INSTREAM HABITAT ASSESSMENT - A GEOMORPHOLOGICAL APPROACH

by

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THE BROOK

I come from haunt of coot and hern,
I make a sudden sally
And sparkle out among the fern,
To bicker down a valley.

By thirty hills I slurry down,
Or slip between the ridges,
By twenty thorps, a little town,
And half a hundred bridges.

I murmur under moon and stars
In brambly wilderness;
I linger by my shingly bars;
I loiter round my cresses;

And out again I curve and flow
To join the brimming river,
For men may come and men may go,
But I go on for ever.

TENNYSON

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ABSTRACT

Instream habitat assessment methods are required to evaluate the biological quality of streams in relation to flow and channel morphology and to distinguish the effects of river management on the instream biota. A range of techniques are described and developed in this study ranging from a simple reconnaissance survey to the detailed Physical Habitat Simulation Model (PHABSIM) in order to establish a method for the classification of river channels, identification of key parameters that determine the biota and assessment of the influence of flow and bed morphology on habitat availability.

The Anglian region, and in particular the River Glen, Lincolnshire, provides the focus with an emphasis on the problems of low flows and the impact of the Gwash-Glen interbasin transfer on habitat availability. The method for the definition of channel sectors is developed based on map sources and reconnaissance level survey of physical habitat and hydrology. An empirical relationship between an invertebrate-based score, the BMWP and habitat variables for 28 streams highlights the importance of water quality, flow in relation to channel width, instream hydraulics and instream cover. Utilisation of PHABSIM illustrates the role of bed morphology as a key factor in determining the pattern of hydraulic conditions present, i.e. the diversity of velocities and depths, as well as substrate types and therefore the availability of suitable habitat for target species. Recommendations are proposed for the appropriate use of each technique so that *in situ* habitat can be assessed for its present ecological value and possible manipulations of physical variables can be evaluated in terms of their impact on the aquatic environment.

KEY WORDS Fluvial Geomorphology, Instream Habitat Assessment, Classification, Flow requirements, PHABSIM, Anglian region.

CHAPTER 1 - INTRODUCTION

> *"The evolution of the discipline [Geography], in terms both of its aims and its professional organisation, must be seen as an adaptation to external conditions..."* (Harvey 1974, p.18).

The external conditions described above, driven by government policy and public opinion (both economic and political), are in a state of constant flux. As a result, geographical knowledge, whatever that has meant, has been continually growing and changing (Grano 1981). Geographers have sought to respond to these needs by contributing, in both research and education, to the discovery and diffusion of techniques in various spheres such as urban, regional and environmental management. However, some would say that this has been achieved by a fragmentation of the discipline into a number of sub-specialisms. As a consequence, the central idea of geography which promotes the ideas of sustainability through the study of both human geography and the physical environment has been neglected (Stoddart 1987).

A revolution in scientific endeavour occurred in the 1950's with the increasing application of analytical and experimental techniques and the quantitative description of systems. The quantitative revolution in Geography (labelled as such by Burton 1963), occurred as a response to these external influences during the 1960's, and was largely concerned with the application of statistical methodology to geographical systems of interest, the development of mathematical models and construction of formal theories of spatial organisation. This permeated most spheres of Geography and brought about a distinct change in the approaches used as highlighted by P. Haggett's *Locational Analysis in Human Geography* (Haggett 1965) and R. Chorley's and B. Kennedy's *Physical Geography: A Systems Approach* (Chorley and Kennedy 1971).

Since 1970, many geographers have advocated the need to proceed towards applications of physical geography in relation to management of the environment (e.g. Chandler 1970a, Douglas 1972, Jones 1983). Gregory (1987) more recently perceived the application of physical geography developing from four stages concerned progressively with description and depiction of environment, with environmental evaluation, with environmental impact and with environmental prediction. Consequently, the physical geographer has had to address the objectives of environmental design. However, such approaches have not been the sole prerogative of the physical geographer. As a consequence of a wider interest in the environment, it has been necessary to become more familiar with the methods used by practitioners of other disciplines and to develop the ability to assess the efficiency of alternative design strategies. For instance, experience of the adverse effects of river channelisation has led to the search for alternative methods which do not have such dramatic downstream effects and which minimise the degradation of environmental quality. Approaches have been developed for the use of environmentally-sensitive river engineering (Gardiner 1988, Gardiner 1991) and for restoring those channels that have already suffered the deleterious impacts in the past (Swales 1989, Petersen 1992)

There has long been a tendency for geomorphology to be dominant in physical geography (Brown 1975), and the content of geomorphology has shown signs of imbalance towards fluvial geomorphology and hydrology (Gregory 1987). Hydrology is spread across several academic disciplines and demonstrates how the subject matter of physical geography can be embraced within other disciplines. Hydrology entered the curriculum of geography in higher education in the UK in the 1960's and has developed an approach that is quite distinct from the study of the same subject in other disciplines e.g. engineering. In geography it focuses on describing and explaining the water cycle and the water balance rather than its engineering counterpart where estimating and analysing precipitation and runoff components with a strong mathematical emphasis provides the core. However, more recently there has been a shift towards 'water resources hydrology' where estimating and analysing available water resources, supply and demand are foremost. This approach provides the scientific basis for the exploitation and prediction of water resources and is increasingly concerned with environmental issues (Walling 1987).

Hydrologists have identified a range of variables which describe the hydraulic characteristics of rivers (Neill and Galay 1967, Kellerhals et al 1976, Mosley 1981) and these factors have tended to relate to the physical characteristics of rivers which are important for river engineering and physical hydrology. River classification schemes have been developed based on the hydrological network and geomorphic features in order to split the channel into a number of distinct reaches or sectors. The definition of river reaches is necessary in order to maintain some degree of certainty that appropriate management is being applied in the most suitable location. Definition of spatial units is the primary task and therefore the underlying aim is a geographical one. Hydrology and fluvial geomorphology provide the specific information in order to accomplish this, both of which are fundamental to physical geography. Under these circumstances, the claim that the process is firmly rooted in physical geography is plainly apparent.

Quantitative and process-based research on rivers that provide the basis for environmentally-sensitive water management began during the 1950's and 1960's. Truly integrated studies of fluvial environments are more recent. Modern approaches to the study of rivers are founded in two important works: *Fluvial Processes in Geomorphology* by L.B. Leopold, M.G. Wolman and J.P. Miller (Leopold et al 1964), and *The Ecology of Running Waters* by H.B.N. Hynes (1970). A number of earlier works had already established relationships between flow and current velocity and salmonid fish, macroinvertebrates and macrophytes. Two of the first papers to emphasise the importance of flow as an ecological factor were Phillipson (1954) and Wickett (1954). However, the first major important catalyst for linking flows and ecology was *River, Ecology and Man* edited by R.T. Ogelsby, C.A. Carlson and J.A. McCann, published in 1972 (Ogelsby et al 1972). This evolved in response to a new, and rapidly growing insistence that river quality - in terms of nature conservation, aesthetics and recreation - be weighed along with consumptive and ecologically destructive uses. At the time, river management and flow allocation remained an 'art' rather than a science, as illustrated by Fraser's statement (Fraser 1972, p.277):

> *"Discharge recommendations are often based more on a biologist's or engineer's guess than on a quantified evaluation of the relationship between discharge and the ecology of the stream, its aesthetics and other in-place uses".*

During the late 1970's in the USA, a host of techniques began to be developed to define the effect of flow changes on the instream biota and evaluate the instream habitat ranging from the relatively simple to more refined approaches. A significant response to the intensifying need for an objective method to assess instream-flow allocations was the development of the Instream Flow Incremental Methodology (IFIM) by the US Fish and Wildlife Service Cooperative Instream Flow Group (Bovee 1982). The methodology has become one of the most widely used methods in North America for estimating the effect of changes in flow on trout habitat (Conder and Annear 1987) and provides a useful guide for determining low-flow requirements, particularly in late summer and autumn (Hill et al 1991).

However, the role of flow and its associated hydraulic characteristics in structuring river ecosystems received little development until the early 1980's (Newbury 1984, Nowell and Jumars 1984). Prior to this, stream ecologists had focused on energy flows, carbon fluxes and macroinvertebrate life histories (Resh 1985). Nevertheless, studies of biotic responses to flows and especially to changes of flows have gained considerable momentum over the past decade. During this more recent period, hydrological, geomorphological and biological research have become integrated to establish a new understanding for lotic ecosystems (e.g. Resh et al 1988, Statzner et al 1988, Stalnaker et al 1989) and their land-water ecotones (Naiman and Decamps 1990).

In the UK, advances in linking hydrology and ecology have lagged behind those in the US. At a symposium held in 1970, on Conservation and Productivity of Natural Waters (Edwards and Garrod 1972), organised by the British Ecological Society and the Zoological Society of London, Morgan (p.143) notes:

> *"In the long term it would be desirable to gain knowledge of the wider implications of the amounts of water let down rivers on the ecosystem as a whole".*

Importantly, Morgan urged the focusing of efforts on the intricate relationships between animals and plants and their environment if better management is to be achieved. Significant advances were slow to be made although influential reviews were published by Brooker (1981), Milner et al (1981) and Petts (1984a). From a geographical viewpoint, a milestone occurred with the publication of Mosley's review of *River Channel Inventory, Habitat and Instream Flow Assessment* in Progress in Physical Geography (Mosley 1985). This signalled physical geography staking its claim in this interdisciplinary subject area. Subsequent related research in geography has focused on the refinement of many of these techniques and the classification of rivers across a variety of spatial scales (e.g. Thorne and Easton 1994, Petts et al in press). Indeed research continued across a wide spectrum of disciplines, but despite detailed studies of the River Tees below Cow Green reservoir (Armitage 1978, Crisp et al 1983) in a study of compensation flows in the UK, Gustard et al (1987) concluded that the primary research need remained the development of quantitative relationships between freshwater biota and the physical and chemical variables at a scale appropriate to the river reach. A marked acceleration of research effort followed the foundation of a new journal, *Regulated Rivers*, which seeks to integrate scientific research and scientifically based management and the *Fourth International Symposium on Regulated Streams*, held at Loughborough in 1988 (Petts and Wood 1988, Petts et al 1989). Subsequently, IFIM was introduced (Bullock and Gustard 1992, Petts 1992) and progress made in addressing biological responses to water abstraction (Armitage and Petts 1992, Bickerton et al 1993).

As already established, the development and evaluation of techniques that determine the effect of flow and morphological change on the instream biota are not the sole prerogative of the physical geographer. An interdisciplinary perspective involving hydrology, geomorphology, ecology, biology and engineering amongst others is both necessary and fundamental to a truly holistic approach to river management. The role of the physical geographer is to provide a perspective on those elements which are by tradition the most pertinent to the geographer. In the case of instream habitat assessment these lie within the classification of rivers based on different spatial scales in order to ensure that investigations are carried out in sections of the river that are representative. Also, the characterisation and evaluation of fluvial geomorphology is intrinsic to the definition of instream flow requirements. However, perhaps more importantly, the physical geographer should also be in a position to provide an overview and overall understanding of the various elements of such a project. In other words:

> *"...the environmental geomorphologist [should be] in a position to not only bridge the gap with peer natural scientists but also to translate various pieces of puzzle into a composite whole"* (Coates 1982 p.166).

Since the review of pertinent techniques by Mosley (1985), these approaches have continued to be pursued within the realms of geography and have helped in the pursuit for the development of environmentally-sensitive approaches for managing rivers.

1.1 The Present Study

The Water Act 1989 established the National Rivers Authority (NRA) within the UK to preserve and improve the water environment. This has led to a growing demand to develop catchment management plans to meet river quality objectives and environmental targets. In particular, methods are required to assess biological quality in relation to flow and channel morphology and to distinguish the effects of river management on the instream biota. This study attempts to apply, develop and test a range of techniques applicable for instream habitat assessment with an emphasis on the role of geomorphology in river management. In particular the methods are used to assess biological quality in relation to flow and channel morphology and to distinguish the effects of river management on the instream biota. The following chapter considers the classification of river channels into distinct types, sectors and reaches based on hydrological and physical parameters to provide a basis for the appropriate management of a river system as a whole. This is followed by a brief discussion of the importance of habitat and a description of instream habitat assessment methods under a number of different categories. Chapter three examines the application of the classification process to the River Glen catchment, Lincolnshire and the evaluation of a habitat inflection method in order to assess the impact of the operation of the Gwash-Glen interbasin transfer. A procedure to identify the key habitat variables influencing the biological quality of streams at the reach scale is discussed in chapter four. Habitat parameters were identified and quantified at 28 sites within the Anglian region in order to establish the factors determining invertebrate assemblages and an associated biotic score. Chapter five outlines the data requirements and use of the more detailed IFIM to three rivers, the River Glen, Wissey and Babingley. Field data and hydraulic simulations were undertaken in order to make recommendations regarding flow-habitat relationships with particular emphasis on the effect of low flows. The method was also developed to establish the importance of bed morphology in the provision of habitat and for defining sites in need of restoration. It is intended that the application of the various methods, with recognition of all relevant spatial and temporal scales, will provide an approach to allow a more effective assessment of habitat that is both scientifically defensible and practicable for management. Consequently, the fundamental role of geomorphology in river management will be emphasised.

CHAPTER 2 - LITERATURE REVIEW

2.1 The Background and Need for Classification

With the increased demand for water supply, coupled with a rise in environmental awareness, there has been a growing need for improved approaches to assess the impacts of water resource schemes and especially for allocating water for the maintenance of instream habitat (Petts and Maddock 1994). River regulation (including for domestic, agricultural, hydro-electric power and flood control requirements), water abstraction and interbasin transfer schemes continue to be advanced, all of which impose an unnatural flow regime. For instance, of the 1310 UK gauging stations evaluated in 1982 (DOE 1982), only 11 per cent were classified as having a flow regime that was 'natural'. Furthermore, channel morphology has also experienced a long history of manipulation. For at least the past 550 years, British rivers have been subjected to various manipulations for flood and agricultural drainage schemes (Brookes 1988). Consequently, large proportions of main river, particularly in regions with built up areas near to major rivers or in lowland agricultural areas have been affected by engineering works such as straightening, embanking and dredging (Brookes et al 1983). As a result of these widespread flow and channel manipulations, natural or even semi-natural river systems are a rare commodity (Boon 1992).

In response to these developments, a number of approaches have been developed for the mitigation of such impacts. Instream habitat assessment methods attempt to describe and assess the present stream resource (Milner et al 1985), flow allocation techniques try to assess the discharge requirements of the instream biota (Gore and Nestler 1988) and fishery enhancement recommendations often involve the use of habitat improvement structures to physically recreate the habitat that may be degraded due to engineering works (Swales 1989). Application of all these techniques requires a multidisciplinary framework including fields such as hydrology, geomorphology, engineering, ecology and biology. However, integration has been slow due to the difficulty in the understanding and exchange of technical information. Many people working on impact analysis suggest they have developed an 'intuitive feel' after years of experience through trial and error but this knowledge is difficult to impart to others (Rosgen 1985). In order to bridge the communication and knowledge gap, all disciplines need a consistent frame of reference when describing river channels. One such method is the use of stream classification for describing distinct channel sectors which exhibit a set of discrete variables. More importantly, the definition and classification of channel sectors is essential in order to provide a practical framework for ecologically-sensitive river management. The approach is firmly rooted in the 'fluvial hydrosystem perspective' (Petts and Amoros 1993) which recognises the importance of the whole river corridor - the river channel, riparian zone, floodplain and alluvial aquifer and is viewed as a four-dimensional system including longitudinal, lateral, vertical and temporal changes. The outcome is designed to facilitate the development of realistic recommendations for managing complex river systems.

> *"Classification systems have been used for centuries to organise information about ecological systems by scientists and resource managers"* (Naiman et al 1992).

Backiel (1964) makes reference to these earlier works on zonation, such as Borne (1877). Indeed, he reports how even early in this century the zonation of rivers had been accepted in practice and the system was already outlined in standard texts (Thienemann 1925). However, the classification of fluvial systems remains in a formative stage because of the complex variability over broad temporal and spatial scales (Salo 1990) and because running waters have only recently become recognised as ecological systems in their own right (Vannote et al 1980).

The effect of flow on instream biota has been widely demonstrated (e.g. Brooker 1981, Petts 1984b, Milner et al 1985, Boon 1988, Hellawell 1988, Mann 1988), but the effects may be masked by environmental factors that determine regional variations and downstream patterns of biota and biological processes within catchments (Armitage and Petts 1992). The geomorphic characteristics of streams vary spatially from headwaters to the sea (Langbein and Leopold 1966) as well as temporally in response to disturbance patterns. Discharge, channel width and depth, mean flow velocity, gradient and bed material grain size have all been shown to exhibit characteristic downstream trends (Schumm 1977, Knighton 1980, 1984). Channel size increases systematically through a river system as the increasing drainage area contributes larger flows to the main channel. The granular materials that make up the bed and banks customarily vary downstream according to the differential transport rates of different particle sizes, selective entrainment, sorting and abrasion (Knighton 1984). Accordingly, headwaters are relatively narrow, high gradient streams and may be dominated by cobble and boulders as the larger fractions are derived here and cannot be moved very far. The downstream reaches of larger rivers are characteristically low gradient, wide, deep and formed in sand and silt. The controls on the fluvial system, including geological history, climate, physiographic setting and vegetation all change along a river. Some changes may be subtle, as sediment load is modified in a long, slowly aggrading channel. Others are abrupt, as at major tributary junctions (Kellerhals and Church 1989). Because of the significant correlation between channel scale and position in a drainage system, classification of river channels on the basis of their position in the drainage basin is of some interest.

The general principles of classifying rivers for the purpose of assessing conservation potential have been reviewed by Macan (1961), Hawkes (1975) and Naiman et al (1992). River classification based on geomorphic features came into prominence in the 1940's (Horton 1945 Huet 1950). Horton's stream ordering, as modified by Strahler (1952, 1957) allowed the classification of streams based on the hydrological network from map evidence. This method was found to correlate closely with many stream habitat parameters used in past classifications (e.g pool depth, pool width, streamflow and gradient). Its use was advocated as a common reference as species diversity of aquatic organisms exhibited similar trends to stream order (Harrel et al 1967).

Almost all classification schemes based on physical habitat features have been founded on the perception that stream units (i.e. segment, reach, channel, riffle/pool) are discrete and can therefore be delineated. For example, Frissell et al (1986) defined longitudinal boundaries of segment types by easily measured tributary junctions, major waterfall, or other structural discontinuities. However, this idea of abrupt change has been challenged with an alternative view of gradational change (Vannote et al 1980, Cushing et al 1983).

As a response to the downstream progression in the physical properties of natural streams, the instream biota has also been shown to exhibit a similar change. Because key physical parameters often change gradually along the stream continuum, and it is a combination of these parameters that provide the habitat for the instream biota, it should be expected that species composition would change in a similar manner. According to the River Continuum Concept (RCC; Vannote et al 1980, Minshall et al 1985, Cummins 1988) invertebrate communities have evolved to be in equilibrium with the most probable set of physical conditions that are generally predictable from the downstream changes in geomorphology. Headwater streams are dominated by riparian shading and litter inputs and so the invertebrates are dominated by shredders which utilise riparian litter as their food source once it has been appropriately conditioned by aquatic micro-organisms. The mid-reaches are less dependent upon direct riparian litter input and with increased width and reduced canopy shading, the shredders are reduced and the scrapers are more important as attached microalgae become more abundant. The large rivers are dominated by fine particulate organic matter, and the increased transport load of this material together with increased depth results in reduced light penetration and the dominance of collectors.

Similar zonations based on fish species have provided the basis for the classification of river sectors (Huet 1950, 1959). Shelford (1911) originally described the longitudinal distribution of fishes in temperate stream habitat in terms of the geological age of stream beds. The concept of ranking streams based on bifurcation ratios, drainage density and stream length was advanced by Horton (1945) and applied by Kuehne (1962) to the fish distribution of Doe Run, a tributary of Kentucky River. Huet (1959) discussed the effects of both gradient and width as applied to Western European streams and classified the rivers based on four zones. The trout zone included reaches of streams with steep gradients, coarse substrates and with well aerated and cool water (rarely exceeding 20°C). The Grayling zone included larger streams with depths up to 2 m and gradients less than the trout zone, although still possessing riffles and pools. Substrate was expected to be finer, dominated by gravel. Further downstream, rivers of moderate gradient and current with alternating rapids and quiet waters provides the basis for the Barbel zone. The lower stretches of rivers, canals and ditches fall into the realms of the Bream zone where the current is slight, summer temperatures high, water turbid and often deeper than 2 m. Therefore, the upper two zones are dominated by the salmonid species, and the lower waters part of the cyprinid region. This scheme was developed for German rivers and was subsequently criticised for not being applicable elsewhere. For instance, in British rivers it was suggested that Minnow and Chub are more suitable 'key' species rather than Grayling and Bream in their respective zones and the Barbel is missing from Scandinavian rivers (Illies 1958). Some criticism was levelled at zonation because the distinctions between sectors was not as sudden as the method suggested and in fact, 'border zones' rather then 'border lines' were more apparent where changes in species composition always seemed to occur gradually (Hawkes 1975). Therefore, an approach similar to the RCC would seem more appropriate but also applicable to fish. Nevertheless, studies (e.g. Harrel and Dorris 1968, Gorman and Karr 1978, Platts 1979) have highlighted strong correlations between broad scale stream basin parameters, habitat and fish population structure.

A river may be considered across a spectrum of scales, each with a different degree of sensitivity and recovery time (Frissell et al 1986) (figure 2.1 overleaf). At the broadest scale, the drainage basin changes only slowly in response to natural or artificial disturbances. Conversely, at the smallest scale, 'pioneer' patches are highly sensitive to disturbance and quick to respond to natural and artificial changes of the environment. However, these small scale habitats are also considered to be the ones that will recover most quickly if external factors allow. For instance, gravel bars, sand berms and new cutoff channels, 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. The intermediate level scale can be seen as the link between these two extremes. This incorporates channel reach and form which is determined by larger scale attributes (e.g. lithology, gradient, climate) but influences in-channel features (e.g. depth, substrate and velocity).

For the assessment of instream habitat, a three-level classification system has been proposed (Petts and Maddock 1994). First the river system may be divided into TYPES (e.g. upland, intermediate and lowland), reflecting position along the river. At this level of analysis such variables as altitude, distance from source and the slope of the valley floor are important. Secondly, each type may be divided into SECTORS. Within, each sector, water quality, sediment load, and hydrological regime are seen as invariant between sites. Thirdly, each sector is divided into REACHES on the basis of local variations in channel morphology or river-margin vegetation. Variations between individual reaches within a sector 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. Along natural rivers, channel morphology often has the same general form throughout each sector.

The accurate definition and classification of channel sectors relies on specific information at both the catchment and the reach scale. Classifications into river types may be possible based on broad measurements from map sources. However, the sector scale classification requires a more detailed database and accurate definition relies on the use of reconnaissance level surveys. These provide information on habitat characteristics on a different scale, but before describing their

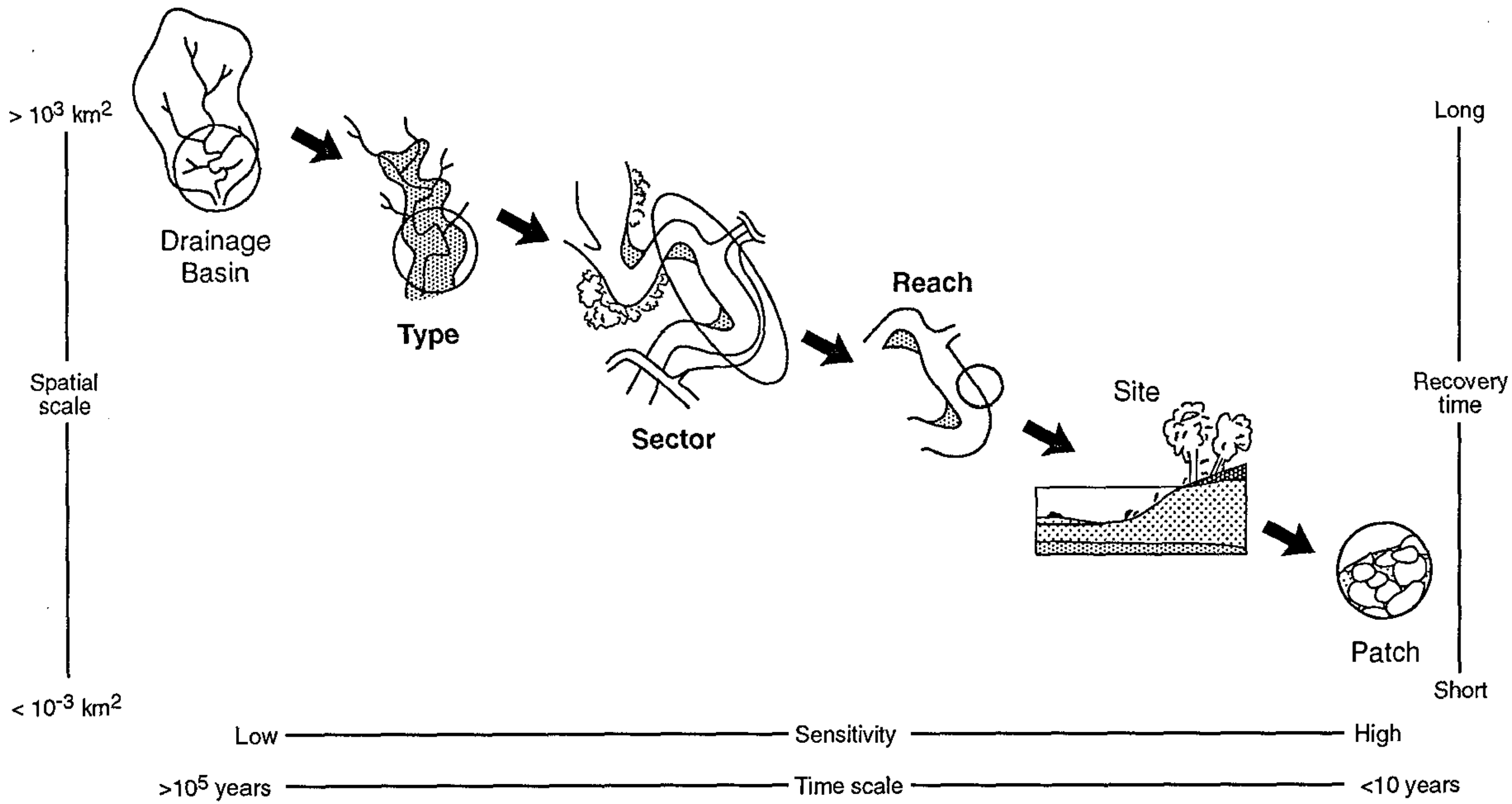


Figure 2.1 - A functional classification of rivers

features, it is necessary to define the components of habitat and how it can be assessed.

2.2 The Importance of Habitat

Habitat (or 'liveable space'; Bovee 1982) can be defined as the local physical, chemical and biological features that provide an environment for the instream biota. It is affected by instream and surrounding topographical features, and is a major determinant of aquatic community potential. There is considerable evidence to suggest that both the quality and quantity of available habitat affect the structure and composition of resident biological communities (Hynes 1968, Sheldon 1968, Whitton 1975, Karr and Schlosser 1978, Ward and Stanford 1979, Schoof 1980, Meffe and Sheldon 1988, Calow and Petts 1994). Furthermore, the attainable biological potential of a site is primarily determined by the quality of the habitat at that site (Plafkin et al 1989).

The classification and characterisation of habitat has led to the recognition of a number of different spatial and temporal scales for analysing environmental units related to stream ecosystems (Frissell et al 1986). Spatial scales range from the region and catchment, to the reach level, and the site and 'patch' scale and are similar to the 'superior', 'macrohabitat' and 'microhabitat' proposed by Hermansen and Krog (1984).

2.2.1 The region or catchment scale

At the broadest scale, the environment is relatively stable and biota are determined by the overall features of the region, its topography and altitude and its geomorphic/land-use pattern (Hughes et al 1990). This in turn produces a broad pattern of hydrology, temperature and chemistry (Elwood et al 1983). For instance, Poff and Ward (1989) successfully attempted to categorise nine stream types based on stream communities and streamflow patterns of 78 stream communities in the USA. At the basin and reach scale, zonation schemes have used stream order (Lotrich 1973), hydraulic stress and power (Statzner 1987), temperature (Gar and Flittner 1974) and habitat heterogeneity (Gorman and Karr 1978, Gorman 1988). For instance, Huet's (1959) widely reported study produced a longitudinal zonation of European rivers base on four zones that have characteristic fish faunas and related these to river gradient and width. Similar zonations have also been described for rivers in the USA (Trautman 1942). Penczak (1972) separated the fish communities at 117 sites in the Nida drainage basin, Poland, according to those described by Huet (1959) and separated them according to river gradient, width, depth, temperature and bankside features. However, longitudinal zonation does not explain how stream reaches influence assemblages.

2.2.2 The reach scale

The distribution of habitat types within reaches has not received much attention. At this scale of approach, habitat features of different river sections such as average flow velocity, morphological type (e.g. riffle/pools) and bankside cover are deemed influential. Most studies compare the biota with habitat between sections along the river course (e.g. Lewis 1969) although some (e.g. The Nechako River Project 1987) include a comparison in the lateral dimension (from marginal to mainstream habitats). Bisson et al (1982) have refocused awareness on habitats as channel units first by creating a typology based on hydrological features, followed by an examination of fish distributions among these habitats (Bisson et al 1988).

2.2.3 The microhabitat scale

The importance of habitat stratification at the reach scale has been reasserted by Kershner and Snider (1992) who advocate that this needs to be integrated with the information taken at the broader scales outlined above and more detailed microhabitat information. The exact positions chosen by resident salmonids appears to be related to small scale physical characteristics, especially depth, velocity and substrate (Lewis 1969, Devore and White 1978, Shirvell and Dungey 1983). Brown trout were found to prefer distinct velocities according to whether they were feeding or spawning and chose similar microhabitats regardless of the available habitat in different rivers (Shirvell and Dungey 1983). Moyle and Baltz (1985) determined the microhabitats of 8 species of Californian stream fishes and found that fish have a considerable overlap in their preferences for river depth, velocity and substrate. However, in contrast to this study for American warmwater fish, the microhabitat occupied by European cyprinids in the Rio Matarrana, in Spain (Grossman et al 1987) revealed that fish selected deep areas which had undetectable river velocity. The most widely used instream flow technique at this level is the Instream Flow Incremental Methodology (IFIM) developed by the US Fish and Wildlife Service (Bovee and Milhous 1978, Bovee 1982) (see section 2.4.7). Information from this is used in the computer-based Physical Habitat Simulation Model (PHABSIM) to generate flow/habitat relationships from field information of velocity, depth, substrate and cover from numerous transects and flow conditions. This information can then be used to assess the impact of a change in flow and/or physical structure of the channel on the instream biota.

2.3 The Components of Habitat

Combining information pertinent to all the scales discussed above, Stalnaker (1979) concluded that four main components determine the productivity of any instream habitat, namely:

- the flow regime
- water quality
- the physical nature of the channel
- the energy budget (e.g. temperature, sediments, organic matter and nutrients) (Stalnaker 1979)

However, the magnitude of these components are altered significantly by direct and indirect human interference. For instance, the ever increasing demand for water supply for domestic, industrial, agricultural and hydro-electric power generation means that schemes for river regulation, water abstraction and inter-basin transfer will continue to be advanced (Petts 1988, Petts and Maddock 1994). This leads to environmental degradation due to inadequate summer flows with important secondary effects (e.g. siltation (Petts 1984b), increased temperatures (Smith 1979), reduced oxygen levels (Edwards and Crisp 1982), and changed hydraulic conditions (Cragg-Hine 1985)). Streamflow must also be adequate at other critical times and across the whole flow regime to maintain ecological integrity including winter flushing flows (to maintain substrate quality and prevent vegetation encroachment) (Reisser et al 1989) and even floodplain-maintenance flows to create disturbance and sustain habitats for pioneer species and the mosaic of landform-sediment-vegetation units (Petts and Maddock 1994).

In areas of good or excellent habitat, biological communities will reflect degraded conditions when water quality effects are present. Problems may arise from numerous sources including pollution from rural land (Jose 1988), sewerage works (Brewin and Martin 1988), industrial discharges (Alabaster 1969) and runoff from urban areas (Helliwell 1978). The variable tolerance to pollution of different species is well documented (Wilhm, 1975, Resh and Rosenberg 1984) and provides the basis for the use of a variety of biota for indicators of pollution. Benthic macroinvertebrates are particularly suitable as ecological indicators because their habitat preference and relatively low mobility cause them to be directly affected by substances that enter the environment. They are also easier to identify, analyse and preserve than microscopic organisms and less mobile than fish that can migrate rapidly to escape the effect of deleterious substances. They are also present across a wide variety of habitat types and river systems (Plafkin et al 1989). This has led to the development of numerous indices that incorporate macroinvertebrate presence and abundance to indicate water and habitat quality (Chandler 1970, Chutter 1972, BMWP 1978, Wright et al 1989).

Physical alteration of the channel through engineering and maintenance works are also widespread (Brookes 1988) with the resultant impact on morphological diversity (Swales 1989), instream vegetation growth (Wade 1978), loss of gravels (Schoof 1980), coarse organic debris (Bilby and Likens 1980) and riparian vegetation (Swales 1982). Strong and widespread evidence suggests that this in turn has a widespread and usually detrimental influence on the instream biota (e.g. Congdon 1971, Keller 1976, Brookes 1985, 1988, Brussock et al 1985, Hey 1990).

Energy can flow into running water ecosystems from solar radiation via temperature and photosynthesis, from the input of dissolved and particulate matter, and as nutrients (Calow 1992). Energy, once part of the system, passes from one trophic group (primary producers, decomposers, herbivores, carnivores, i.e. trophic levels) to another. Alteration of the three former mentioned components of habitat (i.e. flow, water quality and channel morphology) will affect both the rates of energy input and subsequent transmission through the system (Newbold 1992). The instream energy budgets have been highlighted as a strong determinant of community structure and disturbance by flow regulation, pollution and land management (e.g. forestation and deforestation) can produce changes in the composition of the biota (Odum 1985).

2.4 Instream Habitat Assessment Techniques

As a result of a long history of human interference of each of these four components (both separately and in combination, directly and indirectly), there are few remaining examples of 'natural' or 'semi-natural' river systems and indeed;

"rivers have been used by man more than any other type of ecosystem" (Boon 1992, p.11).

Instream habitat evaluation methods attempt to assess the interaction and relative importance of these four components in order quantify the stream habitat resource. Upto date, methodologies have largely originated in the USA. Some have focused on existing flow records for the allocation of instream flows in order to provide sufficient habitat. Fish populations tend to provide a basis for human instream use and so early methods concentrated on their requirements (Wesche and Rechard 1980). Subsequent developments have realised that other instream users e.g. invertebrates (Gore and Judy 1981, Armitage et al 1987), birds (Robertson et al 1983) and plants (Mountford and Gomes 1990) have an intrinsic right to survive and so have gained recognition. Others have attempted to measure the actual physical attributes of selected reaches to estimate production. At the most complex level, detailed field data is combined with computer simulations to model biological response. With these developments, there now exists an array of techniques, each relying on a different amount of knowledge to analyse instream habitat needs and has different situations in which it can be best applied. They can be categorised into two basic groups according to the approaches they use.

The first, namely rapid assessment techniques involve making an assessment of either flow requirements or instream habitat availability with minimal time and effort. A further subdivision can be made between discharge methods, reconnaissance level surveys, habitat inflection methods, scoring systems and empirical model methods. As their name suggests, rapid assessment techniques make an evaluation of either flow requirements or instream habitat availability with minimal time and effort. The second type, namely biological response techniques, require a much more detailed approach and employ habitat suitability criteria for target species to develop a relationship between habitat variables and biota. This group includes field data interpolation methods and the Instream Flow Incremental Methodology. Consequently, a hierarchy of approaches can be summarised as evident in table 2.1. The methods are arranged to stress a continuum from the simple to complex and the following section describes the important attributes of each type with reference to specific examples.

Table 2.1 - Summary of instream habitat assessment techniques

Rapid Assessment Techniques

- Discharge methods
- Reconnaissance level surveys
- Habitat inflection methods
- Scoring systems
- Empirical models

Biological Response Methods

- Field data interpolation methods
- IFIM

2.4.1 Discharge methods

Initially, streamflow was the parameter examined in most detail, particularly with its relationship to fish habitat. This gave rise to the discharge methods (Mosley 1985) which use flow records and require no fieldwork. Baxter (1961) originally developed a method for defining minimum flows for salmonids which assumes that median June flows are optimal for fisheries and sets recommendations for the remainder of the year relative to this flow considering natural flow variation. Using a similar approach, Tennant (1976) established the 'Montana' method which recommends flow needs based on percentages of the average annual flow. On the basis of field studies in Montana, Wyoming and Nebraska over 38 different flows at 50 cross-sections on 196 stream miles, affecting both coldwater and warmwater fisheries, habitat quality was found to be remarkably similar in most streams when they carried the same percentage of their average annual flow. Depths and velocities were shown to be significantly reduced and substrate exposed as the instantaneous flow dropped below 10% of the average annual flow. Consequently, this was established as the absolute minimum needed to sustain short-term survival. A flow of 30% of the average annual flow was required to maintain good habitat for aquatic life; at this flow, widths, depths and velocities were generally satisfactory with streambanks providing some cover, and larger fishes could pass most riffles. Optimum habitat was provided by flows of 60-100%, which were considered to sustain excellent to outstanding habitat. The table below (2.2) provides the full range of instream flow regimes outlined by Tennant (1976) but on a two season basis rather than for annual figures.

Table 2.2 - Instream flow regimes for fish, wildlife, recreation and related environmental resources (Tennant 1976).

Description of flows	Recommended base flow regimes Oct. - Mar.	Apr. - Sept.
Flushing or maximum	200% of the average flow	
Optimum range	60-100% of the average flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	10% of average flow to zero flow	

Orth and Maughan (1981) attempted to evaluate the applicability of this method to Oklahoma streams. They concluded that in different environments flow recommendations may require modification. Rather than be based on two 6-month periods, seasonal and possibly monthly variation should be accounted for. The method also ignores the specific physical character of the stream and so is best utilised to obtain a preliminary estimate of flow requirements followed by more intensive field analysis if time and financial constraints permit. Other limitations cited relate to the assumptions that past flows can be used to estimate optimal flows and that past hydrologic and hydraulic parameters will not change significantly over time. These assumptions imply an aquatic resource management philosophy based on past conditions rather than optimising stream production or minimising the adverse impacts of flow reduction and do not consider the cumulative impacts of low flows on fish populations. Nevertheless, when compared to recommendations for minimum flow requirements produced by more detailed techniques, the actual figures were very similar (Orth and Maughan 1982). Therefore, although these methods do not provide site specific information on the effects of altered flows on habitat availability, they have the advantage of requiring no field studies, and thus can still be useful to enable a preliminary estimate of the quantity of flow necessary for instream uses.

2.4.2 Reconnaissance level surveys

Reconnaissance level surveys incorporate a mixture of qualitative assessment and morphometric measurement to build up a record of the form of a river based on field observation. They are designed to formalise the types of habitat observations and evaluations that may be routinely made by geomorphologists or stream ecologists, but not usually recorded in such a disciplined way. This information can then be used to aid the classification and definition of channel segments with similar habitat characteristics.

Newson (1989) suggested the 'fluvial auditing' approach to classify and record the features of the channel and bordering slopes in a drainage basin with an emphasis upon assessment of the sediment dynamics of the system and the trend of morphological change over the 'medium term' (i.e. 10-100 years). By noting the location and dimensions of selected fluvial features (e.g. riffles and pools) and recording their type, density and distribution, the aim was to assess the evidence for balance, or lack of it, in the sediment system of the basin in question. Specific measurements incorporated features under the headings of channel pattern, dimensions, sediments, bank erosion and bed material characteristics in order to achieve this aim.

Existing river corridor survey methodology (NRA 1992) also goes some way towards recording the instream geomorphological features, but not at the level of detail that is suggested above and hence not at the resolution necessary for a geomorphologist to make firm conclusions regarding the state of the fluvial system. The emphasis is on key conservation elements within the river corridor which require preservation, for example meander features, vertical banks, trees and macrophytes. However, instream habitat features are not recorded as part of a rigorous and quantitative methodology (as this was never the fundamental aim of the survey) and hence the information cannot be used to describe the instream habitat in any rigorous manner and hence facilitate the definition of channel sectors.

Hey (1990) reiterated the need for more baseline data using geomorphological surveys in parallel with standard engineering and river corridor surveys. This has recently been reaffirmed by Thorne and Easton (1994). Hey (1990) suggested that the detail of the survey needs to be tailored depending on the nature of the management problem but should include due recognition of one or more of the following:

1) Establish the morphology of the reach (cross-section, profile and plan shape) and identify natural control features, such as rock-ledges/bars as well as artificial structures such as weirs.

2) Establish the nature and composition and stratigraphy of the bed and bank sediment.

3) Establish the nature of both bed and rooted vegetation.

4) Identify flow conditions including the location of zones of flow convergence (scour) and divergence (fill).

5) Relate flow processes (4) to channel morphology (1).

6) Assess the stability of the river using aerial photographs and previous surveys identifying areas of erosion or deposition.

7) Establish the nature of floodplain morphology and sedimentary characteristics.

(after Hey 1990)

This type of assessment is similar to that of Newson (1989). Both rely on the collection of field data which must then be analysed by a fluvial geomorphologist in order to establish the current state of the reach, i.e. whether it is relatively stable or susceptible to change. The emphasis is clearly on geomorphology as that was their original intention and indeed a physical habitat survey must also incorporate many of these fundamental features as it is the instream geomorphology that often determines the instream biota (e.g. Hynes 1968, Karr and Schlosser 1978, Ward and Stanford 1979, Meffe and Sheldon 1988). However, the stress is less likely to be on the detailed measurement of certain parameters needed for geomorphological surveys, such as the composition of the bank sediments or the floodplain morphology, when the emphasis is on conducting a survey over whole systems in order to classify the instream habitat into sectors and reaches at the broad scale.

Although the emphasis on the specific features that are measured may be different depending on the nature of the project, this type of reconnaissance level survey has a fundamental role to play in describing physical habitat at the broad scale and establishing the classification of reaches and sectors . The need, succinctly described by Thorne and Easton (1994), relies on information for:

1) the provision for scientific and repeatable observation and interpretation of channel morphology and instream habitat

2) the supply of useful information for developing schemes to rehabilitate and restore geomorphic features in engineered streams in addition to highlighting those that need to be conserved those natural systems.

(after Thorne and Easton 1994)

2.4.3 Habitat inflection methods

These approaches examine the instream habitat in conjunction with discharge. However, unlike discharge methods and reconnaissance surveys, they employ measurement of the actual hydraulic characteristics of the stream at one or more flows (e.g. Swank and Phillips 1976). The wetted perimeter, i.e. the length of wetted contact between the stream and its channel, is the most common parameter to be assessed under different flows as it is presumed to provide an index of fish rearing and invertebrate habitat. There is a rapid increase in wetted perimeter from zero discharge to the discharge at an inflection point, beyond which additional discharge results in only minor increases in wetted perimeter. Loar and Sale (1981) also suggested that minimum streamflows can then be designated by highlighting the inflection point where the chosen attribute e.g. wet width, starts to rapidly decline (as shown in figure 2.2 below). They suggested that transects used for field observation should be placed across riffles because their rectangular cross sections results in a more pronounced inflection point in the wetted perimeter-discharge curve.

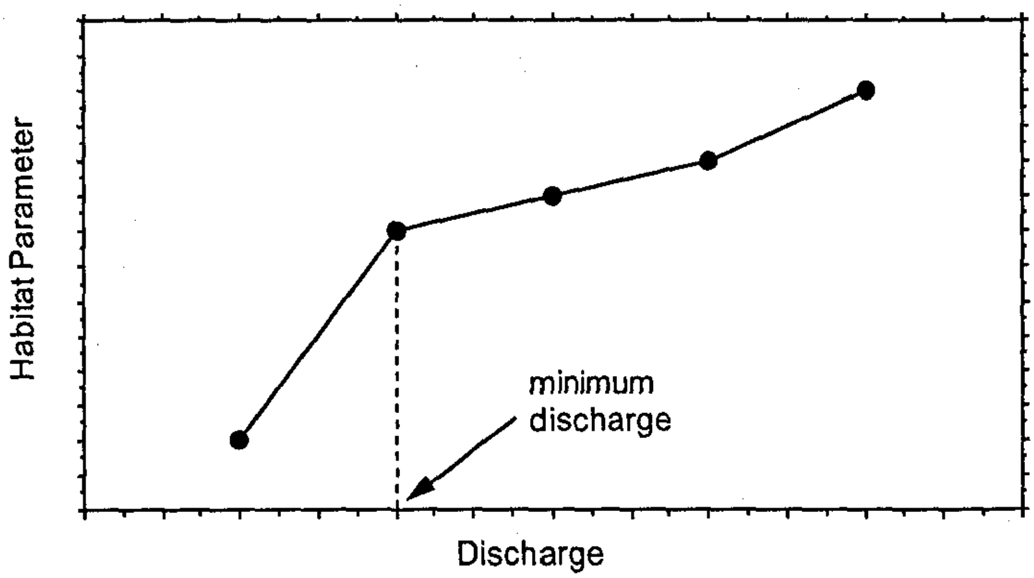


Figure 2.2 - Example of a habitat discharge relationship and estimation of minimum flow using the inflection point method described by Loar and Sale (1981).

These studies have been criticised because without information on water velocities, it may be difficult to determine whether or not the habitat is suitable at the recommended flow (Wesche and Rechard 1980). Water surface elevations, flow velocities, tractive force and hydraulic radii can be simulated using computer programs (e.g. US Bureau of Reclamation Water Surface Profile (WSP) Program (Cochnauer 1976)) and these may also exhibit similar relationships with discharge. The principal advantage of habitat methods is that they require relatively little fieldwork and yet overcome some of the criticisms of the discharge methods because they provide specific information from the stream or river in question. However, these methods do not pay any consideration to the specific habitat requirements of instream biota. This shortcoming is addressed by scoring systems.

2.4.4 Scoring systems

These techniques are based on the premise that the biological potential of a site is primarily determined by the quality of the habitat at that site. Inventory work is based on cross-sections located along a selected reach and take account of instream habitat, channel morphology and structural features of the bank and riparian vegetation. Spacing of the cross-sections can be placed randomly; at regular intervals; to describe critical conditions or the character of specific habitats like riffles and pools; or to define critical or limiting conditions. The number of measured cross sections has also varied from study to study but has most commonly been four or five (Platts et al 1983).

It is not surprising that from the range of approaches evident, studies have incorporated different attributes because they have been developed in different areas and with different target species under consideration. Table 2.3 overleaf indicates some of the attributes deemed important in earlier studies.

Data requirements for this type of approach are very similar to the reconnaissance level surveys already discussed although they are undertaken along representative or critical reaches rather than the whole system. However, the aim of a scoring system is to provide a relative index of habitat quality at a particular site by assigning a rating or score to the physical, chemical and biological characteristics present. The various habitat parameters are weighted to emphasise the most biologically significant parameters. All parameters are evaluated for each station studied. The ratings are then totalled and compared to a reference to provide a final habitat ranking. Scores increase as habitat quality increases. To ensure consistency in the evaluation procedure, descriptions of the physical parameters and relative criteria are included in the rating form.

Table 2.3 - Examples of habitat attributes used in evaluation schemes (after Milner et al 1985)

A. Catchment attributes

Geomorphological features	Hydrological features	Water chemistry features
Latitude	Average daily flow	pH
Longitude	Average seasonal flow	Hardness
Altitude	Pattern	Alkalinity
Geology	Extreme flow variations	Nitrogen (NO_2)
Catchment area	Stability of flow regime	Phosphorus
Total channel lengths	Precipitation	Dissolved solids
Drainage density		Conductivity
Mean basin length		Chloride
Mean basin slope		Temperature
Distance from source		
Forest ratio		

B. Site attributes

Channel width
Channel depth
Water width
Water depth
Substrate composition
Instream cover-debris, rocks, macrophytes
Bankside cover-undercut banks, overhanging vegetation, tree roots
Sinuosity
Bank erosion
Water surface area
Volume
Flow type
Riffle: pool ratio
Velocity
Gradient
Fish food abundance
Fish food diversity

The most established of these are the Rapid Bioassessment Protocols (RBP's) for use in streams and rivers (Plafkin et al 1989) derived from initial recommendations by Platts et al (1983) and based on the evaluation of various habitat parameters to provide an assessment of habitat quality. This technique was developed in the USA and is now being utilised there to provide a yardstick for assessing habitat quality.

The RPB approach separates habitat parameters into three principal categories: primary, secondary and tertiary parameters. Primary parameters are those that characterise the stream 'microscale' habitat and are considered to have the greatest direct influence on the structure of the indigenous communities. The primary parameters, which include characterisation of the bottom substrate and available cover, estimation of embeddedness, and estimation of the flow or velocity and depth regime, have the widest score range (0-20) to reflect their contribution to habitat quality. The secondary parameters measure the 'mesoscale' habitat such as channel morphology characteristics. These parameters evaluate: channel alteration, bottom scouring and deposition, and stream sinuosity. The secondary parameters have a score of 0-15. Tertiary parameters evaluate riparian and bank structure and comprise three parameters: bank stability, bank vegetation, and streamside cover. These tertiary parameters have a score range of 0-10.

Habitat evaluations are first made on the instream habitat, followed by channel morphology, and finally on structural features of the bank and riparian vegetation. The actual habitat assessment process involves rating the nine parameters as excellent, good, fair, or poor based on the criteria outlined above. A total score is obtained for each biological station and compared to a site-specific control or regional reference station. The ratio between the score for the station of interest and the score for the control or regional reference provides a percent comparability measure for each station. This use of a percent comparability evaluation allows for regional and stream-size differences which affect flow or velocity, substrate, and channel morphology. Applied to the UK, some regions, e.g. East Anglia, are characterised by streams having a low channel gradient. Although such streams typically do not provide the diversity of habitat or fauna afforded by steeper gradient streams, they are characteristic of certain regions. Using this approach, these streams may be evaluated relative to other low gradient streams.

Drake and Sheriff (1987) developed a methodology to assess the environmental impact of abstractions and for setting minimum flow requirements based on a scoring system for the Yorkshire Water area, UK. The scoring system itself was developed on a subjective basis relating to fisheries, angling, aquatic ecology, terrestrial ecology, amenity and recreation with guidelines for scoring within each category provided. Weightings of each factor were applied to stress those that were considered to be the most sensitive to artificial reductions in low flow. For instance, fisheries and aquatic ecology have scales ranging from 1 to 16 whereas water-borne recreation has a maximum value of 3. Scores are allocated for each category and totalled to provide a site score. Using the environmental weighting (EW) as a measure of sensitivity of rivers, a relationship was derived with a prescribed low flow. It was recognised that on average, natural flows drop below the dry weather flow (DWF - mean of the series of annual minimum 7-day flows) once every 2.33 years. Therefore it was postulated that the environment would be adjusted to the frequency of such an event. On sensitive rivers with a high EW (50+ score) it was suggested that the abstraction should not result in a decline of the DWF whereas those of lower quality i.e. EW of 0-9 would not suffer if flows were drawn down frequently to 0.5 of DWF. Intermediate categories were outlined for various EW and multiples of DWF. As a consequence, the technique has been adopted within the area in which it was developed and has been successfully applied to a large number of applications for net abstractions from streams and rivers in the North Yorkshire area.

The NRA Thames Region are currently developing a new approach to setting and monitoring of Standards of Service (SOS) for Flood Defence (NRA Thames Region 1992). This has involved the creation of a 'Reach Specification Methodology' that incorporates information concerning hydrology, hydraulics, land use, river maintenance, geomorphology, ecology and fisheries, and land drainage. The assessment of geomorphology takes on a two tier approach. Firstly, in conjunction with NRA Thames Region geomorphology staff, geomorphologically sensitive areas and reaches that do not require assessment are identified. Secondly, detailed geomorphological assessment collates field information on flows, bed material, vegetation and channel dimensions. This information is then used to assess how the channel is likely to change, and how rapidly (i.e. the stability of the channel). An experimental procedure has also been developed within the ecological assessment section which involves scoring the ecologically important geomorphological features in a similar way to the RPB approach. Features are scored from 1 (worst) to 5 (best) under the categories of river and banks (substrate, bed morphology, margins and banks) and floodplain and corridor (unrecreatable or valuable but recreatable). By calculating the river corridor and floodplain score from the completed form, an immediate and relatively objective estimate of the ecological interest of the reach is apparent.

A new project being led by Scottish Natural Heritage has a similar aim. SERCON (System For Evaluating Rivers for Conservation) has set its objectives in terms of finding ways to incorporate a wide range of ecologically relevant information into the conservation value assessment process, and of increasing the degree of standardisation and objectivity. This ecologically relevant information includes the measurement and assessment of various geomorphological features across a wide range of spatial scales. Although this is still in its formative stages, it will probably evolve along the lines of a scoring/rating system not unlike those described above (Boon in press).

These type of methods are more useful than the simple checklist approaches and reconnaissance level surveys as they provide an index of habitat quality that can be quickly understood by non-geomorphologists. However, this may in fact be detrimental if it leads to misinterpretation of the results or the scoring system is not applicable to the region in which it is being applied. The fundamental concept of a scoring system suggests that certain characteristics e.g. flow or depth regime can be weighted to emphasise the most biologically significant in relation to each other. The standardisation of the physical characteristics that are to be measured has also proved problematic. The actual weightings in these particular systems have been devised based on professional judgement and experience and in reality, seemingly unimportant factors may be 'undervalued'. This is not true for the methods outlined below. These techniques are based on actual field data that have established the relationship between the physical and chemical attributes to the biological characteristics at selected sites. Therefore they go some way in attempting not only to recognise the important features but also evaluate their relative importance.

2.4.5 Empirical model methods

Regression models have been developed to predict biological characteristics based on existing physical features. Measurement of physical and chemical attributes has enabled the construction of simple empirical relationships that account for a high degree of variability in the size of a population likely to occur at a particular site (Binns and Eiserman 1979, Bowlby and Roff 1986, Milner et al 1985, Scarnecchia and Bergersen 1987, Wesche et al 1987). Perhaps the most successful of these was the Binns and Eiserman (1979) approach that involved the development of trout habitat models that successfully predict trout biomass density in streams. They developed the Habitat Quality Index (HQI), two regression models that related 11 trout habitat variables that represent food, shelter, streamflow variation and maximum summer stream temperature to trout biomass density in Wyoming streams. The problem of non-linearity between physical and biotic variables was recognised and so a rating system was developed. Each variable in the model is rated with respect to its quality to trout from 0 (worst) to 4 (best) according to a rating schedule (table 2.4). The two models both performed well in predicting trout biomass density in Wyoming streams with model I explaining 35% and model II

Table 2.4 - Trout habitat variables used in the Habitat Quality Index (Binns and Eiserman 1979).

Variable	Definition of variable and associated score				
	0	1	2	3	4
Late summer flow index[1]	<0.1	0.1-0.15	0.16-0.25	0.26-0.55	>0.55
Annual flow variation	Intermittent flow	Seldom dry, extreme fluctuation, base flow very limited	Never dry, moderate fluctuation, base flow 2/3 of channel	Small fluctuation, stable base flow in most of channel	Little or no fluctuation
Maximum summer temp. (°C)	<6; >26.4	6-8; 24.2-26.3	8.1-10.3; 21.5-24.5	10.4-12.5; 18.7-21.4	12.6-18.6
Nitrate (mg/l)	<0.01; >2.0	0.01-0.04 0.91-2.0	0.05-0.09; 0.51-0.9	0.1-0.14; 0.26-0.5	0.15-0.25
Benthic invertebrate density (no./m²)	<2,550	2,551-9,950	9,951-24,950	24,951-500,000	>500,000
Benthic invertebrate diversity	<0.80	0.80-1.19	1.20-1.89	1.90-3.99	>3.99
Shelter (%)	<10	10-25	26-40	41-55	>55
Eroding banks (%)	75-100	50-74	25-49	10-24	0-9
Submerged aquatic vegetation	Lacking	Little	Occasional patches	Frequent patches	Well developed & abundant
Water velocity (cm/s)	<8; >122	8-15.4; 106.6-122	15.5-30.3; 91.4-106.5	30.4-45.5; 76.1-91.3	45.6-76
Stream width (m)	<0.6; >46	0.6-2; 23-46	2.1-3.5; 15.1-22.9	3.6-5.3; 6.7-15	5.4-6.6

[1] Late summer flow index is defined as the following ratio: mean yearly flow/mean flow during August and first half of September

explaining 86% of the variance at the test sites in Wyoming. However, a weakness of such an approach was highlighted by Bowlby and Roff (1986) when they tested the models in Ontario. Model performance was very weak which suggested that some habitat variables apparently play different roles in limiting trout populations in Wyoming than in Ontario. Therefore, HQI and perhaps most empirical models that might be created to predict biotic indices such as trout density may be useful only on a regional basis (Bowlby and Imhof 1989). Nevertheless, published results appear encouraging with biomass and habitat measurements being highly correlated. Predictions of abundance using scoring systems for habitat features can then be used.

Most of these earlier models were developed in the USA and solely with the goal of predicting fish abundance. However, an empirical model to evaluate Welsh salmonid fisheries called HABSCORE has been developed by the Environmental Appraisal Unit of the National Rivers Authority Welsh Region (Milner et al 1985). The approach is very similar to that of the RBP's and HQI with a site visit to measure various physical and chemical parameters in order to make judgements on carrying capacity of the stream or river and as the name suggests, provides a score as an index of habitat quality and carrying capacity. When applied to the area in which it was developed, comparisons between observed and predicted abundance explained variances of up to 93.6% (Milner et al 1985). However, similar to the problems that have been experienced in the USA, the application to other areas in Britain may require to modification in order to acknowledge the importance of other factors in determining habitat quality.

A national classification of sites based on the invertebrate community has also been developed by the Institute of Freshwater Ecology (IFE) as part of its computer software package called RIVPACS (River Invertebrate Prediction and Classification System) (Wright et al 1989). Within the program, there is the ability to use the physico-chemical attributes of a site to predict the macroinvertebrate community to be expected in the absence of environmental stress (Wright et al 1992). The predictions are based on a data base that includes information on the macroinvertebrate fauna of 438 unpolluted sites on almost 80 river systems throughout Britain. Using the model, it should be possible to define the individual sites which are of high conservation interest with respect to their macroinvertebrates, and also pinpoint the geomorphological features that are influential in determining those qualities.

Clearly, construction of regression models to predict changes in biotic indices with changes in habitat parameters has met with some success. It has been possible to visit independent sites, examine the given attributes and make reasonable predictions about the biological quality of that site provided it is in a similar geological, climatic, and biotic unit (GCBU) or region as advocated by Bowlby and Imhof (1989). With this requirement fulfilled, there is considerable potential for this type of approach. Model development and testing may prove time consuming in the first instance, but once established it provides a rapid assessment technique that can easily be applied in determining the actual or potential change in habitat quality and hence biotic quality relating to flood defence schemes or indeed any manipulation of habitat.

2.4.6 Field data interpolation methods

These employ habitat suitability criteria for target species to develop relationships between habitat variables and biota. Newcombe (1981) estimated the relative capacity of a stream to support fish by measuring water depth and velocity over a range of discharges. These are then weighted in accordance with frequency distributions of water depth and water velocity preferred by various life-history phases of target species. The procedure assumes that two variables alone, water depth and water velocity, are sufficient to estimate the relative capacity of a stream to support fish at any discharge. Furthermore, the method incorporates the concept of weighted usable area (WUA) on a transect and thus is similar to some procedures used elsewhere (Bovee 1982). Transect field data was converted into area which is weighted for usefulness as fish habitat by factors derived from habitat suitability curves (Bovee and Milhous 1978). Weighted areas, summed for a transect, produce a weighted cross-sectional area. The amount of usable habitat on a reach is the sum for all transects on the reach. Field data was collected under various target flows to provide points on the WUA-discharge curve. When applied to streams in Vancouver Island, British Columbia and a braided section of a stream on South Island, New Zealand (Glova and Duncan 1985), the method provided data to estimate changes in the capacity of target streams in relation to discharge. This allowed a more reliable estimate of minimum flow requirements to be estimated when compared to the Montana method (Tennant 1976) as it was based on actual field data and requirements of fish species known to occupy the streams (i.e. coho salmon, chinook salmon, and steelhead). The disadvantage of this approach is that each point on the WUA-discharge relationship requires the collection of a set of field data for a number of points across a number of transects. Gathering field data is expensive and target flows have to be different enough to avoid clustering of the data points. This may not always be feasible due to the prevailing weather conditions. The technique may also need to be applied to assess the impact of a proposed flow change which does not occur under present conditions. The effects on habitat availability in this situation can only be estimated via extrapolation which may not have the desired level of accuracy. This problem is somewhat overcome by the most detailed and complex of the instream habitat assessment methods as outlined below.

2.4.7 Instream Flow Incremental Methodology

The need to incorporate the demands of particular instream uses was also recognised by the Instream Flow Service Group (US Fish and Wildlife Service) who developed the Instream Flow Incremental Methodology (IFIM) outlined by Bovee (1982). This is based on field measurements of water depth, velocity, substrate composition and cover at calibration flows to enable the suitability of habitat for a particular species to be described in a similar manner to that described above (Newcombe 1981). The main difference is that incremental changes in streamflow can then examined to predict the corresponding effect on availability of suitable microhabitat for a target species over the full range of flows by using the Physical Habitat Simulation System (PHABSIM). PHABSIM is a set of computer models that are the cornerstone of the IFIM described above. Essentially, PHABSIM is used to relate changes in discharge or channel structure to changes in physical habitat availability for a chosen species. This is a much more sophisticated approach than discharge or habitat methods. Nevertheless it has received criticisms due to the lack of evidence that predictions can be observed in the field and the intense field effort and large number of man hours required to obtain meaningful results (e.g. Orth and Maughan 1982, Mathur et al 1985).

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 (Bovee 1982).

PHABSIM considers microhabitat as defined under this methodology to consist of two basic components i.e. rigid structural characteristics and variable hydraulic conditions.

Structural habitat characteristics reflect the hydrogeomorphology of the channel e.g. bed configuration, channel width or substrate composition and are assumed to be constant over a range of flows. The hydraulic variables which affect microhabitat utility are width, depth, and velocity. All three respond differently to changing discharge in conjunction with the structural nature of the channel and so the physical microhabitat is a complex array of combinations of these parameters. This array is redefined with a different set of depth, velocity, and structure combinations each time the discharge changes.

A natural stream contains a complex mosaic of physical features. One given species may find an area of deep, slow flowing water desirable whilst another may prefer an area of deep, fast flowing water. Alternatively, a third species may find neither conditions suitable. In order to quantify physical habitat, the area associated with each combination of features and an evaluation of that combination in terms of its suitability as a habitat for a particular species must be defined. When flow changes, the hydraulic variables will alter and so under the new flow, physical habitat has to be requantified.

PHABSIM consists of four basic components representing the process of;
1) data collection, including the detailed surveying and measurement of water surface elevation, water velocity, water depth and substrate at known discharges across selected transects usually under three different flow conditions
2) hydraulic simulation, to describe the water surface elevations, depths and velocities experienced under intermediate and hence unmeasured flows using the PHABSIM programs
3) suitability index curve development, to describe and quantify the habitat requirements of selected target species based on a range of water depths, velocities and substrate types, and
4) habitat simulation, which utilises the PHABSIM programs to combine the hydraulic characteristics of the reach with habitat requirements of the target species.

With the final step completed, an example of the standard PHABSIM output is shown in figure 2.3 below. This information can then be used to make judgements regarding the effect of an alteration in discharge on the availability of suitable habitat for target species. WUA is a discrete value which is produced for each reach, each life stage and species, and each target flow.

PHABSIM is then capable of presenting biological information in a format suitable for entry into the water resource planning process. The main characteristics which account for its popularity and acceptance over other methods include that it is a method which uses an objective, quantified definition of physical 'habitat', and it has the ability to model the consequences of fish habitat of two or more different streamflows (incremental changes in streamflow). However, despite the widespread use and development of PHABSIM it has some critics who challenge the assumptions, logic, and mathematics of the method.

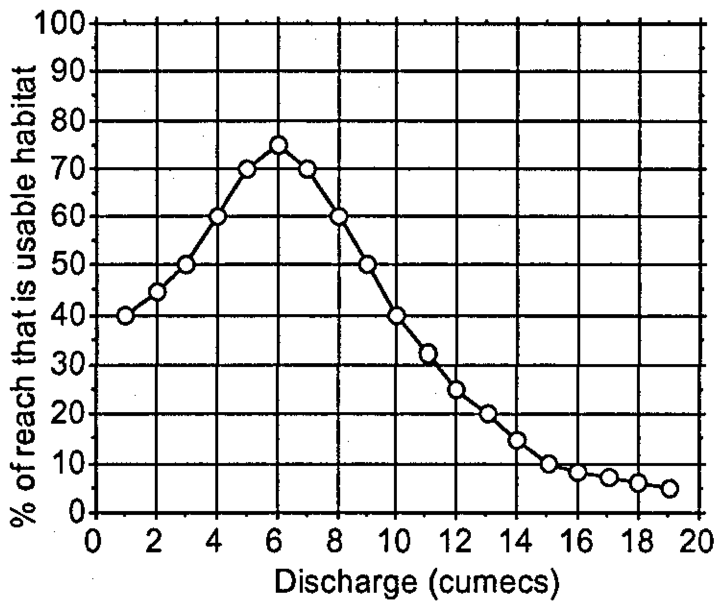


Figure 2.3. Hypothetical example of output from the PHABSIM process.

Criticisms of PHABSIM and the interpretation and application of the weighted usable area (WUA) index focus on the lack of evidence that fish populations respond to changes in WUA (Mathur et al 1985, Shirvell 1986). Various attempts have been made to compare the relationship between WUA and fish standing stocks and have met with a wide range of success. Examples are quoted from being very good (r2=0.89, Anderson 1984; r2=0.88, Nelson et al 1984; r2=0.84, Gowan 1984) to poor with no significant relationship (Rimmer 1985, Conder and Annear 1987). Reasons for the lack of any significant relationship are varied and commonly focus on the invalidity of assumptions made within the PHABSIM process (Shirvell 1986), the inaccuracy of the hydraulic and habitat computer simulations (Osborne et al 1988, Gan and Macmahon 1990), the problems associated with the application of habitat suitability curves (Shirvell 1989, Thomas and Bovee 1993) and the lack of biological interactions incorporated within the model (Orth 1987).

Many of these criticisms have been addressed by the clarification and reiteration of what PHABSIM is actually intended to do, and the fact that many of the failings result from its misuse, i.e. it is being applied for purposes that it was never intended (Gore and Nestler 1988). For instance, Gore and Nestler assert that 'the implied relationship between WUA/discharge predictions and biomass is the most serious misconception in the IFIM process' (Gore and Nestler 1988, p.96). They strongly emphasise 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) *and do 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. Predictions are therefore made in terms of habitat availability and not biomass. Ecological interactions are not incorporated into the model, nor were they ever intended to be.

With these considerations, PHABSIM output can be used as a management tool for a number of purposes. Traditionally it has been applied to predict changes in habitat availability with changes in streamflow and for the assessment of ecologically acceptable flow regimes (Bullock et al 1991, Petts et al 1992, Johnson et al 1993). However, it may also be utilised as a tool for defining sites for habitat restoration (Petts and Maddock 1994).

2.5 Summary of Techniques

Although there is a recognised need, quantitative and comprehensive habitat evaluation has not yet formed a part of river management throughout the UK. Upto date, methodologies have been largely developed in the USA and are only beginning to be adequately tested in this country. Criticism has been aimed at rapid assessment techniques for ignoring the specific character of the stream whilst more sophisticated approaches have met with disapproval for the length of time required to obtain meaningful results. However, recently developed methods have improved evaluation procedures by providing objective and quantitative assessments of river channels in non-monetary terms.

It has been demonstrated how the host of techniques outlined fall into a number of categories. Discharge methods (e.g. Montana method) provide a quick way of defining minimum flow requirements to maintain suitable habitat based on flow records. Reconnaissance level surveys (e.g. fluvial auditing) classify and record the features of the channel and bordering slopes. a geomorphologist can then draw conclusions regarding the balance, or lack of it, within the fluvial system. Habitat inflection methods employ actual measurement of habitat characteristics under one or more flows to define when the chosen attribute e.g. wet width, starts to rapidly decline. Scoring systems (e.g. RPB's) take the checklist approach one stage further by providing a relative index of habitat quality at a site. Ratings are weighted to emphasise what are considered to be the most biologically significant parameters. Empirical model methods (e.g. HQI, HABSCORE) are very similar but are developed from actual field data that accurately define the most biologically significant parameters rather than from professional experience and judgement. Finally, biological response methods (e.g. Fields interpolation methods and IFIM) utilise habitat suitability criteria with field data. These are the most sophisticated but also require the most intense field effort and at the most detailed level, computer simulation time. Nevertheless, this type of approach is more likely to produce information that is considered to be scientifically and legally defensible (US Department of the Interior 1979).

The range of instream habitat assessment techniques that have been discussed can be arranged from simple to complex. The following chapter describes the use of a technique to define and classify stream sectors and reaches based on map sources and field data. This is followed by a pilot study on the River Glen, Lincolnshire which incorporates a habitat inflection method. Chapter four evaluates a procedure to define the key habitat variables influencing the biological quality of stream reaches which includes a scoring system and empirical model method. A biological response method, i.e. PHABSIM is utilised in chapter five to provide a more detailed analysis of instream flow requirements and stress the importance of bed morphology for three catchments in the Anglian region. Throughout their applications, the role of geomorphology in river management will be highlighted.

CHAPTER 3 - DEFINING CHANNEL SECTORS AND EVALUATING HABITAT CHANGES WITH DISCHARGE - RAPID ASSESSMENT ON THE RIVER GLEN, LINCOLNSHIRE.

3.1 Definition of Reaches Using Reconnaissance Level Surveys

Recent studies have stressed both the lack of available information on instream habitat at even the most basic level, and the value and potential application of such information (Newson 1989, Hey 1990, Thorne and Easton 1994). The previous chapter discussed the characteristics of reconnaissance level surveys and highlighted how they incorporate a mixture of qualitative assessment and morphometric measurement to build up a record of the form of a river based on field observation. They are designed to formalise the types of habitat observations and evaluations that may be routinely made and this information can then be used to aid the classification and definition of channel segments with similar habitat characteristics. For instance, evidence for major changes in habitat characteristics can be used to define any changes in character of the main river. Adjacent like reaches can be combined to form sectors having relatively uniform internal characteristics.

The following sections describe the data requirements and methodology of a reconnaissance level survey that will allow the definition of distinct channel types, sectors and reaches. For this particular methodology, the emphasis is clearly on instream habitat features to classify the river into sectors within which fauna and flora are related to flows and channel structure. The methodology is then illustrated by describing its application to the River Glen catchment, Lincolnshire.

3.2 Development of a Reconnaissance Level Survey to Define Channel Types and Sectors

3.2.1 Data requirements

A preliminary classification of sites along a river should be based on the sector scale, as described above. The criteria used to define sectors are those variables that influence the important hydrological, geomorphological and ecological processes at the catchment scale and for which the relevant information is readily accessible from published sources. These may include all or a combination of:

- 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 response (rock type and land-use);
- a measure of local controls (riparian land-use).

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 if available (NRA 1992). This is considered to be the appropriate reconnaissance level scale as the sources are readily available and use of smaller scale maps (e.g. 1:500 000 or 1:100 000) may lead to loss of essential channel network information. For instance, smaller scale maps may not include intermittent or ephemeral streams, or indeed perennial ones of a small size (Gregory and Walling 1973). More detailed (field) information should then be obtained. This requires a complete physical habitat survey of the entire channel length, supported by routine hydrological surveys and/or comprehensive gauging station flow data. It is suggested that the specific analysis of the various sources is undertaken via a two-phase process, both of which are described in more detail in the following sections.

3.2.2 *Methodology - Phase 1: preliminary classification*

Map sources are used to 'order' the main stream reaches between tributary confluences and to define for each reach its 'magnitude' and slope. Numerous approaches have been developed and the first to be widely adopted was proposed by Horton (1945). In this system, each finger-tip tributary was designated a first order stream, two second orders combined to give a third order stream and so on. Once this initial ordering had been completed the highest order stream was projected back to the headwaters along the stream which involved least deviation from the mainstream direction. Therefore this approach a second re-ordering process. However, this method is inappropriate for the definition of channel types and sectors because information is required to delimit the main channel to aid the classification process and as outlined above, this system assigns this stream the same value along its entire length.

These objections were overcome to some extent by the modification proposed by Strahler (1952). This approach used a similar numbering system in the first instance but omitted the second re-ordering process so that all unbranched channel segments are of the same order, and only one segment is designated the highest order rather than the whole trunk stream as above. Indeed the simplicity and ease of application of this method commended its widespread use in the 1960's.

The advantage of stream network classification for definition of distinct sectors lies in the recognised importance of the hydrology of the reach, and the applicability of these systems in providing a simple index of this parameter. If all other factors were constant, then order of a channel sector should be directly related to the size of the channel network upstream and hence associated with the likely streamflow values that the particular sector will experience. However, the Strahler method of ordering has one limitation for this purpose: the order of the trunk stream is not changed by the addition of tributary streams of a lower order. This is obviously a limitation in that a large number of lower order streams can enter the main channel, and hence have a significant input in hydrological terms, but not change the Strahler number.

Shreve (1967) proposed a simple system for classifying channel segments where each first order segment is designated magnitude one and each subsequent link designated as a magnitude equal to the sum of all first order segments which are tributary to it. In other words, the magnitude of a channel segment is the sum of the magnitudes of the tributaries at its upstream junction.

For the purpose of the classification of channel types and sectors at the initial level, it is proposed that the drainage network be assessed based on the Strahler and Shreve systems. The Strahler modification of Horton's method has been used extensively and is a well known descriptor of network characteristics. Furthermore, the Shreve system was chosen as it is considered to be "more descriptive of the total network and may relate more closely to streamflow values" (Petts and Foster, 1985).

Geological, soil, and land-use maps can then be examined to divide the catchment into broad areas. Major changes in 'type' are then used to define any likely discontinuities in the downstream change in character of the main river. For instance, geological maps may highlight the distinction between areas where the river flows over relatively permeable/impermeable strata. Land-use maps may also highlight the zonation of forested/arable/urban areas. Land-use data may be available from a range of sources, all with some degree of variability in terms of coverage, detail and reliability. Two land utilisation surveys of England and Wales have been conducted (Stamp 1931, Stamp and Coleman 1963) and can provide valuable information on the predominant utilisation of land within the catchment and importantly the riparian zone on a more local scale. If a more detailed analysis is deemed necessary due to the specific requirements of the project (e.g. analysis of hydrological change in relation to catchment characteristics), changes in land-use may be examined from a comparison of the two surveys in conjunction with the agricultural census data that is compiled by The Ministry of Agriculture, Fisheries and Food (MAFF) on an annual basis. River Corridor Surveys (NRA 1992) are undertaken for the National Rivers Authority (NRA) on a routine basis to assess the significant features with a conservation value for the river and riparian zone. If necessary, these may also be available to determine any measures of local control that could influence the classification process.

With the assimilation of the above information, adjacent like reaches can be combined to form sectors having relatively uniform internal characteristics. It must be stressed that this process is designed to aid initial definition and hence does not infer that all the sources are necessarily evaluated in great detail. It is intended to provide a framework for the second phase and help determine the important locations that are likely to signify distinct changes in the downstream character of the river. A segment boundary should be placed at all major tributaries, diversions, and other locations where the flow regime undergoes a significant change. The use of stream network classification based on map evidence should provide information to establish these divisions. A segment or sector boundary is also placed wherever a significant change in channel morphology occurs. These locations often coincide or are obvious enough that boundary placement is easy. However, other locations reflect more subtle changes, requiring determination of the significance of the change. The second phase is designed to elucidate this and involves the collection of instream habitat data of the whole system at the reconnaissance level and hydrological data at the sector scale. Therefore, the completion of phase one will help in the decision-making process when hydrological field sites are being determined.

3.2.3 Methodology - Phase 2: classification from field evidence

This section involves assessing the character of the river under a specified target flow. The nature of the target flow will be determined by the specific nature of the project, e.g. a low flow study would clearly target a representative low flow for field assessment. The characteristics of the channel in question can be assigned into two distinct categories, i.e. habitat survey information and hydrological information.

3.2.4 Habitat survey

Ideally, the entire river should be surveyed in order to monitor instream physical habitat. A common approach in the past has been to collect physical habitat information at the reach scale and extrapolating this data to the sector scale (Bovee 1982). However, others (e.g. Snider et al 1987) have questioned whether representative reaches accurately represented conditions within a given area because sector scale characterisation had not been completed in the first instance. Therefore, this methodology proposes that a number of simple and rapid measurements can be made to overcome this problem and facilitate a more accurate definition of sectors and reaches. Measurements taken during the survey accord with three criteria, i.e. habitat type, habitat condition and habitat scale.

3.2.5 Habitat type and condition

Six main habitat types and conditions are described in accordance with the definitions proposed by Keller and Melhorn (1978), Gorman and Karr (1978) and Helm (1985). Inevitably, the definition of habitat type in the field is not always easy, even when clear definitions are available. Nevertheless, it is the consistency of definition of similar habitat types within the whole river system that is required in order to facilitate the subsequent analysis and definition of distinct sectors. Furthermore, the detailed measurement of each habitat type would render the method inappropriate as a rapid assessment tool for whole river systems and hence an inevitable degree of subjectivity in habitat definition must be accepted. Nevertheless, the clear statement of definition criteria based on physical attributes helps to keep this subjectivity to a minimum. The definitions are listed below and have been split into two main categories according to whether they are considered to provide good quality or poor quality habitats in biologically productive terms. Inevitably, this division is somewhat subjective, but has been designed to highlight those habitats that are intrinsically linked with morphological diversity (e.g. riffles and pools) and those associated with morphological uniformity (e.g. deep and stagnant runs/ponded reaches). The fundamental influence of bed morphology on the structure and function of biotic communities has been recognised for some time (Whittaker 1956) and the evidence that habitats of great physical contrast may exhibit equally great contrasts in the functional structure of the respective biotic communities (Benke et al 1984).

Good quality habitats include:-

Riffle	Shallow rapids where the water flows swiftly over completely or partially submerged obstructions to produce surface agitation, but standing waves are absent.
Glide/Shallow Run	Areas of swiftly flowing water, without surface agitation or waves, which approximates uniform flow and in which the slope of the water surface is roughly parallel to the overall gradient of the stream reach. These usually extend for greater distances downstream than riffles.
Pool	A portion of the stream with reduced current velocity, often with water deeper than the surrounding areas, and which is frequently used by fish for resting and cover. They are differentiated from deep runs (see below) by the fact that they are delineated at the upstream and downstream boundaries by the presence of distinct riffles.

Poor quality habitats include:-

Deep Run	A slow moving relatively deep type of run. Calm water flowing smoothly and gently, with moderately low velocities (0-10cm/sec) and little or no surface turbulence. These are differentiated from pools by the lack of distinct riffles at there boundaries or the fact that they extend for much greater distances downstream.
Stagnant Run	A relatively deep type of run (as above) but with no visible flow.
Dry channel	A natural water course where the channel contains no water and hence the stream is either ephemeral or intermittent.

3.2.6 Habitat scale

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 whichever is the closer. This sampling strategy is clearly biased to one specific habitat type, but has been devised to monitor a specific habitat type that is fundamental to the biological productivity of the channel and one that is commonly removed as a consequence of insensitive river engineering. Therefore it may be considered as a good indicator of naturalness and habitat quality in a broad sense within certain areas. Other records, such as the maximum water depth over riffles, substrate sizes present, the nature of instream and overhanging cover, or bank character (erosional, stable, depositional) may be added according to the purpose of the investigation. A typical physical habitat survey sheet is illustrated in figure 3.1 overleaf.

After the habitat assessment is complete, each sector can be described in terms of habitat scale - recognising that the proportion of dry bed may in fact be a natural state and therefore 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 and of reaches within the same sector.

3.2.7 Hydrological survey

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 that may have been undertaken for specific purposes in the past. The need for more detailed hydrological data may then be considered essential due to either the lack of existing data or the complex and variable hydrology of the target catchment. In particular situations, groundwater gains and/or losses can result in significant deviations in streamflow with no apparent source based on map evidence alone. Large portions of some drainage basins may not contain any significant tributaries, yet receive inflow from groundwater. These variations can be detected when measuring discharge from carefully selected sites. Sites for routine hydrological surveys should be chosen with reference to:-

a) location of existing gauging stations;

b) distribution of channel sectors determined during phase 1;

c) areas known for importance in terms of water gains/losses from the channel;

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																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11																			
12																			
13																			
14																			
15																			
16																			
17																			
18																			
19																			
20 D/S																			

NOTES

HABITAT KEY

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

SUBSTRATE KEY

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)

Figure 3.1 - Typical physical habitat survey sheet

d) sites used for previous stream gauging surveys to allow comparison; and

e) ease of access e.g. road bridges, farm tracks, public footpaths etc.

Routine hydrological surveys should use standard current-meter techniques (BSI 1980) at the shortest time intervals that are feasible, preferably monthly or less, especially during periods when the target flows occur.

With the completion of phase 2, information can be reviewed to assess the appropriateness of the initial classification of channel sectors based on phase 1, and alterations can be made if necessary. The main channel is now dissected into distinct reaches based on flow regime, channel morphology and the nature of the instream habitat.

3.3 Application to the River Glen, Lincolnshire

3.3.1 Catchment characteristics

The River Glen, a tributary of the River Welland, lies within the Anglian region of the National Rivers Authority (NRA). The catchment is made up of two distinct zones. The upstream section is made up of two principal tributaries i.e. the West Glen and East Glen which join to form the River Glen. Kates Bridge Gauging Station (GS) separates the two zones and the catchment area upstream is 342 km^2 (132 sq. miles). Downstream, the River Glen possesses characteristics of a lowland river as it flows across the low gradient Fenland (figure 3.2).

The upstream zone, which has provided the focus of this research, consists of the West Glen and East Glen rivers which flow in parallel north-south aligned valleys, incised into a broadly west-southwest to east-northeast folded Jurassic plateau of Oolite (limestone) and Lias, the majority overlain to various depths by glacial drift. Various studies (Kent 1939, Rice 1968, Wyatt 1971, Straw and Clayton 1979) all point to the catchment being traversed in preglacial times by West-East flowing rivers, which are thought to bisect the present day rivers at Little Bytham (TF016180) - Witham-on-the-Hill - Toft - Thurlby (TF095170) and at Burton Coggles (SK986262) - Osgodby (TF022286).

Previous studies have highlighted the intrinsic links between the surface hydrology of the West and East Glen and the groundwater flow in the Lincolnshire Limestone.

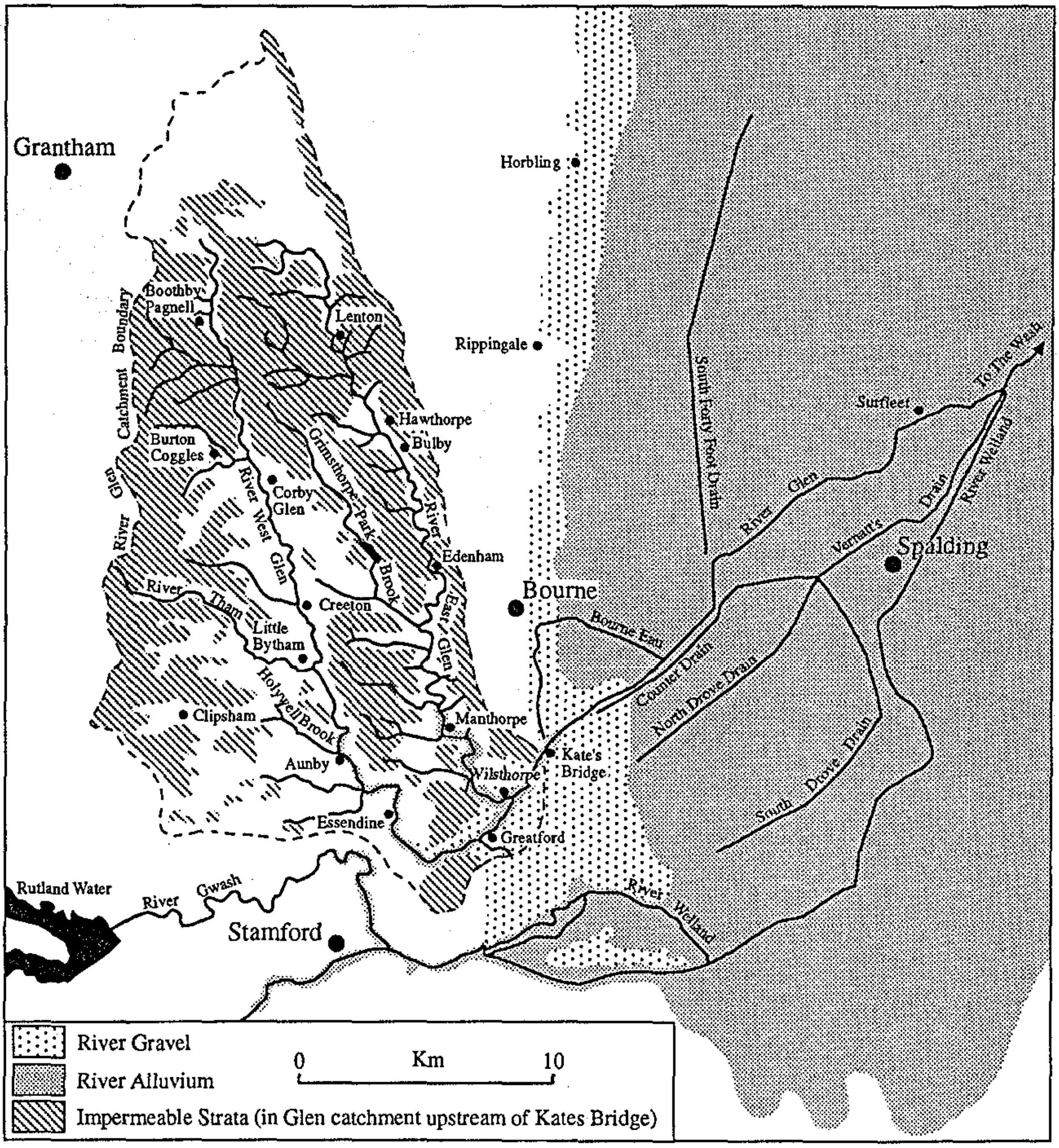


Figure 3.2 - The River Glen catchment.

The catchment geology is a mixture of Lincolnshire and Great Oolitic Limestone, Upper Estuarine Series and younger Jurassic strata. The Lincolnshire Limestone which has been described in detail by Downing and Williams (1969) and Swinnerton and Kent (1976) is generally about 30 m thick and dips gently eastwards at about one degree so that it outcrops along a five km tract between Grantham in the north and Stamford in the south. The groundwater divide in the west relates approximately to the topographic watershed. The northern and southern limits are defined by the Systen-Dembebly Monocline and the Marholm-Tinwell Fault respectively.

The catchment can be divided into the areas of the unconfined and confined aquifers in the Lincolnshire Limestone. The limestone is generally unconfined in the west of the Glen catchment where there is a varying degree of cover from Jurassic clays and Pleistocene boulder clays. In the confined region to the east, the limestone is overlain by clays and silts of the upper Estuarine Series. Relatively impermeable clays and silts of the Lower Estuarine Series, Northampton sands and Upper Lias clays tend to occur below the limestone. The groundwater gradient is clearly west to east and tracer studies (Booker 1981) have shown that there are primary routes following the fissures within the Limestone and crossing the West Glen and East Glen valleys. These primary groundwater flow paths have their sources in an area of sink-holes in the Limestone outcrop in the west of the catchment to the north and south of Castle Bytham (SK988185) and Little Bytham (TF016180) drift valley (Wyatt 1971).

The Lincolnshire Limestone is an important aquifer in South Lincolnshire and has consequently been extensively developed for public water supply over a long period (Burgess and Smith 1979). There is a long history of water abstraction and records of water in boreholes suggest a progressive decline in maximum and minimum rest levels since about 1940 and there has been an eastward movement of the western limit of artesian overflow.

Indeed, the artificial channelisation of the River Glen dates from the 16th and 17th centuries. Problems of drainage and embanking were reported between 1650 and 1675 by William Dugdale (Dugdale 1772). The East Glen and West Glen at this time appear to have been ephemeral or intermittent. The notebooks of John Grundy of Spalding (1719-1783), a local drainage engineer document his work dating from 1745-66 and indicate that the Grimsthorpe Park Brook, a tributary of the East Glen dried up in summer (Petts et al 1989). He described the ground as "chasmmy and full of swallows". Given the similarity of geological and topographical settings it is likely that other parts of the drainage pattern had a similar flow pattern. Probably the first documented channelisation works in the upstream zone were planned by Grundy in 1756 where his 'improvement' of the East Glen at Edenham (TF066216) along a stretch between two (road) bridges involved "a new cut to straighten the channel" and is still evident today. Subsequent alteration of the channel has been widespread and analysis of the 1860 Ordnance Survey maps have highlighted at least 24 locations of channelisation, where the former meandering channel has been converted to a straight course, commonly due to the building of the local railway network. Land drainage has been carried out on a routine basis for the majority of this century, involving dredging and embanking and there is no doubt that these works have contributed to the degradation of the river, reducing habitat diversity and creating unsuitable conditions for some species (Petts et al 1992).

3.3.2 Review of existing information - Hydrology

Two surveys of the hydrological characteristics of the West Glen and East Glen had previously been conducted (Downing and Williams 1969, Smith 1977) and were examined to compliment the data available from the network of seven gauging stations, most of which had been operating since the late 1960's and early 1970's.

Conditions of flow in the catchment in July 1967 and January 1968 were described by Downing and Williams (1969). This enabled them to present an overview of the downstream flow variations during high and low flow and to locate the influence of important sources and sinks of water. Interactions between surface and groundwater were clearly evident under three categories:

1. sink-holes
2. springs
3. permeable reaches

The influence of the sink-holes is most evident around the Limestone outcrop in the west of the catchment to the north and south of Castle Bytham (SK988185) and Little Bytham *(TF016180) drift valley (Hindley 1965). An estimated 80% of all* rapid recharge is derived from approximately 15 large sink-holes in the area, both on the valley sides and in the channel bed itself (Rushton et al 1982). Three perennial springs are also easily apparent in the West Glen (Creeton, Little Bytham and Holywell) and contribute water to tributaries that supply an estimated 95% of the spring flow from the Glen catchment (Booker 1981) and are clearly important in terms of the maintenance of flows during dry periods. The occurrence of influent (water lost from the channel) and effluent conditions (water gained) along permeable reaches produces an even more complex pattern. Changes in discharge along a reach occur due to an exchange of water between the surface water and groundwater via the permeable substrate of the river bed. The pattern can be confused further by the same reach displaying both influent and effluent conditions depending on local groundwater levels.

A total of nine gauging surveys were undertaken by Smith during the 1975-77 drought (Smith 1977). The object was to define flows sustained by baseflow/springflow in the catchment rather than the peak flows and to determine ephemeral and perennial water courses. This allowed a more detailed picture of the river to be constructed on a reach by reach scale and estimates of maximum gains and losses were also established.

3.3.3 Review of existing information - Habitat

During a review of information available relating the to the River Glen catchment (Adams 1989) it was clear that there was little primary information available that described the geomorphological or habitat characteristics within the catchment. Four electrofishing surveys and invertebrate records from 44 sites within the catchment gave indirect evidence relating to geomorphology based on the species present and knowledge on their specific habitat requirements. It is clear from the data and related reports that the River Glen system can be divided into two separate fisheries;

1) the West and East Glen and the River Glen between the confluence and Thurlby Fen, with relatively high populations of Dace, Chub, Brown Trout with Pike and Eel, and
2) the River Glen below Thurlby Fen with relatively high populations of Common Bream and Roach, but frequently dominated by Pike and occasionally Eel. The weirs at Greatford, Kates Bridge and Fletland Mill restrict fish movement within this zone.

Analysis of the invertebrate records was undertaken by Bickerton (1992) using two multivariate methods of analysis (i.e. TWINSPAN (Hill 1979) and CANOCO (Ter Brak 1988)). Samples were standardised into faunal groups and analysis suggested that the invertebrate communities could be separated into three types;

1) upland type - River Tham and middle West Glen,

2) intermediate type - East Glen, lower west Glen and upper River Glen, and

3) lowland type - lower River Glen and Bourne Eau (Bickerton 1992).

Based on the review of existing information, it was evident that two sets of field data were imperative if the classification of the river into a series of sectors was to be achieved. Firstly there was little specific information on instream geomorphology, and secondly, the hydrological characteristics were clearly very variable over even very short distances and a more detailed picture was needed to facilitate the definition and classification process.

3.3.4 The definition process - Phase 1

The stream network was ordered using the Strahler (1952) and Shreve (1967) systems based on the Ordnance Survey maps of the catchment at the 1:25 000 scale. The results are shown in figure 3.3 where the sectors are also defined. The map illustrated highlights the network at the 1:50 000 resolution for clarity within the diagram. The downstream ends of each sector are defined by junctions of the main channel with major tributaries.

Differences in the construction of the indices 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' at their confluence. Sectors were defined based on the morphometry of the basin and provisional divisions were located at the entry of significant changes in the network values calculated. This resulted in the definition of five sectors for the West Glen river and three sectors for the East Glen. However, the review of existing information has already highlighted the variability in streamflows over short river lengths due to the nature of the underlying strata, and in particularly the presence of sink-holes. Accordingly, the tributaries may not be expected to supply the streamflow that may normally be expected and the initial definition was very tentative. The need for the extensive habitat survey and detailed hydrological information was particularly important in such a hydrologically and geologically complex catchment.

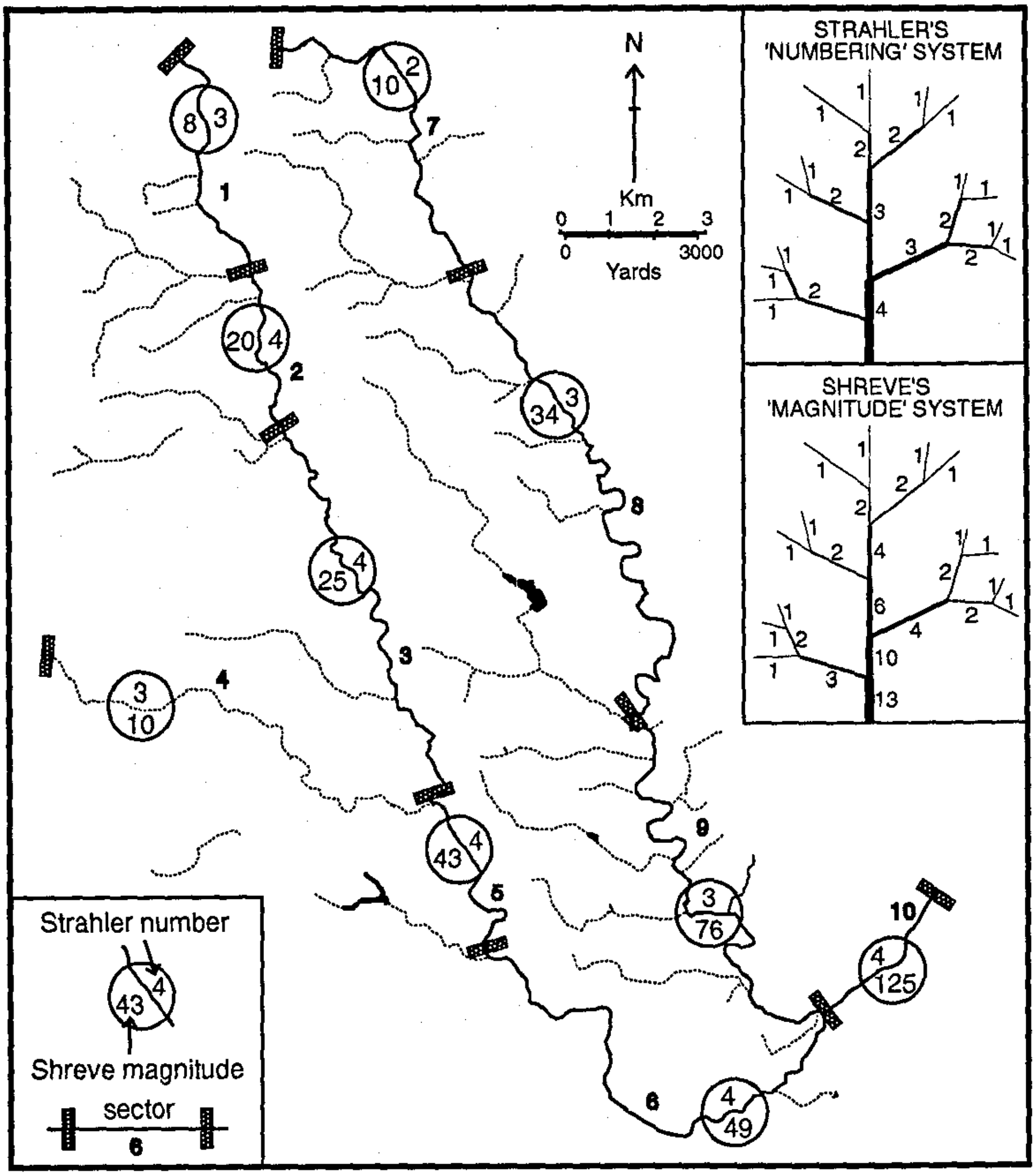


Figure 3.3 - Provisional definition of channel sectors with their associated stream 'magnitude'

3.3.5 The definition process - Phase 2: physical habitat survey

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 as described above (see section 3.2.4). Channel width and water width was also recorded to the nearest 10 cm. 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.

The complete set of results from the survey are shown in Appendix 1. The moving average plots (based on each consecutive ten data points) of channel width against distance downstream for the West and East Glen are shown in figures 3.4a and 3.4b respectively. Both rivers show an overall increasing trend with the West Glen increasing quicker than the East Glen. The West Glen varies between 0.9 - 10.4 m whereas the East Glen varies between 0.7 - 8.3 m. The arrows indicate the location of major tributaries with the majority, especially for the West Glen, preceding an increase in width. A notable decline in channel width occurs below Greatford sluice reflecting the reduced peak flows downstream of the flood diversion channel.

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 figures 3.5a and 3.5b. In contrast to figures 3.4a and 3.4b, these highlight a very different picture for each river. The West Glen was largely dry from the source as far as Boothby Pagnell WTW. Wet width then shows an increasing trend as far as the sink-holes just downstream of Burton Coggles gauging station where the channel 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.

On the East Glen the channel was largely dry to Ropsley WTW. Water was ponded in the channel downstream of here until it was lost via seepage about 1.5 km downstream. Lenton WTW marked the end of the dry section whereafter wet width values increased until below Edenham. The entire flow was lost to the bed through

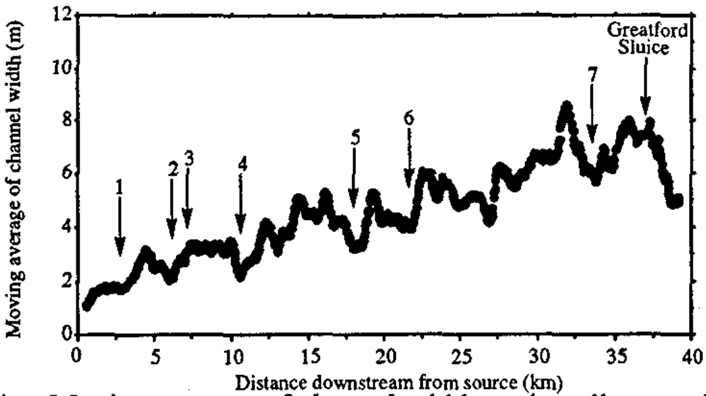


Figure 3.4a - Moving average of channel width against distance downstream for the WEST GLEN. Arrows 1-7 represent the location of major tributaries.

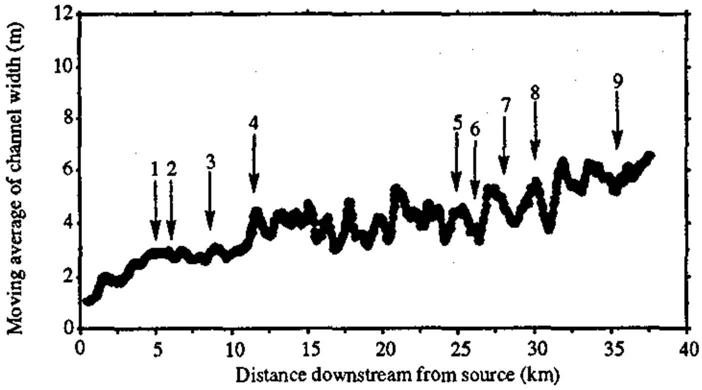


Figure 3.4b. - Moving average of channel width against distance downstream for the EAST GLEN. Arrows 1-9 represent the location of major tributaries.

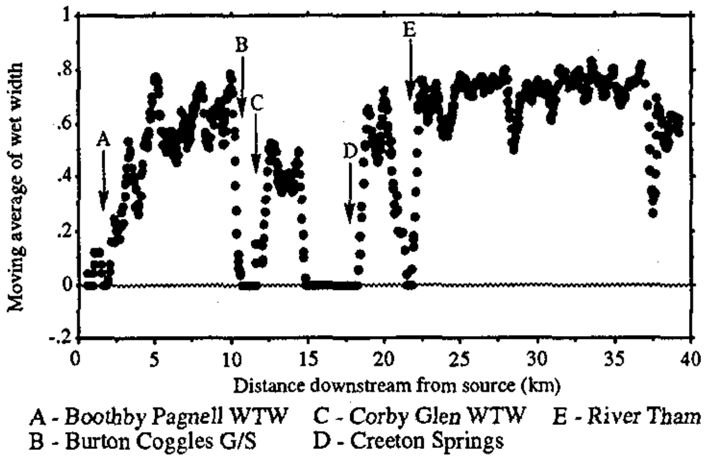


Figure 3.5a. - Moving average of wet width against distance downstream for the WEST GLEN

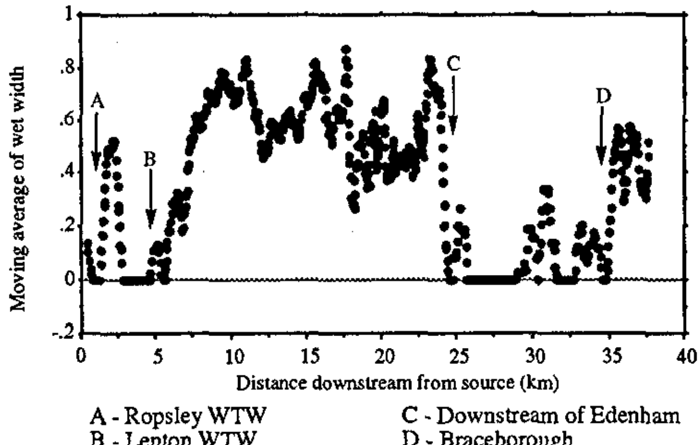


Figure 3.5b. - Moving average of wet width against distance downstream for the EAST GLEN

seepage here and the remaining stretch was largely dry to Braceborough where ponded sections were apparent to the confluence with the West Glen.

Both graphs highlight the importance of the WTW on the main channel during this period in maintaining water levels downstream. A comparison also indicates how the River Tham influences wet width values for the lower section of the West Glen whereas the East Glen has no comparable tributary and consequently its downstream section was largely dry.

3.3.6 The definition process - Phase 2: hydrological survey

Flows were monitored at 17 sites throughout the catchment of which eight sites lay on the West Glen, seven on the East Glen, one on a tributary of the East Glen and one on the main River Glen (figure 3.6). These supplement the continuous data recorded by the network of seven NRA gauging stations. Sites were selected to give a detailed picture of the hydrological response of the catchment and the extent of the gains/losses that had been recognised by Downing and Williams (1969) and Smith (1977). Exact locations were similar to those used in previous studies to allow comparison with historical data. Ease of access was a further important consideration. Measurements were taken using a standard Ott current meter type C2"10.150" in January, March and May 1990, and at approximate monthly intervals thereafter until November 1991 for a total of 21 surveys. At each site, the most uniform cross section was selected which provided uniform flow conditions. Sections with large variations in speed or large areas of slow moving water were avoided. Marker pegs were fixed to each bank to form a permanent transect at right angles to the flow and velocities and depth recorded with the meter at regular intervals across the transect at 0.6 depth (from the surface). Discharges were calculated from these measurements using the mean section method (BSI 1980).

Results of the detailed flow gauging surveys are shown in Appendix 2. Figure 3.7 shows the average monthly flows experienced at the five main river gauging stations over the period compared with the long-term averages measured since each station became operational (i.e. at Kates Bridge since 1960, Burton Coggles, Irnham and Manthorpe since 1969 and at Shillingthorpe since 1970). At each station, with the exception of Shillingthorpe, the flows were only greater than the long-term average during one of the 23 months i.e. February 1990. Shillingthorpe GS had above average levels during the latter part of 1991 as flows were augmented by the Gwash-Glen interbasin transfer.

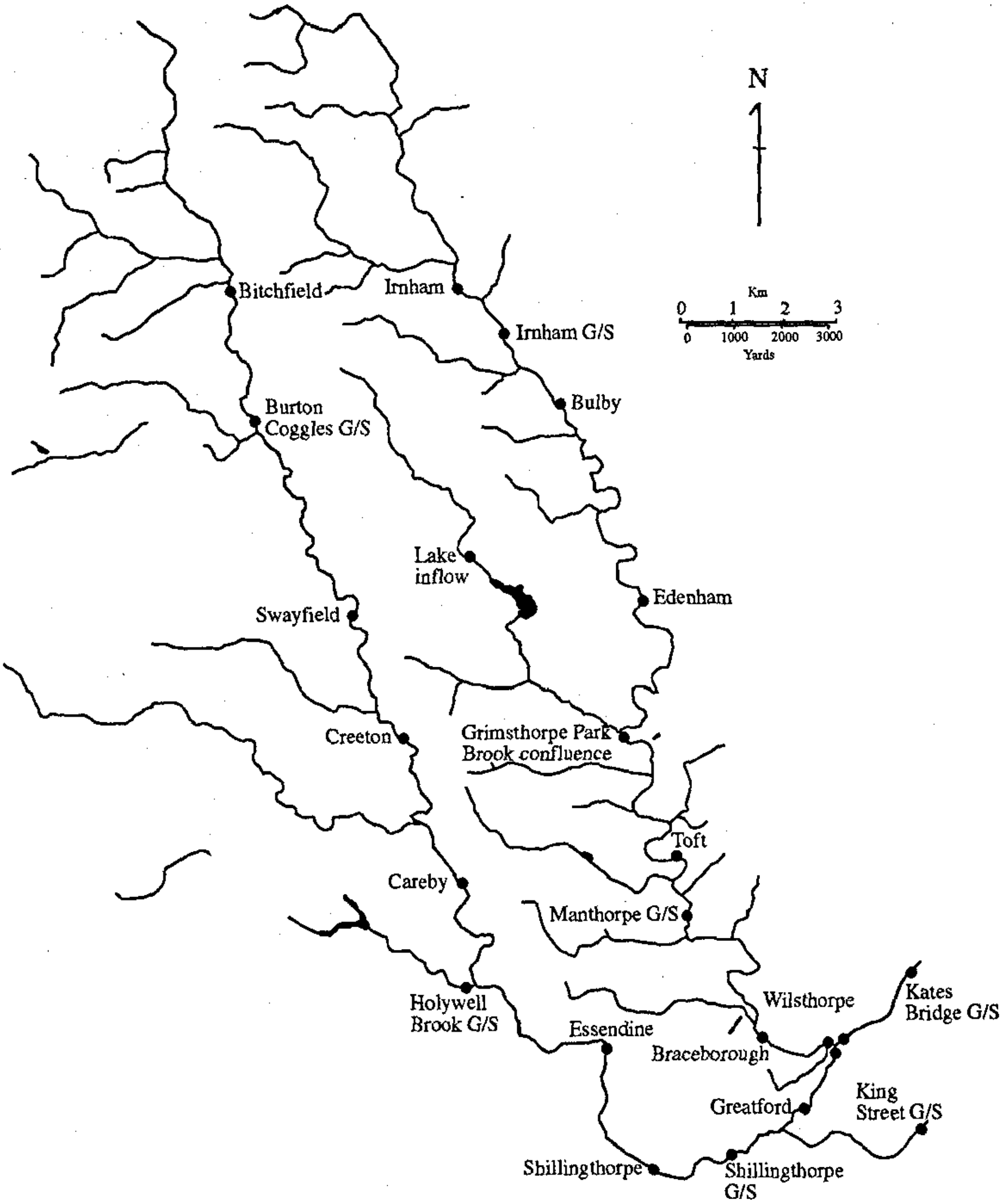


Figure 3.6 - Location of the flow monitoring sites within the Glen catchment

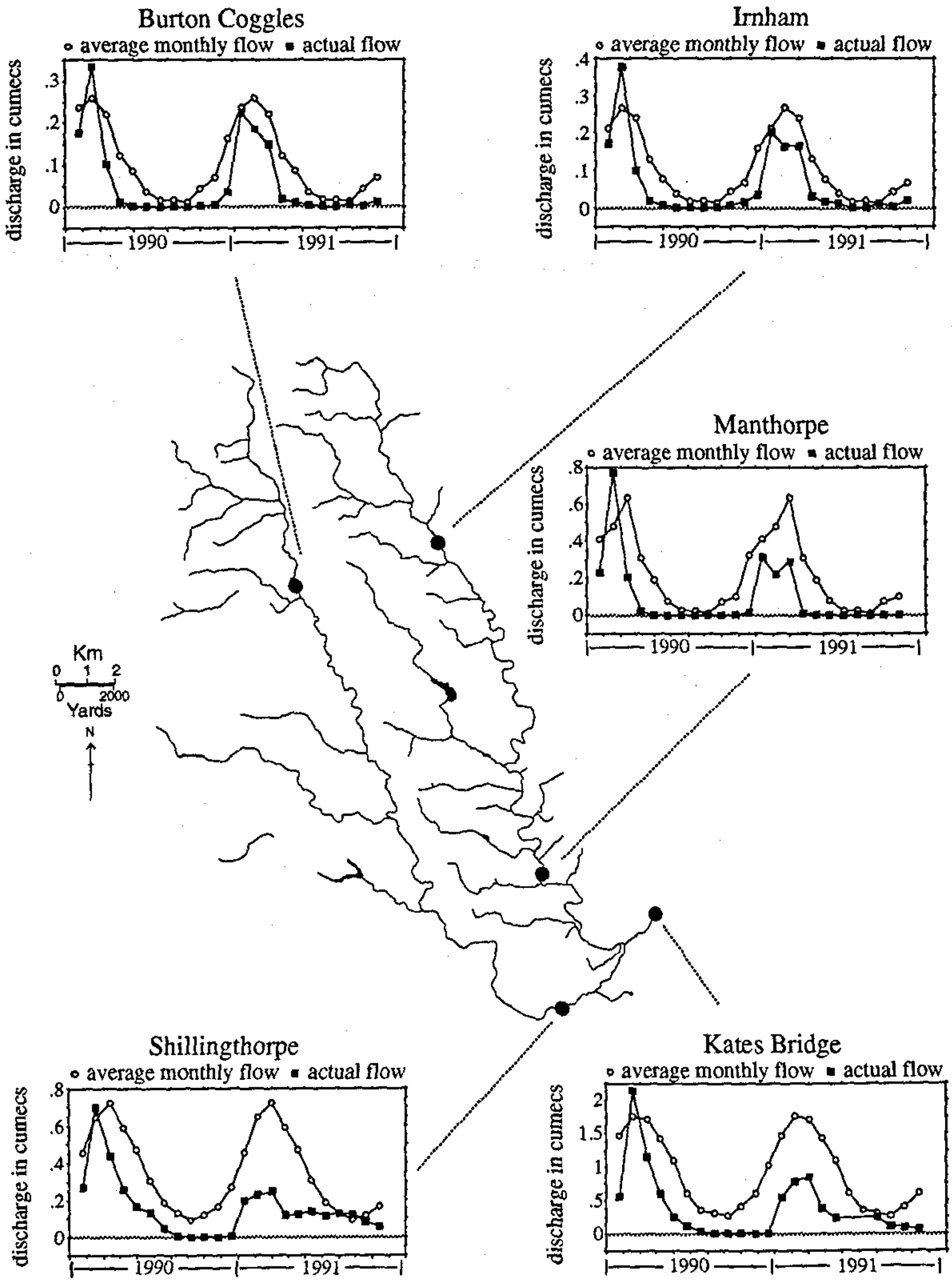


Figure 3.7 - Long term average monthly flows (∘) and actual recorded (▪) flows during 1990 and 1991 for the five main river gauging stations. Long term average monthly flows for each station are based on the period from when flow records commenced (i.e. Burton Coggles 1964, Irnham 1969, Manthorpe 1968, Shillingthorpe 1968 and Kates Bridge 1960) to 1991 inclusive.

Low rainfall during the period enabled the development of a detailed picture of the magnitude and extent of low flows experienced throughout the catchment. From the flows measured by the stations and those from the current meter surveys it has been possible to describe the West Glen river and East Glen river based purely on their hydrological response. At this level, reaches are defined by monitoring site boundaries. The following section describes each reach in more detail in terms of its start and end point, sources of water and extent of any gains or losses. Reference is made to figures 3.8 and 3.12 which show the flows recorded at each site over the period in cubic metres per second (cumecs). Figures 3.9 and 3.13 are also used to highlight gains and/or losses along selected reaches. In both sets of figures, the discharges recorded during the highest flow on 1/3/91 have been removed in order to allow greater resolution when examining the extent of the low flows experienced at each site.

3.3.7 Description of hydrological results - West Glen

1. Old Somerby Water Treatment Works (WTW) (SK969337) to Boothby Pagnell WTW (SK974306).
This reach experiences ephemeral flow with only the uppermost 500 m actually containing water in the channel during summer due to the discharge from Old Somerby WTW.

2. Boothby Pagnell WTW (SK974306) to Burton Coggles Gauging Station (GS) (SK986262).
Flow can fall to zero as was recorded at Bitchfield during the 27/7/90 and 27/9/91 surveys but water remains ponded in the channel for the majority of the reach.

3. Burton Coggles GS (SK986262) to Corby Glen (SK995249).
The upper part of this reach becomes dry under extreme conditions. However, downstream of the potholes located in the stream bed at SK988260 the channel remains dry for long periods. The potholes themselves are described in more detail by Hindley (1965). Discharge measurements suggest that they can be responsible for a reduction in flow by upto 0.0250 cumecs. For instance, flows at Burton Coggles GS on 7/4/91 was 0.0250 which had been reduced to zero at the next site downstream. Similarly on 15/3/90, flows decreased by 0.0215 cumecs from 0.0370 at the GS to 0.0155 downstream. Under low flows, the small swallow-holes in the channel bed consume the entire flow. As discharge increases, then

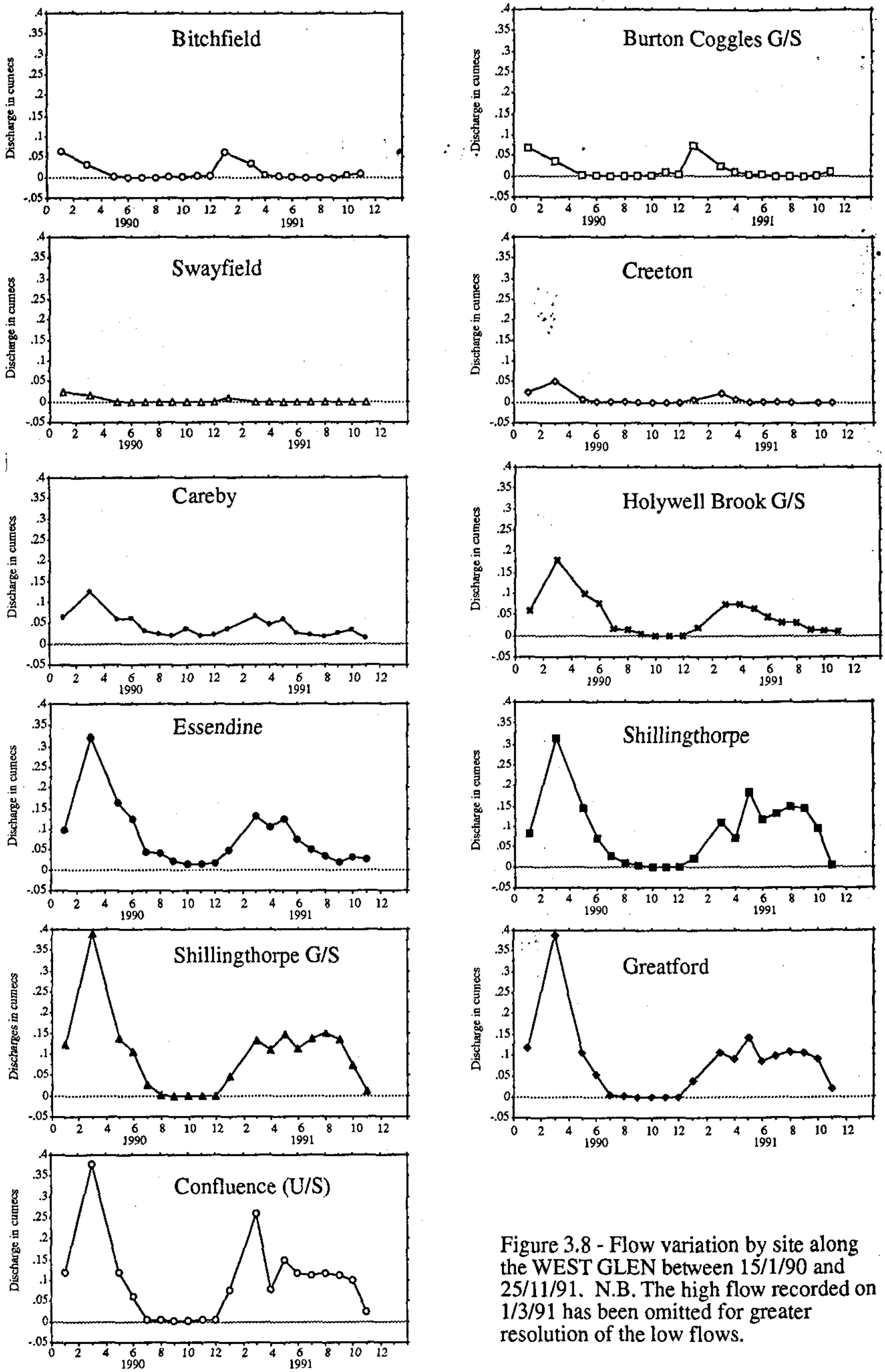


Figure 3.8 - Flow variation by site along the WEST GLEN between 15/1/90 and 25/11/91. N.B. The high flow recorded on 1/3/91 has been omitted for greater resolution of the low flows.

larger sinks that have been ring-fenced on the margins of the channel become active and hence the capacity to decrease discharge becomes greater.

4. Corby Glen (SK995249) to Eager Farm road bridge (SK997234).
Flow from a drain in Corby Glen and downstream at the WTW combine to maintain pools of water in the channel along this reach although flow can be undetectable in the lower part.

5. Eager Farm road bridge (SK997234) to Creeton Springs (TF010203).
This section remains totally dry for long periods, only flowing when the capacity of the potholes at Burton Coggles is exceeded. The uppermost section contains water when the flows from Corby Glen WTW are sufficient. Discharges recorded near Swayfield (TF007223) in the middle of this reach indicated flow on only 4 out of 21 occasions.

6. Creeton Springs (TF010203) to 2 km downstream (TF016190).
Although for long periods no flow enters this reach from the main channel upstream, flow only ceases under extreme conditions (e.g. 25/10/90) due to the inputs from Creeton Springs. Even in these circumstances water remains ponded along the majority of the channel.

7. 2 km downstream of Creeton Springs (TF016190) to River Tham confluence (TF016180).
As flow recedes from Creeton Springs, then this stretch becomes totally dry. This was the case when flows fell to 0.007 cumecs at Creeton springs on 21/6/90 and remained dry until the 25/1/91 survey. Similarly it was dry again by 28/5/91 when flows upstream were 0.0025 cumecs and remained so to the end of the period.

8. River Tham confluence (TF016180) to Essendine (TF050127).
This reach experiences perennial flow supplied by the River Tham and the ephemeral Holywell Brook. Figure 3.9 shows the amount of gains/losses during the recording period. The vertical axis represents time with the beginning of 1990 at the top and the latter part of 1991 at the bottom. The horizontal scale indicates the amount of water that is gained or lost along the stretch in cumecs after taking contributions from Holywell Brook into account. Clearly, for the majority of the time the channel experiences a small loss in the range of 0.005 to 0.02 cumecs.

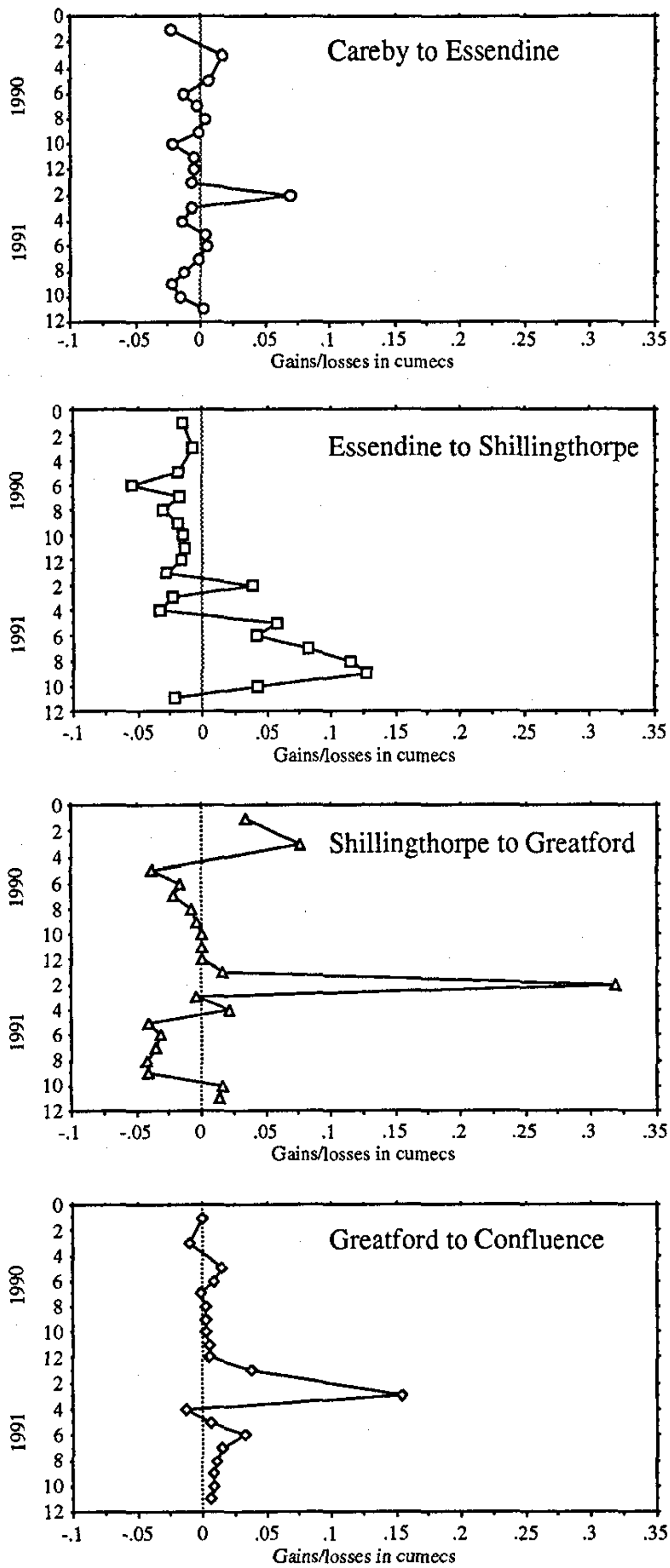


Figure 3.9 - Gains/losses along selected reaches of the WEST GLEN.

The large gains that occurred under high flow probably represent inputs from field drains and low order tributaries which are normally dry.

9. Essendine (TF050127) to Shillingthorpe Gravel Pit (TF059111).
Flow is perennial although total discharge decreases along the reach as water drains from the bed. This is evident in figure 3.9. Losses during the first half of the recording period were largely consistent around 0.02 cumecs. The gains in the latter part of the period are due to the operation of the Gwash-Glen transfer scheme augmenting discharge along the reach.

10. Shillingthorpe Gravel Pit (TF059111) to downstream of Greatford (TF088121).
Totally dry conditions prevailed under the extreme conditions between 25/9/90 and 19/12/90 before the Gwash-Glen transfer scheme came into operation. Losses occur for the majority of the period as evident in figure 3.9. Similar to reach 8, large gains occurred during high flow due to the contributions from low order tributaries.

11. Downstream of Greatford (TF088121) to the East Glen confluence (TF095133).
Perennial flow occurs with gains along the channel before and after the transfer scheme became operational. Even under extreme conditions when the upstream reach was dry, this stretch experienced a small amount of flow with no tributary inputs. Figure 3.9 highlights these small gains with much higher gains during high flow.

Two further flow surveys were completed in more detail on reaches 9 to 11. One was undertaken on 29/3/90 when the entire reach was experiencing flow and another on 25/9/90 when a large proportion was dry with the results shown in figure 3.10.

A disused gravel pit is evident at TF058110 and is connected to the main channel in two ways. Two buried metal pipes connect the top level of the pit to the channel just upstream of the bridleway at TF060110. Consequently, when water levels in the pit reach a maximum, these drain water from the pit into the river and augment flow. This is evident in figure 3.10 where an increase in flow is evident during the survey of 29/3/90. Conversely, when the water level drops, there is clear evidence

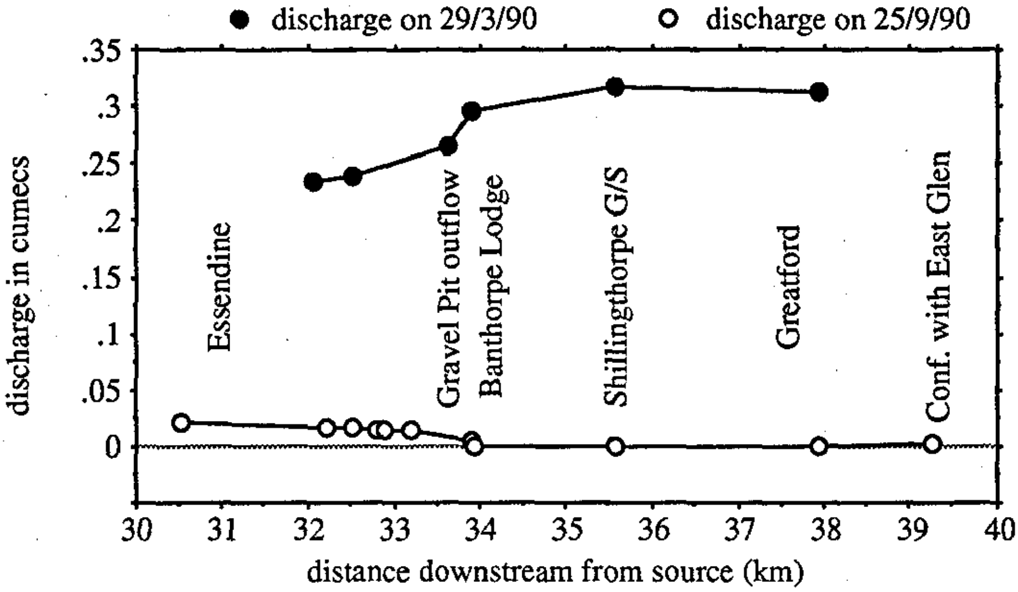


Figure 3.10 - Downstream flow variations on the lower West Glen on the 29/3/90 and 25/9/90.

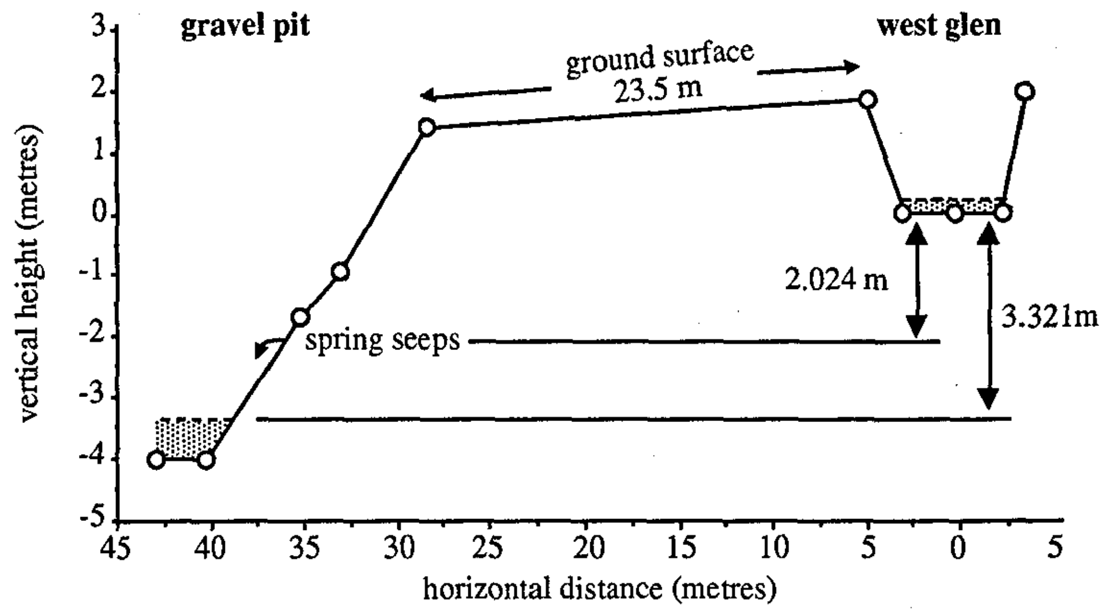


Figure 3.11 - Cross-section between the West Glen upstream of Banthorpe Lodge and the gravel pit

of seeps along the side of the pit nearest the river where water is draining through the permeable gravels. Indeed, a survey of the heights of the river bed, seeps and water level in the pit indicated these seeps were over 2 m below the river bed (shown in figure 3.11).

The survey undertaken on 25/9/90 shown in figure 3.10 indicates a contrasting picture to that of 29/3/90. On this occasion, flowing water only occupies the channel downstream to Banthorpe Lodge (TF062109) and in the lowermost stretch down to the East Glen confluence. Furthermore, the entire upper reach exhibited influent conditions. Discharge in the lowermost reach downstream of Greatford was characterised by a steady increase in flow with distance downstream and no evidence of a single point source. This also reiterates the conclusions presented in figure 3.9 for reach 11 where consistent gains have been recorded throughout the period.

3.3.8 Description of hydrological results - East Glen

1. Ropsley (SK992337) to Ropsley WTW (TF002337).

This short stretch is characterised by ephemeral flow with the channel becoming totally dry.

2. Ropsley WTW (TF002337) to 1.5 km downstream (TF013337).

Flow is ephemeral depending on the discharge from the WTW which maintains the ponded water in the channel.

3. 1.5 km downstream of Ropsley WTW (TF013337) to Lenton WTW (TF023303).

Similar to reach 2, flow is ephemeral although because it is beyond the influence of Ropsley WTW, the channel becomes totally dry.

4. Lenton WTW (TF023303) to Irnham GS (TF037273).

The WTW maintains water in the channel although flow decreases to zero under dry conditions. Zero discharge was recorded on one occasion in each year of the recording period.

5. Irnham GS (TF037273) to Edenham WTW (TF066216).

As discharge declines upstream, influent conditions result in the channel becoming totally dry. This was the case for three consecutive months during 1990 and 1991.

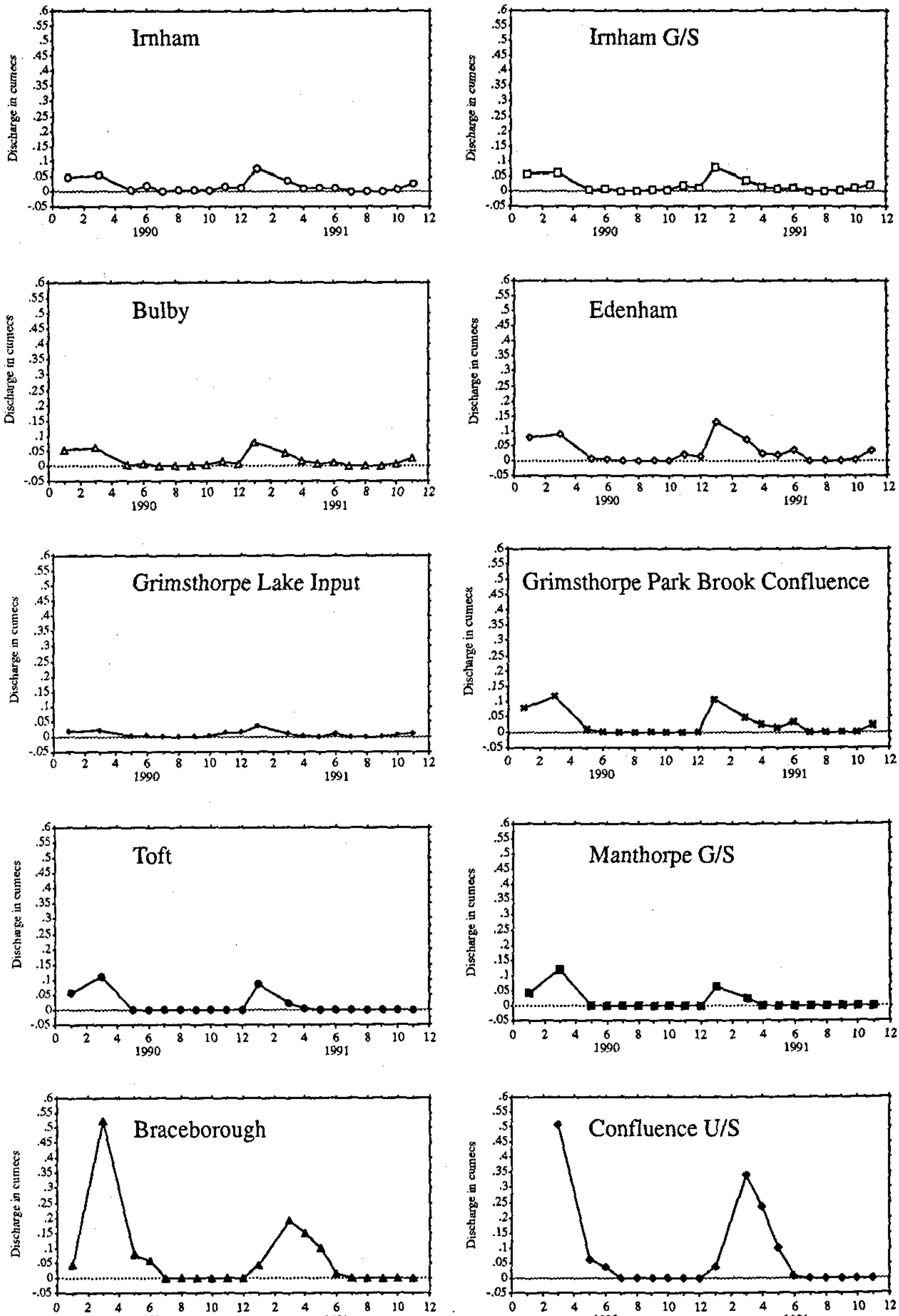


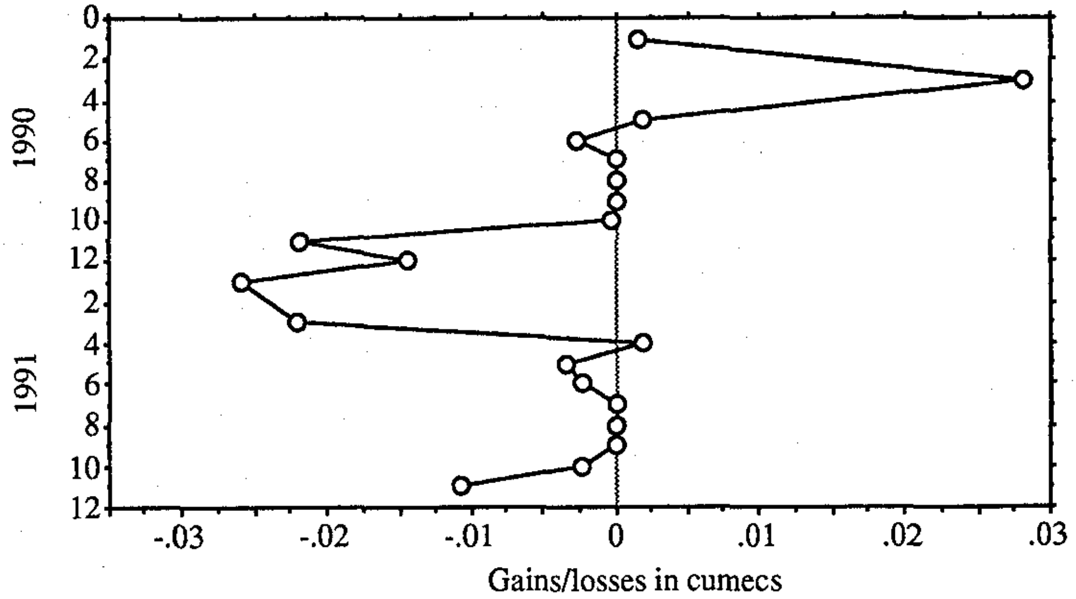
Figure 3.12 - Flow variation by site along the EAST GLEN between 15/1/90 and 25/11/91.
N.B. The high flow recorded on 1/3/91 has been omitted for greater resolution of low flows.

6. Edenham WTW (TF066216) to Pasture Hill Farm road bridge (TF064204).
Flow is ephemeral under extreme conditions although water levels are maintained by the WTW.

7. Pasture Hill Farm road bridge (TF064204) to just downstream of Manthorpe GS (TF066156).
As flows decline, the water front migrates upstream until the whole reach becomes totally dry. From the discharge data, the reach has been split into two sections. In the upper reach from Edenham to the confluence with Grimsthorpe Park Brook, gains do occur under high flows such as those experienced during early 1990 but under low flow conditions, losses are great enough to consume the entire flow (figure 3.13). The large gain on 1/3/91 was supplied by Grimsthorpe Park Brook flowing out of the lake in the grounds of Grimsthorpe Castle. This was the only occasion during the period when this tributary was flowing. The losses experienced in the lower reach, which extends down to Toft, are shown in figure 3.13. The values of zero represent the periods when there was no flow entering the reach at the upstream end. Therefore the channel was influent on all occasions.

8. Just downstream of Manthorpe GS (TF066156) to Braceborough (TF082134).
This stretch also becomes totally dry but only under more extreme conditions than the reach upstream. This is due to flows being maintained for longer periods by tributaries at Bowthorpe Park Farm (TF066155) and TF079138. Figure 3.14 highlights the flow variation downstream on the East Glen from Edenham to the West Glen confluence for the periods March-June 1990 and April-July 1991. During both periods, it is clear that flows are considerably higher at Braceborough than upstream. A more detailed survey undertaken on 22/3/90 was carried out to establish the source of these inputs. The first area of increase occurred at TF067155 just downstream of Manthorpe GS where three sources were discovered. The first, supplying 0.009 cumecs arose from springs in a small woodland next to the channel. Immediately downstream, approximately 0.005 cumecs was draining in from a tributary whose source rises just south of Witham on the Hill. The third was emerging from a bankside field drain on the opposite bank. These three combined resulted in the elevated discharge of 0.285 further downstream. The next main tributary was at TF076144 where water rising at Braceborough Spa fed a flow of 0.135 cumecs into the channel. The final source was located at TF079138 where a tributary originating near Monk's Wood, north east of Carlby, supplied 0.011 cumecs.

Edenham to Grimsthorpe Park Brook Confluence



Grimsthorpe Park Brook Confluence to Toft

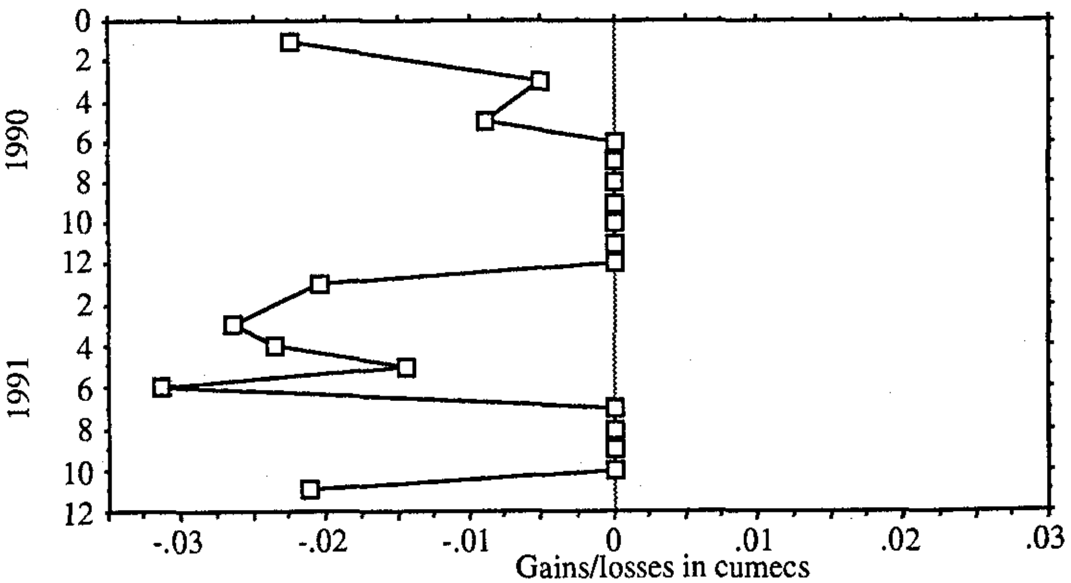


Figure 3.13 - Gains/losses along selected reaches of the EAST GLEN.

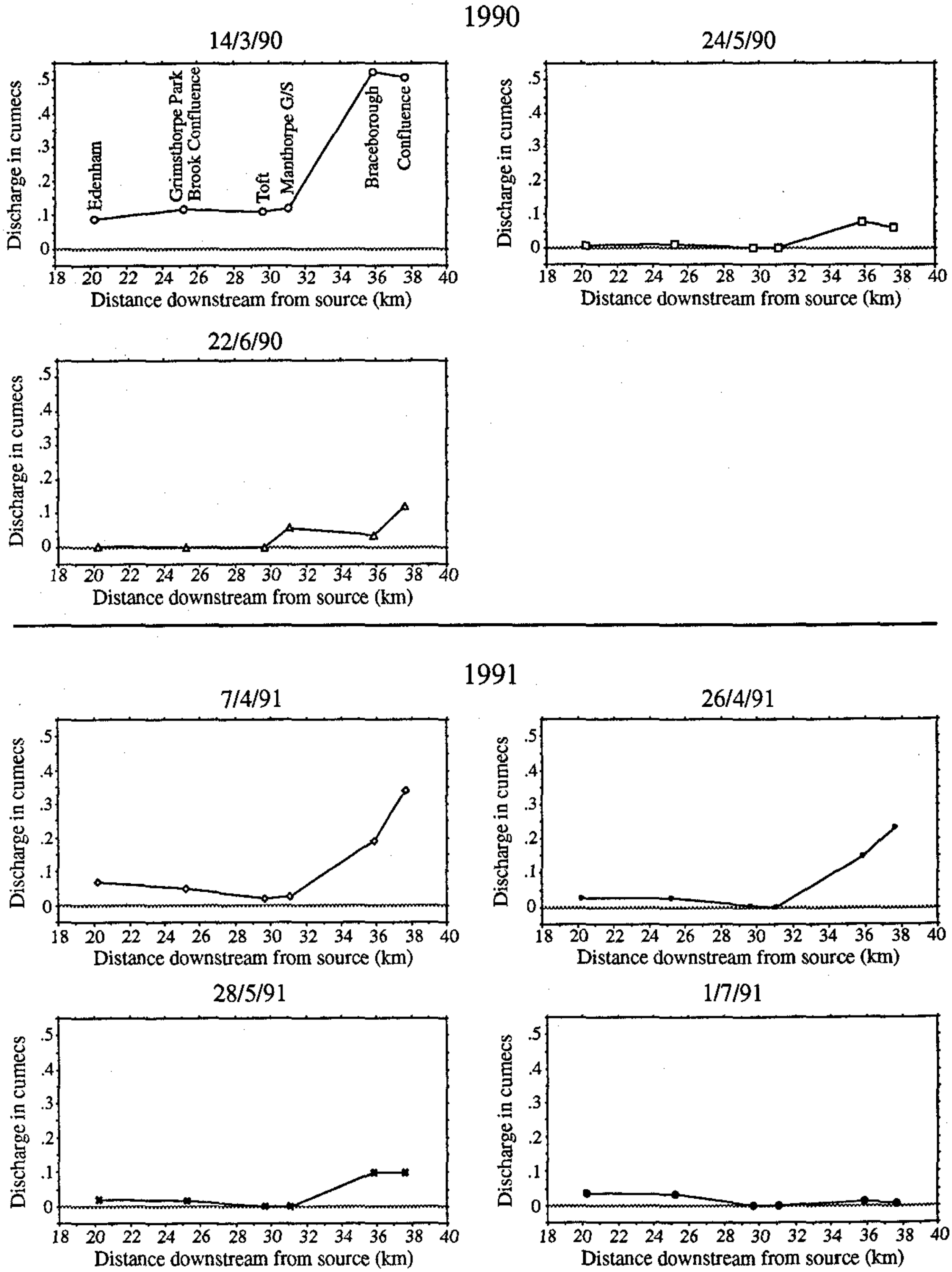


Figure 3.14 - Downstream flow variations in discharge on the East Glen between Edenham and the West Glen confluence during selected periods in 1990 and 1991. The graphs highlight the increases in flow between Manthorpe G/S and Braceborough and their rapid decline.

These sources however have tended to decline rapidly over a short period in both years as shown in figure 3.14. Flows at Braceborough were entirely fed by them by the 24/5/90 survey as the site at Manthorpe GS had dried up. However, by 27/7/90 Braceborough had virtually suffered the same fate. Similarly in 1991, flows at Manthorpe GS had ceased by 26/4/91 but 0.1472 cumecs was recorded at Braceborough but by 29/7/91 flows had also ceased at Braceborough as these tributaries had dried up.

9. Braceborough (TF082134) to the West Glen confluence (TF095133).
Flow is ephemeral and declines at the same rate as reach 8 although water remains in some deeper pools and in the channel at the confluence supplied by the West Glen which backs up along the East Glen.

It is clear that under such conditions, large stretches of both the West and East Glen suffer severe impacts. Surveys undertaken in July of 1990 and 1991 indicated zero flow for almost the entire length of the East Glen with the majority of the channel being totally dry. A similar picture was experienced through July to September in 1990 and 1991 upstream of Creeton on the West Glen.

These reaches are shown in figure 3.15 and have been split into two basic groups, i.e. perennial flow and ephemeral flow. Further subdivisions highlight which perennial sections experience consistent losses from the channel bed and whether the ephemeral sections become either totally dry or contain ponded water but with no flow. The Water Treatment Works on the main channel have been indicated due to their important influence on the classification of selected reaches. 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 (Straw

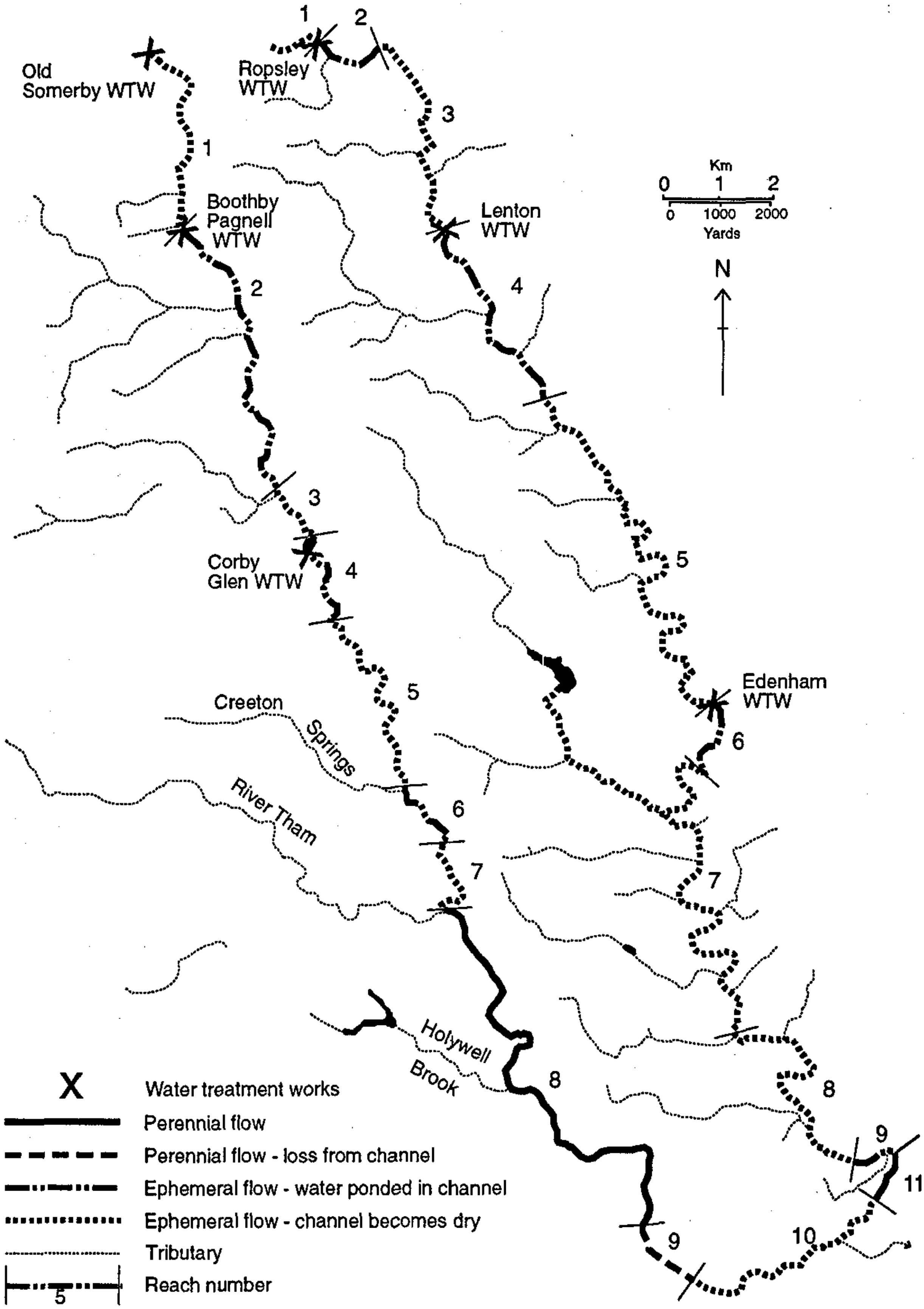


Figure 3.15 - Map of West and East Glen split into distinct reaches based on the nature of the channel during low flow.

and Clayton 1979). 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 1.2tcmd).

3.4 Comparison Of Gains/Losses Between Reaches

3.4.1 Calculation of gains/losses

The previous section described the discharge variations along the West and East Glen during 1990 and 1991 and defined a number of distinct reaches. From the results it has also been possible to compare the amount of water that is gained or lost along some of these reaches. Consequently, table 3.1 highlights the amount of water being gained or lost along selected reaches of the West and East Glen. The points that delineate each reach are based on the gauging sites which are given along with their associated grid references in the tables of results in appendix 2. The discharge measurements from which the gains/losses calculations are based are also shown in these tables. The variations in gains/losses have already been highlighted for these reaches in figures 3.9 and 3.14 over the gauging period. However, to allow a true comparison between each stretch in terms of the actual amounts of water that is migrating between the surface water and the channel bed, the reaches have been standardised based on their total bed area.

Reach lengths were calculated from the 1:2500 main river maps. Average channel widths were calculated from the measurements taken during the physical habitat survey which recorded width to the nearest 10 cm at every 50 m or every riffle, whichever was the closer. Total bed area for each stretch was calculated by simply multiplying the first column by the second. The fourth and fifth columns show the gains/losses in cubic metres of water per metre squared of channel bed per day ($m^3/m^2/d^{-1}$) and were calculated from the amount of flow change along the reach and the bed area. Averages values in column four were calculated based on those occasions when water was both flowing into the upstream end and out of the downstream end of the reach. For instance, flow had reached zero at a point upstream of Shillingthorpe on 25/10/90 and so it would be inappropriate to use the whole bed area in working out losses for the Essendine - Shillingthorpe reach on this date as the reach had the capacity to lose more water. Column five highlights the maxima over the recording period for each reach. The maximum gain for the Greatford - Confluence stretch utilised the 1/7/91 data as although this was not the date when the greatest gains occurred, it was the time when the greatest gains occurred without any visible tributaries augmenting flow along the reach.

3.4.2 Results

Table 3.1 - Gains/losses along selected reaches of the West and East Glen

Reach	Total Length (m)	Average Width (m)	Bed Area (m^2)	Average Gains/ Losses ($m^3m^{-2}d^{-1}$)	Maximum Gains/ Losses ($m^3m^{-2}d^{-1}$)
WEST GLEN					
Careby - Essendine	6650	5.66	37639	-0.02	-0.10
Essendine - Shillingthorpe	3348	6.82	22833	-0.11	-0.21
Shillingthorpe - Greatford	3614	7.16	25876	-0.09	-0.14
Greatford - Confluence	1692	5.59	9458	+0.07	+0.29
EAST GLEN					
Edenham - GPB Confluence	4936	4.33	21373	-0.05	-0.10
GPB Confluence - Toft	5090	4.54	23109	-0.08	-0.12

The results show how the greatest losses occur along the Essendine - Shillingthorpe reach for both average and maximum values in terms of amounts of water per unit bed area over time. Similar but slightly smaller losses are evident in the next reach downstream followed by gains in the subsequent reach from Greatford to the confluence with the East Glen. Upstream of Essendine, average losses tend to be small. The two reaches on the East Glen also exhibit losses with the Grimsthorpe Park Brook (GPB) confluence - Toft reach having the slightly higher values. However, in comparison they are lower than the levels along the two reaches between Essendine and Shillingthorpe on the West Glen.

The rate of average gains along the Greatford-Confluence reach are similar to the rate of loss in the two reaches upstream. However, the origin of this upwelling water was not clear. It has been hypothesised that the influent nature of the channel between Essendine and Shillingthorpe was due to the presence of aridity cracks that had opened up during previous drought periods and subsequently conveyed rapid recharge into the confined zone of the aquifer (Booker 1977). However, figure 3.2 highlights how the river in this area flows over permeable gravels masked by a veneer of alluvium. Indeed the presence of permeable gravels in this reach has already been discussed in connection with respect to the disused gravel pit at TF058110. Therefore an alternative suggestion is that the water re-emerging into the channel downstream of Greatford may have its origin in this area. In order to examine these alternatives, an investigation was undertaken using intragravel temperature profiles. The following section outlines the concept of using temperature profiles to determine the origin of intragravel water followed by a description of its use on the lower reaches of the West Glen.

3.5 Determination of the Origin of Intragravel Water Using Temperature Profiles

3.5.1 Background

Growing attention has been directed towards the study of streams and their interaction with the underlying groundwater. This has been fuelled by the attention given to the distribution of sediment dwelling organisms (hyporheos) (e.g. Bishop 1973, Godbout and Hynes 1982) the contribution of contaminated groundwater as a source of non-point pollution (Lee and Hynes 1977), the importance of groundwater-fed areas for spawning (ADFG 1985) and in the transport and storage of solutes and particulate substances (Bencala et al 1984, Kennedy et al 1984).

Very deep groundwaters can be ancient and are often saline but are unlikely to interact with the stream bed. However, even shallow waters remain for long periods which can on average be measured in tens of years (Hynes 1983). For instance the age of the groundwater in the unconfined zone of the Lincolnshire Limestone aquifer varies from recent to 9000 years before present (B.P.) and in the confined zone from recent to 25000 years B.P. (Downing et al 1977). This catchment is also characterised by rapid recharge which occurs when water enters the Lincolnshire Limestone aquifer through swallow holes and moves rapidly towards the confined region. Even thus, water takes a minimum of 35 weeks to travel from swallow holes in the north to the southern reaches (Booker 1977) and hence along with mixing, is likely to adjust to the temperatures of the older groundwater.

Numerous studies have been undertaken to compare intragravel and surface water temperature regimes (e.g. Wilson et al 1980, Hartman and Leahy 1983, Shepherd 1984, Shepherd et al 1986, White et al 1987. Results suggest that intragravel temperatures appear to be buffered by the substrate and can influence temperature patterns to more than 50 cm deep in places.

Laboratory flume experiments undertaken by Vaux (1968) indicated that streamwater downwelling occurred where the longitudinal bed profile was convex or where there was an increase in streambed elevation i.e. the transition from an upstream pool to a riffle. Where the shape of the bed was concave or where there was a decrease in streambed elevation, i.e. the transition from a riffle to a downstream pool, water upwelling in the substratum occurred.

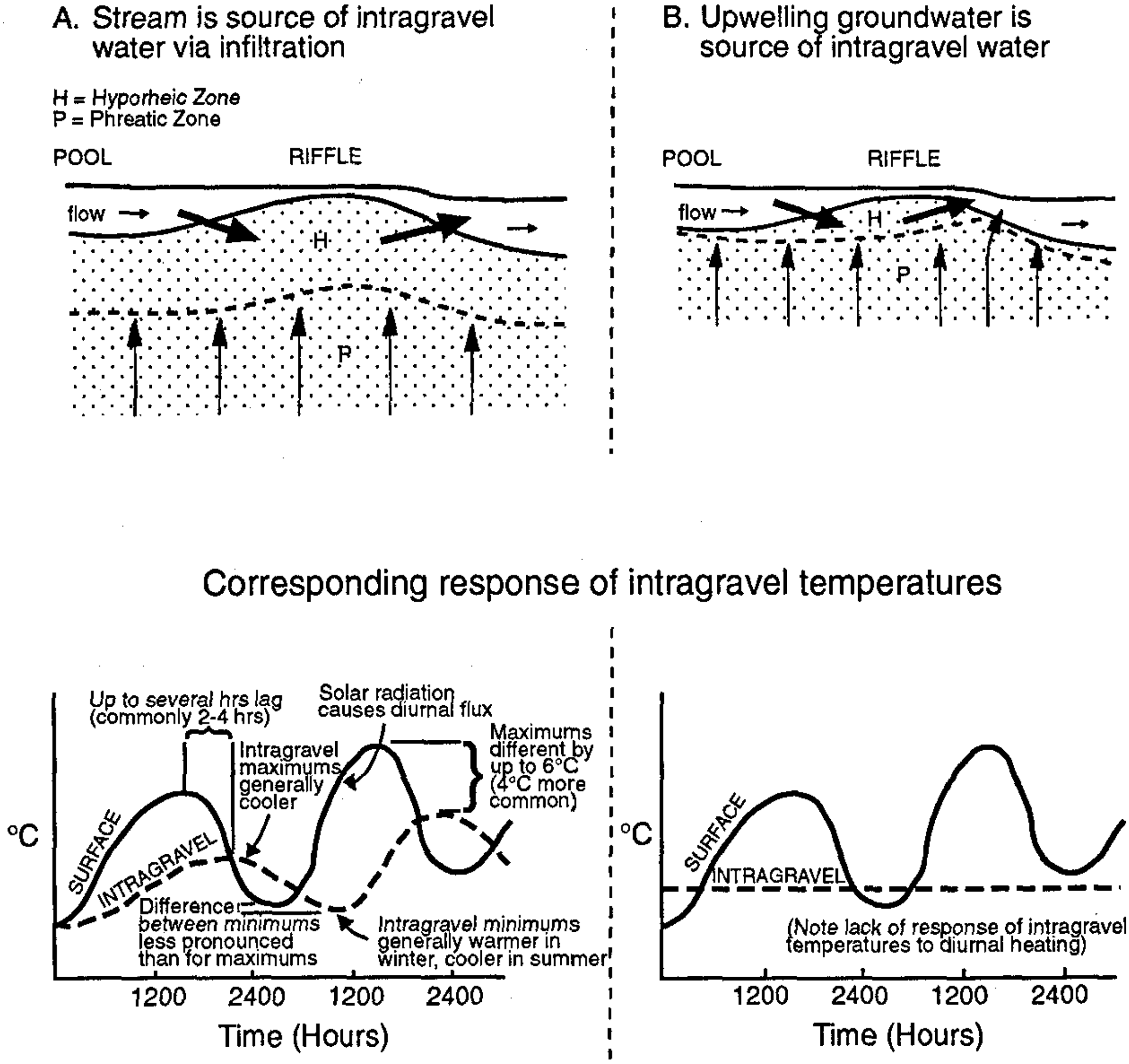


Figure 3.16 - General summer diurnal surface and intragravel water temperature patterns (after Shepherd et al 1986 and Creuze des Chatelliers and Reygrobellet 1990).

From the studies described above, a more detailed picture has been constructed on the patterns of upwelling, downwelling and underflow that occur along streambeds depending on water pressure, stream elevation and bed permeability and their associated temperature profiles. This is summarised in figure 3.16 above which shows the situations in which the stream or groundwater is likely to be the source of intragravel water and the resultant temperature patterns.

In situation A, streamwater enters the substrate at the upstream end of the riffle and re-emerges at the downstream end. Temperature patterns within the streambed show a different response to the surface water variations in two main ways:

1. a clear timelag is apparent between maximums and minimums of surface water temperatures and those of the interstitial water,
2. intragravel water temperature displays much less variation than surface water.

In situation B, surface water still filters into the riverbed at the upstream end of the riffle and re-emerges at the downstream end. However, groundwater is also much closer to the streambed and enters the stream where the riffle merges with the pool. Intragravel temperatures at this point show no diurnal variation but mirror the constant temperature of their source, i.e. the deep groundwater. It is important to note that Creuze des Chatelliers and Reygrobellet (1990) suggest these groundwater discharge areas occur at discrete points rather than along the whole reach. Consequently, any study undertaken to determine the location of such areas must focus on the downstream end of riffles.

3.5.2 Study sites

The discharge surveys discussed earlier highlighted the interaction between the river and aquifer within the Glen catchment. In particular, the reach of the West Glen from Essendine to the confluence with the East Glen contained three types of sub reaches:

1. those that showed few gains or losses of water and hence little interaction between surface and groundwater,
2. those that experienced consistent losses (influent conditions) and
3. those that showed consistent gains (effluent conditions).

Six sites were selected along the reach, the locations of which are shown in figure 3.17. Site 1, located upstream of Essendine (TF051135), was chosen because the discharge data indicated that there was little interaction between the river and aquifer

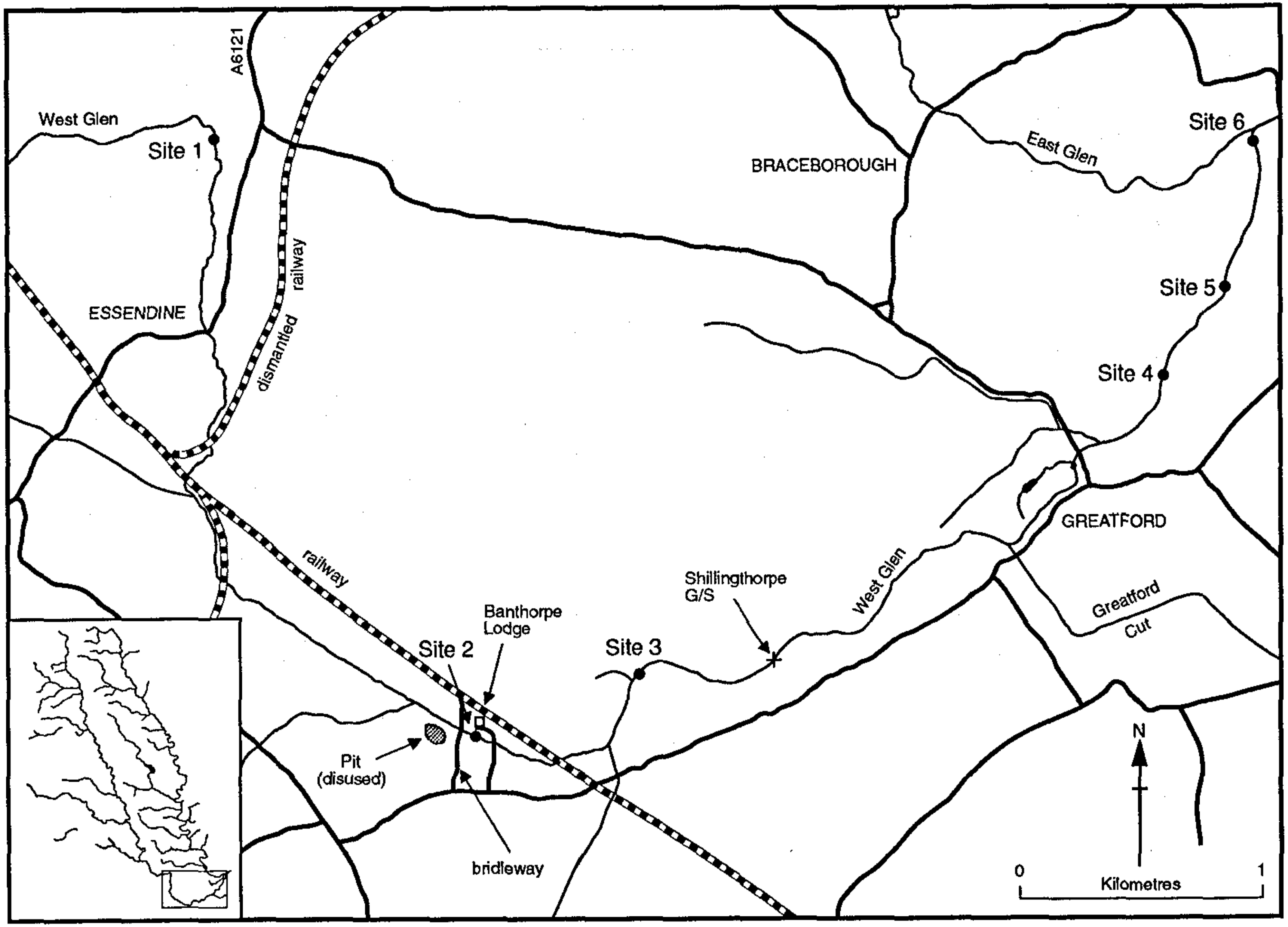


Figure 3.17 - Location of sites used for the temperature surveys on the West Glen

here. Site 2 was located in the reach that had displayed consistent losses from the channel bed. The exact location, near Banthorpe Lodge (TF062109), was chosen as this was where the water front ceased flowing during the detailed survey undertaken on 25/9/90 shown in figure 3.10 and hence influent conditions were evident. Influent conditions have also been demonstrated along the reach between Shillingthorpe and Greatford (figure 3.9) and so site 3 was located at TF067113. The reach downstream of Greatford had demonstrated gains in flow on a consistent basis (figure 3.9). Therefore, three sites were located along this reach to try to establish the location of any groundwater discharge zones. Site 4 was located at the point where detectable flow commenced during the detailed 25/9/90 survey (TF091124). Site 5 was chosen midway between here and the confluence (TF094127) and site 6 just upstream of the confluence itself (TF095133).

3.5.3 Method

Temperature was measured using a steel probe encasing four thermistors located at 25 cm intervals and connected to a chart recorder. The probe was inserted into the channel bed to a depth of 60 cm on the downstream end of a riffle at each site. Consequently, the uppermost thermistor recorded water temperature 15 cm above the channel bed, the second was positioned 10 cm within the substrate, the third at 35 cm depth and the lowest at a depth of 60 cm (referred to as +15, -10, -35 and -60 respectively). At each site, the datum was set at the streambed and not the stream water surface in order to make the results easier to interpretate. Also, the streambed was a more stable reference point as the water surface fluctuated between sampling dates.

The six sites were monitored on two occasions i.e. once during June - October 1991 when surface water temperature variations were relatively high and once during October - December 1991 when water temperatures were lower. The probe was left recording for five to seven days. Figures 3.18 to 3.23 show the results for each site during the two recording periods. In each case, results from the first two days of the record have not been used in any analysis to allow the river bed time to settle after inserting the probe. From the remaining data, the three consecutive days that displayed the greatest variation in surface water temperature were extracted for analysis (except during the first period at site 1 when only two days were available). This was done to make any response of intragravel temperatures to changes in surface water temperatures easier to detect.

3.5.4 Results and discussion

Sites that have groundwater discharging into the stream will be characterised by stable intragravel temperatures of approximately 8°C. Alternatively, intragravel water originating from the crest of the riffle will mirror surface water temperature fluctuations but with a buffered response.

Figures 3.18 to 3.23 show the results of the temperature surveys undertaken at each site with temperature in °C on the vertical axis and time on the horizontal axis. Two diagrams are shown for each site, one for the summer survey and one for the autumn/winter survey. from the wealth of raw data, a statistical summary of the temperatures recorded at each level during both surveys has been calculated (tables 3.2a and 3.2b).

Examining all sites, surface water temperatures ranged from 12.1-20.2°C during the first survey. During the same period, intragravel temperatures at -60 cm ranged from 11.6-18.2°C. In comparison, surface water temperatures during the second period varied between 2.8-12.6°C and 6.8-11.0°C at -60 cm depth. At each site during the first survey, a progressive decline is apparent in the average temperatures from streamwater down through the substrate except at site 3. A general reverse trend is noted during the second surveys, particularly where streamwater temperatures were lowest. For instance, the coldest average streamwater temperature was recorded at site 1 (4.3°C) and a clear pattern of increasing temperature with depth was apparent. However, during the second survey at sites 3 and 4, streamwater temperatures were still relatively high (10.5 and 11.3°C respectively) and the trend matched that of the first recording period. The standard deviation (sd) has also been calculated for each trace to provide a description of the variability of the results at each point. Again, a clear pattern is evident with the greatest variability occurring in surface water temperatures and decreasing with depth. For instance, during both surveys at site 1, the sd of the streamwater was in the range 0.719-0.786, decreasing through the substrate to 0.380-0.391 at -10 cm, 0.219-0.254 at -35 cm and 0.119 at -60 cm.

From the results it is clear that the most notable difference occurs between the traces from sites 2 and 3 and those from sites 5 and 6. The first surveys from sites 2 and 3 exhibit a similar pattern in that the peaks and troughs in the surface water temperature can be traced down through the gravel with a timelag and buffered response. These results are characterised by only a small decrease in average

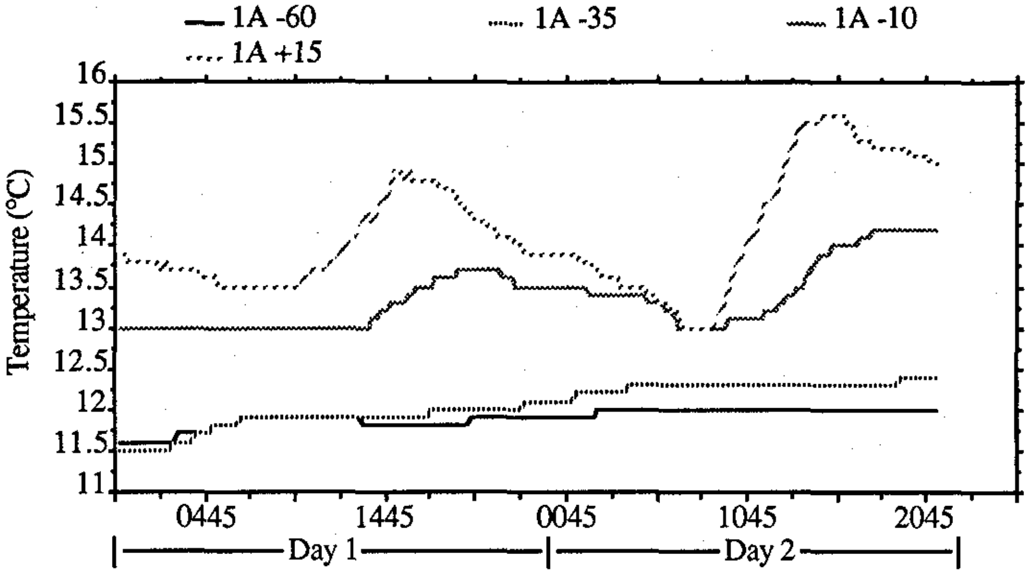


Figure 3.18a - Temperature survey results for site 1. Day 1 = 9/10/91

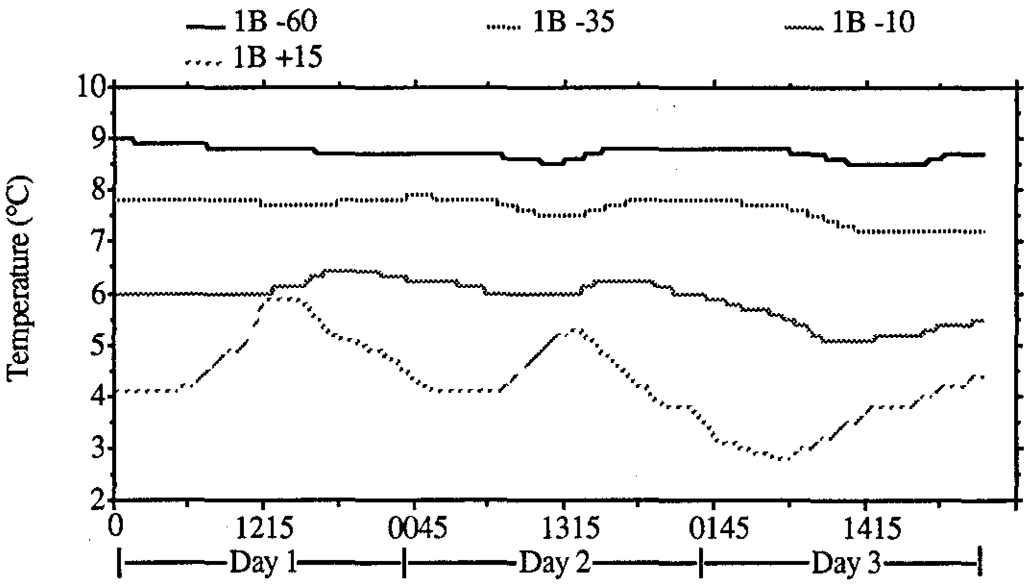


Figure 3.18b - Temperature survey results for site 1. Day 1 = 14/11/91

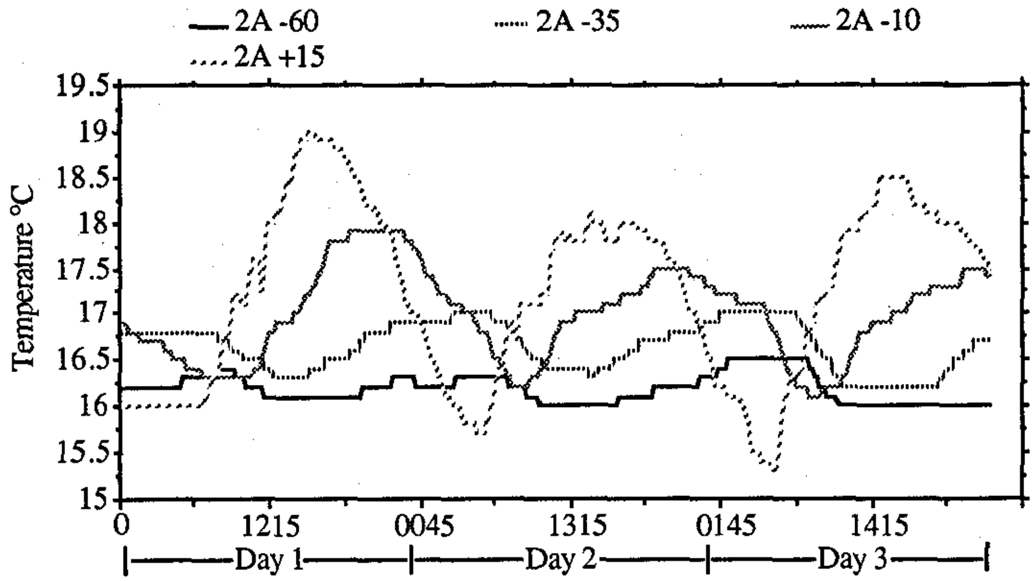


Figure 3.19a - Temperature survey results for site 2. Day 1 = 17/7/91

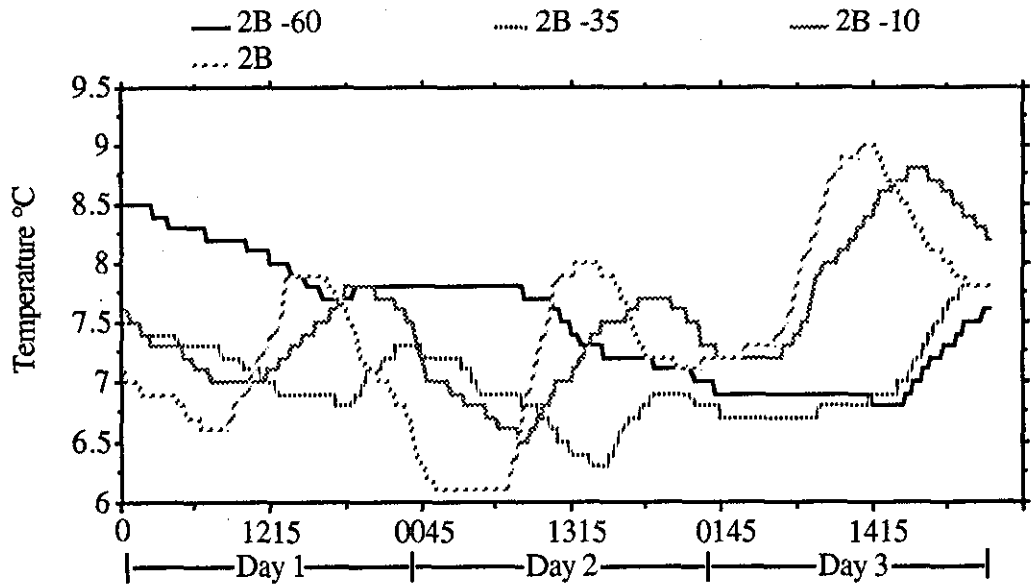


Figure 3.19b - Temperature survey results for site 2. Day 1 = 17/10/91

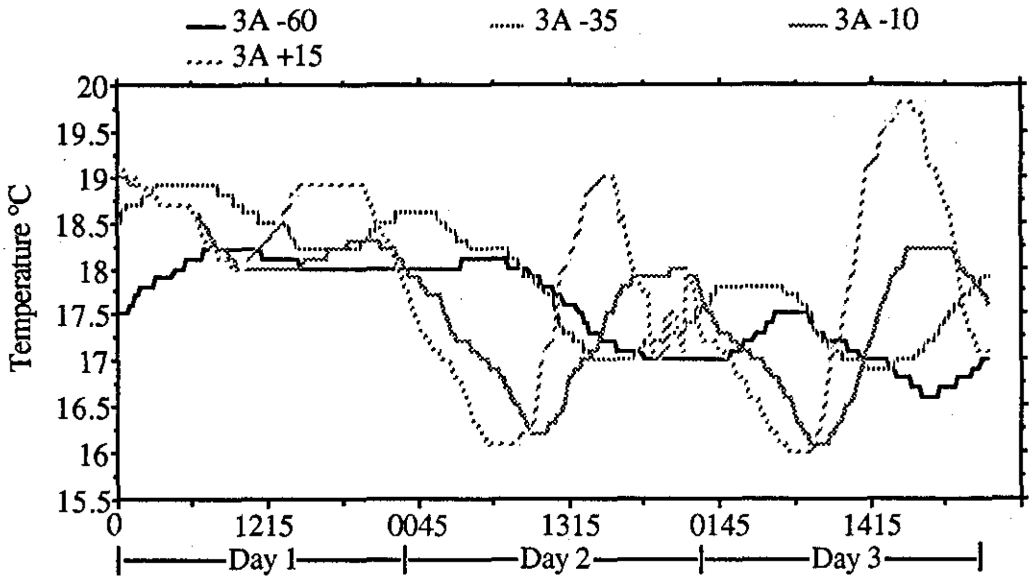


Figure 3.20a - Temperature survey results for site 3. Day 1 = 8/8/91

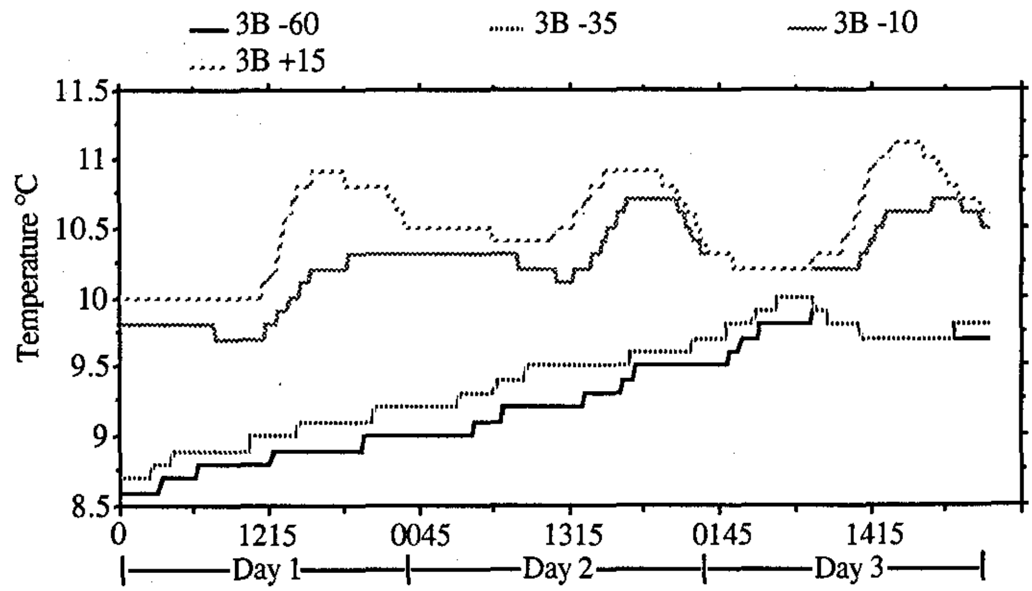


Figure 3.20b - Temperature survey results for site 3. Day 1 = 23/10/91

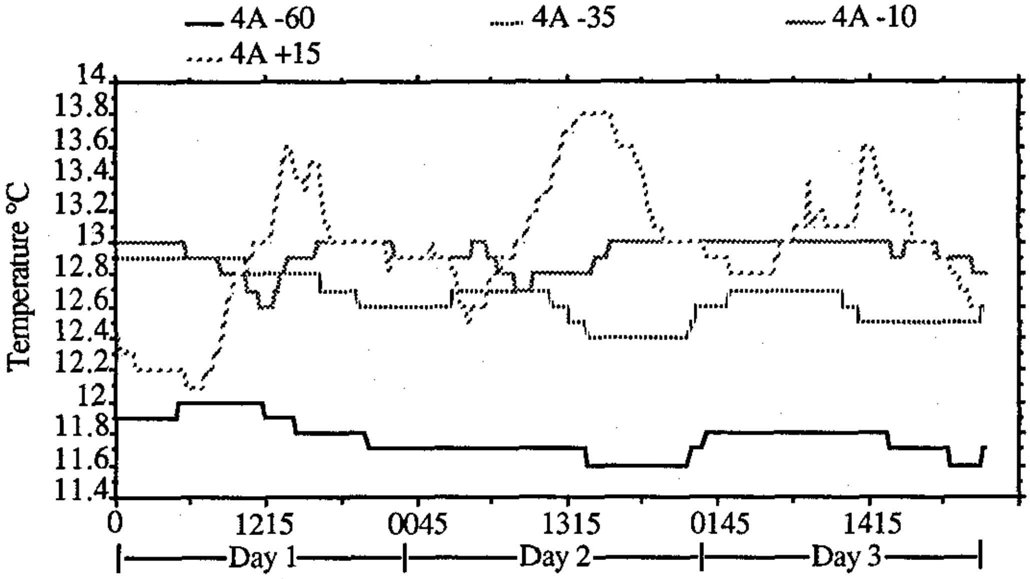


Figure 3.21a - Temperature survey results for site 4. Day 1 = 14/6/91

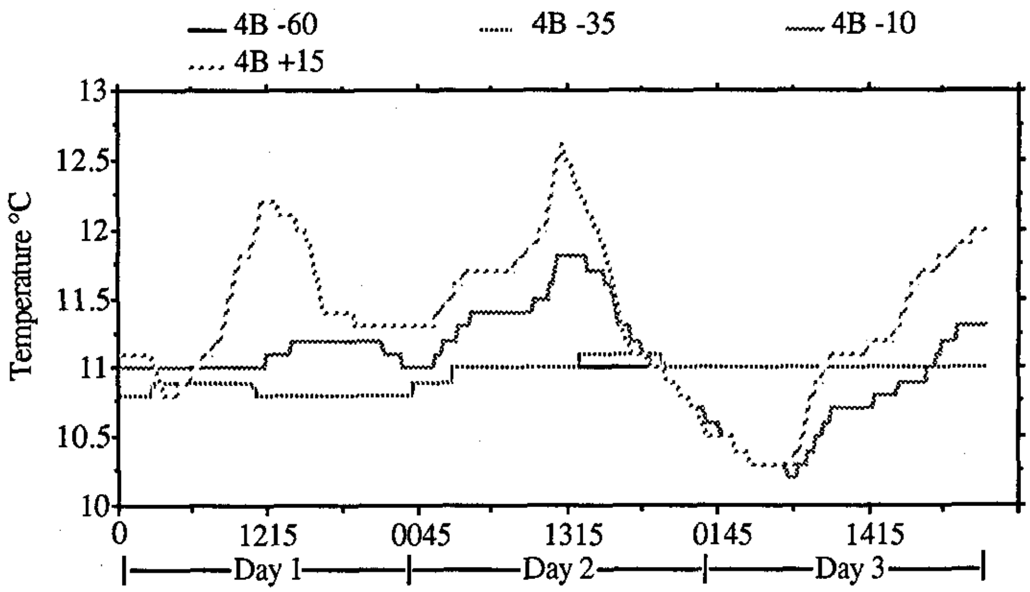


Figure 3.21b - Temperature survey results for site 4. Day 1 = 28/10/91

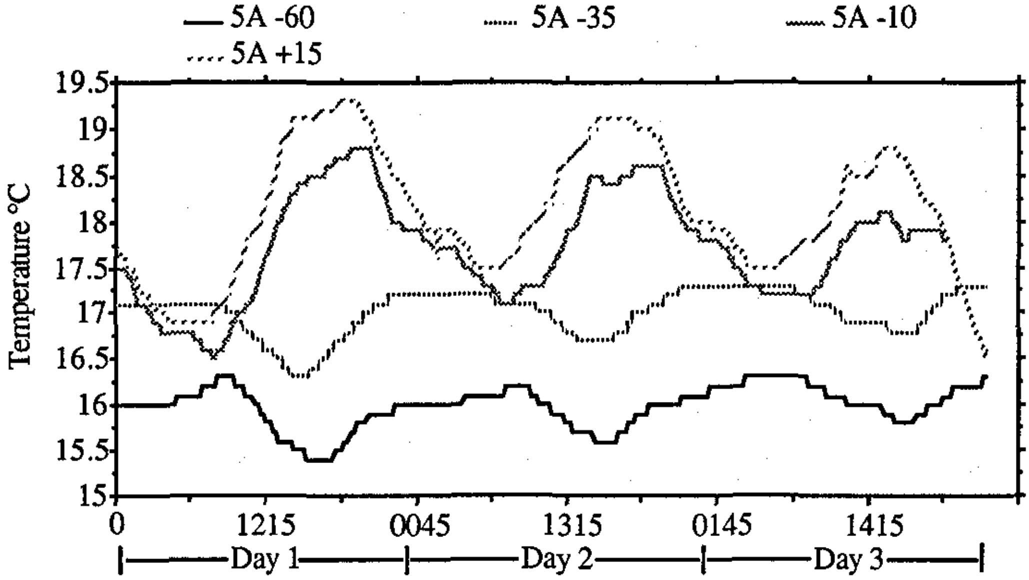


Figure 3.22a - Temperature survey results for site 5. Day 1 = 14/8/91

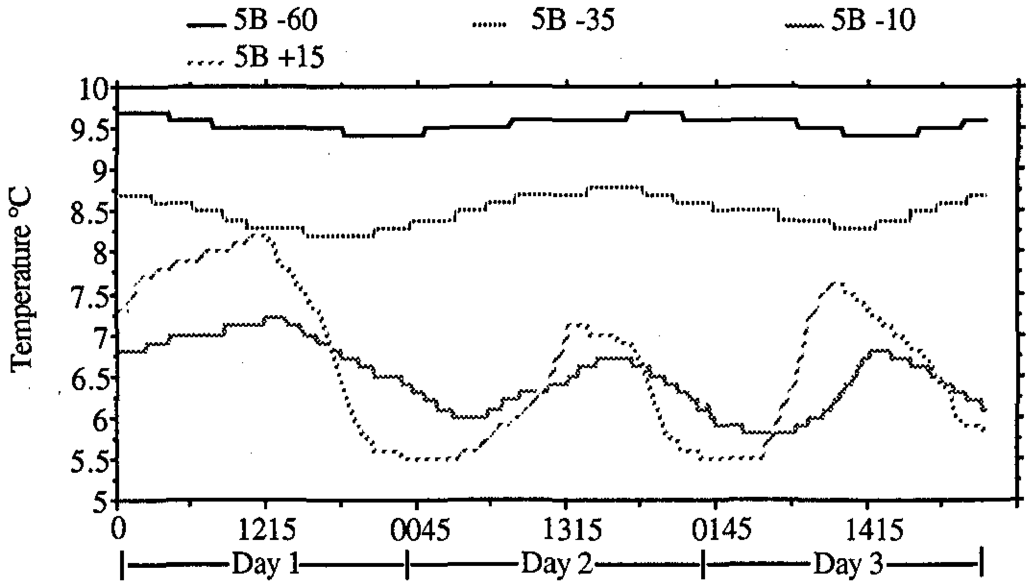


Figure 3.22b - Temperature survey results for site 5. Day 1 = 3/11/91

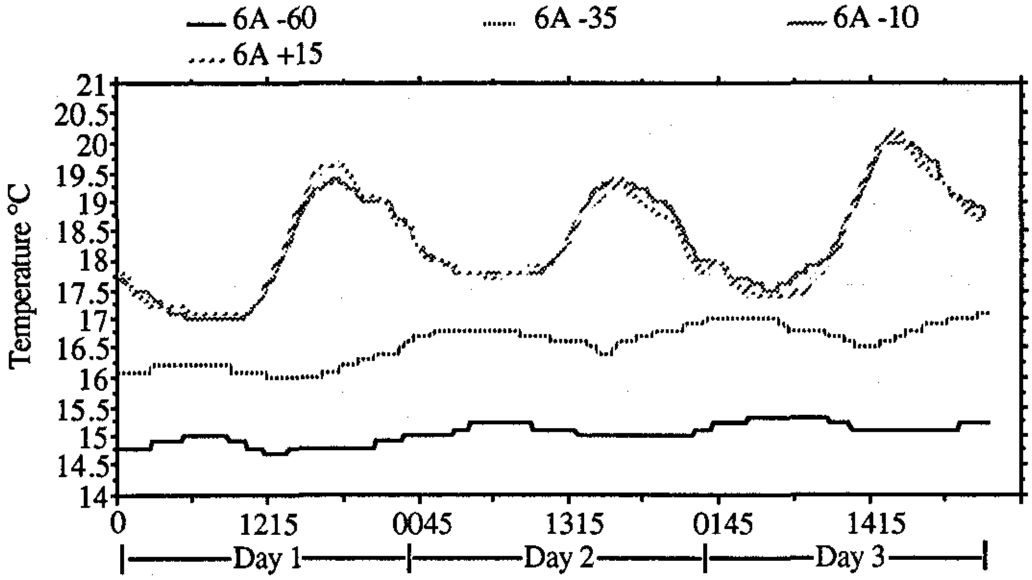


Figure 3.23a - Temperature survey results for site 6. Day 1 = 26/7/91

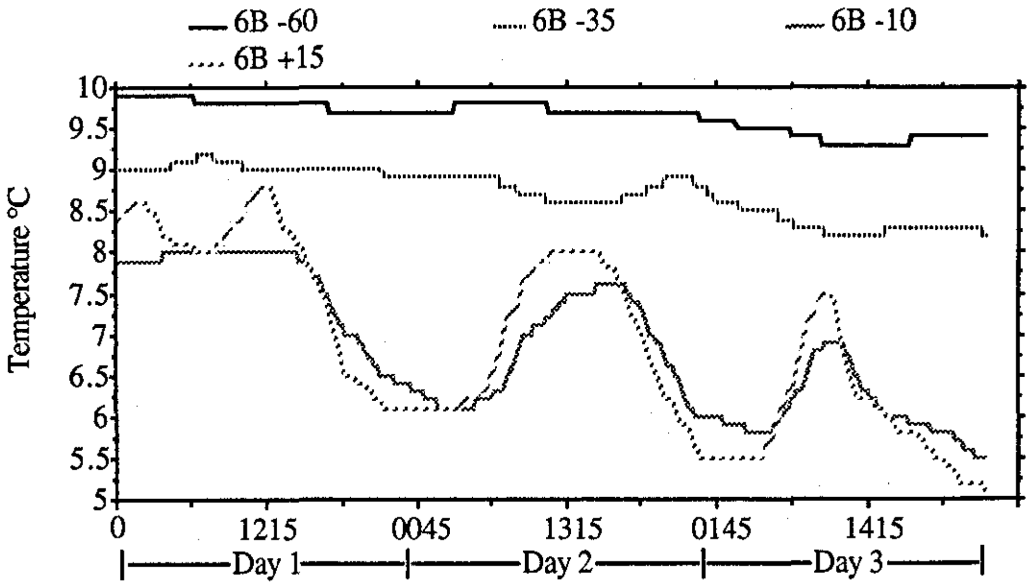


Figure 3.23b - Temperature survey results for site 6. Day 1 = 7/11/91

Table 3.2a. - Summary of temperature results for each site during the first survey.

Site No.	Date Started	Vert. Dist. From Bed (cm)	No.of Data Points	Average Temp. °C	Standard Dev.	Min. Temp. °C	Max. Temp. °C
1.	9/10/91	+15	182	14.1	.719	13.0	15.6
	"	-10	"	13.4	.391	13.0	14.2
	"	-35	"	12.1	.254	11.5	12.4
	"	-60	"	11.9	.119	11.6	12.0
2.	17/7/91	+15	289	17.2	.983	15.3	19.0
	"	-10	"	17.0	.498	16.1	17.9
	"	-35	"	16.6	.264	16.2	17.0
	"	-60	"	16.2	.154	16.0	16.5
3.	8/8/91	+15	289	17.9	1.058	16.0	19.8
	"	-10	"	17.6	.751	16.1	19.0
	"	-35	"	17.9	.638	16.9	18.9
	"	-60	"	17.6	.501	16.6	18.2
4.	14/6/91	+15	289	13.0	.409	12.1	13.8
	"	-10	"	12.9	.097	12.6	13.0
	"	-35	"	12.7	.154	12.4	12.9
	"	-60	"	11.8	.116	11.6	12.0
5.	14/8/91	+15	289	18.1	.706	16.5	19.3
	"	-10	"	17.7	.587	16.5	18.8
	"	-35	"	17.0	.248	16.3	17.3
	"	-60	"	16.0	.277	15.4	16.3
6.	26/7/91	+15	289	18.3	.856	17.1	20.2
	"	-10	"	18.3	.839	17.0	20.0
	"	-35	"	16.6	.326	16.0	17.1
	"	-60	"	15.0	.161	14.7	15.3

Table 3.2b. - Summary of temperature results for each site during the second survey.

Site No.	Date Started	Vert. Dist. From Bed(cm)	No.of Data Points	Average Temp. °C	Standard Dev.	Min. Temp. °C	Max. Temp. °C
1.	14/11/91	+15	289	4.3	.786	2.8	5.9
	"	-10	"	5.9	.380	5.1	6.4
	"	-35	"	7.6	.219	7.2	7.9
	"	-60	"	8.7	.119	8.5	9.0
2.	17/10/91	+15	289	7.4	.751	6.1	9.0
	"	-10	"	7.5	.570	6.5	8.8
	"	-35	"	7.0	.330	6.3	7.8
	"	-60	"	7.5	.504	6.8	8.5
3.	23/10/91	+15	289	10.5	.332	10.0	11.1
	"	-10	"	10.2	.284	9.7	10.7
	"	-35	"	9.4	.362	8.7	10.0
	"	-60	"	9.3	.390	8.6	9.9
4.	28/10/91	+15	289	11.3	.544	10.3	12.6
	"	-10	"	11.0	.362	10.2	11.8
	"	-35	"	11.0	.094	10.8	11.1
	"	-60	"	10.9	.083	10.8	11.0
5.	3/11/91	+15	289	6.6	.896	5.5	8.2
	"	-10	"	6.5	.396	5.8	7.2
	"	-35	"	8.5	.174	8.2	8.8
	"	-60	"	9.5	.092	9.4	9.7
6.	7/11/91	+15	289	6.8	1.082	5.1	8.8
	"	-10	"	6.8	.811	5.5	8.0
	"	-35	"	8.7	.298	8.2	9.2
	"	-60	"	9.7	.184	9.3	9.9

temperature with depth (i.e. 1°C at site 2 and 0.3°C at site 3) but a much greater decrease in the sd (i.e. from 0.983 to 0.154 at site 2 and from 1.058 to 0.501 at site 3). The sd values show a similar decrease for the first surveys at sites 5 and 6 (i.e. from 0.706 to 0.277 at site 5 and from 0.856 to 0.161 at site 6). However, in contrast to sites 2 and 3 the average temperature of the intragravel water is clearly lower (as shown in figures 3.21a and 3.22a), with values 2.1°C less than surface water at site 5 and 3.3°C lower at site 6.

The temperature profiles from sites 2 and 3 confirm the influent nature of the channel there and suggest intragravel water is moving directly down through the substrate at those points.

Sites 5 and 6 are situated downstream of Greatford where the hydrological surveys indicated the channel experiences effluent conditions. As described above, the temperature profiles from these sites are subtly different from sites 2 and 3 and two factors can be extracted to provide evidence of the origin of the upwelling water. Firstly, at -60 cm there is a definite diurnal variation which suggests that intragravel water has a surface rather than deep groundwater origin. However, the greater difference between surface and intragravel temperatures indicates that this intragravel water is fed into the substrate some distance upstream rather than in the immediate locale as with sites 2 and 3.

3.5.6 Summary Of Temperature Survey Results

Hydrological surveys had established the interactive nature between surface and intragravel water along the lower reach of the West Glen. Sites 2 and 3 were selected because of the influent nature of the channel and temperature profiles shown in figures 3.18a and b and 3.19a reiterate the surface origin of the intragravel water. Sites 5 and 6 were located in the reach that had been shown to experience effluent conditions. The traces for these sites in figures 3.21 and 3.22 highlight important differences than those described above. In these four cases, intragravel temperatures are not as responsive to surface water temperature changes although a definite diurnal variation is exhibited by the traces. This suggests that the intragravel water originates from surface water infiltrating into the substrate some distance upstream rather than at that immediate point as with sites 2 and 3. Consequently, water entering the stream along the stretch of the West Glen below Greatford is likely to have originated from surface water draining from the channel upstream and not the upwelling of deeper groundwater. Indeed, none of the sites exhibited the temperature profiles that would be expected from a site with direct upwelling from deeper groundwater. Table 3.3 below summarises the nature of each site.

Table 3.3 - Summary of influent/effluent conditions for each site.

Site No.	Nature of Channel
1	Influent
2	Influent
3	Influent
4	Effluent
5	Effluent
6	Effluent

3.5.7 Summary of gains/losses

Detailed investigations of the nature and extent of gains and losses from the West Glen between Essendine and Greatford confirm 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 $m^3m^2d^{-1}$; the middle reach dried out in 1990. The maximum rates of water loss equate to about 5tcmd (0.055m^3s^{-1}) through the Essendine to Shillingthorpe reach. In the downstream reach, return-flow from the gravels, at average rates of about 0.03$m^3m^2d^{-1}$, sustains perennial flow. The maximum rate of return flow recorded was 0.253 $m^3m^2d^{-1}$.

3.6 Final Definition of the Types, Sectors and Reaches

The results of the physical habitat assessment and detailed hydrological survey, both suggested that the catchment could be split into a number of discrete sectors. However, it is only through the amalgamation of these data, in conjunction with the NRA fisheries data and invertebrate records that an holistic classification can be drawn up. Figure 3.24 highlights the variations in habitat quality and percentage of the reach that was dry during the physical habitat survey for the West Glen and East Glen respectively. Each individual transect along the entire river was assigned a value of +1 for good quality, 0 where the channel was dry and -1 for poor quality as designated earlier. The lines on the graphs have been constructed by using the moving average of each twenty consecutive values. A habitat quality of 1.0 indicates

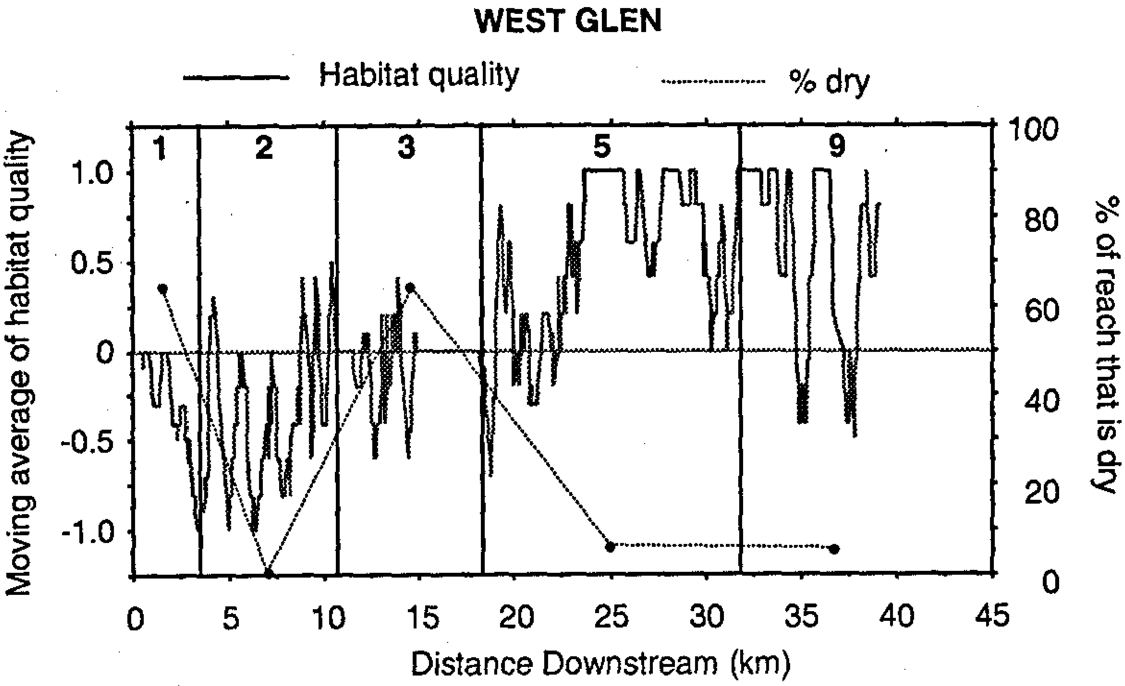


Figure 3.24a - Variations in habitat quality and % of channel dry for the East Glen

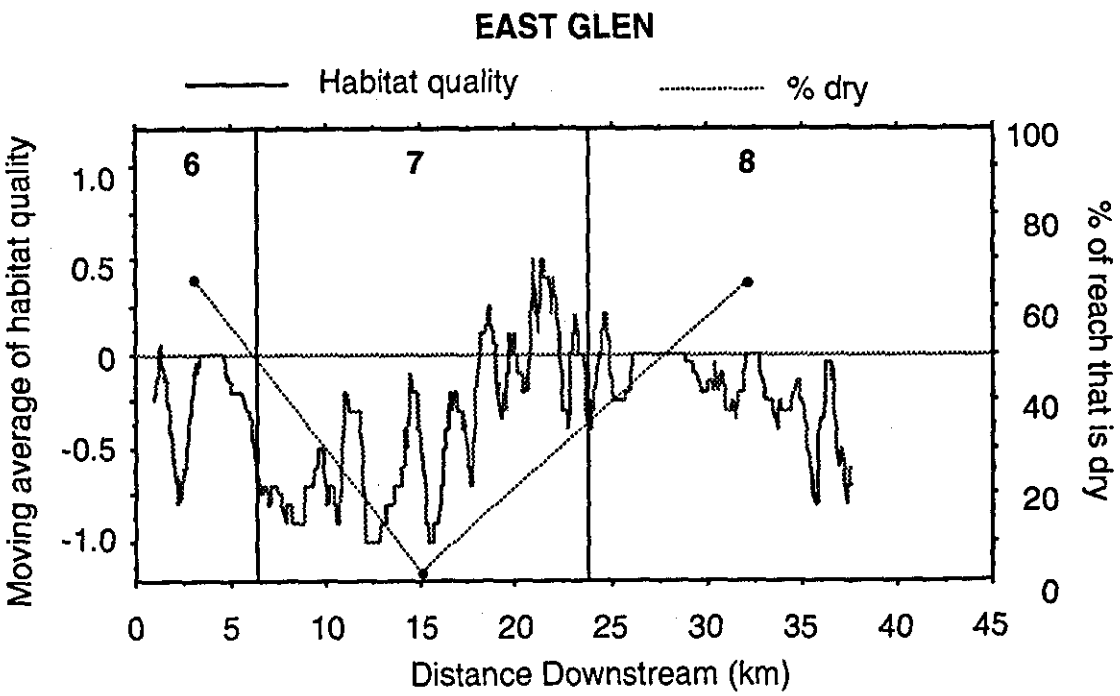


Figure 3.24b - Variations in habitat quality and % of channel dry for the West Glen

good quality whereas poor quality is represented by figures approximating to minus 1.0. The moving average was utilised to smooth the erratic nature of the transect data and to make trends along the river more apparent. The percentage of the reach dry is also illustrated to highlight the differences between the given sectors. Evidently the West Glen has been split into five reaches and the East Glen into three. Sector number four was allocated to the River Tham, a tributary of the West Glen. Even at this level, designation of boundaries between sectors is somewhat subjective. However, synthesis of the hydrological and habitat information makes this a much more certain process than reliance on broad scale characteristics taken from map sources. For instance, initial designation of the downstream end of sector five on the West Glen was positioned at the junction with Holywell Brook. Detailed information suggests that the division between five and six should be further downstream which marks the transition between a channel with perennial flow and one that is dominated by loss of water from the channel through the bed. More specific data relating to sector characteristics are highlighted in table 3.4 along with the actual locations of each.

In this situation, results support the classification of the Glen catchment into three river types (upland, intermediate and lowland) and 10 sectors (figure 3.25). The study in particular demonstrates that due to the intermittent nature of the West Glen river upstream from Little Bytham and the entire East Glen river, the course of the main river Glen effectively begins at Creeton and Castle Bytham springs.

The upland type sectors comprise sectors 1,2,3,4,6,7,8 and sector 5. The majority of the sectors have low invertebrate community diversity with low and intermittent discharges. Flows reach zero for periods of the year, as they have not only in the past but also from time to time for at least 200 years (Petts et al 1992). Morphological diversity is low and most reaches have been channelised to some degree. Within sector 5, flows are maintained by spring flows and the lower Tham, in particular, sustains good quality habitat. Invertebrate assemblages are more diverse and the characteristic fish species are Dace and Brown Trout.

The lowland type sites are sustained by perennial flow with low velocities and deep run habitat. The invertebrate fauna indicate the water quality is good. In such channels, water depth is more important than flow velocity for determining habitat diversity. Morphological diversity is distinctly lacking, due to the heavily channelised nature of the entire reach.

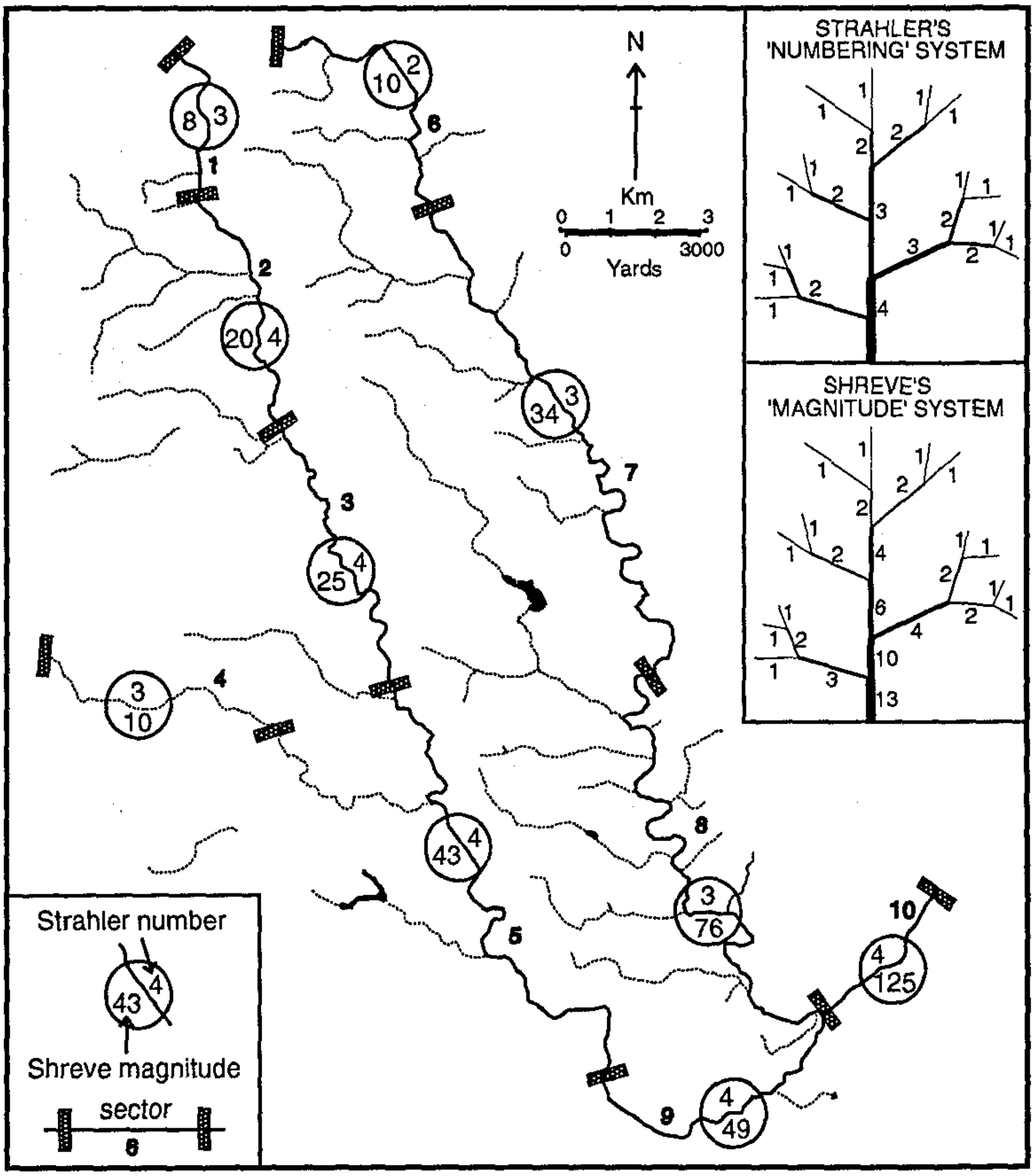


Figure 3.25 - Definition of channel sectors with their associated stream 'magnitude'

Table 3.4 - 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	ILAB	LE
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

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

The use of the geomorphological characteristics to describe sectors, and reaches within sectors, is illustrated in figures 3.26 and 3.27. Figure 3.26 compares the physical habitat of two representative reaches in different sectors on the West Glen; from Little Bytham to Careby and from Shillingthorpe to Greatford. For each case, the downstream variation of channel width, and the summary 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 rifles 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 3.27 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 3.26 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 pie diagrams highlight the predominance (>75%) of deep and stagnant run type habitats in the upstream reach whereas they occur less frequently downstream (50%).

3.6.1 Summary of the definition process

A summary diagram of types, sectors and low flow characteristics within the entire River Glen catchment (including the lower Glen) is illustrated in figure 3.28.

Although most workers agree on the desirability of classifying zones both for management purposes and to facilitate the study of river ecology, there is less agreement on its feasibility (Hawkes 1975). It is clearly of practical value in river and fishery management. With the increasing needs for water conservation, both quantitatively and qualitatively, a system of river type and sector classification is

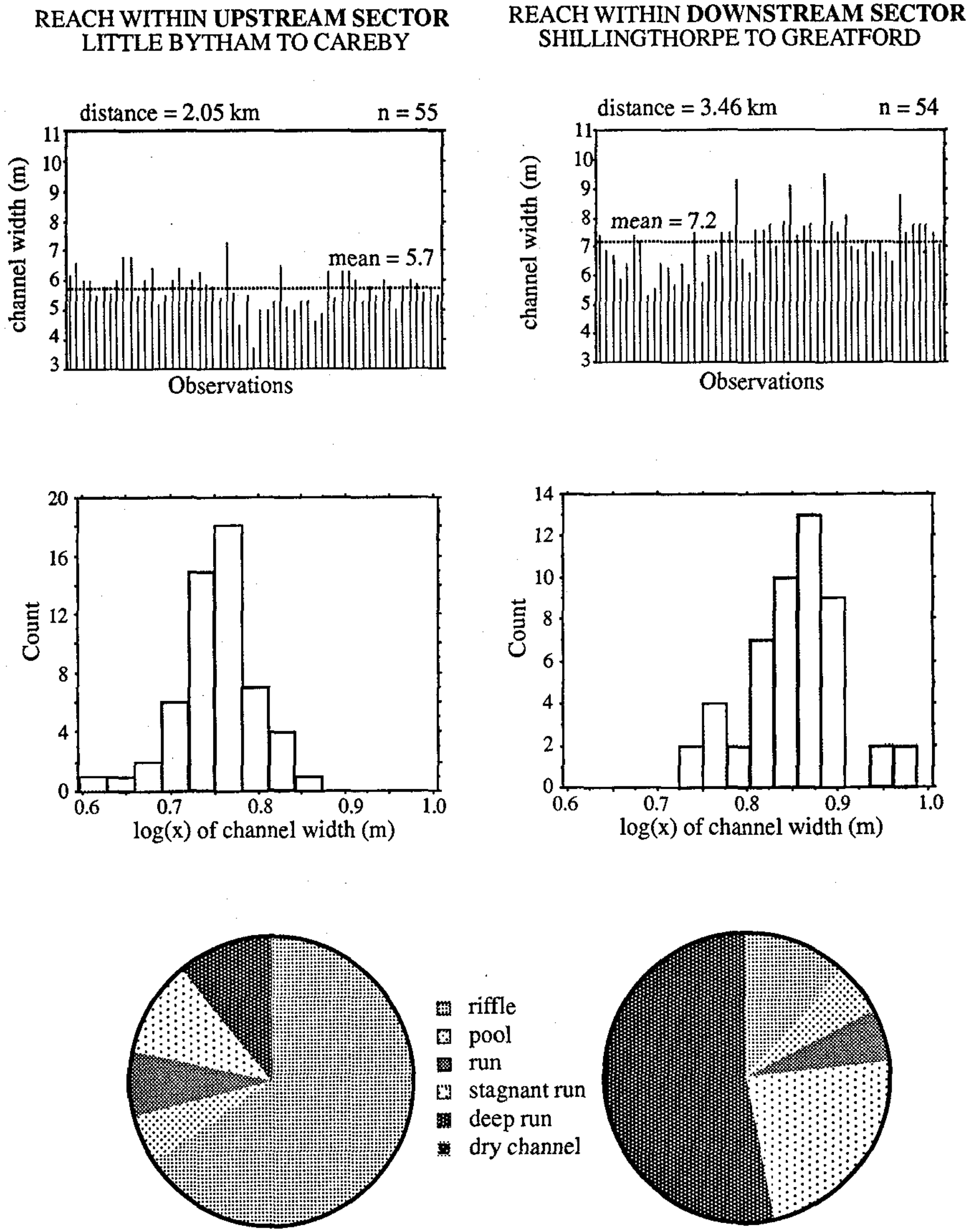


Figure 3.26 - A comparison of the physical habitat of **two reaches in different sectors** along the West Glen. The top graph represents the size of the channel, the middle graph highlights the frequency distribution of the channel width and the pie charts highlight the relative importance of the six habitat types along each reach.

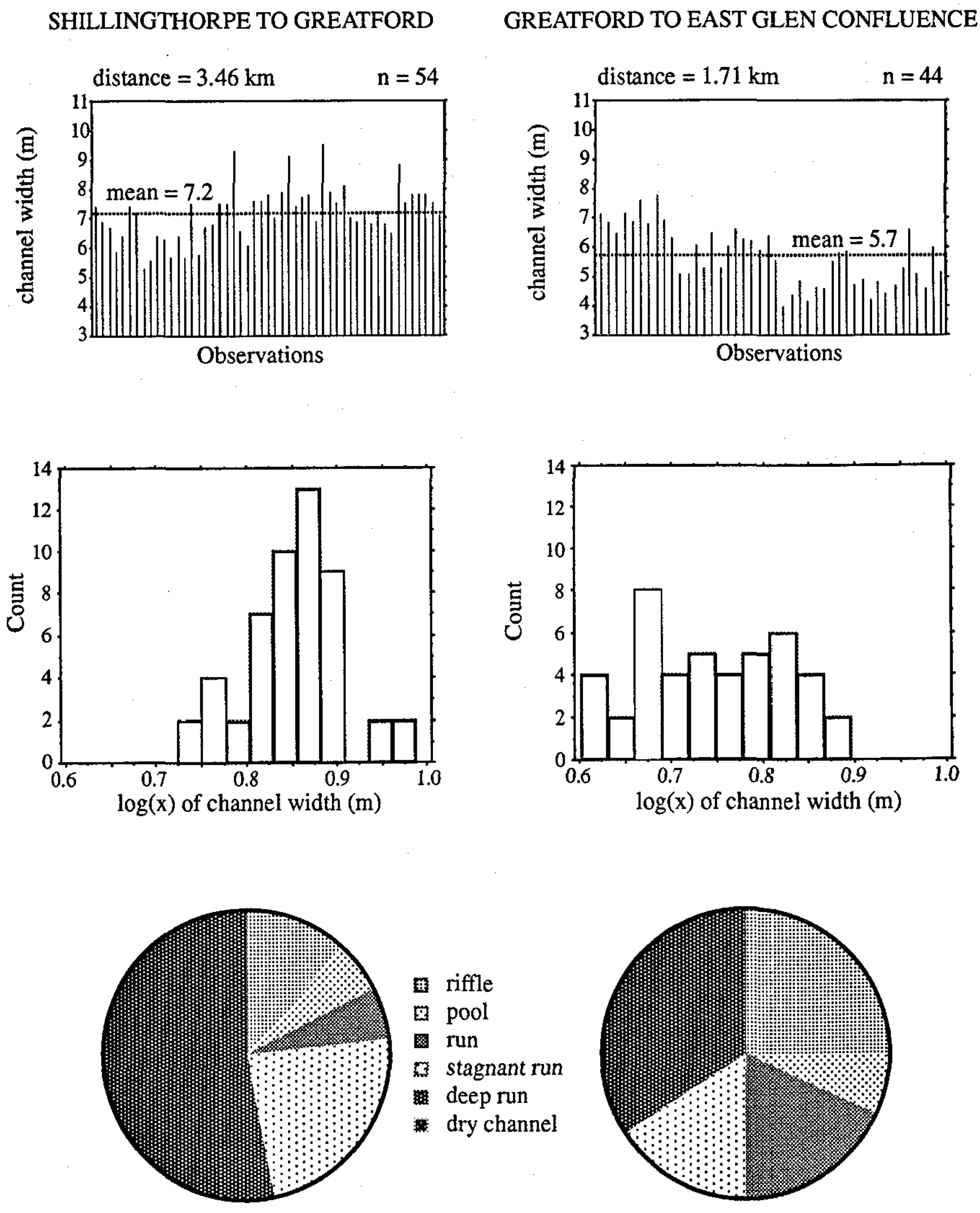


Figure 3.27 - A comparison of the physical habitat of two reaches **within the same sector** along the West Glen. The top graph represents the size of the channel, the middle graph highlights the frequency distribution of the channel width and the pie charts highlight the relative importance of the six habitat types along each reach.

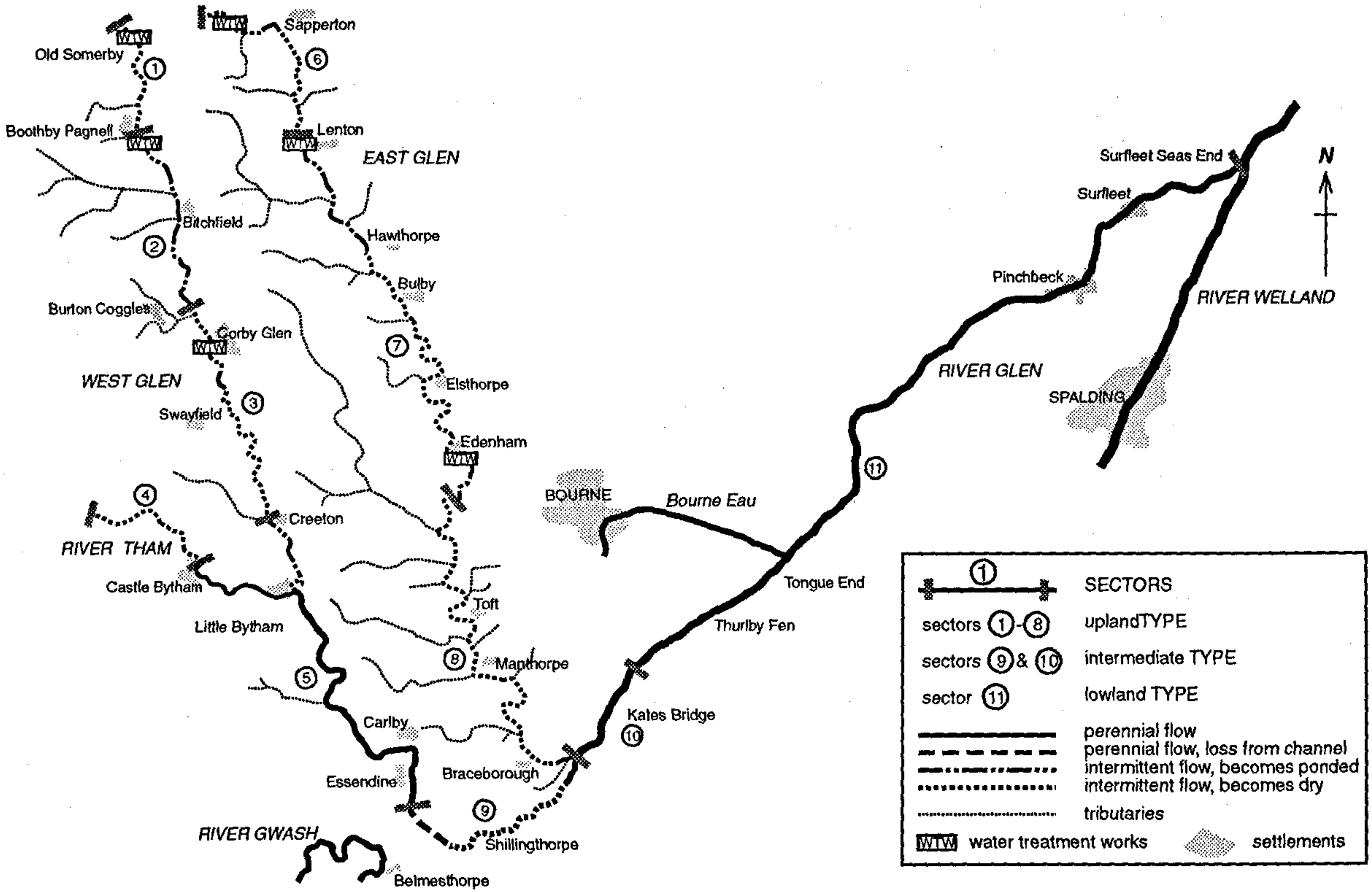


Figure 3.28 - River Glen: sectors, types and low flow characteristics

invaluable in predicting the likely effect on the ecology of the river of projected management policies such as water abstraction and flow regulation.

Methods for the definition of such types and sectors have been widely proposed, based on numerous physical and biological parameters and over a host of spatial scales. However, it is clear that the accurate definition requires reconnaissance level surveys as a prerequisite. These will provide the baseline data for such a process and also allow detailed information taken from representative reaches within them to be extrapolated in a more assured manner. Furthermore, it will ensure that classification is undertaken at the appropriate level. Too coarse a classification that only defines broad types alone would not be very helpful in applying general management principles, while too fine a classification could result in the definition of vast numbers of distinct reaches that would be of little practical use.

Ideally, schemes of classification should be universally applicable, but because of zoogeographic differences and geomorphic regions, schemes of classification are best restricted to the broad areas where they were originally developed. The classification process described in this chapter was developed within a distinct region, i.e. the low gradient Anglian region. It is therefore unlikely to be widely applicable outside this area, particularly where the physical and biotic features of streams are very different e.g upland areas. Definition of boundaries may also be problematic, particularly where the features being used for classification exhibit a slow uniform change rather than distinct variability between locations. Nevertheless, rigid guidelines help to formalise this procedure and reduce subjectivity although total elimination is not recognised as an achievable goal.

As yet there is no classification system available that has the attributes demanded for an 'ideal' classification system, i.e. ability to encompass broad spatial and temporal scales, integrate structural and functional characteristics under various disturbance regimes, be low cost and provide ease of understanding across all resource managers (Naiman 1992). Nevertheless the approach described above is intended to enable definition at three spatial scales, i.e. type, sector and reach. This is based on both broad scale sources (e.g. maps) and standardised field methods to identify the spatial array and physical dimensions of a number of habitat units. The river can then be partitioned into zones with similar physical and biotic characteristics, and hence enable river managers to make more objective decisions regarding the management of the river as a whole.

3.7 Evaluating Physical Habitat Changes with Discharge Using a Habitat Inflection Method

3.7.1 Introduction

The previous section has already established the importance and application of reconnaissance level surveys in order to provide the basis for scientific and repeatable observation and interpretation of channel morphology. They are also fundamental in supplying useful information for developing a classification and definition of channel sectors that are geomorphologically similar to aid the decision-making process for developing schemes to rehabilitate and restore instream habitat. However, they simply describe the situation under one flow at one particular point in time. The importance of flow has been extensively documented in determining the condition of the aquatic habitat. Research on the effects of flow manipulation on the biota has focused on rivers below dams which often experience increased baseflows, reduced flood flows and regular flow fluctuations for hydro-power generation (Petts 1984). Indeed, it is the flow variability, and not just the maintenance of minimum flow, that is fundamental to the holistic streamflow management (Hill et al 1991). Requirements must consider 1) overbank flows that inundate riparian and floodplain areas, 2) floodflows that form the floodplain and valley features, 3) in-channel flows that sustain the functioning of the instream system and 4) in-channel flows that meet critical fish requirements and 5) surface and groundwater regimes to sustain the functioning of the hyporheic system (Petts and Maddock 1994).

With regard to fish populations, the utilisation of a variety of microhabitats during different life stages makes assessment of flow relationships especially problematic. Nevertheless, water depth, velocity and substrate have been considered as important variables in a physical habitat sense (Bovee 1978, Gorman and Karr 1978, Stalnaker 1979). Over the range of flows at the lower end of the annual range, wetted bed area changes most significantly at riffles whereas flow velocity is most variable in pools. Habitat inflection methods examine the instream habitat in conjunction with discharge and therefore have the advantage over discharge methods and reconnaissance surveys because they employ measurement of the actual hydraulic characteristics of the stream at one or more flows.

A previous section (3.3.1) has already introduced the catchment characteristics of the River Glen catchment, Lincolnshire. However, a specific proposal for development of the water resources within the area created the need to assess the effect of a change in discharge on habitat availability. The following parts outline this proposal in more detail and describe the use of a habitat inflection method to make a rapid assessment of its impact.

3.7.2 Background to the Gwash-Glen interbasin transfer

Virtually all major rivers in the UK are regulated directly or indirectly by impoundments, interbasin transfers, pumped storage reservoirs or groundwater abstractions (Petts 1988). Interbasin transfers are becoming a more realistic option for effective water management as land for impoundment becomes scarce and more expensive. In the UK, interbasin transfers typically involve water transfers from direct-supply reservoirs, with the redistribution of water locally, to settlements a few tens of kilometres downstream of the dam, to other tributary catchments within the same basin, and across major water sheds (Higgs and Petts 1988). In places, this has been a fundamental aspect of the local water management system for many years. In the River Wye, approximately 5 per cent of the mean flow at Monmouth is piped to Birmingham (Edwards and Brooker 1982). Transfers such as this can have important implications for the instream biota of both the supply and recipient rivers in terms of hydrology and flow regime, water quality and sedimentation and erosion (O'Keefe and Davies 1991).

The concept of a fully developed abstraction regime for the Southern Lincolnshire Limestone was described in a document published in 1969 (Downing and Willliams 1969). During the period 1970-78, concern for the River Glen catchment strengthened as the groundwater resources were progressively developed and flows declined to critical levels. The 1969 report also highlighted the potential for integrated and inter-basin scale water management particularly with reference for augmenting low flows in the River Glen. Subsequently, the Welland and Nene (Empingham Reservoir) and mid-Northamptonshire Water Act 1970 (Clause 34) granted powers to discharge water to the River Glen from the River Gwash. Ecological information, such as the decline of the apparently good trout fishery and the loss of over 150,000 fish in the lower river Glen in 1976 coincident with extremely low groundwater levels and flows, was used as further evidence of the effects of over abstraction.

Throughout the 1980's there developed a growing need to increase abstractions from the Southern Lincolnshire Limestone. However, the inadequacy of the limestone in meeting the demands of the former Peterborough Division and increasing abstractions from the Limestone subject to compensating the River Glen by surface transfers were highlighted (AWA 1982). This document also stated the motive for maximising abstractions from the Southern Lincolnshire Limestone: "Limestone water is much cheaper than Rutland (reservoir) water and therefore it is desirable to use as much Limestone water as possible". In 1982, the net saving was estimated as £1.6 million.

Demand continued to increase throughout the 1980's, and coupled with the drought conditions experienced at the end of the decade which were having serious implications for flows in the West Glen, and after an environmental assessment of the proposed water resource development (Petts et al 1990), the Gwash-Glen transfer was finally implemented and commenced augmentation in May 1991. The NRA has annual volumetric reservation within Rutland Water (operated by Anglian Water Services) and it may call on this allocation to be released into the River Gwash where it is abstracted approximately 1.5km above Belmesthorpe gauging station (TF042104) and pumped across the catchment divide and into the West Glen river downstream of Essendine (TF050117) (see figure 3.29).

The following section describes the application of a technique to assess the impact of both the natural and proposed flow regime on the instream habitat of the West Glen downstream of the transfer scheme. In order to achieve this, a habitat inflection method was utilised.

3.7.3 Application and results

In order to assess the impact of the transfer scheme on the physical habitat availability in sector, three surveys were conducted under different discharges. Section 2.4.3 has already outlined how habitat methods employ the measurement of actual hydraulic characteristics along a reach at one or more flows. Data from the physical habitat survey discussed above was combined with two further surveys under different discharges to examine the response of the physical habitat along an approximately 10 km long reach of the West Glen. The reach, which stretches from upstream of Essendine (TF050127) to the confluence with the East Glen

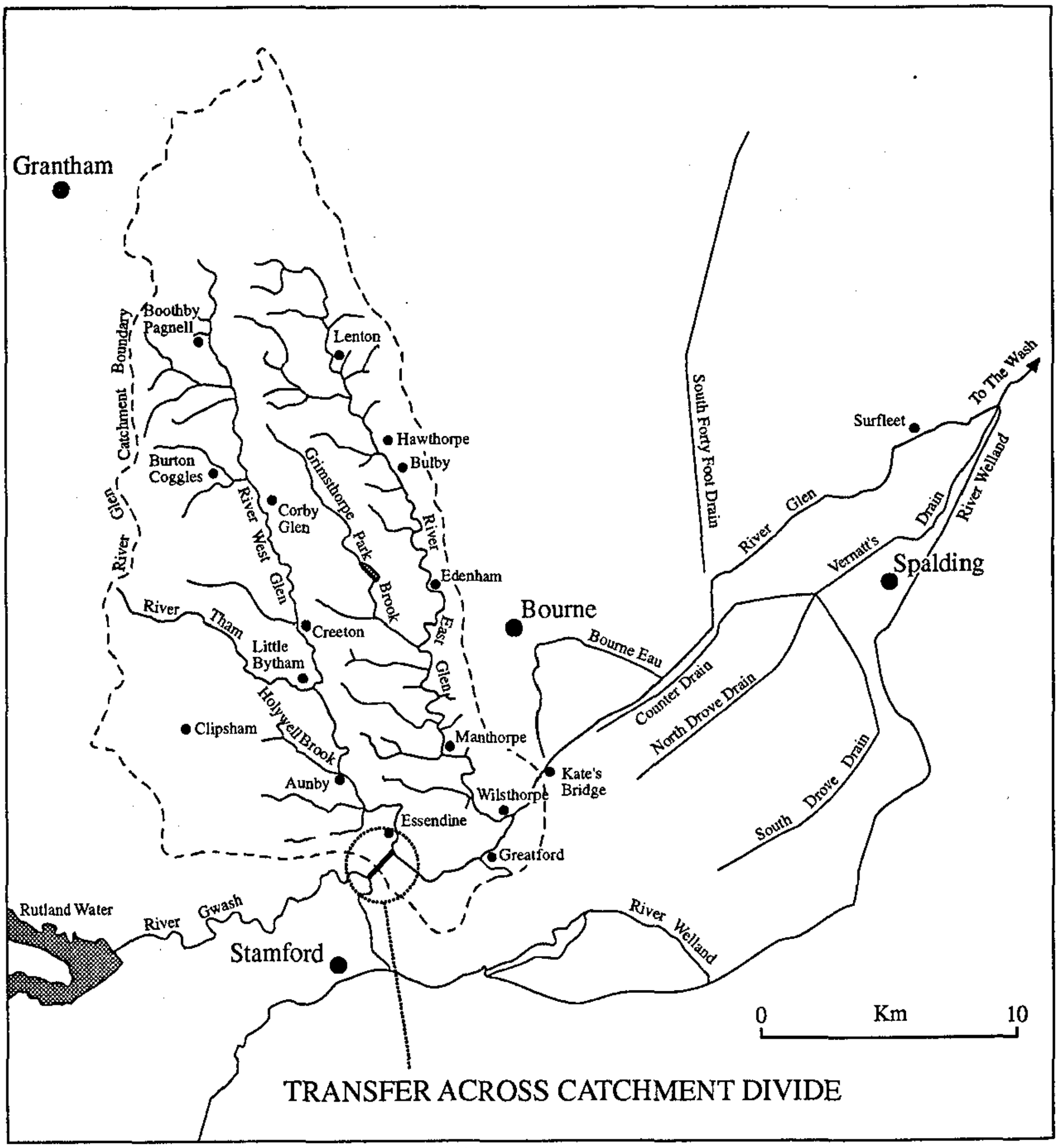


Figure 3.29 - Location of the Gwash-Glen interbasin transfer

confluence was primarily selected because it is dissected by the Gwash - Glen transfer input point and so provides valuable information on the impact of the scheme.

The first survey, as outlined above was part of the full survey of the West and East Glen. Average discharge along the reach were 0.04 cumecs during this period. The second survey was completed whilst average discharge was at an elevated level of 0.3 cumecs. Similar to the first survey, measurements were taken at the same places and recorded channel and water width in order that the wet width could be calculated.

The third survey was completed on 14/11/91 whilst the Gwash Glen transfer was in operation. The upstream section was characterised by the natural flows whereas the downstream section had augmented flows. Consequently, it has been possible to compare the 2.18 km reach upstream of the transfer with the 6.66 km reach downstream as far as the East Glen confluence. In addition to the measurements that were taken during the first two surveys, thalweg depth was also recorded to the nearest centimetre. Discharge upstream at Essendine was the lowest of all three surveys at 0.028 cumecs whereas downstream, the transfer augmented flows measured at Shillingthorpe G/S to 0.075 cumecs, a level intermediate to the previous two surveys. The effect on the wet width is shown in figure 3.30a. Clearly in the upstream section, values for the third survey are the lowest of all three but below the transfer point they are raised to an intermediate level.

Figure 3.30b was also undertaken to assess the relationship between physical habitat and flow. Data for a 90 m long representative reach within sector 9 was used to determine the most effective flow for sustaining the optimum amount of wetted bed area. Values are seen to increase rapidly to a value of about 75% at 0.042 cumecs; with increasing flows the gain in wetted bed width is very slow.

Using the thalweg depth data, it has also been possible to determine an important influence of the transfer on physical habitat. The table set out below summarises some key parameters which highlight this influence.

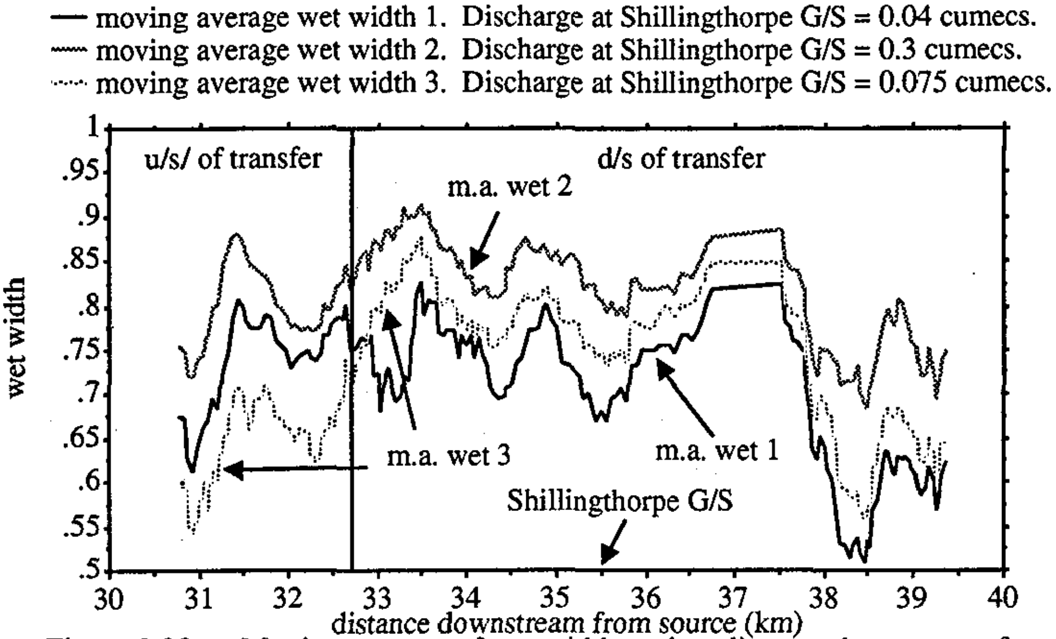


Figure 3.30a. - Moving average of wet width against distance downstream from source for the three surveys from Essendine to the East Glen confluence on the West Glen

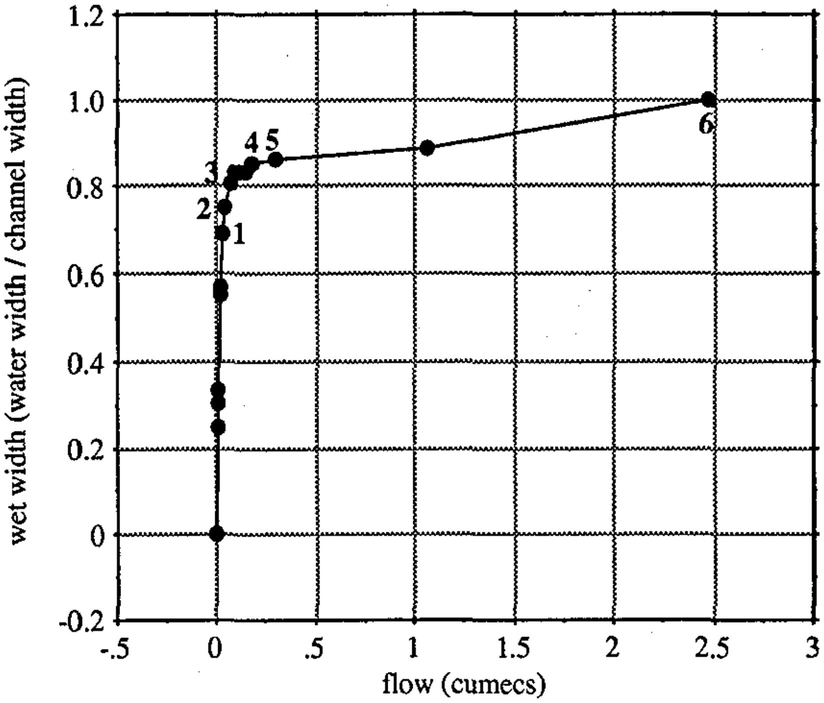


Figure 3.30b - Wet width against discharge relationship at Shillingthorpe.

Table 3.5 - Survey results utilised to construct the wet width-discharge relationship shown in figure 3.30b above.

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

Table 3.6 - Some key statistics highlighting the influence of the transfer on physical habitat

Type of cross-sections included	no. measured	ave. water width (m)	ave. wet width (%)	ave. depth (cm)
All cross sections - upstream	46	4.80	65.3	22
All cross sections - downstream	131	4.77	74.6	26
Riffles + runs only - upstream	13	3.72	53.7	10
Riffles + runs only - downstream (all sections)	44	4.28	71.1	20
Riffles + runs only - downstream A	24	4.99	80.4	24
Riffles + runs only - downstream C	19	3.27	58.5	16

By comparing the data for all cross sections it would appear that there is little difference between the upstream and downstream section. Average water width is slightly lower in the downstream section but the channel width is also narrower and hence the average wet width increases from 65.3% upstream to 74.6% downstream. Similarly, a small increase in average thalweg depth is evident. However, when the data for the riffles and runs only are compared, a more striking difference is highlighted. Downstream of the transfer there is a clear increase in average water width from 3.72 m to 4.28 m with the corresponding increase in average wet width from 53.7% to 71.1%. However, the most prominent change is evident by comparing the average depths over riffles and runs. Upstream, average depths are 10 cm which are elevated to 20 cm downstream of the transfer, an increase of 100%. Figure 3.31a illustrates the depth at all cross sections along the whole reach. To assess any significant difference between the upstream and downstream sections the student's t test was applied to all the cross sections with the resulting t value = 2.23 indicating a significant difference at the 95%ile level. Figure 3.30b clearly shows the difference between the upstream and downstream sections when just examining riffles and runs. In this case, the t value = 6.27 and so the difference is significant at the 99.9%ile level. The downstream section has also been divided into three distinct reaches. Clearly downstream reach A has higher values of average water width, wet width and depth than reach C as shown in table 3.6 above. Section B has no riffle/run type habitats due to the ponding effects of Shillingthorpe G/S and the mill sluice in Greatford.

Minimum habitat requirements in other studies have suggested a low flow depth of 10 cm is required to sustain invertebrate communities (O'Keefe and Davies 1991). Flows of 0.028 cumecs during the third survey at Essendine are just sufficient to

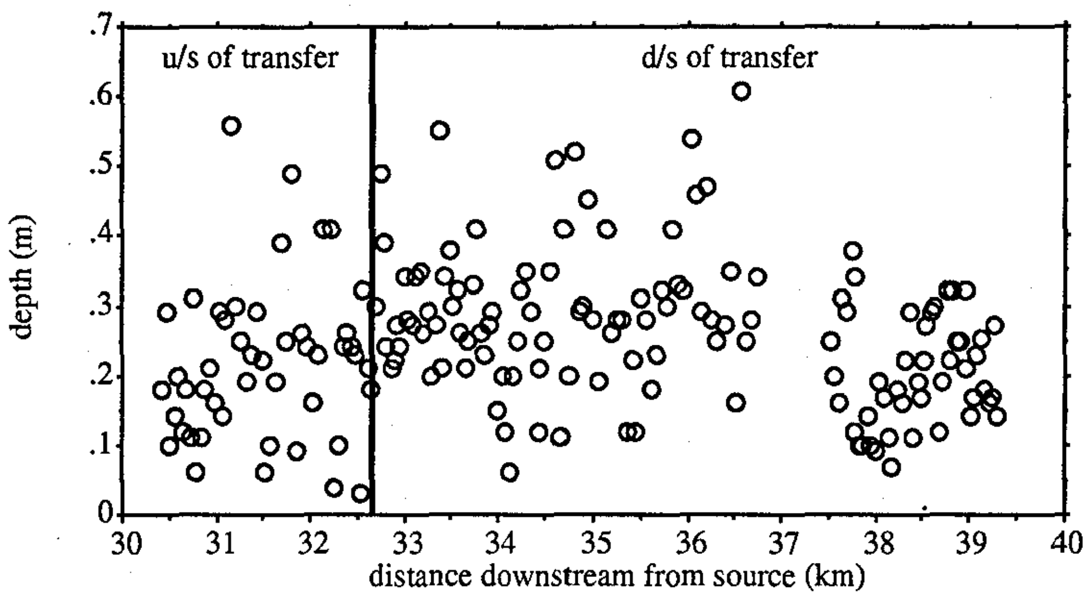


Figure 3.31a - Depth against distance downstream for all cross sections on the West Glen between Essendine and the East Glen confluence.

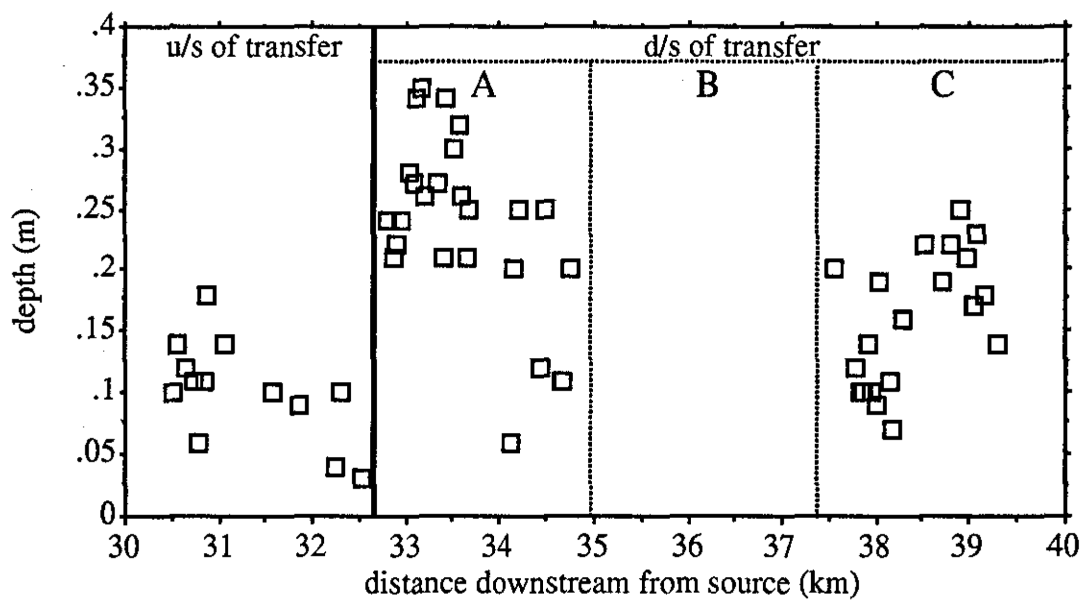


Figure 3.31b - Depth against distance downstream for riffles and runs only on the West Glen between Essendine and the East Glen confluence.

maintain water levels over such areas at an average of 10 cm. However, during the previous summer, flows had fallen below this level by 25/9/90 and were consistently below this for the following three monthly surveys. An invertebrate sample taken as part of the routine sampling by the NRA Anglian region upstream of the transfer in May 1991 gave an unusually low BMWP score of 65. This low score may reflect the impact of the low flows during the previous summer when this 10 cm threshold was crossed over a long period. A similar sample taken in October 1991 resulted in a score of 125. This may indicate the invertebrate community had recovered to some degree as discharge had been above the threshold throughout the year.

The improvement in invertebrate assemblages may be expected when the actual flows over the previous period are compared with the minimum flows defined by the habitat inflection method (table 3.7). It is only during the summer of 1991 that the low flows are maintained near to the flow that is defined by the physical habitat data, i.e. 0.075 cumecs. This also highlights the importance of the interbasin transfer, where unsupported flow (i.e. actual flows minus augmentation) would be greatly below those required to support adequate wet width.

Table 3.7 - Flow recommendations for the Shillingthorpe sector, based on the habitat inflection method.

Discharge (m^3s^{-1})	Recommendation and derivation
0.026	Dry Weather Flow (DWF) summer 1989
0.000	DWF summer 1990
0.010	minimum unsupported flow 1991
0.068	minimum supported flow summer 1991
0.075	discharge defined by habitat inflection method

3.8 Summary

The application of a habitat method to a selected reach of the West Glen has highlighted the importance of the instream geomorphology on the physical habitat under three different discharges. It has also described the impact of the transfer scheme on the channel downstream. The advantage of this type of approach is that it requires relatively little fieldwork and yet overcome some of the criticisms of the discharge methods because they provide specific information from the stream or river in question. This chapter has also illustrated the use of sector and reach classification and the application of a habitat inflection method to aid management of the River Glen. The classification process relies heavily on hydrological information from map sources and field data on physical habitat and morphology to confirm boundary location. The habitat inflection method involves cross-sectional measurements, also based on the physical nature of the channel, to determine the effect of changes in discharge on habitat availability. In this particular study, the flows suggested by the method as minimum requirements seem vindicated by evidence from the biota. Data for the 90 m long representative reach which was resurveyed on 14 different occasions was based on transect measurements based on riffles alone as these were considered to be likely to provide a more pronounced inflection point due to their shape. This type of measurement does not account for changes in water velocity which is undoubtedly a crucial factor in the supply of microhabitat. Further study may be necessary to include velocity variations in pools as these may be more representative of the habitat requirements of fish whereas the riffle biased sampling favours invertebrate needs. Furthermore, such techniques do not account for the specific habitat requirements of the instream ecology, habitat is simply assumed to be affected by total wetted bed area. To address this matter, two methods are discussed in the following sections. The following chapter describes the use of a method to determine more accurately which parameters determine habitat and biological quality which incorporates the development of an empirical model method. This is followed by a biological response method i.e. PHABSIM to define the flow requirements, the influence of bed morphology, and designation of sites in need for habitat restoration.

CHAPTER 4 - IDENTIFYING KEY HABITAT VARIABLES INFLUENCING THE BIOLOGICAL QUALITY OF STREAM REACHES

4.1 Introduction.

Different species of fish, macroinvertebrates and plants possess characteristic behavioural traits which cause it to occupy different habitat types 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.

An array of habitat assessment techniques attempt to quantify the stream resource via the measurement of key parameters along a representative reach (e.g. Binns and Eiserman 1979, Bowlby and Roff 1986, Milner et al 1985, Scarnecchia and Bergersen 1987, Wesche et al 1987, Platts et al 1989). Of primary importance is that these techniques measure the most influential characteristics that determine habitat quality. However, assessment methods face a number of intrinsic problems and these have been neatly summarised by Milner et al (1985):-

1) which attributes to measure,
2) how to measure them and
3) in the case of scoring systems, how to transform them into an index or rating to indicate habitat quality.

Of the biotic, physical and chemical parameters that integrate to form the environmental conditions to which instream biota respond - producing observed patterns of distribution and levels of abundance - certain ones appear to be more direct in their mode of control. It is the determination of these key variables, and the development of a method to describe these variables along representative reaches that provides the focus of this chapter. The main characteristics of empirical model methods, why the identification of the key habitat variables that influence the biological quality of stream reaches is necessary, and how it has been approached in the past has been discussed in detail in chapter one. This chapter attempts to define a method that describes the steps necessary to quantify the interaction and relative importance of the physical and chemical variables influencing the habitat for instream biota. This method is then illustrated by examining the application of the technique define a simple model between an invertebrate score, the BMWP (Biological Monitoring Working Party 1978), and key habitat variables for 28 streams in East Anglia, UK. The relationship was validated for the River Glen to which it was then applied to assess the improvement in BMWP with flow augmentation.

4.2 Development of an approach

Figure 4.1 illustrates the sequence of steps necessary to define the most important variables in providing 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.

4.2.1 Selection of biota in question

The first step must be to define whether fish, invertebrates or aquatic vegetation (or indeed a combination of these) are to be the focus of investigation. This may be determined by the specific nature of the project. For instance, a project driven by the need to assess the environmental impact of a proposal on an important salmon fishery would focus on the requirements of the chosen species. 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.

4.2.2 Site selection

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 (Wright et al 1989) 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.

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 the

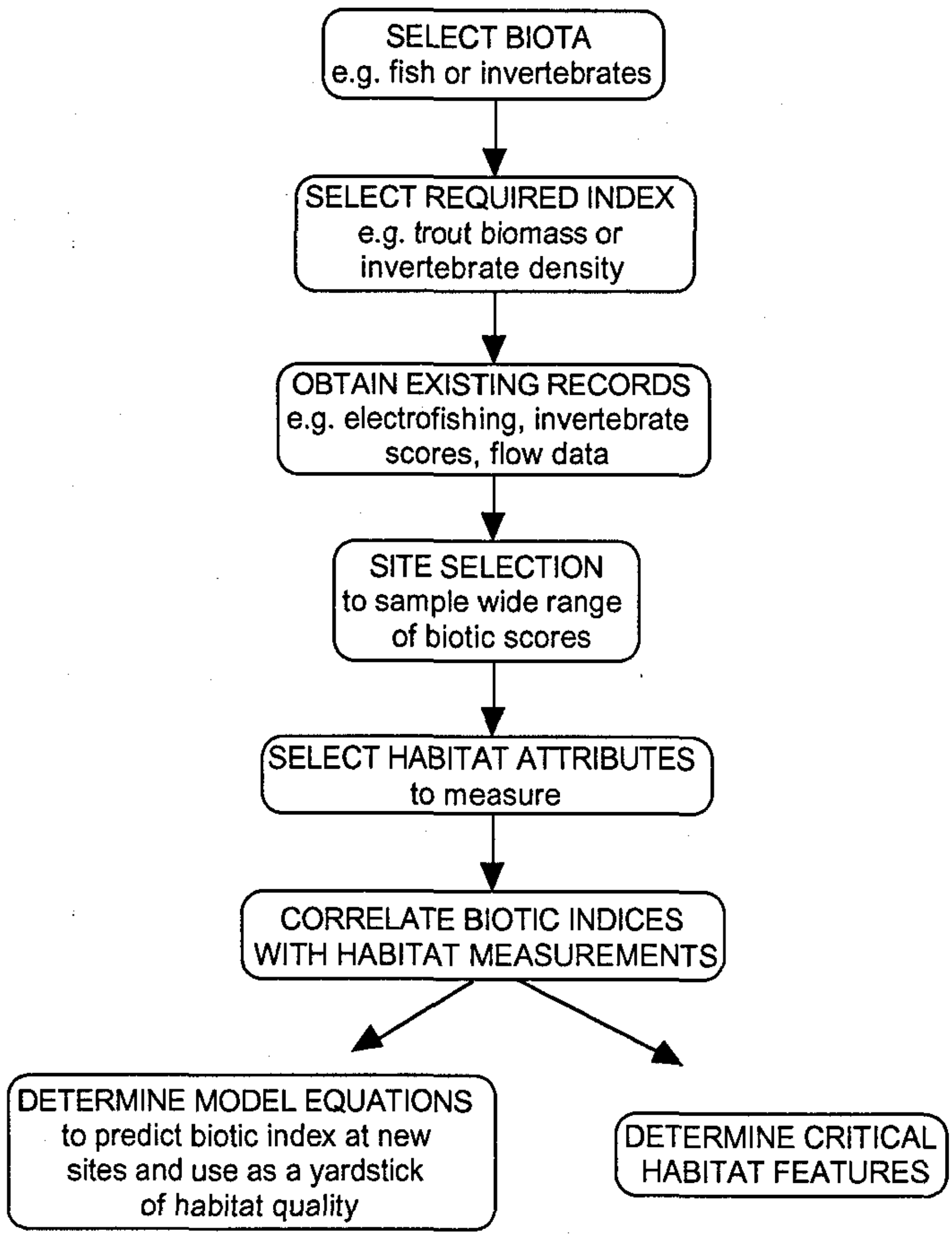


Figure 4.1 - Proposed methodology for the identification of key habitat variables influencing biological quality of stream reaches

fisheries or invertebrate surveys. Biological monitoring sites should be selected only if the data is consistent over a minimum of three years.

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. 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. If existing information on the biotic quality is not available, then this data will have to be collected at the same time as the habitat measurements. For instance, electrofishing or invertebrate sampling may need to be conducted concurrently with the physical habitat measurements.

4.2.3 Habitat measurements

Each chosen site 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.

4.2.4 Linking biological quality with habitat

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

4.3 Biological Indicators of Pollution

The variable tolerance to pollution of different species is well documented (Wilhm, 1975, Resh and Rosenberg 1984) and provides the basis for the use of a variety of biota for indicators of pollution. The major groups of organisms that have been used as biological indicators are algae (Butcher 1946, Round 1981), Bacteria (Suckling 1944, Maltby and Booth 1991), benthic macroinvertebrates (Chandler 1970, Chutter 1972, BMWP 1978, Extence 1987, Metcalfe 1989, Plafkin et al 1989) and fish (Lindroth 1949, Karr 1981, Fausch et al 1990). Benthic macroinvertebrates are approximately >0.5mm (Cummins 1975) and stand as a link between the algae and micro-organisms, which serve as their primary food resources, and the fish (and other vertebrates), for which they are prey (Cummins 1992). They are particularly suitable as ecological indicators because their habitat preference and relatively low mobility cause them to be directly affected by substances that enter the environment. They are also easier to identify, analyse and preserve than microscopic organisms and less mobile than fish that can migrate rapidly to escape the effect of deleterious substances. They are also present across a wide variety of habitat types and river systems (Plafkin et al 1989).

Throughout the 1960's, use of qualitative approaches, such as correlating the presence, absence, or approximate relative abundance of certain macroinvertebrates with pre-established classifications of environmental quality, was emphasised. This approach was influenced by the almost century-old European "Saprobien system" for assessing the pollutional status of lotic (running water) habitats. During the 1970's the emphasis shifted towards quantitative approaches that typically included calculation of diversity indices and detailed statistical analyses. However, in recent years there has been a renewed interest in the use of qualitative techniques, primarily because of the high cost of quantitative approaches, resulting in the development of rapid assessment approaches. This has reduced the intensity of study necessary at individual sites in an attempt to minimise effort (and cost) and yet enable the presentation of results of site surveys in a way that they can be understood by non-specialists, i.e. by using site scores or indices to represent environmental quality (Metcalfe-Smith 1994).

The Trent Biotic Index (TBI) was first introduced in the UK by the Trent River Board in the late 1950's and was described by Woodiwiss (1964) its originator. The TBI of a site increases with better water quality and ranges from 0 to 10. It is based on the known tolerances and susceptibilities of selected indicator species to organic pollution. As its name suggests, the TBI was devised for use in the River Trent. This led to criticisms that it was not widely applicable beyond this immediate area as well as being insensitive in good quality, mildly polluted waters. Such pollution often produces a change in abundance response from some of the biota, but the Index taking account only of species richness does not record such a change.

This was addressed by Chandler (1970b) who produced a scoring system that takes into account both species richness and the abundance of each species with scores ranging from 0 to 2000. However it is demanding in terms of effort since it requires greater taxonomic precision and a record of abundance for each species (Couillard and Lefebvre 1985). A similar approach was developed for South African rivers but was again criticised for being region specific (Chutter 1972).

The Biological Monitoring Working Party (BMWP) of the Standing Technical Advisory Committee on Water Quality, set up by the Department of the Environment in 1976, recommended that a score system should be developed for the 1980 National River Survey in the UK. The new score system was developed through questionnaires, surveys and discussion. To simplify the actual process of recording and scoring, the BMWP decided that the amount of identification should be reduced and their score/index uses family data only. The abundance of each group is not taken into account. Each family is given a score value appropriate to its overall response to organic pollution.

Invertebrate assemblages are routinely monitored across a wide network of sites throughout the U.K. by the NRA to provide valuable information on water quality variations. Such monitoring exercises are based on the premise that different groups of aquatic animals show different resistance to pollution and each species thrives best under a narrow range of environmental conditions. Consequently, they are considered to integrate the effects of both long term and intermittent pollution events. Monitoring is carried out to detect changes in communities and results from the lists of taxa are analysed to produce a score, class or index. Although this reduces the amount of information conveyed, it provides a useful tool for non-biologists to make decisions involving the management of running water ecosystems. The BMWP score system is now in regular use by the NRA and River

Table 4.1 - The BMWP score system.

Siphlonuridae Heptageniidae Leptophlebiidae Ephemerellidae Potamanthidae Ephemeridae Taeniopterygidae Leuctridae Capniidae Perlodidae Perlidae Chloroperlidae Aphelocheiridae Phryganeidae Molannidae Beraeidae Odontoceridae Leptoceridae Goeridae Lepidostomatidae Brachycentridae Sericostomatidae	10
Astacidae Lestidae Agriidae Gomphidae Cordulegasteridae Aeshnidae Corduliidae Libellulidae Psychomyiidae Philopotamidae	8
Caenidae Nemouridae Rhyacophilidae Polycentropodidae Limnephilidae	7
Neritidae Viviparidae Ancylidae Hydroptilidae Unionidae Corophiidae Gammaridae Platycnemididae Coenagriidae	6
Mesoveliidae Hydrometridae Gerridae Nepidae Naucoridae Notonectidae Pleidae Corixidae Haliplidae Hygrobiidae Dytiscidae Gyrinidae Hydrophilidae Clambidae Helodidae Dryopidae Elminthidae Chrysomelidae Curculionidae Hydropsychidae Tipulidae Simuliidae Planariidae Dendrocoelidae	5
Baetidae Sialidae Piscicolidae	4
Valvatidae Hydrobiidae Lymnaeidae Physidae Planorbidae Sphaeriidae Glossiphoniidae Hirudidae Erpobdellidae Asellidae	3
Chironomidae	2
Oligochaeta (whole class)	1

Protection Boards for local and national surveys. To date few criticisms of the system have appeared in the literature although Extence et al (1987) has proposed an alternative approach for the Anglian region.

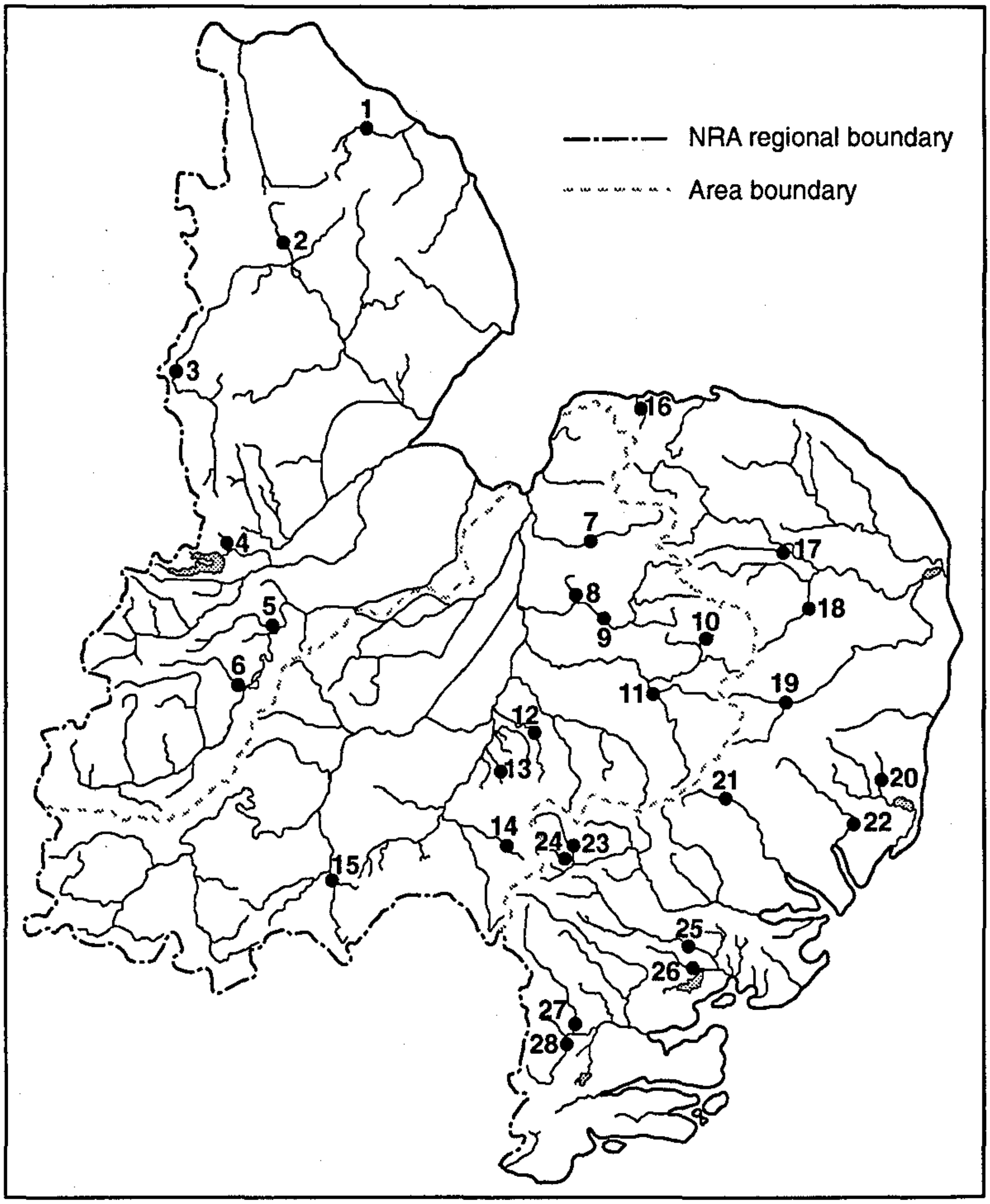
Individual families were assigned a score of 1 - 10 which reflected their tolerance to pollution with low scores for pollution tolerant families and high scores for pollution intolerant ones (see table 4.1). Summing the individual scores of all families present in a sample gives the site score. It has been clearly established that such scores are sensitive to organic pollution. However, score variation is also present without any evidence of changes in water quality and the BMWP system has been used as an indicator of biological or habitat quality in a broader sense. It was the aim of this study to establish the environmental parameters, that were determining the score, and to assess its potential for use as an indicator of habitat quality.

4.4 Application of the Approach in the Anglian Region - Method and Study Sites

4.4.1 Site selection criteria and location

Empirical models to date have largely focused on fish, and in particular salmonid species. However, the emphasis of the following technique was placed on the invertebrate communities within a specific geographic region, i.e. East Anglia. Twenty eight sites throughout the Anglian region were selected in order to record a number of physical attributes (see figure 4.2). Initially, site choice was based on two factors. Firstly, each site had to be a NRA Anglian region biological monitoring site and secondly, a gauging station had to be present.

From the locations that met both these criteria, historical records were obtained of the invertebrates present over a maximum record of ten years (see Appendix 4). Assemblages were expressed in terms of BMWP scores (Biological Monitoring Working Party, 1978). Furthermore, the locations were selected that represent a wide range of average scores i.e. BMWP scores from 25 to 180 as shown in table 4.2.



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 4.2 - Study site location

Table 4.2 - The 28 sites sampled and their associated BMWP score.

No.	River	Site Name	Grid ref.	BMWP	Area(km^2)
24.	Stour Brook	Sturmer	TL697440	25	34.5
21.	Gipping	Stowmarket	TM057579	35	128.9
28.	Wid	Writtle	TL686060	50	136.3
12.	Snail	Fordham	TL630703	55	60.6
23.	Stour	Kedington	TL708450	58	76.2
13.	Swaffham Lode	Swaffham Bulbeck	TL553628	66	36.4
16.	Burn	Burnham Overy	TF842427	67	80.0
27.	Chelmer	Springfield	TL713071	68	190.3
19.	Waveney	Billingford	TM168782	74	149.4
2.	Barlings Eau	Langworth Bridge	TF066766	74	210.1
26.	Roman River	Bounstead Bridge	TL985205	77	52.6
20.	Alde	Farnham	TM360601	77	63.9
3.	Witham	Claypole Mill	SK842480	88	297.9
15.	Hiz	Arlesey	TL190379	90	108.0
14.	Granta	A604 Linton bypass	TL570464	91	59.8
22.	Deben	Naunton Hall	TM321532	95	163.1
5.	Willow Brook	Fotheringhay	TL067933	97	89.6
6.	Harpers Brook	Old Mill Bridge	SP983799	98	74.3
18.	Tas	Shotesham	TM226994	100	146.5
1.	Waithe Beck	Brigsley	TA253016	101	108.3
10.	Thet	Shropham Redbridge	TL996923	105	145.3
25.	Colne	Lexden	TL962261	114	238.2
17.	Tud	Costessey Park	TG169112	121	73.2
8.	Stringside	Stoke Ferry - White Bridge	TF716006	127	98.8
4.	North Brook	Empingham	SK957089	128	36.5
11.	Little Ouse	Euston A1088 Road Bridge	TL893802	139	128.7
7.	Nar	Marham	TF723119	169	153.3
9.	Wissey	Northwold	TL771965	180	274.5

The fieldwork was completed between 26th July and 15th August 1990. At each site, measurements were recorded at twenty transects, spaced approximately at every seven times channel width or at every riffle, whichever was closer. At each transect, the geomorphological character was recorded e.g. riffle, run, or pool and whether flow was visible or not. Channel width and water width were also measured. The raw data for each site is shown in Appendix 3.

Habitat evaluation using empirical models has already been reviewed in chapter one. It has been assessed by some workers (e.g. Binns and Eiserman 1979, Milner et al 1985, Bowlby and Roff 1986, Wesche et al 1987, Scarnecchia and Bergersen 1987) by measuring selected habitat attributes and deriving an empirical equation relating these to fish populations. Concurrent electrofishing in their studies enabled existing fish abundance to be used to calibrate the models. This was not done in this study, but the invertebrate data allowed the construction of a similar, empirically derived equation, based on the measured environmental parameters, to evaluate the instream habitat.

Milner et al (1985) has already recognised the difficulty of transforming the habitat measurements into a form that will correlate with the biological expression of the habitat quality. Another problem is that different studies have used many different habitat variables in alternative combinations of which examples are have been indicated in table 2.3. Consequently, a number of these have been used in this investigation and new ones developed.

4.4.2 Chemical and physical attributes included

Stream classification based on geomorphic characteristics has become increasingly prominent since the 1940's as fisheries biologists and land managers have recognised their strong link to patterns of species distribution and abundance. Almost all classification schemes based on physical habitat features have been founded on the perception that stream units (i.e. segment, reach, channel, riffle/pool) are discrete, and can therefore be delineated (Naiman et al 1992). Within this study, measurements can be divided into catchment and reach scale attributes.

Six physical characteristics were measured at the catchment level. Catchment area (km^2) upstream of the gauging station was obtained from the Institute of Hydrology's (IH) Hydrometric Register 1981-1985 (IH 1988). Other catchment attributes were measured from Ordnance Survey (OS) 1:50000 scale maps including distance downstream from source, stream order in terms of the Shreve number (1967) and Strahler number (1952), altitude and gradient.

The chemical parameter used is that of the National Water Council (NWC) classification system. This examines the levels of a number of different chemical constituents along the entire river network and ranks separate reaches into one of five categories. Class 1A represents the best quality declining to 1B, 2, 3 or 4. Table 4.3 below summarises some of the criteria used.

Table 4.3 - NWC river quality classification.

River Class	Quality Criteria	Potential Uses
1A Good Quality	Dissolved oxygen (DO) saturation greater than 80%. Biochemical oxygen demand (BOD) not greater than 3mg/l. Ammonia not greater than 0.4mg/l.	Suitable for potable supply abstractions. High class fisheries. High amenity value.
1B Good Quality	DO > 60% saturation.	Less high quality than BOD < 5mg/l.
Class 1A but usable		
	Ammonia < 0.9mg/l.	for similar purposes.
2 Fair Quality	DO > 40% saturation. BOD < 9mg/l.	Suitable for potable supply after advanced treatment.
3 Poor Quality	DO > 10% saturation. BOD < 17mg/l.	Usable for low grade industrial purposes.
4 Bad Quality	Anaerobic at times.	Grossly polluted.

NWC classifications were obtained for the 28 sites from each of the 1981, 1983-4, 1984, 1985, 1986, 1987, 1988 and 1989 surveys. By assigning each NWC class a score between 1 and 4, an average was calculated for the whole period .

Width has long been established as a major determinant of the biota of instream habitats (Pennak 1971). When coupled with depth , it provides a simple measure of the quantity of habitat available. Consequently, average channel width and thalweg depth were recorded.

The flow regime that a habitat experiences has been recognised as one of the four main components that determine its productivity (Stalnaker 1979). Binns and Eiserman (1979) used late summer streamflow and annual stream flow variation and Wesche et al (1987) used average annual baseflow as a percent of average annual daily flow. To introduce a stochastic element, Milner et al (1985) suggested that the baseflow index (BFI) be incorporated into future analyses. Consequently this study used this index quoted by the IH in their Hydrometric Register and Statistics 1981-1985 (IH 1988). Basically, the index which is scored as values between 0 and 1, is calculated using gauged mean daily flows from the archived records and represents the degree of variability of river runoff over time. Catchments that derive a large proportion of their runoff from stored sources and have a steady flow regime such as chalk catchments are likely to score 0.9. Alternatively, rivers draining impervious clay catchments may well have a BFI of 0.3.

Tennant (1976) concluded that the aquatic habitats of 196 stream-miles at 58 cross-sections and 38 different flows were significantly reduced when the instantaneous flow fell below 10% of the average flow. Consequently, a critical time for the instream habitat in terms of stress is when low flows are being experienced. Several studies that have focused on the impact of river regulation have reported the enhancement in benthic animal density and biomass but reductions in diversity (Armitage 1978, Extence 1981, Hey 1990) as a result of flow reduction and stabilisation. However, it is not just the intensity of the flow reduction, but also the nature of the channel at that site that must be accounted for. Several studies have shown that the variety of habitat types, influenced by the structure of the bed greatly affects the natural stock density of the fish fauna and biomass by upto 90% as well as invertebrate abundance, composition and distribution (Moog and Janecek 1991). The impact of channel structure is particularly influential during periods of low flow, when bed homogeneity can lead to insufficient depth of water to support biotic diversity and flows are spread across the entire channel rather than being concentrated into narrower zones which maintain flow velocities.

To incorporate this, the following measure has been utilised to attempt to combine these two measures. Q^{95}/channel width was used to represent the degree to which the wet width would respond to low flows. Q^{95} represents the flow that is equalled or exceeded for 95% of the time, i.e. it is a measure of low flow experienced at any particular site. Q^{95} was chosen as an indicator of low flow rather than for instance

Q^{99} for two reasons. Firstly, any lower value may not be accurate due to intrinsic problems of gauging structures accurately recording very small discharges. Secondly it is quoted in the IH Hydrometric Register and Statistics 1981-1985 (IH 1988). A channel with a relatively high flow during drought conditions which is concentrated in a narrow channel will support greater depths and flow velocities than a wide channel with low drought flows. Consequently, the former would be expected to produce a better habitat quality.

Pennak (1971) suggested that the nature of the substrate is perhaps the single most important factor with respect to biological significance. Some studies (e.g. Hynes 1970, Ward 1976) have indicated that heterogeneity of substratum particle size is critically important in providing varied microhabitats that can sustain a diverse and abundant fauna. However, others (e.g. Williams 1980, Scullion et al 1982) have reported the lack of a relationship between invertebrate abundance and substrate composition. Nevertheless, they do recognise that it is of ecological significance, by either providing a uniform habitat of diverse particle size or a range of microhabitats of different particle size groupings (Moog and Janecek 1991). The stability of the substrate has also been recognised as an important factor although it is rarely considered due to the inherent problems in quantifying it (Giberson and Hall 1988, Cobb et al 1992).

As stated previously, substrate was identified on a presence or absence basis for each of the Wentworth size classification (Wentworth, 1922) categories. This was then converted into an index by dividing the percentage of the 20 transects that had gravel present by those that had silt or detritus present. Therefore, a high value would represent a reach with a majority of transects containing gravel, and few with silt or detritus. Alternatively, a very low score would be attained by the opposite scenario. A value of zero indicates no gravel present at any cross-sections.

Cover has also been shown to have important effect on the instream habitat and was recognised in this study under two headings i.e. instream and overhanging. Invertebrate biomass is usually three to ten times greater in a stream with a thick growth of submerged rooted aquatics than in a similar one without due to the additional spatial and food niches (Pennak 1971). Some insects (e.g. Elmidae) will scrape algal epiphytes of macrophytes, and other invertebrates and fish feed on detritus composed largely of dead plant material (Hynes 1970, Fox 1992).

Therefore, instream cover was visually estimated in terms of the total percentage of the wetted cross-sectional area across the transect that is taken up by objects protruding up into it. These could take the form of vegetation and/or cobbles or boulders. Streamside vegetation, sometimes referred to as the riparian zone or buffer strip, can provide important habitat for the breeding and oviposition phases of the terrestrial life stage of aquatic invertebrates as well as habitat for birds (Robertson et al 1990). It can also provide important shading to reduce maximum water temperature and be an important source of allocthonous material. There is also strong evidence that riparian buffer strips retain and reduce nitrogen and phosphorus (Peterjohn and Correll 1984, Pinay and Decamps 1988) that may otherwise be released as subsurface flow from agricultural land. Overhanging cover was therefore considered to be a potentially important parameter and was estimated by assessing the percentage of the total wet width that was shaded from above the water surface.

The physical nature of the water present was also summarised in an index that was based on the measurement of two physical parameters. The percent of the channel bed that was taken up by water was calculated as well as the percent of cross sections with visible flow. These were then combined into one by adding the two values and dividing by two to give a percentage value. This was subsequently divided by one hundred to give an index of between 0 and 1.

4.4.3 Rating system

In the past, some authors have recognised the non-linearity that exists between some of the attributes measured and their influence on instream habitat quality. Consequently, rating systems have been introduced. Binns and Eiserman (1979) used a simple rating system scoring each measured attribute on a scale from 0-4 which resulted in significant correlations with trout standing crop. A similar method was therefore tried on this data for the six attributes that were the most significantly correlated with the BMWP score in their raw form. Each parameter was scored on a five point scale from 0 (worst) to 4 (best). For instance, a site that had 50% of the 20 transects with gravel present and 50% of them with silt or detritus present, then this would be rated 3. A site with the same amount of transects with gravel but all having silt or detritus present would achieve a rating of 2. Rating characteristics are shown in table 4.4 below.

Table 4.4 - Rating characteristics of the six chosen parameters.

	Score				
Attribute	0 (worst)	1	2	3	4 (best)
Average NWC score	1	1.01 - 2.75	2.76 - 3.13	3.14 - 3.99	4
Baseflow index	0	0.01 - 0.41	0.42 - 0.49	0.50 - 0.89	0.90 - 1.00
Q^{95}/channel width	0	0.001 - 0.010	0.011 - 0.046	0.047 - 0.054	>0.055
% gravel/% silt or det	0	0.01 - 0.100	0.101 - 0.588	0.589 - 1.059	>1.059
% instream cover	0	1 - 6	7 - 26	27 - 43	44 - 100
Wet width - % flow	0	0.01 - 0.69	0.70 - 0.75	0.76 - 0.91	0.92 - 1.00

4.5 Results

Relationships between the chosen parameters and BMWP scores were investigated using simple and stepwise regression techniques. The subsequent analysis is based on two groups; those that use actual measured data and those that use the rating table. Table 4.5 indicates the correlation coefficients between BMWP score and the various habitat attributes using simple regression. As stated above, the six most significantly correlated attributes were rated and the correlation coefficients for the rated values are also shown in table 4.5. Q95 was not rated separately as it is already incorporated with the channel width index. The rated values showed increased correlations for two out of the five parameters.

Simple regression between the actual values for each attribute and BMWP score indicate a wide variety of results. Regression values range from 0.001 for average overhanging cover to 0.441 for average NWC score. Noticeably, all parameters that were measured from the 1:50000 OS maps rather than in the field, i.e. catchment area, distance downstream, gradient, Strahler number and Shreve index were not correlated and gave r^2 values of less than 0.1. This demonstrates the importance of the reach rather than the catchment characteristics.

To construct model 1, stepwise regression was then used on the same parameters to extract the most influential one and weight them according to their importance to form an equation to predict BMWP score.

Table 4.5 - *Correlation coefficients between measured habitat attributes and BMWP scores in order of significance.*

Attribute	actual r^2
Average overhanging cover	.001
Distance downstream	.001
Catchment area (km^2)	.003
Average channel width	.015
Altitude	.023
Average thalweg depth	.025
Gradient	.030
% channel bed wet	.043
Strahler number	.050
% riffle transects	.055
Shreve number	.073
% transects with visible flow	.189
Baseflow index	.214
% gravel/% silt or detritus	.244
% wet width - % flow index	.245
Q95	.270
Q^{95}/channel width	.336
% instream cover	.348
Average NWC chemical score	.441

Based on the actual measured values this extracted the NWC chemical score, Q^{95}/channel width % instream cover and the wet width - flow index into the following equation:

BMWP = -39.387
+ (chemical score x 19.79)
+ (Q^{95}/channel width x 466.703)
+ (% instream cover x 0.847)
+ (wet width - flow index x 52.657).

Using this equation, predictions for all 28 sites gives an $r^2 = 0.880$.

For model 2, the scores obtained from the rating table were added for each site. The total for each site was correlated with BMWP score and is described by the equation:

$$\text{BMWP score} = (10.029 \times \text{total of rating scores}) - 48.292.$$

This improved predictability as the r^2 value increases to 0.913. Predicted BMWP scores against actual average scores are shown for the two methods in figures 4.3a and 4.3b. The two models were also analysed to test their sensitivity to variations of certain attributes included in their calculation. In other words, the models have been used for predictive purposes to examine the effect of a change in the envionmental parameters included in the models. For instance, the predicted effect on changes in Q^{95} are explored which may result from flow augmentation or abstraction. Channel width variations are also examined as are water quality and instream cover changes. Prediction of the effect of an alteration in four of these is also determined. Results are shown for three sample sites in table 4.6 below. The sites were selected to represent a range of initial BMWP scores.

The difference in the construction of each model has a clear influence on its predictive ability. Model 1 uses actual values and so an alteration automatically leads to a change in the predicted score. Alternatively, because model 2 uses ratings, unless the change is great enough to cause the site to move from one class to another for that attribute score the prediction remains the same. This is shown in figure 4.4. Q^{95} variations are indicated across a range of possibilities with the associated BMWP predictions for the river Wissey. The smooth curve produced by model 1 can be contrasted with the stepped effect of model 2 as the Q^{95} value crosses the threshold from one score to another. The high predicted score even with very low Q^{95} values is noteworthy.

4.6 Discussion

The two instream habitat models described here are foundered on the initial research undertaken for an EA (Petts et al 1990) and those developed by others (e.g. Binns and Eiserman 1979, Milner et al 1985, Scarnecchia and Bergersen 1987, Wesche et al 1987). Both use data collected in the field and from other published sources. Field data for the first relies on measurements in terms of channel bed width, % instream cover, measurements of wet width and the % of cross-sections with visible flow at twenty transects whereas the second also requires substrate estimates. Published data sources include the NWC chemical classification and the IH Baseflow index. NRA Anglian region supplied archived flow data and

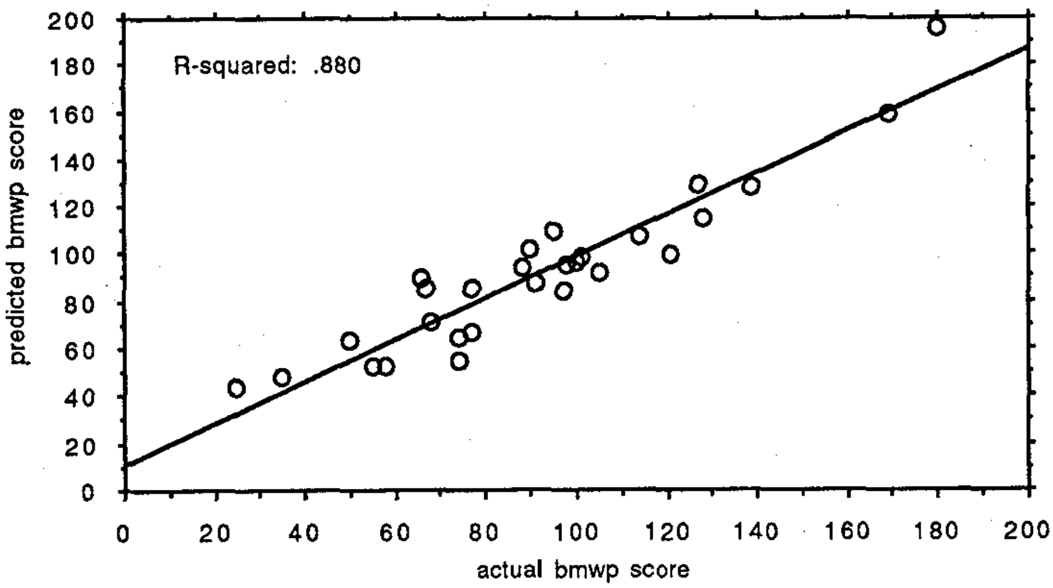


Figure 4.3a - Predicted BMWP scores against actual values using model 1.

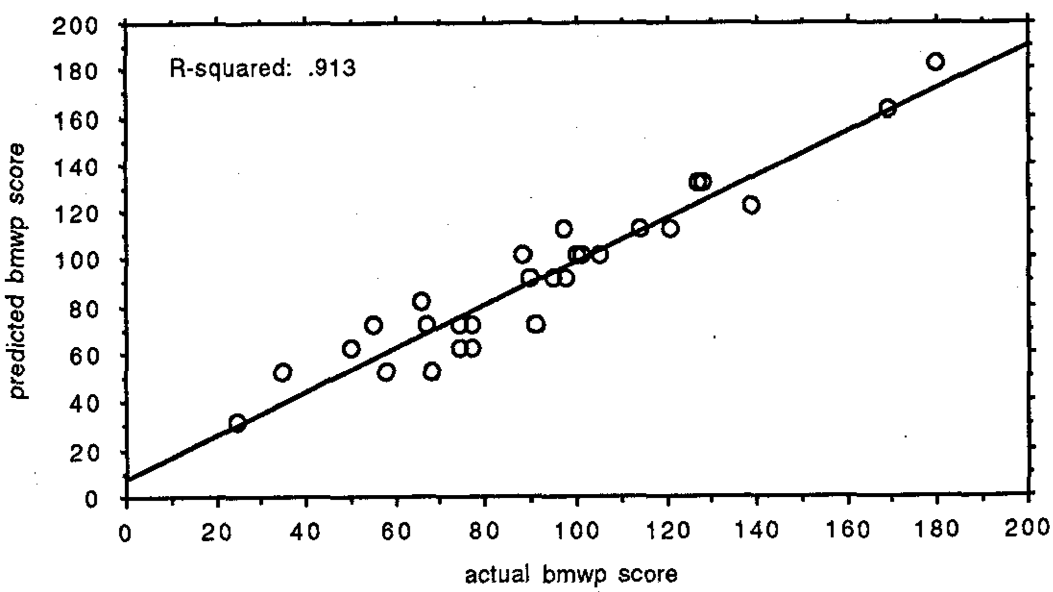


Figure 4.3b - Predicted BMWP scores against actual values using model 2.

Table 4.6 -Variations in predicted BMWP scores for the two models with changes in environmental variables at three sites. The effects of various scenarios are predicted for three rivers using both models.

	Nar		Tas		Stour	
Variable	model 1	model 2	model 1	model 2	model 1	model 2
Actual	169	169	100	100	53	53
Predicted	159	162	96	102	53	52
+1 NWC class	179	162	116	122	73	62
-1 NWC class	139	152	76	92	33	42
1.5 x Q^{95}	192	162	104	112	55	52
0.75 x Q^{95}	143	162	93	102	53	52
1.5 x channel width	137	162	91	102	53	52
0.75 x channel width	181	162	102	102	54	52
2 x Q^{95}/channel width	226	162	112	112	56	52
0.5 x Q^{95}/channel width	126	162	89	102	52	52
2 x instream cover	164	172	111	112	56	62
0.5 x instream cover	157	162	90	102	51	52
-1 NWC class + 0.75 x Q^{95} + 1.5 x channel width + 0.5 x instream cover	103	152	66	92	30	42

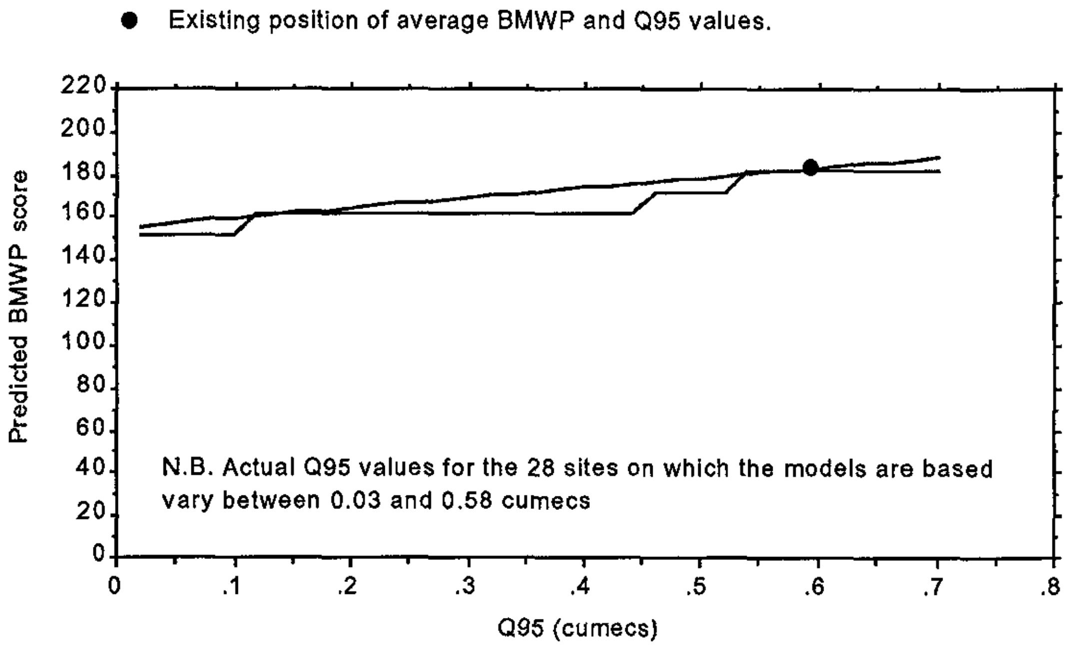


Figure 4.4 - Variation of predicted BMWP with Q95 for the two models for the river Wissey.

invertebrate scores. The model using the raw data requires just four variables to attain a high degree of correlation with the BMWP score (r^2 = 0.880). Rating values for the six variables used in the second model increases predictive ability to r^2 = 0.913. Consequently, neither require detailed or intense field efforts or subsequent visits. When correlating fish biomass and production with environmental variables, other studies have found the single most important parameter varies in type and for the degree to which it correlates e.g. annual streamflow variation r = 0.80 (Binns and Eiserman 1979), average annual baseflow as a percent of average annual daily flow r^2 = 0.36 (Wesche et al 1987), elevation r^2 = 0.42 (Scarnecchia and Bergersen 1987) and hardness r^2 = 0.699 (Milner et al 1985). Although this study has not used fish but invertebrate assemblages, the single most important parameter has a similar correlation i.e. average NWC classification score = 0.441 in model 1 and 0.418 in model 2. Furthermore, previously published models have accounted for between 52% and 97% of the variance in fish biomass and the two models have predictive abilities at the upper part of this range for the invertebrate score.

There are relatively small variations in altitude and gradient over the whole region and so as expected, these parameters have little impact on the invertebrate score. Furthermore, the insignificance of the other attributes measured from the 1:50000 OS maps reflects the importance of the local variations in physical habitat at the reach scale such as instream cover and flow related to channel width rather than those measured at the catchment scale.

The models developed within this report have attempted to utilise easily obtainable data in order to assess the instream habitat. To further improve any model that uses empirical equations based on measured physical and chemical attributes to predict invertebrate score requires a phase of testing. Milner et al (1985) has established that the calibration procedure is sometimes confused with independent testing. It is stressed that the compilation of new data sets is essential so further application and testing can proceed. This has been achieved by examining a number of sites within the Glen catchment, the results of which are described below.

4.7 Model Test Within the Glen Catchment

In order to test the models on independent data, six sites within the Glen catchment were visited on the 22nd and 23rd of August 1991. Three sites were selected on the West Glen, two on the East Glen and one on the River Glen downstream of the

East and West Glen confluence. Physical habitat attributes were recorded in accordance with the first survey (see Appendix 5). Flow and water quality data were obtained from Anglian NRA and a summary of site results are shown in table 4.7. In each case, the actual values are shown in each column followed by the rating value in brackets. For instance, Burton Coggles has an average NWC score over 10 years of 1.88 which according to the rating table scores a value of 1. The baseflow index for Little Bytham was not available. By examining the last column, it is clear that all but two sites (i.e. Shillingthorpe and Kates Bridge) had unusually low wet width-% flow values. This can be attributed to the fact that the survey was completed under exceptionally low flow conditions. Consequently, the river was entirely dry over a large proportion of the reaches at Burton Coggles and Braceborough, and flows were close to zero at Edenham. The relatively high values at Shillingthorpe and Kates Bridge are due to the maintenance of flows from the Gwash-Glen transfer.

From these habitat parameters, predictions were made using both empirical equations and the results shown in table 4.8. In each case, results have been compared with the BMWP score of the routine invertebrate sample taken by Anglian NRA closest to the survey date. For instance at Braceborough, the actual BMWP score on 3/10/91 was 49. Model 1 using the actual data predicted a score of 53 whereas model 2 using the rated values predicted a score of 52. Predictions for Little Bytham using model 2 require a baseflow index. As none was available, an estimated value of 0.92 was used due to the stable nature of the flow at this site. Long term flow records for Shillingthorpe and Kates Bridge to calculate Q95 do not take into account the interbasin transfer that was operational throughout the summer. Consequently, a value of 0.1 cumec was used for these simulations derived from the flow records of summer 1991. The fourth column represents the long term average BMWP score for these sites. However, as discussed above, the surveys were undertaken during extreme low flow conditions with low wet width-% flow index values. Under long term average conditions these would be expected to be much higher and so the predictions that the long term averages have been compared with have utilised wet width-% flow index values of 0.92.

To determine if the model predictions were significant, regressions were carried out against the associated BMWP scores at each site. The results are shown in figures 4.5 to 4.8. In each case, adjusted r^2 values are quoted as these take into account the number of data points being compared.

Table 4.7 - Selected habitat parameters for sites within the Glen catchment.

Site Name	Average NWC Score	Baseflow Index	Q95/ Channel Width	% Gravel/ % Silt or Detritus	% Instream Cover	Wet Width -% Flow Index
Burton Coggles	1.88 (1)	0.403 (1)	0.0003 (1)	0.600 (3)	15 (2)	0.129 (1)
Little Bytham	3.25 (3)	n/a	0.0050 (1)	0.666 (3)	35 (3)	0.588 (1)
Shillingthorpe	3.75 (3)	0.832 (3)	0.0040 (1)	2.000 (4)	29 (3)	0.941 (4)
Edenham	2.86 (2)	0.330 (1)	0.0007 (1)	0.579 (2)	22 (2)	0.419 (1)
Braceborough	3.00 (2)	0.352 (1)	0 (0)	0.750 (3)	28 (3)	0.167 (1)
Kates Bridge	3.88 (3)	0.600 (3)	0.0033 (1)	0.778 (3)	60 (4)	0.920 (4)

Table 4.8 - Comparison of recorded BMWP scores against predicted values.

				With Wet Width - Flow at 0.92		
Site Name	Actual Score	Model 1 Prediction	Model 2 Prediction	Average Score	Model 1 Prediction	Model 2 Prediction
Burton Coggles	0	18	42	73	58	72
Little Bytham	95	88	102 *	119	106	132 *
Shillingthorpe	142	118 **	142 **	141	112	132
Edenham	80	58	42	77	85	72
Braceborough	49	53	52	93	93	82
Kates Bridge	162	143 **	142 **	135	137	132

* No baseflow index is available for Little Bytham therefore an assumed value of 0.92 has been used to calculate model 2 predictions.

** Predictions made using an increased Q95 value of 0.1 cumec due to the interbasin transfer.

Model 1 predictions compared with the actual values gives an adjusted $r^2 = 0.959$ (p=0.0004 therefore significant at the 99.9%ile) whereas model 2 predictions gives an adjusted r^2 value of 0.753 (p=0.0158, significant at 98%ile). Comparing the model 1 predictions with the long term average values results in an adjusted r^2 value of 0.731 (p=0.0188, significant at 98%ile) and model 2 gives an adjusted r^2 of 0.908 (p=0.0021, significant at 99%ile).

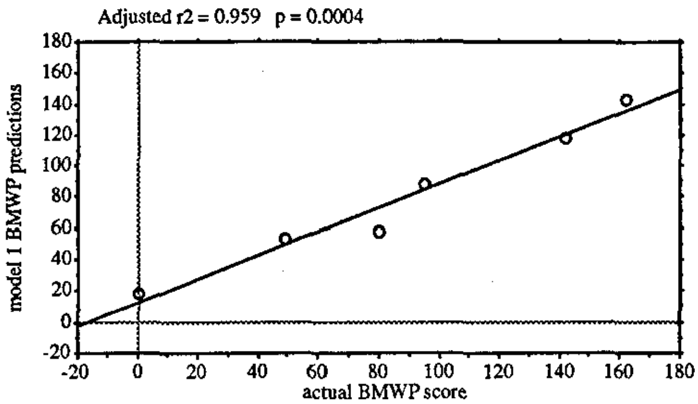


Figure 4.5 - Comparison between actual BMWP scores against model 1 predictions.

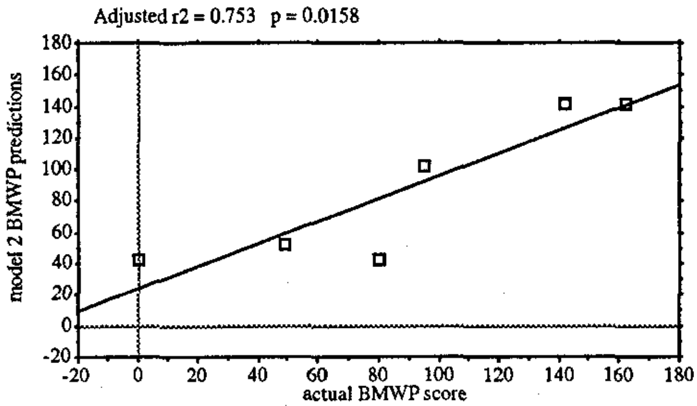


Figure 4.6 - Comparison between actual BMWP scores against model 2 predictions.

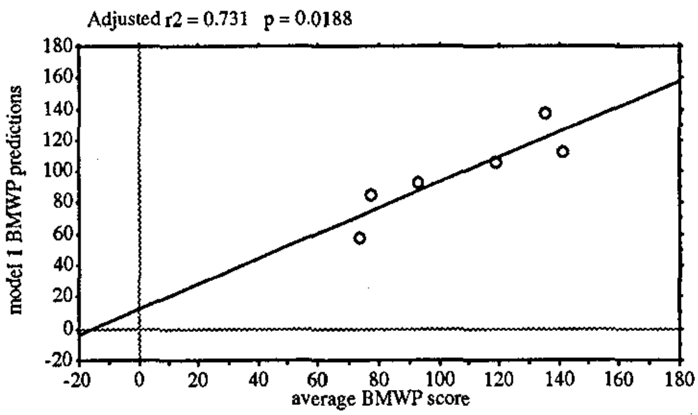


Figure 4.7 - Comparison between average BMWP scores against model 1 predictions.

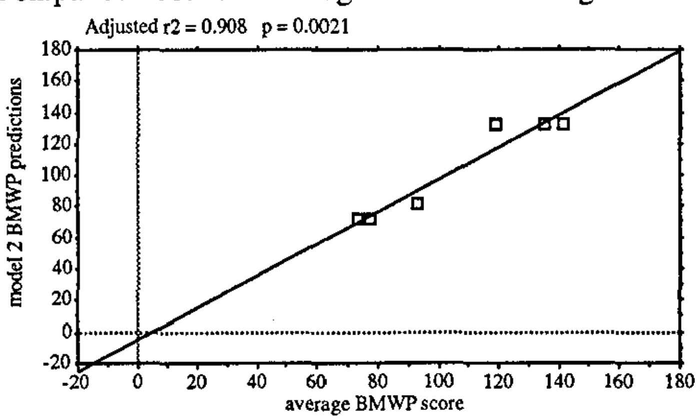


Figure 4.8 - Comparison between average BMWP scores against model 2 predictions.

Clearly the models still perform well on this independent data set which lies within the same region as where the models were developed. Other workers (e.g. Bowlby and Roff 1986, Scarnecchia and Bergersen 1987) have discovered that similar models do not perform so well when applied to geographical areas different than those in which they were originally established. Only further evaluation outside the Anglian region would enable the models to be tested on streams that are geomorphologically different.

4.8 Summary

Empirical models to date have largely focused on fish, and in particular salmonid species. However, a similar model between an invertebrate score, the BMWP (Biological Monitoring Working Party), and habitat variables has recently been described. For 28 streams in East Anglia, UK, field data were obtained during summer low-flow at approximately 100 points from 20 transects. All sites had long term invertebrate records showing a stable BMWP and good quality flow-gauging data. Comparisons between observed and predicted abundance accounted for up to 91% of the variance. The relationship was validated for the River Glen to which it was then applied to assess the improvement in BMWP with flow augmentation. In particular, the regression analysis has been successfully deployed as part of a prediction exercise.

Results suggest that the models have potential application in two main areas. Firstly, they attempt to define which environmental parameters are important in influencing invertebrate assemblages expressed as BMWP scores, at the site scale. This has led to a method that seeks to assess the *in situ* habitat for its present ecological value. At this stage, success in producing empirical equations that account for a high degree of the variability in invertebrate scores within various streams indicates the inherent importance of the habitat features that were measured. Both models suggest that water chemistry primarily determines the overall quality of the river as described by the BMWP score but other environmental parameters are important. Most important of these is discharge per unit width. Secondly, possible manipulations of physical and chemical variables can be evaluated in terms of their impact on the aquatic environment. For instance, even with no alteration of water quality, the increase of low flows, indexed here by Q95 and the BFI, would improve BMWP. Reducing low-flow channel width, to increase Q95/channel width and increase the wet width-% flow index would have a positive effect and BMWP could also be improved by increasing instream cover. Consequently, by using the empirical relationships, the effect of abstracting or augmenting water could be determined or the enhancement of instream cover be assessed. River managers would then have the potential to examine the full range of management scenarios that are open to them and make an objective and quantifiable assessment of the likely impact of each.

CHAPTER 5 - ASSESSING BIOLOGICAL RESPONSES TO HABITAT VARIATIONS WITHIN STREAM SECTORS (PHABSIM)

5.1 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 storm events, the distribution of hydraulic conditions is determined by 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.

The demand for habitat assessment methods that is now materialising in the U.K. has been evident in the U.S.A., particularly the western United States since the mid 1970's (see section 2.4). A similar situation of increasing demands for irrigation, domestic, and industrial water supply led to the development of a variety of methods to assess fish habitat tradeoffs against other uses of water. The Instream Flow Incremental Methodology (IFIM) developed by the U.S. Fish and Wildlife Service Cooperative Instream Service Group (IFG) has been considered by some to be "the most scientifically and legally defensible method available for most instream flow problems" (U.S. Department of the Interior 1979). It is also one of the most widely used methods in North America for estimating the effect of changes in flow on trout habitat (Conder and Annear 1987) and is described as "the current state of the art" (Orth 1987).

The initial step required is the definition of suitable reaches for detailed study. This process builds on the steps described in chapter 3 which can then be used to define a more detailed study to pinpoint particular reaches for habitat improvement. Detailed field-survey data are then input into a simulation model (PHABSIM, Bovee 1982). The Physical Habitat Simulation Model (PHABSIM) is a set of computer models that are the cornerstone of the IFIM described above. Essentially, PHABSIM is used 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 (Bovee 1982).

PHABSIM considers microhabitat as defined under this methodology to consist of two basic components i.e. rigid structural characteristics and variable hydraulic conditions.

Structural habitat characteristics reflect the hydrogeomorphology of the channel e.g. bed configuration, channel width or substrate composition and are assumed to be constant over a range of flows. The hydraulic variables which affect microhabitat utility are width, depth, and velocity. All three respond differently to changing discharge in conjunction with the structural nature of the channel and so the physical microhabitat is a complex array of combinations of these parameters. This array is redefined with a different set of depth, velocity, and structure combinations each time the discharge changes.

A natural stream contains a complex mosaic of physical features. One given species may find an area of deep, slow flowing water desirable whilst another may prefer an area of deep, fast flowing water. Alternatively, a third species may find neither conditions suitable. In order to quantify physical habitat, the area associated with each combination of features and an evaluation of that combination in terms of its suitability as a habitat for a particular species must be defined. When flow changes, the hydraulic variables will alter and so under the new flow, physical habitat has to be requantified.

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.

The following sections outline the requirements of each of these components in turn.

5.1.1 Data collection

An initial survey must be completed to quantify the physical habitat availability for the whole length of the river system as presented in chapter 3. Following this 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 a re 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. PHABSIM can then be used to determine sectors which need restoration.

Provided that the reach is suitable for hydraulic simulation (i.e. macrohabitat conditions such as temperature variations and water quality will be suitable) hydraulic conditions are characterised at usually three known (calibration) streamflows from measurements taken along transects within the reach. Data collection is based on field measurements at a number of transects along a chosen reach under three different flows, i.e. low flow, medium flow and high flow conditions. 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. Essentially, these field measurements determine the amounts 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.

5.1.2 Hydraulic simulation

Hydraulic simulation models are then used to estimate depths, velocities and substrates at unmeasured flows (Bovee and Milhous 1978). 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).

The following sections briefly outline each of the underlying concepts behind each application. A complete and detailed description of the theories underpinning each program has been discussed by Bovee and Milhous (1978). It should be stressed that the dimensional units of the input parameters used to determine hydraulics and habitat availability are recorded and expressed in Imperial units.

IFG4

The most accurate method of obtaining a relationship between stage and discharge is to measure the discharge at various stages and to develop an empirical equation relating discharge to stage. This relationship is influenced by a number of factors, e.g. cross-sectional area, shape, slope and roughness and it is the interaction of these factors which control the relationship. Essentially, the IFG4 program uses an empirical equation between stage (i.e. water surface elevation) and discharge of the following form:

$$WSL = a\,Q^{b} \qquad \text{(Equation 5.1)}$$

where:

WSL = stage or water surface elevation

Q = discharge

a, b = regression coefficients from measures values of discharge and stage.

Using a log transformation for this equation, results in a linear function of the form:

$$\text{Log}\,(WSL - SZF) = \text{Log}\,(a) + b * \text{Log}\,(Q) \qquad \text{(Equation 5.2)}$$

where the water surface elevation has been adjusted by the stage of zero flow (SZF). Given two or more measurements of the stage - discharge relationship at a cross section, the above equation is then solved for the coefficients a and b which then serves as the basis upon which predicted stage is computed for any specified discharge. This is highlighted in figure 5.1 below.

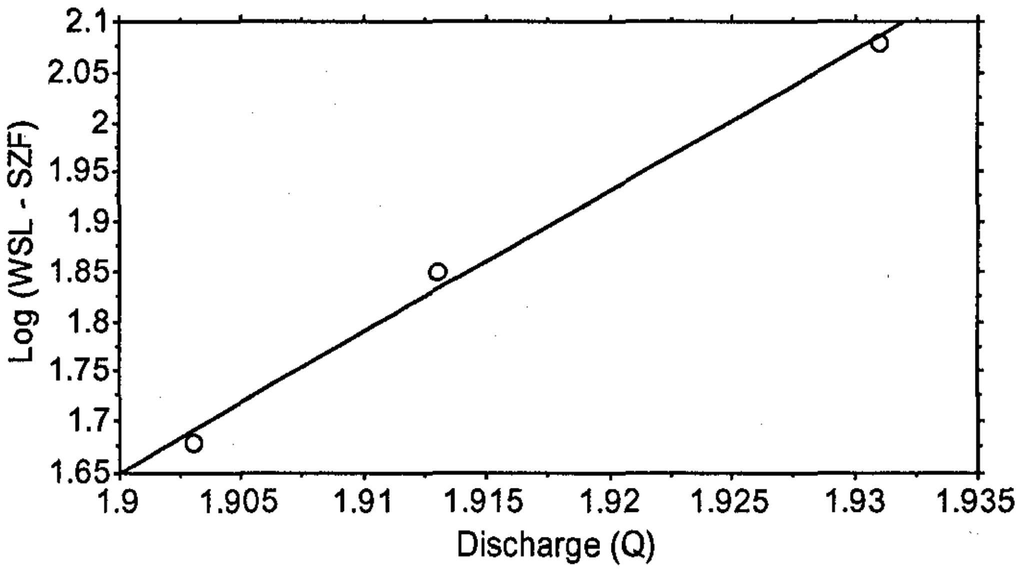


Figure 5.1 - Example of a stage discharge relationship generated by IFG4

It is also important to note that the IFG4 treats each cross section independently of all others in the data set.

After satisfactory development of this relationship, velocities are predicted by solving Manning's equation. Velocity data is used from one of the measured flows to derive Manning's n from the following equation.

$$n_i = [\ 1.49 * S_e^{1/2} * d_i^{2/3}\ ] / v_i \qquad \text{(Equation 5.3)}$$

where:

n_i = Estimated Manning's n value at vertical i

S_e = Energy slope for transect

d_i = Depth at vertical i

v_i = Velocity at vertical i

The apparent discharge for the transect is then determined from the predicted velocity values. This discharge may not necessarily be the same as the discharge requested in the simulation and so a Velocity Adjustment Factor (VAF) is obtained through the use of a mass balance to rectify this.

MANSQ

Similar to the IFG4 program, MANSQ treats each transect independently but will only simulate water surface elevations and not velocities. The Manning's equation can be written in the form:

$$Q = [\ (1.49 / n) * S^{1/2}\ ] * A * R^{2/3} \qquad \text{(Equation 5.4)}$$

where:
Q = Discharge
n = Manning's n
S = Slope
A = Area of cross-section
R = Hydraulic radius

which can be simplified to :

$$Q = K\ A\ R^{2/3} \qquad \text{(Equation 5.5)}$$

and the value of K is determined from one set of discharge-water surface elevation pairs. The MANSQ program calculates the average velocity in the channel and is not used to simulate individual cell velocities. Manning's equation is solved for n at one discharge for which the measurements of the water surface elevation and the discharge at the measured flow, the hydraulic slope and the dimensions of the cross section have been made. Manning's n is solved in accordance with the equations above and assumed constant in subsequent calculations where new stages are calculated for different discharges.

WSP

The Water Surface Profile (WSP) program differs from the previous two programs in that it treats cross-sections as dependent on the adjacent one downstream. The calculation of water surface elevations start from a known water surface elevation at the most downstream transect and uses the 'standard step backwater' method to calculate the water surface elevation at the next upstream cross section. This next cross section then becomes the downstream cross section and the water surface elevation for the next upstream is determined. The program provides very detailed depth and transverse velocity information. In this case, the model allows the computation of the change in roughness as a function of discharge by using roughness multipliers.

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 but may represent the most difficult step in the process of analysing streamflows.

5.1.3 Suitability index curve development

The third step utilises the information developed in suitability index curves. Different species of fish, macroinvertebrates and aquatic macrophytes 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. 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).

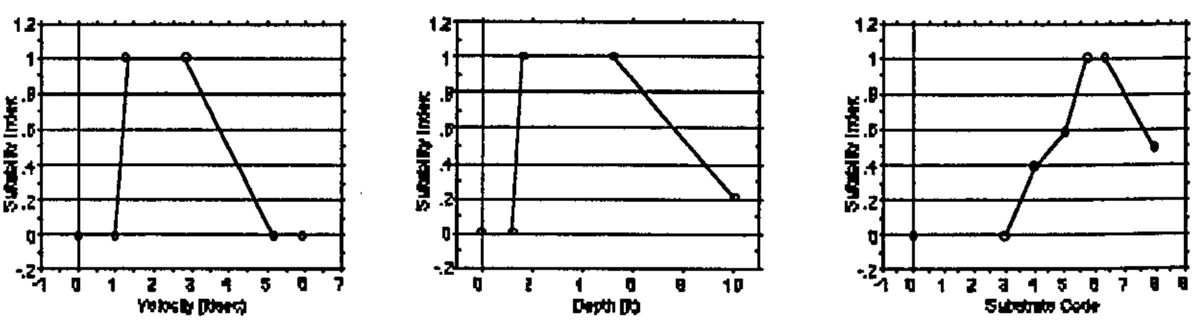


Figure 5.2 - Examples of habitat suitability curves for adult Brown trout.

Curves can be developed from a variety of sources and are called 'probability of use', 'preference' or 'suitability' curves depending on whether they are based on instantaneous measurements in the field, expert opinion, or from literature sources. Further information concerning the development and evaluation of habitat suitability criteria for use in the IFIM has been described by Bovee (1986).

5.1.4 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. Similar to the hydraulic simulation, PHABSIM contains a number of different programs that can be used for this purpose, each of which has specific conditions in which it can be most suitably applied.

Individual suitabilities are extracted from the habitat preference curves and these are combined to give a single cell suitability in one of three ways. Multiplicative aggregation is given by:

$$C_i = V_i * D_i * S_i \qquad \text{(Equation 5.6)}$$

where:

C_i = Composite suitability of cell i

V_i = Suitability associated with velocity in cell i

D_i = Suitability associated with depth in cell i

S_i = Suitability associated with substrate in cell i

Alternatively, the geometric mean can be used which implies a compensation effect. For example, if two of the three individual composite suitabilities are within the optimum range and the third is very low, the third individual composite suitability has a reduced effect on the computation of the composite suitability. It is calculated by:

$$C_i = (V_i * D_i * S_i)^{1/3} \qquad \text{(Equation 5.7)}$$

Finally, the aggregate of the individual suitability factors using the concept of the limiting factor can be calculated by:

$$C_i = \text{Min} (V_i, D_i, S_i) \qquad \text{(Equation 5.8)}$$

Once the composite suitability has been determined, the amount of Weighted Usable Area (WUA) is computed according to the equation:

$$WUA = \sum A_i * C_i \qquad \text{(Equation 5.9)}$$

where:
WUA = Total weighted usable area in stream at specified discharge
C_i = Composite suitability for cell i
A_i = Surface area of cell i

With the final step completed, the user will have been through the standard PHABSIM information flow as shown in figure 5.4 overleaf. An example of the standard PHABSIM output is shown in figure 5.3 below. This information can then be used to make judgements regarding the effect of an alteration in discharge on the availability of suitable habitat for target species.

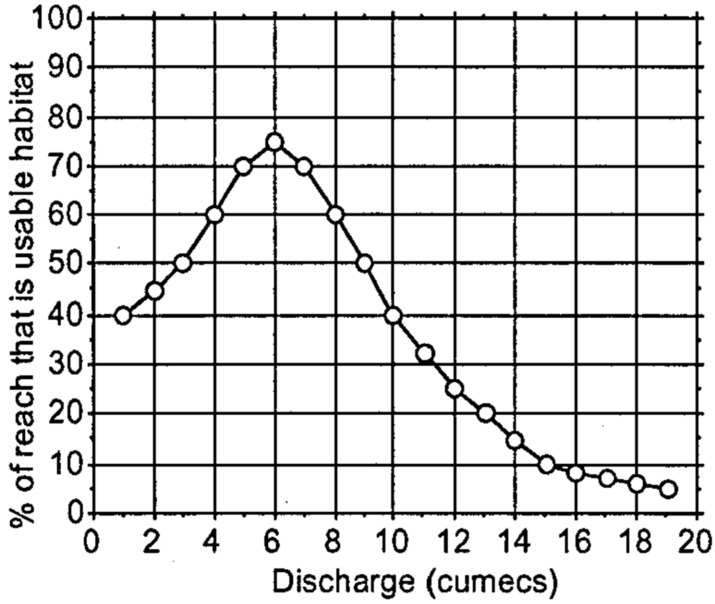


Figure 5.3 - Hypothetical example of output from the PHABSIM process.

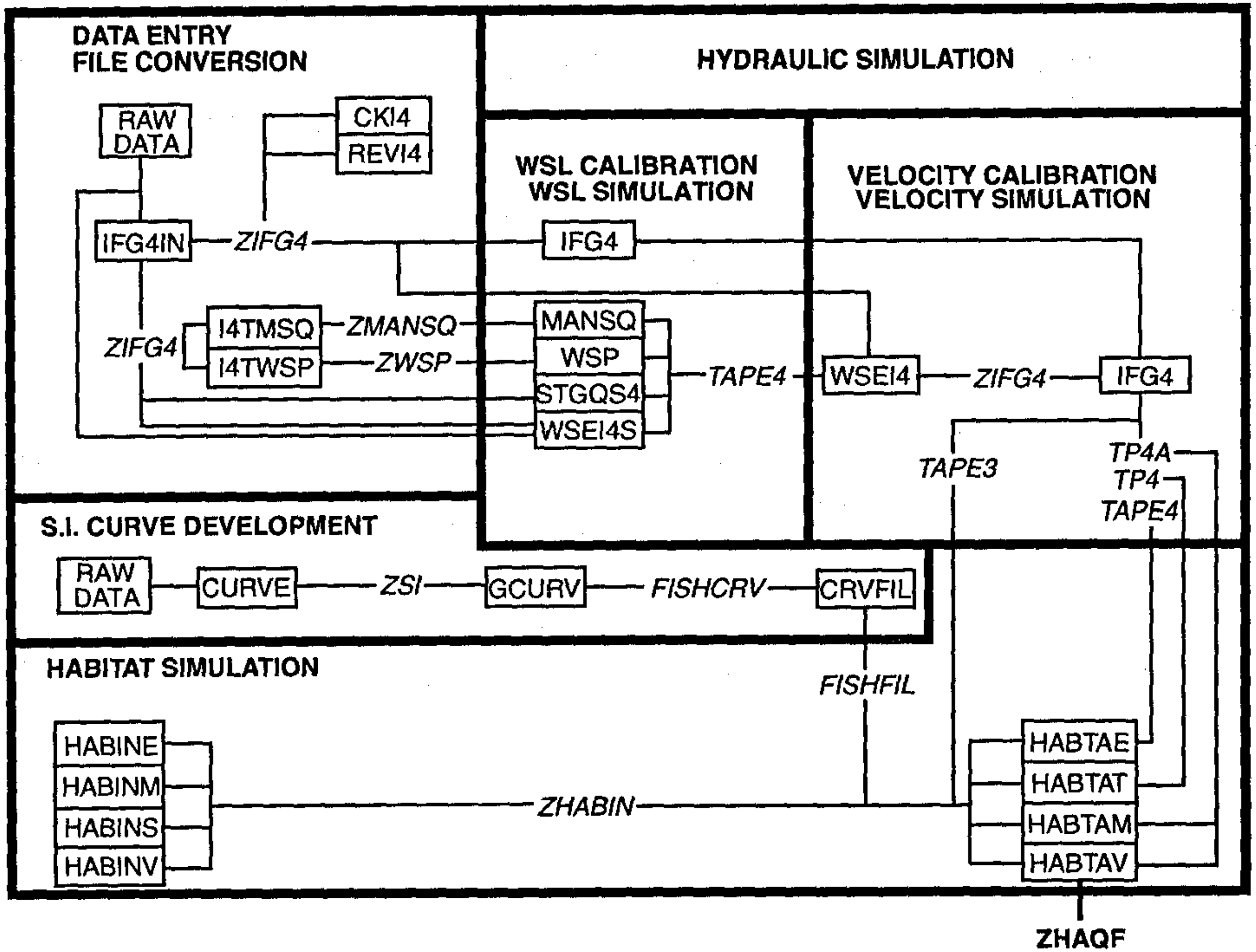


Figure 5.4 - PHABSIM information flow. Programs are contained within boxes and default file names are italicised (Hardy 1991).

WUA is a discrete value which is produced for each reach, each life stage and species, and each target flow. Results are usually expressed in one of two formats, each with their advantages and disadvantages, namely:

- WUA in square feet per thousand feet of stream length.
- WUA as a percentage of the total habitat available along the reach.

The first method is perhaps the most commonly reported and allows the actual amount of usable habitat to be evaluated over different target flows. Variations in total habitat availability can also be compared between reaches. However, in certain circumstances, it may be more useful to understand the actual amount of habitat available in relation to the total amount and therefore express the output as a percentage. In this format, results eliminate the effect of increased stream area due to increased flows. For instance, a reach may provide a greater amount of usable habitat under a higher discharge for a selected species, but total area will also have increased, and in fact the percentage of the total may be less. Therefore, the use of % usable habitat rather than absolute amounts provides this added dimension. In this format, output is particularly applicable for determining sites for habitat restoration and so all results are standardised in this format below.

With these considerations, PHABSIM output can be used as a management tool for a number of purposes. Traditionally it has been applied to predict changes in habitat availability with changes in streamflow and for the assessment of ecologically acceptable flow regimes (Bullock et al 1991, Petts et al 1992, Johnson et al 1993). However, it may also be utilised as a tool for defining sites for habitat restoration, and these applications are outlined below.

5.1.5 Defining ecologically acceptable flow regimes

As shown in figure 5.3 above, the standard display of output from the PHABSIM suite of programs highlight changes in physical habitat for each life stage of the target species as the discharge is raised or lowered. The points of the curves that seem to have the most importance in terms of flow allocation are places where the curve reaches :

- a maximum value,
- inflection pontes, below which there is sudden and steep decline in usable habitat, or
- zero.

This information can then be used in the formulation of recommendations regarding instream flow requirements or mitigation plans. Unfortunately, the maxima and minima are often unrealistic representations of the amount of habitat actually available in the stream. For example, if their was an inexhaustible supply of water and any desired amount could be reserved for instream flow, the logical choice would be to pick a flow which provides the most habitat. In the example above (figure 5.3), this would occur at 6 cumecs. However, this may represent an exceptionally high flow with regard to the natural flow regime or be beyond the economically viable realms of a proposed augmentation scheme. Furthermore, this only represents the output for one species and life stage at one reach. Competing species, life stages and reaches may also be important, each with different flow requirements. Obviously, the relationship between the total habitat and discharge is an essential piece of information, but not the only one. some knowledge about the annual water supply is at least as important as the habitat - discharge relationship. Furthermore, spawning, incubation, and rearing of fry are usually seasonal activities and adult fish may not live in the stream year-round, particularly in terms of diadromous fish (McDowall, 1992). Therefore knowledge about species periodicity may also be required.

A further dimension in respect to habitat analysis relates to the fact that changes in habitat may not only be quantified in regard to amount, but also in relation to frequency. In the same way that a time series can be produced from flow data, habitat time series can be constructed. Based on the development of the habitat - discharge, each flow experienced can be converted into an associated area of habitat available. Provided streamflow data is available in the appropriate format, this can then be used to analyse the actual habitat availability that has occurred over selected time scales from hours to years. Impact analysis can then examine the graphical output of the habitat time series to elucidate the influence of changes in discharge due to both natural (e.g. floods and droughts) and human-induced (e.g. flow augmentation or abstraction) causes. Proposals can also be evaluated by comparing time series with and without the project in operation.

Taking the frequency element one stage further, it is also possible to produce habitat duration curves in the same way as flow duration curves are created for hydrological analyses. Habitat duration curves show the percentage of the time that a habitat is equalled or exceeded. The percent usable habitat versus discharge relationship can be bell-shaped resulting in two or more discharges, each with different probabilities of occurrence, producing the same total amount of habitat.

The probability of having a certain amount of habitat available at any time is a function of the combined probabilities of having the associated flows in the stream. they are constructed in much the same way as flow duration curves, i.e. by listing the habitat areas from the time series from highest to lowest and producing a cumulative percentage based on the percent of time that each value has occurred. The most important area beneath the curve is the portion representing probabilities of exceedance between 50% and 90% as these represent the most commonly occurring conditions that the biota may be adjusted to. However, the values greater than 90-95% may also be critical as they represent the extreme conditions of limited habitat.

5.1.6 Defining sites for habitat restoration

The relationship between available habitat and discharge may be used to identify sites which have limited available habitat during 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 (Brookes 1988). 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 (Meffe and Sheldon 1988). The analysis can be used to determine the habitat quality of reaches, 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.

The following section outlines the use of PHABSIM within three different catchments, each within the Anglian Region but with a different emphasis. The first, the River Glen catchment, provides an example of use for evaluating the impact of an interbasin transfer and for defining sites for habitat restoration. The second in the River Wissey catchment assesses the impact of low flows across a range of sites and outlines the use of habitat-area time series. The third utilises habitat-area time series and habitat duration curves to determine the flow requirements of the river and in particular to define an ecologically acceptable low flow within the River Babingley.

5.2 Use of PHABSIM Within the Glen Catchment

5.2.1 Site selection

Selection of sites was based on a requirement to compare habitat availability between the West and East Glen and between upstream and downstream sites on each river. Three sites were selected on the West Glen (Creeton TF015196, Essendine TF050118 and Shillingthorpe TF056114) and two on the East Glen (Edenham TF063223 and Braceborough TF081136). Creeton and Shillingthorpe were selected to compare the upper and lower reaches of the West Glen and Edenham and Braceborough were chosen to compare similar sites on the East Glen. Essendine was also chosen as an extra site to provide a comparison with Shillingthorpe which are upstream and downstream of the Gwash-Glen transfer input point respectively. Each site consists of a riffle - pool - riffle - pool - riffle sequence. Figure 5.5 shows the location of these sites.

5.2.2 Hydraulic data

The guidelines established by Bovee and Milhous (1978) were followed to a large extent to collect data for the hydraulic simulation models. However, cross-stream measurements were recorded at a more intensive spacing than suggested with a reduction in the amount of data collected for the longitudinal profile. Five transects were established along each reach in order to sample the microhabitat variability present at each site. 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. Survey markers were placed on either side of the stream at these transects and their exact position surveyed relative to each other. This enables the accurate mapping of the reach for hydraulic simulation. Stream widths were recorded at each cross-section and the transect profiles were also surveyed. Water depths and velocities were measured using a standard Ott current meter type C2"10.150" across each transect at approximately equidistant points. The number of measuring points across each transect is shown in table 5.1 overleaf. Each transect is represented by between 17 and 33 points.

Mean velocities were measured at 0.6 times the depth. Substrate type was also recorded for each point based on the presence of Wentworth (1922) grain size categories using the scheme proposed by Trihey and Wegner (1981) shown in table 5.2 below. A mixture of two adjacent substrate types can also be described with this code. For example, a code of 5.5 indicates a substrate mixture of 50% gravel

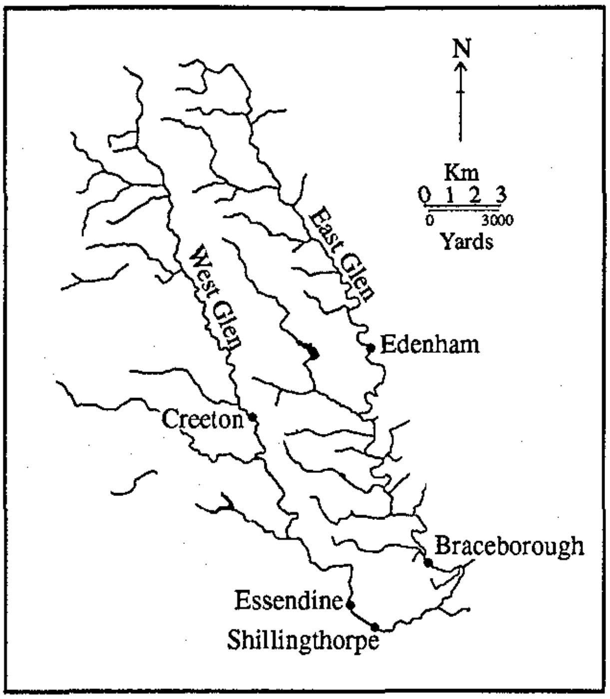


Figure 5.5 - PHABSIM site location within the Glen catchment.

Table 5.3 - Discharges and their associated percentile flows during data collection at each site - the River Glen.

Site	Low (cumecs)	%ile Flow	Medium (cumecs)	%ile Flow	High (cumecs)	%ile Flow
Creeton	0.0008	93	0.0725	37	0.2287	16
Essendine	0.0113	96	0.0786	80	0.1622	58
Shillingthorpe	0.0266	95	0.1833	55	2.4742	4
Edenham	0.0108	78	0.1581	22	1.0018	4
Braceborough	0.0071	71	0.0949	44	0.5866	16

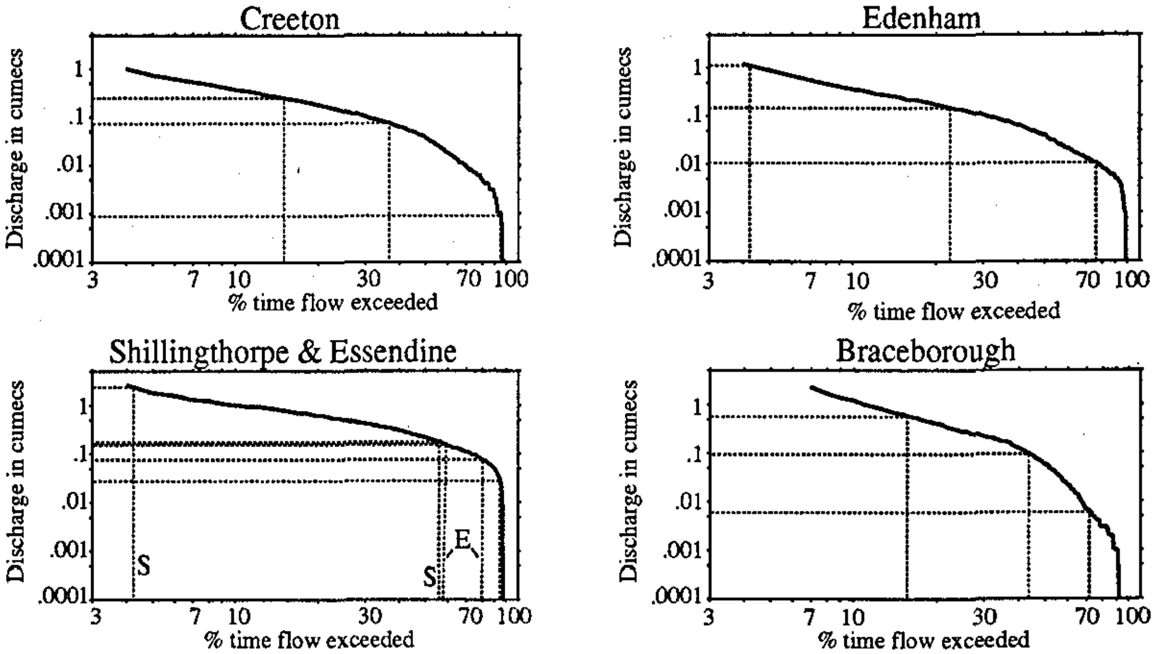


Figure 5.6 - Flow duration curves for each site (dotted lines refer to measured flows).

and 50% rubble. Similarly, a code of 4.2 indicates a mixture of 80% sand and 20% gravel.

Table 5.1 - Number of observation points per transect - the River Glen. (N.B. Cross-sectional measurements are more intensive than suggested (Bovee 1982) with a reduction in the data collected for the longitudinal profile, i.e. the number of transects).

	Transect No.					Max. Water
Site	1	2	3	4	5	Width (m)
Creeton	25	27	25	19	25	4.1
Essendine	19	19	17	17	17	5.5
Shillingthorpe	30	32	33	32	29	6.6
Edenham	20	22	21	22	20	6.4
Braceborough	20	21	20	20	20	5.4

Table 5.2 - Substrate classification scheme after Trihey and Wegner (1981).

Code No.	Substrate Type
1.	Plant Detritus
2.	Mud
3.	Silt (< 0.062 mm)
4.	Sand (0.062 - 2 mm)
5.	Gravel (2 - 64 mm)
6.	Rubble (64 - 250 mm)
7.	Boulder (250 - 4000 mm)
8.	Bedrock (solid rock)

Each site was visited under three different flows i.e. low, medium and high calibration flows. On each occasion, water surface elevations and velocities were recorded whereas substrate is assumed to be constant and was therefore only recorded on one of the visits. For each stage that was surveyed, the discharge estimates at all cross-sections were averaged to obtain the overall stream discharge. The discharges at each site during the surveys are shown with the associated %ile flow from the nearest gauging station in table 5.3 and figure 5.6. The three flows for which four of the sites were sampled successfully covered the majority of the normal flows experienced by those particular sites. However, due to the drought conditions experienced throughout the fieldwork phase, the high flow end of the spectrum is not extensively covered for the Essendine site.

5.2.3 Ecological data

Microhabitat suitability curves utilised in this study were originally developed by Armitage and Ladle (1989). The curves themselves were developed based on experience and local knowledge of UK conditions. Curves have been used for three life stages (i.e. fry, juvenile and adult) for Brown trout, Dace and Chub and are expressed as suitability functions of depth, velocity and substrate.

5.2.4 PHABSIM simulation and results

For each site, data was processed through the standard paths described in sections 5.1.1 to 5.1.4 and shown diagramatically in figure 5.4. The flows that are simulated at each site are constrained by certain bounds laid down by the PHABSIM system based on realistic extrapolations from observed data. For instance, it is not possible to simulate hydraulic conditions under extreme high flows based on the measured data set during extreme low flows. Consequently, simulated flows never fall below 0.4 times the lowest calibration flow or 2.5 times the highest calibration flow. Hydraulic conditions were simulated with a combination of the IFG4 and WSP hydraulic simulation programs. For all habitat simulations, the most widely used multiplicative composite suitability index function was adopted as described in section 5.1.4 and Equation 5.6.

Results are expressed in terms of the % of each reach that is usable habitat for the particular fish species over a range of flows. Full details of the actual values generated for each site are shown in Appendix 6. These values have also been illustrated graphically by site in figures 5.7 to 5.11. Each figure contains three graphs, one each for the different species considered. The graphs for Chub contain two lines rather than three as the adult and juvenile life stages are considered to have similar habitat suitability preferences. The vertical axis considers the amount of the reach that is usable habitat. The horizontal axis is an expression of discharge with low flows at the extreme left and high flows at the right extreme. Rather than display actual flow values, the graphs highlight the relative importance of the absolute flow with respect to the flow duration curve for the site in order to allow a direct comparison between sites. For instance, taking the Q95 as a measure of the low flow experienced at a site, the Shillingthorpe Q95 is approximately 0.02 cumecs whereas a comparable low flow at Edenham may be represented by 0.003

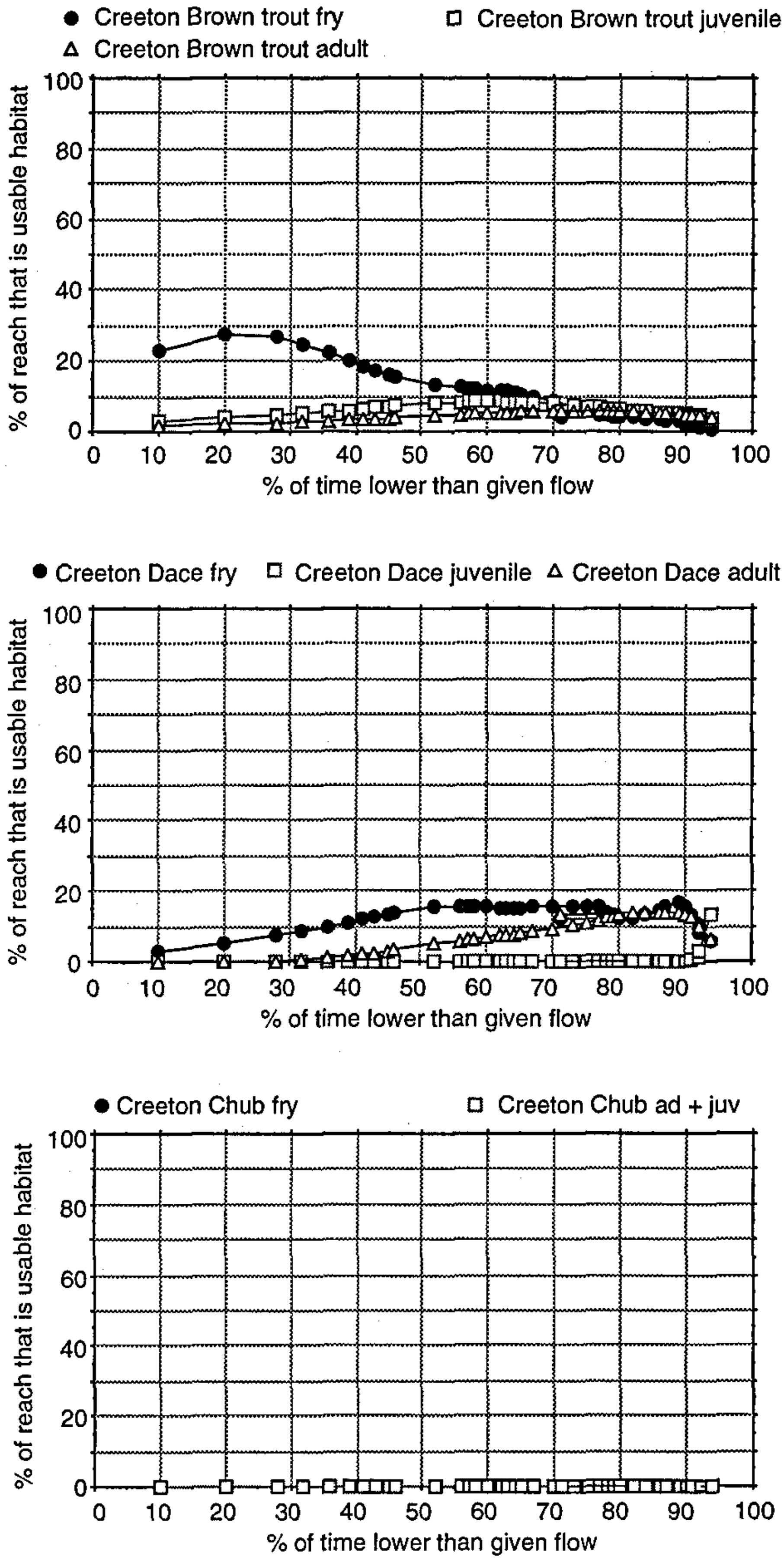
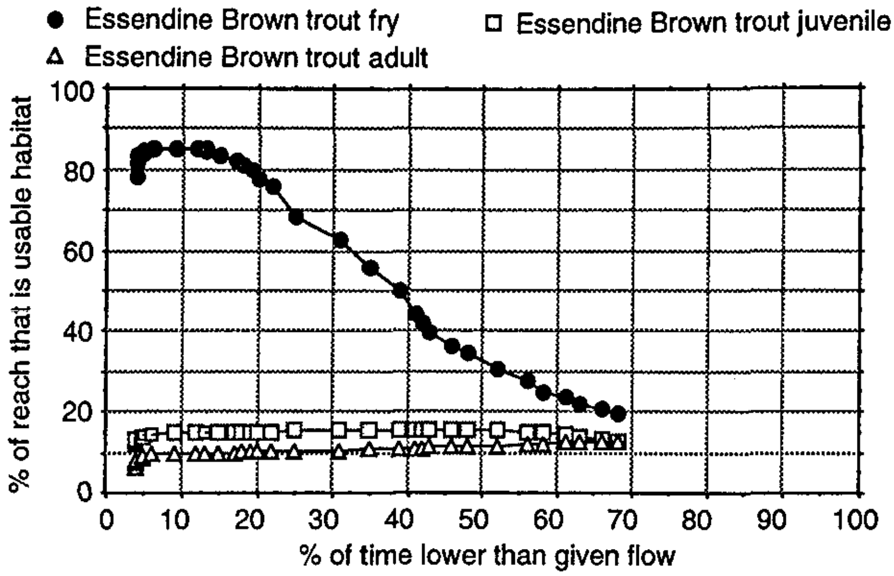
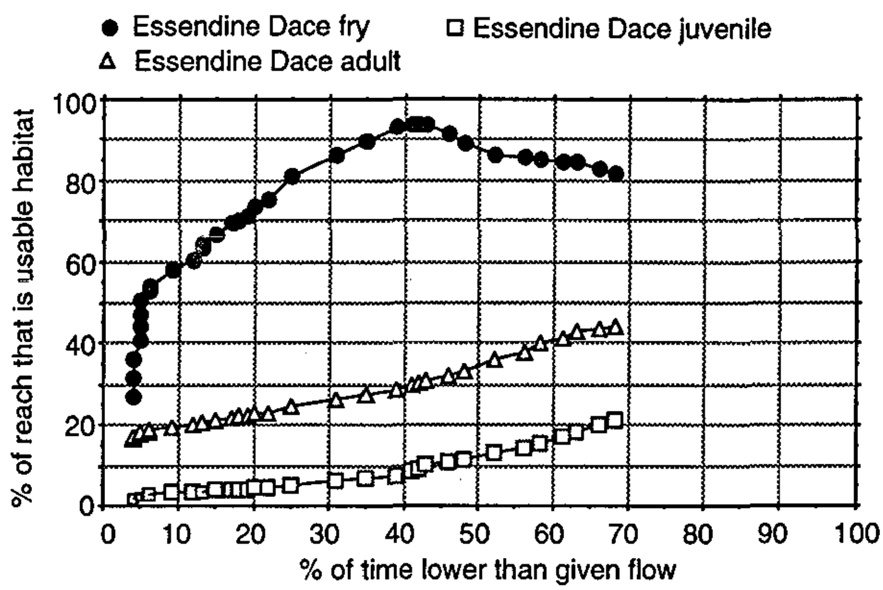


Figure 5.7 - % usable habitat versus discharge relationship for Creeton





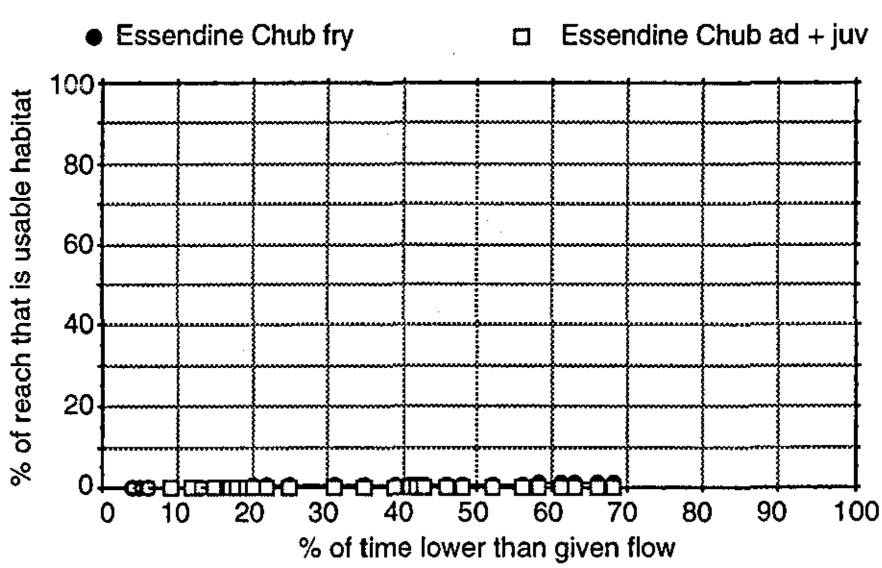


Figure 5.8 - % usable habitat versus discharge relationship for Essendine

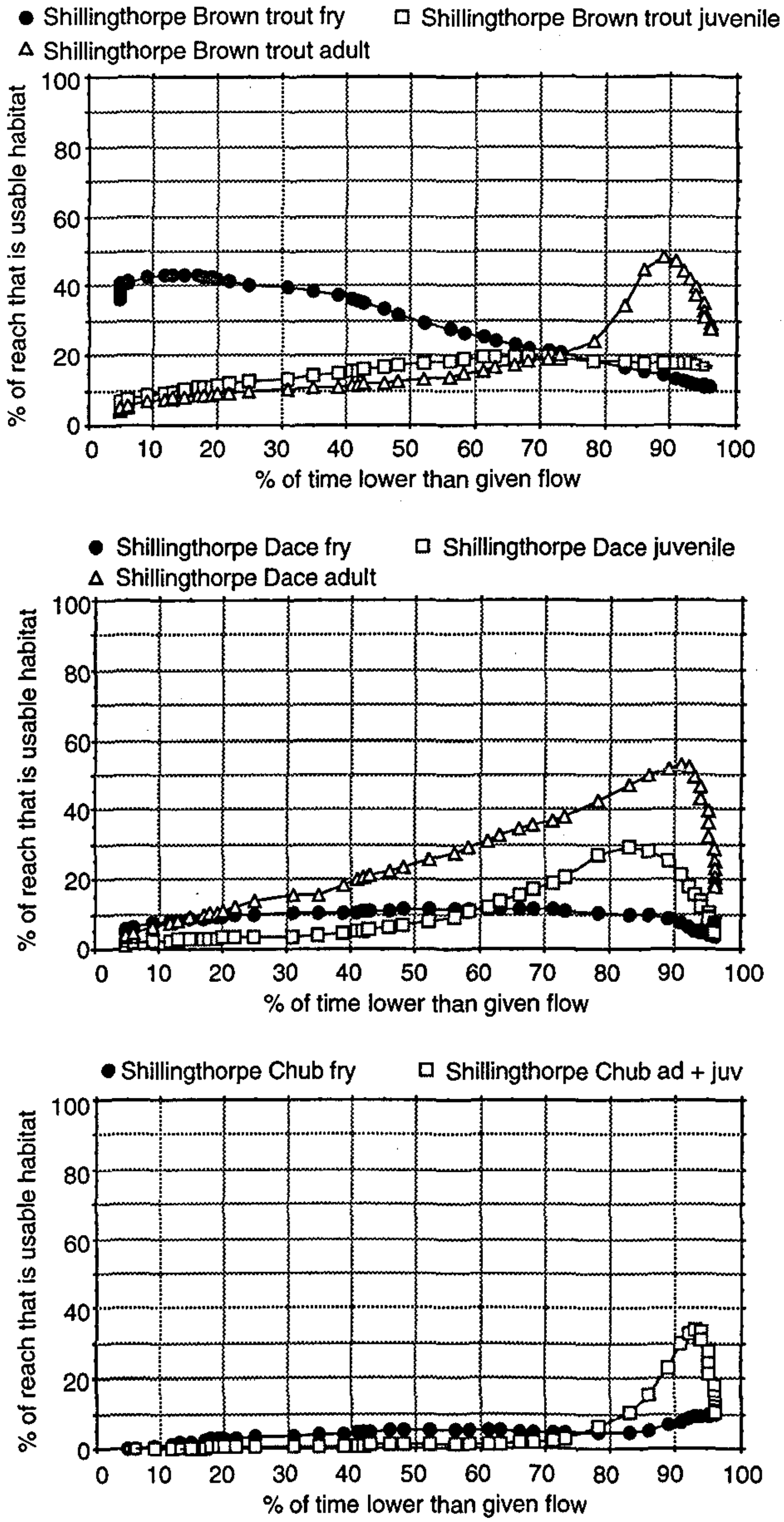


Figure 5.9 - % usable habitat versus discharge relationship for Shillingthorpe

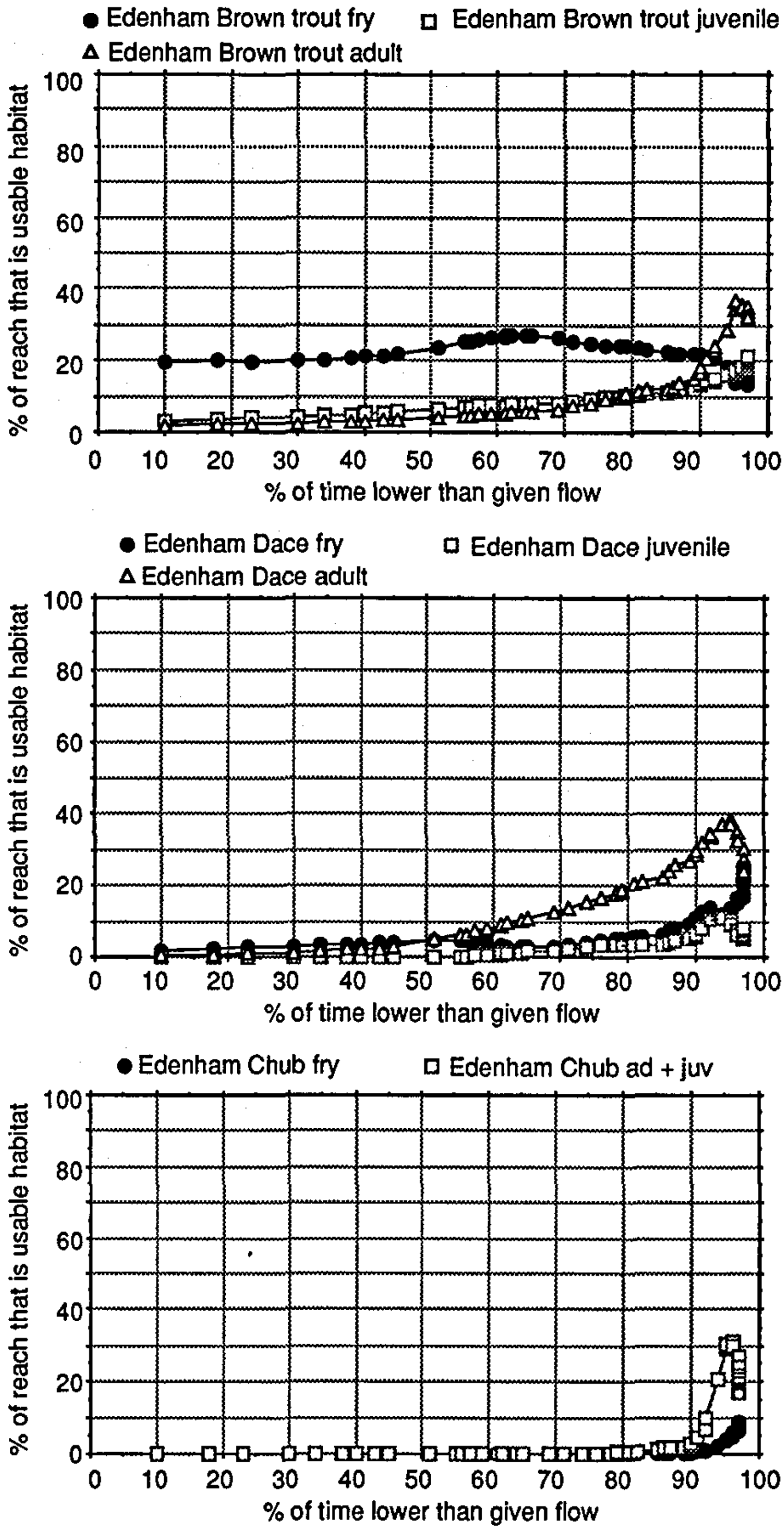


Figure 5.10 - % usable habitat versus discharge relationship for Edenham

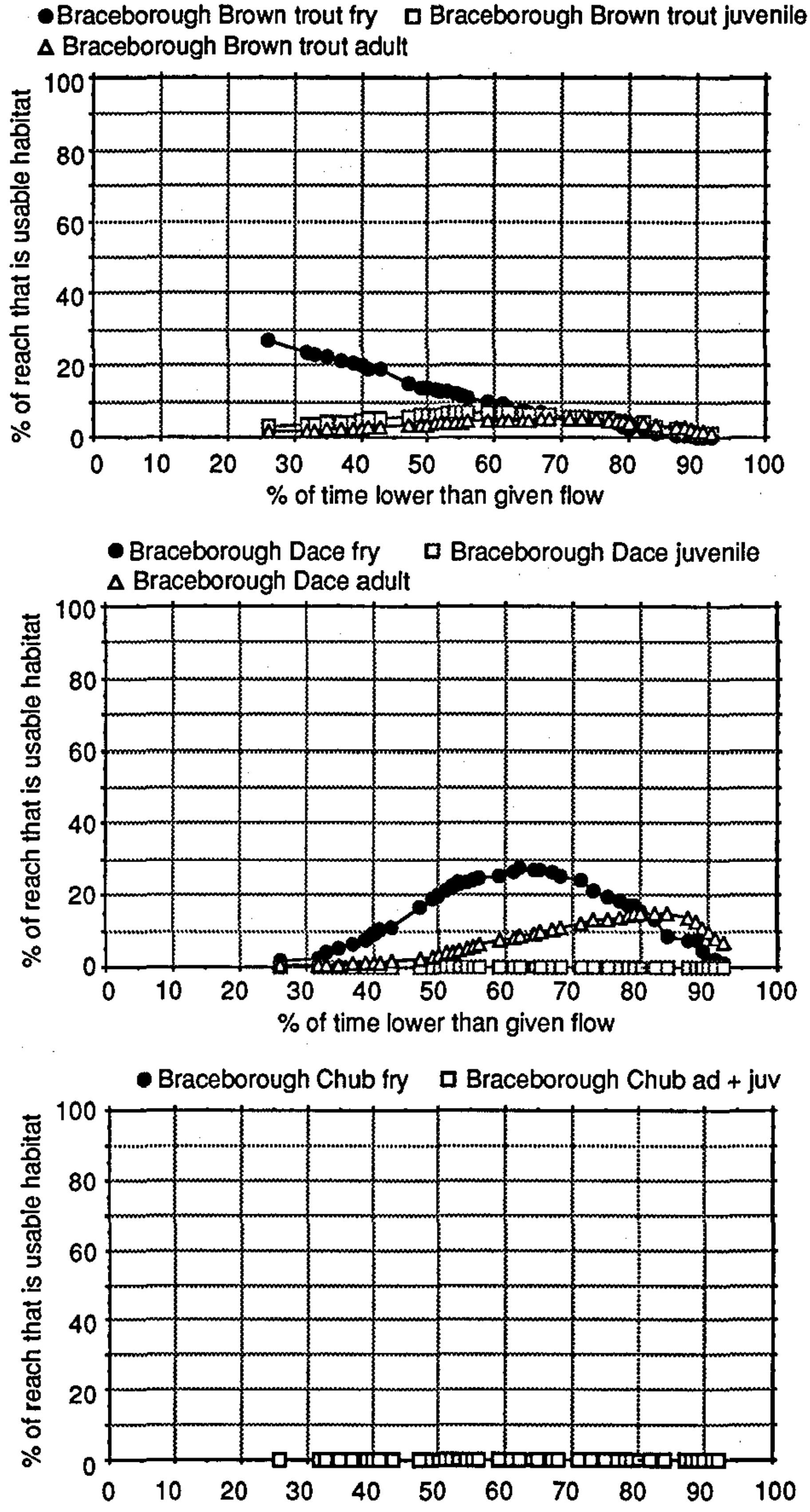


Figure 5.11 - % usable habitat versus discharge relationship for Braceborough

cumecs, i.e. an order of magnitude lower. Consequently, the scale of % of time lower than given flow is used to recognise the relative occurrence of each flow for each site. The following discussion examines each figure in turn moving through the sites in a downstream direction, firstly on the West Glen and followed by the East Glen.

Figure 5.7 highlights the results for Creeton. More habitat is usable by Brown trout fry under the lower flows than any other species for this particular reach. The curves for Dace show an increasing habitat availability with increasing flow and no habitat is available under any of the flows normally experienced for Chub. Similar to Creeton, figure 5.8 shows how the Essendine reach is preferable to Brown trout fry under low flows. However, the actual values are much higher peaking at 84.88%. Values for Dace also increase with discharge and again actual values are much higher than at Creeton. No habitat is usable by Chub. The curve shapes for Brown trout and Dace at Shillingthorpe (figure 5.9) are similar to those at Creeton but the actual amounts of usable habitat are relatively higher. Conversely, habitat usable by Chub is available over a large extent of the discharges albeit in small amounts. On the East Glen at Edenham, the curves show a similar picture with the low flows being more suitable to Brown trout than any other of the selected species. Also Chub habitat does become apparent in small amounts under the high flows. Finally, figure 5.11 shows how there is no usable habitat in the selected reach at Braceborough for Chub and Dace juvenile. Although actual values are low, more habitat is usable to the fry life stages of Brown trout and Dace than any other.

With this description of figures 5.7 to 5.11 it is apparent that three main conclusions can be drawn from their results with respect to the amount of habitat available to each selected species and life stage:

1) most habitat tends to be usable by Brown trout fry under the low flows experienced at each site,
2) habitat availability curves for Brown trout tend to decrease under the higher discharges whereas habitat availability for Dace tends to increase with flow, and
3) 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.

Furthermore, it is apparent that the sites fall into two distinct groups when their results are compared. The first group consists of Creeton, Essendine and Braceborough and all three are characterised by:

1) decreasing habitat available to all life stages of Brown trout under higher flows and
2) no habitat available to Chub.

The second group which contains the remaining sites of Shillingthorpe and Edenham have the opposite characteristics of:

1) maintaining Brown trout habitat at levels of between 10-40% of the reach under the higher flows, and
2) containing Chub habitat albeit in small amounts and only under the high flows at Edenham.

Clearly these latter sites provide more habitat overall for the given flows and life stages used in this study. When a site has little usable habitat it is due to the fact that the hydraulic variables are not suitable to that particular species at that site. In turn these hydraulic variables are determined by the nature of the hydrogeomorphology, i.e. the nature and shape of the bed. Consequently, the bed morphology of the sites within the Glen catchment were examined in order to determine any significant difference between them.

5.2.5 Comparison of bed morphology between sites

Based on the original field measurements, figure 5.12 has been constructed to show the depth variations between each of the sites under the low, medium and high flow. The vertical axis for each chart highlights the number of points in that reach that were counted with the particular value and the horizontal axis describes the depth in feet. 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 much broader spectrum of water depths is apparent including water up to three feet deep at Shillingthorpe. Clearly, this highlights the need for deeper pools in providing habitat over the full range of flows. These provide areas of relatively deeper slack water under the low flows

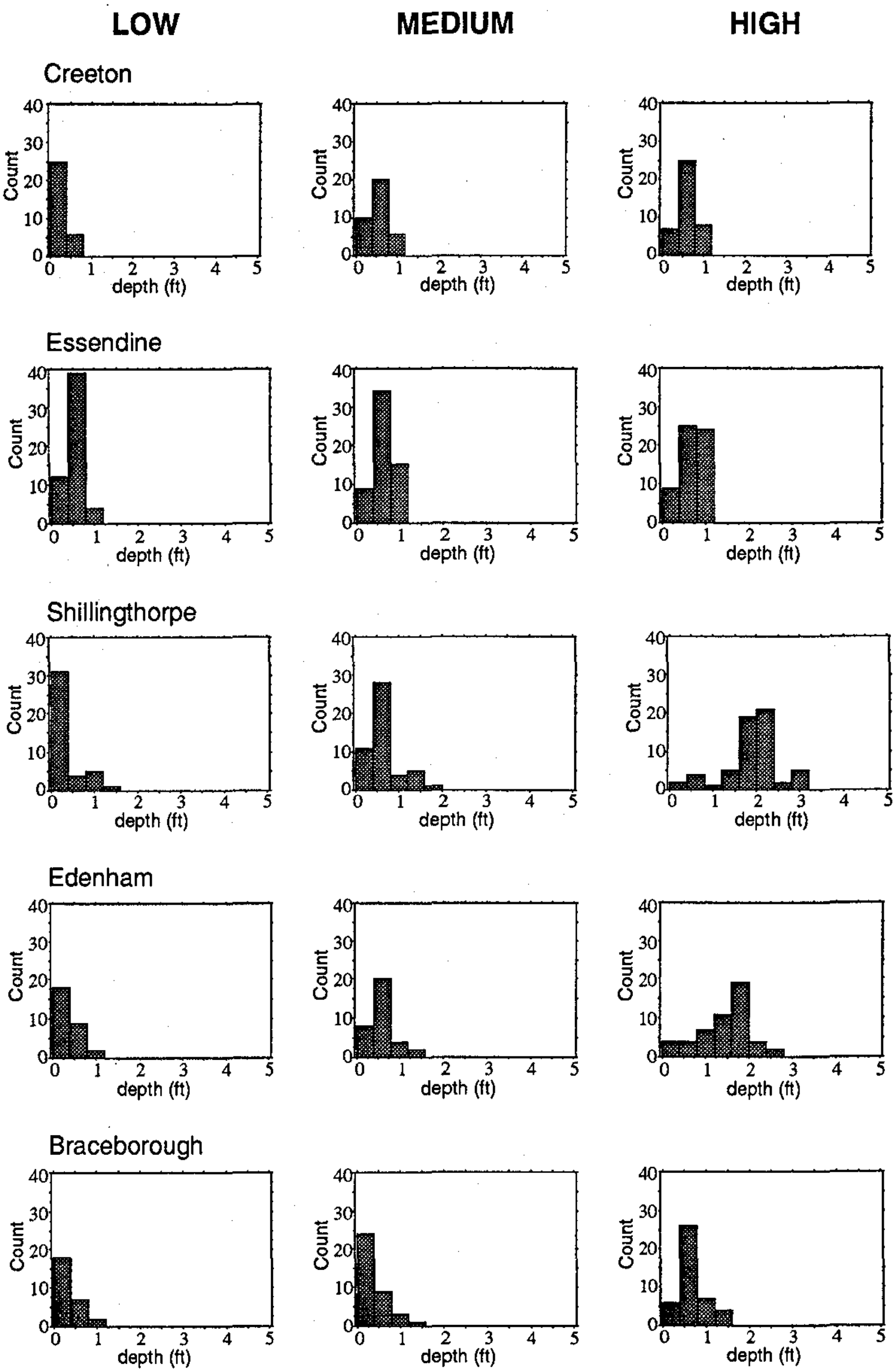


Figure 5.12 - Frequency distributions of depth at each site under low, medium and high flow.

maintaining habitat for species which prefer these areas such as the juvenile and adult life stages of Brown trout, Dace adults and all the Chub life stages. Under higher flows these areas can provide refugia to certain species and a full range of depths provides a mosaic of habitat in terms of depths and velocities and increases the likelihood of a suitable habitat being provided at some particular point. Where there is limited morphological variability, then under the higher flows the reach contains no variability in terms of depths or velocities with fast flowing and relatively shallow water prevailing. This provides habitat for only a limited number of life stages and species.

5.2.6 Conclusions

A physical habitat survey of the entire lengths of the West and East Glen allowed the detailed mapping and quantification of the nature and extent of instream habitat availability for each river. This in turn allowed the development of a habitat method in order to examine physical habitat changes with discharge for an approximately 10 km reach of the West Glen. The positive effect of the Gwash-Glen transfer on the physical habitat was clearly demonstrated by this technique. Finally, a biological response method, i.e. PHABSIM was utilised to determine fish habitat versus discharge tradeoffs at five sites within the catchment. Further analysis of the results generated by PHABSIM has undeniably highlighted the need for areas of deeper water within the main channel to provide habitat for selected species over the full range of flows experienced.

From these studies it has been possible to conclude that the key recommendations for instream habitat management are:-

1) in order for any instream habitat improvement to be effective it is necessary to provide adequate water quality,
2) the increase of low flows is beneficial for the instream biota and so the Gwash-Glen transfer should be operated at maximum levels permissible.
3) reducing low flow channel width would have a positive effect on the biota
4) maintaining and enhancing geomorphological variability along the stream bed will improve habitat quality.

Results suggest that for the upstream sectors of the West Glen and for the majority of the East Glen, while flows continue to reach zero for periods of the year as they have in the past then the opportunities for instream habitat improvement are severely limited. The existence of sluice gates within the reach with adequate flow e.g. at Greatford and Fletland Mill further limit the extent of the river to which habitat improvement could be effectively achieved. Therefore it is recommended that any instream enhancement be concentrated on the stretch of the West Glen between the interbasin transfer outflow point and Banthorpe Lodge as shown in figures 5.13 and 5.14.

5.3 Use of PHABSIM Within the Wissey Catchment

5.3.1 Site selection

The River Wissey, Norfolk is a largely arable catchment underlain by chalk. The underlying aquifer has a long history of groundwater abstraction and as a result, recent worries have been expressed about the potential impact that this may be having on the river flows. As a consequence, the NRA instigated a research and development project to examine the effect of flow variations on the instream habitat. Sites used for PHABSIM evaluation were selected based on an initial physical habitat and hydrological survey of the whole river which defined distinct channel sectors (Petts and Bickerton 1993a). Specific sites were chosen to be representative of the sectors and to coincide with those used for invertebrate sampling as part of the project. For PHABSIM simulation, each site consisted of a riffle - pool - riffle - pool - riffle sequence. Figure 5.15 shows the location of these sites.

5.3.2 Hydraulic data

The guidelines established by Bovee and Milhous (1978) were followed to collect data for the hydraulic simulation models. Seven transects were established along each reach in order to sample the microhabitat variability present at each site. 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. Moving upstream, cross-section two was placed across the centre of a pool, transects three, four and five across the middle riffle, cross-section six across the upstream pool and transect seven across the upstream riffle. Survey markers were placed on either side of the stream at these transects and their exact position surveyed relative to each other. This enabled the accurate mapping of the reach for hydraulic simulation. Stream widths were recorded at each cross-section and the transect profiles were also surveyed. Water depths and velocities were measured using a standard Ott current meter type C2"10.150" across each transect at approximately equidistant points. The number

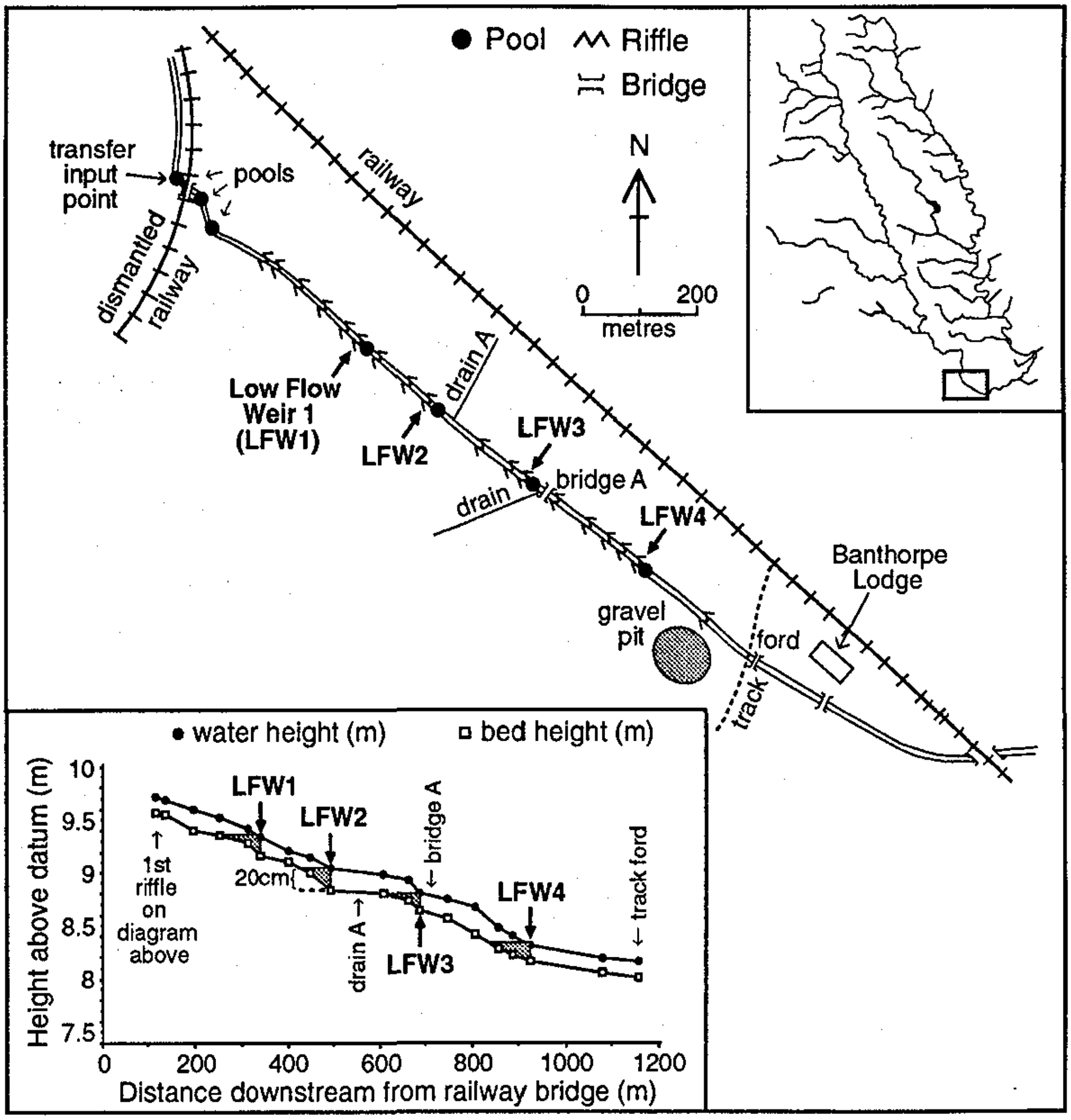


Figure 5.13 - Selected reach for instream habitat improvement on the West Glen near Shillingthorpe with suggested location of low flow weirs and associated pools downstream.

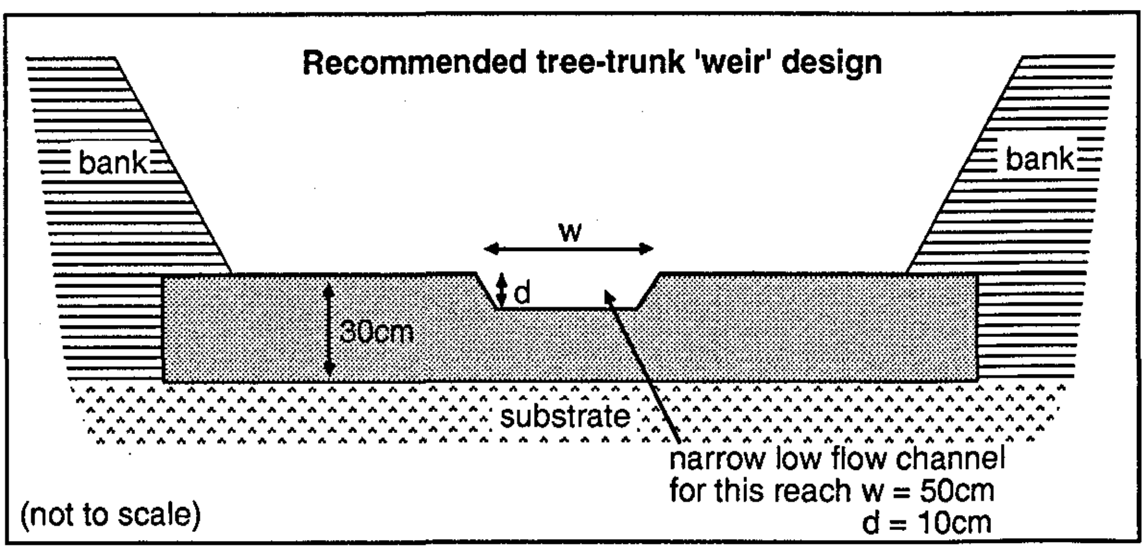


Figure 5.14 - Recommended tree-trunk 'weir' design

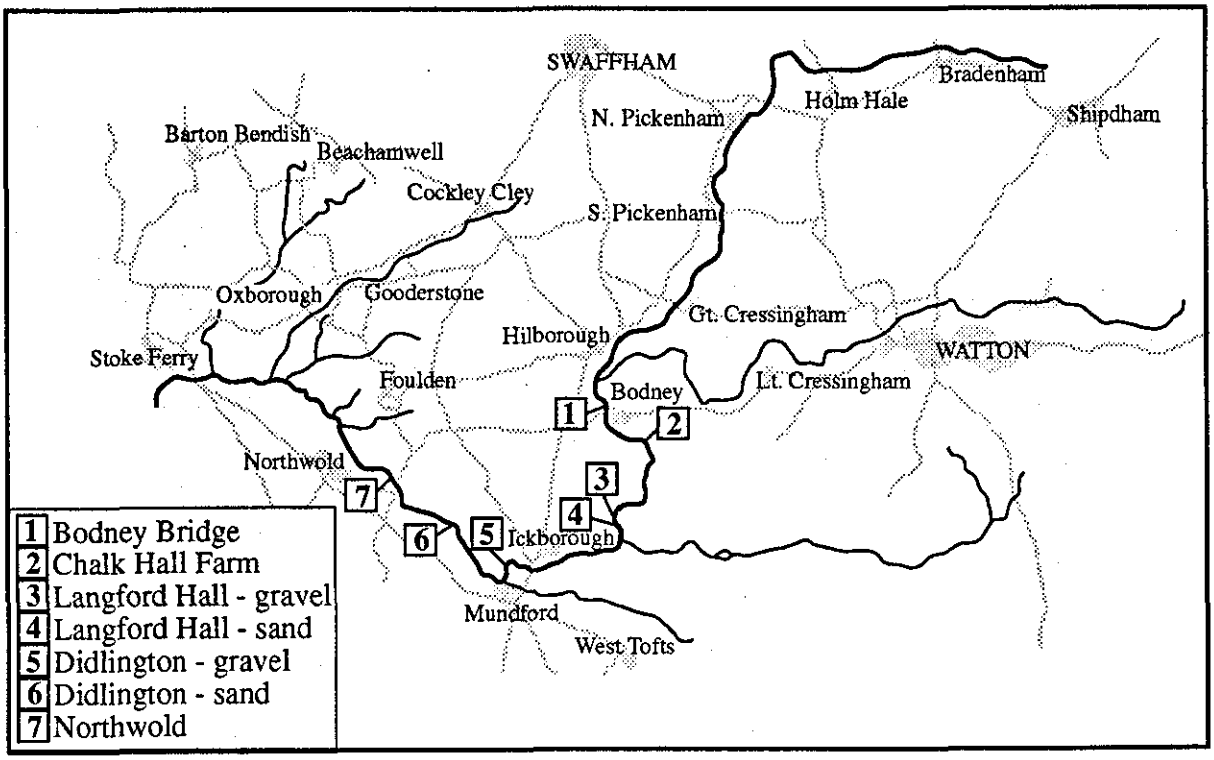


Figure 5.15 - PHABSIM study site location within the Wissey catchment.

Table 5.5 - Discharges at Northwold gauging station during the field surveys at each site - the River Wissey.

SITE NAME	LOW FLOW (cumecs)	MEDIUM FLOW (cumecs)	HIGH FLOW (cumecs)
Bodney Bridge	.225	.749	1.756
Chalk Hall Farm	.225	.749	2.326
Langford Hall - gravel	.225	.711	1.756
Langford Hall - sand	.225	.711	2.326
Didlington - gravel	.231	.705	1.756
Didlington - sand	.234	.701	2.326
Northwold	.234	.705	1.756

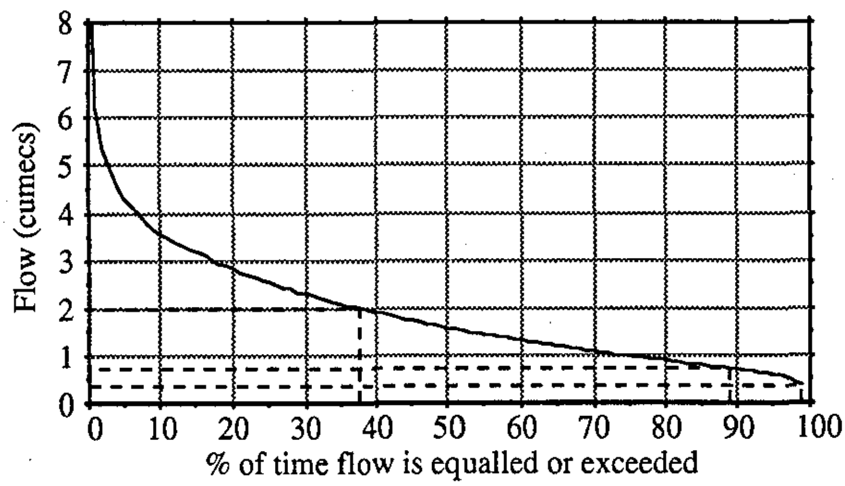


Figure 5.16 - Flow duration curve for Northwold gauging station (1961-1987) and the associated percentiles at which calibration flows were measured.

of measuring points across each transect is shown in table 5.4 below. Each transect is represented by between 15 and 38 points.

Table 5.4 - Number of observation points per transect - the River Wissey

	Transect No.							Max. Wat.
Site	1	2	3	4	5	6	7	Width (m)
Bodney Bridge	19	18	19	20	18	16	17	8.5
Chalk Hall Farm	18	21	19	20	16	16	19	8.0
Didlington Gravel	23	24	38	33	22	18	23	12.5
Didlington Sand	25	25	19	22	23	20	20	10.0
Langford Gravel	23	19	32	31	24	19	20	13.0
Langford Sand	20	18	19	20	21	15	28	12.0
Northwold	25	25	30	28	24	22	28	11.5

Mean velocities were measured at 0.6 times the depth. Substrate type was also recorded for each point based on the presence of Wentworth (1922) grain size categories using the scheme proposed by Trihey and Wegner (1981) and described previously in section 5.2.2.

Each site was visited under three different flows i.e. low, medium and high calibration flows. On each occasion, water surface elevations and velocities were recorded whereas substrate is assumed to be constant and was therefore only recorded on one of the visits. For each stage that was surveyed, the discharge estimates at all cross-sections were averaged to obtain the overall stream discharge. The discharges at each site during the surveys are shown with the associated %ile flow from the nearest gauging station in table 5.5 and figure 5.16. The three flows for which the sites were sampled, successfully covered the majority of the normal flows experienced.

5.3.3 Ecological data

Microhabitat suitability curves utilised in this study were originally developed by Armitage and Ladle (1989) and Mountford and Gomes (1989). The curves themselves were developed based on experience and local knowledge of UK conditions. Curves have been used based on the existing species within the river system evident from the NRA electrofishing and invertebrate surveys. These were:-

• seven species of fish (Brown trout, Dace, Chub, Roach, Bream, Pike and Perch),

• four life stages for each fish species (i.e. spawning, fry, juvenile and adult),

• four species of aquatic invertebrates (i.e. one stonefly (*Leuctra fusca*), two caseless caddis (*Rhyacophila dorsalis* and *Polycentropus flavomaculatus*) and one pea mussel (*Sphaerium corneum*)).

Habitat preferences are expressed in each case as suitability functions of depth, velocity and substrate.

5.3.4 PHABSIM simulation and results

For each site, data was processed through the standard paths described in sections 5.1.1 to 5.1.4 and shown diagramatically in figure 5.4. The flows that are simulated at each site are constrained by certain guidelines laid down by the PHABSIM system based on realistic extrapolations from observed data. For instance, it is not possible to simulate hydraulic conditions under extreme high flows based on the measured data set during extreme low flows. Consequently, simulated flows never fall below 0.4 times the lowest calibration flow or 2.5 times the highest calibration flow. Hydraulic conditions were simulated with a combination of the IFG4 and WSP hydraulic simulation programs. For all habitat simulations, the most widely used multiplicative composite suitability index function was adopted as described in section 5.1.4 and Equation 5.6.

5.3.5 Habitat versus discharge relationships

Output from the PHABSIM simulations were used to illustrate the habitat versus discharge relationships for the selected life stages and species. A full list of these results are shown in Appendix 7. An example of this relationship is shown in figure 5.17 which highlights the results for Brown trout at Northwold. Habitat is expressed as a percentage of the reach that is usable habitat for the chosen species/life stage and discharge is expressed in m^3s^{-1}. From this diagram it is possible to recognise three main features;

- critical flows below which the habitat availability rapidly declines,
- critical flows below which no habitat is available,
- the species and life stages for which the reach is most suitable.

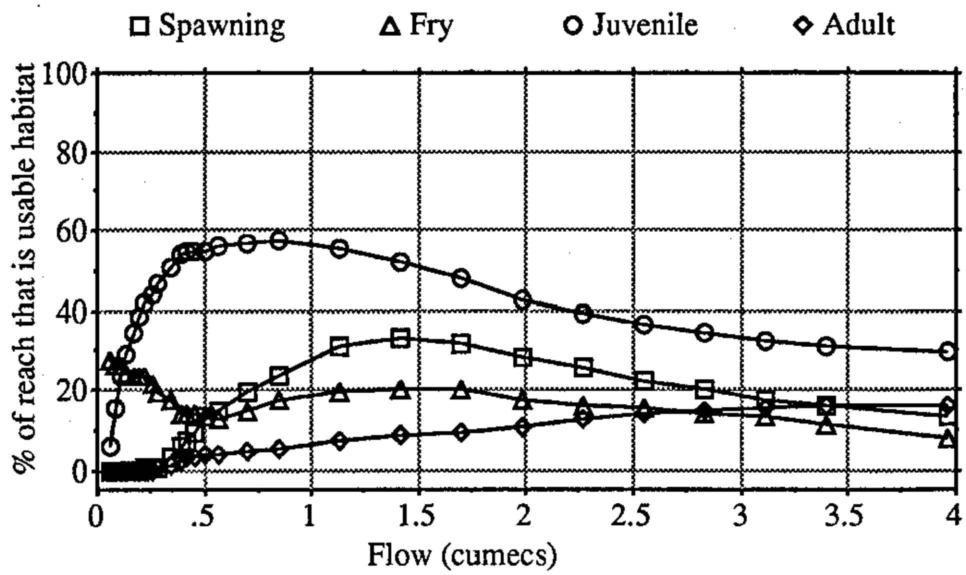


Figure 5.17 - Habitat-discharge relationships for Brown trout at Northwold

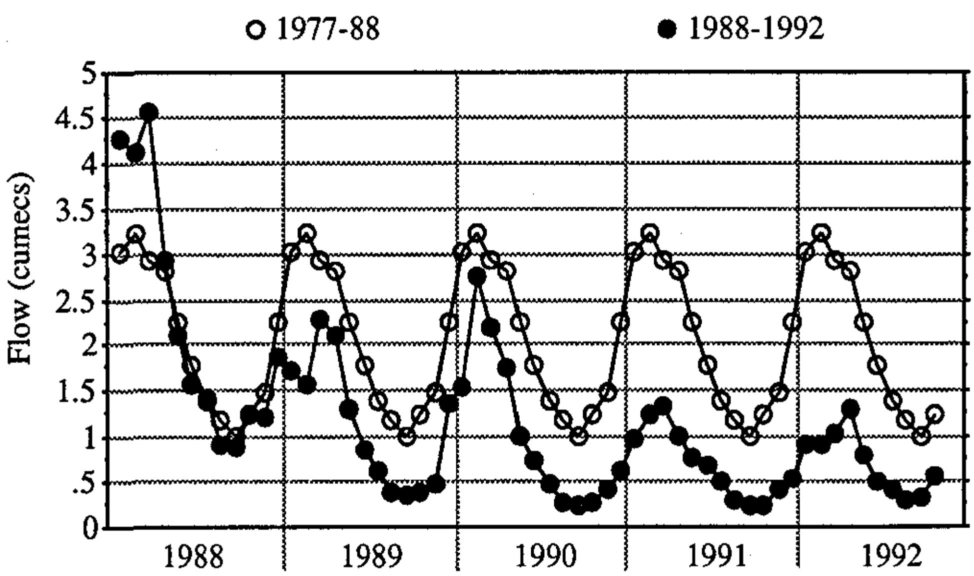


Figure 5.18 - Discharge-time series based on average monthly flows at Northwold

From this example it is evident that the Northwold reach is more suitable for the juvenile life stage of Brown trout but habitat availability rapidly declines below flows of 0.45 m^3s^{-1}. Also, the reach is characterised by no suitable habitat for the adult life stage when flows are below 0.20 m^3s^{-1}.

These relationships highlight critical flows which are essential for the maintenance of habitat for each life stage. Further conclusions can be made when these results are assessed in conjunction with the actual flows that are experienced at the site. Long term average monthly flows, based on the period 1977-88 can be compared to those experienced during subsequent years (1988-92) as shown in figure 5.18. During the 1977-88 period taken as a whole, average monthly flow varied from 3.227 m^3s^{-1} in February to 1.015 m^3s^{-1} in September. In the subsequent years, average monthly flow was consistently below the long term average from October 1988 with a minimum value of 0.228 m^3s^{-1} in September 1991. The following section models the effect of these reduced flows on habitat availability for the selected species.

5.3.6 Habitat area-time series

The results of the discharge versus percent usable area relationships have been combined with the actual discharges experienced during the drought to show the effect these reduced flows have had on habitat area available for each life stage of Brown trout at the Northwold site. Consequently, for this reach figure 5.19 indicates the habitat area-time series for the 1977-88 'average' conditions and for 1988-92 for each life stage of Brown trout.

For spawning:-

- the amount of suitable spawning areas normally ranges from 21% to 49% of the reach,
- spawning areas were available but in reduced amounts during November/December 1990 and 1991,
- flows during January 1991 and 1992 increased to levels which maintained habitat for spawning at long term average conditions.

For fry:-

- a relatively constant proportion of the reach is usable over the majority of the simulated flows (i.e. 15-20%),
- percent usable area actually increases under the lower flows.

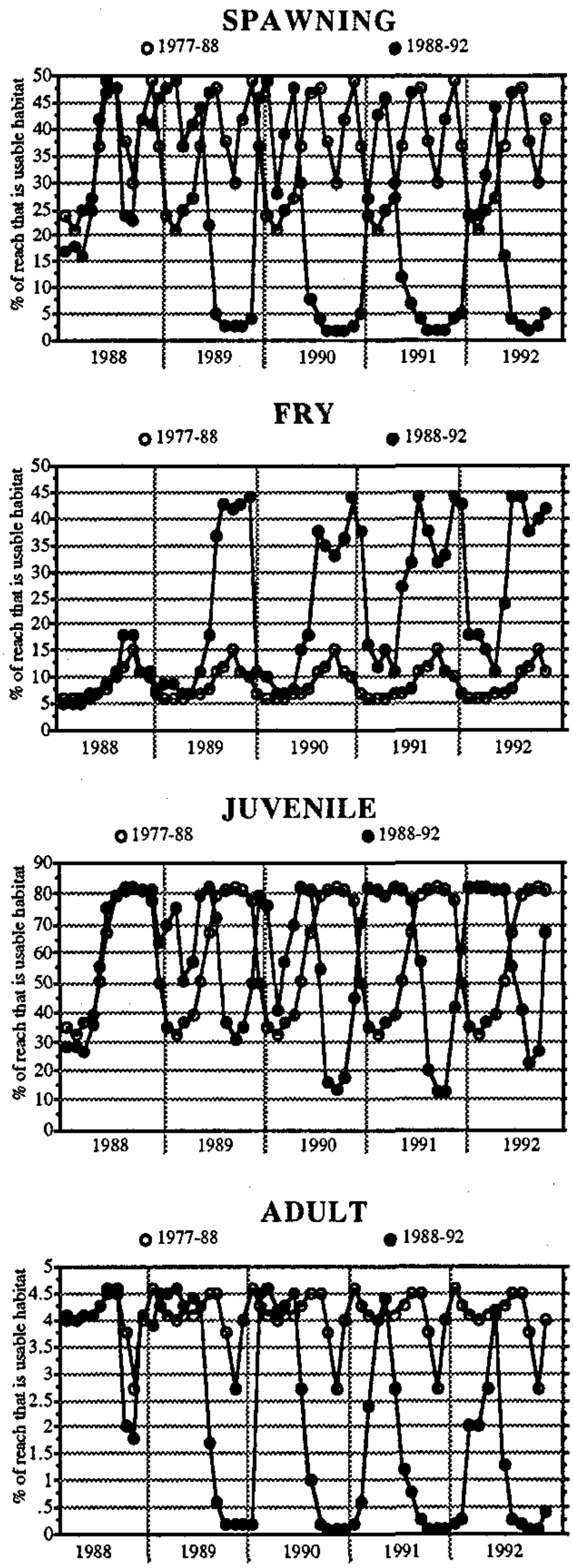


Figure 5.19 - Habitat time-series for Brown trout at Northwold

Thus, the habitat area-time series for the fry life stage shows that the area of habitat available increased during the drought.

For juveniles:-

- under average conditions, % usable habitat varies between 31-81%,
- under the drought conditions usable habitat varied around average conditions except during summer 1990 and 1991 but nevertheless did not fall below 11% of the total reach.

For adult Brown trout:-

- under average conditions, % usable habitat varies between 2.7-4.5%.
- maximum habitat is available during late winter/spring,
- suitable habitat was virtually eliminated during the late summer periods of 1989-1992.

Clearly these diagrams provide information on how the reduced flows have affected habitat availability during the drought period in relation to the long term average. However, they only provide evidence at one of the seven sites and for one of the seven fish species. The following section provides further analysis in order to evaluate the impact of reduced flows on all the other species/life stages and at the other sites.

5.3.7 Habitat availability under reduced flows

Many existing methods (e.g. Tennant 1976, Orth and Maughan 1981) for prescribing minimum flows are based on the premise that the resident biota are adapted to exist during the average low flow conditions experienced in the recent past. Therefore, long term average flows may be used as a benchmark and reductions below this level will exert stress on the natural system. Below this discharge, the shape of the habitat versus discharge relationship is critical in defining whether the selected species/life stage will be adversely affected by reduced flows. This is illustrated by the different curves in figure 5.20. The top four diagrams highlight four different responses to reducing flow below the minimum average monthly flow and these are outlined below. Within each typology it is possible to distinguish responses at a more detailed level, illustrated in the four diagrams in the lower half. The response of habitat availability below 'average' low flow conditions can be characterised as follows;

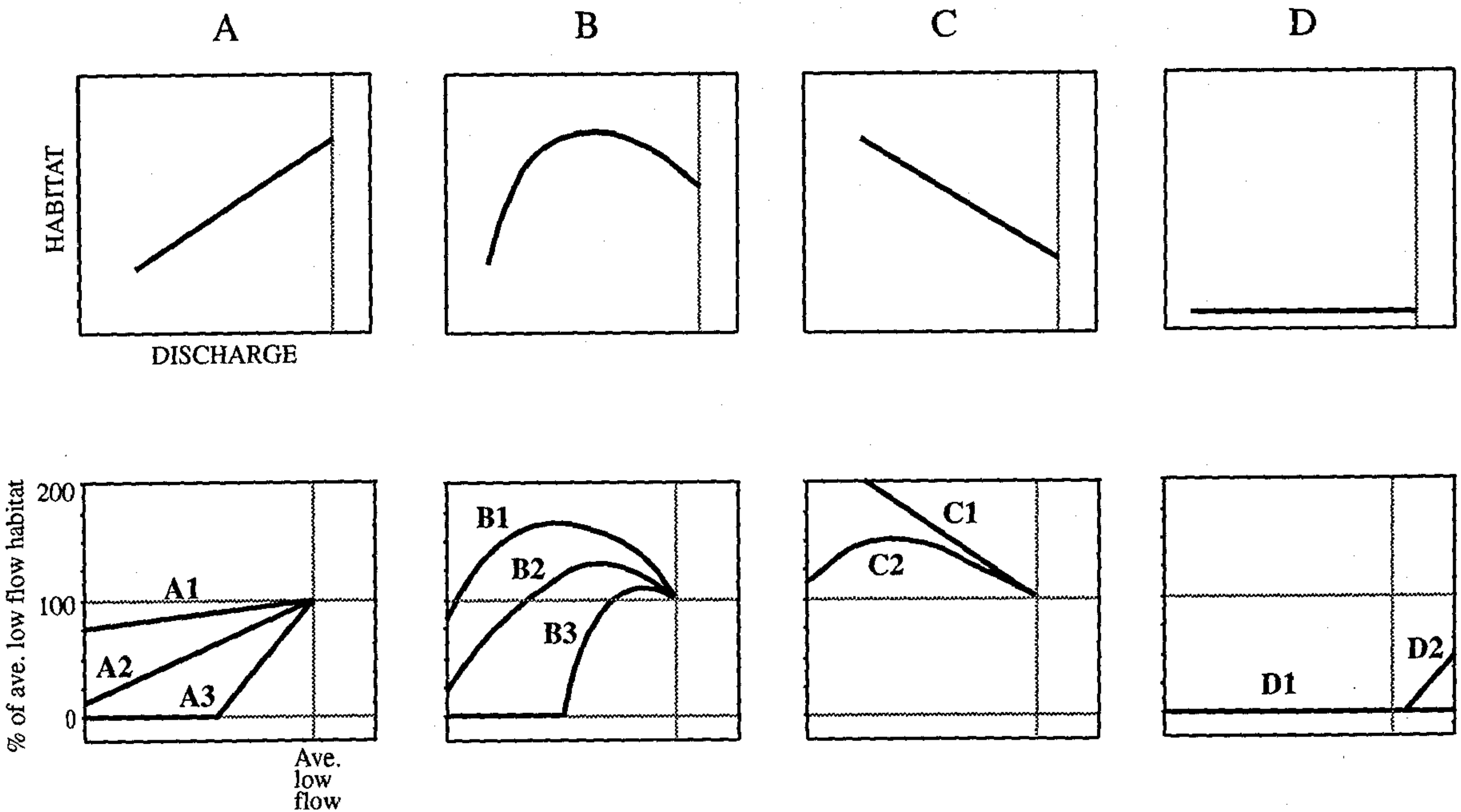


Figure 5.20 - Response of habitat availability under low flows

- **Type A** - reduced habitat
  - A1 slow reduction but maintained above 50% of the initial level,
  - A2 steady reduction with habitat always present but falling below 50% of initial level,
  - A3 rapid reduction with a critical flow below which no habitat is available.
- **Type B** - rise in habitat but falls below initial level at lower flow
  - B1 habitat increases as flow reduces until extreme low flows,
  - B2 initial rise but falls below 50% of initial levels under extreme low flows,
  - B3 initial rise but falls at rapid rate to a critical flow below which no habitat is available.
- **Type C** - habitat remains above initial levels
  - C1 constant rise with reduced flows,
  - C2 habitat falls under lower flows but still remains above initial levels.
- **Type D** - no habitat available below minimum average monthly flow
  - D1 no habitat available even under higher discharges,
  - D2 some habitat becomes available under higher discharges.

Based on this typology, it is evident that certain categories will be more susceptible to reductions in flow below average levels than others. For instance, species with type A responses suffer decreasing habitat availability and are likely to be the most susceptible to these conditions with sub-type A3 being more prone than A1. Within the B category, B3 will be affected in a similar manner as flows fall below a critical threshold. Category C species will not be affected beyond normal low flow level habitat and category D species experiences no habitat at this level.

In order to examine the effect of a reduction in flow below the minimum average monthly flow (i.e. 1.015 m^3s^{-1} at Northwold), each habitat versus discharge relationship was examined and the % usable habitat available at that discharge noted. This value is shown in table 5.6 below. In order to standardise flows at the upstream sites to discharges at Northwold, the current meter gauging data collected during the invertebrate surveys were utilised. This related flows at Bodney Bridge and Chalk Hall Farm at 0.5 of those at Northwold ($r^2 = 0.89$ and 0.88), flows at the Langford sites at 0.6 times the Northwold values ($r^2 = 0.89$) and 0.9 times the levels at Northwold for the Didlington sites ($r^2 = 0.92$). The maximum depth in metres during the medium flow calibration set (whilst flow at Northwold was approximately 0.72 m^3s^{-1}) is also shown to give an indication of the river bed configuration. Didlington Sand has the greatest value at this discharge of 0.6 m and was characterised by a general absence of shallows along the majority of the reach. For each species listed below, the site which provides the greatest proportion of habitat is shown in bold type. Over half (10 of the 19) of the species have the largest proportion of habitat available at Didlington Sand. This is due to these species preferring deep water habitats and the associated nature of this site as described above.

Table 5.6 - Maximum depth and % usable habitat available under minimum average monthly flow.

		Bodney Bridge	Chalk Hall Farm	Lang-ford Gravel	Lang-ford Sand	Did-lington Gravel	Did-lington Sand	North-wold
Max. depth (m)		0.48	0.47	0.50	0.49	0.56	**0.60**	0.53
Brown	fry	16	13.5	35	**40**	27	22.5	15
trout	juvenile	80	55	58	66	66	68	**81**
	adult	2.8	3.2	1.6	2	**4.8**	0	2.8
Dace	fry	**2.4**	0.05	0.8	0.7	1.6	1.5	0.7
	juvenile	22	12.6	29.2	33	31.6	**72**	23.5
	adult	36	18	27	28	37	**69**	32
Chub	fry	0.9	0	0.4	0.03	1.28	**2.1**	0
	adult & juvenile	9	5.5	5.6	5.5	9.5	**35**	6.4
Roach	fry	4	6	**12**	9	10	8	3.5
	adult & juvenile	0.48	0	0.06	0	0.4	**0.82**	0
Bream	fry	0.57	0	**1.85**	0.3	0.2	0.7	0.08
	juvenile	0	0	0	0	0	0	0
	adult	0	0	0	0	0	0	0
Pike	fry	0	0	0	0	0	**1.28**	0
	juvenile	15.6	7.2	17	13.4	14.6	**18.5**	9.6
	adult	2.5	1.0	2.62	2.4	3.3	**8.75**	1.68
Perch	fry	4.2	3.4	**12**	3.2	2.5	7.75	0.95
	juvenile	21.8	6.5	25.6	37.5	19.8	**71**	8.2
	adult	17	5.8	21.6	34	16.4	**70**	9.5

From these benchmark values of habitat availability under 'average' low flow conditions, the habitat versus discharge relationships were examined in order to evaluate each species susceptibility to reduced flows. The results of this is illustrated in figure 5.21 with a key at the top of each page. In each column chart, discharge at Northwold gauging station is indicated on the vertical axis and site along the horizontal axis. Columns shaded in black indicate that at that particular flow, habitat availability is actually higher than under the 1.015 m^3s^{-1} benchmark. Lighter shading indicates reduced habitat with clear sections highlighting flows at which no habitat is available at that particular site for the chosen species and life stage. Each diagram can therefore be used to gauge the response of habitat availability as flow decreases for all species and life stages at each site. The following section outlines the response of each species to a reduction in discharge. The letter in brackets after the species/life stage is given where a curve type can be applied at the majority of sites.

<u>Brown trout fry</u> (C)

Percent usable area actually increases under the lower flows and therefore apart from at Northwold (below discharges of 0.45 m^3s^{-1}) habitat is at increased levels at all sites than at the benchmark flow.

<u>Brown trout juvenile</u> (A2 & B2)

All sites experience reduced habitat below 0.70 m^3s^{-1} and all have less than 50% of the low flow level below 0.28 m^3s^{-1}.

<u>Brown trout adult</u> (A3)

Bodney Bridge has no habitat at the selected flows and all others experience rapidly reducing habitat availability. Habitat is maintained in some proportion at all sites at flows above 0.78 m^3s^{-1}. All adult habitat is lost at all sites when flows fall below 0.20 m^3s^{-1}.

<u>Dace fry</u> (A)

All sites have reduced habitat at flows less than 0.50 m^3s^{-1} and all have less than 50% normal low flow levels below 0.20 m^3s^{-1}.

<u>Dace juvenile</u>

All sites experience reduced habitat below 0.45 m^3s^{-1} with three sites having less than 50% original levels below discharges of 0.14 m^3s^{-1}.

<u>Dace adult</u> (A2)

Reductions in Dace adult habitat are largely uniform at all sites with less than 50% available under 0.27 m^3s^{-1}.

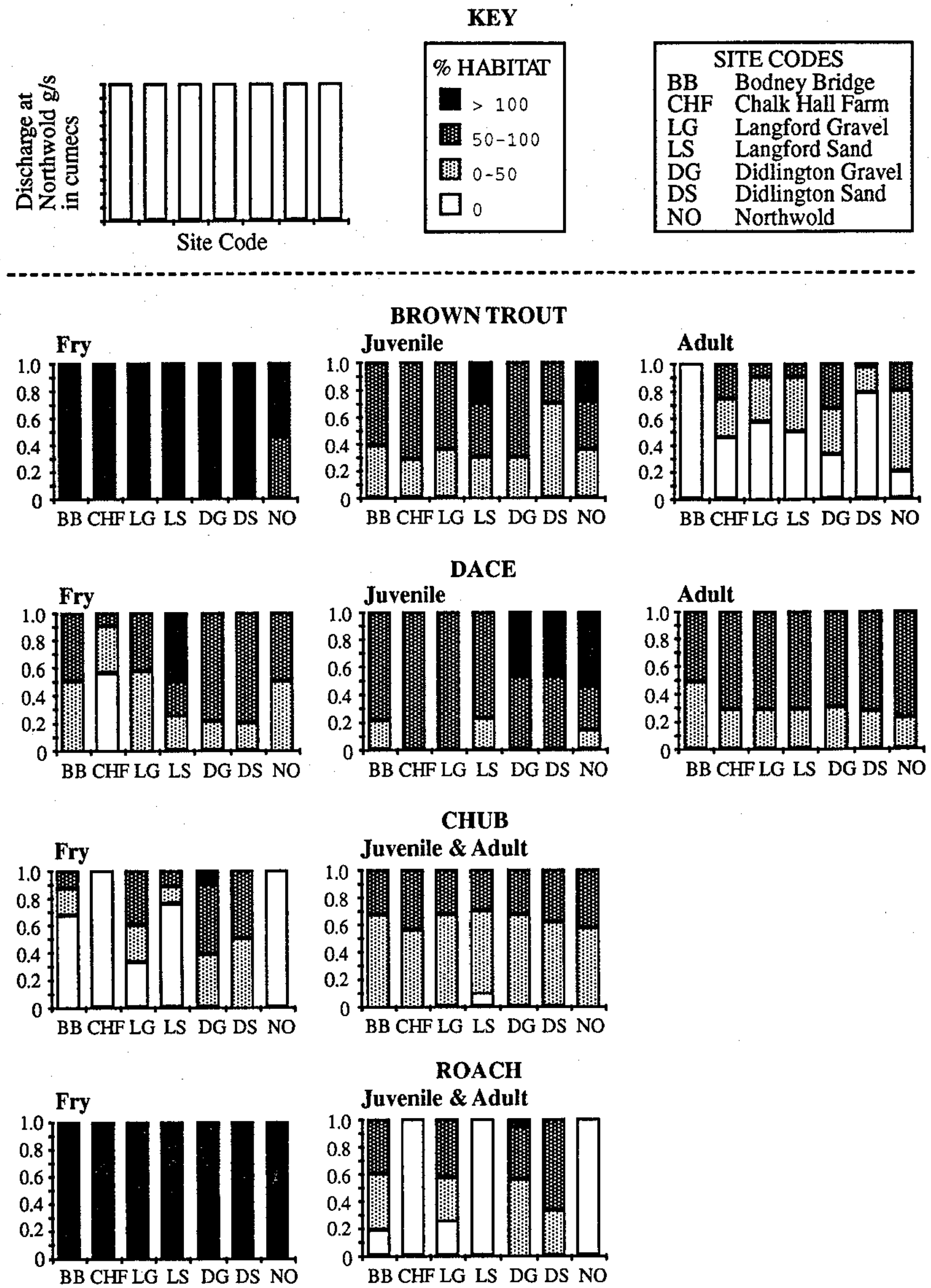
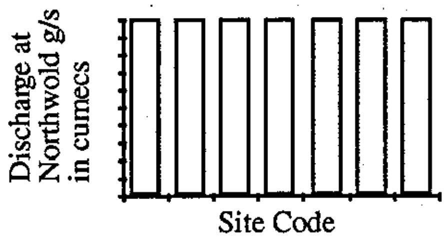


Figure 5.21 - Effect of reduced flows on habitat availability for chosen species/life stages

KEY



% HABITAT

- > 100
- 50-100
- 0-50
- 0

SITE CODES

BB	Bodney Bridge
CHF	Chalk Hall Farm
LG	Langford Gravel
LS	Langford Sand
DG	Didlington Gravel
DS	Didlington Sand
NO	Northwold

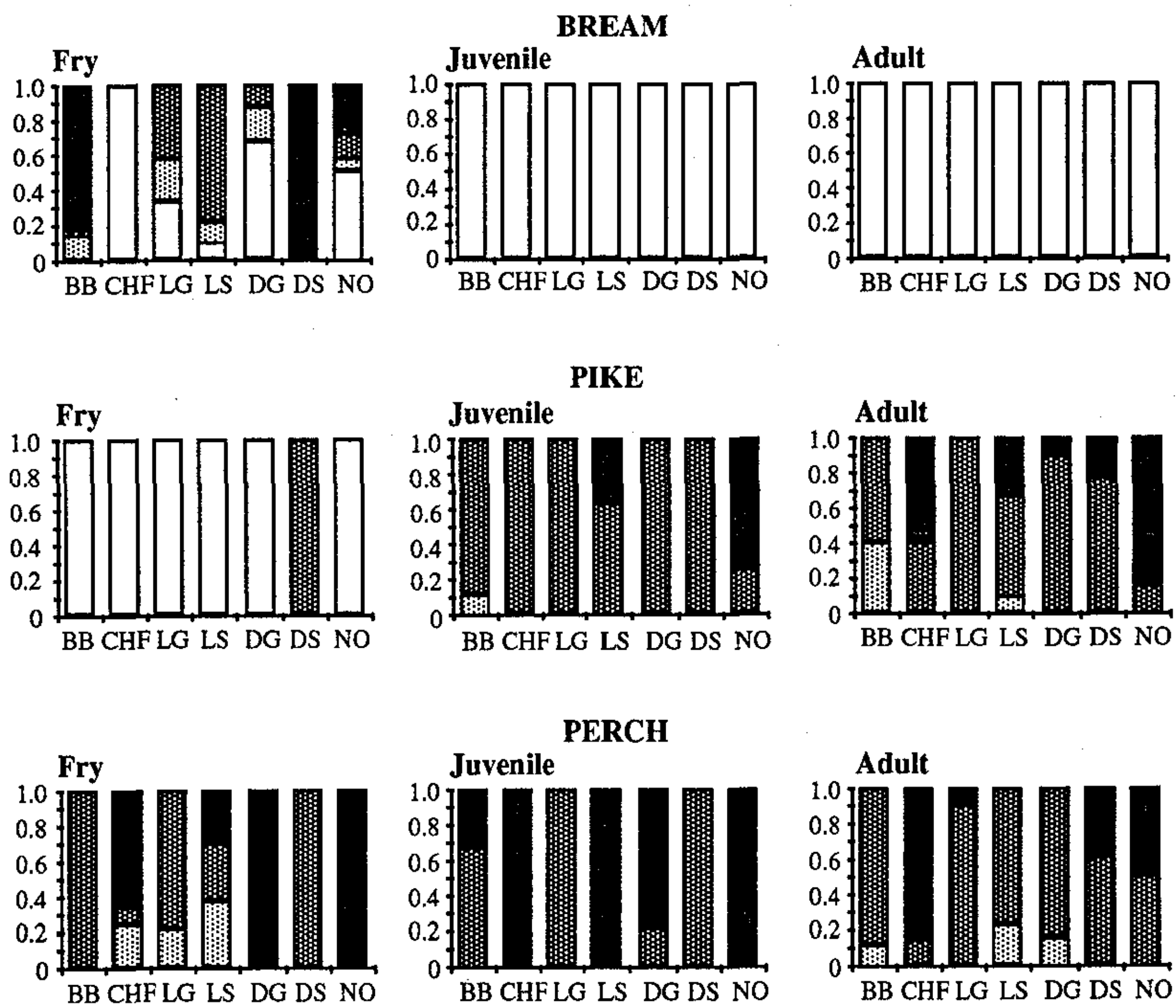


Figure 5.21 contd. - Effect of reduced flows on habitat availability for chosen species/life stages

Chub fry

The first site to lose all habitat is Langford Sand at a critical discharge of $0.75m^3s^{-1}$. Below flows of 0.33 m^3s^{-1}, only two sites maintain some habitat and these occur at less than 50% of the normal low flow levels.

Chub juvenile and adult (A2)

Similar to Dace adult, all experience reductions in habitat with little inter-site differences. A flow above 0.10 m^3s^{-1} is necessary to maintain some habitat at all sites.

Roach fry (C)

Due to their preference for lower velocities and depths, all sites experience greater habitat availability under lower flows and roach fry are not susceptible to flow reduction.

Roach adult and juvenile (A)

Three sites have no habitat availability under the selected discharges. Of the remaining four, a minimum discharge of 0.25 m^3s^{-1} is necessary to ensure some habitat remains available.

Bream fry

This species/life stage experiences very different responses at each site. For instance, at Didlington Sand, habitat remains above low flow levels, no habitat is available at Chalk Hall Farm and rapid reductions to zero habitat are present at Langford Gravel, Langford Sand, Didlington Gravel and Northwold.

Bream juvenile (D)

no habitat available at any site below average low flow values.

Bream adult (D)

no habitat available at any site below average low flow values.

Pike fry (D)

no habitat available at six of the seven sites below average low flow values.

Pike juvenile (A)

All sites experience reduced habitat below 0.25 m^3s^{-1} and a discharge of 0.12 m^3s^{-1} is necessary to maintain habitat above 50% levels at Bodney Bridge.

Pike adult (B)

A discharge of 0.17 m^3s^{-1} is necessary below which all sites experience reduced habitat.

Perch fry

Two sites experience increased habitat over the full range of flows examined whereas three fall below their 50% levels at a discharge of 0.22 m^3s^{-1}.

Perch juvenile

Three sites experience increased habitat over the full range of flows examined whereas four fall below their original levels at a discharge of 0.22 m^3s^{-1}.

Perch adult

Four sites initially exhibit an increase in habitat availability as flow reduce but a discharge above 0.14 m^3s^{-1} is essential below which all sites have some reduction.

5.3.8 Spawning habitat

Habitat versus discharge relationships were also simulated for the spawning requirements of each fish species and the results are shown in Appendix A. From these results, table 5.7 below was constructed to illustrate the discharge necessary to maintain some spawning habitat for each species at each site. As with section 5.3.7, discharges have been standardised and refer to the flows in m^3s^{-1} necessary at Northwold gauging station.

Table 5.7 - Discharge requirements (in m^3s^{-1}) at Northwold gauging station to maintain some spawning habitat.

Species	Bodney Bridge	Chalk Hall Farm	Lang-ford Gravel	Lang-ford Sand	Did-lington Gravel	Did-lington Sand	North-wold
Brown trout	0.66	0.40	0.37	0.57	0.38	1.58	**0.14**
Dace	0.66	0.40	0.42	none	0.83	1.89	**0.14**
Chub	0.44	0.22	0.23	0.18	0.15	0.16	**0.14**
Roach	1.00	0.80	none	none	**0.44**	1.58	0.71
Bream	none	none	none	3.80	none	**0.38**	none
Pike	0.84	4.40	2.40	0.94	0.15	**0.12**	none
Perch	**0.06**	**0.06**	0.09	**0.06**	0.14	0.11	0.14

The minimum discharge necessary to maintain some spawning habitat for each species has been highlighted in bold type. Clearly a discharge of 0.44 m^3s^{-1} is required to maintain some spawning habitat for all species. None of the species normally spawn between July and September and therefore the value of 0.44 m^3s^{-1} is required during the subsequent months.

5.3.9 Habitat versus discharge relationships for invertebrates

Results of the PHABSIM simulations are listed in Appendix 7. Figure 5.22 highlights the discharge versus habitat relationships for the four species of

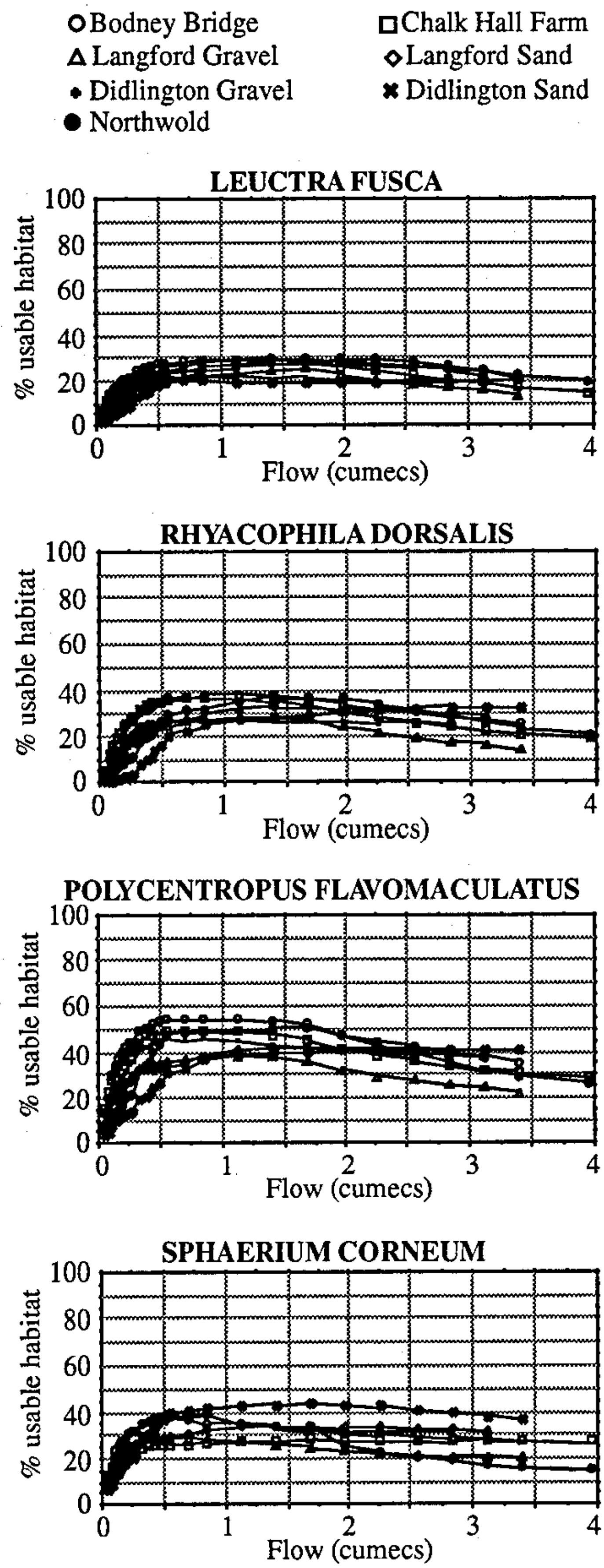


Figure 5.22 - Habitat-discharge relationships for four invertebrate species

invertebrates for each site. In each case, it is possible to define a broad threshold below which the amount of usable habitat rapidly declines. A general threshold below which habitat reaches less than half the optimum values can also be arbitrarily defined. From figure 5.22 it is evident that;

- habitat for *Leuctra fusca* begins to rapidly decline at flows below 0.51 m^3s^{-1} and is reduced to less than half optimum values 0.34 m^3s^{-1}.
- habitat for *Rhyacophila dorsalis* begins to rapidly decline below 0.51 m^3s^{-1} and is reduced to less than half peak values below 0.34 m^3s^{-1}.
- habitat for *Polycentropus flavomaculatus* rapidly declines at discharges at Northwold gauging station of 0.57 m^3s^{-1} and is reduced below half optimum values at discharges less than 0.28 m^3s^{-1}.
- habitat for *Sphaerium corneum* begins to rapidly decline at flows below 0.51 m^3s^{-1} and is reduced to less than half optimum values below 0.31 m^3s^{-1}.

Taken as a whole for the seven chosen sites, the invertebrates selected begin to experience a reduction in the availability of suitable habitat below discharges of 0.51-0.57 m^3s^{-1}. Only half optimum values of percent usable habitat are available as flows decline 0.28-0.34 m^3s^{-1}.

5.3.10 Conclusions and recommendations

Analysis of the availability of suitable physical habitat at seven sites on the River Wissey and for seven species of fish and four species of aquatic invertebrate using PHABSIM suggest that:-

- Brown trout adults will be the most susceptible to reduced flows in the Wissey catchment because they have;
    1) a relatively constant proportion of habitat available under the normal flow regime,
    2) exhibit a rapid decline in suitable habitat at discharges below those normally experienced,
    3) experience total loss of habitat under extreme low flow conditions.

- from those species/life stages that have suitable habitat available under average low flow conditions (1.015 m^3s^{-1}), the first total loss of habitat occurs below a discharge of 0.78 m^3s^{-1} at Northwold gauging station (i.e. for Brown trout adults at Didlington Sand).

- total loss of habitat at all sites for any species occurs at discharges below 0.20 m^3s^{-1} (i.e. for Brown trout adults).

Therefore, PHABSIM results suggest that under ideal conditions, flows should not fall below 0.78 m^3s^{-1} at Northwold gauging station. This would maintain some suitable habitat for all species and life stages that experience available habitat under the normal flow regime. A discharge of 0.20 m^3s^{-1} at Northwold may be considered as an absolute minimum flow, below which a total loss of habitat may be experienced by selected species.

5.4 Use of PHABSIM Within the Babingley Catchment

5.4.1 Site selection

The River Babingley is a small but high quality Chalk stream in north Norfolk, UK, with a good stock of Brown Trout (*Salmo trutta*). In response to increasing demands upon the chalk aquifer for public water supply, an assessment was made of the instream flow needs using both the range of hydrological methods and PHABSIM (Petts and Maddock 1994). One site was selected and deemed to be representative of the sector based on a research and development project undertaken for the NRA by the Petts and Bickerton (1993b). This is shown in figure 5.23. Long term average monthly flows, based on the period 1976-87, compared to those experienced during subsequent years highlight the extent of the recent drought. Average monthly flows peak in March at a discharge of 0.770 cumecs falling to 0.339 cumecs in September (figure 5.24).

5.4.2 Hydraulic data

PHABSIM simulations were undertaken using the standard procedures outlined by Bovee (1982). Point measurements of water surface elevation, depth, velocity and substrate size were recorded at 50 cm intervals across each of the five transects under three flows. Corresponding flows at Castle Rising gauging station on each occasion were 0.115 m^3s^{-1}, 0.147 m^3s^{-1} and 0.273 m^3s^{-1} on the 16/10/92, 18/12/91 and 30/3/92 respectively. These flows correspond to Q_{99}, Q_{96} and Q_{77} based on the flow duration curve for the period 1963-1992.

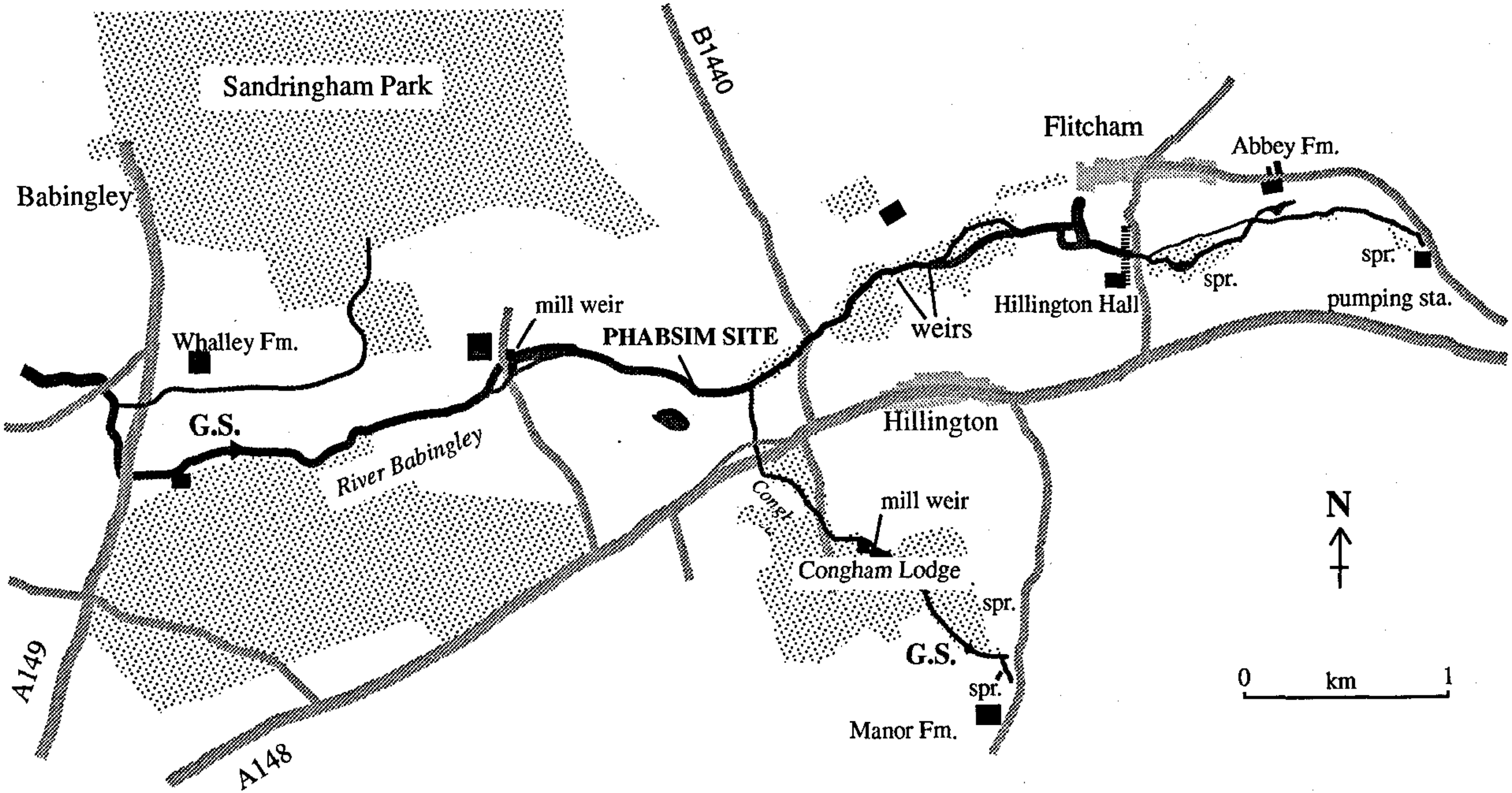


Figure 5.23 - PHABSIM site location within the Babingley catchment.

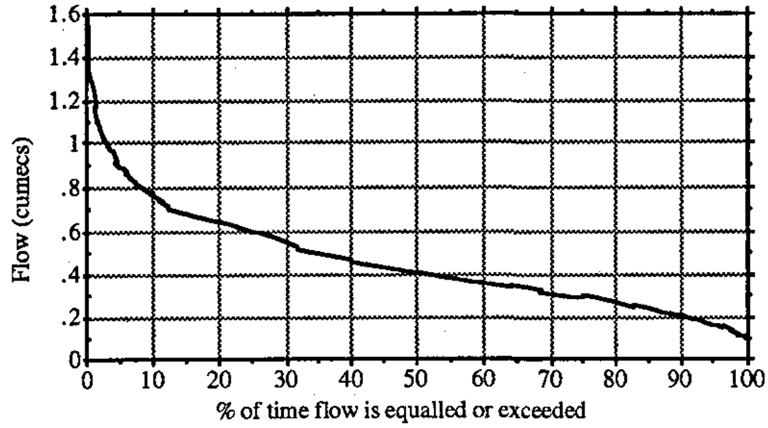


Figure 5.24a - Flow duration curve (1963-92)

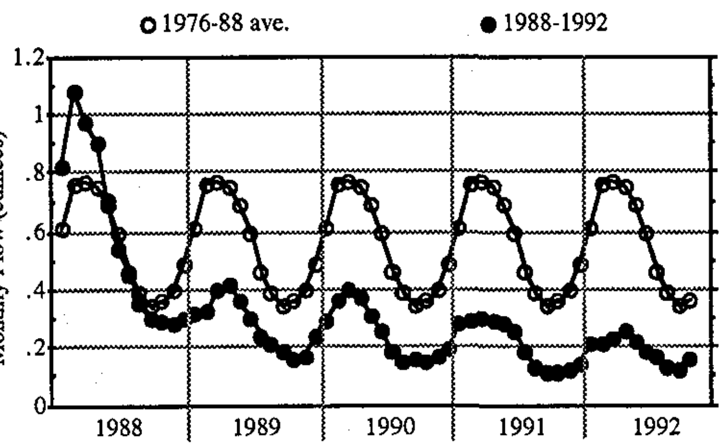


Figure 5.24b - Average monthly flows

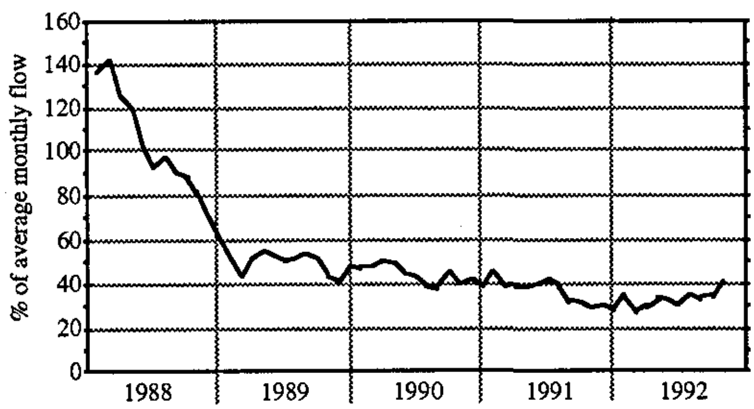


Figure 5.24c - Actual monthly flows as a % of long term (1976-87) average

These data were then input into the PHABSIM software and computer simulations carried out to examine the hydraulic characteristics of the reach under a full range of flows normally experienced at the site using a combination of the IFG and WSP programs.

5.4.3 Ecological data

Habitat suitability versus discharge relationships were then calculated using PHABSIM utilising habitat suitability curves created by Armitage and Ladle (1991) for:

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

5.4.4 PHABSIM simulation and results

Results are shown for Brown trout and invertebrate simulations in Figure 5.25a and 5.25b. The results for trout suggest that

- a greater proportion of the reach is usable habitat for the fry than any other life stage;
- there is little usable habitat for the adult life stage (due to the lack of deep pools with good flow within the reach) for the majority of flows and none below 0.28 cumecs; and
- clear reductions in usable habitat can be defined for each life stage when flows fall below critical levels, i.e.
    - below 0.09 m^3s^{-1} for fry
    - below 0.17 m^3s^{-1} for juvenile
    - below 0.28 m^3s^{-1} for spawning
    - below 0.28 m^3s^{-1} adult habitat reaches zero

Figure 5.25b describes the results for the selected invertebrates. These suggest that there is approximately double the amount of habitat available for *Polycentropus flavomaculatus* and *Sphaerium corneum* than *Leuctra fusca* and *Rhyacophila dorsalis*. Similar to the results for Brown trout, clear reductions of habitat availability are evident below a critical discharge. In this case however, all species show a reduction below the same discharge: 0.127 m^3s^{-1}.

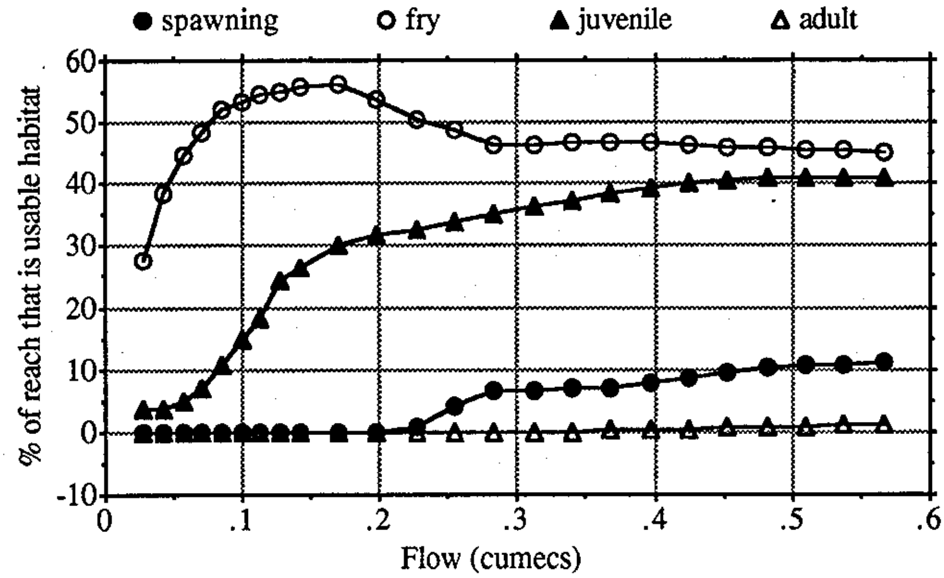


Figure 5.25a - Discharge versus habitat relationships for Brown Trout

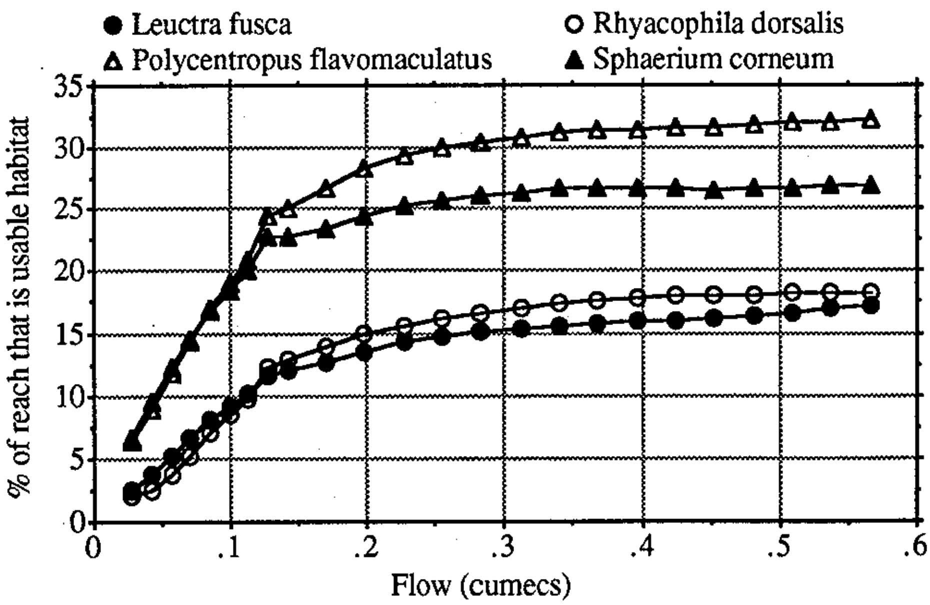


Figure 5.25b - Discharge versus habitat relationships for four species of invertebrates

These relationships highlight critical flows which are essential for the maintenance of habitat for each life stage. Further conclusions can be made when these results are assessed in conjunction with the actual flows that are experienced at the site. Long term average monthly flows, based on the period 1976-87 can be compared to those experienced during subsequent years (1988-92). The following section models the effect of reduced flows on habitat availability for the selected species.

5.4.5 Habitat area-time series

The results of the discharge versus percent usable area relationships have been combined with the actual discharges experienced during the drought to show the effect these reduced flows have had on habitat area available for each life stage of Brown trout. Consequently, for this reach Figures 5.26a - 5.26d indicate the habitat area-time series for 'average' conditions and for 1988-92 for each life stage of Brown trout.

For spawning:-

- the amount of suitable spawning areas remained below average conditions for the whole period after June 1988,
- spawning areas were available but in reduced amounts during December/January 1989/90 and January 1991,
- flows during winter 1991/92 provided no suitable habitat for spawning.

For fry:

- a large proportion of the reach is usable over the majority of the simulated flows,
- percent usable area actually increases under the lower flows before rapidly declining below 0.09 cumecs.

Thus, the habitat area-time series for the fry life stage shows that the initially large area of good habitat increased during the drought.

For juveniles:-

- under average conditions, % usable habitat varies between 37-41%,
- under the drought conditions usable habitat was consistently below average conditions but nevertheless did not fall below 15% of the total reach.

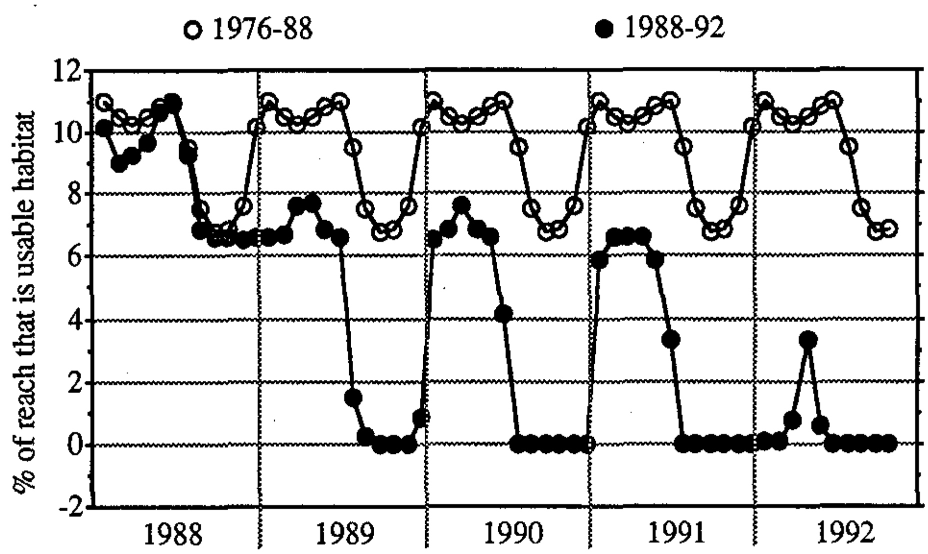


Figure 5.26a - Habitat area-time series for Brown trout **spawning**

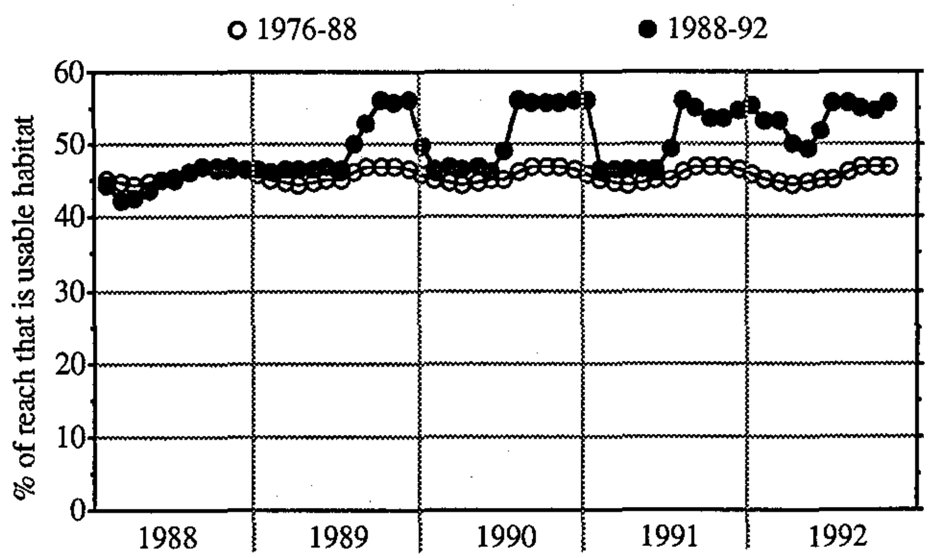


Figure 5.26b - Habitat area-time series for Brown trout **fry**

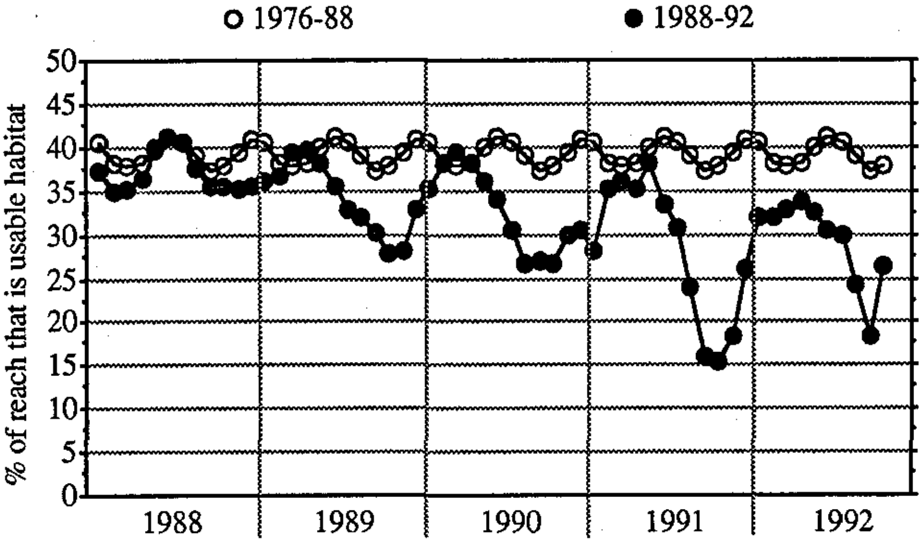


Figure 5.26c - Habitat area-time series for Brown Trout **juvenile**

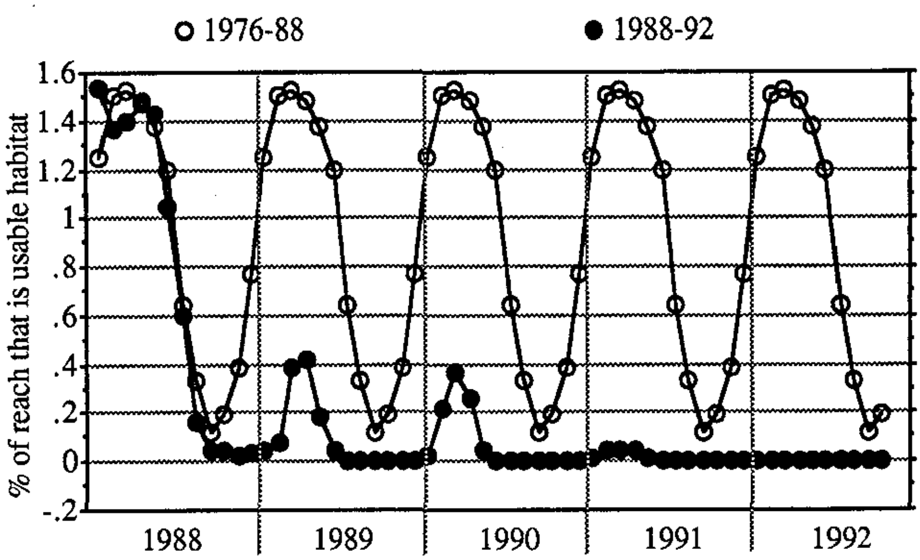


Figure 5.26d - Habitat area-time series for Brown Trout **adult**

For adult Brown trout:-

- maximum habitat is available during winter/spring,
- suitable habitat was reduced to 25% of that available under average conditions during the spring of 1989 and 1990,
- little habitat has been available since mid-1990.

5.4.6 Impact analysis using habitat duration curves

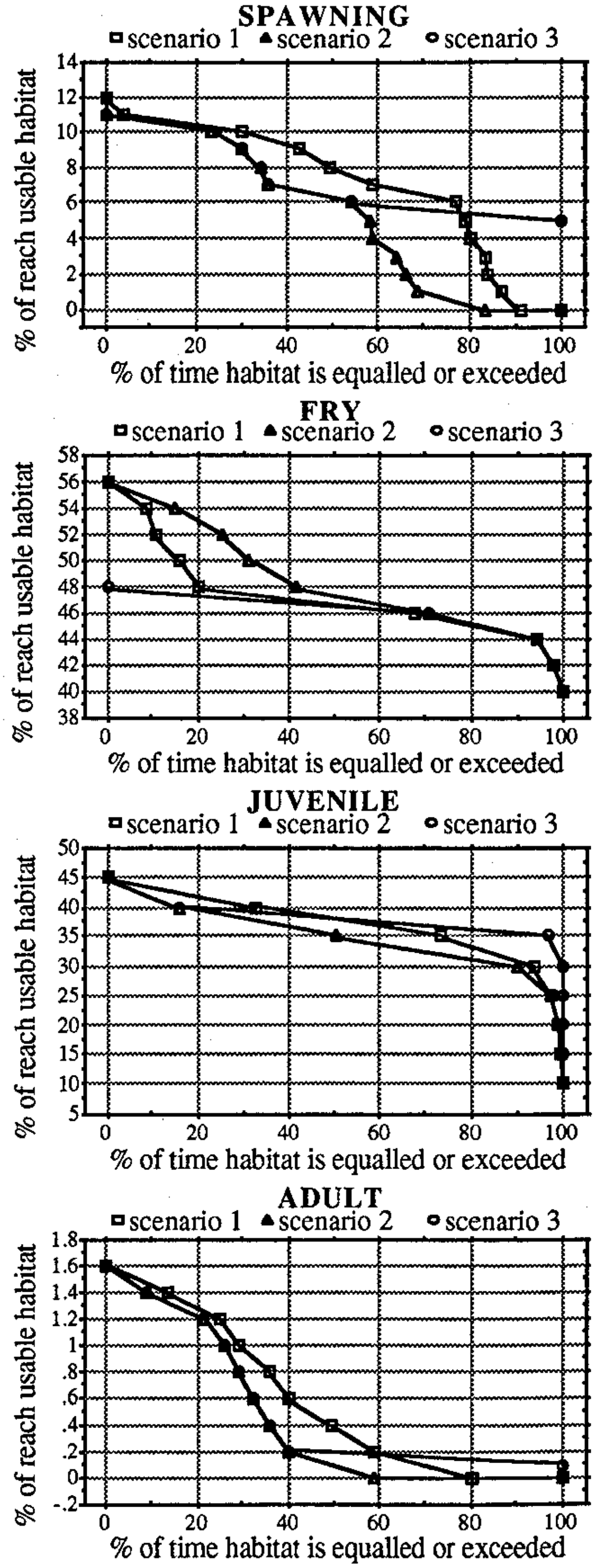
A habitat duration curve is a cumulative frequency plot that shows the probability of a certain amount of habitat being equalled or exceeded during a given time period. The percent usable habitat versus discharge relationship can be bell-shaped resulting in two or more discharges, each with different probabilities of occurrence, producing the same total amount of habitat (e.g. the curve for Brown trout fry in Figure 5.25a).

Figure 5.27 shows the habitat duration curves for the four life stages of Brown trout in the River Babingley at site G. Each diagram shows three curves:-

- one based on the flow duration statistics for the period 1963-92;
- a second based on a curve with the same Q_{10} (0.761 m^3s^{-1}) and Q_{95} (0.157 m^3s^{-1}) values but with average daily flow (0.455 m^3s^{-1}) reduced by 30%; and
- a third based on a curve with the same Q_{10} (0.761 m^3s^{-1}), Q_{95} augmented to reflect a maintained minimum flow of 0.283 m^3s^{-1} as recommended in Section 4.3.3. and with average daily flow (0.455 m^3s^{-1}.) reduced by 30%.

The areas of greatest interest beneath the curves lie in two areas. The first area is the portion representing probabilities of exceedance between 50% and 95%. The median habitat value has biological significance because it represents a measure of central tendency. Habitat values with exceedance probabilities greater than 95% may be considered to represent extreme conditions of limited habitat and are by definition, rare events. The second area is the amount of time that habitat values are at their lowest or equal to zero.

Spawning Habitat:- it is evident that a significant amount (25%) of suitable habitat is lost between the 50th and 95th percentiles due to the proposed reduction in average daily flow. Furthermore, spawning habitat reaches zero for 10% of the time under present conditions but would occur for approximately 18% of the time with reduced flows.



Scenario 1 - based on existing flow duration curve (1963-92)

Scenario 2 - based on flows with 30% reduced mean flow but identical Q10 & Q95

Scenario 3 - based on flows with 30% reduced mean, identical Q10 & 0.28 cumecs minimum flow

Figure 5.27 - Brown trout habitat duration curves for three scenarios

Fry:- it is evident that the proposed flow scenario has shifted the curve to the right. Impacts on fry habitat would be very minor with small increases in available habitat under the reduced flow regime.

Juvenile:- habitat would be reduced under the low flow scenario but by relatively insignificant amounts. For instance, median habitat values would change from 38% to 35% of the reach.

Adult:- the most critical change in habitat would be experienced by the adult life stage. Under existing flows, 0.4% of the reach is usable at the 50th percentile and habitat reaches zero for the final 20% of the time. However, under reduced average daily flows, the 50th percentile habitat value would be reduced to 0.1% and zero habitat would be experienced for approximately 42% of the time.

5.4.7 Conclusions

PHABSIM simulations suggest that at site G:

- suitable spawning habitat rapidly declines at flows below 0.28 m^3s^{-1},
- usable habitat for adults is only available at flows above 0.28 m^3s^{-1} and
- over 40% of the reach is consistently usable for fry and over 32% of the reach is consistently usable for juveniles at flows over 0.28 m^3s^{-1}.

Therefore an absolute minimum flow of 0.28 m^3s^{-1} at Castle Rising gauging station is recommended to maintain physical habitat conditions for the Brown trout populations within the River Babingley.

Reducing average daily flow by 30% but maintaining Q_{10} and Q_{95} at existing values would:-

- slightly increase Brown trout fry habitat,
- slightly reduce habitat for Brown trout juveniles,
- restrict spawning habitat,
- increase availability of zero habitat for adults from 20% to 42% of the time.

Reducing average daily flow by 30%, maintaining Q_{10} at existing values and maintaining a minimum flow at 0.28 m^3s^{-1} would:-

- sustain spawning habitat at 40% of the maximum available habitat;
- not affect fry, which are high-flow limited;

- double habitat for juveniles under normal extreme low flow conditions; and
- sustain some, albeit limited, habitat for adults over the full range of flows.

5.5 Summary

Essentially, the IFIM process using PHABSIM is used to relate changes in discharge or channel structure to changes in physical habitat availability for a chosen species. Examples from this study have highlighted its use in a traditional sense to define optimum and critical flows for selected target species for the River Glen, Wissey and Babingley. The PHABSIM model has been criticised on a number of points and these have already been mentioned previously. These are summarised in Appendix 9. Due to these uncertainties, it is recommended that PHABSIM is used to define optimum flows, the rate of changes in habitat between different flows, and the designation of critical discharges where habitat availability reaches zero. Actual values in habitat, either expressed in WUA per thousand feet of stream, or percentage of the reach usable, cannot be advocated with total certainty due to the inherent number of possibilities available during simulation (Gan and McMahon 1990). The development and validation of dynamic fishery population models including response to flow-related limiting events is still a research goal and as such it is not known what difference a habitat availability of 65% will have when compared to one of 80% for instance (Stalnaker 1994). The potential use of habitat time series analysis has also been demonstrated.

By using recent historical hydrological time series coupled with habitat-discharge relationships determined by PHABSIM for the site under consideration, the effective habitat time series can be used to identify limiting times in terms of habitat availability. This can be used to highlight the reasons for poor year classes or unusually low survival of adults as illustrated with the River Babingley study. Further potential use in the future lies with the assessment of alternative or competing flow scenarios for proposed developments.

The model has also been utilised to highlight the importance of bed morphology in the provision of habitat. Detailed information from the River Glen has demonstrated its use to help solve two important questions. Firstly it can help define those areas in most need of habitat restoration. Sites with low percentage habitat availability for a range of species is indicative of morphological homogeneity. Secondly it can highlight which specific features of morphology are the limiting ones i.e. inadequate pool depths or lack of shallow water provided by riffle habitats. This is equally as important as it will determine the potential recommendations that may be made in relation to habitat modification strategies. These could take the form of structural modifications to streams including artificial cover devices, deflectors, and weirs. Nonstructural modifications include deepening pools, raising the elevation of riffles, importing special substrate materials, or otherwise increasing bed profile diversity without the use of structures. This is another demonstration of the need for an understanding of fluvial geomorphology as the investigator must evaluate the structures in terms of their effectiveness in improving habitat, the frequency with which they must be replaced, installation and maintenance cost, and the chances of increased flood potential.

In future, it is envisaged that PHABSIM will undergo further refinement and development, both in terms of linking the physical habitat results with population dynamics and the refinement of data requirements. Discharge and channel structure combine to define the range of physical microhabitat conditions available to a species. The appropriate use of PHABSIM will enable the investigator to assess instream flow requirements in conjunction with morphology, and recommendations may involve the alteration of both elements to maintain or enhance habitat, perhaps shifting the emphasis away from the flow aspect to the morphological component as the demand for water continues to grow.

CHAPTER 6 - CONCLUSION

Since 1970, physical geography has moved towards a more applied approach, particularly in relation to management of the environment. As a consequence of this and indeed the nature of environmental research, the emphasis has moved more and more towards a multidisciplinary stance. The involvement of the physical geographer in river management from a research standpoint is a good example of these developments (Gregory 1987) although application of the results has tended to be slow.

Growing demands for water supply mean that schemes for river regulation, water abstraction and inter-basin transfer will continue to be advanced. Simultaneously, the strengthening of demands for environmental protection will require that improved approaches are developed for assessing the impacts of water resource schemes and especially for allocating water to in-river needs. A situation of increasing demands for irrigation, domestic, and industrial water supply has been evident in the U.S.A. since the mid 1970's and led to the development of a variety of methods to assess fish habitat tradeoffs against other uses of water. A similar situation is now materialising in the U.K. These methods rely on differing techniques and levels of reconnaissance and can be arranged from simple to complex. The first, namely rapid assessment techniques, involve making a physical characterisation of the channel based on a predetermined inventory and are used to provide a yardstick for assessing habitat quality and setting minimum flow requirements. The second type, namely biological response techniques, require a much more detailed approach and employ habitat suitability criteria for target species to develop a relationship between habitat variables and biota.

A host of techniques are described and developed in this study ranging from a simple reconnaissance survey to the detailed PHABSIM in order to establish a method for the classification of river channels, identification of key parameters that determine the biota and assessment of the influence of flow and bed morphology on habitat availability. In many situations in the past, one technique has been selected and applied to define habitat availability and flow requirements. More rarely, a combination of approaches is used. Results indicate that in fact, one interpretation technique may complement or supplement another so the investigation has a variety of options to choose from. The goal of any interpretative technique is to make it easier to solve problems. The law of diminishing returns can operate at any level of analysis; i.e. a more complex analytical technique such as PHABSIM (Bovee 1982) may not result in a better or easier solution than would a simpler technique such as the Montana method (Tennant 1978). The essential difference between simple and complex techniques is that simple techniques are usually based on one or two large assumptions. Complex solutions may require more, but usually smaller, assumptions. Therefore, the investigator should understand three things before selecting an interpretative technique:

- the complexity of the problem
- the complexity of the solution technique, and
- the assumptions inherent to the solution technique.

The best interpretative technique for a problem is the one that provides an insight into the problem and suggests a solution without requiring assumptions the investigator is unwilling to accept or defend. Subjective intuitive assessment may be the only option in some circumstances, but other studies (e.g. Milner et al 1985) have demonstrated that a low level of precision is likely with such evaluations, particularly when carried out over a range of stream types. However, precision costs money although their increased level of accuracy by applying more complex methods may well provide an increased level of cost-effectiveness. In selecting an appropriate method the manager must decide what level of uncertainty they are willing to accept in the final recommendations. Guidelines must be developed for determining whether quantitative or qualitative approaches are to be used. Ultimately this choice will depend on the purpose of the study and the sensitivity required. This study has described and developed a variety of approaches and detailed their use in specific situations. In particular, it has highlighted:

- development and application of a method for the designation of channel types, sectors and reaches to ensure management objectives are applied at an appropriate scale
- the use of a reconnaissance level survey to highlight the geomorphological status of the stream or river for habitat provision
- an empirical model method to identify key parameters that determine the instream biota
- application of PHABSIM for defining flow requirements and evaluating the importance of bed morphology for the provision of usable habitat.

Recommendations can now be made in relation to their use as part of an integrated framework or as individual methods.

6.1 Classification

A river may be considered across a spectrum of scales, each with a different degree of sensitivity and recovery time (Frissell et al 1986). The first step for establishing an instream flow regime and defining representative sites for more detailed study must be the description and definition of the bounds of the stream reach to which the flow and habitat applies, i.e. from point A on a river to point B downstream. This definition of the reach is necessary in order to maintain some degree of certainty that appropriate management is being applied in the most suitable location. For the assessment of instream habitat, this study proposes a three-level classification system. First the river system may be divided into TYPES (e.g. upland, intermediate and lowland), reflecting position along the river. At this level of analysis such variables as altitude, distance from source and the slope of the valley floor are important. Secondly, each type may be divided into SECTORS. Within, each sector, water quality, sediment load, and hydrological regime are seen as invariant between sites. Thirdly, each sector is divided into REACHES on the basis of local variations in channel morphology or river-margin vegetation. Variations between individual reaches within a sector 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. Along natural rivers, channel morphology often has the same general form throughout each sector.

The characterisation will depend to an extent on subjective assessment. However, this study has developed guidelines to help make this a more objective process. Two main parameters, i.e. discharge and the physical structure of the channel, combine to define the range of microhabitat conditions available to a species and these provide the primary information to aid the definition process. The process of definition is a tradeoff between the certainty of accurate boundary location and the time (and therefore cost) required to assign them. Phase one of reach definition involves the analysis of broad scale catchment features and in particular the channel network to recognise the importance of hydrology. During phase two, more detailed information is collated on the whole river system, or at least the part in focus including specific data on habitat type, condition and scale and flow variations. This enables the refinement of reach classification based on an extensive database and definition of representative or critical reaches necessary for any detailed surveys that may follow.

Ideally, schemes of classification should be universally applicable, but because of zoogeographic differences and geomorphic regions, schemes of classification are best restricted to the broad areas where they were originally developed. The classification process described here was developed within a distinct region, i.e. the low gradient Anglian region. Therefore it should only be tentatively applied outside this area, particularly where the physical and biotic features of streams are very different e.g upland areas. Definition of boundaries may also be problematic, particularly where the features being used for classification exhibit a slow uniform change rather than distinct variability between locations. Nevertheless, rigid guidelines help to formalise this procedure and reduce subjectivity although total elimination is not recognised as an achievable goal.

6.2 Rapid Assessment

Rapid assessment techniques make an assessment of either flow requirements or instream habitat availability with minimal time and effort. They involve sampling and analysis that are designed to fulfil two objectives. First, effort (and cost) is reduced in assessing environmental conditions at a site, relative to that needed in quantitative approaches. This can be achieved in several ways e.g. the number of sites or habitats sampled are reduced. A second objective is to summarise the results of site surveys in a way that they can be understood by nonspecialists such as managers, other decision makers, and the concerned public. This is done by using analysis measures that express results as single scores, as well as by placing the scores obtained in categories of environmental quality based on regional background data.

Rapid assessment in this study has involved (1) the use of reconnaissance level surveys to aid the definition and classification of channel sectors, (2) the identification of changes in habitat with changes in flow using a habitat inflection method, and (3) the identification of key parameters that determine the instream biota through the development of an empirical model method. All three have inherent problems similar to those discussed above. Rapid assessment methods place the emphasis on using minimal time and effort and therefore forego some of the level of detail and accuracy that is associated with more quantitative techniques. Nevertheless, they provide a greater level of precision than subjective intuitive assessment, particularly when applied across a range of stream types, and the use of empirical model methods have shown high correlations between physical parameters and the existing biota in this study and elsewhere (e.g Binns and Eiserman 1979, Wesche et al 1987). Consequently they can quantify the stream habitat resource, explain the cause of declines in populations and help make recommendations for maintaining, recreating or enhancing instream habitat.

In general, rapid assessment protocols have been developed to apply to small, shallow streams. Methods for larger streams and sampling strategies in these systems need to be developed. Methods and the parameters that are measured also need to be calibrated. For example, the results may not be applicable to other types of impact, or to streams in other regions. Continued international or interagency cooperation in developing and calibrating methods, and establishing ecoregion-based tolerances and background data is essential. For instance, the empirical relationship between the invertebrate-based score and habitat variables developed here, and the HABSCORE approach developed by Milner et al (1985) are region specific (i.e. HABSCORE was developed for the upland trout streams of Wales) and it is only through the proper analysis and testing elsewhere that their wider applicability can be evaluated properly.

In future, more sophisticated methods of assigning scores also are needed. In addition, scoring system should attempt to indicate impact on a linear scale. Currently, a score of 2 is not twice as 'good' or 'bad' as a score of 4; this seems to be a major problem with most scoring systems. Geographical variations in tolerance must also be considered when developing scores for different regions. For instance, variability and unpredictability may be an inherent characteristic of upland streams and hence only extreme variations will have an effect on the biota. In the Anglian region, flows are relatively more constant and predictable and quantification of flow variations that occur beyond the long term mean may be fundamental to impact assessment.

The success of any rapid assessment approach ultimately depends on the ability to detect impacted and unimpacted conditions. Therefore, efforts to reduce costs must not be carried to the point that information used in the analysis does not adequately represent the site examined. Likewise, the analysis and summarisation should not be so simplified that impact-related conditions are not detected.

6.3 PHABSIM

Non-linear relationships between biomass and habitat variables are among the most difficult problems to manage by standard linear analyses. Rapid assessment methods attempt to solve this problem with the use of a rating system that transforms the data into linear categories. However, determination of the rating characteristics of each category still remains a subjective manner. The IFIM attempts to solve the problem of nonlinear relationships with habitat suitability curves (Bovee and Milhous 1978). Essentially, the IFIM process using PHABSIM is used to relate changes in discharge or channel structure to changes in physical habitat availability for a chosen species. Examples from this study have highlighted its use in a traditional sense to define optimum and critical flows for selected target species for the River Glen, Wissey and Babingley. However, the model has also been utilised to highlight the importance of bed morphology in the provision of habitat. According to model predictions, channelised reaches on the River Glen for instance are those that have the least variety in bed morphology and hence habitat availability for a range of species. This information can then be utilised to help solve two important questions. Firstly it can help define those areas in most need of habitat restoration, and secondly it can highlight which specific features of morphology are the limiting ones i.e. inadequate pool depths or lack of shallow water provided by riffle habitats.

However, the use of these habitat suitability curves and associated methodology have been criticised by Mathur et al (1985) on the basis that (1) a positive linear relationship of weighted usable area (Bovee 1982) and fish biomass has not been well demonstrated, (2) the assumption of independence among habitat variables is not valid for depth or water velocity, and leads to unrealistic predictions, and (3) habitat suitability curves should not be treated as probability functions. Moyle and Baltz (1985) also criticised the IFIM habitat suitability curves because (1) they do not incorporate habitat availability and, thus, are not preference curves, and (2) they ignore inter- and intraspecific competitive interactions. Habitat suitability curves also ignore predator-prey interactions which may also be important. Despite these criticisms, the primary purpose of IFIM is to predict changes in available habitat with flow changes rather than the simulation of ecological interactions (Gore and Nestler 1988). As long as this proviso is adhered to, the IFIM could and should be used and modified to provide an effective tool for assessing instream flow needs and the effect of bed morphology and channel structure on habitat availability.

Discharge and channel structure combine to define the range of physical microhabitat conditions available to a species. However, in certain locations, physical habitat availability may not be the limiting factor on the instream biota. Water quality is related to streamflow as many chemicals exhibit a concentration decrease with increased discharge and vice versa. Temperature alone may have significant effects on a community, in addition to its role as a driving variable in the determination of dissolved oxygen concentrations (Walling and Webb 1992). A disruption in the thermal regime of a river may make certain stream reaches uninhabitable for some species but not for others. In some cases, the temperature may be so high that a reach will be totally uninhabitable or so low that growth is impaired. If water quality is clearly a limiting factor for the entire stream and nothing can be done to remedy the problem then it is pointless conducting a detailed evaluation of the physical habitat. An exception might be the determination of physical habitat potential to evaluate the benefits obtained by eliminating the water quality problem. For instance, on the upper reaches of the West and East Glen rivers, river flows during summer are often dominated by water treatment works effluent discharges, and storm runoff contains high sediment loads due to agricultural runoff. In this case, the instream biota is limited by these problems, but physical habitat evaluation can highlight the potential of these sites with improvements in water quality.

PHABSIM is undoubtedly a tool that is currently only utilised when detailed analysis is required. The sheer number of rivers that require assessment on a routine basis in the UK means a rapid technique is required in the majority of situations, and only a more detailed approach at those sites perceived to have some economic or ecological importance (e.g.. Sites of Special Scientific Importance). In the short-term, results suggest that reconnaissance level surveys and existing rapid assessment approaches provide valuable information on the instream habitat and are therefore necessary as techniques to be applied in isolation where time and/or money is limited, or as essential initial step of a more detailed study.

In the future, it is envisaged that PHABSIM may be refined to reduce its data and simulation requirements. Results predicted for different target species from a variety of cross-sectional types could be compared from detailed PHABSIM analyses. Where simulations consistently predict similar responses for similar cross-sections on different rivers, simple tables may be produced to negate the need for detailed studies that are simply reproducing previous work. Presuming a pattern arises, a sensitivity analysis could refine the physical measurements necessary to characterise the cross-sectional types in the field. Other studies have already demonstrated that cross-sectional morphology can be defined with a satisfactory level of accuracy based on a few measurements in appropriate places. This would enable the assessor to visit the selected site, characterise the habitat based on simple measurements and predict habitat versus discharge relationships based on an existing database that exists for those particular cross-sectional types and target species. For instance, the rapid field assessment may suggest that the selected reach is characterised by pool type 'b' (based on simple width, depth, velocity and substrate measurements) for 30% of the whole, and these habitats require flow 'x' to maintain habitat above critical levels. The other 70% may be riffle type 'c' which require flow 'y' to provide habitat for the target species. The various flow scenarios could be compared and combined to provide a flow for the reach as a whole. These results could then be extrapolated to the rest of the sector if habitat types had been defined and quantified already by a reconnaissance level survey of the whole river prior to this.

6.4 Channel Modification

Channel modification to enhance the physical structure of the stream is one way to increase or maintain habitat availability. This alternative is most feasible when channels have already been modified to increase water conveyance or when water supplies are so short that negotiation over instream flows will not succeed. This study has demonstrated how the specific features of bed morphology that are limiting habitat availability can be determined, and hence appropriate channel modification be recommended. After assessment of the effect that flow augmentation had on habitat availability had been made due to the Gwash-Glen transfer on the West Glen river, it was clear that further improvement could be created by habitat modification. PHABSIM had highlighted the lack of deep pools and hence it was recommended that these habitats should be recreated by placing appropriate structures in the stream. Structural modifications to streams used elsewhere include artificial cover devices, deflectors, and weirs. Nonstructural modifications include deepening pools, raising the elevation of riffles, importing special substrate materials, or otherwise increasing bed profile diversity without the use of structures. Whenever channel modifications are contemplated the investigator must evaluate them in terms of their effectiveness in improving habitat, the frequency with which they must be replaced, installation and maintenance cost, and the chances of increased flood potential. A basic understanding of fluvial geomorphology is essential for the selection of appropriate structures. Imposition of the wrong type of solution may cause more serious degradation than without the improvement. For instance gravel placement will be ineffective in a low gradient river with a silt/clay substrate because the interstices are likely to fill with the natural finer bed material (Swales 1989). Studies from numerous locations highlight how habitat development is dependent on physical processes and so the link between hydrology, energy potential and habitat enhancement is essential (e.g. Swales and O'Hara 1980, Brookes 1992, Jutila 1992, Kern 1992).

6.5 Summary

Analyses such as those outlined above allow definition of a range of minimum flows. However, it is still not possible to determine the exact effect of a range of flow scenarios, each with different durations. For example, a desirable flow may be compared with that which sustains habitat at about 50% of potential values. Exceptionally, under severe natural drought conditions, flows could be reduced to this emergency minimum ecological flow. Although for the duration of the drought this flow may eliminate habitat almost entirely, some evidence suggests that the biota should recover rapidly once flows return to 'normal', particularly if the river system has a history of episodic disturbances. This recovery is principally due to the adaptive strategies of species within the community for coping with frequent disturbance (Milner 1994). Communities living in a more stable physical/chemical environment are likely to be less adapted to respond rapidly when disturbed. Both invertebrate and fish species have been reported to recover within one year where the community has a history of similar droughts (Larimore et al 1959) but this may be longer, particularly for fish in other areas because it takes time for juveniles to pass through yearly age classes before recovery is complete.

It should be apparent that assessment of potential effects of flow alteration on habitat availability is a difficult task. From a biological standpoint, assessment based purely on physical habitat may be inadequate as the methods do not take into account the effects of altered flows on factors such as growth, competition, mortality, and movements of populations. It is still not possible to accurately predict fish or invertebrate population sizes under various flow regulation scenarios. It is not possible for instance to detail the effect of a range of discharges, each with varying intensity and timespans. The impact on habitat availability can be assessed with the procedures outlined above, but the translation into an assessment on the biota is not yet feasible. Indeed, the lack of evidence that the biota responds to changes in flow and the inability to predict population responses to flow alterations remain frustrations which will persist until intensive long term research is initiated (Orth 1987).

Nevertheless, the importance of discharge and geomorphology should be apparent. Historically, flow has been seen as the most important parameter. Biota are adapted to the natural flow regime and their presence or absence will be determined to an extent by discharge. However, it is the bed morphology that determines the patterns of velocities, depths and shear stresses, which in turn determines the suitability of the microhabitat. Incorporation of the geomorphological element in conjunction with discharge as part of habitat assessment is a necessary prerequisite to a truly holistic approach. These two factors have also been highlighted as suitable parameters for the selection of boundaries to mark distinct channel sectors.

The geomorphological approach discussed and illustrated by application in the Anglian region attempts to offer a holistic method for the assessment of degraded river systems. This is illustrated in figure 6.1 overleaf. This type of approach is designed to achieve ecologically-sensitive water development by using integrated biological and habitat studies to evaluate hydrological methods for instream flow assessment based upon a regional (river type) and longitudinal, within-river (river sector) channel classification. By defining which environmental parameters are important in influencing the instream biota, and being able to evaluate the impact of possible manipulations of physical variables on the aquatic environment, river managers will have the potential to examine the full range of management scenarios that are open to them and make objective and quantifiable assessment of the likely impact of each.

6.6 Future Developments

Development of deterministic ecosystem models may be an unrealistic objective because of the stochastic nature driving the hydrological and geomorphological processes and the complexity of biological interactions (Petts and Maddock 1994). Consequently, the development of functional ecosystem models remains a long-term ambition. However, there is a clear need to define the relationship between flow, habitat and biotic production. Essentially, the relationship between habitat features and instream biota need to be validated and tested. On a more detailed level, three main objectives can be clarified:

- validation of rapid habitat assessment procedures across a range of stream types
- appropriate refinement of PHABSIM to reduce its data and simulation requirements in order to make it more widely applicable in a management context
- development of guidelines to determine whether quantitative or qualitative approaches are to be used in each situation.

Physical geography can continue to make an important contribution by focusing on the classification of streams across a range of spatial and temporal scales so that management is applied at an appropriate level. Furthermore, the importance of bed morphology as well as flow for the provision of habitat must continue to be stressed with the development of instream habitat assessment methods that incorporate this fundamental element.

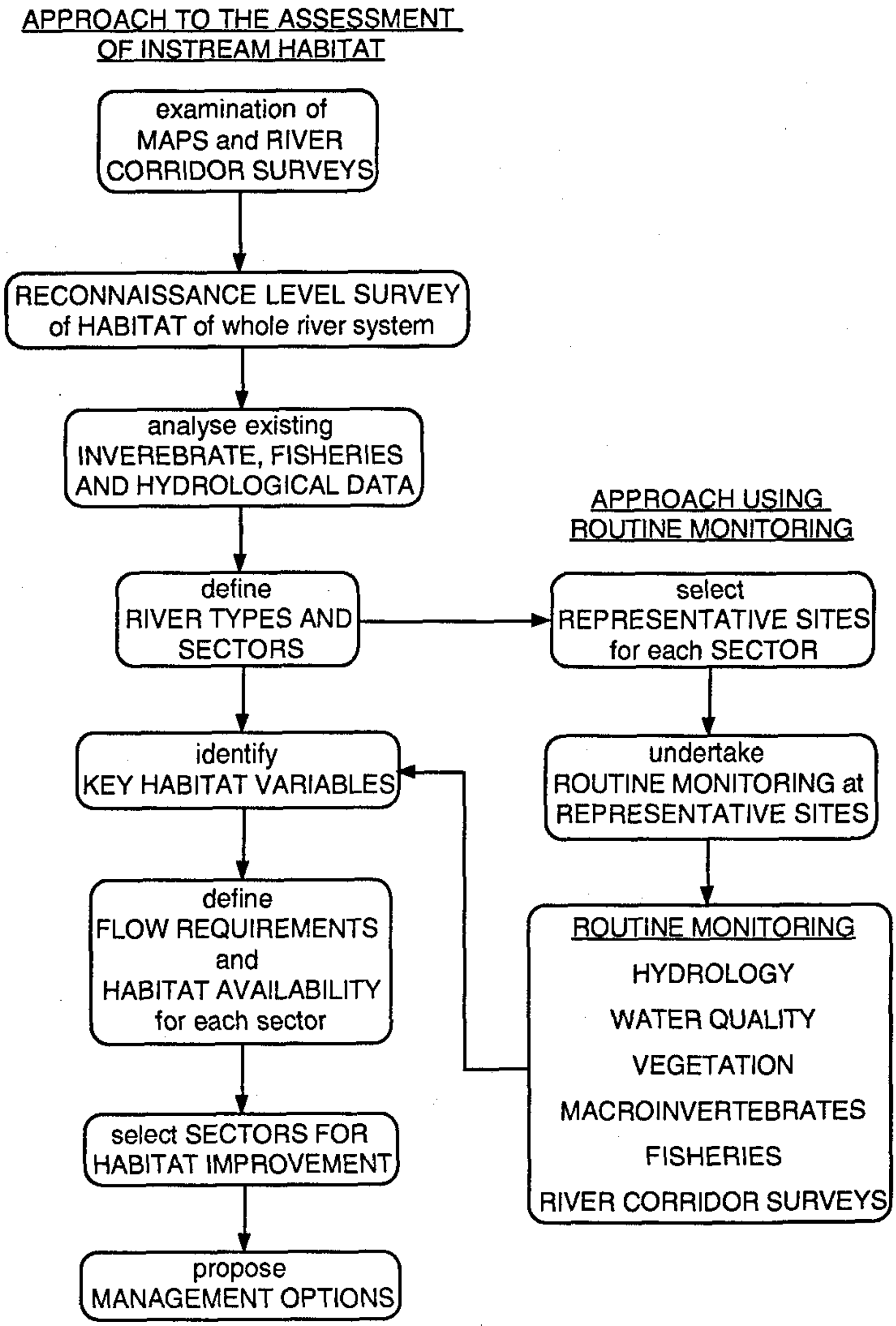


Figure 6.1 - Recommended approach for the assessment of degraded river systems using instream habitat assessment criteria.

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APPENDICES

APPENDIX 1

RIVER GLEN PHYSICAL HABITAT SURVEY RESULTS

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach	Distance	Cumulative	Channel	Water	Channel	Reach	Distance	Cumulative	Channel	Water	Channel
Number	Down.	Distance	Width	Width	Type	Number	Down.	Distance	Width	Width	Type
	(m)	(m)	(m)	(m)			(m)	(m)	(m)	(m)	
UWGL 001	0	0	1.6	0.7	5	UEGL 001	0	0	0.7	0.2	5
	60	60	0.9	0.0	4		50	50	1.1	0.4	5
	60	120	1.0	0.0	4		50	100	1.0	0.3	5
	60	180	1.0	0.0	4		50	150	1.0	0.2	5
	60	240	0.9	0.0	4		50	200	1.1	0.2	5
	60	300	1.1	0.0	4		50	250	1.2	0.0	4
	60	360	1.0	0.0	4		50	300	0.9	0.0	4
	60	420	1.2	0.0	4		50	350	0.9	0.0	4
	60	480	1.1	0.0	4		50	400	1.0	0.0	4
	60	540	1.3	0.0	4		50	450	1.3	0.0	4
UWGL 002	60	600	1.3	0.0	4	UEGL 002	50	500	1.1	0.0	4
	50	650	1.6	0.0	4		50	550	1.0	0.0	4
	50	700	1.6	0.0	4		125	675	1.3	0.0	4
	50	750	1.4	0.0	4		50	725	0.9	0.0	4
	50	800	1.7	0.0	4		50	775	1.3	0.0	4
	50	850	1.4	0.0	4		50	825	1.2	0.0	4
	50	900	1.5	0.0	4		50	875	1.5	0.0	4
	50	950	1.7	0.7	5		50	925	1.3	0.0	4
	50	1000	1.6	0.6	5		50	975	1.3	0.0	4
	50	1050	1.7	0.7	5	UEGL 003	50	1025	1.4	0.0	4
UWGL 003	50	1100	1.5	0.0	4		52	1077	1.5	0.0	4
	47	1147	1.8	0.0	4		53	1130	2.1	0.0	4
	48	1195	1.6	0.0	4		52	1182	1.8	0.0	4
	47	1242	1.4	0.0	4		53	1235	2.0	0.0	4
	48	1290	1.6	0.0	4		52	1287	1.6	0.0	4
	47	1337	1.8	0.0	4		53	1340	2.2	1.2	6
	48	1385	2.0	0.0	4		52	1392	1.9	1.0	5
	47	1432	1.7	0.0	4		53	1445	1.7	1.0	5
	48	1480	1.7	0.0	4		52	1497	2.5	1.4	5
	47	1527	1.7	0.0	4	UEGL 004	53	1550	2.6	1.4	5
UWGL 004	48	1575	1.6	0.0	4		40	1590	1.4	0.2	1
	52	1627	1.8	0.0	4		10	1600	2.1	1.2	5
	53	1680	2.0	0.0	4		50	1650	1.8	0.9	5
	52	1732	1.5	0.0	4		50	1700	1.5	0.6	5
	53	1785	1.6	0.0	4		50	1750	2.1	0.6	5
	52	1837	1.8	0.0	4		50	1800	1.7	1.1	5
	53	1890	1.6	0.3	5		50	1850	1.6	1.0	5
	52	1942	1.4	0.0	4		50	1900	2.0	1.2	5
	53	1995	2.0	0.6	5		50	1950	1.7	0.7	5
	52	2047	1.7	0.5	5		50	2000	1.9	1.4	5
UWGL 005	53	2100	2.0	1.7	5	UEGL 005	50	2050	1.9	0.3	5
	52	2152	1.8	0.0	4		50	2100	2.0	1.2	5
	53	2205	1.9	0.0	4		50	2150	1.5	1.1	5
	52	2257	1.7	0.0	4		25	2175	2.7	0.4	1
	53	2310	2.2	0.0	4		50	2225	1.5	0.8	5
	52	2362	1.4	1.2	5		50	2275	1.5	0.9	5
	53	2415	1.7	0.0	4		50	2325	1.4	0.0	4
	52	2467	1.7	0.0	4		50	2375	1.6	0.0	4
	53	2520	1.5	0.0	4		50	2425	1.8	0.0	4
	52	2572	1.6	0.6	5		50	2475	1.7	0.0	4
UWGL 006	53	2625	2.0	1.0	5		50	2525	2.0	0.0	4
	52	2677	1.6	0.0	4	UEGL 006	50	2575	2.6	0.0	4
	53	2730	1.6	0.0	4		52	2627	1.9	0.0	4
	52	2782	1.8	0.8	5		53	2680	1.9	0.0	4
	53	2835	1.9	1.0	5		52	2732	1.6	0.0	4
	52	2887	1.8	0.9	5		53	2785	2.0	0.0	4
	53	2940	1.7	1.0	5		52	2837	2.0	0.0	4
	52	2992	1.9	0.7	5		53	2890	1.8	0.0	4
	53	3045	1.8	0.8	5		52	2942	2.2	0.0	4
	52	3097	1.8	1.2	5		53	2995	2.2	0.0	4
UWGL 007	53	3150	2.4	1.9	5		52	3047	2.3	0.0	4
	67	3217	2.0	0.8	5	UEGL 007	53	3100	2.6	0.0	4
	68	3285	1.8	1.1	5		55	3155	2.1	0.0	4
	67	3352	2.8	0.4	5		55	3210	2.3	0.0	4
	68	3420	2.2	0.8	5		55	3265	2.6	0.0	4
	67	3487	2.0	0.0	4		55	3320	2.7	0.0	4
	68	3555	2.9	0.2	5		55	3375	2.5	0.0	4
	67	3622	2.2	1.2	5		55	3430	2.6	0.0	4
	68	3690	2.2	0.0	4		55	3485	2.2	0.0	4
	67	3757	2.4	0.0	4		55	3540	2.6	0.0	4

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	43	10359	2.4	0.0	4		50	10850	3.2	2.7	6
	43	10402	2.0	0.0	4		50	10900	3.0	2.7	6
	43	10445	2.4	0.0	4		50	10950	3.5	3.1	6
	43	10488	2.2	0.0	4	EGLE 008	50	11000	3.2	2.5	6
WGLE 014	37	10525	2.2	0.0	4		60	11060	4.4	2.2	5
	50	10575	2.3	0.0	4		60	11120	3.6	2.1	5
	50	10625	3.2	0.0	4		60	11180	5.9	2.5	5
	50	10675	2.3	0.0	4		60	11240	3.9	2.4	5
	50	10725	3.2	0.0	4		60	11300	3.3	2.2	5
	50	10775	3.0	0.0	4		60	11360	5.0	3.3	5
	50	10825	2.4	0.0	4		60	11420	4.8	3.5	5
	50	10875	2.6	0.0	4		60	11480	4.7	3.8	5
	50	10925	2.6	0.0	4		60	11540	4.1	2.4	5
	50	10975	2.5	0.0	4	EGLE 009	60	11600	4.6	2.7	5
WGLE 015	50	11025	2.9	0.0	4		50	11650	4.9	2.6	5
	50	11075	2.7	0.0	4		50	11700	3.0	1.8	5
	50	11125	2.7	0.0	4		50	11750	3.6	1.7	5
	50	11175	3.2	0.0	4		50	11800	3.7	1.9	5
	50	11225	2.6	0.0	4		50	11850	4.0	1.8	5
	50	11275	3.1	0.0	4		50	11900	3.7	1.6	5
	50	11325	3.0	0.0	4		50	11950	3.5	2.1	5
	50	11375	2.7	0.0	4		50	12000	4.6	1.5	5
	50	11425	2.9	0.0	4		50	12050	3.3	1.1	5
	50	11475	2.9	0.0	4	EGLE 010	50	12100	3.7	1.3	5
WGLE 016	50	11525	2.7	0.0	4		50	12150	3.4	1.7	5
	15	11540	3.4	2.7	2		50	12200	3.3	2.5	5
	50	11590	3.8	2.8	5		50	12250	3.0	1.6	5
	50	11640	2.5	0.0	4		50	12300	3.3	1.9	5
	24	11664	3.5	0.0	4		50	12350	4.0	1.4	5
	32	11696	3.5	0.0	4		50	12400	4.2	2.7	5
	50	11746	3.4	0.0	4		50	12450	3.1	1.9	5
	50	11796	4.0	0.0	4		50	12500	3.9	2.0	5
	50	11846	4.0	0.0	4		50	12550	4.0	2.2	5
	50	11896	4.5	0.0	4	EGLE 011	50	12600	3.4	2.6	5
	50	11946	4.4	0.0	1		59	12659	4.1	2.6	5
	42	11988	4.1	0.8	1		59	12718	4.0	2.4	5
WGLE 017	37	12025	3.8	2.4	5		59	12777	4.4	2.4	5
	50	12075	3.8	2.4	5		59	12836	5.4	1.7	6
	50	12125	5.5	1.7	6		59	12895	4.2	2.4	5
	50	12175	3.6	1.8	5		59	12954	4.1	2.8	5
	50	12225	3.5	1.7	1		59	13013	4.6	1.4	5
	48	12273	4.7	2.0	5		59	13072	5.1	2.9	5
	50	12323	3.3	1.6	6		59	13131	3.6	1.9	5
	50	12373	3.5	1.9	5		59	13190	3.3	1.8	6
	50	12423	3.9	1.7	5	EGLE 012	60	13250	4.1	2.5	5
	50	12473	3.7	2.3	5		65	13315	5.0	3.0	5
	50	12523	4.7	2.8	5		65	13380	4.0	2.3	5
	51	12574	3.7	1.9	5		66	13446	2.7	1.6	5
WGLE 018	51	12625	3.1	2.0	5		65	13511	4.6	4.0	5
	46	12671	2.9	0.8	1		66	13577	4.4	2.6	1
	48	12719	2.6	1.5	5		42	13619	5.6	3.6	5
	46	12765	2.7	1.4	1		65	13684	3.5	1.5	5
	46	12811	2.8	0.9	1	EGLE 013	66	13750	2.7	1.8	5
	40	12851	3.3	1.5	5		57	13807	3.7	2.4	5
	45	12896	3.5	1.5	5		57	13864	3.5	2.2	5
	46	12942	5.2	1.3	5		58	13922	4.7	3.1	5
	46	12988	2.7	1.2	1		57	13979	5.8	2.2	1
	10	12998	2.2	0.7	1		35	14014	4.6	2.5	1
	20	13018	3.6	0.8	1		20	14034	4.6	2.7	5
	37	13055	3.9	2.1	5		58	14092	3.0	2.2	5
WGLE 019	45	13100	3.6	0.8	5		48	14140	4.8	2.5	1
	48	13148	3.9	1.6	5		35	14175	4.4	2.4	1
	48	13196	3.8	1.5	5		19	14194	4.1	2.4	5
	48	13244	4.3	1.2	3		58	14252	3.8	2.7	5
	48	13292	3.7	1.3	1	EGLE 014	48	14300	4.1	1.9	1
	33	13325	4.2	2.0	1		40	14340	3.8	2.0	1
	13	13338	3.6	1.8	5		42	14382	3.6	1.0	1
	48	13386	4.2	2.3	5		18	14400	4.3	2.4	5
	48	13434	3.2	1.3	1		46	14446	3.8	2.3	1
	48	13482	3.5	1.5	5		25	14471	3.1	1.6	5

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
WGLE 001	68	3825	3.9	3.4	5		55	3595	2.6	0.0	4
	35	3860	2.1	0.7	1	UEGL 008	55	3650	2.7	0.0	4
	23	3883	2.5	0.8	1		48	3698	2.2	0.0	4
	50	3933	3.1	1.6	3		47	3745	2.2	0.0	4
	55	3988	3.2	0.8	1		48	3793	2.4	0.0	4
	24	4012	2.8	1.1	1		47	3840	2.3	0.0	4
	55	4067	3.1	2.7	5		48	3888	2.4	0.0	4
	55	4122	2.7	1.9	5		47	3935	2.8	0.0	4
	47	4169	3.0	0.7	1		48	3983	2.7	0.0	4
	55	4224	2.9	2.1	5		47	4030	2.5	0.0	4
	55	4279	3.4	2.9	5		48	4078	2.7	0.0	4
WGLE 002	71	4350	3.2	1.4	3	UEGL 009	47	4125	2.8	0.0	4
	47	4397	3.9	1.7	5		48	4173	2.8	0.0	4
	45	4442	2.7	0.6	1		47	4220	2.6	0.0	4
	47	4489	2.8	1.1	5		48	4268	2.8	0.0	4
	47	4536	2.1	1.6	5		47	4315	3.0	0.0	4
	47	4583	2.2	1.9	5		48	4363	2.9	0.0	4
	47	4630	2.9	2.4	5		47	4410	3.0	0.0	4
	47	4677	3.1	2.2	5		48	4458	2.4	0.0	4
	47	4724	2.4	2.2	5		47	4505	2.9	0.0	4
	46	4770	2.5	2.3	5		48	4553	2.8	0.0	4
WGLE 003	55	4825	2.0	1.5	5	UEGL 010	47	4600	3.0	0.0	4
	50	4875	1.9	1.2	5		53	4653	2.9	0.6	5
	50	4925	2.5	2.3	5		52	4705	3.1	1.4	5
	50	4975	2.9	0.8	3		53	4758	2.8	0.0	4
	50	5025	2.9	2.6	5		52	4810	2.8	1.2	5
	50	5075	2.7	2.4	5		53	4863	2.8	0.0	4
	50	5125	2.1	0.9	3		52	4915	3.0	0.0	4
	50	5175	3.1	2.9	5		53	4968	2.9	0.0	4
	50	5225	2.4	1.1	5		52	5020	3.0	0.5	5
	50	5275	3.1	0.5	3		53	5073	2.8	0.0	4
WGLE 004	50	5325	2.4	1.9	5	UEGL 011	52	5125	2.9	0.0	4
	52	5377	2.1	1.2	5		50	5175	2.9	0.0	4
	53	5430	2.2	0.7	3		50	5225	3.0	0.0	4
	52	5482	2.0	0.6	3		50	5275	2.9	0.0	4
	53	5535	2.1	0.7	3		50	5325	2.4	0.0	4
	52	5587	2.3	2.0	5		50	5375	3.1	0.0	4
	53	5640	2.6	2.3	5		50	5425	3.0	0.0	4
	52	5692	2.0	0.5	5		50	5475	3.0	0.0	4
	53	5745	1.6	0.8	3		50	5525	2.7	0.0	4
	52	5797	2.1	1.8	5		50	5575	2.8	0.0	4
WGLE 005	53	5850	1.8	0.9	5	UEGL 012	50	5625	2.9	1.0	5
	52	5902	1.9	0.7	5		53	5678	3.2	1.0	5
	53	5955	2.0	1.0	5		52	5730	3.0	1.4	5
	52	6007	2.5	0.6	5		53	5783	2.5	0.7	5
	53	6060	2.6	2.0	5		52	5835	3.2	1.2	5
	52	6112	1.9	1.3	5		53	5888	2.2	0.0	4
	53	6165	2.9	0.6	5		52	5940	2.5	0.0	4
	52	6217	3.0	0.5	5		53	5993	3.0	1.1	5
	53	6270	3.2	2.9	5		52	6045	2.7	0.8	5
	52	6322	2.7	1.0	5		53	6098	2.4	1.0	5
WGLE 006	53	6375	3.4	1.2	5	UEGL 013	52	6150	2.4	0.6	5
	61	6436	2.2	1.9	5		50	6200	2.9	1.4	5
	61	6497	1.8	0.5	3		50	6250	2.8	1.2	5
	61	6558	3.1	2.6	5		50	6300	3.2	1.1	5
	60	6618	2.6	1.9	5		50	6350	2.6	0.0	4
	50	6668	3.0	2.6	5		50	6400	3.0	1.1	5
	28	6696	2.3	0.9	1		50	6450	3.1	0.9	5
	61	6757	3.1	2.6	5		50	6500	2.9	0.4	5
	61	6818	2.9	1.1	5		50	6550	3.3	0.0	4
	41	6859	3.0	1.4	1		50	6600	2.9	0.0	4
	60	6919	2.6	1.5	5	UEGL 014	50	6650	3.1	1.0	5
WGLE 007	31	6950	3.4	1.3	5		50	6700	2.7	0.0	4
	53	7003	4.2	2.1	2		50	6750	2.6	0.9	5
	11	7014	3.2	1.3	1		50	6800	2.8	1.3	5
	30	7044	2.5	1.3	1		50	6850	2.6	1.3	5
	53	7097	2.7	1.6	5		50	6900	2.8	1.1	5
	53	7150	3.2	2.5	5		50	6950	2.9	1.6	5
	53	7203	3.6	2.5	6		50	7000	2.7	1.4	5
	48	7251	2.9	1.4	1		50	7050	3.0	0.7	3

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	53	7304	4.1	2.8	5		50	7100	2.5	2.0	5
	53	7357	3.5	2.6	5	EGLE 001	50	7150	2.4	1.2	5
	53	7410	3.2	1.7	5		65	7215	2.7	1.4	5
	54	7464	3.2	2.4	5		65	7280	2.4	1.3	5
WGLE 008	11	7475	2.9	1.5	5		65	7345	2.2	1.6	5
	47	7522	3.0	2.0	5		65	7410	2.7	1.2	5
	48	7570	3.6	2.6	5		65	7475	2.6	2.0	5
	47	7617	3.0	2.5	5		65	7540	3.1	1.0	5
	48	7665	4.2	2.9	1		65	7605	2.7	2.2	5
	47	7712	2.6	1.8	5		65	7670	3.0	2.0	5
	48	7760	3.1	2.8	5		65	7735	2.8	1.4	5
	47	7807	2.9	1.7	5	EGLE 002	65	7800	2.4	1.4	5
	48	7855	3.0	2.6	5		52	7852	3.0	1.3	5
	47	7902	2.8	2.0	5		53	7905	2.9	1.1	6
WGLE 009	48	7950	4.2	2.9	2		52	7957	2.4	1.8	5
	52	8002	3.1	1.2	3		53	8010	2.5	1.4	5
	53	8055	2.4	1.9	5		52	8062	2.1	1.5	5
	52	8107	3.2	2.7	5		53	8115	2.8	2.2	5
	53	8160	4.2	1.9	5		52	8167	2.5	1.9	5
	52	8212	3.8	0.6	3		53	8220	2.5	1.6	5
	53	8265	3.4	0.6	3		52	8272	2.7	1.9	5
	52	8317	3.1	1.5	5	EGLE 003	53	8325	2.4	1.8	5
	53	8370	2.6	1.7	5		52	8377	3.7	3.2	5
	52	8422	2.7	1.4	5		53	8430	2.7	1.1	5
WGLE 010	53	8475	4.1	3.6	5		52	8482	3.0	2.6	5
	10	8485	3.0	0.6	1		53	8535	3.2	1.8	5
	49	8534	3.0	2.1	5		52	8587	3.1	2.0	5
	49	8583	2.6	2.2	5		53	8640	2.8	1.6	5
	40	8623	3.3	2.9	1		52	8692	2.9	2.1	5
	49	8672	3.2	2.7	5		53	8745	3.4	2.8	5
	9	8681	2.7	1.0	1		52	8797	2.8	1.7	5
	50	8731	3.7	1.4	1	EGLE 004	53	8850	3.0	2.0	6
	49	8780	4.2	3.5	1		55	8905	2.8	2.1	6
	49	8829	3.4	1.2	1		55	8960	3.1	1.6	6
	47	8876	2.6	1.4	1		55	9015	2.8	2.5	5
	49	8925	2.6	1.9	5		55	9070	3.0	2.4	5
WGLE 011	50	8975	3.6	2.8	5		55	9125	3.2	2.6	5
	58	9033	3.0	2.1	5		55	9180	3.0	2.6	5
	58	9091	3.4	2.9	5		55	9235	2.5	1.9	5
	59	9150	3.1	2.6	5		55	9290	2.8	2.5	5
	58	9208	3.6	2.9	2		55	9345	2.8	2.4	5
	30	9238	3.6	0.6	1	EGLE 005	55	9400	2.6	1.1	6
	20	9258	3.4	1.8	5		100	9500	2.7	1.9	5
	58	9316	3.0	2.4	5		47	9547	2.9	2.3	5
	20	9336	3.1	0.7	1		47	9594	2.9	1.6	1
	47	9383	2.8	0.9	1		26	9620	2.7	2.0	5
	17	9400	3.0	1.6	1		47	9667	2.5	1.9	5
	20	9420	2.5	1.6	1		46	9713	2.4	1.9	5
	14	9434	2.4	1.9	5		47	9760	3.0	2.2	5
	59	9493	2.9	1.1	1		47	9807	3.0	2.2	5
	20	9513	3.6	3.3	5		47	9854	3.4	2.8	5
WGLE 012	12	9525	3.9	3.6	5	EGLE 006	46	9900	2.6	2.0	5
	46	9571	3.8	2.5	1		50	9950	3.2	1.4	5
	46	9617	2.4	0.9	1		50	10000	3.0	2.0	5
	46	9663	3.6	3.2	5		50	10050	2.3	1.3	5
	47	9710	3.4	2.7	5		50	10100	3.5	2.9	5
	46	9756	2.9	1.6	1		50	10150	2.6	0.7	3
	39	9795	3.9	3.5	5		50	10200	2.9	2.5	5
	46	9841	3.7	3.4	5		50	10250	3.2	2.5	5
	47	9888	3.8	3.5	5		50	10300	3.5	3.0	5
	47	9935	3.5	3.0	5		50	10350	2.7	1.7	5
WGLE 013	65	10000	3.9	3.0	5		50	10400	3.1	2.6	5
	35	10035	2.4	0.7	1		50	10450	3.0	1.8	5
	62	10097	2.1	0.5	3	EGLE 007	50	10500	2.8	1.9	5
	63	10160	2.4	0.3	1		50	10550	2.8	2.1	5
	20	10180	2.4	0.4	1		50	10600	3.2	2.6	5
	26	10206	2.1	0.7	6		50	10650	3.7	3.2	5
	24	10230	1.9	0.0	4		50	10700	3.0	2.4	6
	43	10273	2.1	0.0	4		50	10750	3.1	2.7	6
	43	10316	2.3	0.0	4		50	10800	2.7	2.2	6

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	48	13530	3.3	0.6	1		47	14518	5.0	2.7	5
	48	13578	3.5	0.4	3		46	14564	3.8	2.4	5
WGLE 020	47	13625	4.2	2.4	5		47	14611	4.2	3.2	5
	52	13677	3.7	1.5	3		46	14657	4.7	3.6	5
	53	13730	3.4	1.9	5		47	14704	3.8	3.0	5
	52	13782	4.0	1.1	6	EGLE 015	46	14750	4.0	3.1	5
	53	13835	6.3	2.1	6		50	14800	4.2	3.6	5
	52	13887	4.5	0.9	3		50	14850	4.2	2.4	5
	53	13940	4.5	2.0	5		50	14900	3.9	2.2	5
	52	13992	4.6	2.0	5		50	14950	5.4	3.5	5
	53	14045	4.7	2.1	5		50	15000	7.4	3.0	5
	52	14097	4.1	1.8	5		50	15050	5.2	2.1	5
WGLE 021	53	14150	5.2	3.7	5		50	15100	4.2	3.5	5
	46	14196	5.9	3.8	5		50	15150	2.9	2.5	5
	47	14243	6.2	4.0	5		50	15200	3.1	2.6	5
	46	14289	4.6	0.7	3	EGLE 016	50	15250	4.8	3.8	5
	47	14336	5.2	4.1	5		50	15300	3.7	3.2	5
	46	14382	5.9	1.5	3		50	15350	2.9	2.2	5
	47	14429	4.1	0.0	4		50	15400	3.0	2.4	5
WGLE 022	46	14475	4.1	0.0	4		50	15450	2.8	2.3	5
	50	14525	5.0	0.0	4		50	15500	4.1	3.0	5
	50	14575	4.4	0.0	4		50	15550	3.0	2.4	5
	50	14625	4.3	0.0	4		50	15600	3.4	3.0	5
	50	14675	4.9	0.0	4		50	15650	3.5	2.8	1
	50	14725	4.5	0.0	4		50	15700	3.8	2.3	5
	50	14775	4.6	0.0	4	EGLE 017	50	15750	4.1	3.2	5
	50	14825	3.9	0.0	4		53	15803	3.9	2.7	5
	50	14875	5.0	0.0	4		54	15857	3.1	2.4	5
	50	14925	4.2	0.0	4		53	15910	3.2	2.7	5
WGLE 023	50	14975	4.4	0.0	4		54	15964	3.8	2.6	5
	52	15027	4.7	0.0	4		53	16017	5.7	3.2	1
	52	15079	4.6	0.0	4		15	16032	4.9	3.4	5
	52	15131	5.3	0.0	4		54	16086	3.9	2.9	1
	52	15183	4.4	0.0	4		53	16139	3.3	2.6	5
	53	15236	3.8	0.0	4		54	16193	3.6	2.9	1
	52	15288	4.6	0.0	4		53	16246	4.6	2.7	1
	52	15340	5.0	0.0	4	EGLE 018	54	16300	4.1	1.3	5
	52	15392	4.1	0.0	4		44	16344	4.5	0.3	1
	52	15444	3.9	0.0	4		36	16380	3.6	3.0	5
	53	15497	4.0	0.0	4		44	16424	3.2	2.6	5
WGLE 024	53	15550	3.8	0.0	4		44	16468	2.9	0.7	1
	50	15600	4.0	0.0	4		44	16512	3.1	2.1	5
	50	15650	5.3	0.0	4		44	16556	3.8	1.3	1
	50	15700	5.1	0.0	4		48	16604	2.9	2.7	5
	50	15750	5.2	0.0	4		44	16648	2.6	1.6	5
	50	15800	4.9	0.0	4		44	16692	3.0	0.7	1
	50	15850	5.6	0.0	4		40	16732	2.7	1.4	5
	50	15900	5.8	0.0	4	EGLE 019	43	16775	2.6	1.5	5
	50	15950	5.4	0.0	4		55	16830	3.2	2.4	5
	50	16000	3.9	0.0	4		55	16885	3.2	2.6	5
WGLE 025	50	16050	5.2	0.0	4		55	16940	3.7	3.3	5
	50	16100	6.1	0.0	4		55	16995	4.4	3.3	5
	50	16150	6.1	0.0	4		55	17050	3.3	1.2	1
	50	16200	4.8	0.0	4		55	17105	2.8	2.2	5
	50	16250	4.1	0.0	4		55	17160	3.6	1.1	1
	50	16300	4.1	0.0	4		22	17182	3.1	1.7	5
	50	16350	4.6	0.0	4		56	17238	3.5	0.9	1
	50	16400	3.6	0.0	4	EGLE 020	37	17275	3.3	1.7	5
	50	16450	3.5	0.0	4		41	17316	4.3	3.7	5
	50	16500	3.8	0.0	4		41	17357	3.6	3.2	5
	50	16550	4.2	0.0	4		41	17398	3.5	3.1	5
WGLE 026	50	16600	4.4	0.0	4		41	17439	4.5	4.0	5
	52	16652	3.8	0.0	4		41	17480	4.9	4.1	5
	53	16705	4.6	0.0	4		41	17521	4.4	3.8	5
	52	16757	3.8	0.0	4		41	17562	5.0	4.6	5
	53	16810	5.1	0.0	4		41	17603	4.3	3.1	2
	52	16862	4.2	0.0	4		41	17644	4.8	4.3	5
	53	16915	4.3	0.0	4		41	17685	5.2	4.7	5
	52	16967	4.1	0.0	4		41	17726	5.3	1.1	1
	53	17020	4.2	0.0	4	EGLE 021	24	17750	5.3	1.4	1

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	52	17072	4.9	0.0	4		45	17795	4.2	0.6	1
WGLE 027	53	17125	3.7	0.0	4		36	17831	4.7	0.6	1
	50	17175	4.1	0.0	4		22	17853	3.3	1.3	1
	50	17225	4.4	0.0	4		21	17874	3.4	0.2	1
	50	17275	4.2	0.0	4		26	17900	2.7	1.7	1
	50	17325	3.4	0.0	4		53	17953	4.1	0.8	1
	50	17375	3.9	0.0	4		44	17997	3.7	0.4	1
	50	17425	5.2	0.0	4		54	18051	2.3	1.6	5
	50	17475	3.5	0.0	4		53	18104	3.8	0.6	1
	50	17525	3.3	0.0	4		45	18149	4.3	0.6	1
	50	17575	3.0	0.0	4		47	18196	3.3	2.3	5
WGLE 028	50	17625	3.1	0.0	4	EGLE 022	54	18250	3.8	2.5	5
	52	17677	3.0	0.0	4		73	18323	4.1	3.3	5
	53	17730	3.2	0.0	4		72	18395	4.1	3.8	5
	52	17782	2.9	0.0	4		73	18468	2.8	0.0	4
	53	17835	3.2	0.0	4		72	18540	4.0	3.6	2
	52	17887	3.6	0.0	4		73	18613	2.7	0.0	1
	53	17940	3.6	0.0	4		43	18656	3.0	2.1	5
	52	17992	3.2	0.0	4		72	18728	3.1	2.1	5
	53	18045	3.2	0.0	4	EGLE 023	72	18800	2.1	0.0	4
	52	18097	3.2	0.0	4		46	18846	3.2	0.0	4
WGLE 029	53	18150	2.8	0.0	4		48	18894	3.9	0.7	1
	55	18205	3.6	0.0	4		18	18912	3.3	1.9	1
	55	18260	3.4	2.0	5		46	18958	3.5	1.5	1
	55	18315	3.3	0.0	4		16	18974	3.1	2.1	5
	55	18370	4.5	0.0	4		46	19020	3.5	1.8	5
	55	18425	3.1	1.8	5		47	19067	3.9	2.1	5
	55	18480	3.1	1.9	5		46	19113	3.2	1.2	1
	55	18535	2.9	2.2	5		46	19159	4.5	1.1	5
	55	18590	3.8	1.5	5		47	19206	3.0	2.3	5
	55	18645	4.5	3.7	5		30	19236	3.9	3.3	5
WGLE 030	55	18700	4.0	3.3	5		46	19282	4.3	2.8	5
	55	18755	5.5	3.3	6		47	19329	3.5	0.9	1
	55	18810	5.9	3.3	6	EGLE 024	21	19350	3.4	2.7	5
	55	18865	4.6	2.9	6		40	19390	3.8	0.9	1
	55	18920	5.4	3.5	6		40	19430	4.2	3.9	5
	55	18975	5.3	3.3	6		40	19470	4.8	3.7	5
	55	19030	4.9	3.3	6		40	19510	4.9	1.2	1
	55	19085	5.7	3.3	6		15	19525	4.2	3.6	2
	55	19140	5.6	2.0	6		35	19560	3.3	0.8	1
	55	19195	5.5	1.5	1		17	19577	3.5	1.7	1
WGLE 031	55	19250	4.8	2.4	5		26	19603	4.6	0.9	1
	30	19280	5.2	2.5	1		19	19622	4.7	0.8	1
	50	19330	5.5	2.4	2		25	19647	3.8	1.5	1
	50	19380	5.0	3.2	2		21	19668	4.1	1.9	1
	25	19405	4.8	3.2	1		27	19695	3.7	2.1	1
	50	19455	4.0	1.7	5		20	19715	3.9	1.8	5
	15	19470	4.6	2.2	1		30	19745	4.7	3.9	5
	45	19515	5.0	1.5	1		30	19775	4.2	3.5	2
	37	19552	4.5	1.5	1		20	19795	3.6	3.0	2
	37	19589	3.8	1.6	1		108	19903	4.0	1.3	1
	48	19637	4.8	2.5	1		6	19909	5.4	3.8	2
	14	19651	4.4	2.0	1	EGLE 025	41	19950	3.8	3.0	5
	34	19685	3.6	2.8	2		40	19990	3.6	2.7	5
	20	19705	4.1	2.5	1		37	20027	2.3	0.6	1
	30	19735	5.2	3.5	1		40	20067	3.9	2.6	5
WGLE 032	15	19750	4.0	2.8	5		17	20084	4.1	3.0	5
	50	19800	3.6	2.7	5		37	20121	3.5	2.5	5
	10	19810	4.0	2.7	1		38	20159	3.9	2.1	5
	45	19855	4.3	2.6	1		37	20196	3.2	0.6	1
	50	19905	5.0	4.2	5		12	20208	3.6	0.5	1
	50	19955	3.8	2.8	5		40	20248	2.8	0.4	1
	50	20005	5.1	4.1	5		16	20264	3.3	0.3	1
	50	20055	3.6	1.6	3		44	20308	2.8	0.6	1
	50	20105	5.5	3.2	1		42	20350	3.2	1.3	1
	50	20155	4.6	2.6	5		37	20387	3.5	2.7	5
	50	20205	4.3	2.2	5	EGLE 026	38	20425	4.7	2.8	5
	30	20235	4.6	0.8	1		53	20478	4.6	3.5	5
WGLE 033	15	20250	4.7	2.6	5		53	20531	4.9	2.5	5
	14	20264	2.1	0.8	1		53	20584	5.8	0.7	1

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	37	20301	4.2	2.2	1		53	20637	6.1	3.9	5
	48	20349	4.0	1.5	1		53	20690	5.3	2.4	1
	50	20399	4.3	3.7	5		53	20743	5.0	2.6	1
	50	20449	4.0	3.2	5		15	20758	5.6	2.5	1
	26	20475	5.4	0.4	1		35	20793	5.2	1.8	1
	25	20500	6.1	0.0	4		25	20818	5.3	1.9	1
	50	20550	4.3	0.0	4		25	20843	5.6	1.9	1
	50	20600	4.5	0.0	4		25	20868	3.9	1.4	1
	50	20650	4.8	0.0	4		53	20921	4.7	1.8	1
	50	20700	2.1	0.0	4	EGLE 027	54	20975	5.3	3.0	5
WGLE 034	50	20750	2.5	1.6	5		52	21027	4.8	2.9	5
	56	20806	4.5	4.1	5		30	21057	5.5	1.5	1
	55	20861	4.7	1.7	5		53	21110	5.9	4.8	5
	56	20917	4.8	0.0	4		52	21162	4.8	1.1	1
	55	20972	4.4	0.0	4		53	21215	5.1	3.4	5
	56	21028	4.2	0.0	4		35	21250	4.6	1.3	1
	55	21083	5.0	0.0	4		52	21302	5.3	1.2	1
	56	21139	3.2	0.0	4		12	21314	3.4	1.3	1
	55	21194	4.0	0.0	4		53	21367	4.0	1.3	1
WGLE 035	56	21250	3.9	0.0	1		52	21419	4.3	3.4	5
	79	21329	4.2	0.0	4		53	21472	3.9	1.2	1
	78	21407	2.8	0.0	1	EGLE 028	53	21525	4.1	3.0	5
	79	21486	4.3	0.0	4		50	21575	4.4	1.9	1
	78	21564	3.8	0.0	4		16	21591	4.3	1.4	1
	79	21643	3.9	0.0	4		19	21610	4.7	1.8	1
	78	21721	4.7	0.0	4		70	21680	5.3	2.7	1
WGLE 036	79	21800	4.8	0.0	4		70	21750	4.6	1.9	1
	50	21850	4.3	2.5	5		66	21816	2.6	1.9	5
	50	21900	4.5	3.7	5		66	21882	3.8	1.1	5
	15	21915	4.6	1.2	1		23	21905	4.4	1.2	1
	50	21965	5.0	0.6	1		65	21970	5.0	1.2	5
	50	22015	4.8	3.6	5		9	21979	5.4	1.5	1
	50	22065	4.6	4.1	5	EGLE 029	46	22025	4.8	1.8	1
	30	22095	6.2	4.5	1		52	22077	2.9	1.1	5
	50	22145	6.6	5.0	1		52	22129	3.4	2.6	5
	50	22195	6.0	5.1	2		51	22180	4.9	3.5	5
	36	22231	6.0	4.4	1		50	22230	4.6	2.7	5
	50	22281	5.5	4.2	1		10	22240	4.6	0.9	1
	12	22293	5.8	3.8	1		29	22269	3.4	1.9	1
	50	22343	5.6	4.3	5		29	22298	3.7	2.5	5
WGLE 037	7	22350	6.0	3.9	5		29	22327	5.3	4.7	2
	100	22450	6.8	5.1	5		29	22356	3.8	2.1	5
	37	22487	6.8	5.2	1		29	22385	5.0	4.3	2
	27	22514	5.5	4.2	1		21	22406	3.8	0.7	1
	46	22560	6.0	3.8	1		29	22435	3.4	2.0	5
	39	22599	6.4	4.1	1		31	22466	2.9	0.9	1
	30	22629	5.2	3.8	1		29	22495	3.3	1.3	5
	18	22647	5.5	1.8	1	EGLE 030	30	22525	3.8	2.5	5
	46	22693	6.0	5.2	2		53	22578	4.4	1.8	5
	32	22725	6.4	2.8	1		27	22605	4.2	0.8	1
	56	22781	5.7	2.6	1		60	22665	4.1	2.8	5
	35	22816	6.0	2.7	1		60	22725	5.6	4.2	2
	49	22865	6.3	5.8	1		41	22766	4.7	1.9	1
	46	22911	5.9	5.0	3		42	22808	5.3	4.4	3
	21	22932	5.8	2.8	1		41	22849	4.5	3.8	3
	46	22978	5.4	5.0	5		42	22891	4.8	4.3	3
WGLE 038	47	23025	7.3	6.3	2		10	22901	4.6	3.2	1
	30	23055	5.6	2.4	1		41	22942	4.5	3.9	3
	28	23083	4.5	3.6	1		42	22984	4.4	3.6	3
	45	23128	5.5	4.1	3	EGLE 031	41	23025	4.8	3.6	3
	25	23153	3.7	2.8	1		48	23073	4.0	3.5	5
	47	23200	5.0	2.5	1		48	23121	3.6	3.1	5
	45	23245	5.0	4.0	5		48	23169	3.6	3.1	3
	45	23290	5.3	4.5	5		47	23216	3.6	2.9	5
	33	23323	6.5	5.0	1		48	23264	4.3	2.7	5
	32	23355	5.1	3.8	3		48	23312	4.8	3.2	5
	47	23402	5.0	1.4	1		48	23360	4.9	3.7	5
	45	23447	5.3	3.6	3		32	23392	5.3	1.6	5
	19	23466	5.3	4.0	1		48	23440	5.9	4.7	5
	45	23511	4.6	4.1	6		40	23480	4.7	3.6	1

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
WGLE 039	39	23550	4.9	3.5	6		48	23528	4.1	3.5	5
	45	23595	6.3	2.4	1	EGLE 032	47	23575	3.9	2.7	5
	18	23613	5.4	2.3	1		48	23623	3.9	2.9	5
	25	23638	6.3	5.4	6		48	23671	3.5	2.1	5
	14	23652	6.3	2.6	1		48	23719	3.9	3.2	5
	37	23689	6.0	2.4	1		48	23767	3.7	3.0	5
	25	23714	5.3	3.5	6		15	23782	4.3	3.1	1
	31	23745	5.8	1.8	1		48	23830	3.5	0.4	1
	25	23770	5.5	4.7	6		48	23878	2.9	1.3	3
	27	23797	6.0	5.0	1		35	23913	2.9	1.2	1
	45	23842	5.8	2.2	1		44	23957	3.5	1.0	1
	25	23867	5.0	3.0	1		48	24005	2.8	0.0	4
	32	23899	5.8	3.5	1		48	24053	2.9	0.0	4
	47	23946	6.0	3.1	1		48	24101	3.2	0.0	4
	25	23971	5.9	4.7	6	EGLE 033	49	24150	4.4	0.0	4
	43	24014	5.6	3.6	1		52	24202	5.0	0.0	4
	25	24039	5.7	2.5	1		53	24255	4.5	0.0	4
	31	24070	5.5	3.0	1		52	24307	3.8	0.0	4
WGLE 040	30	24100	5.7	3.1	6		53	24360	4.4	0.0	4
	36	24136	5.9	2.8	1		52	24412	3.3	0.0	4
	37	24173	5.2	4.0	1		53	24465	3.7	0.0	4
	37	24210	5.2	3.8	6		52	24517	4.9	0.0	4
	37	24247	5.1	3.8	1		53	24570	4.7	0.0	4
	36	24283	5.9	2.4	3		52	24622	5.2	0.0	4
	37	24320	5.8	2.9	3	EGLE 034	53	24675	4.1	0.0	4
	37	24357	5.4	4.8	3		52	24727	3.9	3.2	2
	36	24393	5.3	2.8	1		53	24780	5.1	0.0	4
	37	24430	5.4	4.1	6		52	24832	4.5	0.0	4
	22	24452	4.4	2.2	1		53	24885	3.8	0.0	4
	37	24489	5.4	4.3	6		52	24937	4.2	0.0	4
	15	24504	4.0	2.3	1		53	24990	4.5	0.8	5
	36	24540	5.2	4.5	6		52	25042	4.4	1.9	5
	37	24577	4.8	4.0	6		53	25095	4.8	2.8	5
	37	24614	5.1	3.9	6		52	25147	3.7	2.4	5
WGLE 041	36	24650	4.7	3.8	3	EGLE 035	53	25200	4.3	0.0	4
	55	24705	5.0	3.8	3		52	25252	6.5	0.0	4
	55	24760	4.7	2.7	3		53	25305	3.9	0.0	4
	55	24815	4.7	3.9	3		52	25357	4.2	0.0	4
	55	24870	4.8	3.5	3		53	25410	3.8	0.0	4
	55	24925	5.0	4.0	3		52	25462	3.5	0.0	4
	55	24980	5.0	4.0	3		53	25515	3.6	0.0	4
	55	25035	5.0	4.0	6		52	25567	3.0	0.0	4
	55	25090	4.6	3.6	6		53	25620	3.8	0.0	4
	55	25145	4.8	3.1	6		52	25672	4.1	0.0	4
WGLE 042	55	25200	5.2	3.2	6	EGLE 036	53	25725	2.9	0.0	4
	50	25250	5.0	4.3	6		50	25775	3.9	0.0	4
	50	25300	5.5	4.4	6		50	25825	4.2	0.0	4
	51	25351	5.1	2.4	3		50	25875	4.1	0.0	4
	50	25401	5.3	4.5	6		50	25925	4.2	0.0	4
	50	25451	5.0	3.6	6		50	25975	4.1	0.0	4
	51	25502	4.9	3.4	3		50	26025	3.5	0.0	4
	47	25549	5.1	3.0	1		50	26075	3.2	0.0	4
	50	25599	5.9	4.6	6		50	26125	4.2	0.0	4
	50	25649	4.7	3.3	3		50	26175	2.1	0.0	4
WGLE 043	51	25700	4.6	3.6	6		50	26225	2.3	0.0	4
	57	25757	5.1	2.9	6	EGLE 037	50	26275	2.2	0.0	4
	58	25815	6.0	5.0	2		58	26333	3.7	0.0	4
	57	25872	5.6	4.2	6		58	26391	4.0	0.0	4
	58	25930	5.6	5.3	2		59	26450	6.4	0.0	4
	57	25987	4.9	4.1	6		58	26508	5.6	0.0	4
	58	26045	4.2	2.5	3		58	26566	4.9	0.0	4
	57	26102	4.6	3.1	6		59	26625	5.2	0.0	4
	58	26160	5.7	4.6	6		58	26683	4.9	0.0	4
	57	26217	5.0	3.1	6		58	26741	4.8	0.0	4
WGLE 044	58	26275	5.2	4.1	6	EGLE 038	59	26800	5.1	0.0	4
	57	26332	4.4	3.8	6		58	26858	5.5	0.0	4
	57	26389	5.1	4.1	6		58	26916	5.8	0.0	4
	57	26446	5.5	3.3	3		59	26975	5.2	0.0	4
	56	26502	3.6	1.9	1		58	27033	4.8	0.0	4
	57	26559	3.6	3.3	1		58	27091	5.2	0.0	4

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		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	39	26598	3.9	3.2	1		59	27150	4.6	0.0	4
	57	26655	4.2	3.1	2		58	27208	5.7	0.0	4
	57	26712	4.0	3.3	6		58	27266	5.8	0.0	4
	57	26769	3.0	1.8	6	EGLE 039	59	27325	5.6	0.0	4
WGLE 045	56	26825	4.9	4.1	2		72	27397	4.6	0.0	4
	90	26915	4.8	2.7	6		72	27469	4.4	0.0	4
	90	27005	5.4	4.7	2		72	27541	4.1	0.0	4
	40	27045	6.4	4.7	6		72	27613	5.4	0.0	4
	40	27085	5.3	4.4	3		73	27686	4.8	0.0	4
	40	27125	5.6	4.4	6		72	27758	4.9	0.0	4
	47	27172	7.4	4.2	1		72	27830	4.5	0.0	4
	39	27211	6.0	5.2	1		72	27902	4.4	0.0	4
	64	27275	5.6	4.7	2	EGLE 040	73	27975	4.5	0.0	4
	26	27301	6.2	4.0	1		58	28033	4.5	0.0	4
WGLE 046	24	27325	7.7	5.8	2		58	28091	3.4	0.0	4
	5	27330	5.8	4.1	1		59	28150	4.0	0.0	4
	38	27368	5.8	3.8	1		58	28208	4.0	0.0	4
	62	27430	5.0	4.5	6		58	28266	4.1	0.0	4
	43	27473	7.5	5.5	1		59	28325	4.1	0.0	4
	20	27493	6.2	5.1	1		58	28383	3.7	0.0	4
	44	27537	6.3	4.1	1		58	28441	3.8	0.0	4
	63	27600	6.1	5.2	3	EGLE 041	59	28500	4.2	0.0	4
	62	27662	5.5	4.5	3		62	28562	4.3	0.0	4
	63	27725	6.1	5.1	6		63	28625	5.0	0.0	4
	62	27787	6.7	6.1	3		62	28687	3.5	0.0	4
WGLE 047	63	27850	5.4	4.4	6		63	28750	3.4	0.0	4
	48	27898	5.1	3.2	1		62	28812	4.4	0.0	4
	48	27946	6.2	3.6	1		63	28875	4.9	0.0	4
	47	27993	5.9	3.8	1		62	28937	4.8	1.2	5
	45	28038	6.0	2.3	1	EGLE 042	63	29000	5.1	0.0	4
	62	28100	5.4	3.9	6		55	29055	5.4	0.0	4
	43	28143	6.0	2.7	1		56	29111	3.9	0.0	4
	40	28183	5.3	2.7	1		55	29166	5.4	0.0	4
	49	28232	5.3	2.8	1		56	29222	4.4	0.0	4
	47	28279	5.0	2.7	1		55	29277	4.6	0.0	4
	63	28342	5.6	1.7	1		56	29333	4.6	0.0	4
WGLE 048	33	28375	5.5	1.8	1		55	29388	5.1	1.5	5
	50	28425	4.9	3.5	6		56	29444	4.9	0.0	4
	50	28475	5.8	4.1	1	EGLE 043	56	29500	4.3	0.0	4
	36	28511	6.1	3.8	1		57	29557	4.5	0.0	4
	50	28561	5.6	4.5	6		57	29614	5.8	4.6	5
	50	28611	5.8	3.8	3		57	29671	7.2	0.0	4
	50	28661	6.4	4.5	3		46	29717	4.9	3.7	5
	50	28711	6.3	3.6	1		56	29773	5.4	0.0	4
	50	28761	7.1	5.8	2		57	29830	6.4	0.0	4
	32	28793	5.8	3.2	1		57	29887	4.9	0.0	4
	37	28830	5.5	4.5	1		57	29944	5.6	0.0	4
WGLE 049	45	28875	5.8	2.5	1	EGLE 044	56	30000	4.6	0.0	4
	35	28910	4.9	4.1	1		58	30058	6.2	0.0	4
	66	28976	5.5	3.6	6		58	30116	4.5	0.0	4
	67	29043	7.1	6.1	6		58	30174	4.6	0.0	4
	20	29063	5.6	4.3	1		58	30232	4.4	0.0	4
	34	29097	6.6	4.2	1		58	30290	4.9	0.0	4
	67	29164	5.9	5.3	6		58	30348	4.4	3.6	5
	10	29174	6.0	3.3	1		58	30406	3.9	0.5	1
	21	29195	6.1	5.6	1		48	30454	4.0	0.0	4
	67	29262	7.5	5.4	3		59	30513	4.1	1.6	1
WGLE 050	38	29300	6.0	3.5	3	EGLE 045	12	30525	4.1	3.1	5
	50	29350	5.1	4.0	1		55	30580	4.2	2.1	5
	51	29401	6.9	4.7	6		55	30635	3.9	3.1	5
	17	29418	6.3	3.6	1		55	30690	3.2	0.0	4
	50	29468	7.0	4.1	6		55	30745	3.5	0.0	4
	31	29499	6.7	4.3	1		55	30800	3.8	0.0	4
	51	29550	5.6	4.5	2		55	30855	2.7	0.0	4
	49	29599	7.6	4.7	1		55	30910	4.6	1.3	5
	50	29649	7.1	5.7	3		55	30965	4.9	3.2	5
	49	29698	7.2	5.7	1		55	31020	4.8	1.3	5
	51	29749	6.5	5.2	6	EGLE 046	55	31075	4.7	0.8	5
	50	29799	6.4	5.0	6		55	31130	6.1	0.0	4
WGLE 051	51	29850	7.1	5.2	6		55	31185	5.6	0.0	4

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	55	29905	6.4	5.6	5		55	31240	5.8	0.0	4
	55	29960	6.1	4.4	5		55	31295	4.8	0.0	4
	26	29986	6.5	3.7	1		55	31350	5.3	0.0	4
	55	30041	6.2	3.1	6		55	31405	5.1	0.0	4
	55	30096	6.5	5.1	2		55	31460	6.5	0.0	4
	55	30151	6.9	5.8	6		55	31515	6.6	0.0	4
	55	30206	7.2	4.3	3		55	31570	6.6	0.0	4
	55	30261	7.4	5.2	2	EGLE 047	55	31625	6.6	0.0	4
	55	30316	7.2	6.2	2		50	31675	6.3	0.0	4
	55	30371	4.7	3.5	3		50	31725	6.7	0.0	4
WGLE 052	54	30425	7.1	5.0	6		50	31775	6.2	0.0	4
	44	30469	6.8	5.9	2		50	31825	6.5	0.0	4
	39	30508	6.8	5.3	1		50	31875	6.3	0.0	4
	44	30552	6.5	3.8	3		50	31925	5.3	0.0	4
	44	30596	5.7	3.8	6		50	31975	5.3	0.0	4
	40	30636	7.5	5.4	1		50	32025	5.2	0.0	4
	44	30680	7.0	5.1	6		50	32075	5.3	0.0	4
	44	30724	6.6	3.6	3	EGLE 048	50	32125	5.3	0.0	4
	44	30768	6.3	5.3	2		52	32177	5.8	0.0	4
	21	30789	7.5	2.4	1		53	32230	5.3	0.0	4
	47	30836	6.7	4.4	1		52	32282	6.2	0.0	4
	44	30880	6.5	2.8	3		53	32335	5.5	0.0	4
WGLE 053	45	30925	6.3	4.0	1		52	32387	5.0	0.0	4
	53	30978	6.2	5.4	5		53	32440	4.6	0.0	4
	53	31031	6.3	5.4	5		52	32492	5.7	0.0	4
	23	31054	6.3	4.9	1		53	32545	5.2	0.0	4
	52	31106	7.4	5.7	2		52	32597	6.2	0.0	4
	53	31159	6.8	5.4	5	EGLE 049	53	32650	5.4	0.0	4
	53	31212	7.2	5.3	6		50	32700	4.8	0.0	4
	53	31265	8.2	6.0	6		50	32750	5.4	0.0	4
	53	31318	7.9	6.8	6		50	32800	5.2	1.6	5
	53	31371	8.7	7.4	6		50	32850	5.5	3.8	5
	52	31423	8.0	6.5	6		50	32900	5.4	1.0	5
WGLE 054	52	31475	10.4	8.3	6		50	32950	5.5	0.0	4
	55	31530	8.4	5.9	6		50	33000	4.5	0.0	4
	55	31585	7.8	5.5	3		50	33050	4.8	2.2	2
	55	31640	8.3	6.4	6		50	33100	5.1	1.9	2
	55	31695	7.9	6.3	6	EGLE 050	50	33150	6.3	0.0	4
	55	31750	7.5	6.5	6		50	33200	6.2	0.0	4
	55	31805	9.7	7.0	6		50	33250	6.2	0.0	4
	55	31860	9.0	5.4	3		50	33300	6.1	0.0	4
	55	31915	8.1	6.4	6		50	33350	6.4	0.0	4
	55	31970	8.0	5.9	6		50	33400	6.6	0.0	4
WGLE 055	55	32025	7.9	4.9	6		50	33450	7.3	0.0	4
	50	32075	7.3	5.6	6		50	33500	6.2	1.4	5
	50	32125	8.1	6.3	6		50	33550	6.8	0.0	4
	100	32225	5.2	4.2	6		50	33600	4.7	3.0	2
	34	32259	6.1	4.5	1	EGLE 051	50	33650	5.7	0.0	4
	46	32305	6.4	5.2	1		47	33697	5.8	0.0	4
	45	32350	6.8	5.5	6		48	33745	5.7	2.2	5
	45	32395	6.9	5.7	6		47	33792	6.5	0.0	4
	45	32440	7.8	6.0	6		48	33840	7.2	0.0	4
	45	32485	7.2	6.1	6		47	33887	5.5	0.0	4
	32	32517	6.8	4.7	1		48	33935	6.0	0.0	4
	45	32562	7.6	6.1	6		47	33982	6.3	2.1	5
	44	32606	7.6	5.9	6		48	34030	5.8	2.3	5
WGLE 056	44	32650	6.1	5.3	6		47	34077	6.1	2.5	5
	46	32696	7.4	2.6	6	EGLE 052	48	34125	5.8	0.0	4
	47	32743	5.9	4.9	6		50	34175	6.7	0.0	4
	46	32789	5.5	4.9	6		50	34225	6.0	0.0	4
	23	32812	6.9	5.6	1		50	34275	5.5	0.0	4
	47	32859	6.2	5.1	1		50	34325	5.4	0.0	4
	26	32885	6.2	4.1	1		50	34375	5.6	0.0	4
	47	32932	5.2	4.6	6		50	34425	5.3	0.0	4
	18	32950	6.3	2.3	1		50	34475	5.8	0.0	4
	46	32996	6.0	4.5	2		50	34525	5.1	0.0	4
	35	33031	6.4	2.9	1		50	34575	6.0	0.0	4
	49	33080	6.6	5.1	1	EGLE 053	50	34625	6.1	0.0	4
	48	33128	6.5	5.7	1		53	34678	6.3	0.0	4
WGLE 057	47	33175	6.4	4.0	1		52	34730	6.3	0.0	4

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	39	33214	5.8	4.1	1		53	34783	5.4	0.0	4
	42	33256	5.7	5.0	6		52	34835	6.1	0.0	4
	41	33297	6.3	5.6	6		53	34888	5.1	1.6	5
	36	33333	6.1	5.2	1		52	34940	4.7	1.4	5
	42	33375	6.5	5.2	6		53	34993	5.5	3.3	5
	18	33393	5.8	4.9	1		52	35045	4.7	2.6	5
	44	33437	5.6	4.9	1		53	35098	4.8	2.2	5
	41	33478	5.8	5.4	6	EGLE 054	52	35150	4.8	2.2	5
	45	33523	6.5	3.2	1		55	35205	5.0	3.6	5
	42	33565	5.6	4.5	1		55	35260	6.8	3.8	5
	41	33606	6.5	4.5	3		55	35315	5.3	2.6	5
	38	33644	5.0	4.3	1		55	35370	5.3	2.1	5
	40	33684	6.0	3.3	1		55	35425	6.3	1.3	5
WGLE 058	41	33725	5.4	4.4	6		55	35480	5.4	3.9	5
	44	33769	5.0	4.4	2		55	35535	5.9	3.4	5
	44	33813	5.7	4.8	2		55	35590	6.3	5.2	5
	44	33857	5.7	4.9	5		55	35645	5.8	4.3	5
	43	33900	7.4	4.6	6	EGLE 055	55	35700	5.3	2.1	5
	44	33944	6.5	4.8	6		51	35751	4.5	1.7	1
	44	33988	8.0	5.5	6		35	35786	5.2	4.3	5
	44	34032	6.7	5.4	6		51	35837	5.8	0.0	4
	43	34075	7.4	4.6	6		20	35857	6.1	0.2	1
	44	34119	6.9	5.4	3		12	35869	5.9	0.4	1
	44	34163	6.7	4.2	1		23	35892	5.1	1.1	1
	44	34207	5.9	4.3	6		32	35924	5.7	0.8	1
WGLE 059	43	34250	6.4	4.2	6		23	35947	6.2	1.1	1
	50	34300	7.4	5.5	6		50	35997	8.3	5.6	5
	50	34350	7.2	4.1	6		51	36048	6.4	4.7	5
	80	34430	5.3	4.1	1		51	36099	6.0	4.9	5
	20	34450	5.6	4.2	5		51	36150	5.6	4.5	5
	50	34500	6.4	5.4	3	EGLE 056	50	36200	6.1	4.0	5
	50	34550	6.3	5.5	5		49	36249	5.6	1.0	1
	50	34600	5.7	4.8	5		10	36259	5.8	1.6	1
	60	34660	6.4	5.4	1		49	36308	4.8	1.0	1
	40	34700	5.7	4.8	2		49	36357	5.0	3.4	5
WGLE 060	50	34750	7.5	4.8	1		49	36406	5.3	3.9	5
	50	34800	5.8	4.6	5		49	36455	6.2	2.9	5
	50	34850	6.7	5.2	5		49	36504	6.7	5.3	5
	50	34900	6.8	5.5	5		49	36553	6.4	4.8	5
	50	34950	7.5	4.4	5		49	36602	5.7	1.7	1
	50	35000	7.5	5.7	3		49	36651	6.8	3.4	5
	50	35050	9.3	4.3	1	EGLE 057	49	36700	6.8	0.4	5
	100	35150	6.6	5.4	5		52	36752	5.3	3.3	5
	50	35200	6.1	4.7	2		53	36805	5.2	2.6	5
WGLE 061	50	35250	7.6	6.1	5		52	36857	6.1	3.4	5
	55	35305	7.6	2.8	6		53	36910	6.5	2.9	5
	55	35360	7.8	6.6	6		52	36962	6.6	1.1	5
	55	35415	7.0	3.9	6		53	37015	6.6	1.3	5
	34	35449	7.9	5.7	1		52	37067	5.9	1.1	1
	55	35504	9.1	6.3	6		53	37120	6.8	2.6	5
	55	35559	7.4	4.9	6		52	37172	6.5	0.8	5
	55	35614	7.7	5.6	6	EGLE 058	53	37225	7.4	1.1	5
	55	35669	7.8	6.5	6		45	37270	5.4	4.4	5
WGLE 062	56	35725	6.9	6.0	6		46	37316	5.9	1.2	5
	61	35786	9.5	6.2	6		45	37361	6.6	2.6	5
	61	35847	7.9	6.0	6		46	37407	5.8	4.1	5
	61	35908	7.5	6.4	6		45	37452	7.4	1.4	1
	61	35969	8.1	5.9	6		40	37492	6.9	4.2	5
	61	36030	7.0	5.0	6		46	37538	7.0	0.7	1
	61	36091	6.9	4.8	6		45	37583	6.5	4.5	5
	61	36152	7.1	5.1	6		46	37629	6.9	5.3	5
	61	36213	6.8	5.0	6		46	37675	7.5	4.9	5
WGLE 063	62	36275	7.2	5.9	6						
	58	36333	6.8	5.4	6						
	58	36391	6.5	5.5	6			RIVER	GLEN		
	59	36450	8.8	6.7	6						
	58	36508	7.5	6.0	6	GLEN 001	0	0	7.5	5.3	2
	58	36566	7.8	6.3	2		50	50	7.6	6.5	1
	59	36625	7.8	6.8	5		50	100	6.3	5.0	5

Appendix 1 River Glen physical habitat survey results

		WEST	GLEN					EAST	GLEN		
Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type	Reach Number	Distance Down. (m)	Cumulative Distance (m)	Channel Width (m)	Water Width (m)	Channel Type
	58	36683	7.8	6.9	5		50	150	6.4	5.5	5
	58	36741	7.5	6.5	5		50	200	7.9	7.3	5
WGLE 064	199	36940	6.4	0.0	4		50	250	8.1	7.7	5
	290	37230	9.5	0.0	4		50	300	8.0	7.6	5
	35	37265	8.2	0.0	4		50	350	7.5	7.4	5
WGLE 065	35	37300	8.2	0.0	4		50	400	9.1	8.9	5
	47	37347	4.0	0.0	4		50	450	8.9	8.8	5
	47	37394	6.0	0.0	4	GLEN 002	50	500	10.0	9.8	5
	47	37441	5.5	4.7	5		50	550	9.4	9.2	5
	47	37488	9.2	5.6	5		50	600	10.5	10.4	5
	48	37536	7.1	5.7	6		50	650	11.5	11.0	5
	22	37558	6.8	2.5	1		50	700	12.6	12.2	5
	47	37605	6.5	4.8	5		50	750	12.0	11.7	5
	47	37652	7.1	5.1	5		50	800	12.9	12.3	5
	47	37699	6.9	5.1	5		40	840	13.2	12.6	5
	48	37747	7.6	5.4	5		90	930	12.8	12.0	5
WGLE 066	28	37775	6.8	5.2	5		50	980	11.8	11.2	5
	15	37790	7.7	4.7	1	GLEN 003	100	1080	13.0	12.6	5
	47	37837	6.9	3.5	3		50	1130	12.7	12.3	5
	41	37878	6.3	2.6	1		50	1180	11.5	11.0	5
	47	37925	5.1	3.5	3		50	1230	12.5	11.7	5
	25	37950	5.1	3.3	1		80	1310	13.2	12.9	5
	46	37996	6.1	3.7	1		70	1380	14.7	14.4	5
	47	38043	5.3	2.4	3		50	1430	12.6	12.3	5
	47	38090	6.5	4.1	5		40	1470	13.2	12.8	5
	48	38138	5.3	1.2	1		70	1540	12.7	12.1	5
	47	38185	6.0	3.3	3	GLEN 004	60	1600	14.1	13.6	5
	47	38232	6.6	3.7	6		120	1720	12.3	8.3	5
	47	38279	6.3	2.3	1		50	1770	8.0	7.2	5
WGLE 067	46	38325	6.2	3.5	6		50	1820	8.6	7.1	5
	41	38366	4.1	3.2	6		50	1870	8.0	7.5	5
	41	38407	6.4	3.0	6		50	1920	10.0	8.4	5
	40	38447	5.6	2.8	6		50	1970	10.6	8.8	5
	41	38488	4.0	2.8	6		50	2020	6.9	5.5	5
	20	38508	4.4	2.4	1		50	2070	8.7	7.4	5
	41	38549	4.9	3.2	2		50	2120	12.0	10.2	5
	40	38589	4.2	2.8	2	GLEN 005	50	2170	13.3	12.7	5
	41	38630	4.6	3.4	2						
	41	38671	4.6	3.4	6						
	41	38712	5.5	3.0	1						
	41	38753	5.8	3.2	6						
	32	38785	5.9	2.6	1						
WGLE 068	40	38825	4.7	3.3	6						
	41	38866	4.9	3.3	6						
	41	38907	4.2	2.4	3						
	41	38948	4.8	2.9	5						
	15	38963	4.4	2.7	1						
	41	39004	4.7	3.1	6						
	41	39045	5.3	3.1	3						
	41	39086	6.6	3.1	3						
	41	39127	5.1	3.2	6						
	41	39168	4.6	3.1	3						
	41	39209	6.0	3.3	6						
	41	39250	5.2	1.8	6						

APPENDIX 2

RIVER GLEN DISCHARGE SURVEY RESULTS

Appendix 2 - Results of the West Glen discharge surveys (figures shown are in cumecs)

Date	Bitchfield - SK985285	Burton Coggles G/S - SK987261	Swayfield - TF007223	Creeton - TF015195	Careby - TF025166	Holywell Brook G/S - TF026148	Essendine - TF051135	Shillingthorpe - TF058111	Shillingthorpe G/S - TF074112	Greatford - TF088121	Confluence (U/S) - TF095132	East Glen (U/S) - TF095133	Wilsthorpe - TF096133	Kates Bridge G/S - TF106147	King Street G/S - TF109106
15/1/90	.0625	.0690	.0242	.0227	.0631	.0590	.0987	.0838	.1210	.1182	.1185	.0724	.1909	.1800	.0530
15/3/90	.0310	.0370	.0155	.0505	.1257	.1790	.3206	.3129	.3910	.3880	.3773	.5561	.9334	.9910	.0700
25/5/90	.0008	.0010	0	.0066	.0592	.0970	.1630	.1437	.1380	.1053	.1209	.0458	.1667	.1850	.0200
21/6/90	.0003	.0010	0	.0017	.0603	.0760	.1241	.0694	.1050	.0532	.0617	.0093	.0710	.1010	.0340
27/7/90	0	0	0	.0005	.0309	.0160	.0437	.0204	.0270	.0043	.0031	.0002	.0033	.0050	.0270
22/8/90	.0001	0	0	.0011	.0230	.0140	.0407	.0098	.0020	.0023	.0049	.0001	.0050	.0040	.0320
25/9/90	.0007	0	0	.0002	.0189	.0050	.0220	.0034	0	0	.0026	.0001	.0027	.0050	0
25/10/90	.0006	.0010	0	0	.0366	0	.0151	0	0	0	.0025	.0002	.0027	.0100	.0130
28/11/90	.0051	.0080	0	.0001	.0194	0	.0138	0	0	0	.0043	0	.0043	.0080	.0100
19/12/90	.0038	.0050	0	.0002	.0217	0	.0168	0	0	0	.0047	.0001	.0048	.0110	.0150
25/1/91	.0601	.0740	.0078	.0055	.0360	.0200	.0493	.0218	.0470	.0386	.0758	.0343	.1101	.1820	.0110
1/3/91	.6120	.5670	.6745	.6774	.9019	.0540	1.0247	1.0642	.9840	1.3823	n/a	n/a	n/a	3.1070	.0330
7/4/91	.0329	.0250	0	.0219	.0647	.0740	.1326	.1097	.1320	.1056	.2596	.3395	.5991	.4850	.0320
26/4/91	.0061	.0090	0	.0077	.0461	.0720	.1038	.0702	.1090	.0913	.0782	.2334	.3116	.2890	.0250
28/5/91	.0028	.0030	0	.0025	.0582	.0640	.1257	.1839	.1470	.1428	.1492	.0978	.2470	.2160	.0300
1/7/91	.0020	.0030	0	.0020	.0265	.0430	.0745	.1162	.1130	.0844	.1168	.0056	.1224	n/a	.0120
29/7/91	.0002	0	0	.0011	.0217	.0340	.0501	.1326	.1380	.0970	.1116	.0003	.1119	n/a	.0320
27/8/91	.0001	0	0	.0001	.0160	.0300	.0333	.1484	.1500	.1070	.1183	.0006	.1189	.1460	.0320
27/9/91	0	0	0	n/a	.0264	.0130	.0180	.1454	.1340	.1045	.1135	.0005	.1140	.1340	.0190
30/10/91	.0061	.0020	0	.0002	.0335	.0120	.0308	.0962	.0730	.0900	.0993	.0004	.0997	.0990	.0080
25/11/91	.0100	.0110	0	.0002	.0131	.0100	.0257	.0046	.0110	.0184	.0250	.0001	.0251	.0490	.0110

n/a - not available

Appendix 2 - Results of the East Glen discharge surveys (figures shown are in cumecs)

Date	Irnham G/S - TF038273	Irnham - TF029282	Bulby - TF048259	Edenham (U/S) - TF062221	Grimsthorpe Lake Input - TF030232	Grimsthpe. Pk. Bk. Conf. - TF058193	Toft - TF067171	Manthorpe G/S - TF068159	Braceborough - TF081136	Confluence (U/S) - TF095133	West Glen (U/S) - TF095132	Wilsthorpe - TF096133	Kates Bridge G/S - TF106147	King Street G/S - TF109106
18/1/90	.0459	.0560	.0541	.0767	.0183	.0783	.0559	.0430	.0414	n/a	n/a	n/a	.2010	.0460
14/3/90	.0529	.0610	.0611	.0880	.0219	.1161	.1111	.1200	.5223	.5078	.3109	.8187	.9730	.0510
24/5/90	.0033	.0030	.0036	.0071	.0020	.0089	0	0	.0766	.0602	.1247	.1849	.1860	.0340
22/6/90	.0158	.0080	.0057	.0026	.0022	0	0	0	.0566	.0365	.0829	.1194	.1130	.0330
27/7/90	0	0	0	0	0	0	0	0	.0001	.0002	.0031	.0033	.0050	.0270
22/8/90	.0032	.0010	.0003	0	0	0	0	0	<.0001	.0001	.0049	.0050	.0040	.0320
25/9/90	.0048	.0040	.0009	0	0	0	0	0	<.0001	.0001	.0026	.0027	.0050	0
25/10/90	.0029	.0050	.0021	.0003	.0016	0	0	0	<.0001	.0002	.0025	.0027	.0100	.0130
28/11/90	.0136	.0170	.0141	.0218	.0130	0	0	0	<.0001	0	.0043	.0043	.0080	.0100
19/12/90	.0100	.0120	.0080	.0144	.0130	0	0	0	<.0001	.0001	.0047	.0048	.0110	.0150
25/1/91	.0760	.0790	.0783	.1316	.0347	.1057	.0853	.0620	.0429	.0343	.0758	.1101	.1820	.0110
1/3/91	.6772	.5810	.9325	1.1932	.1692	1.7592	1.8293	1.4480	2.0313	n/a	n/a	n/a	3.1070	.0330
7/4/91	.0366	.0370	.0431	.0690	.0121	.0469	.0204	.0240	.1903	.3395	.2596	.5991	.4850	.0320
26/4/91	.0114	.0150	.0163	.0240	.0049	.0258	.0023	0	.1472	.2334	.0782	.3116	.2890	.0250
28/5/91	.0104	.0080	.0051	.0179	.0015	.0144	0	0	.0977	.0978	.1492	.2470	.2160	.0300
1/7/91	.0090	.0120	.0095	.0337	.0088	.0313	0	0	.0138	.0056	.1168	.1224	n/a	.0120
29/7/91	.0005	0	0	0	.0001	0	0	0	0	.0003	.1116	.1119	n/a	.0320
27/8/91	.0002	.0010	0	0	0	0	0	0	0	.0006	.1183	.1189	.1460	.0320
27/9/91	0	.0040	0	0	0	0	0	0	0	.0005	.1135	.1140	.1340	.0190
30/10/91	.0055	.0090	.0051	.0024	.0059	0	0	0	0	.0004	.0993	.0997	.0990	.0080
25/11/91	.0242	.0200	.0242	.0319	.0107	.0211	0	0	0	.0001	.0250	.0251	.0490	.0110

n/a - not available

APPENDIX 3

28 SITE HABITAT SURVEY RESULTS FOR BMWP TEST

Appendix 3 28 site habitat survey results for BMWP test

transect no.	dist. down. (m)	cum. dist. (m)	habitat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	detritus	clay	silt	sand	gravel	cobble	boulder	bedrock	% instream cover	% over-hanging cover	% bank-side cover
Walthe	**Beck**																	
1	0	0	2	1	3.4	2.5	0.10	0	0	1	1	1	0	0	0	5	100	0
2	25	25	2	1	3.2	2.6	0.10	0	0	0	1	1	1	0	0	5	100	5
3	25	50	3	1	3.4	1.9	0.25	1	0	1	1	1	0	0	0	10	80	5
4	25	75	3	1	4.1	3.8	0.10	1	0	1	1	1	0	0	0	10	80	5
5	25	100	3	1	4.3	3.7	0.35	1	0	1	1	1	0	0	0	10	60	2
6	20	120	2	1	3.9	3.1	0.10	0	0	0	1	1	1	0	0	5	100	5
7	25	145	3	1	3.6	2.2	0.25	0	0	1	1	1	1	0	0	50	50	10
8	25	170	3	1	3.7	3.2	0.30	1	0	1	1	0	0	0	0	10	40	10
9	25	195	3	1	3.8	3.5	0.15	1	0	1	1	1	1	0	0	10	100	2
10	25	220	3	1	3.2	2.7	0.40	1	0	1	1	0	0	0	0	10	40	5
11	25	245	3	1	3.3	2.8	0.25	1	0	1	1	1	1	0	0	80	0	10
12	25	270	3	1	3.9	3.5	0.25	1	0	1	1	0	1	0	0	0	100	10
13	25	295	3	1	3.7	3.3	0.20	1	0	1	1	1	0	0	0	30	0	20
14	25	320	3	1	3.8	3.2	0.20	1	0	1	1	1	0	0	0	80	0	50
15	25	345	3	1	3.5	3.2	0.20	1	0	1	1	1	0	0	0	50	0	5
16	25	370	3	1	3.4	3.0	0.15	1	0	1	1	1	1	0	0	10	80	10
17	25	395	3	1	3.5	2.9	0.20	1	0	1	1	1	0	0	0	80	0	10
18	25	420	2	1	3.4	2.9	0.10	0	0	1	1	1	0	0	0	40	0	20
19	25	445	3	1	3.1	1.5	0.35	1	0	1	1	1	0	0	0	50	0	50
20	20	465	2	1	3.9	2.8	0.10	0	0	1	1	1	0	0	0	40	0	20
Barlings	**Eau**																	
1	0	0	1	1	7.2	5.3	0.05	0	0	1	1	1	1	0	0	40	0	15
2	30	30	3	1	6.7	5.8	0.25	1	0	1	0	0	0	0	0	10	0	5
3	30	60	3	1	7.8	6.7	0.20	1	0	1	1	1	0	0	0	10	0	10
4	30	90	3	1	7.9	6.5	0.20	1	0	1	0	0	0	0	0	5	0	5
5	30	120	3	1	6.4	5.4	0.15	1	0	1	0	0	0	0	0	2	40	2
6	30	150	1	1	6.2	3.9	0.50	1	0	1	1	1	0	0	0	20	0	0
7	30	180	2	1	6.1	3.9	0.15	1	0	1	1	1	0	0	0	2	0	20
8	30	210	3	1	6.5	4.2	0.10	1	0	1	1	1	0	0	0	5	0	5
9	30	240	1	1	6.1	2.9	0.50	0	0	0	1	1	0	0	0	2	0	5
10	30	270	2	1	6.3	2.9	0.10	1	0	1	1	1	0	0	0	5	0	5
11	25	295	1	1	5.9	3.7	0.50	1	0	1	1	1	0	0	0	2	0	2
12	30	325	3	1	5.7	4.3	0.15	1	0	1	1	1	0	0	0	30	0	5
13	30	355	3	1	5.3	4.4	0.25	1	0	1	1	1	0	0	0	5	0	10
14	30	385	3	1	5.6	4.1	0.15	1	0	1	1	1	0	0	0	5	0	5
15	15	400	1	1	4.8	2.9	0.50	1	0	1	1	1	0	0	0	5	0	10
16	30	430	3	1	5.7	4.2	0.30	1	1	1	1	1	0	0	0	0	0	10
17	30	460	3	1	6.3	4.8	0.15	1	1	1	1	1	0	0	0	0	0	2
18	30	490	3	1	6.3	5.0	0.20	1	1	1	0	0	0	0	0	5	20	0
19	30	520	3	1	6.6	5.4	0.20	1	1	1	1	1	0	0	0	20	0	20
20	30	550	3	2	6.1	4.7	0.25	1	1	1	1	1	0	0	0	0	0	20
Witham																		
1	0	0	1	1	10.3	8.4	0.20	0	0	1	1	1	1	0	0	20	0	2
2	30	30	3	1	10.2	9.3	0.40	0	0	1	1	0	1	0	0	20	0	2
3	30	60	2	1	10.8	9.7	0.35	0	0	1	1	1	1	0	1	10	0	5
4	20	80	1	1	11.9	9.4	0.20	0	0	0	1	1	1	0	1	50	0	0
5	30	110	2	1	10.0	6.4	0.35	1	0	0	1	1	1	0	0	10	0	2
6	30	140	1	1	10.5	8.8	0.30	1	0	1	1	1	1	0	0	60	0	0
7	30	170	1	1	11.4	10.8	0.25	0	0	0	1	1	1	0	0	50	0	2
8	30	200	3	1	10.4	9.6	0.40	1	0	1	1	1	0	0	0	30	0	0
9	30	230	3	1	11.3	10.1	0.40	1	0	1	1	1	0	0	0	20	0	0
10	30	260	3	1	10.5	10.2	0.50	1	1	1	1	1	0	0	0	50	0	5
11	30	290	3	1	11.4	10.8	0.55	1	0	1	1	1	0	0	0	30	0	2
12	30	320	3	1	11.1	10.6	0.60	1	0	1	1	1	0	0	0	20	0	5
13	30	350	3	1	11.0	10.5	0.75	1	0	1	1	1	0	0	0	30	0	2
14	30	380	3	2	10.5	9.4	0.50	1	0	1	1	1	0	0	0	10	0	5
15	30	410	3	2	9.5	8.8	0.75	1	0	1	1	1	0	0	0	10	0	2
16	30	440	3	2	9.7	9.3	1.00	1	0	1	1	1	0	0	0	30	0	2
17	30	470	3	2	10.1	9.4	0.80	1	0	1	1	0	0	0	0	20	0	2
18	30	500	3	2	10.5	9.8	0.40	1	0	1	1	1	0	0	0	5	0	5
19	30	530	2	1	10.9	10.1	0.20	1	0	1	1	1	0	0	0	10	0	10
20	30	560	2	1	12.1	11.3	0.15	0	0	0	1	1	0	0	0	30	0	5
North	**Brook**																	
1	0	0	2	1	5.2	3.5	0.15	0	0	1	1	1	1	0	0	20	50	0
2	30	30	3	1	4.3	3.2	0.25	1	0	1	1	0	1	0	0	10	80	0
3	30	60	2	1	4.4	3.0	0.15	0	0	0	1	1	1	0	0	30	100	0
4	30	90	3	1	4.7	3.6	0.35	1	0	1	1	1	0	0	0	5	0	0
5	30	120	3	1	3.6	3.1	0.45	1	0	1	1	0	0	0	0	0	0	10
6	30	150	3	1	3.4	2.9	0.35	1	0	1	1	0	0	0	0	20	30	5
7	30	180	2	1	3.6	3.1	0.05	0	0	0	1	1	1	0	0	30	0	2
8	30	210	3	1	3.8	3.5	0.30	1	0	1	1	1	0	0	0	5	0	2
9	30	240	3	1	3.4	3.2	0.55	1	0	1	1	1	0	0	0	10	0	5
10	30	270	1	1	4.9	4.2	0.10	1	0	1	1	1	1	0	0	10	100	2
11	30	300	3	1	6.5	6.0	0.30	1	0	1	1	1	1	1	0	70	100	0
12	30	330	1	1	4.7	3.8	0.10	0	0	0	1	1	1	1	0	50	100	2
13	30	360	3	1	3.1	2.9	0.45	1	0	1	1	0	1	0	0	10	100	0
14	30	390	3	1	3.5	3.1	0.35	1	0	1	1	1	1	0	0	80	80	2
15	30	420	3	1	3.3	2.9	0.40	1	0	1	1	0	1	0	0	0	100	5
16	30	450	2	1	4.7	4.2	0.25	1	0	1	1	1	1	0	0	60	100	0
17	30	480	2	1	4.3	3.1	0.20	1	0	1	1	1	1	0	0	0	100	0
18	30	510	3	1	4.4	3.2	0.30	1	0	1	1	1	1	0	0	20	80	2
19	30	540	3	1	4.7	4.1	0.50	1	0	1	1	1	1	0	0	35	100	0
20	30	570	1	1	3.9	3.2	0.10	0	0	0	0	1	1	1	0	10	100	2

Appendix 3 28 site habitat survey results for BMWP test

transect no.	dist. down. (m)	cum. dist. (m)	habitat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	detritus	clay	silt	sand	gravel	cobble	boulder	bedrock	% instream cover	% overhanging cover	% bankside cover
Willow	**Brook**																	
1	0	0	2	1	7.1	6.6	0.20	0	0	0	1	1	0	0	0	10	40	5
2	30	30	2	1	7.3	6.5	0.25	0	0	0	1	1	0	0	0	10	0	20
3	30	60	3	1	5.9	4.7	0.30	1	0	0	1	1	0	0	0	20	75	10
4	30	90	2	1	5.8	5.2	0.25	0	0	0	1	1	0	0	0	30	0	5
5	30	120	3	1	5.3	4.8	0.45	0	0	1	1	1	0	0	0	30	0	10
6	30	150	2	1	5.9	5.2	0.25	0	0	0	1	1	0	0	0	5	30	5
7	30	180	2	1	6.5	6.0	0.20	0	0	0	1	1	0	0	0	10	0	10
8	30	210	2	1	7.1	6.6	0.20	0	0	0	1	1	0	0	0	20	80	5
9	30	240	2	1	7.5	7.1	0.20	0	0	0	1	1	0	0	0	5	50	5
10	30	270	2	1	7.1	5.6	0.15	0	0	0	1	1	0	0	0	0	20	5
11	30	300	2	1	6.6	6.1	0.10	0	0	0	1	1	0	0	0	0	50	2
12	30	330	3	1	4.9	4.6	0.45	0	0	1	1	1	0	0	0	20	0	10
13	30	360	2	1	5.7	5.3	0.20	0	0	0	1	1	0	0	0	50	0	5
14	30	390	2	1	6.9	5.3	0.15	0	0	0	1	1	0	0	0	0	0	5
15	30	420	3	1	4.9	4.6	0.40	0	0	1	1	1	0	0	0	10	25	10
16	30	450	2	1	4.7	4.3	0.25	0	0	0	1	1	0	0	0	5	0	10
17	30	480	2	1	5.3	4.9	0.20	0	0	0	1	1	0	0	0	5	0	5
18	30	510	3	1	4.7	4.2	0.30	0	0	0	1	1	0	0	0	10	10	10
19	30	540	2	1	6.2	5.9	0.15	0	0	0	1	1	0	0	0	0	0	2
20	30	570	2	1	5.9	3.7	0.25	0	0	0	1	1	0	0	0	0	0	5
Harpers	**Brook**																	
1	0	0	2	1	5.3	3.2	0.10	0	0	1	1	1	0	0	0	10	0	5
2	30	30	2	1	6.2	4.3	0.15	0	0	1	1	1	1	0	0	100	0	2
3	30	60	2	1	5.1	2.9	0.05	0	0	1	1	1	0	0	0	70	0	0
4	20	80	1	1	3.2	2.4	0.15	0	0	1	1	1	1	0	0	10	0	5
5	30	110	3	1	4.1	3.7	0.80	1	1	1	1	1	1	0	0	20	0	20
6	30	140	2	1	2.8	1.9	0.15	0	0	1	1	1	1	0	0	20	30	10
7	30	170	3	1	3.7	3.0	0.40	1	1	1	1	1	1	0	0	20	100	5
8	30	200	1	1	3.2	2.7	0.10	1	0	1	1	1	1	0	0	10	0	0
9	30	230	3	1	3.3	2.8	0.30	1	1	1	1	0	0	0	0	40	0	10
10	30	260	3	1	3.7	3.1	0.35	1	1	1	1	1	0	0	0	10	0	5
11	30	290	3	1	4.5	3.8	0.40	1	0	1	1	1	0	0	0	10	50	2
12	30	320	3	1	4.4	4.0	0.80	1	1	1	1	1	0	0	0	0	40	2
13	30	350	3	1	3.9	3.3	0.70	1	0	1	1	1	0	0	0	10	80	5
14	10	360	2	1	3.5	3.1	0.25	1	0	1	1	1	0	0	0	5	0	20
15	30	390	3	1	4.5	3.9	0.50	1	0	1	1	1	1	0	0	0	0	2
16	30	420	3	2	4.9	4.1	0.50	1	0	1	1	1	1	0	0	10	0	10
17	30	450	3	2	4.2	3.8	0.30	1	0	1	1	1	1	0	0	10	0	30
18	30	480	1	1	4.4	4.1	0.50	0	0	0	1	1	1	0	0	10	0	10
19	30	510	3	1	4.8	4.1	0.35	1	0	1	1	1	1	0	0	5	0	2
20	30	540	3	1	4.3	4.3	0.40	1	0	1	1	1	1	0	0	5	30	2
Nar																		
1	0	0	1	1	9.2	7.4	0.25	0	0	0	1	1	0	0	0	20	80	10
2	30	30	2	1	9.1	8.3	0.20	0	0	1	1	1	0	0	0	5	80	5
3	30	60	3	1	8.2	7.1	0.40	0	0	1	1	1	1	0	0	10	60	5
4	30	90	2	1	8.4	7.4	0.20	0	0	1	1	1	0	0	0	10	40	5
5	30	120	2	1	8.7	7.3	0.20	0	0	1	1	1	1	0	0	0	60	2
6	30	150	3	1	7.4	6.2	0.25	1	0	1	1	1	0	0	0	0	100	5
7	30	180	3	1	8.9	6.9	0.80	1	0	1	1	0	0	0	0	10	100	2
8	30	210	1	1	7.5	7.2	0.05	0	0	0	0	1	1	0	0	0	80	2
9	30	240	2	1	8.4	6.9	0.10	0	0	0	1	1	1	0	0	0	90	5
10	30	270	1	1	9.1	8.2	0.05	0	0	0	1	1	1	0	0	0	40	5
11	30	300	3	1	9.0	5.6	0.20	0	0	1	1	1	0	0	0	0	40	10
12	30	330	1	1	8.4	6.0	0.10	0	0	1	1	1	1	0	0	0	80	5
13	30	360	1	1	7.0	6.2	0.05	0	0	0	1	1	1	0	0	5	50	5
14	30	390	1	1	8.2	7.1	0.05	0	0	0	0	1	1	0	0	5	80	5
15	30	420	1	1	8.4	7.0	0.10	0	0	0	0	1	1	0	0	0	80	5
16	30	450	3	1	6.9	6.3	0.25	1	0	1	1	1	0	0	0	10	0	10
17	30	480	3	1	5.8	5.1	0.45	1	0	1	1	0	0	0	0	5	5	15
18	30	510	3	1	5.4	4.9	0.30	1	0	1	1	1	0	0	0	5	0	10
19	20	530	1	1	7.4	6.8	0.10	0	0	0	0	1	1	0	0	5	0	15
20	30	560	3	1	7.4	6.9	0.25	1	0	1	1	1	0	0	0	10	5	10
Stringsi	**de**																	
1	0	0	3	2	9.0	9.0	1.00	1	0	1	0	0	0	0	0	90	20	2
2	50	50	3	2	9.5	9.2	1.00	1	0	1	0	0	0	0	0	80	25	5
3	50	100	3	2	8.4	8.1	1.00	1	0	1	0	0	0	0	0	60	60	5
4	50	150	3	2	8.0	7.8	1.00	1	0	1	0	0	0	0	0	50	90	5
5	50	200	3	2	8.4	8.2	1.00	1	0	1	0	0	0	0	0	90	10	5
6	50	250	3	2	8.1	7.9	1.00	1	0	1	0	0	0	0	0	80	10	2
7	50	300	3	2	7.9	7.3	1.00	1	0	1	0	0	0	0	0	70	5	5
8	50	350	3	2	7.3	7.0	1.00	1	0	1	0	0	0	0	0	80	0	2
9	50	400	3	2	7.1	6.7	1.00	1	0	1	0	0	0	0	0	20	0	5
10	50	450	3	2	7.4	6.5	1.00	1	0	1	0	0	0	0	0	75	0	10
11	50	500	3	2	7.0	6.2	1.00	1	0	1	0	0	0	0	0	70	0	10
12	50	550	3	2	5.9	5.4	1.00	1	0	1	0	0	0	0	0	60	0	5
13	50	600	3	2	6.6	6.1	1.00	1	0	1	0	0	0	0	0	95	0	5
14	100	700	3	1	5.8	5.0	1.00	0	0	1	1	1	0	1	0	50	0	5
15	50	750	3	1	6.0	4.8	1.00	0	0	1	1	1	0	0	0	30	0	0
16	45	795	1	1	4.7	4.1	0.10	0	0	1	1	1	1	0	0	60	0	2
17	50	845	3	1	4.5	3.9	0.30	1	0	1	1	1	1	0	0	20	0	10
18	50	895	3	1	4.8	4.3	0.25	1	0	1	1	1	0	0	0	50	0	5
19	50	945	3	1	4.8	4.0	0.40	1	0	1	1	1	1	0	0	50	0	10
20	50	995	3	1	4.8	4.1	0.30	1	0	1	1	1	0	0	0	40	0	15

tran-sect no.	dist. down. (m)	cum. dist. (m)	hab-itat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	det-ritus	clay	silt	sand	gra-vel	cob-ble	bou-lder	bed-rock	% inst-ream cover	% over-hanging cover	% bank-side cover
Wissey																		
1	0	0	2	1	10.9	10.0	0.30	0	0	1	1	1	1	0	0	5	0	5
2	50	50	3	1	11.2	11.1	0.55	0	0	1	1	1	1	0	0	50	0	1
3	50	100	3	1	9.9	9.3	0.80	0	0	1	1	1	1	0	0	80	0	10
4	50	150	3	1	9.0	8.9	1.00	0	0	0	1	1	0	0	0	80	0	2
5	50	200	3	1	8.8	8.5	1.00	0	0	0	1	1	0	0	0	80	0	2
6	50	250	3	1	8.7	8.6	1.00	0	0	0	1	1	1	0	0	80	0	2
7	60	310	3	1	10.2	10.1	1.00	0	0	0	1	1	0	0	0	90	20	1
8	70	380	3	1	9.0	8.8	1.00	0	0	0	1	1	1	0	0	90	15	2
9	50	430	3	1	7.9	7.7	1.00	0	0	0	1	1	0	0	0	90	0	5
10	50	480	3	1	9.9	8.8	1.00	0	0	0	0	1	1	0	0	80	0	5
11	50	530	3	1	11.4	10.9	1.00	0	0	0	1	1	1	0	0	90	0	2
12	50	580	3	1	8.7	8.2	1.00	0	0	0	0	1	1	0	0	90	10	5
13	50	630	2	1	11.9	11.4	0.65	0	0	0	1	1	1	0	0	70	0	5
14	50	680	3	1	9.8	9.4	1.00	0	0	0	1	1	1	0	0	80	0	5
15	50	730	3	1	9.9	9.7	1.00	0	0	0	0	1	1	0	0	80	0	2
16	50	780	3	1	8.7	8.3	1.00	0	0	0	0	1	0	0	0	90	10	5
17	50	830	3	1	9.9	9.3	1.00	0	0	0	1	1	1	0	0	60	10	2
18	50	880	3	1	11.5	11.1	1.00	0	0	0	1	1	0	0	0	60	0	2
19	50	930	3	1	10.2	9.7	1.00	0	0	0	0	1	1	0	0	70	10	5
20	50	980	3	1	9.3	9.0	1.00	0	0	0	1	1	1	0	0	80	0	5
Thet																		
1	0	0	2	1	5.9	5.1	0.25	1	0	0	1	1	1	1	0	50	0	0
2	30	30	2	1	8.6	7.8	0.20	1	0	1	0	1	1	0	0	30	30	2
3	30	60	3	1	6.6	5.7	0.30	1	0	1	0	1	0	0	0	50	10	5
4	30	90	3	1	7.3	6.5	0.40	1	0	1	0	1	0	0	0	60	50	5
5	30	120	2	1	6.1	5.5	0.30	1	0	1	0	1	0	0	0	50	50	5
6	30	150	3	1	7.4	6.4	0.45	1	0	1	0	1	0	0	0	30	60	5
7	30	180	3	1	7.0	5.9	0.80	1	0	1	0	0	0	0	0	30	10	2
8	30	210	3	1	6.9	6.2	0.60	1	0	1	0	0	0	0	0	20	40	2
9	30	240	3	1	6.3	5.6	0.50	1	0	1	0	1	0	0	0	15	50	5
10	30	270	3	1	7.3	6.3	0.60	1	0	1	0	0	0	0	0	20	40	2
11	20	290	3	1	6.9	6.4	0.35	1	0	1	0	1	0	0	0	20	40	2
12	30	320	3	1	7.5	7.0	0.70	1	0	1	0	0	0	0	0	20	100	0
13	30	350	3	1	7.4	6.8	0.55	1	0	1	0	0	0	0	0	15	60	10
14	30	380	3	1	7.2	6.3	0.65	1	0	1	0	1	0	0	0	15	40	5
15	30	410	3	1	6.8	6.2	0.60	1	0	1	0	1	0	0	0	25	0	10
16	30	440	3	1	7.1	6.6	0.65	1	0	1	0	1	0	0	0	15	0	10
17	30	470	3	1	6.9	6.3	0.90	1	0	1	0	1	0	0	0	15	0	5
18	30	500	3	1	7.7	7.1	0.70	1	0	1	0	1	0	0	0	10	10	5
19	30	530	2	1	8.1	7.4	0.45	1	0	1	1	1	0	0	0	20	0	2
20	30	560	3	1	7.6	7.0	0.50	1	0	1	1	0	0	0	0	30	0	20
Little	**Ouse**																	
1	0	0	3	1	7.2	5.8	0.30	0	0	0	1	1	1	1	0	80	0	5
2	16	16	1	1	7.8	6.6	0.10	0	0	0	0	1	1	0	0	60	90	10
3	30	46	3	1	7.0	6.4	0.40	1	0	1	1	1	0	0	0	80	0	5
4	30	76	3	1	6.6	5.9	0.45	1	0	1	1	0	0	0	0	90	0	5
5	30	106	3	1	7.6	6.8	0.35	1	0	1	1	1	0	0	0	70	80	2
6	30	136	2	1	7.6	6.7	0.25	1	0	1	1	1	0	0	0	70	20	5
7	7	143	1	1	7.0	5.8	0.15	0	0	0	1	1	1	0	0	80	0	10
8	30	173	2	1	6.2	5.2	0.25	1	0	1	1	1	0	0	0	80	0	10
9	30	203	2	1	5.7	4.7	0.20	1	0	1	1	1	0	0	0	60	0	15
10	30	233	1	1	6.4	4.3	0.10	0	0	0	1	1	1	0	0	40	0	10
11	30	263	3	1	6.8	6.0	0.35	1	0	1	1	1	0	0	0	30	0	20
12	30	293	3	1	7.1	6.4	0.50	1	0	1	1	0	0	0	0	40	0	20
13	30	323	1	1	6.4	4.5	0.50	1	0	1	1	1	1	0	0	50	50	10
14	30	353	3	1	7.3	6.4	0.30	1	0	1	1	0	0	0	0	50	0	20
15	30	383	3	1	6.8	5.7	0.25	1	0	1	1	0	0	0	0	50	100	15
16	30	413	3	1	7.0	6.4	0.25	1	0	1	1	1	0	0	0	75	0	20
17	30	443	2	1	5.6	5.0	0.20	1	0	0	1	1	1	0	0	80	0	10
18	25	468	1	1	7.0	4.0	0.10	1	0	0	0	1	1	0	0	30	100	2
19	30	498	3	1	10.3	7.8	0.30	0	0	1	1	0	0	0	0	5	0	2
20	30	528	3	1	11.6	8.7	0.20	0	0	1	1	0	0	0	0	0	0	2
Snail																		
1	0	0	2	1	6.3	5.5	0.15	0	0	0	1	1	1	0	0	20	100	2
2	20	20	1	1	5.9	4.7	0.10	0	0	0	1	1	1	0	0	10	100	2
3	30	50	2	1	5.9	5.0	0.20	0	0	1	1	1	1	0	0	10	80	2
4	30	80	3	1	7.5	7.0	0.30	1	0	1	1	0	0	0	0	10	30	0
5	30	110	3	1	7.1	6.4	0.20	1	0	1	1	1	0	0	0	10	40	10
6	25	135	1	1	5.6	5.2	0.05	0	0	0	1	1	1	0	0	5	0	10
7	30	165	3	1	4.8	3.9	0.20	1	0	1	1	1	1	0	0	20	10	5
8	30	195	3	1	5.5	5.0	0.25	0	0	1	1	1	0	0	0	0	60	2
9	30	225	3	1	6.5	6.0	0.20	1	0	1	1	1	0	0	0	0	0	2
10	30	255	1	1	6.4	5.3	0.10	0	0	1	1	1	0	0	0	10	70	5
11	30	285	3	1	5.6	5.1	0.20	1	0	1	1	0	0	0	0	5	80	2
12	30	315	3	1	6.7	6.0	0.40	1	0	1	1	0	0	0	0	5	60	5
13	30	345	3	1	4.6	4.2	0.35	1	0	1	1	1	0	0	0	20	0	0
14	30	375	3	1	5.9	5.6	0.35	1	0	1	1	0	0	0	0	50	30	0
15	30	405	3	1	6.6	5.5	0.20	1	0	1	0	0	0	0	0	30	0	2
16	30	435	3	1	6.6	5.8	0.35	1	0	1	0	0	0	0	0	20	0	5
17	30	465	3	1	7.3	6.8	0.30	1	0	1	1	0	0	0	0	70	0	10
18	30	495	3	2	6.8	5.9	0.60	1	0	1	0	0	0	0	0	0	100	0
19	30	525	3	2	6.5	5.9	0.40	1	0	1	0	0	0	0	0	50	80	2
20	30	555	3	1	7.6	6.7	0.50	1	0	1	0	0	0	0	0	40	20	5

Appendix 3 28 site habitat survey results for BMWP test

tran-sect no.	dist. down. (m)	cum. dist. (m)	hab-itat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	det-ritus	clay	silt	sand	gra-vel	cob-ble	bou-lder	bed-rock	% inst-ream cover	% over-hanging cover	% bank-side cover
Swaffham																		
1	0	0	2	1	6.3	5.0	0.20	1	0	1	1	0	0	0	0	30	0	0
2	30	30	2	1	6.9	5.8	0.10	1	0	1	1	0	0	0	0	40	0	0
3	30	60	2	1	7.9	6.5	0.10	1	0	1	0	0	0	0	0	30	0	0
4	30	90	2	1	7.3	6.0	0.10	1	0	1	0	0	0	0	0	20	0	0
5	30	120	2	1	6.2	5.2	0.10	1	0	1	0	0	0	0	0	20	0	0
6	30	150	2	1	5.8	5.0	0.10	1	0	1	0	0	0	0	0	10	0	0
7	30	180	2	1	6.5	5.0	0.15	1	0	1	0	0	0	0	0	15	0	0
8	30	210	2	1	6.1	5.1	0.10	1	0	1	0	0	0	0	0	10	0	0
9	30	240	2	1	5.9	5.0	0.10	1	0	1	0	0	0	0	0	15	0	0
10	30	270	2	1	6.5	5.4	0.15	1	0	1	0	0	0	0	0	10	0	0
11	30	300	2	1	7.1	6.0	0.10	1	0	1	0	0	0	0	0	50	0	0
12	30	330	2	1	6.5	5.2	0.15	1	0	1	0	0	0	0	0	30	0	0
13	30	360	2	1	6.9	5.9	0.15	1	0	1	0	0	0	0	0	20	0	0
14	30	390	2	1	6.3	5.6	0.15	1	0	1	0	0	0	0	0	20	0	0
15	30	420	2	1	5.8	4.9	0.10	1	0	1	0	0	0	0	0	5	0	2
16	30	450	2	1	6.4	5.5	0.15	1	0	1	0	0	0	0	0	20	0	0
17	30	480	2	1	6.1	4.9	0.15	1	0	1	0	0	0	0	0	5	0	2
18	30	510	2	1	6.0	5.3	0.15	1	0	1	0	0	0	0	0	5	0	0
19	30	540	2	1	6.9	5.2	0.15	1	0	1	0	0	0	0	0	2	0	2
20	30	570	2	1	5.9	4.5	0.10	1	0	1	0	0	0	0	0	10	0	0
Granta																		
1	0	0	3	2	5.5	4.9	0.30	1	0	1	1	1	1	0	0	10	0	0
2	30	30	3	2	3.6	3.1	0.30	1	0	1	1	1	1	0	0	30	0	10
3	30	60	3	2	4.2	3.5	0.35	1	0	1	1	1	1	0	0	10	0	10
4	30	90	3	2	4.8	3.8	0.45	1	0	1	1	1	1	0	0	20	0	5
5	10	100	1	1	3.9	2.8	0.05	1	0	0	1	1	1	0	0	30	40	20
6	30	130	3	2	3.3	2.4	0.50	1	0	1	1	1	1	0	0	40	0	2
7	30	160	3	2	3.7	3.3	0.45	1	0	1	1	0	0	0	0	20	0	5
8	30	190	3	2	3.3	3.0	0.50	1	0	1	1	0	0	0	0	30	0	10
9	30	220	3	2	4.4	4.0	0.70	1	0	1	1	1	1	0	0	20	0	10
10	20	240	2	1	3.4	3.0	0.15	1	0	0	1	1	1	0	0	0	0	20
11	30	270	3	2	3.6	2.7	0.50	1	0	1	1	1	0	0	0	10	0	5
12	25	295	1	1	3.5	1.6	0.10	1	0	0	1	1	1	0	0	80	0	50
13	30	325	3	2	5.5	4.9	0.20	1	0	1	1	1	0	0	0	0	100	5
14	30	355	3	1	3.6	2.6	0.15	1	0	1	1	1	0	0	0	5	100	2
15	15	370	1	1	3.7	2.9	0.05	1	0	0	1	1	1	0	0	20	0	20
16	20	390	2	1	4.1	2.2	0.10	0	0	0	1	1	0	0	0	0	100	0
17	20	410	1	1	3.8	3.1	0.05	0	0	0	1	1	0	0	0	0	100	20
18	30	440	3	1	2.6	1.9	0.20	1	0	1	1	1	0	0	0	50	0	50
19	20	460	1	1	3.4	2.6	0.05	1	0	0	1	1	1	0	0	20	0	10
20	30	490	2	1	2.9	2.1	0.15	1	0	1	1	1	1	0	0	0	0	10
Hiz																		
1	0	0	3	1	7.5	6.9	1.00	1	0	1	0	1	0	0	0	40	0	2
2	30	30	3	1	9.1	7.8	1.00	1	0	1	0	1	0	0	0	20	40	5
3	30	60	3	1	7.9	7.4	1.00	1	0	1	0	0	0	0	0	60	0	2
4	30	90	3	1	8.9	8.5	1.00	1	0	1	0	0	0	0	0	10	0	0
5	30	120	3	1	10.0	9.4	1.00	1	0	1	0	0	0	0	0	5	0	0
6	30	150	3	1	9.5	8.7	1.00	1	0	1	0	0	0	0	0	20	0	2
7	30	180	3	1	9.3	8.4	1.00	1	0	1	0	0	0	0	0	20	0	2
8	30	210	3	1	9.9	9.5	1.00	1	0	1	0	0	0	0	0	15	0	5
9	30	240	3	1	8.5	7.9	1.00	1	0	1	0	0	0	0	0	5	0	2
10	30	270	3	1	8.9	8.3	1.00	1	0	1	0	0	0	0	0	10	0	5
11	30	300	3	1	9.3	8.6	1.00	1	0	1	0	0	0	0	0	15	5	2
12	30	330	3	1	9.4	8.8	1.00	1	0	1	0	0	0	0	0	30	0	5
13	30	360	3	1	8.9	8.6	1.00	1	0	1	0	0	0	0	0	10	0	2
14	30	390	3	1	10.1	9.2	1.00	1	0	1	0	0	0	0	0	5	0	5
15	30	420	3	1	10.8	10.0	1.00	1	0	1	0	0	0	0	0	5	0	2
16	30	450	3	1	10.7	9.8	1.00	1	0	1	0	0	0	0	0	2	0	2
17	30	480	3	1	10.7	10.1	1.00	1	0	1	0	0	0	0	0	5	0	2
18	30	510	3	1	11.4	10.8	1.00	1	0	1	0	0	0	0	0	10	0	0
19	30	540	3	1	13.0	12.5	1.00	1	0	1	0	0	0	0	0	10	20	0
20	30	570	3	2	14.2	13.6	1.00	1	0	1	0	0	0	0	0	30	0	2
Burn																		
1	0	0	3	1	7.5	6.6	0.25	1	0	1	1	0	0	0	0	10	0	5
2	30	30	3	1	7.6	6.7	0.30	1	0	1	0	0	0	0	0	0	0	5
3	30	60	3	1	7.4	7.0	0.30	1	0	1	0	0	0	0	0	0	5	5
4	30	90	3	1	8.0	7.4	0.25	1	0	1	0	0	0	0	0	0	0	5
5	30	120	3	2	7.2	6.4	0.25	1	0	1	0	0	0	0	0	5	0	10
6	30	150	3	2	7.5	6.3	0.30	1	0	1	0	0	0	0	0	0	0	5
7	30	180	3	2	7.6	7.0	0.30	1	0	1	0	0	0	0	0	0	30	10
8	30	210	3	2	6.7	5.7	0.30	1	0	1	0	0	0	0	0	0	10	20
9	30	240	3	2	6.1	5.5	0.35	1	0	1	0	0	0	0	0	0	30	10
10	30	270	3	1	6.8	6.1	0.30	1	0	1	0	0	0	0	0	0	50	10
11	30	300	3	1	7.7	6.6	0.35	1	0	1	0	0	0	0	0	0	5	30
12	30	330	3	1	7.8	6.9	0.30	1	0	1	0	0	0	0	0	0	5	40
13	30	360	3	1	6.2	5.7	0.35	1	0	1	0	0	0	0	0	10	0	40
14	30	390	3	1	6.8	6.1	0.35	1	0	1	0	0	0	0	0	0	10	10
15	30	420	3	1	7.4	7.0	0.35	1	0	1	0	0	0	0	0	0	30	2
16	30	450	3	1	7.4	6.8	0.30	1	0	1	0	0	0	0	0	0	80	5
17	30	480	3	1	6.6	5.9	0.35	1	0	1	0	0	0	0	0	5	0	30
18	30	510	3	2	6.6	6.1	0.35	1	0	1	0	0	0	0	0	10	50	40
19	30	540	3	2	7.7	6.7	0.30	1	0	1	0	0	0	0	0	0	0	20
20	30	570	3	2	9.0	8.0	0.50	1	0	1	0	0	0	0	0	0	0	10

Appendix 3 28 site habitat survey results for BMWP test

tran-sect no.	dist. down. (m)	cum. dist. (m)	hab-itat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	det-ritus	clay	silt	sand	gra-vel	cob-ble	bou-lder	bed-rock	% inst-ream cover	% over-hanging cover	% bank-side cover
Tud																		
1	0	0	1	1	6.4	4.6	0.10	0	0	0	0	1	1	0	0	10	10	10
2	30	30	2	1	5.7	4.1	0.05	1	0	0	0	1	1	0	0	10	0	2
3	30	60	3	1	5.0	4.4	0.20	1	0	1	1	0	0	0	0	10	40	10
4	30	90	3	1	4.5	3.5	0.15	1	0	1	1	0	0	0	0	40	20	5
5	30	120	1	1	4.6	2.6	0.05	0	0	0	0	1	1	0	0	20	80	40
6	30	150	1	1	4.8	3.8	0.05	1	0	1	1	1	1	0	0	5	100	0
7	30	180	2	1	4.9	4.0	0.10	1	0	0	1	1	1	0	0	40	0	20
8	30	210	1	1	5.3	4.3	0.10	0	0	0	0	1	1	0	0	10	50	10
9	30	240	1	1	4.3	3.5	0.05	0	0	0	0	1	1	0	0	15	0	5
10	30	270	2	1	5.0	2.7	0.05	0	0	0	1	1	1	0	0	60	0	30
11	30	300	3	1	5.8	3.4	0.20	1	0	1	1	1	0	0	0	5	50	5
12	30	330	2	1	4.4	3.6	0.10	0	0	0	1	1	1	0	0	50	20	5
13	30	360	2	1	4.0	3.2	0.10	1	0	1	1	1	1	0	0	5	40	5
14	30	390	3	2	4.5	3.5	0.40	1	0	1	1	1	0	0	0	10	60	2
15	30	420	3	1	4.8	4.2	0.30	1	0	1	1	1	0	0	0	90	0	2
16	30	450	3	1	4.4	3.7	0.30	1	0	1	1	1	0	0	0	90	0	2
17	30	480	3	1	4.4	3.3	0.25	1	0	1	1	1	0	0	0	80	0	5
18	30	510	3	1	4.7	4.2	0.20	1	0	1	1	1	1	0	0	70	40	20
19	30	540	3	1	4.4	3.7	0.20	1	0	1	1	1	1	0	0	80	30	20
20	30	570	3	2	5.2	4.6	0.40	1	0	1	1	1	1	0	0	30	100	2
Tas																		
1	0	0	3	1	8.9	7.0	0.35	1	0	1	1	1	1	0	0	0	20	5
2	30	30	3	1	9.0	7.5	0.30	1	0	1	1	1	0	0	0	0	60	2
3	30	60	3	1	6.8	5.9	0.25	1	0	1	1	1	0	0	0	20	30	5
4	30	90	3	1	7.5	6.7	0.20	1	0	1	1	1	0	0	0	20	0	2
5	30	120	1	1	8.3	7.3	0.15	1	0	0	1	1	1	0	0	40	70	5
6	30	150	3	1	8.0	7.6	0.20	1	0	1	1	1	0	0	0	20	20	20
7	30	180	1	1	7.4	6.4	0.15	1	0	0	1	1	1	0	0	60	0	5
8	30	210	3	1	7.8	7.1	0.25	1	0	1	1	1	0	0	0	0	100	2
9	30	240	3	1	7.6	6.8	0.20	1	0	1	1	1	0	0	0	10	50	5
10	30	270	2	1	8.9	8.0	0.10	0	0	0	1	1	0	0	0	20	50	2
11	30	300	1	1	9.2	8.7	0.05	0	0	0	1	1	0	0	0	60	60	2
12	30	330	3	1	8.6	6.4	0.15	1	0	1	1	1	0	0	0	5	100	0
13	30	360	3	1	8.1	6.9	0.15	1	0	1	1	1	0	0	0	5	80	2
14	30	390	3	1	9.2	8.0	0.15	1	0	1	1	1	0	0	0	5	60	5
15	30	420	3	1	8.9	7.7	0.30	1	0	1	1	1	0	0	0	15	80	2
16	30	450	3	1	7.8	6.2	0.35	1	0	1	1	0	0	0	0	0	100	5
17	30	480	3	1	8.4	7.3	0.40	1	0	1	1	0	1	0	0	5	100	2
18	30	510	3	1	6.6	5.8	0.35	1	0	1	1	0	0	0	0	5	0	2
19	30	540	3	2	6.7	5.9	0.40	1	0	1	1	0	0	0	0	50	60	10
20	30	570	3	2	6.5	5.6	0.50	1	0	1	1	0	0	0	0	5	30	10
Wavene	**y**																	
1	0	0	3	1	7.5	7.1	0.20	1	0	1	1	1	1	0	0	40	20	10
2	30	30	3	2	10.1	10.0	0.60	1	0	1	1	1	0	0	0	40	60	2
3	30	60	3	2	10.6	9.6	0.90	1	0	1	1	1	0	0	0	40	40	2
4	30	90	3	2	12.2	11.1	1.00	1	0	1	1	1	0	0	0	20	0	5
5	30	120	3	2	12.0	11.4	1.00	1	0	1	1	1	0	0	0	20	0	2
6	30	150	3	2	11.3	10.8	1.00	1	0	1	1	1	1	0	0	20	0	2
7	30	180	3	2	11.2	10.3	1.00	1	0	1	1	1	0	0	0	30	0	5
8	30	210	3	2	10.7	8.6	1.00	1	0	1	1	1	0	0	0	50	0	5
9	30	240	3	2	9.4	9.1	1.00	1	0	1	1	1	0	0	0	20	80	2
10	50	290	3	2	11.2	10.6	1.00	1	0	1	1	1	0	0	0	50	10	2
11	30	320	3	2	10.9	10.7	1.00	1	0	1	1	1	0	0	0	10	0	0
12	30	350	3	2	10.7	10.4	1.00	1	0	1	1	1	0	0	0	10	0	0
13	30	380	3	2	12.2	11.9	1.00	1	0	1	1	1	0	0	0	10	0	0
14	30	410	3	2	11.4	11.7	1.00	1	0	1	1	1	0	0	0	10	0	2
15	30	440	3	2	10.5	9.7	1.00	1	0	1	1	1	0	0	0	10	0	2
16	30	470	3	2	11.5	10.9	1.00	1	0	1	1	1	0	0	0	10	0	1
17	30	500	3	2	11.3	10.6	1.00	1	0	1	1	1	0	0	0	15	0	1
18	30	530	3	2	11.2	10.2	1.00	1	0	1	1	1	0	0	0	5	0	2
19	30	560	3	2	11.0	10.4	1.00	1	0	1	1	1	0	0	0	5	0	1
20	30	590	3	2	11.8	11.4	1.00	1	0	1	1	1	0	0	0	15	0	2
Alde																		
1	0	0	3	1	4.1	3.4	0.20	1	0	1	1	0	0	0	0	0	100	10
2	30	30	3	1	5.0	4.8	0.30	1	0	1	1	0	0	0	0	5	20	0
3	20	50	2	1	3.3	2.1	0.05	0	0	0	1	1	0	0	0	40	0	50
4	30	80	3	2	4.0	3.6	0.25	1	0	1	1	0	0	0	0	20	0	5
5	30	110	2	1	5.4	2.3	0.15	1	0	1	1	0	0	0	0	0	100	10
6	30	140	1	1	3.6	2.8	0.10	1	0	1	1	1	0	0	0	0	0	20
7	30	170	3	2	3.8	3.5	0.40	1	0	1	0	0	0	0	0	10	0	10
8	14	184	2	1	2.8	2.4	0.25	1	0	1	1	1	0	0	0	40	0	5
9	30	214	2	1	3.4	2.3	0.20	1	0	1	1	1	0	0	0	70	50	2
10	25	239	1	1	3.4	3.0	0.20	1	0	1	1	1	0	0	0	70	0	10
11	30	269	3	1	3.7	2.7	0.40	1	0	1	1	0	0	0	0	90	10	20
12	30	299	1	1	3.5	2.4	0.10	1	0	1	1	1	1	0	0	10	0	40
13	30	329	1	1	4.4	3.7	0.05	1	0	0	1	1	1	0	0	0	100	40
14	17	346	1	1	4.0	2.7	0.05	0	0	0	1	1	1	0	0	0	100	0
15	30	376	3	2	5.2	4.8	0.50	1	0	1	1	0	0	0	0	40	0	5
16	15	391	1	1	2.2	1.7	0.10	0	0	0	1	1	0	0	0	10	0	20
17	30	421	1	1	2.4	1.9	0.10	1	0	0	1	1	0	0	0	5	0	5
18	30	451	3	2	5.1	4.8	0.30	1	0	1	1	0	0	0	0	30	100	2
19	25	476	1	1	2.1	1.6	0.10	1	0	0	1	1	0	0	0	10	80	2
20	30	506	3	2	4.8	4.4	0.40	1	0	1	1	0	0	0	0	50	100	5

Appendix 3 28 site habitat survey results for BMWP test

transect no.	dist. down. (m)	cum. dist. (m)	habitat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	detritus	clay	silt	sand	gravel	cobble	boulder	bedrock	% instream cover	% overhanging cover	% bankside cover
Gipping																		
1	0	0	2	1	6.8	5.8	0.10	1	0	1	1	1	1	0	0	5	10	2
2	14	14	1	1	4.2	3.0	0.10	1	0	1	1	1	1	0	0	5	0	5
3	25	39	2	1	4.8	4.1	0.10	1	0	1	1	1	1	0	0	5	0	10
4	25	64	1	1	4.2	3.6	0.05	1	0	1	1	1	1	0	0	10	0	2
5	30	94	3	1	5.3	4.0	0.10	1	0	1	1	1	1	0	0	2	0	2
6	30	124	3	2	5.6	4.3	0.15	1	0	1	1	1	1	0	0	2	0	0
7	30	154	3	2	5.5	4.1	0.15	1	0	1	1	1	1	0	0	2	0	2
8	30	184	3	2	5.8	4.4	0.20	1	0	1	1	1	1	0	0	5	10	2
9	30	214	3	2	5.6	4.0	0.20	1	0	1	1	1	1	0	0	0	50	0
10	30	244	3	2	4.9	3.9	0.20	1	0	1	1	1	1	0	0	5	40	2
11	20	264	1	1	5.7	4.8	0.10	1	0	1	1	1	1	0	0	10	0	5
12	30	294	3	2	6.7	5.8	0.20	1	0	1	1	1	1	0	0	20	0	2
13	30	324	3	2	7.2	5.1	0.25	1	0	1	1	1	0	0	0	20	0	2
14	30	354	1	1	5.7	4.6	0.10	1	0	1	1	1	0	0	0	20	0	20
15	30	384	3	2	6.8	6.1	0.20	1	0	1	1	1	1	0	0	10	50	2
16	30	414	3	2	5.9	5.6	0.25	1	0	1	1	1	1	0	0	5	0	5
17	30	444	3	2	6.1	5.8	0.20	1	0	1	1	1	1	0	0	10	50	0
18	30	474	3	2	6.8	6.0	0.20	1	0	1	1	1	1	0	0	5	0	2
19	30	504	3	2	6.6	6.1	0.25	1	0	1	1	1	1	0	0	20	0	5
20	30	534	3	2	7.1	6.3	0.30	1	0	1	1	1	1	0	0	5	70	5
Deben																		
1	0	0	1	1	8.1	5.4	0.05	1	0	0	1	1	1	0	0	30	0	0
2	30	30	2	1	7.5	6.8	0.10	1	0	1	1	1	0	0	0	40	0	5
3	30	60	1	1	7.7	5.7	0.05	1	0	1	1	1	0	0	0	10	0	2
4	30	90	3	1	8.9	7.8	0.15	1	0	1	1	1	0	0	0	50	20	0
5	30	120	2	1	6.9	5.6	0.10	1	0	1	1	1	0	0	0	20	20	0
6	30	150	2	1	11.7	10.9	0.20	1	0	1	1	1	1	0	0	50	30	0
7	25	175	1	1	9.3	8.5	0.10	1	0	0	1	1	1	0	0	60	20	0
8	30	205	3	1	8.4	7.8	0.50	1	0	1	1	1	0	0	0	60	0	5
9	30	235	2	1	9.0	8.0	0.15	1	0	1	1	1	0	0	0	50	0	2
10	30	265	3	2	7.7	6.8	0.70	1	0	1	1	1	0	0	0	100	0	2
11	30	295	1	1	9.3	7.8	0.10	1	0	0	1	1	1	0	0	50	0	2
12	30	325	1	1	8.3	7.6	0.10	1	0	0	1	1	1	0	0	50	0	2
13	30	355	2	1	7.7	6.5	0.10	1	0	1	1	1	1	0	0	20	0	5
14	30	385	3	2	7.8	6.4	0.60	1	0	1	1	1	1	0	0	90	0	10
15	30	415	2	1	7.2	6.0	0.15	1	0	0	1	1	1	0	0	10	0	30
16	15	430	1	1	7.4	5.7	0.05	1	0	0	1	1	1	0	0	50	50	5
17	30	460	3	2	9.9	8.8	0.80	1	0	1	1	1	1	0	0	60	0	2
18	30	490	2	1	9.7	9.0	0.30	1	0	1	1	1	1	0	0	60	0	2
19	30	520	2	1	8.6	8.1	0.15	1	0	0	1	1	1	0	0	30	0	10
20	30	550	3	1	8.5	7.7	0.20	1	0	1	1	1	1	0	0	30	0	2
Stour																		
1	0	0	1	1	6.2	5.7	0.10	0	0	1	1	1	1	0	0	5	100	0
2	30	30	3	1	4.9	3.3	0.30	0	0	1	1	1	0	0	0	10	100	0
3	30	60	3	1	4.7	3.3	0.25	0	0	1	1	1	0	0	0	5	100	0
4	30	90	3	1	5.1	4.4	0.40	0	0	1	1	1	0	0	0	5	50	0
5	30	120	2	1	4.8	3.1	0.20	0	0	1	1	1	1	0	0	0	50	0
6	30	150	3	1	4.4	3.2	0.25	0	0	1	1	1	0	0	0	25	100	2
7	30	180	3	1	5.2	4.1	0.40	0	0	1	1	1	0	0	0	0	100	0
8	30	210	3	1	5.0	3.5	0.20	0	0	1	1	1	0	0	0	5	100	2
9	30	240	3	1	5.3	4.5	0.20	0	0	1	1	1	0	0	0	5	20	58
10	30	270	3	1	4.8	3.7	0.25	0	0	1	1	1	0	0	0	10	60	5
11	30	300	3	1	7.4	7.1	0.30	0	0	1	1	1	1	0	0	0	0	2
12	30	330	3	1	7.4	7.0	0.40	0	0	1	1	0	0	0	0	0	0	5
13	30	360	3	1	7.2	5.1	0.65	0	0	1	1	0	0	0	0	2	30	0
14	30	390	3	1	7.1	6.8	0.70	0	0	1	1	0	0	0	0	0	50	2
15	30	420	3	1	7.5	6.9	0.65	0	0	1	1	0	0	0	0	0	20	0
16	30	450	3	1	6.9	6.2	0.65	0	0	1	1	0	0	0	0	0	50	0
17	30	480	3	1	7.4	7.1	0.75	0	0	1	1	0	0	0	0	0	100	0
18	30	510	3	1	7.8	7.2	0.70	0	0	1	1	0	0	0	0	5	60	2
19	30	540	3	1	7.9	7.4	0.65	0	0	1	1	0	0	0	0	2	20	0
20	30	570	3	1	7.6	7.0	0.65	0	0	1	1	0	0	0	0	0	80	0
Stour	**Brook**																	
1	0	0	1	1	5.2	2.3	0.10	0	0	0	1	1	1	0	0	5	100	2
2	20	20	1	1	3.9	3.4	0.10	1	0	1	1	1	1	0	0	20	100	5
3	25	45	1	1	4.1	3.2	0.05	1	0	1	1	1	1	0	0	20	80	2
4	20	65	1	1	4.1	3.1	0.10	1	0	1	1	1	1	0	0	20	20	2
5	25	90	3	2	4.7	4.0	0.25	1	0	1	1	1	0	0	0	10	80	0
6	25	115	3	1	5.5	4.3	0.25	1	0	1	1	1	0	0	0	25	80	0
7	20	135	1	1	4.1	3.6	0.10	1	0	1	1	1	1	0	0	10	50	2
8	25	160	3	2	5.7	4.9	0.35	1	0	1	1	1	1	0	0	50	50	0
9	25	185	3	1	4.9	3.8	0.25	1	0	1	1	1	0	0	0	20	60	0
10	15	200	1	1	4.8	4.1	0.05	1	0	1	1	1	0	0	0	35	10	2
11	25	225	3	1	4.2	2.0	0.10	1	0	1	1	1	0	0	0	40	60	0
12	20	245	1	1	4.8	3.1	0.10	1	0	1	1	1	1	0	0	25	100	0
13	20	265	3	2	4.2	3.1	0.25	1	0	1	1	1	1	0	0	5	80	0
14	25	290	1	1	5.9	2.3	0.05	0	0	1	1	1	1	0	0	5	100	0
15	25	315	1	1	4.6	2.9	0.10	0	0	1	1	1	1	0	0	30	50	2
16	25	340	3	1	3.6	2.3	0.20	1	1	1	1	1	0	0	0	10	100	0
17	25	365	3	2	4.3	3.8	0.45	1	1	1	1	0	1	0	0	20	80	2
18	20	385	1	1	5.2	2.7	0.15	1	1	0	0	0	0	0	0	60	10	0
19	25	410	3	2	6.1	5.0	0.20	1	1	1	1	1	0	0	0	60	70	0
20	25	435	3	2	7.3	3.2	0.25	1	1	1	1	0	0	0	0	40	5	0

Appendix 3 28 site habitat survey results for BMWP test

tran-sect no.	dist. down. (m)	cum. dist. (m)	hab-itat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	det-ritus	clay	silt	sand	gra-vel	cob-ble	bou-lder	bed-rock	% inst-ream cover	% over-hanging cover	% bank-side cover
Colne																		
1	0	0	2	1	8.4	7.2	0.30	0	0	1	1	1	0	0	0	5	0	0
2	30	30	2	1	9.1	8.5	0.25	1	0	1	1	1	1	0	0	50	0	10
3	15	45	1	1	7.3	6.9	0.15	0	0	0	0	1	0	0	0	50	5	5
4	30	75	3	1	7.7	7.3	0.30	1	0	1	1	1	1	0	0	60	0	5
5	30	105	3	1	9.3	8.7	0.35	1	0	1	1	1	0	0	0	60	0	10
6	30	135	3	1	6.3	4.9	0.40	1	0	1	1	1	0	0	0	20	0	10
7	30	165	3	2	6.1	5.2	0.80	1	0	1	1	1	0	0	0	60	0	5
8	30	195	2	1	7.8	6.9	0.25	1	0	1	1	1	0	0	0	30	0	2
9	30	225	3	1	5.8	5.0	0.75	1	0	1	1	1	1	0	0	60	0	5
10	30	255	3	1	7.1	6.6	0.80	1	0	1	1	1	0	0	0	60	0	2
11	30	285	3	1	7.4	6.2	1.00	1	0	1	1	1	1	0	0	80	0	15
12	30	315	3	1	8.2	7.1	1.00	1	0	1	1	1	1	0	0	50	80	5
13	30	345	2	1	7.1	4.2	0.20	1	0	0	1	1	1	0	0	40	0	2
14	30	375	3	1	6.7	5.9	0.40	1	0	1	1	1	0	0	0	20	0	2
15	30	405	2	1	8.1	7.1	0.20	1	1	1	1	1	0	0	0	80	0	0
16	30	435	3	2	8.4	8.0	1.00	1	0	1	1	0	0	0	0	75	30	2
17	30	465	3	2	7.2	6.8	1.00	1	1	1	1	0	0	0	0	85	0	0
18	30	495	3	1	7.5	6.9	1.00	1	0	1	1	1	0	0	0	60	0	2
19	30	525	3	2	6.2	4.8	1.00	1	0	1	1	1	0	0	0	90	0	5
20	30	555	3	2	7.2	6.9	1.00	1	0	1	1	1	0	0	0	100	0	0
Roman	**River**																	
1	0	0	3	1	6.9	6.5	0.40	1	0	1	1	1	0	0	0	5	5	5
2	20	20	3	1	4.5	2.3	0.40	1	0	1	1	0	0	0	0	20	0	2
3	20	40	3	1	2.8	2.4	0.45	1	0	1	0	0	0	0	0	20	0	2
4	20	60	3	1	3.0	2.5	0.50	1	0	1	0	0	0	0	0	10	100	0
5	20	80	3	2	3.2	2.8	0.55	1	0	1	0	0	0	0	0	10	100	0
6	20	100	3	2	7.8	6.6	0.60	1	0	1	0	0	0	0	0	5	100	0
7	20	120	3	2	5.0	4.5	0.45	1	0	1	0	0	0	0	0	5	100	2
8	20	140	3	2	4.9	4.2	0.60	1	0	1	1	0	0	0	0	10	10	0
9	20	160	3	2	3.6	3.2	1.20	1	0	1	1	0	0	0	0	5	100	2
10	20	180	3	2	3.7	3.4	0.80	1	0	1	1	0	0	0	0	10	100	10
11	20	200	3	2	4.1	3.8	1.00	1	0	1	1	0	0	0	0	0	100	0
12	20	220	3	2	3.9	3.3	1.00	1	0	1	1	0	0	0	0	2	100	0
13	20	240	3	2	4.8	4.3	0.70	1	0	1	0	0	0	0	0	5	75	2
14	20	260	3	2	3.6	3.4	1.10	1	0	1	0	0	0	0	0	5	20	2
15	20	280	2	1	4.8	4.3	0.80	1	0	1	0	0	0	0	0	80	40	2
16	20	300	3	2	3.7	3.1	0.80	1	0	1	0	0	0	0	0	5	60	2
17	20	320	2	1	3.8	3.3	0.50	1	0	1	0	0	0	0	0	50	20	0
18	20	340	3	2	4.5	4.1	0.65	1	0	1	0	0	0	0	0	0	0	2
19	20	360	3	2	5.0	4.7	0.40	1	0	1	0	0	0	0	0	0	5	0
20	20	380	3	2	4.0	3.6	0.50	1	0	1	0	0	0	0	0	5	80	2
Chelmer																		
1	0	0	3	2	12.6	12.2	1.00	1	0	1	1	0	0	0	0	20	0	0
2	30	30	3	2	12.8	12.4	1.00	1	0	1	1	0	0	0	0	20	0	5
3	30	60	3	2	12.5	11.3	1.00	1	0	1	1	0	0	0	0	10	0	5
4	30	90	3	2	11.2	10.8	1.00	1	0	1	1	0	0	0	0	10	10	10
5	30	120	3	2	12.7	12.4	1.00	1	0	1	1	0	0	0	0	5	20	2
6	30	150	3	2	10.7	10.5	1.00	1	0	1	1	0	0	0	0	5	10	0
7	30	180	3	2	11.6	11.3	1.00	1	0	1	1	0	0	0	0	5	0	2
8	30	210	3	2	10.7	10.3	1.00	1	0	1	1	0	0	0	0	5	10	5
9	30	240	3	2	12.4	11.7	1.00	1	0	1	1	0	0	0	0	20	0	5
10	30	270	3	2	11.3	10.7	1.00	1	0	1	1	0	0	0	0	5	0	0
11	30	300	3	2	11.4	11.0	1.00	1	0	1	1	0	0	0	0	20	0	5
12	30	330	3	2	11.0	10.1	1.00	1	0	1	1	0	0	0	0	5	0	5
13	30	360	3	2	12.6	11.8	1.00	1	0	1	1	0	0	0	0	30	0	2
14	30	390	3	2	12.1	11.6	1.00	1	0	1	1	0	0	0	0	25	0	5
15	30	420	3	2	12.3	11.9	1.00	1	0	1	1	0	0	0	0	20	40	2
16	30	450	3	2	12.6	12.0	1.00	1	0	1	1	0	0	0	0	10	0	2
17	30	480	3	2	11.9	11.5	1.00	1	0	1	1	0	0	0	0	10	20	0
18	30	510	3	2	12.1	11.8	1.00	1	0	1	1	0	0	0	0	5	0	0
19	30	540	3	2	10.6	10.0	1.00	1	0	1	1	0	0	0	0	10	0	5
20	30	570	3	2	11.4	10.8	1.00	1	0	1	1	0	0	0	0	5	0	2
Wid																		
1	0	0	3	1	8.3	7.5	0.30	1	0	1	1	1	1	0	0	10	10	30
2	30	30	3	1	6.4	5.9	0.45	1	0	1	1	1	1	0	0	0	20	2
3	30	60	3	1	6.6	5.9	0.30	1	0	1	1	1	1	0	0	0	0	2
4	30	90	3	1	6.1	5.5	0.40	1	0	1	1	1	1	0	0	0	0	0
5	30	120	3	1	9.7	8.6	0.45	1	0	1	1	1	1	0	0	5	0	0
6	30	150	1	1	8.7	3.9	0.15	1	0	1	1	1	1	0	0	0	0	5
7	30	180	2	1	8.0	6.9	0.20	1	0	1	1	1	1	0	0	5	20	0
8	30	210	3	1	7.3	6.9	0.70	1	0	1	1	1	1	0	0	5	50	2
9	30	240	3	1	7.4	6.8	0.35	1	0	1	1	1	1	0	0	20	0	10
10	30	270	3	1	7.8	7.0	0.40	1	0	1	1	1	1	0	0	5	0	10
11	30	300	2	1	7.0	6.5	0.15	1	0	1	1	1	1	0	0	0	20	58
12	30	330	2	1	7.9	7.0	0.20	1	0	1	1	1	1	0	0	5	0	5
13	30	360	1	1	6.9	6.2	0.05	1	0	1	1	1	1	0	0	0	0	2
14	30	390	3	1	7.1	6.5	0.30	1	0	1	1	1	1	0	0	0	0	20
15	30	420	3	1	6.8	6.2	0.40	1	0	1	1	1	1	0	0	20	5	2
16	30	450	3	1	7.6	7.1	0.60	1	0	1	1	1	1	0	0	10	0	0
17	30	480	3	1	8.1	7.8	0.80	1	0	1	1	1	1	0	0	10	0	10
18	30	510	3	2	8.6	8.1	1.00	1	0	1	1	1	1	0	0	10	0	10
19	30	540	3	2	7.8	7.1	1.00	1	0	1	1	1	1	0	0	10	0	2
20	30	570	3	2	7.8	7.2	1.00	1	0	1	1	1	1	0	0	5	10	5

APPENDIX 4

BMWP SCORES BY SITE 1980-1990

Appendix 4 BMWP scores by site 1980-1990

Site	1980	1980	1981	1981	1982	1982	1983	1983	1984	1984	1985	1985	1986	1986
Waithe Beck		•	•	•	96	•	111	92	106	101	91	111	73	117
Barlings Eau		•	•	•	62	•	72	72	55	72	62	81	64	93
Witham		•	•	•	84	•	95	89	65	85	61	93	88	127
North Brook	135	•	122	•	122	•	122	•	•	•	•	•	•	•
Willow Brook	83	73	77	98	94	109	78	•	110	•	93	•	90	•
Harpers Brook		•	80	•	103	•	89	•	122	•	116	•	107	•
Nar	166	•	167	•	195	•	160	•	184	•	142	•	175	•
Stringside	149	•	137	•	117	•	134	•	160	•	•	•	154	•
Wissey	160	•	194	•	200	•	214	•	198	•	223	•	168	•
Thet	158	•	183	•	154	•	86	105	124	•	•	•	95	•
Little Ouse	143	•	137	130	•	•	147	132	187	•	135	•	119	•
Snail	64	•	57	•	67	•	60	•	76	•	43	•	61	•
Swaffham Lode	57	72	70	•	77	•	74	•	72	•	•	•	89	68
Granta	96	138	123	•	116	•	96	•	•	•	109	•	96	•
Hiz	72	•	57	•	110	•	137	•	101	•	101	136	88	•
Burn	42	•	63	•	64	•	68	•	78	•	57	•	67	•
Tud	144	•	104	•	108	•	125	•	126	•	135	•	126	•
Tas	101	•	117	•	83	•	110	•	105	•	112	•	109	•
Waveney	60	•	71	•	83	•	54	•	87	•	67	•	74	•
Alde	78	•	60	•	78	•	85	•	89	•	84	•	76	•
Gipping	30	•	33	•	37	•	40	•	•	•	46	•	30	•
Deben	90	•	99	•	136	•	107	•	79	•	111	•	93	•
Stour	73	•	83	•	71	44	37	62	72	76	20	30	42	41
Stour Brook	8	•	17	21	•	•	28	•	•	•	•	•	35	•
Colne	78	•	82	103	127	•	100	124	120	•	129	•	135	•
Roman River	77	•	70	105	116	•	106	•	87	•	77	•	71	•
Chelmer		•	•	•	•	•	•	•	•	•	•	•	•	•
Wid	44	•	35	55	58	55	61	•	72	•	67	•	32	•

Site	1986	1987	1987	1987	1988	1988	1988	1989	1989	1989	1989	1990	1990	Ave.
Waithe Beck	•	117	106	92	101	105	108	101	101	•	•	92	•	101
Barlings Eau	•	70	71	68	86	86	82	78	90	•	•	66	•	74
Witham	104	82	79	92	94	91	82	99	80	•	•	75	•	88
North Brook	•	110	112	106	114	94	154	180	140	•	•	156	•	128
Willow Brook	•	104	•	•	102	•	•	146	•	•	•	•	•	97
Harpers Brook	•	95	•	•	77	•	•	100	99	•	•	93	•	98
Nar	•	180	•	•	173	•	•	149	•	•	•	•	•	169
Stringside	•	120	•	•	141	•	•	104	•	•	•	56	•	127
Wissey	•	212	•	•	186	•	•	128	•	•	•	101	•	180
Thet	•	64	•	•	62	•	•	53	•	•	•	72	•	105
Little Ouse	•	141	•	•	176	•	•	109	135	135	•	126	•	139
Snail	•	64	•	•	60	•	•	50	38	•	•	47	29	55
Swaffham Lode	•	73	60	•	62	•	•	52	38	•	•	54	77	66
Granta	•	75	•	•	85	•	•	85	82	42	•	57	70	91
Hiz	•	70	•	•	78	•	•	73	70	89	•	83	•	90
Burn	•	73	•	•	87	•	•	73	65	67	•	67	•	67
Tud	•	119	•	•	110	•	•	108	105	122	119	99	•	118
Tas	•	•	•	•	•	•	•	83	95	101	•	99	•	101
Waveney	•	71	•	•	86	•	•	75	71	•	•	93	•	74
Alde	•	•	•	•	68	•	•	72	74	•	•	77	•	77
Gipping	•	74	•	•	41	32	•	28	10	•	•	24	•	35
Deben	•	•	•	•	102	•	•	71	106	78	•	108	•	98
Stour	•	31	56	•	46	50	•	72	63	86	•	98	•	58
Stour Brook	•	26	•	•	21	•	•	31	33	•	•	27	•	25
Colne	•	130	•	•	117	•	•	129	127	107	•	102	•	114
Roman River	•	90	•	•	66	•	•	50	55	40	•	65	•	77
Chelmer	•	•	•	•	•	•	•	74	69	68	•	61	•	68
Wid	•	56	•	•	48	•	•	52	46	31	•	44	•	50

APPENDIX 5

RIVER GLEN HABITAT SURVEY RESULTS FOR BMWP TEST

transect no.	dist. down. (m)	cum. dist. (m)	habitat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	detritus	clay	silt	sand	gravel	cobble	boulder	bedrock	% instream cover	% overhanging cover	% bankside cover
Burton	**Cogg.**																	
1	20	20	5	2	3.2	0.0	0.00	1	1	1	1	1	1	0	0	10	0	5
2	20	40	5	2	2.2	0.0	0.00	1	1	1	1	1	1	0	0	20	0	5
3	20	60	5	2	2.5	0.0	0.00	1	1	1	1	1	1	0	0	0	0	5
4	20	80	3	2	2.7	0.3	0.02	1	1	1	1	1	1	0	0	0	0	2
5	20	100	3	2	3.4	2.7	0.15	1	1	1	1	1	1	0	0	0	0	10
6	20	120	3	2	3.1	2.4	0.26	1	1	1	1	1	1	0	0	0	0	2
7	20	140	5	2	3.5	0.0	0.00	1	1	1	1	1	1	0	0	60	0	0
8	20	160	5	2	2.3	0.0	0.00	1	1	1	1	1	1	0	0	20	0	2
9	20	180	1	2	3.5	0.0	0.00	1	1	1	1	1	1	0	0	20	10	5
10	20	200	3	2	3.4	1.7	0.18	1	1	1	1	1	1	0	0	10	0	5
11	20	220	5	2	2.8	0.0	0.00	1	1	1	1	1	1	0	0	0	0	2
12	20	240	1	2	3.9	0.0	0.00	1	1	1	1	1	1	0	0	0	0	2
13	20	260	5	2	3.1	0.0	0.00	1	1	1	0	0	0	0	0	0	0	0
14	20	280	5	2	3.3	1.0	1.20	1	1	1	0	0	0	0	0	10	0	0
15	20	300	5	2	2.8	0.7	0.80	1	1	1	0	0	0	0	0	20	0	0
16	20	320	5	2	3.2	1.0	0.12	1	1	1	0	0	0	0	0	20	0	0
17	20	340	5	2	3.3	2.2	0.26	1	1	1	0	0	0	0	0	30	0	0
18	20	360	5	2	3.1	1.5	0.21	1	1	1	0	0	0	0	0	40	0	0
19	20	380	3	2	4.2	3.1	0.10	1	1	1	0	0	0	0	0	40	0	0
20	20	400	3	2	4.6	0.0	0.00	1	1	1	0	0	1	0	0	0	0	0
Little	**Byth.**																	
1	0	0	1	1	5.2	3.9	0.13	1	1	1	1	1	1	0	0	40	40	10
2	13	13	1	1	5.1	3.3	0.08	1	0	1	1	1	1	0	0	20	0	5
3	25	38	3	2	5.3	4.0	0.13	1	1	1	1	1	1	0	0	5	40	5
4	25	63	1	1	4.7	3.6	0.10	1	1	1	1	1	1	0	0	15	0	5
5	20	83	1	1	5.2	3.2	0.18	1	1	1	1	1	1	0	0	50	0	5
6	25	108	3	2	4.7	4.2	0.24	1	1	1	1	1	1	0	0	10	10	2
7	25	133	3	2	5.9	4.5	0.29	1	1	1	0	0	1	0	0	0	20	0
8	25	158	3	2	4.7	3.9	0.29	1	1	1	0	0	1	0	0	20	80	2
9	25	183	3	2	4.2	2.6	0.25	1	1	1	0	0	1	0	0	80	0	2
10	25	208	3	2	3.9	2.7	0.11	1	1	1	1	0	1	0	0	50	0	0
11	25	233	3	2	5.1	4.1	0.18	1	1	1	1	0	1	0	0	30	0	0
12	10	243	1	1	4.1	2.1	0.10	1	1	1	1	1	1	0	0	90	0	2
13	25	268	1	1	5.2	3.7	0.14	1	1	1	1	1	1	0	0	40	80	0
14	25	293	3	2	5.4	4.8	0.29	1	1	1	0	0	1	0	0	0	20	2
15	25	318	3	2	5.4	4.9	0.20	1	1	1	0	0	1	0	0	5	20	2
16	25	343	3	2	5.3	4.9	0.19	1	1	1	0	0	1	0	0	0	20	2
17	20	363	1	1	5.6	4.5	0.12	0	0	0	1	1	1	0	0	80	0	5
18	25	388	3	2	5.4	4.6	0.14	1	1	1	1	1	1	0	0	40	50	0
19	25	413	1	1	5.0	4.5	0.08	0	0	0	1	1	1	0	0	70	10	0
20	25	438	3	1	4.8	3.5	0.20	1	1	1	1	1	0	0	0	60	0	0
Shillingt	**horpe**																	
1	0	0	1	1	5.6	5.0	0.20	0	0	0	1	1	1	0	0	70	30	0
2	20	20	3	1	6.4	5.0	0.28	0	0	1	1	1	1	0	0	30	30	2
3	20	40	3	1	6.2	6.0	0.26	0	0	1	1	1	1	0	0	5	5	0
4	20	60	1	1	6.0	5.2	0.15	0	0	0	1	1	1	0	0	50	30	5
5	20	80	3	1	5.7	4.7	0.24	0	0	0	1	1	1	0	0	50	30	5
6	15	95	1	1	5.4	5.1	0.19	0	0	0	1	1	1	0	0	50	20	5
7	20	115	3	1	4.4	3.6	0.42	0	0	1	1	1	0	0	0	40	0	2
8	20	135	3	1	4.8	4.5	0.29	0	0	1	1	1	0	0	0	10	0	0
9	20	155	1	1	5.4	4.7	0.20	0	0	1	1	1	1	0	0	30	0	2
10	15	170	1	1	5.6	5.2	0.12	0	0	0	1	1	1	0	0	20	50	2
11	20	190	3	1	6.3	5.6	0.19	0	0	1	1	1	0	0	0	30	10	2
12	15	205	1	1	6.4	5.9	0.16	0	0	0	1	1	1	0	0	30	0	2
13	20	225	3	1	5.4	4.9	0.20	0	0	1	1	1	0	0	0	10	5	2
14	20	245	3	1	6.1	5.3	0.22	0	0	0	1	1	0	0	0	20	5	0
15	20	265	3	1	6.2	5.5	0.26	1	1	1	1	1	0	0	0	20	0	2
16	20	285	1	1	6.0	5.4	0.17	0	0	0	1	1	1	0	0	20	5	0
17	20	305	3	1	6.1	5.7	0.20	0	0	1	1	1	0	0	0	10	0	2
18	20	325	3	1	6.6	5.3	0.26	0	0	1	1	1	0	0	0	30	5	2
19	20	345	1	1	5.9	5.1	0.16	0	0	0	1	1	0	0	0	30	0	5
20	20	365	1	1	6.0	5.0	0.15	0	0	0	1	1	1	0	0	20	5	0
Edenha	**m**																	
1	0	0	1	1	6.7	3.4	0.02	1	1	1	1	1	1	0	0	10	10	10
2	20	20	3	2	5.2	3.4	0.07	1	1	1	1	1	1	0	0	10	0	0
3	20	40	3	2	6.3	3.3	0.03	1	1	1	0	0	0	0	0	5	0	2
4	20	60	3	2	5.5	4.5	0.09	1	1	1	0	0	0	0	0	10	0	0
5	20	80	3	2	5.4	4.2	0.12	1	1	1	0	0	0	0	0	2	10	0
6	20	100	1	1	4.5	3.2	0.02	1	1	1	1	1	0	0	0	20	0	5
7	20	120	3	2	5.2	4.0	0.03	1	1	1	1	1	0	0	0	10	10	0
8	20	140	3	2	3.7	2.8	0.23	1	1	1	1	1	0	0	0	10	0	2
9	20	160	3	2	4.8	3.9	0.18	1	1	1	0	0	0	0	0	10	0	0
10	20	180	3	2	4.5	3.4	0.18	1	1	1	0	0	0	0	0	0	0	0
11	20	200	3	2	4.7	2.2	0.05	1	1	1	1	1	0	0	0	20	5	0
12	20	220	1	1	5.2	0.8	0.01	0	0	0	1	1	0	0	0	0	0	5
13	20	240	3	2	3.4	3.1	0.22	1	1	1	1	0	0	0	0	2	0	0
14	20	260	3	2	3.2	2.3	0.16	1	1	1	1	0	0	0	0	2	0	2
15	20	280	1	1	2.4	0.8	0.01	1	1	1	1	1	0	0	0	90	0	2
16	20	300	3	2	3.2	1.1	0.02	1	1	1	1	0	0	0	0	90	0	2
17	20	320	3	2	3.7	0.6	0.03	1	1	1	1	1	0	0	0	90	40	2
18	20	340	3	2	4.0	1.8	0.08	1	1	1	1	1	0	0	0	30	0	2
19	20	360	3	2	3.0	2.1	0.14	1	1	1	1	1	0	0	0	20	0	0
20	20	380	1	1	2.5	0.6	0.01	0	0	1	1	0	0	0	0	0	0	10

Appendix 5 River Glen habitat survey results for BMWP test

tran-sect no.	dist. down. (m)	cum. dist. (m)	hab-itat type	flow type	channel width (m)	water width (m)	thalweg depth (m)	det-ritus	clay	silt	sand	gra-vel	cob-ble	bou-lder	bed-rock	% inst-ream cover	% over-hanging cover	% bank-side cover
Bracebo	**ro.**																	
1	0	0	3	2	6.3	1.3	0.02	1	1	1	1	1	0	0	0	30	0	0
2	20	20	3	2	5.0	4.3	0.20	1	1	1	1	1	0	0	0	40	0	2
3	20	40	3	2	5.1	4.0	0.08	1	1	1	1	1	0	0	0	20	0	2
4	20	60	5	2	6.5	0.0	0.00	1	1	1	1	1	0	0	0	0	100	2
5	20	80	5	2	4.8	0.0	0.00	1	1	1	1	1	0	0	0	30	0	0
6	20	100	5	2	5.1	0.0	0.00	1	1	1	1	1	0	0	0	2	0	0
7	20	120	5	2	5.1	0.0	0.00	1	1	1	1	1	0	0	0	20	0	0
8	20	140	5	2	5.3	0.0	0.00	1	1	1	1	1	0	0	0	10	0	0
9	20	160	5	2	4.6	0.0	0.00	1	1	1	0	1	0	0	0	5	0	0
10	20	180	5	2	4.7	0.0	0.00	1	1	1	0	1	0	0	0	10	30	0
11	20	200	3	2	4.9	2.0	0.06	1	1	1	0	0	0	0	0	10	30	0
12	20	220	1	2	6.0	1.3	0.02	1	1	1	0	1	0	0	0	40	40	2
13	20	240	1	2	5.8	4.3	0.34	1	1	1	0	0	0	0	0	20	80	0
14	20	260	1	2	5.1	3.4	0.15	1	1	1	0	1	0	0	0	10	20	0
15	20	280	1	2	5.2	3.8	0.14	1	1	1	0	1	0	0	0	20	40	2
16	20	300	1	2	4.9	3.0	0.16	1	1	1	0	0	0	0	0	20	60	0
17	20	320	1	2	5.0	1.9	0.04	1	1	1	0	0	0	0	0	60	50	0
18	20	340	1	2	5.7	2.3	0.04	1	1	1	0	0	0	0	0	80	10	0
19	20	360	3	2	5.5	2.8	0.09	1	1	1	0	1	0	0	0	30	50	0
20	20	380	3	2	6.3	1.3	0.02	1	1	1	0	1	0	0	0	100	0	0
Kates B	**ridge**																	
1	0	0	1	1	9.2	7.6	0.08	0	0	1	1	1	1	0	0	20	0	5
2	20	20	3	1	10.2	9.2	0.38	0	0	1	1	0	1	0	0	70	0	2
3	20	40	3	1	8.9	8.2	0.48	0	0	1	1	1	1	0	0	20	0	2
4	20	60	3	1	9.1	8.6	0.51	1	1	1	1	1	0	0	0	90	0	5
5	20	80	3	1	9.2	8.4	0.56	1	1	1	1	1	0	0	0	80	0	2
6	20	100	3	1	7.1	6.1	1.00	1	1	1	1	0	0	0	0	70	0	0
7	20	120	3	1	9.1	6.5	1.00	1	1	1	1	0	0	0	0	70	0	0
8	20	140	3	1	8.1	6.3	1.00	1	1	1	1	0	0	0	0	80	0	0
9	20	160	3	1	8.6	6.4	0.58	1	1	1	1	0	0	0	0	70	0	0
10	20	180	3	1	7.4	5.8	0.51	1	1	1	1	1	0	0	0	75	0	0
11	20	200	3	1	7.8	6.2	0.40	1	1	1	1	1	0	0	0	60	0	0
12	20	220	3	1	8.1	7.0	0.35	1	1	1	1	1	0	0	0	70	0	0
13	20	240	3	1	7.2	5.1	0.32	1	1	1	1	1	0	0	0	80	0	0
14	20	260	3	1	6.2	5.4	0.40	1	1	1	1	1	0	0	0	50	0	0
15	20	280	3	1	6.8	5.8	0.37	1	1	1	1	1	0	0	0	50	0	0
16	20	300	3	1	6.6	6.1	0.44	1	1	1	1	1	0	0	0	40	0	0
17	20	320	3	1	8.1	7.6	0.44	1	1	1	1	0	0	0	0	20	0	2
18	20	340	3	1	6.6	5.7	0.45	0	0	0	1	1	1	0	0	40	0	2
19	20	360	3	1	6.2	4.7	0.49	0	0	0	1	1	1	0	0	100	0	0
20	20	380	3	1	8.9	6.9	1.00	0	1	1	1	1	1	0	0	40	5	0

APPENDIX 6

RIVER GLEN PHABSIM RESULTS

Appendix 6 River Glen PHABSIM results

flow cfs	flow cumecs	But.Cog. %time exceed.	Creet. gross area	Creet. trout fry	Creet. trout juv	Creet. trout adult	Creet. dace fry	Creet. dace juv	Creet. dace adult	Creet. chub fry	Creet. chub juv+ad
0.1	0.0028	90	5360	23.27	2.74	1.49	3.08	0.00	0.00	0.00	0.00
0.2	0.0057	80	5805	27.34	3.80	2.05	5.43	0.00	0.07	0.00	0.00
0.3	0.0085	72	6107	26.82	4.52	2.43	7.25	0.00	0.27	0.00	0.00
0.4	0.0113	68	6347	24.76	5.08	2.72	8.64	0.00	0.61	0.00	0.00
0.5	0.0142	64	6526	22.27	5.56	2.98	9.94	0.00	1.07	0.00	0.00
0.6	0.0170	61	6673	20.27	5.98	3.20	10.92	0.00	1.57	0.00	0.00
0.7	0.0198	59	6810	18.60	6.35	3.39	11.81	0.00	2.04	0.00	0.00
0.8	0.0227	57	6935	17.34	6.68	3.56	12.58	0.00	2.51	0.00	0.00
0.9	0.0255	55	7050	16.17	6.98	3.72	13.18	0.00	2.96	0.00	0.00
1.0	0.0283	54	7146	15.41	7.27	3.87	13.76	0.00	3.38	0.00	0.00
1.5	0.0425	48	7534	13.49	8.18	4.51	15.54	0.00	5.12	0.00	0.00
1.8	0.0510	44	7713	12.60	8.33	4.80	15.55	0.00	5.81	0.00	0.00
1.9	0.0538	43	7776	12.24	8.37	4.91	15.56	0.00	6.13	0.00	0.00
2.0	0.0567	42	7837	11.96	8.39	4.99	15.57	0.00	6.37	0.00	0.00
2.2	0.0623	40	7881	11.76	8.37	5.11	15.29	0.00	6.79	0.00	0.00
2.4	0.0680	38	8027	11.51	8.34	5.23	15.00	0.00	7.24	0.00	0.00
2.5	0.0708	37	8079	11.42	8.32	5.31	14.86	0.00	7.44	0.00	0.00
2.6	0.0737	36	8122	11.11	8.27	5.37	14.98	0.00	7.60	0.00	0.00
2.8	0.0793	35	8206	10.47	8.17	5.46	15.21	0.00	8.02	0.00	0.00
3.0	0.0850	33	8294	9.79	8.06	5.59	15.43	0.00	8.43	0.00	0.00
3.5	0.0992	30	8490	8.47	7.76	5.73	15.50	0.00	9.31	0.00	0.00
4.0	0.1134	27	8674	6.99	7.55	5.86	15.55	0.00	10.16	0.00	0.00
4.5	0.1275	25	8836	5.90	7.11	5.88	15.48	0.00	10.80	0.00	0.00
5.0	0.1417	23	8983	4.74	6.66	5.92	15.36	0.00	11.62	0.00	0.00
5.5	0.1559	22	9106	4.43	6.38	5.89	13.71	0.00	12.39	0.00	0.00
5.7	0.1615	21	9173	4.31	6.28	5.88	13.18	0.00	12.52	0.00	0.00
6.0	0.1700	20	9234	3.99	6.12	5.83	12.00	0.00	13.03	0.00	0.00
6.5	0.1842	29	9331	3.92	5.92	5.68	12.11	0.00	13.41	0.00	0.00
7.0	0.1984	18	9427	3.80	5.82	5.51	12.21	0.00	13.81	0.00	0.00
8.0	0.2267	16	10161	3.51	5.58	5.36	13.16	0.00	13.99	0.00	0.00
9.0	0.2550	14	10260	3.33	5.40	5.30	14.45	0.00	14.05	0.00	0.00
10.0	0.2834	13	10351	2.99	5.34	5.20	15.79	0.00	14.05	0.00	0.00
11.0	0.3117	11	10437	2.74	5.18	5.10	16.89	0.00	13.82	0.00	0.00
12.0	0.3401	10	10518	2.28	4.99	5.00	15.67	0.07	13.46	0.00	0.00
13.0	0.3684	10	10594	1.89	4.80	4.86	14.46	0.20	13.12	0.00	0.00
14.0	0.3967	9	10658	1.71	4.60	4.73	13.01	0.47	12.37	0.00	0.00
15.0	0.4251	8	10724	1.53	4.37	4.59	10.55	1.32	11.00	0.00	0.00
16.0	0.4534	8	10778	1.38	4.19	4.46	8.21	3.15	9.97	0.00	0.00
20.0	0.5668	6	11009	0.80	3.42	3.93	5.78	13.36	6.18	0.00	0.00
25.0	0.7085	5									
30.0	0.8501	4									
35.0	0.9918	4									
40.0	1.1335	3									
45.0	1.2752	3									
50.0	1.4169	3									
55.0	1.5586	3									
60.0	1.7003	3									
65.0	1.8420	3									
70.0	1.9837	3									
75.0	2.1254	3									
80.0	2.2671	3									
85.0	2.4088	3									
90.0	2.5504	3									
95.0	2.6921	3									
100.0	2.8338	3									
105.0	2.9755	3									

Appendix 6 River Glen PHABSIM results

flow cfs	flow cumecs	Shilling. %time exceed.	Essen. gross area	Essen. trout fry	Essen. trout juv	Essen. trout adult	Essen. dace fry	Essen. dace juv	Essen. dace adult	Essen. chub fry	Essen. chub juv+ad
0.1	0.0028	96									
0.2	0.0057	96									
0.3	0.0085	96									
0.4	0.0113	96									
0.5	0.0142	95									
0.6	0.0170	95									
0.7	0.0198	95									
0.8	0.0227	95									
0.9	0.0255	94									
1.0	0.0283	94									
1.5	0.0425	91									
1.8	0.0510	88	12222	84.87	14.90	9.78	60.19	3.47	20.20	0.08	0.00
1.9	0.0538	87	12252	84.84	14.94	9.80	62.98	3.53	20.48	0.10	0.00
2.0	0.0567	87	12291	84.40	14.98	9.83	64.61	3.62	20.87	0.12	0.00
2.2	0.0623	85	12335	83.31	15.03	9.86	66.89	3.76	21.31	0.17	0.00
2.4	0.0680	83	12418	82.17	15.13	10.04	69.26	4.11	21.91	0.21	0.00
2.5	0.0708	82	12436	81.19	15.15	10.06	70.34	4.17	22.23	0.25	0.00
2.6	0.0737	81	12486	79.95	15.15	10.10	71.47	4.26	22.39	0.28	0.00
2.8	0.0793	80	12516	77.46	15.15	10.19	73.36	4.37	22.83	0.34	0.00
3.0	0.0850	78	12574	75.92	15.53	10.30	75.34	4.67	23.15	0.42	0.00
3.5	0.0992	75	12620	68.56	15.34	10.47	81.03	5.26	24.75	0.44	0.00
4.0	0.1134	69	12804	62.42	15.53	10.63	86.16	6.26	26.34	0.46	0.00
4.5	0.1275	65	12941	56.02	15.66	10.92	89.54	7.18	27.58	0.50	0.00
5.0	0.1417	61	13072	49.84	15.77	11.01	92.92	7.75	28.88	0.55	0.00
5.5	0.1559	59	13125	44.11	15.75	11.13	93.51	8.67	30.04	0.55	0.00
5.7	0.1615	58	13156	42.17	15.71	11.20	93.64	9.44	30.46	0.56	0.00
6.0	0.1700	57	13173	39.87	15.73	11.26	93.90	10.31	31.31	0.63	0.00
6.5	0.1842	54	13258	36.42	15.61	11.29	91.38	10.98	32.17	0.65	0.00
7.0	0.1984	52	13309	34.23	15.68	11.51	89.07	11.44	33.53	0.67	0.00
8.0	0.2267	48	13494	30.28	15.66	11.78	86.27	13.15	36.09	0.77	0.00
9.0	0.2550	44	13671	27.48	15.21	12.02	85.51	14.51	38.10	0.84	0.00
10.0	0.2834	42	13834	24.80	14.81	12.26	84.82	15.79	40.32	0.92	0.00
11.0	0.3117	39	14004	23.31	14.26	12.42	84.63	17.27	41.48	1.00	0.00
12.0	0.3401	37	14175	21.74	13.72	12.58	84.55	18.64	42.82	1.07	0.00
13.0	0.3684	34	14302	20.79	13.20	12.68	83.02	19.90	43.77	1.16	0.04
14.0	0.3967	32	14429	19.80	12.71	12.79	81.55	21.02	44.06	1.24	0.12
15.0	0.4251	29									
16.0	0.4534	27									
20.0	0.5668	22									
25.0	0.7085	17									
30.0	0.8501	14									
35.0	0.9918	11									
40.0	1.1335	9									
45.0	1.2752	8									
50.0	1.4169	7									
55.0	1.5586	6									
60.0	1.7003	6									
65.0	1.8420	5									
70.0	1.9837	5									
75.0	2.1254	5									
80.0	2.2671	4									
85.0	2.4088	4									
90.0	2.5504	4									
95.0	2.6921	4									
100.0	2.8338	4									
105.0	2.9755	4									

Appendix 6 River Glen PHABSIM results

flow cfs	flow cumecs	Shilling. %time exceed.	Shilling. gross area	Shilling. trout fry	Shilling. trout juv	Shilling. trout adult	Shilling. dace fry	Shilling. dace juv	Shilling. dace adult	Shilling. chub fry	Shilling. chub juv+ad
0.1	0.0028	96									
0.2	0.0057	96									
0.3	0.0085	96									
0.4	0.0113	96									
0.5	0.0142	95	15259	36.41	5.74	3.85	4.45	1.37	3.27	0.00	0.00
0.6	0.0170	95	15603	38.20	6.11	4.27	4.79	1.52	3.52	0.00	0.00
0.7	0.0198	95	15915	39.58	6.45	4.65	5.13	1.67	3.83	0.00	0.00
0.8	0.0227	95	16203	40.60	6.75	4.99	5.48	1.80	4.13	0.00	0.00
0.9	0.0255	94	16471	41.25	7.03	5.34	5.81	1.92	4.43	0.00	0.00
1.0	0.0283	94	16723	40.75	7.30	5.65	6.06	1.99	4.71	0.00	0.01
1.5	0.0425	91	17374	42.29	8.60	6.84	7.24	2.29	6.37	0.63	0.07
1.8	0.0510	88	17460	43.09	9.36	7.39	7.77	2.48	7.48	1.31	0.11
1.9	0.0538	87	17491	43.20	9.58	7.58	7.96	2.49	7.77	1.58	0.12
2.0	0.0567	87	17518	43.23	9.83	7.79	8.17	2.62	8.20	1.65	0.13
2.2	0.0623	85	17565	43.13	10.27	8.09	8.55	2.76	9.02	1.92	0.19
2.4	0.0680	83	17616	42.91	10.68	8.41	8.90	2.99	9.91	2.48	0.26
2.5	0.0708	82	17640	42.69	10.89	8.56	9.09	3.07	10.33	2.61	0.30
2.6	0.0737	81	17661	42.43	11.09	8.72	9.18	3.13	10.51	2.72	0.32
2.8	0.0793	80	17705	41.90	11.46	9.03	9.34	3.19	10.80	2.98	0.36
3.0	0.0850	78	17748	41.54	11.84	9.21	9.50	3.24	12.15	3.07	0.40
3.5	0.0992	75	17841	40.48	12.66	9.87	9.78	3.51	13.99	3.33	0.51
4.0	0.1134	69	17935	39.64	13.47	10.29	10.07	3.69	15.55	3.71	0.61
4.5	0.1275	65	18015	38.49	14.22	10.72	10.23	4.23	15.57	3.99	0.69
5.0	0.1417	61	18095	37.49	14.88	11.18	10.39	4.72	18.48	4.26	0.77
5.5	0.1559	59	18160	36.21	15.52	11.62	10.61	5.19	19.96	4.48	0.83
5.7	0.1615	58	18185	35.63	15.77	11.75	10.66	5.28	20.41	4.60	0.84
6.0	0.1700	57	18223	34.88	16.09	11.97	10.81	5.65	21.20	4.74	0.88
6.5	0.1842	54	18268	33.30	16.60	12.33	11.02	6.21	22.53	4.98	0.94
7.0	0.1984	52	18307	31.85	17.10	12.63	11.23	6.80	23.71	5.22	1.00
8.0	0.2267	48	18384	29.37	17.96	13.25	11.39	8.05	25.77	5.25	1.10
9.0	0.2550	44	18456	27.78	18.61	13.87	11.46	9.38	27.70	5.02	1.20
10.0	0.2834	42	18526	26.40	19.03	14.78	11.55	10.85	29.50	5.24	1.29
11.0	0.3117	39	18595	25.10	19.32	15.64	11.66	12.30	31.19	5.29	1.37
12.0	0.3401	37	18660	23.91	19.53	16.44	11.71	13.90	32.78	4.92	1.43
13.0	0.3684	34	18721	22.87	19.57	17.26	11.59	15.63	34.30	4.48	1.55
14.0	0.3967	32	18780	21.99	19.53	18.21	11.46	17.43	35.61	4.39	1.79
15.0	0.4251	29	18837	21.12	19.49	19.13	11.34	19.20	36.98	4.37	2.04
16.0	0.4534	27	18883	20.44	19.23	20.27	10.89	20.77	38.03	4.42	2.90
20.0	0.5668	22	19091	18.27	18.37	24.27	10.35	26.97	42.43	4.55	6.36
25.0	0.7085	17	19310	16.84	18.21	34.27	10.02	29.36	46.84	4.66	10.13
30.0	0.8501	14	19505	15.50	18.06	44.56	9.60	28.39	49.87	5.39	15.26
35.0	0.9918	11	19696	14.26	17.90	48.35	8.88	25.25	51.98	6.79	22.76
40.0	1.1335	9	19880	13.28	17.79	46.98	7.70	21.30	52.86	7.69	29.63
45.0	1.2752	8	20044	12.52	17.68	44.42	6.26	18.03	52.17	8.67	32.78
50.0	1.4169	7	20188	11.95	17.53	41.95	5.29	15.67	49.66	9.35	34.03
55.0	1.5586	6	20324	11.53	17.37	39.66	4.94	14.05	46.57	9.23	33.28
60.0	1.7003	6	20453	11.32	17.06	37.23	4.73	12.10	43.25	9.24	30.94
65.0	1.8420	5	20576	11.21	16.89	34.91	4.73	10.48	39.71	9.15	27.77
70.0	1.9837	5	20721	11.17	16.82	32.91	4.46	9.30	35.94	9.25	24.41
75.0	2.1254	5	20872	11.13	16.76	31.01	4.05	8.36	32.26	9.51	21.08
80.0	2.2671	4	21016	11.11	16.73	29.40	3.72	7.72	28.68	9.64	18.00
85.0	2.4088	4	21154	11.20	16.68	28.14	3.62	7.11	25.32	9.85	15.21
90.0	2.5504	4	21288	11.07	16.68	27.95	3.63	6.47	22.71	10.20	13.37
95.0	2.6921	4	21417	11.00	16.69	27.80	3.68	5.87	20.67	10.43	12.09
100.0	2.8338	4	21584	10.95	16.71	27.65	3.81	5.32	19.09	10.46	11.08
105.0	2.9755	4	21752	10.83	16.73	27.64	3.87	4.82	17.89	10.26	10.27

Appendix 6 River Glen PHABSIM results

flow cfs	flow cumecs	Irnham %time exceed.	Eden. gross area	Eden. trout fry	Eden. trout juv	Eden. trout adult	Eden. dace fry	Eden. dace juv	Eden. dace adult	Eden. chub fry	Eden. chub juv+ad
0.1	0.0028	95									
0.2	0.0057	90	4270	19.45	2.94	1.72	1.75	0.00	0.54	0.00	0.00
0.3	0.0085	82	4885	19.84	3.46	2.04	2.45	0.00	0.72	0.00	0.00
0.4	0.0113	77	5454	19.48	3.83	2.27	2.93	0.00	1.00	0.00	0.00
0.5	0.0142	70	6024	19.84	4.11	2.45	3.12	0.00	1.36	0.00	0.00
0.6	0.0170	66	6574	20.09	4.33	2.59	3.20	0.00	1.71	0.00	0.00
0.7	0.0198	62	6976	20.59	4.60	2.76	3.33	0.00	2.04	0.00	0.00
0.8	0.0227	60	7212	21.06	4.93	2.98	3.53	0.00	2.37	0.00	0.00
0.9	0.0255	57	7397	21.36	5.24	3.19	3.80	0.00	2.57	0.00	0.00
1.0	0.0283	55	7572	21.66	5.50	3.38	3.94	0.00	2.99	0.00	0.00
1.5	0.0425	49	8197	23.80	6.54	4.25	4.54	0.00	5.06	0.00	0.00
1.8	0.0510	45	8430	25.00	6.98	4.63	4.61	0.19	6.28	0.00	0.00
1.9	0.0538	44	8575	25.37	7.11	4.77	4.63	0.25	6.58	0.00	0.00
2.0	0.0567	43	8674	25.83	7.26	4.91	4.67	0.32	7.19	0.00	0.00
2.2	0.0623	41	8843	26.24	7.43	5.12	4.11	0.58	7.99	0.00	0.00
2.4	0.0680	39	9000	26.63	7.63	5.33	3.53	0.81	8.78	0.00	0.00
2.5	0.0708	39	9082	26.85	7.73	5.43	3.21	0.94	9.19	0.00	0.00
2.6	0.0737	38	9150	26.81	7.80	5.51	3.11	1.04	9.51	0.00	0.00
2.8	0.0793	36	9281	27.04	7.91	5.67	2.89	1.27	10.23	0.00	0.00
3.0	0.0850	35	9426	27.14	8.07	5.86	2.68	1.48	10.91	0.00	0.00
3.5	0.0992	31	9613	26.24	8.33	6.52	3.09	1.97	12.41	0.00	0.00
4.0	0.1134	29	9927	25.14	8.68	7.43	3.58	2.46	14.08	0.00	0.00
4.5	0.1275	26	10143	24.68	9.10	8.13	4.04	2.79	15.38	0.00	0.00
5.0	0.1417	24	10350	24.26	9.51	9.00	4.56	3.18	16.84	0.00	0.00
5.5	0.1559	22	10458	24.10	9.81	9.97	4.91	3.19	18.00	0.00	0.20
5.7	0.1615	21	10639	24.01	9.98	10.21	5.03	3.21	18.40	0.00	0.26
6.0	0.1700	21	10748	23.88	10.21	10.77	5.29	3.22	19.20	0.00	0.38
6.5	0.1842	19	11002	23.41	10.47	11.40	5.49	3.35	20.41	0.00	0.59
7.0	0.1984	18	11256	22.97	10.69	11.93	5.70	3.48	21.00	0.00	0.78
8.0	0.2267	15	11871	22.49	10.98	12.15	6.25	3.69	22.32	0.00	1.19
9.0	0.2550	14	12141	21.95	11.56	12.70	7.36	4.12	24.10	0.00	1.44
10.0	0.2834	13	12334	21.70	12.15	13.73	8.31	4.86	25.73	0.00	1.67
11.0	0.3117	11	12511	21.76	12.11	15.10	9.26	5.40	27.16	0.00	1.81
12.0	0.3401	10	12681	21.74	13.24	16.63	10.25	5.92	28.48	0.00	2.08
13.0	0.3684	10	12843	21.70	13.72	18.35	11.08	6.36	29.65	0.05	2.79
14.0	0.3967	9	13000	21.42	14.13	20.61	12.48	8.33	31.97	0.35	4.73
15.0	0.4251	8	13153	21.19	14.56	22.98	13.81	10.32	34.00	0.66	6.78
16.0	0.4534	8	13297	20.68	14.79	24.01	13.50	10.48	34.63	0.93	9.52
20.0	0.5668	6	13870	18.57	16.14	28.81	12.27	10.97	37.37	2.19	20.64
25.0	0.7085	5	14556	15.30	16.87	34.51	13.03	10.15	38.55	3.62	29.20
30.0	0.8501	5	15234	13.80	17.23	36.76	13.77	8.93	37.22	4.10	30.65
35.0	0.9918	4	15853	14.17	17.80	35.84	15.18	7.58	34.91	4.44	30.92
40.0	1.1335	4	16461	14.47	18.27	35.20	16.42	6.17	32.78	5.75	29.72
45.0	1.2752	3	17203	14.07	18.42	33.76	16.93	5.29	30.21	6.46	27.20
50.0	1.4169	3	18266	13.45	18.26	35.16	16.69	4.67	27.52	6.71	24.34
55.0	1.5586	3	19510	13.82	18.04	34.97	17.93	4.48	25.10	6.54	21.84
60.0	1.7003	3	20396	14.23	18.21	32.74	20.30	4.42	23.70	6.52	20.62
65.0	1.8420	3	21022	14.69	18.67	31.78	22.04	5.02	23.12	6.70	19.40
70.0	1.9837	3	21535	14.62	19.31	32.12	24.17	5.64	22.99	7.11	17.98
75.0	2.1254	3	21946	14.27	20.08	32.92	24.91	6.17	23.18	7.56	17.21
80.0	2.2671	3	22324	13.91	20.81	32.88	25.96	7.32	23.64	8.05	16.75
85.0	2.4088	3	22672	13.58	21.46	32.14	25.36	8.22	24.27	8.47	16.52
90.0	2.5504	3									
95.0	2.6921	3									
100.0	2.8338	3									
105.0	2.9755	3									

Appendix 6 River Glen PHABSIM results

flow cfs	flow cumecs	Manth. %time exceed.	Brace. gross area	Brace. trout fry	Brace. trout juv	Brace. trout adult	Brace. dace fry	Brace. dace juv	Brace. dace adult	Brace. chub fry	Brace. chub juv+ad
0.1	0.0028	85									
0.2	0.0057	74	7174	26.79	3.13	1.85	1.74	0.00	0.52	0.00	0.00
0.3	0.0085	68	8725	23.84	3.19	1.86	2.49	0.00	0.59	0.00	0.00
0.4	0.0113	67	9459	22.91	3.49	2.01	3.77	0.00	0.68	0.00	0.00
0.5	0.0142	65	9710	22.56	3.88	2.21	5.18	0.00	0.79	0.00	0.00
0.6	0.0170	63	10414	21.19	4.03	2.28	6.30	0.00	0.88	0.00	0.00
0.7	0.0198	61	10672	20.63	4.31	2.43	7.70	0.00	0.99	0.00	0.00
0.8	0.0227	60	10869	19.98	4.57	2.56	8.94	0.00	1.12	0.00	0.00
0.9	0.0255	59	11050	19.22	5.04	2.80	10.06	0.00	1.31	0.00	0.00
1.0	0.0283	57	11202	19.22	5.04	2.80	11.13	0.00	1.50	0.00	0.00
1.5	0.0425	53	11719	14.83	5.82	3.30	16.40	0.00	2.49	0.00	0.00
1.8	0.0510	51	11948	13.98	6.10	3.51	18.72	0.00	3.03	0.00	0.00
1.9	0.0538	50	12017	13.61	6.19	3.58	19.41	0.00	3.27	0.00	0.00
2.0	0.0567	50	12094	13.55	6.29	3.65	20.36	0.00	3.43	0.00	0.00
2.2	0.0623	49	12201	13.13	6.43	3.76	21.48	0.00	3.81	0.00	0.00
2.4	0.0680	48	12304	12.58	6.57	3.88	22.67	0.00	4.26	0.00	0.00
2.5	0.0708	47	12361	12.47	6.63	3.94	23.20	0.00	4.49	0.00	0.00
2.6	0.0737	47	12402	12.37	6.68	3.98	23.43	0.00	4.71	0.00	0.00
2.8	0.0793	46	12484	11.83	6.81	4.08	23.75	0.00	5.10	0.00	0.00
3.0	0.0850	45	12572	11.49	6.93	4.18	24.07	0.00	5.47	0.00	0.00
3.5	0.0992	44	12753	10.66	6.96	4.35	24.69	0.00	6.41	0.00	0.00
4.0	0.1134	41	12929	9.90	7.01	4.52	25.36	0.00	7.30	0.00	0.00
4.5	0.1275	39	13048	9.03	6.93	4.64	26.41	0.00	8.01	0.00	0.00
5.0	0.1417	38	13153	8.16	6.85	4.76	27.36	0.00	8.64	0.00	0.00
5.5	0.1559	36	13241	7.49	6.73	4.80	27.25	0.00	9.19	0.00	0.00
5.7	0.1615	36	13276	7.24	6.68	4.83	27.18	0.00	9.43	0.00	0.00
6.0	0.1700	35	13325	6.79	6.60	4.85	27.09	0.00	9.76	0.00	0.00
6.5	0.1842	33	13402	6.61	6.44	4.89	26.21	0.00	10.33	0.00	0.00
7.0	0.1984	32	13478	6.42	6.30	4.94	25.30	0.00	10.82	0.00	0.00
8.0	0.2267	29	13617	5.98	5.97	4.96	24.07	0.00	11.94	0.00	0.00
9.0	0.2550	27	13743	5.48	5.70	4.96	21.07	0.00	12.99	0.00	0.00
10.0	0.2834	25	13861	4.95	5.42	4.90	19.62	0.00	13.44	0.00	0.00
11.0	0.3117	23	13970	4.57	5.18	4.83	18.25	0.00	13.84	0.00	0.00
12.0	0.3401	22	14072	3.80	4.85	4.70	17.43	0.00	14.25	0.00	0.00
13.0	0.3684	21	14169	3.02	4.52	4.54	16.99	0.00	14.68	0.00	0.00
14.0	0.3967	20	14260	2.78	4.31	4.46	15.75	0.00	15.01	0.00	0.00
15.0	0.4251	20	14348	2.58	4.10	4.31	14.47	0.00	15.19	0.00	0.00
16.0	0.4534	18	14417	2.25	3.89	4.12	13.23	0.00	15.15	0.00	0.00
20.0	0.5668	16	14701	0.95	3.03	3.60	8.42	0.00	14.99	0.00	0.00
25.0	0.7085	13	14923	0.71	2.43	3.08	7.51	0.00	14.00	0.00	0.00
30.0	0.8501	12	15083	0.55	1.91	2.60	7.52	0.00	12.56	0.00	0.00
35.0	0.9918	11	15251	0.34	1.66	2.13	4.35	0.00	11.11	0.00	0.00
40.0	1.1335	10	15391	0.27	1.41	1.74	2.00	0.00	9.60	0.00	0.00
45.0	1.2752	9	15519	0.22	1.13	1.51	2.28	0.00	7.96	0.00	0.00
50.0	1.4169	8	15613	0.13	0.91	1.36	0.97	0.00	6.69	0.00	0.00
55.0	1.5586	8									
60.0	1.7003	8									
65.0	1.8420	7									
70.0	1.9837	7									
75.0	2.1254	7									
80.0	2.2671	7									
85.0	2.4088	6									
90.0	2.5504	6									
95.0	2.6921	6									
100.0	2.8338	6									
105.0	2.9755	6									

APPENDIX 7

RIVER WISSEY PHABSIM RESULTS

flow cfs	flow cumecs	Nrthwld % time exceed.	Bo Bri Brn Trt spawn	Bo Bri Brn Trt fry	Bo Bri Brn Trt juv	Bo Bri Brn Trt adult	Bo Bri Dace spawn	Bo Bri Dace fry	Bo Bri Dace juv	Bo Bri Dace adult	Bo Bri Chub spawn	Bo Bri Chub fry	Bo Bri Chub juv+ad	Bo Bri Roach spawn	Bo Bri Roach fry	Bo Bri Roach juv+ad	Bo Bri Bream spawn	Bo Bri Bream fry	Bo Bri Bream juv
2.0	0.0566	99	0.00	38.31	5.56	0.00	0.00	0.10	6.12	4.00	0.00	0.00	0.01	0.00	38.10	0.00	0.00	0.07	0.00
3.0	0.0849	99	0.00	44.79	10.62	0.00	0.00	0.15	7.78	4.89	0.00	0.00	0.08	0.00	44.37	0.00	0.00	0.39	0.00
4.0	0.1132	99	0.00	47.38	18.07	0.00	0.00	0.21	9.33	5.99	0.00	0.00	0.16	0.00	41.66	0.01	0.00	0.49	0.00
5.0	0.1415	99	0.00	48.63	24.79	0.00	0.00	0.27	11.11	7.38	0.00	0.00	0.29	0.00	38.05	0.02	0.00	0.54	0.00
6.0	0.1698	99	0.00	48.66	31.80	0.00	0.00	0.34	12.72	8.73	0.00	0.00	0.44	0.00	31.63	0.03	0.00	0.58	0.00
7.0	0.1981	99	0.00	48.15	37.36	0.00	0.00	0.40	14.22	10.24	0.00	0.00	0.62	0.00	23.85	0.04	0.00	0.61	0.00
8.0	0.2264	99	0.00	47.60	41.93	0.00	0.00	0.46	15.33	11.55	0.26	0.00	0.80	0.00	16.93	0.05	0.00	0.59	0.00
9.0	0.2547	99	0.00	46.32	46.60	0.00	0.00	0.51	16.17	13.14	0.57	0.00	1.08	0.00	14.10	0.07	0.00	0.58	0.00
10.0	0.2830	99	0.00	45.30	50.88	0.00	0.00	0.55	16.45	14.72	1.05	0.00	1.34	0.00	11.56	0.08	0.00	0.55	0.00
12.0	0.3396	99	0.05	40.06	57.89	0.00	0.46	0.65	17.11	17.49	2.88	0.00	1.96	0.00	7.34	0.11	0.00	0.50	0.00
14.0	0.3962	99	0.48	32.21	64.65	0.00	1.48	0.73	17.35	20.02	5.44	0.07	2.55	0.00	6.53	0.13	0.00	0.43	0.00
15.0	0.4245	98	1.15	29.19	67.37	0.00	2.30	0.78	17.47	21.40	6.71	0.13	2.92	0.00	6.18	0.15	0.00	0.39	0.00
16.0	0.4528	98	2.56	26.59	69.58	0.00	2.97	0.84	17.60	22.60	7.90	0.20	3.33	0.00	5.84	0.17	0.00	0.36	0.00
18.0	0.5094	97	6.51	24.94	73.48	0.00	4.91	0.94	17.97	24.97	10.29	0.28	4.09	0.02	5.64	0.20	0.00	0.29	0.00
20.0	0.5660	96	11.82	24.08	76.40	0.00	8.00	1.07	18.17	27.22	11.83	0.39	4.96	0.09	5.83	0.25	0.00	0.21	0.00
25.0	0.7075	90	20.49	20.91	80.54	0.57	19.13	1.36	20.98	31.16	20.58	0.58	6.86	1.54	5.76	0.35	0.00	0.09	0.00
30.0	0.8490	82	28.03	18.94	81.84	2.31	24.47	1.78	23.11	34.64	33.82	0.78	8.34	4.56	4.84	0.46	0.00	0.50	0.00
40.0	1.1320	68	41.96	13.97	78.91	3.26	28.73	2.79	21.16	37.24	56.31	1.06	9.63	10.00	3.41	0.50	0.00	0.63	0.00
50.0	1.4150	56	42.87	11.49	73.71	3.29	28.85	3.94	20.85	37.05	61.86	1.09	10.73	9.89	2.29	0.46	0.00	0.68	0.00
60.0	1.6980	46	40.28	9.35	68.11	4.44	28.70	4.95	17.79	35.54	62.06	0.21	12.27	11.34	2.48	0.56	0.00	0.58	0.00
70.0	1.9810	38	36.13	8.72	62.33	7.63	26.45	5.91	17.46	33.18	59.47	0.00	14.47	8.45	2.78	0.67	0.00	0.52	0.00
80.0	2.2640	31	31.92	8.27	57.41	11.05	22.60	6.23	17.90	30.48	52.71	0.00	15.23	8.17	3.01	0.80	0.00	0.44	0.00
90.0	2.5470	25	28.65	7.80	53.12	13.99	21.50	6.73	17.36	27.78	39.94	0.00	14.89	7.06	2.92	0.92	0.00	0.35	0.00
100.0	2.8300	20	25.37	7.60	49.53	16.24	20.67	7.30	16.65	26.00	33.27	0.00	14.04	6.64	2.89	0.99	0.00	0.25	0.00
110.0	3.1130	16																	
120.0	3.3960	12																	
140.0	3.9620	7																	

Appendix 7 River Wissey PHABSIM results - BODNEY BRIDGE

flow cfs	flow cumecs	Bo Bri Bream adult	Bo Bri Pike spawn	Bo Bri Pike fry	Bo Bri Pike juv	Bo Bri Pike adult	Bo Bri Perch spawn	Bo Bri Perch fry	Bo Bri Perch juv	Bo Bri Perch adult	Bo Bri Leuct. fusca	Bo Bri Rhyac. dorsal.	Bo Bri Polyc. flavom.	Bo Bri Sphae. corn.	Bo Bri Ran. fluit.
2.0	0.0566	0.00	0.00	0.00	7.62	1.07	13.05	2.98	19.68	8.70	5.63	4.85	12.84	11.57	2.86
3.0	0.0849	0.00	0.00	0.00	8.81	1.25	14.54	3.15	21.01	9.95	8.57	9.05	18.87	16.13	4.02
4.0	0.1132	0.00	0.00	0.00	9.40	1.38	15.38	3.18	21.45	10.78	11.33	13.20	24.43	19.85	4.95
5.0	0.1415	0.00	0.00	0.00	10.06	1.49	16.16	3.26	22.16	11.98	13.45	16.16	29.00	22.78	5.58
6.0	0.1698	0.00	0.00	0.00	10.63	1.58	16.85	3.15	22.76	12.96	15.30	18.85	33.26	25.27	6.00
7.0	0.1981	0.00	0.00	0.00	11.12	1.66	17.53	3.04	23.08	13.95	16.94	21.01	36.44	27.17	6.31
8.0	0.2264	0.00	0.00	0.00	11.59	1.73	18.09	3.04	23.48	14.68	18.38	22.95	39.42	28.74	6.48
9.0	0.2547	0.00	0.00	0.00	12.09	1.80	18.73	3.04	24.11	15.33	19.74	24.61	41.72	30.17	6.60
10.0	0.2830	0.00	0.00	0.00	12.59	1.86	19.53	3.06	24.81	15.62	21.06	26.18	43.89	31.58	6.74
12.0	0.3396	0.00	0.00	0.00	13.44	2.06	21.58	3.26	26.32	16.47	22.74	28.62	46.96	33.44	6.61
14.0	0.3962	0.00	0.00	0.00	14.03	2.17	21.43	3.26	26.63	16.81	24.04	30.51	48.99	34.83	6.93
15.0	0.4245	0.00	0.02	0.00	14.33	2.23	21.14	3.39	26.74	17.01	24.56	31.27	49.82	35.41	7.13
16.0	0.4528	0.00	0.08	0.00	14.42	2.27	20.65	3.53	26.66	17.23	25.06	32.06	50.62	35.92	7.16
18.0	0.5094	0.00	0.16	0.00	14.71	2.34	20.92	3.64	26.30	17.59	25.82	33.26	51.76	36.71	7.04
20.0	0.5660	0.00	0.27	0.00	15.06	2.41	21.62	3.87	26.31	17.81	26.47	34.19	52.66	37.27	6.58
25.0	0.7075	0.00	0.49	0.00	15.66	2.47	19.49	3.75	25.87	18.04	27.58	35.92	53.83	37.02	5.68
30.0	0.8490	0.00	0.74	0.00	15.82	2.55	15.28	4.00	24.01	17.94	28.09	36.92	54.32	36.35	5.64
40.0	1.1320	0.00	0.60	0.00	15.61	2.49	13.11	4.25	20.20	16.38	28.83	37.70	54.29	34.59	5.87
50.0	1.4150	0.00	0.30	0.00	15.42	2.54	14.06	4.93	19.96	13.55	29.29	37.28	53.13	33.36	6.06
60.0	1.6980	0.00	0.04	0.00	15.94	2.60	12.83	5.83	19.02	13.75	29.31	36.26	51.28	32.31	6.37
70.0	1.9810	0.00	0.32	0.00	16.62	2.73	11.55	6.33	17.86	15.13	28.90	34.93	49.00	31.41	6.67
80.0	2.2640	0.00	0.62	0.00	17.61	2.83	11.41	6.69	18.12	17.01	27.89	33.41	46.45	30.56	5.83
90.0	2.5470	0.00	0.94	0.00	17.82	2.96	11.84	6.91	18.83	17.09	26.96	31.62	43.88	29.73	5.72
100.0	2.8300	0.00	1.14	0.00	17.77	3.09	12.34	7.13	19.06	16.05	25.94	29.81	41.51	28.91	5.82
110.0	3.1130														
120.0	3.3960														
140.0	3.9620														

Appendix 7 River Wissey PHABSIM results - BODNEY BRIDGE

flow	flow	Nrthwld	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F
cfs	cumecs	% time	Brn Trt	Brn Trt	Brn Trt	Brn Trt	Dace	Dace	Dace	Dace	Chub	Chub	Chub	Roach	Roach	Roach	Bream	Bream	Bream
		exceed.	spawn	fry	juv	adult	spawn	fry	juv	adult	spawn	fry	juv+ad	spawn	fry	juv+ad	spawn	fry	juv
2.0	0.0566	99	0.00	27.80	5.63	0.00	0.00	0.28	6.91	8.25	0.00	0.00	0.56	0.00	44.56	0.00	0.00	0.56	0.00
3.0	0.0849	99	0.00	26.04	15.59	0.00	0.00	0.00	11.25	7.08	0.00	0.00	0.29	0.00	24.06	0.00	0.00	0.00	0.00
4.0	0.1132	99	0.00	26.13	23.20	0.00	0.00	0.00	11.76	8.16	1.92	0.00	0.49	0.00	20.84	0.00	0.00	0.00	0.00
5.0	0.1415	99	0.00	24.34	28.75	0.00	0.00	0.00	11.71	9.03	4.90	0.00	0.76	0.00	17.54	0.00	0.00	0.00	0.00
6.0	0.1698	99	0.00	23.62	34.01	0.00	0.00	0.00	12.13	10.20	7.90	0.00	1.06	0.00	15.67	0.00	0.00	0.00	0.00
7.0	0.1981	99	0.03	23.71	38.61	0.00	0.17	0.00	12.59	11.33	10.24	0.00	1.39	0.00	14.90	0.00	0.00	0.00	0.00
8.0	0.2264	99	0.21	23.17	41.54	0.00	0.85	0.00	12.49	11.94	11.79	0.00	1.74	0.00	11.71	0.00	0.00	0.00	0.00
9.0	0.2547	99	0.29	21.12	43.76	0.04	1.88	0.00	12.70	12.61	12.64	0.00	2.16	0.00	9.62	0.00	0.00	0.00	0.00
10.0	0.2830	99	0.30	19.52	46.16	0.27	2.83	0.00	12.71	13.29	13.05	0.00	2.62	0.00	8.97	0.00	0.00	0.00	0.00
12.0	0.3396	99	3.18	17.13	50.55	1.00	5.20	0.01	12.54	14.65	14.31	0.00	3.49	0.00	8.15	0.00	0.00	0.00	0.00
14.0	0.3962	99	5.60	14.01	53.67	2.40	7.13	0.02	12.81	16.34	15.87	0.00	4.39	0.60	6.12	0.00	0.00	0.00	0.00
15.0	0.4245	98	7.22	13.93	54.30	2.95	7.87	0.03	12.75	16.85	16.67	0.00	4.70	1.21	5.38	0.00	0.00	0.00	0.00
16.0	0.4528	98	9.10	14.02	54.33	3.05	8.77	0.04	12.59	17.18	17.29	0.00	4.98	1.84	5.61	0.00	0.00	0.00	0.00
18.0	0.5094	97	12.97	13.39	54.82	3.49	11.22	0.06	12.65	18.02	18.64	0.00	5.59	2.87	6.20	0.00	0.00	0.00	0.00
20.0	0.5660	96	14.88	12.73	56.21	4.06	13.33	0.11	12.85	19.15	19.85	0.00	6.32	3.06	6.87	0.00	0.00	0.00	0.00
25.0	0.7075	90	19.23	14.77	56.73	4.73	19.29	0.66	12.45	21.18	21.91	0.03	7.86	3.02	5.16	0.00	0.00	0.00	0.00
30.0	0.8490	82	23.50	17.61	57.44	5.39	25.51	1.92	10.87	23.09	25.00	0.31	9.44	4.15	7.76	0.00	0.00	0.00	0.00
40.0	1.1320	68	31.16	19.48	55.61	6.99	26.97	3.54	9.86	24.80	34.69	0.81	11.78	7.50	8.57	0.03	0.00	0.24	0.00
50.0	1.4150	56	33.23	20.01	51.57	8.22	25.19	4.22	10.37	24.77	38.52	1.27	12.44	10.00	6.78	0.08	0.00	1.55	0.00
60.0	1.6980	46	31.56	19.90	47.72	9.40	24.87	5.45	11.24	24.48	35.32	1.84	12.27	10.34	5.90	0.14	0.00	1.98	0.00
70.0	1.9810	38	28.18	17.31	42.54	10.81	23.51	6.27	12.32	23.77	31.20	2.57	12.13	8.92	4.43	0.20	0.00	2.03	0.00
80.0	2.2640	31	25.56	15.77	38.91	12.41	21.03	6.92	16.73	23.47	30.15	3.25	12.52	8.66	1.93	0.27	0.00	1.38	0.00
90.0	2.5470	25	22.38	15.03	36.43	14.04	19.05	7.31	18.81	23.26	25.13	4.17	13.08	8.10	1.29	0.36	0.00	2.98	0.00
100.0	2.8300	20	19.82	14.21	34.12	14.89	17.51	7.99	18.93	23.40	20.25	5.39	13.09	8.35	1.14	0.44	0.00	3.09	0.00
110.0	3.1130	16	17.31	13.25	32.29	15.50	15.48	8.14	18.81	23.82	18.40	6.47	13.39	9.47	1.11	0.58	0.00	3.20	0.00
120.0	3.3960	12	15.77	11.45	30.96	15.78	13.95	8.64	18.48	24.51	18.23	7.47	14.56	10.20	1.11	0.79	0.00	3.09	0.00
140.0	3.9620	7	13.52	8.09	29.43	15.97	12.05	7.50	17.53	25.46	17.51	9.49	16.63	9.70	1.09	1.28	0.07	2.76	0.00

Appendix 7 River Wissey PHABSIM results - CHALK HALL FARM

flow	flow	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F	C H F
cfs	cumecs	Bream	Pike	Pike	Pike	Pike	Perch	Perch	Perch	Perch	Leuct.	Rhyac.	Polyc.	Sphae.	Ran.
		adult	spawn	fry	juv	adult	spawn	fry	juv	adult	fusca	dorsal.	flavom.	corn.	fluit.
2.0	0.0566	0.00	0.00	0.00	7.58	0.81	21.82	1.30	10.33	5.35	6.67	5.11	14.70	13.23	3.50
3.0	0.0849	0.00	0.00	0.00	5.84	0.87	18.83	0.78	8.92	7.14	10.81	11.83	21.72	16.06	3.06
4.0	0.1132	0.00	0.00	0.00	6.38	0.91	18.89	1.52	9.40	7.15	13.24	15.89	26.60	18.48	3.12
5.0	0.1415	0.00	0.00	0.00	6.37	0.91	18.24	2.46	9.49	6.61	14.58	18.58	29.59	19.57	2.96
6.0	0.1698	0.00	0.00	0.00	6.41	0.95	18.80	3.25	9.77	6.43	16.10	21.29	33.12	21.28	2.97
7.0	0.1981	0.00	0.00	0.00	6.51	0.99	19.43	3.35	9.65	6.31	17.22	23.41	35.49	22.29	2.86
8.0	0.2264	0.00	0.00	0.00	6.40	0.96	19.30	3.21	9.26	6.05	18.10	25.10	37.42	22.87	2.71
9.0	0.2547	0.00	0.00	0.00	6.41	0.94	16.75	3.19	9.20	6.01	19.15	26.96	39.23	23.22	2.74
10.0	0.2830	0.00	0.00	0.00	6.41	0.95	13.76	3.16	9.12	5.96	20.14	28.73	41.05	23.57	2.74
12.0	0.3396	0.00	0.00	0.00	6.51	0.96	11.30	3.15	8.70	5.86	21.91	31.47	44.04	24.23	2.81
14.0	0.3962	0.00	0.00	0.00	6.78	1.02	8.55	3.28	7.86	5.74	23.44	33.61	46.59	25.28	3.12
15.0	0.4245	0.00	0.00	0.00	6.95	1.02	8.52	3.34	7.34	5.66	23.92	34.19	47.27	25.41	3.26
16.0	0.4528	0.00	0.00	0.00	7.14	1.01	8.70	3.32	6.82	5.49	24.08	34.41	47.40	25.31	3.15
18.0	0.5094	0.00	0.00	0.00	7.54	1.00	8.60	3.39	6.38	5.79	24.46	34.65	47.44	25.21	2.87
20.0	0.5660	0.00	0.00	0.00	8.09	1.01	8.65	4.11	7.17	6.07	25.22	35.32	48.14	25.48	2.95
25.0	0.7075	0.00	0.00	0.00	8.68	1.06	8.22	5.42	8.85	4.93	26.19	35.93	48.16	25.59	3.30
30.0	0.8490	0.00	0.00	0.00	10.61	1.10	7.81	5.94	9.64	4.97	27.70	36.90	49.16	26.24	3.85
40.0	1.1320	0.00	0.00	0.00	15.17	1.21	9.52	11.78	16.58	5.65	28.83	36.49	48.66	27.03	4.80
50.0	1.4150	0.00	0.00	0.00	16.63	1.29	11.62	13.18	21.03	6.98	28.84	35.09	47.17	27.50	5.73
60.0	1.6980	0.00	0.00	0.00	17.44	1.64	15.66	13.28	22.31	8.48	27.85	33.07	44.58	27.70	7.04
70.0	1.9810	0.00	0.00	0.00	18.39	2.30	18.57	13.56	22.75	10.24	25.60	29.91	40.91	27.06	8.29
80.0	2.2640	0.00	0.76	0.00	19.30	2.89	20.50	14.06	23.71	15.44	23.41	27.66	38.19	27.04	8.32
90.0	2.5470	0.00	1.67	0.00	19.99	3.37	21.60	12.75	23.58	18.86	21.46	25.47	35.68	27.07	7.94
100.0	2.8300	0.00	1.83	0.00	21.13	4.11	21.86	12.02	23.38	20.05	19.72	23.41	33.43	27.01	7.54
110.0	3.1130	0.00	1.99	1.36	21.84	4.73	21.40	12.60	23.26	20.19	18.34	21.72	31.89	27.06	7.52
120.0	3.3960	0.00	2.78	1.88	22.19	5.26	21.03	13.26	23.96	20.80	17.03	20.51	30.62	27.09	7.07
140.0	3.9620	0.00	3.75	1.35	23.21	6.20	21.45	12.87	23.74	21.83	14.47	18.44	28.35	27.00	7.01

Appendix 7 River Wissey PHABSIM results - CHALK HALL FARM

flow	flow	Nrthwld	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv	D Grv
cfs	cumecs	% time	Brn Trt	Brn Trt	Brn Trt	Brn Trt	Dace	Dace	Dace	Dace	Chub	Chub	Chub	Roach	Roach	Roach	Bream	Bream	Bream
		exceed.	spawn	fry	juv	adult	spawn	fry	juv	adult	spawn	fry	juv+ad	spawn	fry	juv+ad	spawn	fry	juv
2.0	0.0566	99																	
3.0	0.0849	99																	
4.0	0.1132	99																	
5.0	0.1415	99	0.00	35.57	15.30	0.00	0.00	0.65	15.96	12.50	1.08	0.05	0.06	0.00	33.14	0.03	0.00	1.22	0.00
6.0	0.1698	99	0.00	38.98	19.04	0.00	0.00	0.73	18.43	13.99	3.22	0.25	0.15	0.00	32.04	0.05	0.00	1.25	0.00
7.0	0.1981	99	0.00	40.95	23.80	0.00	0.00	0.81	20.31	15.44	5.61	0.49	0.24	0.00	30.40	0.06	0.00	1.27	0.00
8.0	0.2264	99	0.00	41.53	27.33	0.00	0.00	0.89	22.25	16.99	7.79	0.54	0.45	0.00	29.31	0.08	0.00	1.30	0.00
9.0	0.2547	99	0.00	42.08	31.26	0.00	0.00	0.97	23.85	18.24	10.28	0.56	0.60	0.00	27.69	0.09	0.00	1.14	0.00
10.0	0.2830	99	0.00	42.53	34.80	0.00	0.00	1.06	25.98	19.56	12.01	0.60	0.89	0.00	25.92	0.11	0.00	0.97	0.00
12.0	0.3396	99	0.50	42.37	43.72	0.00	0.00	1.23	28.40	21.94	16.48	0.65	1.38	0.00	23.71	0.13	0.00	0.57	0.00
14.0	0.3962	99	1.31	40.70	51.45	0.20	0.00	1.38	30.26	24.16	21.52	0.69	1.93	0.14	18.99	0.16	0.00	0.15	0.00
15.0	0.4245	98	1.69	39.94	54.20	0.44	0.00	1.39	30.86	25.18	24.39	0.70	2.26	0.29	16.95	0.17	0.00	0.00	0.00
16.0	0.4528	98	2.14	38.67	56.79	0.71	0.00	1.40	31.23	26.02	26.31	0.72	2.62	0.55	15.05	0.18	0.00	0.00	0.00
18.0	0.5094	97	3.43	37.14	60.90	1.23	0.38	1.41	32.36	27.67	30.50	0.75	3.28	1.18	12.31	0.20	0.00	0.00	0.00
20.0	0.5660	96	5.64	35.30	63.18	1.67	1.97	1.44	33.08	29.33	33.55	0.79	4.10	1.96	11.15	0.22	0.00	0.00	0.00
25.0	0.7075	90	13.60	30.45	66.44	3.21	7.91	1.51	32.44	32.37	36.25	0.92	6.08	3.15	10.56	0.27	0.00	0.02	0.00
30.0	0.8490	82	19.12	27.54	67.13	4.38	13.74	1.59	32.56	36.75	39.09	1.45	9.26	5.00	9.99	0.40	0.00	0.12	0.00
40.0	1.1320	68	27.72	22.87	63.91	6.40	26.55	1.76	27.45	35.81	40.40	0.42	11.13	9.47	9.02	0.40	0.00	0.11	0.00
50.0	1.4150	56	29.94	21.21	58.94	7.76	29.91	1.12	24.31	33.53	37.71	0.46	11.39	9.89	8.85	0.27	0.00	0.40	0.00
60.0	1.6980	46	29.91	21.29	56.00	8.25	27.48	1.28	21.40	33.43	40.08	0.56	13.14	9.22	8.97	0.14	0.00	0.69	0.00
70.0	1.9810	38	31.90	22.89	54.75	8.79	28.28	2.24	19.90	33.61	42.16	0.71	15.05	8.32	9.82	0.16	0.00	4.26	0.00
80.0	2.2640	31	32.51	22.78	53.63	9.51	27.84	3.36	18.73	33.41	43.36	0.87	15.88	7.83	10.82	0.18	0.00	4.66	0.00
90.0	2.5470	25	31.95	21.53	52.70	10.26	28.97	3.97	18.05	32.79	39.77	1.05	16.21	8.26	10.46	0.20	0.00	4.76	0.00
100.0	2.8300	20	30.54	20.94	51.73	10.94	29.38	4.59	18.27	32.73	36.88	1.23	16.73	8.63	9.57	0.24	0.00	5.05	0.00
110.0	3.1130	16																	
120.0	3.3960	12																	
140.0	3.9620	7																	

Appendix 7 River Wissey PHABSIM results -DIDLINGTON GRAVEL

flow cfs	flow cumecs	D Grv Bream adult	D Grv Pike spawn	D Grv Pike fry	D Grv Pike juv	D Grv Pike adult	D Grv Perch spawn	D Grv Perch fry	D Grv Perch juv	D Grv Perch adult	D Grv Leuct. fusca	D Grv Rhyac. dorsal.	D Grv Polyc. flavom.	D Grv Sphae. corn.	D Grv Ran. fluit.
2.0	0.0566														
3.0	0.0849														
4.0	0.1132														
5.0	0.1415	0.00	0.58	0.00	13.94	2.05	31.72	9.62	19.11	8.08	9.20	8.90	20.56	20.45	4.64
6.0	0.1698	0.00	0.70	0.00	14.25	2.18	33.68	10.04	19.48	8.65	10.54	10.52	23.43	22.94	5.41
7.0	0.1981	0.00	0.79	0.00	14.33	2.28	34.88	10.32	19.94	9.21	11.96	12.53	26.48	25.47	6.06
8.0	0.2264	0.00	0.92	0.00	14.50	2.40	36.35	10.29	20.47	9.84	13.33	14.32	29.08	27.72	6.63
9.0	0.2547	0.00	0.98	0.00	14.62	2.46	37.24	10.12	20.84	10.43	14.55	15.99	31.64	29.61	7.04
10.0	0.2830	0.00	1.08	0.00	14.70	2.54	38.53	9.91	21.29	11.23	15.62	17.59	33.86	31.23	7.22
12.0	0.3396	0.00	1.16	0.00	14.79	2.66	39.78	8.70	21.50	12.36	17.41	20.50	37.70	33.76	7.59
14.0	0.3962	0.00	1.18	0.00	14.78	2.78	39.20	7.47	21.41	13.31	18.76	22.58	40.52	35.55	7.84
15.0	0.4245	0.00	1.19	0.00	14.76	2.83	38.31	6.86	21.38	13.55	19.23	23.13	41.39	35.97	7.91
16.0	0.4528	0.00	1.06	0.00	14.70	2.88	36.96	6.16	21.25	13.82	19.62	23.80	42.42	36.35	7.94
18.0	0.5094	0.00	0.56	0.00	14.57	2.93	36.20	4.72	21.12	14.29	20.40	24.95	44.06	37.08	7.99
20.0	0.5660	0.00	0.09	0.00	14.53	3.01	34.17	3.81	21.04	14.72	21.00	25.65	44.81	37.51	7.94
25.0	0.7075	0.00	0.00	0.00	14.47	3.11	26.59	2.34	20.78	15.14	22.13	26.98	46.01	38.10	7.80
30.0	0.8490	0.00	0.00	0.00	14.84	3.39	27.25	2.48	20.87	16.47	22.06	27.29	46.00	38.41	7.12
40.0	1.1320	0.00	0.00	0.00	13.76	2.93	15.25	2.43	14.42	15.75	21.63	27.47	44.45	34.80	6.19
50.0	1.4150	0.00	0.00	0.00	12.90	2.67	11.15	2.92	10.61	13.76	20.79	26.36	42.05	32.11	5.76
60.0	1.6980	0.00	0.00	0.00	12.82	2.51	9.56	3.56	9.77	11.07	20.49	25.93	41.41	31.05	5.22
70.0	1.9810	0.00	0.00	0.00	13.91	2.44	10.52	4.36	10.12	10.07	20.30	25.79	41.56	31.04	5.26
80.0	2.2640	0.00	0.02	0.00	16.46	2.40	11.20	5.42	11.47	9.62	20.09	25.50	41.55	31.16	5.27
90.0	2.5470	0.00	0.06	0.00	18.55	2.33	11.88	7.64	14.37	9.23	20.17	25.30	41.34	31.18	5.67
100.0	2.8300	0.00	0.45	0.00	19.25	2.32	12.83	9.74	17.04	9.84	19.98	24.85	40.74	31.16	5.70
110.0	3.1130														
120.0	3.3960														
140.0	3.9620														

Appendix 7 River Wissey PHABSIM results -DIDLINGTON GRAVEL

flow cfs	flow cumecs	Nrthwld % time exceed.	D Snd Brn Trt spawn	D Snd Brn Trt fry	D Snd Brn Trt juv	D Snd Brn Trt adult	D Snd Dace spawn	D Snd Dace fry	D Snd Dace juv	D Snd Dace adult	D Snd Chub spawn	D Snd Chub fry	D Snd Chub juv+ad	D Snd Roach spawn	D Snd Roach fry	D Snd Roach juv+ad	D Snd Bream spawn	D Snd Bream fry	D Snd Bream juv
2.0	0.0566	99																	
3.0	0.0849	99																	
4.0	0.1132	99	0.00	47.35	0.37	0.00	0.00	0.63	39.65	24.65	0.00	0.31	1.55	0.00	21.68	0.21	0.00	1.11	0.00
5.0	0.1415	99	0.00	51.73	0.64	0.00	0.00	0.68	44.56	27.46	0.01	0.45	2.05	0.00	18.75	0.25	0.00	1.15	0.00
6.0	0.1698	99	0.00	55.09	1.08	0.00	0.00	0.73	49.05	29.98	0.15	0.52	2.69	0.00	16.53	0.28	0.00	1.18	0.00
7.0	0.1981	99	0.00	56.35	1.64	0.00	0.00	0.77	52.63	32.30	0.41	0.56	3.51	0.00	14.91	0.32	0.00	1.20	0.00
8.0	0.2264	99	0.00	55.93	2.27	0.00	0.00	0.81	55.73	34.45	0.72	0.60	4.46	0.00	13.77	0.35	0.00	1.21	0.00
9.0	0.2547	99	0.00	54.31	3.03	0.00	0.00	0.85	58.22	36.53	0.96	0.64	5.47	0.00	13.34	0.38	0.00	1.23	0.00
10.0	0.2830	99	0.00	52.55	4.03	0.00	0.00	0.89	60.79	38.39	1.23	0.67	6.45	0.00	12.92	0.40	0.00	1.20	0.00
12.0	0.3396	99	0.00	47.97	6.31	0.00	0.00	0.96	65.46	42.10	2.28	0.76	8.66	0.00	12.11	0.44	0.06	1.18	0.00
14.0	0.3962	99	0.00	42.86	8.90	0.00	0.00	1.03	69.05	45.73	3.61	0.89	11.13	0.00	11.40	0.49	0.14	1.16	0.00
15.0	0.4245	98	0.00	41.00	10.77	0.00	0.00	1.06	70.29	47.34	4.33	0.94	12.31	0.00	11.07	0.50	0.16	1.13	0.00
16.0	0.4528	98	0.00	38.82	12.94	0.00	0.00	1.10	71.25	49.04	5.19	1.00	13.65	0.00	10.78	0.52	0.20	1.10	0.00
18.0	0.5094	97	0.00	35.03	19.03	0.00	0.00	1.16	72.27	52.23	7.21	1.12	16.28	0.00	10.30	0.57	0.26	1.04	0.00
20.0	0.5660	96	0.00	31.65	26.64	0.00	0.00	1.22	72.55	55.28	9.91	1.23	19.03	0.00	10.16	0.61	0.31	0.98	0.00
25.0	0.7075	90	0.00	26.25	46.77	0.00	0.00	1.38	72.58	62.01	25.42	1.59	26.23	0.00	8.73	0.71	0.45	0.88	0.00
30.0	0.8490	82	0.00	23.21	65.52	0.02	0.00	1.49	72.06	67.97	47.64	1.97	33.71	0.00	8.32	0.80	0.58	0.74	0.00
40.0	1.1320	68	0.00	19.15	79.68	0.61	0.00	1.47	71.24	74.13	73.56	2.62	48.45	0.00	7.80	1.01	0.79	0.52	0.00
50.0	1.4150	56	0.53	16.42	81.45	5.89	0.00	1.44	71.36	75.61	76.87	3.11	59.85	0.02	6.45	1.18	0.98	0.42	0.00
60.0	1.6980	46	11.17	14.28	82.27	17.77	0.01	1.50	70.10	76.06	77.25	3.49	64.97	0.25	5.26	1.34	1.06	1.66	0.00
70.0	1.9810	38	37.01	13.36	82.87	23.98	0.24	1.60	64.59	76.05	77.68	3.76	67.51	0.36	4.42	1.46	1.11	1.92	0.00
80.0	2.2640	31	50.49	12.64	83.19	26.90	0.89	1.81	57.62	75.97	78.04	3.98	69.18	0.35	3.54	1.57	1.13	2.00	0.00
90.0	2.5470	25	57.02	12.08	83.35	28.18	2.94	1.84	50.37	75.69	78.08	4.25	70.57	0.35	2.96	1.68	1.15	1.85	0.00
100.0	2.8300	20	61.64	11.89	83.05	28.92	5.42	2.01	42.98	74.66	78.05	4.50	71.49	0.35	2.32	1.77	1.12	1.63	0.07
110.0	3.1130	16	64.74	11.64	81.53	29.18	6.86	2.17	36.77	71.80	78.03	4.82	72.19	0.35	2.00	1.85	1.05	1.47	0.21
120.0	3.3960	12	65.85	11.39	79.20	29.44	6.84	2.37	32.82	67.83	77.97	5.14	72.09	0.34	1.55	1.92	0.99	1.30	0.34
140.0	3.9620	7	66.65	10.65	73.11	29.65	7.12	2.73	28.38	58.35	76.19	5.36	65.23	0.10	0.91	2.01	0.86	1.81	0.53

Appendix 7 River Wissey PHABSIM results - DIDLINGTON SAND

flow	flow	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd	D Snd
cfs	cumecs	Bream	Pike	Pike	Pike	Pike	Perch	Perch	Perch	Perch	Leuct.	Rhyac.	Polyc.	Sphae.	Ran.
		adult	spawn	fry	juv	adult	spawn	fry	juv	adult	fusca	dorsal.	flavom.	corn.	fluit.
2.0	0.0566														
3.0	0.0849														
4.0	0.1132	0.00	0.94	1.01	15.92	6.24	72.53	7.31	70.67	55.62	3.33	0.56	6.56	11.04	5.48
5.0	0.1415	0.00	0.96	1.03	15.99	6.71	75.37	7.53	71.07	59.21	4.17	0.87	7.92	13.28	6.12
6.0	0.1698	0.00	0.98	1.05	16.05	7.06	77.69	7.37	71.25	62.09	5.02	1.27	9.22	15.37	6.60
7.0	0.1981	0.00	0.99	1.06	16.01	7.30	79.32	6.99	70.62	63.92	5.86	1.71	10.39	17.23	6.94
8.0	0.2264	0.00	1.00	1.08	16.02	7.47	80.41	6.62	69.95	65.08	6.76	2.19	11.59	19.01	7.25
9.0	0.2547	0.00	1.01	1.09	16.11	7.64	81.33	6.38	69.56	65.83	7.76	2.68	12.79	20.75	7.53
10.0	0.2830	0.00	1.03	1.10	16.20	7.78	82.09	6.39	69.33	66.56	8.94	3.37	14.09	22.52	7.82
12.0	0.3396	0.00	1.05	1.12	16.42	8.04	83.35	6.41	69.43	67.65	11.19	5.14	16.76	25.81	8.07
14.0	0.3962	0.00	1.07	1.15	16.69	8.25	84.43	6.43	69.74	68.48	13.15	7.59	19.37	28.77	8.01
15.0	0.4245	0.00	1.08	1.16	16.78	8.32	84.73	6.46	69.86	68.73	14.18	9.21	20.72	30.25	7.99
16.0	0.4528	0.00	1.09	1.17	16.86	8.40	85.09	6.51	70.00	69.13	15.00	10.67	21.88	31.55	7.91
18.0	0.5094	0.00	1.11	1.18	17.00	8.50	85.52	6.62	70.27	69.71	16.65	13.78	24.26	34.11	7.84
20.0	0.5660	0.00	1.13	1.20	17.13	8.59	85.92	6.81	70.22	69.96	17.97	16.44	26.33	36.23	7.79
25.0	0.7075	0.00	1.18	1.23	17.82	8.78	86.55	7.12	70.16	70.34	19.44	20.26	29.80	39.12	7.52
30.0	0.8490	0.00	1.23	1.27	18.35	8.81	87.36	7.65	70.95	70.02	19.69	22.08	32.16	40.26	7.36
40.0	1.1320	0.00	1.35	1.32	19.16	8.48	86.02	8.30	71.15	69.85	19.61	24.56	36.00	41.46	6.88
50.0	1.4150	0.00	1.45	1.37	19.65	8.12	70.98	9.04	65.59	70.41	19.50	26.49	38.70	42.32	6.41
60.0	1.6980	0.00	1.44	1.30	19.37	7.82	41.79	9.31	49.00	70.64	19.43	27.87	39.70	43.02	6.49
70.0	1.9810	0.00	1.29	1.12	19.20	7.50	29.44	8.82	35.42	64.13	19.37	28.98	39.98	43.48	6.52
80.0	2.2640	0.00	1.15	0.95	19.16	7.22	23.44	8.40	28.21	48.42	19.39	30.03	40.13	43.08	6.41
90.0	2.5470	0.00	0.98	0.78	19.19	6.98	22.05	8.83	24.52	40.86	19.40	30.96	40.22	41.94	6.28
100.0	2.8300	0.00	1.00	0.73	18.92	6.71	21.75	9.10	22.68	35.76	19.45	31.77	40.27	40.42	6.24
110.0	3.1130	0.00	1.15	0.68	18.43	6.45	21.42	9.21	21.77	31.62	19.54	32.27	40.31	38.92	6.19
120.0	3.3960	0.00	1.33	0.46	17.99	6.22	21.04	8.91	21.13	28.17	19.61	32.42	40.31	37.77	6.10
140.0	3.9620	0.00	1.54	0.22	17.02	5.87	20.55	8.02	20.11	25.07	20.12	32.46	40.15	35.83	5.84

Appendix 7 River Wissey PHABSIM results - DIDLINGTON SAND

flow	flow	Nrthwld	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv	L Grv
cfs	cumecs	% time	Brn Trt	Brn Trt	Brn Trt	Brn Trt	Dace	Dace	Dace	Dace	Chub	Chub	Chub	Roach	Roach	Roach	Bream	Bream	Bream
		exceed.	spawn	fry	juv	adult	spawn	fry	juv	adult	spawn	fry	juv+ad	spawn	fry	juv+ad	spawn	fry	juv
2.0	0.0566	99																	
3.0	0.0849	99	0.00	49.15	8.47	0.00	0.00	0.04	16.17	8.86	0.00	0.00	0.07	0.00	36.70	0.00	0.00	0.00	0.00
4.0	0.1132	99	0.00	53.13	11.52	0.00	0.00	0.06	19.25	10.26	0.00	0.00	0.12	0.00	33.45	0.00	0.00	0.00	0.00
5.0	0.1415	99	0.00	53.35	15.36	0.00	0.00	0.11	21.88	11.89	0.16	0.00	0.22	0.00	32.65	0.00	0.00	0.00	0.00
6.0	0.1698	99	0.00	52.85	21.10	0.00	0.00	0.16	23.89	13.39	1.12	0.00	0.33	0.00	32.22	0.01	0.00	0.00	0.00
7.0	0.1981	99	0.00	52.00	27.18	0.00	0.00	0.19	24.76	14.54	2.99	0.00	0.42	0.00	30.15	0.01	0.00	0.00	0.00
8.0	0.2264	99	0.07	51.70	33.15	0.00	0.00	0.24	25.71	16.02	4.99	0.05	0.60	0.00	26.76	0.02	0.00	0.04	0.00
9.0	0.2547	99	0.24	51.35	37.57	0.00	0.14	0.28	26.32	17.28	7.70	0.09	0.84	0.00	21.59	0.02	0.00	0.13	0.00
10.0	0.2830	99	0.49	51.52	41.33	0.00	0.74	0.32	26.72	18.53	10.17	0.12	1.14	0.00	17.92	0.02	0.00	0.38	0.00
12.0	0.3396	99	0.98	50.60	47.20	0.00	2.68	0.41	26.91	20.54	14.30	0.18	1.87	0.00	15.59	0.03	0.00	0.95	0.00
14.0	0.3962	99	1.56	45.48	51.31	0.07	5.21	0.51	27.77	22.52	18.53	0.24	2.76	0.00	14.49	0.04	0.00	1.47	0.00
15.0	0.4245	98	1.75	42.88	53.09	0.17	6.45	0.54	28.01	23.14	19.98	0.26	3.09	0.00	14.14	0.04	0.00	1.50	0.00
16.0	0.4528	98	1.94	40.95	54.47	0.33	7.12	0.60	28.45	24.06	21.00	0.29	3.59	0.00	13.98	0.04	0.00	1.56	0.00
18.0	0.5094	97	4.01	37.79	56.37	0.63	7.38	0.70	28.96	25.32	22.36	0.34	4.50	0.00	13.18	0.05	0.00	1.65	0.00
20.0	0.5660	96	7.80	35.75	57.58	1.22	8.04	0.80	29.29	26.46	23.46	0.38	5.31	0.02	12.18	0.06	0.00	1.81	0.00
25.0	0.7075	90	16.07	30.50	58.88	3.21	14.71	1.05	28.88	28.43	25.95	0.47	6.98	0.00	9.81	0.08	0.00	2.14	0.00
30.0	0.8490	82	26.13	28.91	58.77	4.42	16.76	1.28	25.95	30.13	28.41	0.68	8.49	0.00	9.15	0.10	0.00	2.36	0.00
40.0	1.1320	68	32.07	26.82	56.53	5.67	19.34	1.59	21.93	31.28	33.36	1.18	11.07	0.00	7.87	0.12	0.00	2.39	0.00
50.0	1.4150	56	32.32	26.03	52.91	6.66	19.85	1.87	20.81	28.98	36.27	1.60	12.97	0.00	6.89	0.08	0.00	2.12	0.00
60.0	1.6980	46	29.32	24.53	48.23	7.69	16.15	2.14	21.34	25.92	36.32	2.10	11.86	0.00	6.14	0.12	0.00	1.86	0.00
70.0	1.9810	38	24.71	23.07	42.84	7.73	6.76	2.38	21.17	22.56	28.93	2.13	8.86	0.00	5.00	0.16	0.00	1.68	0.00
80.0	2.2640	31	20.35	21.40	38.39	7.48	6.26	2.62	22.18	21.04	24.32	2.31	7.10	0.00	3.68	0.20	0.00	1.68	0.00
90.0	2.5470	25	17.17	20.14	34.94	7.37	4.85	2.80	23.30	20.51	23.81	2.82	6.45	0.00	2.76	0.25	0.00	1.93	0.00
100.0	2.8300	20	15.25	19.45	33.01	7.19	5.43	2.96	24.08	20.23	20.16	3.35	6.06	0.00	2.20	0.34	0.00	2.19	0.00
110.0	3.1130	16	14.23	18.60	31.19	6.86	5.40	3.12	23.99	20.12	17.77	3.91	5.71	0.00	2.10	0.41	0.00	2.34	0.00
120.0	3.3960	12	13.57	17.14	29.86	6.41	4.46	3.27	23.52	20.57	15.67	4.56	6.14	0.00	2.15	0.48	0.00	2.48	0.00
140.0	3.9620	7	11.85	13.74	28.07	5.83	3.53	3.57	22.57	21.50	14.02	5.63	7.45	0.00	2.11	0.60	0.13	2.73	0.00

Appendix 7 River Wissey PHABSIM results - LANGFORD HALL GRAVEL

flow cfs	flow cumecs	L Grv Bream adult	L Grv Pike spawn	L Grv Pike fry	L Grv Pike juv	L Grv Pike adult	L Grv Perch spawn	L Grv Perch fry	L Grv Perch juv	L Grv Perch adult	L Grv Leuct. fusca	L Grv Rhyac. dorsal.	L Grv Polyc. flavom.	L Grv Sphae. corn.	L Grv Ran. fluit.
2.0	0.0566														
3.0	0.0849	0.00	0.00	0.00	11.43	1.76	26.14	5.16	17.65	14.27	6.19	5.00	12.56	13.52	4.66
4.0	0.1132	0.00	0.00	0.00	12.29	1.90	27.26	5.54	18.10	15.40	8.28	7.19	16.19	16.51	5.50
5.0	0.1415	0.00	0.00	0.00	13.31	2.09	28.75	6.62	19.42	16.64	10.36	10.01	19.51	19.39	6.04
6.0	0.1698	0.00	0.00	0.00	14.18	2.23	29.86	7.53	20.60	17.55	12.27	12.63	22.53	21.96	6.48
7.0	0.1981	0.00	0.00	0.00	14.25	2.30	30.26	8.04	21.14	17.82	13.29	14.19	24.25	23.16	6.64
8.0	0.2264	0.00	0.00	0.00	14.37	2.41	31.14	8.72	22.07	18.17	14.37	15.70	26.04	24.55	6.74
9.0	0.2547	0.00	0.00	0.00	14.56	2.46	31.86	9.18	22.86	18.45	15.23	16.98	27.53	25.52	6.85
10.0	0.2830	0.00	0.00	0.00	14.79	2.51	32.50	9.71	23.70	18.72	16.01	18.15	28.94	26.39	6.99
12.0	0.3396	0.00	0.00	0.00	15.27	2.52	33.11	10.03	24.07	18.95	17.00	19.78	31.02	27.30	6.83
14.0	0.3962	0.00	0.00	0.00	15.90	2.57	32.48	10.14	24.37	19.89	17.87	21.23	32.70	28.00	6.66
15.0	0.4245	0.00	0.00	0.00	16.02	2.55	30.52	10.26	24.43	20.10	18.28	21.92	33.37	28.14	6.73
16.0	0.4528	0.00	0.00	0.00	16.36	2.58	29.45	10.67	24.77	20.58	18.65	22.45	33.86	28.32	6.85
18.0	0.5094	0.00	0.00	0.00	16.70	2.59	27.90	11.17	25.08	21.30	19.29	23.52	34.86	28.52	6.76
20.0	0.5660	0.00	0.00	0.00	16.98	2.62	26.13	11.86	25.60	21.95	19.73	24.17	35.52	28.72	6.70
25.0	0.7075	0.00	0.00	0.00	17.13	2.62	19.62	13.00	25.67	20.69	20.90	25.86	36.83	28.45	6.81
30.0	0.8490	0.00	0.00	0.00	16.84	2.59	18.31	13.67	24.99	18.67	21.82	26.93	37.55	28.04	6.74
40.0	1.1320	0.00	0.00	0.00	16.85	2.52	18.76	13.44	22.88	15.72	23.17	28.17	38.05	26.74	6.74
50.0	1.4150	0.00	0.51	0.00	16.99	2.46	20.47	12.91	22.13	15.81	24.36	27.96	36.98	25.38	6.77
60.0	1.6980	0.00	1.09	0.00	17.29	2.50	20.86	13.30	22.98	17.70	25.04	27.06	35.67	24.50	6.80
70.0	1.9810	0.00	1.39	0.00	17.32	2.66	20.51	14.06	23.72	18.60	23.95	25.45	33.58	23.59	6.76
80.0	2.2640	0.00	1.55	0.11	17.33	2.90	20.58	14.96	24.64	19.41	22.49	23.58	31.55	22.87	6.63
90.0	2.5470	0.00	1.71	0.91	17.27	3.12	19.75	14.80	24.13	20.39	19.85	21.16	28.55	21.83	6.50
100.0	2.8300	0.00	1.93	1.13	17.19	3.30	20.01	14.64	23.62	22.14	18.10	19.31	26.70	21.25	6.14
110.0	3.1130	0.00	1.99	1.05	17.17	3.47	20.56	14.43	23.06	23.21	16.55	17.66	24.99	20.70	5.63
120.0	3.3960	0.00	1.93	0.86	17.23	3.64	20.93	14.31	22.56	23.34	15.25	16.07	23.53	20.26	5.39
140.0	3.9620	0.00	1.68	0.52	17.50	4.00	19.86	14.17	21.68	22.86	12.91	13.87	21.42	19.61	5.03

Appendix 7 River Wissey PHABSIM results - LANGFORD HALL GRAVEL

flow cfs	flow cumecs	Nrthwld % time exceed.	L Snd Brn Trt spawn	L Snd Brn Trt fry	L Snd Brn Trt juv	L Snd Brn Trt adult	L Snd Dace spawn	L Snd Dace fry	L Snd Dace juv	L Snd Dace adult	L Snd Chub spawn	L Snd Chub fry	L Snd Chub juv+ad	L Snd Roach spawn	L Snd Roach fry	L Snd Roach juv+ad	L Snd Bream spawn	L Snd Bream fry	L Snd Bream juv
2.0	0.0566	99	0.00	67.75	2.03	0.00	0.00	0.10	8.93	7.10	0.00	0.00	0.00	0.00	39.62	0.00	0.00	0.00	0.00
3.0	0.0849	99	0.00	76.26	4.66	0.00	0.00	0.18	12.55	9.03	0.00	0.00	0.12	0.00	40.56	0.00	0.00	0.13	0.00
4.0	0.1132	99	0.00	78.64	12.91	0.00	0.00	0.22	14.46	10.12	0.25	0.00	0.17	0.00	38.54	0.00	0.00	0.13	0.00
5.0	0.1415	99	0.00	81.44	20.45	0.00	0.00	0.30	16.42	11.60	0.75	0.00	0.28	0.00	36.44	0.00	0.00	0.18	0.00
6.0	0.1698	99	0.00	83.35	28.49	0.00	0.00	0.39	18.06	13.09	1.69	0.00	0.40	0.00	34.64	0.00	0.00	0.21	0.00
7.0	0.1981	99	0.00	84.41	36.16	0.00	0.00	0.47	19.22	14.58	3.35	0.00	0.61	0.00	31.69	0.00	0.00	0.23	0.00
8.0	0.2264	99	0.00	84.81	42.50	0.00	0.00	0.54	19.99	16.12	5.72	0.00	0.91	0.00	28.21	0.00	0.00	0.23	0.00
9.0	0.2547	99	0.00	84.61	48.20	0.00	0.00	0.60	20.84	17.47	9.58	0.00	1.18	0.00	23.37	0.00	0.00	0.22	0.00
10.0	0.2830	99	0.00	82.47	53.34	0.00	0.00	0.67	22.15	18.89	13.91	0.00	1.53	0.00	20.72	0.00	0.00	0.22	0.00
12.0	0.3396	99	0.05	74.84	60.54	0.03	0.00	0.78	25.10	21.39	22.09	0.00	2.23	0.00	18.10	0.00	0.00	0.22	0.00
14.0	0.3962	99	0.86	59.84	65.35	0.09	0.00	0.88	29.77	24.39	28.23	0.00	3.42	0.00	11.38	0.00	0.00	0.21	0.00
15.0	0.4245	98	2.06	56.71	66.15	0.15	0.00	0.86	31.09	25.24	29.58	0.00	3.86	0.00	10.09	0.00	0.00	0.20	0.00
16.0	0.4528	98	4.74	47.33	63.32	0.57	0.00	0.74	31.64	25.36	30.72	0.00	4.46	0.00	8.47	0.00	0.00	0.18	0.00
18.0	0.5094	97	7.94	41.26	64.99	1.47	0.00	0.70	33.60	27.13	33.82	0.01	5.23	0.00	9.17	0.00	0.00	0.27	0.00
20.0	0.5660	96	21.79	35.15	68.75	3.39	0.00	0.90	33.93	31.25	38.08	0.08	7.12	0.00	9.89	0.00	0.00	0.44	0.00
25.0	0.7075	90	32.90	35.35	71.87	4.53	0.00	1.11	32.12	34.99	41.32	0.14	9.15	0.00	9.47	0.00	0.00	0.52	0.00
30.0	0.8490	82	45.02	35.58	76.43	6.69	0.00	1.51	30.31	41.46	50.12	0.37	14.29	0.00	11.48	0.02	0.00	0.76	0.00
40.0	1.1320	68	49.35	34.24	80.70	8.97	0.00	1.87	31.23	45.63	61.63	0.71	19.88	0.00	9.49	0.04	0.00	0.63	0.00
50.0	1.4150	56	50.03	28.98	81.72	11.17	0.00	2.23	29.77	47.39	66.35	1.10	23.10	0.00	4.99	0.07	0.00	0.60	0.00
60.0	1.6980	46	48.98	24.64	81.37	13.15	0.00	2.55	29.59	47.97	64.41	0.92	24.89	0.00	2.70	0.11	0.00	0.80	0.00
70.0	1.9810	38	47.34	19.10	79.26	15.23	0.00	3.04	28.88	48.90	63.16	1.14	27.88	0.00	2.28	0.16	0.00	1.57	0.00
80.0	2.2640	31	45.00	14.62	76.24	16.53	0.00	3.54	31.18	48.73	62.77	1.49	30.00	0.00	1.85	0.21	0.03	1.65	0.00
90.0	2.5470	25	42.94	10.77	73.61	17.37	0.00	4.11	34.23	48.72	64.69	1.86	32.03	0.00	1.16	0.25	0.05	1.68	0.00
100.0	2.8300	20	40.72	8.22	71.20	17.82	0.00	4.50	32.86	48.53	61.42	2.28	33.09	0.00	0.94	0.28	0.08	1.85	0.00
110.0	3.1130	16	38.66	6.95	68.99	18.07	0.00	4.92	30.51	48.52	58.06	2.87	33.83	0.08	0.86	0.31	0.09	1.87	0.00
120.0	3.3960	12	34.41	5.60	65.02	18.30	0.00	5.32	26.89	47.69	55.26	3.93	36.26	0.26	0.58	0.45	0.05	1.74	0.00
140.0	3.9620	7																	

Appendix 7 River Wissey PHABSIM results - LANGFORD HALL SAND

flow cfs	flow cumecs	L Snd Bream adult	L Snd Pike spawn	L Snd Pike fry	L Snd Pike juv	L Snd Pike adult	L Snd Perch spawn	L Snd Perch fry	L Snd Perch juv	L Snd Perch adult	L Snd Leuct. fusca	L Snd Rhyac. dorsal.	L Snd Polyc. flavom.	L Snd Sphae. corn.	L Snd Ran. fluit.
2.0	0.0566	0.00	0.00	0.00	7.97	1.28	17.91	0.08	43.24	12.84	5.46	2.65	8.36	10.22	5.92
3.0	0.0849	0.00	0.00	0.00	8.60	1.47	20.49	0.38	44.71	15.45	8.19	4.75	11.35	13.50	7.85
4.0	0.1132	0.00	0.00	0.00	8.72	1.50	20.89	0.63	44.84	15.81	11.43	8.58	15.10	16.55	9.31
5.0	0.1415	0.00	0.00	0.00	9.32	1.64	22.81	0.76	45.76	17.01	13.85	11.73	18.06	19.03	10.30
6.0	0.1698	0.00	0.00	0.00	9.92	1.78	24.77	1.02	46.69	18.37	15.73	14.39	20.59	21.01	10.97
7.0	0.1981	0.00	0.00	0.00	10.64	1.91	26.71	1.43	48.30	19.48	17.20	16.58	22.73	22.63	11.38
8.0	0.2264	0.00	0.00	0.00	11.34	2.05	28.85	1.77	50.12	20.32	18.34	18.34	24.61	23.98	11.66
9.0	0.2547	0.00	0.00	0.00	11.73	2.14	30.35	2.09	51.55	21.17	19.23	19.80	26.34	24.95	11.64
10.0	0.2830	0.00	0.00	0.00	12.27	2.23	31.37	2.40	53.04	22.46	19.93	20.91	27.79	25.79	11.59
12.0	0.3396	0.00	0.00	0.00	13.08	2.31	31.10	2.63	54.11	25.30	21.08	22.69	30.15	27.08	11.39
14.0	0.3962	0.00	0.00	0.00	13.67	2.40	29.01	3.12	53.22	29.83	22.25	24.57	32.50	28.36	11.18
15.0	0.4245	0.00	0.00	0.00	13.80	2.43	28.21	3.21	51.68	31.23	22.60	25.13	33.11	28.74	11.05
16.0	0.4528	0.00	0.00	0.00	13.05	2.31	22.84	3.13	44.90	31.87	21.67	24.15	31.73	27.51	9.97
18.0	0.5094	0.00	0.00	0.00	13.26	2.37	16.95	3.20	40.30	33.61	22.21	24.69	32.32	28.13	9.68
20.0	0.5660	0.00	0.04	0.00	13.88	2.51	10.90	3.21	29.09	34.07	23.21	25.89	33.40	29.50	9.86
25.0	0.7075	0.00	0.09	0.00	14.46	2.63	10.32	3.73	25.51	26.01	24.15	27.27	34.81	30.60	9.77
30.0	0.8490	0.00	0.44	0.00	16.09	2.77	11.89	4.42	25.76	19.94	25.72	29.93	37.77	32.13	9.60
40.0	1.1320	0.00	0.91	0.00	17.58	2.97	15.04	5.83	33.85	19.53	26.56	31.45	40.33	33.22	9.33
50.0	1.4150	0.00	1.28	0.16	17.09	3.05	15.03	5.83	32.99	21.06	27.24	32.31	41.59	33.41	9.91
60.0	1.6980	0.00	1.32	0.31	16.76	3.37	17.02	5.08	28.87	24.20	27.56	32.54	41.67	33.39	9.42
70.0	1.9810	0.00	1.07	0.37	16.27	3.78	17.68	4.52	25.39	24.29	27.43	32.29	41.28	33.34	9.62
80.0	2.2640	0.00	0.88	0.48	16.03	4.07	17.52	3.84	21.97	26.68	26.95	31.90	40.61	33.02	8.38
90.0	2.5470	0.00	0.88	0.83	16.13	4.40	17.27	3.34	19.74	29.96	26.15	31.33	39.81	32.81	7.27
100.0	2.8300	0.00	0.96	0.90	16.29	4.60	18.01	3.34	18.51	28.06	25.28	30.65	38.99	32.42	6.55
110.0	3.1130	0.00	1.08	0.94	16.70	4.81	18.60	3.55	18.19	26.02	24.22	29.90	38.14	31.99	5.57
120.0	3.3960	0.00	1.76	1.02	16.96	4.97	18.95	3.88	19.06	23.59	22.19	28.39	36.43	30.96	4.57
140.0	3.9620														

Appendix 7 River Wissey PHABSIM results - LANGFORD HALL SAND

flow cfs	flow cumecs	Nrthwld % time exceed.	North Brn Trt spawn	North Brn Trt fry	North Brn Trt juv	North Brn Trt adult	North Dace spawn	North Dace fry	North Dace juv	North Dace adult	North Chub spawn	North Chub fry	North Chub juv+ad	North Roach spawn	North Roach fry	North Roach juv+ad	North Bream spawn	North Bream fry	North Bream juv
2.0	0.0566	99																	
3.0	0.0849	99																	
4.0	0.1132	99																	
5.0	0.1415	99	1.17	26.19	7.11	0.00	0.07	0.05	12.71	11.61	2.22	0.00	0.48	0.00	47.73	0.00	0.00	0.00	0.00
6.0	0.1698	99	1.61	28.20	8.81	0.00	0.33	0.07	13.59	12.54	2.18	0.00	0.54	0.00	46.56	0.00	0.00	0.00	0.00
7.0	0.1981	99	1.64	30.69	11.56	0.01	0.45	0.08	14.20	13.26	2.82	0.00	0.63	0.00	45.66	0.00	0.00	0.00	0.00
8.0	0.2264	99	1.82	33.54	13.71	0.04	0.92	0.12	15.76	14.72	3.57	0.00	0.86	0.00	44.95	0.00	0.00	0.00	0.00
9.0	0.2547	99	1.94	35.88	15.84	0.07	0.92	0.17	17.20	16.12	3.97	0.00	1.11	0.00	44.47	0.00	0.00	0.00	0.00
10.0	0.2830	99	2.11	37.83	19.34	0.07	0.95	0.18	17.89	16.87	4.99	0.00	1.18	0.00	42.09	0.00	0.00	0.00	0.00
12.0	0.3396	99	2.26	41.32	29.61	0.13	0.99	0.18	18.86	18.08	8.90	0.00	1.26	0.00	37.45	0.00	0.00	0.00	0.00
14.0	0.3962	99	2.84	44.32	39.34	0.18	1.01	0.24	21.72	20.44	11.81	0.00	1.51	0.00	33.48	0.00	0.00	0.00	0.00
15.0	0.4245	98	3.09	44.62	44.60	0.19	1.01	0.25	23.01	21.56	14.20	0.00	1.69	0.00	29.93	0.00	0.00	0.00	0.00
16.0	0.4528	98	3.26	44.68	49.41	0.19	1.05	0.27	24.00	22.55	16.12	0.00	1.86	0.00	26.61	0.00	0.00	0.00	0.00
18.0	0.5094	97	3.32	43.99	59.05	0.26	0.76	0.34	26.73	25.01	20.11	0.00	2.52	0.00	20.21	0.00	0.00	0.00	0.00
20.0	0.5660	96	3.61	41.58	67.44	0.43	0.22	0.40	28.39	27.03	24.18	0.00	3.24	0.00	15.30	0.00	0.00	0.03	0.00
25.0	0.7075	90	6.94	30.93	80.22	0.92	0.40	0.56	30.73	30.35	34.44	0.01	4.90	0.26	5.75	0.00	0.00	0.09	0.00
30.0	0.8490	82	20.14	19.43	81.79	1.58	3.66	0.60	28.72	30.91	36.84	0.01	5.72	1.18	3.73	0.00	0.00	0.09	0.00
40.0	1.1320	68	38.36	12.00	80.72	3.62	26.50	0.83	20.06	31.92	37.10	0.00	6.91	2.70	3.95	0.00	0.00	0.06	0.00
50.0	1.4150	56	48.90	10.32	80.46	4.70	36.03	1.67	15.82	35.42	45.54	0.00	9.03	5.13	3.35	0.00	0.00	0.58	0.00
60.0	1.6980	46	48.95	8.90	70.47	4.56	38.43	1.63	7.89	27.36	43.10	0.00	7.36	3.93	3.13	0.00	0.00	0.58	0.00
70.0	1.9810	38	44.82	7.47	60.04	4.47	38.05	1.75	5.92	20.26	36.12	0.00	5.83	2.27	2.83	0.00	0.00	0.70	0.00
80.0	2.2640	31	37.27	6.77	51.31	4.29	34.76	1.97	5.09	15.92	27.66	0.00	4.83	0.85	2.46	0.00	0.00	0.93	0.00
90.0	2.5470	25	30.53	6.45	44.20	4.19	27.37	2.20	4.67	13.60	22.28	0.00	4.39	0.94	2.45	0.00	0.00	1.16	0.00
100.0	2.8300	20	26.14	6.16	38.91	4.12	24.72	2.33	4.51	12.19	20.38	0.00	4.16	0.93	2.42	0.00	0.00	1.38	0.00
110.0	3.1130	16	22.44	5.94	34.71	4.02	22.43	2.43	4.43	11.05	15.96	0.00	4.05	0.15	2.33	0.00	0.00	1.37	0.00
120.0	3.3960	12	19.28	5.35	31.14	3.92	18.04	2.49	4.38	10.10	10.86	0.00	3.90	0.06	2.43	0.00	0.00	1.34	0.00
140.0	3.9620	7																	

Appendix 7 River Wissey PHABSIM results - NORTHWOLD

flow cfs	flow cumecs	North Bream adult	North Pike spawn	North Pike fry	North Pike juv	North Pike adult	North Perch spawn	North Perch fry	North Perch juv	North Perch adult	North Leuct. fusca	North Rhyac. dorsal.	North Polyc. flavom.	North Sphae. corn.	North Ran. fluit.
2.0	0.0566														
3.0	0.0849														
4.0	0.1132														
5.0	0.1415	0.00	0.00	0.00	8.97	1.64	28.78	1.87	11.29	6.45	5.90	4.81	10.69	10.92	2.60
6.0	0.1698	0.00	0.00	0.00	9.14	1.71	29.63	2.04	11.30	6.23	6.94	5.88	12.47	12.78	3.07
7.0	0.1981	0.00	0.00	0.00	9.18	1.74	30.02	2.13	11.21	6.19	8.17	7.12	14.49	14.71	3.31
8.0	0.2264	0.00	0.00	0.00	9.54	1.87	32.60	2.48	11.38	7.17	9.31	8.02	16.41	16.78	3.75
9.0	0.2547	0.00	0.00	0.00	9.83	1.97	34.69	2.82	11.64	8.05	10.50	9.09	18.53	18.96	4.22
10.0	0.2830	0.00	0.00	0.00	9.86	1.97	35.05	2.86	11.55	8.15	11.85	10.79	21.04	21.06	4.54
12.0	0.3396	0.00	0.00	0.00	9.76	1.90	33.38	2.72	11.47	7.80	14.40	14.57	26.24	25.09	5.05
14.0	0.3962	0.00	0.00	0.00	9.96	1.96	34.96	2.87	11.50	8.51	16.58	17.57	30.88	29.08	5.92
15.0	0.4245	0.00	0.00	0.00	10.02	1.97	35.23	2.88	11.55	8.74	17.65	19.05	33.20	30.72	6.29
16.0	0.4528	0.00	0.00	0.00	10.09	1.97	35.34	2.89	11.58	8.84	18.74	20.60	35.50	32.29	6.64
18.0	0.5094	0.00	0.00	0.00	10.33	2.05	36.30	2.63	11.80	9.68	20.64	23.57	39.55	35.15	6.67
20.0	0.5660	0.00	0.00	0.00	10.56	2.10	34.63	2.23	12.00	10.60	21.91	26.00	42.64	37.01	6.55
25.0	0.7075	0.00	0.00	0.00	10.79	2.08	25.70	1.35	12.79	12.95	23.52	29.34	47.14	38.71	6.54
30.0	0.8490	0.00	0.00	0.00	10.16	1.86	13.74	0.96	9.53	12.76	24.45	31.70	48.59	38.47	5.65
40.0	1.1320	0.00	0.00	0.00	9.30	1.53	5.22	0.95	7.20	7.10	25.73	35.02	49.30	34.80	3.80
50.0	1.4150	0.00	0.00	0.00	9.64	1.49	5.13	1.31	7.32	6.21	26.61	36.58	50.15	33.79	3.72
60.0	1.6980	0.00	0.00	0.00	8.16	0.99	4.56	1.23	6.43	4.92	28.04	37.15	49.11	28.22	3.34
70.0	1.9810	0.00	0.00	0.00	7.09	0.77	4.53	1.15	6.29	3.90	28.97	36.06	46.49	24.99	2.88
80.0	2.2640	0.00	0.00	0.00	6.46	0.66	4.46	1.06	6.32	3.86	29.05	33.79	42.63	22.46	2.51
90.0	2.5470	0.00	0.00	0.00	6.14	0.62	4.49	0.95	6.43	3.89	27.96	31.20	38.85	20.42	2.48
100.0	2.8300	0.00	0.00	0.00	6.05	0.61	4.54	0.96	6.56	3.92	25.91	28.50	35.16	18.69	2.42
110.0	3.1130	0.00	0.00	0.00	6.07	0.60	4.58	0.97	6.53	3.99	23.77	25.69	31.68	17.08	2.35
120.0	3.3960	0.00	0.00	0.00	6.08	0.60	4.64	0.98	6.24	4.02	21.50	23.16	28.63	15.68	2.38
140.0	3.9620														

Appendix 7 River Wissey PHABSIM results - NORTHWOLD

APPENDIX 8

RIVER BABINGLEY PHABSIM RESULTS

flow cfs	flow cumecs	Bbgly Brn Trt spawn	Bbgly Brn Trt fry	Bbgly Brn Trt juv	Bbgly Brn Trt adult	Bbgly Dace spawn	Bbgly Dace fry	Bbgly Dace juv	Bbgly Dace adult	Bbgly Chub spawn	Bbgly Chub fry	Bbgly Chub juv+ad	Bbgly Roach spawn	Bbgly Roach fry	Bbgly Roach juv+ad	Bbgly Bream spawn	Bbgly Bream fry	Bbgly Bream juv
1.0	0.0283	0.00	27.79	3.66	0.00	0.00	0.13	0.45	2.58	0.00	0.00	0.00	0.00	34.78	0.00	0.00	0.00	0.00
1.5	0.0425	0.00	38.44	3.50	0.00	0.00	0.21	1.01	3.29	0.00	0.00	0.00	0.00	40.14	0.00	0.00	0.00	0.00
2.0	0.0566	0.00	44.83	4.79	0.00	0.00	0.29	2.50	3.95	0.00	0.00	0.00	0.00	41.89	0.00	0.00	0.07	0.00
2.5	0.0708	0.00	48.57	7.11	0.00	0.00	0.38	4.17	4.80	0.00	0.00	0.00	0.00	43.13	0.00	0.00	0.16	0.00
3.0	0.0849	0.00	52.07	10.87	0.00	0.00	0.46	4.87	5.43	0.18	0.00	0.00	0.00	42.19	0.00	0.00	0.27	0.00
3.5	0.0991	0.00	53.57	14.75	0.00	0.00	0.45	6.28	6.24	0.97	0.00	0.00	0.00	41.40	0.00	0.00	0.51	0.00
4.0	0.1132	0.00	54.56	18.24	0.00	0.00	0.57	7.19	6.91	2.21	0.00	0.00	0.00	40.83	0.00	0.00	0.59	0.00
4.5	0.1274	0.00	54.92	24.32	0.00	0.00	0.91	8.12	7.65	4.14	0.00	0.00	0.00	36.99	0.00	0.00	0.56	0.00
5.0	0.1415	0.00	55.67	26.31	0.00	0.00	0.92	9.26	8.36	6.25	0.00	0.00	0.00	36.48	0.00	0.00	0.50	0.00
6.0	0.1698	0.00	56.33	30.21	0.00	0.00	1.11	10.85	9.61	9.56	0.00	0.00	0.00	34.62	0.00	0.00	0.53	0.00
7.0	0.1981	0.00	53.69	31.74	0.00	0.10	1.36	11.87	10.68	10.75	0.00	0.00	0.00	32.86	0.00	0.00	0.55	0.00
8.0	0.2264	0.72	50.42	32.83	0.00	0.46	1.62	13.23	11.74	11.22	0.00	0.00	0.00	32.53	0.00	0.00	0.58	0.00
9.0	0.2547	4.13	49.01	33.97	0.00	0.80	1.84	13.87	12.62	11.50	0.00	0.00	0.00	32.29	0.00	0.00	0.60	0.00
10.0	0.2830	6.55	46.45	35.29	0.02	0.67	2.05	13.75	13.45	11.75	0.00	0.03	0.00	32.51	0.00	0.00	0.62	0.00
11.0	0.3113	6.62	46.30	36.30	0.05	2.09	2.26	13.60	14.39	11.68	0.00	0.08	0.00	32.64	0.00	0.00	0.69	0.00
12.0	0.3396	6.83	46.66	37.42	0.12	4.48	2.49	13.57	15.58	11.59	0.03	0.22	0.00	32.80	0.00	0.00	0.85	0.00
13.0	0.3679	7.05	46.76	38.42	0.26	5.68	2.68	12.96	16.51	11.53	0.07	0.44	0.00	32.64	0.00	0.00	0.95	0.00
14.0	0.3962	7.61	46.60	39.38	0.39	7.10	2.86	12.50	17.17	11.70	0.09	0.60	0.00	32.19	0.00	0.00	1.11	0.00
15.0	0.4245	8.68	46.37	40.12	0.49	8.54	3.04	12.13	17.45	11.95	0.07	0.76	0.00	31.43	0.00	0.00	1.45	0.00
16.0	0.4528	9.56	46.11	40.48	0.63	9.45	3.21	12.56	17.59	12.25	0.04	0.96	0.00	30.66	0.00	0.00	1.67	0.00
17.0	0.4811	10.22	45.78	40.78	0.76	10.95	3.46	13.26	17.93	12.62	0.00	1.12	0.00	29.73	0.00	0.00	1.78	0.00
18.0	0.5094	10.60	45.52	40.99	0.90	12.42	3.69	13.77	18.24	12.96	0.00	1.20	0.00	28.72	0.00	0.00	1.95	0.00
19.0	0.5377	10.86	45.32	40.98	1.03	13.63	3.91	14.62	18.47	13.60	0.00	1.23	0.00	27.30	0.00	0.00	2.00	0.00
20.0	0.5660	11.13	45.27	41.04	1.15	14.84	4.16	15.29	18.70	12.83	0.00	1.24	0.00	26.27	0.00	0.00	1.56	0.00
25.0	0.7075	10.71	45.10	39.60	1.44	14.54	5.05	20.86	19.31	11.77	0.00	1.12	0.00	20.73	0.02	0.00	2.22	0.00
30.0	0.8490	10.16	44.23	37.17	1.57	15.01	5.58	26.61	21.08	14.20	0.23	1.72	0.00	16.66	0.07	0.00	2.51	0.00
40.0	1.1320	8.18	40.89	32.90	1.21	11.95	6.78	32.26	23.35	14.56	0.50	2.05	0.53	11.66	0.16	0.00	4.25	0.00

Appendix 8 River Babingley PHABSIM results

flow cfs	flow cumecs	Bbgly Bream adult	Bbgly Pike spawn	Bbgly Pike fry	Bbgly Pike juv	Bbgly Pike adult	Bbgly Perch spawn	Bbgly Perch fry	Bbgly Perch juv	Bbgly Perch adult	Bbgly Leuct. fusca	Bbgly Rhyac. dorsal.	Bbgly Polyc. flavom.	Bbgly Sphae. corn.	Bbgly Ran. fluit.
1.0	0.0283	0.00	0.00	0.00	8.63	0.23	5.16	4.65	10.16	0.54	2.57	2.06	6.49	6.64	2.03
1.5	0.0425	0.00	0.00	0.00	9.55	0.34	7.12	5.60	12.66	0.89	3.70	2.40	8.93	9.53	3.43
2.0	0.0566	0.00	0.00	0.00	10.56	0.43	8.81	6.13	14.03	1.13	5.19	3.74	11.73	12.31	4.69
2.5	0.0708	0.00	0.00	0.00	11.34	0.53	10.67	5.95	15.88	1.44	6.59	5.18	14.27	14.57	5.53
3.0	0.0849	0.00	0.00	0.00	11.67	0.57	11.38	5.39	16.56	1.51	8.15	7.12	17.04	16.78	6.05
3.5	0.0991	0.00	0.00	0.00	12.37	0.67	12.91	5.24	17.91	1.65	9.20	8.59	19.12	18.49	6.59
4.0	0.1132	0.00	0.00	0.00	12.92	0.73	13.84	5.04	18.58	1.71	10.11	9.80	20.95	20.13	6.87
4.5	0.1274	0.00	0.00	0.00	13.58	0.79	14.77	4.80	19.73	1.93	11.56	12.30	24.53	22.69	7.24
5.0	0.1415	0.00	0.00	0.00	13.99	0.84	15.74	4.70	20.65	2.38	11.92	12.76	25.12	22.84	7.41
6.0	0.1698	0.00	0.00	0.00	14.98	0.91	17.09	5.37	22.79	3.15	12.67	13.84	26.75	23.46	7.76
7.0	0.1981	0.00	0.00	0.00	15.63	0.98	16.41	5.89	25.06	3.80	13.54	14.82	28.36	24.36	8.24
8.0	0.2264	0.00	0.00	0.00	16.36	1.09	14.14	6.41	27.10	4.78	14.21	15.58	29.38	25.23	8.68
9.0	0.2547	0.00	0.00	0.00	16.72	1.16	14.91	6.61	28.32	5.85	14.75	16.12	30.05	25.76	8.61
10.0	0.2830	0.00	0.00	0.00	17.03	1.21	14.54	6.65	28.57	5.69	15.10	16.67	30.52	26.19	8.79
11.0	0.3113	0.00	0.00	0.00	17.64	1.28	14.68	6.74	28.77	5.93	15.40	17.04	30.86	26.40	8.97
12.0	0.3396	0.00	0.00	0.00	18.51	1.38	15.42	7.17	29.20	6.76	15.62	17.35	31.20	26.74	9.10
13.0	0.3679	0.00	0.00	0.00	19.14	1.46	16.23	7.61	30.02	7.27	15.75	17.63	31.38	26.80	9.38
14.0	0.3962	0.00	0.00	0.00	19.56	1.52	17.11	7.91	30.53	7.16	15.87	17.83	31.52	26.77	9.81
15.0	0.4245	0.00	0.00	0.00	19.86	1.56	17.98	8.04	30.98	6.45	15.99	18.00	31.66	26.65	9.95
16.0	0.4528	0.00	0.00	0.00	20.18	1.62	18.92	8.36	31.65	7.00	16.09	18.02	31.72	26.50	10.11
17.0	0.4811	0.00	0.00	0.00	20.68	1.70	20.18	8.94	32.65	7.82	16.36	18.07	31.93	26.65	10.54
18.0	0.5094	0.00	0.00	0.00	21.08	1.79	21.27	9.44	33.61	8.50	16.65	18.19	32.13	26.78	10.79
19.0	0.5377	0.00	0.09	0.00	21.38	1.90	22.64	9.91	34.40	9.39	16.92	18.24	32.20	26.87	11.09
20.0	0.5660	0.00	0.13	0.00	21.78	2.00	24.02	10.32	35.18	10.21	17.19	18.28	32.31	27.01	11.48
25.0	0.7075	0.00	0.57	0.00	22.96	2.44	30.64	12.29	38.00	15.43	18.13	17.92	31.92	27.48	12.07
30.0	0.8490	0.00	1.02	0.00	24.19	2.95	36.23	13.28	40.11	21.12	18.17	17.08	30.88	27.96	12.19
40.0	1.1320	0.00	1.22	0.00	24.43	3.86	41.36	12.95	41.82	27.58	16.10	14.67	28.12	28.11	12.47

Appendix 8 River Babingley PHABSIM results

A. UNDERLYING ASSUMPTIONS

1. Physical habitat is the only limiting factor	Both the water temperature and water quality in the reach are assumed to be suitable for the species of interest and will not become limiting following the streamflow alteration.
2. WUA-population relationships	Biological interactions such as predation, competition and prey availability are not considered within PHABSIM. In its defence, IFIM points out that its purpose is to predict changes in available physical habitat with flow changes rather than the simulation of ecological interactions.
3. Rigid channel structure	The channel structure along the reach must remain constant and will not be affected by the streamflow alteration.
4. Representative reaches	Results from target reaches are commonly extrapolated to large stretches of river without ensuring that the physical habitat elsewhere is similar to that in the target reach.

B. ASSUMPTIONS WITH HYDRAULIC SIMULATION

5. Transects located at hydraulic controls	Transects must be located at right angles to flow and across hydraulic controls. However, with decreasing streamflow, some hydraulic controls (e.g. riffles) migrate upstream and their dominant flow direction is altered.
6. Cover/substrate are constant	IFIM assumes that substrate size and cover do not change with discharge.
7. Velocities recorded at critical locations	Fieldwork involves measuring water velocity at 0.6 depth which is not necessarily the position in the water column that the fish occupy (nose velocity). Nose velocities can be predicted with PHABSIM based on regression relationships between water velocity at 6/10 of the depth and the water velocity at the fish's position.

C. ASSUMPTIONS WITH HABITAT SIMULATION

8. Habitat variables behave independently	PHABSIM multiplies the 'probability' of using a certain value of one habitat variable by the 'probability' of using a certain value of another habitat variable and hence implies that fish perceive and judge the suitability of variables independently in their selection of habitat.
9. Transferability of suitability curves	Development of habitat suitability curves is a relatively costly process and where possible, many studies have used curves developed elsewhere. However, different populations of the same species may have different suitability curves for the same habitat variable and hence site-specific curves should be developed.
10. Sampling methods to derive suitability curves	Habitat conditions preferred by a single population of fish can be different depending on the method (i.e. electrofishing, gill nets or direct underwater observation) used to determine the fish's location.

APPENDIX 9 RECOGNISED SHORTFALLS OF PHABSIM