River Wissey Investigations: Linking Hydrology and Ecology

Executive Summary

University of Birmingham

Project Report OI\526\1\A

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This report is intended for use by water resources and conservation staff in determining the relationships between flows and ecology of rivers. It should be read in conjunction with the other Operational Investigations reports from this project (ie. Summary of Recommended Approach to Setting Flows for Ecological Objectives; Manual for Using Macroinvertebrates to Assess In-River Needs; and Main Report Part 2).

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CONTENTS.

1. INTRODUCTION.

This project provides a detailed examination of the ecology of the River Wissey, a renowned trout stream in north Norfolk. Specific attention is given to the relationships between flows and the flora and fauna of the river. The study was commissioned by the National Rivers Authority in 1991, following concerns about the ecological impacts of falling flows. The project had three aims:

i) to assess the current ecological status of the Wissey and to place the current situation in an historical context;

ii) to evaluate flow-macroinvertebrate relationships for (i) environmental assessments of flow-related impacts and (ii) setting flows to meet in-river needs; and

iii) to define a Ecologically Acceptable Flow Regime for the River Wissey on the basis of all available information and approaches.

1.1 Research structure.

The research followed a four-stage process:

Part 1 (Reported as Main Report 1994)

i. The *preliminary description* of the river based on both the collation of existing information and field surveys, and *classification* of the river system into sectors and reaches using a range of statistical techniques.

ii. The *comprehensive description* of the physical habitat and biota within the main sectors giving special attention to *seasonal variations*.

iiia. The *experimental assessment* of the relationships between biota and flows, using *representative* sites based upon data obtained during two low-flow years (1991-2)

Part 2. (Reported as Main Report 1997)

iiib The *experimental assessment* of the relationships between biota and flows, using *representative* sites,.developing iiia by incorporating a 'normal flow' year (1994)

iv. The *critical testing* of the relationships between biota and flow established for the Wissey to nine other Chalk streams in the Anglian Region, using data collected by the NRA.

1.2 Outputs.

This report summarizes the findings relevant to i) above that are fully elaborated in a two-volume Main Report. The use of macroinvertebrates to assess in-river needs (objective ii) is discussed in a Manual and a separate Report summarizes the investigations on methods for linking hydrology and ecology (objective iii). A full list of outputs from this project is given in Table 1.

Table 1. Outputs from the River Wissey investigations.

Main Report: Part I 1994: a descriptive assessment and evaluation of ecological impacts during the 1991-92 low-flow years.

Annex A:	River corridor and wetlands; the diatom community and NRA fish survey data; water chemistry; and channel-bed sediments and surface water-groundwater interactions.
Annex B:	Aquatic macrophytes and their influence on hydraulics and sedimentation.
Annex C:	PHABSIM analyses.
Annex D:	Macroinvertebrates: distribution and use in habitat assessment, based on survey data from 1991-1992 and NRA data, 1964-1991.

Main Report: Part II 1997: recommendations on physical habitat and flow management for the River Wissey and other Chalk streams in Norfolk.

Manual for using Macroinvertebrates to Assess In-river Needs 1997: the use of macroinvertebrates to assess in-river flow needs.

Summary of a Recommended Approach to Setting Flows for Ecological Objectives 1997.

Executive Summary of the River Wissey Invesigations 1997 (this report).

2. DESCRIPTION AND CLASSIFICATION.

The comprehensive review of secondary data sources included information held by the EA on flows, groundwater levels, water quality, macroinvertebrates, river plants and fish. This was supplemented by data from other secondary sources and from a preliminary field survey.

In general, the river was found to have considerable conservation value but different parts of the drainage network were adversely affected by (i) dredging and channel works (Upper Wissey), (ii) pollution (Wissey from Swaffam through South Pickenham, and Watton Brook), and (iii) low flows (most sites; parts of the Gadder and Stringside Brook dried up during 1991-92).

The features of the fauna, flora and physical habitat (Tables 2 and 3) and hydrology (Table 4) of the River Wissey suggest that:-

- there are some important sites for conservation of biodiversity;
- the aquatic and riparian ecosystems are adapted to the naturally regulated (i.e. groundwater-dominated) flow regime;
- the flow regime is dependent upon winter rainfalls (to recharge the aquifer between November and May).
- the river can be divided into five sectors (Figure 1 and Table 3).

Table 2. Ecological Characteristics of the River Wissey

The river corridor has exceptional conservation value at both regional and national levels, with wet meadow and wet alluvial carr. No invasive riparian weeds were found.

The two headwater wetland sites surveyed in detail (Mill Covert near Gooderstone and Rookery Farm on the River Gadder) yielded three nationally rare and one nationally vulnerable species of diptera, all being specifically dependent on wetland habitats.

Water quality is high throughout most of the river, exceptions being the Watton Brook and on the Wissey below the Swaffham sewage treatment works outfall. During the low-flow period (1991-2) nitrogen levels were high in the upper river (>10 mgl^{-1} TON) and orthophosphate levels exceeded 1 mgl^{-1} below the Swaffham and Watton STWs.

The river channel form changes progressively downstream to a width of about 12m at the Stanford Stream confluence. However, the morphology of the river is strongly influenced by ditching and dredging, ponding behind mill weirs, and riparian management: classic gravel-bed, riffle-pool reaches (eg through Chalk Hall Farm) contrast with ponded sand-bed reaches (eg Langford Hall) and dredged reaches (eg Bodney Bridge); and macrophyte-rich reaches (eg Chalk Hall Farm, to Langford Hall) contrast with heavily shaded, macrophyte-poor reaches (Langford Hall to Ickborough).

In-river flora and fauna are rich and considered to be typical of good-quality fast-flowing Chalk streams. The aquatic flora is dominated by *Ranunculus* and *Rorippa*. The invertebrate fauna included more than 120 taxa but none is nationally rare. One intermittent site (Beachamwell) supported a number of locally unusual stoneflies.

Fish biomass in the main river is about 14 gm^{-2} in a 'normal' year.

'Good quality' spawning gravels for trout have a limited distribution, being restricted by (i) high proportions of sand or (ii) the shallow (<15cm) depth of clean gravel.

Figure 1. THE RIVER WISSEY.
Sectors (S) and reaches (R) are numbered, eg. S2R3 = reach 3 of sector 2.

○ EA biological monitoring sites.

● Field survey sites. Primary sites are named in boxes.

Inset map shows location of the Rivers Wissey and Babingley in East Anglia.

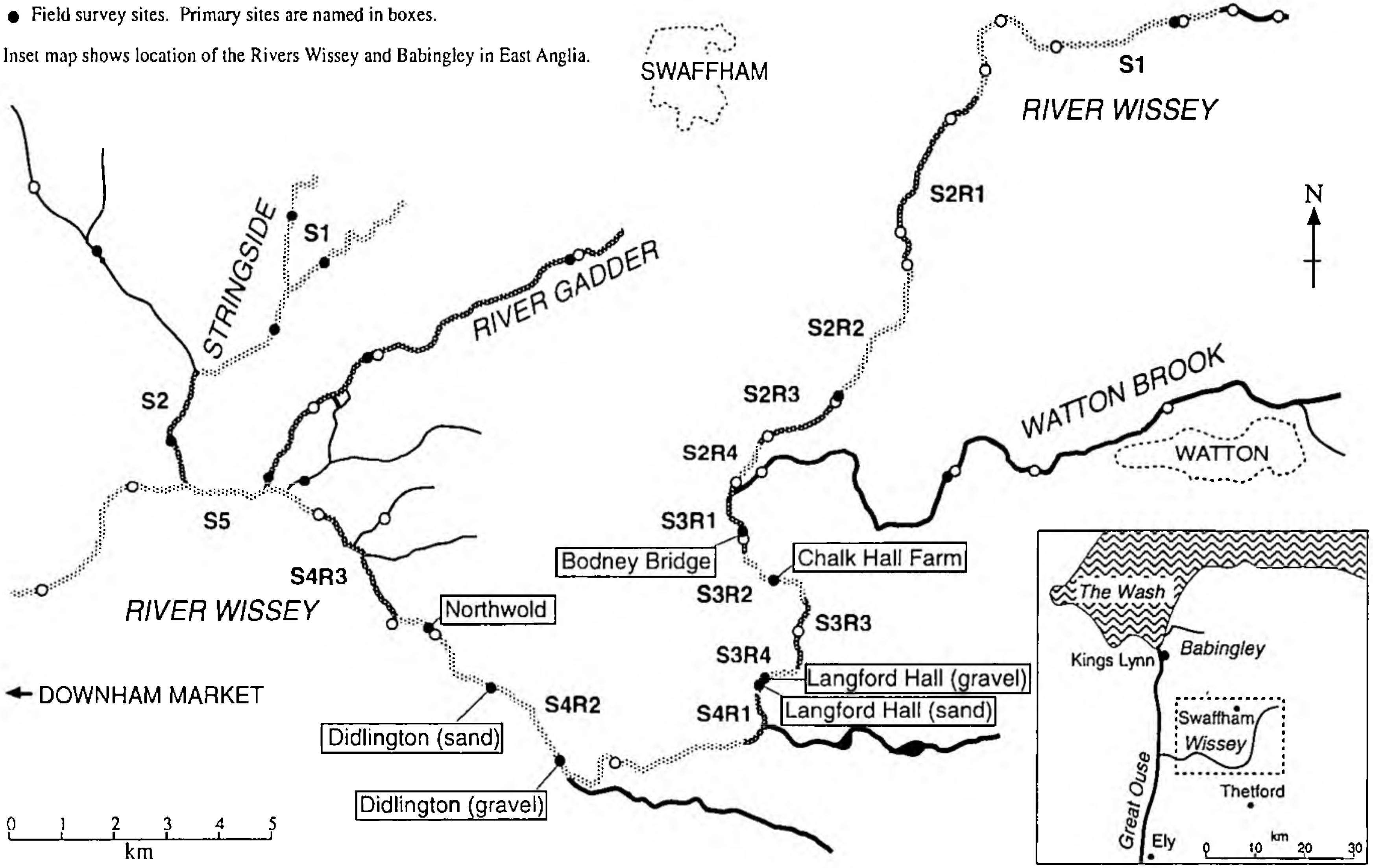

Table 3. River Wissey Sectors (see also Figure 1). Five sectors were defined on the basis of (i) hydrology, (ii) water quality, (iii) geomorphology, (iv) in-river biota and (v) riparian habitats.

Sector 1: **Upper Wissey to North Pickenham**. Ditched, moderately eutrophic, spring-fed stream, characterised by disturbance tolerant riverine flora and an impoverished invertebrate fauna.

Sector 2: **North Pickenham to the Watton Brook confluence**. This sector is degraded both physically (channel and bank management) and chemically (Swaffham STW discharge) and this is reflected by the instream flora and fauna, and riparian habitats.

Sector 3: **Between the Watton Brook and Stanford Stream confluences**. The quality of flows from Watton Brook is poor but there is a wide range of in-river and riparian habitats below Bodney Bridge. The rich flora and diverse invertebrate community are typical of fast-flowing, calcareous streams with a diversity of physical habitats. Dominant fish species: eel with brown trout (stocked) and dace (coarse fish are selectively removed).

Sector 4: **Stanford Stream confluence to Oxborough**. An important sector with similar characteristics to sector 3, but dominated by deeper in-river habitats with sandy runs and shallow, fine gravel riffles. Dominant fish species: eel with brown trout (stocked) and dace (coarse fish are selectively removed).

Sector 5: **Oxborough and downstream**. A canalized, fenland river, with typical diverse fauna and flora. Dominant fish species: eel with dace, pike and chub.

2.1 Flows.

The hydrological characteristics of the River Wissey are summarized in Table 4. The flows recorded at Northwold gauging station, illustrated in Figure 2, clearly show the droughts of 1975-76 and 1988-92 , but there is no obvious long-term pattern of decline. For example, considering the two 15 year periods winter 1961-2 to 1975-6 and 1976-7 to 1991-2, the first period included 6 years during which mean monthly flows failed to reach 3 cumecs and the latter included 7 years during which this flow was not exceeded. The 1988-92 drought appears to be unusual because seven low winter flow years, ending in with the winter of 1991-2, occurred in a sequence broken only by the wet winter of 1987-88. These flows had a major impact on the summary flow statistics, including the long-term mean daily flow and the 95th percentile flow (cf 1956-88 and 1956-94 in Table 4).

Table 4. Hydrological characteristics of the River Wissey. All figures are based on gauged data.

Water Balance 1956-88:	Rainfall (653mm)=Runoff (218mm)+ Losses (435mm) (Losses are mainly by evapotranspiration, but include abstraction).

Rainfalls during years of survey:
1991: 507mm 1992: 689mm (1993: 807mm) 1994: 681mm

Streamflows as gauged at Northwold (Drainage area 275 km^2), 1956-1988:

Monthly average flows:	High -	February (2.8 cumecs)
	Low -	September (0.8 cumecs)
Highest recorded daily mean flow:	12.86 cumecs.	
Mean daily flow	1.9 cumecs (1956-94=1.81 cumecs)	
95%'ile flow:	0.58 cumecs (1956-94=0.47 cumecs)	

Mean flows during years of survey 1991 - 1992: 0.479 cumecs 1994: 2.15 cumecs
Minimum flow at Northwold during 1988-1992: 0.149 cumecs in September (lowest flow on record).

Groundwater levels:
Watershed borehole levels strongly related to winter rainfall
Valley bottom borehole levels related to river levels
River shows major gains from groundwater between North Pickenham and Hilborough
Stanford tributary shows strong positive hydrological gradient from groundwater to stream between Sturston Carr and Buckenham Tofts.

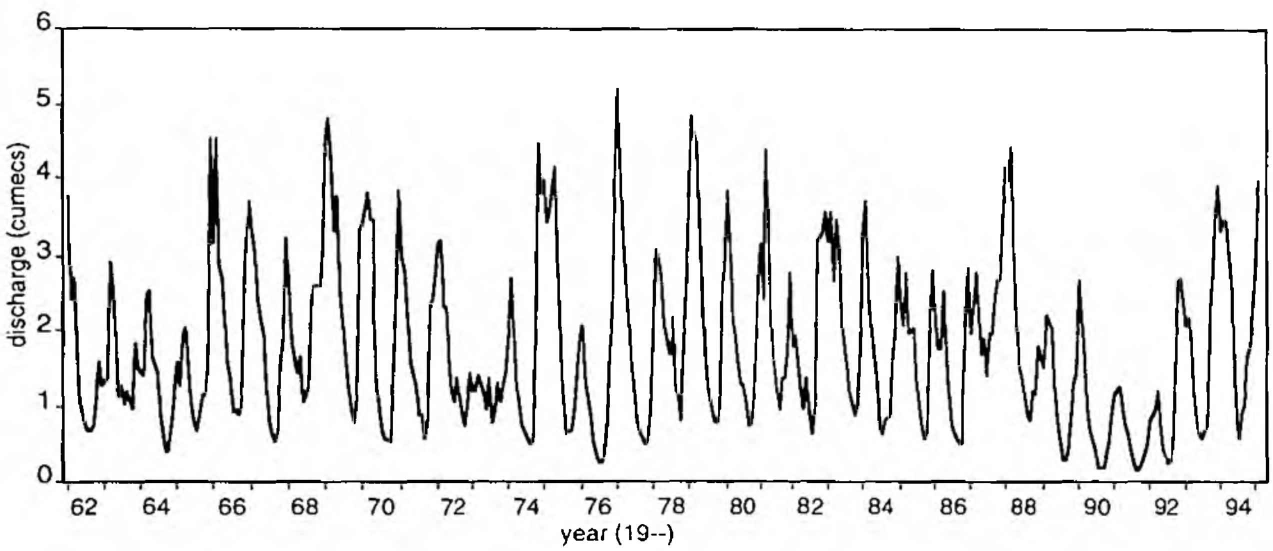

Figure 2. Mean monthly flows recorded at Northwold gauging station, 1962-1994.

2.2 Aquatic invertebrates.

Aquatic invertebrates are sensitive indicators of the quality of the river environment being influenced by both water quality and physical habitats. The surveys demonstrated that the aquatic invertebrate communities in the Wissey were severely impacted by the drought but recovered rapidly once flows returned to 'normal'. Several taxa were found to be highly sensitive to flow levels. Comparing October 1994 (mean flow of 0.91 cumecs - slightly above the long-term average) and October 1991 (mean flow of 0.20 cumecs), the total abundance of macroinvertebrates was 36% lower, and the number of species and families was reduced by 30% and 26% respectively. In sector 3, the number of taxa increased from 61 in 1991 to 87 in 1994 and abundances (per m^2) increased from 15,200 to 23,700 over the same period.

The effects of low flows on the macroinvertebrate community were both direct (changes of hydraulic habitat) and indirect (influenced by siltation and macrophytes). Macrophyte cover was reduced by 36% in 1991 compared with 1994, and *Ranunculus* cover was 88% lower in the drought year.

3. ASSESSMENT OF FLOW-BIOTA RELATIONSHIPS.

The project developed a novel approach to assessing in-river flow needs and this is summarized in Figure 3. The study focussed on two sectors (3 and 4: Table 3) which were shown to have special conservation interest. Summary of the results are given in Table 5. Four approaches were used for the ecological analyses (Figure 3A).

3.1 Hydrological indices.

Hydrological indices were obtained from the literature, mainly from work in USA. These included flow-duration indices (eg the 95th percentile flow) and proportions of the mean daily flow (eg 20% of the mean daily flow).

3.2 Historical analyses.

Macroinvertebrate and flow records provided by the EA were analysed for the period 1962-1994. The results demonstrated highest diversity in the mid-1980s and reduced faunas in the 1970s and in 1989-92. This pattern was shown to integrate (a) long-term improvements in water-quality, (b) responses to variations in flow and (c) physical habitat degradation. Statistical analyses were used to isolate the effect of flow and to establish a highly significant relationship between the number of taxa and flows, specifically the deviation of the 7-day low flow for the month of survey from the long-term average.

3.3 Field survey.

Analyses used field data from seven representative sites (primary sites) in sectors 3 and 4, supplemented by 14 secondary or tertiary sites on smaller streams. A 'site' was defined as a reach of 10 times channel width in length. Differences between sites reflected channel form, substrate and macrophyte cover. Surveys were undertaken in May and October 1991 and February, May and October 1992, with additional surveys at three primary sites in February, May and October 1994. Each survey of a primary site involved a minimum of 140 hydraulic measurements, vegetation mapping and 12 macroinvertebrate surveys. Fewer data were obtained from the other sites.

Relationships were established between the abundance of the more frequent invertebrate taxa (occuring in >20% of the 501 samples from the primary sites) and environmental variables. The analyses revealed that:

• the primary variables explaining the distribution of invertebrate taxa, both seasonally and between years, were flow and macrophyte growth (these two variables determine the spatial pattern of velocities, depths and silt accumulation);
• the invertebrate communities showed season-specific relationships ;
• data from a single spatial survey of a range of hydraulic habitats for the end-of-summer, low flow period can be used to estimate changes with flow between years;
• family-level data can be used;
• 6 taxa are particularly sensitive to flow on the Wissey -

Baetidae Ephemeridae Elmidae Hydropsychidae *Athripsodes cinereus* Simuliidae

Methods for developing habitat preference curves (eg Figure 4A) have also been evaluated and, for the Wissey, multiple regression on three variables (velocity, depth and macrophyte cover) was demonstrated to be most appropriate. Suitability surfaces (eg Figure 4B) have been developed to provide a look-up guide for assessing flow-related habitat quality.

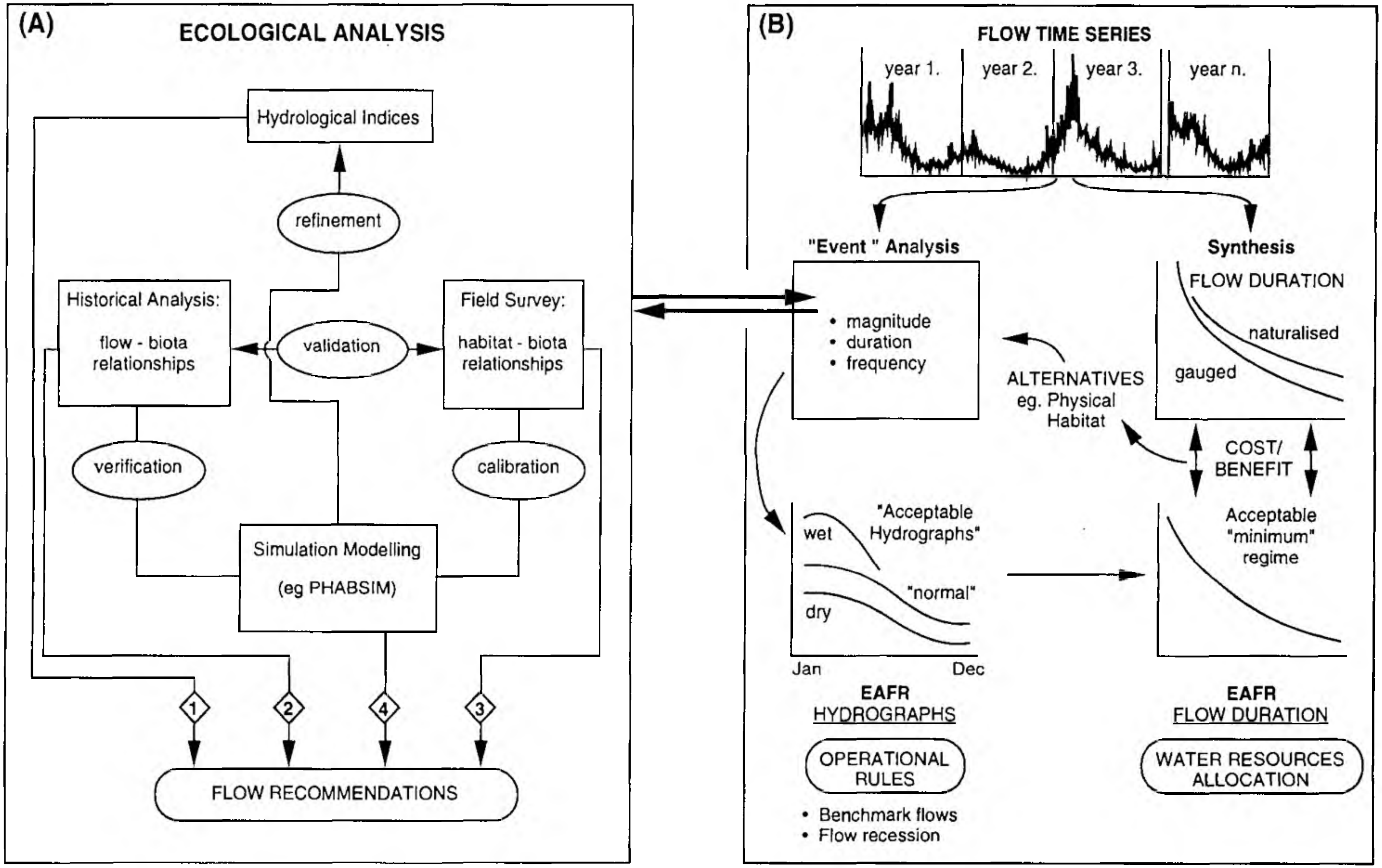

Figure 3. Methodology for the determination of Ecologically Acceptable Flow Regimes (EAFRs), based on integrated investigation of hydrology and ecology. A) The Wissey study and B) the input of the Wissey study to determining the Ecologically Acceptable Flow Regime (EAFR) following the Babingley recommendations (Petts, 1995).

3.4 Simulation modelling.

Modelling used the PHysical HABitat SIMulation (PHABSIM) set of computer models, developed in the United States, to relate changes in discharge to habitat availability for target species or life stages. Habitat suitability curves for two target species, trout and dace, for UK conditions, but not specifically Chalk streams, were taken from published sources. Data from field surveys of the primary sites in February and May 1991 and May 1992 were used to calibrate the model. The results demonstrated that:

- suitable habitat for adult trout was virtually eliminated during the late summers of 1989-1992;
- spawning habitat for trout was severely reduced in 1990 and 1991;
- habitat for juvenile trout and dace was available throughout the drought.

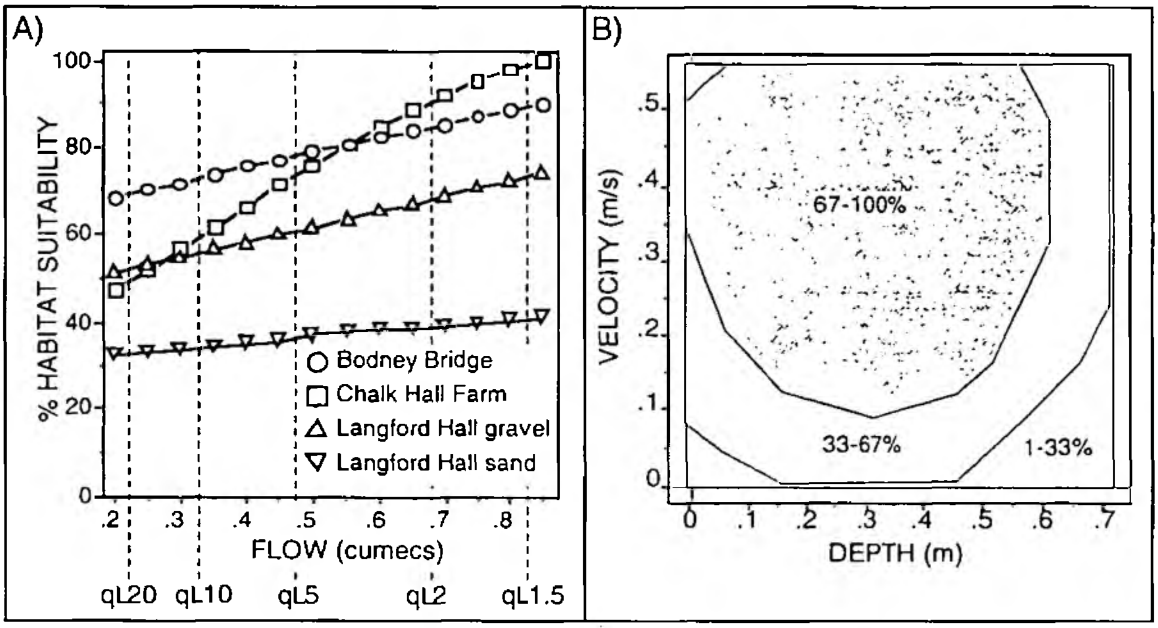

Figure 4. Habitat preference curves and suitability surfaces for one indicator taxon (Baetidae) in the River Wissey, Sector 3. A) Habitat preference curves, showing habitat suitability with discharge relationships for 5 sites in Sector 3. B) Suitability surface, showing habitat suitability under different depth/velocity combinations.

4. THE RIVER WISSEY: IN-RIVER FLOW NEEDS.

Results of the detailed analyses of data for the River Wissey focused on two sectors (Sectors 2 and 3, Table 3) which are of particular importance as trout fisheries, and more generally because of their high conservation value. The ecological significance of a range of flows was established using the methods summarized in section 4 and an innovative procedure was developed to define Ecologically Acceptable Flow Regimes - EAFRs - (Figure 3B). The underlying principles are:-

a) the aquatic and riparian ecosystems are determined by the prevailing flow regime;
b) high-flow years are important for sustaining the ecological integrity of a river;
c) natural ecosystems are resilient to rare droughts but may be severely degraded by sustained low flows;
d) any persistent change in the frequency and duration of flows (high, medium or low) will change the aquatic and riparian ecosystems;

4.1 Determining the Ecologically Acceptable Flow Regime.

The procedure involved four steps (Figure 3B): (i) define ecological targets and the "benchmark" flow to meet each target ('event analysis'); (ii) define annual hydrographs, with acceptable frequencies (chosen subjectively, but guided by the historical series of flows), for a range of hydrological conditions: eg wet year, normal year, dry year and drought year; (iii) combine the hydrographs to derive a flow duration curve; (iv) compare the Ecologically Acceptable Flow Regime with the gauged and naturalised flow duration curves, integrate the needs of other users, and consider alternatives (eg improved habitat management). These stage may require a revision of the desired targets if a balanced allocation of water is to be achieved.

The approach focuses on four benchmark flows for each target:
Optimum Ecological Flow (OEF) - the flow that optimises the environmental conditions for the target, eg maximises usable habitat for the target species or achieves the maximum species diversity. This condition is rare in nature but is important for sustaining the integrity of the ecosystem.
Desirable Ecological Flow (DEF) - the flow that provides 'normal' environmental conditions for the target and maintains connectivity throughout the river system by sustaining usable habitat in all reaches.
Adequate Ecological Flow (AEF) - the flow below which the target shows major changes, eg the flow that sustains low-flow habitat for target species or a specified number of species. The AEF must be maintained in most years but may be inceeded during rare droughts.
Threshold Ecological Flow (TEF) - the flow that must be sustained at all times, even during the rarest drought, to prevent catastrophic change; the flow that sustains habitat refuges for a target species or a minimum acceptable number of species.

In addition, these flows must be defined giving regard to the **Channel Maintenance Flow (CMF)**, usually taken as the bankfull flow, to maintain the overall structure of the channel and **Habitat Maintenance Flows (HMF)**, usually defined as a proportion of the CMF (often 40%), which flush the channel of accumulated fine sediments and organic detritus. **Spate flows (SF)** should also be considered on those rivers having important migratory fish populations. These high flows are largely unaffected by groundwater abstraction but can be markedly affected by surface water abstractions and reservoir storage.

Once established, the EAFR can be used to define:

(i) the abstractable volume,

(ii) prescribed flows (hands-off flows) that may be attached to abstraction licences, and

(iii) maintained flows requiring river support.

4.2 The River Wissey.

4.2.1 Components of the EAFR.

In the Wissey study, the chosen targets were:

trout -	over-wintering habitat for adult trout
	end-of-summer habitat for juveniles
	spawning habitat (autumn)
dace -	adult habitat
	spawning habitat (spring)
invertebrates -	changes in abundance of flow sensitive taxa (end-of summer minimum flow)
	changes in number of taxa from long-term records (end-of summer minimum flow).

The flows determined for the River Wissey are summarized in Table 5 and the resulting hydrographs are shown in Figure 5. The 'acceptable' flows were determined for a range of annual flow frequencies, defined for the purposes of constructing a range of annual hydrographs as: wet year - flows exceeded 1:3 years, normal year - flows exceeded 1:2 years, dry year - flows inceeded 1:5 years, and drought year -flows inceeded 1:20 years. Two EAFRs were determined (Figure 6): i) for invertebrates, dace and adult trout, and ii) for invertebrates and dace. An EAFR for macroinvertebrates alone was not produced because of the similarity with the dace and macroinvertebrate benchmark flows (which also sustain habitat for juvenile trout).

Table 5. Benchmark flows determined for the River Wissey (sectors 3 and 4, having 4 and 3 reach types, respectively).

season	benchmark	macroinvertebrates and dace	macroinvertebrates, dace and juvenile salmonids	macroinvertebrates, dace and adult salmonids
end of summer	OEF	0.85		0.90
	DEF	0.55		0.60
	AEF	0.35	0.30	0.40
	TEF	0.20	0.20	0.30
autumn				
November	OEF	1.40		1.40
"	DEF	0.55[1]		0.90
December	AEF	0.40		0.40
"	TEF	0.35		0.30
winter				
February	OEF	3.50[2]		3.50
"	DEF	2.50		3.50
March	AEF	1.40		2.00
"	TEF	1.00		0.90
April[3]	OEF	2.35		2.50
"	DEF	2.00		2.00
"	AEF	1.30		1.35
"	TEF	1.10		1.20
May	OEF	1.40		
"	DEF	1.00		
"	AEF	0.90		
"	TEF	0.70		

[1] Flow greater than 0.5 cumecs, and must equal or exceed end-of-summer DEF.
[2] With flow exceeding 8.5 cumecs for part of the time.
[3] Flows needed to achieve end-of-summer targets under dry-year flow recession.

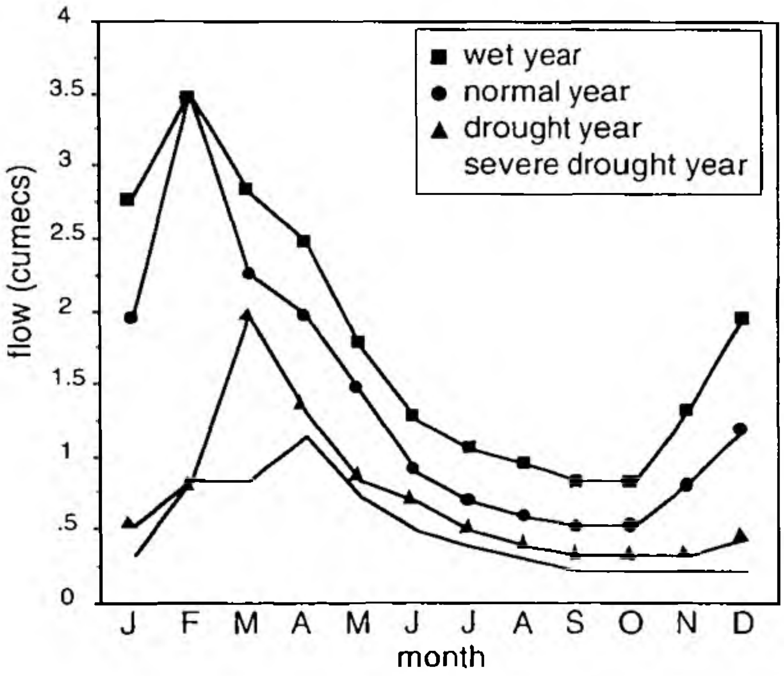

Figure 5. Monthly flows to meet the ecological needs of invertebrates, dace and trout on the River Wissey, in wet, normal, drought and severe drought years.

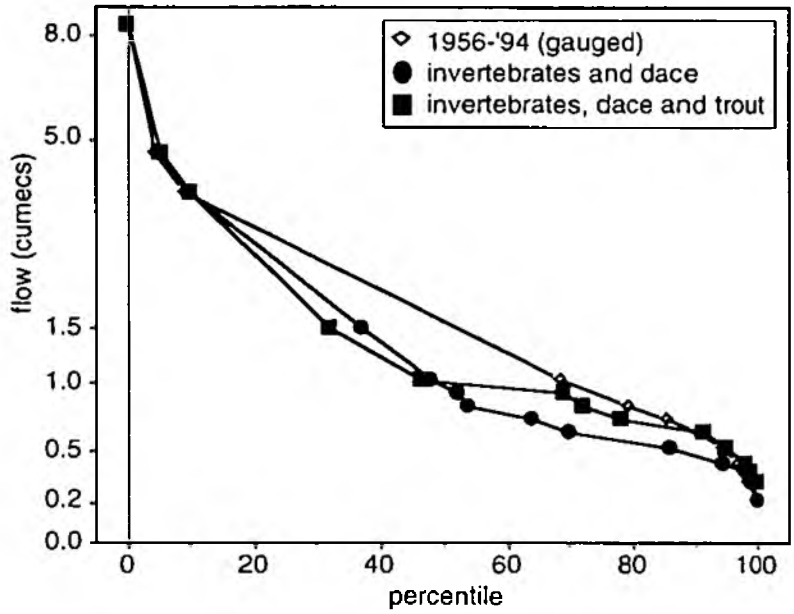

Figure 6. EAFRs (flow duration percentiles) to meet the ecological needs of i) invertebrates and dace and ii) invertebrates, dace and trout on the River Wissey, in comparison with the long-term (1956-'94) gauged flow.

4.2.2 Abstractable Volumes.

The results allow specification of the acceptable maximum volume of abstractions:

Runoff - Environmental needs = Abstractable volume

Thus, for the Wissey (based on the EAFR for trout, dace and invertebrates in Table 6), having an average in-river flow requirement of 1.42 cumecs, equivalent to 163 mm of runoff, the **acceptable maximum abstraction (from both groundwater and surface water) is 0.4 cumecs (which equates to 45 mm of runoff or 34.5 Mld) plus average actual abstraction net of actual effluent returns.**

4.2.3 Control Rules.

The information gained from in-river flow analyses (see Table 6) may be used to recommend flow control rules including 'hands-off' flows (HOF) for surface-water abstraction licenses and maintained flows (MF) to protect in-river needs. The following are examples. Whether or not they are practicable must be evaluated locally. If they are not, a precautionary approach should be adopted.

To sustain the Wissey as a trout stream:

1. Winter HOF (November to June inclusive) = 1.4 cumecs *but a 30-day flow of more than 3.5 cumecs must be spared* *each* *year if such flow occurs naturally and a 15 day flow of more than 8 cumecs should be spared at least once every 5 years.* The time-period (November-June), has been chosen to protect the river during the key months (November, May, and June).

2. Summer HOF (July to October inclusive) = 0.90 cumecs (cf the gauged 95th percentile flow for the period 1956-94 of 0.47 cumecs)

In a drought year (with an acceptable frequency of no shorter than 1:5 years) the controls on abstractions may be relaxed:

3. If flow on 1st February has not reached 1.4 cumecs, the HOF for February through June may be reduced to 1.0 cumec and the summer HOF may be lowered to 0.6 cumecs.

End-of-summer maintained flows may also be specified:

4. End-of-the summer flows should normally be maintained, by groundwater support if necessary, at a minimum of 0.4 cumecs (about 20% of the mean daily flow).

5. Exceptionally, under 1:20 year drought conditions, the minimum maintained flow may be reduced to 0.30 cumecs (about half the 1956-94 gauged 95th percentile flow 0.58 cumecs).

4.3 Use of Q95.

The tradition of using the 95th percentile flow (Q95), based on historical data, is open to question because the statistic is highly variable (see Table 3). The full-record (1956-94) statistic for the Wissey (0.47 cumecs[1]) approximates the EAFR Q95 and may be useful for describing the ecologically acceptable flow duration curve. However, the flow under-estimates the volume required to protect the river ecosystem in 'normal' (DEF = 0.60 cumecs) and, especially, wet years (OEF = 0.9 cumecs), but over-estimates the in-river needs during dry years (AEF = 0.4 cumecs) and severe droughts (TEF = 0.3 cumecs).

The research has shown that for both the protection of river ecosystems and the optimization of water resources for abstractions requires more complex rules than a single end-of-summer minimum flow, such as Q95. It is recommended that ecological flows should be defined for all periods of importance for the ecological target(s). For example, for the Wissey the range of targets included trout spawning (November), channel maintenance (February), dace spawning (May) and number of invertebrate taxa (September).

[1] This value is calculated from the historical gauged flows. In practise the naturalised Q95 has been used where possible to determine flows to protect the environment (or the groundwater resource allocation to support this flow); this often provides a higher Q95 than the value based on gauged flows.

5. OTHER RECOMMENDATIONS.

In addition to the flow recommendations detailed above, the study has provided a catchment perspective on the Wissey. The conservation value, potential for enhancement and recommendations for management of the Wissey and its tributaries are summarised in Table 6. Specific attention should be given to:

- creating buffer zones along most of the headwater streams to reduce nutrient and fine sediment inputs from agricultural land; control instream macrophyte growth by shading, thus reducing maintenance costs and ecologically damaging dredging activities; and improving the conservation value of the river corridor.

- from Hilborough to Buckenham Tofts weir ensure that no works are undertaken to degrade the channel form and riparian areas.

- from Buckenham Tofts weir downstream, habitat diversity should be improved along the channel margins by creating eddies, backwaters and marginal cover; the careful location of dead trees would be advantageous, and gravel accumulation and limited bank erosion should not be revented.

- during dry summers, management of macrophytes should be limited to the maintenance of a few, fast-flowing runs.

- monitoring of water quality and flows should be undertaken at Hilborough, below the Watton Brook confluence (an important control point in the stream network) in order to monitor long-term trends and short-term incidences.

- monitoring of groundwater levels surveyed into river levels is recommended between North Pickenham and Hilborough, an important reach for groundwater discharge maintaining flows during dry periods.

Table 6. Conservation value, potential for enhancement and recommended management for the River Wissey and tributaries.

Sector/reach	Character	Present conservation value	Potential for enhancement	Recommendations
Wissey, Sector 1. Bradenham to Ernford House.	Heavily managed, ditched section through arable surroundings. Good gravel substrate and moderate flow velocities. Upper reach is intermittent.	Low. Some organic pollution and high-nutrient arable runoff problems.	Good. A relatively natural, attractive stream could be achieved with moderate investment in management.	Introduce buffer zones / reduce frequency of dredging to allow emergents / riparian flora to develop. Any additional measures to increase channel diversity.
Wissey, Sector 2. Ernford House to Watton Brook confl.	Moderate to low intensity of management, mainly pasture / wet meadow. Silty runs with few gravel riffles.	Mixed. Some excellent wet meadows of very high value. Instream habitat moderate / poor. Organic pollution problems.	Good. Riparian habitat already quite good, instream habitat could be improved.	Preserve and extend wet meadow areas. Reduce access for stock to riparian margins to limit grazing and poaching. Control organic pollution problem - at source or through root exclusion zones / ponds.
Wissey, Sector 3. Watton Brook confl. to Buckenham Tofts.	Semi-natural, typical Chalk stream. Good pool-riffle structure but some ponding from sluices.	Excellent. Instream habitat good, especially around Chalk Hall Fm., with diverse substrate, flora and invertebrate and fish fauna. Riparian woodland of moderate value.	Moderate. Instream habitat requires preservation rather than enhancement. Riparian alluvial woodland could be significantly improved.	Preserve instream habitat. Replace riparian plantation trees with native species and let understory develop naturally.
Wissey, Sector 4. Buckenham Tofts to College Farm.	Semi-natural , with deep run habitat predominating in-stream. Mainly plantation surrounding.	Moderate. Instream habitat of only moderate quality for invertebrates and flora due to predominance of deep runs. Good adult trout habitat.	Good. Instream habitat fulfils function as adult trout habitat; fry habitat and riparian flora could be greatly improved.	Improve marginal habitat for fry / invertebrates by increasing diversity. Develop backwater areas. Replace riparian plantation trees with native species.
Wissey, Sector 5. College Farm to Whittington.	Heavily managed, fenland section.	Moderate. Habitat typical for this type of section, with good coarse fishery. Riparian zone is poor.	Moderate. Natural character and drainage function will limit potential for instream improvements.	Introduce buffer zones. Create adjacent fish fry habitats - backwater areas. Any measures to increase habitat diversity.
River Gadder. Cockley Cley to Gooderstone.	Intermittent in upper section with artificial lakes; perennial in lower section with wet woodland / meadow.	Good. Natural, if recently more frequent, drying out severely limits instream habitat above spring-head, but seasonally wet meadows at Mill Covert are extremely valuable habitat for rare invertebrates.	Moderate. Intermittency of upper reach limits instream improvements. However, wet meadow areas could be extended.	Preserve and extend wet meadow areas around the springs. Wildfowl lakes are being created above Gooderstone Water Gardens - selective removal of willows and extension of wetlands around these lakes would be an improvement.

Table 6 (continued). Conservation value, potential for enhancement and recommended management for the River Wissey and tributaries.

Sector/reach	Character	Present conservation value	Potential for enhancement	Recommendations
River Gadder. Gooderstone to Wissey confl.	Run-type instream habitat through pasture and arable land in the lower part. Dense emergent vegetation in places controlled by cutting.	Moderate / low. Grazing and arable cultivation limit riparian vegetation in most parts. A brown trout population existed prior to 1990.	Moderate. Riparian flora could be improved.	Limit stock access to banks in pasture areas to allow regeneration of riparian zone. Develop buffer zones in lower reach and improve channel management for fish fry habitat.
Stringside Stream. Upstream of Barton Bendish and Beachamwell tributaries	Intermittent headwaters through arable land.	Low. Heavily dredged.	Good. These tributaries are more frequently dry than the upper main river, limiting potential for instream improvements. However; in these intensive arable areas small streams / ditches provide valuable damp refugia for a variety of invertebrates and even birds and small mammals, and provide landscape interest.	Anything to improve riparian zone - both in extent and diversity. Develop buffer zones and aim to reduce dredging / cutting in the medium-term.
Stringside Stream. Beachamwell to confl. with Barton Bendish stream (Lode Dyke).	Intermittent, wooded stream u/s Oxborough Wood; perennial, spring-fed stream through woodland / arable land d/s Eastmoor.	Mixed. In the Beachamwell section there is an interesting aquatic invertebrate fauna associated with the intermittent flows. Lower section of lesser interest.	Moderate. The perennial section could be improved by measures to increase extent and diversity of riparian and instream flora.	Oxborough Woods are already under management to improve the conservation value of the woodland. Instream flora through the Woods may be improved by selective woodland thinning.
Stringside Stream. Confl. with Barton Bendish stream to confl. with Wissey.	Ponded by G.S. in upper section and from main river in lower. Heavily dredged except immediately d/s G.S.	Poor, except for a small section d/s G.S. where the flow is faster and riparian trees prevent access for dredging machinery. Coarse fish proliferate in the lower section, which provides a valuable refuge from the main river during high flows.	Poor. Ponding and necessary drainage work will limit possibilities for enhancement.	Extensions of buffer zone above and below G.S. - increase shading to reduce necessity for frequent dredging.
Watton Brook. Downstream of Watton.	Gravel bed, naturally riffle-pool stream but dredged and cultivated up to banks. Organic pollution problems.	Poor. Very little interest.	Good. Instream habitat could drastically improve if water quality was raised. Potential also for improving riparian habitat.	Buffer zones. Improve / reduce effluent entering stream. Reduce cutting and manage channel to increase instream and riparian macrophytes which will may improve water quality.