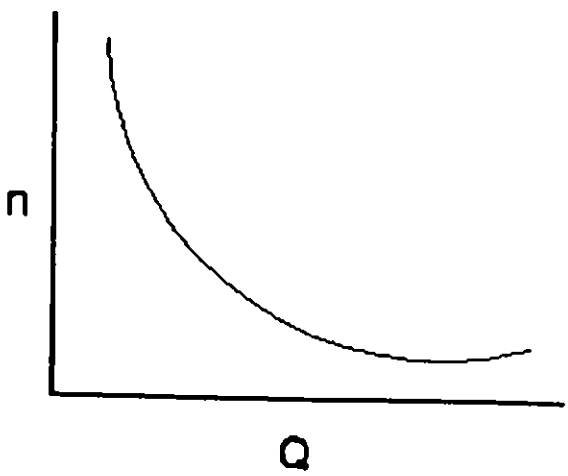


Figure 2.5 Relationship of Mannings n with discharge at a point

To model variable Mannings n it is a condition of IFG4 that the VAF must vary with the simulated discharges and conform to the form shown in Figure 2.6, thereby mirroring the n/Q relationship. In the relationship between the VAF and simulated discharges the VAF equals one at the calibration discharge used to set the value of Mannings n (Q_{CAL}), and is < 1 for Q_{SIM} less than Q_{CAL} and > 1 for Q_{SIM} greater than Q_{CAL}. The decrease in VAF for discharges lower than that used to set Mannings n is the IFG4 solution to modelling the theoretically expected increase in Mannings n as discharge decreases. Typical values of the VAF range from 0.2 up to 2.5 - 3.0. The modeller must check that the VAF:Q_{SIM} relationship is conforming to this shape if variable Mannings n is to be adequately modelled.

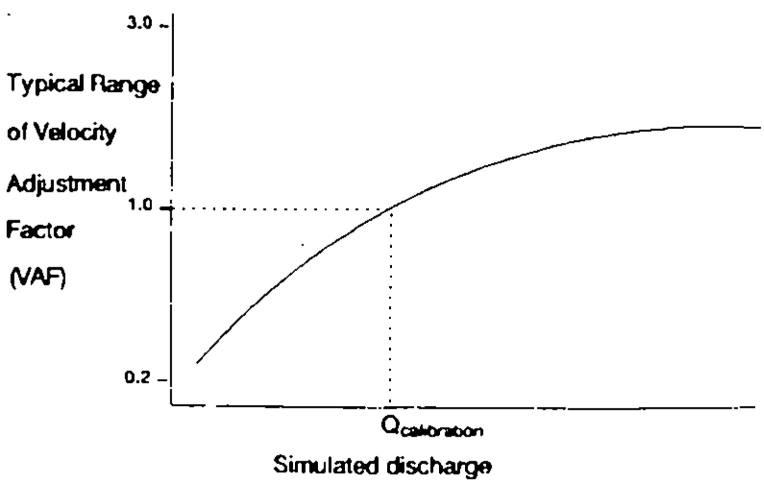


Figure 2.6 Relationship of the Velocity Adjustment Factor with discharge necessary to model variable Mannings n.

2.3.2 MANSQ

MANSQ simulates water surface elevations only, treats each cross-section independently, and fails under conditions of backwater effects. MANSQ should be used to feed predicted water surface elevations into an IFG4-format data set when IFG4 fails because of internally poor rating equations.

MANSQ uses Mannings equation for predicting velocity, in which the terms n and S are considered as a conveyance factor, CF. The term CF is calibrated by solving Mannings equation using data from one calibration data set. The calibration of CF leaves the cross-sectional area and wetted perimeter known as a combined term but not known individually. At a simulation discharge, the individual values of A and R are solved by iterative calculation and comparison with their respective values in the calibration data set. Once A and R are known then the water surface elevation can be calculated from the channel bed profile.

Variable Mannings n with discharge is dealt with in MANSQ by varying CF. The relationship between CF and discharge is established by regression using three calibration data sets, from which the exponent, the Beta coefficient, is used. When only one set of calibration observations are available, then the value of the Beta coefficient should be based on empirical judgement of the channel bed material. The MANSQ routine is explained in more detail below.

The Mannings equation (in imperial units) for predicting velocity is given by

$$v = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where v = velocity (ft/s)
n = Mannings n
R = hydraulic radius
S = slope of energy gradient (ft/ft)

and R = A/WP

where A = cross-sectional area (ft^2)
WP = wetted perimeter (ft)

Because Q = vA, so substituting Mannings equation

$$Q = \frac{1.49}{n} S^{1/2} R^{2/3} A$$

When it is assumed that S and n are independent of Q and are constant the term

$$\left[\frac{1.49}{n} S^{1/2}\right]$$

can be considered as a conveyance factor, CF, such that

$$Q = CF\ R^{2/3}\ A$$

One set of calibration data is used to define the value of CF as explained in the following section. Later it is shown that CF is variable and 3 sets of calibration data are used to account for this.

CALIBRATION OF A CONSTANT CONVEYANCE FACTOR

For any one calibration discharge Q_{CAL}, then the discharge Q, the water surface elevation WSL, and the x,BE coordinates of the channel bed profile are known. From these data the value of A can be derived and the value of R is calculated as follows

$$WP = \sqrt{(\Delta x^2) + (\Delta BE^2)}$$

$$\text{and } R = \frac{A}{WP}$$

Then, the constant conveyance factor, CF, is calculated from

$$CF = \frac{Q_{CAL}}{AR^{2/3}}$$

DERIVATION OF WATER SURFACE ELEVATIONS FOR SIMULATION DISCHARGES

In the general equation

$$\frac{Q_{SIM}}{CF} = A\ R^{2/3}$$

the term $AR^{2/3}$ is known as a term but the terms A and R are not known individually. The derivation of the water surface elevation, w· for Q_{SIM} is achieved by iterative calculation of the values of A and R. In doing so the first step is to assume an arbitrary water surface elevation, WSL, and calculate an arbitrary A and R, termed $\hat{A}$ and $\hat{R}$, and thence $\hat{A}\hat{R}^{2/3}$. Calculate the corresponding $\hat{Q}_{SIM}$ and compare to Q_{SIM}. If $\hat{Q}_{SIM}$ is greater than Q_{SIM} then $\hat{WSL}$ should be decreased, or $\hat{WSL}$ increased if $\hat{Q}_{SIM}$ is less than Q_{SIM} until the unique solution of $\hat{WSL}$ is found where $\hat{Q}_{SIM} = Q_{SIM}$.

CALIBRATION OF A VARIABLE CONVEYANCE FACTOR

Up to now MANSQ has assumed n and S to be constant, and therefore that CF is independent of discharge. However, whilst MANSQ continues to assume that S is independent of discharge, variations of n with Q (of the form shown in Figure 2.5) are accommodated by the Beta coefficient from a regression of CF against Q based on several calibration discharges. This is achieved as follows.

As shown in Fig. 2.5, $n = \alpha Q^{\beta}$. Because CF = f(n,S), so providing S is assumed to be a constant then $CF = aQ^{b}$

By employing a data set with at least 3 calibration flows, for which $CF_{CAL1,2,3}$ and $Q_{CAL1,2,3}$ are known, then the Beta coefficient b can be derived by regression. For any simulation discharge, the value of the CF can be calculated from

$$CF_{SIM} = aQ^{b}_{SIM}$$

MANSQ calculates and expresses the value of the CF to be used at a simulation discharge (CF_{SIM}) as a ratio to the constant CF derived from the single calibration data set (i.e. CF_{CAL}) as follows

$$\frac{CF_{SIM}}{CF_{CAL}} = \frac{aQ^{b}_{SIM}}{aQ^{b}_{CAL}} = \left[\frac{Q_{SIM}}{Q_{CAL}}\right]^{b}$$

so

$$CF_{SIM} = CF_{CAL}\left[\frac{Q_{SIM}}{Q_{CAL}}\right]^{b}$$

CF_{SIM} can be calculated for any discharge and replaces the constant CF during the calculation of A and R in the iterative calculation of water surface elevation.

If only one set of calibration observations are available, such that the Beta coefficient cannot be calculated by regression then an estimated b value of 0.1 to 0.3 should be input, based on empirical judgement of the bed material. Generally, the larger the bed material then the larger the value of b. b is positive and typically exhibits an empirical range from 0.1 to 0.5, with a mean value of 0.22 (Milhous R., Pers. comm.).

2.3.3 WSP

WSP differs from both IFG4 and MANSQ which treat transects independently because WSP is specifically designed to consider backwaters and achieves this by considering water surface elevations at transects as dependent. In the same way as MANSQ, WSP is concerned only with the prediction of WSLs, which are then fed into an IFG4-format data set for velocity prediction. WSP is used where MANSQ fails due to the breakdown of the CF relationship with discharge caused by backwater effects.

A simple energy balance model through a channel reach takes the form

$$\begin{bmatrix}\text{ENERGY FLUX}\\ \text{INTO THE}\\ \text{CONTROL VOLUME}\end{bmatrix} - \begin{bmatrix}\text{ENERGY FLUX}\\ \text{OUT OF THE}\\ \text{CONTROL VOLUME}\end{bmatrix} + \begin{bmatrix}\text{TIME RATE OF}\\ \text{ENERGY CHANGE}\\ \text{WITHIN THE}\\ \text{CONTROL VOLUME}\end{bmatrix} = 0$$

Energy (E) at a point in a channel is the sum of the internal, kinetic and potential energies:

$$E = U + \frac{V^2}{2} + gBE$$

where U = internal energy due to fluid temperature

V = velocity of the fluid

g = gravitational acceleration

BE = Bed elevation above reference level

Dividing through by g, then

$$E = \frac{P}{\gamma} + \frac{V^2}{2g} + BE$$

where P = Fluid pressure

γ = Specific weight of fluid

The energy balance model can then be written as

$$\left[\frac{P_1}{\gamma} + \frac{V_1^{\,2}}{2g} + BE_1\right] - \left[\frac{P_2}{\gamma} + \frac{V_2^{\,2}}{2g} + BE_2\right] + \left[H_L\right] = 0$$

where H_L = head loss, caused by the dissipation of energy to heat generation through the channel section.

Because pressure is specific weight times depth so

$$\frac{P}{\gamma} = \text{DEPTH.}$$

The energy balance simplifies to

$$\frac{V_1^{\,2}}{2g} + BE_1 + d_1 = \frac{V_2^{\,2}}{2g} + BE_2 + d_2 + H_L$$

Employing this energy balance model as illustrated in Figure 2.7, then the head loss h_L between the two transects (A,B)

$$h_L = E_B - E_A$$

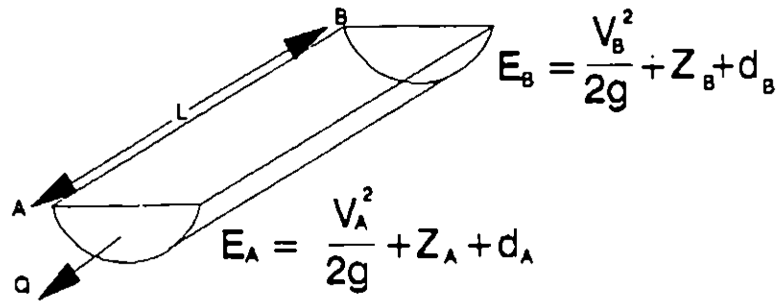


Figure 2.7 Energy balance model as the basis of WSP

The basis of WSP is the calibration of the head loss between transects, which is turned around to project changes in head, and hence water surface elevations, to upstream transects.

The solution of WSP is based on two definitions of the slope of the energy grade line, S:

DEFINITION 1

$$S_1 = \frac{h_L}{L}$$

DEFINITION 2 Mannings equation can be solved for S such that

$$S_2 = \frac{n^2\ Q^2}{2.22\ R^{4/3}\ A^2}$$

in which the only unknown is Mannings n.

WSP projects the water surface elevation upstream from A to B to solve S_2 for the stretch A to B. To do so requires a starting value of Mannings n (initially an estimate), which is optimised iteratively until

$$S_1 = S_2$$

In the projection procedure, the projected water surface elevation at B may not be equal to that measured in the field due to an incorrect n, so the iterative optimisation adjusts n to achieve agreement. If the projected level is less than the observed level then Mannings n should be increased. Alternatively, if the projected level is greater than the observed level then Mannings n should be decreased.

Widely varying values of n should not be set at different transects, unless there is a strong physical justification for doing so. Rather, a constant n value should be used throughout a reach, essentially minimising the errors in under- or over-predicting water surface elevation at individual transects, similar to fitting a least squares regression line.

When projecting water surface elevations upstream it is necessary to know the stage/discharge relationship at the transect furthest downstream. A water surface elevation is calculated at this transect for the simulation discharge and the solution of S_1 allows the projection of water levels upstream to all other transects.

Again, it must be recognised that so far n has been assumed to be independent of discharge. Variable Mannings n is dealt with in WSP by roughness multipliers. Roughness multipliers are the values by which n must be modifed, and themselves vary with discharge. The values for a simulation discharge are derived by solving Mannings n for a range of calibration discharges, and identifying the ratio of n for the lower discharges to n for the highest discharge. This ratio is the roughness multipler, and when plotted against discharge allows the fitting of a best-fit relationship, thereby enabling the derivation of the multiplier for any simulation discharge. Roughness multipliers are greater than 1.0 for flows lower than the highest calibration discharge, and it is ideally the highest calibration discharges which should be used to solve S_2.

2.3.4 Mixed models

Since none of the hydraulic simulation routines can describe all possible channel conditions it is often necessary to use more than one model to simulate water surface elevations at all discharges at each cross section. The mixed model approach uses different hydraulic simulation models for the ranges of flow where each hydraulic model produces the best simulation results for that transect. "Best" simulation results can be judged on the shape of VAF curves, on checking that water surface slopes are not negative (i.e. that water levels do not increase in a downstream direction), that in IFG4 the exponent of the stage-discharge relationship is between 1.5 and 3 and that the mean error of the Q against stage regression is low, and preferably less than 5%.

2.4 MICROHABITAT SUITABILITY CRITERIA

IFIM is based on the assumption that species exhibit discrete and quantifiable preferences for a range of velocities, depths and cover/substrate characteristics.

A requisite input into the HABTAT component of PHABSIM is the numerical representation of the suitability of the physical variables for the specific species being studied. The basic form for the expression of suitability is a habitat suitability curve, or other categories of curve called utilization curves or preference curves. The distinction between the criteria is the base from which the curves are founded. Essentially, there are three categories (Bovee, 1986):

Category I: the habitat criteria are derived from life history studies in the literature or from professional experience and judgement, and are based on the adjudged suitability of physical habitat variables for target life stages.

Category II: the habitat criteria are based on frequency analysis of microhabitat conditions utilised by different life stages and species as identified by field observations. These criteria are termed "utilisation curves" because they depict the conditions that were being used when the species were observed. Utilisation functions may not always accurately describe a species' preference because the preferred physical conditions may be absent or limited at the time of observation.

Category III: these are Category II curves in which the criteria are corrected for the bias by factoring out the influence of limited habitat availability. This correction is aimed at increasing the transferability of the criteria to streams that differ from those where the criteria were originally developed, or in the same stream at different flows.

A subsequent category, Category IV, has since been added which are conditional curves, essentially Category III curves conditioned for variable factors such as cover and season.

There are three principal formats in which the microhabitat criteria (i.e. the suitability/utilisation/preference for depth, velocity and cover/substrate) can be expressed; binary criteria, univariate curves, or multivariate response surfaces, as depicted in Figure 2.8.

The binary format establishes a suitable range of conditions for each variable as it pertains to a life stage of a species; within that range the suitability rating is 1.00, beyond it the rating is 0.00. Univariate curves developed from the concept that within the range of conditions considered suitable there is a narrower range that species select as preferred or optimal. The peak of the curve is the optimal value of the physical variable and the tails represent the bounds of suitability. The primary advantage of the multivariate response surfaces is the ability to express interactions among the variables.

2.5 WEIGHTED USABLE AREA AND COMPOSITE SUITABILITY INDICES

Total usable area is defined in terms of the plan area of the water surface within a river reach, expressed in ft^2/1000 ft of river length. Total usable area is the summation of the plan surface area of each of the individual cells within the river reach, some of which (principally the near bank cells) will

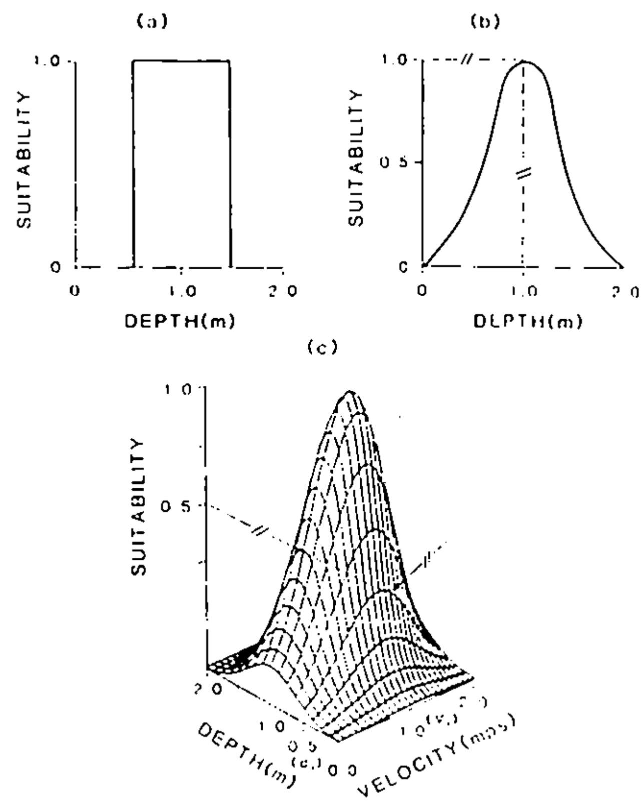


Figure 2.8 Examples of the three formats of habitat criteria: (a) binary, (b) univariate curve, (c) multivariate response surface

vary in plan area with discharge. The net suitability of use of a given cell is quantified by the Weighted Usable Area (WUA). The suitability of a cell may be determined by one of four Composite Suitability Indices (CSI), as presented below, where A_i is the plan area of cell i, and f(v), f(d) and f(c) are the habitat suitability indices for velocity, depth and channel index (cover or substrate) respectively:

MULTIPLICATIVE CSI

$$WUA_i = A_i \times f(v) \times f(d) \times f(c)$$

GEOMETRIC MEAN CSI

$$WUA_i = A_i \times [f(v) \times f(d) \times f(c)]^{0.333}$$

MINIMUM CSI

$$WUA_i = A_i \times MIN[f(v), f(d), f(c)]$$

USER SUPPLIED CSI

$$WUA_i = A_i \times USER\ SELECTED\ FUNC[f(v), f(d), f(c)]$$

The multiplicative CSI, in which the gross area of the cell is multiplied by all suitability indices, is normally used and implies a "cumulative effect" mechanism, a synergistic action whereby optimum habitat availability is achieved only if all variables are optimal (Gan & McMahon, 1990). The geometric mean CSI implies a compensatory mechanism, such that if two of the three variables are in the optimal range then the value of the third variable has little effect unless it is zero. The minimum CSI implies a "limiting factor mechanism" such that when the cell area is multiplied only by the minimum of the factors the habitat is no better than its worst component. The user supplied CSI allows the PHABSIM modeller user to define the nature of the CSI function according to the explicit interactions which are sought.

Weighted Usable Area is calculated cell by cell and summed for the whole reach. Under different flow conditions the values of the physical properties within a cell vary and consequently the habitat suitability indices may alter accordingly to calculate a new weighting factor. At different flows the plan area of certain cells will alter. The variations in these two factors combine to create a Weighted Usable Area relationship with discharge for a river reach.

3. PROGRAMME OF WORK

Schedule 6 of the NRA contract outlines the activity schedule which comprises of the following tasks.

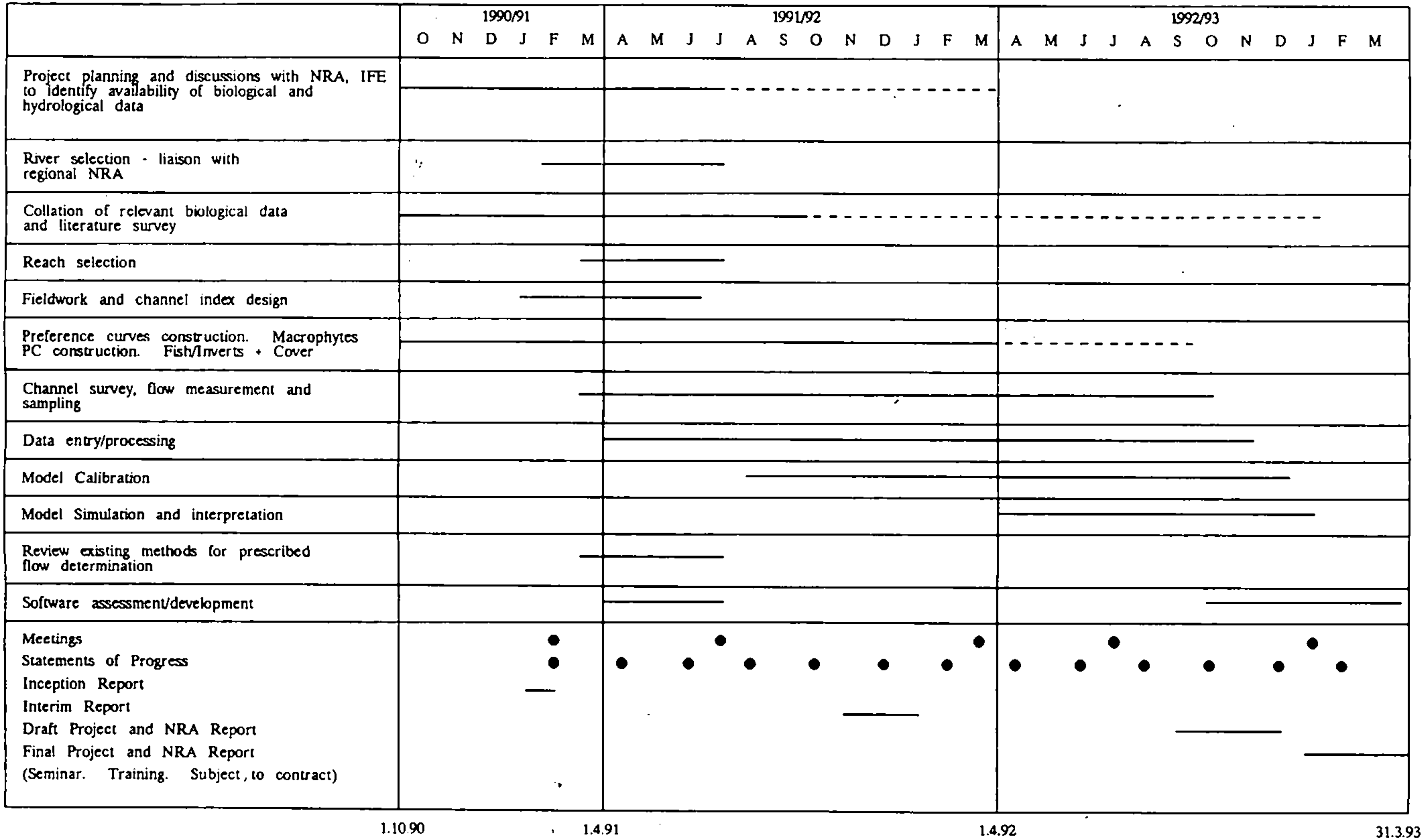
3.1 Collation of data and information

Accept that the IFIM and PHABSIM techniques are the relevant method by which results are to be achieved and collate all relevant data accordingly: including previous NERC research and that from specific river studies in NRA (or predecessor Authority) research on biology and particularly on matters relating to fish populations and migrations. Liase with other related research programmes.

The literature search will collate available data on fish habitat requirements with emphasis on the UK. These data will be used in the assessment and development of habitat preference curves and in the identification of under-researched areas. Data on critical stages in fish life histories will be collated in order to define better the habitat requirements of each life stage. Physical criteria for defining mesoscale habitat are to be defined.

SCHEDULE 6

ACTIVITY SCHEDULE



Information on the concept of cover in relation to habitat requirements will be collated for use in the generation of preference curves for all target species. Interaction with the University of Loughborough is anticipated at this stage. Information on alternative cover and substrate calassification schemes to be collated. Information from the literature regarding the habitat requirements of at least two species of macrophyte will be collated and used. The range of variation in velocity, depth and discharge characteristic of rivers in England and Wales to be collated in order to establish the range of values of these variables over which preference curve information is required. In addition the impact of macrophyte growth on depth, velocity, discharge relationships will be reviewed.

3.2 Assessment of PHABSIM software

a. The most recent menu-driven upgraded PHABSIM software to be loaded and tested.

b. Existing data files from sites on the rivers Gwash and Blithe to be used to test the relative merits of the range of hydraulic model available within the PHABSIM model. This will be extended during the course of the study when modelling different river systems e.g. those with artificial controls on stage discharge relationship.

3.3 Selection of sample rivers

A provisional sample of rivers has been identified (Figure 3.1) that can be studied for application of the IFIM technique, and will lead to the recognition of the viability of the method in England and Wales. This sample of rivers should be representative of the range of river types present in England and Wales thus facilitating extrapolation to other rivers.

River and site selection was initially guided by ecological criteria (as defined by RIVPACS). For each of the ten RIVPACS groups a list of rivers and sites was produced to ensure that the full range of river and habitat types will be examined. 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 may be compared with other flows and to aid hydrological modelling. Thus any rivers that do not have a working hydrological gauging station have been 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 kilometers 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 hydrological data was low or there are problems of high artificial influences.

The problem of the increase in the amount of fieldwork required when studying large rivers must also be taken into account. Thus, where possible, rivers that have a catchment area of over 150 km^2 have been excluded in favour of smaller study areas. However in order to examine the full range of

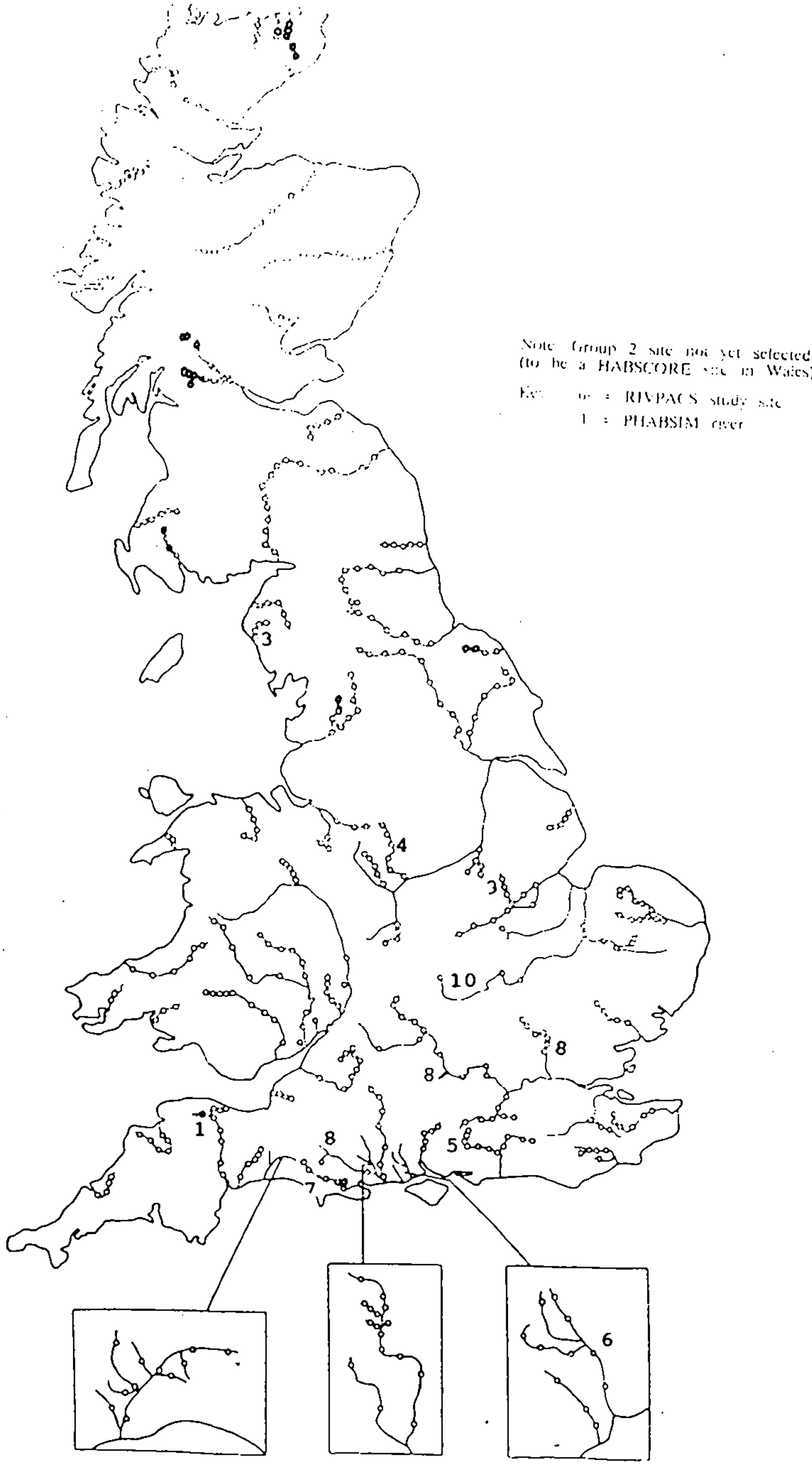


Figure 3.1 Position of provisional river sample sites and RIVPACS study sites.

river types at least one larger river will be surveyed.

Aside from the necessity to cover the full range of hydrological and ecological river types, there is also a need to examine sites where problems occur that are relevant to other sites in the U.K. For instance, a river that is controlled by gates such as the Gt. Ouse; a river that is influenced by a reservoir such as the Blithe and the Gwash; a chalk stream with or without nearby water abstractions etc. Conversely, it is also important to ensure that rivers that are natural are sampled so that the survey is representative and so that data is obtained on sites that may undergo future water resource development.

Finally, some sites have been selected that may not fulfill all of the above criteria. This is because the benefits that can be gained where data from other work on the rivers outweighs any problems that may occur.

LIST OF PREFERRED RIVERS AND SITES:

Group 1:
The River Exe at Warren Farm (South West).
Group 2:
A river from the HABSCORE data set in Wales (yet to be decided)
Group 3:
The River Ehen at Ennerdale Bridge (North West).
Group 4:
The River Blithe at Hamstall Ridware (Severn Trent).
Group 5:
The River Rother upstream of Liss Station (Southern).
Group 6:
The River Lymington at Balmorlawn (Southern).
Group 7:
The River Frome (mill Stream) at East Stoke (Wessex).
Group 8:
The River Mimram at Panshangar Park (Thames) or River Pang (Thames) or River Piddle (Wessex) (site to be decided).
Group 9:
The River Gwash (site to be decided)(Anglian).
Group 10:
The Great Ouse at Shornbrook (Anglian)

3.4 Fieldwork programme

Undertake fieldwork to generate data for the establishment of hydraulic and biological data sets to meet at least the minimum data requirements of PHABSIM.

Hydraulic data will be sampled on a transect basis, with transects selected to represent the mesoscale physical habitat types within the reaches. Transects will be placed using either a 'representative reach' or 'habitat mapping' approach. In the former approach a continuous reach is selected which contains all representative microhabitat types present in the river. Transects are placed appropriately within the reach so as to best model the different habitat types.

In the latter approach transects are placed at points where different microhabitats exist so that each different habitat type is modelled independently in disjointed reaches. Information from each of these smaller reaches is then mapped according to the proportion of the particular habitat type present in the length of river to be studied. For the purpose of this study mapping will be restricted to at most 10km up and downstream of the RIVPACS sampling site.

At each reach a network of headpin control points will be installed, surveyed in terms of elevation and their elevation calculated and checked. At each transect, a bed elevation survey and application of a suitable substrate/cover code will be followed by a minimum of three observations of water surface elevations at different known discharges and at least one set of observations of velocity, preferably at the higher flows.

For each of the river reaches selected invertebrate samples will be collected. Samples taken in representative microhabitats will indicate the relative abundance of target species and will provide a detailed anlysis of invertebrate distribution in relation to flow velocity, depth, substratum type and available cover. Each of the reaches will be fished on one occasion to provide data on the relative abundance of species and the structure of fish populations. Time-permitting, observations will be made in order to compare fish population structures from regulated and non-regulated reaches.

The IFE River Laboratory Mill Stream will be used to test the effects of reduced flows upon habitat availability and longitudinal distributions of fish species. The Mill Stream has a controllable flow and the discharge does not exceed 3 cumecs at normal flows. The probable range of flows available will be from 0.25 cumecs to 1.5 cumecs. the channel has a wide range of cross-sectional profiles and includes riffles, runs, bends and pools within the 1km experimental reach. IFE owns the rights to the Mill Stream along both banks for its entire length together with various side channels and ditches, offering on-site security and opportunities for experimental replication. The experiments will provide essential data on fish movement in response to flow reductions.

3.5 Habitat preference curve construction

a. Invertebrates

During the DOE contract (Bullock, *et al.*, 1990), invertebrate samples were collected on the rivers Blithe and Gwash at the same time as model calibration measurements were made. When identified these will yield invaluable data for the construction of habitat preference curves for target species in two contrasting river types. As the fieldwork programme progresses further samples will provide similar data within a range of contrasting rivers. The RIVPACS database will be used to prepare habitat preference curves for additional species. Field derived data from microhabitats will be compared with that from RIVPACS data which are derived from integrated samples (ie. all microhabitats are sampled but bulked together).

b. Fish

Information from the literature search will be used to assess and improve existing habitat preference curves and to develop additional curves for other species and spcific species life stages. Data from fishing on the rivers Blithe and Gwash will contribute information on the growth and structure of the fish populations which is essential to assess habitat suitability.

c. Macrophytes

Macrophytes are important components of the cover available for fish, they provide habitat for invertebrates and are essential in maintaining habitat suitability for certain critical life stages. Habitat preference curves will be produced for at least two species of macrophyte including a submerged mainstream species such as Ranunculus penicillatus and an emergent marginal species (Glyceria, Phalaris, Sparganium).

d. Testing and validation

Data from the field studies will provide detailed information on the distribution of target invertebrate species in relation to flow velocity, depth, substratum type and cover. Comparison of these with predictions of available habitat (Weighted Usable Area) will potentially enable the establishment of a relationship between relative abundance and available habitat. If time permits attempts will be made to compare fish population structures in regulated and unregulated rivers to identify whether moderate flow reductions have major impacts on fish population structure. Information to be used in this task will come from observations made in the fieldwork programme, from the literature and from regional National Rivers Authority fisheries staff. The application and output vof other fish habitat models in current use in the UK will be compared with that of IFIM

3.6 Data processing, entry, quality control and running of model simulations

Processing of hydraulic data and loading into PHABSIM system through RIFG4IN. Data scrutiny and quality control. Selection of most appropriate hydraulic model based on available data. Calibration of hydraulic models and assessment of diagnostics and optimisation criteria. Loading of coordinates from habitat preference curves Simulation runs and generation of WUA versus discharge relationships.

3.7 Evaluation of results for setting ecologically acceptable flows in selected rivers and potential for extrapolation

Interpretation of WUA versus discharge relationships to ascertain the procedure for setting minimum ecologically acceptable flows, giving cognisance to the different requirements of different life stages and species, and to the seasonal requirements of certain life stages. Establish within the framework of macroscale (major river groups) and mesoscale (pools,riffles,glides etc.) habitat features how results from the study reaches can be transferred to other, non-sampled, river reaches in the United Kingdom.

This work will be more clearly focussed if the minimum ecological flow is set for at least one of the sites. This will provide a more constructive basis for evaluating the procedure for applying the model to this problem.

4. SUMMARY OF OUTPUT

a. Hydraulic data.

b. Habitat preference curves for target species.

c. Relationship between discharge and available habitat, time series and frequency analysis, analysis of seasonal variation.

d. Recommendation for transferring results to other rivers/reaches

5. TARGETS AND TIMESCALES

Work Item	Date completed	Month
1: Start date	1.10.90	0
2: Inception Report	1.3.91	5
3: First phase of assessment of PHABSIM software	1.8.91	10
4: Collation of data and information	1.8.91	10
5: Selection of sample rivers	1.8.91	10
Identification of reaches	1.8.91	10
6: Preliminary evaluation of results for setting EAFs in selected rivers and potential for extrapolation	1.1.92	15
7: Fieldwork programme	1.11.92	25
8: Data processing, entry, quality control and running of model simulations	1.12.92	26
5: Final evaluation of results for setting EAFs in selected rivers and potential for extrapolation	1.2.93	28

REPORTING

Statements of Progress at two monthly intervals

Interim report: at 16 months 1.2.92

Draft final report: at 27 months 1.1.92

Final report: at 30 months 31.3.92

Note: In view of the need to continue the fieldwork programme until 1.11.92 and complete data processing, entry, quality control and running of model simulations by 1.12.92 the draft final report will not include completed analysis of data from all sites.

6. FINANCE

BREAKDOWN OF COSTS BY ITEM (£)

Item	1990/91	1991/92	1992/93	Overall
Staff	32	60	60	152
Travel and subsistence	3	20	10	33
Capital items	-	-	-	-
Consumables	7	10	5	22
Subcontracts	21	36.5	23.5	81
Final report	-	-	5	5
Other Costs	-	-	-	-
Total	63	126.5	103.5	293

FOOTNOTE
In addition to the 293K costs incurred by the Institute of Hydrology and its collaborating organisation, additional costs of 18K will be incurred by NRA during the project, itemised as 14K staff time 2K travel and subsistence and 2K consumables.

7. PROJECT MANAGEMENT

Project manager: Alan Gustard (IH) - liason with Dr Terry Newman (NRA)

Project leader : Ian Johnson (IH)

Fieldwork Supervisor: Craig Elliot

IFE Subcontract:

Project leader : Patrick Armitage (IFE) - liason with Dr. Alistair Ferguson (NRA)

In the task of collation of relevant data and information IFE will be responsible for coordinating with programmes at IFE, IH responsible for coordinating with programmes at IH and NRA responsible for cordinating with programmes outside of the Terrestial and Freshwater Sciences Directorate of NERC, including those within NRA and outside.

Against a background of expanding but disparate research activities in this field, cooperation with other research groups is both benificial for data gathering and essential for delicacy of interaction.

8. REFERENCES

Bartholow, J.M. and Waddle, T.J. 1986. Introduction to Stream Network Habitat Analysis. Instream Flow Information Paper No. 22. U.S.D.I. Fish & Wildlife Service Biol. Rep. 86(8), 242 pp.

Bovee, K.D. 1986. Development and Evaluation of Habitat Suitability Criteria for Use in the Instream Flow Incremental Methodology. US Fish & Wildlife Service, Instream Flow Information Paper No. 21, US Fish Wildl. Serv. Biol. Rep. 86(7), 235 pp.

Bullock, A., Gustard, A. & Grainger, G.S. 1990. Instream Flow Requirements of Aquatic Ecology in Two British Rivers - Application and Assessment of the Instream Flow Incremental Methodology using the PHABSIM system. Institute of Hydrology, Wallingford.

Drake, P.J. & Sherriff, J.D.F. 1987. A method for managing river abstractions and protecting the environment. J. Water and Environ. Management, 27-38.

Gan, K. & McMahon, J. 1990. Variability of results from the use of PHABSIM estimating habitat area. Regulated Rivers: Research and management, Vol. 5, 233-239 (1990).

Gore, J.A. & Nestler, J.M. 1988. 'Instream Flow Studies in perspective'. Regulated Rivers, Research & Management Vol. 2, 93-101.

Gregory, K.J. & Walling, D.E. 1973. Drainage basin, form and process. Edward Arnold, London.

Gustard, A., Cole, G., Marshall, D.C.W. & Bayliss, A.C. 1987. A study of compensation flows in the United Kingdom, Institute of Hydrology Report 99.

Institute of Hydrology, 1980. Low Flow Studies. Institute of Hydrology, Wallingford.

Jahn, L.R. 1990. Managing Riverine Values & Uses. Rivers - Studies in the Science, Environmental Policy and Law of Instream Flow. Vol. 1, No. 1.

Lamb, B.L. & Doerksen, H.R. 1987. Instream Water Use in the United States - Water Laws & Methods for Determining Flow Requirements. National Water Summary 1987 - Water Supply & Use: Instream Water Use, 109-116.

Petts, G.E. 1989. Methods for assessing minimum ecological flows in British rivers. BHS National Hydrology meeting - Prescribed Flows, Abstraction & Environmental Protection.

Petts, G.E. 1990. Application of the Instream Flow Incremental Methodology in the United Kingdom. Report by the Freshwater Environments Group, Department of Geography, Loughborough University.

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