River Glen:
River Channel Assessment - Main Report

October 1992

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RIVER CHANNEL ASSESSMENT

WITH PARTICULAR REFERENCE TO PROBLEMS OF LOW FLOWS

INCLUDING THE EXAMPLE OF THE RIVER GLEN

MAIN REPORT

Undertaken for the National Rivers Authority, Anglian Region

By

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October 1992

Brown trout caught from the River Glen
at Aunby, 1986

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FOREWORD

The Water Resources Act (1991) defines the NRA's responsibilities for maintaining and improving the natural water environment. These responsibilities include:

- Maintenance and improvement of water quality;
- Provision of flood defence, including the protection of property and people;
- Management of water resources;
- Maintenance and improvement of fisheries;
- Conservation of the natural water environment and promotion of water-based recreation and navigation.

In order to provide value for money in meeting these responsibilities, the NRA is developing methods of assessing priorities for river improvements. This can only be achieved by studying the river environment as a whole and presenting the recommendations for these improvements in the form of catchment management plans. There are many aspects to this planning process which need investigation in order to identify the natural resources, identify the current and potential uses, quantify the potential improvements and describe what can be achieved with the available resources.

The results of the River Glen catchment study provide a basic methodology for a structured approach to describing the river system in relation to the natural resources. A sector-scale approach underpins the development of realistic recommendations for managing this complex river system which are made in the Report.

The study provides methodologies which will benefit the development of other catchment management plans.

Dr Alastair J. D. Ferguson
Anglian NRA
Project Leader

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The Report comprises an Executive Summary, a Main Report and five Annexes. The Main Report presents an approach for assessing the environmental quality of rivers, especially - but not exclusively - in relation to low-flow problems, using the River Glen as a case study. The five Annexes comprise: A) The Database, B) Analysis of NRA Invertebrate Records, C) Hydrological Assessment, D) Channel Substrate Analysis, and E) Physical Habitat Assessment. Many colleagues helped at some stage with the different aspects of the project. In particular, we wish to thank our technical staff for their support: Vernon Poulter, Stuart Ashby, Erica Milwain, Jamie Merrick and Bill Lawry.

We are grateful to many people within the Authority for their cooperation and contributions to the research. In particular we wish to record our thanks to Dr A. Ferguson for his encouragement, constructive critisism, and contribution to project development. We are also pleased to acknowledge the assistance of Dr. C. A. Extence, M. L. Stark, R. V. Enstone, Dr R. A. Baxendale, J. Ulyatt and D. J. Watling.

1. INTRODUCTION

1.1 Background

The drought of 1976 created an awareness within the water industry and among the general public of the potential consequences of abstractions from groundwater and surface waters for the fauna and flora or rivers and streams. It also created an appreciation of the potential conflicts between water resources developments and environmental interests. The current drought has led to further concern for river degradation caused by extreme low flows. However, many influences can cause a river to be degraded. The principle environmental factors causing degradation may be classified into the following three groups.

i) Water-quality:-

- pollution from rural land (e.g. fertilisers, silage, pesticides, sediment from soil erosion);
- pollution from sewage works;
- pollution from industrial discharges;
- runoff from urban areas (e.g. roads, car parks).

ii) Streamflow:-

- inadequate summer flows with important secondary effects, e.g. siltation, stagnation (increased temperatures and reduced oxygen levels), changed hydraulic conditions;
- delay of autumn streamflow rise;
- lack of winter flushing flows.

iii) Channel engineering and maintenance works:-

- reduced morphological diversity;
- reduced instream vegetation growth;
- loss of gravels;
- loss of coarse organic debris;
- loss of riparian vegetation (especially wetlands and trees).

Many degraded rivers reflect the history of agricultural intensification, industrialization and urban growth over the past 250 years. Streamflow changes, for example, have been caused by a range of human activities including land drainage, land-use change, urban growth, water resource developments and flood control.

The National Rivers Authority has a statutory responsibility to further conservation, improve fisheries and promote recreation through regulatory, operational and advisory activities. In particular, the Authority is required to:
"so exercise its functions as to further the conservation and enhancement of natural beauty and the conservation of flora, fauna and geological or physiological features of special interest..." (Section 48 Wildlife and Countryside Act 1981 & Section 16.1 Water Resources Act 1991).

One river for which concern has been growing since the mid-1970's is the River Glen, Lincolnshire (Figure 1.1). The river drains low-lying hills formed of permeable Lincolnshire Limestone and summer river levels are maintained by spring flows from the limestone aquifer. Reports suggest that by 1976, abstractions had already lowered groundwater levels and springflows below their natural state. Further they suggest that the declining flows in the River Glen had had deleterious effects on the biology and fisheries of the river.

1.2 <u>The Project</u>

The River Glen, in common with other catchments, requires management plans to meet river quality objectives and environmental targets. In particular methods are required to assess biological quality in relation to flow and to distinguish between the effects on biota of the different factors identified in 1.1.

The project, commissioned by the National Rivers Authority, Anglian Region (formerly Anglian Water Authority), has two primary aims:

i) to develop an approach for assessing the main management-influenced and natural factors affecting the flora and fauna of rivers;

ii) to apply the approach to the River Glen and to make recommendations as to how the river could be managed to enhance its conservation value and fish stocks, especially in relation to sport fishing.

The Report is in two main parts. This, the first part, describes the approach developed during the Project, summarizes the application of the various methods to the River Glen, and presents recommendations for river enhancement.

The second part comprises six Annexes and provides a detailed examination of the River Glen catchment.

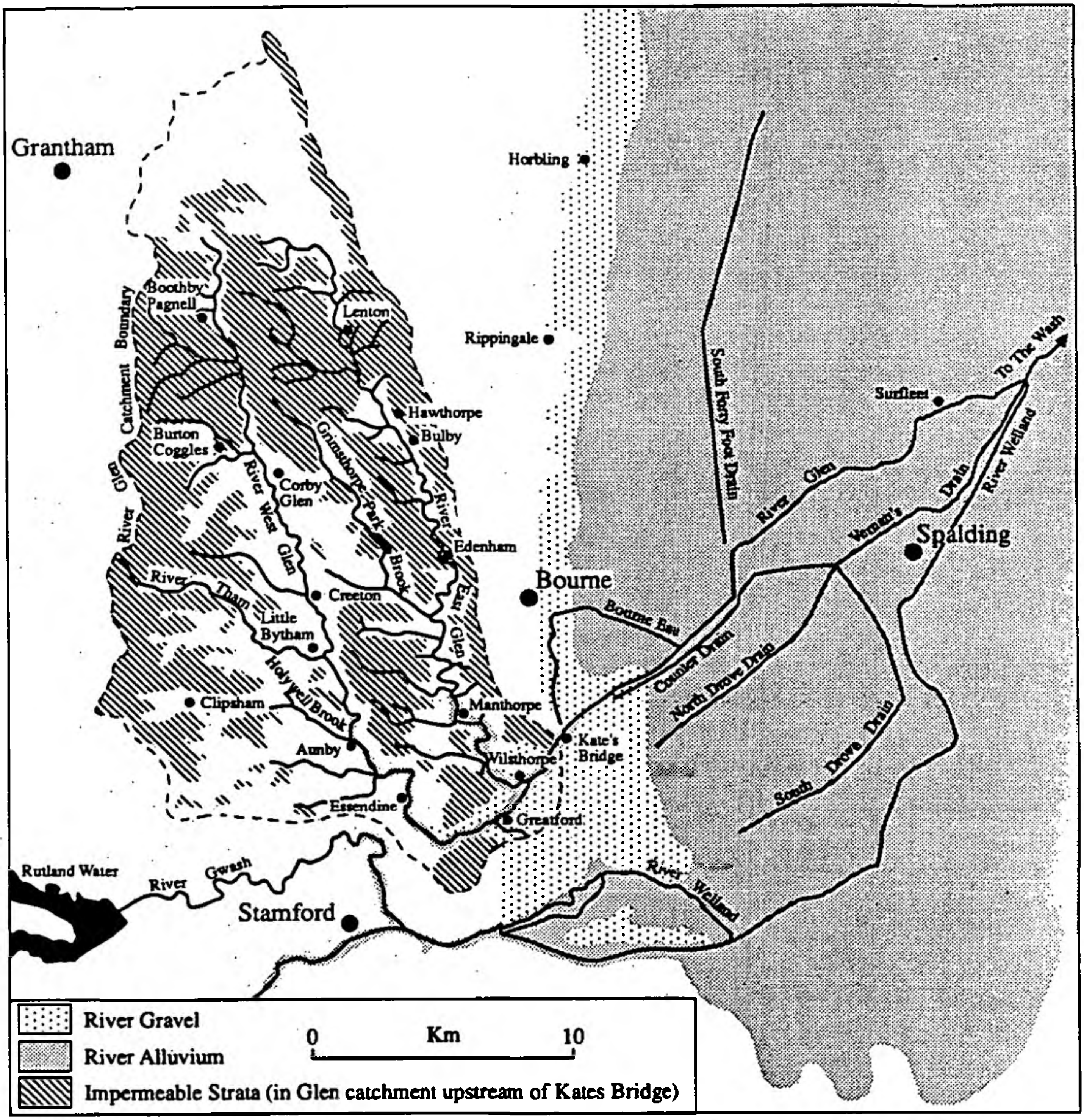

Figure 1.1 - The Glen catchment.

1.3 Rationale for Restoration

Any assessment of the cause of river degradation, and of the options for rehabilitation, must be scientifically-based and practicable for management. Over the past three decades scientific research on rivers has elucidated many of the complex relationships that link hydrology, geomorphology and ecology, as well as defining biotic interactions. The challenge has been to present the scientific information in such a way so as to be appropriate for management. In this context, following the recommendations of the 12th Report of the Royal Commission of Environmental Pollution (1988), 'reasonably practicable' means having regard, among other things, for local conditions and circumstances, the financial implications, and the current state of technical knowledge.

River management involves the consideration of three main options (Boon, 1992).

- For rivers that are essentially pristine, there is an overwhelming case for *preservation*; the challenge is to distinguish and then allow natural change, whilst protecting the river from artificial influences. In most cases, the pressures for land and water development, and the resulting problems of waste disposal, will require management to limit artificial changes within the catchment and to mitigate the impacts of human actions.
- At the other extreme are rivers or sectors that have become so severely degraded that in the short and medium terms the only management option is to accept *dereliction.*
- Acceptance of the need to define some rivers as derelict, at least in the short term, may be necessary to direct resources not only to high quality rivers and sectors deserving protection but also to those that have a fair chance of being improved by the third option, *restoration.*

The rationale for restoring fluvial hydrosystems relates to their values for biological conservation:

- to maintain essential ecological processes;
- to preserve genetic diversity; and
- to ensure sustainable utilization of species and ecosystems.

The focus is on the long-term benefits of biological conservation to humans.

River corridors are particularly important in biological conservation and environmental restoration for five reasons:

- they have high biological diversity;
- they have high biological productivity;
- they contain refuge habitats;
- they include refugia from the pre-industrial period; and
- they are sources for species dispersal.

River corridors also have a range of socio-economic values related to their recreational potential and high visual quality. In the UK rivers have particularly high value as game and coarse fisheries. For example, declared catches of Sea Trout in England and Wales between 1983-86 had an estimated minimum value of £55 million (Elliot, 1989).

In a recent socioeconomic study to prioritise recreation activities (NRA R&D Project 276) Glyptis et al (1992) emphasized the importance of both water-based and water-related recreation. River corridors are particularly attractive for casual recreation (Green and Tunstall, 1992). Public are attracted to river corridors that are (i) unpolluted; (ii) quiet, rich in flora and fauna, and form attractive landscapes; and (iii) have basic facilities such as toilets and paths, reflecting important public concerns for the safety of children and general public health. The proximity of housing to a river corridor can also substantially increase the attractiveness of an area as a place to live.

1.4 Approach

A framework is required to direct scientific information to restoration objectives, recognising the multifunctional nature of catchment management, involving: water resources, water quality, flood control and land drainage, fisheries, recreation, conservation and navigation. The approach employed herein defines appropriate space and time scales which are both practicable for management and scientifically defensible.

1.4.1 Consideration of scale

A river may be considered at the scale of the drainage basin, which changes only slowly in response to natural or artificial disturbances, or at the scale of small 'pioneer' patches, such as sediment deposits and marginal backwaters, which are highly sensitive to disturbance and quick to respond to natural and artificial changes of the environment (Figure 1.2). <u>To assess river degradation, and the options for management, the appropriate scale is the sector.</u>

A hierarchy of scales are available. Within the drainage basin a sequence of river types may be defined, corresponding to upland, lowland and intermediate situations. At this level of analysis such variables as altitude, distance from source and the slope of the valley floor are important.

Each river type may be sub-divided into discrete sectors which comprise distinctive sets of patches. Variations between individual sites within a sector, each comprising a particular subset of patches, relates to local conditions (bank sediments, riparian vegetation, spring inflows, sewage outfall, etc.) or short-term changes, such as may occur following a major flood event. For example, erosion and deposition during a flood may create a locally braided site within an otherwise stable, meandering channel sector.

Pioneer patches, such as the gravel bar, sand berm, and new cutoff channel, are highly sensitive to environmental variations, especially to changes of the magnitude and frequency of floods and of the sediment load regime (both amount and size distribution). However, they recover relatively quickly from short-term perturbations.

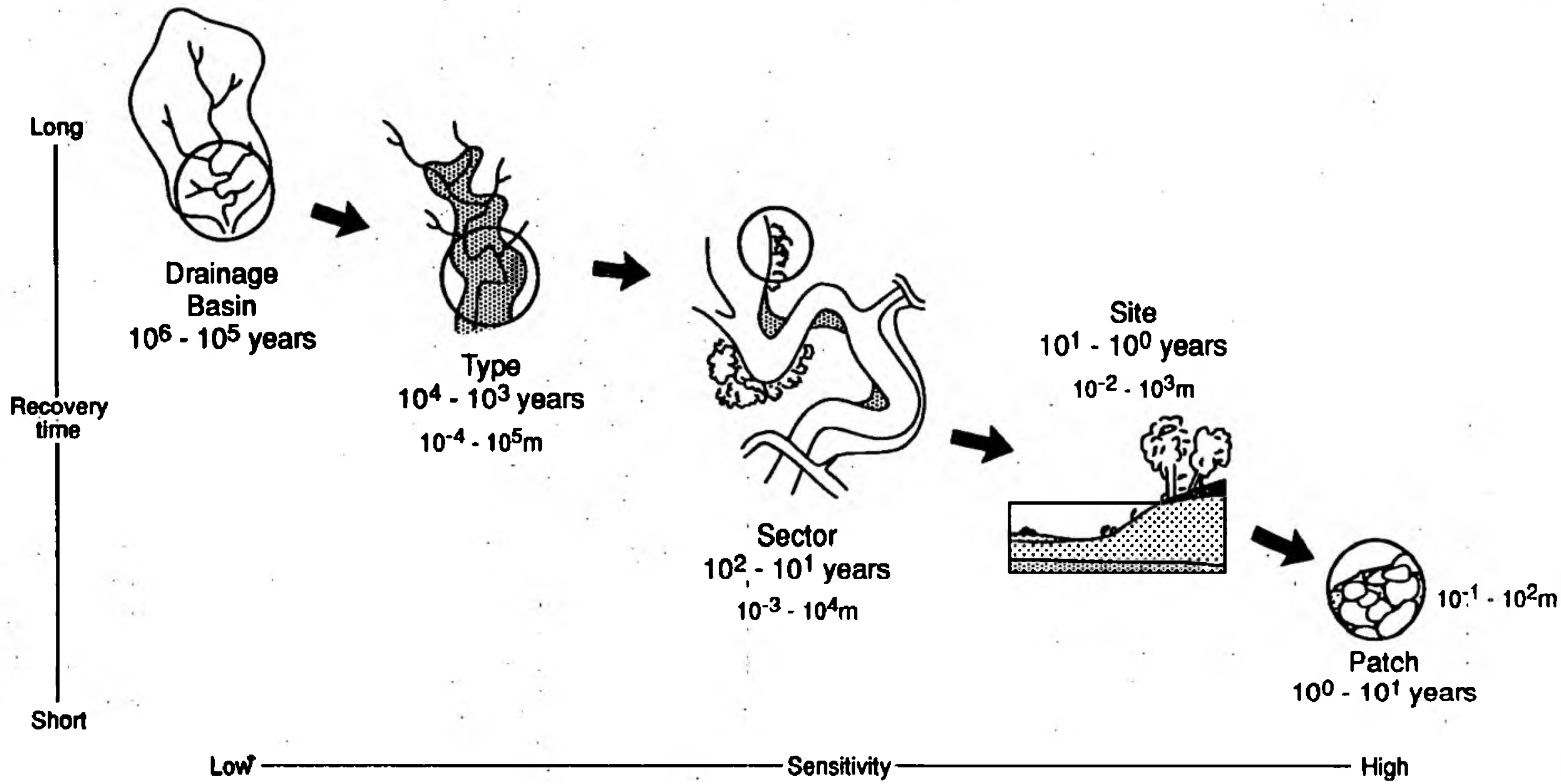

Figure 1.2 A functional classification of rivers

1.4.2 Scientific basis

The approach, which adopts the 'fluvial hydrosystem perspective' (Petts and Amoros, 1993), provides a practical framework for ecologically-sensitive river management by emphasizing three important principles:

i) Each sector must be viewed in the context of its *catchment* as its hydrology, sediment supplies and water-quality are dominated by inputs from upstream.

- Water-quality, especially the influence of point- and diffuse-source pollution, is the major constraint for sector-scale restoration.
- The allocation of water is required for restoration, incorporating minimum flows, an appropriate flow regime based on average monthly flows, and high flow 'events' at the appropriate time(s) of year.
- Changes of sediment yield from headwater catchments, reflecting landuse practices, and the interruption of sediment transfer along rivers by dams and weirs (many of which are several centuries old) place major constraints on restoration.

ii) Within each sector, relationships may be defined between environmental processes, channel morphology and biota.

- Each sector can be described by a more or less complex arrangement of aquatic, semi-aquatic and terrestrial patches (habitats) of different type (defined primarily by morphological, sedimentological, and vegetational criteria) and age (reflected by successional criteria for each type).
- The arrangement of patches within a sector changes over time in response to successional processes and disturbance (by erosion and deposition). The location of specific patches within a sector may change over a timescale of 10-100 years, but the composition of patches within each sector will remain relatively stable, about an average condition.

iii) *Lateral exchanges* play an important role in sustaining the functioning of river sectors. The role of the ecotone concept in river management is to focus attention on the transitional zone, or dynamic boundary, at the land-water interface (Petts, 1990). The concept emphasis two points:

- the importance of river margins for aquatic fauna and flora; and
- the role of fluvial dynamics in sustaining the structural and functional characteristics of the river margins.

River margins are important for running-water ecosystems because they act as buffer zones between the channel and adjacent land-uses, they provide habitat for aquatic biota during high flows, and they contribute organic matter ranging from fine particulate material to coarse debris. River margins ecosystems are determined primarily by hydrological variations and geomorphological disturbance, and are highly sensitive to external controls.

1.5 Application

This Report develops the above approach in six stages, each one being illustrated by reference to the River Glen:

- Preliminary Assessment
  - i) Database Assessment & Historical Appraisal;
  - ii) Definition and Classification of Sectors;
- Analysis of Biological Records
  - iii) Analysis of NRA Fisheries Records;
  - iv) Analysis of NRA Invertebrate Records;
- Development of Flow-Habitat-Biota Relationships
  - v) Identification of Key Environmental Variables influencing Biological Quality within Channel Sectors;
  - vi) Assessment of Biological Responses to Habitat Variables within Channel Sectors (PHABSIM).

The Report concludes with recommendations for restoring the River Glen. An assessment of the ecological effects of the Gwash-Glen water transfer are presented in an Appendix. Based on experience gained during the River Glen Project, recommendations are also made to further improve the approach.

2. DATABASE ASSESSMENT & HISTORICAL APPRAISAL

2.1 Database assessment

Information about rivers and their catchments is obtained and archived by the different functions within the National Rivers Authority, and by other organisations. The collation, synthesis and critical evaluation of the information available is an important first step in any study of river systems concerned with environmental degradation, not least because of the many factors that may be involved (see Section 1.1). It is important to examine all hydrological and ecological data relating to the present and recent periods, but it is also necessary to investigate the historical character of the river. This last is especially important if the causes of degradation are to be assessed objectively, as many 'impacts', such as channelisation, have a long history extending over 100 years or longer. There are five main types of data required to fully assess the nature of river degradation, as outlined below.

2.1.1 Background data

Background data ncludes topographic maps, geological information (maps, borehole logs, and reports), land-use data (maps and records), and land-drainage records. For example, land-use data may be derived from the 1st (1931) and 2nd (1963) Land Utilization Surveys, and agricultural census data assembled by MAFF/ADAS on an annual basis. There may also be important historical documents concerning public health, transport engineering (roads, railways and especially navigation), and water/river developments (dam building, flood control works etc.).

2.1.2 Hydrological data

Hydrological data include rainfall data, flow data from gauging stations and current-metering surveys, borehole data describing groundwater levels, and records of artificial influences (abstractions and effluent returns). Observations of notable events may be assembled from Annual Reports of the NRA, the former River Boards and Water Authorities, and from newspaper cuttings.

Data on artificial influences are available from three sources. i) The Abstraction Licence Consents Register is a catalogue of all abstraction licences granted within specified catchment areas which contains information on the maximum amount of water a licensee is permitted to abstract. ii) The Annual Abstraction Licence returns record the actual amounts of water abstracted. iii) All permitted effluents are recorded on the COPA register.

2.1.3 Water-quality data

Water-quality data include effluent returns, data from continuous monitoring sites and routine sampling surveys, and records of pollution incidents.

2.1.4 Information on the channel

Information on the channel is available from grant-aid submissions, reports and maintenance files related to Capital Works and Channel Maintenance. River Corridor Surveys, undertaken by the NRA, English Nature and other conservation groups can also prove valuable. A series of topographic maps, surveyed at different dates, can provide particularly useful information on changes of channel pattern.

2.1.5 Biological data

Biological data include invertebrate sampling records, usually undertaken as part of water-quality surveys, and quantitative fisheries surveys. Information on rare species, especially mammals and birds, are available from conservation bodies such as English Nature and the Royal Society for the Protection of Birds, and local conservation trusts can usually provide valuable data on Red Data Book species as well as more common ones.

2.2 The River Glen Database

A review of baseline data for the River Glen is presented in Annex A: 'The Nature, Availability and Extent of Data and Information relating to the River Glen and its Catchment'.

Quantitative data for elucidating the causes of environmental degradation along the River Glen are restricted to the past three decades, and for most purposes to the post-1980 period. From the viewpoint of low flow studies this is a particular problem because the baseline 1960's happened to be an unusually wet decade. More details about the flows are given in '*An Environmental Assessment of the Proposed Increased Development of the Southern Lincolnshire Limestone*' a report by G.E.Petts prepared on behalf of the National Rivers Authority Anglian Region, in 2 volumes, and published in May 1990.

The history of flows in the Glen, especially floods, can be reconstructed in qualitative terms, by using a range of documentary evidence which extends back to the mid 18th Century.

2.2.1 Background data

Topographic maps are available from 1860. Geological information is available from several publications, and a 1:25000 map has been produced. Twenty geological profiles for boreholes within about 800m of the main river courses are available.

Land-use maps have been compiled from the 1st Land Utilisation Survey of Britain (1931) and the 2nd Land Utilisation Survey of England and Wales (1963). Although the majority of the catchment lies within Lincolnshire, five parishes lie in the former county of Rutland and Agricultural Census Data (Parish Summaries) are held in the MAFF Offices in Lincoln and Leicester. There is also a 1971 air survey with 218 photographs in stereo pairs, and an accompanying report.

A series of 'area of benefit maps', produced in 1986, define land-use categories within floodable land adjacent to the river. Land drainage data are limited: the area is not within any Internal Drainage Boards operational area, and the responsibility of the River Board, Water Authority, and now National Rivers Authority extends only to Main River. MAFF/ADAS Field Drainage Experimental Unit hold a database on field drainage schemes which records when and where approval has been given by the Ministry for a grant to be made to an applicant farmer (95% of all such works qualify for grant support). However, only Parish data, and not field data, are available.

2.2.2 Hydrological data

Rainfall data for 22 stations are available for the Glen catchment. One station (Irnham, NGR TF022265) has a rainfall record from 1904 to 1968, but in general prior to 1970 data are sporadic in both spatial and temporal coverage. The longest continuous rainfall record to present, at Old Somerby (NGR SK964339), dates only from 1972.

Streamflow is recorded at 14 stations, the longest record being initiated in 1960 (Kates Bridge). With the exception of Kates Bridge, many stations have low-flow weirs and are drowned-out during flood discharges. Current-meter surveys were undertaken in January 1976 and March 1977. Also, a large number of internal reports and scientific papers are available, especially on the groundwater hydrology of the catchment.

Surface water abstractions from the Glen are mainly for spray irrigation and the exercise of license rights is, as expected, most severe between June and August during dry summers. There are 12 sewage treatment outlets and two private (industrial) outlets, each having legal water-quality effluent consent conditions.

2.2.3 Water-quality data

Records of pollution incidents are available from 1950. Chemical monitoring of the Glen has evolved over three periods:

1964-74	Average, maximum and minimum values for nine chemical parameters are available for one site on each of the West Glen (Corby Glen) and East Glen (Edenham), two sites on the main Glen (Tongue End and Surfleet), and four sites on the Bourne Eau.
1975-88	Data for 32 sites are available from the annual '712 Statistical Summary Report' which gives summary data for each site, and individual site data are held on archive. Water quality data for groundwater are also available, as are records of samplings downstream of registered/permitted effluents.
1988-present	There has been a marked reduction in spatial coverage since 1988 but the frequency of sampling has increased, with a target of once each month.

Core parameters, pH, conductivity, water temperature and dissolved oxygen prevail throughout the dataset but prior to 1988, the data is of limited value for this study because i) there is a lack of continuity from year to year in the number of samples collected, and ii) the streamflow at the sample site at the time of survey was not recorded. The latter limitation relates to the problem of separating trends in water quality from the fluctuating influence of dilution associated with runoff variations.

2.2.4 Data on the channel

Data on the channel are available from four main sources: the river corridor survey undertaken in 1989; 'in house' Capital Grant Aid submissions and project appraisal reports (the oldest being the 1960 River Glen Improvement Scheme Report); 'in house' operations maintenance files from about 1985; and anecdotal newspaper cuttings dating back to the 1880's. Flood damage to the embankments along the lower Glen have been recorded back to 1821.

The 1860 Ordnance Survey maps record 24 locations of channelisation, where the former meandering channel has been converted to a straight course.

2.2.5 Biological Data

Biological data is of three types:

i) *Invertebrate records* are available for 44 sites on the Glen and its tributaries, with the earliest records being for 1976. Data relate to a 3-minute kick sampling to incorporate all habitats within a 50m reach. Problems relate to the lack of consistency in the number of sites sampled during the year, the frequency and timing of sampling during the year, and the variable taxonomic level of identification between records.

ii) *Vegetation surveys* were carried out during the 1970's by the Nature Conservancy Council (now English Nature) and a river corridor survey was published in 1989 (NRA, 1989).

iii) *Fisheries surveys* were not undertaken systematically before 1980, although material in River Board Annual Reports and local newspapers highlight mortalities, the quality and quantity of sport, and stocking. The baseline survey of 1980 electrofished 23 sites. Subsequent surveys were undertaken in 1983/4, 1986 and 1988.

2.3 The River Glen: a Historical Appraisal

Review of the available information on the Glen indicates that the degradation of the environmental quality of the river, which is suggested in particular by the fisheries data, has taken place over a long period of time. Perception of the potential quality of the river may be exaggerated because the baseline for information happens to be the 1960's - high-flow decade.

There is a long history of water abstraction from the Lincolnshire Limestone, and records of water levels in boreholes suggest a progressive decline of maximum and minimum reset levels since about 1940. Over the same period there has been an eastward movement of the western limit of artesian overflow.

Ecological information, such as the decline of the apparently good trout fishery (see frontispiece) and the loss of over 150,000 fish in the lower Glen in 1976 coincident with extremely low groundwater levels and flows, has been used as evidence of the effects of over abstraction.

Water-quality problems have declined in recent years but sewage effluent remains responsible for poor quality in some reaches, although this may be exacerbated by the current low rainfall and low flow conditions. Furthermore, land-use change between 1932 and 1963 included an expansion of the arable area which may have resulted not only in increased storm runoff but also increased nutrient loads in the river.

The morphology of the channel has been drastically altered throughout its length, by ditching and straightening. Earliest works occurred during the 18th and 19th centuries. There is no doubt that these and subsequent works have contributed to the degradation of the river, reducing habitat diversity and creating unsuitable conditions for some species.

Perhaps the most interesting document found during the search, was the note book of John Grundy of Spalding (1719-1783), housed in the library of the Institution of Civil Engineers. During works within the area of the Grimsthorpe Estate he described the ground as "chasmmy and full of swallows". His descriptions indicate that in the 1740's the Grimsthorpe Brook was an ephemeral stream, drying-up during summer. This suggests that much of the upper Glens, at least, may have been ephemeral even under pristine conditions.

Grundy also noted that many swallow holes were infilled with soils and muds. It is not unlikely that dredging associated with channelisation and land-drainage schemes may have reactivated swallow holes, or at least removed the stratum of "clay and strong soil" that Grundy describes as lining the channel floor. Probably the first channelisation works on the Glen, the East Glen at Edenham, was planned by Grundy in 1756 - his 'improvement' of the stretch between two (road) bridges involved "a new cut to straighten the channel".

3. DEFINITION AND CLASSIFICATION OF CHANNEL SECTORS

3.1 Aim

To define distinct channel sectors within which fauna and flora are related to flows and channel structure.

3.2 Data requirements

A preliminary classification of sites along a river should be based on the sector scale, as described in 1.3, above. The criteria used to define sectors are those variables that influence the important hydrological, geomorphological and ecological processes:

- a measure of scale (stream length, drainage area, stream order, stream magnitude);
- a measure of location (altitude);
- a measure of hydraulic energy (slope);
- measures influencing hydrological response (rock type and land-use);
- a measure of local controls (riparian landuse).

A general classification of sectors should be derived by reference to topographic maps (1:25,000 scale) showing the stream network, geological/soil/land use maps, and river corridor surveys. More detailed (field) information should then be obtained. This requires a complete physical habitat survey of entire channel length, supported by routine hydrological surveys and/or comprehensive gauging station flow data.

3.3 Methodology

3.3.1 Phase I

i) Map sources are used to 'order' the main stream reaches between tributary confluences and to define for each reach its 'magnitude' and slope, as illustrated in Figure 3.1.
ii) Geological, soil, and landuse maps are examined to divide the catchment into areas. Major changes in 'type' are then used to define any likely discontinuities in the downstream change in character of the main river.
iii) Land-use data and river corridor surveys are used to define the riparian character of each reach.
iv) Reports and other documentary evidence are also considered.
v) Adjacent like reaches are then combined to form sectors having relatively uniform internal characteristics.

3.3.2 Phase II

Designed to assess the character of the river under low flow.

i) Survey entire river under low flow conditions monitoring instream physical habitat, a typical record sheet is given in Table 3.1. Measurements taken during this survey fall into three categories:

a) habitat type
b) habitat condition
c) habitat scale

Good quality habitats are:

riffles (i.e. areas of relatively shallow water with visible flow and a broken water surface at low flow);
runs (i.e. areas of shallow-moderate, uniform, water depth with visible flow, without a broken water surface and usually occuring over greater distances than riffles);
pools (i.e. areas of relatively deep water delineated at the upstream and downstream boundaries by the presence of distinct riffles).

Poor quality habitats are:

deep runs with visible flow;
stagnant runs with deep water and no visible flow;
dry channels.

Habitat scale is determined by measuring channel-bed width and water width (to the nearest 10cm). Measurements should be recorded at every 50m or at every riffle site which ever is the closer. Other records, such as the maximum water depth over riffles or bank character (erosional, stable, depositional) may be added according to the purpose of the investigation.

Each sector can then be described in terms of habitat scale - recognising that the proportion of dry bed can be of benefit for some terrestrial species as well as to the detriment of others - and the relative importance of the different habitat types and conditions. Presentation of sector characteristics involves frequency diagrams, e.g. of channel width, which highlight both the average condition and the variability within the sector, and pie diagrams showing the percentages in each habitat type or condition, to allow comparisons of reaches between different sectors (see Figure 3.3) and of reaches within the same sector (see Figure 3.4).

DATE__________ RIVER______________ SITE__________ GRID REF.__________

TRAN-SECT NO.	DIST DOWN (M)	HABITAT						CHANNEL WIDTH (M)	WATER WIDTH (M)	THALWEG DEPTH (CM)	SUBSTRATE							% COVER	
		A	B	C	D	E	F				D 1	S 2	S 3	G 4	C 5	B 6	B 7	IN	OVER
1 U/S																			
2																			
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NOTES

HABITAT
A = RIFFLE
B = RUN
C = POOL
D = DEEP RUN
E = STAGNANT RUN
F = DRY

SUBSTRATE
1 D = PLANT DETRITUS
2 S = SILT (< 0.063 mm)
3 S = SAND (0.063 - 2 mm)
4 G = GRAVEL (2 - 64 mm)
5 C = COBBLE (64 - 250 mm)
6 B = BOULDER (250 - 4000 mm)
7 B = BEDROCK (solid rock)

Table 3.1 - Typical physical habitat survey sheet.

ii) Design a stream gauging network.

All existing hydrological data should be reviewed, including the extent of the gauging station network and quality of data, and any previous stream gauging surveys. Sites for routine hydrological surveys should be chosen with reference to:-

a) location of existing gauging stations;
b) distribution of channel sectors;
c) areas known for importance in terms of water gains/losses from the channel;
d) sites used for previous stream gauging surveys to allow comparison; and
e) ease of access e.g. road bridges, farm tracks, public footpaths

Routine hydrological surveys use standard current-meter techniques at the shortest time intervals that are feasible, preferably monthly or less, especially during low-flow periods.

iii) Target key habitats.

For particular investigations detailed study may be required of key habitats and it may be necessary to undertake specialist field work. One of the most common problems is the siltation of salmonid spawning habitat.

3.4 Application to River Glen

Full details of the Glen are presented in Annex C. Synthesis and review of information available on the River Glen allowed the provisional classification of the river into a series of sectors which were then refined using three sets of field data: physical habitat survey, hydrological survey, and target habitat assessment to assess the suitability of channel substrate for salmonid spawning habitat.

The 'scale' of each channel sector defined by the morphometry of the drainage network, and the location of each sector within the network, is illustrated using Strahler's 'ordering' and Shreve's 'magnitude' systems (Figure 3.1). Differences in the construction of each index are highlighted by comparing the East and West Glen. The West Glen has the higher stream order but the East Glen contains more first-order streams and consequently has a greater Shreve 'magnitude'. Table 3.2 summarises the chief characteristics of each sector.

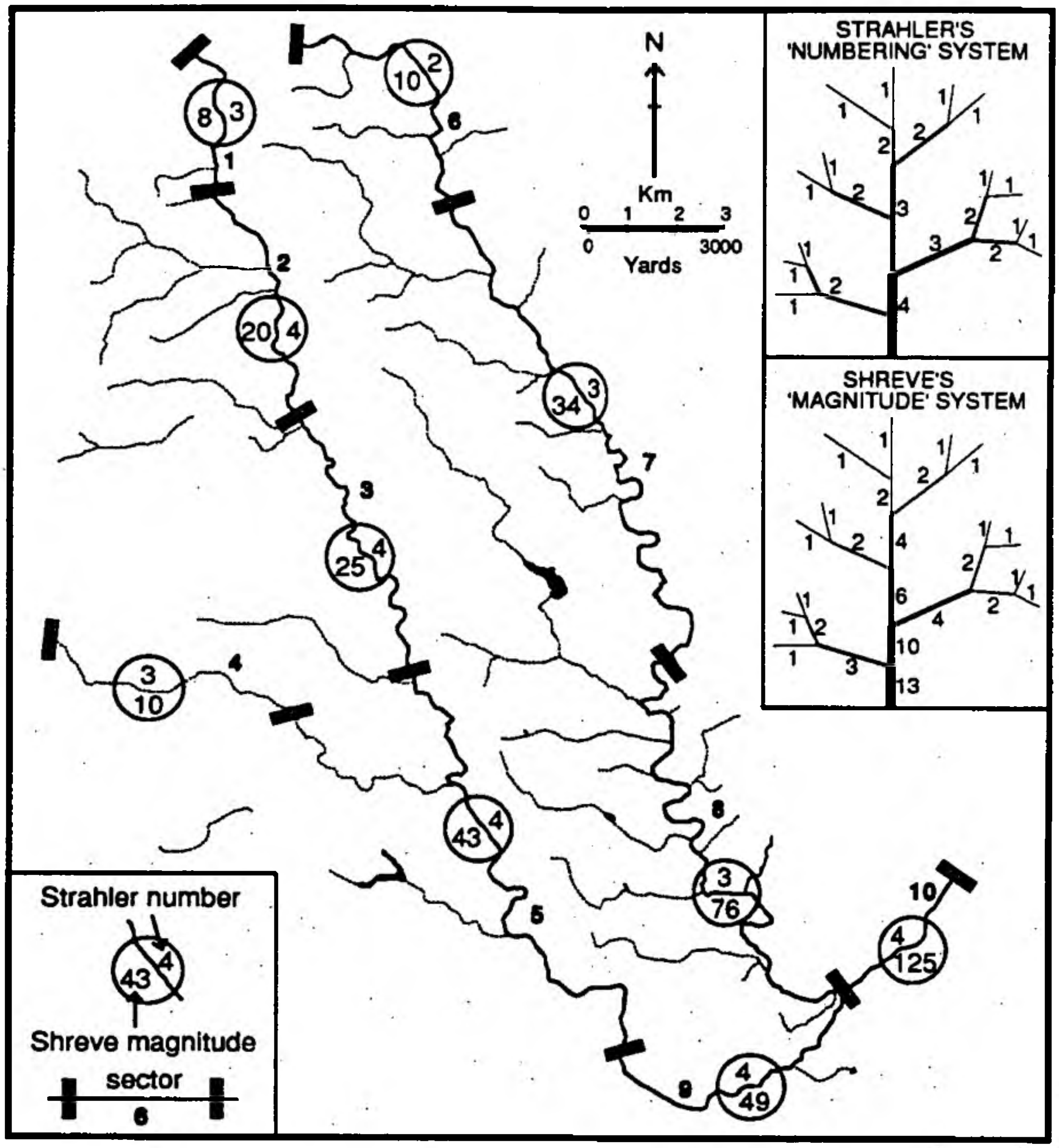


Figure 3.1. - Definition of channel sectors with their associated stream 'magnitude'

Table 3.2. - General characteristics of channel sectors.

Sector Number	Length (km)	Average Channel Width (m)	Maximum Strahler Number	Maximum Shreve Order	Altitude (m.a.s.l.)	Slope	% Riffles	% Pools	% Run	% Dry	% Stagnant Run	% Deep Run
1	3.75	1.7	3	8	99	.0048	0	0	0	64	36	0
2	6.38	2.9	4	20	81	.0028	23	2	10	0	64	1
3	8.16	3.9	4	25	63	.0025	8	1	4	65	20	2
4	7.55	N/A	3	10	114	.0081	NO	DA	TA	AVA	LAB	E
5	13.76	5.6	4	43	43	.0016	37	7	12	6	12	26
6	6.70	2.2	2	10	91	.0058	2	0	0	65	32	1
7	17.26	3.8	3	34	52	.0016	25	3	3	1	65	3
8	13.72	5.2	3	76	24	.0010	6	2	0	65	27	0
9	7.19	6.5	4	49	21	.0015	25	6	8	4	15	42
10	2.17	10.6	4	125	10	.0009	3	3	0	0	94	0

A physical survey of the West and East Glens from their source to the confluence was undertaken between 21/8/89 and 28/9/89. A full set of 1:2500 scale maps of the main river were obtained from the NRA Anglian region. Each A4 size map contained a coded reach approximately 500 m in length. Measurements in the field were taken at every tenth of the reach length or at every riffle site, whichever was the closer. At each point, the location was assigned to a habitat category (see 3.3.1). A total number of 823 measuring points were recorded along 39.25 km of the West Glen and 762 points along 36.77 km of the East Glen.

A simple habitat index was defined as water width divided by channel width. A value of 1.0 represents the entire bed taken up by water and a dry bed has a value of 0. By using each ten consecutive data points, the moving average of the wet width against distance downstream for both rivers is shown in Figure 3.2. The headwaters of the West Glen were dry downstream to Boothby Pagnell WTW. Wet width then shows an increasing trend as far as the potholes (Plate 4) just downstream of Burton Coggles gauging station where the channel again becomes dry. Flows were then intermittent until the confluence with the River Tham whereafter wet width remained at values of approximately 0.7 channel width. The pattern on the East Glen shows a contrasting picture with the middle reaches containing water and the lower reaches (i.e. below Edenham) dominated by a dry channel.

The use of geomorphological characteristics to describe sectors, and reaches within sectors, is illustrated in Figures 3.3 and 3.4. Figure 3.3 compares the physical habitat of two representative reaches in different sectors: from Little Bytham to Careby and from Shillingthorpe to Greatford. For each case, the downstream variation of channel width, and the summary distribution of widths are presented, together with pie diagrams describing the proportion of habitat types. The data clearly shows the difference between the good quality upstream sector dominated by riffles and the poor habitat quality of the downstream sector dominated by deep and stagnant runs. The poor quality of this reach is related mainly to ponding by a weir at Greatford, but even in the upper part the river has been channelised.

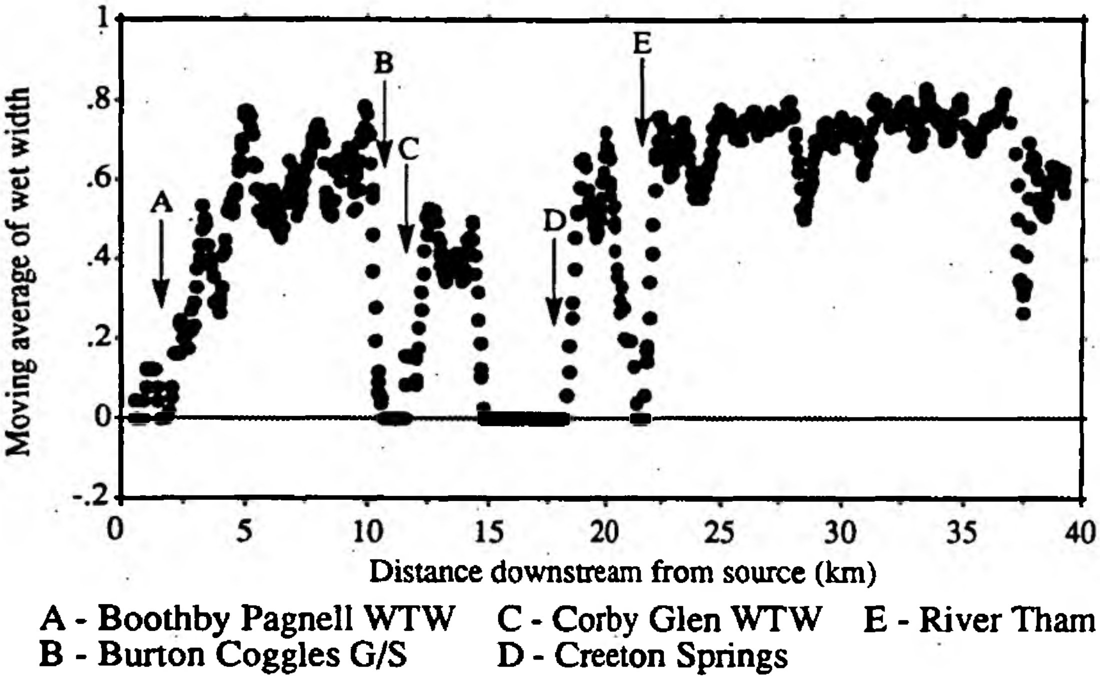


Figure 3.2a. - Moving average of wet width against distance downstream for the WEST GLEN

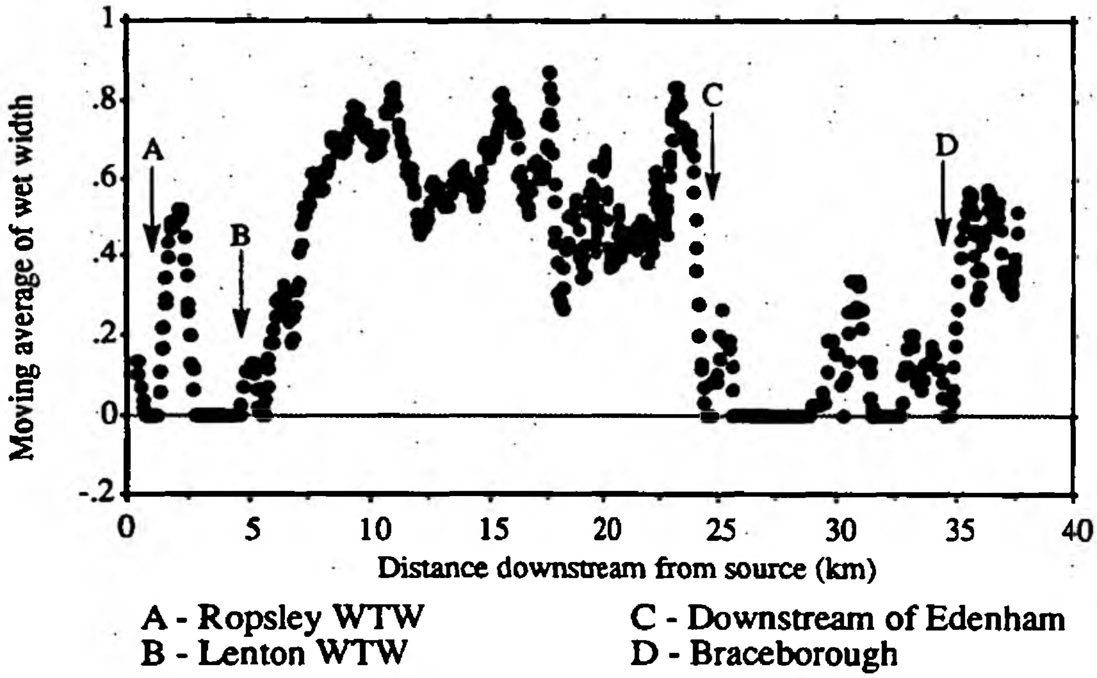


Figure 3.2b. - Moving average of wet width against distance downstream for the EAST GLEN

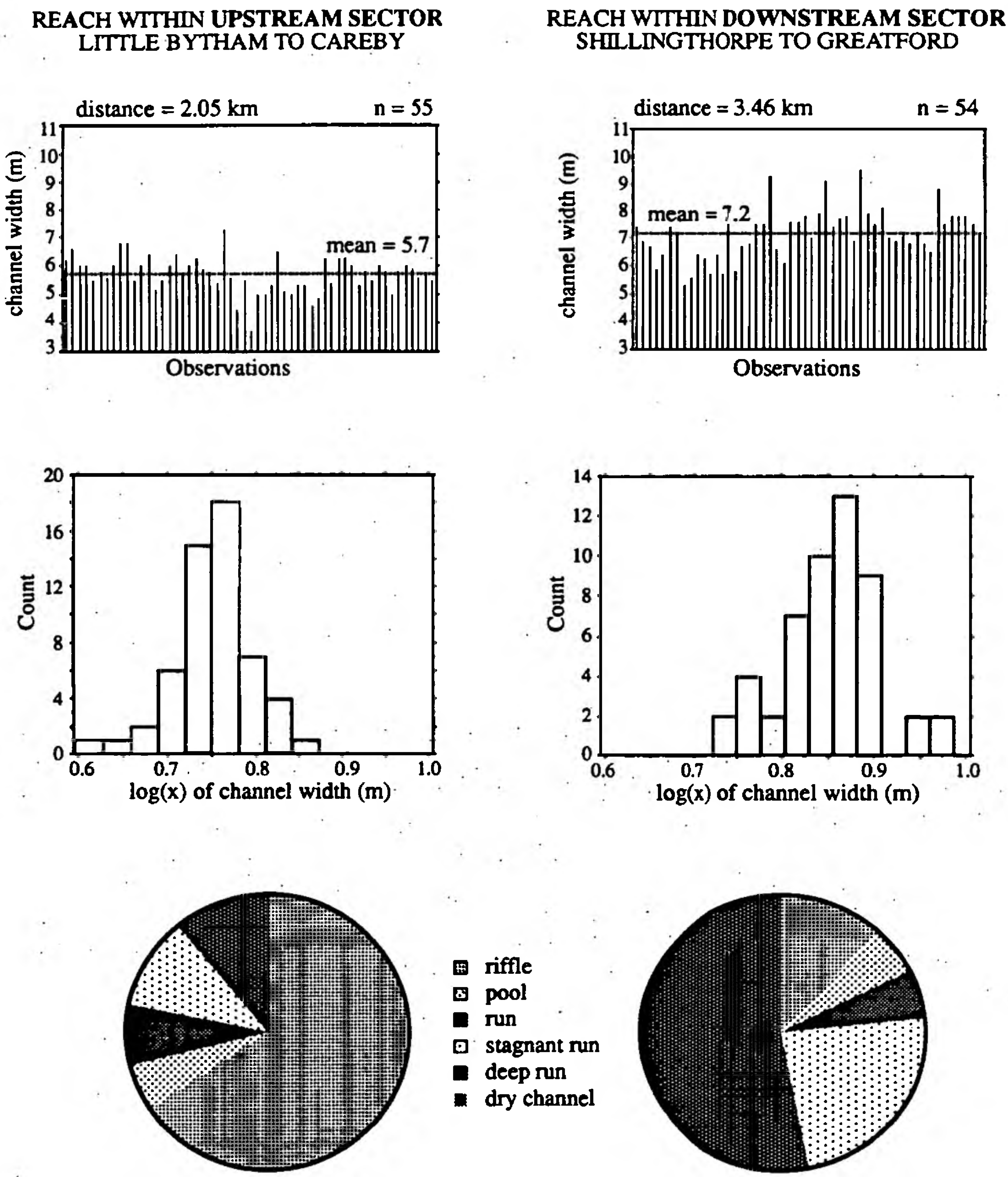


Figure 3.3. - A comparison of the physical habitat of two reaches in different sectors along the West Glen. The top graph represents the size of the channel, the middle graph highlights the frequency distribution of the channel width and the pie charts highlight the relative importance of the six habitat types along each reach.

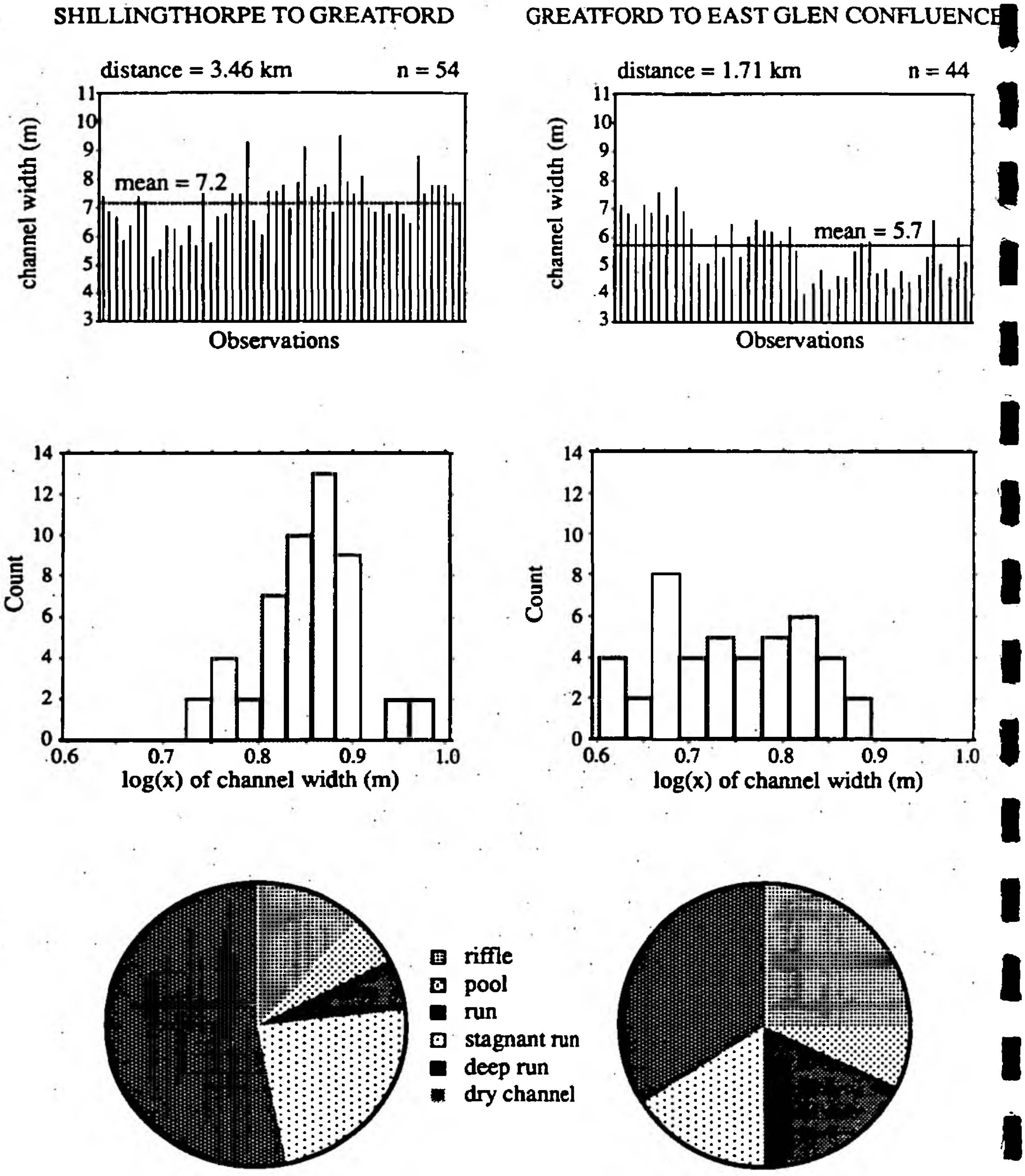


Figure 3.4. - A comparison of the physical habitat of two reaches within the same sector along the West Glen. The top graph represents the size of the channel, the middle graph highlights the frequency distribution of the channel width and the pie charts highlight the relative importance of the six habitat types along each reach.

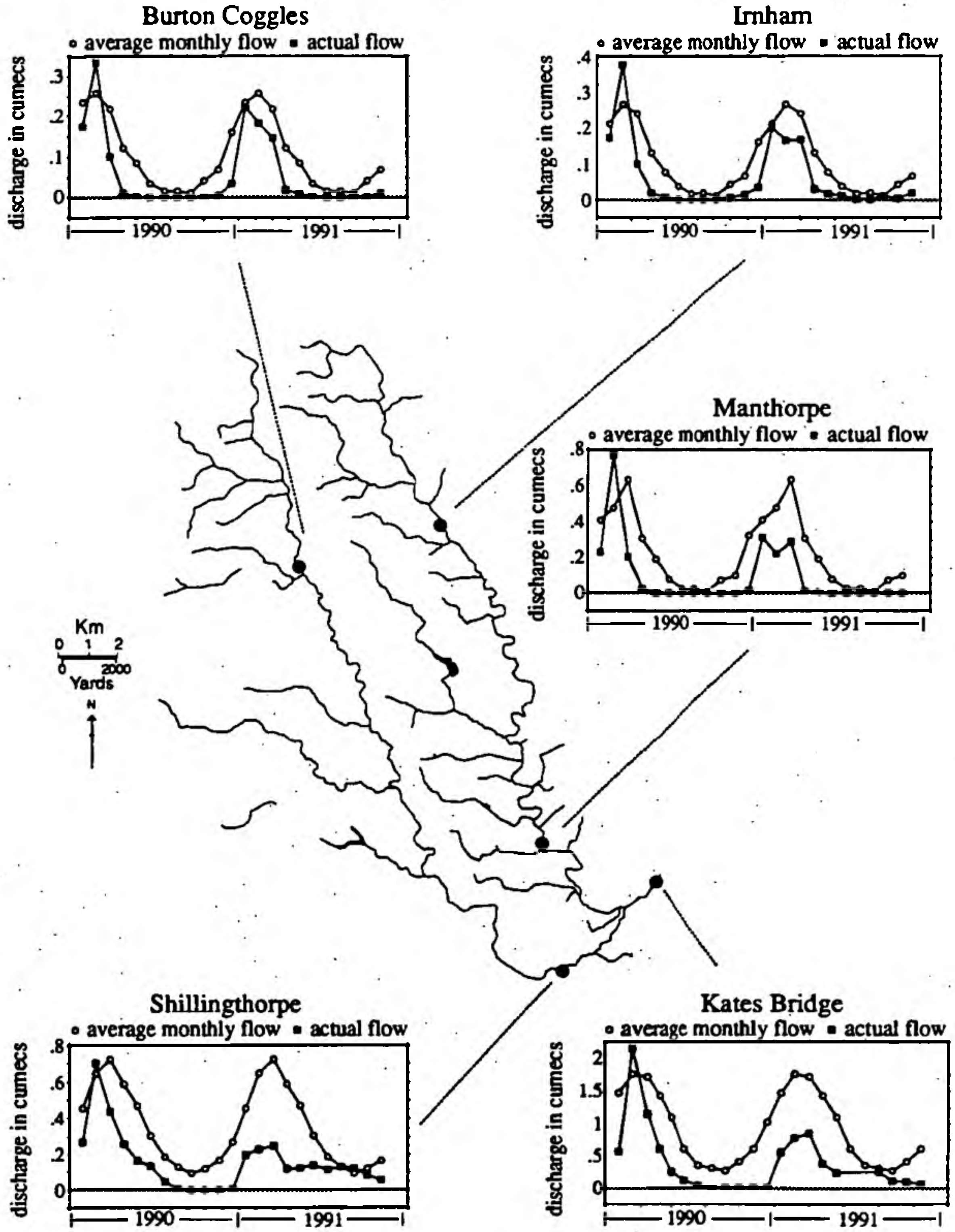


Figure 3.5. - Long term average monthly flows (∘) and actual recorded (▪) flows during 1990 and 1991 for the five main river gauging stations. Long term average monthly flows for each station are based on the period from when flow records commenced (i.e. Burton Coggles 1964, Irnham 1969, Manthorpe 1968, Shillingthorpe 1968 and Kates Bridge 1960) to 1991 inclusive.

Figure 3.4 compares the same characteristics for two reaches within the same sector, from Shillingthorpe to the East Glen confluence. The upstream reach is the same as that used in Figure 3.3 and the downstream sector is from Greatford to the East Glen confluence. This highlights the decrease in overall channel size downstream of Greatford Cut due to the diversion of floodwaters from the main channel and also the improved distribution of habitat types within this lower reach.

The hydrological survey involved current-metering at 17 sites chosen to supplement the information provided by the network of 7 NRA gauging stations (Figure 3.5). Site selection was also based on previous current-meter surveys undertaken during the 1975-77 drought. At each site, 21 surveys were made between January 1990 and November 1991. The occurrence of extreme low flows throughout the study period is clearly seen.

The results allow detailed analysis of the hydrological dynamics within sectors, enabling the downstream pattern in the duration and magnitude of gains and losses to be defined. On the basis of these results the sites were classified as:

i)	perennial flow -	a)	stable flow or with gains
		b)	with consistent losses
ii)	intermittent flow -	a)	goes completely dry
		b)	retains pools

The Water Treatment Works, especially those at Boothby Pagnell, Corby Glen, Lenton and Edenham, are seen to sustain pools at intermittent-flow sites that would otherwise become dry. On the West Glen downstream from Essendine the river is dominated by losses. Here the river flows over substantial alluvial gravels, representing the former delta of the late-glacial river Glen/Gwash/Welland. From the confluence of the East and West Glens downstream to Kates Bridge, influent conditions are experienced with average gains of 0.054 $m^3m^{-2}d^{-1}$ (about 1.2 tcmd).

Detailed investigations of the nature of gains and losses from the West Glen between Essendine and Greatford used both current-metering and a temperature profiling technique. The results confirmed the pattern of influent and effluent conditions along the channel and suggested that this sector comprises three groups of sites. In the upper and middle reaches, water loss through the channel bed occurs at rates of up to 0.227 $m^3m^{-2}d^{-1}$; the middle reach dried out in 1990. The maximum rates of water loss equate to about 5 tcmd (0.055 m^3s^{-1}) through the Essendine to Shillingthorpe reach. In the downstream reach return-flow from the gravels, at average rates of about 0.03 $m^3m^{-2}d^{-1}$, sustains perennial flow. The maximum rate of return flow recorded was 0.253 $m^3m^{-2}d^{-1}$.

3.5 Target Habitat

A perception of the West and East Glens as trout streams highlighted the need to assess the quality of target habitats, in this case the quality of river gravels as spawning habitat. The rationale for this study was the established negative relationship between trout production and the degree of siltation of spawning grounds, which may be enhanced by the lack of flushing flows. In general terms habitat quality is inversely related to the proportion of the substrate that is finer the 2 mm (i.e. the proportion of sand, silt and clay). Full details are given in Annex D.

A freeze-sampling method (Petts et al., 1989) was used to obtain undisturbed depth profiles through the channel substrate at 16 sites. At each site five 'cores' were removed yielding a composite sample weight of over 20kg.

The substrate comprises a surface layer of fine to medium gravel (24-62 mm) but this is only one particle deep. Beneath this layer the substrate is of sandy gravel (less than 30% finer than 2 mm) or gravelly sand (more than 30% finer than 2 mm). Clean gravels, with less than 20% finer than 2 mm, occur only on the upper Tham and at Braceborough where the average depth of substrate is very restricted, being 9 cm and 11.6 cm respectively. At most sites the depth of substrate exceeded 25 cm. Moderately clean gravels within the upper 15 cm of the substrate are found at Aunby, Carlby and Essendine, although beneath this layer the substrate is quite compact. Below Essendine, the substrate contains high levels of fines throughout the profile.

The sediment data defined three distinct sectors: from Greatford downstream; from below Essendine to Greatford; and from Essendine to Little Bytham. These sectors correspond to those defined on the basis of hydrological characteristics. None of the sectors provide high quality spawning grounds, either because of the small size of the gravel, the large amounts of fines within the substrate, or the shallow depth of substrate. Nevertheless, the Little Bytham-Essendine sector contains substrate that provides usable spawning habitat.

4. ANALYSIS OF NRA FISHERIES DATA

4.1 Fish Records

Data are available for five electrofishing surveys in 1980, 1984, 1986 and 1988. It is clear from these data and related reports that the River Glen system can be divided into two separate fisheries: 1) the West and East Glens and the Glen between the confluence and Thurlby Fen, and 2) the Glen below Thurlby Fen. The weirs at Greatford, Kates Bridge and Fletland Mill restrict fish movement.

4.2 Spatial variation in biomass and species composition

Figure 4.1 displays the longitudinal changes in species composition along the River Glen system. Based on the relative dominance of species, the system can be roughly divided into the following zones.

- Middle West Glen - relatively high proportions of Dace and Brown Trout occur at Little Bytham and Aunby, together with lesser proportions of Pike and Eel.

- Lower West Glen, and main Glen to Thurlby Fen - high proportions of Dace and Chub, but with Pike or Eel frequently dominant.

- Lower East Glen - dominated by Dace and Eel with rare Brown Trout, probably excluded by extreme low flows and organic pollution.

- Lower Glen from Thurlby Fen to Surfleet Seas End - relatively high proportions of Common Bream and Roach, but frequently dominated by Pike and occasionally Eel.

These zones correspond well with groups of physically defined sectors (Section 3). It is notable that there is a difference in species composition between Kates Bridge, Wilsthorpe and Thurlby Fen, and the other lower Glen sites, a division that coincides with the sharp transition in surface geology from delta gravels (upstream) to fen peat, silts and clays (downstream).

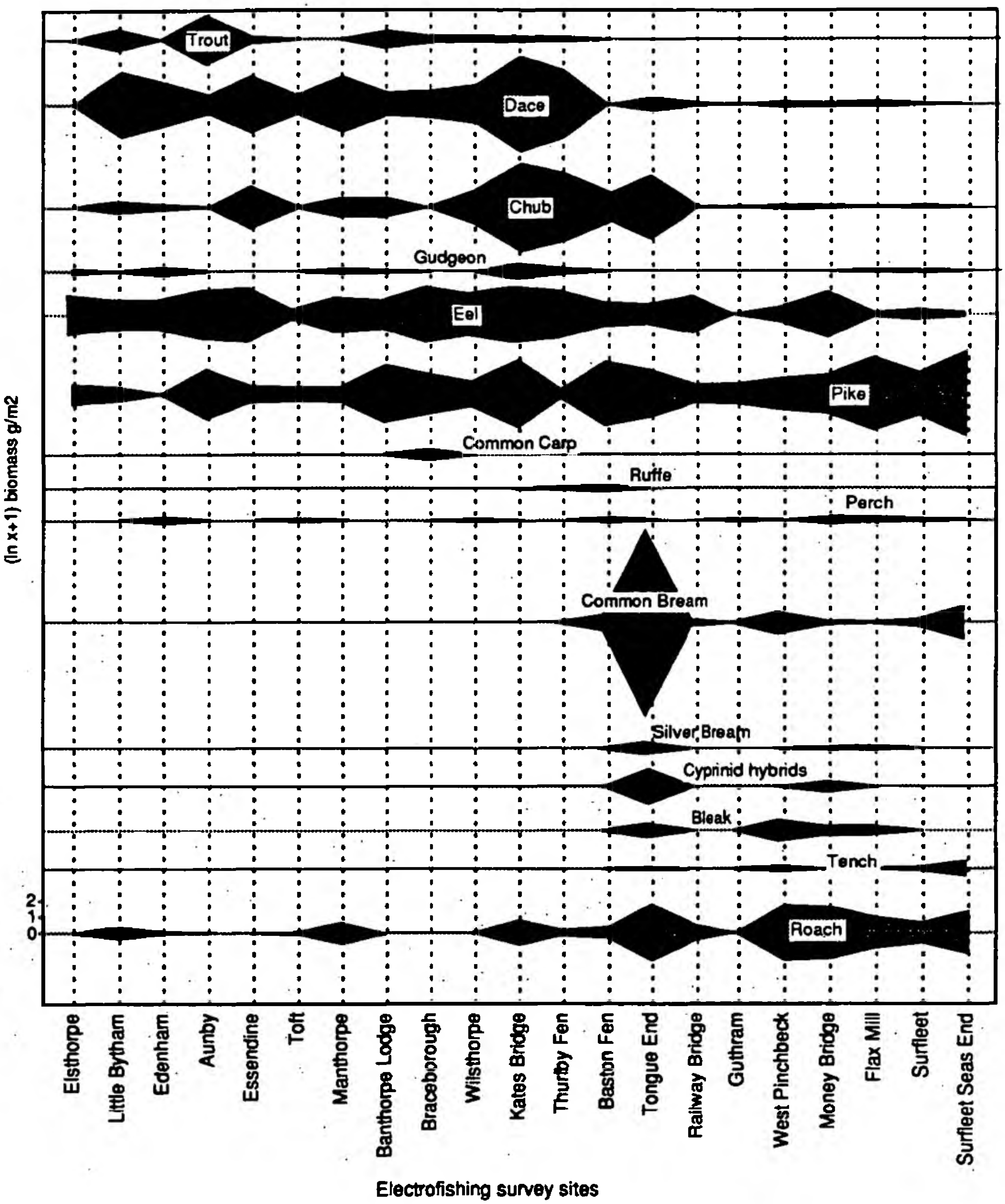


Figure 4.1 Mean fish biomass (ln g/m2) for all species, from four NRA electrofishing surveys: 1980, '84, '86 and '88. Sites are arranged in approximate order of stream length.

4.3 Biomass and species composition changes between surveys

Figure 4.2 illustrates the change in mean biomass (gm^{-2}) of the most abundant fish species at each survey for the West, East and lower Glens. Wilsthorpe has been included in the lower Glen category. Reports suggest that fish populations in both sections were severely reduced by the 1976 drought, with the effects on the populations still evident up to the 1986 survey.

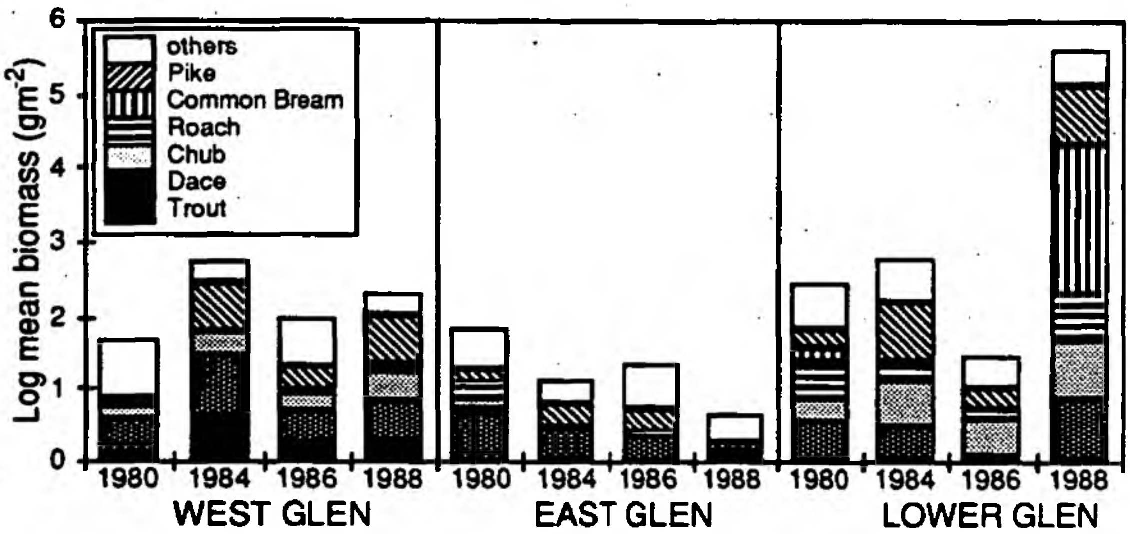


Figure 4.2 Variation in biomass of dominant fish species (1980 to 1988)

Populations were believed to be stable in 1986, ten years after the previous major drought. Recovery was thought to have been more effective in the West Glen than the East Glen where flows remained relatively low. In 1988 the West Glen showed a markedly higher biomass, with Pike the dominant species (36%), Dace subdominat (27%). Brown Trout formed 10% of the biomass. The East Glen showed a general decline in biomass from 1980 to 1988. In the last survey Eels were the dominant species (67%).

In the lower Glen the post-1976 recovery was aided by a program of restocking, with the addition of 9,500 fish pre-1984. The dominance of Pike observed in the 1984 survey and the large decline in biomass in 1986 prompted recommendations for further additions of Roach and Bream. Over half of the recommended weight of fish had been stocked by the time of the 1988 survey, which recorded a marked improvement in biomass and a shift from Pike to Bream as the dominant species, although this observation was mainly due to an exceptional catch of Bream at Tongue end.

4.4 Biomass, species composition and habitat

Biomass and species composition differences in the West and East Glens mirror differences in biological quality measured using macroinvertebrates (see Section 5).

High catches of Dace and Chub at Kates Bridge and Thurlby Fen have been attributed to the concentration of fish in deeper areas in this otherwise shallow section. Recommendations for the building of fish weirs to increase depths were made in 1988.

In the lower Glen, reports from the 1988 survey and angling records suggest that the distribution of cyprinids is highly contagious; the location of high fish concentrations being dependent on flows, turbidity and temperature and hence highly seasonal. Overall the Common Bream population is regarded as satisfactory for angling requirements, with the status of the Roach population less clear but believed satisfactory.

5. ANALYSIS OF NRA INVERTEBRATE RECORDS

5.1 NRA invertebrate records

For most British rivers, records of the invertebrate fauna exist from a number of sites which have been routinely monitored over a period of years using a standardised kick-, sweep- and search-sampling technique. Frequency of sampling, and taxonomic level of identification, varies between records. However, for most rivers the data are sufficient to allow an analysis of spatial and temporal variability in the invertebrate fauna which can be interpreted in the light of information on the physical nature, pollution and hydrological history of the catchment.

5.2 Method of analysis

Figure 5.1. illustrates a sequence of analyses designed to elucidate the maximum information from a set of invertebrate records for a hypothetical river system. It is assumed that some, at least qualitative, information is also available on the habitat characteristics of the system, including substrate type, macrophyte development, water chemistry, hydrology and management, and recent and long term changes in these variables.

5.2.1 Collation and standardisation of invertebrate records

Information from the recording forms, or print-outs of records held on computer, is entered into a spreadsheet (e.g. Microsoft EXCEL). The first column contains a list of taxa, and subsequent columns each represent a sample record, with 1's entered against taxa collected in the sample, and headed by a sample code indicating location and date. Rows are inserted as and when new taxa are recorded. After all the records have been entered, rows are sorted into taxonomic order. Where a taxon could have been recorded under several names e.g. *Baetis vernus* could have been recorded variously under Baetidae, Other Baetidae, *Baetis* sp., *Baetis* indet., *Baetis vernus/tenax* or *Baetis vernus*, it is necessary to standardise by grouping such records to the appropriate taxonomic level, i.e. in this example in the single row: Baetidae (Figure 5.1.a).

5.2.2 Classification and ordination of samples

Two multivariate methods of analysis - TWINSPAN (Hill, 1979) and CANOCO (Ter Brak, 1988) - when used in combination are effective in assessing the similarities and differences in invertebrate community data (Figure 5.1.b).

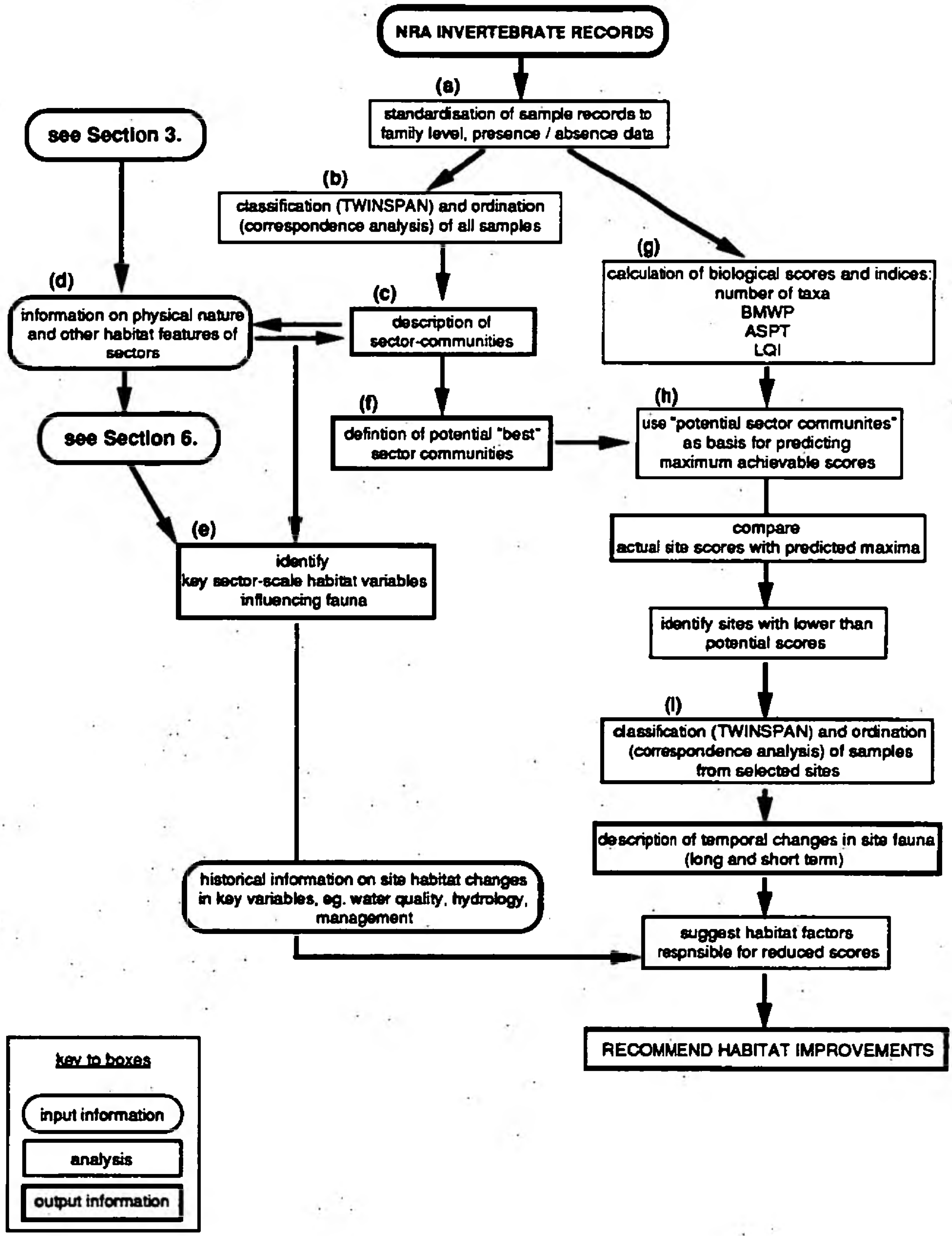


Figure 5.1. Proposed methodology for the analysis of NRA invertebrate records.
(a) - (i) indicate stages of analysis referred to in the text.

Sample classification using TWINSPAN

Two-Way Indicator Species Analysis can be used to classify samples on the basis of the standardised faunal data into groups from different river types, sectors, reaches and sites sharing similar invertebrate communities.

TWINSPAN classifies samples into a series of end groups using a hierarchical system of divisions. Each division is characterised by a list of "preferential" taxa which are significantly more frequent in one side of the division or the other. It also identifies "indicator" taxa, on the basis of the presence or absence of which alone the same classification could be produced. The "indicator" taxa chosen are frequently the rarer taxa associated with each group, rather than more common taxa with large differences in frequency, even though these may be more ecologically significant. The preferential taxa of the main TWINSPAN ordination are therefore more useful in describing the common characteristics of the groups, although indicator taxa are useful as a shorthand for the differences between groups and are commonly shown in the dendrograms drawn from the output. In some instances "key" taxa can be defined - these are the most strongly preferential taxa whose presence or absence is believed to be particularly significant in group-separation.

TWINSPAN places greater weight on similarities in taxa present than on the absence of taxa, with the result that samples with very reduced communities tend to be grouped with others of which their faunas are subsets, at least in the earlier divisions. For this reason the TWINSPAN classifications should be viewed in conjunction with the correspondence analysis ordinations (see below) which are more effective at identifying sites with an absence of commoner taxa.

Sample ordination using CANOCO

A suitable ordination method for presence / absence data is correspondence analysis: available as an option in the CANOCO package.

Correspondence Analysis allows samples to be grouped according to similarities in their taxonomic composition. As such it is a useful tool both on its own for grouping samples and for confirming the groupings produced by complementary analyses such as TWINSPAN.

Correspondence Analysis is recommended in preference to any form of Detrended Correspondence Analysis (e.g. DECORANA). In the analysis of large data sets of invertebrate records to investigate major differences in groups of samples, the small benefits of detrending in eliminating some mathematical errors are considered to be outweighed by the problems that exist with the detrending process which invalidate the interpretation of the distance between points in the ordination diagram. Detrended analyses are more appropriate to examine differences between individual samples in relation to linear environmental variables.

5.3 Spatial variation and identification of sector type-communities

By using the above methods of classification and ordination it is possible to identify groupings of samples at different spatial scales.

Commonly, samples of different dates from the same site will group relatively closely (i.e. will be classed together at a high level in the TWINSPAN analysis, and group closely on the first and second axes of the correspondence analysis ordination diagram).

On the next scale, sites within sectors are expected to group together, and may join with adjacent sectors. This latter conforms to the idea that there will be a longitudinal change in fauna, or continuum, down the river system.

Depending on the size and physical diversity within the system under investigation, sector scale groupings of sites may be apparent, superimposed on the longitudinal pattern of change. These are most easily identified from the correspondence analysis ordination diagram, which indicates (qualitatively) the magnitude of differences between groups of samples. The number of sampling sites will limit the resolution of sector-scale differences where sectors are short and contain few sites, but in this case, type-scale groupings should still be apparent. Having identified sector- (or type-) groups, these can be related to TWINSPAN end groups by determining which end groups contain the majority of samples from the proposed sectors. The most strongly preferential taxa given by TWINSPAN for these groups can then be used to define the main faunal characteristics of these sectors (Figure 5.1.c). These taxa can be described as the "key taxa".

5.4 Potential sector communities

In addition to defining "key taxa", the TWINSPAN analysis can be used to estimate the potential "best" community (Figure 5.1.f) which any site in the reach could support, by compiling a total list of taxa associated with the TWINSPAN end groups representing the sector. The proposition that any site in the sector could potentially support this "best" community is based on the assumption that the fauna is limited by a range of habitat variables at the sector (or type) scale, but that within the limits of these variables, local factors at reach and site scale are influential. These local factors are potentially open to human influence through management, should habitat improvements be considered, which alter the distribution and proportion of habitats within the sector.

5.4.1 Biological scores and indices

Biological scores and indices (Figure 5.1.g) of water quality are frequently used to compare the status of a site at time of sampling with previous sampling occasions. It is suggested that the method of defining "potential best reach communities" described above could be used as a guide to setting target scores (Figure 5.1.h), which would take into account the reach-scale limiting habitat factors and hence provide realistic achievable targets. Differences between observed and calculated potential scores could be used to identify priority sites for habitat improvement.

5.5 Comparison with RIVPACS

The current NRA preferred option for ecological classification of sites on a national basis is the 'Ecological Quality Index' (EQI) based upon RIVPACS predictions (NRA, 1991). Superficially the proposed method fulfils the same rôle as RIVPACS in predicting the range of fauna which a given reach could support, but the proposed method facilitates the derivation of site EQI's at the local level. The two methods differ fundamentally in two ways:

- RIVPACS requires physical habitat information only, whereas the new method uses historical invertebrate data.
- RIVPACS predictions are based on a limited range of habitat variables, whereas the new method is responsive to the range of limiting factors at the local scale.

The method proposed herein is more sensitive at the sector scale than RIVPACS which has the advantage of being relatively easy to apply and can be used nationally. Where detailed information on a river system is required and sufficient background invertebrate data exists (or can be collected), it may be profitable to apply both methods. Indeed, differences between the two sets of predictions may give an insight into local controlling habitat factors otherwise overlooked.

5.6 Identification of key habitat variables

In order to usefully interpret the sector scale groupings of sites suggested by the invertebrate fauna, information on the physical nature of the reaches is needed (Figure 5.1.d; and see section 5.4 above). By comparing the known habitat preferences of the key taxa with the habitat characteristics of the proposed reaches, the key habitat variables of each reach which are influencing the fauna can be identified (Figure 5.1.e).

Separate analysis of the data from individual sites (Figure 5.1.i) to investigate long and short term changes in the invertebrate fauna is valuable in ascertaining the controlling habitat variables at this very local scale, and should be considered an essential precursor to decisions on habitat improvement. Examination of changes in the invertebrate fauna in conjunction with information on changes in other site characteristics can assist in the choice of remedial measures.

5.7 Analysis of the River Glen invertebrate records

The above methodology has been constructed with reference to, and tested against, the invertebrate records for the River Glen catchment.

5.7.1 The data set

The data set comprises invertebrate records from 44 sites on the main River Glen and its tributaries. These can be allocated to the *a priori* series of physically defined sectors (Figure 3.1). Sites are shown in Figure 5.2. Records for each site vary in frequency and distribution throughout the 1976-91 period. Because the taxonomic level of identification varies between records, the data used in the analyses have been reduced to presence / absence and family level.

5.7.2 Reach and site level differences in invertebrate fauna

TWINSPAN classification and ordination using correspondence analysis revealed distinct river type-, site- and (to a limited extent) sector-level differences in fauna which can be related to a variety of water quality, hydrological, hydraulic and other environmental variables. Figure 5.3 summarises the classification of sites (emboldened site codes indicate the majority of samples from this site falling in this group; plain text indicates just two or more samples). "Key taxa" are those showing strong preference for the group indicated. Classification and ordination distinguished four groupings of sites:

- sites from the Tham and middle West Glen, sites characterised by a rich fauna including taxa associated with upland environments;
- sites from the lower Glen (below Kates Bridge) and Bourne Eau, characterised by a rich fauna including taxa associated with lowland environments;
- sites from the lower West Glen, Braceborough at the bottom of the East Glen, and Kates Bridge, characterised by an intermediate fauna, sharing taxa with both the upland and lowland sites, and in many cases having higher diversities than either of these two;
- sites from the East Glen, upper West Glen and upper Tham, characterised by impoverished faunas.

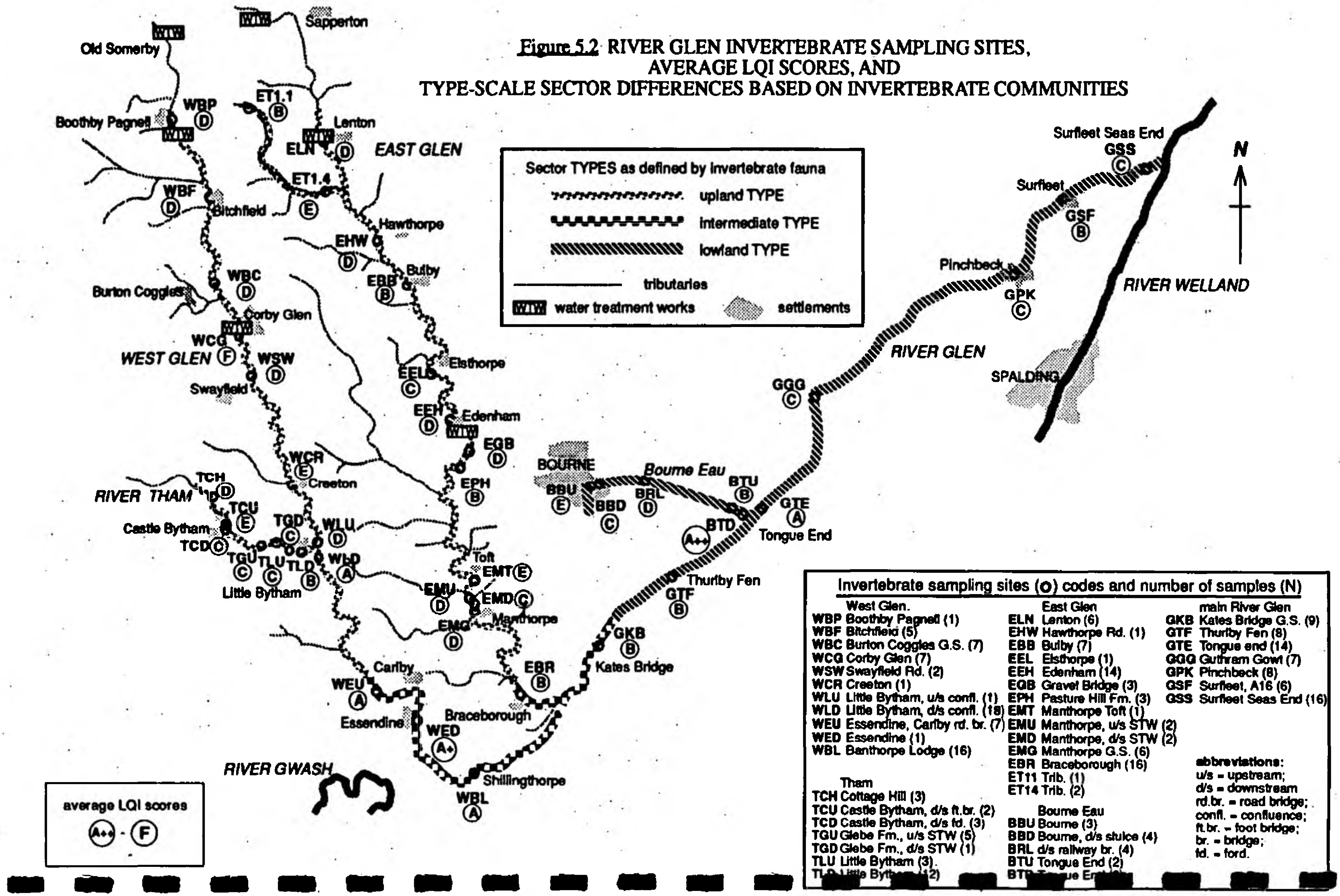


Figure 5.2 RIVER GLEN INVERTEBRATE SAMPLING SITES, AVERAGE LQI SCORES, AND TYPE-SCALE SECTOR DIFFERENCES BASED ON INVERTEBRATE COMMUNITIES

TWINSPAN division	8	9	10	11	12	13	14	15
TWINSPAN end groups	1-4	5-8	9-12	13-16	17-19	20-23	24-27	28-31
sites	**BTD** GTE GTF GTE	**GTF** **GTE** **GGG** **GPK** **GSS** **GSF** **BBU** **BBD** **BRL** **BTU** GKB EBR	**TCH** GTF GSS GPK WCG	**ELN** **EBB** **EEH** **EGB** **EPH** **EMG** **EBR** **WBF** **WBC** **WCG** TCU GKB WEU WBL	GKB	**EBR** **WEU** **WBL** **GKB** WLD	**WBF** EBR EEH WLD WBL	**WLD** **TCD** **TGU** **TLD** **TLU** EBR WBL
group description	lowland, slow-flowing, abundant macrophytes, good water quality, rich fauna	lowland, slow-flowing, macrophytes, reasonable water quality and fauna	intermittent, or poor water quality, very reduced fauna	poor habitat, poor fauna	good,diverse habitat, rich fauna	moderate flow, some macrophytes moderate water quality, intermediate fauna	moderate flow, clean substrates, rich fauna	moderate/fast flow, stable, clean substrates, macrophytes, rich fauna
key taxa	Leptoceridae, Hydrometridae, Gerridae, Notonectidae, Unionidae	Cladocera, Copepoda, Hydroptilidae	Cladocera, Copepoda	Glossiphonidae, Erpobdellidae, Asellidae, Sialidae, Caenidae, Elminthidae, Hydrobiidae, Planorbidae	Coenagriidae, Valvatidae, Helodidae, Psychodidae	Piscicolidae, Copepoda, Ephemeridae, Polycentropodidae, Psychomyidae, Gyrinidae		Dendrocoelidae, Piscicolidae, Rhyacophilidae, Hydroptilidae, Ancylidae, Goeridae, Glossosomatidae
	Piscicolidae, Cladocera, Coenagriidae, Hydroptilidae, Valvatidae, Physidae				Ephemerellidae, Notonectidae Physidae, Sericostomatidae, Gyrinidae		Rhyacophilidae, Ancylidae	
	Ostracoda, Cladocera, Coenagriidae, Valvatidae				Leptophlebidae, Ephemeridae, Ephemerellidae, Rhyacophilidae, Hydropsychidae, Limnephilidae, Goeridae, Ancylidae, Simuliidae, Polycentropodidae			

Figure 5.3. Summary of site groupings based upon TWINSPAN classification of samples. Key taxa are those showing a strong preference for the group indicated.

5.7.3 Habitat-fauna relationships

By comparing the faunal classification of sites with habitat information for the Glen catchment (Section 3) a close relationship was found between invertebrate fauna and habitat at the type and (to a lesser degree due to the limited number of samples) sector scales.

At the type scale, upland, intermediate and lowland sites could be defined using both fauna and habitat information, with the exception of two sites: the West Glen at Essendine and East Glen at Braceborough both possessed intermediate-type faunas, despite being physically classified as upland-type. A probable explanation for this is that both occur just upstream of the intermediate zone boundary, and could therefore be easily colonised by upstream migrating invertebrates.

At the sector scale, the relationship between the sites with upland type faunas and the sites with impoverished faunas could be clarified, and it is suggested that the majority of the latter group are best regarded as a restricted subset of the upland type, with the key habitat variable being low-flow characteristics (intermittent or perennial flow). For example, the West Glen at Bitchfield has an upland fauna, whereas sites in adjacent sectors upstream and downstream, have impoverished faunas. This reflects the fact that under low flows the sector containing Bitchfield has perennial flow whilst adjacent sectors go dry. Similarly, the Tham sites above Castle Bytham belong to the group with impoverished faunas, whereas those below Castle Bytham belong in the upland group. This reflects a change from an intermittent-flow sector to a perennial one where the Tham is sustained by Castle Bytham springs.

Habitat uniformity within the lower Glen did not suggest that this heavily-managed section should be subdivided into more than one sector, and this is supported by the analysis of the fauna, which is also relatively uniform.

5.7.4 Biological quality

Biological quality varied between sites in a way consistent with the divisions described above.

- The highest scoring sites were around the lower Tham and the West Glen below the Tham confluence, reflecting the diverse fauna of these sites and particularly the predominance of high-scoring insect taxa characteristic of these high-quality habitats.

- High scores were also obtained from the lower Glen sites round the Bourne Eau confluence - water and habitat quality is also high, but due to physical habitat differences the actual taxa present are very different from the Tham / West Glen.

- The interrelated factors: small size, intermittent flow and poor water quality are assumed to be responsible for the poor scores in the East and upper West Glens.

5.7.5 Temporal changes

The trend in biological scores during the period 1976-1991 demonstrated overall improvement the majority of sites showing a steep rise in all scores from 1976 to the mid to late 1980's, followed by a slight decline in 1991. Patterns of change did vary between sites: notably the lower main Glen sites displayed constant improvement in scores, "intermediate sites" showed a slight decline in 1990-91, and some East Glen sites steadily declined.

5.7.6 Within-site temporal changes

Detailed analysis of a number of sites confirmed the temporal trends mentioned above but revealed different faunal changes associated with temporal changes in biological quality. Responses to detrimental changes in habitat quality are complex, involving either:

- a reversion to a poorer fauna similar to that many years earlier, or
- a reduction of the fauna of the previous year.

5.7.7 Seasonal changes

Evidence was found for seasonal differences in the frequency of individual taxa and biotic scores, particularly ASPT. The greater seasonality in the life-histories of higher-scoring insect taxa, and/or the effects of low flows on the occurrence of taxa or sampling efficiency may account for the changes in ASPT. Variability in the frequency of sampling in each month prevented detailed investigation of seasonal changes using this data set.

5.7.8 Changes in invertebrate fauna with changing biological quality

Diversity within the higher LQI classes was high, with sector and site scale differences as clear within LQI classes as within the whole data set. This supports the theory that site- and sector-specific differences other than water quality are vital in determining the fauna. This was confirmed by examining changes in fauna associated with changes from LQI class B and C to class A-A++. Lower and higher scoring samples were classified separately, and three community types identified in each classification. For individual sites, the "improved" fauna associated with a change from the lower to higher class almost invariably belonged to the same community type, i.e. was the new fauna was predictable and dependent on the initial fauna, which in turn was related to specific sectors. Figure 5.4 summarises the dominant within-class sector groups and the taxa associated with changes from the lower to higher class.

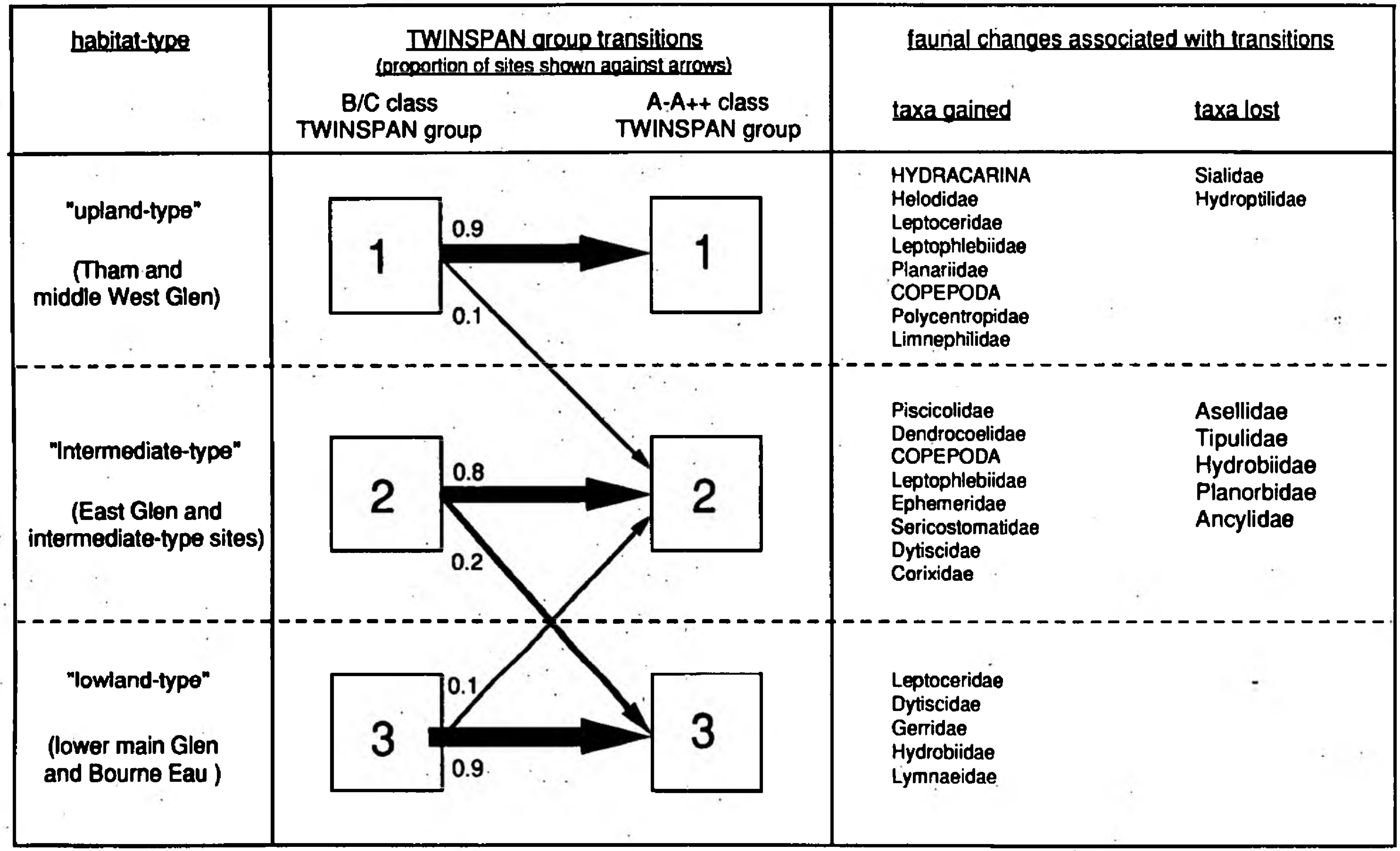


Figure 5.4. Predictability of change between LQI class B/C and class A-A++ samples within river type. Separate classification of the two LQI class groups allowed each to be divided into three sample-types (boxes), with "upland"(1), "intermediate"(2) and "lowland"(3) type faunas. In approximately 90% of cases where a site improved from LQI class B or C to class A-A++, the higher-class sample was classified as being of the same faunal type as the lower class sample.

6. IDENTIFICATION OF KEY HABITAT VARIABLES INFLUENCING THE BIOLOGICAL QUALITY WITHIN CHANNEL SECTORS

6.1 Introduction

Different species of fish, macroinvertebrates and plants possess characteristic behavioural traits which cause them to occupy different habitats in streams. Accurate quantification of the habitat variables which influence the biota in a stream has major repercussions for:

a) explaining the cause of declines in populations and
b) in making recommendations for maintaining, recreating or enhancing instream habitat for particular species.

The following section outlines the steps necessary to quantify the interaction and relative importance of the physical and chemical variables influencing the habitat for instream biota.

6.2 Method

Figure 6.1 illustrates the sequence of steps necessary to define the most influential variables for describing instream habitat for particular species. The aim is to establish spatial relationships between biota or biotic indices and environmental variables for rivers of similar type, that is within the same general biogeographic region. Only sites showing stable biotic characteristics are examined. Poor quality sectors may then be compared with good quality sectors and recommendations made for restoring the poor sector and protecting the good one.

6.2.1 Selection of biota in question

The first step must be to define whether fish, invertebrates or aquatic vegetation are to be the focus of investigation. Then the particular index that describes the variable must be selected. For fisheries this may be biomass or numbers for all fish present or one particular type, such as trout. Alternatively for invertebrates this may be number of taxa or one of the established biological indices such as BMWP or ASPT.

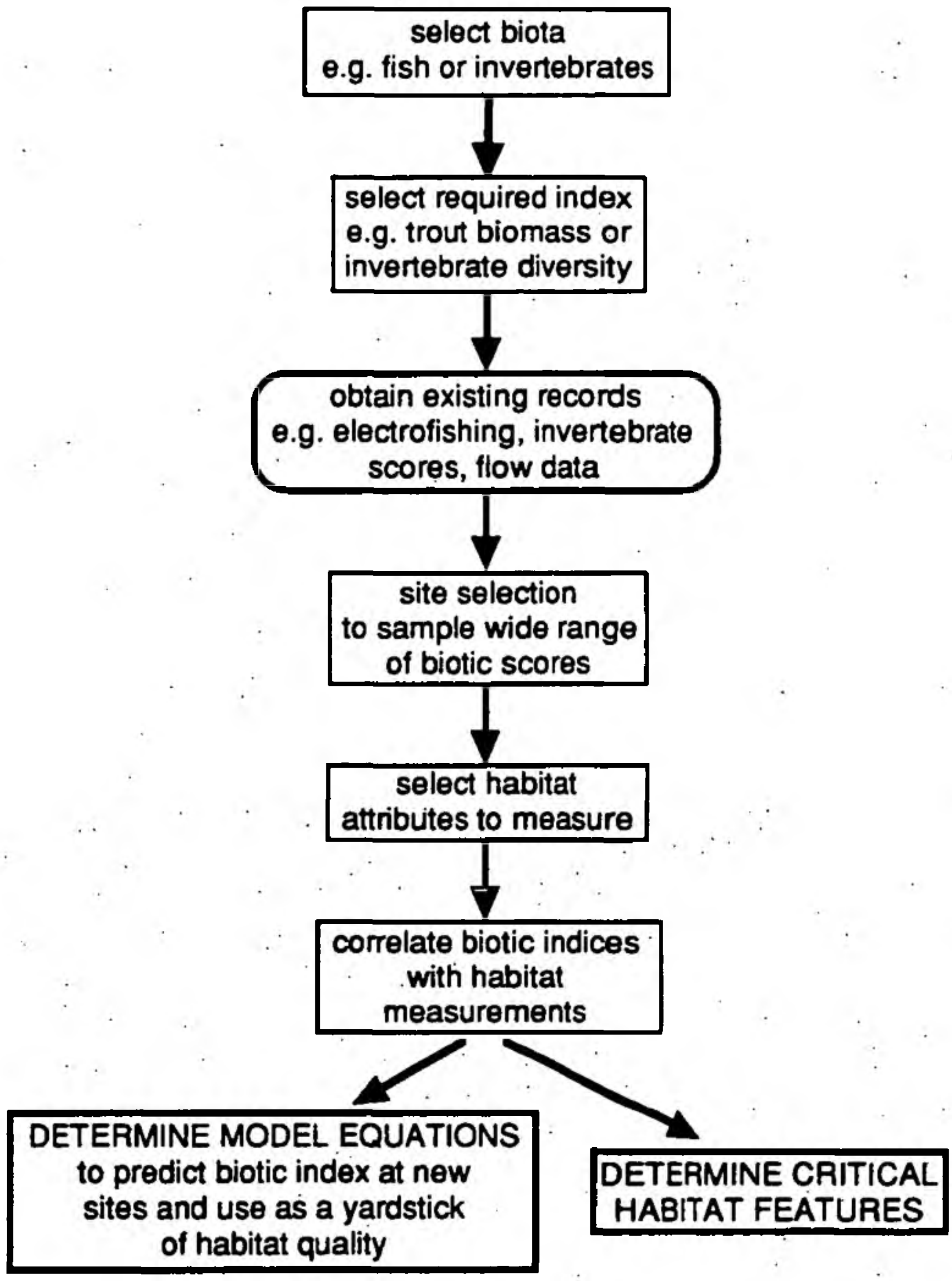


Figure 6.1. Proposed methodology for the identification of key habitat variables influencing biological quality of stream reaches.

6.2.2 Site selection

i) Data to be used in the analysis will be obtained from sites within the same biogeographic region, defined by climate, geology and topography. As a guide, the RIVPACS model divides England and Wales into six primary regions: distinguishing hard-rock, wet, upland streams from soft-rock, dry, lowland streams within which headwater, middle-order and large river sectors may be defined.

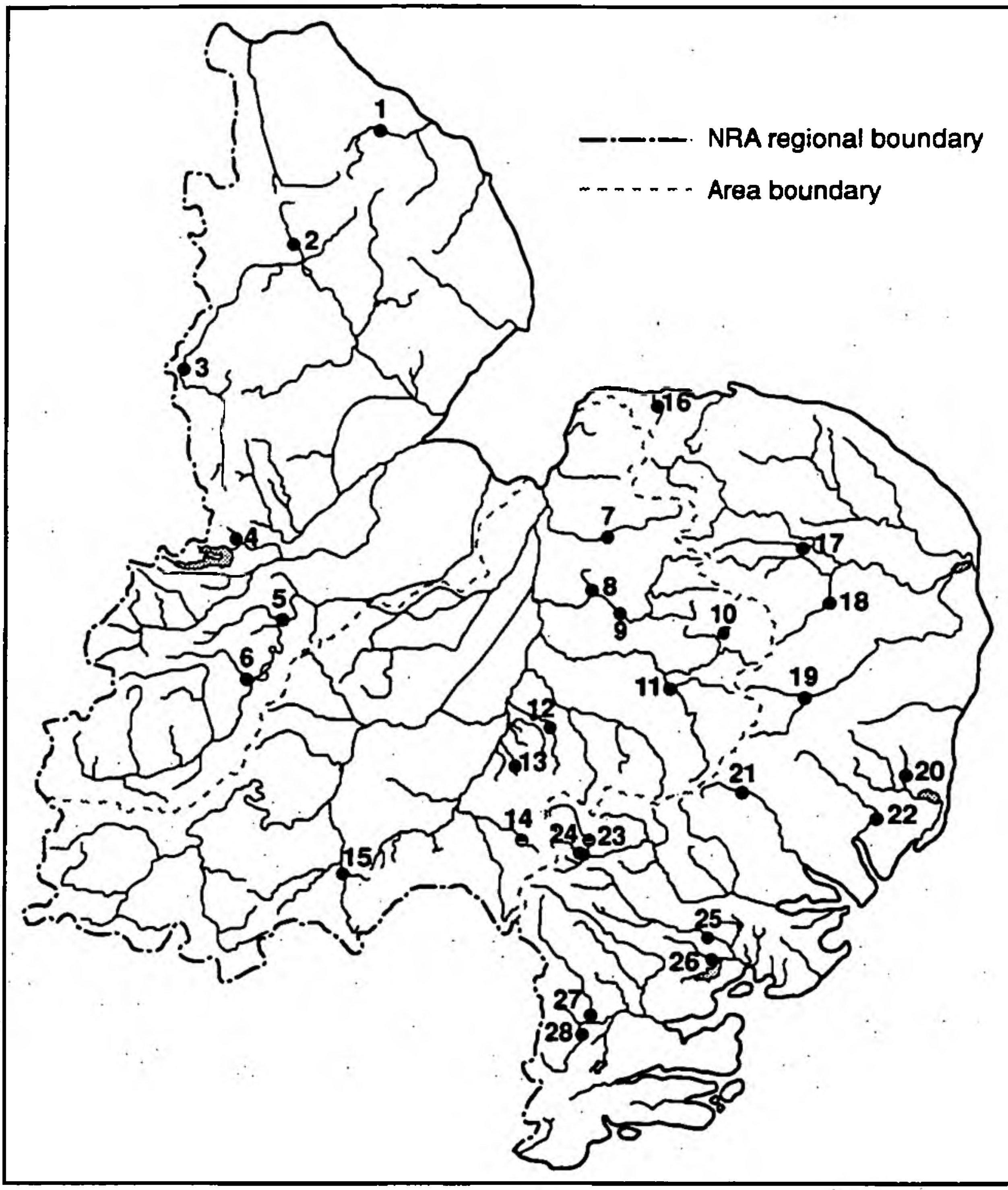
ii) The distribution of gauging stations within the region should be ascertained and compared with the distribution of sites used for routine monitoring as part of fisheries or invertebrate surveys. Biological monitoring sites should be selected only if the data is consistent over a minimum of three years.

iii) Discharge has been established as exerting an influence on the habitat availability of particular species and so sites should be selected that have a close proximity to a gauging station. Sites should be selected only if they have flow records corresponding to the period of biotic surveys.

iv) From these, a final selection will be made to choose sites that exhibit a range of biological quality, i.e. from sites with poor quality (low biomass or scores) to those with good quality.

6.2.3 Habitat measurement

Each site chosen should be visited in order to define the existing habitat conditions. Many different habitat variables can be measured in different combinations ranging from large scale physical variables such as catchment area or elevation, hydrological variables such as average daily flow or chemical variables such as pH or conductivity. Clearly the choice of variables measured will depend on the biota being sampled but as many attributes should be measured during the fieldwork as feasibly possible. Measurements should also be taken at a number of transects that sample all habitat types along a reach rather than at one particular transect as fisheries or invertebrate surveys are also likely to sample on a reach rather than single transect scale.



Northern Area
1 Waithe Beck
2 Barlings Eau
3 Witham
4 North Brook
5 Willow Brook
6 Harpers Brook

Central Area
7 Nar
8 Stringside
9 Wissey
10 Thet
11 Little Ouse
12 Snail
13 Swaffham Lode
14 Granta
15 Hiz

Eastern Area
16 Burn
17 Tud
18 Tas
19 Waveney
20 Alde
21 Gipping
22 Deben
23 Stour
24 Stour Brook
25 Colne
26 Roman River
27 Chelmer
28 Wid

Figure 6.2. Study site location

6.2.4 Linking biological quality with habitat

Once the habitat parameters have been measured in the field they must be compared with a biological expression of habitat quality. This can be accomplished by using simple regression to determine which habitat attributes are the most strongly related to the biota. Stepwise regression can be utilised on the raw data in order to extract the most influential habitat parameters and to form an empirical equation to predict biological quality at any particular site. This enables rapid field visits to establish the expected biological quality by the measurement of a few habitat parameters. It also establishes the most important features determining habitat quality which will aid in the preservation and enhancement of instream habitat for selected species.

6.3 Identifying key habitat variables influencing invertebrate scores.

The above methodology has been used with BMWP scores - a standard biological quality index - for streams within the 'East Anglian' biogeographic region (see Annex E).

6.3.1 The data set

Twenty eight sites throughout the region were selected to achieve a wide range of BMWP invertebrate scores. These sites are shown in Figure 6.2. Broad scale physical characteristics were obtained from published sources (e.g. Institute of Hydrology's Hydrometric Register), such as catchment area upstream from the sample site, and from the 1:50000 O.S. maps, such as stream order. Chemical water quality was expressed by the National Water Council (NWC) classification system obtained from the NRA archives. Each site was visited in order to record a number of physical habitat parameters (see Table 3.1). A total of 19 environmental variables were considered.

6.3.2 Empirical relationships

Using these data it was possible to relate the habitat parameters to the average BMWP scores at each site using stepwise regression. The empirical equation derived utilises the four most influential habitat variables to predict BMWP score with an r-squared value of 0.880.

The four primary variables are:

- an index of water quality (NWC score);
- a hydrological index (the unit Q95 which is the 95th percentile flow-duration statistic divided by /channel width);
- a cover index (the percentage of channel bed with instream cover provided by aquatic vegetation); and
- a hydraulic index (wet width and the % of reach with visible flow).

The equation is expressed as:

BMWP = -39.387
+ (chemical score x 19.79)
+ (Q95/channel width x 466.703)
+ (% instream cover x 0.847)
+ (wet width - flow index x 52.657).

6.3.3 Model test within the Glen catchment

In order to test the model on independent data, six sites within the Glen catchment were selected using the criteria defined in 6.2.2, above. Physical and chemical attributes were measured as defined by the model above and the prediction from the model was compared with average BMWP scores determined from the NRA invertebrate sample data (Table 6.1).

Table 6.1 Comparison of predicted and observed average BMWP scores. Predicted values are based on both actual and (categorical) data.

Site	Observed	Predicted
Burton Coggles	73	58 (72)
Little Bytham	119	106 (132)
Shillingthorpe	141	112 (132)
Edenham	77	85 (72)
Braceborough	93	93 (82)
Kates Bridge	135	137 (132)

The model performs well on this independent data set. All predictions were highly significant (at the 98% level). However, regional variations are likely to require modification of the model. Evaluation outside the Anglian region is required to test the model on streams that are geomorphologically different.

6.4 Applications

Results suggest that the model has potential application in two main areas. First, the model illuminates the relative importance of environmental parameters that influence invertebrate assemblages, expressed as BMWP scores, at the site scale. This has led to a method that seeks to assess the instream habitat for its present ecological value. As expected, water chemistry primarily determines the overall quality of the river as described by the BMWP score but other environmental parameters are shown to be influential. Most important of these is discharge per unit channel width. Secondly, the empirical relationships, provide guidelines for mitigating the effect of low flows. Possible manipulations of physical and chemical variables can be evaluated in terms of their impact on the aquatic environment. For instance, with no alteration of water quality, flow augmentation is shown to improve BMWP. With no increase in flow, reducing channel bed width, to increase discharge per unit width and increase the wet width-% flow index, would also have a positive effect, as would an increase in instream cover.

7. ASSESSING BIOLOGICAL RESPONSES TO HABITAT VARIATIONS WITHIN STREAM SECTORS (PHABSIM).

7.1 Introduction

The morphology of a stream channel is a key component for river management influencing the productivity and biological quality of the instream habitat. In particular the hydraulic conditions - the diversity of velocities, depths, and shear stresses - determine the suitability of a channel for different biota. For most of the year, the exception being during flood events, the distribution of hydraulic conditions is determined by the cross-sectional and longitudinal morphology of the channel. The following section outlines a methodology for describing the biological response to physical habitat and uses this information to determine sites with potential for habitat improvement or restoration.

7.2 Methodology

Figure 7.1 charts the steps required to describe the physical habitat of a stream. This information can then be used to define a more detailed study to pinpoint particular reaches with potential for habitat improvement. Detailed field-survey data are then input to a simulation model (PHABSIM, Bovee 1982) to relate changes in discharge or channel structure to changes in physical habitat availability for a chosen species. The underlying principles of PHABSIM are:

1) the chosen species exhibits preferences within a range of habitat conditions that it can tolerate;
2) these ranges can be defined for each species; and
3) the area of stream providing these conditions can be quantified as a function of discharge and channel structure.

PHABSIM consists of four basic components representing the process of:

1) data collection;
2) hydraulic simulation;
3) suitability index curve development; and
4) habitat simulation.

7.2.1 Preliminary survey

An initial survey must be completed to quantify the physical habitat availability for the whole length of the river system as presented in Section 3.

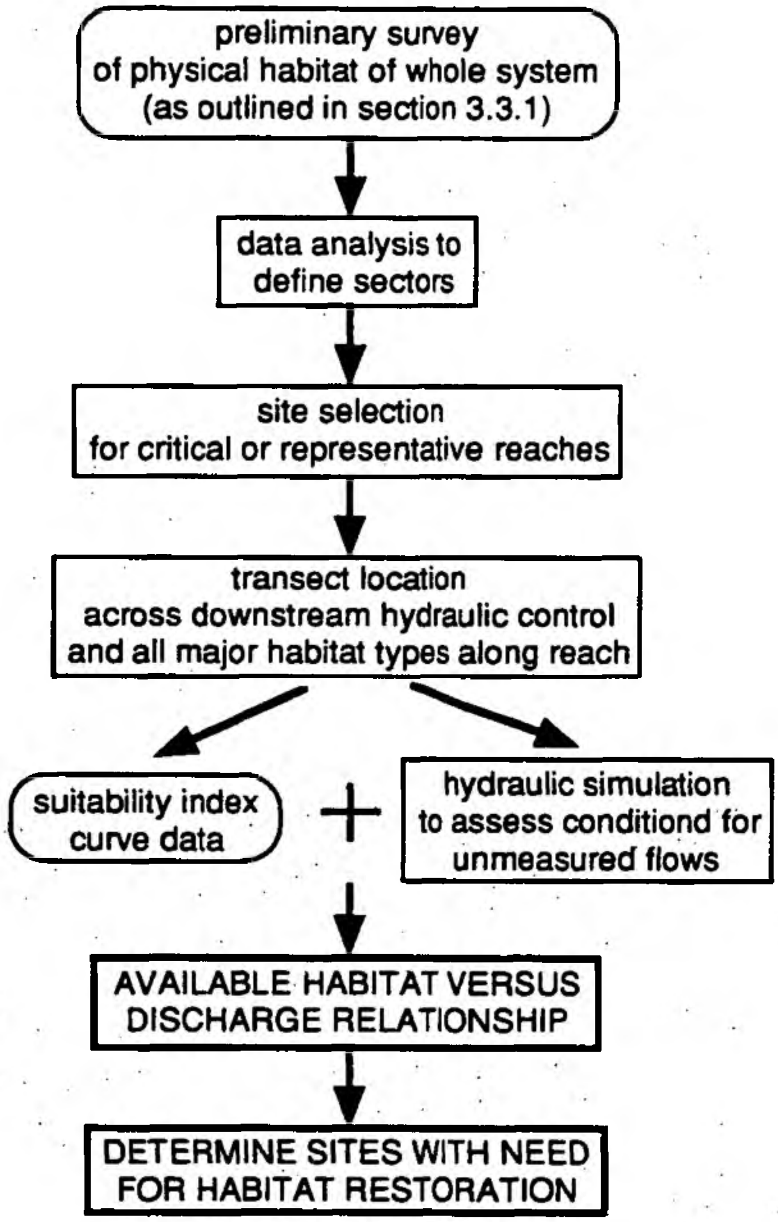


Figure 7.1. Proposed methodology for the use of PHABSIM to determine sites with need for habitat restoration.

7.2.2 Site selection

Following the preliminary survey, further investigations may be required to provide more detailed information on physical habitat availability under different flow regimes. For this purpose the initial survey will provide information to define two types of reach:

- critical reaches i.e. they provide a particular type of habitat that is otherwise limited within the system
- representative reaches i.e. they are similar to any other reach within a sector and, ideally, contain all the habitat patches found in the entire sector.

A typical reach for analysis using PHABSIM has a length of the order of 20 channel widths. The Physical Habitat Simulation (PHABSIM) System - a set of computer models - can then be used to determine sectors which need restoration. Note that currently the model, developed in USA, uses only imperial units.

7.2.3 Data collection

Hydraulic conditions are characterised usually at three known (calibration) streamflows from measurements taken along transects within the reach. Transects are located at right angles to the flow so as to sample:

1) all the hydraulic controls, i.e. physical aspects of the streambed that determine the height of the water surface upstream, and
2) all habitat types that are represented along the reach.

Point measurements of flow velocity, depth, water surface level, substrate and cover need to be undertaken at exactly the same points at intervals across each transect during each visit and hence the reach has to be surveyed in detail prior to this. The field measurements describe the relative proportion of different habitat conditions in the channel at particular discharges. In order to describe how these conditions change under discharges that have not been measured in the field, PHABSIM is used for hydraulic simulation purposes.

7.3 Hydraulic simulation

Hydraulic simulation models are used to estimate depths, velocities and substrates at unmeasured flows. The techniques used to simulate the hydraulic condition in a stream can have a significant impact on the habitat versus streamflow relationship determined in the habitat simulation portion of PHABSIM. The approaches available for calculation of water surface elevation at unknown discharges fall into one of three categories:

1) the stage-discharge relationship (the IFG4 program);
2) the use of Manning's equation (the MANSQ program); and
3) the standard step backwater method (the WSP program).

In many situations it may be necessary to use a mixture of models to simulate the hydraulic characteristics of the reach over the full range of flows. For instance, under low flows the IFG4 program may simulate water surface elevations and velocities most accurately whereas WSP may be more suitable over the higher flows. The correct choice of hydraulic model(s) as well as the proper calibration can be time consuming and may represent the most difficult step in the process of analysing streamflows.

7.4 Suitability index curve development

The third step utilises the information developed in suitability index curves. Different species of fish and macroinvertebrates occupy different habitat types in streams. Knowledge about the conditions that provide favourable habitat for a species, and those that do not, is defined as habitat suitability criteria: characteristic behavioural traits of a species which cause it to select specific habitat types in terms of preferred water velocities, depths and substrates. For example, the habitat suitability curves for adult brown trout are shown below (Figure 7.2). A separate graph is constructed for the depths, velocities and substrate types. These are based on the fact that a functional relationship exists between a response variable (e.g. depth, velocity or substrate) and the degree to which the variable is "usable" over a scale of 0.0 (no use) to 1.0 (maximum use).

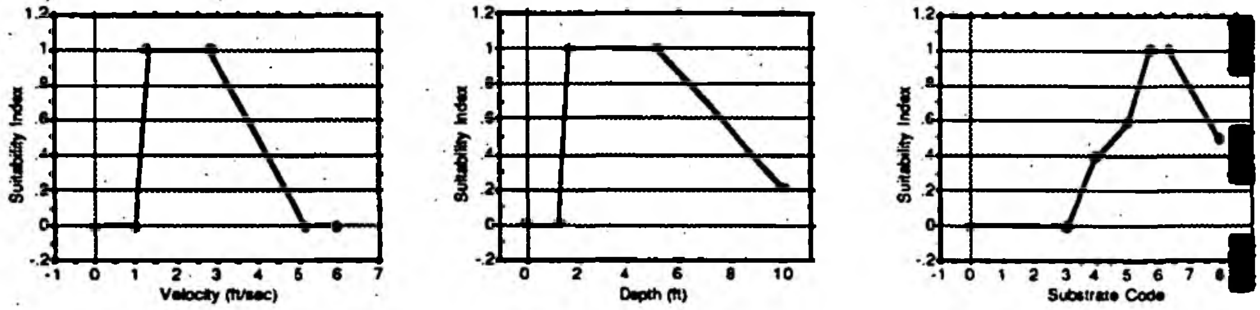


Figure 7.2. Examples of habitat suitability curves for adult Brown Trout.

7.5 Habitat simulation

The final step is that of habitat simulation. Hydraulic simulation has already been applied to determine the characteristics of the stream in terms of depth, velocity and substrate as a function of discharge. Physical habitat or weighted usable area (WUA) in the reach is then quantified based on the suitability of the variables simulated by the hydraulic models for a target organism. PHABSIM contains a number of different programs that can be used for this purpose, each having specific conditions for their application. The effects of changes in streamflow on the physical habitat available for the target organism can then be evaluated by changes in the amount of WUA. This enables PHABSIM to present biological information in a format suitable for entry into the water resource planning process.

It must be emphasised that predictions of PHABSIM are explicitly made in terms of changes to the physical properties of the aquatic habitat (i.e. velocity, depth and substrate). The model does not predict changes in the biomass of organisms. Failure to recognise this fact has led to much criticism in the literature when PHABSIM results were applied and interpreted without consideration for other factors such as water quality, temperature, food availability and fishing mortality.

The method is currently being tested on a national basis including a wide range of rivers, for the National Rivers Authority (Project B02(90)1).

7.6 Defining sites for habitat restoration

The relationship between available habitat and discharge may be used to identify sites which have limited available habitat during the given flows for target species. Habitat is defined by hydraulic variables that under low flows (up to about 0.6 bankfull) are determined by the nature and shape of the channel bed.

Examination of the variation of depths and velocities with discharge can be particularly illuminating. For example, a site with a uniform bed structure, such as a straightened reach, will provide a limited range of depths and velocities along its length and so provide a very limited range of habitat types. Alternatively, a reach with a well developed riffle-pool sequence will contain a much broader spectrum of water depths and velocities and hence provide a much wider range of habitats. The analysis can be used to determine the habitat quality of reaches, and then sectors, where 'quality' is related to the configuration of the bed morphology. Thus, sectors can be identified with the potential for improvement via instream habitat restoration.

7.7 Application to the River Glen

The above methodology has been tested within the Glen catchment and the results are outlined below (see also Annex E).

7.7.1 Physical habitat survey

Based on the survey data described in Section 3, five representative reaches were selected for further analysis using PHABSIM. These allow comparison of habitat availability between the West and East Glen and between upstream and downstream sites on each river.

7.7.2 Use of PHABSIM

Five transects were established along each reach in order to sample the microhabitat variability. In each case, the most downstream transect was placed at right angles to the flow across a hydraulic control, i.e. the crest of a riffle, and cross-sections upstream were located at sites where a clear change in habitat was evident. Each site consists of a riffle - pool - riffle - pool - riffle sequence and was visited under three different flows i.e. low, medium and high calibration flows. Hydraulic conditions were simulated with a combination of the IFG4 and WSP hydraulic simulation programs. Microhabitat suitability curves utilised in this study were originally developed by Armitage and Ladle (1989) based on experience and local knowledge of UK conditions. Curves have been used for three life stages (fry, juvenile and adult) for Brown Trout, Dace and Chub, and are expressed as suitability functions of depth, velocity and substrate.

7.7.3 Results

Results are expressed in terms of the percentage of each reach that is usable habitat for the particular fish species and life stage over a range of flows. Three main conclusions can be drawn:

- most habitat tends to be usable by Brown Trout fry under the low flows experienced at each site;
- habitat availability for Brown Trout tends to decrease under higher discharges whereas habitat availability for Dace tends to increase with flow; and
- there is very little Chub habitat at any of the sites with none at three and only small amounts under higher flows at Shillingthorpe and Edenham.

The sites fall into two distinct groups.

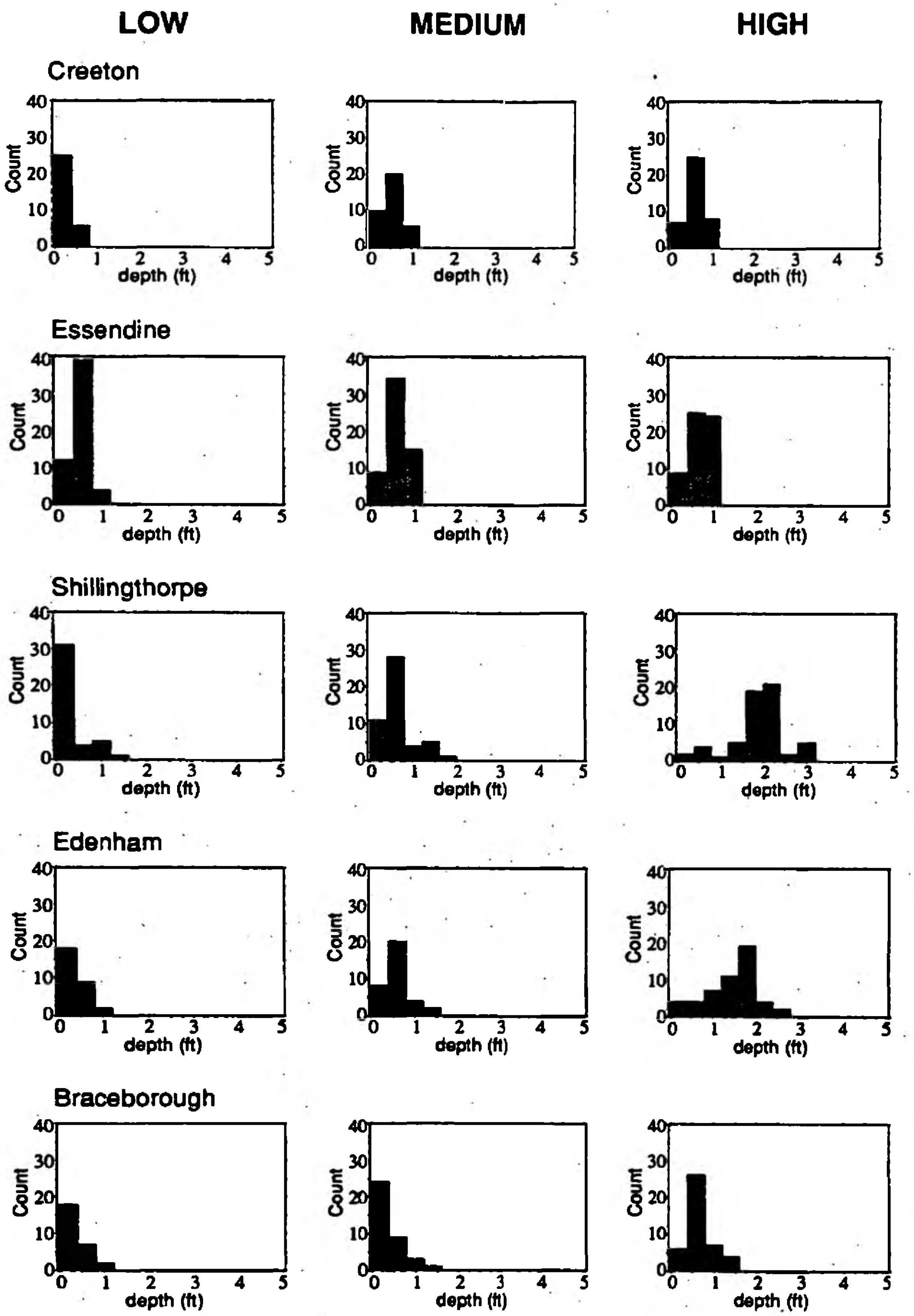
- The first group consists of Creeton, Essendine and Braceborough which are characterised by:
  i) decreasing habitat available to all life stages of Brown Trout under higher flows and
  ii) no habitat available to Chub.

- The second group which contains the remaining sites of Shillingthorpe and Edenham have the opposite characteristics of:
  i) maintaining Brown Trout habitat at levels of between 10-40% of the reach under the higher flows, and
  ii) containing Chub habitat albeit in small amounts and only under the high flows at Edenham.

7.7.4 Comparison of bed morphology between sites

Based on the original field measurements, Figure 7.3 has been constructed to show the depth variations between each of the sites under the low, medium and high flow. From these charts it is clearly apparent that even under the higher flows there is a distinct lack of deeper water at those sites with the least habitat available i.e. Creeton, Essendine and Braceborough. Alternatively, under these flow conditions at Edenham and Shillingthorpe a broader spectrum of water depths is apparent including water up to three feet deep at Shillingthorpe.

The above highlights the major habitat deficiency throughout all channelised reaches - the lack of deep pools to provide habitat for fish over the full range of flows, especially for the juvenile and adult life stages of Brown Trout, Dace adults and all the Chub life stages.



<u>Figure 7.3</u> Frequency distributions of depth at each site under low, medium and high flow.

8 RECOMMENDATIONS

8.1 Restoration of the River Glen

The results of the physical habitat assessment (Section 3), analyses of NRA fisheries data (Section 4) and invertebrate records (Section 5) support the classification of the Glen into three **river types** (upland, intermediate and lowland) and 11 **sectors** (Figure 8.1 and see Figure 3.1). *The study demonstrates that the course of the main River Glen effectively begins at Creeton and Castle Bytham springs.*

i) The **upland type** sectors comprise sectors 1,2,3,4,6,7,8 and sector 5.

The majority of sectors with low BMWP scores have low and intermittent discharges. Flows reach zero for periods of the year (Plates 1a and 2), as they have not only in the recent past but also from time to time for at least 200 years.

Within Sector 5, flows are maintained by spring flows and the lower Tham, in particular, sustains good quality habitat (Plate). Invertebrate scores are up to LQI Class A and the characteristic fish species are Dace and Trout. The substrate sediments are relatively clean and provide suitable Trout spawning habitat.

ii) The **lowland type** sites are sustained by perennial flow with low velocities and deep run habitat (Plate 3). The invertebrate fauna indicate that the water-quality is good. In such channels, water depth is more important than flow velocity for determining habitat diversity.

iii) **Intermediate type** sites have large proportions of riffle habitat although the impact of the weirs at Kates Bridge, Fletland Mill (Plate 4a) and Greatford is to create ponded reaches characterised by long deep runs. These sites have a diverse invertebrate fauna and are characterised by Dace and Chub.

Prior to the implementation of an inter-basin transfer scheme to augment flows in sector 9 and downstream, the Shillingthorpe sector, which went dry in 1990, isolated sector 5 from the downstream river (sectors 10 and 11).

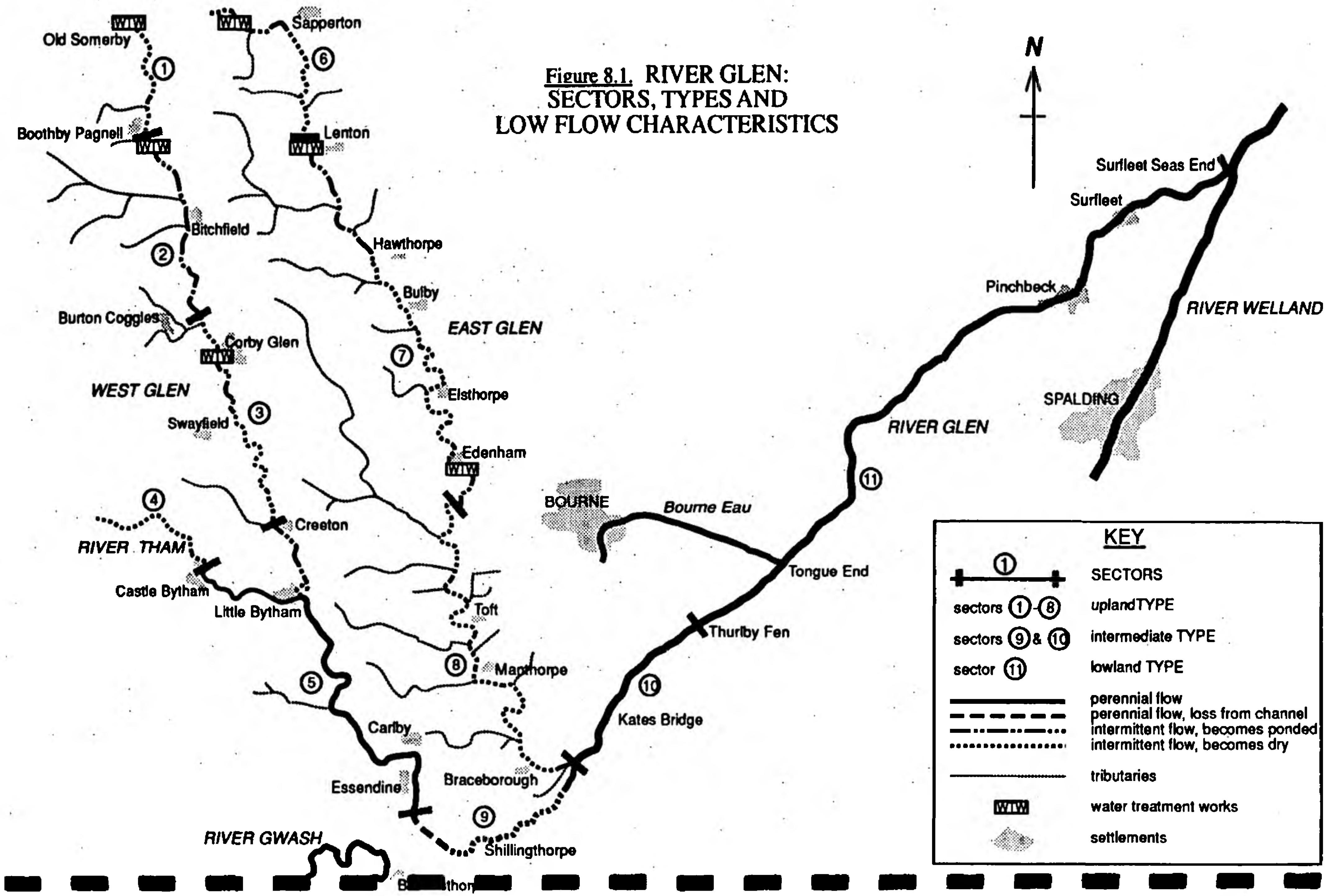


Figure 8.1. RIVER GLEN: SECTORS, TYPES AND LOW FLOW CHARACTERISTICS

8.1.1 Headwater streams

The upper sectors (1-4 and 6-8) of the East and West Glens are naturally ephemeral but most reaches have been channelised to some degree. Restoration of a natural channel form, especially restoring the natural sinuosity and associated bed forms would enhance the morphological - and habitat - diversity. The value of instream enhancement would become particularly apparent during wet years when flows become perennial, but the creation of pools could also increase the duration of ponded conditions during flow recession.

The main function of these sectors today is to convey storm runoff. However, such runoff transports a load of fine sediment - soil eroded from cultivated fields (e.g. Plate 5) - and sediment-associated nutrients and pesticides. Through many reaches cultivation occurs up to the channel banks. High yields of fine sediment and associated pollutants could cause siltation and habitat degradation especially within the important sectors 5, 9 and 10 (see 8.1.3).

Within Sectors 1-4 and 6-8, including any tributaries, *it is recommended that buffer zones be established along the channels.* The creation of buffer zones will have two major benefits:

- They would create important habitat for wildlife providing a corridor of ecological interest and potential recreational value;

- They would trap fine sediments (and associated nutrients and pollutants) from surface runoff thereby protecting the river downstream from siltation during storm events.

Ideally, land on the valley floor should be set aside from cultivation creating buffer zones along each bank of the channel that are as wide as possible. The set aside land could be used for low intensity grazing, or (ideally) planted for native woodland. In any case the buffer zone should be at least 5 metres wide; a width of 15 metres is considered necessary to optimise their runoff control and conservation enhancement functions.

8.1.2 Middle sectors

In sectors 5, 9 and 10, important opportunities exist for restoration although options are constrained by the weirs. This F1 fishery comprises two different river types: upland (sector 5 with Trout and Dace) and intermediate (sectors 9 and 10 with Dace and Chub). *It is recommended that actions be taken to protect and enhance these sectors.* Priority actions are to:

- maintain water quality (see 8.1.2); and
- maintain flows.

The Gwash-Glen Transfer has realised considerable benefits by maintaining flows in sector 9 (see Appendix A). Review of the results of the project enable minimum flows to be defined but *it must be emphasized that above the minimum a positive relationship exists between flow and ecological criteria, especially for fish, over the normal range of summer flows* i.e. the higher the flow the better the fishery. Minimum flow requirements to maintain ecological values are given below and these requirements have largely been confirmed by post-project appraisal.

Table 8.1 Flow Recommendations for sector 9, based upon Petts (1990) and this Report. Flows are those at Shillingthorpe gauging station.

Discharge (m^3s^{-1})	Recommendation and derivation
0.500	to provide optimum fish habitat[1]
0.155	to provide optimum habitat[2]
0.100	to protect aquatic habitat[3]
0.050	minimum for fish habitat[4]
0.040	minimum for salmonid habitat[5]
0.040	optimum wetted bed width[6]
0.010	minimum for LQI=A[7]
0.005	minimum for LQI=B[6]

Discharge (m^3s^{-1})	Actual 7-day minimum flows during period
0.026	minimum flow summer 1989
0.000	minimum flow summer 1990
0.010	minimum unsupported flow summer 1991
0.068	minimum supported flow summer 1991

[1]Based on PHABSIM, for all life stages of Dace and Brown Trout
[2]30% of average daily flow (Orth and Leonard, 1987)
[3]20% of average daily flow (Orth and Leonard, 1987)
[4]10% of average daily flow (Orth and Leonard, 1987)
[5]field data for Glen (Petts, 1989)
[6]field data for representative reach in sector 9 (see Figure A4)
[7]field data for Glen (Petts, 1989)

For the River Glen at Shillingthorpe, *to maintain the general ecological character of the river, indexed by good BMWP and LQI scores, the minimum flow needs to be only 0.04* m^3s^{-1} *but to maintain fish habitat a much higher minimum flow of at least 0.1* m^3s^{-1} *is required.* For the period 1972-87, 0.04 m^3s^{-1} and 0.1 m^3s^{-1} equate to the 92 percentile and 73 percentile flows respectively.

Table 8.2 Proportion of channel area usable by Brown Trout and Dace at different flows within sector 9.

Fish and Life Stage	Discharge (m^3s^{-1})	Weighted Usable Area
Trout - adult	0.3 (0.1)	15% (10%)
Trout - juvenile	0.3 (0.1)	20% (15%)
Dace - adult	0.3 (0.1)	30% (20%)
Dace - juvenile	0.3 (0.1)	12% (4%)

The planned target flow at Kates Bridge was 0.278 m^3s^{-1} (24 tcmd) - which because of bed losses would have required flows of up to 0.3 m^3s^{-1} at Shillingthorpe (the 40th percentile flow based on the 1972-87 record). This has not been achieved but for the 1960-86 period the number of days in each year that the flow fell below target at Kates Bridge ranged widely, from none to 365! Nevertheless, the increased depths that would be associated with such a flow would provide significantly better habitat for fish compared with a flow of 0.1 m^3s^{-1}, as indicated in Table 8.2. At Kates Bridge between 1960 and 1986, flows above 0.278 m^3s^{-1} were experienced for 260 days each year, on average.

With reference to flows at Shillingthorpe, it is recommended that to optimize fish habitat, flows should be maintained above 0.3 m^3s^{-1} throughout the year, with flows of at least 0.5 m^3s^{-1} in April and May, a situation that occurs naturally once in every 5-7 years, on average. To achieve good fish habitat:

- *flows of at least 0.3* m^3s^{-1} *should be maintained from November through to the end of May;* during periods of severe water shortage flows may be reduced to 0.2 m^3s^{-1} from December to March inclusive but the higher flow should be maintained during critical periods of the year, i.e. during November, April and May;

- *minimum flows in June, July and August should follow the natural dry-summer recession (respectively 0.2* m^3s^{-1}, *0.15* m^3s^{-1} *and 0.10* m^3s^{-1}*);*

- *flows in September and October should be maintained at 0.10* m^3s^{-1}.

Further efforts should focus on instream habitat improvements, not least to maximize the benefits of the water transfer scheme. Indeed, *the benefits of flow augmentation would be enhanced by habitat diversification and the flow required to achieve optimum conditions would be reduced.* The magnitude of the difference in Table 8.1 between the optimum flow for fish based on field measurements (0.5 m^3s^{-1}) and the general guide to maintain optimum habitat (0.155 m^3s^{-1}) may reflect the lack of morphological diversity within this sector.

Instream biological quality could be improved by:

- increasing the unit discharge under low flow conditions by reducing low-flow channel width;
- enhancing morphological diversity, at least by introducing pools;
- improving instream cover; and
- planting riparian trees on the south bank, providing shade to control instream macrophyte growth.

Particular benefits will arise by enhancing sector 9 which has been channelised (Figure 8.2) such that the channel today is straight and incised (Plate 6). The meandering course of the former channel is evidenced by cutoffs that can be seen in the field and from air photographs. The natural channel probably had a sinuosity of about 1.3 and slope of 1.16 m km^{-1}, compared with values for the present river of 1.0 and 1.5 m km^{-1} respectively. Ideally, the channel pattern should be restored. A meandering course would be associated with flow asymmetry, pools and riffles, creating a more diverse range of habitats.

In any case, diversification of channel morphology within this channelised sector would yield benefits for biota, and should be considered a priority. Improvements should include the creation of pools at least 15 m long and 0.5 m-deep under low flow conditions, and narrowing short stretches to increase the unit discharge. The creation of pools will require the introduction of low weirs supported by periodic dredging in the absence of winter scouring floods. It is suggested that log weirs be installed (Figure 8.2b and Plate 6b). These have the added benefit of introducing organic surfaces which will markedly enhance invertebrate production.

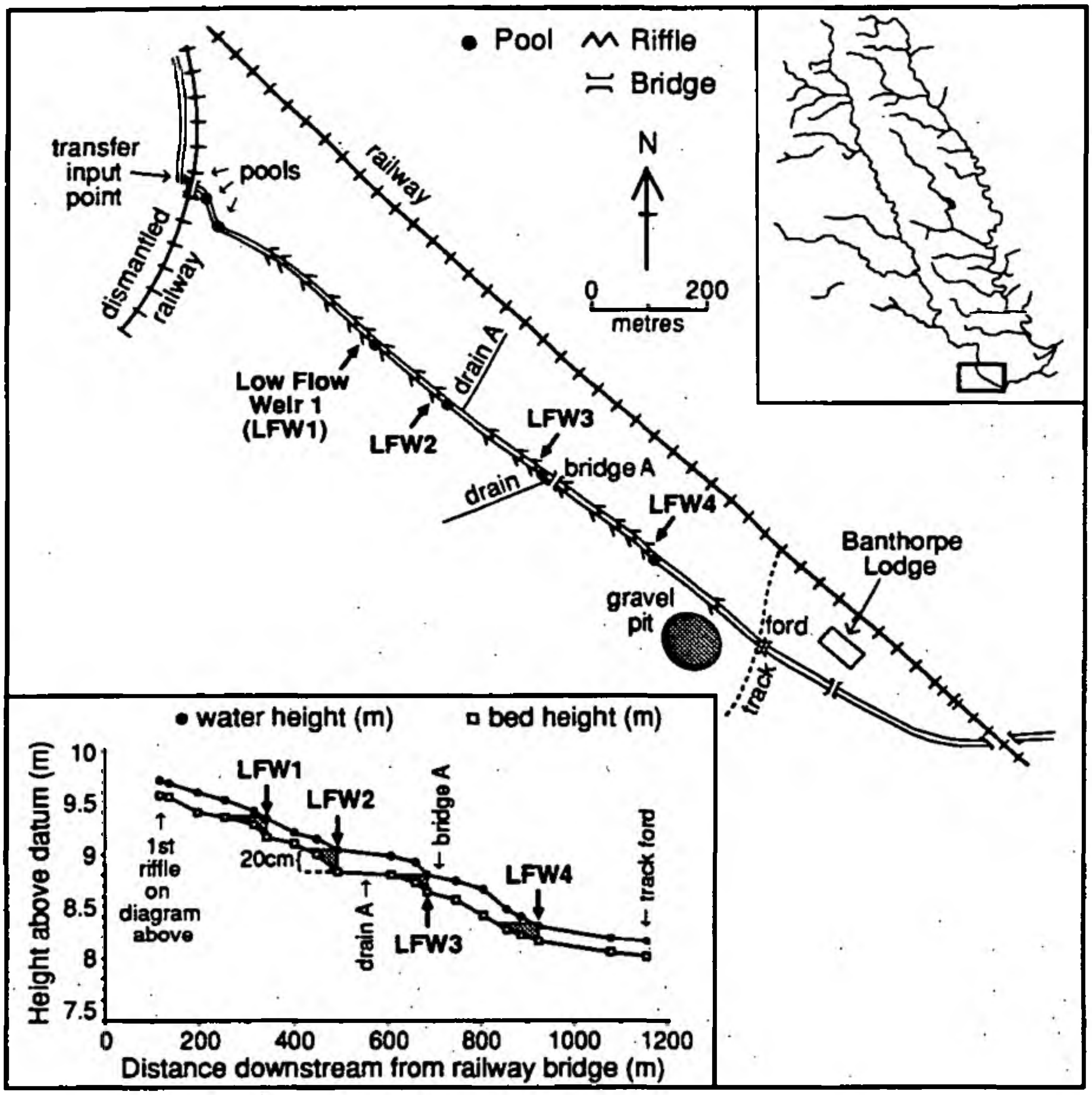


Figure 8.2a. Selected reach for instream habitat improvement on the West Glen near Shillingthorpe with suggested location of low flow weirs and associated pools downstream.

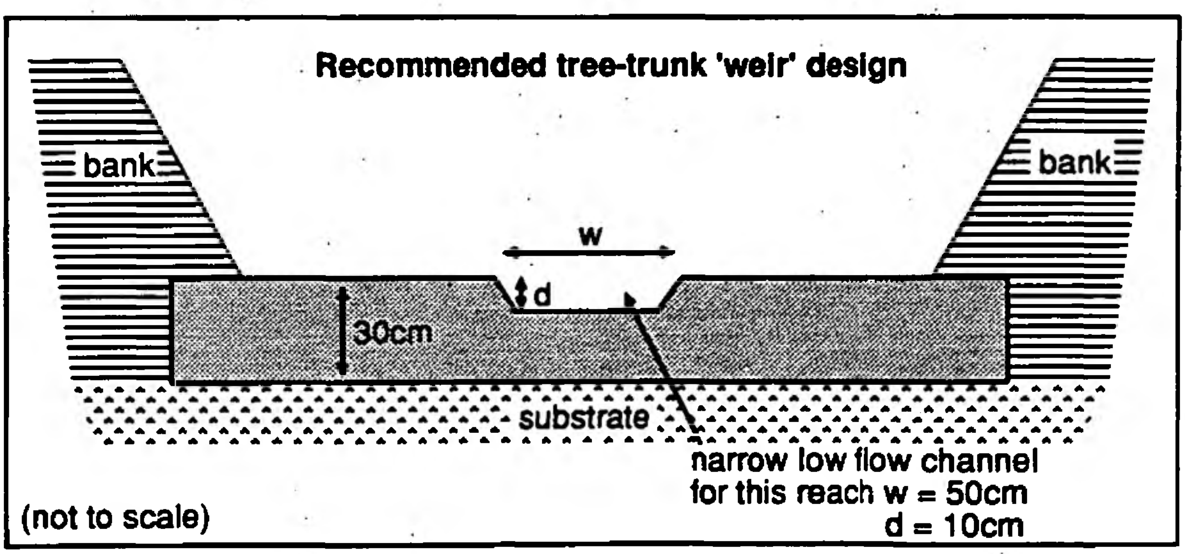


Figure 8.2b. Recommended tree-trunk 'weir' design

8.1.3 Lowland sector

Throughout Sector 11 the channel is artificial but the slow-flowing river sustains an important coarse fishery and contains a diversity of plants and invertebrates. However, the landscape quality and ecological quality of different reaches within this Sector vary markedly (Plate 3). *It is recommended that enhancement measures should be introduced,* comprising:

- Diversifying instream and marginal habitat, especially creating pools, marginal shallows, embayments and 'wetland' patches; and

- Planting riparian trees, especially on the south bank, to provide instream cover and shade to control the development of aquatic macrophytes.

8.2 Application and Development of the Approach

The Approach presented herein and illustrated by application to the River Glen offers an approach to the assessment of degraded river systems. It is recommended that Sector Classification should be the basis not only for river restoration but also for determining Catchment Management Plans.

The information for classifying sectors could be obtained during River Corridor Survey providing that appropriate instream physical habitat data is included. Currently, such information is lacking. *It is recommended that future River Corridor Surveys include an instream habitat assessment (see Section 3).* The project has demonstrated the controlling influence of water depth for fish habitat in upland and intermediate river types. Therefore, *it is recommended that future instream habitat surveys should include maximum depth at each transect and the maximum (pool) depth between each transect.*

A major problem encountered during the study was the difficulty of achieving an integrated analysis of the hydrological and biological data because of a lack of coordination in routine data collection. *Thus, it is also recommended that consideration is given to an improved system of biological monitoring once sectors have been defined.* Figure 8.2 summarises the proposed methodology. Within each sector, or at least within target sectors having special biological value or being of particular concern, indicator or representative sites should be selected for fully coordinated, routine monitoring.

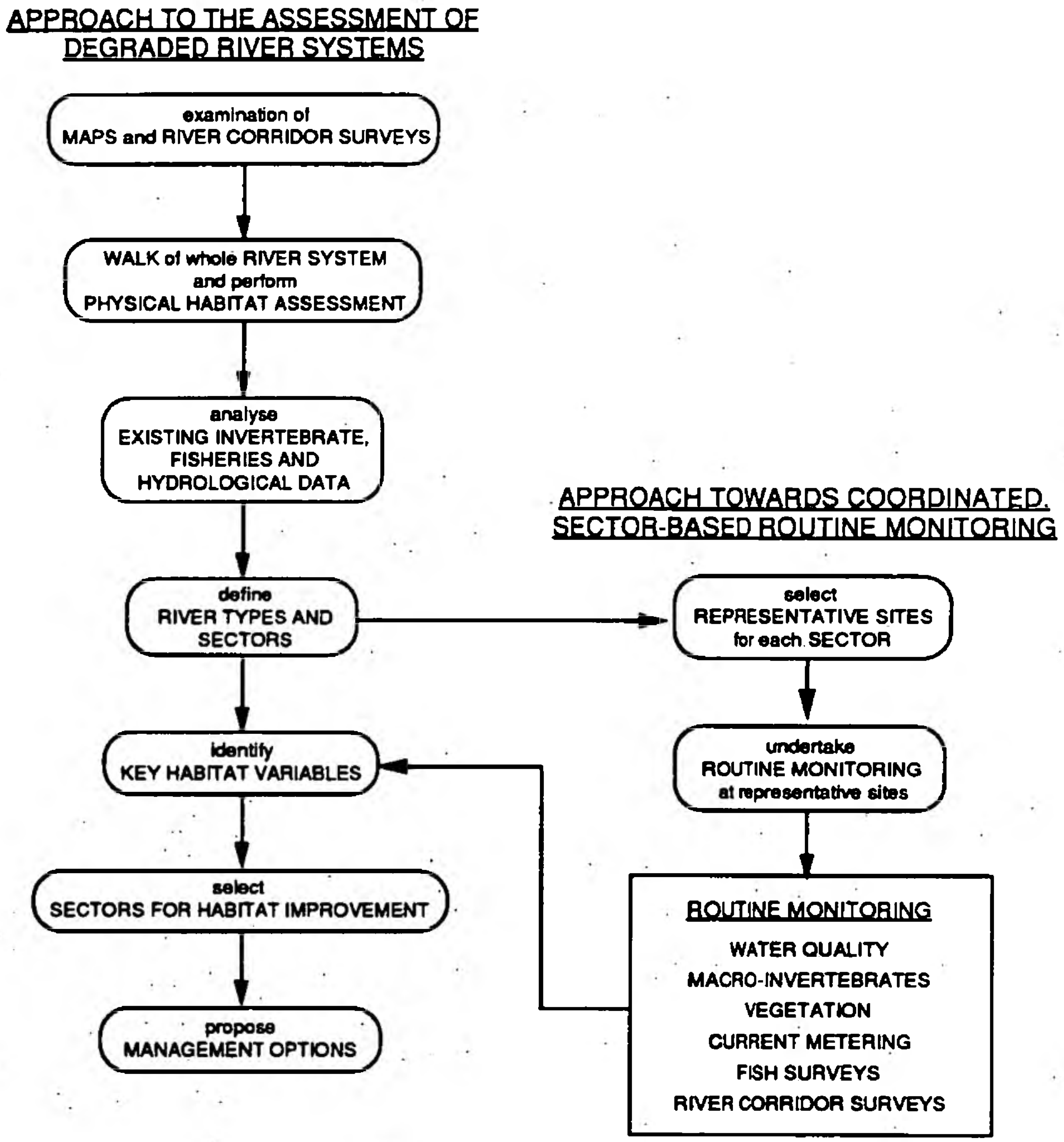


Figure 8.3 Recommended approach to assessment of degraded river systems and improved, coordinated routine monitoring.

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APPENDIX 1. APPRAISAL OF BENEFITS ARISING FROM THE GWASH-GLEN TRANSFER

A1.1 The Gwash-Glen transfer

River flows in the West Glen downstream from NGR TF050117, at the upper limit of sector 9 (see Figure 8.1) have been augmented since May 1991 by the Gwash-Glen interbasin transfer. The actual rate of augmentation is dependent upon abstraction rates, channel losses and fishery requirements and the five year allocation from Rutland Water.

A1.2 Effect on flows

The Environmental Assessment of the proposed water resource development of the Glen (Petts, 1990; C-4 to C-9) defined the flow recession for the Shillingthorpe gauging station, which was described by the 1975 data and validated against data series for two other years chosen at random (1979 and 1988). 1975 was a relatively dry year following one of slightly above average rainfall. Data for the three years of this study are presented in Figure A1 commencing with the first day in the year the flow fell below 0.23 m^3s^{-1}. The 1989 data series - the first year of this study - closely fits the expected curve, as do the first parts of the 1990 and 1991 series. In 1990, however, the flow declined dramatically after day 78 (July 9th), and the river became dry on 6th August. The flow returned to the expected level for one day (20th August). In 1991 the Gwash-Glen transfer maintained flows above levels expected from the normal flow recession.

The positive impact of flow augmentation is seen better in Figure A2, because in each of the three years, the flow on May 18th was well below the 0.23 m^3s^{-1} threshold. This reflects the failure of winter recharge. The transfer should compensate for the recharge failure by maintaining flows at the 'normal' dry-summer level (here defined as the 1975 level). In 1991 the flow at Shillingthorpe fell below the threshold early in the year, on March 12th. Water transfer commenced on May 21st and raised river levels but these remained below normal levels until 21st August. Subsequently, flows were maintained at about normal levels for the remainder of the summer.

log 10x of flow	actual flow (cumecs)
0.00	1.00
-0.50	0.32
-1.00	0.10
-1.50	0.03
-2.00	0.01
-2.50	0.003
-3.00	0.001

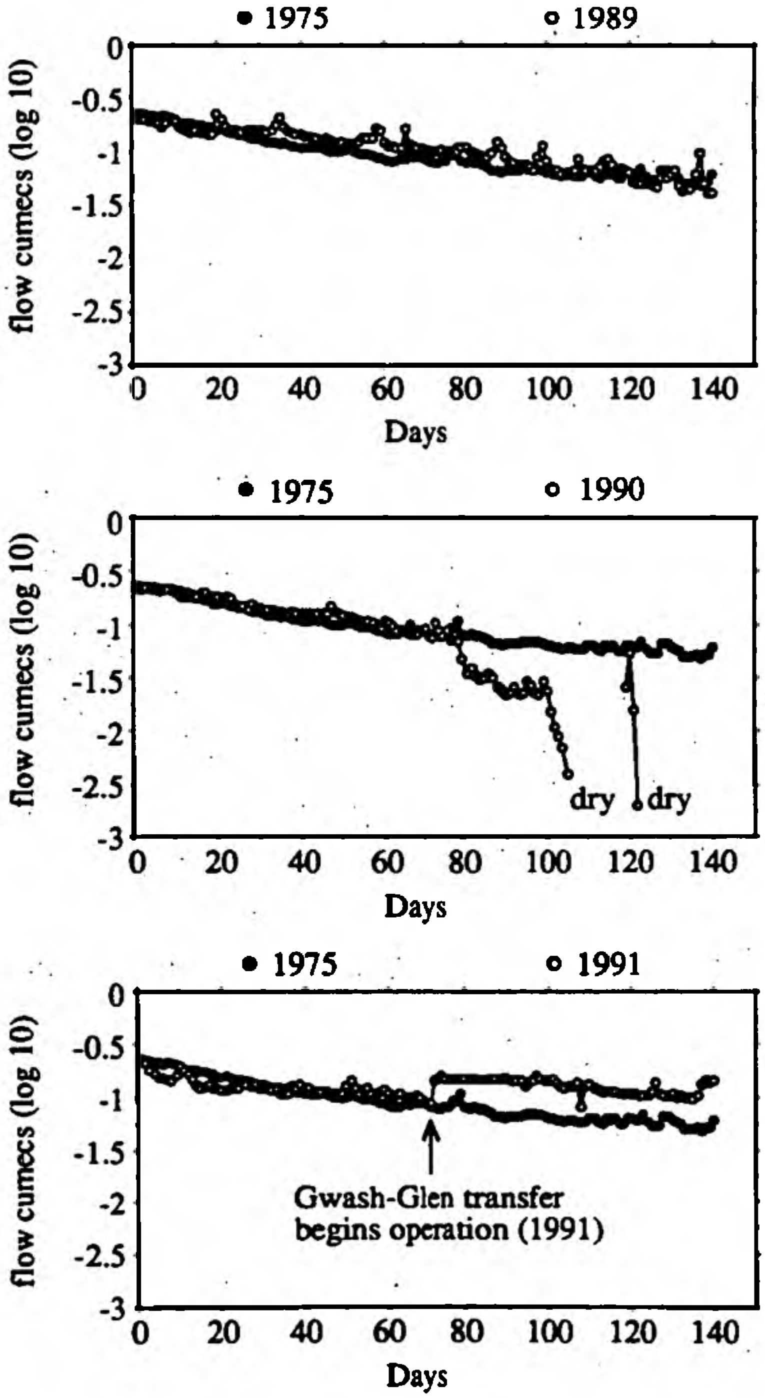

Figure A.1. Flow recession curves beginning when flows fall below 0.3 cumecs at Shillingthorpe in 1989, 1990 and 1991 compared with 1975.

log 10x of flow	actual flow (cumecs)
0.00	1.00
-0.50	0.32
-1.00	0.10
-1.50	0.03
-2.00	0.01
-2.50	0.003
-3.00	0.001

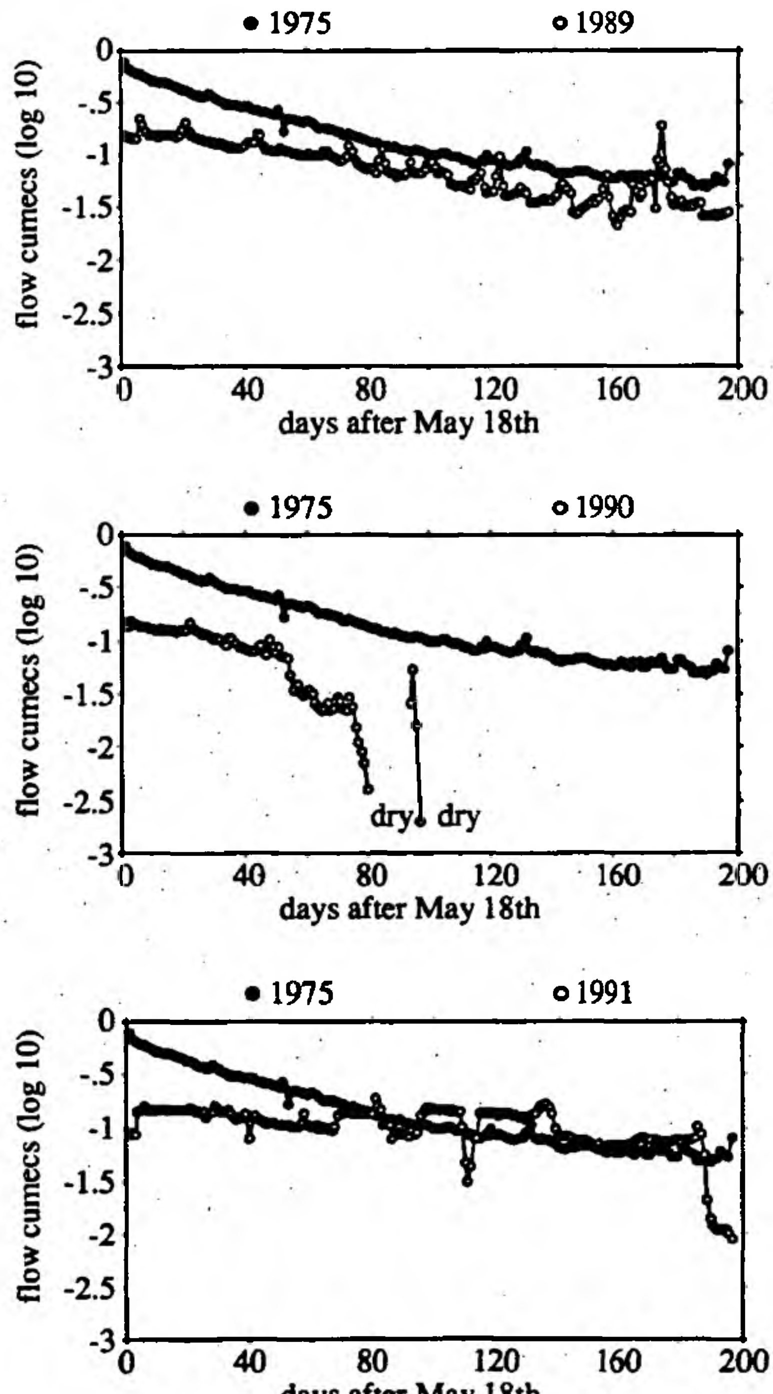

Figure A.2. Flow recession curves beginning on May 18th at Shillingthorpe in 1989, 1990 and 1991 compared with 1975.

A1.3 Effect on habitat

In order to assess the impact of the transfer scheme on the physical habitat availability in sector 9, three surveys were conducted under different discharges. Using the quotient of wet width to channel width as the habitat index (Figure A3) the benefit of flow augmentation is clearly seen. The third survey was completed on 14/11/91 whilst the Gwash Glen transfer was in operation. In contrast to the reach upstream of the transfer, there was a significant (about 25%) improvement in physical habitat availability. The abrupt change at 37.5 km coincides with the Greatford sluice below which the channel has a more asymetric (see Figure 3.4).

A1.4 Ecological value of flow augmentation

Three approaches were used to assess the ecological value of flows.

i) Using data for a 90 m-long representative reach within sector 9 it is possible to determine the most effective flow for sustaining the optimum area of wetted bed. Wetted bed width is seen to increase rapidly to a value of about 75% at 0.04 m^3s^{-1}; with increasing flows the gain in wetted bed width is very slow. During the summer of 1991, the inter-basin transfer maintained flows above 0.13 m^3s^{-1} on average.

ii) Using the empirical model developed in Section 6, the effect of maintaining flows at the normal dry-summer level (defined as 1975) would maintain the BMWP score at about 125.

iii) Using PHABSIM the amount of usable habitat for adult Dace and Brown Trout was determined for the full range of flows (Figure A4). The shaded area defines the low flows that are eliminated by augmentation. Whilst habitat is limited for all summer flows, the usable area increases with increasing flow and for Dace (the dominant fish species in sector 9) reaches 20% at the maintained flow of 0.13 m^3s^{-1}. Without instream habitat improvements, the optimum flow appears to be 0.5 m^3s^{-1}, but for the 1972-87 period this flow equates to the 25 percentile flow.

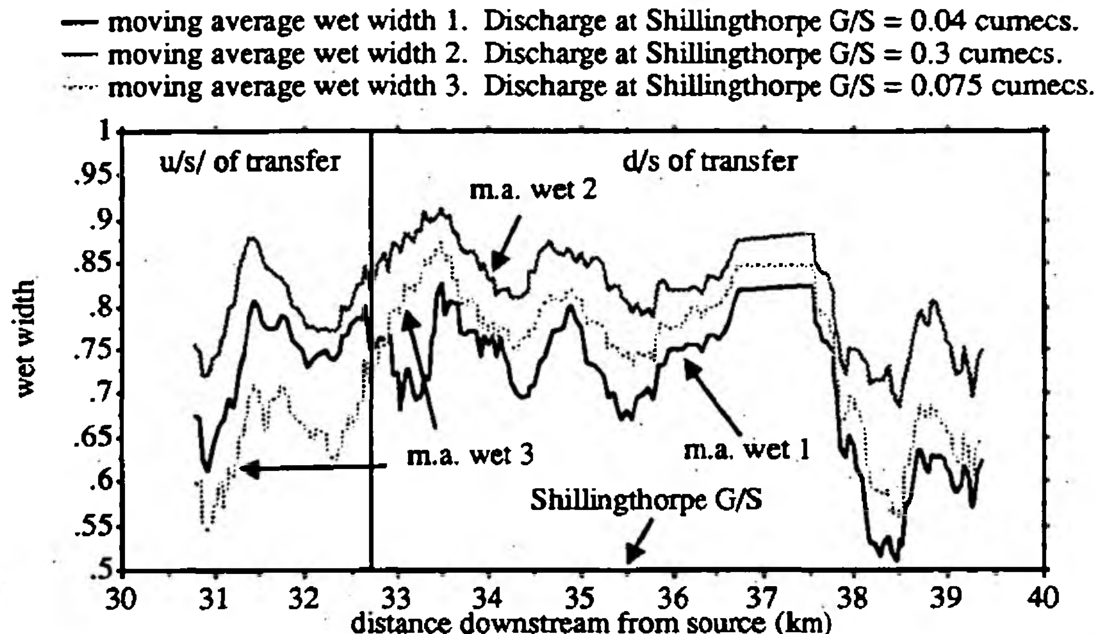

Figure A.3a. Moving average of wet width against distance downstream from source for the three surveys from Essendine to the East Glen confluence on the West Glen

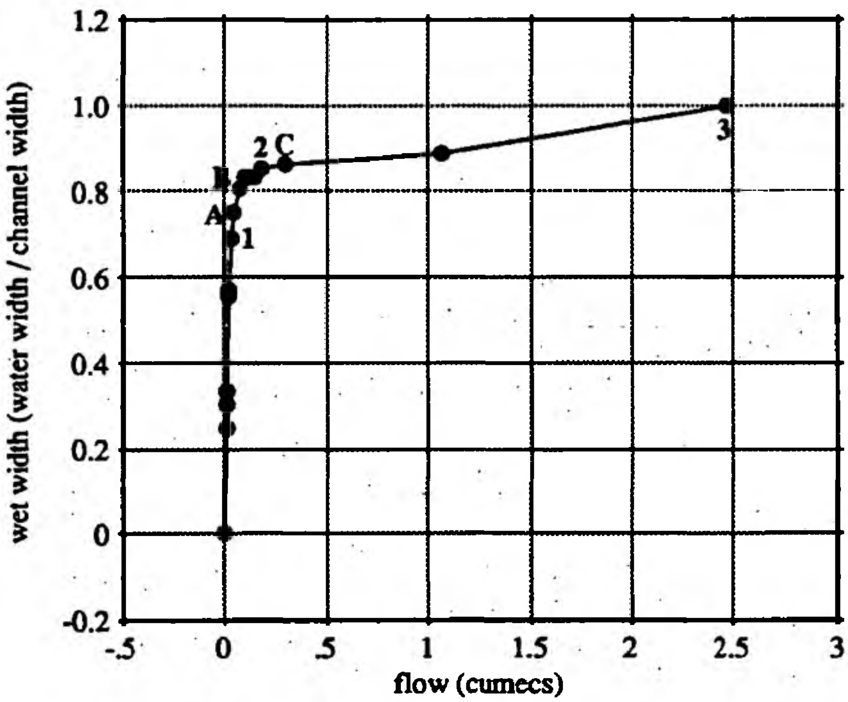

Figure A.3b. Wet width against discharge relationship at Shillingthorpe.

Table A.1. - Survey results utilised to construct the relationship shown in figure A.3b above.

	Q cumecs	%ile flow 72-87	%ile flow 80-87	wet-width
A = Habitat survey 1	.040	92	99	.75
B = Habitat survey 2	.075	81	95	.81
C = Habitat survey 3	.300	41	51	.86
1 = PHABSIM survey - low flow	.027	94	99	.69
2 = PHABSIM survey - medium flow	.183	54	69	.85
3 = PHABSIM survey - high flow	2.474	4	4	1.00

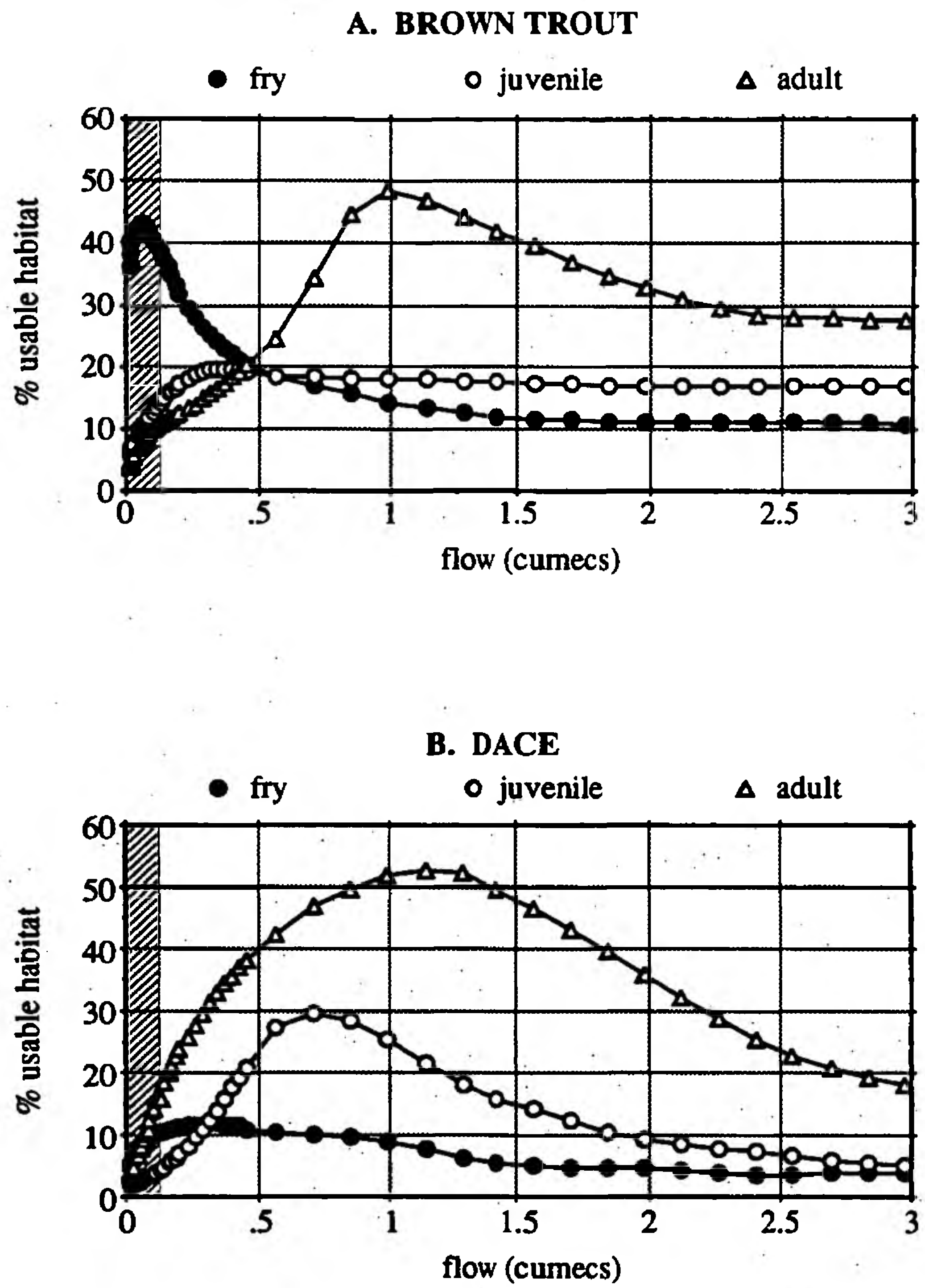

Figure A.4. % usable area for A) Brown Trout and B) Dace against discharge at Shillingthorpe downstream of the transfer outflow. The curves are derived using PHABSIM. The shaded area highlights the low flows eliminated due to the operation of the transfer

A1.5 Observed impacts on biota

NRA invertebrate records for the latter part of the 1991 for sites below the transfer demonstrate the important influence of the transfer (Figure A5), and support the prediction of ii) above. At Banthorpe Lodge the channel bed had been dry for three months during the previous summer and BMWP scores fell to zero. However, by July 1991 - after three months of flow augmentation - the BMWP had risen back to 142 compared with the long term average of 141 for this site. Further downstream at Kates Bridge BMWP scores of 167 and 162 were recorded during 7/91 and 10/91 respectively. Prior to this, the previous highest score for the site from 13 samples spanning the last 15 years had been 158. At unsupported sites, no such improvement was evident.

A1.6 Assessment of invertebrate recovery following flow augmentation

A correspondence analysis was applied to the 1991 sample data for two sites immediately upstream of the outflow (Essendine and outflow US) and two immediately downstream (outflow DS and Shillingthorpe), together with data from historical records for Essendine and Shillingthorpe. Figure A6 illustrates the results of the ordination and highlights four important points.

- The fauna of all sites was severely reduced in spring 1991 - samples to the left of axis one and bottom of axis 2 posess larger numbers of taxa.
- Spring 1991 samples have greater similarity with those pre-1980 than post 1980 - the latter group towards the bottom left of the ordination.
- All sites show a marked recovery in October 1991 - indicated by a shift from upper right to bottom left.
- Sites downstream of the transfer outflow show a greater recovery than those upstream.

Differences still exist between the October 1991 samples and the other post-1980 samples (they plot higher on axis 2 and further left on axis 1), this may reflect incomplete recovery and/or differences in sampling technique.

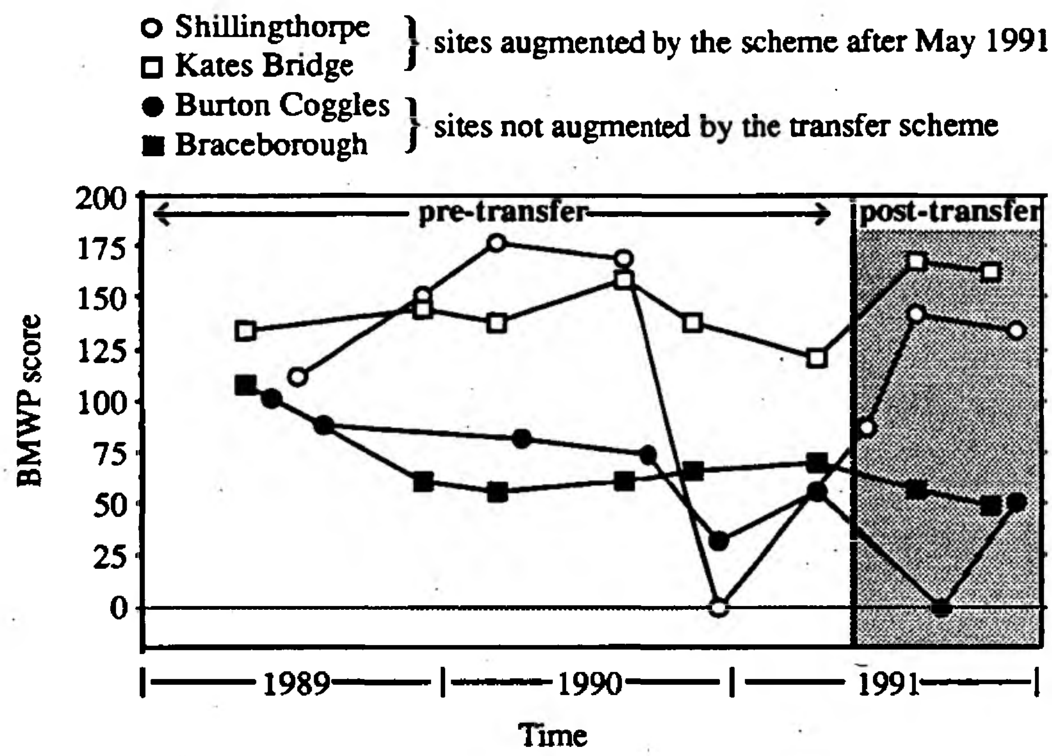

Figure A.5. BMWP scores (from NRA data) during 1990 and 1991 highlighting the recovery of sites below the transfer after the scheme commenced.

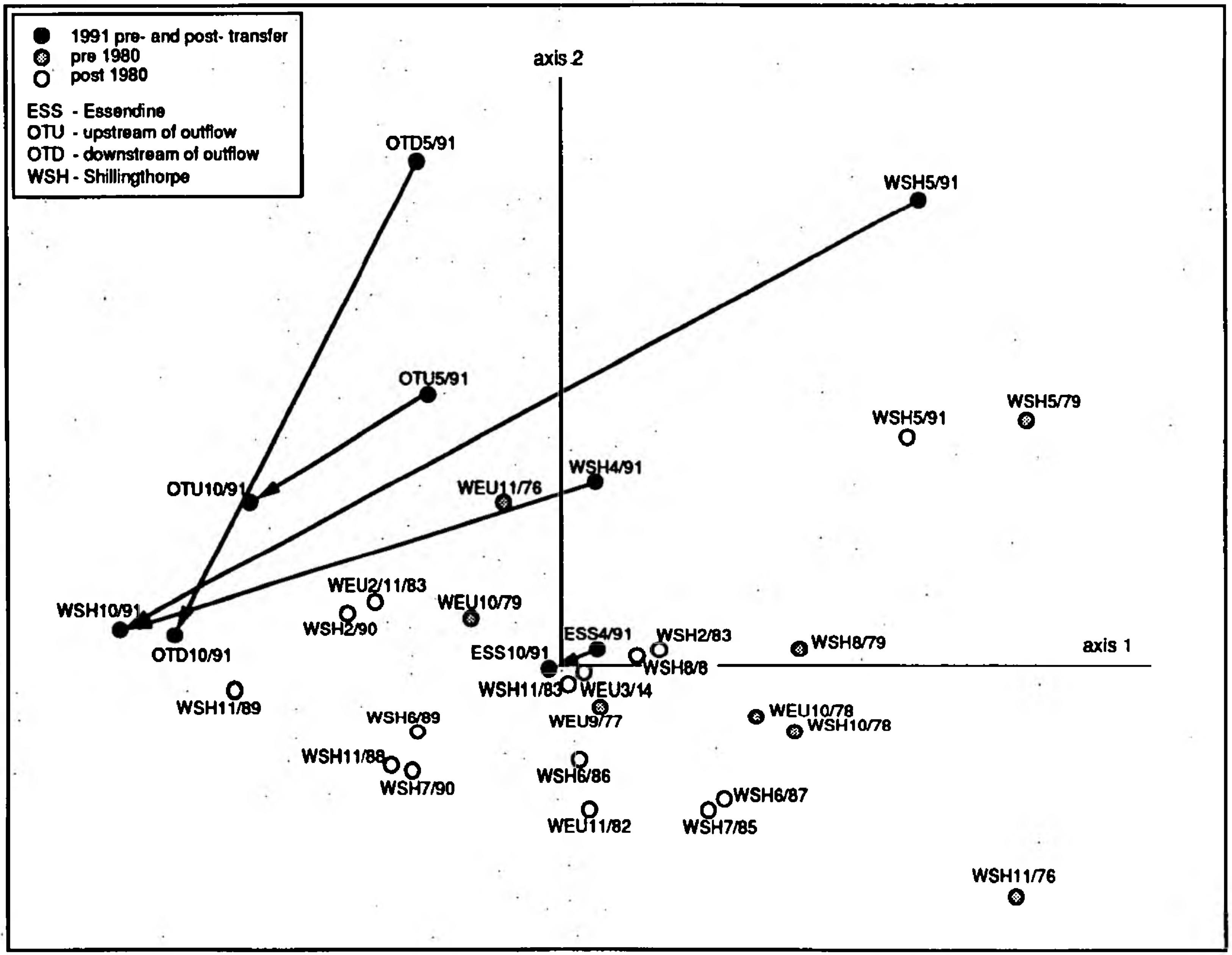

Figure A6. Ordination based on a Correspondence Analysis of invertebrate data from samples collected in 1991 before and after and above and below the transfer (Essendine, Shillingthorpe and sites immediately above and below the outflow), and historical NRA invertebrate records for Essendine and Shillingthorpe. Arrows indicate the shift in relative position of sites during 1991.

On examining the individual taxa distinguishing the 1991 samples from previous years, the similarity with pre-1980 situation is clarified (Figure A7). Thirteen taxa which were present throughout the 1980's but not in spring 1991 were also absent pre-1980. These are in additon to the 8 taxa that disappeared for the first time from all sites in spring 1991. By October 1991 three taxa had reappeared both upstream and downstream of the outflow, while three more only reappeared downstream. Of these the Piscicolidae and Mollanidae require perennial flows and their reappearance suggests a major improvement due to the transfer.

A1.7 Summary

Flow augmentation has maintained flows through sector 9 at about the levels experienced during a normal dry summer, at least from August through October. In 1990 the channel was dry and flows were low throughout the 1990-91 winter. Flow support was introduced on May 21st and the maintenance of flows during the summer led to ecological enhancement, manifested most clearly by the recovery of the invertebrate community. However, whilst offering some protection for fish, flows must be increased if the fish stock is to be enhanced (see 8.1.3).

A major problem for managing groundwater-dominated rivers results from the failure of winter recharge, because river support may be needed during the autumn and spring, as well as during the summer. In April and early May 1991 river support of at least 15 tcmd would have been required to maintain the recommended minimum flows; in November 1990, 26 tcmd would have been required.

Instream habitat improvements, especially the creation of pools, would enhance the ecological benefits of the transfer scheme (see 8.1.4), especially for fish. It is likely that such improvements would reduce the magnitude of the flow needed to optimise habitat for fish.

TAXA DISAPPEARING FOR THE FIRST TIME IN SPRING 1991	TAXA ABSENT SPRING 1991; ALSO ABSENT PRE-1980	
Glossosomatidae Hydroptilidae Polycentropodidae Rhyacophilidae OSTRACODA	Notonectidae Coenagriidae Veliidae PORIFERA Goeridae Ancylidae Leuctridae Helodidae Gerridae	
Sericostomatidae **Lymnaeidae**	**Leptophlebiidae** **Agriidae**	TAXA RETURNING IN OCT. 1991
Corixidae	**Piscicolidae** **Molannidae**	ONLY RETURNING D/S OUTFLOW

Figure A7. Faunal changes before and after implementation of transfer scheme.

APPENDIX 2. PLATES

Plate 1:	a) The upper West Glen at Burton Coggles gauging station. b) The River Tham.
Plate 2:	a) and b) Potholes in the channel bed at NGR SK988260.
Plate 3:	The lower Glen at Pinchbeck (a) and Tongue End (b).
Plate 4:	Examples of artificial influences on the River Glen: a) Fletland Mill and b) channel maintenance on the West Glen at Creeton.
Plate 5:	Intensive landuse with cultivation close to the river banks affects much of the upper Glens e.g. a) at Creeton on the West Glen and b) at Irnham on the East Glen.
Plate 6:	Sector 9. a) A general view looking upstream from NGR TF061110 and b) an example of a log weir used in a successful restoration programme for trout (tributary of the Salmon River, USA).

Plate 1: The upper West Glen below Burton Coggles (above) and the River Tham (right)

Plate 2: a) and b) Potholes in the channel bed at NGR SK988260.

Plate 3: The lower Glen at Pinchbeck (top) and Tongue End (bottom).

Plate 4: Examples of artificial influences on the River Glen: Fletland Mill (top) and channel maintenance on the West Glen at Creeton (bottom).

Plate 5: Intensive landuse with cultivation close to the river banks affects much of the upper Glens e.g. at Creeton on the West Glen (top) and at Irnham on the East Glen (bottom).

Plate 6: Sector 9. A general view looking upstream from NGR TF061110 (top) and (bottom) an example of a log weir used in a successful restoration programme for trout (tributary of the Salmon River, USA).