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ENVIRONMENT AGENCY

River Stour and Pant/Blackwater PHABSIM Studies

APRIL 2001

FINAL REPORT

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WS/Atkins Consultants Ltd

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Cover photographs (top to bottom):

1. Pant 4 (Kelvedon), Transect 4D, looking upstream
2. Pant 4 (Kelvedon), Transect 3C
3. Stour 3 (Wissington), Transect 2B
4. Stour 4 (Langham), Transect 1A, looking downstream

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EXECUTIVE SUMMARY

This report outlines the methodology and findings of a study carried out on behalf of the Environment Agency Anglian Region. The study used the Physical Habitat Simulation (PHABSIM) method to examine the effect of variable flow rates from the Ely Ouse to Essex water transfer scheme (EOETS) on fish, invertebrate and macrophyte habitats in the Rivers Stour and Pant/Blackwater in Suffolk and Essex.

Following a walkover survey of the catchment, six study sites were originally selected: three on the Stour and three on the Pant/Blackwater. At each site, a number of transects were identified for detailed data collection. These were selected with the intention of them representing habitat conditions in the rivers as a whole. During the execution of the fieldwork, two more sites (one on each study river) were added at the request of the Environment Agency, bringing the total to eight sites. Data collection included measurements of the following: channel cross-sections and longitudinal sections, substrate type, in-channel vegetation, overhanging vegetation, flow velocity, water surface level. Velocity and water surface levels were measured at three or four discharge levels in order to be able to simulate the full range of flows expected in the rivers.

The PHABSIM hydraulic model was successfully calibrated for six of the eight study sites. The two exceptions were sites in the middle reaches of each river, where it became apparent that regulation of water levels by mill owners downstream of the site had caused water levels to increase at lower flows. The six sites that were successfully calibrated were taken forward to the next stage of modelling, the habitat simulation stage, where useable habitat area for a number of key species is calculated for a given set of discharge rates.

Thirteen indicator species or life stages were selected for habitat simulation. The selected fish species comprised brown trout (adult, juvenile and spawning), chub (adult, juvenile and spawning), and roach (adult, juvenile and spawning). In addition two species of invertebrate (caddis flies and mayflies) and two species of macrophyte (watercress and water milfoil) were selected. Curves for Habitat Suitability Indices (HSI) for the fish species were taken from a recent study that developed these curves specifically for fish species in East Anglian rivers. HSI curves for invertebrates and macrophytes were taken from previously-published studies.

The habitat simulation indicated that at least 20% of the available area within the three sites on the Stour was potentially available as habitat for all species and lifestages, with the exception of caddis fly, for which >20% was available only at two sites, and juvenile and spawning chub, for which >20% was available only at one site. A similar pattern was found for the Pant/Blackwater, although on this river spawning trout and roach were also potentially subject to scarcity of useable habitat. Although these habitat areas are 'potentially' available, actual availability of these areas of habitat would require optimal discharge (Q_{opt}). In general, the long-term median (Q_{50}) flow in the Stour approximated the Q_{opt}, for most species and lifestages, although juvenile chub and roach suffered from lack of habitat as a result of flow

velocities being too high for these delicate life stages. In the Pant/Blackwater sites, the long-term Q_{50} was generally less than Q_{opt} although juvenile chub and roach also suffered from habitat shortage on this river, for the same reason as on the Stour.

Habitat time-series analysis was carried out for one site on the upper Stour, and two on the upper Pant/Blackwater, to investigate fish habitat availability under observed and naturalised flow regimes during the period 1992-1996. The model results showed that the augmented flows generally provide a benefit in terms of trout habitat, particularly during the summers when the EOETS was operated for environmental support purposes. A similar pattern was found for chub and roach, although there were occasions when flow velocities as a result of the EOETS were supra-optimal, resulting in a reduction in habitat compared to naturalised flows.

On the basis of the model output, ecologically-acceptable discharges have been defined for each of the six sites, as follows:

Site	Historical Q_{50} (m^3/s)	Acceptable Q range (July-March) (m^3/s)	Acceptable Q range (April-June) (m^3/s)
River Stour			
Kirtling Green	0.342	Up to 1.50	Up to 0.40
Bowers Hall Farm	0.664	Up to 2.0	Up to 0.75
Langham	1.875	Up to 5.0	Up to 5.0
River Pant/Blackwater			
Great Sampford	0.112	0.1 to 1.0	0.1 to 1.0*
Little Sampford	0.112	0.2 to 1.3	0.3 to 0.6
Kelvedon	0.928	0.3 to 2.0	0.5 to 1.2

*will be limited by Q_{max} at downstream sites

In general, this flow regime allows increased transfers via the EOETS and the Wixoe transfer, without significant loss of habitat on the Stour, and with a concomitant increase in habitat availability on the Pant/Blackwater. The only significant adverse effect would be on juvenile coarse fish, which already suffer from supra-optimal flow velocities, particularly within upstream reaches. The proposed pipeline between Kirtling Green and Wixoe would allow management of supra-optimal flows within this reach, while allowing increased discharge in the Stour downstream of Wixoe, and within the Pant/Blackwater. A potential alternative to this pipeline, which might be more cost-effective while yielding benefits from conservation, aesthetics and flood storage perspectives, would be re-profiling of the channel within this reach to create additional channel capacity as well as habitat for juvenile and spawning coarse fish. It is recommended that this option be examined further.

GLOSSARY

Calibration flow	the flow at which a complete set of WSL and flow measurements are made at a given site, the data from which are used to calibrate the IFG4 hydraulic model
DMF	Daily mean flow
EA	Environment Agency
EIA	Environmental Impact Assessment
EOETS	Ely Ouse to Essex water Transfer Scheme
GS	Gauging Station
h	stage, i.e. the height of water surface above datum
HABTAE	habitat model within PHABSIM, used to combine simulated hydraulic data with HSIs for the appropriate target species/life stages to produce simulations of available habitat with flow
HSI	Habitat Suitability Index
IFG4	hydraulic model within PHABSIM: predicts depth of flow and medium column velocities across the stream as a function of discharge, in order to develop the depth and velocity data required by the habitat simulation programmes.
IFIM	Instream Flow Incrementatal Methodology: a methodology developed by the US Fisheries and Wildlife Service to quantify habitat availability under a given flow regime
IOC	Input/Output Code (for example for controlling the running of IFG4 or HABTAE models)
Mesohabitat	habitat classification on a 'whole river reach' basis
PHABSIM	Physical Habitat Simulation: one of the main components of IFIM
Q_{opt}	Optimum discharge: the discharge at which a given species/life stage has greatest area of habitat available (see WUA) at a given site
Q_x	(where x lies between 1 or 99) historical discharge exceeded x % of the time

STW	Sewage Treatment Works
TAA	Total Available Area: the area of riverbed covered in water at a given flow
VAF	Velocity Adjustment Factor: a factor (automatically) computed and used by PHABSIM to adjust Mannings n at different flows. In theory, the VAF should be equal to unity for the calibration flow at each transect, smaller than unity for flows less than the calibration flow and larger than unity for flows greater than the calibration flow.
WSL	Water Surface Level (above datum)
WTW	Water Treatment Works
WUA	Weighted Useable Area: that part of TAA that provides habitat suitable for a given species/life stage.
WUAQT	Habitat time series modelling programme within PHABSIM. Creates a time series of habitat data using the WUA vs flow output from the HABTAE model and either a monthly or daily set of flow times series data.

1. INTRODUCTION

STUDY RIVERS AND THE ELY OUSE TO ESSEX TRANSFER SCHEME

1.1 The study areas for this project are the River Stour between Kirtling Green and Stratford St Mary and the River Pant/Blackwater between Great Sampford and Langford. The River Pant changes its name to the Blackwater at Courtaulds Gates, Braintree and is in fact a single river.

1.2 There are a variety of habitats in these rivers, from natural gravel-bottomed reaches to heavily engineered impoundments, often associated with water mills and other structures. The River Stour is designated under the EC Freshwater Fisheries Directive as a cyprinid fishery from Clare downstream to the tidal limit at Cattawade. No brown trout were present in the Stour at the commencement of routine monitoring by the EA in 1984, however these have appeared in the headwaters since then. The source of these fish is unknown, but may have been the result of introduction by landowners near Kedington, or by migration of known populations from headwaters of tributaries of the Stour. Chub and roach have been present throughout the Stour since before 1984.

1.3 The River Pant/Blackwater is designated as a salmonid fishery between Great Sampford and Wethersfield, and as a cyprinid fishery downstream to Langford. Brown trout were found in the headwaters of the Pant in the 1984 surveys, but there has been noticeable downstream extension of range in recent years (from Wethersfield to Bocking).

1.4 The water quality standards imposed by the Directive are usually met in both rivers.

1.5 Both rivers receive water from the Ely Ouse to Essex Water Transfer Scheme (EOETS) (Figures 1.1 and 1.2). Water is taken from the Cut-Off Channel at Blackdyke in Cambridgeshire, and pumped over the watershed to the River Stour at Kirtling Green. From there, it flows down most of the length of the river before being abstracted at Langham and Stratford St Mary to supply both Langham WTW and Abberton Reservoir. A proportion of the water may be re-abstracted from the Upper River Stour at Wixoe, and transferred to the River Pant/Blackwater at Great Sampford. From there it flows throughout the length of that river to support abstractions at Langford, both for direct supply and to maintain levels in Hanningfield Reservoir. Although the scheme first became operational in 1972, major water transfers were not needed until the 1989-92 drought. High transfer rates also occurred between 1995-98.

1.6 The facility also exists to transfer water from Wixoe to the upper reaches of the River Colne, but this has only been used occasionally, to alleviate low flows for amenity and water quality management purposes.

Figure 1.1 – Schematic Plan of the Ely Ouse – Essex Transfer Scheme (EOETS)

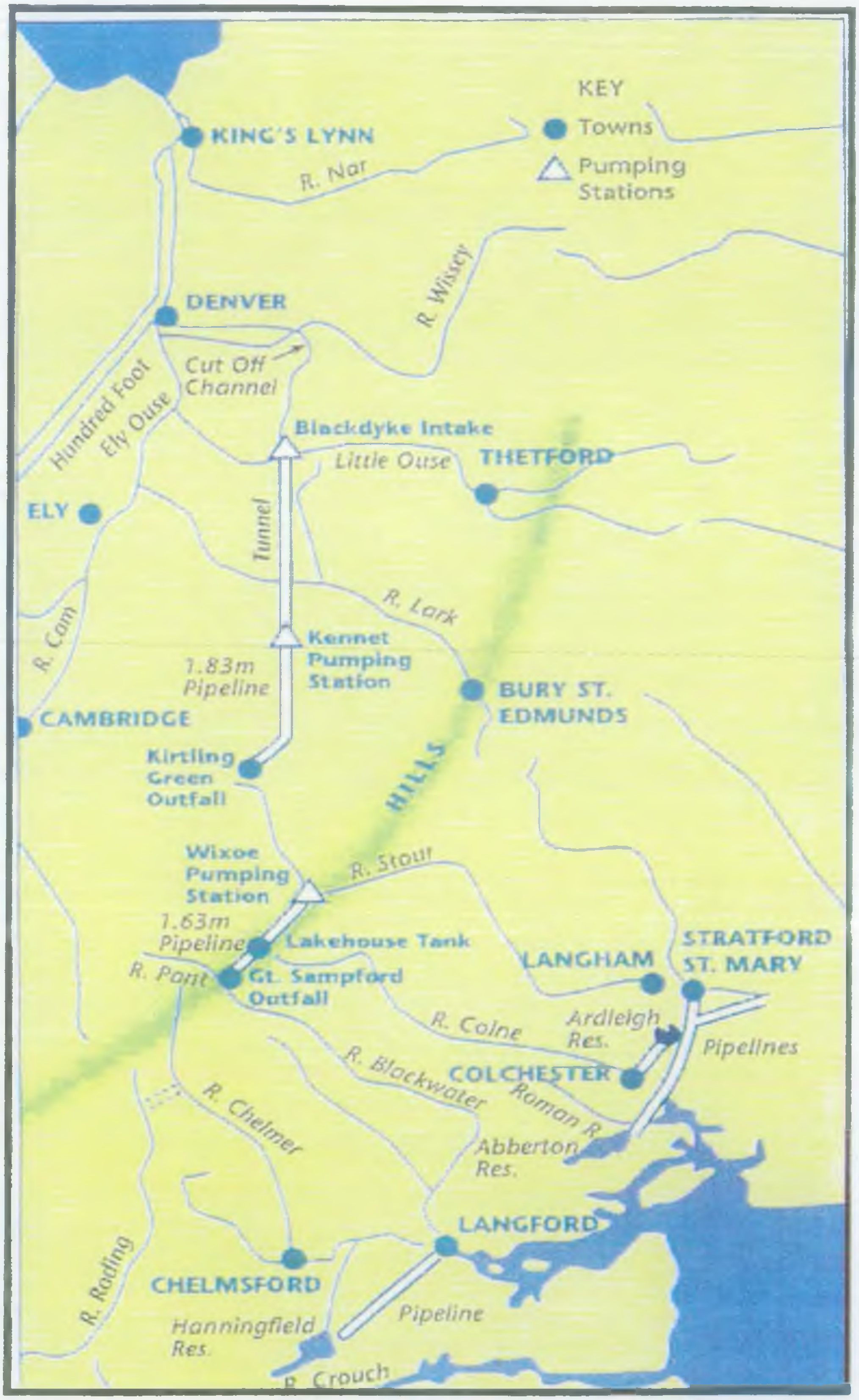
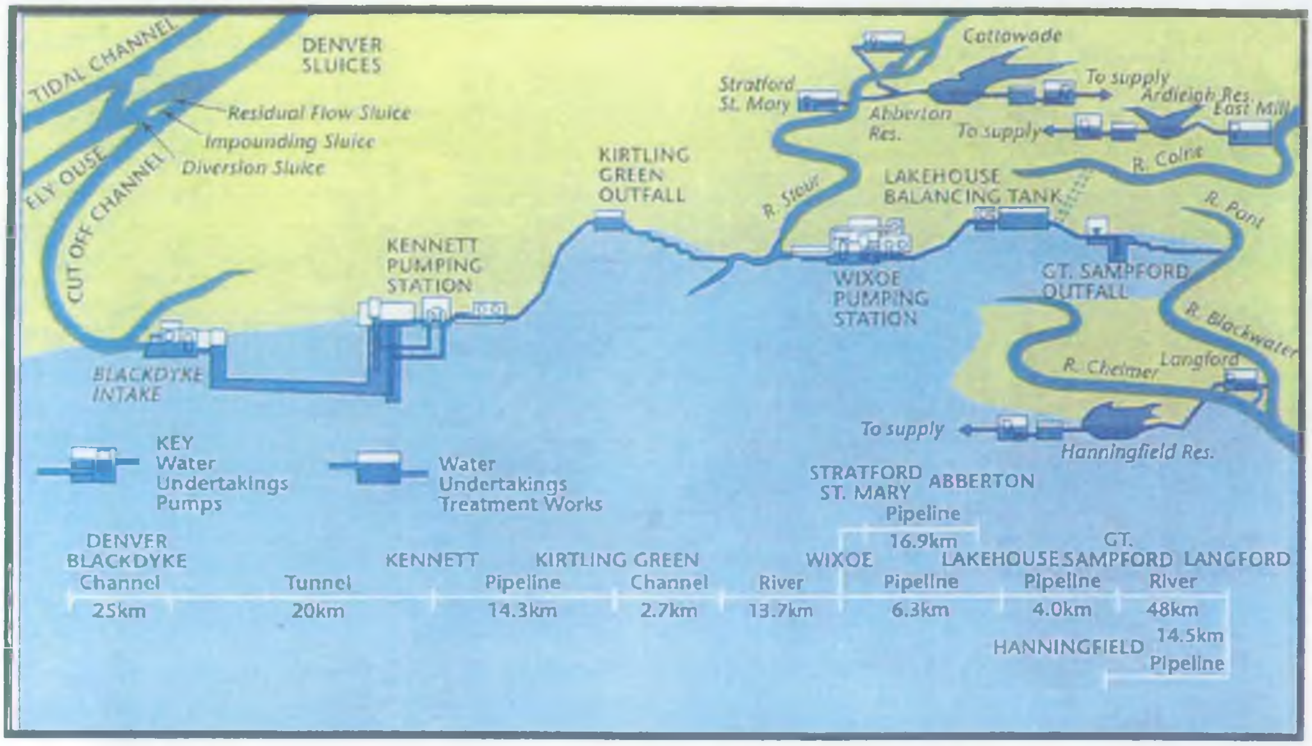


Figure 1.2 – Schematic Diagram (Elevation) of the Ely Ouse-Essex Transfer Scheme (EOETS)



THE PROBLEM

1.7 An Environmental Impact Assessment (EIA) of the transfer scheme was commissioned in 1994, and concluded that the scheme was not having any severe negative impact on fish populations. However, when the EIA study was commissioned, data from the three-year rolling programme of fisheries surveys were only available up to 1993. The River Stour was surveyed again in 1994 and 1997, and the Pant/Blackwater in 1996. The biomass of fish in the River Pant has remained fairly stable, but in the Blackwater had declined to almost half of the 1993 levels. Decreases in stocks in the River Stour have also been observed, dating back to 1991. Angling clubs are concerned at the overall decline in the quality of their fishing. There is evidence of poor recruitment in both rivers and further investigation is required as to whether this is a natural phenomenon or the result of human influences, including EOETS operation.

1.8 PHABSIM modelling has been carried out on the uppermost reaches of both rivers as part of the impact assessment (Entec, 1998*a*, 1998*b*). This work indicated that both very low natural flows and high artificial flows caused by the EOETS may result in sub-optimum habitat qualities for all life stages of the studied species of fish (chub, dace, roach and brown trout) and the two studied species of plant (*Ranunculus* and *Nasturtium*). Various invertebrate taxa were also included in the study (Ephemeridae, *Heptagenia lateralis*, *Habrophlebia fusca*, Leuctridae, Chloroperlidae, Sericostomatidae, Gammaridae and *Gammarus pulex*). The modelling work indicated that with the exception of *H. fusca*, the freshwater invertebrates were tolerant of increasing flows but that available habitat is lost at very low flows.

1.9 To this time, the modelling had been confined to the uppermost reaches of the rivers, immediately downstream of the transfer outfalls, where maximum impacts might reasonably be expected. However, the measurements taken did not allow assessment of the impact of the highest transfer flows on these reaches, as no transfers at rates approaching the maximum rates had been undertaken during the available field work period.

STUDY OBJECTIVES

1.10 The purpose of this study has been to extend the PHABSIM modelling approach in accordance with the recommendations made in the Environmental Impact Assessment reports.

1.11 The specific objectives of the study were:

(i) To extend PHABSIM modelling to the maximum flow ranges generated by EOETS at the upper reaches of each site studied to date.

(ii) To extend PHABSIM modelling to three further sites throughout the length of each river, in order to determine fully the extent to which adverse habitat conditions might occur.

(iii) To use the output from the PHABSIM modelling work to determine whether a more sympathetic operating regime is required for the EOETS to optimise habitat availability for important fish, plant and invertebrate species.

(iv) To recommend a more sympathetic operating regime for the transfer scheme, if one is required.

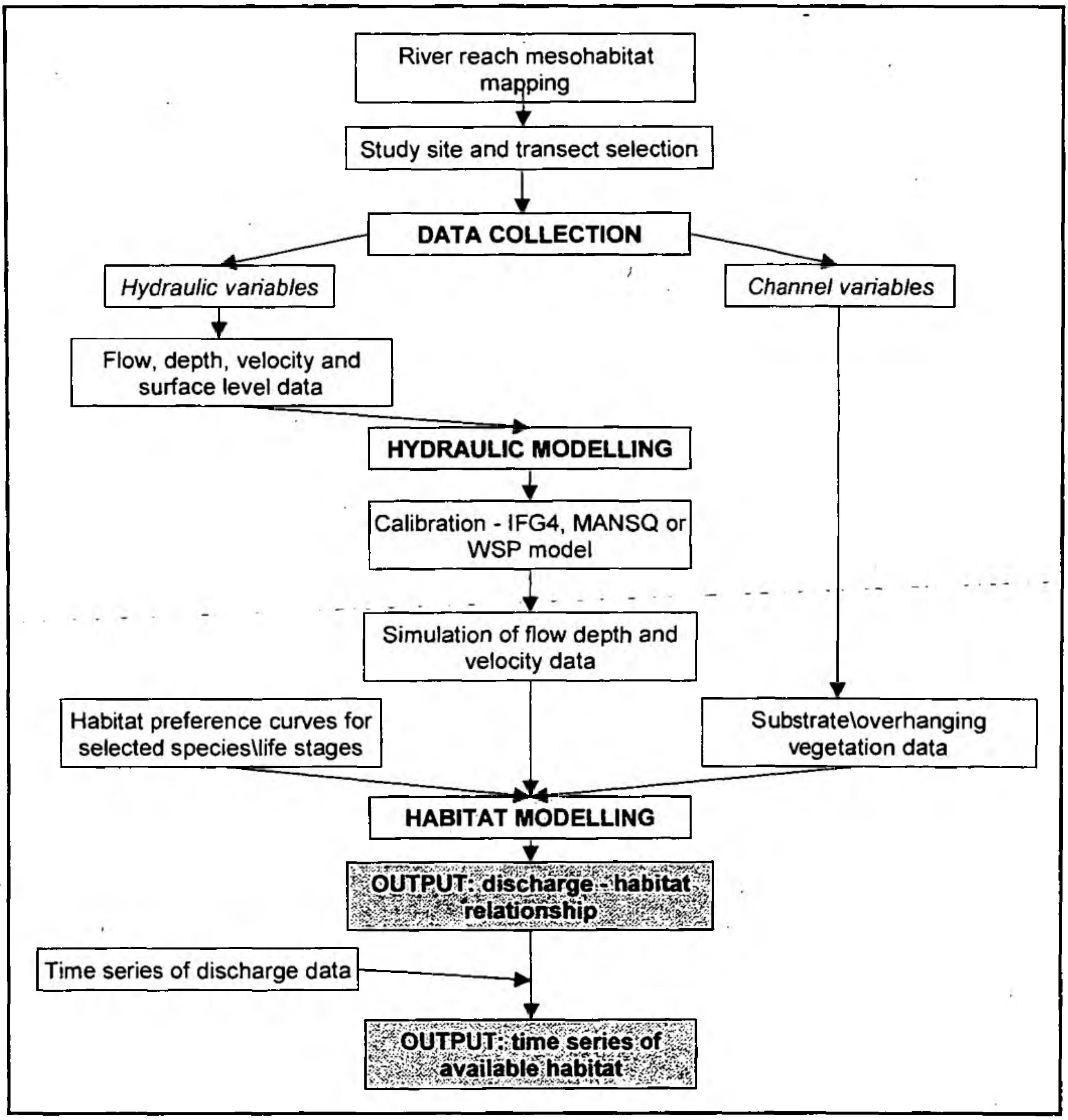
2. APPLICATION OF PHABSIM

INTRODUCTION TO PHYSICAL HABITAT SIMULATION (PHABSIM)

2.1 In the past, environmental data have been used in a qualitative way to ascribe water resources attributes to river systems. The Instream Flow Incremental Methodology (IFIM) was developed by the US Fisheries and Wildlife Service in the early 1980s. PHABSIM is one of the main components of IFIM and is a methodology that allows quantification of the amount of suitable habitat for species under a given flow regime. The primary assumption behind PHABSIM is that aquatic species react to changes in the hydraulic environment, and that individual organisms tend to select the most favourable habitats, with preference decreasing as conditions become less favourable (Stalnaker, 1979). The amount of instream habitat suitable for use varies with discharge, and PHABSIM is used to estimate this relationship for selected aquatic species. PHABSIM is used when the physical habitat is the limiting factor for the development of a healthy population of a given species. The methodology is therefore not appropriate if other factors such as water quality or water temperature are the limiting factors in a particular river.

2.2 There are two main components of PHABSIM: hydraulic simulation and habitat simulation. The model combines these components, for the river reach under investigation, to generate a discharge-habitat relationship. In order to evaluate the impact of different flow management options on the available habitat, flow regimes (historical, naturalised or proposed) can be modelled, and the variation in available habitat for the aquatic species simulated. The flow chart in Figure 2.1 shows the stages involved in a typical PHABSIM study.

Figure 2.1 - Conceptual outline of a PHABSIM study.

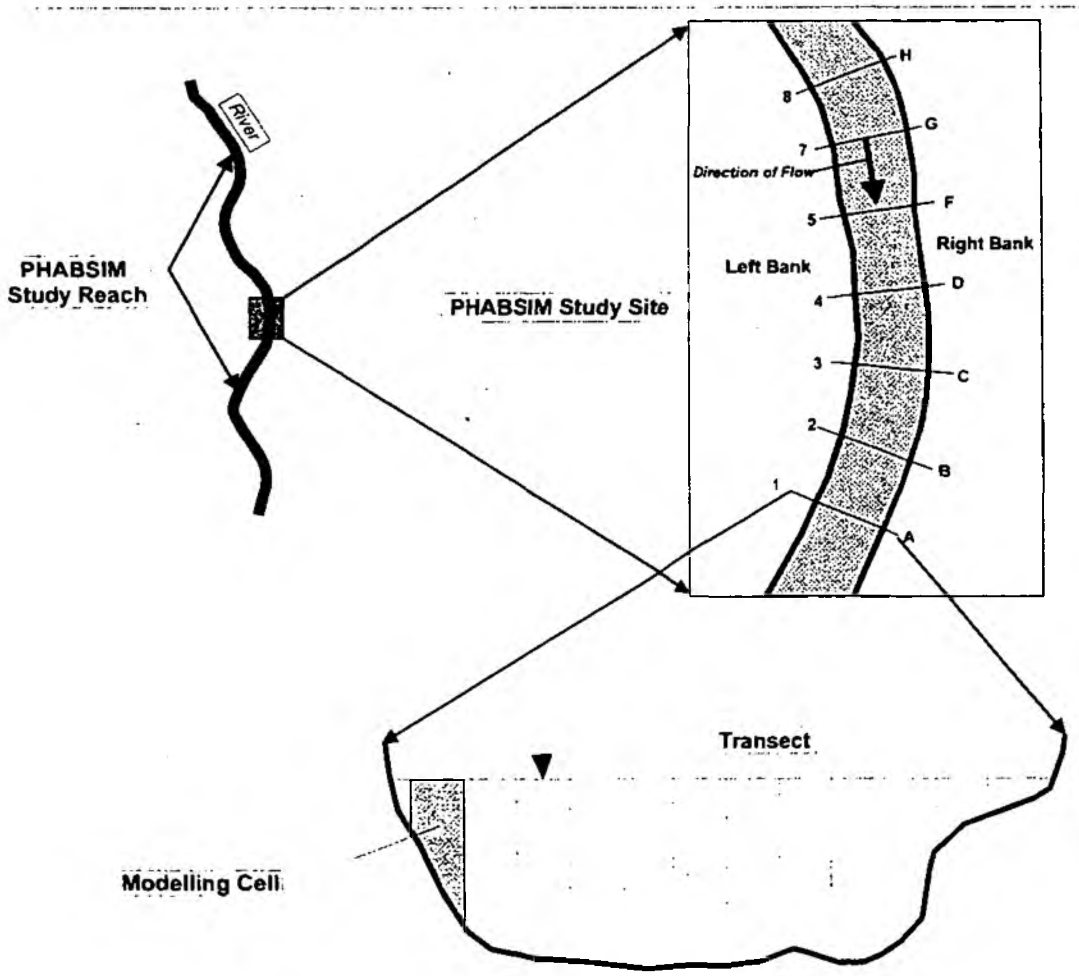


PHABSIM STUDY SITE SELECTION

2.3 A key part of the PHABSIM methodology is the selection of a study site (SS) representative of the reach of interest, in terms of mesohabitat. A walk-over survey of six study reaches was carried out to estimate the distribution of mesohabitat, and the results are presented in the relevant tables in Chapter 3. A site was then located which represented the range of mesohabitats identified within the reach.

2.4 The framework for PHABSIM data collection is based around transects located within the SS. The transects are positioned according to a number of criteria, as defined in the Environment Agency R&D Technical Report W20 (Elliott *et al.*, 1996), and are delineated in the field by markers on both banks of the river. The data requirements of both the hydraulic and habitat components of the PHABSIM system must be satisfied by the measurements taken from these transects. Figure 2.2 shows the structure and different scales of the units used in the PHABSIM study (note the use of US convention in bank labelling, with the left bank defined as if the viewer is looking upstream).

Figure 2.2 - PHABSIM terminology and transect numbering system.

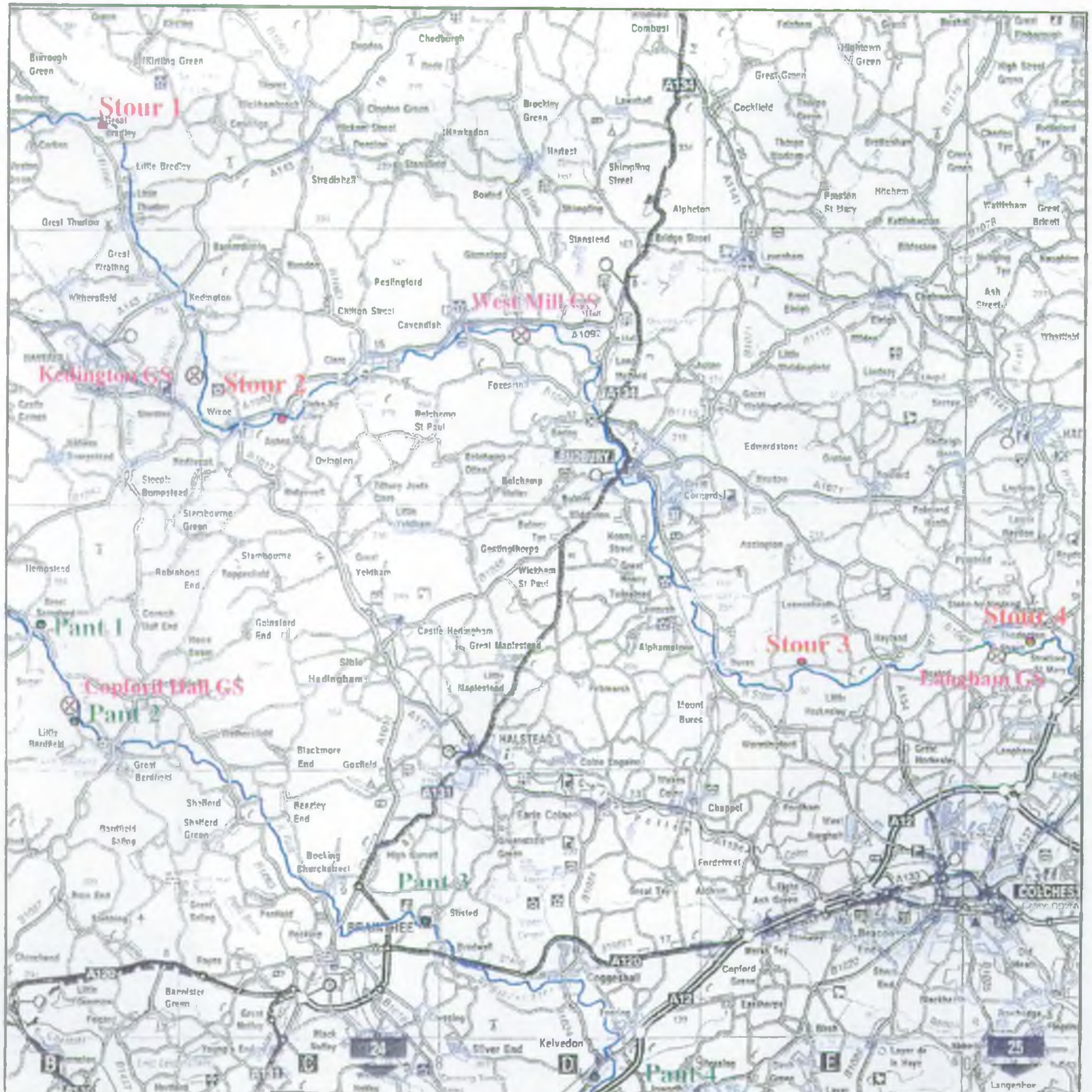


2.5 For this study, three sites on each of the two rivers were originally selected for detailed investigation (referred to in this report as Stour 2 – 4 and Pant 2 – 4). During the course of the project, one more site was added on each river (Stour 1 and Pant 1) at the request of the client. Locations of each study site, and dates of fieldwork are outlined in Table 2.1 below. Locations of study sites in relation to gauging stations are shown on Figure 2.3 (note that Appleford GS is downstream of Pant 4 site, and therefore is not shown on the map). The locations of study reaches at each site (within which individual transects were set up) are shown on the figures in Section 3.

Table 2.1 – Locations of PHABSIM study sites and dates of fieldwork

Site Code	Location	NGR	Fieldwork Dates			
			Low flow	Medium Flow 1	Medium Flow 2	High Flow
River Stour						
Stour 1	Kirtling Green	TL 672 538	1/7/99	2/9/99	----	5/5/99
Stour 2	Bowers Hall Fm	TL 798 456	1/7/99	3/2/99	5/5/99	10/5/99
Stour 3	Wissington	TL 938 337	2/7/99	4/2/99	----	10/5/99
Stour 4	Langham	TM 027 345	2/7/99	6/5/99	4/2/99	10/5/99
River Pant/Blackwater						
Pant 1	Great Sampford	TL 647 350	29/6/99	3/9/99	----	7/5/99
Pant 2	Little Sampford	TL 654 338	29/6/99	3/2/99	2/9/99	7/5/99
Pant 3	Stisted Mill	TL 794 243	30/6/99	2/2/99	----	7/5/99
Pant 4	Kelvedon	TL 860 180	3/9/99	30/6/99	5/2/99	6/5/99

Figure 2.3 - Locations of study sites and gauging stations on the Stour and Pant/Blackwater



SELECTION OF INDICATOR SPECIES

2.6 Brown trout (*Salmo trutta*) during its adult, spawning and juvenile life stages was selected as the main target species for this study by Environment Agency fishery staff. This species/life stages was selected as it is present in the headwaters of both study rivers, and there is evidence that its distribution may be moving downstream. In addition, two cyprinid species were selected as they are present throughout the study rivers: chub and roach.

2.7 Two invertebrate taxa were selected for PHABSIM modelling: the caseless caddis fly (*Hydropsyche pellucidula*) and mayflies (Family Ephemeridae).

2.8 Two macrophyte species were also selected for investigation. HSI curves for water crowfoot (*Ranunculus*) have been generated and extensively used as the species is common in many of the chalk streams for which the methodology has been applied in the UK. This species is commonly modelled in conjunction with watercress (*Rorippa nasturtium-aquaticum*) in order to represent the natural temporal succession that occurs in many streams from spring to summer. However, as water crowfoot has not been recorded in either of the study rivers, it was decided to use water milfoil (*Myriophyllum* sp.) as being more representative of these rivers. Modelling water milfoil along with watercress meant that the physical extremes of macrophyte habitat were examined, with water milfoil representing deeper, main channel habitats, possibly with faster flows. Conversely, watercress is representative of marginal habitats, with shallow water depth, silty beds and slower flow velocities.

Selection of HSI Curves

2.9 The hydraulic output of PHABSIM is combined with habitat suitability indices (HSI) to produce an estimate of habitat availability for each of the target species\life stages. Bovee (1986) defines three types of suitability index curves that may be used for IFIM simulations using PHABSIM. The distinction between the different categories of HSI curve is the way in which they are derived, as follows:

- Category I: habitat criteria are derived from life history studies in the literature and/or professional experience and judgement, and are based on the adjudged suitability of physical habitat variables for target species life-stages.
- Category II: habitat criteria are refined, based on frequency analysis of microhabitat conditions utilised by the species, identified by field observations. These criteria are termed 'habitat utilisation curves' because they depict the conditions that were being used when the species were observed. Utilisation functions may not always accurately describe a species' preference because the preferred physical conditions may be absent or limited at the time of observation.
- Category III: these are Category II curves in which the criteria are refined further by factoring out the influence of limited habitat availability. This correction is aimed at increasing the transferability of the criteria to streams that differ from these where the criteria were originally developed. Category III curves are referred to as 'habitat preference curves'. Habitat preference for values given in a microhabitat variable is defined as the ratio of habitat

utilisation to habitat availability. In general, the greater the diversity of habitats present in the stream used for sampling, the closer together will be the Category II and III curves derived from the utilisation and availability data.

2.10 Category II or III habitat utilisation curves have not been developed specifically for either of the rivers under assessment. The majority of such curves developed in the UK have been produced for upland streams, and therefore are not especially suitable for the lowland streams under examination. However, a range of Category I curves are available, and those selected for use in PHABSIM simulation are detailed in Table 2.2. The actual HSI curves used are presented in Appendix 1.

Table 2.2 –Category I HSI curves selected for modelling, and sources of curves

Common name	Scientific Name	Life Stage	Source of HSI curve
Brown trout	*Salmo trutta*	Adult Juvenile Spawning	WS Atkins (2000)
Chub	*Leuciscus cephalus*	Adult Juvenile Spawning	WS Atkins (2000)
Roach	*Rutilis rutilis*	Adult Juvenile Spawning	WS Atkins (2000)
Caddis fly	*Hydropsyche pellucidula*	Larva	WS Atkins (1998)
Mayflies	Family Ephemeridae	Larva	Johnson *et al.* (1993)
Water milfoil	*Myriophyllum spicatum*	-	Adapted from Bullock *et al.* (1991) curve for *Ranunculus**
Watercress	*Rorippa nasturtium-aquaticum*	-	Elliott *et al.* (1996)

*adapted by extending the upper end of the range of suitable water depths and flow velocities.

2.11 The HSI curves for the three fish species were developed specifically for East Anglian rivers, in a bespoke study commissioned by the Environment Agency (WS Atkins, 2000).

3. DATA COLLECTION

3.1 Three sets of hydraulic data were collected at each study site; each set comprising measurements of velocity and depth for each modelling cell in every transect (see Figure 2.2). The proximity of gauging stations (GSs) along the rivers meant that it was possible to directly compare the discharges measured in the field with those recorded at the GSs. The results of the data collection exercise for the Stour and Pant/Blackwater are presented in this chapter.

3.2 The habitat maps presented in this section of the report outline the findings of our walkover surveys of the study rivers. However, it was decided in discussion with the Environment Agency that a 'critical reach' approach would be adopted for the habitat-modelling phase of the project. Under this approach, rather than selecting transects at each site in order to represent the mesohabitat distribution throughout the study river, the mesohabitat type considered to be most sensitive to change in flow regime was deliberately over-represented. For this reason, the mesohabitat mapping results presented below do not necessarily agree with the mesohabitat distribution across the transects selected at each study site. This approach has implications for the habitat model settings, which are discussed further in paragraph 4.47.

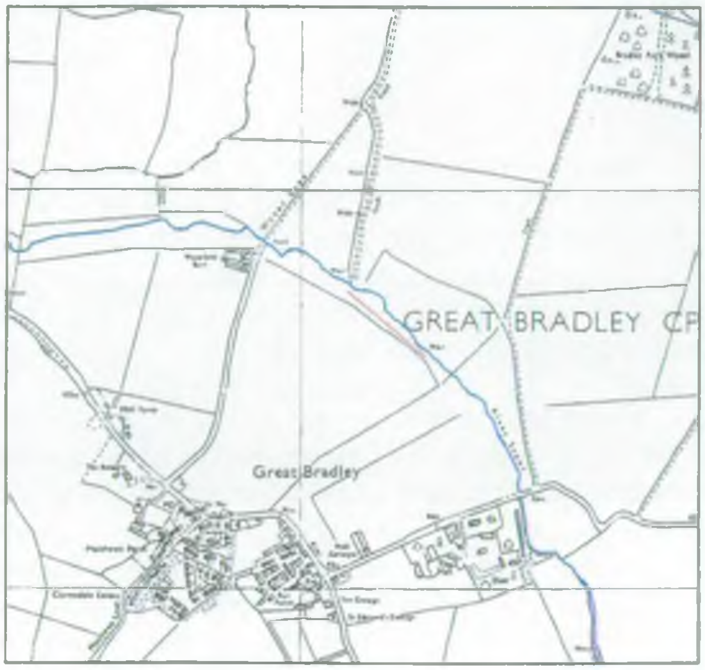
RIVER STOUR

River Stour at Kirtling Green Outfall (Stour 1)

3.3 The general location of the Stour 1 site is shown in Figure 2.3, and the location of the area in which study transects were set up is shown by the red line in Figure 3.1 below*.

* ©Ordnance Survey

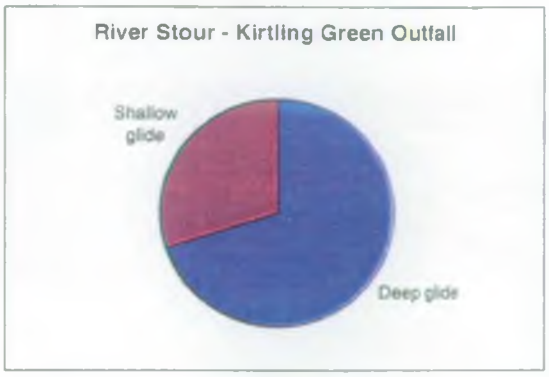
Figure 3.1 - Location of transects at Stour 1 site (Kirtling Green)



Mesohabitat Mapping

3.4 This site was not included in the original project brief, and was therefore not included in the original walkover survey of the study rivers, which was carried out in autumn 1998. A brief mesohabitat survey was carried out in the immediate vicinity of the study site during September 1999. Mesohabitat classification followed the methods of Johnson *et al.* (1994). The results are presented in Figure 3.2 below.

Figure 3.2 - Distribution of mesohabitat types in the Stour 1 study reach.



3.5 It was intended to locate the transects at this site at the same point as those used in the Entec study. However, the bank markers were removed at the end of that study, and photographs were only available for one of the transects (with chainages to the other transects) so it was not possible to position the transects in exactly the same location. The available information was used to make an estimate of the transect positions.

Flow Data Collection

3.6 One of the specific objectives of the study was to extend the flow ranges of the PHABSIM models developed by Entec. During the study it became apparent that the models for both the Stour 1 and Pant 1 sites were not available from Entec, so it was necessary to construct models for these sites afresh. It should be noted that the field site had been set up when this became apparent, and therefore the location of the transects was based on the information available from Entec.

3.7 The field data for the Stour 1 site along with the GS flows at Kedington are presented in Table 3.1. Note that the PHABSIM model only requires a full set of discharge measurements at all transects under one flow scenario, therefore the data presented for all sites do not include discharge measurements at all transects and flows.

Table 3.1 - Measured flow rates (m^3/s) during PHABSIM data collection at Stour 1 site and discharge data for Kedington GS.

Stour 1	**Low Flow**	**Medium Flow**	**High Flow**
Date	01/07/99	02/09/99	05/05/99
Transect 1A	0.156	1.089	-
Transect 2B	0.146	1.152	-
Transect 3C	0.153	1.099	-
Transect 4D	0.163	1.199	2.388
Average	**0.155**	**1.135**	**2.388**
Discharge @ Kedington GS	**0.239**	**1.078**	**2.463**
% of time exceeded	68	20	7

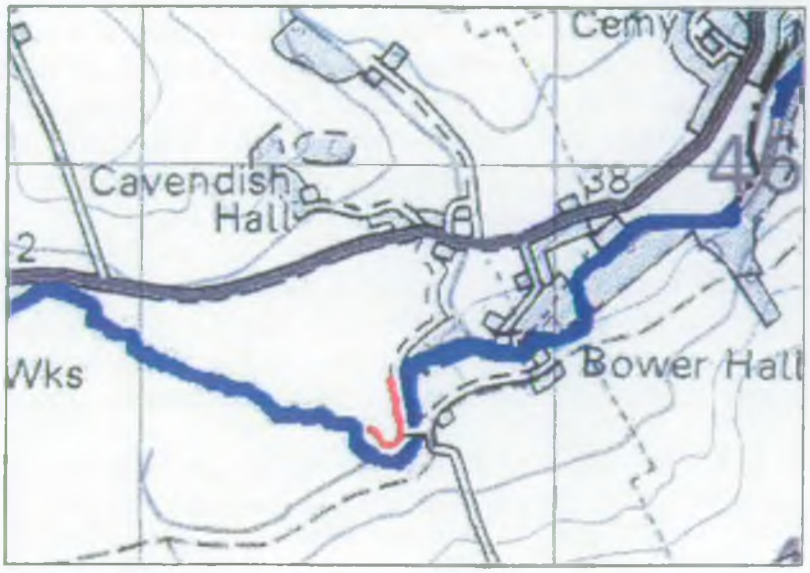
3.8 The observed flows are well distributed over the flow range at this site. GS flows are slightly lower than the field measurements but the differences are not thought to have an impact on the accuracy of the PHABSIM model. The overall quality of the collected data is considered reasonable and fit for purpose.

3.9 The substrate at this study site consists mainly of sand and gravel in the middle of the cross-section, whilst clay is the dominant substrate along the banks. Few areas of clean gravel were identified and substrate larger than gravel was found only rarely during the surveys.

River Stour at Bowers Hall Farm (Stour 2)

3.10 The general location of the Stour 2 site is shown in Figure 2.3, and the location of the area in which study transects were set up is shown by the red line in Figure 3.3 below.

Figure 3.3 – Location of transects at Stour 2 site (Bowers Hall Farm)



Mesohabitat Mapping

3.11 Results of the mesohabitat surveys carried out in the autumn of 1998 are presented in Table 3.2 below.

Table 3.2 - Mesohabitat mapping results for the River Stour between Wixoe and Sudbury.

Mesohabitat	Total length (m)	Percentage of reach length
Deep glide	130	53.1
Shallow glide	55	22.4
Riffle	60	24.5
Deep Slack	0	0

Flow Data Collection

3.12 Data collected for the study site at Bowers Hall along with the flow data for Westmill GS are presented in Table 3.3.

Table 3.3 - Measured flow rates (m^3/s) during PHABSIM data collection at Stour 2 site and discharge data for Westmill GS.

Stour 2	Low Flow	Medium2 Flow	Medium1 Flow	High Flow
Date	01/07/99	05/05/99	03/02/99	10/05/99
Transect 1A (Deep Glide)	0.378	0.950	1.237	-
Transect 2B (Shallow Glide)	0.464	1.075	1.170	2.917
Transect 3C (Deep Glide)	-	-	1.278	-
Transect 4D (Shallow Glide)	-	-	1.226	2.729
Transect 5E (Deep Glide)	-	-	1.303	-
Average	**0.421**	**1.012**	**1.243**	**2.823**
Discharge @ Westmill GS	**0.515**	**1.199**	**1.491**	**2.654**
% of time exceeded	80	35	31	9

3.13 The Westmill GS flows are within ±20% of the measured flow data at all flows. The overall quality of the collected data is considered reasonable and fit for purpose.

3.14 The substrate at this study site is very mixed with gravel and cobbles in the middle of the riverbed and silt and clays and occasional boulders closer to the banks. In-river vegetation was abundant during the summer period and this made data collection more difficult due to very low flow velocities.

River Stour at Wissington (Stour 3)

3.15 The general location of the Stour 3 site is shown in Figure 2.3, and the location of the area in which study transects were set up is shown by the red line in Figure 3.4 below.

Figure 3.4 – Location of transects at Stour 3 site (Wissington)

Mesohabitat Mapping

3.16 Results of mesohabitat surveys carried out in the autumn of 1998 are presented in Table 3.4 below.

Table 3.4 - Mesohabitat mapping results for the River Stour between Sudbury and Bures.

Mesohabitat	Total length (m)	Percentage of reach length
Deep glide	200	100
Shallow glide	0	0
Riffle	0	0
Deep Slack	0	0

Flow Data Collection

3.17 The flow data colected for the Stour 3 study site at Wissington along with the measured flows are presented in Table 3.5.

Table 3.5 - Measured flow rates (m^3/s) during PHABSIM data collection at Stour 3 site and discharge data for Lamarsh GS.

Stour 3	Low Flow	Medium Flow	High Flow
Date	02/07/99	04/02/99	10/05/99
Transect 1A (Deep Glide)	0.794	3.079	3.408
Transect 2B (Deep Glide)	-	3.117	-
Transect 3C (Deep Glide)	-	3.227	-
Average	**0.794**	**3.141**	**3.408**
Discharge @ Lamarsh GS	**GS not operating**	**2.402**	**2.641**
% of time exceeded		22	17

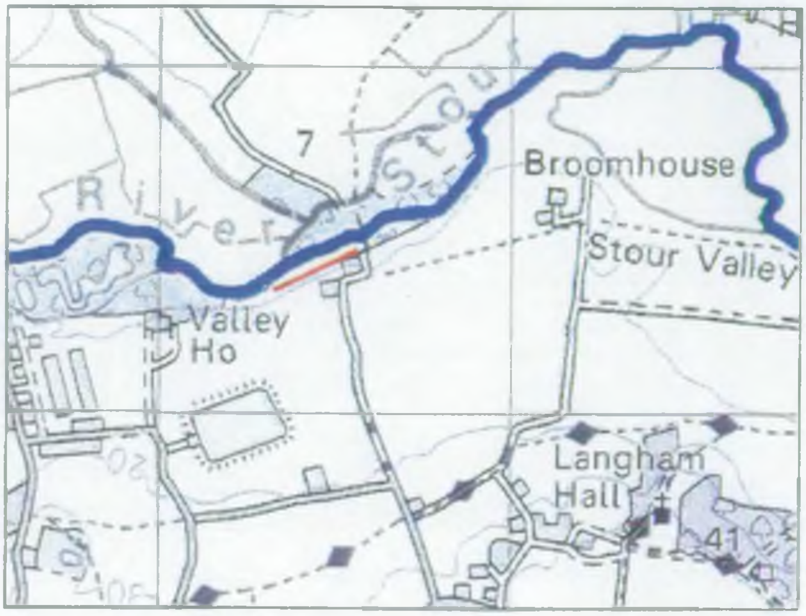
3.18 The Lamarsh GS flows were always more than 20% lower than measured flows at Wissington. This is most probably due to the location of the GS, which is 7.5 km upstream of the PHABSIM study site. The study site was not well suited for measuring flows due to very low flow velocities as a result of the abundance of in-river macrophytes during the summer period. It was therefore decided to conduct flow velocity measurements at Transect 1A only during low and high flows. The number of flow measurements is sufficient to calibrate the PHABSIM hydraulic model using the recommended modelling approach.

3.19 The substrate at the sampled transects consists of boulders, cobbles and gravels mixed with silt and clay. Silt and clay were dominant in places close to the banks of the river.

River Stour at Langham (Stour 4)

3.20 The general location of the Stour 4 site is shown in Figure 2.3, and the location of the area in which study transects were set up is shown by the red line in Figure 3.5 below.

Figure 3.5 – Location of transects at Stour 4 site (Langham)



Mesohabitat Mapping

3.21 Results of mesohabitat surveys carried out in the autumn of 1998 are presented in Table 3.6 below.

Table 3.6 - Mesohabitat mapping results for the River Stour downstream of Malting Farm Cottage.

Mesohabitat	Total length (m)	Percentage of reach length
Deep glide	200	93.0
Shallow glide	15	7.0
Riffle	0	0
Deep Slack	0	0

Flow Data Collection

3.22 An overview of the field data and the observed flows at Langham GS is presented in Table 3.7.

Table 3.7 - Measured flow rates (m^3/s) during PHABSIM data collection at Stour 4 site and discharge data for Langham GS.

Stour 4	**Low Flow**	**Medium1 Flow**	**Medium2 Flow**	**High Flow**
Date	02/07/99	06/05/99	04/02/99	10/05/99
Transect 1A (Deep Glide)	1.102	-	2.341	-
Transect 2B (Deep Glide)	-	-	3.024	-
Transect 3C (Deep Glide)	1.050	1.634	3.138	3.137
Average	**1.076**	1.634	**2.834**	**3.137**
Discharge @ Langham GS	**1.120**	**1.480**	**3.356**	**2.610**
% of time exceeded	75	60	20	33

3.23 The Langham GS flows are within ±20% of the measured flow data at all flows. The overall quality of the collected data is considered reasonable and fit for purpose.

3.24 The substrate at this study site is dominated by sand, gravels and cobbles with occasional patches of clay. The cross-sections are 20 to 25 m wide and have a near-rectangular shape with steep banks.

RIVER PANT/BLACKWATER

River Pant at Great Sampford Outfall (Pant 1)

3.25 The general location of the Pant 1 site is shown in Figure 2.3, and the location of the area in which study transects were set up is shown by the red line in Figure 3.6 below*.

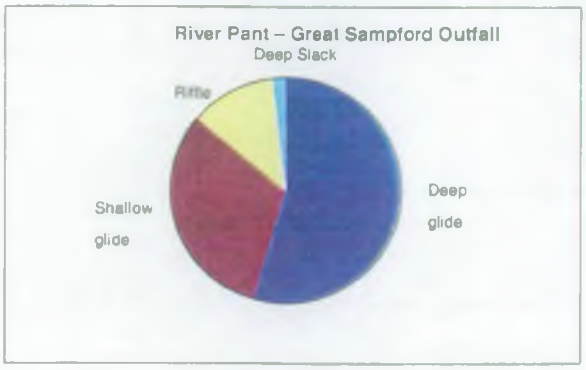
Figure 3.6 – Location of transects at Pant 1 site (Great Sampford)

* ©Ordnance Survey

Mesohabitat Mapping

3.26 This site was selected for the earlier Entec study, although no mesohabitat mapping was conducted as part of that project. A walkover survey was carried out as part of the current project, and the resultant data are shown in Figure 3.7 below.

Figure 3.7 - Distribution of mesohabitat types in the Pant 1 study reach.



3.27 As with Stour 1 (discussed in paragraph 3.5), the model for this site was constructed after the field site had been set up, and the selection of transects was dictated by the available Entec data.

Flow Data Collection

3.28 The flow data collected at this study site is presented in Table 3.8.

Table 3.8 - Measured flow rates (m^3/s) during PHABSIM data collection at Pant 1 site and discharge data for Copford Hall GS.

Pant 1	**Low Flow**	**Medium Flow**	**High Flow**
Date	29/06/99	03/09/99	07/05/99
Transect 1A	0.021	0.749	1.522
Transect 2B	0.022	-	1.520
Transect 3C	0.042	0.873	1.570
Transect 4D	0.025	-	1.437
Transect 5E	-	0.782	1.528
Average Flow	**0.027**	**0.801**	**1.515**
Discharge @ Copford Hall GS	**0.078**	**0.622**	**1.364**
% of time exceeded	74	26	10

3.29 Copford Hall GS is located 4.5 km downstream of the study site. Neverthelesss, under medium and high flow conditions, the measured flows at Great Sampford were approximately 20% higher than those measured at Copford Hall. During the low flow measurements the GS registered higher flows than those measured at the study site. The reason for this difference is unknown but could be linked to inaccuracies during low flow conditions of the GS or the collected field data, or to losses of water into the river bank (and possibly the gravels) between the Great Sampford EOETS discharge site and the GS.

3.30 The substrate at this site consisted mainly of silt and clay. Gravels and cobbles are present in isolated spots at some of the transects. Sands were identified very sporadically and no substrate larger than cobbles were found as the dominant substrate along this study site.

River Pant at Little Sampford (Pant 2)

3.31 The general location of the Pant 2 site is shown in Figure 2.3, and the location of the area in which study transects were set up is shown by the red line in Figure 3.8 below.*

Figure 3.8 – Location of transects at Pant 2 site (Little Sampford)

Mesohabitat Mapping

3.32 Results of mesohabitat surveys carried out in the autumn of 1998 are presented in Table 3.9 below.

* ©Ordnance Survey

Table 3.9 - Mesohabitat mapping results for the River Pant between Little Sampford and Shalford.

Mesohabitat	Total length (m)	Percentage of reach length
Deep glide	625	54.1
Shallow glide	370	32.0
Riffle	120	12
Deep Slack	20	1.7

Flow Data Collection

3.33 The collected flow data are presented in Table 3.10, along with the flows observed at Copford Hall GS.

Table 3.10 - Measured flow rates (m^3/s) during PHABSIM data collection at Pant 2 site and discharge data for Copford Hall GS.

Transect	**Low Flow**	**Medium Flow**	**High Flow**
Date	29/06/99	03/02/99	07/05/99
Transect 1A (Shallow Glide)	0.082	0.203	-
Transect 2B (Shallow Glide)	0.088	0.232	1.475
Transect 3C (Deep Glide)	-	0.241	-
Transect 4D (Shallow Glide)	0.082	0.211	1.452
Transect 5E (Riffle)	-	0.243	-
Transect 6F (Deep Glide)	-	0.237	-
Average Flow	**0.084**	**0.228**	**1.463**
Discharge @ Copford Hall GS	**0.166**	**0.309**	**1.368**
% of time exceeded	59	45	10

3.34 Flows at the study site during low and medium flows were smaller than those observed at Copford Hall GS. During the high flow measurements, the flows at the study site and the GS were very similar. Considering that the high flow measurements at Transects 2B and 4D were very similar (1.475 and 1.452 m^3/s respectively), this suggests that the GS underestimates higher flows in the river. The overall assessment is that the data collected at this site are of a good quality.

3.35 Most transects along this study site are dominated by gravels and cobbles, mixed with sand and clay in places. Substrate larger than cobbles are rarely found and are not present as a dominant substrate at any of the transects.

River Blackwater at Stisted Mill (Pant 3)

3.36 The general location of the Pant 3 site is shown in Figure 2.3, and the location of the area in which study transects were set up is shown by the red line in Figure 3.9 below.

Figure 3.9 – Location of transects at Pant 3 site (Stisted)

Mesohabitat Mapping

3.37 Results of mesohabitat surveys carried out in the autumn of 1998 are presented in Table 3.11 below.

Table 3.11 - Mesohabitat mapping results for the River Pant between Shalford and Coggeshall.

Mesohabitat	Total length (m)	Percentage of reach length
Deep glide	1035	86.3
Shallow glide	105	8.8
Riffle	20	1.7
Deep Slack	40	3.3

Flow Data Collection

3.38 The collected flow data for the PHABSIM study site and the Stisted Mill GS are presented in Table 3.12.

Table 3.12 - Measured flow rates (m^3/s) during PHABSIM data collection at Pant 3 site and discharge data for Stisted GS.

Pant 3	Low Flow	Medium Flow	High Flow
Date	30/06/99	02/02/99	07/05/99
Transect 1A (Shallow Glide)	-	1.092	1.252
Transect 2B (Deep Glide)	-	0.926	-
Transect 3C (Deep Glide)	0.426	0.969	-
Transect 4D (Deep Glide)	-	1.033	-
Transect 5E (Deep Glide)	0.483	0.957	1.713
Average Flow	**0.455**	**0.995**	**1.483**
Discharge @ Stisted GS	**0.490**	**1.070**	**1.526**
% of time exceeded	55	25	15

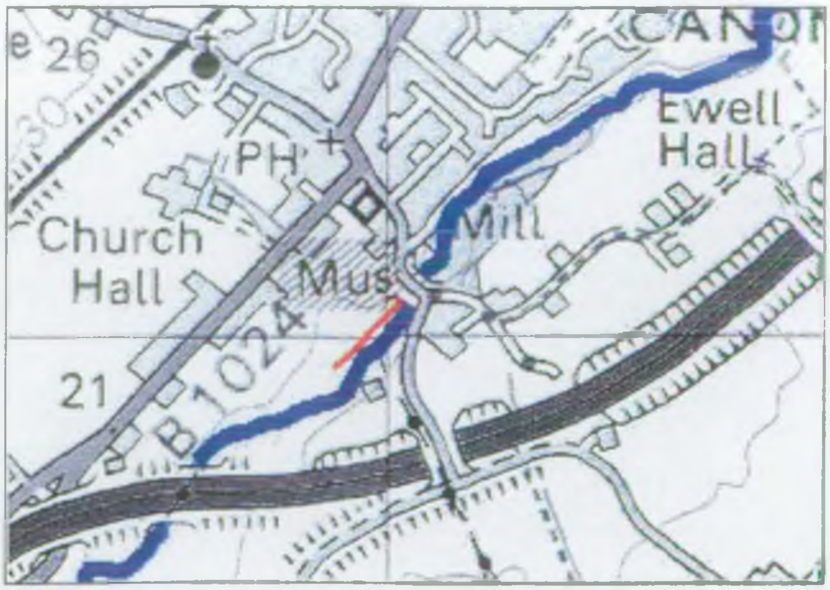
3.39 Stisted GS is approximately 200 m upstream from the furthest upstream cross-section (Transect 5E) of the PHABSIM study site. The GS flows and the collected flows for the PHABSIM model are within ±10% at all flows. The overall quality of the collected data is considered reasonable and fit for purpose.

3.40 The dominant substrate at all transect is silt and clay. Other substrate are found in isolated spots but these are not dominant at any of the transects. In-river macrophyte growth is abundant during the summer making flow measurements more difficult and significantly decreasing the flow velocity.

River Blackwater at Kelvedon (Pant 4)

3.41 The general location of the Pant 4 site is shown in Figure 2.3, and the location of the area in which study transects were set up is shown by the red line in Figure 3.10 below.

Figure 3.10 – Location of transects at Pant 4 site (Kelvedon)



Mesohabitat Mapping

3.42 Results of mesohabitat surveys carried out in the autumn of 1998 are presented in Table 3.13 below.

Table 3.13 - Mesohabitat mapping results for the River Blackwater between Coggeshall and Langford.

Mesohabitat	Total length (m)	Percentage of reach length
Deep glide	790	90.8
Shallow glide	80	9.2
Riffle	0	0
Deep slack	0	0

Flow Data Collection

3.43 An overview of the field data for this study site and the Appleford GS is presented in Table 3.14 below.

Table 3.14 - Measured flow rates (m^3/s) during PHABSIM data collection at Pant 4 site and discharge data for Appleford GS.

+	Low Flow	Medium Flow	High Flow
Date	03/09/99	30/06/99	06/05/99
Transect 1A (Shallow Glide)	0.346	0.574	-
Transect 2B (Deep Glide)	0.458	0.537	1.596
Transect 3C (Deep Glide)	0.296	-	-
Transect 4D (Deep Glide)	0.312	0.647	1.457
Average Flow	**0.353**	**0.586**	**1.527**
Discharge @ Appleford GS	**0.322**	**0.684**	**1.709**
% of time exceeded	98	65	22

3.44 The measured flows and the GS data are similar and relatively small differences between the data sets were found. The overall quality of the collected data is considered reasonable and fit for purpose.

3.45 The substrate along this stretch of the river varies over relatively short distances. Three of the four transects at the study site consist of sand, gravel and cobbles in the centre of the river with clay and silts closer to the banks of the river. In contrast, the fourth transect is dominated by silt and clay with some larger boulders in between.

4. PHABSIM MODEL CALIBRATION

INTRODUCTION

4.1 PHABSIM is used to simulate flow velocity and water surface level across a range of discharges. For the present study, model output is based on field measurements at three or four different flows. Based on this field information, PHABSIM was used to simulate the velocity and water surface level at 25 different flows across the desired range.

4.2 The quality of calibration of the PHABSIM model in this study was assessed using the following information:

(i) Cross-section plots with measured water surface levels (WSLs) at measured discharges

(ii) Longitudinal plots of water surface level at measured and simulated discharges

(iii) Plots of stage-discharge regressions for all cross-sections, showing measured water surface levels and discharges

(iv) Plots of Velocity Adjustment Factors (VAF) over the range of simulated discharges for all cross-sections.

(v) Plots of measured and simulated flow velocities in individual cells across each cross-section

4.3 In the remainder of this section of the report, information and analysis pertaining to each of the above criteria is presented for each of the sites on the Stour and on the Pant/Blackwater in turn.

STOUR 1: KIRTLING GREEN OUTFALL

Cross-sectional water surface levels

4.4 The cross-sectional profiles of the selected transects for the Stour 1 site are presented in Appendix 2.3. The WSLs surveyed at each of the three measured flows are also provided. WSLs increases with flow, as expected. The size of the increases is relatively consistent between transects and flows.

Longitudinal water surface levels

4.5 Longitudinal profiles of WSLs through the study site are presented in Appendix 2.4. Figure 2.4a shows the observed and simulated profiles for the three measured flows: 0.15 m^3/s, 1.14 m^3/s and 2.39 m^3/s. The simulated and observed profiles are closely matched throughout the flow range. Profiles are shown for a range of simulated flows in Figure 2.4b.

Stage-discharge regressions

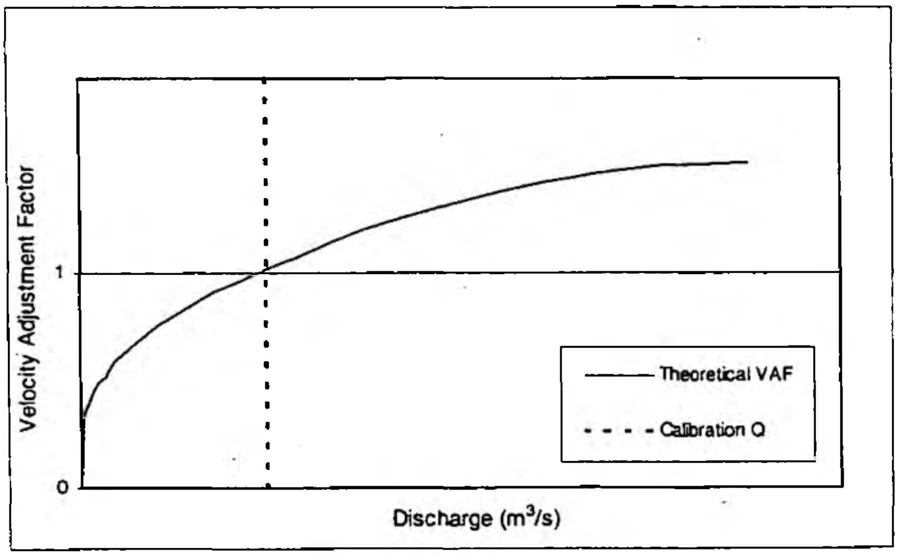
4.6 Comparisons between the stage-discharge (Q(h)) relationships generated by the model for each of the transects and corresponding observed data are given in Appendix 2.5. The relationships show close agreement with field measurements.

Velocity Adjustment Factors (VAFs)

4.7 The flow velocities and corresponding WSLs measured at the calibration flow (1.135 m^3/s in this case) are used by PHABSIM to estimate the channel roughness index (Mannings n). The roughness index is then used in the simulation of velocities and WSLs at other discharges.

4.8 In reality, the value of effective Mannings n at a point would decrease with increasing discharge (the relative magnitude of the channel roughness elements decreases as flow depth increases). The PHABSIM method maintains a constant value of n, and uses a velocity adjustment factor (VAF) to simulate required velocities and WSLs at each transect. In theory, the VAF should be unity for the calibration flow at each transect, smaller than unity for flows less than the calibration flow and larger than unity for flows greater than the calibration flow. The shape of the theoretical VAF curve is shown in Figure 4.1.

Figure 4.1 – Theoretical velocity adjustment factor curve



4.9 The VAF curves for the Stour 1 site are given in Appendix 2.6. All show agreement with the theoretical curve, apart from Transect 4D, which shows an increase in the VAF at flows lower than the calibration discharge. There is no apparent reason for this anomaly, but given the quality of the other calibration parameters for this site, it is unlikely to have a significant impact on the overall results.

Flow velocities in individual cells

4.10 The variations in velocity across each of the transects is presented in Appendix 2.7. Observed and simulated velocity profiles are compared and show close agreement, particularly at the calibration flow.

Model options used for calibration and simulation

4.11 PHABSIM provides a number of options for both hydraulic and habitat modelling. The IFG4 hydraulic model is the preferred option, and was used in all the models produced as part of this study. The HABTAE habitat model was also used, in all models. The standard settings (i.e. the combined suitability factor method (Environment Agency, 1996)) were used to calculate the available habitat from the habitat suitability index curves.

4.12 The input/output codes (IOCs) for the IFG4 and HABTAE routines are given in Appendix 2.8.

STOUR 2: BOWERS HALL FARM

Cross-sectional water surface levels

4.13 The cross-sectional profiles of the selected transects for the Stour 2 site are provided in Appendix 3.3. Four flows were measured at this site: 0.42 m^3/s, 1.012 m^3/s, 1.243 m^3/s and 2.823 m^3/s. The water surface levels surveyed at each of the transects are also presented in Appendix 3.3. There is a relatively small increase in WSL between the three lower flows, and a large increase in WSL at each of the transects at high flow.

Longitudinal water surface levels

4.14 The longitudinal profiles of WSLs through the Stour 2 site are presented in Appendix 3.4. Appendix 3.4a shows the correlation between the observed and simulated profiles. There is a particularly good match at high flow and the calibration is considered to be acceptable at all four flows. Profiles are shown for a range of simulated flows in Appendix 3.4b.

Stage-discharge regressions

4.15 Comparisons between the Q(h) relationships generated by the model for each of the transects and corresponding observed data are given in Appendix 3.5. The excellent match between the observed and simulated data at high flow is demonstrated by this parameter.

Velocity Adjustment Factors (VAFs)

4.16 The variation in VAF at the Stour 2 site across the simulated flow range is shown in Appendix 3.6. The VAF curves show close agreement with the theoretical curve at each transect (although the VAF at the calibration flow is slightly less than unity for all of the transects).

Flow velocities in individual cells

4.17 The lateral velocity profiles for each of the transects are shown in Appendix 3.7. The observed and simulated profiles are well-matched, although the model is not capable of simulating some of the extreme variability in measured velocity (e.g. observed medium 2 flow at transect 3C).

Model options used for calibration and simulation

4.18 The IOCs used in the IFG4 and HABTAE routines are provided in Appendix 3.8.

STOUR 3: WISSINGTON

4.19 The longitudinal profiles of WSLs through the Stour 3 site are presented in Appendix 4.3. The WSL recorded during the low flow field visit is clearly higher than that recorded at medium flow. This was discovered to be a likely result of the operation of an in-river structure downstream of the study site (not owned or operated by the EA), which acts as the dominant control on the flow hydraulics in the site. The PHABSIM hydraulic models utilise relatively simple steady-state procedures, which are not capable of simulating variations in downstream hydraulic controls. It is therefore imperative that a constant downstream hydraulic boundary is included within each study site.

4.20 For this reason the decision was taken not to proceed with the modelling at this site, although the substrate data are presented for future reference purposes.

STOUR 4: LANGHAM

Cross-sectional water surface levels

4.21 The cross-sectional bed profiles of the selected transects for the Stour 4 site are provided in Appendix 5.3. Flow measurements were made under four discharge scenarios: 1.076 m^3/s, 1.634 m^3/s, 2.834 m^3/s and 3.137 m^3/s. Cross-sectional WSLs surveyed at each of the transects are also presented in Appendix 5.3. WSLs increase with flow, as expected, indicating good model calibration.

Longitudinal water surface levels

4.22 The longitudinal profiles of WSLs through the Stour 4 site are presented in Appendix 5.4. Appendix 5.4a shows the correlation between the observed and simulated profiles. There is a particularly good match at high flow and the calibration is acceptable at all four flows. Profiles are shown for a range of simulated flows in Appendix 5.4b.

Stage-discharge regressions

4.23 The simulated Q(h) relationships appear to overestimate the water surface levels at this site at transects 1 and 2. Although there is some divergence from the observed values, it is not thought to have a significant impact on the overall calibration of the model, given the quality of the other parameters. It is possible that the more difficult fieldwork conditions at this site (primarily the greater depth and width of the watercourse and therefore the need to make measurements from a boat) have resulted in fieldwork inaccuracies.

Velocity Adjustment Factors (VAFs)

4.24 The variation in VAF across the simulated flow range is shown in Appendix 5.6. The VAF curves show close agreement with the theoretical curve at each transect (although the calibration flow VAF is slightly less than unity for all of the transects).

Flow velocities in individual cells

4.25 The lateral velocity profiles for each of the transects are shown in Appendix 5.7. The observed and simulated profiles are well-matched, although there is some smoothing evident in the simulated results.

Model options used for calibration and simulation

4.26 The IOCs used in the IFG4 and HABTAE routines are provided in Appendix 5.8.

PANT 1: GREAT SAMPFORD OUTFALL

Cross-sectional water surface levels

4.27 The cross-sectional profiles of the selected transects for the Pant 1 site are presented in Appendix 6.3. The WSLs surveyed at each of the three measured flows are also provided. There is a relatively consistent increase in WSL between transects and flows.

Longitudinal water surface levels

4.28 Longitudinal profiles of WSLs through the study site are presented in Appendix 6.4. Appendix 6.4a shows the observed and simulated profiles for the three measured flows: 0.027 m^3/s, 0.801 m^3/s and 1.515 m^3/s. The simulated and observed profiles are closely matched throughout the flow range. Profiles are shown for a range of simulated flows in Appendix 6.4b.

Stage-discharge regressions

4.29 Comparisons between the stage-discharge (Q(h)) relationships generated by the model for each of the transects and corresponding observed data are given in Appendix 6.5. The relationships show close agreement with field measurements.

Velocity Adjustment Factors (VAFs)

4.30 The variations in VAF at the Pant 1 site across the simulated flow range are shown in Appendix 6.6. The VAF curves show close agreement with the theoretical curve at all transects.

Flow velocities in individual cells

4.31 The variations in velocity across each of the transects is presented in Appendix 6.7. The observed and simulated velocity profiles are well correlated.

Model options used for calibration and simulation

4.32 The IOCs used in the IFG4 and HABTAE routines are provided in Appendix 6.8.

PANT 2: LITTLE SAMPFORD

Cross-sectional water surface levels

4.33 The cross-sectional profiles of the selected transects for the Pant 2 site are presented in Appendix 7.3. The WSLs surveyed at each of the three measured flows are also provided. The relative similarity between the low and medium flows is reflected in the smaller increase in level shown in the plots.

Longitudinal water surface levels

4.34 Longitudinal profiles of WSLs through the study site are presented in Appendix 7.4. Appendix 7.4a shows the observed and simulated profiles for the three measured flows: 0.084 m^3/s, 0.228 m^3/s and 1.463 m^3/s. The simulated and observed profiles are closely matched throughout the flow range. Profiles are shown for a range of simulated flows in Appendix 7.4b.

Stage-discharge regressions

4.35 Comparisons between the stage-discharge (Q(h)) relationships generated by the model for each of the transects and corresponding observed data are given in Appendix 7.5. The relationships show close agreement with field measurements. The similarity between the low and medium flows is illustrated in these plots.

Velocity Adjustment Factors (VAFs)

4.36 The VAF curves for the Pant 2 site are given in Appendix 7.6. All show agreement with the theoretical curve, apart from Transects 4D and 5E, which show an increase in the VAF at the lowest simulated flows. It is likely that these anomalies have occurred as a result of the extremely low flows which were used as part of the simulation. These flows are at or below the Q_{99}, and anomalies of this type are unlikely to have a significant impact on the results for the site.

Flow velocities in individual cells

4.37 The variations in velocity across each of the transects are presented in Appendix 7.7. The observed and simulated velocity profiles are well correlated.

Model options used for calibration and simulation

4.38 The IOCs used in the IFG4 and HABTAE routines are provided in Appendix 7.8.

PANT 3: STISTED

Longitudinal water surface levels

4.39 The longitudinal profiles of WSLs through the Pant 3 site are presented in Appendix 8.3. The WSL recorded during the low flow field visit is clearly higher than that recorded at medium flow. This was discovered to be a likely result of the operation of an in-river structure downstream of the study site (not owned or operated by the EA), which acts as the dominant control on the flow hydraulics in the site. The PHABSIM hydraulic models utilise relatively simple steady-state procedures, which are not capable of simulating variations in downstream hydraulic controls. It is therefore imperative that a constant downstream hydraulic boundary is included within each study site.

4.40 For this reason the decision was taken not to proceed with the modelling at this site, although the substrate data are presented for future reference purposes.

PANT 4: KELVEDON

Cross-sectional water surface levels

4.41 The cross-sectional profiles of the selected transects for the Pant 4 site are presented in Appendix 9.3. The WSLs surveyed at each of the three measured flows are also provided. The levels increase with flow, as expected, although there is a greater difference between the levels for low and medium discharges than might be expected.

Longitudinal water surface levels

4.42 The longitudinal profiles of WSLs through the study site are presented in Appendix 9.4. Appendix 9.4a shows the observed and simulated profiles for the three measured flows: 0.353 m^3/s, 0.586 m^3/s and 1.483 m^3/s. The simulated and observed profiles are closely matched throughout the flow range, especially at the calibration discharge. Profiles are shown for a range of simulated flows in Appendix 9.4b.

Stage-discharge regressions

4.43 Comparisons between the stage-discharge (Q(h)) relationships generated by the model for each of the transects and corresponding observed data are given in Appendix 9.5. The relationships show close agreement with field measurements at low and high discharges, but suggest that the levels at medium flows may be slightly less reliable.

Velocity Adjustment Factors (VAFs)

4.44 The variations in VAF at the Pant 4 site across the simulated flow range are shown in Appendix 9.6. The VAF curves show close agreement with the theoretical curve at all transects.

Flow velocities in individual cells

4.45 The lateral velocity profiles are presented in Appendix 9.7. The observed and simulated velocity profiles are well correlated.

Model options used for calibration and simulation

4.46 The IOCs used in the IFG4 and HABTAE routines are provided in Appendix 9.8.

HABITAT MODELLING SETTINGS

4.47 In order to represent the mesohabitat distribution in the reach of interest, habitat weightings are assigned to each transect in each model. As discussed in section 2, a critical reach approach has been used in this study, which means that each transect is accorded equal weighting (i.e. 0.5) in calculation of the overall habitat availability at a given site.

TIME SERIES ANALYSIS

Input data

4.48 The WUAQT programme within PHABSIM was used to generate habitat time series for fish species at three sites (Stour 1, Kirtling Green, Pant 1, Great Sampford and Pant 2, Little Sampford). River flow records from Kedington and Copford Hall GSs were provided by the EA. Kedington flow data were used to model habitat availability at Kirtling Green. Copford Hall flow data were used to model habitat availability at both Great Sampford and Little Sampford.

4.49 Flow records for both sites were in the form of daily mean flows (DMF) for the five-year period 1 January 1992 to 31 December 1996. Time series analysis was run for two sets of data at each site: observed flows at the respective gauging station, and naturalised flows. Naturalised flow data accounted for licenced abstractions and discharges upstream of the site, and were obtained from a study recently carried out by Entec (Entec, 2000*a*). No allowance was made for potential loss of water from the river channel into the river bed or banks.

4.50 The naturalised data included some 'negative flows', which resulted from the sum of licensed upstream discharges being greater than the sum of upstream abstractions and the flow at the upstream GS. For the purposes of the model, these values were set to 0.01 and 0.001 m^3/s for Copford Hall and Great Sampford respectively. The latter figure is the lowest discharge that can be modelled with PHABSIM. Modelled flows for the two GSs are presented in Figure 4.2 and Figure 4.3 overleaf.

4.51 The historic flow record in this period has three distinct phases. Natural flows in 1993-1994 were higher than in either 1992 or 1995-1996, and in 1993 the EOETS was operated only in summer for environmental support purposes. In 1992, and again in 1995-1996 the EOETS was operated for substantial periods between autumn and spring.

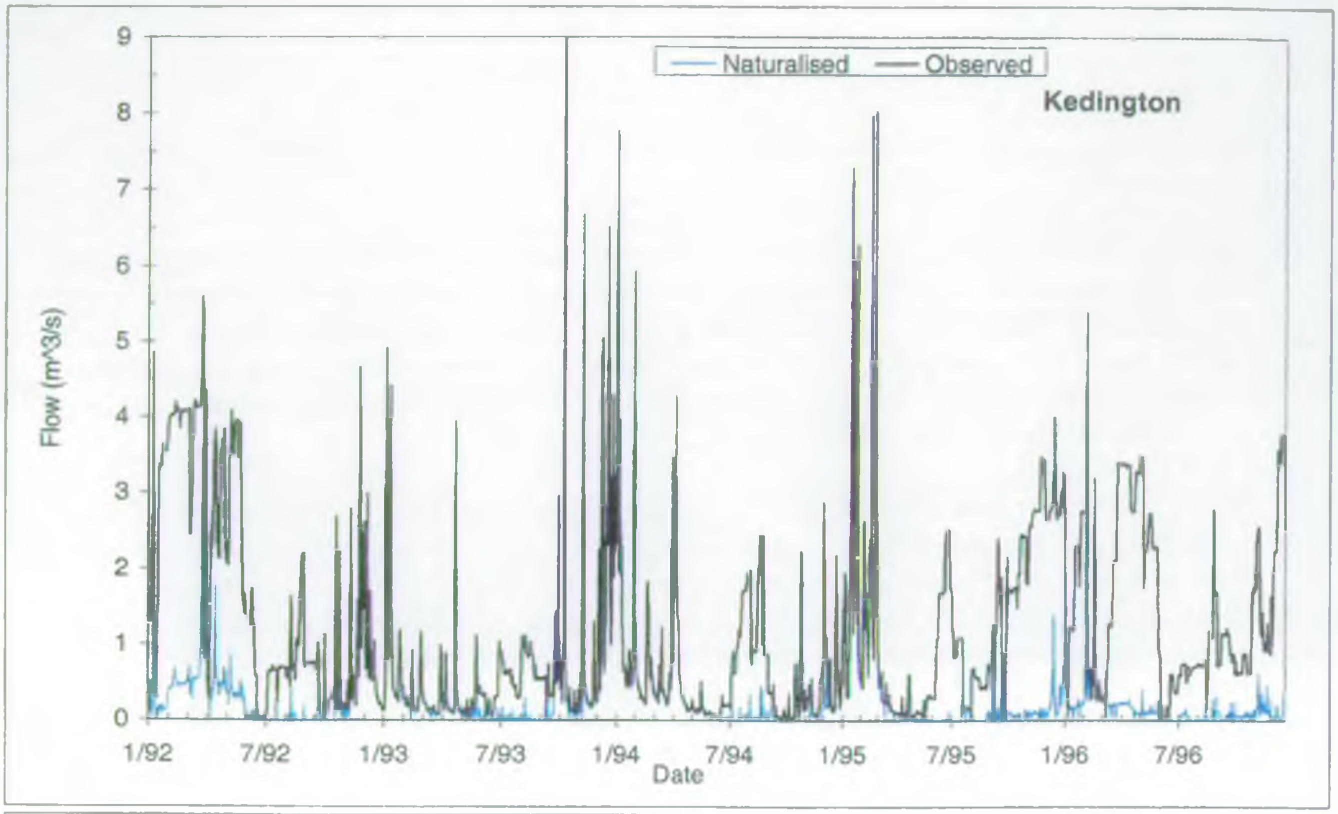
Critical habitat periods

4.52 Available habitat for adult life stages of all species was modelled for the entire five year period (1992-1996). For juvenile and spawning stages, only critical periods were modelled, as shown in Table 4.1 below.

Table 4.1 – Critical periods for juvenile and spawning life stages

Species	Critical period	
	Juvenile	**Spawning**
Brown trout	March-August	October-January
Chub	May-October	April-June
Roach	May-October	April-June

Figure 4.2 : Flow data for River Stour at Kedington GS



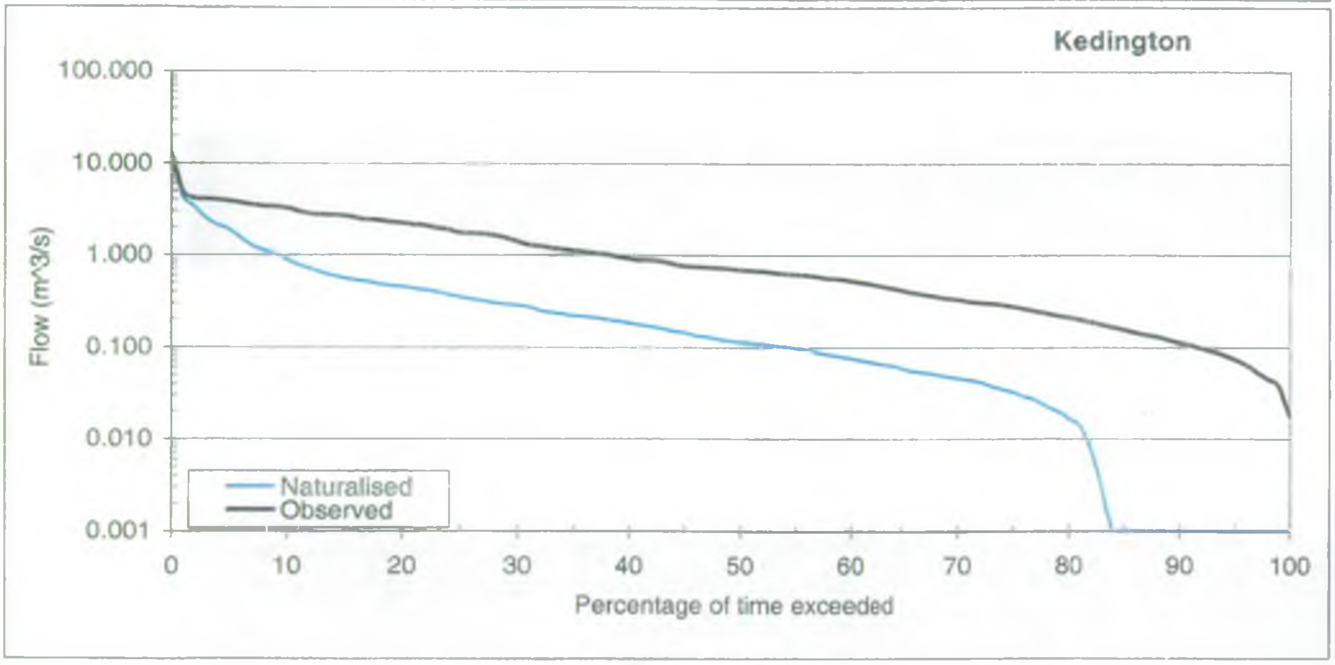
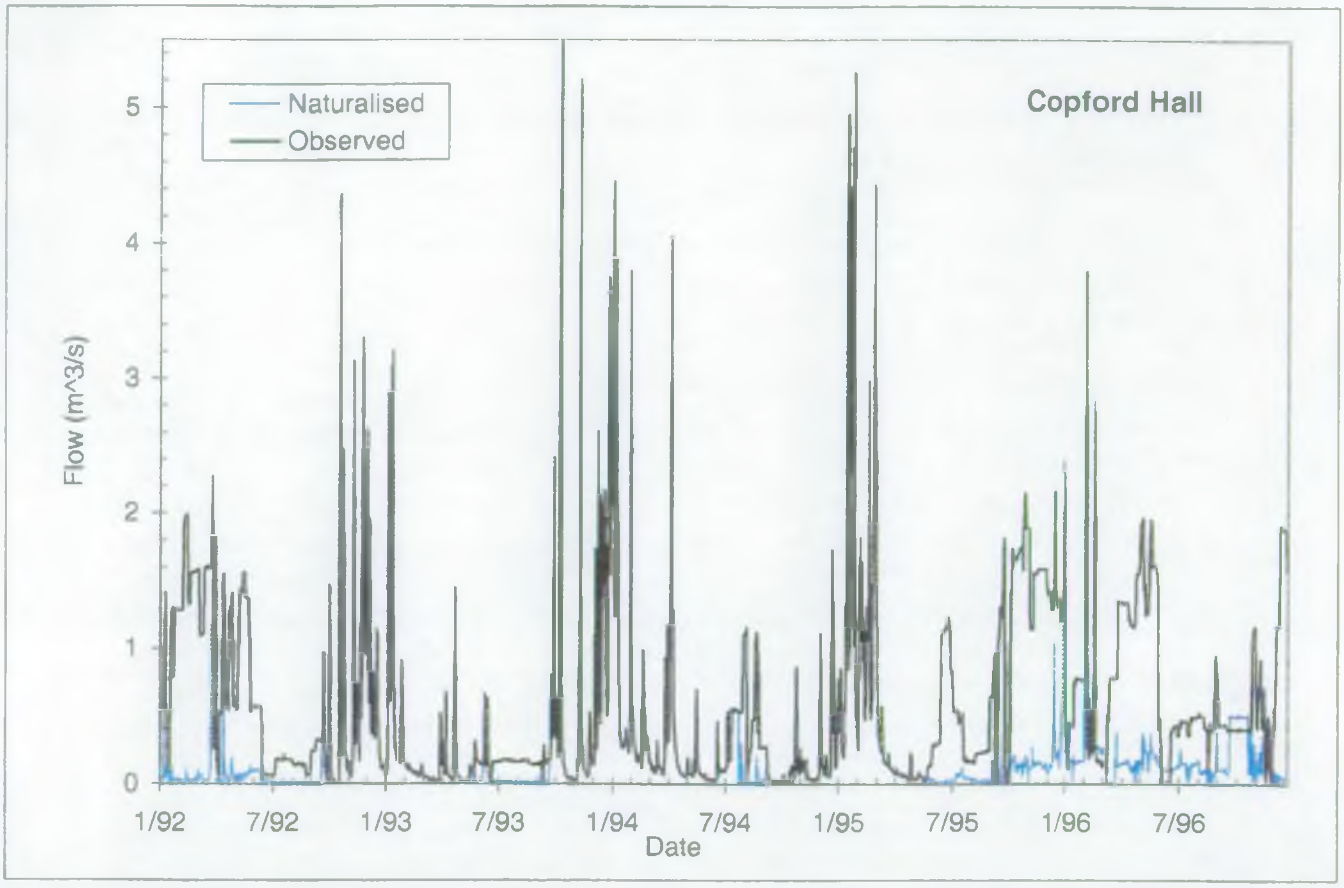
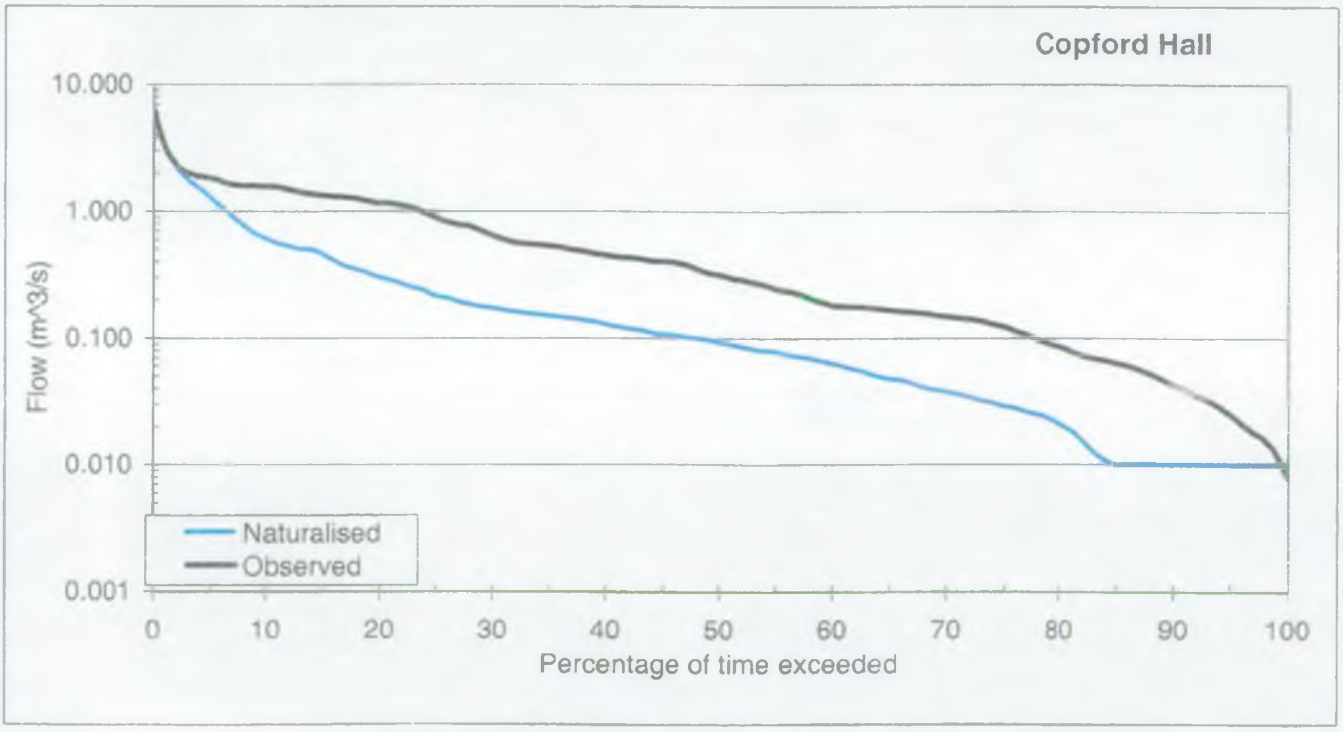


Figure 4.3 : Flow data for River Pant at Copford Hall GS





5. MODEL RESULTS: DISCHARGE/HABITAT RELATIONSHIPS

INTRODUCTION

5.1 The quantitative parameters that PHABSIM calculates under a given flow scenario are the total available area (TAA) of habitat at the site, and the weighted useable area (WUA) for the selected target or indicator species at the site. TAA is defined as the available cross-sectional area of flow; WUA is that part of TAA that provides habitat suitable for the selected species. These indices of potential habitat are calculated by the model, using a combination of the variables representing the microhabitat in the river and the habitat suitability indices (HSIs) of the target species. They give specific information about the suitability of the river for the target species over the selected range of discharges. However, the results presented are intended for comparative purposes only and not as absolute values. Both TAA and WUA have units of m^2/1000 m.

5.2 PHABSIM allows the user to calculate TAA and WUA for up to 25 different flows. In this study, the range of modelled flows is based on the available flow regime information for the nearest GS, and is intended to cover the range of flow from 0.001 m^3/s (effectively zero flow) up to approximately Q_1. The results of the TAA and WUA calculations for each of the sites are presented in the following sections for each of the target species and life stages.

STOUR 1: KIRTLING GREEN OUTFALL

5.3 The curve of TAA versus discharge at Kirtling Green is presented in Figure 5.1a, and shows TAA increasing sharply from 3000 to 5300 m^2/1000 m as discharge increases from 0.01 to 0.2 m^3/s. An inflexion point is apparent at a discharge of 0.2 m^3/s, above which TAA increases only gradually with increased discharge, to a maximum of 7000 m^2/1000 m at the maximum simulated discharge of 7 m^3/s.

5.4 For brown trout, the historical Q_{50} at this site (0.34 m^3/s) was near the optimum predicted by PHABSIM for all life stages (Figure 5.1b). Of all the life stages, spawning trout appear to be most tolerant to moderate increases in discharge, between the historic Q_{50} and approximately 2 m^3/s. Although WUA for all life stages decreases with increased discharge above 1 m^3/s, there is still significant habitat available for adult and juvenile trout (approximately 25% of that at Q_{opt}) at the historical Q_5 flow (2.8 m^3/s), at the maximum modelled flow of 7 m^3/s.

5.5 Maximum habitat for adult chub (Figure 5.1c) was shown to be available at flows slightly in excess of the historic Q_{50} for this site, although significant habitat (between 1250 and 3800 m^2/1000 m) was shown to be available across the full range of modelled flows. Available habitat for juvenile chub was much lower, and reflects the inability of this life stage to tolerate all but very low flow velocities. However, a small amount of habitat area (approximately 200 m^2/1000 m) was found to be available to juvenile chub at all of the modelled flows, except the no-flow scenario. This represents the presence (regardless of discharge), of a small amount of marginal habitat, where water depth, flow velocity and substrate are all acceptable.

5.6 As was the case for adult chub, the greatest area of habitat suitable for spawning chub was available at a flow of 0.5 m^3/s, which is approximately equal to the historical Q_{50}. However, unlike the other two life stages, available habitat decreases sharply with increased flows above Q_{50}, and no habitat is available above 1.5 m^3/s. This reflects the preference of spawning chub for a narrow range of water depths.

5.7 The WUA plots for roach (Figure 5.1d) indicate that flows in the region of the historic Q_{50} offer the maximum useable habitat area for adult, juvenile and spawning stages. WUA for both adults and juveniles decreases only slightly in the range between the Q_{50} and maximum modelled flow, which is approximately equivalent to the historic Q_1, indicating that increased flows will only have a slight impact on available habitat. In contrast, the WUA curve for spawning roach falls away sharply at flows in excess of the historic Q_{50}, and no habitat is available above 1.7 m^3/s. This represents the presence of suitable spawning substrate (gravels and cobbles) only in mid-channel, where flow velocity becomes unacceptably high as discharge increases.

5.8 Q_{opt} for all modelled macrophyte and invertebrate taxa is in the range of 0.2 to 1.0 m^3/s, which is near the historic Q_{50} of 0.34 m^3/s (Figure 5.1e). Mayflies (Family Ephemeridae) are particularly insensitive to increased flows above Q_{50}, with the available habitat at Q_1 (3000 m^2/1000 m) being approximately 80% of that at Q_{50}. Predicted available habitat for the two macrophyte species (watercress and water milfoil) at Q_1 was also relatively high at c. 800 m^3/1000 m, which was approximately 50% of that at Q_{opt}. The caddis fly *Hydropsyche pellucidula* appeared to be particularly sensitive to increased flows at this site, with virtually no useable habitat available above flows of 1.5 m^3/s.

Figure 5.1a. Discharge vs Total Available Habitat Area - Stour1 (Kirtling Green)

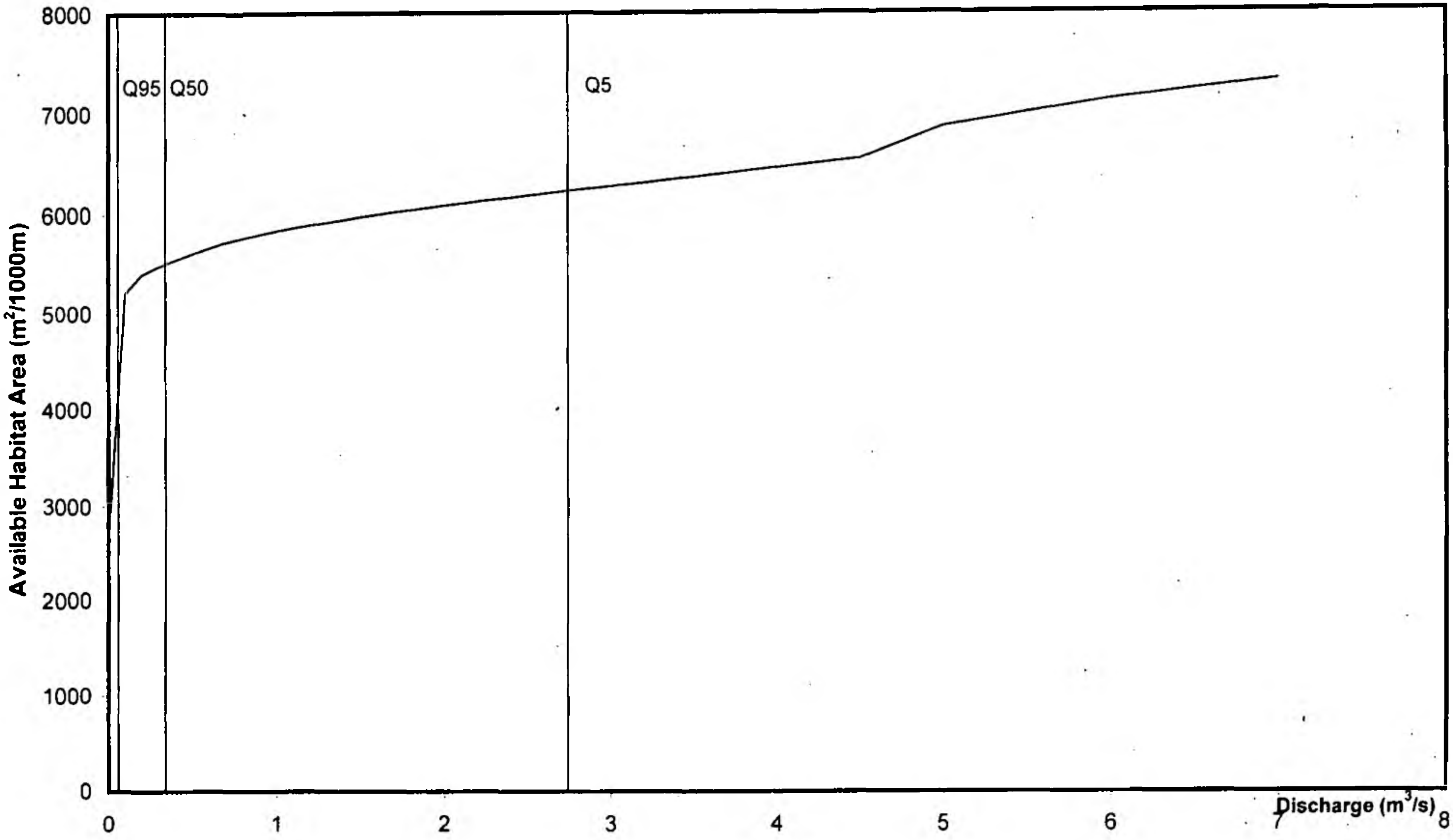


Figure 5.1b. Discharge/ Habitat Availability Relationships for Brown Trout - Stour1 (Kirtling Green)

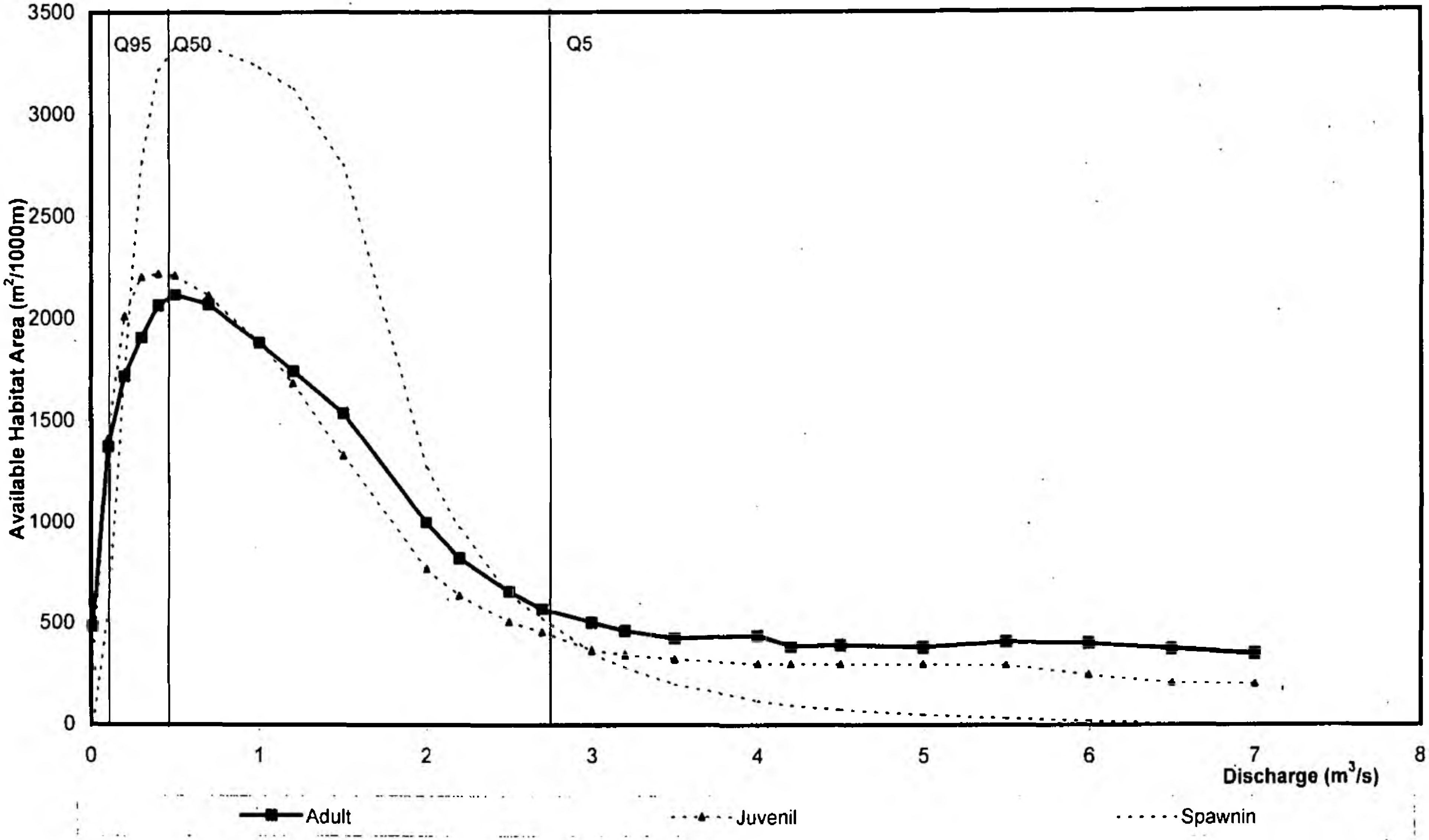


Figure 5.1c. Discharge/ Habitat Availability Relationships for Chub - Stour1 (Kirtling Green)

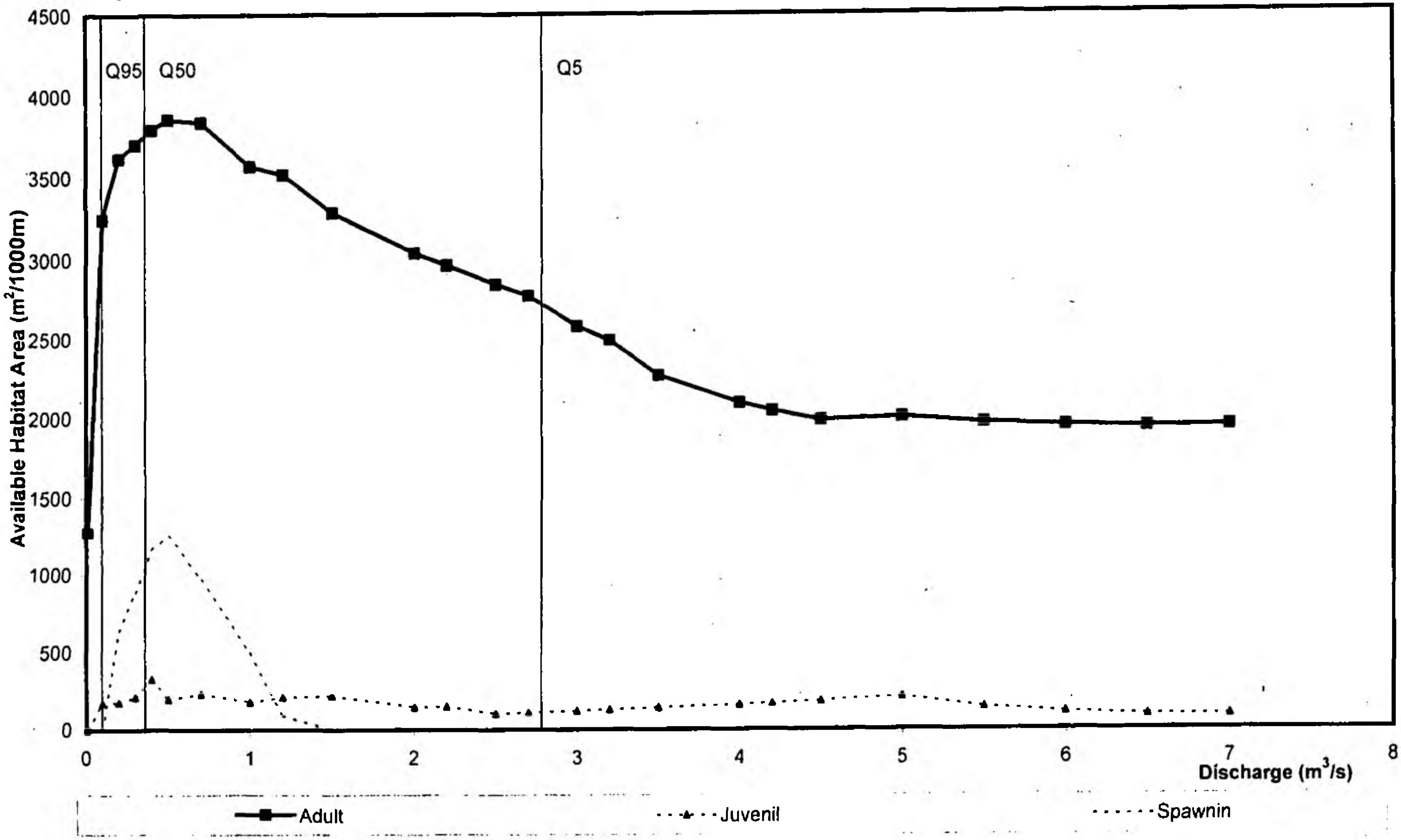


Figure 5.1d. Discharge/ Habitat Availability Relationships for Roach - Stour1 (Kirtling Green)

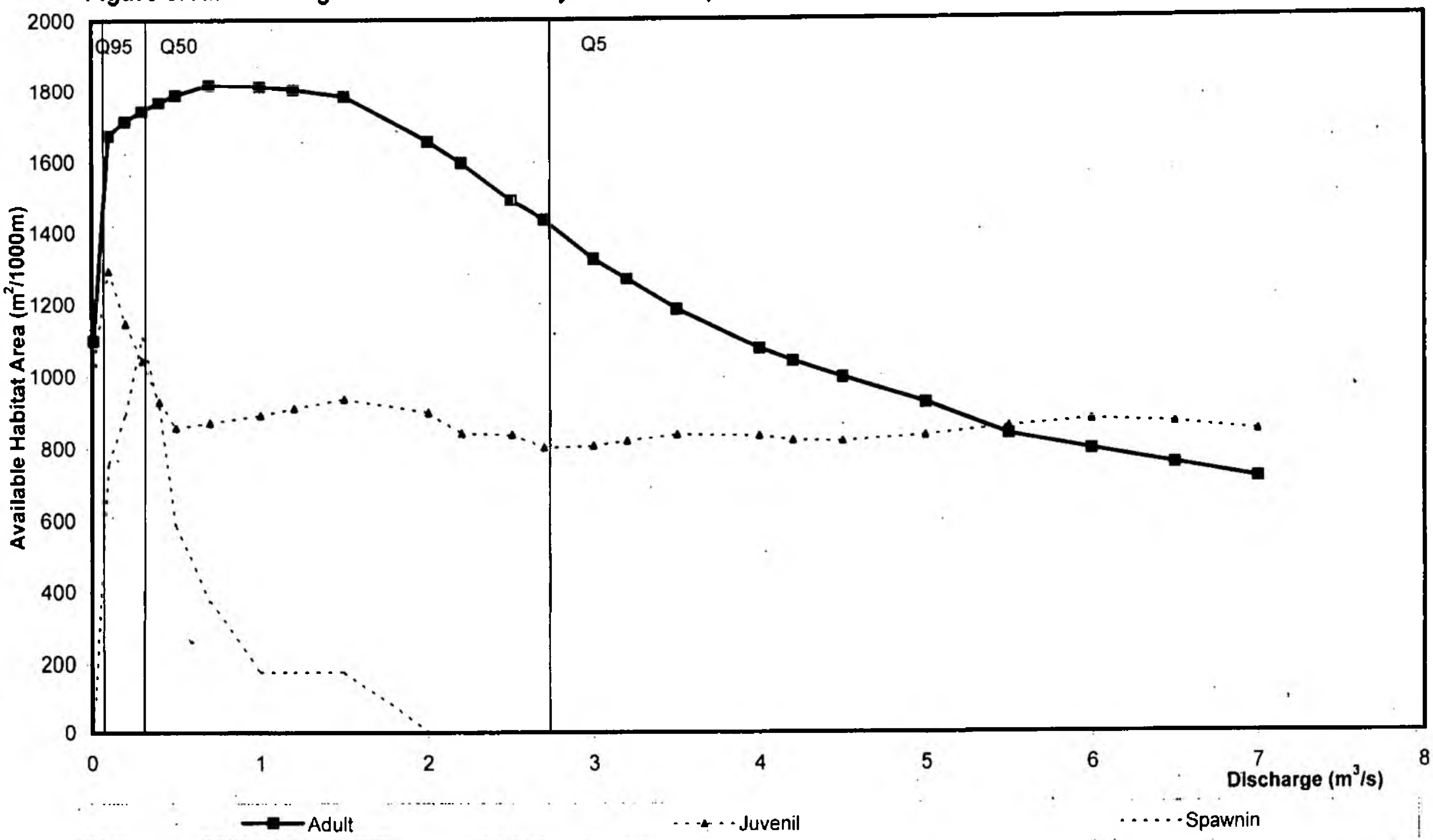
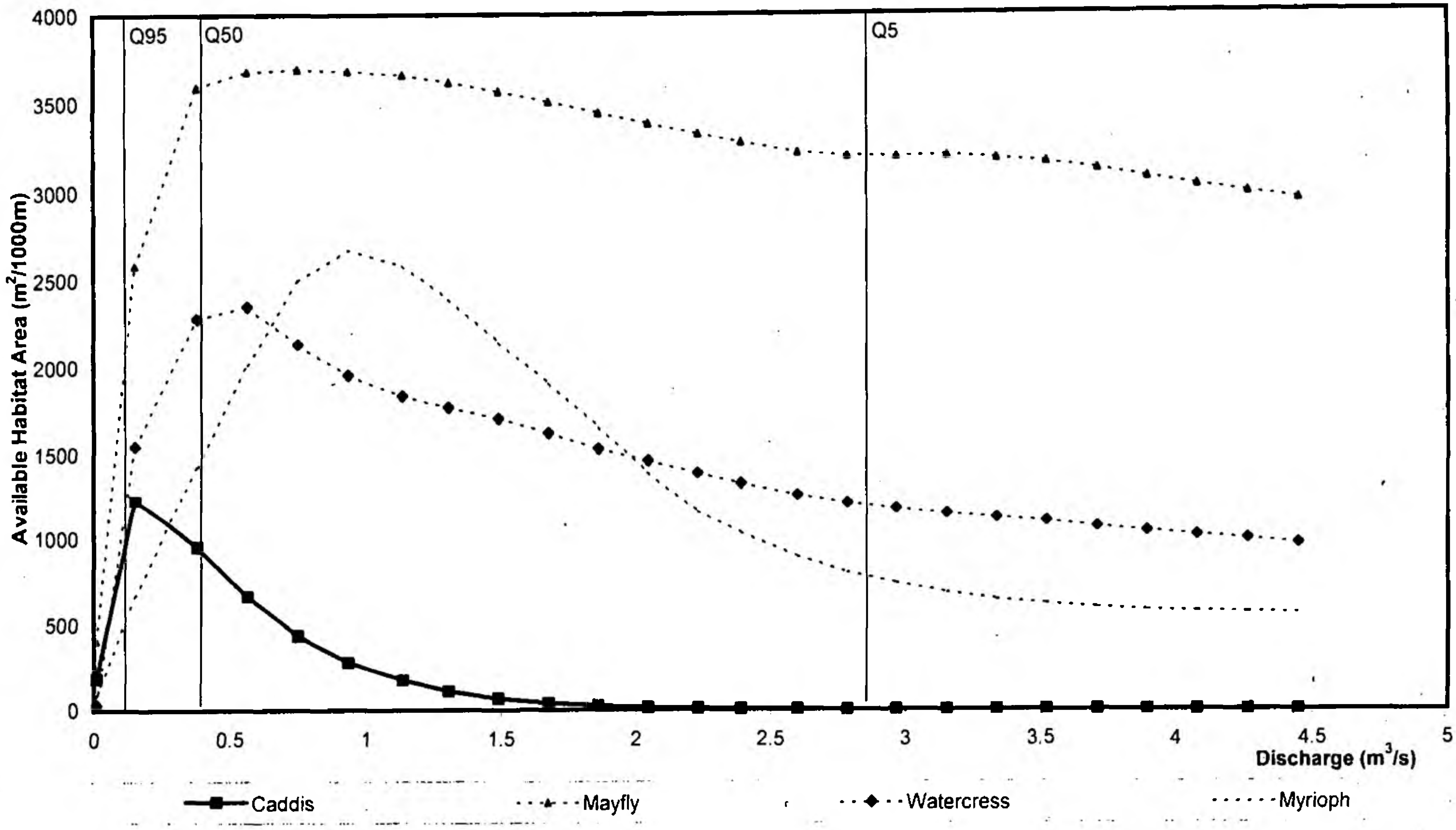


Figure 5.1e. Discharge/Habitat Availability Relationships for Macroinvertebrates and Macrophytes - Stour1 (Kirtling Green)



STOUR 2: BOWERS HALL FARM

5.9 The curve of TAA versus discharge at Bowers Hall Farm is presented in Figure 5.2a, and shows TAA increasing sharply from 6600 to 8200 m^2/1000m as discharge increases from 0.01 to 0.03 m^3/s. As discharge increases beyond this, TAA increases only gradually to a maximum of 10,000 m^2/1000 m at the maximum simulated discharge of 7 m^3/s.

5.10 Figure 5.2b shows the relationship between discharge and WUA for all life stages of brown trout. The WUA curves for all three life stages follow roughly the same pattern: rising to a maximum habitat availability at flows of between 0.5 and 1 m^3/s (which is approximately equal to the historical Q_{50}), and falling away gradually such that the available habitat at the historical Q_5 is approximately 30% of that at Q_{50}, and virtually no habitat is available in the range 6-7 m^3/s.

5.11 Although considerable habitat is available for adult chub at all modelled flows above the historic Q_{95}, much less habitat is available for spawning and juvenile stages than was the case at the Stour 1 site (Kirtling Green) (Figure 5.2c). A moderate area of habitat (up to 1400 m^2/1000 m) is available for spawning chub, between flows of 0.3 and 1.3 m^3/s, but WUA for juveniles does not exceed 150 m^2/1000 m at any of the modelled flows. This is attributed to the deeply-incised nature of the river channel at this site, which causes supra-optimal flow velocity. The small amount of habitat area that is available is due to the presence of marginal areas where both velocity and substrate are suitable.

5.12 As was the case for chub, considerable habitat area (> 4000 m^2/1000 m) is available to adult roach at all modelled flows above the historic Q_{95} (Figure 5.2d). More than 2800 m^2/1000 m of habitat is available to juvenile roach at the lower end of the modelled flow spectrum, but this decreases gradually with increased flow, to approximately 300 m^2/1000 m at the historic Q_1 flow of 7 m^3/s. Although the area of habitat available to spawning roach was similar to that for juveniles at the lower end of the flow spectrum, no habitat is available at flows in excess of 3 m^3/s. As was the case at the Stour 1 site, this is due to the presence of suitable spawning substrate (gravels and cobbles) only in mid-channel, where flow velocity becomes unacceptably high as discharge increases, thus limiting the area of useable habitat.

5.13 Q_{opt} for both macrophyte species and the mayfly family (Ephemeridae) are slightly greater than the historic Q_{50} of 0.7 m^3/s (Figure 5.2e). Mayflies (Family Ephemeridae) are particularly insensitive to increased flows above Q_{50}, with available habitat at Q_5 (3750 m^2/1000 m) over 90% of that at Q_{50}. Predicted available habitat for the two macrophyte species (watercress and water milfoil) at Q_5 was also relatively high (1500 and 2200 m^3/1000 m respectively), which was approximately 50% of that at Q_{opt}. The caddis fly *Hydropsyche pellucidula* appeared to be particularly sensitive to increased flows, with a Q_{opt} of approximately 0.4 m^3/s and virtually no useable habitat available above flows of 2.8 m^3/s.

Figure 5.2a. Discharge/ Total Available Habitat Area Relationship - Stour2 (Bowers Hall Farm)

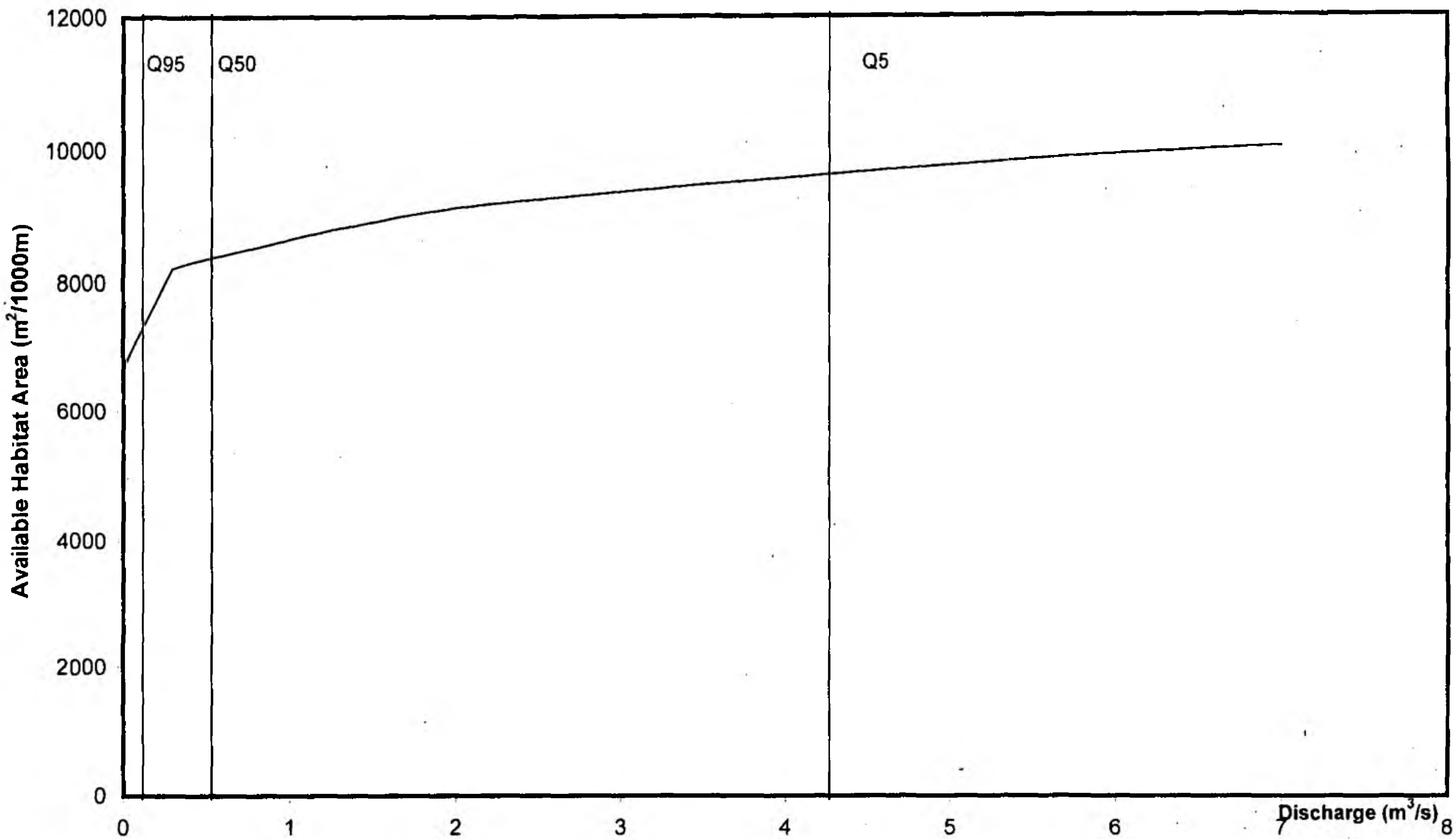


Figure 5.2b. Discharge/ Habitat Availability Relationships for Brown Trout - Stour2 (Bowers Hall Farm)

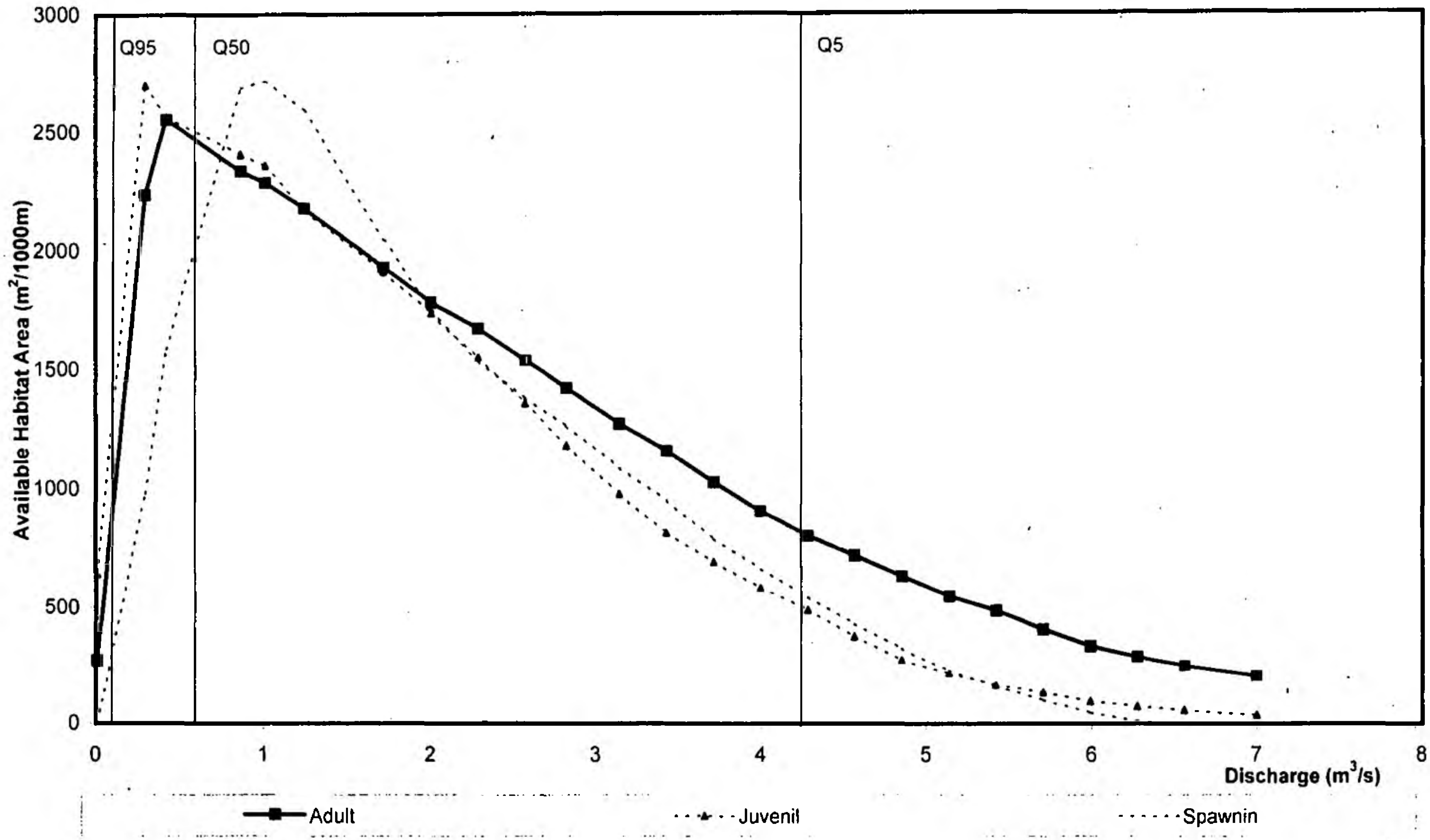


Figure 5.2c. Discharge / Habitat Availability Relationships for Chub - Stour2 (Bowers Hall Farm)

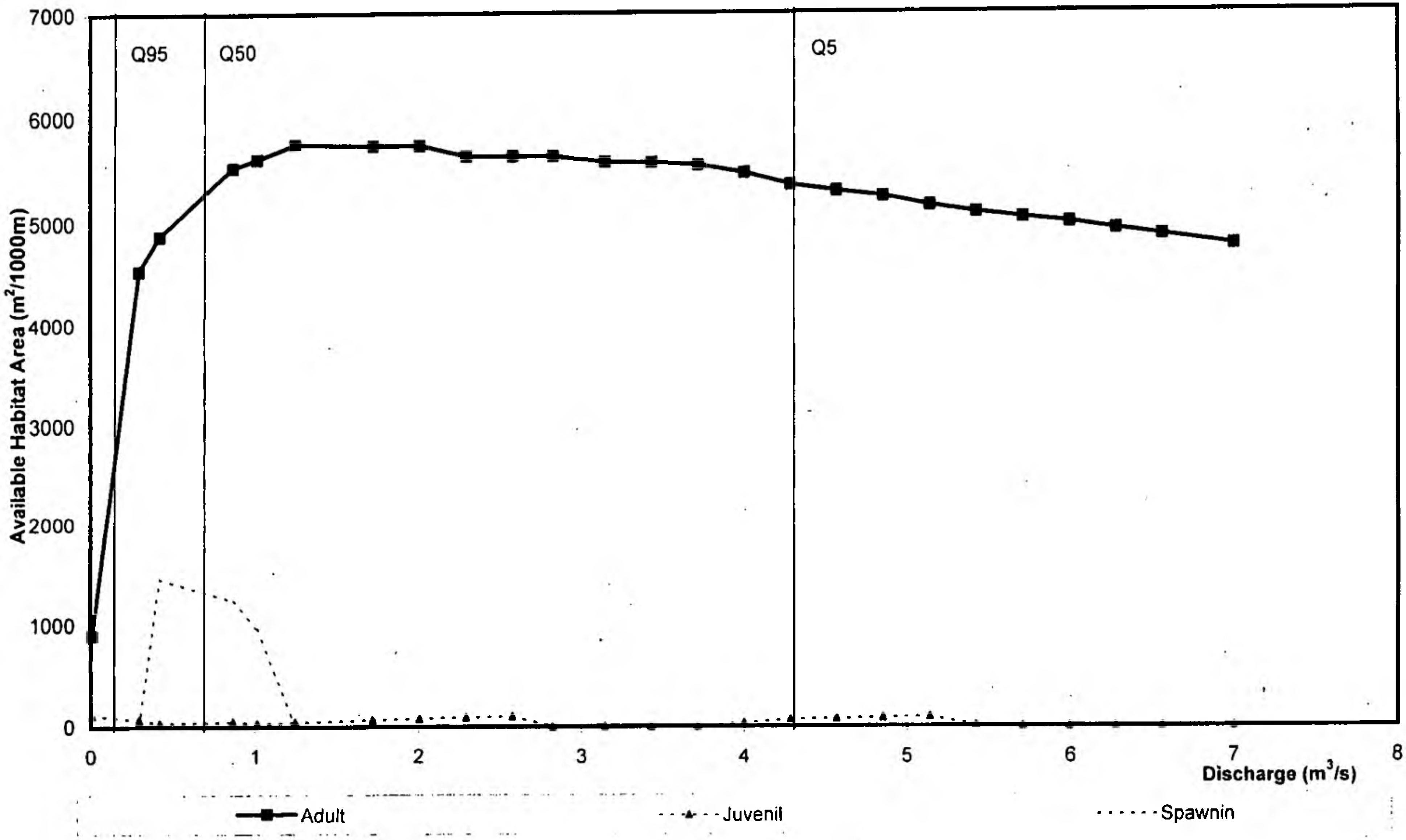


Figure 5.2d. Discharge/ Habitat Availability Relationships for Roach - Stour2 (Bowers Hall Farm)

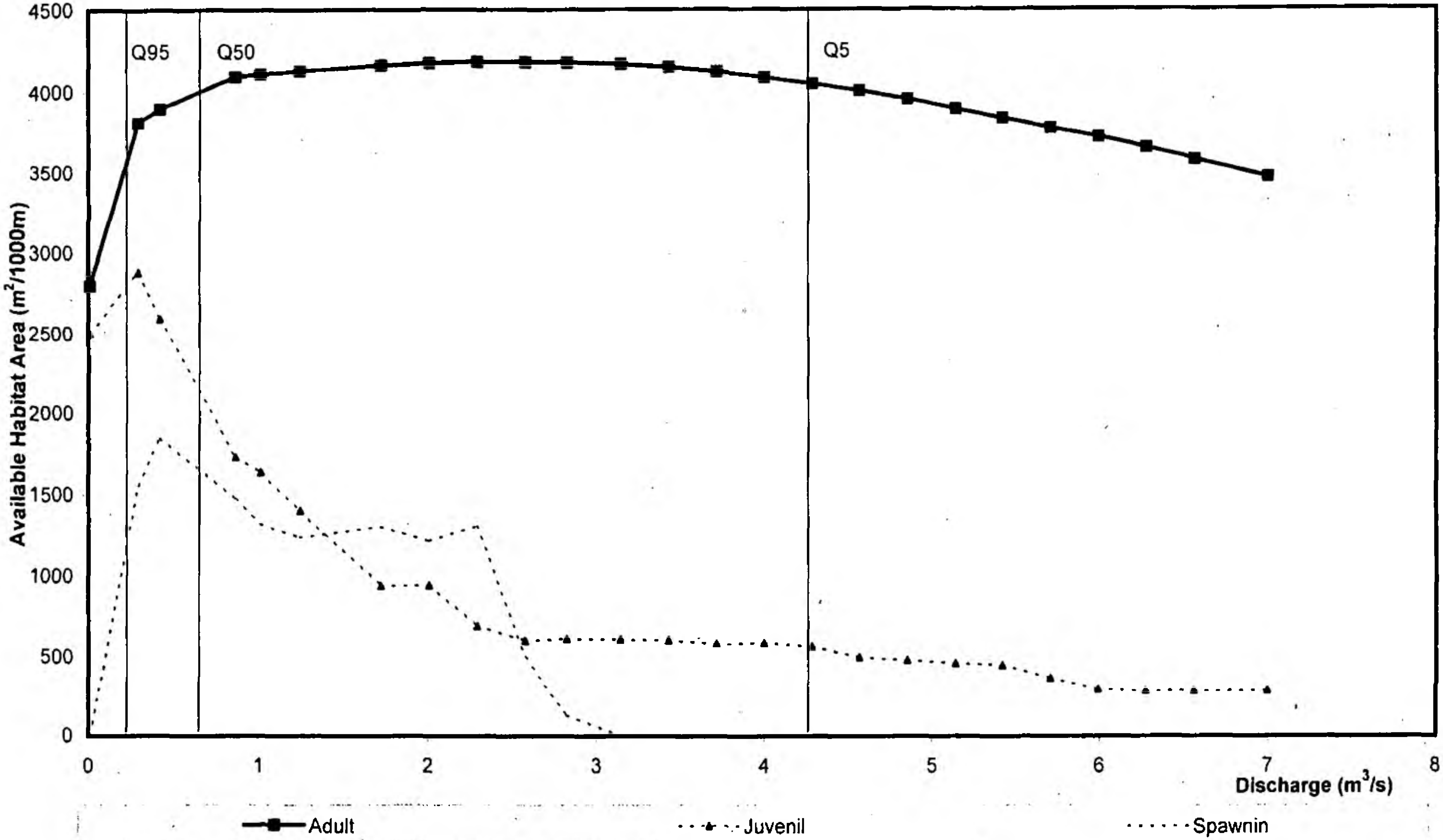
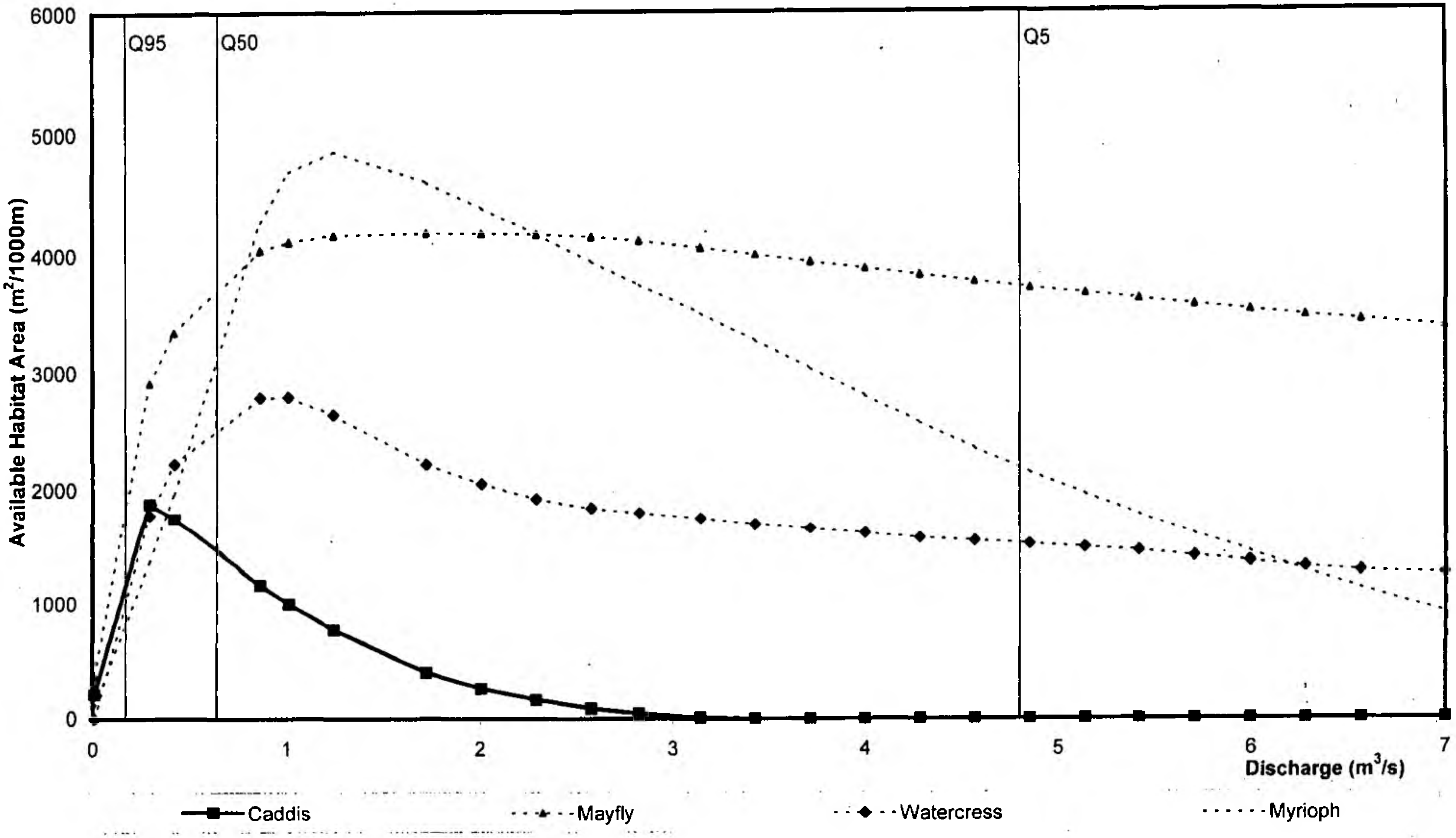


Figure 5.2e. Discharge vs Habitat Availability Relationships Macroinvertebrates and Macrophytes - Stour2 (Bowers Hall Farm)



STOUR 4: LANGHAM

5.14 The curve of TAA versus discharge is presented in Figure 5.3a, and shows TAA increasing sharply from 10,000 to 11,500 m^2/1000 m as discharge increases from 0.01 to 0.45 m^3/s. As discharge increases beyond this, TAA increases only gradually to a maximum of 13,000 m^2/1000 m at the maximum simulated discharge of 15 m^3/s.

5.15 Figure 5.3b shows the effect of discharge on available habitat (WUA) for the three life stages of brown trout. Adult trout were again most tolerant of increased flow, with Q_{opt} approximately equivalent to the historic Q_{50} for this site (1.8 m^3/s) with a WUA of 3400 m^2/1000 m. WUA declines to around 1250 m^2/1000 m as discharge increases to the historic Q_5 of 10 m^3/s. The relationship between discharge and habitat for juveniles is similar to that for adults, although with slightly more habitat available at low flows, and slightly less habitat available at high flows The long right-hand tail of the WUA curve is representative of the continued presence of suitable habitat at the river margins as discharge increases. For spawning trout the Q_{opt} is approximately equivalent to the Q_{50} of 1.8 m^3/s, with a WUA of 2500 m^2/1000 m. A small amount of spawning habitat (200m^2/1000 m) remains available at the historic Q_5.

5.16 It should be noted that the depth and lack of transparency of the water column at this site made accurate assessment of the substrate in mid-channel very difficult without the use of divers. Therefore it is possible that the extent of suitable substrate for all species was underestimated, and therefore the WUA for all species is under-represented.

5.17 WUA plots for adult chub (Figure 5.3c) indicate that Q_{opt} is between 2 and 4 m^3/s, which is slightly above the historic median discharge for this site (1.8 m^3/s). Available habitat in this range is approximately 8500 m^2/1000 m. Considerable habitat was available at all discharges up to the modelled maximum of 15 m^3/s. A small amount of habitat (up to 800 m^2/1000 m) is available for juvenile chub at flows up to 4 m^3/s, again representing suitable marginal habitats.

5.18 No appreciable habitat appeared to be available for spawning chub at any of the modelled flows. This is likely to be due to the difficulty in assessing substrate at this site, and therefore may be an under-representation of the actual habitat available.

5.19 The WUA plots for adult roach (Figure 5.3d) indicate a relatively constant habitat availability of 4000 m^2/1000m up to a discharge of 6 m^3/s. At higher discharges the WUA gradually declines to 2000 m^2/1000m at a discharge of 15 m^3/s. The Q_{opt} for juvenile roach is close to the Q_{95} (0.6 m^3/s) with a WUA of 5500 m^2/1000m. Between Q_{95} and Q_{50} levels decline rapidly to a relatively constant level of 500 m^2/1000m until the maximum modelled discharge of 15 m^3/s is reached. This rapid decline with increasing flow is due to the main river channel becoming unsuitable as flow velocity increases, with habitat becoming increasingly confined to the margins. For spawning roach the Q_{opt} is close to the Q_{50}, where there is a WUA of 3500 m^2/1000m. This gradually declines as velocity increases, with no habitat available for spawning roach above 6 m^3/s.

5.20 WUA plots for macrophyte and invertebrate species are shown in Figure 5.3e. Q_{opt} for both plant species and the mayfly family (Ephemeridae) are similar to the historic Q_{50} of 1.8 m^3/s. WUA for the caddis fly *Hydropsyche pellucidula* is much lower than for other taxa examined, at less than 1000 m^2/1000 m at Q_{opt} (0.5 m^3/s). Both invertebrate taxa and watercress are relatively insensitive to increasing discharge, but WUA for *Myriophyllum* declines most rapidly, to around 30% of the optimum at flows equivalent to the historical Q_5.

Figure 5.3a. Discharge / Total Available Habitat Area Relationship - Stour4 (Langham)

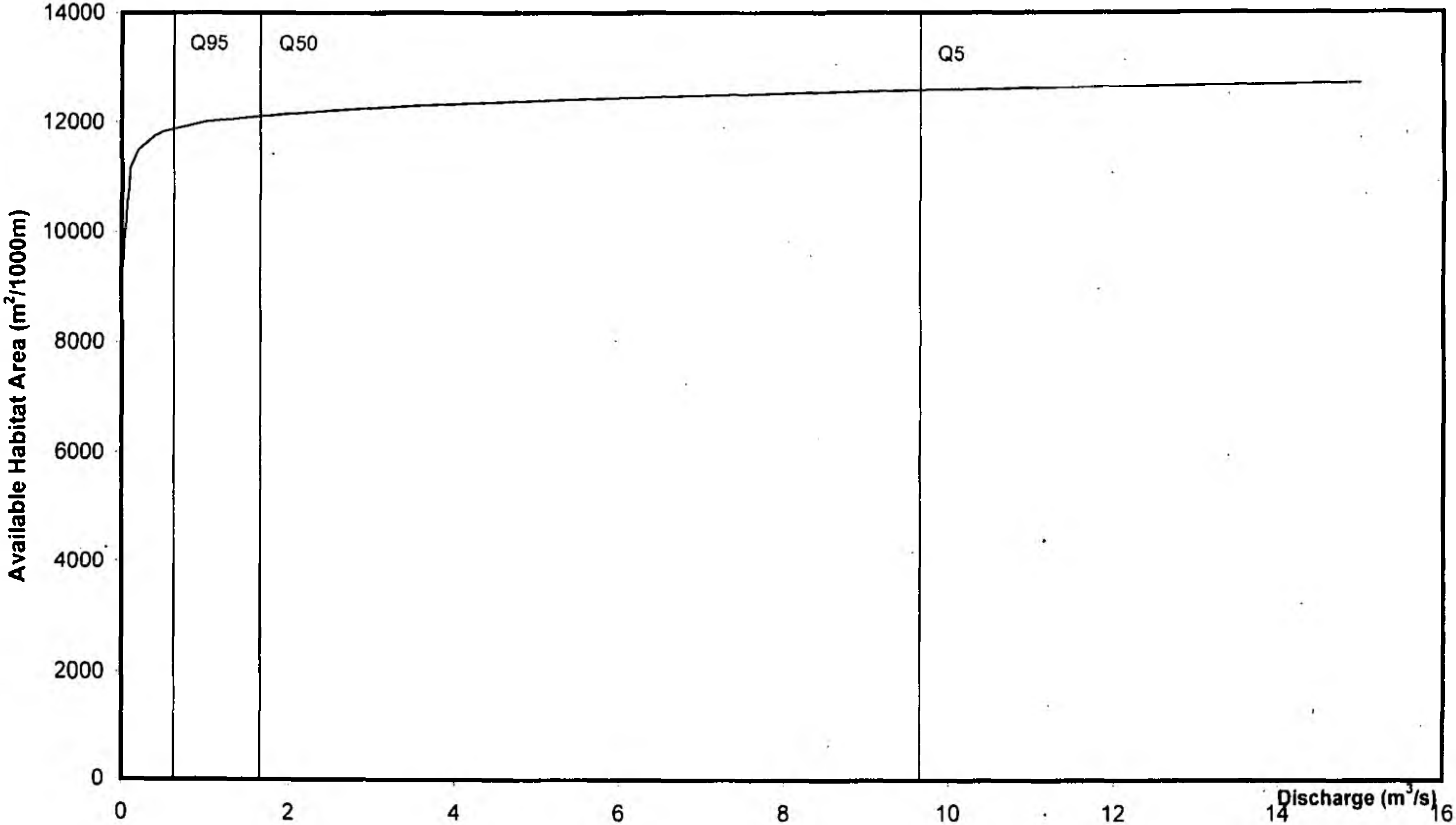


Figure 5.3b. Discharge/ Habitat Availability Relationships for Brown Trout - Stour4 (Langham)

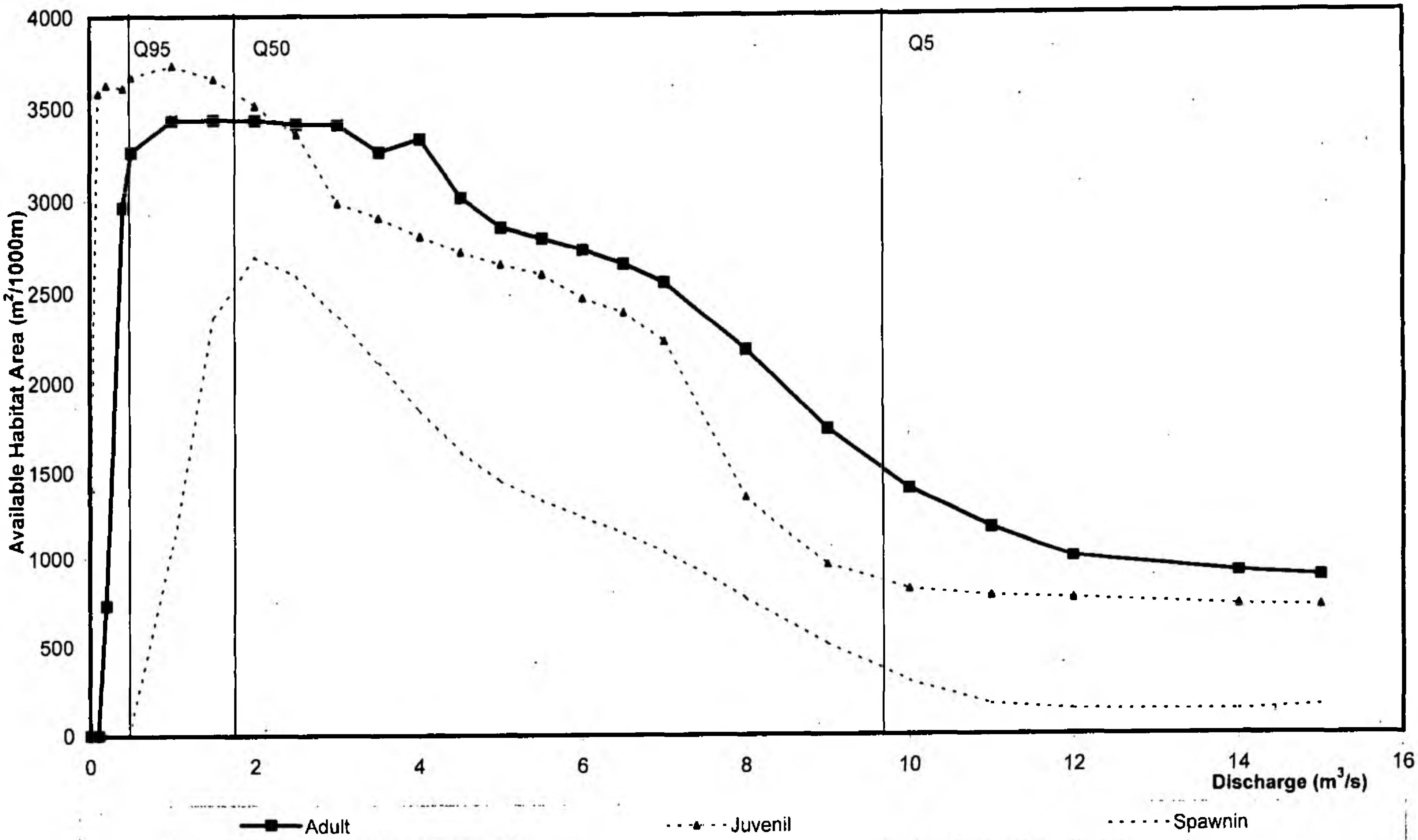


Figure 5.3c. Discharge/ Habitat Availability Relationships for Chub - Stour4 (Langham)

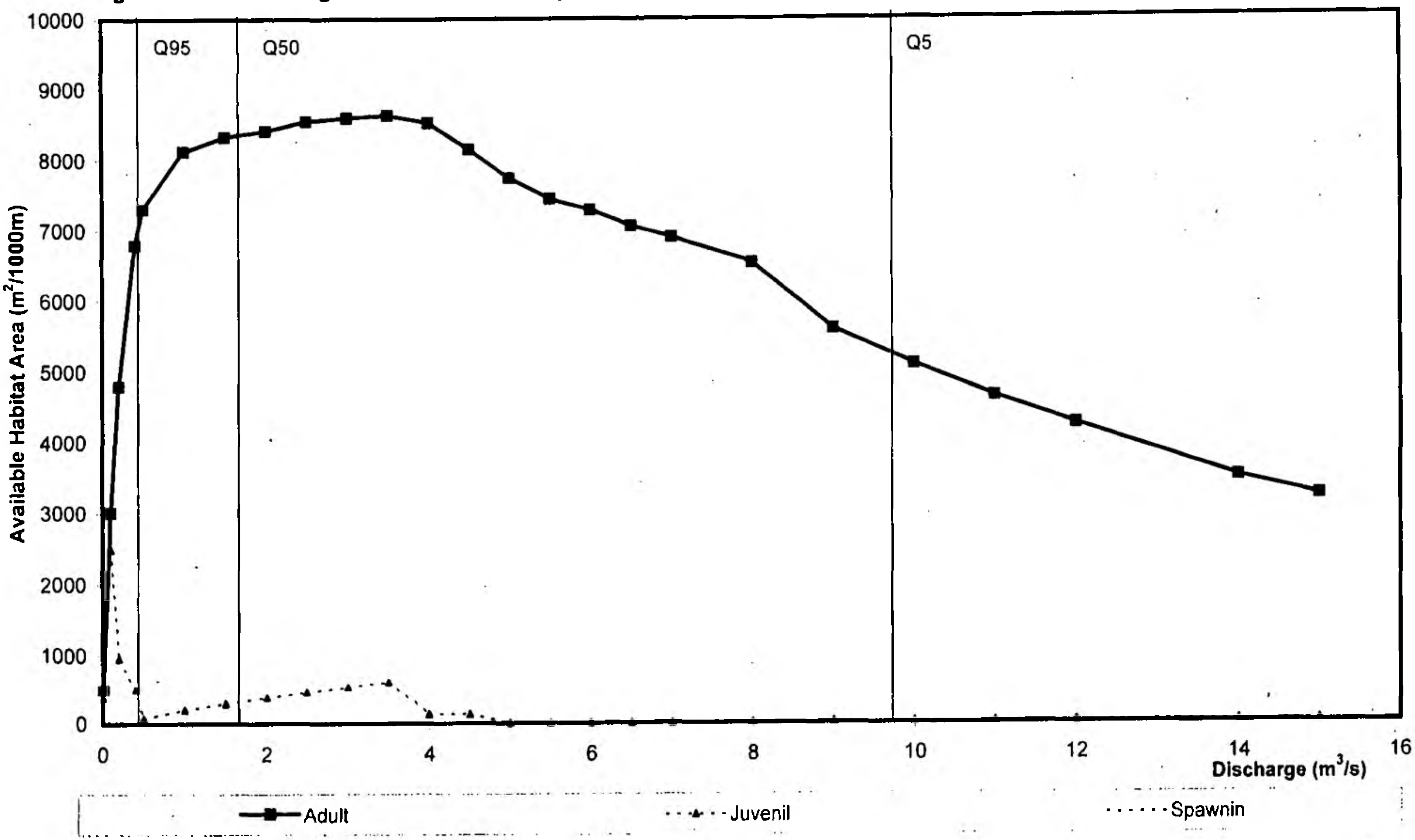


Figure 5.3d. Discharge/ Habitat Availability Relationships for Roach -Stour4 (Langham)

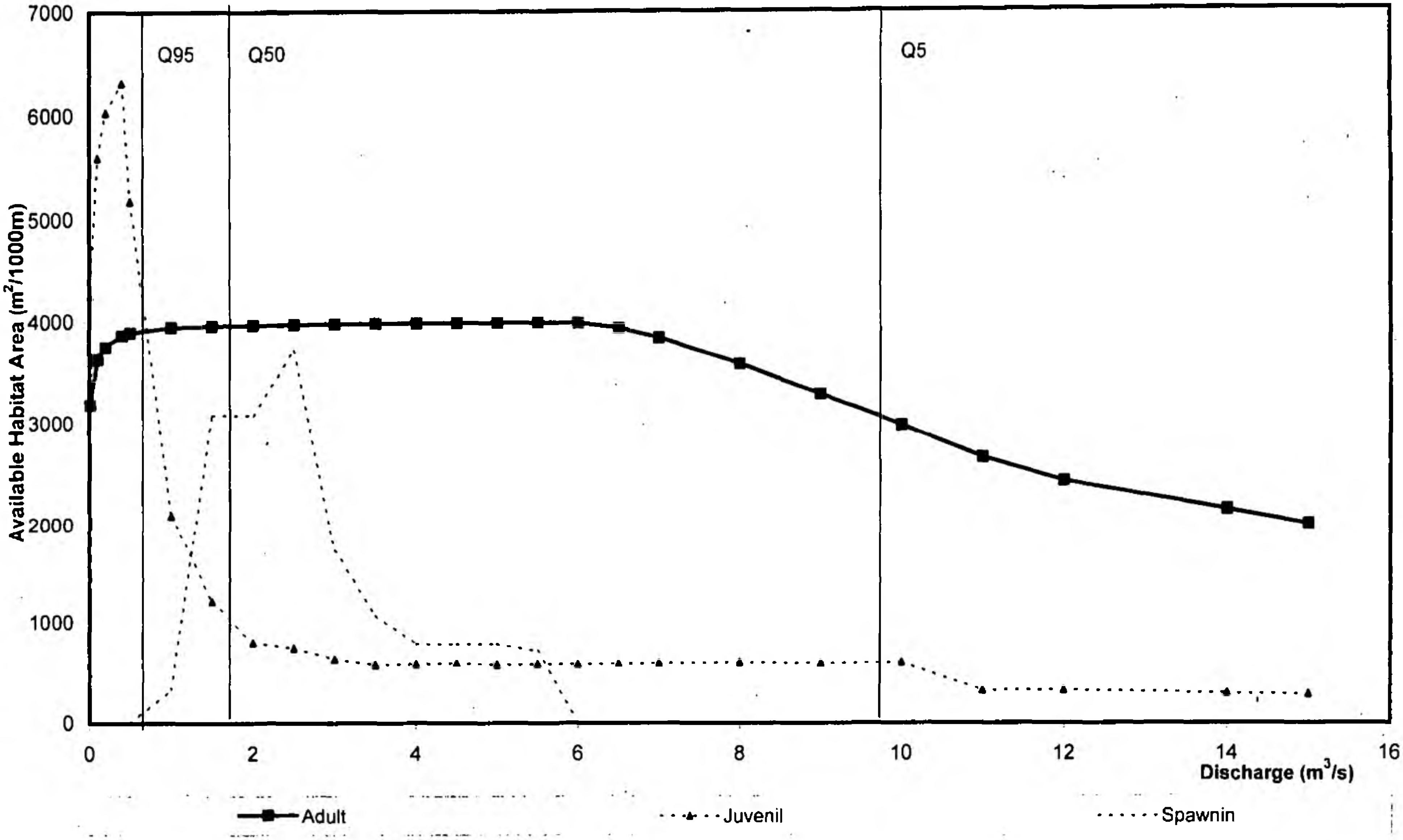
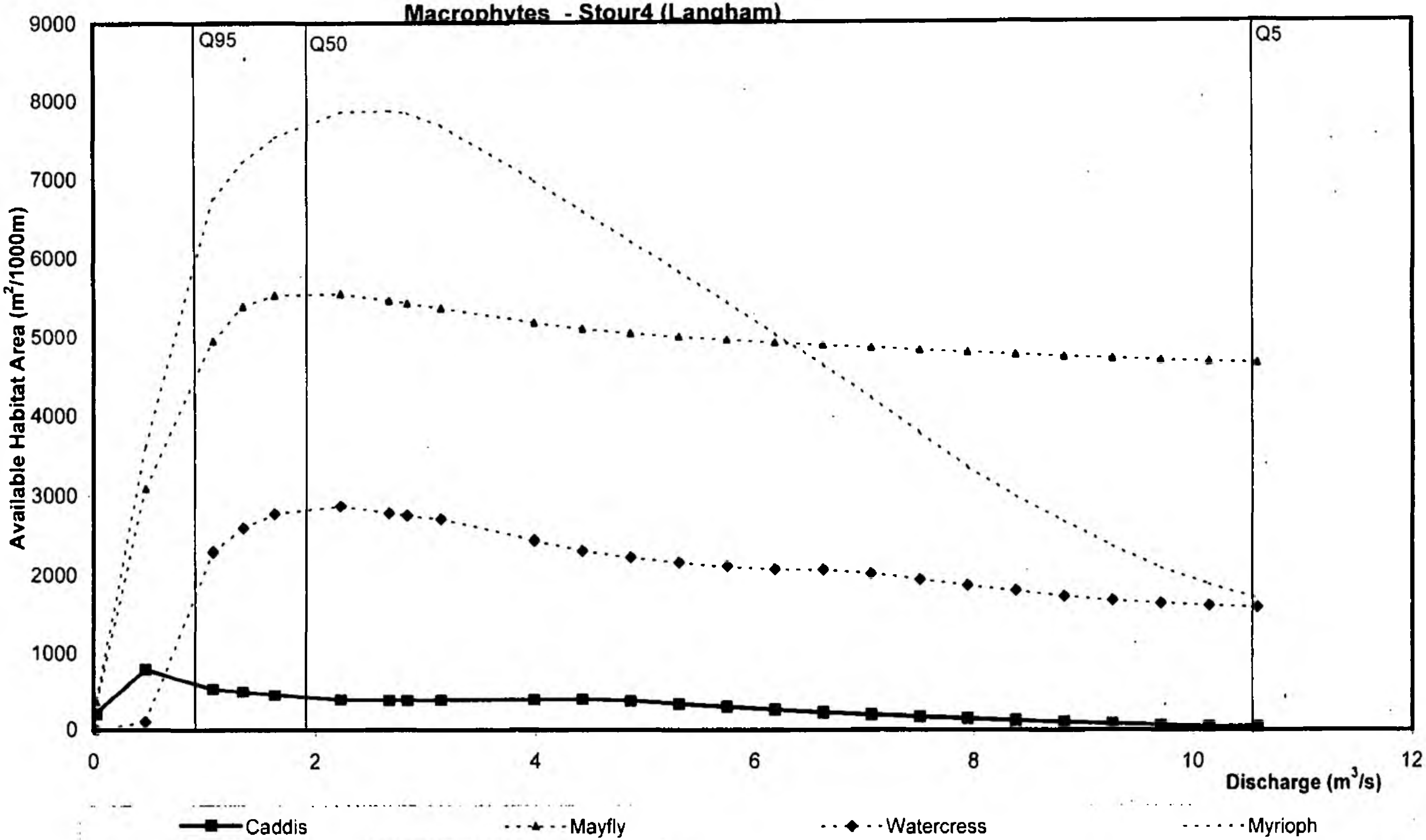


Figure 5.3e. Discharge vs Habitat Availability Relationships for Macroinvertebrates and Macrophytes - Stour4 (Langham)



PANT 1: GREAT SAMPFORD OUTFALL

5.21 The curve of TAA versus discharge is presented in Figure 5.4a, and shows TAA increasing sharply from 2800 to 3500 m^2/1000 m as discharge increases from 0.01 to 0.1 m^3/s. As discharge increases beyond this, TAA increases gradually to a maximum of approximately 4900 m^2/1000 m at the maximum simulated discharge of 3 m^3/s.

5.22 Figure 5.4b shows the effect of discharge on available habitat (WUA) for all life stages of brown trout. Although the WUA as a percentage of TAA is rather low, all life stages have Q_{opt} greater than the historic Q_{50} (0.14 m^3/s), indicating that increased median flows could potentially increase the available habitat for brown trout. Q_{opt} for adult and juvenile trout is in the region of 0.5 m^3/s, which is approximately equivalent to the historic Q_{20}, and WUA for both declines gradually to around 75% of that at Q_{opt} at the historic Q_5. Total available habitat suitable for spawning is reasonable, with 400 m^2/1000 m at Q_{opt}. Maximum WUA is available for spawning between discharges of 0.3 and 1.0 m^3/s, although a small amount of useable habitat (approximately 150 m^2/1000m) is still present at the maximum simulated discharge. Spawning habitat appears to be limited by lack of suitable substrate.

5.23 WUA plots for chub (Figure 5.4c) indicate that Q_{opt} for adult chub is between 0.5 and 1.5 m^3/s, which is greater than the historic Q_{50} (0.2 m^3/s). The plots indicate that more habitat is available for adult chub than for adult trout, and that adult life chub would not be particularly sensitive to increased river discharges, with WUA remaining relatively constant up to the historic Q_5 (1.4 m^3/s). Beyond the Q_5 the WUA declines gradually to 2400 m^2/1000m by 3 m^3/s.

5.24 WUA is low for both other life stages of chub. Most habitat is available for juvenile chub at the lowest modelled flow, although the WUA never exceeds 500 m^2/1000m. This is interpreted as being the result of tight flow velocity preferences in the HSI curves, which reflects the field and laboratory studies in the literature. There is no appreciable habitat for spawning chub at any flows at this site, probably as a result of depth limitation.

5.25 Figure 5.4d illustrates WUA at modelled discharges for the life stages of roach. The Q_{opt} band for adult roach is wide, and covers flows between 0.2 m^3/s (the historic Q_{50}) and 1.4 m^3/s (the historic Q_5). The maximum WUA is approximately 2250 m^2/1000m, declining to 1600 m^2/1000 m at 3 m^3/s. Q_{opt} for juvenile roach is 0.1 m^3/s (equivalent to the Q_{95}), with a WUA of 1900 m^2/1000m. Between Q_{opt} and 0.5 m^3/s habitat for this life stage declines rapidly with increasing flows to less than 400 m^2/1000 m at the historic Q_5 flow (1.4 m^3/s). For spawning roach, the Q_{opt} is 0.7 m^3/s, with a WUA of 600 m^2/1000m. Above Q_5, WUA for spawning roach declines, with no habitat available beyond 2.0 m^3/s. As was the case at other sites, the decline in spawning habitat with increasing discharge (which is more pronounced than the decrease in juvenile habitat), is due to suitable spawning substrate being located mainly in mid-channel, where flow velocities rapidly become supra-optimal as discharge increases.

5.26 Q_{opt} for both macrophyte species and the mayfly family (Ephemeridae) are slightly greater than the historic Q_{50} of 0.14 m^3/s (Figure 5.4e). Mayflies are again particularly insensitive to increased flows above Q_{opt}, with available habitat at Q_5

(1450 m^2/1000 m) over 90% of that at Q_{opt}. Predicted available habitat for the two macrophyte species (watercress and water milfoil) is also relatively insensitive to increasing discharges with WUA at Q_5 approximately 85% and 75% of WUA at Q_{opt}. WUA for the caddis fly *Hydropsyche pellucidula*, however is particularly sensitive to increased flows, with a Q_{opt} of approximately 0.1 m^3/s (equivalent to Q_{50}) and virtually no useable habitat available above flows over the historic Q_5.

Figure 5.4a. Discharge vs Total Available Habitat Area Relationship - Pant 1 (Great Sampford)

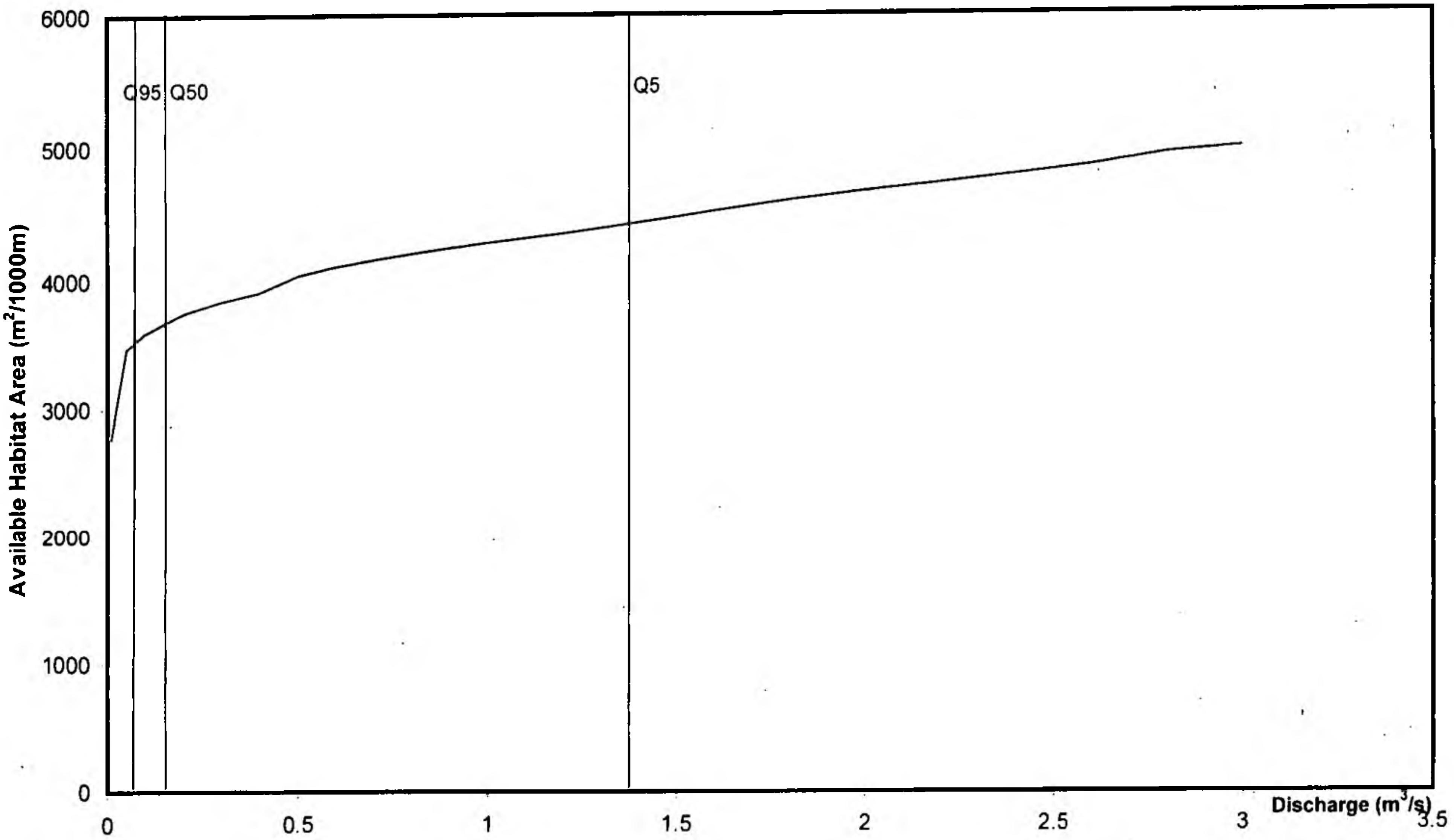


Figure 5.4b. Discharge / Habitat Availability Relationships for Brown Trout - Pant1 (Great Sampford)

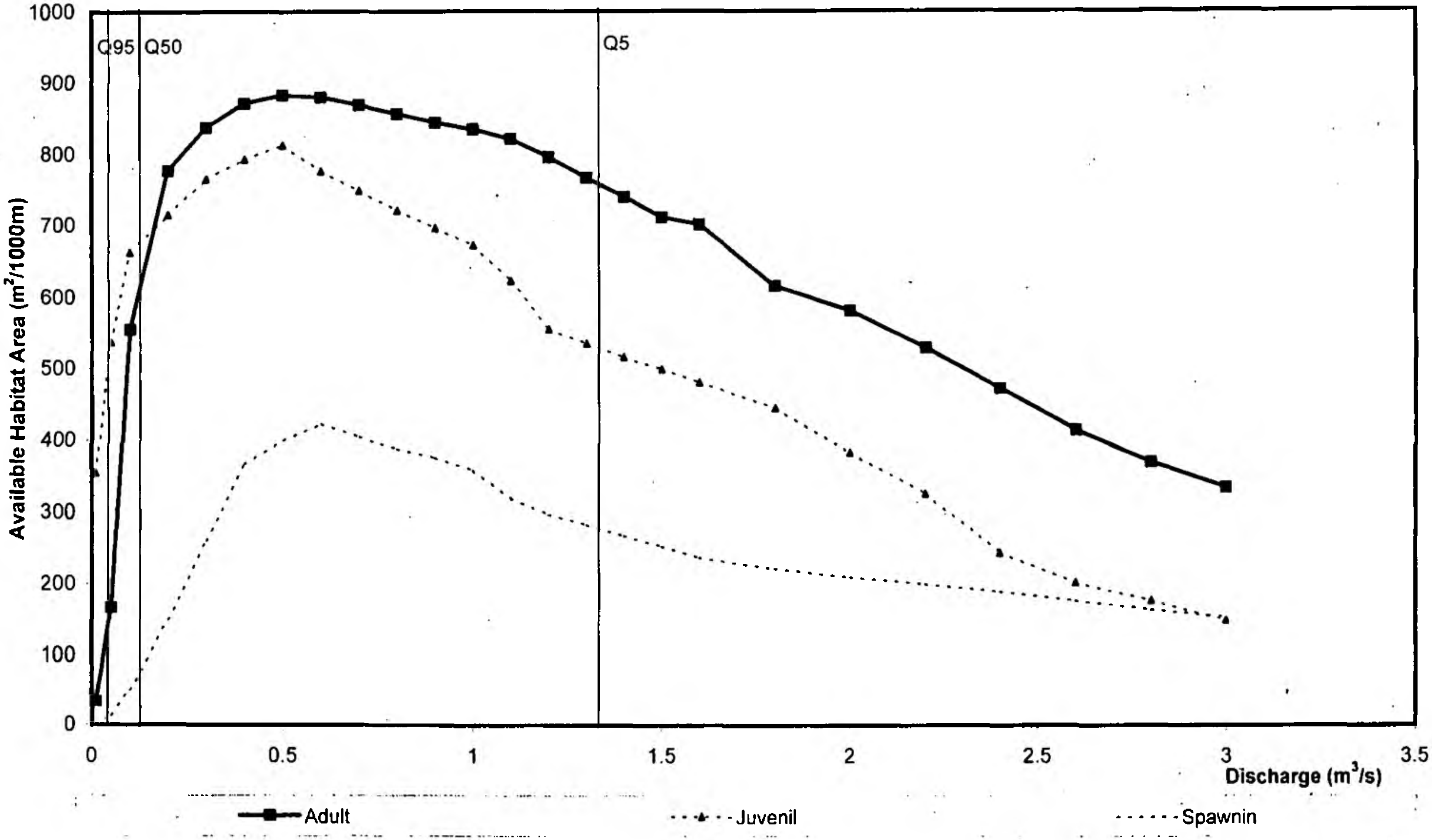


Figure 5.4c. Discharge/ Habitat Availability Relationships for Chub - Pant1 (Great Sampford)

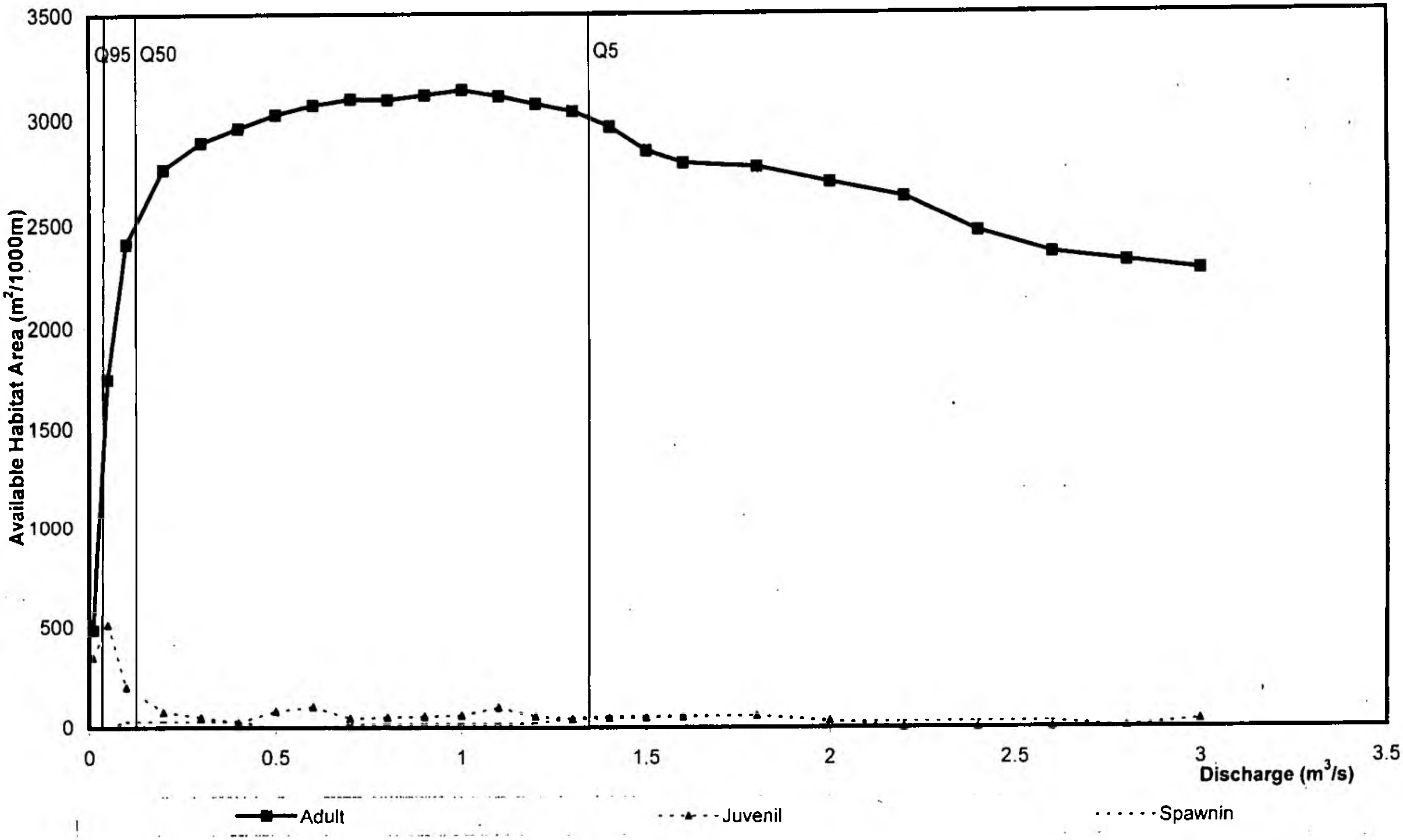


Figure 5.4d. Discharge/ Habitat Availability Relationships for Roach - Pant1 (Great Sampford)

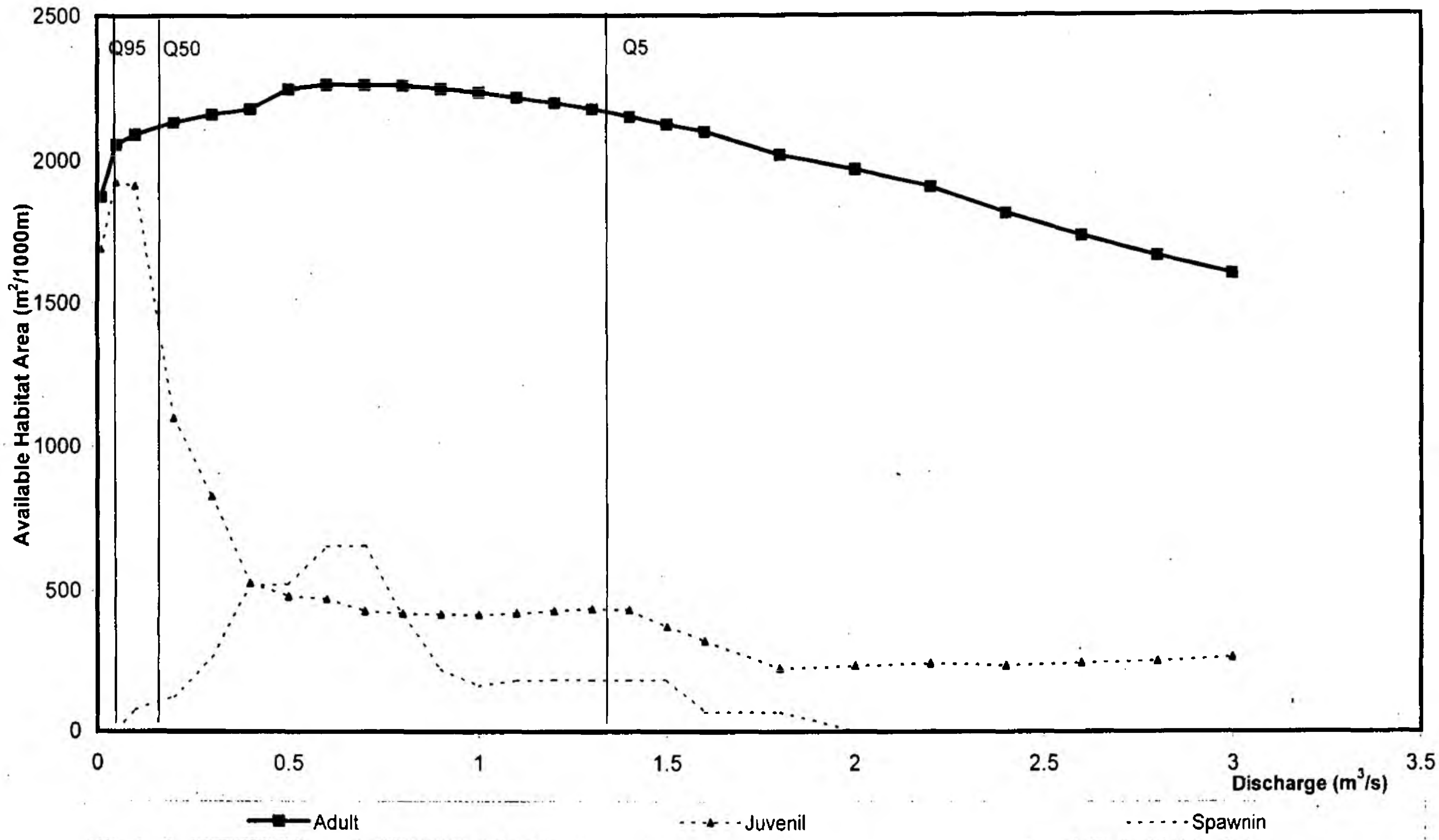
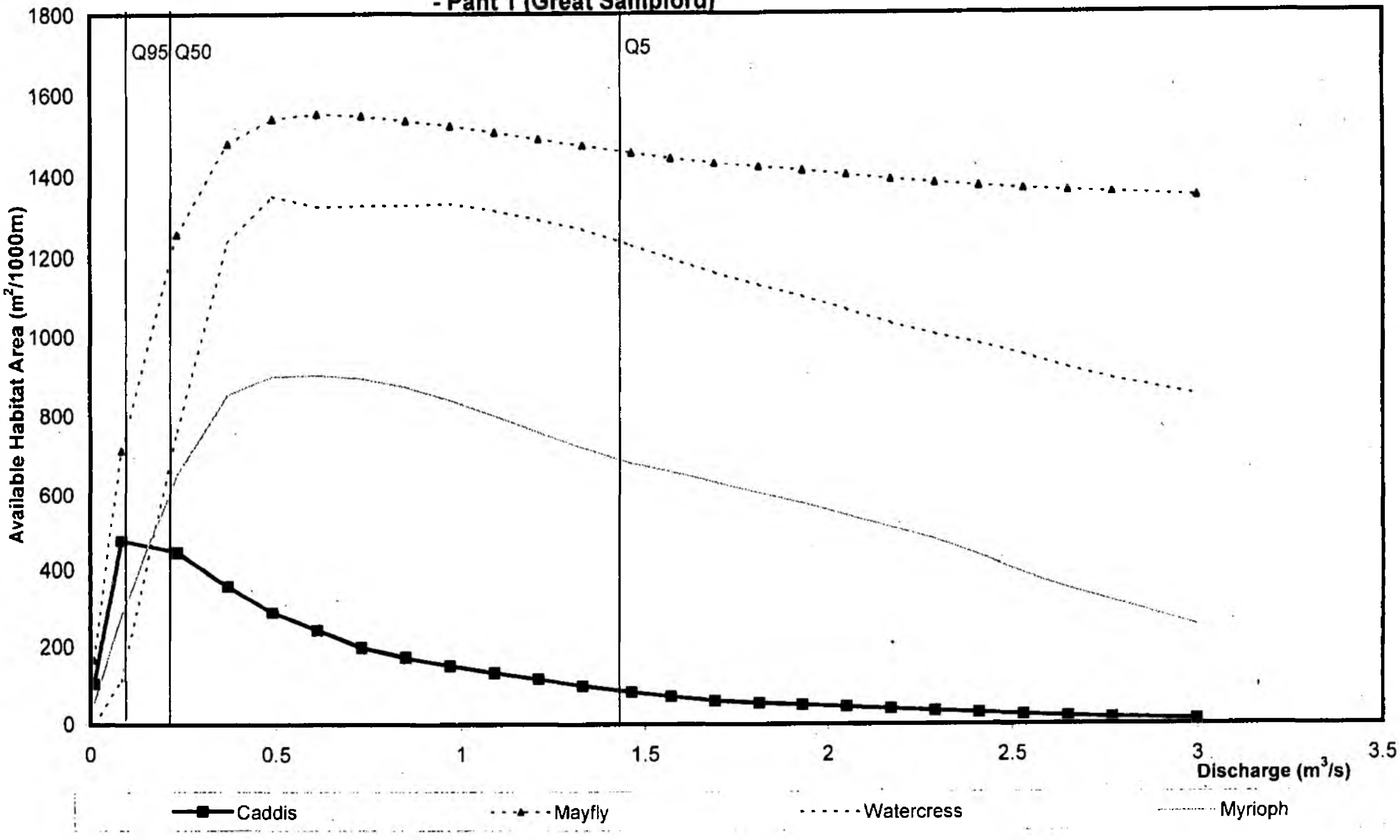


Figure 5.4e. Discharge vs Habitat Availability Relationships for Macroinvertebrates and Macrophytes - Pant 1 (Great Sampford)



PANT 2: LITTLE SAMPFORD

5.27 The curve of TAA versus discharge is presented in Figure 5.5a, and shows TAA increasing sharply from 3250 to 4200 m^2/1000 m as discharge increases from 0.01 to 0.1 m^3/s. As discharge increases beyond this, TAA increases gradually to a maximum of approximately 5100 m^2/1000 m at the maximum simulated discharge of 3 m^3/s. This represents a slight increase in TAA from the upstream site at Great Sampford, as would be expected given the slightly wider river channel.

5.28 Figure 5.5b shows the effect of discharge on available habitat (WUA) for all life stages of brown trout. All life stages have Q_{opt} between 0.25 and 0.6 m^3/s, which is slightly higher than the historic Q_{50}. Spawning brown trout have the highest WUA of 2800 m^2/1000 m, declining to 70% of this value at the Q_5. This appears to be due to the predominance of suitable spawning substrate (gravels and cobbles) at this site. The WUA available to juveniles declines steadily from 2250 m^2/1000 m at Q_{opt} to 175 m^2/1000m at a discharge of 3 m^3/s. Adult trout exhibit a very similar curve to juvenile life stages. The curves indicate that moderate increases in median flows would not be detrimental to the habitat for brown trout at this site.

5.29 WUA plots for adult chub (Figure 5.5c) indicate that Q_{opt} for this life stage is around 0.5 m^3/s, which is greater than the historic Q_{50} flow (0.2 m^3/s). WUA decreases gradually as flows increase beyond this to a value of 1600 m^2/1000 m at 3 m^3/s. There is some available habitat for chub spawning at all flows between 0.15 and 1.5 m^3/s. The Q_{opt} is 0.5 m^3/s with a WUA of 1000 m^2/1000 m. No habitat is present beyond 1.5 m^3/s. While a very small amount of habitat is available for juvenile chub at very low flows, none is available at flows above 0.3 m^3/s, which reflects the detrimental effect of high flow velocity on this life stage.

5.30 Figure 5.5d shows WUA curves for the various life stages of roach. Q_{opt} for adults is in the region of 0.2 to 1.0 m^3/s, with a WUA of approximately 2000 m^2/1000m. At the maximum simulated discharge of 3 m^3/s, the WUA was still about 50% of that available at Q_{opt}. The Q_{opt} for juvenile roach is at Q_{95}: habitat then declines to below 100m^2 /1000m at discharges above 0.4 m^3/s. Spawning roach has a Q_{opt} of 0.3 m^3/s with a WUA of 1000 m^2/1000. This declines rapidly with increased discharge: above 1.5 m^3/s, no habitat is available.

5.31 Q_{opt} for both macrophyte species and the invertebrate species are slightly greater than the historic Q_{50} of 0.2 m^3/s (Figure 5.5e). Mayflies (Family Ephemeridae) are again particularly insensitive to increased flows above Q_{opt}, with available habitat falling less than 15% from 3000 m^2/1000 m at Q_{opt} over the range of modelled discharges. Predicted available habitat for the two macrophyte species (watercress and water milfoil) is also relatively insensitive to increasing discharges with WUA at Q_5 approximately 60% and 80% of WUA at Q_{opt} respectively. As at other sites, WUA for the caddis fly *Hydropsyche pellucidula* is extremely sensitive to increased flows, with a Q_{opt} of approximately 0.25 m^3/s (equivalent to Q_{50}) and virtually no useable habitat available above flows over the historic Q_5 (1.4 m^3/s).

Figure 5.5a. Discharge vs Total Available Habitat Area Relationships - Pant 2 (Little Sampford)

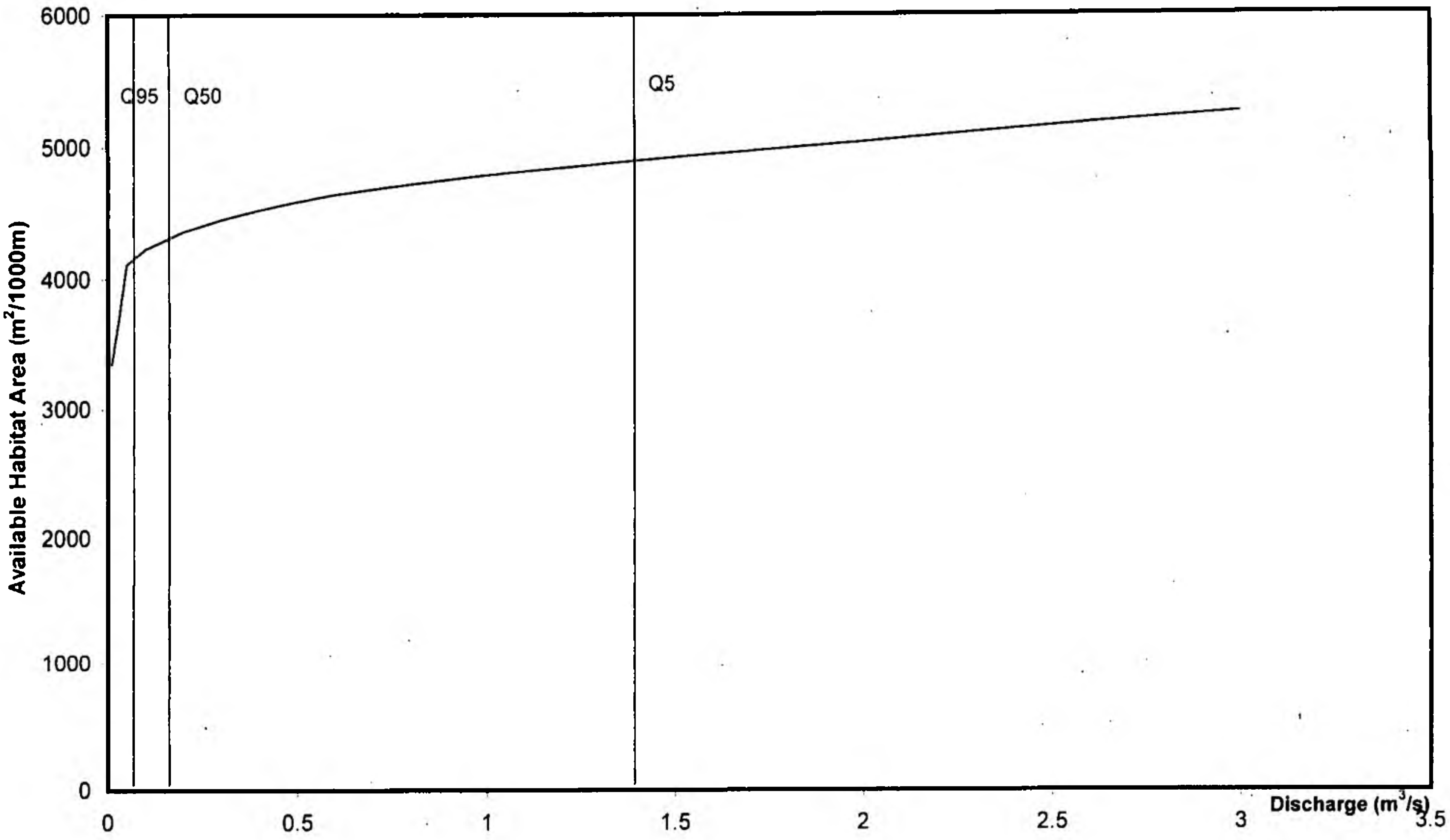


Figure 5.5b. Discharge/ Habitat Availability Relationships for Brown Trout - Pant2 (Little Sampford)

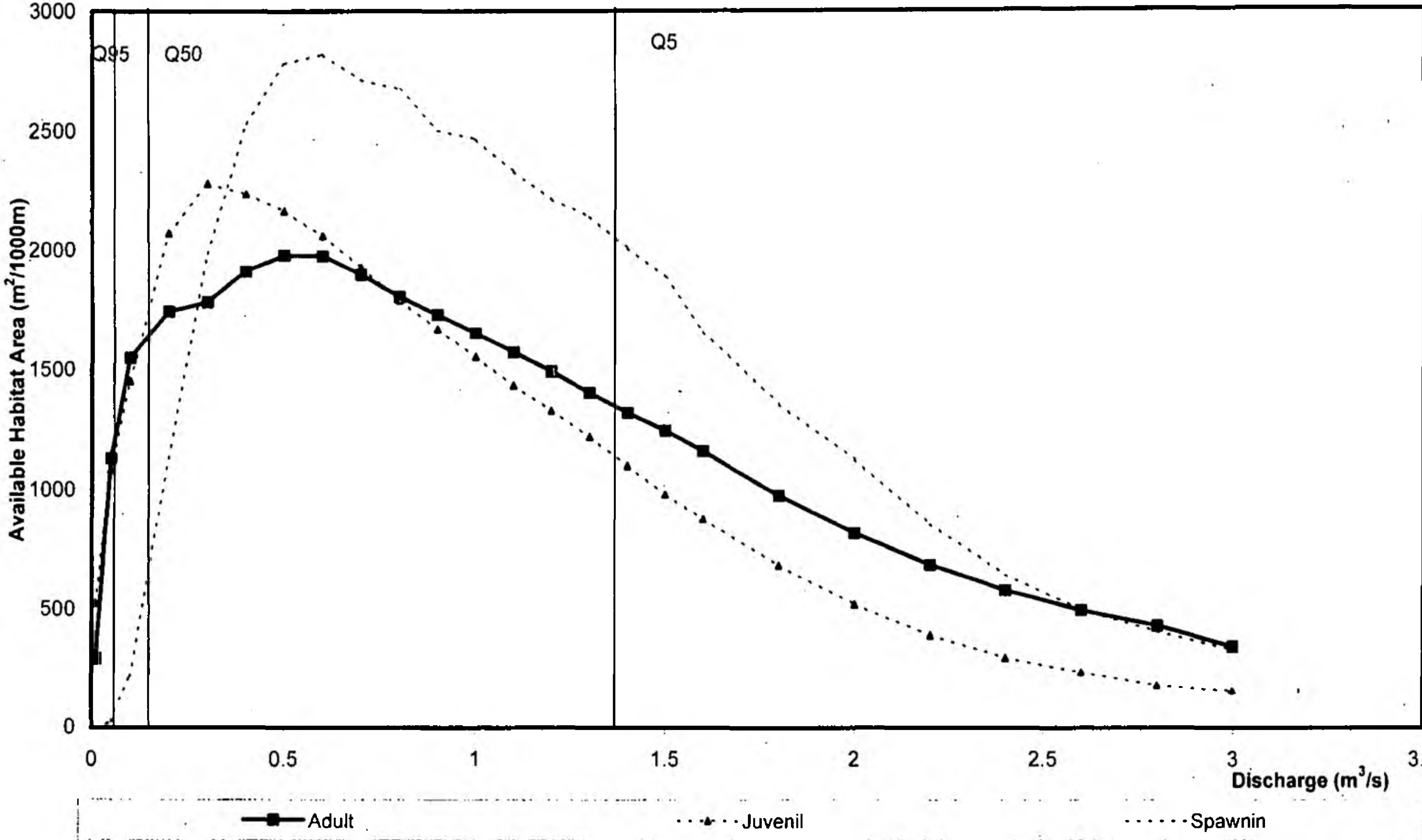


Figure 5.5c. Discharge/ Habitat Availability Relationships for Chub - Pant2 (Little Sampford)

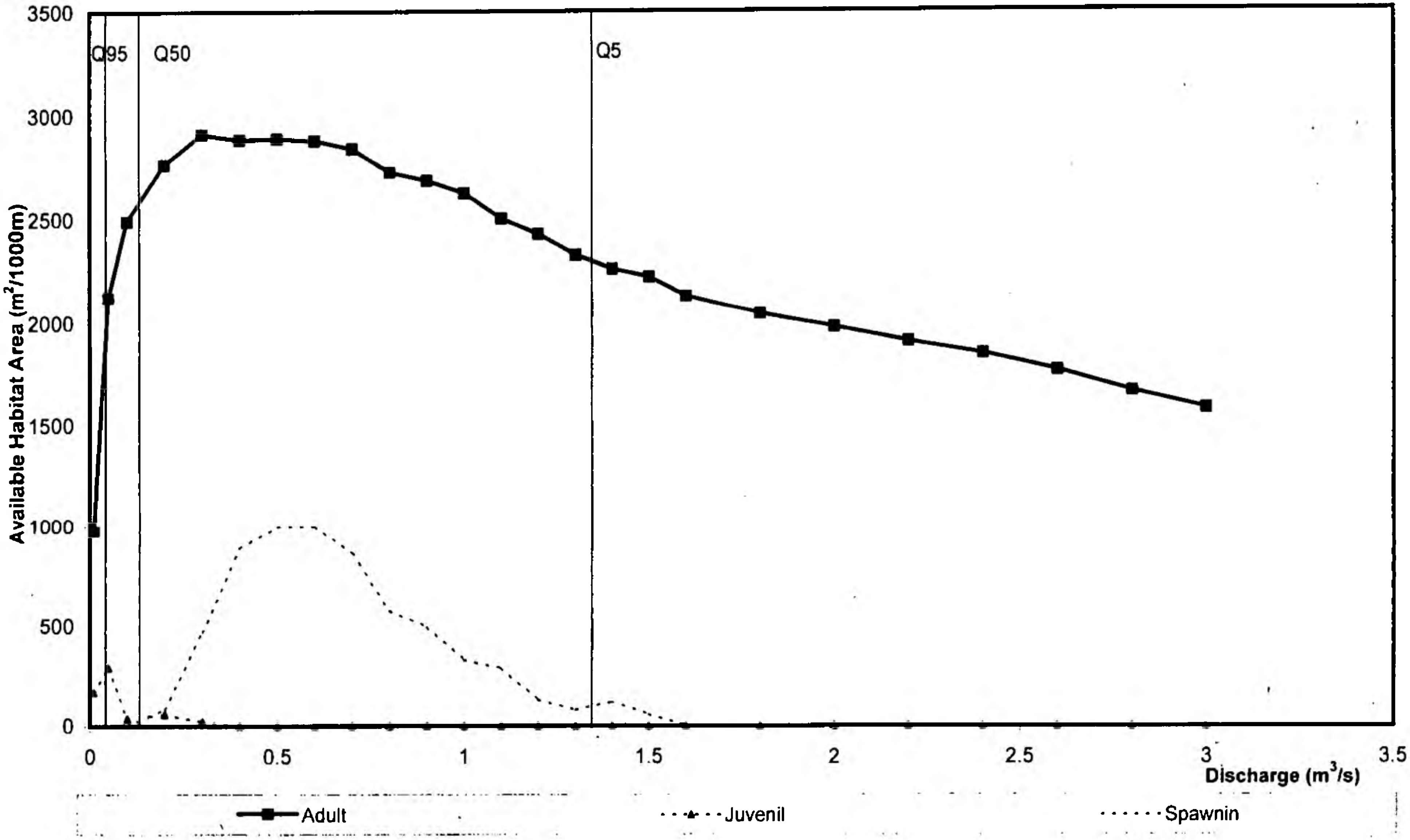


Figure 5.5d. Discharge/ Habitat Availability Relationships for Roach - Pant2 (Little Sampford)

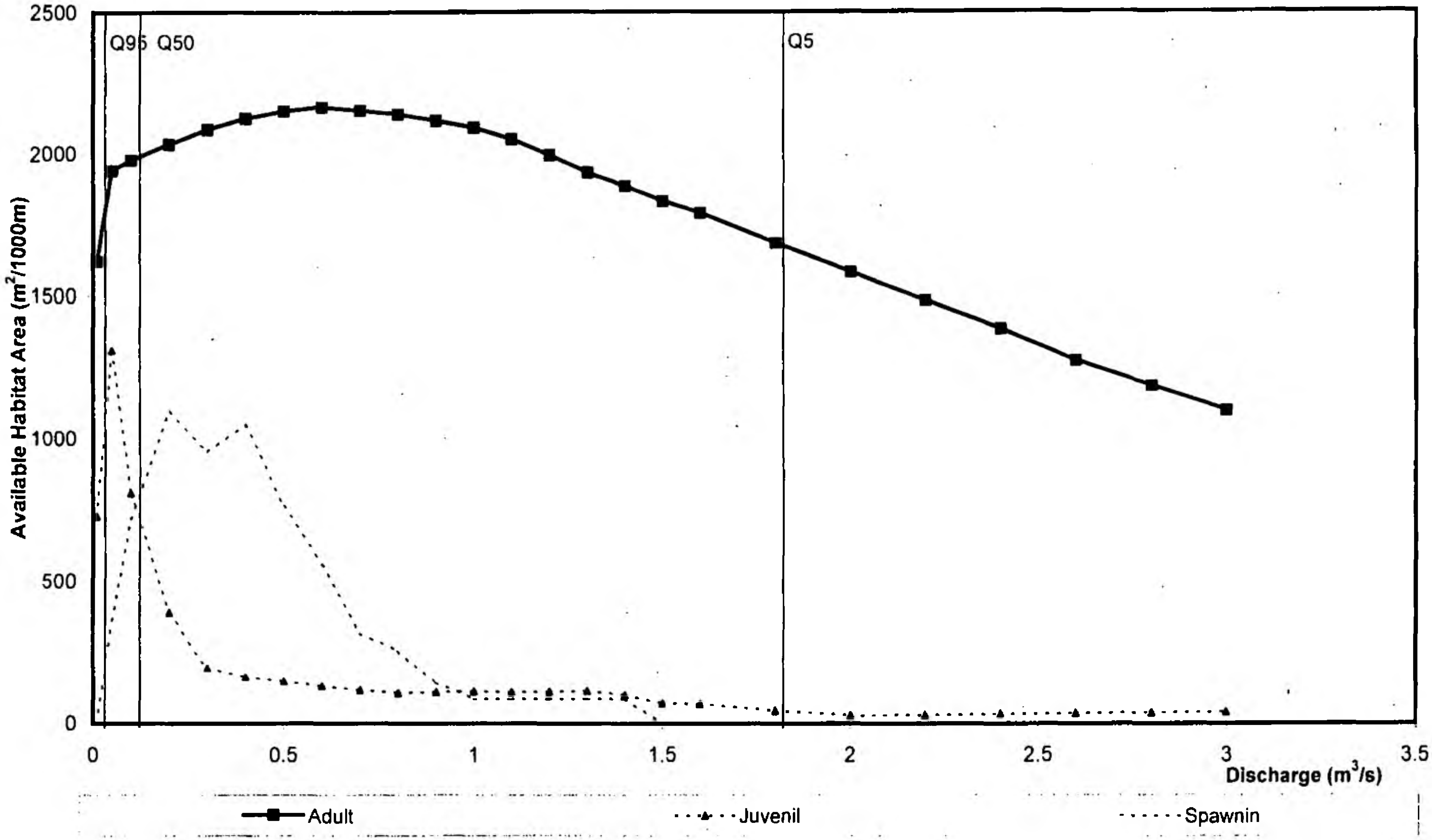
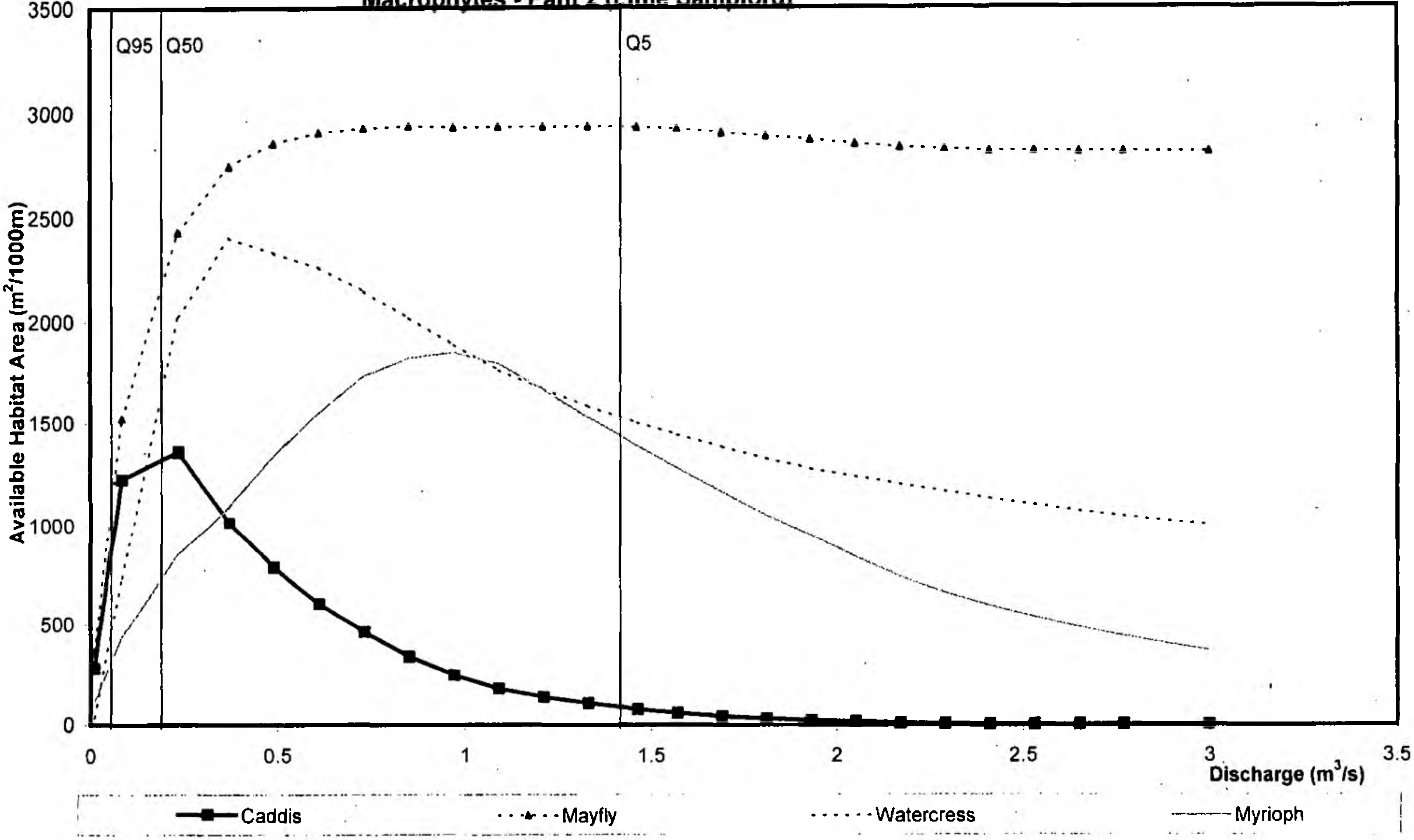


Figure 5.5e. Discharge vs Habitat Availability Relationships for Macroinvertebrates and Macrophytes - Part 2 (Little Sampford)



PANT 4: KELVEDON

5.32 The curve of TAA versus discharge is presented in Figure 5.6a, and shows TAA increasing sharply from 7,000 to 8,000 m^2/1000 m as discharge increases from 0.01 to 0.2m^3/s. As discharge increases beyond this, TAA increases slightly to a maximum of approximately 9,000 m^2/1000 m at the maximum simulated discharge of 4 m^3/s. This represents a further increase in TAA from upstream sites as the size of the river increases downstream.

5.33 Figure 5.6b shows the effect of discharge on available habitat (WUA) for all life stages of brown trout. Q_{opt} for adult and juvenile life stages is approximately 0.7 m^3/s, which is just below the historic Q_{50} for this site. WUA for these life stages is not particularly sensitive to further increases in discharge, declining gradually to approximately 70% of the value at Q_{opt}. for both life stages. There is a relatively large area of habitat suitable for spawning trout over the whole range of flows modelled. Q_{opt} is between 1.0 and 2.0 m^3/s: within this range of flows WUA is approximately 1800 m^2/1000 m.

5.34 WUA plots for adult chub (Figure 5.6c) indicate that Q_{opt} for this life stage is in the region of (and upwards of) the Q_{50} (0.8 m^2/s), with a maximum WUA of 6400 m^2/1000m. The WUA remains constant for adult chub with increased flows up to 3.0 m^3/s. The Q_{opt} for spawning chub is similar to the adult life stage (0.8 m^3/s: equivalent to the Q_{50}) however, above discharges of 1.5 m^3/s no spawning habitat is available. Available habitat for juvenile chub is low (the maximum WUA is 500 m^2/1000m), although a small amount of habitat is available at all flows up to 1.5 m^3/s. This upper limit is a function of the low flow velocities required by this life stage.

5.35 Figure 5.6d shows WUA at modelled discharges for the life stages of roach. This site presents a large useable habitat for adult roach at all discharges within the modelled range, with more than 4000 m^2/1000 m available at all flows. WUA for juvenile life stages decreases slightly with increased flows. From Q_{opt} at 0.3 m^3/s (below Q_{95}) to the top of the modelled range (equivalent to the historic Q_{10}), the WUA for juveniles declines by around 50%. Q_{opt} for spawning roach is 1.25 m^3/s, although available habitat (approximately 1200 m^2/1000) is roughly constant between 0.4 and 1.7 m^3/s.

5.36 Q_{opt} for both macrophyte species and the mayflies (Family Ephemeridae) are around the Q_{50} for the site (0.9 m^3/s) and WUA does not decrease significantly as flows increase beyond this (Figure 5.6f). Q_{opt} for the caddis fly *Hydropsyche pellucidula* is approximately 0.25 m^3/s and WUA for this life stage is more sensitive to increased flows, declining steadily as flows increase to around 25% of Q_{opt} by the maximum simulated discharge (3 m^3/s), equivalent to Q_{10}.

Figure 5.6a. Discharge / Total Available Habitat Area Relationship - Pant4 (Kelvedon)

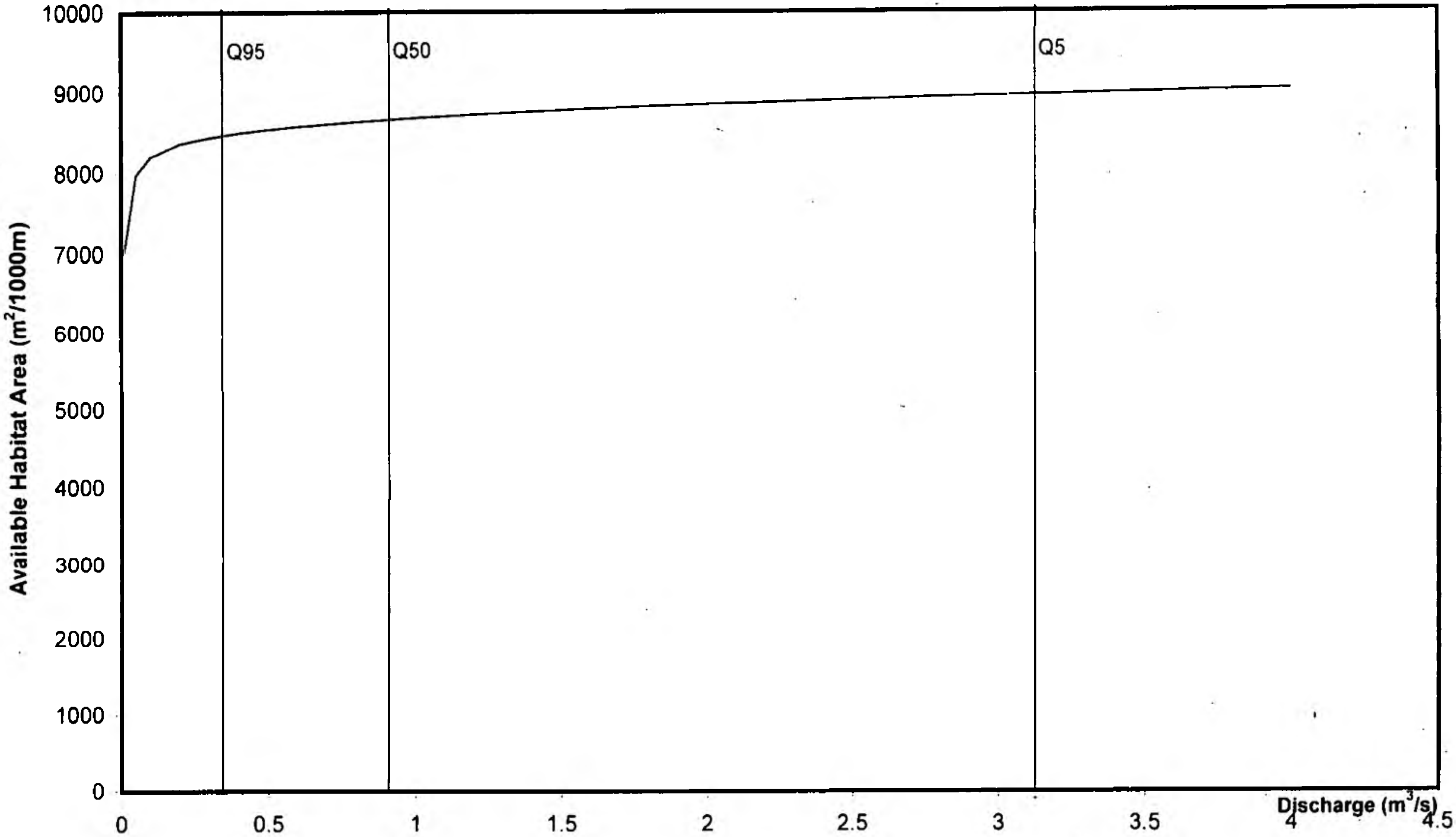


Figure 5.6b. Discharge/ Habitat Availability Relationships for Brown Trout - Pant4 (Kelvedon)

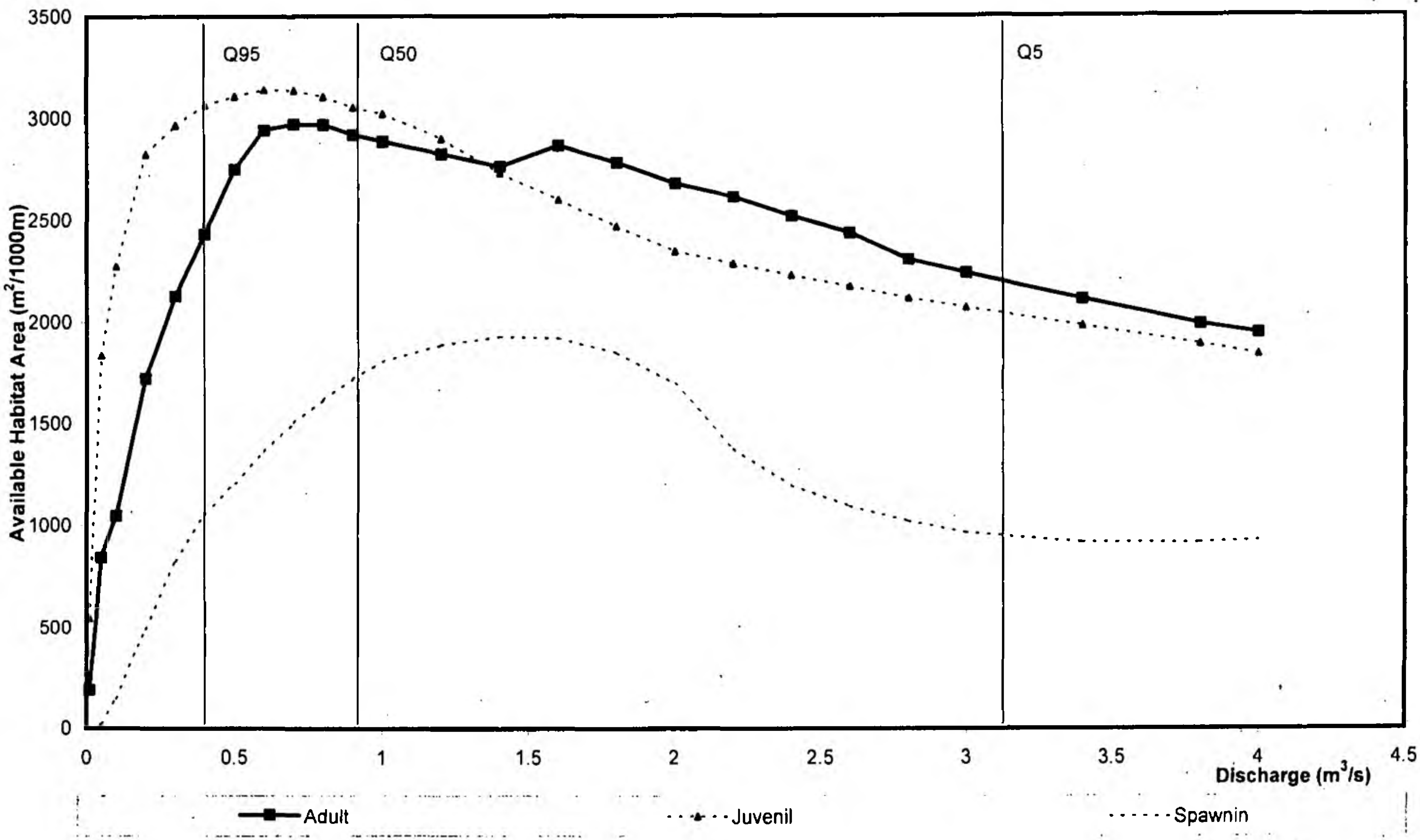


Figure 5.6c. Discharge/ Habitat Availability Relationships for Chub - Pant4 (Kelvedon)

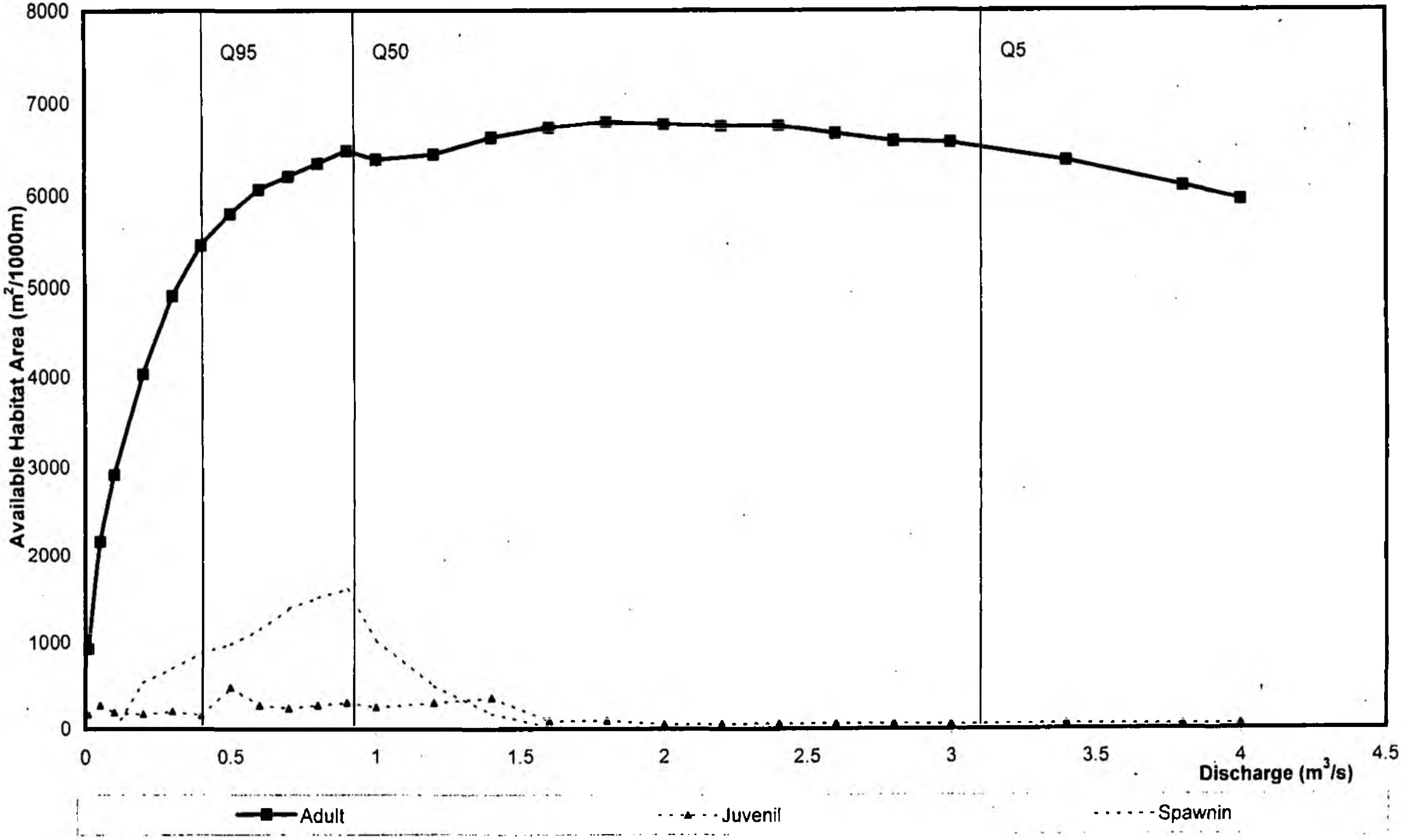


Figure 5.6d. Discharge/ Habitat Availability Relationships for Roach - Pant4 (Kelvedon)

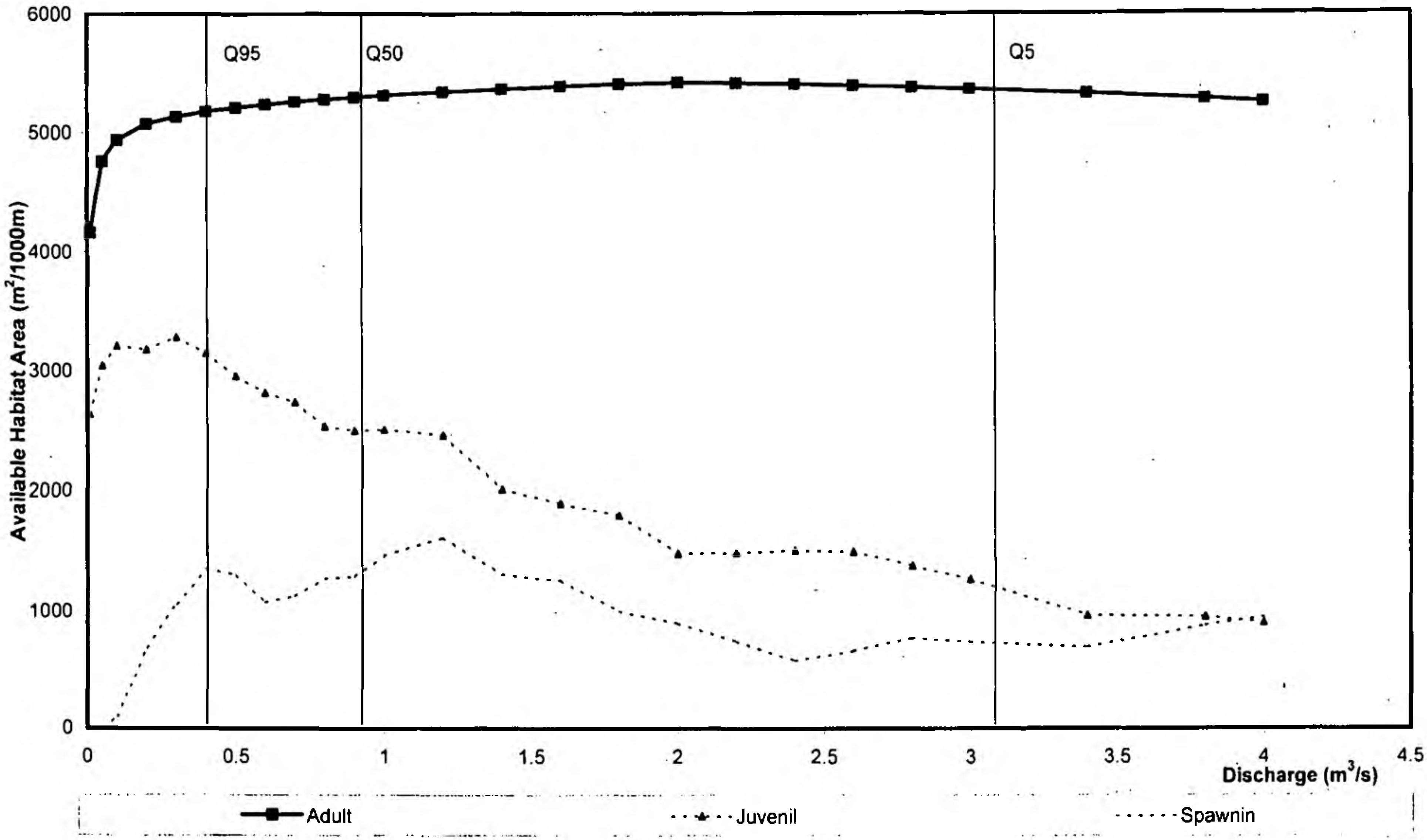
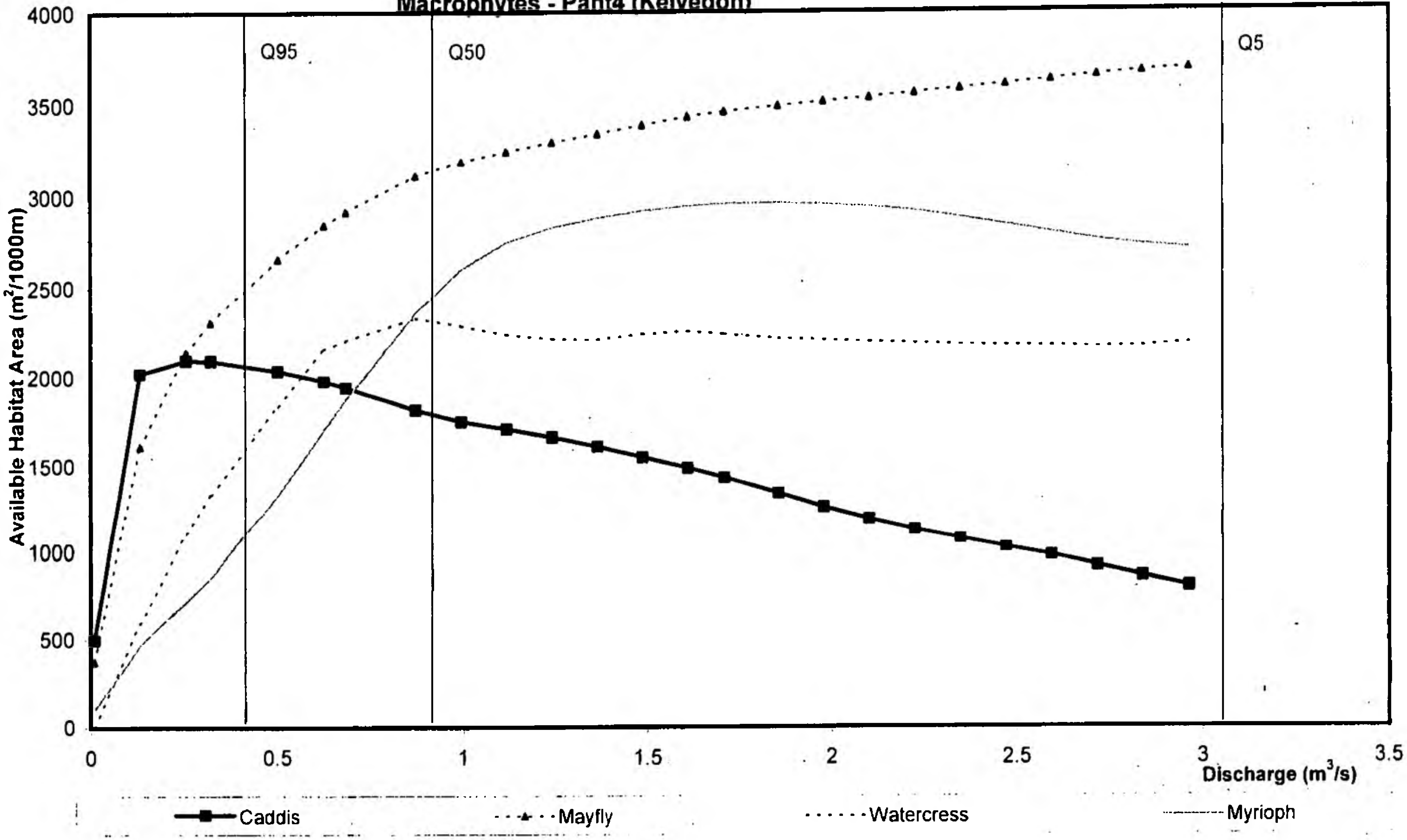


Figure 5.6e. Discharge vs Habitat Availability Relationships for Macroinvertebrates and Macrophytes - Pant4 (Kelvedon)



6. MODEL RESULTS: HABITAT TIME SERIES ANALYSIS

6.1 This section of the report presents the results of habitat time series analyses, which was carried out for the three fish species at three sites: Stour 1 and Pant 1 and 2. No time series analysis was carried out for either invertebrates or macrophytes.

6.2 For each site, three plots are presented for each lifestage, as follows:

(i) Habitat duration curves, showing the percent of time during which a particular area of available habitat is exceeded

(ii) Daily habitat availability for the period 1992-1996 inclusive

(iii) Daily habitat availability for 1992 alone (a 'dry' year, during which there was considerable summer augmentation).

6.3 It should be noted that negative and zero flows within the flow record had to be adjusted to 0.01 m^3/s to allow modelling to be carried out with PHABSIM. This is reflected in non-zero values for habitat being returned, even though there was no flow recorded at that time. The actual value depends on the lifestage being modelled, but can be seen at the right hand side of some of the habitat-duration curves, where the curved follows a horizontal line, normally between 10 and 100 $m^2/1000$ m. This section of the curve should be considered to equate to the habitat at zero discharge.

6.4 The habitat availability graphs for juvenile and spawning life stages include only the data for the critical periods defined in Table 4.1, while the graphs for adult lifestages include all months. The habitat duration curves present data from the same time periods.

STOUR 1: KIRTLING GREEN

6.5 Results of habitat time series analysis for Kirtling Green are presented in Figures 6.1a to 6.1c overleaf, which present results for brown trout, chub and roach respectively.

Brown trout time series data

6.6 The habitat duration curves for brown trout at Kirtling Green (Figure 6.1a) show that the modified flow regime (using the EOETS) has provided an overall benefit to all life stages in terms of increased habitat availability. This is particularly marked for juvenile and spawning lifestages, where operation of the EOETS nearly eliminated periods when zero habitat was available.

6.7 The habitat time series data show that at all times except the springs of 1992 and 1996, operation of the transfer gave a positive or neutral effect in terms of habitat availability for adult brown trout. Summer augmentation in all years resulted in a dramatic increase in available habitat for adults, particularly in 1992.

6.8 Summer augmentation also resulted in a general increase in habitat available to juvenile brown trout. However, there is some evidence of a negative impact on juvenile trout during spring augmentation, particularly during March-May 1992. This reflects the preference of juveniles for very low flow velocities, and the potential for augmented flows to cause these fish to be 'washed out'.

6.9 As can be seen from both the habitat time series and the habitat duration curves, operation of the EOETS had a small overall positive effect on spawning habitat. This was most pronounced during the autumns of 1995 and 1996, when the transfer increased spawning habitat from near-zero to near maximum levels.

Chub time series data

6.10 The habitat-duration curves for chub (Figure 6.1b) show that operation of the EOETS has provided a slight benefit for adult chub, and considerable benefit for juvenile chub. It is evident from the shape of both of these habitat-duration curves, and from Figure 5.1c, that operation of the EOETS has nearly eliminated periods when no habitat is available for these lifestages, particularly by eliminating the summer low flow periods, which equate with zero habitat.

6.11 The habitat-duration curve for spawning chub shows a slightly negative impact on available habitat has arisen from operation of the EOETS. The WUA curve for spawning chub (Figure 5.1c) shows that significant spawning habitat is only available over a narrow range of flows (0.3 – 1.0 m^3/s). It is evident from the habitat time series data that discharge often exceeded this range while the EOETS was operating, whereas the naturalised data indicate that the unadjusted flow would have been below this range.

Roach time series data

6.12 The habitat-duration curves for roach (Figure 6.1c) show that operation of the EOETS has provided benefits for adult and juvenile roach by nearly eliminating periods when effectively zero habitat was available. This is especially noticeable for juvenile roach, where no habitat was available for approximately 30% of the time under the naturalised flow regime, while the observed flows indicate that more than 800 $m^2/1000$ m was available for juvenile roach for approximately 95% of the time. This appears to have been principally within summer periods when the naturalised flow would have been so low as to present zero useable habitat area.

6.13 The habitat-duration curve for spawning roach indicates that operation of the EOETS had a negative effect on spawning habitat. This appears to have been due in particular to operation of the transfer during the springs and early summers of 1992 and 1996, which moved the discharge from the Q_{opt} for this life stage of approximately 0.3 m^3/s, up to and beyond the maximum acceptable discharge of 1.6 m^3/s.

Figure 6.1a. Habitat time series output for brown trout at Stour 1 (Kirtling Green)

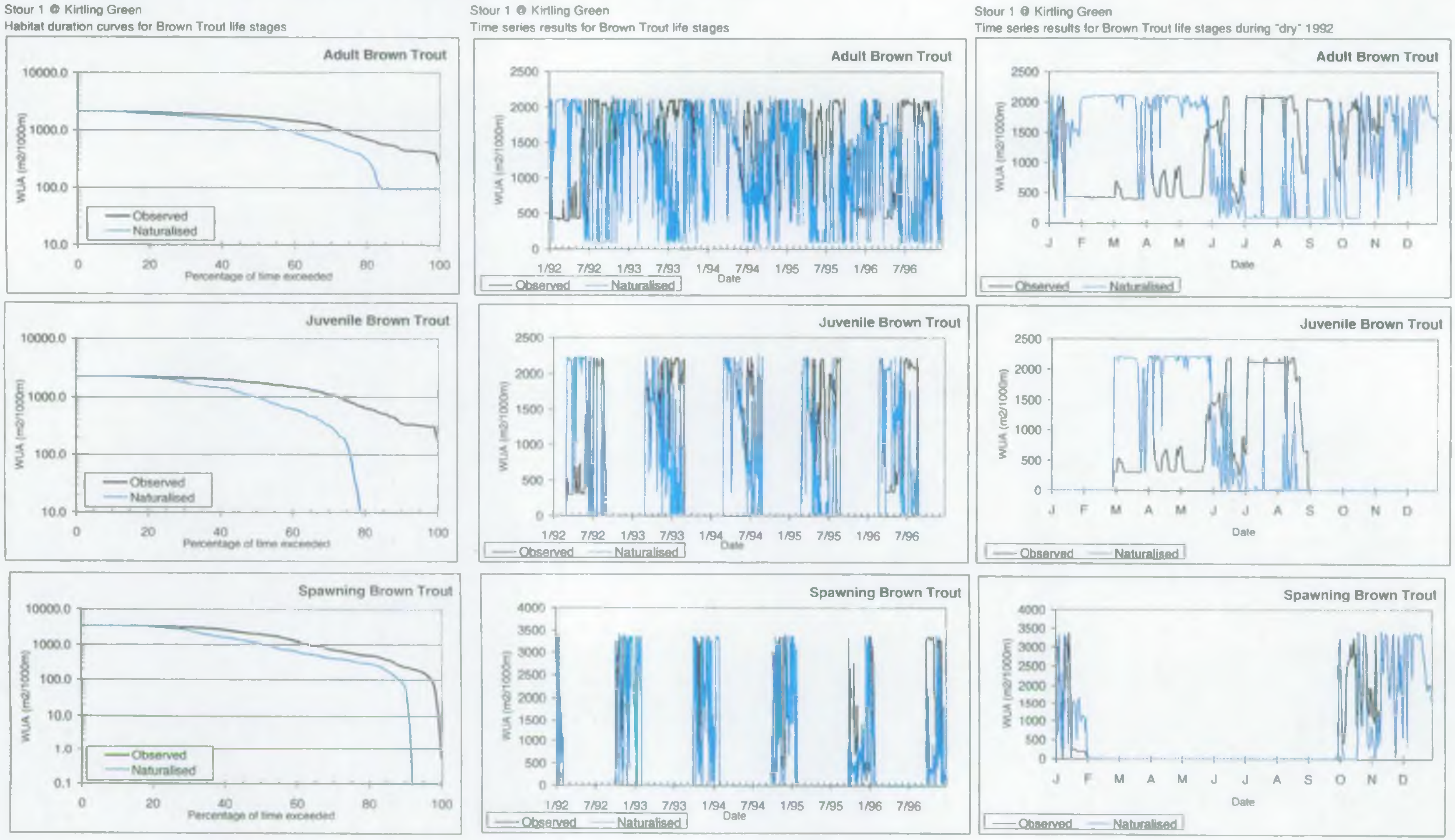


Figure 6.1b. Habitat time series output for chub at Stour 1 (Kirtling Green)

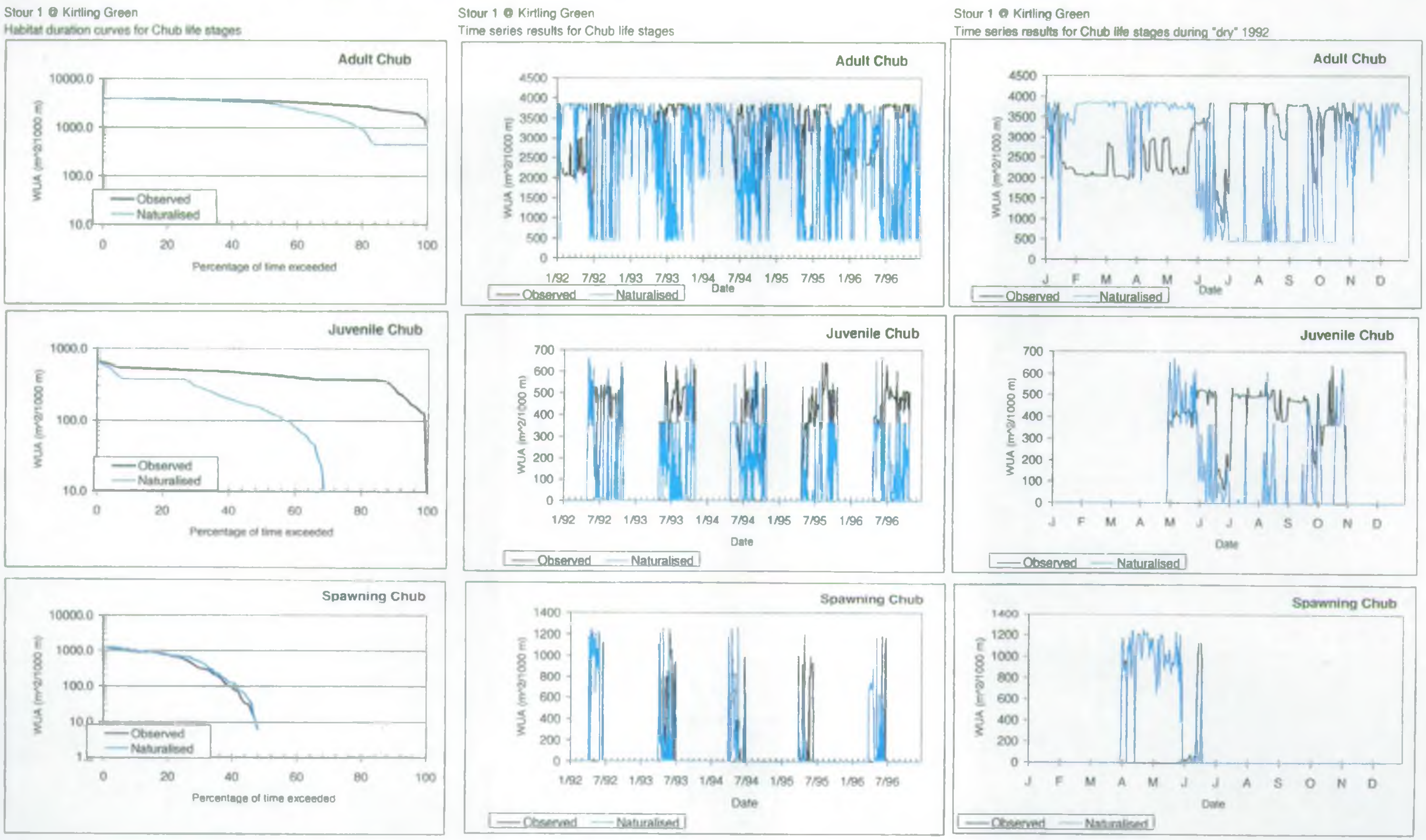
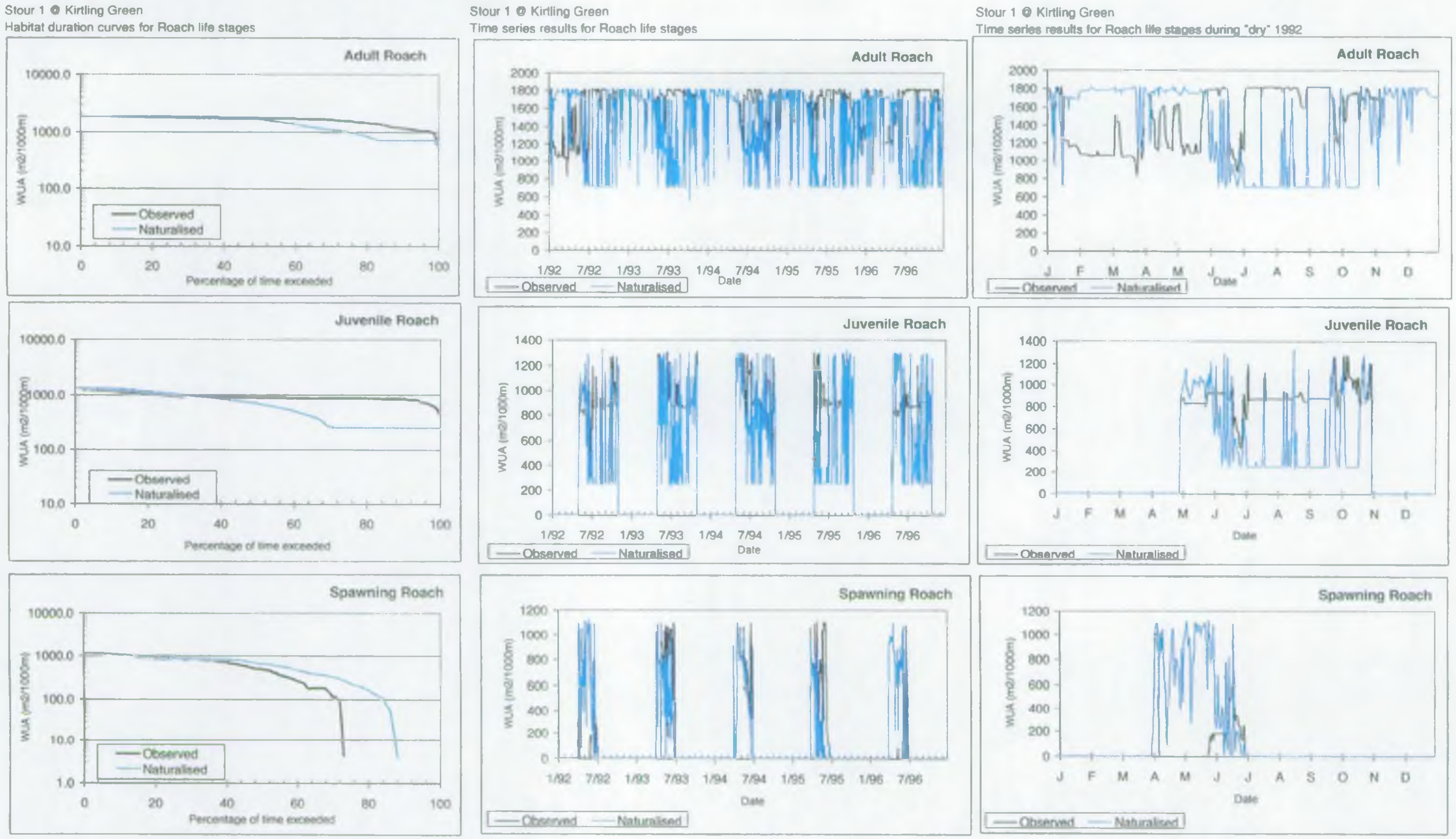


Figure 6.1c. Habitat time series output for roach at Stour 1 (Kirtling Green)



PANT 1: GREAT SAMPFORD

6.14 Results of habitat time series analysis for Great Sampford are presented in Figures 6.2a to 6.2c overleaf, which present results for brown trout, chub and roach respectively.

Brown trout time series data

6.15 The habitat-duration curves for brown trout at Great Sampford (Figure 6.2a) indicate that operation of the EOETS has caused an overall increase in the amount of habitat available for adults, with >100 m^2/1000 m of habitat available for approximately 94% of the time under the observed flow regime, compared to 73% of the time under naturalised flows. A similar pattern can be seen for juvenile brown trout, although the available habitat area under both flows is generally higher than for adults.

6.16 Although operation of the EOETS has only minor benefits for spawning trout in terms of the area of potential spawning habitat available at a given time, the habitat time series graph indicates that in certain years it has extended the length of time for which spawning habitat is available. This is particularly noticeable for October-November 1995 and December 1996.

Chub time series data

6.17 The habitat-duration and time series data for adult chub (Figure 6.2b) show a similar trend to those for brown trout, with operation of the EOETS effectively eliminating periods when no significant habitat would have been available under the natural flow regime. These periods tended to be in summers, when an environmental support flow was maintained, especially the summers of 1992-3 and 1995.

6.18 In contrast, it appears that operation of the EOETS during summer has been disadvantageous to juvenile chub, and has dramatically reduced the amount of habitat available. Figure 5.4c shows that at this site, significant juvenile chub habitat is only available at extremely low flows (<0.1 m^3/s), and the environmental support flows caused this level to be exceeded.

6.19 The habitat duration curves for spawning chub show a minor positive impact from the EOETS. However, in terms of the actual area of habitat available (< 60 m^2/1000 m), this is not considered to be a significant impact.

Roach time series data

6.20 Habitat-duration data for adult roach (Figure 6.2c) indicate no significant overall difference between habitat availability under the observed and naturalised flow regimes. However, from the habitat time series data it can be seen that there have been periods (particularly during the summers of 1992-3 and 1995) when operation of the EOETS has increased the amount of habitat available.

6.21 The pattern for juvenile roach shows that on average, more habitat would have been available under the naturalised flow regime than under the observed flow regime. The observed flows had a particularly negative impact in the summers and autumns of 1994-1996, when available habitat was often reduced to less than 500 m^2/1000 m. This appears to have been due to the flow velocity exceeding the acceptable range as a result of flow augmentation.

6.22 The EOETS had an overall positive impact on available habitat. This is mainly attributable to the transfer being operated during 1992 and 1995, when it made considerably more habitat available than would have been the case under the naturalised flow regime.

Figure 6.2a. Habitat time series output for brown trout at Pant 1 (Great Sampford)

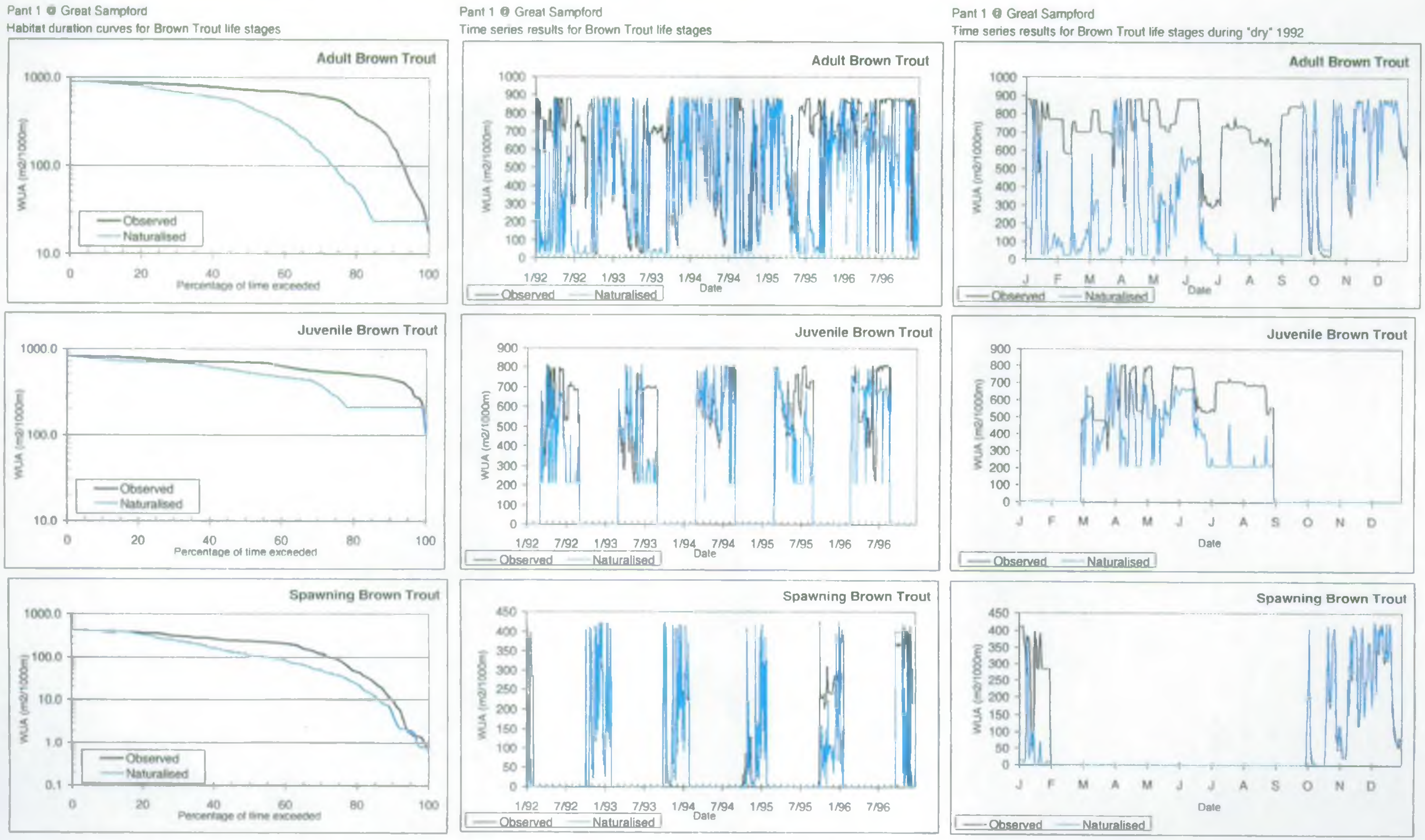


Figure 6.2b. Habitat time series output for chub at Pant 1 (Great Sampford)

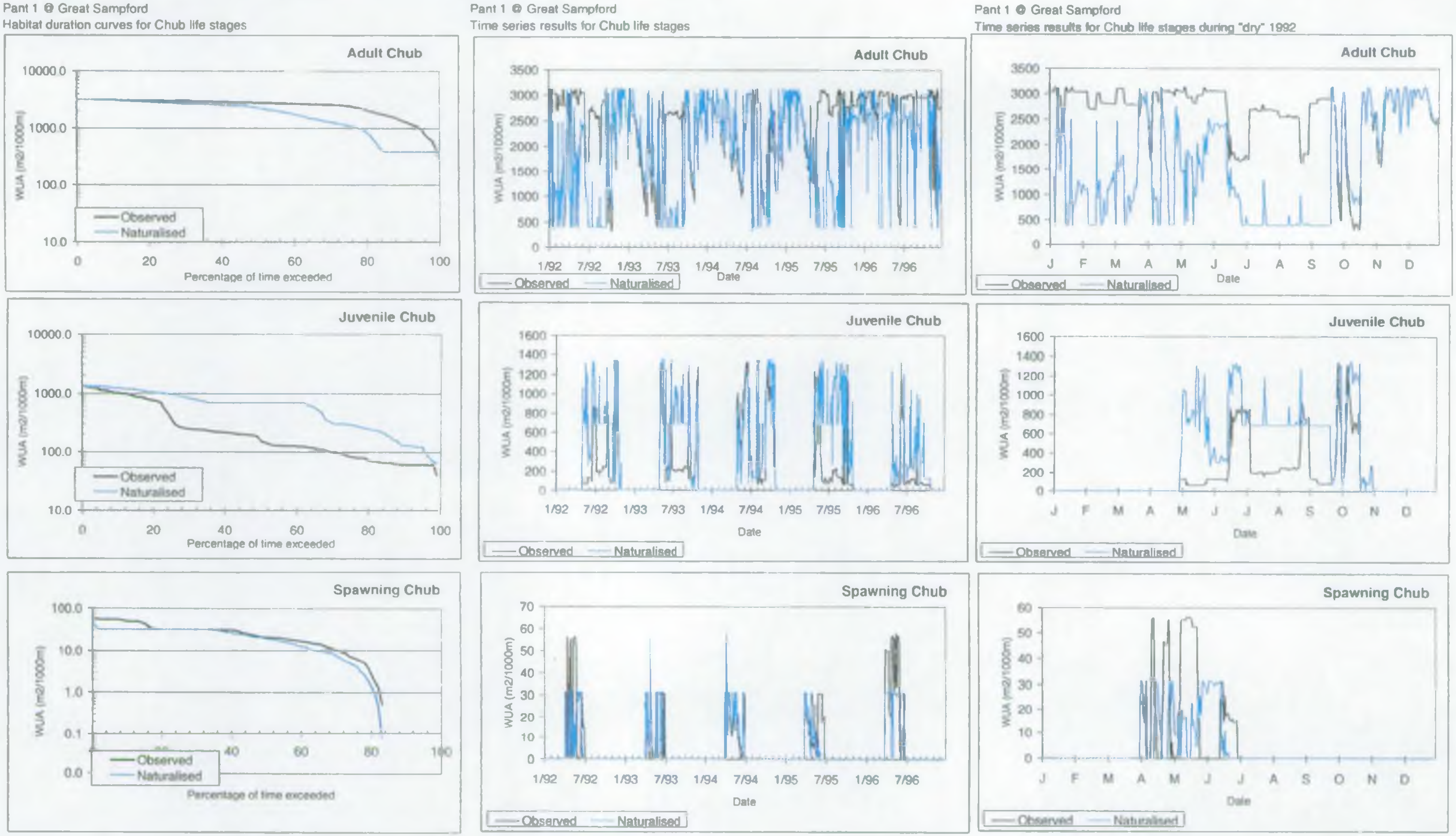
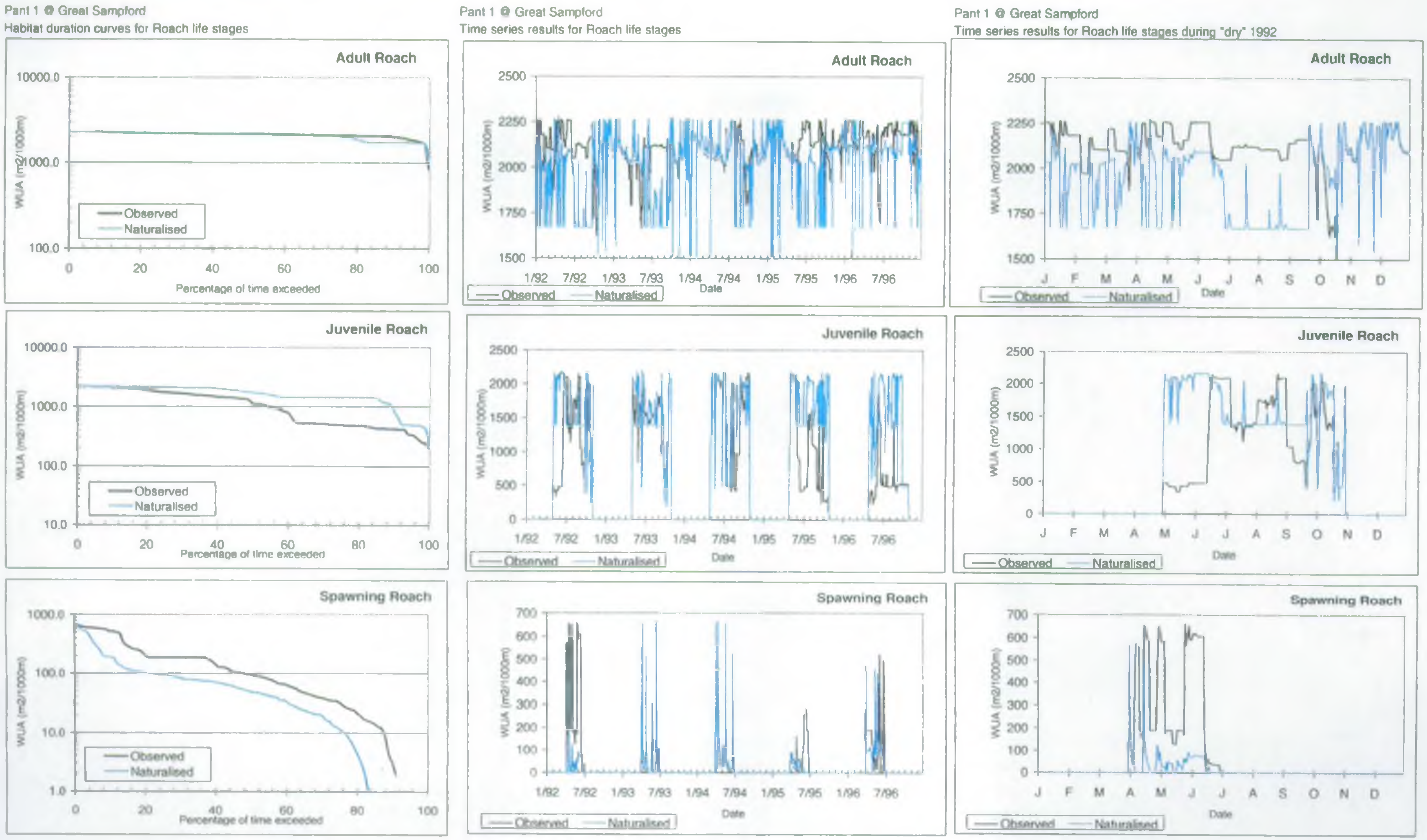


Figure 6.2c. Habitat time series output for roach at Pant 1 (Great Sampford)



PANT 2: LITTLE SAMPFORD

6.23 Results of habitat time series analysis for Little Sampford are presented in Figures 6.3a to 6.3c overleaf, which present results for brown trout, chub and roach.

Brown trout time series data

6.24 Figure 6.3a shows that for all lifestages of brown trout, operation of the EOETS had an overall positive impact in terms of habitat availability. For adult brown trout, this was particularly marked during the summers of 1992-3 and 1995, when habitat availability under the naturalised flow regime would have been near-zero, whereas more than 1500 m^2/1000 m was available under the observed flow regime.

6.25 For juvenile brown trout, benefits were usually discernable in July and August, when operation of the EOETS prevented zero flow (and therefore zero habitat) situations from arising. For spawning brown trout, the main period when there was a benefit in terms of habitat was during the winters of 1995-6, when the EOETS was operating.

Chub time series data

6.26 Figure 6.3b shows that operation of the EOETS had an overall benefit to adult and spawning chub. For adults, this benefit accrued mainly in the summers when the transfer was operated for environmental support purposes (e.g. 1992-3 and 1995).

6.27 In the case of spawning chub, operation of the EOETS increased the time when more than 100 m^2/1000 m was available from 16% to 36% of the record. Particular benefits can be observed in the summers of 1992 and 1995. However, the discontinuous nature of these habitat 'peaks' means that this would have been of little practical use for juvenile chub, as the intervening times of zero habitat are likely to have caused mortality or morbidity.

6.28 As was observed for Great Sampford, summer environmental support flows generally had an adverse impact on habitat for juvenile chub. This is interpreted as being caused by flow velocities exceeding the acceptable range for this life stage.

Roach time series data

6.29 The habitat duration curves for adult roach at Little Sampford (Figure 6.3c) show a pattern very similar to those for roach at Great Sampford, with a slight increase in adult habitat at times that would have been low-flow periods under the natural flow regime, particularly the summers of 1992 and 1993. The main benefits to spawning roach accrued during the early summer of 1995 and 1996, however operation of the EOETS during the late spring of 1993 and, in particular, 1996 caused a reduction in habitat. This is the main cause of the 'observed' habitat-duration curve being below the 'naturalised' habitat-duration curve.

6.30 Operation of the EOETS caused an overall reduction in the availability of habitat for juvenile roach, again as a result of flow velocities becoming unacceptably high. This was most noticeable during the summers of 1992 and 1995-6.

Figure 6.3a. Habitat time series output for brown trout at Pant 2 (Little Sampford)

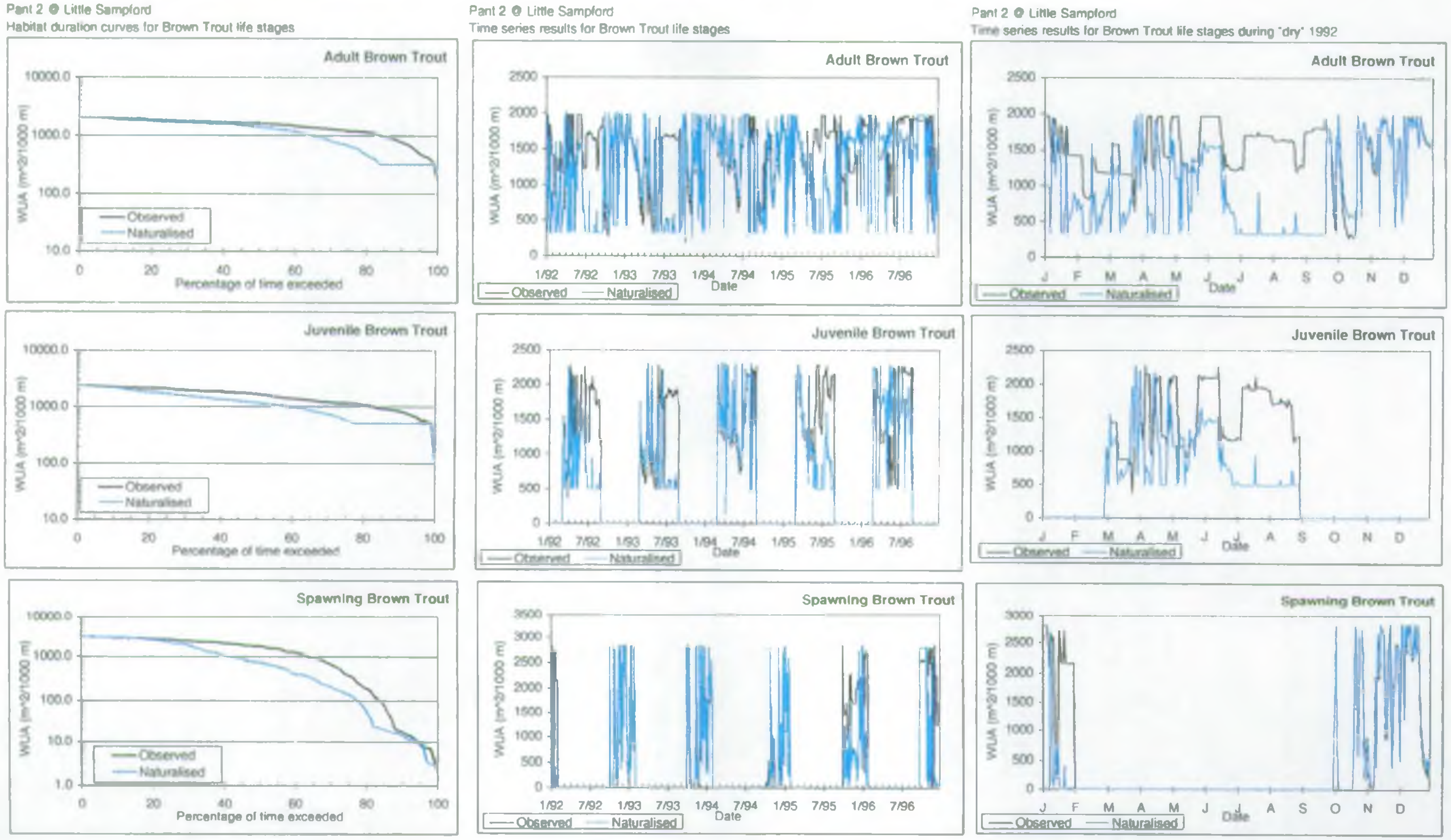


Figure 6.3b. Habitat time series output for chub at Pant 2 (Little Sampford)

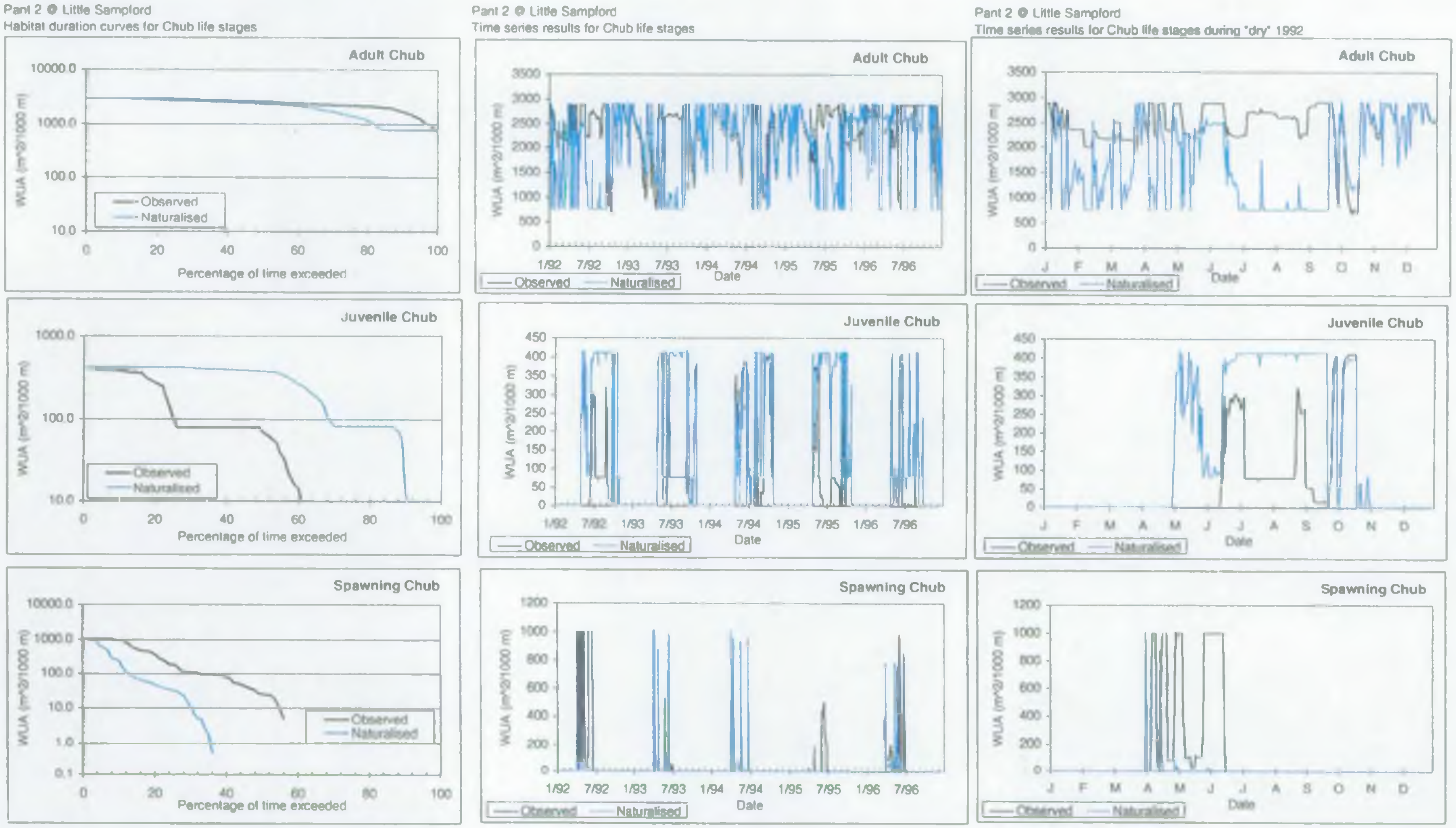
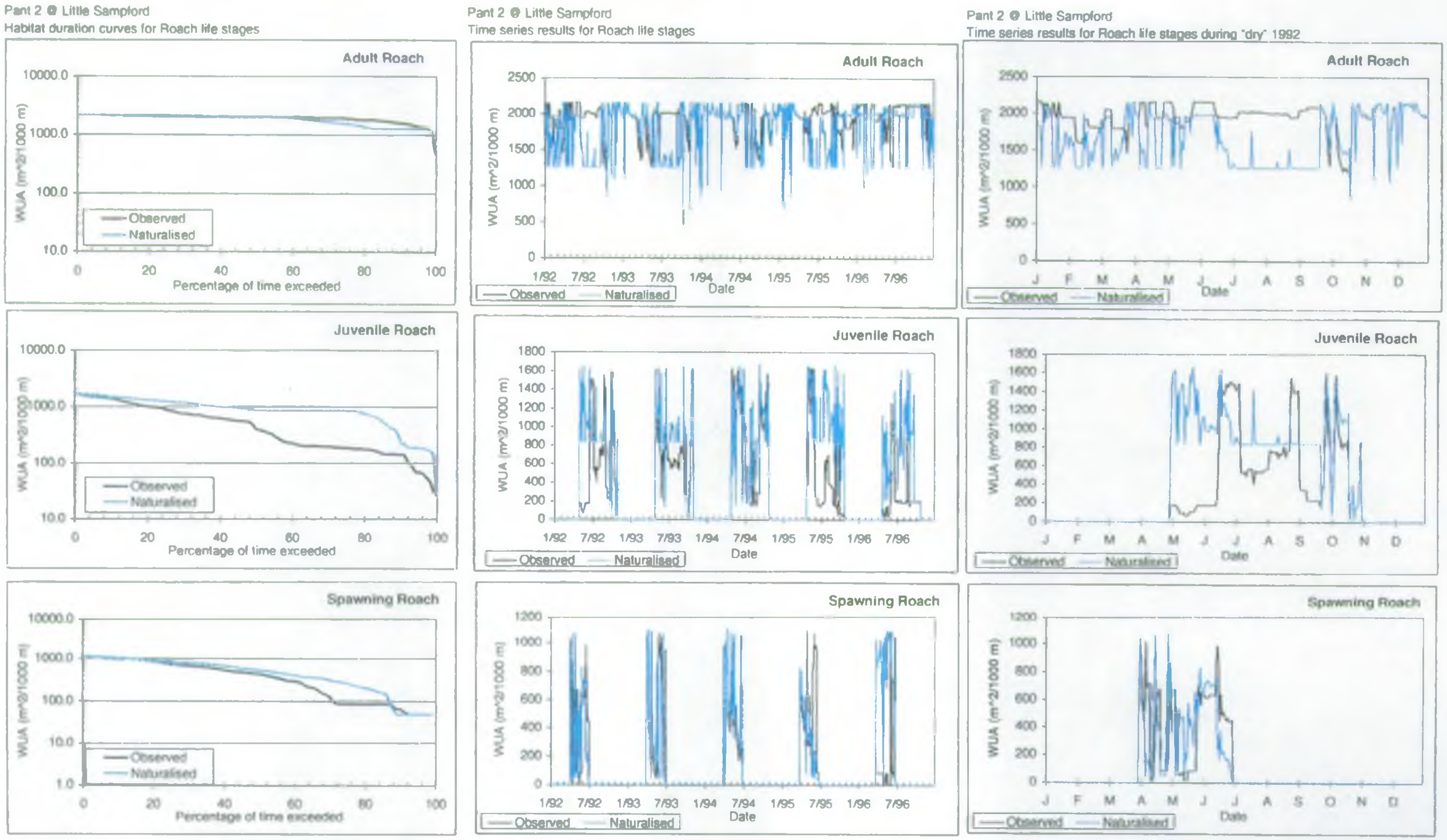


Figure 6.3c. Habitat time series output for chub at Pant 2 (Little Sampford)



7. CONCLUSIONS

CALIBRATION AND USE OF PHABSIM MODEL

7.1 A PHABSIM model was successfully calibrated for three sites on the River Stour and three sites on the River Pant/Blackwater, based on results from a walk-over survey and data collected at the study sites. This report presents the details of the assessment of the calibration and validation of the model, the model output, and the interpretation of the output. Although the model investigates the relationships between discharge and depth, velocity and substrate availability, it should be borne in mind that it does not have the capability to examine other factors such as water quality and temperature, which may also affect habitat suitability.

7.2 Thirteen different species/life stages were investigated, comprising three fish species (three lifestages of each), two invertebrate species and two macrophyte species. The modelling used HSI curves that were developed specifically for low-lying east Anglian rivers during a preceding study (WS Atkins 2000). A review of the model output showed that this compared favourably with previous attempts at PHABSIM modelling using published HSI curves, which were developed for upland catchments with the priority on low-flow studies. Habitat time-series analysis was carried out for the three fish species at one site on the Stour and two sites on the Pant/Blackwater.

INTERPRETATION OF PHABSIM MODEL OUTPUT

7.3 The calibrated PHABSIM model was used to calculate the available habitat area for the selected species/life stages at 25 different flows. A summary of the calculated optimum discharge (Q_{opt}) for each species/life stage is presented in Table 7.1 and Table 7.2 below. When a single peak showing optimal discharge could not easily be discerned, a range of optimum discharge values is presented. Also presented are the ratios of weighted useable area (WUA) to total available area (TAA) at the Q_{opt} for each species/life stage. This parameter allows the suitability of the reach for the various indicator species to be examined.

Table 7.1 – Optimum flow (Q_{opt}) and WUA/TAA ratio at Q_{opt}, for each species/life stage in the River Stour

Species	Life Stage	Stour 1 (Kirtling Green)		Stour 2 (Bowers Hall Fm)		Stour 4 (Langham)	
		Q_{opt} (m^3/s)	WUA/ TAA @ Q_{opt} (%)	Q_{opt} (m^3/s)	WUA/ TAA @ Q_{opt} (%)	Q_{opt} (m^3/s)	WUA/ TAA @ Q_{opt} (%)
Brown Trout	Adult	0.4	40	0.3	31	0.5-4.0	28
	Juvenile	0.3	42	0.2	33	0.1-2.0	31
	Spawning	0.6	58	1.0	31	2.0	23
Chub	Adult	0.5	69	1.0-7.0	66	0.5-4.0	70
	Juvenile	0.1-7.0	5	N/A	N/A	0.1	21
	Spawning	0.5	23	0.4	17	N/A	N/A
Roach	Adult	0.2-2	30	0.4-7.0	45	0.3-6.0	33
	Juvenile	0.1	25	0.3	33	0.3	53
	Spawning	0.3	21	0.4	22	2.6	30
Caddis fly	Larvae	0.15	23	0.3	23	0.5	7
Mayfly	Larvae	0.57	65	1.0	47	1.6	46
Watercress		0.57	42	0.87	33	2.2	65
Water milfoil		0.94	46	1.2	55	2.2	65

N/A = no significant habitat available across range of modelled discharges. Shaded cells indicate <20% of TAA is available as useable habitat at Q_{opt}.

Table 7.2 – Optimum flow (Q_{opt}) and WUA/TAA ratio at Q_{opt}, for each species/life stage in the River Pant/Blackwater

Species	Life Stage	Pant 1 (Gt Sampford)		Pant 2 (Little Sampford)		Pant 4 (Kelvedon)	
		Q_{opt} (m^3/s)	WUA/ TAA @ Q_{opt} (%)	Q_{opt} (m^3/s)	WUA/ TAA @ Q_{opt} (%)	Q_{opt} (m^3/s)	WUA/ TAA @ Q_{opt} (%)
Brown Trout	Adult	0.5	22	0.6	42	0.5-1.5	34
	Juvenile	0.5	20	0.4	51	0.25-1.0	36
	Spawning	0.6	10	0.6	61	1.0-2.0	21
Chub	Adult	0.2-2.0	75	0.3-0.7	65	0.5-4.0	77
	Juvenile	0.05	17	0.05	8	0.01-1.5	6
	Spawning	N/A	N/A	0.6	22	0.9	17
Roach	Adult	0.1-2.0	63	0.1-1.5	48	0.1-4.0	62
	Juvenile	0.05	54	0.05	33	0.1-0.5	39
	Spawning	0.6	18	0.25-0.5	23	0.5-1.5	16
Caddis fly	Larvae	0.084	13	0.234	31	0.256	25
Mayfly	Larvae	0.49	38	0.61	63	2.962	41
Watercress		0.49	34	0.37	54	0.871	27
Water milfoil		0.49	22	0.97	39	1.709	34

N/A = no significant habitat available across range of modelled discharges. Shaded cells indicate <20% of TAA is available as useable habitat at Q_{opt}.

7.4 One of the ultimate objectives of this study is to use the output from the PHABSIM modelling work to determine whether a more sympathetic operating regime is required for the EOETS to optimise habitat availability for important fish, plant and invertebrate species. In order to do this, the data presented in Sections 5 and 6 and Tables 7.1 and 7.2 have been examined with the emphasis on the response of each taxonomic group to alterations in flow regime.

BROWN TROUT

7.5 The WUA/TAA ratio at Q_{opt} is high (30-58%) for adult and juvenile brown trout at the two upstream sites on the Stour although slightly lower (23-31%) at the downstream site (Langham). This indicates that considerable habitat is available at the calculated optimum level of flow. The historical Q_{50} at both sites is approximately equal to the calculated Q_{opt}, although none of the life stages are particularly sensitive to increased discharges above this. For example WUA at the historical Q_5 is still approximately 30-50% of that at Q_{opt}. This may provide some leeway for increasing augmentation flows to either the Pant/Blackwater system or downstream in the Stour, without negative impacts on trout habitat.

7.6 Considerable trout spawning habitat is available at all three sites on the Stour. Although there is relatively less habitat available at Langham, this may have been due to the amount of spawning substrate being underestimated, as a result of the depth and lack of clarity of the water column.

7.7 Results from all three sites on the Pant/Blackwater system indicate that considerable habitat is available for all lifestages of trout at discharges above the historical Q_{95}. At the two upstream sites (Great Sampford and Little Sampford), Q_{opt} for all life stages is approximately 0.5 m^3/s above the historical Q_{50}, which indicates that increased flows would be beneficial for trout at these sites. Increased flows at the Pant 4 (Kelvedon) site are predicted to be neutral or slightly beneficial to all life stages of brown trout.

CHUB

7.8 Of all the species and life stages examined, adult chub appear to be most suited to conditions in the study rivers, with WUA/TAA ratios at Q_{opt} falling between 65% and 77% at all sites. At the two upstream sites on both study rivers, Q_{opt} for adult chub was at slightly higher discharge than the historic Q_{50}, indicating that this lifestage would benefit from increased discharges at these sites. At the furthest downstream site on both rivers, Q_{50} was slightly higher than the Q_{opt} for adult chub, but the shape of the WUA curve indicates that increased discharges would not be particularly detrimental to adult chub, especially at Kelvedon, where WUA at the maximum modelled flow of 4 m^3/s was approximately 90% of that at the Q_{opt} of 2 m^3/s.

7.9 In contrast to adult chub, habitat for juvenile chub appeared to be limited in both study rivers. The greatest WUA at Q_{opt} was 21% of TAA, at Langham, but was generally <10% of TAA at the other sites. At Bowers Hall Farm, virtually no habitat was available for juvenile chub. This is due to the sensitivity of juvenile chub to high flow velocities when 'wash out' occurs, and reflects the velocity preference curves, which were developed (WS Atkins, 2000) from published secondary data (seeAppendix 1.2). At sites such as Kirtling Green and Great Sampford, there was a small amount of habitat available to juvenile chub across the whole modelled discharge range. This reflects the presence of a small amount of slow-flowing marginal habitat, regardless of discharge.

7.10 At two sites on each study river, a moderate amount of chub spawning habitat is available, across a narrow band of discharges approximately at the historic Q_{50}. This habitat becomes available when velocities within cells with acceptable substrate reach the acceptable velocity range as shown in Appendix 1.2. The habitat disappears again when discharge is so high that water depth in these cells becomes supra-optimal.

ROACH

7.11 At Q_{opt}, which approximates the historic Q_{50} at all sites, there is considerable habitat available for adult roach (30-63% of TAA). The available habitat area does not decrease to less than 50% of that at Q_{opt} at the maximum modelled discharge at any of the study sites. Juvenile roach show a similar pattern at Q_{opt}, but their small size and relatively weak swimming ability makes them prone to 'wash-out' as discharge increases. The result is that at the upper end of the modelled flow range, the only habitat available to juvenile roach is a small amount of marginal habitat with sufficiently low flow velocity.

7.12 As was the case for spawning chub, a moderate amount of habitat (16-30% of TAA) suitable for spawning roach is present at the lower end of the flow spectrum at all sites. This habitat disappears as the water depth in cells with appropriate substrate exceeds the acceptable depth as shown in the HSI curve (Appendix 1.3).

INVERTEBRATES

7.13 Both study rivers potentially offer considerable habitat for both of the invertebrate indicator species that were selected for study: the caddis fly *Hydropsyche pellucidula* and mayflies (Order Ephemeroptera). WUA/TAA ratios at Q_{opt} range from 7% for caddis at the Stour 4 site to 65% for mayflies at the Stour1 site. The historical Q_{50} is approximately equal to the modelled Q_{opt} for both taxa at all sites, indicating that historical conditions were roughly optimal.

7.14 It is somewhat surprising that the WUA curve for mayflies has a relatively long right hand tail at all sites, and in fact indicates that mayflies are better suited to high flows than the caddis fly. Mayflies were selected as an indicator species for this study on the grounds that they represent marginal species that require relatively slow water velocities and a silty substrate. This apparent discrepancy appears to be a direct result of the selected HSI curve (taken from Johnson *et al.*, 1993), which gives a suitability index of 0.95 (highly suitable) between velocities of 1.5 and 2 m/s, at the upper end of the velocity spectrum. It is our opinion that this is not realistic, and probably reflects the fact that HSI curve development has historically focussed on low-flow studies, with suitability at high flows not receiving adequate attention.

MACROPHYTES

7.15 As was the case for invertebrates, both study rivers offer considerable potential habitat for both of the macrophyte indicator species that were selected (watercress *Rorippa nasturtium-aquaticum* and water milfoil *Myriophyllum* sp.). WUA/TAA ratios at Q_{opt} range from 22% for water milfoil at the Pant 1 site to 65% for both species at the Stour 4 site. The historical Q_{50} for both species is approximately equal to the modelled Q_{opt} at all sites, indicating that historical conditions were roughly optimal. The WUA curves for both species have long right-hand tails, indicating that neither species is particularly sensitive to increased flows.

7.16 An apparent anomaly is that the WUA curve for watercress more often than not is higher than that for water milfoil at high flows. This is contrary to what would be expected as watercress was selected as being an indicator of plant species that favour low velocities. This result is likely to be an artefact of the origins of the two HSI curves. While the curve for watercress was taken directly from Elliott *et al.* (1996), no existing curve was available for water milfoil, and this was developed for this study based on published curves for water crowfoot (*Nasturtium*) and knowledge of local conditions. The resulting HSI curve for velocity (Appendix 1) has a slightly shorter right-hand tail than the Elliott *et al.* curve for watercress, which would have caused the resulting WUA curves to indicate lower preference for high flows.

SPATIAL HABITAT 'BOTTLENECKS' WITHIN THE STUDY RIVERS

7.17 From the summary data presented in Table 7.1 and Table 7.2, a strategic-level assessment of spatial habitat bottlenecks can be carried out. This allows prioritisation of sites for potential manipulation of flows in order to maximise habitat. For the purposes of this study, a spatial bottleneck is defined as a site where the maximum habitat for a given species/lifestage at Q_{opt} is less than 20% of the TAA at that discharge. Spatial habitat bottlenecks are identified in Table 7.3 below.

Table 7.3 – Spatial habitat 'bottlenecks' within the study rivers

Species	Life Stage	Stour 1	Stour 2	Stour 4	Pant 1	Pant 2	Pant 4
Brown Trout	Adult	OK	OK	OK	OK	OK	OK
	Juvenile	OK	OK	OK	OK	OK	OK
	Spawning	OK	OK	OK	Bottleneck	OK	OK
Chub	Adult	OK	OK	OK	OK	OK	OK
	Juvenile	Bottleneck	Bottleneck	OK	Bottleneck	Bottleneck	Bottleneck
	Spawning	OK	Bottleneck	Bottleneck	Bottleneck	Bottleneck	Bottleneck
Roach	Adult	OK	OK	OK	OK	OK	OK
	Juvenile	OK	OK	OK	OK	OK	OK
	Spawning	OK	OK	OK	Bottleneck	OK	Bottleneck
Caddis fly	Larvae	OK	OK	Bottleneck	Bottleneck	OK	OK
Mayfly	Larvae	OK	OK	OK	OK	OK	OK
Watercress		OK	OK	OK	OK	OK	OK
Water milfoil		OK	OK	OK	OK	OK	OK

7.18 From Table 7.3 it can be seen that of all the species and lifestages examined, most habitat bottlenecks occur for juvenile and spawning chub. For each of these, only one of the six sites presents more than 20% of TAA as useable habitat at Q_{opt} (Stour 1 for spawning chub and Stour 4 for juvenile chub). Minor bottlenecks also occur for spawning roach and trout, and caddis fly larvae, mainly on the Pant/Blackwater.

TEMPORAL HABITAT 'BOTTLENECKS' WITHIN THE STUDY RIVERS

7.19 The time series analysis carried out using discharge habitat data from three study sites, and observed and naturalised discharge data from two GSs has allowed temporal habitat bottlenecks for three fish species to be identified at the three modelled sites.

Brown trout

7.20 Time series analysis shows that under the naturalised flow regime, available habitat for all lifestages of brown trout varies markedly throughout the period analysed, with habitat for adults and juveniles being particularly restricted during the summer months, when naturalised flows were near zero.

7.21 The time series analyses from all three sites show that operation of the EOETS has significantly reduced temporal bottlenecks of adult brown trout habitat, particularly on the Pant/Blackwater during the summers of 1992-3 and 1995, when the naturalised flow was considerably lower than the observed flow. The exception was at Kirtling Green in the late winter and spring of 1992, and to a lesser degree 1996, when observed flows ranged up to 4 m^3/s (equivalent to the historical Q_2), which severely reduced available habitat for prolonged periods. From Figure 4.3, it can be seen that this was at least partly attributable to natural flood flows, and not solely to operation of the EOETS.

7.22 Operation of the EOETS for environmental support purposes yielded a benefit to juvenile brown trout, particularly during the early summer, when naturalised flows were low, and available habitat would therefore have been limited. Spawning brown trout were least affected by its operation, although there were times when it did improve spawning habitat, such as late 1996 at Kirtling Green.

Chub

7.23 In general, temporal variations in adult chub habitat under the naturalised flow regimes were less pronounced than for brown trout, particularly for sites on the Pant/Blackwater. However, the sites on the Pant/Blackwater showed significant periods during summer (especially 1992-3 and 1996), when habitat would have been limited by low flows. As was the case for trout, operation of the EOETS tended to eliminate these temporal bottlenecks, although there were occasions when the augmented flows were supra-optimal, resulting in a reduction in habitat compared to naturalised flows.

7.24 On the Pant/Blackwater, juvenile chub showed the opposite response to adults. Although fluctuations in juvenile habitat under naturalised flows were less pronounced that for adults, operation of the EOETS during summer generally resulted in a reduction in habitat as a result of flow velocities being higher than the acceptable range. At Kirtling Green, the response of juvenile chub habitat to augmented flows was slightly positive, which reflects the small amount of habitat available at all flows (see Figure 5.1c).

7.25 At Kirtling Green and Great Sampford, natural variations in spawning habitat were not as pronounced as for other lifestage, and operation of the EOETS had no overall impact, with a positive impact at some times (e.g. spring 1992 at Great Sampford) being balanced by a negative impact at other times (e.g. early summer 1992). At Little Sampford, there was still marked temporal variation in chub spawning habitat with the EOETS operating, but there was an overall benefit from its operation, particularly in the summer of 1995, when no significant habitat would have been available under naturalised flows.

Roach

7.26 Although under naturalised flows there was significant temporal variation in adult roach habitat at all three sites, this lifestage is relatively insensitive to low flows, therefore this fluctuation was within a band of relatively high habitat availability. As was the case for trout and chub, operation of the EOETS during summer had the effect of filling in the 'troughs' within the habitat time series, thus producing a positive effect. This was especially marked at sites on the Pant/Blackwater.

7.27 At Kirtling Green, operation of the EOETS has a positive effect on juvenile roach habitat, particularly during summer periods. At the two sites on the Pant/Blackwater, the opposite effect occurred, with augmentation generally reducing the amount of habitat available, largely due to increased flow velocity. This is likely to be due to the narrow and deeply incised nature of the river channel at these two sites, which would cause increased discharge to lead directly to increased flow velocities.

7.28 Under the naturalised flow regime, the amount of spawning habitat for roach varied between 0 and 1000 m^2/1000 m at all sites. At Great Sampford, operation of the EOETS had a benefit to spawning roach, particularly in summer 1992 and 1995, when very little habitat would have been available under naturalised flows. However, at the other two sites its operation had a minor negative impact, with occasional periods (e.g. spring 1996 at Little Sampford) when habitat was reduced to zero by increased flows.

RECOMMENDATIONS FOR OPERATION OF THE EOETS

Recommended changes in river flows

7.29 Overall, the results of the modelling indicate the historical flow regime is near to the optimum for the majority of the indicator species and life stages selected for study. This broadly corroborates preliminary work carried out by Entec (1998*a*, 1998*b*) at the Stour 1 and Pant 1 sites. A semi-quantitative approach has been devised for this project, to arrive at an overall recommendation of ecologically-ideal and ecologically-acceptable flows, bearing in mind the number of species examined, and their potentially-conflicting habitat requirements. This approach was a 3-stage process, as follows:

(i) Summarising optimal changes in flow requirement, for each species and lifestage at each site

(ii) Applying a scoring system to prioritise the requirements of the most important species/lifestages

(iii) Deriving overall recommendations for discharges within each river compartment, and any seasonal constraints.

7.30 A summary of the optimal changes in discharge for each species and lifestage at each site, with a qualitative recommendation for modifying the median flow at each site, is presented in Table 7.4 overleaf.

Table 7.4 – Qualitative recommendations for modifying median flows, based on PHABSIM analysis.

Species/lifestage	Stour 1	Stour 2	Stour 4	Pant 1	Pant 2	Pant 4
Adult brown trout	No change	No change	No change	Increase	Increase	Increase
Juvenile brown trout	No change	No change	Slight decrease	Increase	Increase	Increase
Spawning brown trout	No change	No change	No change	Increase	Increase	Increase
Adult chub	Slight increase	Increase	Slight increase	Increase	Increase	Increase
Juvenile chub	Neutral	Neutral (no habitat)	Neutral	Slight decrease	Slight decrease	No change
Spawning chub	Slight increase	No change	Neutral (no habitat)	Neutral (no habitat)	Increase	Neutral
Adult roach	Slight increase	Increase	Neutral	Increase	Increase	Slight increase
Juvenile roach	Neutral/ slight decrease	Slight decrease	Decrease	Slight decrease	Slight decrease	Decrease
Spawning roach	No change	No change	Slight increase	Increase	Slight increase	Neutral
Caddis fly larvae	Slight decrease	Slight decrease	Slight decrease	No change	No change	Slight decrease
Mayfly larvae	Slight increase	Increase	Neutral	Increase	Increase	Increase
Watercress	Slight increase	Slight increase	Neutral	Increase	Increase	Neutral
Water milfoil	Slight increase	Slight increase	Slight increase	Increase	Increase	Increase

7.31 The qualitative recommendations in Table 7.4 were then analysed in a semi-quantitative way, in order to derive an overall recommendation for the optimum flow regime at each site. This was done by assigning the above 'recommendations' with a numerical score on a five point scale, as follows:

Table 7.5 – Scores assigned to flow requirements from Table 7.4

Flow requirement	Score
Increase	+2
Slight increase	+1
No change/neutral	0
Slight decrease	-1
Decrease	-2

7.32 For each species/lifestage, the scores from Table 7.5 were multiplied by a weighting factor for that species/lifestage, such that the species that the habitat requirements of species considered to be most important are assigned a higher weighting. For this assessment, weightings were assigned as follows: salmonids (brown trout) – weighting 3; cyprinids (chub and roach) – weighting 2; invertebrates and macrophytes – weighting 1. The results of this analysis (with and without weightings applied) are shown in Table 7.6. 'Unweighted' scores (assuming all species and lifestages are of equal importance) are also presented for comparison purposes.

Table 7.6 – Recommendations from combined assessment of species flow requirements

Species	Weighting	Stour 1	Stour 2	Stour 4	Pant 1	Pant 2	Pant 4
Adult brown trout	3	0	0	0	2	2	2
Juvenile brown trout	3	0	0	-1	2	2	2
Spawning brown trout	3	0	0	0	2	2	2
Adult chub	2	1	2	1	2	2	2
Juvenile chub	2	0	0	0	-1	-1	0
Spawning chub	2	1	0	0	0	2	0
Adult roach	2	1	2	0	2	2	1
Juvenile roach	2	-1	-1	-2	-1	-1	-2
Spawning roach	2	0	0	1	2	1	0
Caddis fly larvae	1	-1	-1	-1	0	0	-1
Mayfly larvae	1	-1	2	0	2	2	2
Watercress	1	-1	1	0	2	2	0
Water milfoil	1	-1	1	1	2	2	2
Unweighted total		**-2**	**6**	**-1**	**16**	**17**	**10**
Weighted total		**0**	**9**	**-3**	**32**	**34**	**23**

7.33 Under the scoring scheme outlined above, the possible range of weighted scores extends from –50 to +50. The near-zero, or slightly positive weighted and unweighted totals for the Stour sites indicate that the species studied would benefit from, or at worst be unaffected by, a slight increase in flows within the Stour. The high, positive figures in both the weighted and unweighted totals for the

Pant/Blackwater indicate that overall, the species studied would show a clear benefit from increased flows within this river.

7.34 In recommending any changes in flow regime, potential negative impacts on some species/lifestages should be considered. At all sites except Stour 2, a small amount of marginal habitat suitable for juvenile chub is available across the majority of the flow spectrum, so increased flows would not put this lifestage at any greater disadvantage than under the existing situation. However, if these species were considered to be of special sensitivity or cause for special concern, the increases in flow could be confined to periods outside the critical periods for juvenile coarse fish, i.e. avoiding the period May-October, or at least the summer months when these smaller life stages are most prone to being washed out. Further recommendations for enhancing the amount of habitat available to juvenile coarse fish are made in paragraph 7.46 *et seq*.

7.35 Abstractions and discharges other than the EOETS will play a role in determining instream flow, and adjustment to the operational regime of the EOETS alone provides only limited scope for management of the flow regime within individual reaches. This is because only five conceptual 'compartments' are available within the two study rivers. These compartments are based on the locations of the Kirtling Green outfall, Wixoe offtake and Great Sampford outfall, as follows (see Figure 7.1):

(i) Stour: upstream of Kirtling Green (very limited length): subject to natural flow regime plus any backwater effect of EOETS transfer flow

(ii) Stour: Kirtling Green to Wixoe (includes Stour 1 study site): subject to natural flow plus full transfer flow via EOETS

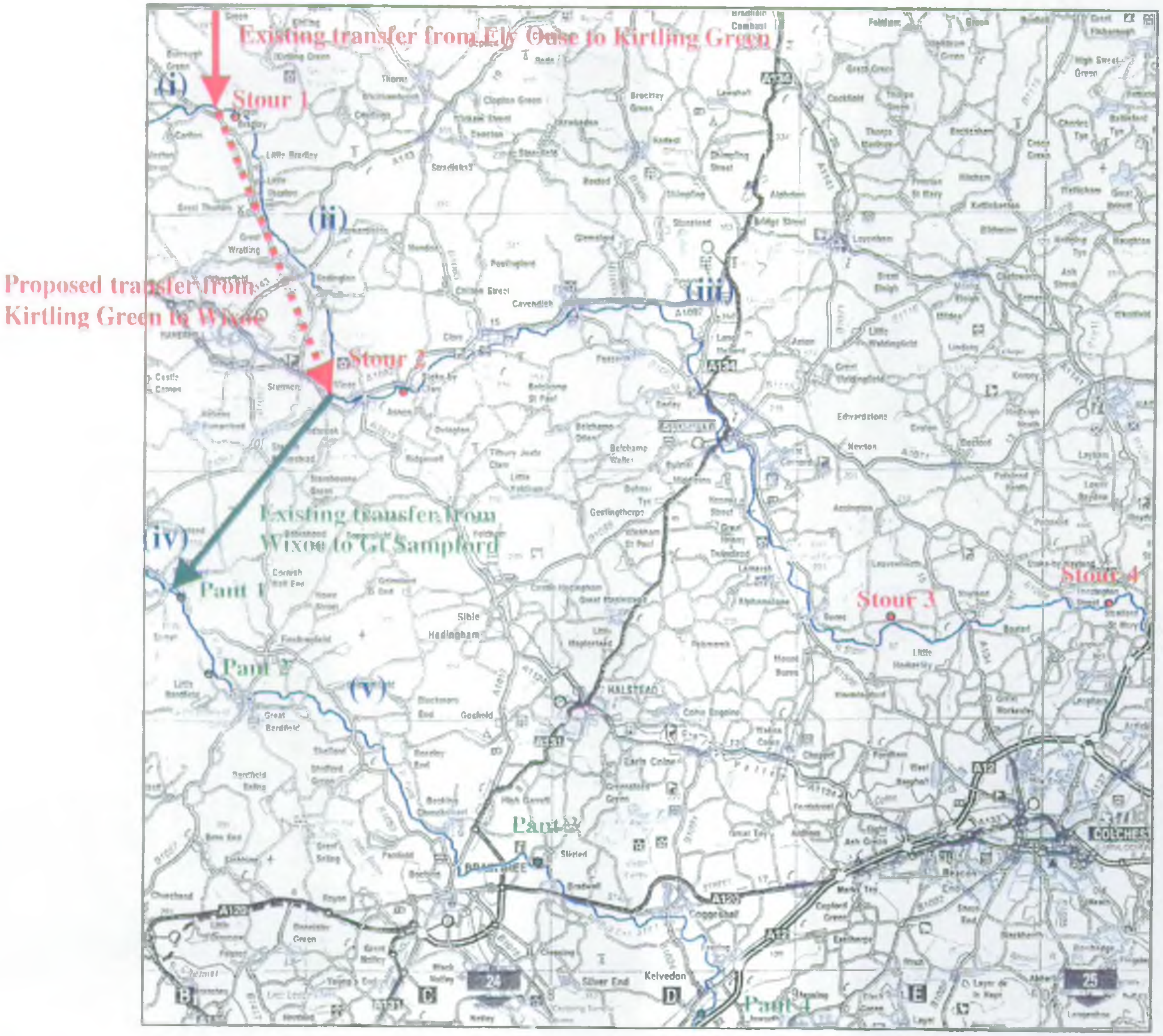
(iii) Stour: Wixoe to Langham/Stratford St Mary (includes Stour 2 & Stour 4 study sites): subject to EOETS transfer flow, less Wixoe transfer flow to Pant/Blackwater)

(iv) Pant/Blackwater upstream of Great Sampford (very limited length): subject to natural flow regime plus any backwater effect of Wixoe transfer flow

(v) Pant/Blackwater: Great Sampford to Langford (includes Pant 1, Pant 2 & Pant 4 study sites): subject to natural flow plus Wixoe transfer flow.

7.36 It must be borne in mind that under the present arrangements of the transfer scheme, any transfer from the EOETS to the Pant/Blackwater via the Wixoe pumping station must pass through compartment (ii). Therefore flows in this compartment currently represent the 'bottleneck' in the system, with upper limits on flows in compartments (iii) and (v) being imposed by the tolerance of the biota in compartment (ii) to high flows from the total EOETS transfer. However, a pipeline has been proposed, which will run between Kirtling Green and Wixoe, and would carry a flow of 50% of the quantity transferred to Kirtling Green, up to a limit of 150 Ml/d, allowing the existing high flows experienced on the upper Stour (average 141 Ml/d) to be reduced to a mean of 110 Ml/d. The value of this proposal is considered further in paragraph 7.40 *et seq*.

Figure 7.1. Locations of river 'compartments' (Roman numerals) on the Stour and Pant/Blackwater, with schematic layouts of existing and proposed transfer pipelines



7.37 Table 7.7 below shows an outline plan, prioritising each compartment in terms of current species/lifestage abundance within each compartment and summarising the existing situation with regard to flow and habitat relationships for priority species/lifestages. The final column outlines the potential changes in discharge that may take place within each compartment without compromising the availability of habitat. In general, the moderate increases in flow within the Pant/Blackwater will provide a benefit in terms of habitat availability.

Table 7.7 – Proposed changes to flow regime within river 'compartments' in the Stour & Pant/Blackwater system

Compartment No. (see para 7.35)	Priority species	Existing situation	Acceptable changes to flow regime
i	Adult/ spawning trout, roach and chub	Q_{50}@ Kedington GS = 0.342 m^3/s (not possible to modify with EOETS)	Not possible to change, however downstream regime needs to consider trout migration into this compartment.
ii	Trout, chub, roach, invertebrates	Q_{50} @ Kedington GS = 0.342 m^3/s. Most species/lifestages will tolerate higher discharge.	Increase Kirtling GreenQ_{50} to 1.5 m^3/s outside roach spawning season. Maintain near-historical Q_{50} for roach spawning season.
iii	All except spawning and juvenile trout and roach.	Q_{50} @ West Mill GS = 0.664 m^3/s. Most species/lifestages will tolerate higher discharge. Q_{50} @ Langham GS = 1.875 m^3/s. Most species/lifestages will tolerate higher discharge.	Increase Q_{50} at Bowers Hall Farm to 1.5-2 m^3/s outside chub/roach spawning season. Maintain near-historical Q_{50} for chub/roach spawning season. Increase Q_{50} at Langham up to 5 m^3/s.
iv	Adult/ spawning trout, roach and chub	Q_{50}@ Copford Hall GS= 0.112 m^3/s (not possible to modify with EOETS).	Not possible to change, however downstream regime needs to consider trout migration into this compartment.
v	All fish species (possibility of prioritising upstream reaches for spawning)	Q_{50} @ Copford Hall GS = 0.112 m^3/s. Most species/lifestage will benefit from higher discharge. Q_{50} @ Appleford GS = 0.928 m^3/s Most species/lifestages will benefit from higher discharge.	Great Sampford: Increase Q_{50} up to 1.0 m^3/s, possibly avoiding juvenile chub/roach season (unless habitat creation is carried out). Little Sampford: Increase Q_{50} up to 1.3 m^3/s, outside roach spawning season. Kelvedon: Increase Q_{50} up to 2.0 m^3/s, outside chub spawning season if possible.

Implementation of recommended changes to the flow regime

7.38 Table 7.8 below summarises the ecologically-acceptable flow ranges at each site within both study rivers. As previously stated, the flow in only three 'compartments' can be independently controlled by the operation of the EOETS and Wixoe transfer: the reaches downstream of Wixoe and Great Sampford, and the reach between Kirtling Green and Wixoe. Reaches further downstream, although directly affected by the EOETS, will also be influenced by other abstractions, discharges, and the operation of flow regulating structures such as sluice gates. The optimum flow ranges for downstream sites (Langham on the Stour, and Kelvedon on the Blackwater) are presented, as they are likely to be of use when applications for new or modified abstraction licences or discharge consents are being considered.

7.39 The optimum flow ranges are split to cover the times within and outside the roach and chub spawning season, as these were the lifestages most sensitive to increased flows.

Table 7.8 – Ecologically-acceptable flow ranges within and outside of chub and roach spawning season (April-June)

Site	Historical Q_{50} (m^3/s)	Acceptable Q range (July-March) (m^3/s)	Acceptable Q range (April-June) (m^3/s)
River Stour			
Kirtling Green	0.342	Up to 1.50	Up to 0.40
Bowers Hall Farm	0.664	Up to 2.0	Up to 0.75
Langham	1.875	Up to 5.0	Up to 5.0
River Pant/Blackwater			
Great Sampford	0.112	0.1 to 1.0	0.1 to 1.0*
Little Sampford	0.112	0.2 to 1.3	0.3 to 0.6
Kelvedon	0.928	0.3 to 2.0	0.5 to 1.2

*will be limited by Q_{max} at downstream sites

PROPOSED PIPELINE BETWEEN KIRTLING GREEN AND WIXOE

Value of the proposed pipeline between Kirtling Green and Wixoe

7.40 Northumbrian Water – Southern Operation (formerly Essex and Suffolk Water) is currently carrying out feasibility and environmental impact assessment studies into a proposal for increasing the capacity of the EOETS to the full licensed quantity of 450 Ml/d (Entec, 2000*b*). The proposal is to construct a pipeline from Kirtling Green to Wixoe. The pipeline would carry a flow of 50% of the quantity transferred to Kirtling Green, up to a limit of 150 Ml/d, allowing the existing high flows experienced on the Upper Stour (average 141 Ml/d) to be reduced to a mean of 110 Ml/d.

7.41 The pipeline would take flows from the transfer route at Kirtling Green Outfall, before the point of entry to the River Stour, and the facility could be provided at Wixoe for alternative discharge points, either direct to Wixoe Pumping Station, from where water is pumped to the Rivers Pant and Blackwater , or to the River Stour downstream of the pumping station.

7.42 The value of this pipeline in terms of potential habitat enhancement can be assessed using the PHABSIM modelling results. Three river compartments, and therefore three of the modelled sites, are of particular concern. These are:

(i) Kirtling Green (Stour 1), which receives the full EOETS flow under the current configuration, and which could potentially benefit from better management of flows if the pipeline is constructed

(ii) Bowers Hall Farm (Stour 2), which could potentially benefit from augmented flows, without the flow upstream of Wixoe being changed, if the pipeline is constructed

(iii) Great Sampford (Pant 1), which could benefit from augmented flows, without the flow upstream of Wixoe being changed, if the pipeline is constructed.

7.43 Under the flow regime that is proposed in Table 7.8, if the maximum ecologically-acceptable flow (July-March) of 2.0 m^3/s at Bowers Hall Farm was to be discharged simultaneously with the maximum ecologically acceptable flow of 1.0 m^3/s at Great Sampford, this would require a total of 2.7 m^3/s to be discharged through Compartment (ii) (Kirtling Green to Wixoe)[1]. As the maximum ecologically-acceptable flow at this site is only 1.5 m^3/s, such a discharge would be detrimental, particularly to trout and caddis flies. As the proposed pipeline is planned to carry 50% of the total quantity transferred to Kirtling Green, up to a limit of 150 Ml/d (equivalent to 1.7 m^3/s), the pipeline option offers scope to pass the maximum ecologically-acceptable flow in both the Pant/Blackwater and the lower Stour, whilst not exceeding the maximum ecologically-acceptable flow between Kirtling Green and Wixoe.

7.44 A similar situation is predicted for transfer flows during the (April-June) chub and roach spawning period, when passage of the maximum ecologically-acceptable flows at Bowers Hall Farm and Great Sampford could potentially require a flow of 1.45 m^3/s in the reach between Kirtling Green and Wixoe. This would exceed the ecologically acceptable flow at Kirtling Green by approximately 1 m^3s. Although more than the proposed 50% of the EOETS transfer flow would need to be passed through the pipeline, it would be within its capacity to pass sufficient flow to Wixoe, such that the in-channel flow between Kirtling Green and Wixoe remained within the ecologically-acceptable range. Therefore the proposed pipeline could offer ecological benefits all year round.

7.45 Although the pipeline is predicted to have a benefit to spawning and juvenile coarse fish in the upper reaches of the Stour, an alternative approach which may be more cost-effective, while simultaneously giving benefits in terms of fish habitat, aesthetics and flood storage capacity is discussed below.

A potential alternative to the proposed Kirtling Green-Wixoe pipeline

7.46 PHABSIM modelling of the Pant and Stour system has shown juvenile chub and roach habitat availability is frequently reduced by augmented flows during the period May-October (see time series 1992-1996). This is almost certainly due to exceedence of the preferred (in some cases critical) flow velocity for this life stage of these species. During the same period, habitat availability for other lifestages of chub, roach and brown trout is generally increased (see time series 1992-1996). It is thus

[1] This figure assumes 0.3 m^3/s of natural flow accretion between Wixoe and Bowers Hall Farm, a figure based on the difference between the historic Q_{MI} values at these two sites.

difficult to envisage how observed flows could be set to benefit adult and spawning lifestages, whilst preventing a limiting habitat bottleneck occurring with respect to juvenile chub and roach.

7.47 However, it is possible that physical habitat manipulation could be undertaken to the benefit of juvenile chub and roach, offsetting the disbenefits of augmented summer flows on habitat availability for these lifestages. In essence, any habitat manipulation would need to focus on the provision of low velocity refuge areas for juvenile coarse fish (Everard, 1998). Typically, this aim could be achieved by the creation of significant lengths of shallow, marginal areas or by the excavation of backwater areas connected to the main channel. The formation of a well vegetated, 2-stage profile to the Pant and Stour channels in critical areas would be of great benefit, provided that the level of the low berms resulting was set to flood at a typical summer discharge, creating the low velocity refuge areas required. Other benefits of this approach include a potentially significant increase in the capacity of the channel, with obvious benefits during high flow events.

7.48 Indeed, it is possible to see how this proposal could be developed in order to increase channel capacity sufficiently to obviate the need for the proposed augmentation pipeline. All additional flow could then be passed down the adjusted, higher capacity, natural channel. The use of agri-environment payments such as Countryside Stewardship could be incorporated into such a scheme to make it more attractive to farmers whose land would be affected. Further modelling of the impacts of this option on key species might be carried out to assess the overall impact on them.

7.49 Other possible high flow refuge areas for juvenile coarse fish could be created by:

- Partial excavation and connection to the river of old ox-bow loops.
- Excavation and connection to the river of old ditch systems.
- Connection of existing ponds or pits to the river system via a wide necked ditch.
- Recreation of water meadow systems.

7.50 Again, some of these options could attract partnership funding from agri-environment schemes.

8. REFERENCES

Bovee, K.D. 1982. A guide to stream habitat analysis using the Instream Flow Incremental Methodology. US Fish & Wildlife Service Instream Flow Information Paper No. 12. FWS/OBS-82/26.

Bullock, A., Gustard, A & Grainger, E. 1991. Instream Flow Requirements of Aquatic Species. Institute of Hydrology Report No. 115.

Elliott, C.R.N, Johnson, I.W., Sekulin, A.E., Dunbar, M.J. & Acreman, M.C. 1996. *Guide to the Use of the Physical Habitat Simulation System*. Environment Agency R&D Technical Report W20.

Entec. 1998*a*. Assessment of the impact of the existing Ely Ouse-Essex Transfer Scheme. Biology and River Corridor Biology. Report No. 28054RR440 i3. Environment Agency Project Number: 100160.

Entec. 1998*b*. Assessment of the impact of the existing Ely Ouse-Essex Transfer Scheme. Fisheries. Report No. 28054RR541 i4. Environment Agency Project Number: 100160.

Entec. 1998c. Assessment of the impact of the existing Ely Ouse-Essex Transfer Scheme. Hydrology. Report No. 28054RR546 i1. Environment Agency Project Number: 100160.

Entec. 2000*a*. Flow naturalisation for selected gauges in the Rivers Stour and Blackwater. Report to Essex and Suffolk Water, December 2000.

Entec. 2000*b*. Strategic environmental assessment of options for water transfer between Norfolk and Essex. Assessment Report – Consultation Draft. Report to Essex and Suffolk Water, January 2000.

Everard, M. 1998. The contribution of reedbeds to floodplain and river systems. pp. 117-141 *in* Bailey, R.G., Jose, P.V & Sherwood, B.R. (eds.) *United Kingdom Floodplains*. Otley, Westbury Press.

Johnson, I.W., Elliott, C.R.N., Gustard, A., Armitage, P.D., Ladle, M., Beaumont, W. & Dawson, F.H. 1993. Ecologically Acceptable Flows. National Rivers Authority R&D Project 282. (Project Record 282/Wx and R&D Note 185).

Johnson, I.W., Elliott, C.R.N. & Gustard, A. 1994. Data requirements and collection procedures for application of the instream flow incremental methodology in the UK. Institute of Hydrology, UK.

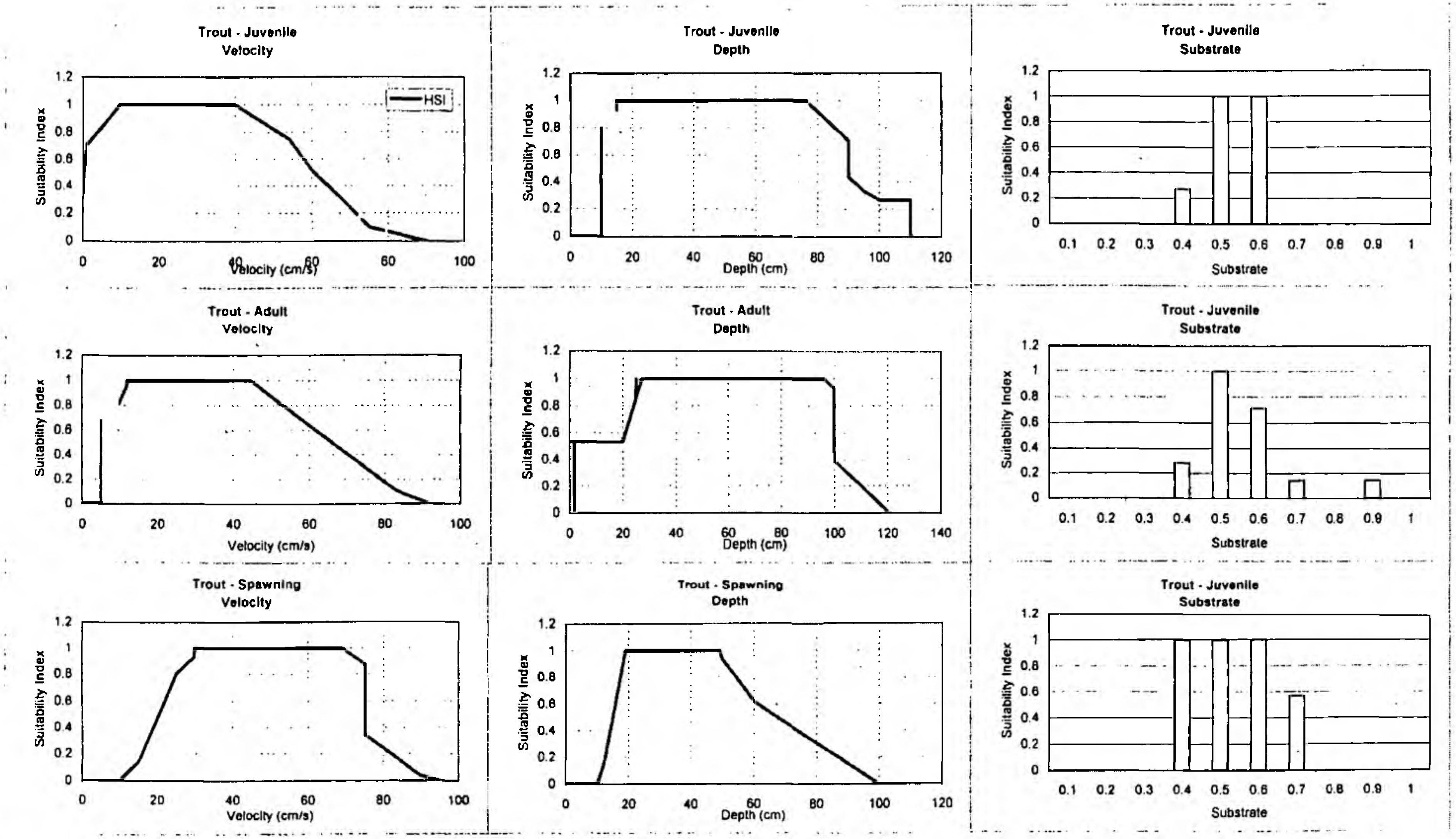
Stalnaker, J.P., 1979. *in* McMahon, T.M. & Finlayson, B.T. 1992: *Stream Hydrology for Ecologists*, Wiley and Sons, Chichester.

WS Atkins. 1997. Application of IFIM/PHABSIM for the Upper River Vyrnwy and Cound Brook. Final Modelling Report for the River Vyrnwy. Report No. AK2077/64/DG/004

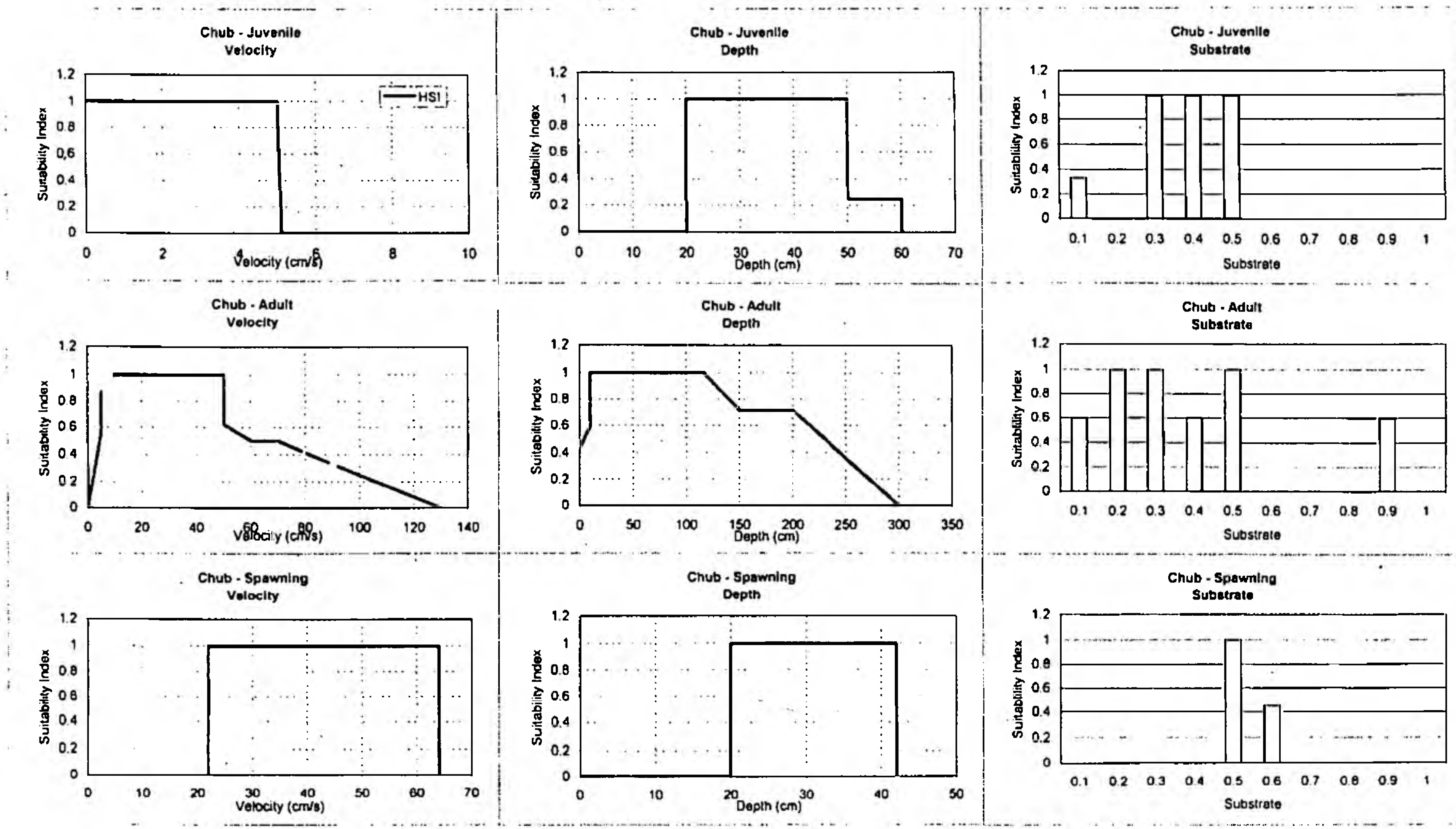
WS Atkins. 1998. Application of PHABSIM on the Rivers Dibb, Wharfe and Ure. Modelling Report: Rivers Wharfe and Dibb. Report No. AK2218/65/dg/016.

WS Atkins. 2000. Development of HSI Curves for Fish Species in Lowland Rivers. Report No. AK2417/63/dg/120, prepared for the Environment Agency.

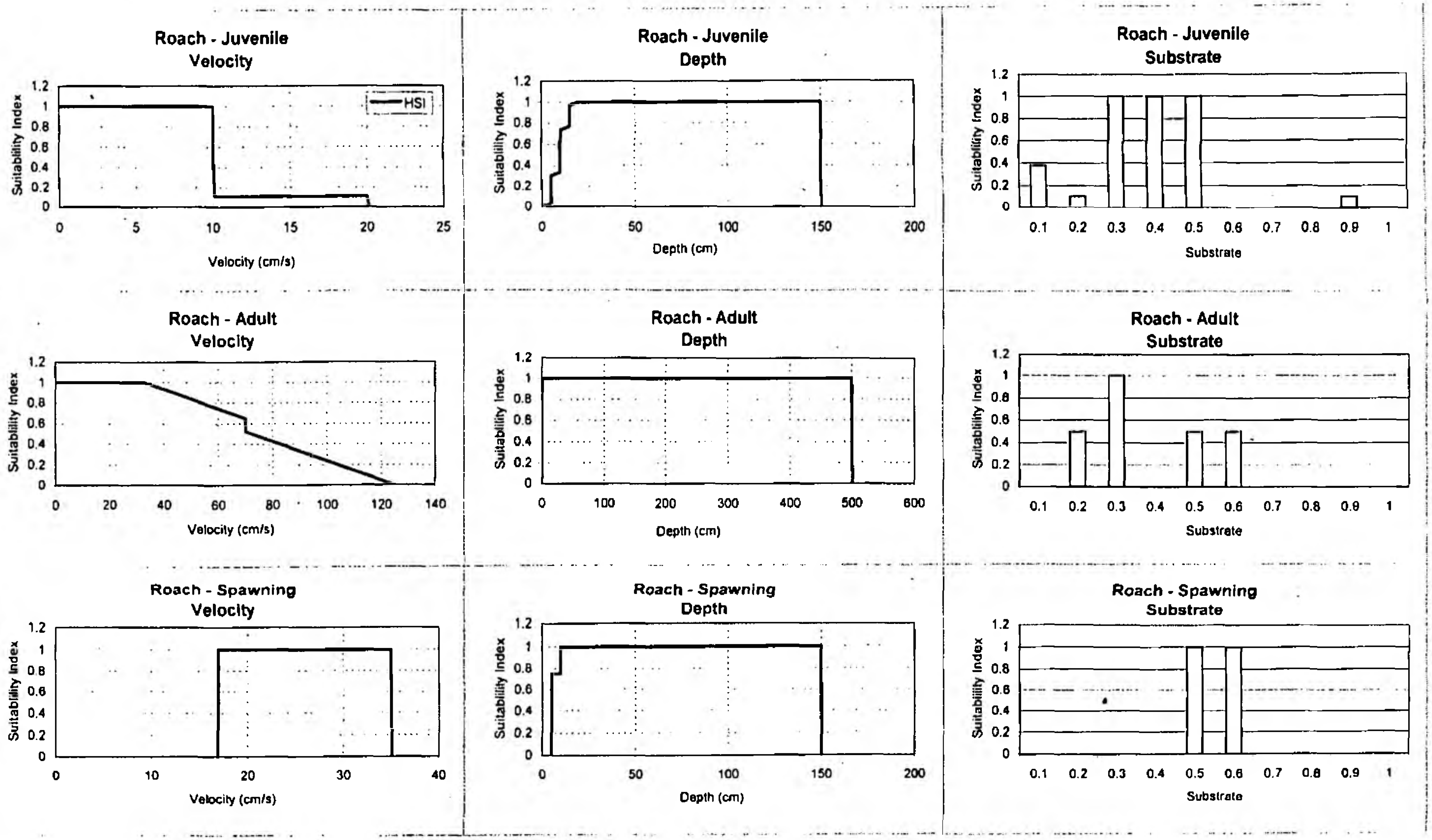
Appendix 1. HABITAT SUITABILITY INDEX CURVES



Appendix 1.1. Habitat Suitability Curves for Brown Trout

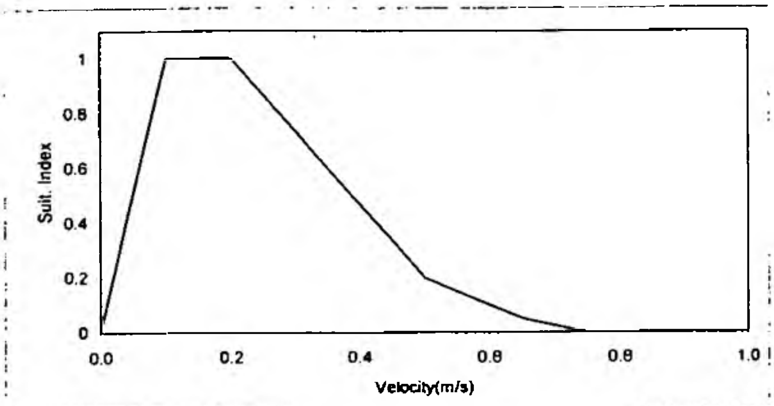


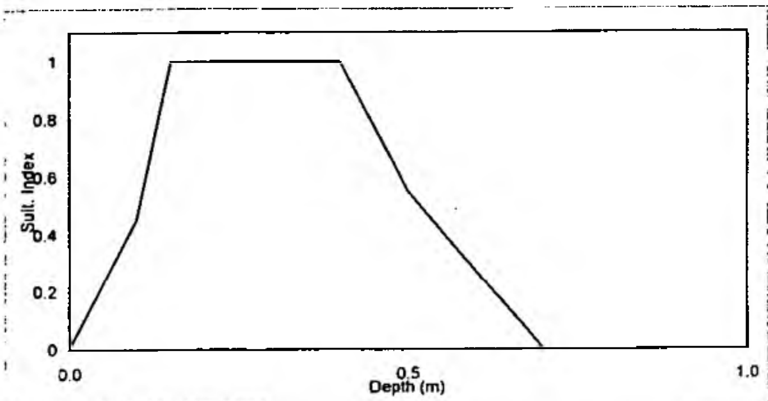
Appendix 1.2. Habitat Suitability Curves for Chub

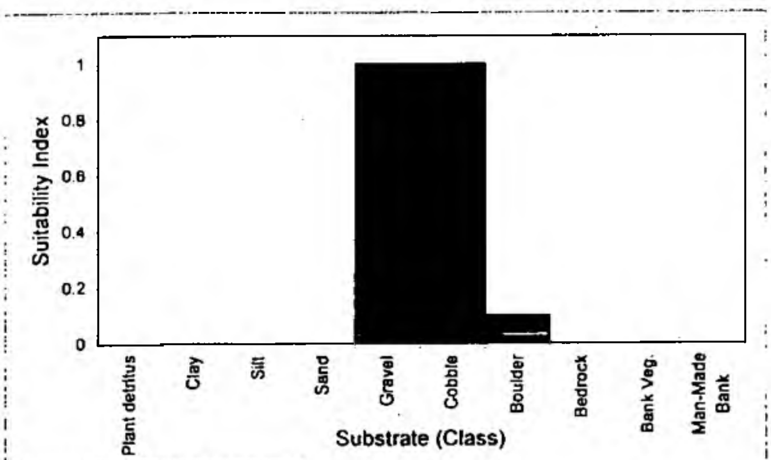


Appendix 1.3. Habitat Suitability Curves for Roach

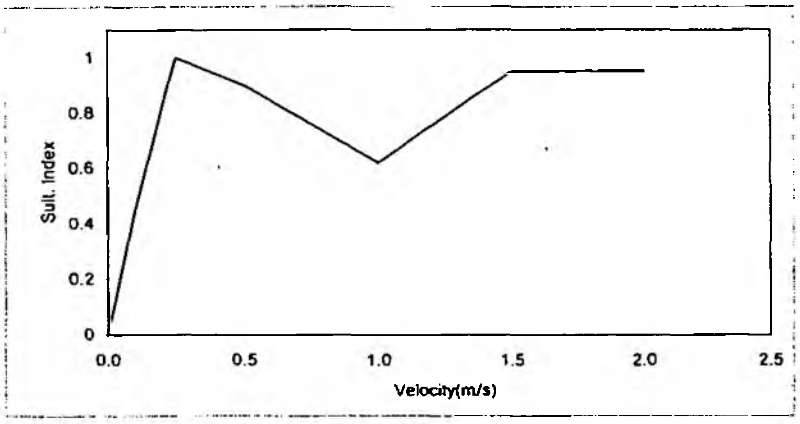
Appendix 1.4. Habitat Suitability Curves for caddis fly *(Hydropsyche pellucidula)*

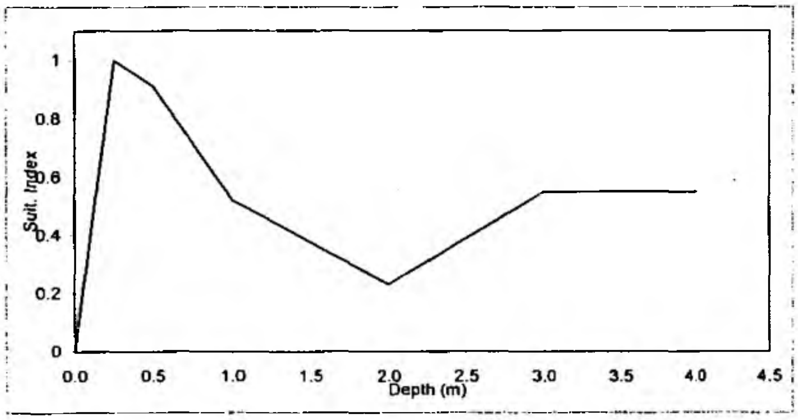


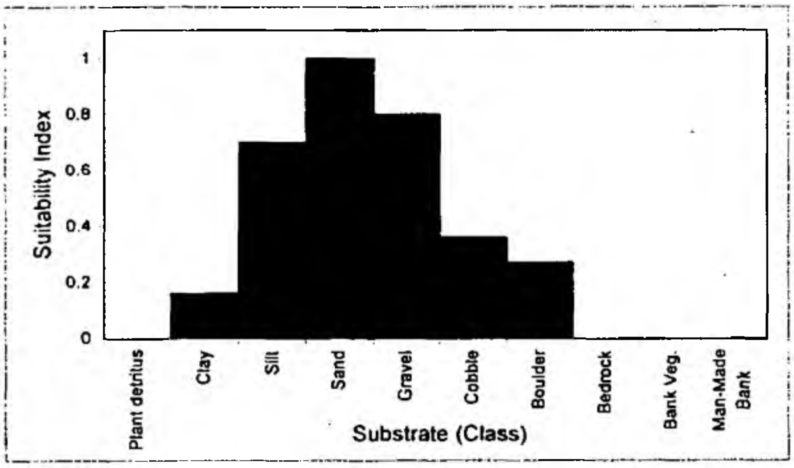




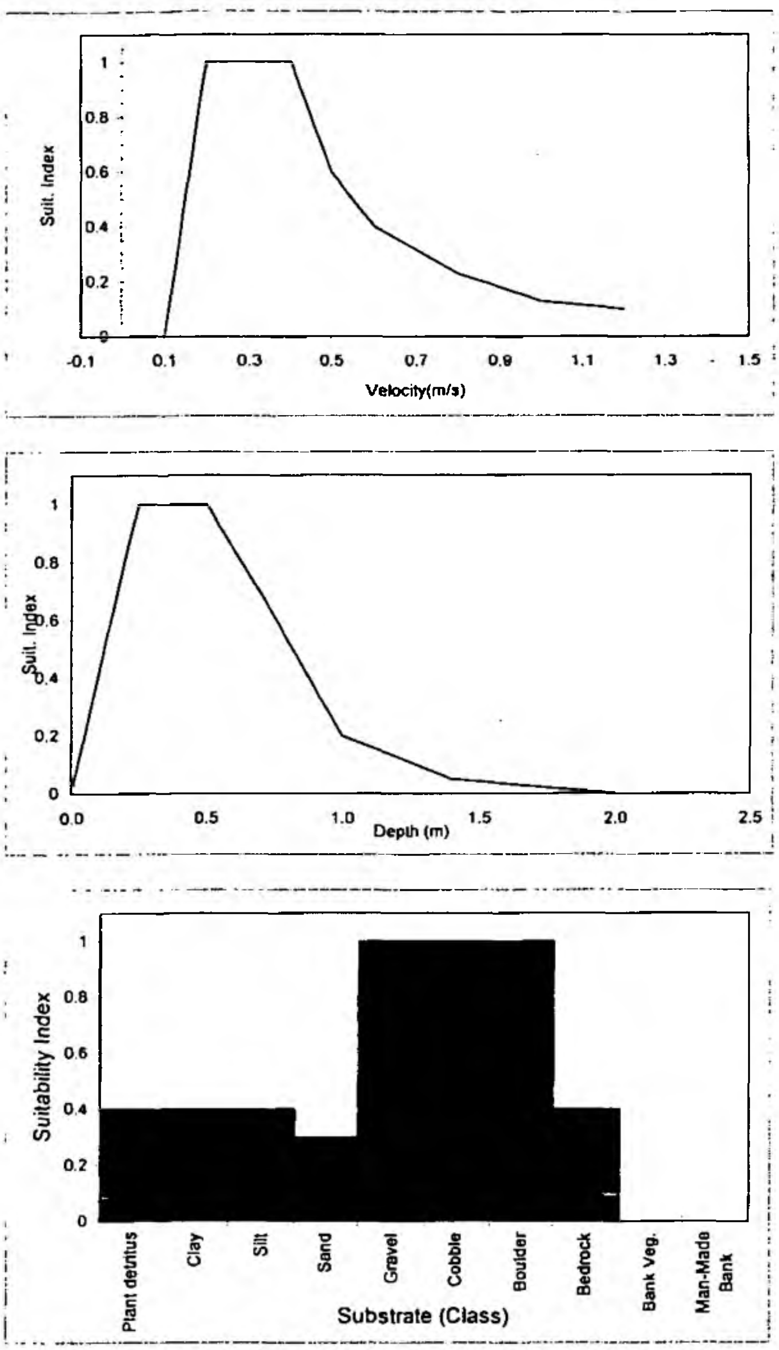
Appendix 1.5. Habitat Suitability Curves for Mayfly (Ephemeridae)



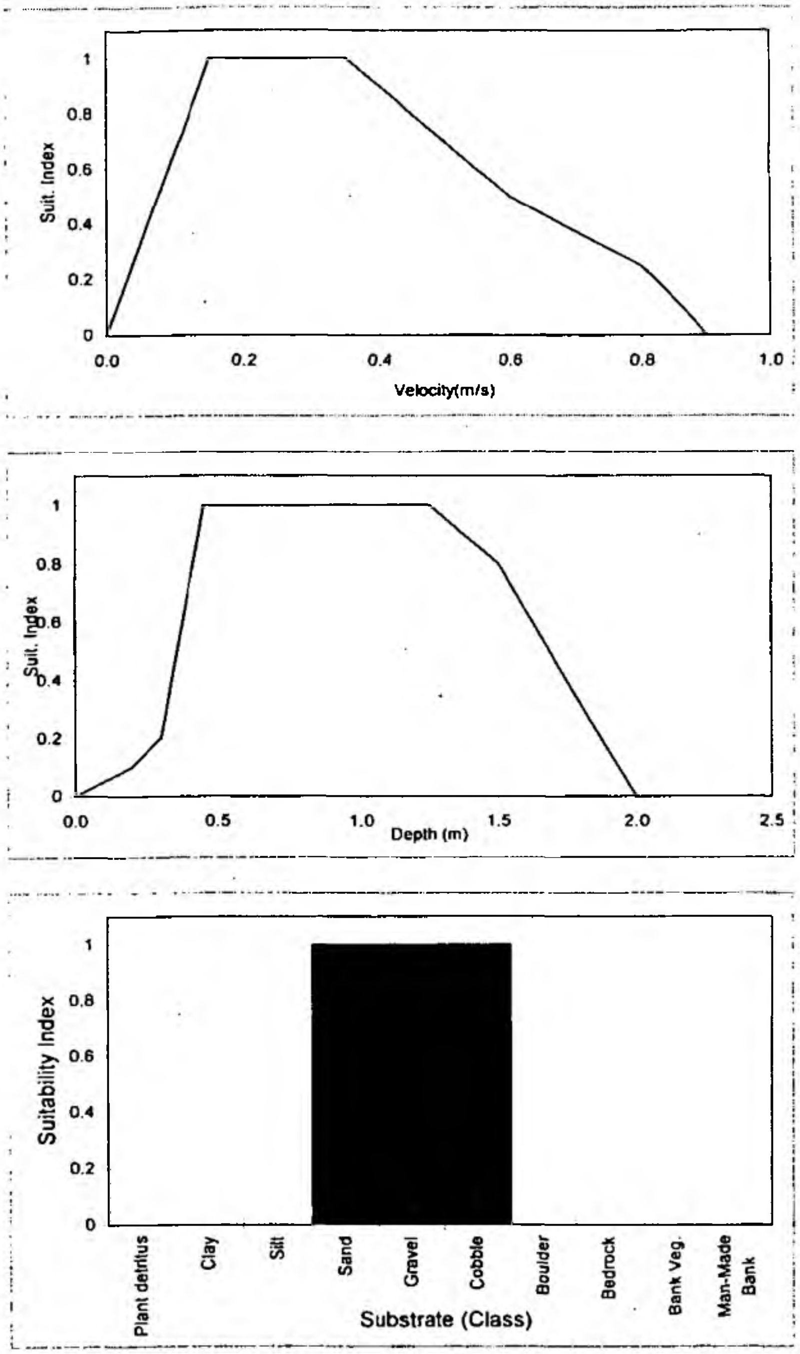




Appendix 1.6. Habitat Suitability Curves for Watercress *(Rorippa nasturtium-aquaticum)*



Appendix 1.7. Habitat Suitability Curves for water milfoil *(Myriophyllum spicatum)*



Appendix 2. *RIVER STOUR DOWNSTREAM OF KIRTLING GREEN*

Appendix 2.1. Hydraulic field measurements

River Stour downstream of Kirtling Green Outfall: low flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	0.65	0.37	0.089	0.021
3	0.50	0.36	0.071	0.013
3.5	0.50	0.36	0.136	0.024
4	0.50	0.33	0.152	0.025
4.5	0.50	0.35	0.125	0.022
5	0.50	0.36	0.130	0.023
5.5	0.50	0.31	0.108	0.017
6	0.50	0.29	0.073	0.011
6.5	0.50	0.00	0.000	0.000
			Total flow	**0.156**

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	0.35	0.22	0.002	0.000
3	0.50	0.35	0.153	0.027
3.5	0.50	0.39	0.219	0.043
4	0.50	0.24	0.258	0.031
4.5	0.50	0.17	0.180	0.015
5	0.50	0.16	0.165	0.013
5.5	0.50	0.15	0.121	0.009
6	0.50	0.11	0.105	0.006
6.5	0.50	0.09	0.056	0.003
7	0.45	0.08	0.010	0.000
7.5	0.60	0.07	0.012	0.001
			Total flow	**0.146**

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.40	0.14	0.019	0.001
2.5	0.50	0.16	0.086	0.007
3	0.50	0.15	0.195	0.015
3.5	0.50	0.16	0.239	0.019
4	0.50	0.18	0.212	0.019
4.5	0.50	0.21	0.192	0.020
5	0.50	0.24	0.195	0.023
5.5	0.50	0.26	0.182	0.024
6	0.50	0.25	0.198	0.025
6.5	0.50	0.28	0.107	0.015
7	0.55	0.26	0.011	
			Total flow	**0.153**

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	0.75	0.12	0.020	0.002
3	0.50	0.13	0.187	0.012
3.5	0.50	0.13	0.319	0.021
4	0.50	0.14	0.250	0.018
4.5	0.50	0.15	0.357	0.027
5	0.50	0.13	0.362	0.024
5.5	0.50	0.16	0.322	0.026
6	0.50	0.14	0.256	0.018
6.5	0.50	0.11	0.308	0.017
7	0.55	0.09	0.129	0.006
			Total flow	**0.163**

River Stour downstream of Kirtling Green Outfall: medium flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.5	0.35	0.48	0.042	0.01
2	0.50	0.68	0.440	0.15
2.5	0.50	0.65	0.470	0.15
3	0.50	0.64	0.490	0.16
3.5	0.50	0.60	0.550	0.17
4	0.50	0.64	0.550	0.18
4.5	0.50	0.62	0.490	0.15
5	0.50	0.59	0.362	0.11
5.5	0.50	0.52	0.023	0.01
6	0.50	0.50	0.023	0.01
6.5	0.65	0.30	0.058	0.01
			Total flow	1.09

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	0.65	0.48	0.022	0.01
3	0.50	0.50	0.143	0.04
3.5	0.50	0.55	0.450	0.12
4	0.50	0.50	0.590	0.15
4.5	0.50	0.44	0.680	0.15
5	0.50	0.42	0.610	0.13
5.5	0.50	0.42	0.570	0.12
6	0.50	0.39	0.690	0.13
6.5	0.50	0.39	0.670	0.13
7	0.50	0.33	0.610	0.10
7.5	0.65	0.36	0.318	0.07
			Total flow	1.15

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.45	0.42	-0.013	0.00
2.5	0.50	0.47	0.061	0.01
3	0.50	0.45	0.384	0.09
3.5	0.50	0.44	0.480	0.11
4	0.50	0.50	0.590	0.15
4.5	0.50	0.51	0.620	0.16
5	0.50	0.52	0.560	0.15
5.5	0.50	0.54	0.520	0.14
6	0.50	0.53	0.490	0.13
6.5	0.50	0.57	0.348	0.10
7	0.55	0.53	0.254	0.07
			Total flow	1.10

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.35	0.20	0.031	0.00
2.5	0.50	0.40	0.024	0.00
3	0.50	0.44	0.362	0.08
3.5	0.50	0.42	0.570	0.12
4	0.50	0.42	0.630	0.13
4.5	0.50	0.43	0.650	0.14
5	0.50	0.42	0.640	0.13
5.5	0.50	0.44	0.660	0.15
6	0.50	0.45	0.690	0.16
6.5	0.50	0.41	0.620	0.13
7	0.75	0.40	0.530	0.16
			Total flow	1.20

River Stour downstream of Kirtling Green Outfall: high flow

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.7	0.35	0.017	0	0.000
2	0.40	0.52	0.100	0.021
2.5	0.50	0.63	0.347	0.109
3	0.50	0.63	0.780	0.246
3.5	0.50	0.65	0.820	0.267
4	0.50	0.66	0.720	0.238
4.5	0.50	0.66	0.780	0.257
5	0.50	0.66	0.780	0.257
5.5	0.50	0.67	0.800	0.268
6	0.50	0.65	0.810	0.263
6.5	0.50	0.65	0.770	0.250
7	0.50	0.60	0.690	0.207
7.5	0.75	0.32	0.022	0.005
			Total flow	2.388

Appendix 2.2. Overhanging vegetation and substrate measurements

River Stour downstream of Kirtling Green Outfall

Transect 1A

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.0	900.0
2	0.5	0.0	900.0
3	1	0.0	900.0
4	1.5	0.0	900.0
5	2	50.0	306.9
6	2.5	50.0	306.9
7	3	0.0	405.7
8	3.5	0.0	405.6
9	4	0.0	405.6
10	4.5	0.0	405.6
11	5	0.0	405.5
12	5.5	0.0	405.5
13	6	0.0	405.6
14	6.5	0.0	405.7
15	7	0.0	304.9
16	7.5	0.0	900.0
17	8	0.0	900.0
18	8.5	0.0	900.0
19	9	0.0	900.0
20	9.5	0.0	900.0

Transect 2B

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.0	900.0
2	0.5	0.0	900.0
3	1	0.0	900.0
4	1.5	0.0	900.0
5	2	50.0	900.0
6	2.5	80.0	300.0
7	3	40.0	306.8
8	3.5	0.0	504.7
9	4	0.0	406.7
10	4.5	0.0	405.6
11	5	0.0	405.6
12	5.5	0.0	405.6
13	6	0.0	405.6
14	6.5	0.0	406.6
15	7	0.0	605.6
16	7.5	0.0	305.9
17	8	0.0	900.0
18	8.5	0.0	900.0
19	9	0.0	900.0
20	9.5	0.0	900.0
21	10	0.0	900.0
22	10.5	0.0	900.0

Transect 3C

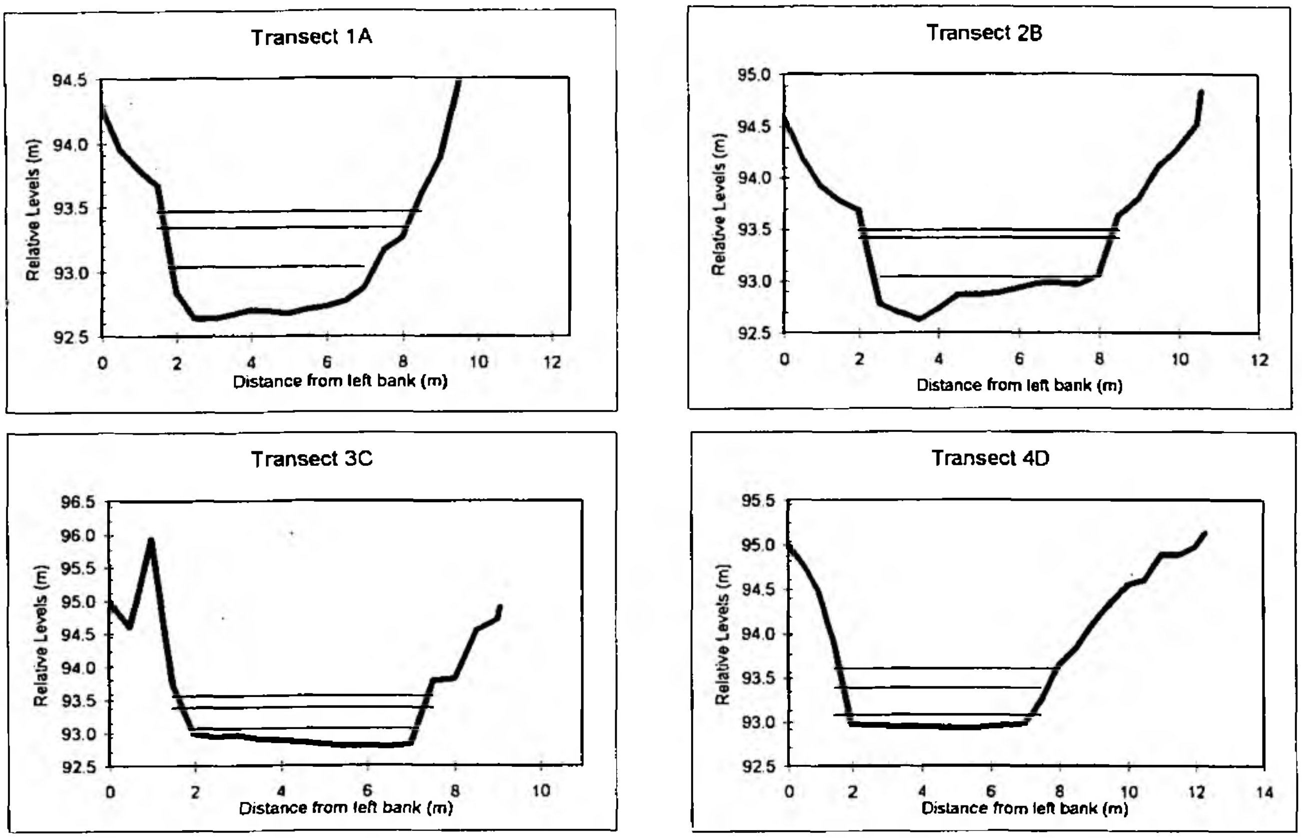
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.0	900.0
2	0.5	0.0	900.0
3	1	0.0	900.0
4	1.5	0.0	900.0
5	2	0.0	405.9
6	2.5	0.0	405.6
7	3	0.0	405.5
8	3.5	0.0	504.6
9	4	0.0	504.6
10	4.5	0.0	504.6
11	5	0.0	504.6
12	5.5	0.0	504.6
13	6	0.0	405.6
14	6.5	0.0	306.6
15	7	0.0	306.7
16	7.5	0.0	900.0
17	8	0.0	900.0
18	8.85	0.0	900.0

Transect 4D

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.0	900.0
2	0.5	0.0	900.0
3	1	0.0	900.0
4	1.5	50.0	900.0
5	2	20.0	301.9
6	2.5	20.0	406.8
7	3	0.0	405.5
8	3.5	0.0	405.5
9	4	0.0	405.5
10	4.5	0.0	405.5
11	5	0.0	504.6
12	5.5	0.0	504.7
13	6	0.0	405.5
14	6.5	0.0	504.8
15	7	0.0	406.7
16	7.5	0.0	301.9
17	8	0.0	900.0
18	8.5	0.0	900.0
19	9	0.0	900.0
20	9.5	0.0	900.0
21	10	0.0	900.0
22	10.5	0.0	900.0
23	11	0.0	900.0
24	11.5	0.0	900.0
25	12	0.0	900.0
26	12.2	0.0	900.0

Appendix 2.3

Stour downstream of Kirtling Green Outfall: bed elevation and water surface levels



Appendix 2.4

River Stour downstream of Kirtling Green Outfall: longitudinal water surface level pro

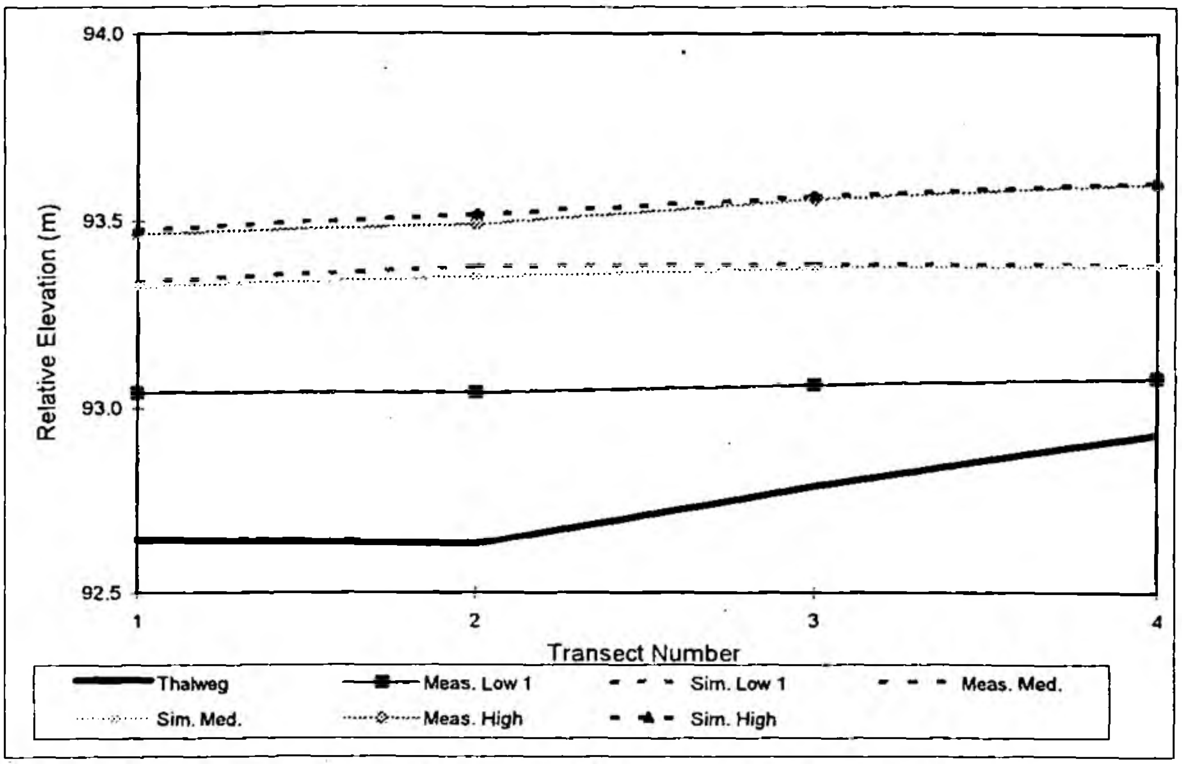


Figure 2.4a: Longitudinal water surface elevation for measured and observed discharges

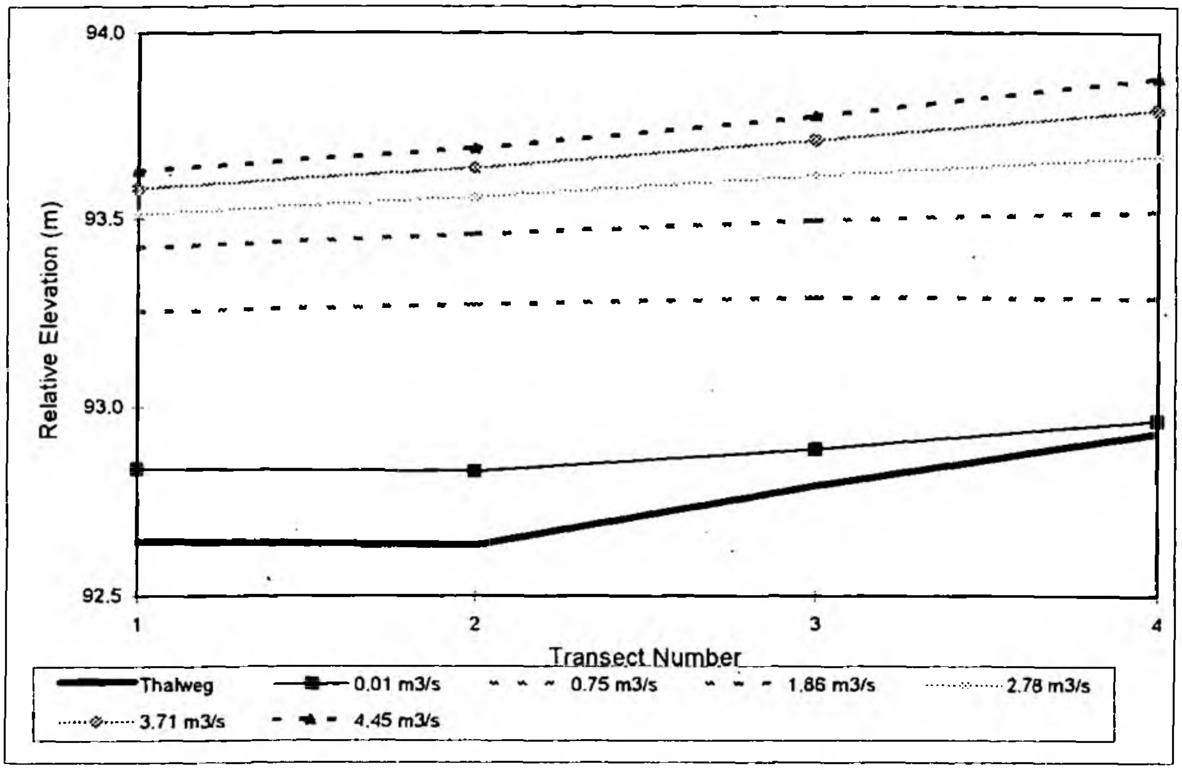
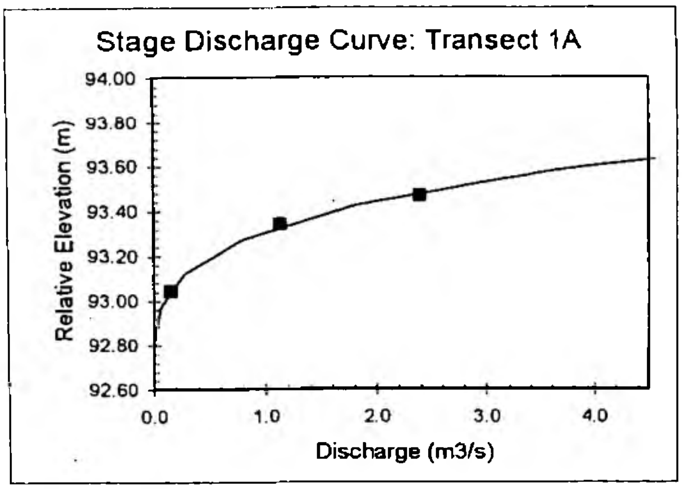
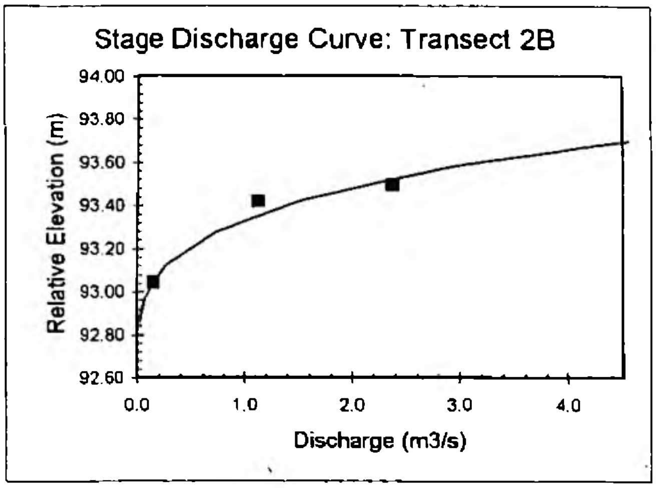


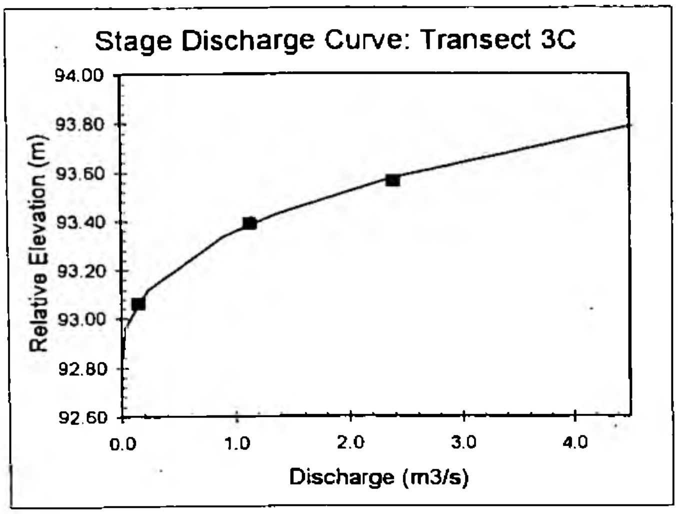
Figure 2.4b: Longitudinal water surface elevation for simulated flows.

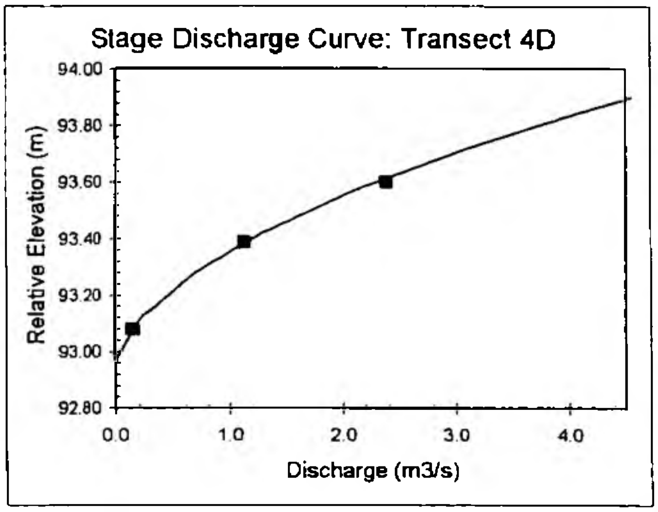
Appendix 2.5

River Stour downstream of Kirtling Green Outfall: stage-discharge relationships



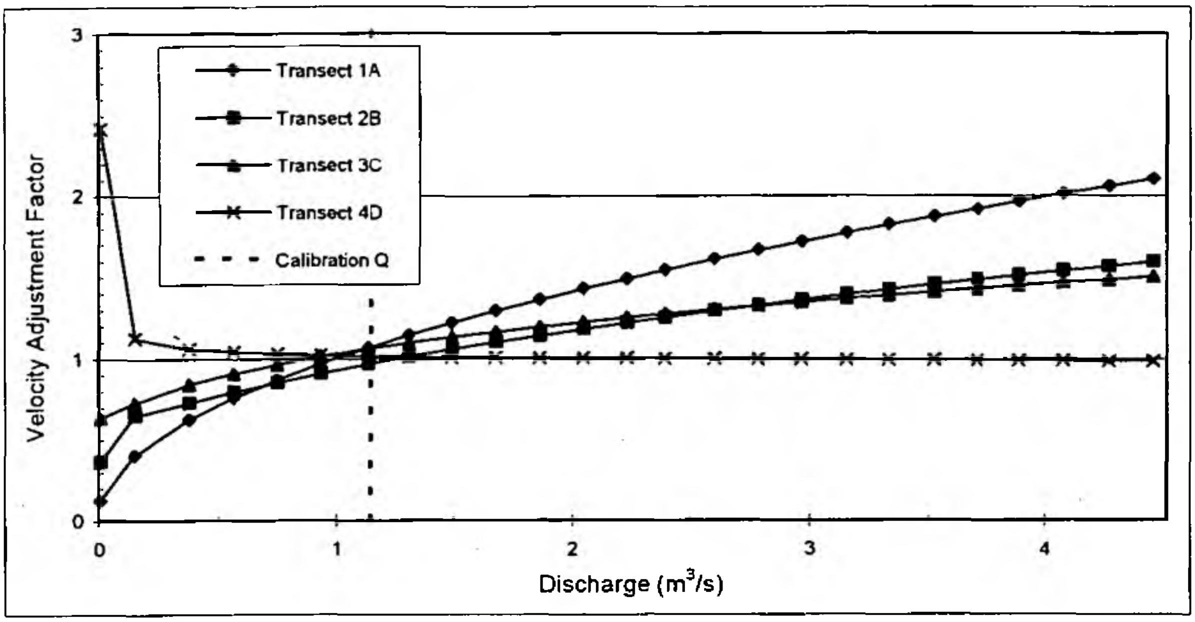






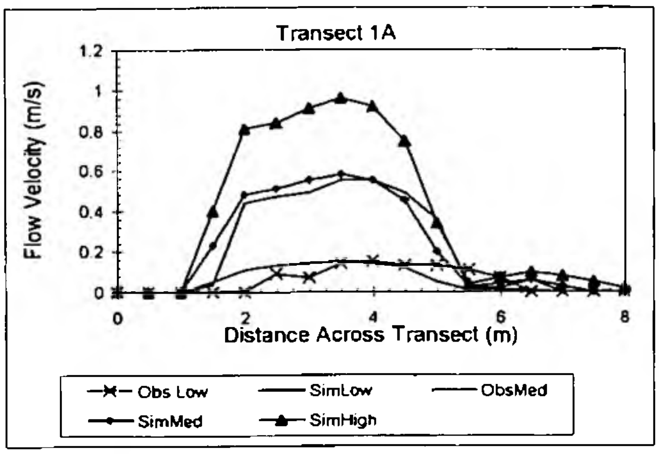
Appendix 2.6

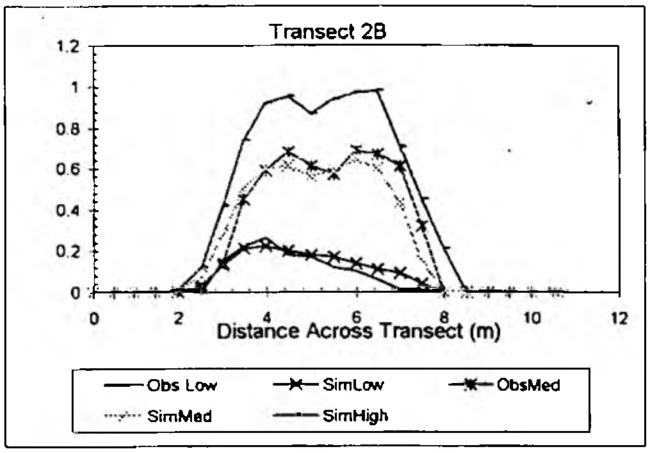
Velocity Adjustment Factors for the River Stour downstream of Kirtling Green Outfall

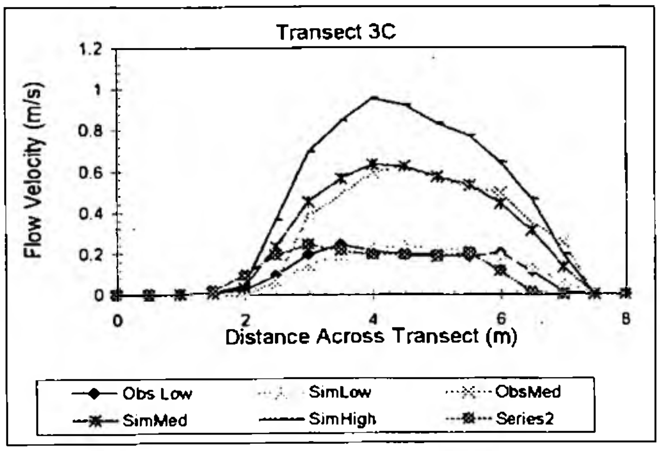


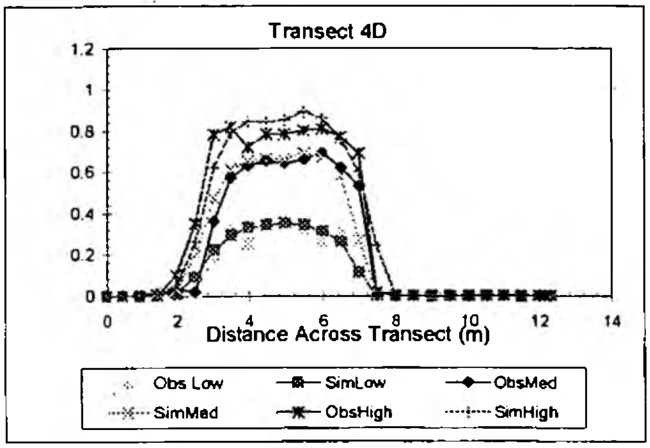
Appendix 2.7

Calibration flow velocities: observed and simulated for Stour Downstream of Kirtling Green Outfall

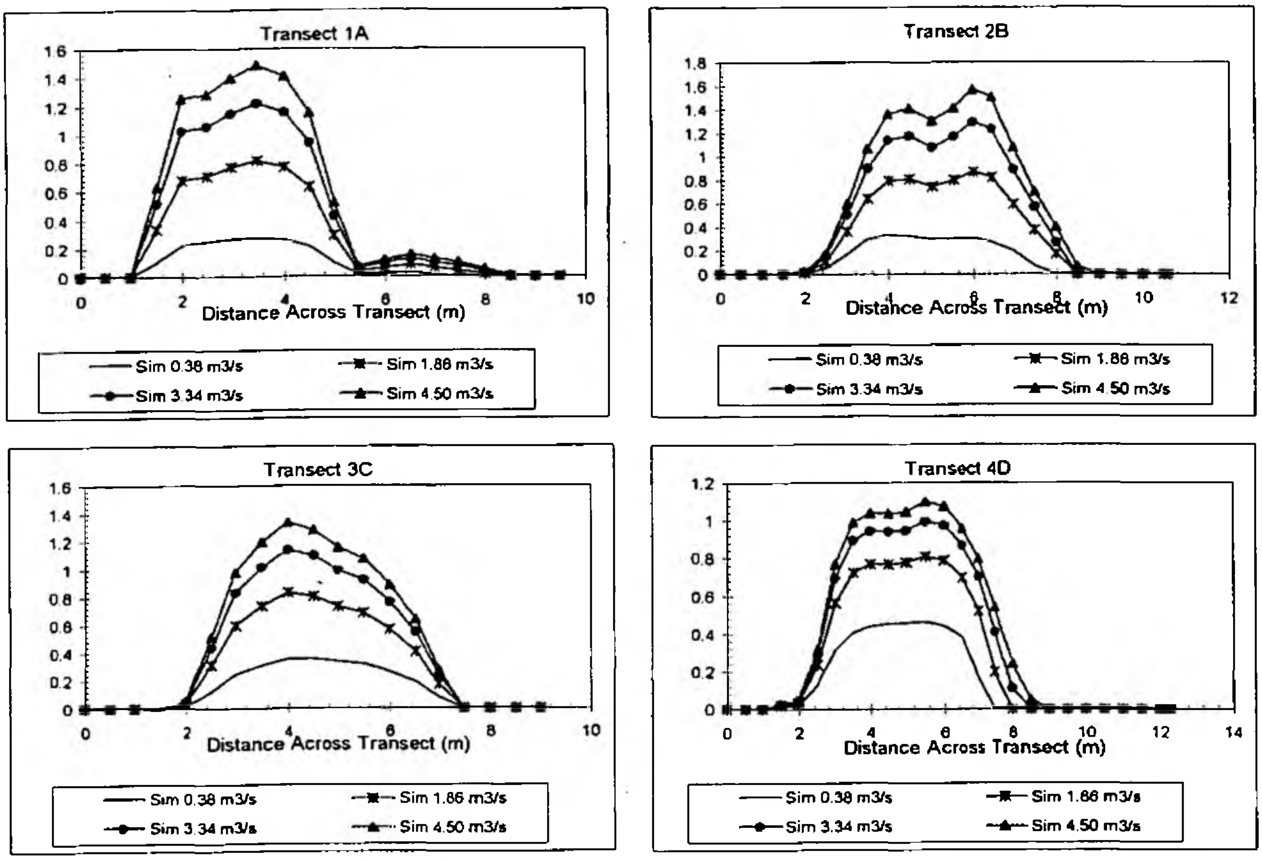








Simulated flow velocities for Stour downstream of Kirtling Green Outfall



Appendix 2.8

Input/output codes for the River Stour downstream of Kirtling Green Outfall

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zhabin	IOC	0110001020000020000000000000000000000000

Appendix 3. RIVER STOUR AT BOWERS HALL FARM

Appendix 3.1. Hydraulic field measurements

River Stour at Bowers Hall Farm: low flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.50	0.65	1.35	0.061	0.054
2.00	0.50	1.28	0.080	0.051
2.50	0.50	1.22	0.053	0.032
3.00	0.50	1.18	0.073	0.043
3.50	0.50	1.12	0.062	0.035
4.00	0.50	1.08	0.038	0.021
4.50	0.50	1.04	0.036	0.019
5.00	0.50	0.98	0.025	0.012
5.50	0.50	0.98	0.040	0.020
6.00	0.50	1.00	0.047	0.024
6.50	0.50	0.99	0.023	0.011
7.00	0.50	1.00	0.050	0.025
7.50	0.50	0.90	0.036	0.016
8.00	0.50	0.77	0.037	0.014
8.50	0.50	0.56	0.006	0.002
9.00	0.45	0.20	0.000	0.000
			Total flow	**0.378**

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.5	0.75	0.23	0.049	0.008
2	0.50	0.33	0.068	0.011
2.5	0.50	0.39	0.124	0.024
3	0.50	0.43	0.144	0.031
3.5	0.50	0.42	0.152	0.032
4	0.50	0.42	0.184	0.038
4.5	0.50	0.43	0.182	0.039
5	0.50	0.42	0.189	0.040
5.5	0.50	0.42	0.180	0.038
6	0.50.	0.43	0.140	0.030
6 5	0.50	0.44	0.154	0.034
7	0.50	0.48	0.137	0.033
7.5	0.50	0.54	0.145	0.039
8	0.50	0.53	0.115	0.030
8.5	0.50	0.44	0.123	0.027
9	0.50	0.38	0.040	0.008
9.5	0.65	0.24	0.006	0.001
			Total flow	**0.464**

River Stour at Bowers Hall Farm: medium1 flow

Transect 2B

Dist Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
3	0.45	0.07	0.009	0.000
3.5	0.50	0.20	0.111	0.011
4	0.50	0.42	0.179	0.038
4.5	0.50	0.42	0.350	0.074
5	0.50	0.35	0.480	0.084
5.5	0.50	0.35	0.297	0.052
6	0.50	0.35	0.361	0.063
6.5	0.50	0.35	0.460	0.081
7	0.50	0.42	0.413	0.087
7.5	0.50	0.42	0.430	0.090
8	0.50	0.44	0.221	0.049
8.5	0.50	0.44	0.460	0.101
9	0.50	0.44	0.278	0.061
9.5	0.50	0.42	0.327	0.069
10	0.65	0.40	0.350	0.091
			Total flow	**0.950**

Transect 4D

Dist Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.3	0.55	0.21	0.064	0.007
1.8	0.50	0.30	0.168	0.025
2.3	0.50	0.42	0.243	0.051
2.8	0.50	0.42	0.319	0.067
3.3	0.50	0.43	0.342	0.074
3.8	0.50	0.44	0.340	0.075
4.3	0.50	0.47	0.360	0.085
4.8	0.50	0.48	0.371	0.089
5.3	0.50	0.50	0.307	0.077
5.8	0.50	0.50	0.286	0.072
6.3	0.50	0.48	0.300	0.072
6.8	0.50	0.52	0.299	0.078
7.3	0.50	0.56	0.269	0.075
7.8	0.50	0.59	0.211	0.062
8.3	0.50	0.56	0.265	0.074
8.8	0.50	0.44	0.249	0.055
9.3	0.50	0.38	0.190	0.036
9.8	0.65	0.11	0.022	0.002
			Total flow	**1.075**

River Stour at Bowers Hall Farm: medium2 flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s	Flow(m3/s)
1.5	0.55	1.35	0.138	0.102
2	0.50	1.32	0.163	0.108
2.5	0.50	1.27	0.199	0.126
3	0.50	1.22	0.172	0.105
3.5	0.50	1.16	0.221	0.128
4	0.50	1.11	0.219	0.122
4.5	0.50	1.08	0.211	0.114
5	0.50	1.03	0.197	0.101
5.5	0.50	1.04	0.135	0.070
6	0.50	1.04	0.127	0.066
6.5	0.50	1.03	0.116	0.060
7	0.50	1.02	0.106	0.054
7.5	0.50	0.98	0.085	0.042
8	0.50	0.86	0.055	0.024
8.5	0.50	0.62	0.020	0.006
9	0.8	0.40	0.029	0.009
			Total flow	1.237

Transect 2B

Dist. Across(m	Rep. Width(m)	Depth(m)	Velocity(m/s	Flow(m3/s)
3.5	0.75	0.30	0.132	0.030
4	0.50	0.38	0.400	0.076
4.5	0.50	0.38	0.420	0.080
5	0.50	0.35	0.560	0.098
5.5	0.50	0.34	0.470	0.080
6	0.50	0.34	0.480	0.082
6.5	0.50	0.38	0.460	0.087
7	0.50	0.40	0.440	0.088
7.5	0.50	0.40	0.460	0.092
8	0.50	0.40	0.410	0.082
8.5	0.50	0.42	0.430	0.090
9	0.50	0.42	0.430	0.090
9.5	0.50	0.42	0.400	0.084
10	0.75	0.39	0.380	0.111
			Total flow	1.170

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s	Flow(m3/s)
1.5	0.40	0.13	-0.006	0.000
2	0.50	0.49	0.049	0.012
2.5	0.50	0.85	0.146	0.062
3	0.50	0.94	0.223	0.105
3.5	0.50	0.99	0.259	0.128
4	0.50	1.00	0.227	0.114
4.5	0.50	1.06	0.261	0.138
5	0.50	1.14	0.206	0.117
5.5	0.50	1.16	0.138	0.080
6	0.50	1.22	0.230	0.140
6.5	0.50	1.24	0.227	0.141
7	0.50	1.24	0.083	0.051
7.5	0.50	1.26	0.176	0.111
8	0.50	1.30	0.059	0.038
8.5	0.50	1.29	0.035	0.023
9	0.50	1.02	0.041	0.021
9.5	0.50	1.04	-0.010	-0.005
10	0.50	0.88	0.017	0.007
10.5	0.50	0.83	-0.007	-0.003
11	0.50	0.47	-0.007	-0.002
11.5	0.55	0.20	-0.007	-0.001
			Total flow	1.279

Transect 4D

Dist. Acros	Rep. Width(m)	Depth(m)	Velocity(m/s	Flow(m3/s)
1.5	0.75	0.14	0.133	0.014
2	0.50	0.32	0.226	0.036
2.5	0.50	0.40	0.287	0.057
3	0.50	0.45	0.362	0.081
3.5	0.50	0.48	0.390	0.094
4	0.50	0.45	0.410	0.092
4.5	0.50	0.46	0.430	0.099
5	0.50	0.45	0.400	0.090
5.5	0.50	0.46	0.405	0.093
6	0.50	0.44	0.396	0.087
6.5	0.50	0.45	0.369	0.083
7	0.50	0.50	0.356	0.089
7.5	0.50	0.55	0.285	0.078
8	0.50	0.55	0.243	0.067
8.5	0.50	0.48	0.324	0.078
9	0.50	0.40	0.266	0.053
9.5	0.50	0.34	0.198	0.034
10	0.35	0.10	-0.007	0.000
			Total flow	1.226

Transect 5E

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s	Flow(m3/s)
1.5	0.75	0.54	0.195	0.079
2	0.50	0.67	0.242	0.081
2.5	0.50	0.76	0.268	0.102
3	0.50	0.83	0.308	0.128
3.5	0.50	0.85	0.327	0.139
4	0.50	0.98	0.352	0.172
4.5	0.50	0.99	0.313	0.155
5	0.50	1.00	0.298	0.149
5.5	0.50	0.87	0.234	0.102
6	0.50	0.79	0.204	0.081
6.5	0.50	0.77	0.144	0.055
7	0.50	0.67	0.159	0.053
7.5	0.95	0.12	0.059	0.007
			Total flow	1.303

River Stour at Bowers Hall Farm: high flow

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	1.05	0.36	0.107	0.04
3	0.50	0.42	0.146	0.03
3.5	0.50	0.57	0.158	0.05
4	0.50	0.71	0.390	0.14
4.5	0.50	0.69	0.540	0.19
5	0.50	0.66	0.700	0.23
5.5	0.50	0.66	0.680	0.22
6	0.50	0.66	0.720	0.24
6.5	0.50	0.71	0.700	0.25
7	0.50	0.70	0.690	0.24
7.5	0.50	0.71	0.690	0.24
8	0.50	0.77	0.580	0.22
8.5	0.50	0.74	0.65	0.24
9	0.50	0.73	0.57	0.21
9.5	0.50	0.73	0.59	0.22
10	0.45	0.69	0.52	0.16
			Total flow	2.917

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.5	0.75	0.59	0.113	0.05
2	0.50	0.69	0.314	0.11
2.5	0.50	0.75	0.404	0.15
3	0.50	0.80	0.440	0.18
3.5	0.50	0.81	0.510	0.21
4	0.50	0.79	0.510	0.20
4.5	0.50	0.81	0.530	0.21
5	0.50	0.77	0.470	0.18
5.5	0.50	0.77	0.500	0.19
6	0.50	0.79	0.480	0.19
6.5	0.50	0.81	0.480	0.19
7	0.50	0.87	0.400	0.17
7.5	0.50	0.87	0.386	0.17
8	0.50	0.88	0.420	0.18
8.5	0.50	0.81	0.350	0.14
9	0.50	0.7	0.4	0.14
9.5	0.38	0.58	0.197	0.04
9.75	0.475	0.56	0.046	0.01
			Total flow	2.729

Appendix 3.2. Overhanging vegetation and substrate measurements

River Stour at Bowers Hall Farm

Transect 1A

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	100.0	900.0
2	0.5	100.0	900.0
3	1	100.0	300.0
4	1.5	80.0	405.5
5	2	60.0	405.5
6	2.5	60.0	506.5
7	3	50.0	406.5
8	3.5	50.0	506.6
9	4	50.0	506.6
10	4.5	40.0	504.6
11	5	40.0	506.6
12	5.5	40.0	405.6
13	6	20.0	405.6
14	6.5	20.0	405.6
15	7	20.0	403.8
16	7.5	10.0	304.6
17	8	10.0	300.0
18	8.5	0.0	300.0
19	9	0.0	300.0
20	9.5	90.0	300.0
21	10	90.0	300.0
22	10.5	90.0	900.0
23	11	90.0	900.0
24	11.5	90.0	900.0
25	12	90.0	900.0
26	12.5	90.0	900.0
27	13	90.0	900.0
28	13.5	90.0	900.0
29	14	90.0	900.0

Transect 2B

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	50.0	900.0
2	0.5	40.0	900.0
3	1	20.0	900.0
4	1.5	0.0	900.0
5	2	0.0	900.0
6	2.5	0.0	900.0
7	3	0.0	900.0
8	3.5	0.0	309.0
9	4	0.0	309.0
10	4.5	0.0	406.8
11	5	0.0	506.8
12	5.5	0.0	506.8
13	6	0.0	506.8
14	6.5	0.0	506.6
15	7	0.0	506.6
16	7.5	0.0	605.7
17	8	0.0	506.9
18	8.5	0.0	506.9
19	9	0.0	405.5
20	9.5	0.0	405.5
21	10	0.0	405.7
22	10.5	0.0	301.9
23	11	0.0	900.0
24	11.5	0.0	900.0
25	11.95	0.0	900.0

Transect 3C

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	90.0	900.0
2	0.5	90.0	900.0
3	1	90.0	900.0
4	1.5	80.0	200.0
5	2	60.0	200.0
6	2.5	30.0	200.0
7	3	20.0	204.8
8	3.5	0.0	205.6
9	4	0.0	504.6
10	4.5	0.0	406.6
11	5	0.0	506.6
12	5.5	0.0	506.5
13	6	0.0	605.6
14	6.5	0.0	605.7
15	7	0.0	605.6
16	7.5	0.0	605.6
17	8	0.0	506.6
18	8.5	0.0	405.6
19	9	0.0	200.0
20	9.5	0.0	200.0
21	10	0.0	200.0
22	10.5	0.0	200.0
23	11	0.0	200.0
24	11.5	0.0	200.0
25	12	0.0	200.0
26	12.5	0.0	900.0
27	12.65	0.0	900.0

Transect 4D

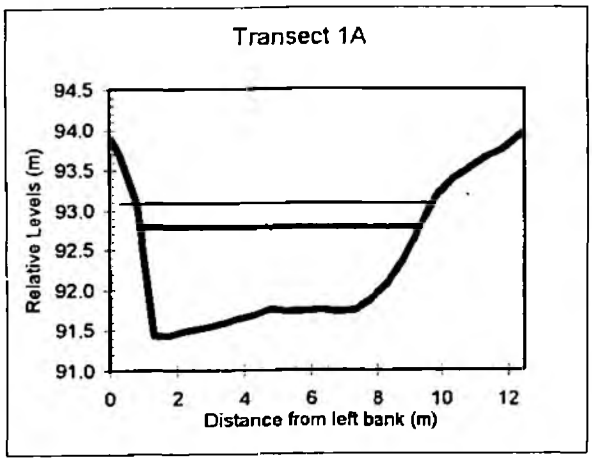
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	100.0	200.0
2	0.5	100.0	900.0
3	1	100.0	900.0
4	1.5	100.0	300.0
5	2	70.0	307.8
6	2.5	70.0	306.6
7	3	60.0	306.6
8	3.5	60.0	306.6
9	4	50.0	603.6
10	4.5	50.0	603.6
11	5	50.0	603.8
12	5.5	40.0	603.8
13	6	40.0	603.8
14	6.5	30.0	603.8
15	7	30.0	306.8
16	7.5	20.0	405.7
17	8	10.0	405.7
18	8.5	10.0	306.8
19	9	0.0	306.8
20	9.5	0.0	304.9
21	10	0.0	200.0
22	10.5	0.0	900.0
23	11	0.0	900.0
24	11.5	0.0	900.0
25	12	0.0	900.0
26	12.4	0.0	900.0

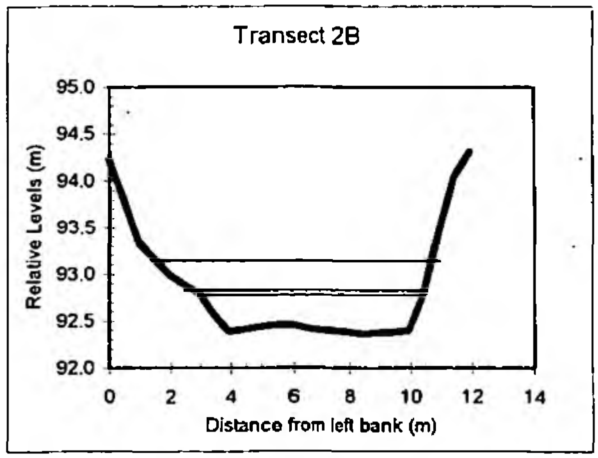
Transect 5E

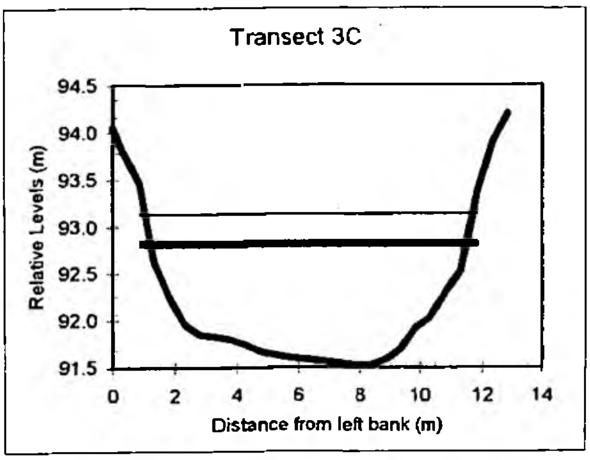
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	20.0	900.0
2	0.5	20.0	900.0
3	1	10.0	306.8
4	1.5	10.0	205.8
5	2	10.0	406.8
6	2.5	0.0	407.6
7	3	0.0	407.8
8	3.5	0.0	407.8
9	4	0.0	605.8
10	4.5	0.0	507.8
11	5	0.0	504.8
12	5.5	0.0	703.8
13	6	0.0	403.6
14	6.5	0.0	304.7
15	7	0.0	305.7
16	7.5	0.0	307.9
17	8	0.0	900.0
18	8.5	0.0	900.0
19	9	0.0	900.0
20	9.5	0.0	900.0
21	10	0.0	900.0
22	10.2	0.0	900.0

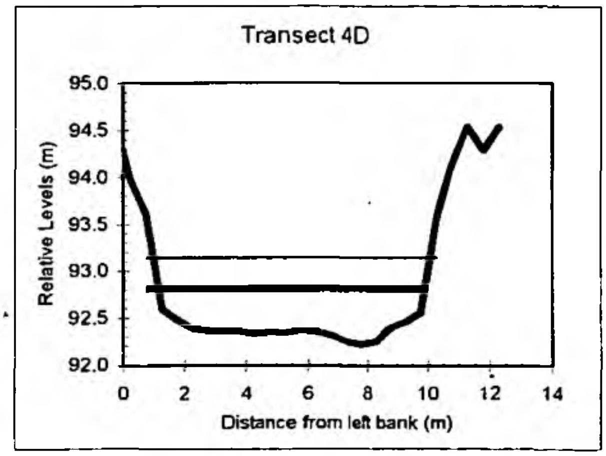
Appendix 3.3

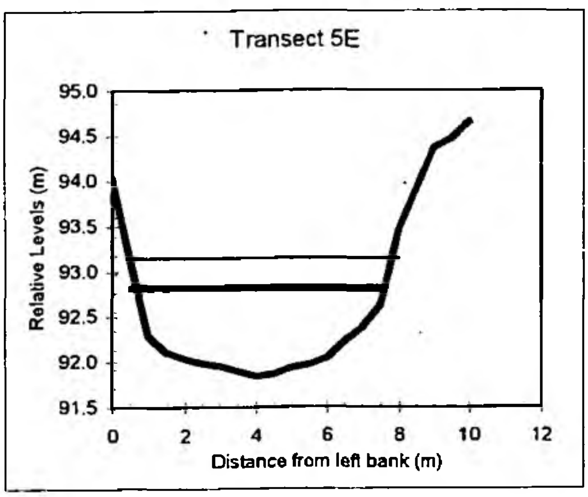
Stour at Bowers Hall Farm: bed elevation and water surface levels











Appendix 3.4

River Stour at Bowers Hall Farm: longitudinal water surface level profiles

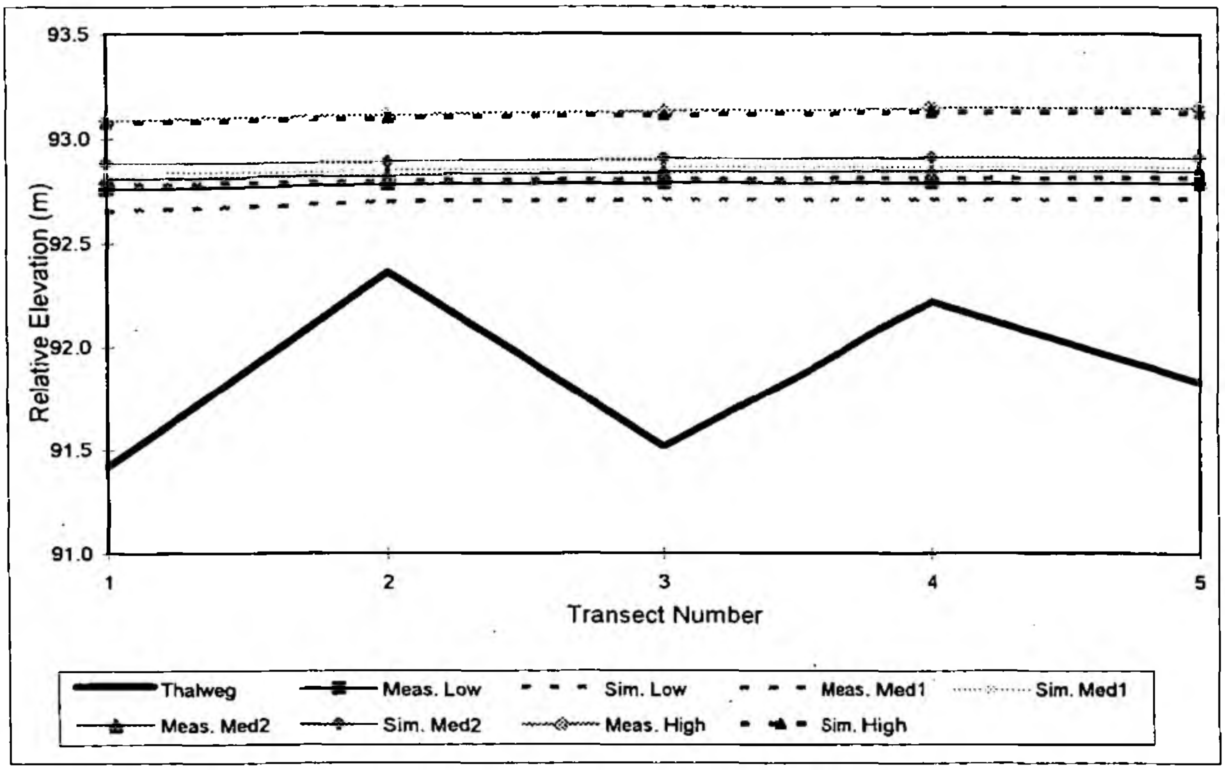


Figure 3.4a: Longitudinal water surface elevation for measured and observed discharges

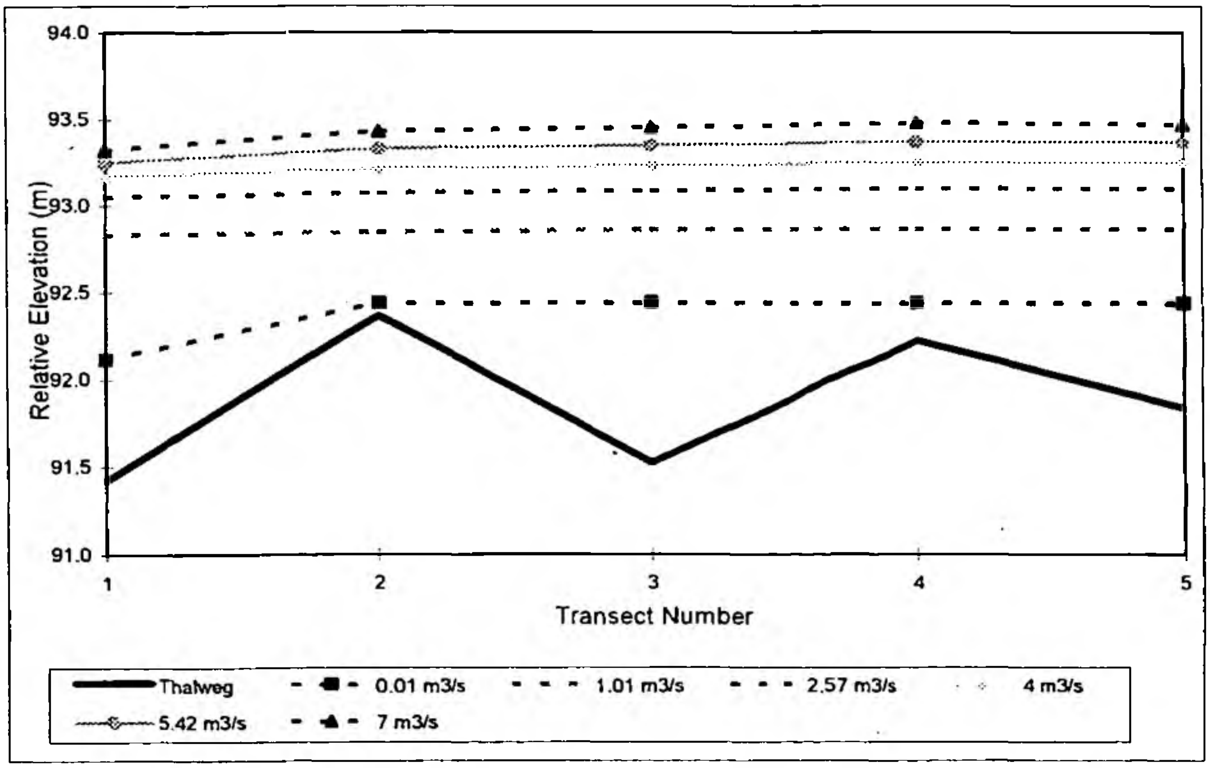
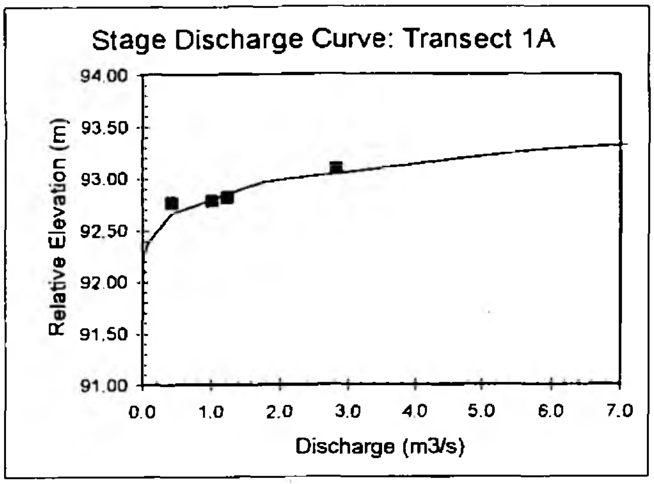
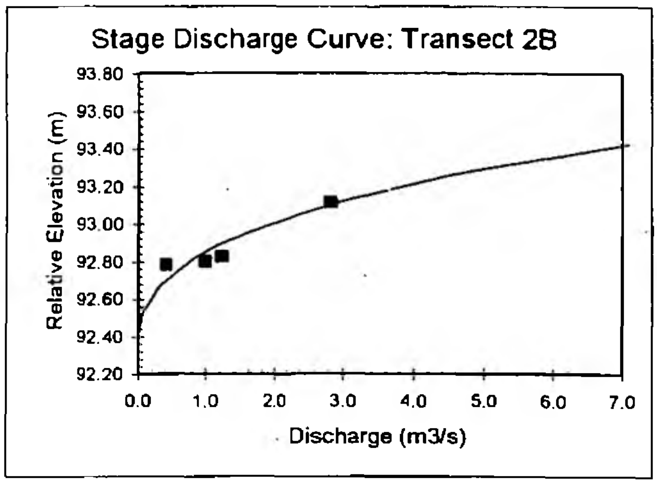


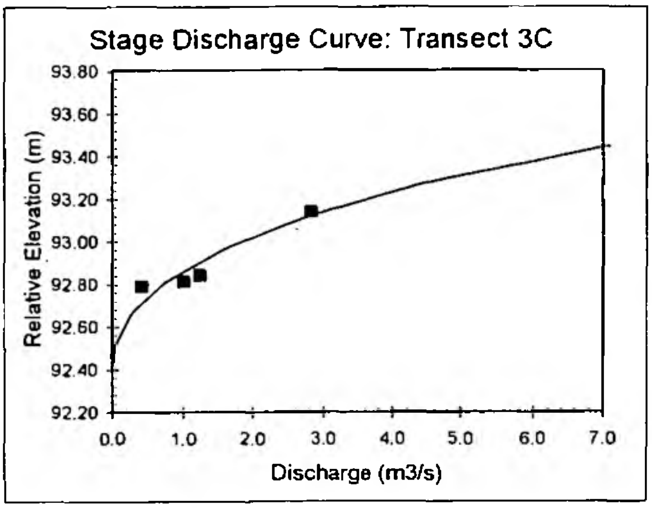
Figure 3.4b: Longitudinal water surface elevation for simulated flows.

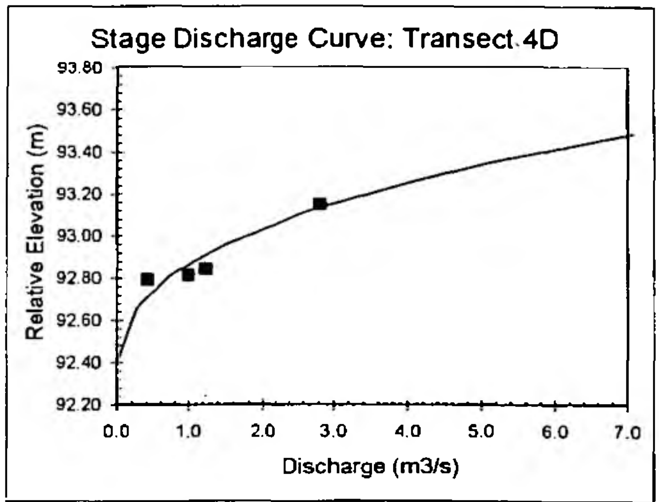
Appendix 3.5

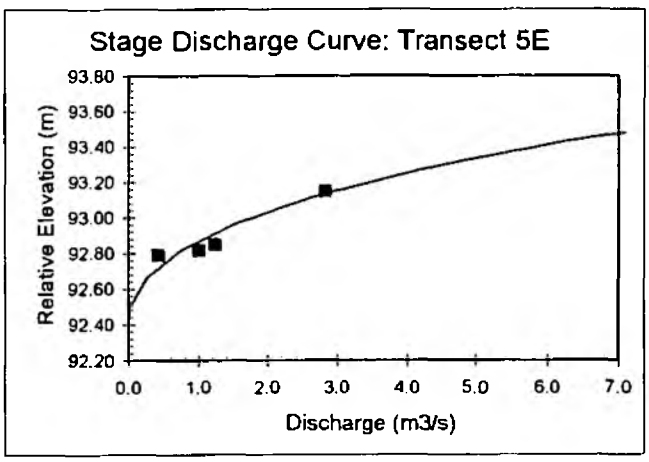
River Stour at Bowers Hall Farm: stage-discharge relationships





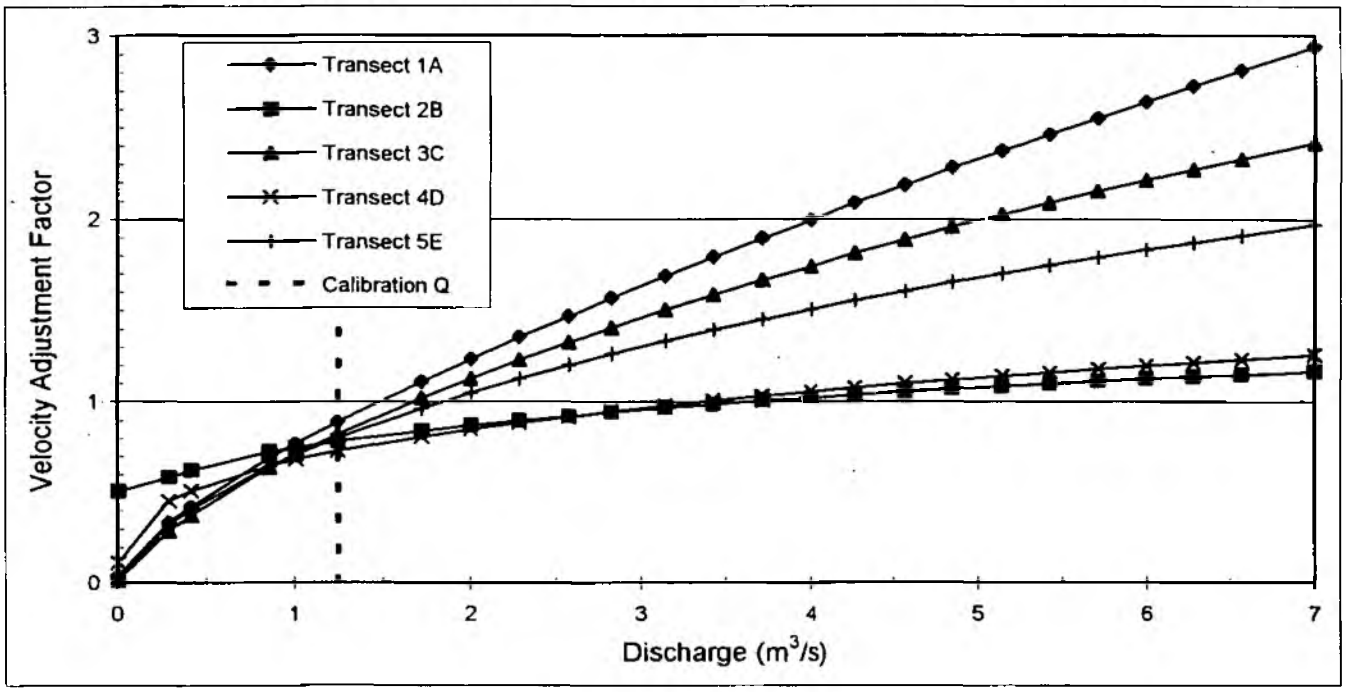






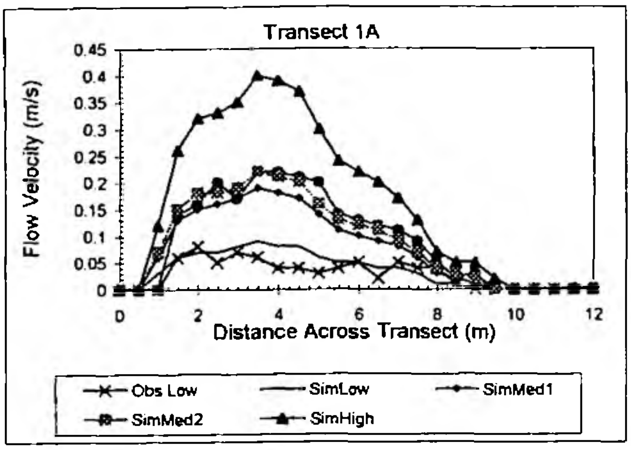
Appendix 3.6

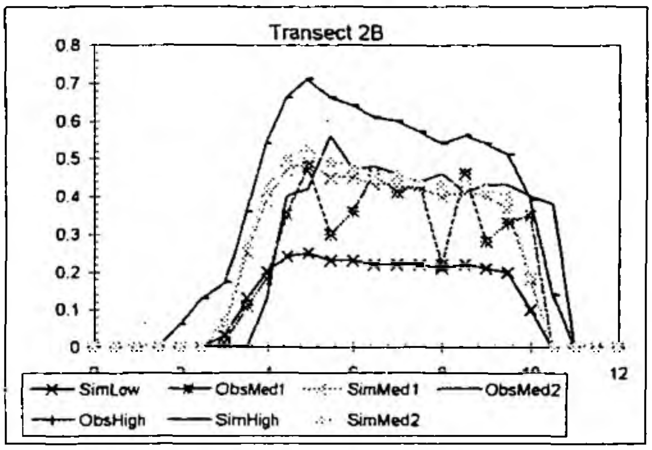
Velocity Adjustment Factors for the River Stour at Bowers Hall Farm

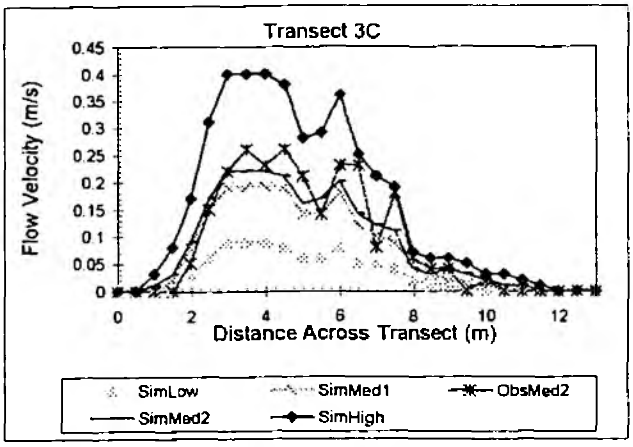


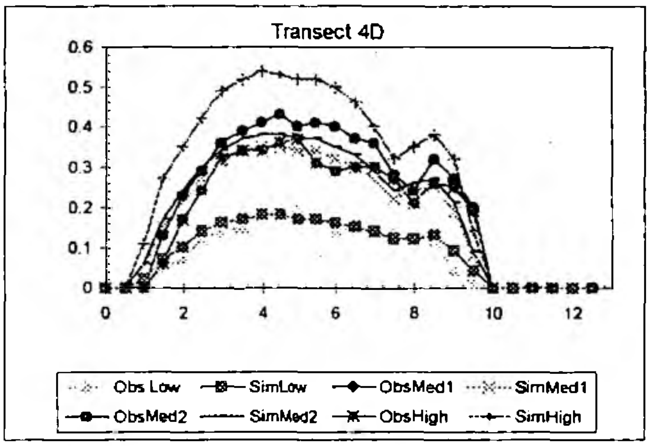
Appendix 3.7

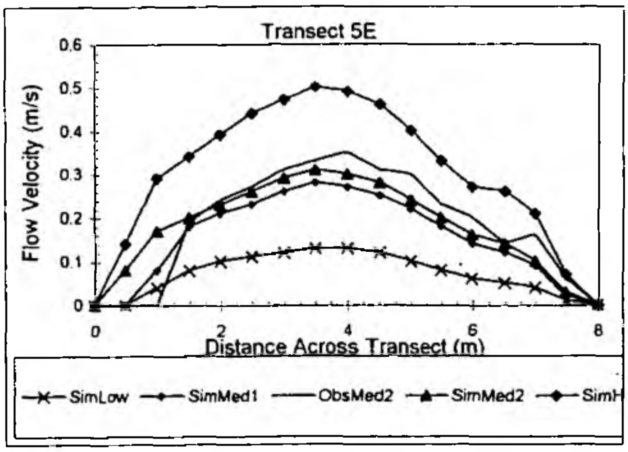
Calibration flow velocities: observed and simulated for Stour at Bowers Hall Farm



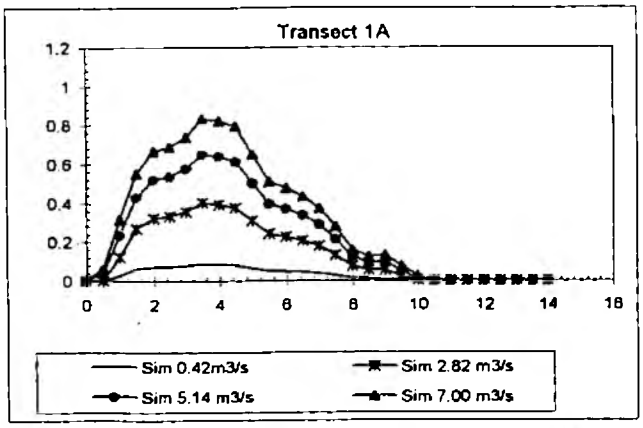


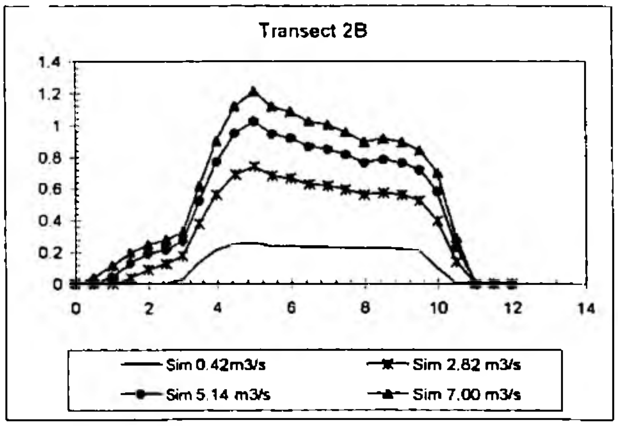


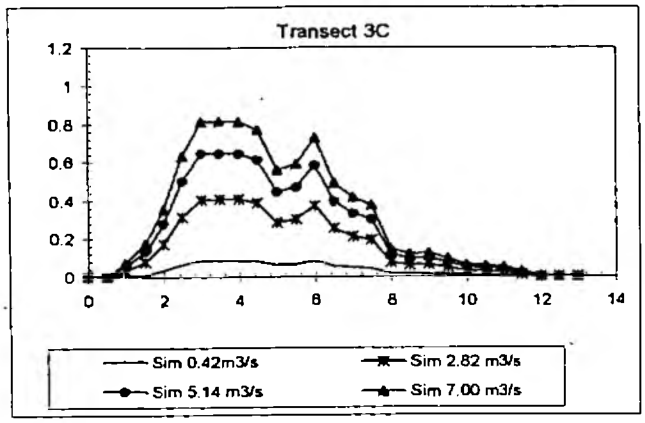


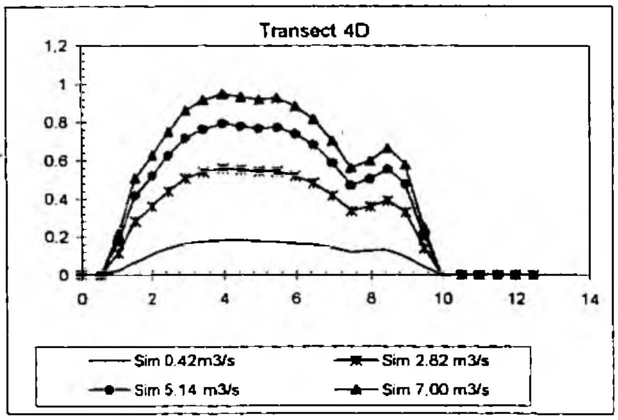


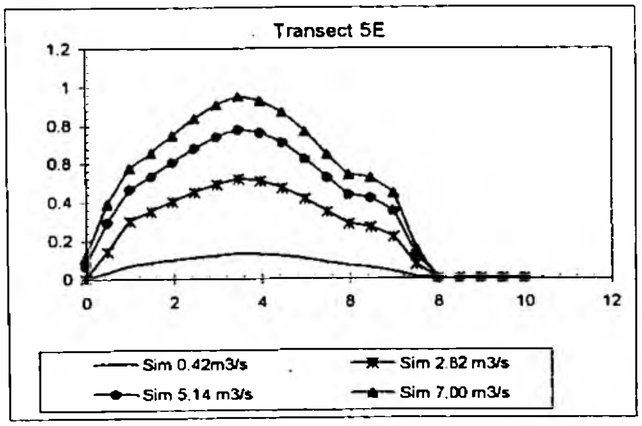
Simulated flow velocities for Stour at Bowers Hall Farm











Appendix 3.8

Input/output codes for the River Stour at Bowers Hall Farm

zifg4	IOC	00001000000010000000
zhabin	IOC	0110001020000020000000000000000000000000

Appendix 4. RIVER STOUR AT WISSINGTON

Appendix 4.1. Overhanging vegetation and substrate measurements

River Stour at Wissington

Transect 1A

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.0	900.0
2	0.5	0.0	900.0
3	1	0.0	900.0
4	1.5	0.0	900.0
5	2	0.0	900.0
6	2.5	0.0	900.0
7	3	0.0	900.0
8	3.5	0.0	900.0
9	4	0.0	300.0
10	4.5	0.0	300.0
11	5	0.0	300.0
12	5.5	0.0	300.0
13	6	0.0	300.0
14	6.5	0.0	305.6
15	7	0.0	503.8
16	7.5	0.0	607.7
17	8	0.0	607.8
18	8.5	0.0	607.7
19	9	0.0	607.6
20	9.5	0.0	607.6
21	10	0.0	605.8
22	10.5	0.0	605.7
23	11	0.0	506.6
24	11.5	0.0	506.6
25	12	0.0	506.6
26	12.5	0.0	506.6
27	13	0.0	506.6
28	13.5	0.0	506.6
29	14	0.0	506.6
30	14.5	0.0	506.6
31	15	0.0	506.6
32	15.5	0.0	503.6
33	16	0.0	503.6
34	16.5	0.0	503.6
35	17	0.0	503.6
36	17.5	0.0	305.5
37	18	0.0	900.0
38	18.5	0.0	900.0
39	19	0.0	900.0
40	19.5	0.0	900.0
41	20	0.0	900.0
42	20.5	0.0	800.0
43	20.8	0.0	900.0

Transect 2B

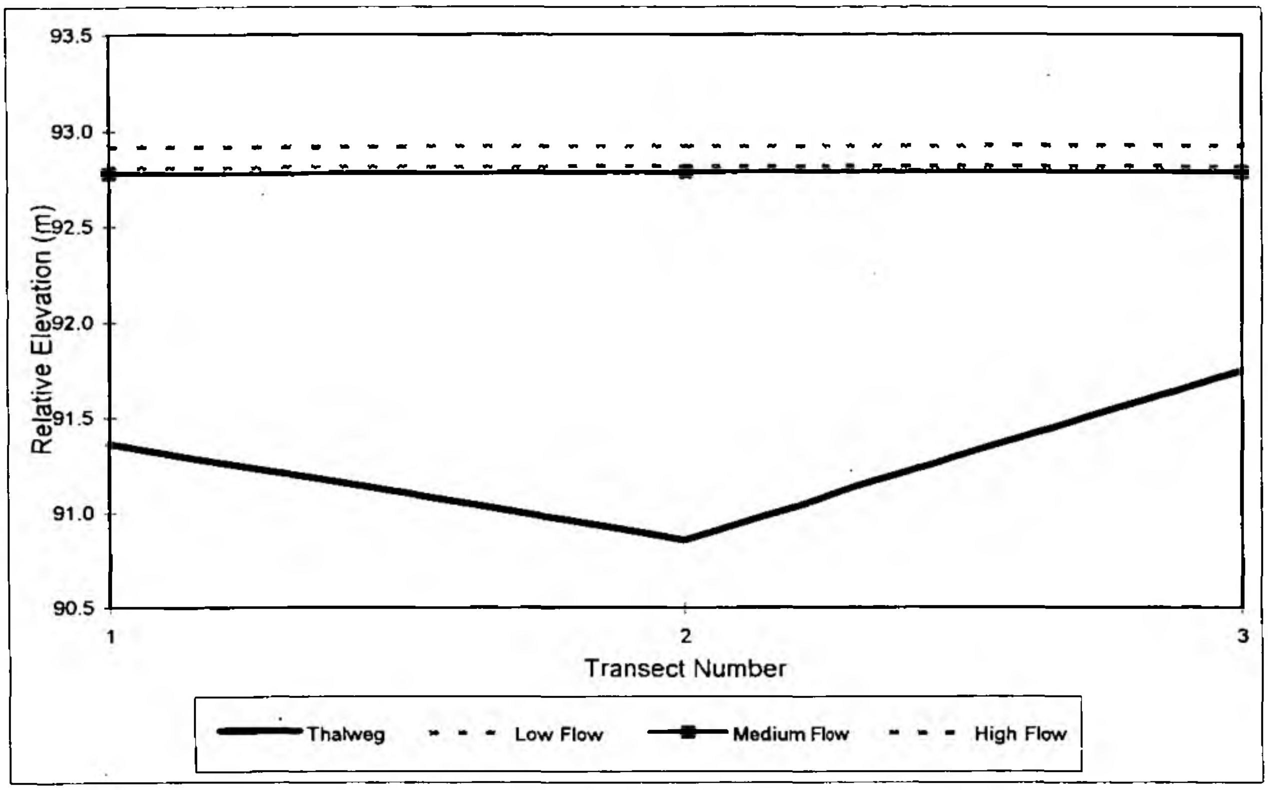
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	80.0	900.0
2	0.5	80.0	900.0
3	1	80.0	900.0
4	1.5	80.0	900.0
5	2	90.0	900.0
6	2.5	90.0	900.0
7	3	90.0	300.0
8	3.5	90.0	300.0
9	4	90.0	300.0
10	4.5	80.0	300.0
11	5	80.0	306.8
12	5.5	70.0	306.7
13	6	70.0	306.7
14	6.5	70.0	306.8
15	7	60.0	603.6
16	7.5	60.0	603.6
17	8	50.0	603.6
18	8.5	50.0	603.6
19	9	40.0	603.6
20	9.5	40.0	603.6
21	10	20.0	603.6
22	10.5	10.0	603.6
23	11	10.0	603.6
24	11.5	10.0	603.6
25	12	0.0	605.6
26	12.5	0.0	605.6
27	13	0.0	605.6
28	13.5	0.0	605.5
29	14	0.0	506.6
30	14.5	0.0	603.6
31	15	0.0	300.0
32	15.5	0.0	200.0
33	16	0.0	200.0
34	16.5	0.0	209.8
35	17	0.0	900.0
36	17.5	0.0	900.0
37	18	0.0	900.0
38	18.5	0.0	900.0
39	18.95	0.0	900.0

Transect 3C

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	70.0	900.0
2	0.5	70.0	900.0
3	1	60.0	900.0
4	1.5	50.0	900.0
5	2	50.0	900.0
6	2.5	50.0	900.0
7	3	30.0	900.0
8	3.5	30.0	900.0
9	4	30.0	900.0
10	4.5	30.0	900.0
11	5	20.0	900.0
12	5.5	20.0	900.0
13	6	20.0	900.0
14	6.5	10.0	900.0
15	7	10.0	900.0
16	7.5	10.0	900.0
17	8	0.0	706.8
18	8.5	0.0	706.8
19	9	0.0	706.8
20	9.5	0.0	206.8
21	10	0.0	206.8
22	10.5	0.0	405.5
23	11	0.0	405.5
24	11.5	0.0	405.5
25	12	0.0	405.5
26	12.5	0.0	405.5
27	13	0.0	200.0
28	13.5	0.0	200.0
29	14	0.0	200.0
30	14.5	0.0	200.0
31	15	0.0	200.0
32	15.5	0.0	200.0
33	16	0.0	200.0
34	16.5	0.0	200.0
35	17	0.0	200.0
36	17.5	0.0	200.0
37	18	0.0	200.0
38	18.5	0.0	200.0
39	19	0.0	900.0
40	19.5	0.0	900.0
41	20	0.0	900.0
42	20.2	0.0	900.0

Appendix 4.2

River Stour at Wissington: longitudinal water surface level profiles



Appendix 5. *RIVER STOUR AT LANGHAM*

Appendix 5.1. Hydraulic field measurements

River Stour at Langham: low flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
4	0.55	0.14	0.038	0.003
5	1.00	0.44	0.110	0.048
6	1.00	0.75	0.127	0.095
7	1.00	0.74	0.144	0.107
8	1.00	0.74	0.152	0.112
9	1.00	0.76	0.134	0.102
10	1.00	0.75	0.184	0.138
11	1.00	0.74	0.129	0.095
12	1.00	0.77	0.147	0.113
13	1.00	0.80	0.138	0.110
14	1.00	0.85	0.145	0.123
15	1.00	0.62	0.085	0.053
16	0.60	0.43	0.007	0.002
			Total flow	**1.102**

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
8.5	0.75	0.39	0.065	0.019
9	0.75	0.42	0.162	0.051
10	1.00	0.45	0.178	0.080
11	1.00	0.48	0.179	0.086
12	1.00	0.50	0.177	0.089
13	1.00	0.55	0.178	0.098
14	1.00	0.57	0.171	0.097
15	1.00	0.61	0.169	0.103
16	1.00	0.70	0.144	0.101
17	1.00	0.61	0.165	0.101
18	1.00	0.45	0.174	0.078
19	1.00	0.40	0.199	0.080
20	1.00	0.34	0.115	0.039
21	1.00	0.30	0.105	0.032
22	1.00	0.45	-0.006	-0.003
23	0.60	0.15	-0.006	-0.001
			Total flow	**1.050**

River Stour at Langham: medium1 flow

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
8.5	0.75	0.43	0.07	0.02
9	0.50	0.46	0.20	0.05
9.5	0.50	0.48	0.22	0.05
10	0.50	0.48	0.25	0.06
10.5	0.50	0.50	0.24	0.06
11	0.50	0.51	0.25	0.06
11.5	0.50	0.51	0.25	0.06
12	0.50	0.54	0.24	0.07
12.5	0.50	0.54	0.25	0.07
13	0.50	0.58	0.26	0.08
13.5	0.50	0.59	0.24	0.07
14	0.50	0.62	0.25	0.08
14.5	0.50	0.64	0.24	0.08
15	0.50	0.66	0.23	0.08
15.5	0.50	0.69	0.21	0.07
16	0.50	0.72	0.20	0.07
16.5	0.50	0.72	0.22	0.08
17	0.50	0.68	0.19	0.06
17.5	0.50	0.60	0.203	0.06
18	0.50	0.52	0.256	0.07
18.5	0.50	0.48	0.262	0.06
19	0.50	0.43	0.266	0.06
19.5	0.50	0.41	0.279	0.06
20	0.50	0.39	0.235	0.05
20.5	0.50	0.42	0.189	0.04
21	0.50	0.46	0.192	0.04
21.5	0.50	0.50	0.164	0.04
22	0.50	0.49	0.009	0.00
22.5	0.50	0.40	-0.006	0.00
23	0.65	0.18	-0.007	0.00
			Total flow	**1.634**

River Stour at Langham: medium2 flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
4.5	1.00	0.32	0.164	0.05
5.5	1.00	0.81	0.300	0.24
6.5	1.00	0.83	0.236	0.20
7.5	1.00	0.82	0.339	0.28
8.5	1.00	0.84	0.359	0.30
9.5	1.00	0.86	0.351	0.30
10.5	1.00	0.84	0.382	0.32
11.5	1.00	0.85	0.400	0.34
12.5	1.00	0.86	0.393	0.34
13.5	1.00	0.92	0.349	0.32
14.5	1.00	0.89	0.287	0.26
15.5	1.40	0.68	0.170	0.16
			Total flow	**2.341**

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
5	0.80	0.62	-0.007	-0.003
6	1.00	0.96	-0.005	-0.005
7	1.00	1.10	0.119	0.131
8	1.00	1.14	0.315	0.359
9	1.00	1.20	0.420	0.504
10	1.00	1.32	0.430	0.568
11	1.00	1.35	0.387	0.522
12	1.00	1.29	0.420	0.542
13	1.00	1.08	0.343	0.370
14	1.00	0.64	0.055	0.035
15	0.7	0.16	0.009	0.001
			Total flow	**3.024**

River Stour at Langham: high flow

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
8.5	0.75	0.53	0.202	0.08
9	0.50	0.56	0.338	0.09
9.5	0.50	0.58	0.337	0.10
10	0.50	0.58	0.361	0.10
10.5	0.50	0.60	0.343	0.10
11	0.50	0.62	0.358	0.11
11.5	0.50	0.63	0.372	0.12
12	0.50	0.64	0.381	0.12
12.5	0.50	0.67	0.384	0.13
13	0.50	0.69	0.371	0.13
13.5	0.50	0.70	0.394	0.14
14	0.50	0.72	0.396	0.14
14.5	0.50	0.75	0.382	0.14
15	0.50	0.78	0.326	0.13
15.5	0.50	0.80	0.392	0.16
16	0.50	0.84	0.369	0.15
16.5	0.50	0.82	0.331	0.14
17	0.50	0.76	0.329	0.13
17.5	0.50	0.69	0.334	0.12
18	0.50	0.62	0.379	0.12
18.5	0.50	0.56	0.309	0.09
19	0.50	0.53	0.373	0.10
19.5	0.50	0.51	0.397	0.10
20	0.50	0.5	0.402	0.10
20.5	0.50	0.51	0.344	0.09
21	0.50	0.58	0.32	0.09
21.5	0.50	0.6	0.308	0.09
22	0.50	0.59	0.174	0.05
22.5	0.50	0.42	-0.09	-0.02
23	0.65	0.21	0.008	0.00
			Total flow	3.137

Appendix 5.2. Overhanging vegetation and substrate measurements

River Stour at Langham

Transect 1A

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	50.0	900.0
3	1	50.0	900.0
5	2	50.0	900.0
9	4	50.0	900.0
11	5	50.0	205.8
13	6	60.0	504.6
15	7	60.0	405.6
17	8	50.0	405.6
19	9	40.0	406.6
21	10	50.0	504.7
23	11	50.0	405.7
25	12	50.0	405.7
27	13	50.0	504.6
29	14	50.0	504.6
31	15	50.0	503.6
33	16	60.0	200.0
35	17	70.0	900.0
37	18	90.0	900.0

Transect 2B

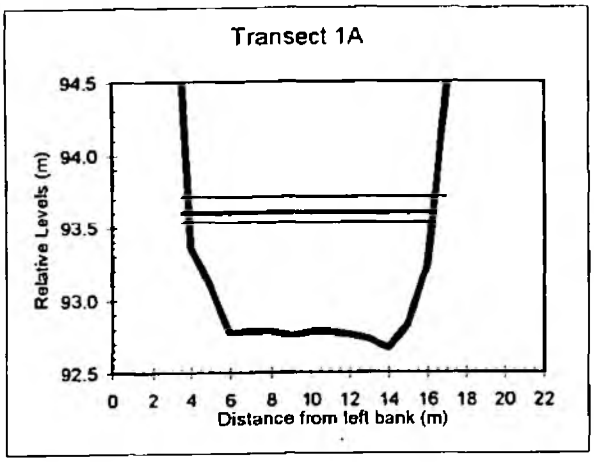
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	100.0	900.0
3	1	90.0	900.0
5	2	90.0	900.0
9	4	90.0	903.6
11	5	80.0	200.0
13	6	70.0	205.9
15	7	60.0	205.9
17	8	60.0	205.9
19	9	60.0	205.9
21	10	50.0	207.8
23	11	50.0	502.6
25	12	50.0	502.8
27	13	50.0	506.8
29	14	40.0	502.7
31	15	30.0	502.6
33	16	20.0	900.0
35	17	30.0	900.0
37	18	40.0	900.0
39	19	50.0	900.0

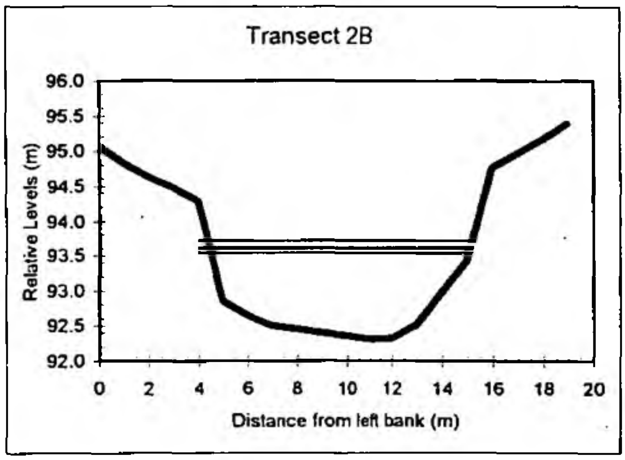
Transect 3C

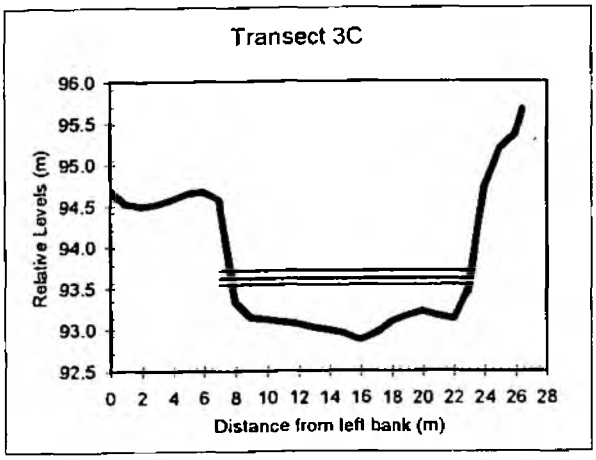
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	90.0	900.0
3	1	90.0	900.0
5	2	90.0	900.0
7	3	90.0	900.0
9	4	90.0	900.0
11	5	90.0	900.0
13	6	90.0	900.0
15	7	80.0	900.0
17	8	80.0	900.0
19	9	90.0	403.8
21	10	80.0	405.6
23	11	70.0	405.6
25	12	50.0	405.6
27	13	50.0	405.6
29	14	50.0	405.6
31	15	50.0	405.6
33	16	50.0	405.6
35	17	50.0	405.6
37	18	50.0	605.7
39	19	70.0	605.7
41	20	80.0	405.6
43	21	100.0	405.6
45	22	100.0	405.6
47	23	90.0	503.8
49	24	90.0	405.6
51	25	90.0	900.0
53	26	90.0	900.0

Appendix 5.3

Stour at Langham: bed elevation and water surface levels







Appendix 5.4

River Stour at Langham: longitudinal water surface level profiles

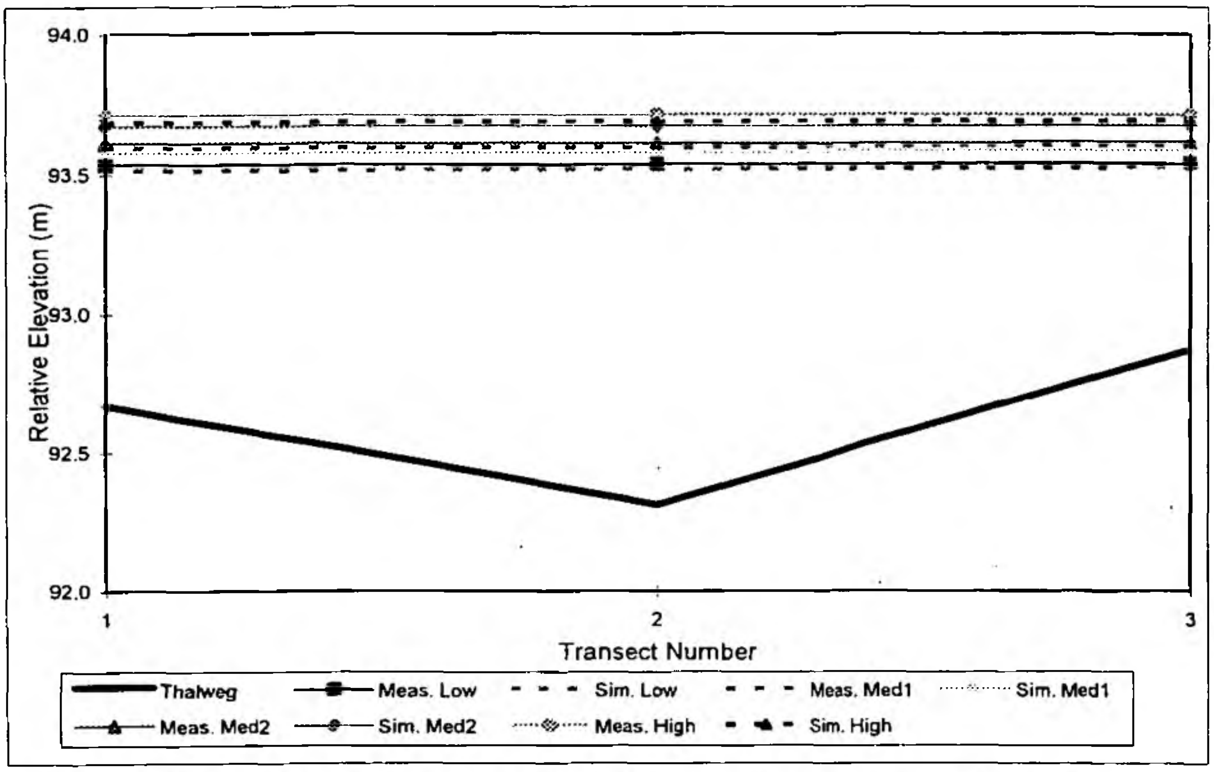


Figure 5.4a: Longitudinal water surface elevation for measured and observed discharges

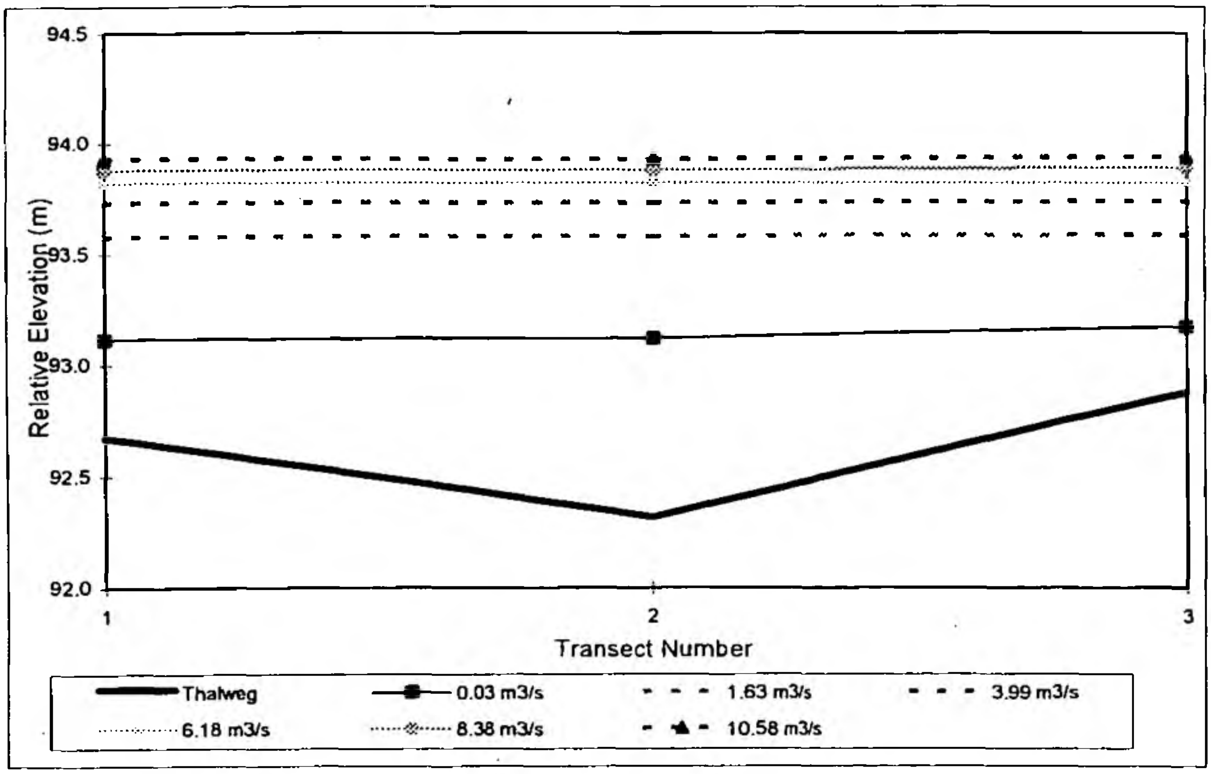
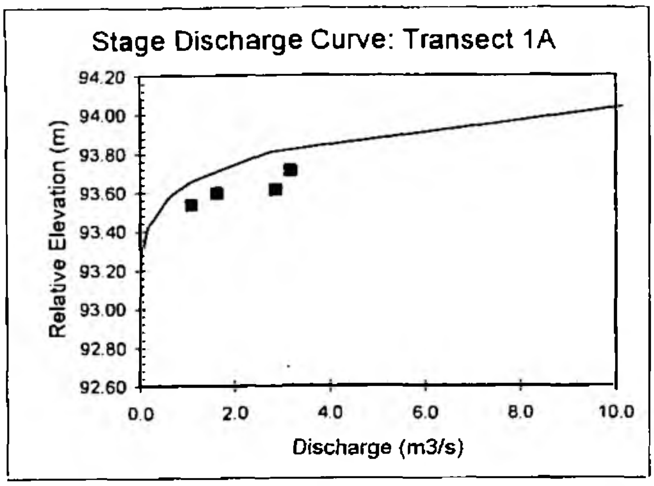
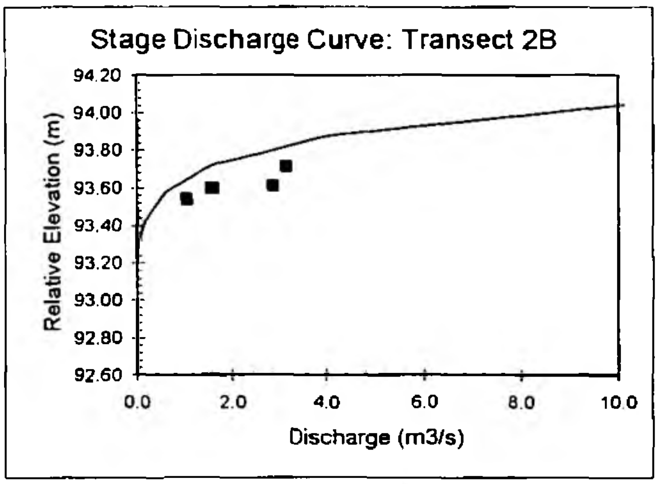


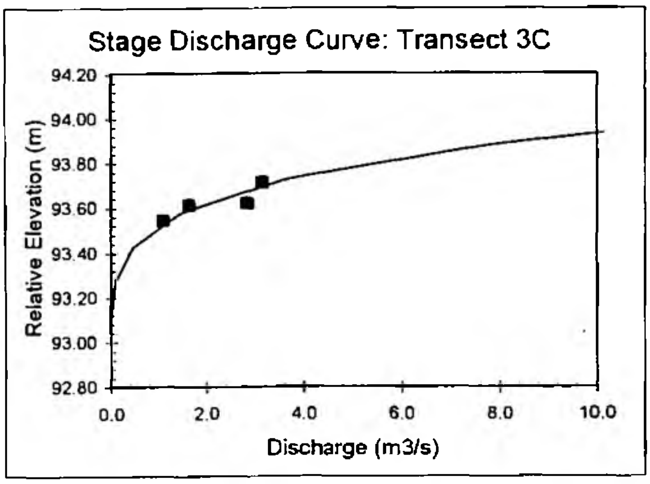
Figure 5.4b: Longitudinal water surface elevation for simulated flows.

Appendix 5.5

River Stour at Langham: stage-discharge relationships

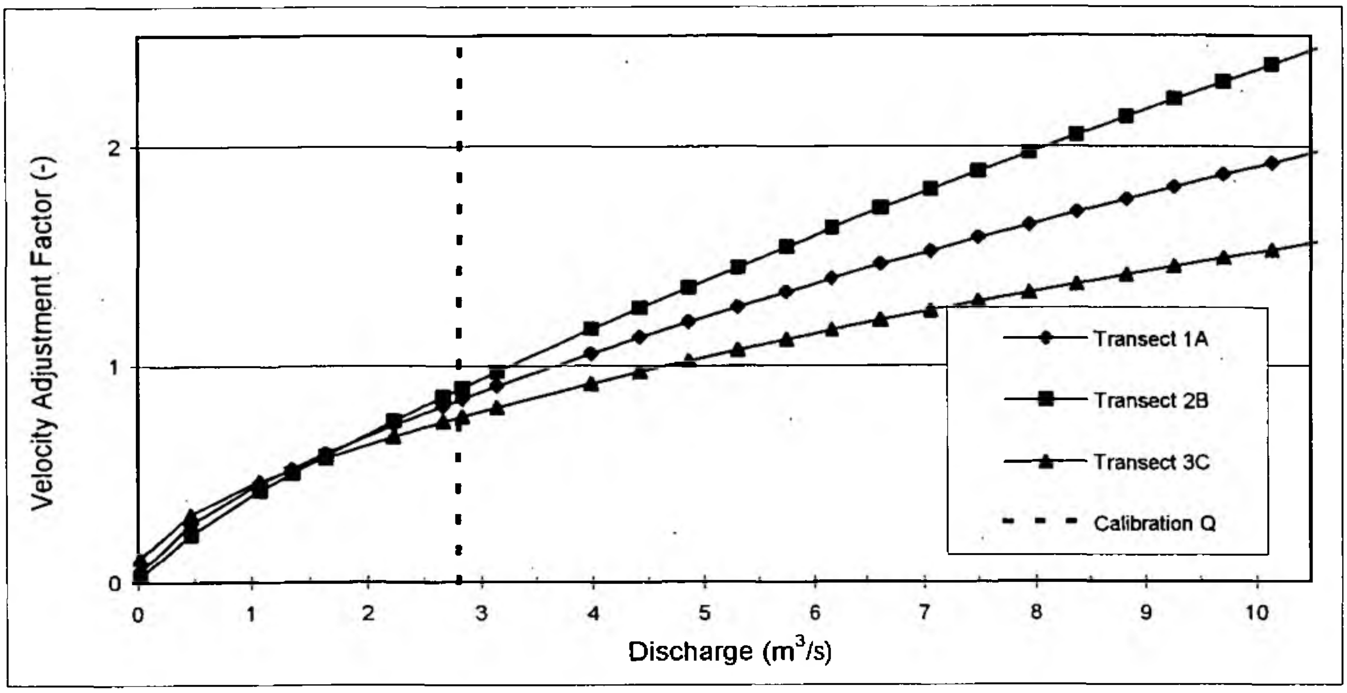






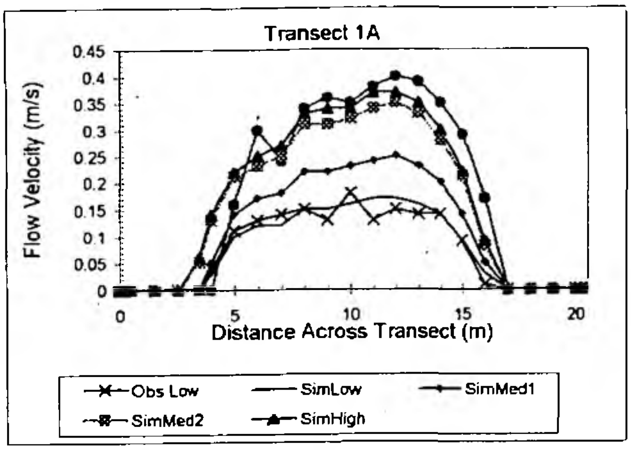
Appendix 5.6

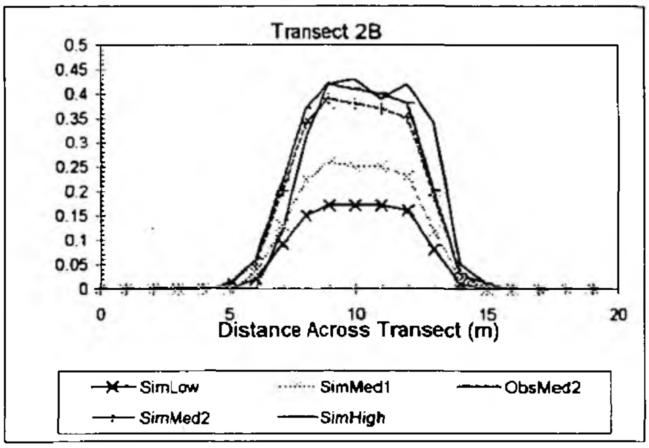
Velocity Adjustment Factors for the River Stour at Langham

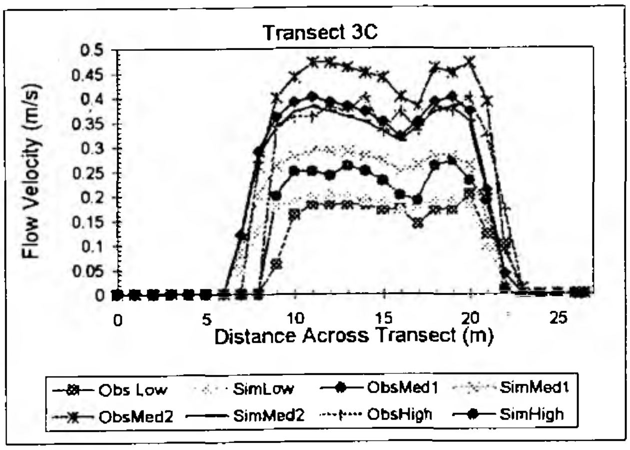


Appendix 5.7

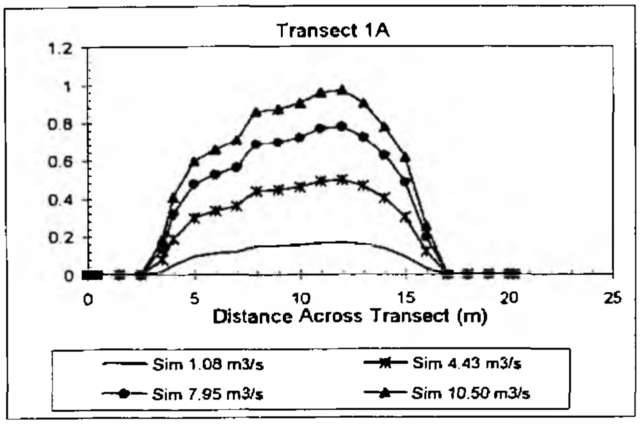
Calibration flow velocities: observed and simulated for Stour at Langham

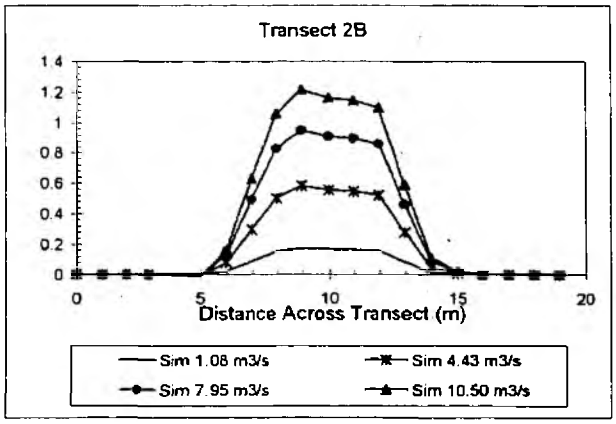


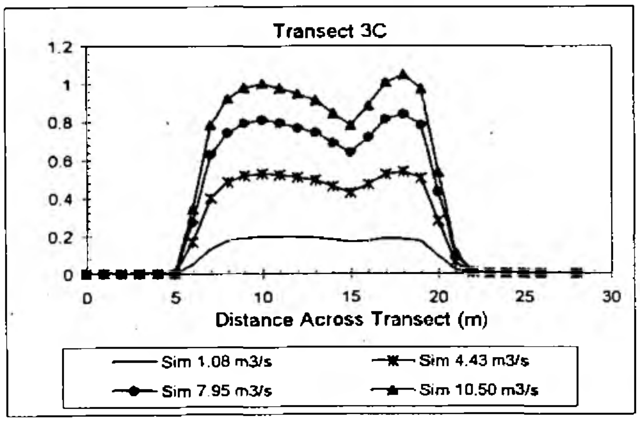




Simulated flow velocities for Stour at Langham







Appendix 5.8

Input/output codes for the River Stour at Langham

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zhabin	IOC	0110001020000020000000000000000000000000

Appendix 6. *RIVER PANT DOWNSTREAM OF GREAT SAMPFORD OUTFALL*

Appendix 6.1. Hydraulic field measurements

River Pant downstream of Great Sampford Outfall: low flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.25	0.275	0.07	0.01	0.000
2.5	0.25	0.11	0.01	0.000
2.75	0.25	0.14	0.04	0.001
3	0.25	0.19	0.05	0.002
3.25	0.25	0.20	0.05	0.002
3.5	0.25	0.21	0.07	0.003
3.75	0.25	0.19	0.07	0.003
4	0.25	0.19	0.07	0.004
4.25	0.25	0.19	0.04	0.002
4.5	0.25	0.16	0.05	0.002
4.75	0.25	0.11	0.01	0.000
5	0.225	0.05	0.01	0.000
			Total flow	0.021

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
3.75	0.33	0.07	0.011	0.000
4	0.38	0.21	0.007	0.001
4.5	0.50	0.35	0.038	0.007
5	0.50	0.24	0.093	0.011
5.5	0.50	0.18	0.017	0.002
6	0.38	0.07	0.028	0.001
6.25	0.275	0.03	0.089	0.001
			Total flow	0.022

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.75	0.33	0.10	0.060	0.002
3	0.38	0.32	0.011	0.001
3.5	0.50	0.57	0.016	0.005
4	0.50	0.69	0.047	0.016
4.5	0.50	0.80	0.019	0.008
5	0.50	0.65	0.028	0.009
5.5	0.50	0.32	0.005	0.001
6	0.35	0.06	0.005	0.000
			Total flow	0.042

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.25	0.33	0.26	0.029	0.002
2.5	0.38	0.42	0.023	0.004
3	0.50	0.42	0.043	0.009
3.5	0.50	0.34	0.040	0.007
4	0.50	0.24	0.009	0.001
4.5	0.50	0.11	0.025	0.001
5	0.38	0.06	0.006	0.000
5.25	0.325	0.04	0.009	0.000
			Total flow	0.025

River Pant downstream of Great Sampford Outfall: medium flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.23	0.42	0.079	0.007
2.25	0.25	0.52	0.072	0.009
2.5	0.25	0.56	0.480	0.067
2.75	0.25	0.63	0.490	0.077
3	0.25	0.65	0.520	0.085
3.25	0.25	0.67	0.550	0.092
3.5	0.25	0.69	0.550	0.095
3.75	0.25	0.67	0.530	0.089
4	0.25	0.68	0.420	0.071
4.25	0.25	0.67	0.363	0.061
4.5	0.25	0.63	0.348	0.055
4.75	0.25	0.58	0.175	0.025
5	0.38	0.50	0.079	0.015
			Total flow	**0.749**

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	0.40	0.47	-0.018	-0.003
3	0.50	0.82	0.043	0.018
3.5	0.50	1.10	0.184	0.101
4	0.50	1.24	0.301	0.187
4.5	0.50	1.29	0.313	0.202
5	0.50	1.21	0.367	0.222
5.5	0.50	0.86	0.335	0.144
6	0.50	0.53	0.012	0.003
			Total flow	**0.873**

Transect 5E

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.5	0.45	0.48	0.354	0.076
2	0.50	0.72	0.620	0.223
2.5	0.50	0.73	0.640	0.234
3	0.50	0.69	0.620	0.214
3.5	0.50	0.65	0.097	0.032
4	0.50	0.17	0.021	0.002
4.5	0.75	0.18	0.010	0.001
			Total flow	**0.782**

River Pant downstream of Great Sampford Outfall: high flow

Transect 1A

Dist Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.33	0.59	0.127	0.024
2.25	0.25	0.70	0.640	0.112
2.5	0.25	0.85	0.680	0.145
2.75	0.25	0.79	0.710	0.140
3	0.25	0.80	0.740	0.148
3.25	0.25	0.84	0.690	0.145
3.5	0.25	0.85	0.700	0.149
3.75	0.25	0.83	0.700	0.145
4	0.25	0.83	0.660	0.137
4.25	0.25	0.82	0.620	0.127
4.5	0.25	0.80	0.490	0.098
4.75	0.25	0.74	0.430	0.080
5	0.25	0.67	0.337	0.056
5.25	0.225	0.54	0.133	0.016
			Total flow	**1.522**

Transect 2B

Dist Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
3	0.45	0.22	0.023	0.00
3.5	0.50	0.58	0.371	0.11
4	0.50	0.98	0.380	0.19
4.5	0.50	0.98	0.700	0.34
5	0.50	0.99	0.700	0.35
5.5	0.50	0.78	0.630	0.25
6	0.38	0.71	0.560	0.15
6.25	0.25	0.64	0.52	0.08
6.5	0.225	0.55	0.460	0.06
			Total flow	**1.520**

Transect 3C

Dist Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	0.55	0.69	-0.006	0.00
3	0.50	1.10	0.221	0.12
3.5	0.50	1.27	0.331	0.21
4	0.50	1.36	0.390	0.27
4.5	0.50	1.44	0.450	0.32
5	0.50	1.28	0.440	0.28
5.5	0.50	1.02	0.450	0.23
6	0.50	0.73	0.324	0.12
6.5	0.4	0.56	0.097	0.02
			Total flow	**1.570**

Transect 4D

Dist Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.45	0.63	0.245	0.07
2.5	0.50	1.06	0.351	0.19
3	0.50	1.06	0.393	0.21
3.5	0.50	1.00	0.570	0.29
4	0.50	0.96	0.510	0.24
4.5	0.50	0.77	0.530	0.20
5	0.50	0.70	0.490	0.17
5.5	0.55	0.65	0.189	0.07
			Total flow	**1.437**

Transect 5E

Dist Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.5	0.45	0.61	0.68	0.187
2	0.5	0.86	0.84	0.361
2.5	0.5	0.87	0.88	0.383
3	0.5	0.84	0.85	0.357
3.5	0.5	0.86	0.52	0.224
4	0.5	0.25	0.075	0.009
4.5	0.75	0.3	0.034	0.008
			Total flow	**1.528**

Appendix 6.2. Overhanging vegetation and substrate measurements

River Pant downstream of Great Sampford Outfall

Transect 1A

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	100.0	900.00
2	0.5	100.0	900.00
3	1	100.0	900.00
4	1.5	100.0	900.00
5	2	100.0	605.60
6	2.5	100.0	605.60
7	3	100.0	605.60
8	3.5	100.0	504.70
9	4	90.0	504.70
10	4.5	90.0	403.60
11	5	80.0	304.60
12	5.5	70.0	900.00
13	6	50.0	900.00
14	6.5	50.0	900.00
15	7	20.0	900.00
16	7.5	20.0	900.00
17	7.7		

Transect 2B

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	100.0	900.00
2	0.5	100.0	900.00
3	1	100.0	900.00
4	1.5	100.0	900.00
5	2	100.0	900.00
6	2.5	100.0	100.00
7	3	70.0	103.60
8	3.5	50.0	103.60
9	4	30.0	305.80
10	4.5	10.0	305.80
11	5	5.0	305.80
12	5.5	0.0	305.80
13	6	0.0	900.00
14	6.5	0.0	900.00
15	7	0.0	900.00
16	7.5	0.0	900.00
17	8	0.0	900.00
18	8.5	0.0	900.00

Transect 3C

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	10.00	900.00
2	0.5	10.00	900.00
3	1	10.00	900.00
4	1.5	10.00	900.00
5	2	10.00	900.00
6	2.5	0.00	203.70
7	3	0.00	305.60
8	3.5	0.00	305.70
9	4	0.00	405.60
10	4.5	0.00	305.60
11	5	0.00	203.70
12	5.5	0.00	203.70
13	6	10.00	203.70
14	6.5	0.00	900.00
15	7	0.00	900.00
16	7.5	0.00	900.00
17	8	0.00	900.00
18	8.5	0.00	900.00
19	9	0.00	900.00
20	9.5	0.00	900.00

Transect 4D

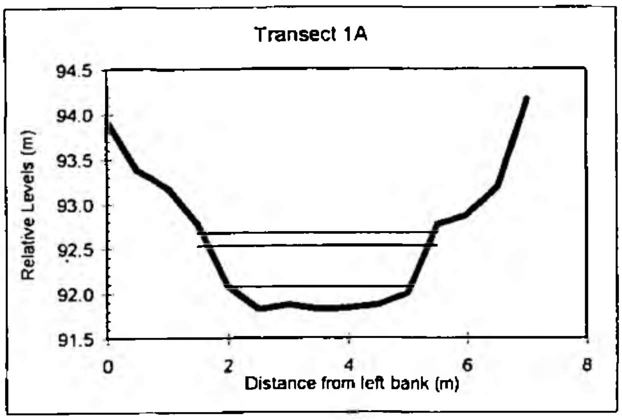
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.00	900.00
2	0.5	0.00	900.00
3	1	0.00	900.00
4	1.5	0.00	900.00
5	2	0.00	900.00
6	2.5	0.00	900.00
7	3	0.00	304.70
8	3.5	0.00	304.70
9	4	0.00	503.60
10	4.5	0.00	306.70
11	5	0.00	504.70
12	5.5	0.00	504.70
13	6	0.00	304.70
14	6.5	40.00	302.70
15	7	0.00	900.00
16	7.5	0.00	900.00
17	8	0.00	900.00
18	8.5	0.00	900.00
19	9	0.00	900.00
20	9.5	0.00	900.00
21	10	0.00	900.00

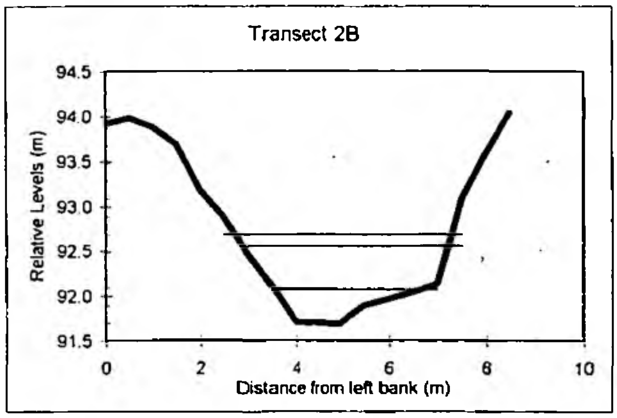
Transect 5E

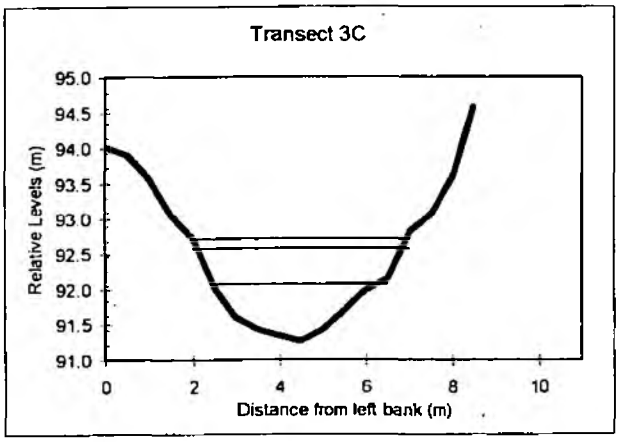
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.00	900.00
2	0.5	0.00	900.00
3	1	50.00	900.00
4	1.5	70.00	203.90
5	2	100.00	604.60
6	2.5	100.00	604.60
7	3	100.00	604.60
8	3.5	100.00	304.80
9	4	100.00	302.70
10	4.5	100.00	302.70
11	5	100.00	302.70
12	5.5	100.00	900.00
13	6	100.00	900.00

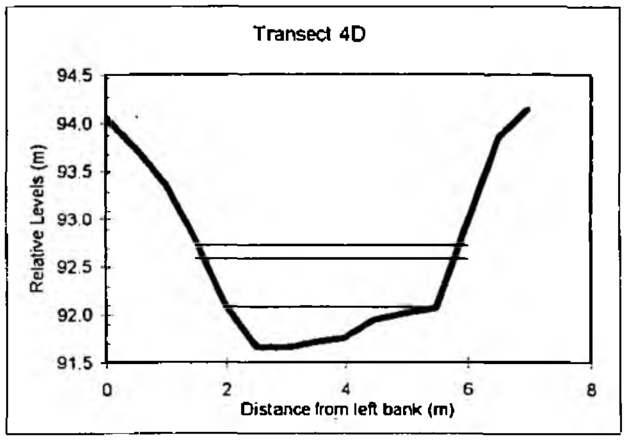
Appendix 6.3

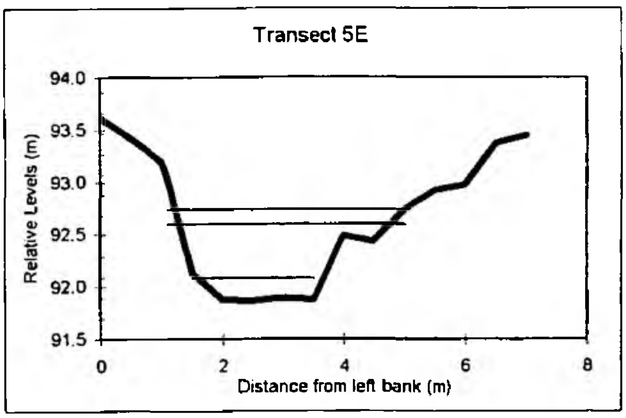
Pant downstream of Great Sampford Outfall: bed elevation and water surface levels











Appendix 6.4

River Pant downstream of Great Sampford Outfall: longitudinal water surface level profiles

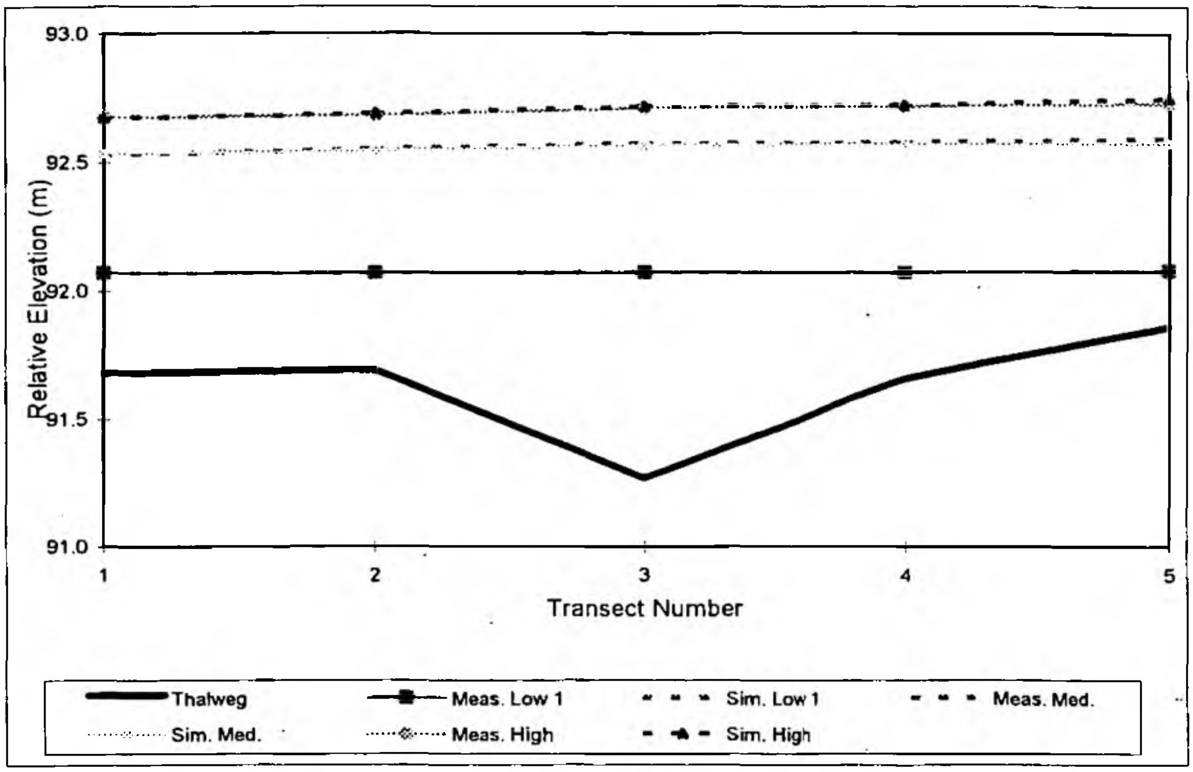


Figure 6.4a: Longitudinal water surface elevation for measured and observed discharges

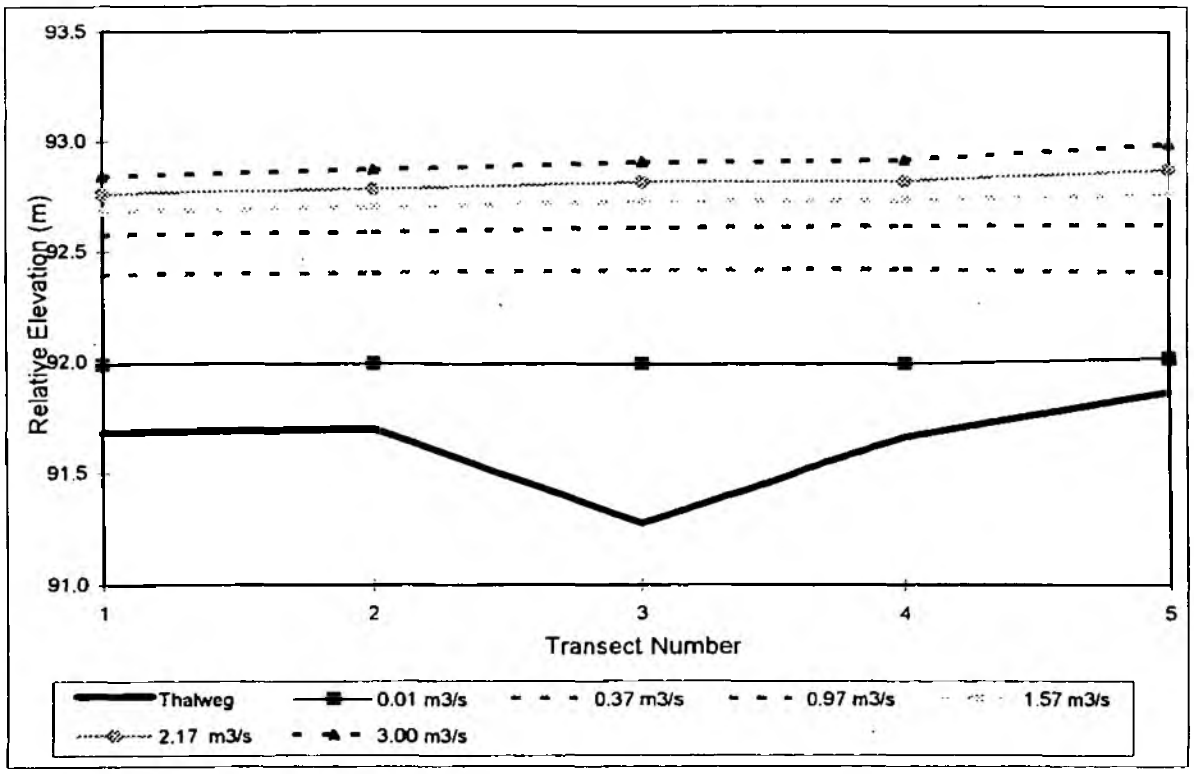
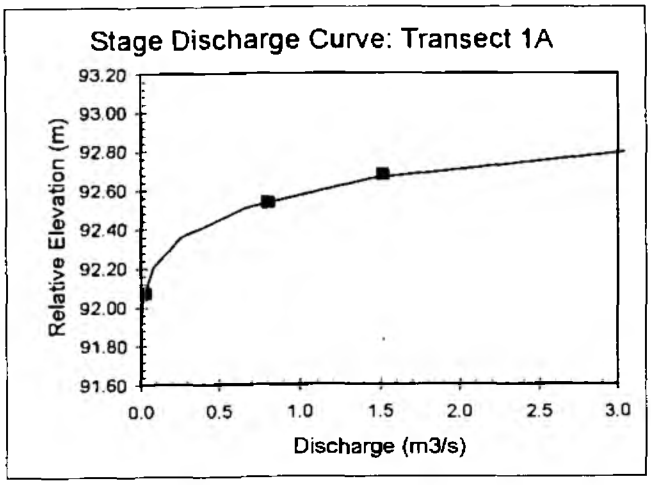
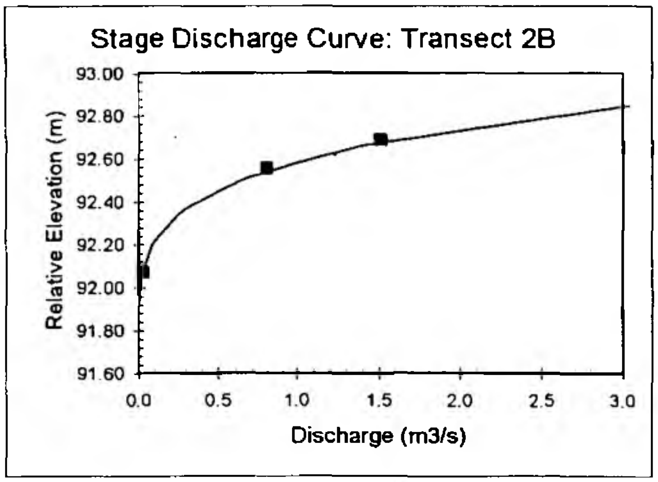


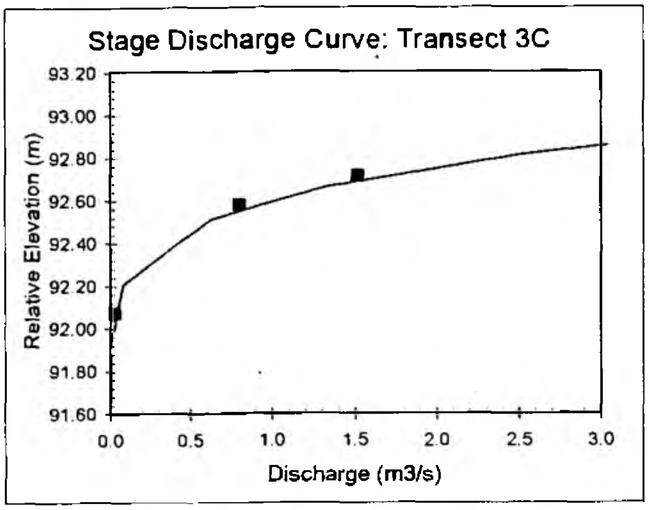
Figure 6.4b: Longitudinal water surface elevation for simulated flows.

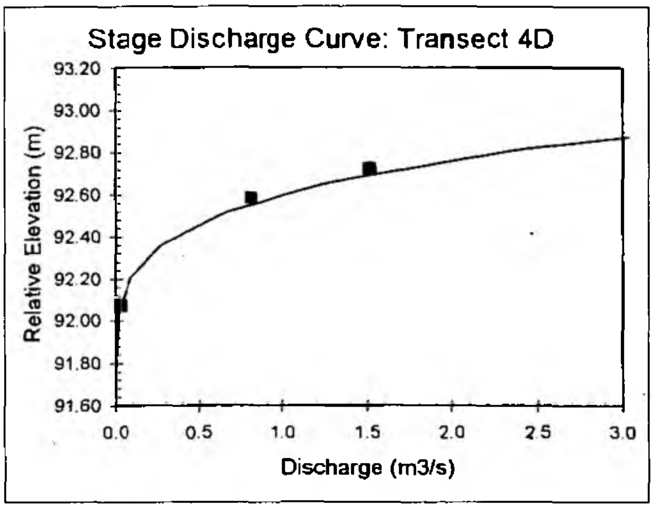
Appendix 6.5

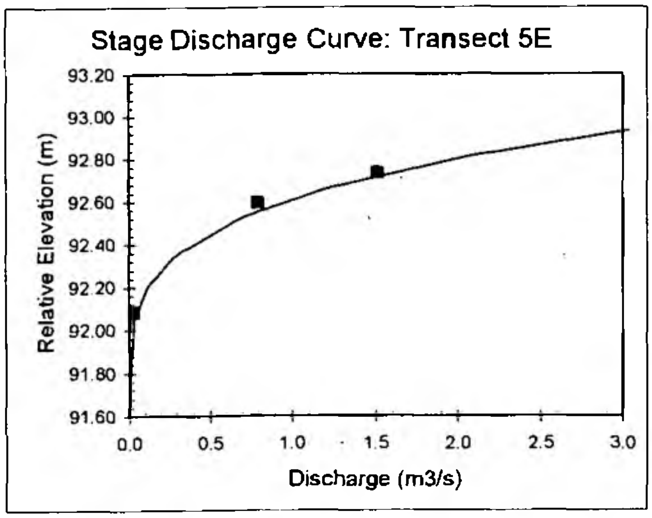
River Pant downstream of Great Sampford Outfall: stage-discharge relationships





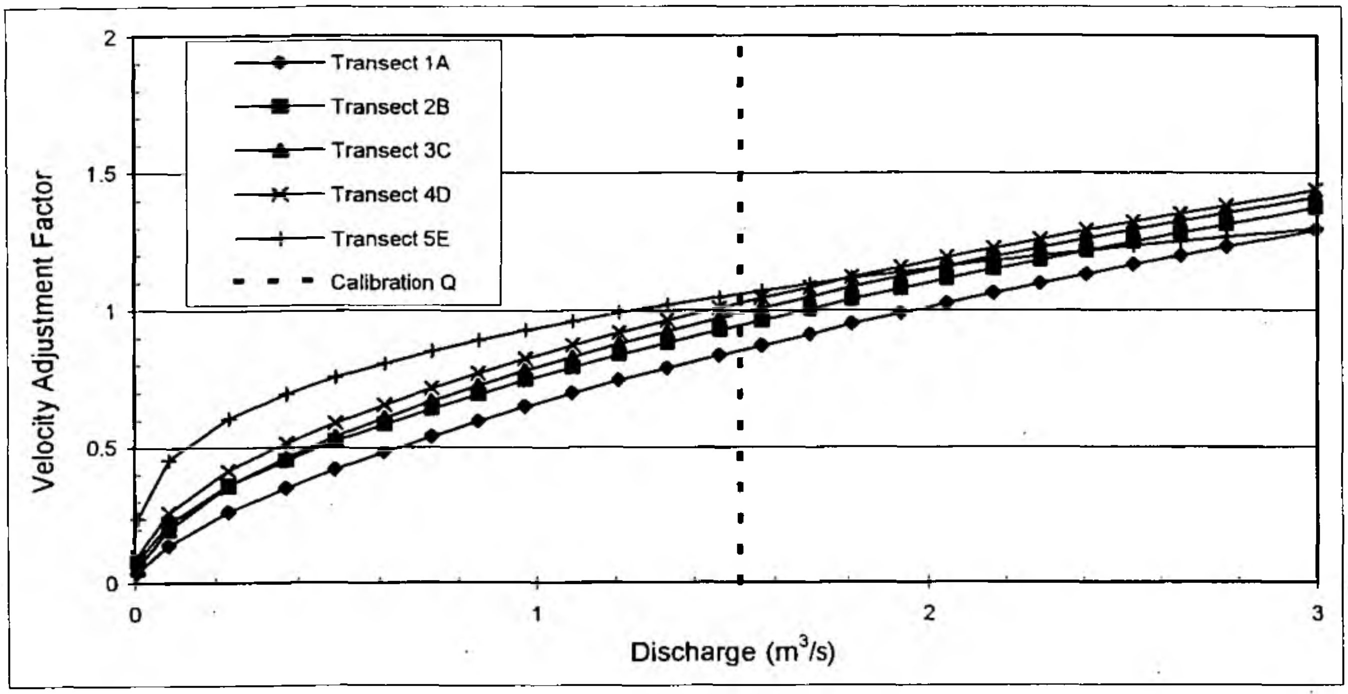






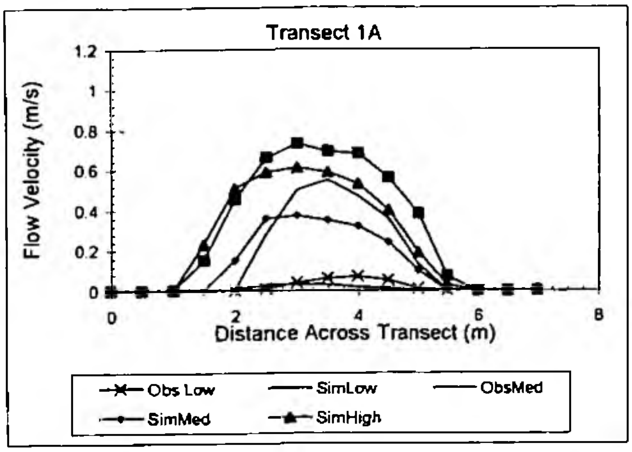
Appendix 6.6

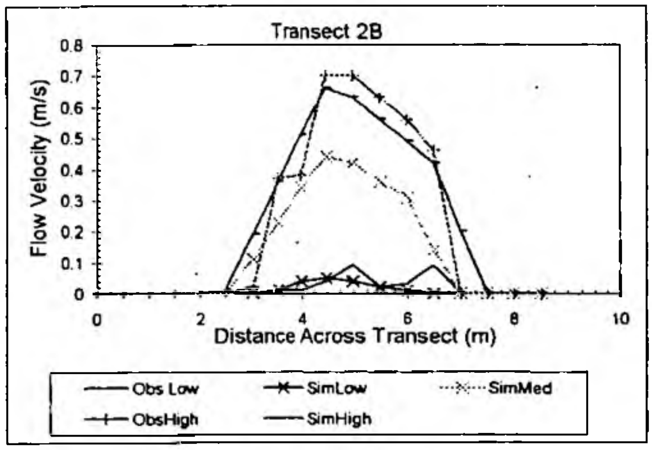
Velocity Adjustment Factors for the River Pant downstream of Gt Sampford Outfall

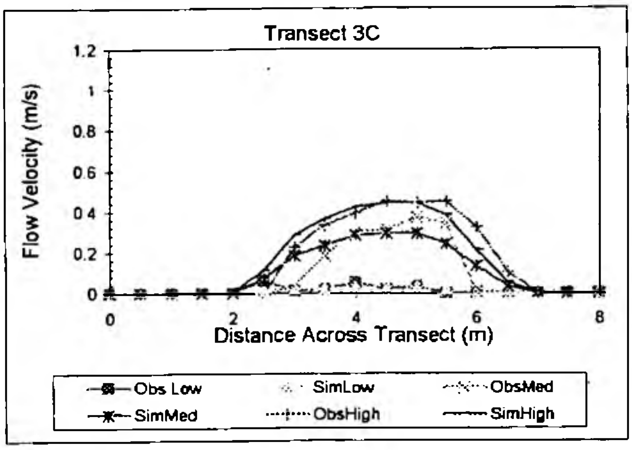


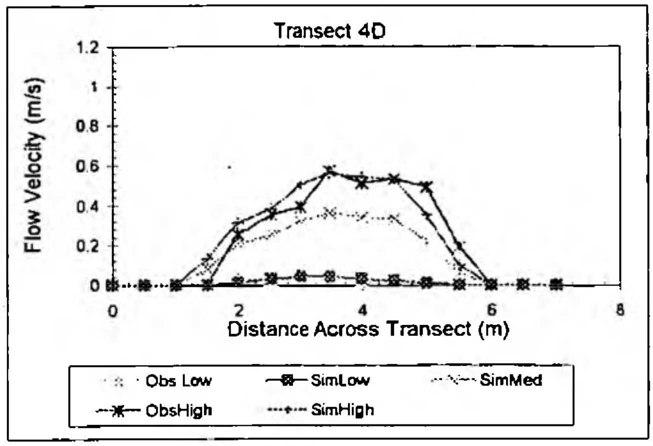
Appendix 6.7

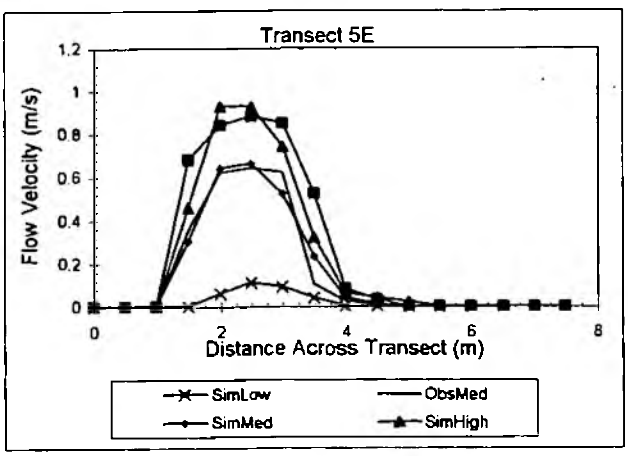
Calibration flow velocities: observed and simulated for Pant downstream of Great Sampford Outfall



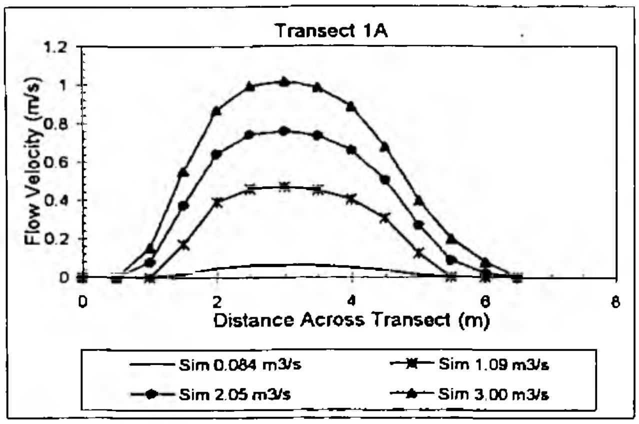


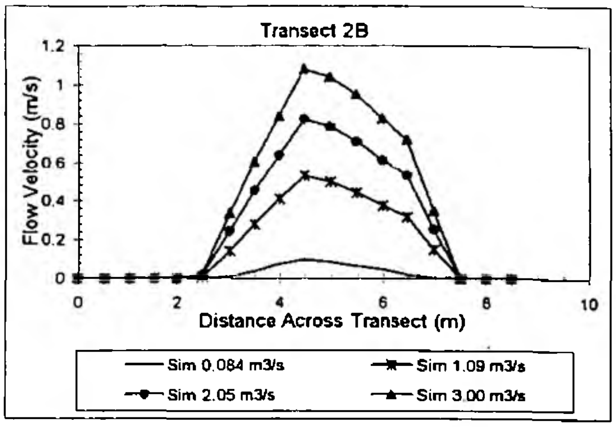


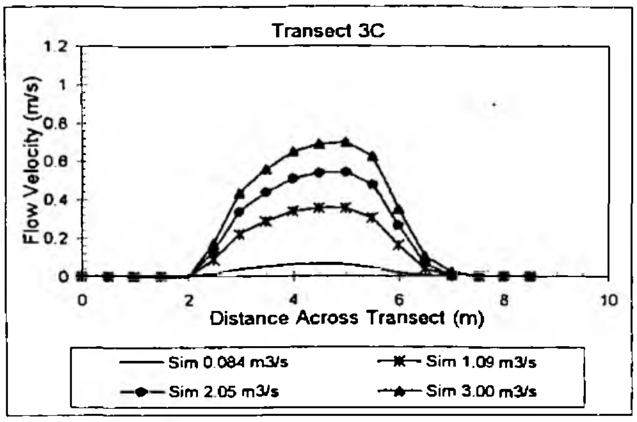


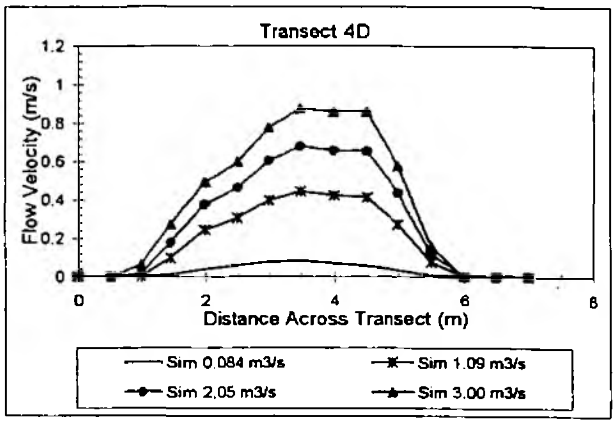


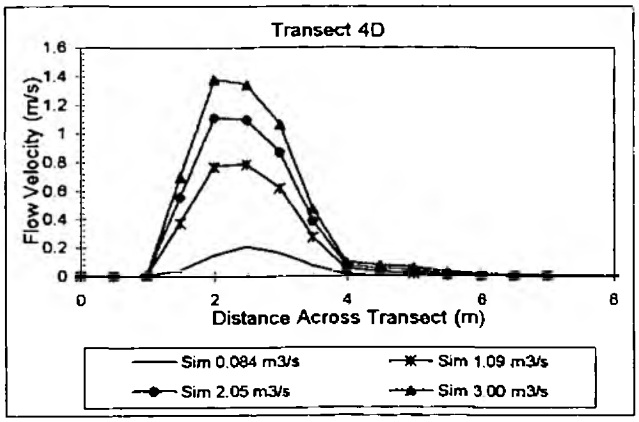
Simulated flow velocities for Pant downstream of Great Sampford Outfall











Appendix 6.8

Input/output codes for the River Pant downstream of Gt Sampford Outfall

zifg4 IOC 00000002000010000000
zhabin IOC 01100010200000200000000000000000000000000

Appendix 7. RIVER PANT AT LITTLE SAMPFORD BRIDGE

Appendix 7.1. Hydraulic field measurements

River Pant at Little Sampford Bridge: low flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.4	0.40	0.07	0.049	0.00
1.9	0.50	0.13	0.100	0.01
2.4	0.50	0.14	0.097	0.01
2.9	0.50	0.16	0.110	0.01
3.4	0.50	0.20	0.119	0.01
3.9	0.50	0.19	0.121	0.01
4.4	0.50	0.18	0.135	0.01
4.9	0.50	0.18	0.076	0.01
5.4	0.50	0.15	0.078	0.01
5.9	0.50	0.12	0.126	0.01
6.4	0.75	0.12	0.046	0.00
			Total flow	**0.082**

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.1	0.55	0.14	0.105	0.01
2.6	0.50	0.14	0.199	0.01
3.1	0.50	0.17	0.191	0.02
3.6	0.50	0.19	0.204	0.02
4.1	0.50	0.21	0.154	0.02
4.6	0.50	0.22	0.008	0.00
5.1	0.50	0.22	0.027	0.00
5.6	0.50	0.22	0.035	0.00
6.1	0.50	0.23	0.029	0.00
6.6	0.65	0.15	0.029	0.00
			Total flow	**0.088**

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.3	0.65	0.14	0.102	0.01
2.8	0.50	0.17	0.119	0.01
3.3	0.50	0.18	0.142	0.01
3.8	0.50	0.18	0.091	0.01
4.3	0.50	0.16	0.146	0.01
4.8	0.50	0.15	0.092	0.01
5.3	0.50	0.15	0.109	0.01
5.8	0.50	0.16	0.152	0.01
6.3	0.7	0.15	0.027	0.00
			Total flow	**0.082**

River Pant at Little Sampford Bridge: medium flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.4	0.75	0.08	0.110	0.007
1.9	0.50	0.18	0.166	0.015
2.4	0.50	0.18	0.193	0.017
2.9	0.50	0.20	0.200	0.020
3.4	0.50	0.24	0.222	0.027
3.9	0.50	0.23	0.217	0.025
4.4	0.50	0.20	0.236	0.024
4.9	0.50	0.20	0.210	0.021
5.4	0.50	0.19	0.187	0.018
5.9	0.50	0.16	0.209	0.017
6.4	0.50	0.16	0.210	0.017
6.9	0.35	0.12	0.080	0.003
			Total flow	**0.203**

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.1	0.65	0.15	0.186	0.018
2.6	0.50	0.19	0.218	0.021
3.1	0.50	0.19	0.254	0.024
3.6	0.50	0.21	0.232	0.024
4.1	0.50	0.24	0.257	0.031
4.6	0.50	0.27	0.214	0.029
5.1	0.50	0.25	0.232	0.029
5.6	0.50	0.25	0.194	0.024
6.1	0.50	0.28	0.175	0.025
6.6	0.65	0.17	0.063	0.007
			Total flow	**0.232**

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.75	0.33	0.10	0.060	0.002
3	0.38	0.32	0.011	0.001
3.5	0.50	0.57	0.016	0.005
4	0.50	0.69	0.047	0.016
4.5	0.50	0.80	0.019	0.008
5	0.50	0.65	0.028	0.009
5.5	0.50	0.32	0.005	0.001
6	0.35	0.06	0.005	0.000
			Total flow	**0.042**

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.3	0.65	0.17	0.154	0.017
2.8	0.50	0.20	0.257	0.026
3.3	0.50	0.20	0.236	0.024
3.8	0.50	0.21	0.283	0.030
4.3	0.50	0.2	0.279	0.028
4.8	0.50	0.18	0.297	0.027
5.3	0.50	0.16	0.287	0.023
5.8	0.50	0.16	0.233	0.019
6.3	0.65	0.12	0.235	0.018
			Total flow	**0.211**

Transect 5E

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.1	LB			
1.5	0.65	0.09	0.740	0.043
2	0.50	0.10	0.301	0.015
2.5	0.50	0.14	0.650	0.046
3	0.50	0.13	0.650	0.042
3.5	0.50	0.14	0.240	0.017
4	0.50	0.11	0.430	0.024
4.5	0.50	0.10	0.470	0.024
5	0.50	0.08	0.420	0.017
5.5	0.55	0.06	0.490	0.016
			Total flow	**0.243**

Transect 6F

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
3	0.35	0.03	0.012	0.000
3.5	0.50	0.20	0.046	0.005
4	0.50	0.24	0.134	0.016
4.5	0.50	0.33	0.172	0.028
5	0.50	0.39	0.173	0.034
5.5	0.50	0.43	0.176	0.038
6	0.50	0.45	0.146	0.033
6.5	0.50	0.44	0.155	0.034
7	0.65	0.44	0.171	0.049
			Total flow	**0.237**

River Pant at Little Sampford Bridge: high flow

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.55	0.49	0.127	0.034
2.5	0.50	0.57	0.280	0.080
3	0.50	0.56	0.430	0.120
3.5	0.50	0.57	0.600	0.171
4	0.50	0.56	0.710	0.199
4.5	0.50	0.56	0.710	0.199
5	0.50	0.51	0.840	0.214
5.5	0.50	0.49	0.780	0.191
6	0.50	0.49	0.680	0.167
6.5	0.55	0.43	0.423	0.100
			Total flow	**1.475**

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	0.75	0.49	0.215	0.079
3	0.50	0.54	0.378	0.102
3.5	0.50	0.58	0.520	0.151
4	0.50	0.59	0.560	0.165
4.5	0.50	0.59	0.580	0.171
5	0.50	0.59	0.610	0.180
5.5	0.50	0.58	0.650	0.189
6	0.50	0.58	0.640	0.186
6.5	0.38	0.57	0.590	0.126
6.75	0.375	0.54	0.510	0.103
			Total flow	**1.452**

Appendix 7.2. Overhanging vegetation and substrate measurements

River Pant at Little Sampford Bridge

Transect 1A

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	90.0	900.00
2	0.5	90.0	900.00
3	1	90.0	900.00
4	1.5	100.0	300.00
5	2	100.0	305.70
6	2.5	100.0	305.70
7	3	100.0	305.70
8	3.5	100.0	506.50
9	4	100.0	506.50
10	4.5	100.0	605.50
11	5	100.0	406.60
12	5.5	100.0	506.90
13	6	100.0	406.80
14	6.5	100.0	203.60
15	7	100.0	900.00
16	7.5	100.0	900.00
17	8	100.0	900.00
18	8.38	100.0	900.00

Transect 2B

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	20.0	900.00
2	0.5	20.0	900.00
3	1	20.0	900.00
4	1.5	20.0	900.00
5	2	20.0	405.60
6	2.5	20.0	405.60
7	3	20.0	405.60
8	3.5	20.0	405.60
9	4	20.0	605.60
10	4.5	20.0	605.60
11	5	30.0	607.90
12	5.5	0.0	506.70
13	6	0.0	403.70
14	6.5	30.0	403.60
15	7	100.0	403.60
16	7.5	0.0	900.00
17	8	0.0	900.00
18	8.55	0.0	900.00

Transect 3C

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	10.00	900.00
2	0.5	10.00	900.00
3	1	10.00	900.00
4	1.5	10.00	900.00
5	2	10.00	900.00
6	2.5	10.00	900.00
7	3	10.00	900.00
8	3.5	0.00	900.00
9	4	0.00	900.00
10	4.5	0.00	304.80
11	5	0.00	405.70
12	5.5	0.00	405.70
13	6	0.00	506.90
14	6.5	0.00	506.90
15	7	0.00	506.90
16	7.5	20.00	506.90
17	8	60.00	203.80
18	8.5	0.00	900.00
19	9	0.00	900.00
20	9.5	0.00	900.00
21	10	0.00	900.00
22	10.15	0.00	900.00

Transect 4D

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	100.00	900.00
2	0.5	100.00	900.00
3	1	100.00	900.00
4	1.5	100.00	900.00
5	2	100.00	203.50
6	2.5	100.00	203.50
7	3	100.00	305.70
8	3.5	100.00	305.70
9	4	100.00	305.70
10	4.5	90.00	405.60
11	5	90.00	405.60
12	5.5	90.00	305.70
13	6	90.00	302.70
14	6.5	90.00	302.70
15	7	80.00	900.00
16	7.5	80.00	900.00
17	8	80.00	900.00
18	8.5	80.00	900.00
19	8.83	60.00	900.00

Transect 5E

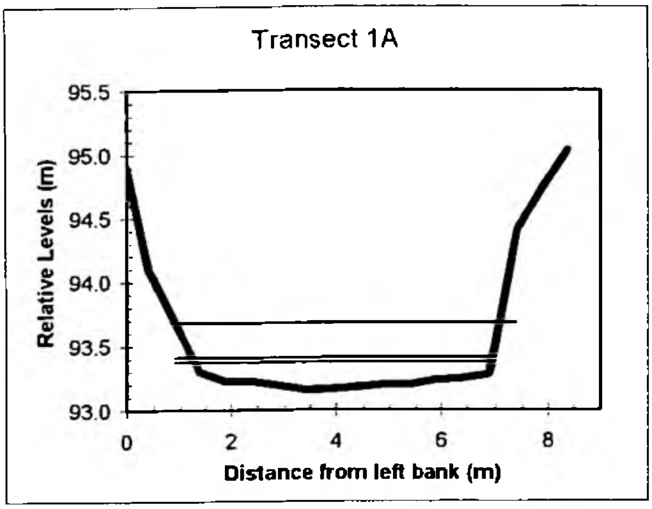
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.00	900.00
2	0.5	0.00	900.00
3	1	0.00	900.00
4	1.5	0.00	506.70
5	2	0.00	506.70
6	2.5	0.00	506.60
7	3	0.00	604.60
8	3.5	0.00	607.90
9	4	0.00	607.90
10	4.5	0.00	607.90
11	5	0.00	506.70
12	5.5	0.00	506.80
13	6	0.00	302.60
14	6.5	0.00	900.00
15	7	0.00	900.00
16	7.5	0.00	900.00
17	8	0.00	900.00
18	8.5	0.00	900.00
19	9	0.00	900.00
20	9.5	0.00	900.00
21	10	0.00	900.00
22	10.52	0.00	900.00

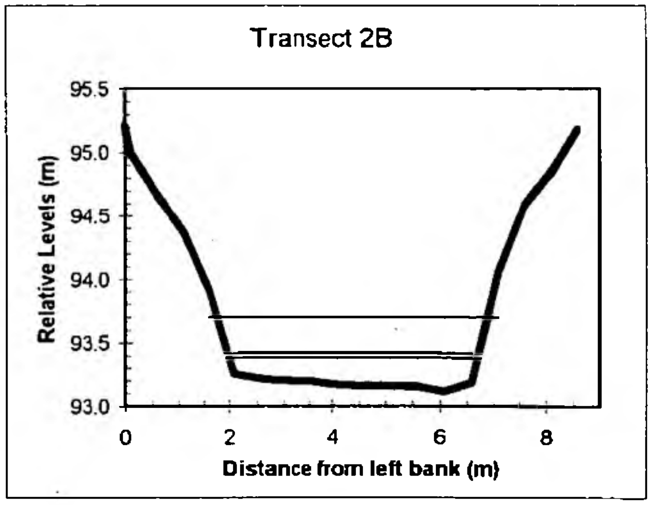
Transect 6F

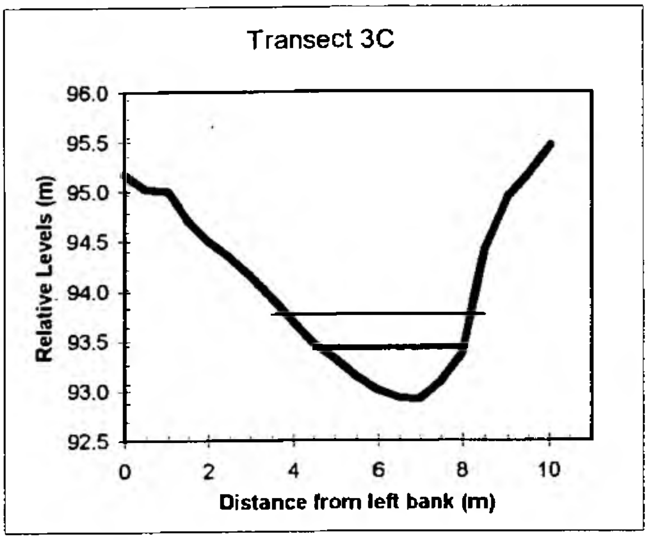
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.00	900.00
2	0.5	0.00	900.00
3	1	0.00	900.00
4	1.5	0.00	900.00
5	2	0.00	900.00
6	2.5	0.00	900.00
7	3	0.00	900.00
8	3.5	100.00	302.60
9	4	50.00	405.90
10	4.5	0.00	405.90
11	5	0.00	504.70
12	5.5	0.00	605.70
13	6	0.00	605.60
14	6.5	0.00	506.60
15	7	20.00	506.60
16	7.5	30.00	403.70
17	8	0.00	900.00
18	8.5	0.00	900.00
19	9.1	0.00	900.00

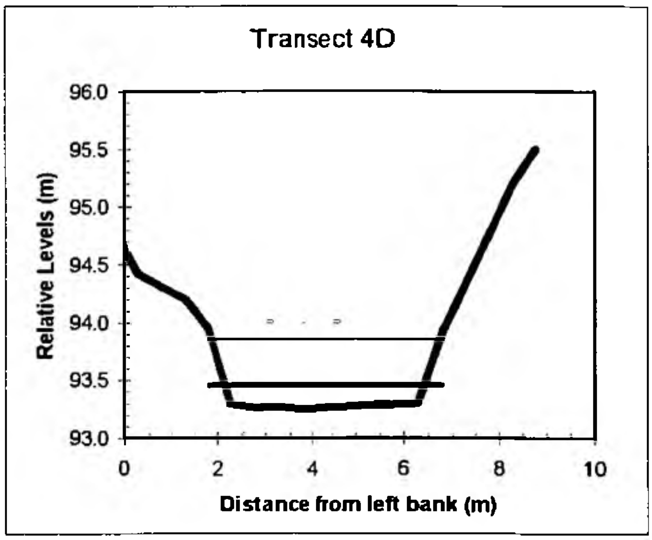
Appendix 7.3

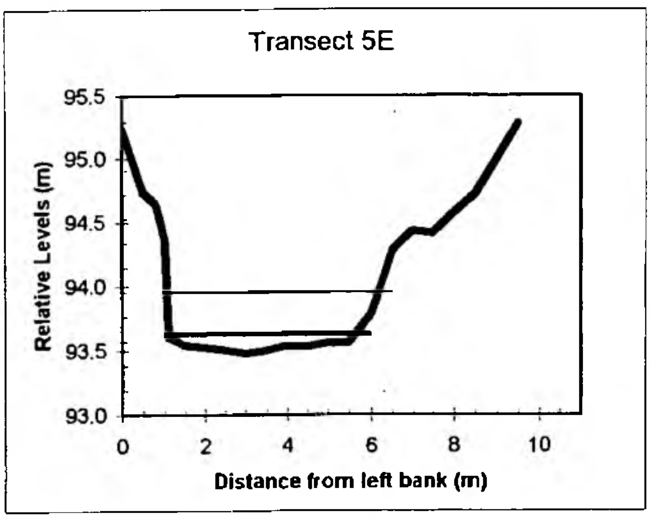
Pant at Little Sampford Bridge: bed elevation and water surface levels

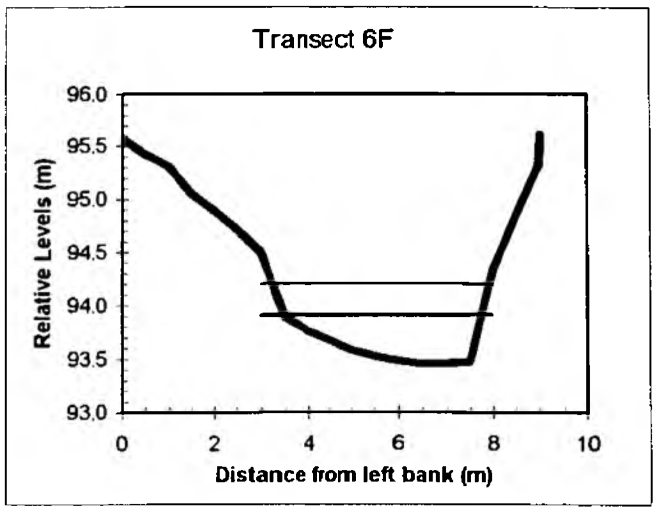












Appendix 7.4

River Pant at Little Sampford Bridge: longitudinal water surface level profiles

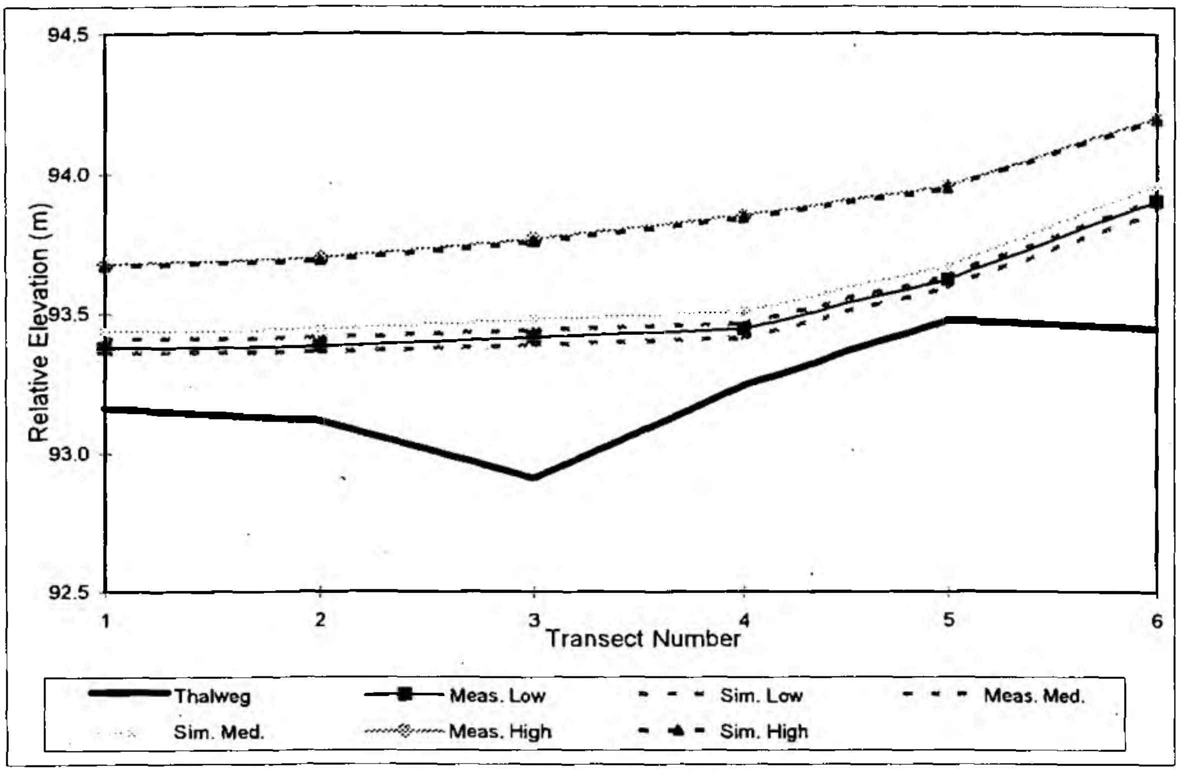


Figure 7.4a: Longitudinal water surface elevation for measured and observed discharges

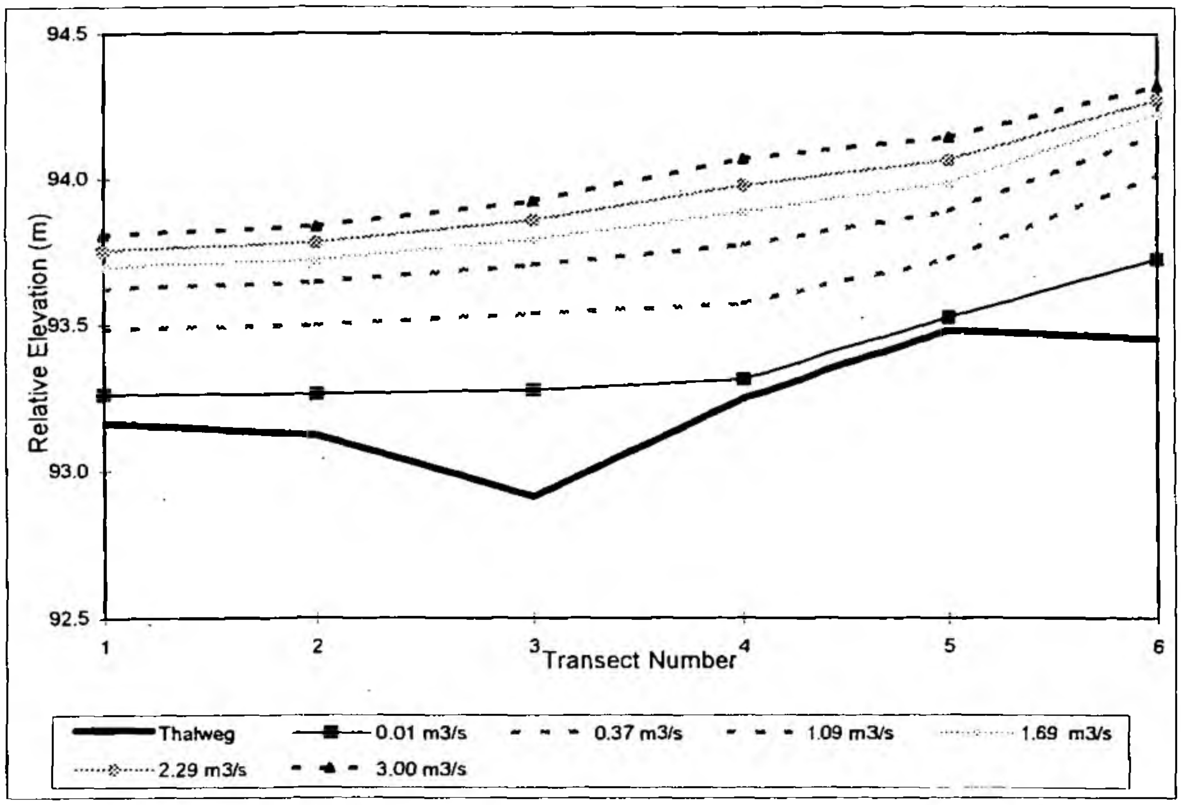
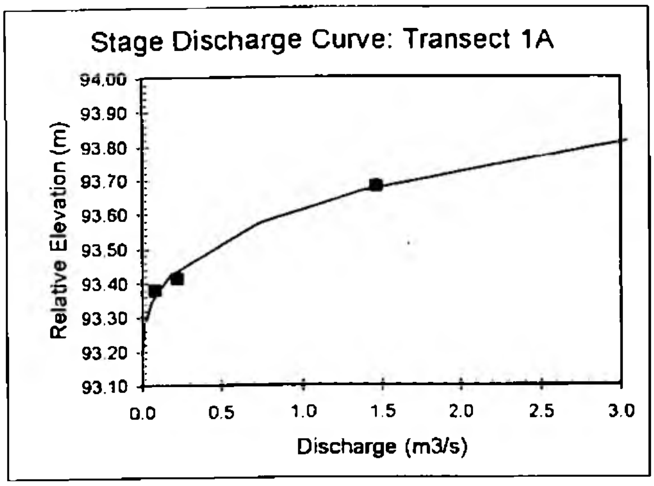
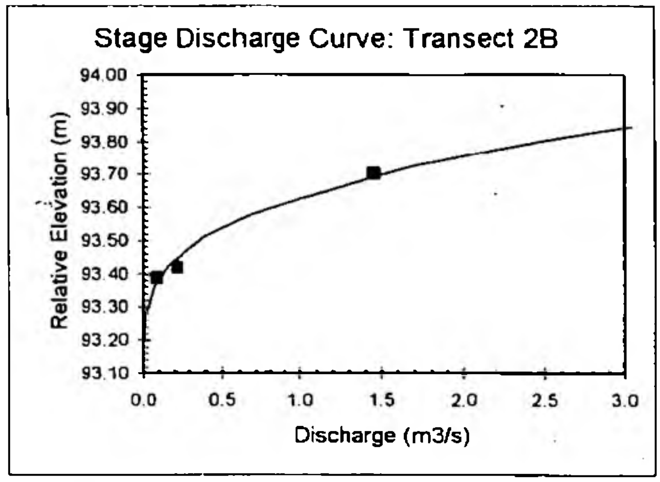


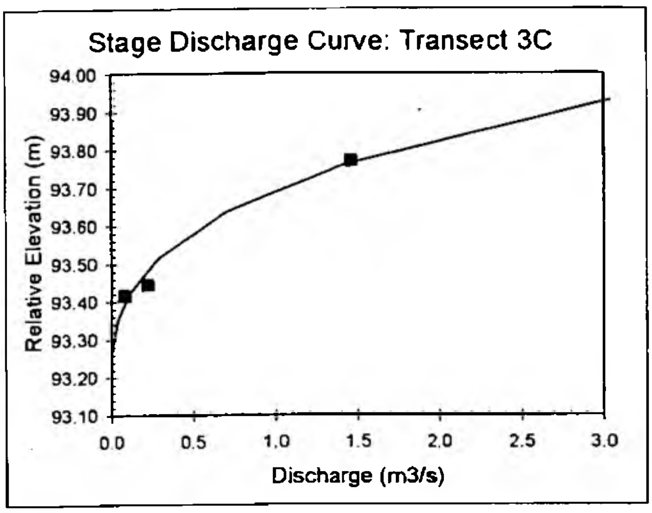
Figure 7.4b: Longitudinal water surface elevation for simulated flows.

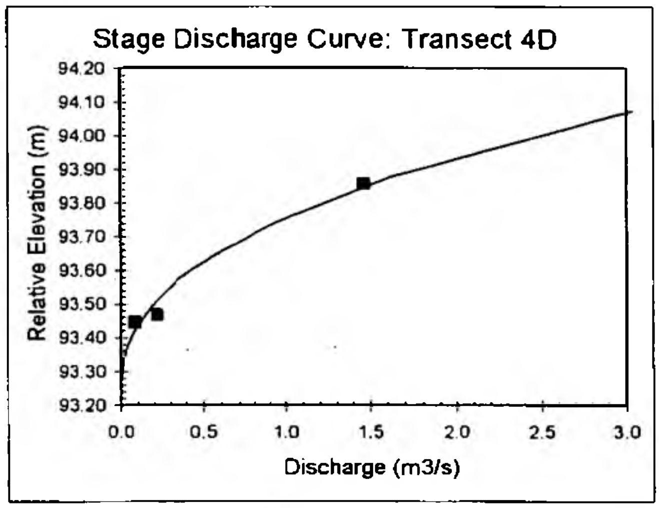
Appendix 7.5

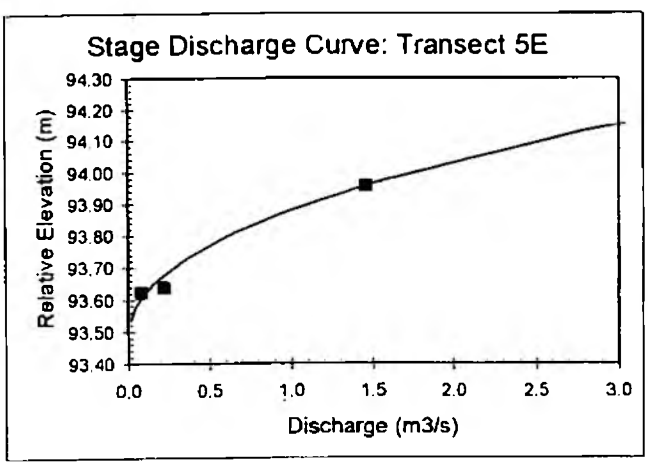
River Pant downstream of Great Sampford Outfall: stage-discharge relationships

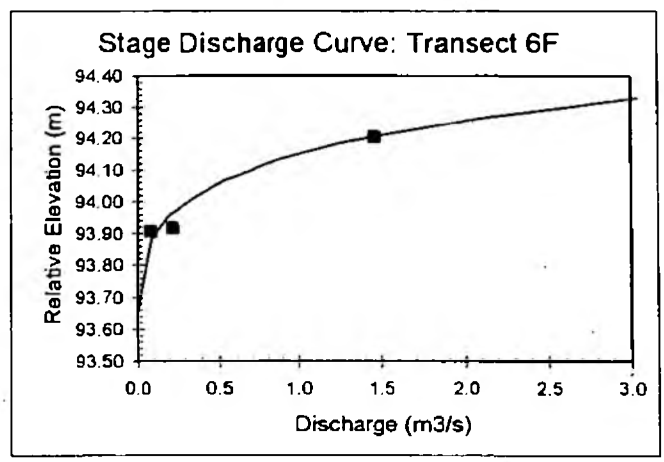






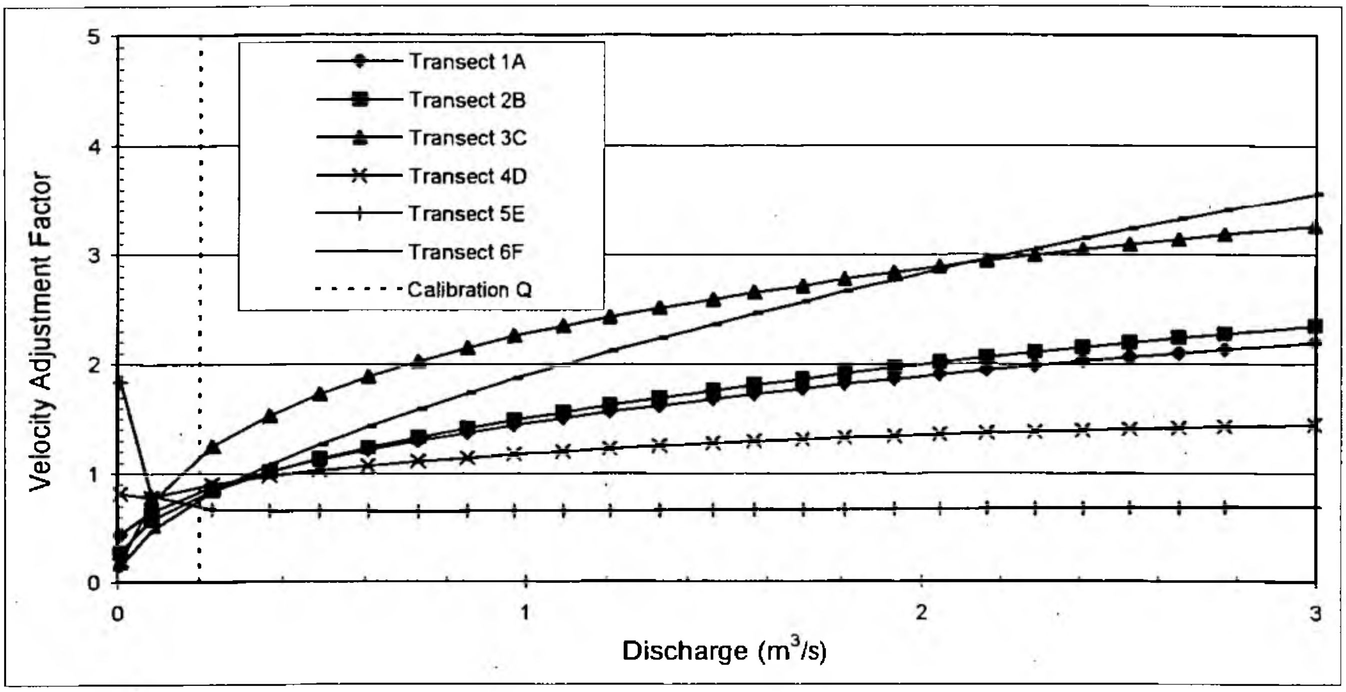




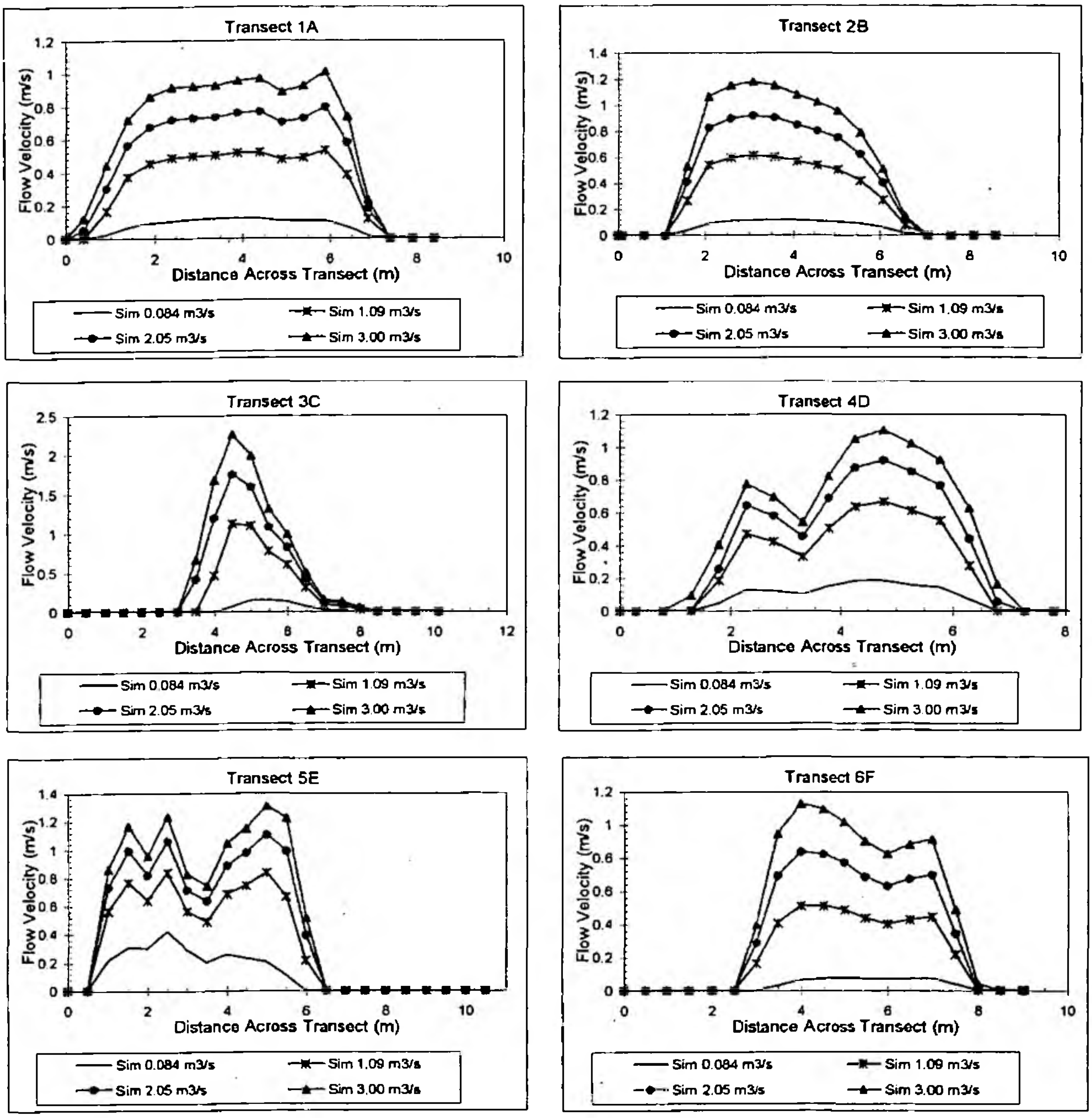


Appendix 7.6

Velocity Adjustment Factors for the River Pant at Lt Sampford Bridge



Simulated flow velocities for Pant at Little Sampford Bridge



Appendix 7.8

Input/output codes for the River Pant at Lt Sampford Bridge

zifg4	IOC	00001000000010000000
zhabin	IOC	0110001020000020000000000000000000000000

Appendix 8. RIVER BLACKWATER AT STISTED MILL

Appendix 8.1. Overhanging vegetation and substrate measurements

River Pant at Stisted Mill

Transect 1A

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.0	900.0
2	0.5	0.0	900.0
3	1	0.0	900.0
4	1.5	0.0	900.0
5	2	0.0	900.0
6	2.5	0.0	900.0
7	3	0.0	900.0
8	3.5	0.0	900.0
9	4	0.0	203.7
10	4.5	0.0	203.7
11	5	0.0	304.7
12	5.5	0.0	304.7
13	6	0.0	304.7
14	6.5	0.0	304.7
15	7	0.0	304.7
16	7.5	0.0	304.7
17	8	0.0	304.7
18	8.5	0.0	304.7
19.0	9	0.0	302.6
20.0	9.5	0.0	302.6
21.0	10	0.0	302.6
22.0	10.5	0.0	302.6
23.0	11	0.0	201.7
24.0	11.5	0.0	200.0
25.0	12	0.0	200.0
26.0	12.5	0.0	900.0
27.0	13	0.0	900.0
28.0	13.5	0.0	900.0
29.0	14	0.0	900.0

Transect 2B

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0	900.0
2	0.5	0	900.0
3	1	0	900.0
4	1.5	0	900.0
5	2	0.0	900.0
6	2.5	0.0	900.0
7	3	0.0	900.0
8	3.5	0.0	900.0
9	4	0.0	200.0
10	4.5	0.0	200.0
11	5	0.0	203.9
12	5.5	0.0	203.9
13	6	0.0	206.8
14	6.5	0.0	504.6
15	7	0.0	504.6
16	7.5	0.0	300.0
17	8	0.0	300.0
18	8.5	0.0	300.0
19	9	0.0	300.0
20	9.5	0.0	300.0
21	10	90.0	900.0
22	10.5	70.0	900.0
23	11	0.0	900.0
24	11.5	0.0	900.0
25	12	0.0	900.0
26	12.5	0.0	900.0
27	13	0.0	900.0
28	13.5	0.0	900.0
29	14	0.0	900.0
30	14.3	0.0	900.0

Transect 3C

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.00	900.0
2	0.5	0.00	900.0
3	1	0.00	900.0
4	1.5	0.00	900.0
5	2	50.00	900.0
6	2.5	10.00	900.0
7	3	0.00	900.0
8	3.5	0.00	900.0
9	4	0.00	900.0
10	4.5	0.00	900.0
11	5	0.00	900.0
12	5.5	0.00	900.0
13	6	0.00	900.0
14	6.5	0.00	900.0
15	7	0.00	201.6
16	7.5	0.00	200.0
17	8	0.00	200.0
18	8.5	0.00	306.7
19	9	0.00	306.7
20	9.5	0.00	305.8
21	10	0.00	305.8
22	10.5	0.00	304.7
23	11	0.00	200.0
24	11.5	0.00	900.0
25	12	0.00	900.0
26	12.5	0.00	900.0
27	13	0.00	900.0

Transect 4D

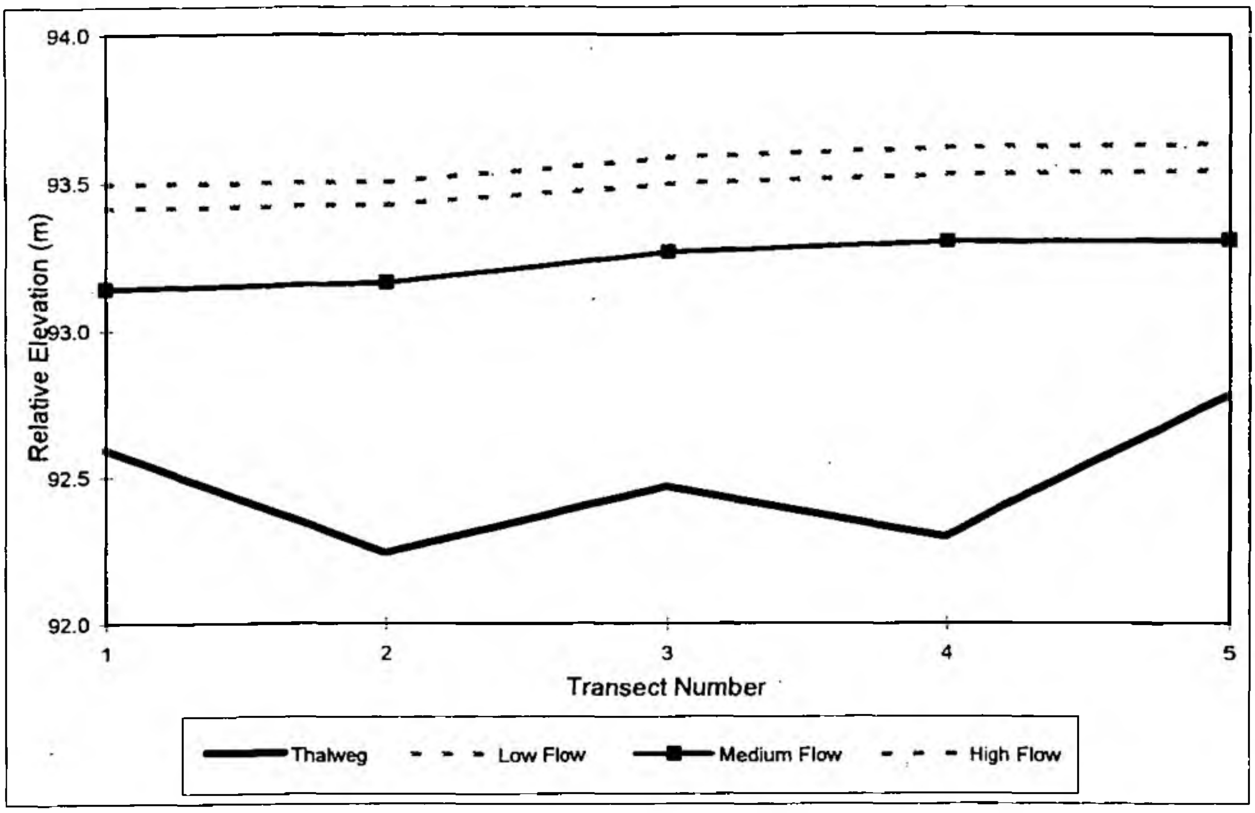
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.00	900.0
2	0.5	0.00	900.0
3	1	0.00	900.0
4	1.5	0.00	900.0
5	2	100.00	900.0
6	2.5	5.00	900.0
7	3	0.00	900.0
8	3.5	0.00	900.0
9	4	0.00	900.0
10	4.5	0.00	900.0
11	5	0.00	900.0
12	5.5	5.00	900.0
13	6	0.00	900.0
14	6.5	0.00	900.0
15	7	0.00	304.8
16	7.5	0.00	304.8
17	8	0.00	304.8
18	8.5	0.00	304.8
19	9	0.00	201.9
20	9.5	0.00	201.9
21	10	0.00	203.7
22	10.5	0.00	203.7
23	11	0.00	900.0
24	11.5	0.00	900.0
25	12	0.00	900.0
26	12.5	0.00	900.0
27	13	0.00	900.0
28	13.5	0.00	900.0
29	14	0.00	900.0

Transect 5E

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.00	900.0
2	0.5	0.00	900.0
3	1	0.00	900.0
4	1.5	0.00	900.0
5	2	0.00	900.0
6	2.5	0.00	900.0
7	3	0.00	900.0
8	3.5	50.00	900.0
9	4	0.00	900.0
10	4.5	0.00	900.0
11	5	20.00	900.0
12	5.5	20.00	305.8
13	6	75.00	306.8
14	6.5	100.00	304.7
15	7	0.00	305.9
16	7.5	0.00	607.9
17	8	0.00	305.8
18	8.5	0.00	305.8
19	9	0.00	900.0
20	9.5	0.00	900.0
21	10	0.00	900.0
22	10.5	0.00	900.0
23	11	0.00	900.0
24	11.5	0.00	900.0
25	12	0.00	900.0
26	12.5	0.00	900.0

Appendix 8.2

River Pant at Stisted Mill: longitudinal water surface level profiles



Appendix 9. *RIVER BLACKWATER AT KELVEDON*

Appendix 9.1. Hydraulic field measurements

River Blackwater at Kelvedon: low flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.5	0.65	0.30	-0.016	-0.003
2	0.50	0.50	-0.006	-0.002
2.5	0.50	0.70	0.003	0.001
3	0.50	0.87	0.025	0.011
3.5	0.50	1.05	0.056	0.029
4	0.50	1.00	0.122	0.061
4.5	0.50	0.92	0.128	0.059
5	0.50	0.79	0.099	0.039
5.5	0.50	0.77	0.115	0.044
6	0.50	0.71	0.086	0.031
6.5	0.50	0.64	0.098	0.031
7	0.50	0.58	0.088	0.026
7.5	0.50	0.55	0.058	0.016
8	0.50	0.51	0.033	0.008
8.5	0.50	0.49	-0.018	-0.004
9	0.50	0.45	-0.015	-0.003
9.5	0.50	0.32	0.008	0.001
10	0.55	0.20	0.006	0.001
			Total flow	**0.346**

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.45	0.32	0.026	0.003
2.5	0.50	0.43	0.038	0.007
3	0.50	0.61	0.027	0.010
3.5	0.50	0.71	0.025	0.013
4	0.50	0.75	0.066	0.037
4.5	0.50	0.72	0.053	0.027
5	0.50	0.73	0.099	0.053
5.5	0.50	0.70	0.101	0.049
6	0.50	0.72	0.061	0.032
6.5	0.50	0.71	0.082	0.041
7	0.50	0.69	0.079	0.038
7.5	0.50	0.67	0.089	0.040
8	0.50	0.66	0.072	0.031
8.5	0.50	0.66	0.094	0.041
9	0.50	0.65	0.075	0.032
9.5	0.50	0.70	0.007	0.003
10	0.50	0.40	0.003	0.000
10.5	0.65	0.15	0.006	0.000
			Total flow	**0.458**

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.75	0.33	0.011	0.003
2.5	0.50	0.58	0.019	0.006
3	0.50	0.87	0.088	0.038
3.5	0.50	1.13	0.065	0.037
4	0.50	1.17	0.064	0.037
4.5	0.50	1.16	0.055	0.032
5	0.50	1.17	0.045	0.026
5.5	0.50	1.16	0.072	0.042
6	0.50	1.07	0.021	0.011
6.5	0.50	0.98	0.029	0.014
7	0.50	0.86	0.055	0.024
7.5	0.50	0.73	0.041	0.015
8	0.50	0.59	0.019	0.006
8.5	0.50	0.50	0.018	0.005
9	0.50	0.24	0.002	0.000
9.5	0.45	0.11	0.008	0.000
			Total flow	**0.295**

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.5	0.70	0.15	0.060	0.006
3	0.50	0.24	0.027	0.003
3.5	0.50	0.26	0.229	0.030
4	0.50	0.27	0.339	0.046
4.5	0.50	0.24	0.239	0.029
5	0.50	0.25	0.359	0.045
5.5	0.50	0.25	0.197	0.025
6	0.50	0.27	0.108	0.015
6.5	0.50	0.28	0.239	0.033
7	0.50	0.29	0.116	0.017
7.5	0.50	0.30	0.077	0.012
8	0.50	0.27	0.144	0.019
8.5	0.50	0.18	0.263	0.024
9	0.50	0.19	0.027	0.003
9.5	0.50	0.15	0.045	0.003
10	0.50	0.13	0.049	0.003
10.5	0.35	0.05	0.027	0.000
			Total flow	**0.312**

River Blackwater at Kelvedon: medium1 flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.60	0.39	0.00	0.001
2.5	0.50	0.54	-0.01	-0.002
3	0.50	0.75	-0.01	-0.002
3.5	0.50	1.00	0.01	0.007
4	0.50	1.10	0.06	0.033
4.5	0.50	1.20	0.13	0.076
5	0.50	1.07	0.15	0.080
5.5	0.50	1.07	0.17	0.088
6	0.50	0.99	0.14	0.070
6.5	0.50	0.89	0.12	0.053
7	0.50	0.82	0.12	0.050
7.5	0.50	0.74	0.11	0.042
8	0.50	0.70	0.09	0.032
8.5	0.50	0.65	0.05	0.016
9	0.50	0.61	0.06	0.019
9.5	0.50	0.60	0.03	0.009
10	0.50	0.51	0.00	0.001
10.5	0.50	0.34	0.01	0.001
11	0.35	0.02	0.01	0.000
			Total flow	**0.574**

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.1	0.65	0.43	0.102	0.029
2.6	0.50	0.59	0.053	0.016
3.1	0.50	0.76	0.028	0.011
3.6	0.50	0.80	0.068	0.027
4.1	0.50	0.86	0.063	0.027
4.6	0.50	0.85	0.077	0.033
5.1	0.50	0.87	0.140	0.061
5.6	0.50	0.83	0.065	0.027
6.1	0.50	0.87	0.108	0.046
6.6	0.50	0.84	0.059	0.025
7.1	0.50	0.83	0.075	0.031
7.6	0.50	0.79	0.157	0.062
8.1	0.50	0.81	0.134	0.054
8.6	0.50	0.79	0.071	0.028
9.1	0.50	0.79	0.063	0.025
9.6	0.50	0.76	0.074	0.028
10.1	0.50	0.51	0.011	0.003
10.6	0.55	0.27	0.038	0.006
			Total flow	**0.537**

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1.8	0.40	0.11	0.066	0.003
2.3	0.50	0.32	0.100	0.016
2.8	0.50	0.38	0.056	0.011
3.3	0.50	0.38	0.269	0.051
3.8	0.50	0.40	0.409	0.082
4.3	0.50	0.41	0.367	0.075
4.8	0.50	0.40	0.321	0.064
5.3	0.50	0.42	0.280	0.059
5.8	0.50	0.41	0.259	0.053
6.3	0.50	0.44	0.066	0.015
6.8	0.50	0.44	0.165	0.036
7.3	0.50	0.45	0.118	0.027
7.8	0.50	0.43	0.033	0.007
8.3	0.50	0.42	0.115	0.024
8.8	0.50	0.37	0.309	0.057
9.3	0.50	0.36	0.270	0.049
9.8	0.50	0.32	0.085	0.014
10.3	0.45	0.24	0.049	0.005
			Total flow	**0.647**

River Blackwater at Kelvedon: medium2 flow

Transect 1A

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.35	0.11	0.000	0.000
2.5	0.50	0.30	0.009	0.001
3	0.50	0.50	-0.007	-0.002
3.5	0.50	0.68	-0.008	-0.004
4	0.50	1.04	0.095	0.049
4.5	0.50	1.06	0.187	0.099
5	0.50	0.99	0.440	0.218
5.5	0.50	0.94	0.440	0.207
6	0.50	0.83	0.382	0.159
6.5	0.50	0.77	0.411	0.158
7	0.50	0.71	0.313	0.111
7.5	0.50	0.61	0.363	0.111
8	0.50	0.55	0.318	0.087
8.5	0.50	0.52	0.267	0.069
9	0.50	0.46	0.170	0.039
9.5	0.50	0.46	0.037	0.009
10	0.50	0.41	-0.008	-0.002
10.5	-10.25	0.10	-0.010	0.010
			Total flow	1.321

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.1	0.35	0.10	0.021	0.001
2.6	0.50	0.28	0.046	0.006
3.1	0.50	0.42	0.075	0.016
3.6	0.50	0.50	0.059	0.015
4.1	0.50	0.55	0.094	0.026
4.6	0.50	0.57	0.097	0.028
5.1	0.50	0.60	0.092	0.028
5.6	0.50	0.57	0.121	0.034
6.1	0.50	0.60	0.115	0.035
6.6	0.50	0.56	0.118	0.033
7.1	0.50	0.58	0.134	0.039
7.6	0.50	0.56	0.125	0.035
8.1	0.50	0.57	0.116	0.033
8.6	0.50	0.56	0.116	0.032
9.1	0.50	0.59	0.121	0.036
9.6	0.50	0.58	0.108	0.031
10.1	-9.85	0.21	0.02	-0.048
			Total flow	0.380

Transect 3C

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2	0.50	0.11	-0.006	0.000
2.5	0.50	0.34	0.029	0.005
3	0.50	0.60	0.038	0.011
3.5	0.50	0.91	0.500	0.228
4	0.50	0.92	0.037	0.017
4.5	0.50	0.94	0.052	0.024
5	0.50	0.93	0.069	0.032
5.5	0.50	0.92	0.051	0.023
6	0.50	0.84	0.013	0.005
6.5	0.50	0.70	0.050	0.018
7	0.50	0.65	0.043	0.014
7.5	0.50	0.49	0.031	0.008
8	0.50	0.38	0.013	0.002
8.5	-8.25	0.16	0.016	-0.021
			Total flow	0.366

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
2.2	LB			
2.3	0.35	0.14	0.193	0.009
2.8	0.50	0.18	0.600	0.054
3.3	0.50	0.18	0.620	0.056
3.8	0.50	0.18	0.620	0.056
4.3	0.50	0.20	0.560	0.056
4.8	0.50	0.19	0.610	0.058
5.3	0.50	0.19	0.630	0.060
5.8	0.50	0.21	0.740	0.078
6.3	0.50	0.23	0.690	0.079
6.8	0.50	0.24	0.580	0.070
7.3	0.50	0.26	0.530	0.069
7.8	0.50	0.22	0.630	0.069
8.3	0.50	0.19	0.540	0.051
8.8	0.50	0.05	0.590	0.015
9.3	0.50	0.09	0.345	0.016
9.8	0.50	0.08	0.113	0.005
10.3	-10.05	0.01	0.000	0.000
			Total flow	0.800

River Blackwater at Kelvedon: high flow

Transect 2B

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s)
1	0.75	0.34	0.042	0.011
1.5	0.50	0.62	0.142	0.044
2	0.50	0.84	0.110	0.046
2.5	0.50	0.84	0.176	0.074
3	0.50	0.84	0.178	0.075
3.5	0.50	0.86	0.243	0.104
4	0.50	0.84	0.236	0.099
4.5	0.50	0.88	0.259	0.114
5	0.50	0.88	0.280	0.123
5.5	0.50	0.91	0.265	0.121
6	0.50	0.88	0.242	0.106
6.5	0.50	0.93	0.234	0.109
7	0.50	0.89	0.229	0.102
7.5	0.50	0.91	0.263	0.120
8	0.50	0.88	0.252	0.111
8.5	0.50	0.78	0.154	0.060
9	0.50	0.66	0.201	0.066
9.5	0.45	0.48	0.111	0.024
			Total flow	1.509

Transect 4D

Dist. Across(m)	Rep. Width(m)	Depth(m)	Velocity(m/s)	Flow(m3/s
2	0.45	0.16	0.045	0.003
2.5	0.50	0.38	0.257	0.049
3	0.50	0.41	0.395	0.081
3.5	0.50	0.41	0.397	0.081
4	0.50	0.41	0.440	0.090
4.5	0.50	0.42	0.420	0.088
5	0.50	0.44	0.550	0.121
5.5	0.50	0.45	0.520	0.117
6	0.50	0.48	0.570	0.137
6.5	0.50	0.47	0.500	0.118
7	0.50	0.47	0.430	0.101
7.5	0.50	0.50	0.450	0.113
8	0.50	0.46	0.430	0.099
8.5	0.50	0.44	0.369	0.081
9	0.50	0.41	0.450	0.092
9.5	0.50	0.34	0.33	0.056
10	0.50	0.34	0.141	0.024
10.5	0.35	0.24	0.075	0.006
			Total flow	1.457

Appendix 9.2. Overhanging vegetation and substrate measurements

River Blackwater at Kelvedon

Transect 1A

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	60.0	900.0
2	0.5	70.0	900.0
3	1	80.0	900.0
4	1.5	80.0	900.0
5	2	70.0	200.0
6	2.5	60.0	200.0
7	3	60.0	300.0
8	3.5	60.0	300.0
9	4	50.0	307.7
10	4.5	60.0	206.9
11	5	60.0	206.8
12	5.5	60.0	506.6
13	6	60.0	506.6
14	6.5	60.0	506.7
15	7	50.0	506.7
16	7.5	40.0	504.7
17	8	40.0	504.6
18	8.5	40.0	405.6
19	9	40.0	405.6
20	9.5	50.0	403.8
21	10	50.0	300.0
22	10.5	50.0	300.0
23	11	50.0	300.0
24	11.5	60.0	302.6
25	12	70.0	900.0
26	12.5	80.0	900.0
27	13	80.0	900.0
28	13.5	80.0	900.0
29	14	70.0	900.0

Transect 2B

No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.0	900.0
2	0.5	0.0	900.0
3	1	0.0	900.0
4	1.5	10.0	200.0
5	2	10.0	300.0
6	2.5	10.0	305.8
7	3	20.0	305.8
8	3.5	20.0	305.8
9	4	30.0	605.7
10	4.5	40.0	405.6
11	5	40.0	504.6
12	5.5	40.0	504.6
13	6	40.0	504.6
14	6.5	50.0	405.6
15	7	50.0	504.6
16	7.5	50.0	504.6
17	8	50.0	405.7
18	8.5	60.0	305.8
19	9	60.0	304.8
20	9.5	70.0	203.9
21	10	80.0	300.0
22	10.5	80.0	300.0
23	11	90.0	300.0
24	11.5	90.0	900.0
25	12	90.0	900.0
26	12.5	90.0	900.0

Transect 3C

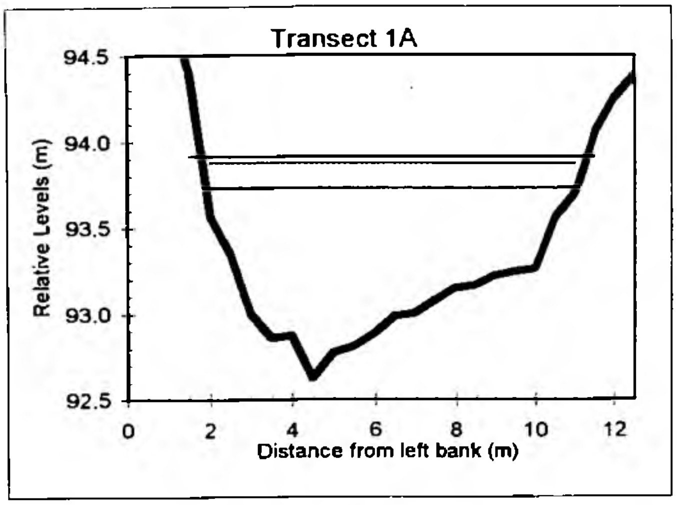
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	50.0	900.0
2	0.5	50.0	900.0
3	1	70.0	900.0
4	1.5	50.0	900.0
5	2	50.0	200.0
6	2.5	50.0	200.0
7	3	50.0	200.0
8	3.5	550.0	207.8
9	4	50.0	207.7
10	4.5	50.0	207.7
11	5	50.0	203.6
12	5.5	60.0	203.6
13	6	60.0	203.6
14	6.5	60.0	203.6
15	7	70.0	203.6
16	7.5	70.0	302.6
17	8	70.0	300.0
18	8.5	70.0	300.0
19	9	70.0	300.0
20	9.5	70.0	30.0
21	10	70.0	302.6
22	10.5	90.0	900.0
23	11	100.0	900.0
24	11.5	100.0	900.0
25	12	100.0	900.0

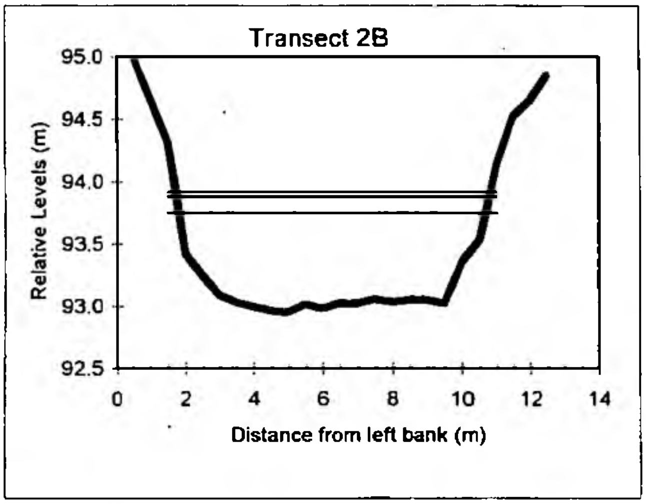
Transect 4D

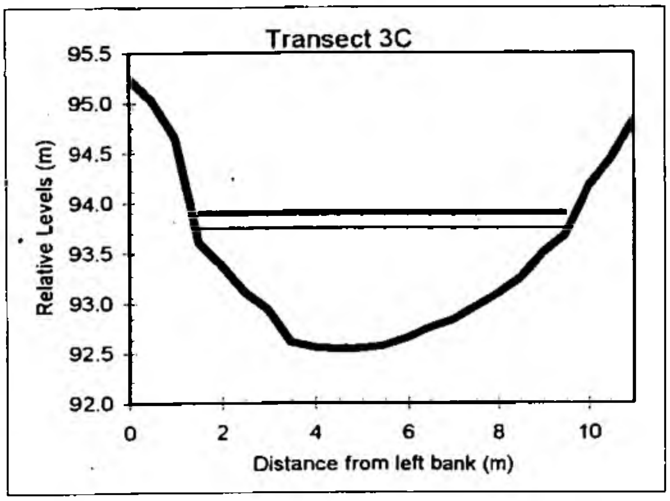
No.	Dist. Across(m)	O.H. Veg (%)	Subs. Index
1	0	0.0	900.0
2	0.5	0.0	900.0
3	1	0.0	900.0
4	1.5	0.0	300.0
5	2	0.0	300.0
6	2.5	0.0	306.8
7	3	0.0	604.6
8	3.5	0.0	604.6
9	4	0.0	504.6
10	4.5	0.0	504.7
11	5	0.0	504.6
12	5.5	0.0	504.6
13	6	0.0	504.7
14	6.5	0.0	504.7
15	7	0.0	603.6
16	7.5	0.0	603.6
17	8	0.0	305.7
18	8.5	0.0	506.6
19	9	0.0	506.6
20	9.5	0.0	506.6
21	10	0.0	506.6
22	10.5	0.0	506.7
23	11	0.0	900.0
24	11.4	0.0	900.0

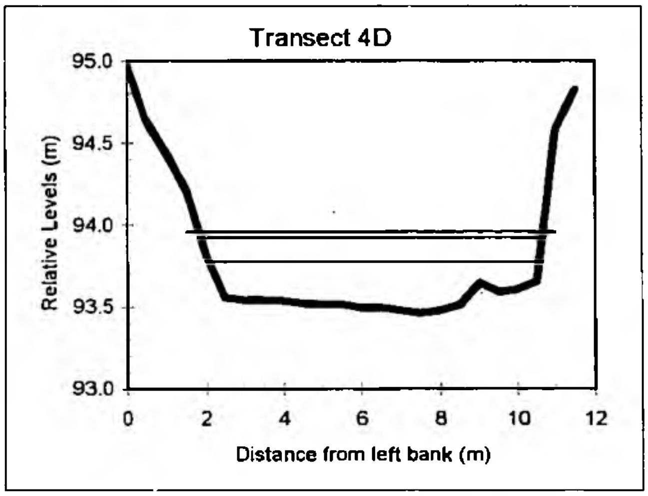
Appendix 9.3

Pant at Kelvedon: bed elevation and water surface levels









Appendix 9.4

River Blackwater at Kelvedon: longitudinal water surface level profiles

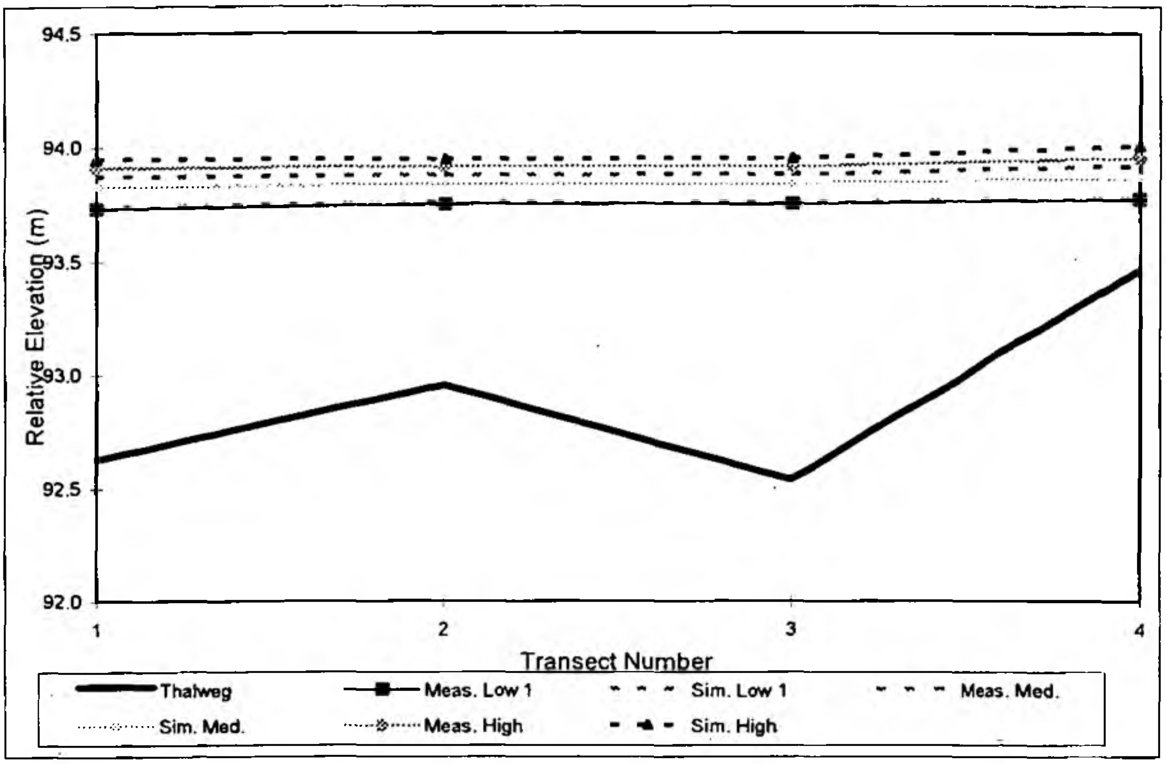


Figure 9.4a: Longitudinal water surface elevation for measured and observed discharges

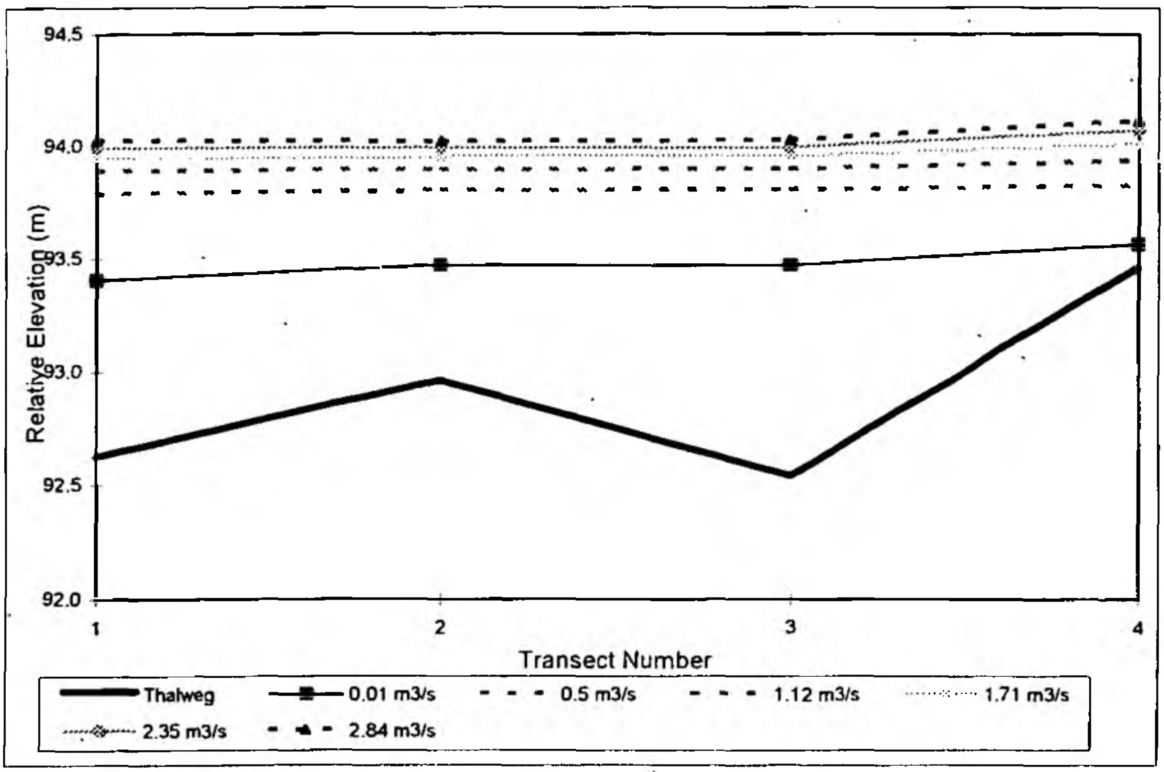
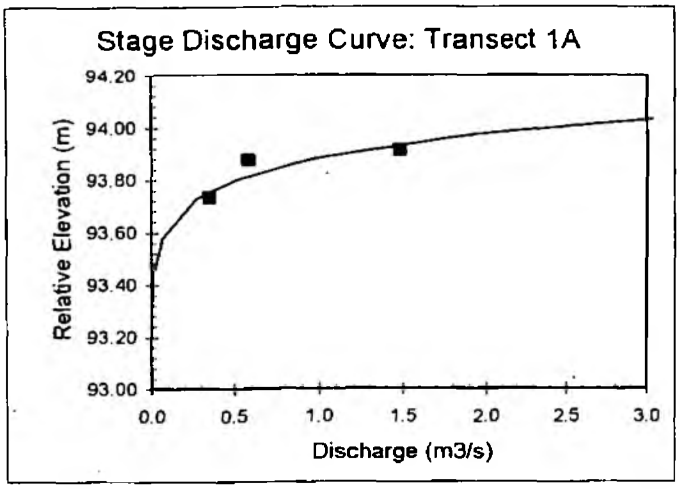
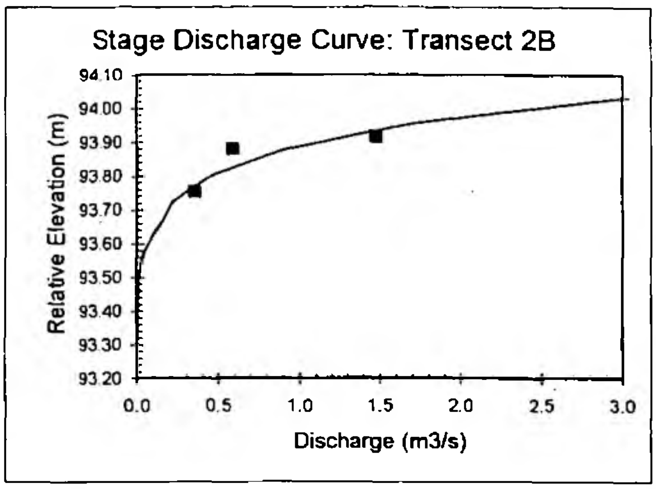


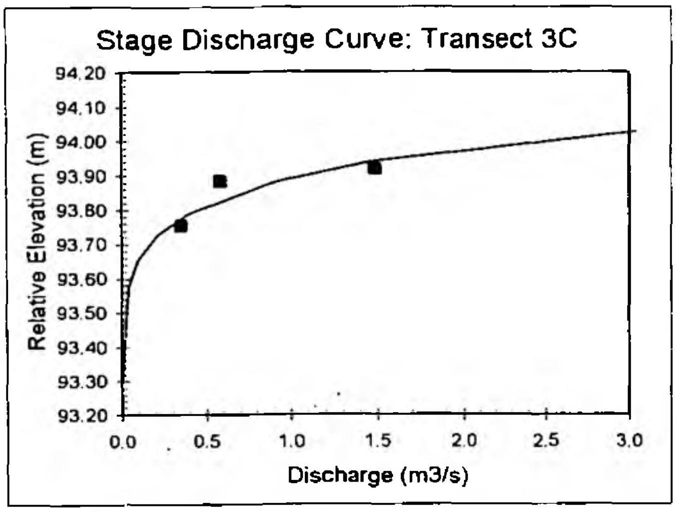
Figure 9.4b: Longitudinal water surface elevation for simulated flows.

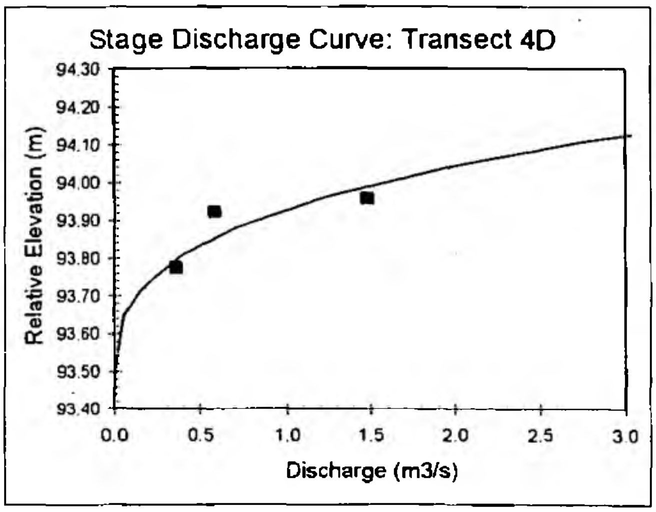
Appendix 9.5

River Pant at Kelvedon: stage-discharge relationships



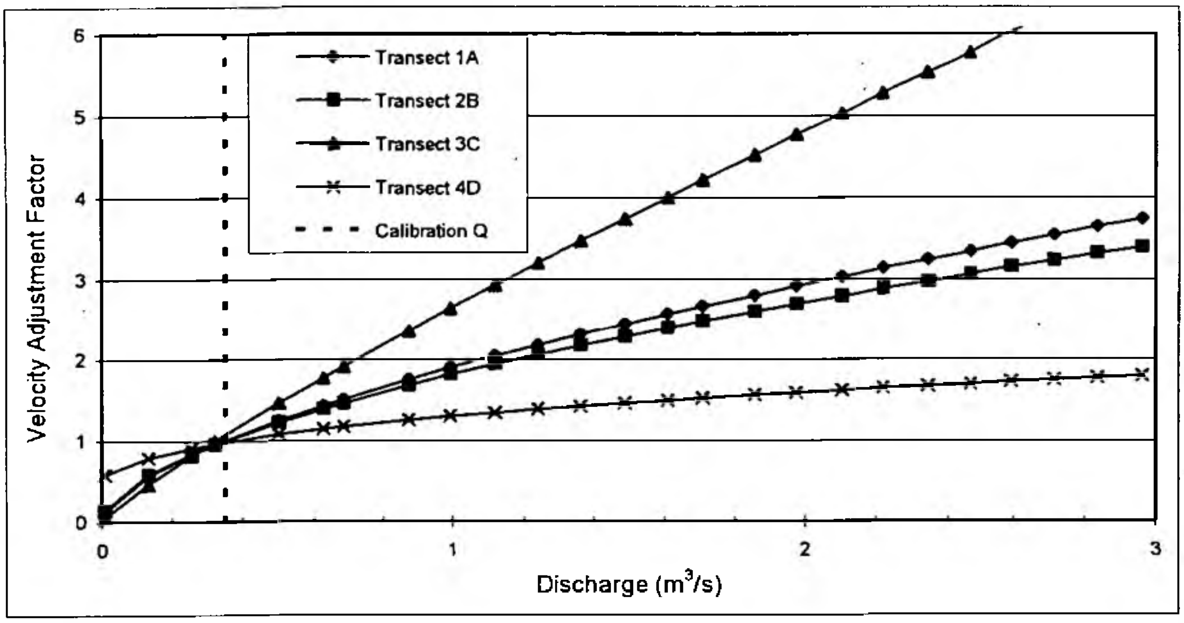






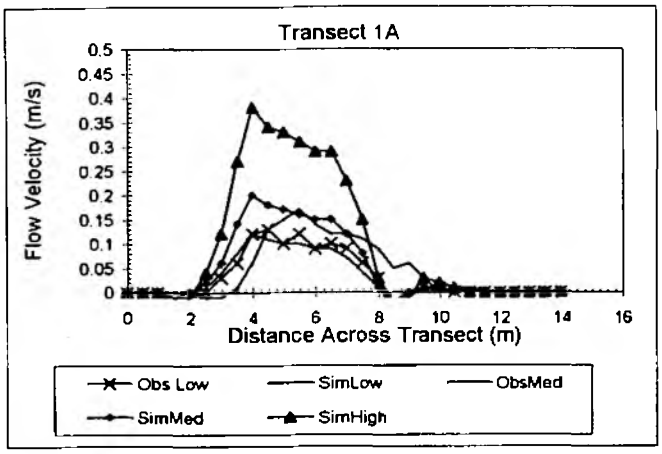
Appendix 9.6

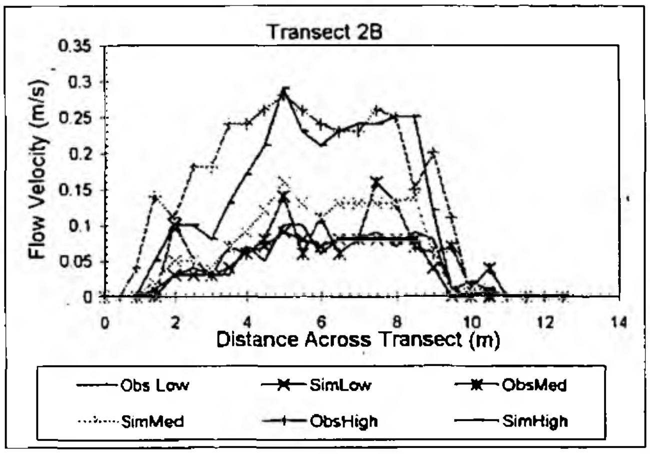
Velocity Adjustment Factors for the River Blackwater at Kelvedon

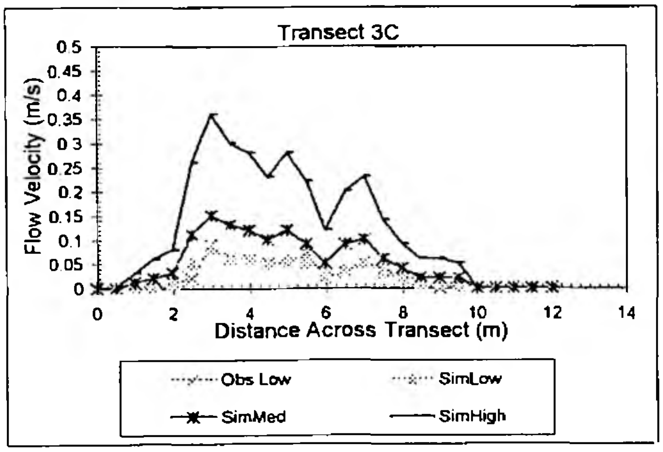


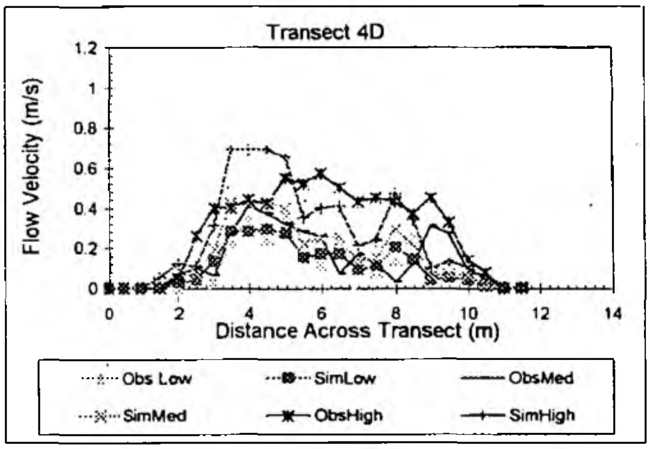
Appendix 9.7

Calibration flow velocities: observed and simulated for Blackwater at Kelvedon

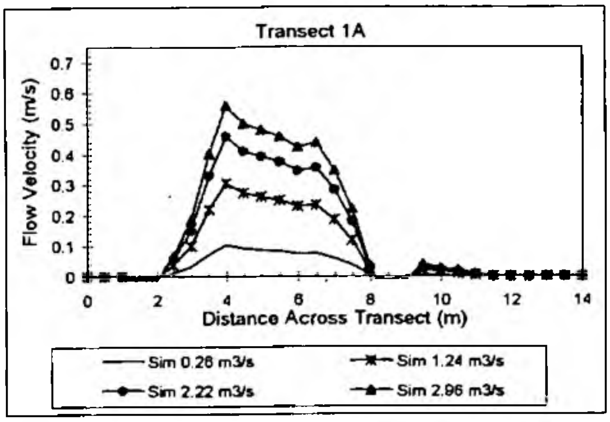


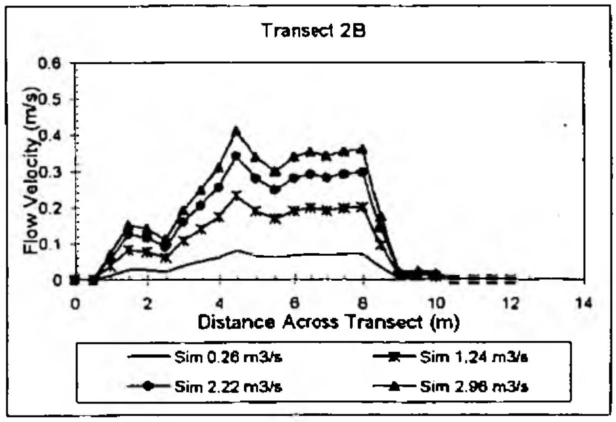


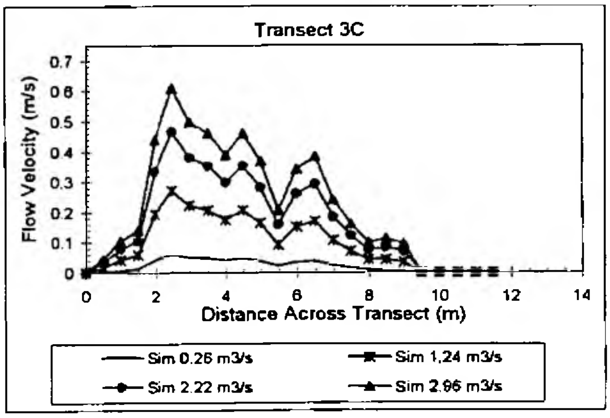


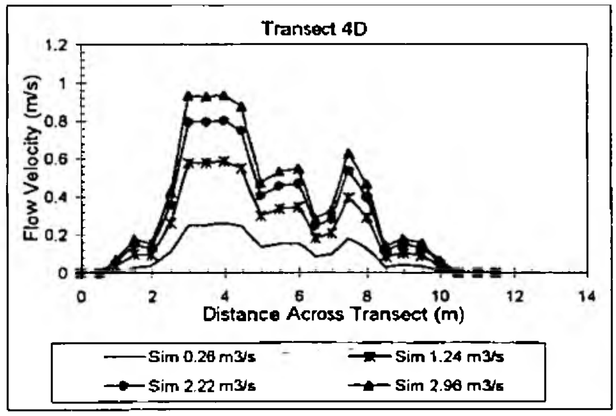


Simulated flow velocities for Blackwater at Kelvedon









Appendix 9.8

Input/output codes for the River Blackwater at Kelvedon

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zhabin	IOC	0110001020000020000000000000000000000000