NRA-Anglian 143
CONTRACT 526

2718

River Wissey Investigations: Linking Hydrology and Ecology

Executive Summary

March 1994

Professor G E Petts
M A Bickerton

Freshwater Environments Group

Anglian Regional Operational Investigation 526

OI/526/2/A

NRA

National Rivers Authority

National Rivers Authority
Anglian Region
Kingfisher House
Goldhay Way
Orton Goldhay
Peterborough PE2 5ZR

Tel: 0733 371811 Fax: 0733 231840

Dissemination Status:
Internal: Released to Regions
External: Released to Public Domain

Initial Dissemination List:

NRA Water Resources and Conservation staff in Anglian Region.

Statement of Use:
This research was commissioned to investigate the influence of flows on the distribution of fauna in the River Wissey. The report should be used by those seeking to determine preliminary and comprehensive descriptions and classifications and to establish the relationships between biota and river flows.

A further phase is currently being undertaken to demonstrate the transferability of this assessment method to other rivers and further develop the assessment of the sensitivity of species to hydrological stress.

Research Contractor:
This document was produced under Anglian Region OI Contract 526 by:

Freshwater Environments Group
Department of Geography
Loughborough University of Technology
Leicestershire
LE11 3TU

NRA Project Leader:
The NRA's Project Leader for Anglian Region OI Contract 526

Mr Peter Barham - Kingfisher House, Peterborough

Additional Copies:
Further copies of this document can be obtained from R&D Co-ordinator, Anglian Region.

River Wissey Investigations: Linking Hydrology and Ecology.

Executive Summary

March 1994

Directed by Professor G.E.Petts

Senior Research Associate: M.A.Bickerton

Freshwater Environments Group,
Department of Geography,
Loughborough University of Technology,
Leicestershire, LE11 3TU.

CONTENTS

LIST OF PARTS

This report briefly summarises the information detailed in the **Main Report** and the following **Annexes**, which include full methodological details, data analyses and data tables.

ANNEX A. River corridor survey, wetlands, surface and hyporheic water temperature, water chemistry, survey of the diatom community, sedimentological characteristics, analysis of NRA fish data.

ANNEX B. Aquatic macrophytes of the River Wissey: Their influence on instream hydraulics and sedimentation.

ANNEX C. Instream flow requirements of the River Wissey: PHABSIM.

ANNEX D. Macroinvertebrates of the River Wissey: Distribution, habitat preferences and use in habitat assessment, based on survey data from 1991-92 and National Rivers Authority biological monitoring data 1964-91.

Acknowledgements:

The research has benefitted from close contact with many members of the National Rivers Authority, Anglian Region and we are very grateful for their support. Particular thanks are extended to Peter Barham, David Evans and Pat Sones.

The research involved a larger number of researchers and their contributions are acknowledged.

Researchers:
Dr P.Barker C.Evans C.Ferguson P.Gell
Dr N.Hughes E.Linton I.Maddock D.Milan
J.Mousley Dr K.Prach Dr R.Wilby

Assistants:
D.Faulkner A.Jefferson W.Lawry
J.Merrick S.Newbery H.Ruffell

1 INTRODUCTION

The Wissey is recognised as a Chalk stream of high conservation value. Its ecological characteristics are likely to be adapted to the good year-round flows that are typical of such rivers. Concerns have been raised about the sustainability of the Wissey's high biological quality under the pressures of increasing water abstraction but little scientific information exists on the crucial link between hydrology and ecology.

This study evaluates the influence of flows on the distribution of fauna in the River Wissey. The research followed a three-stage process:

The *preliminary description* of the river based on the collation of existing information and field surveys and *classification* of the river system into (i) different sectors and (ii) different reaches within each sector, using a range of statistical techniques.

The *comprehensive description* of the physical habitat and biota within representative reaches giving special attention to seasonal variations.

The *establishment of relationships* between biota and flows. This final stage required two steps, relationships were established first between biota and habitat characteristics and then between habitat characteristics and flows.

The Report also includes a review of the range of approaches and methods available to elucidate links between flow and biota, and an assessment of the applicability of these to the determination of in-river flow needs - specifically the flows necessary to sustain the 'natural' ecological values of a river.

2 HYDROLOGY. PHYSICAL HABITAT and ECOLOGY.

2.1 The Hydrological Context.

Figure 1.1 shows the River Wissey catchment. Analyses of rainfall, runoff, streamflow and groundwater-level data over the period 1956-present indicate that the Wissey has a naturally regulated flow regime. Annual maximum groundwater levels are significantly correlated with rainfall during the winter period of aquifer recharge.

2.2 The Ecological Context.

Information on fish populations, instream flora and invertebrates was obtained from the National Rivers Authority and other sources to provide the ecological context for the study. Also, at the outset of the project in January/February 1991, the channel network of the River Wissey was walked to make a general assessment of the river.

Riparian wetlands occur throughout the valley network and, notably on the River Gadder near Cockley Cley, and these are shown to be extremely valuable sites, for example providing habitat for a number of nationally rare flies.

In terms of physical characteristics, the River Wissey incorporates a diversity of habitats. Gravel-bed, riffle-pool reaches contrast with ponded, sand-bed reaches; macrophyte-rich reaches contrast with heavily shaded macrophyte-poor reaches. In most cases, such contrasts reflect recent or historic management practices, especially the effects of dredging and mill weirs.

The river through Hilborough to Didlington contains a classic Chalk-stream flora and a diverse invertebrate fauna. Downstream the river becomes a fenland drain but also has a diverse invertebrate fauna. Small streams throughout the catchment have naturally-poor faunas which have often been further degraded by ditching and pollution, factors that are also reflected by their poor flora.

The fish population is dominated by eel, with dace in the upper river, dace and trout in the middle river, and dace and chub in the lower river. However, the population is artificial because of trout stocking and selective removal of coarse fish. Through biological

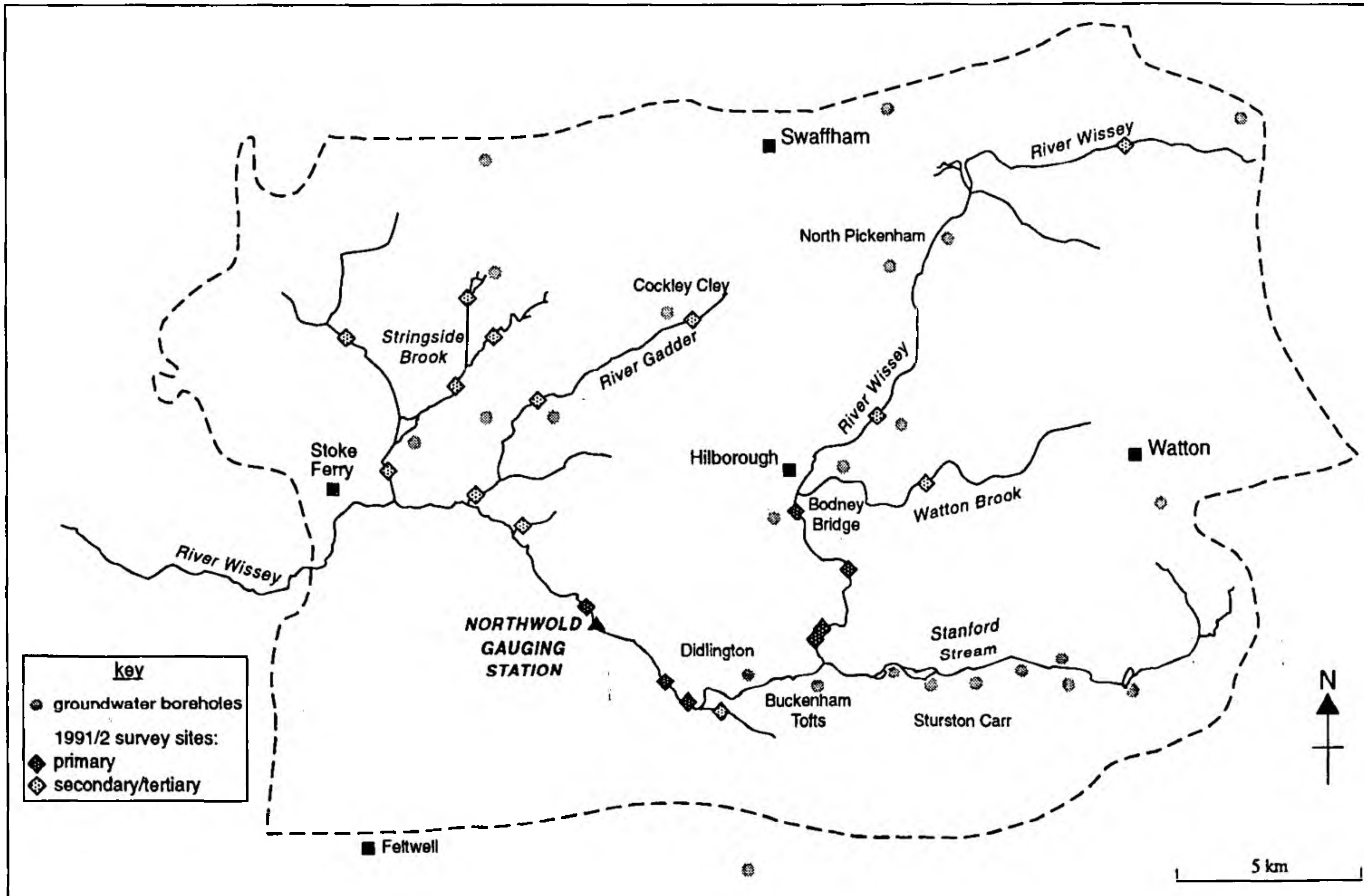

Figure 1 The River Wissey, showing the catchment boundary and locations of groundwater boreholes and survey sites.

interactions, the artificial structure of the fish population is likely to have an effect on the way the 'ecosystem' functions.

The data shows that both trout biomass and invertebrate richness have declined recently, a trend that is correlated with the decline in flows. However, this link may be indirect, reflecting a decline in water quality in the lower Wissey below Stoke Ferry and along Watton Brook, and a degradation of physical habitat elsewhere. It may also relate to the absence during the winter of high flows which are important for rejuvenating instream habitats by flushing any accumulations of fine sediments and organic detritus.

2.3 A Typology of Sites.

Synthesis of the hydrological, geomorphological and ecological information led to the division of the river network into 5 major sectors and 13 reaches chosen as being representative of the range of habitats found within the different sectors. Subsequent research focussed on the main river below the Watton Brook confluence but a selection of sites from the headwater and tributary streams were also included.

3 VARIATIONS OF INSTREAM CHARACTERISTICS 1991-92.

3.1 Introduction.

The core of this project involved detailed investigations of the habitats at the selected sites. These investigations included measurements of flow and water-quality (using chemical and biological methods); studies of the influence of vegetation growth on instream hydraulics and channel-bed sediments; and studies of hydraulic variations with changing discharge within channels of different size and shape. Field surveys were undertaken between May 1991 and October 1992.

3.2 Results.

Throughout the survey period, daily flows at Northwold gauging station were well below normal, as defined by the 1956-88 record (Figure 2) and for most of the period they were below the monthly 95th percentile flow, especially from August 1991 to March 1992. The mean daily flow during the period of field survey (0.479 cumecs) was only about 25% of the long-term mean daily flow (1.9 cumecs).

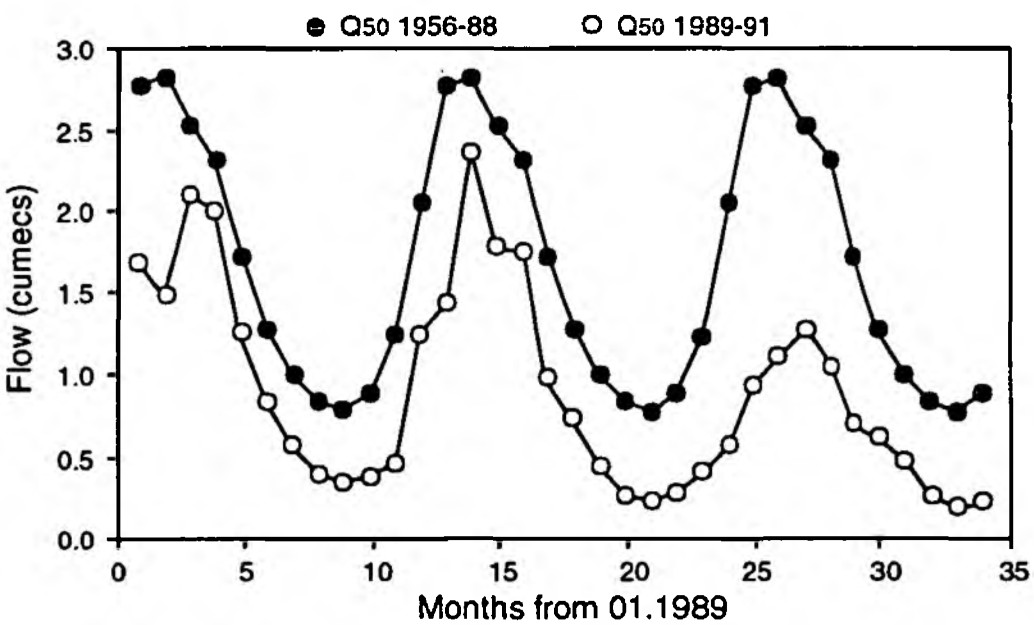

Figure 2 Median monthly flows (Q_{50}) during the 1989-91 drought in comparison to the long term flows at Northwold gauging station.

It is shown that flows at sites along the main river can be predicted from the Northwold gauge record and the similarity in hydrological variability between sites allowed the Northwold gauge to be used as the control point for flow recommendations. It is also demonstrated that about 30% of the flow at Bodney Bridge is from springs and groundwater seepage between Great Cressingham and Hilborough, highlighting the importance of maintaining groundwater levels within this sector.

High nutrient levels were found to characterize the whole river, especially the headwaters. Concentrations tend to decline downstream. Levels were particularly high throughout 1991-2, possibly because of the low flows. Water temperatures during the period peaked at 21.8°C during July. Mean temperatures within the substratum declined markedly with depth, especially in the sand-bed and chalk-bed sites reflecting the influence of sediment permeability.

Using chemical data, a diatom assay and information provided by recent invertebrate surveys, four water-quality types have been defined. They were characterised by progressively decreasing concentrations of orthophosphate and total oxidized nitrogen along a general downstream gradient: (i) Watton Brook ; (ii) the upper Wissey above Hilborough; (iii) River Wissey sectors between Hilborough and Northwold; and (iii) the lower middle river below Northwold.

Hydraulic variations with discharge differed between reaches reflecting channel form; variations of discharge were associated mainly with changes of depth at the sand-bed sites and of velocity at the gravel-bed sites. The channel bed has high sand concentrations and clean gravels suitable for trout spawning often form only a thin layer at the surface of the channel bed. Hydraulic refuges and a patchwork of different habitats were shown to be sustained during declining flows by both a diverse channel form and by macrophyte growth which showed strong seasonality with *Rorippa* dominating in late summer and autumn and *Ranunculus* dominating in early-mid summer.

4 LINKING HYDROLOGY AND ECOLOGY.

4.1 Introduction.

Approaches to link hydrology and ecology have been investigated so that responses of biota to changing flows could be assessed. Particular emphasis was given to the indirect effects of low flows on biota.

Three approaches were used:

(i) established hydrological approaches;
(ii) an established simulation model (PHABSIM); and
(iii) a new approach based upon data on macroinvertebrate distributions in relation to habitat.

The new approach was justified on three grounds. First, in comparison to fish, invertebrates have lower positions in the food chain, are generally less mobile and may have narrower tolerances to habitat changes. Secondly, their rapid colonisation of habitats and short life cycles allow the development not only of river-specific habitat preferences for both species and communities, but also season-specific habitat preferences giving due regard to the different life stages. Thirdly, invertebrate data are collected routinely by the National Rivers Authority and, potentially, an invertebrate-based method might allow routine instream-flow assessment.

4.2 Hydrological approaches.

Traditionally, minimum flows have been set on the basis of discharge criteria. The justification for the hydrological approach is that over the long term, stream flora and fauna have evolved to survive periodic adversities without major population changes. The instream flow is expressed as a hydrological statistic: commonly either as a flow duration statistic (such as the 95th percentile) or as a fixed percentage of the average daily flow (ADF).

4.3 PHABSIM habitat assessment.

The Physical Habitat Simulation (PHABSIM) System is the cornerstone of the Instream Flow Incremental Methodology, which is widely used throughout USA for defining impacts of changing instream flows. PHABSIM is a set of computer models that are used to relate changes in discharge or channel structure to changes in physical habitat availability for a selected species.

A major criticism of PHABSIM is the large database required. This study successfully developed a simplified field-survey procedure. The target species were:-

- seven species of fish (Brown trout, Dace, Chub, Roach, Bream, Pike and Perch),
- four life stages for each fish species (i.e. spawning, fry, juvenile and adult),
- four species of aquatic invertebrates (i.e. one stonefly (*Leuctra fusca*), two caseless caddis (*Rhyacophila dorsalis* and *Polycentropus flavomaculatus*) and one pea mussel (*Sphaerium corneum*)).

The model was calibrated for each site to three flows ranging from 0.23 cumecs to 2.3 cumecs. Simulated flows range from 0.4 times the lowest calibration flow to 2.5 times the highest calibration flow.

Differences between sites in terms of usable area at specific flows reflect channel form, substrate and macrophyte growth.

The simulations were combined with the actual discharges experienced during the drought to show the effect that reduced flows had on habitat area available. For example, Figure 3 shows for adult trout the habitat area-time series for the 1988-92 drought compared with a habitat area plot based upon average monthly flows (1977-87). Such plots are also useful for illustrating the potential effects of any proposed flow-management scenarios.

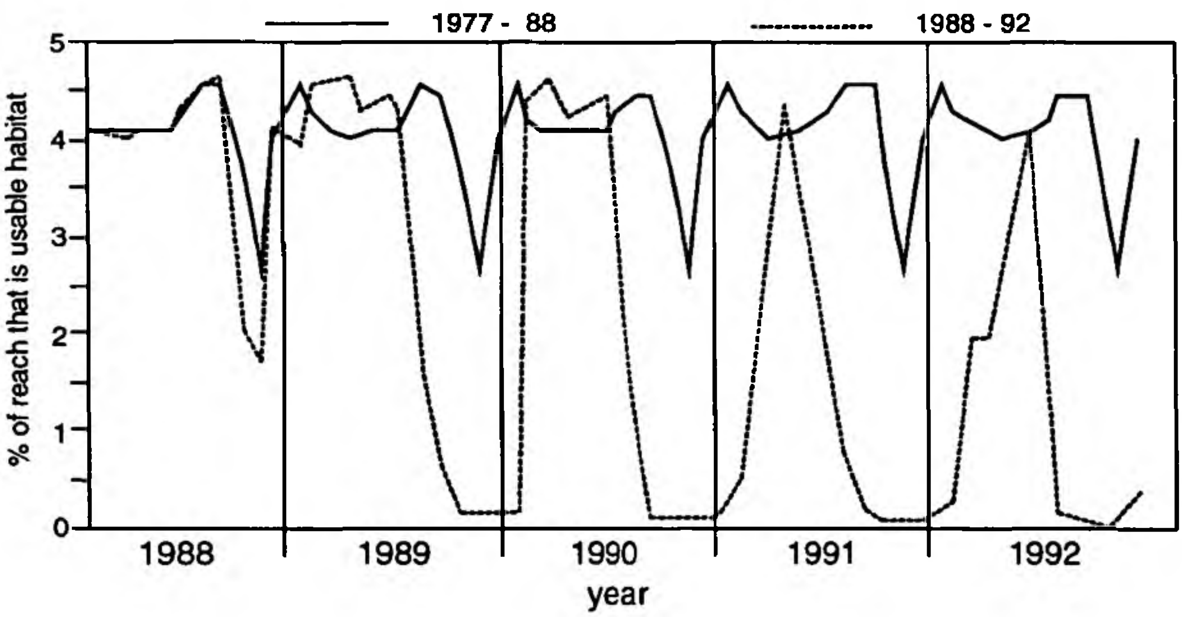

Figure 3 Habitat usable area time series for Brown Trout at Northwold.

4.4 Macroinvertebrates.

Investigations of biological responses to flow variations focused upon the spatial and temporal distributions of aquatic macroinvertebrates. Twenty-one sites were selected for macroinvertebrate sampling and monthly habitat assessment. Sampling was carried out on five occasions: May and October 1991, and February, May and October 1992.

Multivariate analyses were used to relate habitat data to community distributions and to determine the dominant environmental variables influencing these distributions.

The results show definite seasonal shifts in the relative importance of the environmental variables for the invertebrate communities although flow velocity appears to be an important variable in all months and is closely linked with the distribution of gravel. Two groups of taxa are distinguished:-

(i) those preferring riffles or runs with high flow velocities, gravel and sand (including taxa such as Elmid beetles, Leptocerid caddis and Hydrobiid molluscs), and

(ii) those preferring (or tolerant of) riffles or runs with high depth and silt (eg Polycentropus, Lymnaeid molluscs and a number of Hemiptera associated with marginal macrophytes).

Under extreme low flows, the taxa in the first group are likely to be the most stressed as this habitat declines in availability.

In order to establish quantitative relationships between the fauna and specific variables, three established methods of preference curve construction have been evaluated. The independent regression method was found to give the best predictions and to be the easiest method to use, which is a major advantage when dealing with large numbers of taxa and variables.

Preference curves for the key hydraulic variables: flow velocity and depth, were produced for all except the rarest taxa. Separate curves were defined for May, October (combining data for the two years) and February. Relationships between discharge (as gauged at Northwold) and flow velocity and depth were determined for the primary sites using the monthly field data. The Shannon-Weiner diversity index was used to produce a measure of predicted community diversity.

Figure 4 illustrates the method using data for Chalk Hall Farm. From these relationships, optimum discharges (cumecs) - defined as those flows that are associated with maximum species diversity - were determined for each site. The shape of the curve describes the rate of reduction in diversity with declining flow. These curves are particularly valuable for determining the effects of flow reduction and can be used to simulate the loss of diversity associated with any proposed flow-management scenario.

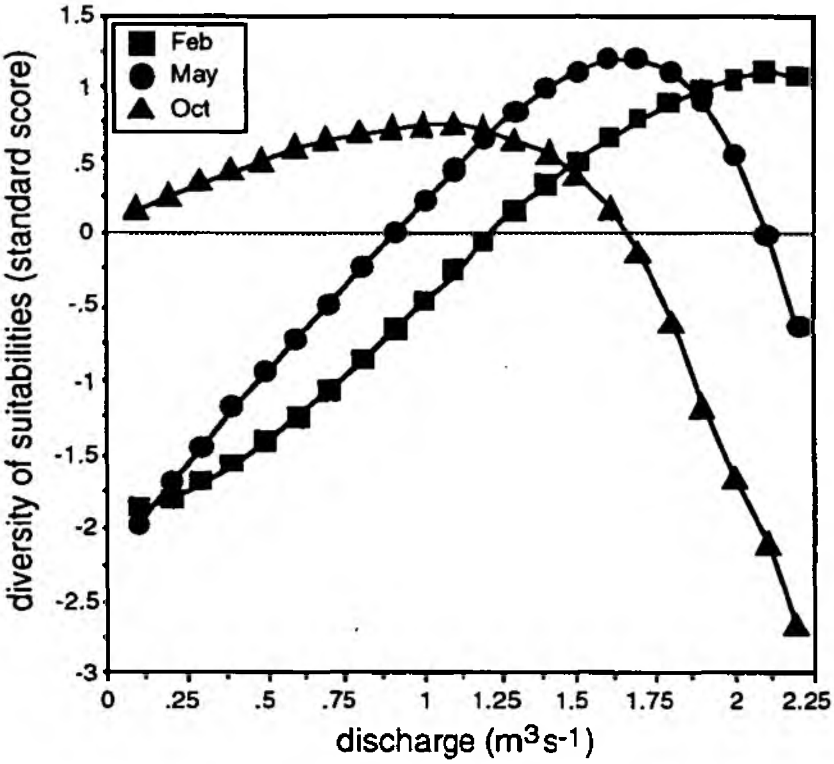

Figure 4 Change in diversity of taxa habitat suitabilities with discharge.
Diversities ($H = - \Sigma(\ln p_i \times p_i)$) are based on all taxa occurring at the site with a cell frequency of >0.5.

5 DISCUSSION AND RECOMMENDATIONS.

5.1 Flow-biota relationships.

The detailed assessment of the ways that flow influences biota, presented in the Annexes to this report, demonstrates five important factors relevant to decisions concerning the setting of minimum flow criteria:-

i) Optimum conditions for biota are provided by long-term average flow conditions, that is, they are adapted to the 'normal' environmental regime.

ii) The habitat ranges of biota are limited by both high flows and low flows at the extremes of the long-term average range.

iii) Most taxa do not have clearly defined thresholds in their tolerance of environmental conditions, rather they display a more or less progressive decline in their preferences as environmental conditions change away from the 'norm'.

iv) In natural channels, when exposed to extreme environmental conditions, species become dependent upon refuge habitats; species are more sensitive to flow extremes in reaches of uniform channel morphology, lacking the necessary structural diversity to maintain these refuges.

v) Classification of a river as sectors and reaches, and then determination of in-river flow needs for each reach type, provides a useful approach for the objective assessment of in-river flow requirements in relation to other users.

5.2 Flow criteria.

The application of a range of hydrological, habitat-based, and biological-response approaches has enabled determination of the minimum flow criteria:-

i) Threshold Ecological Flow to sustain refuges for biota associated with relatively high-velocity, clean substrate, riffle and run habitats (TEF);

ii) Ecological Minimum Flow to provide at least a minimum area of suitable habitat for adult Trout in one reach type within each of sector (EMF);

iii) Desirable Ecological Flow to provide at least a minimum area of suitable habitat for a target species or life stage in every reach type within all sectors (DEF);

iv) Optimum Ecological Flow to provide either the maximum area of suitable habitat for a target species within a river or the maximum community diversity, or which provides the optimum combination (OEF).

Guidelines are presented for using minimum flow criteria to meet environmental objectives (see Main Report Table 4.2).

5.3 Minimum flows for the River Wissey.

The flow recommendations for the River Wissey are given below. However, the report also demonstrates the importance of channel morphology, sites with a classic gravel-bed, riffle-pool form maintaining a range of habitats under lower flows than sites with more uniform morphologies, such as created by dredging and some channel maintenance operations. The recommended minimum flows are:

- the **TEF is 0.30 cumecs**; below this threshold there will be a complete loss of habitat suitable for adult trout and a loss of high-velocity refuges;
- the **EMF is 0.40 cumecs** (the 99th %ile flow; 1956-88);
- the **DEF is 0.9 cumecs**; this flow would maintain some habitat for adult trout within both sectors 3 and 4, excellent habitat for juvenile trout, and a good invertebrate diversity;
- the **OEF is 1.25 cumecs**; this flow is associated with high invertebrate diversity at all sites, good habitat for adult trout throughout the river and excellent habitat for juveniles.

The OEF is rare in natural systems, on the Wissey this high flow has an average duration (1956-88) of less than 20% of the time, and typically occurs during December through April. Similarly, the DEF approximates the median flow for July-October inclusive, and the natural river has experienced flows below this level on many occasions.

5.4 Seasonal flow regime.

Three seasonal flow regimes have been defined, based upon the DEF, EMF and TEF minima. Demonstration that the Desired Ecological Flow regime is closely associated with near optimum biological functions is important, providing evidence to support the assumption that biota are adapted to the normal flows experienced. It also indicates that any variation from this 'norm', *associated with natural climatic variations or artificial influences* , will cause a decline in the suitability of the available habitats for biota.

Specification of minimum flows is a particular problem in Chalk catchments because droughts often persist for more than one year and river support usually involves boreholes that draw water from already depleted aquifers. For such catchments, two flow regimes are recommended: the EMF and TEF flows being used to define minimum flows for each month (Table 1).

Table 1. The seasonal flow regimes for the River Wissey, defining minimum monthly flows at Northwold gauging station.

	Monthly EMF (m^3s^{-1})	Monthly TEF (m^3s^{-1})
January	0.6	0.6
February	0.9	0.6
March	0.9	0.6
April	0.9	0.6
May	0.8	0.5
June	0.7	0.4
July	0.6	0.3
August	0.5	0.3
September	0.45	0.3
October	0.45	0.3
November	0.4	0.3
December	0.4	0.3

5.5 Management Implications.

The following rules were recommended for applying the monthly minimum flows:-

- *It is recommended that river support should be used to maintain the EMF regime during one-year droughts.* The EMF flow regime rules should become operational requiring river support when the flow has fallen below the EMF recommended flows on 14 consecutive days.
- *It is recommended that the Threshold Ecological Flow regime should be applied in the year following one during which the EMF regime was inceeded on 28 or more days or more.*

The recommended flows would enhance the ecological quality of the river during one-year droughts. The EMF regime would benefit the river in 1:4 < 1:6 years. During rare events, that naturally occur perhaps once in every 10 years or more, the TEF regime would protect the river against severe degradation.

Application of the these rules to the flow record for 1956-1993 indicates that river support would have been required on 547 days (less than 4 % of the time) with a frequency of 1:4 years. TEF rules were applied in 12 years but under these rules river support would have been required in only 3 years: 1990, 1991 and 1992. River support lasting for more than 70 days in a year would have been required in 1976, 1989, 1990 and 1991.

5.6 Flushing and Channel maintenance flows.

The flow regime recommended in Table 1 represents a series of minimum monthly flows but to sustain the ecological value of a river also requires high flows to maintain the physical habitats within the channel; here a flow of 3.5 m^3s^{-1} is required. During a series of dry years without flows above the 3.5 m^3s^{-1} threshold, artificial disturbance - additional instream maintenance - may be required to reduce the accumulation of sand and silt at gravel-bed sites and to clean pools. Also, riparian areas and marginal wetlands may require irrigation to maintain local water levels.

5.7 Other recommendations.

In addition to the above flow recommendations detailed, the study has provided a catchment perspective on the Wissey. The conservation value, potential for enhancement and recommendations for management of the Wissey and its tributaries have been identified. Specific attention should be given to:-

- creating buffer zones along most of the headwater streams.
- from Hilborough to the Buckenham Tofts sluice ensure that no works are undertaken to degrade the channel form and riparian areas.
- from Buckenham Tofts sluice downstream, habitat diversity should be improved along the channel margins by creating eddies, backwaters, and marginal cover;
- during dry summers, management of macrophytes should be limited to the maintenance of a few, fast-flowing runs.
- monitoring of water quality and flows should be undertaken at Hilborough, below the Watton Brook confluence, an important control point in the stream network.
- monitoring of groundwater levels surveyed into river levels is recommended between North Pickenham and Hilborough, an important reach for groundwater discharge maintaining flows during dry periods.

Recommendations are also made for further research to develop the method for application to other rivers. With regard to the Wissey, it is recommended that research should be commissioned to investigate the relationship between groundwater discharges and river flows within the reach between North Pickenham and Hilborough.