River Wissey Investigations: Linking Hydrology and Ecology

The Basis for In-river Flow Management

FINAL DRAFT

1. INTRODUCTION

Concern for protecting flows to meet in-river needs has been highlighted by the NRA Report on Determination of Minimum Flows (Project **XXXX**, 1995). The Report recommends the setting of River Flow Objectives (RFO), defined as *flow regimes* , and the promotion of an Ecological Objective (EO) for each sector of river, upon which the RFO should be based. However, there is little information in the scientific literature to guide the decision-making process in defining ecological targets or in the determination of flows to sustain/restore these targets.

Currently, PHysical HABitat SIMulation (PHABSIM) is in use in several countries, but only in the USA has it gained widespread acceptance in practice. Hydrological indices remain popular, especially when they are supported by 'local' ecological information. This study was initiated in 1990 - during a prolonged drought - to develop an approach to setting flows to meet ecological targets, focussing on the River Wissey, Norfolk but also considering the transferability of the information gained to other 'chalk' streams in Anglian Region. A primary aim of the study has been to evaluate information on macroinvertebrate populations for setting flow targets.

2. THE BASIS FOR SETTING ECOLOGICALLY-ACCEPTABLE FLOWS

The Ecological Objective for each sector of river is the fundamental building block for establishing RFOs. The EO may comprise several season- or month-specific targets which may be particular life-stages of rare, 'indicator', or 'desirable' species. Ideally, a flow to meet a desired target should be defined using not only the magnitude of the flow but also information on the timing, duration and frequency of this flow. The approach for defining the Ecologically Acceptable Flow Regime (EAFR) (Figure 1B), developed for the River Babingley (Petts, 1995), a base-flow dominated river, has been applied to the River Wissey. The approach integrates:

- seasonally variable flows to meet specified ecological targets,
- a minimum threshold flow to sustain biota during drought conditions, and
- high flows to maintain physical habitat diversity.

Different types of river will require different approaches to a assess in-river flow needs. A major difference exists between 'lowland' and 'upland' settings: in the former, the ecological health of a river depends mainly on water retention times and may be related to flow using water-quality models, whilst in the latter, the suitability of habitat for aquatic fauna relates to hydraulic conditions - velocity, depth, shear stress etc.- and related variables, especially channel-bed sediments. This study focussed on the latter type of streams.

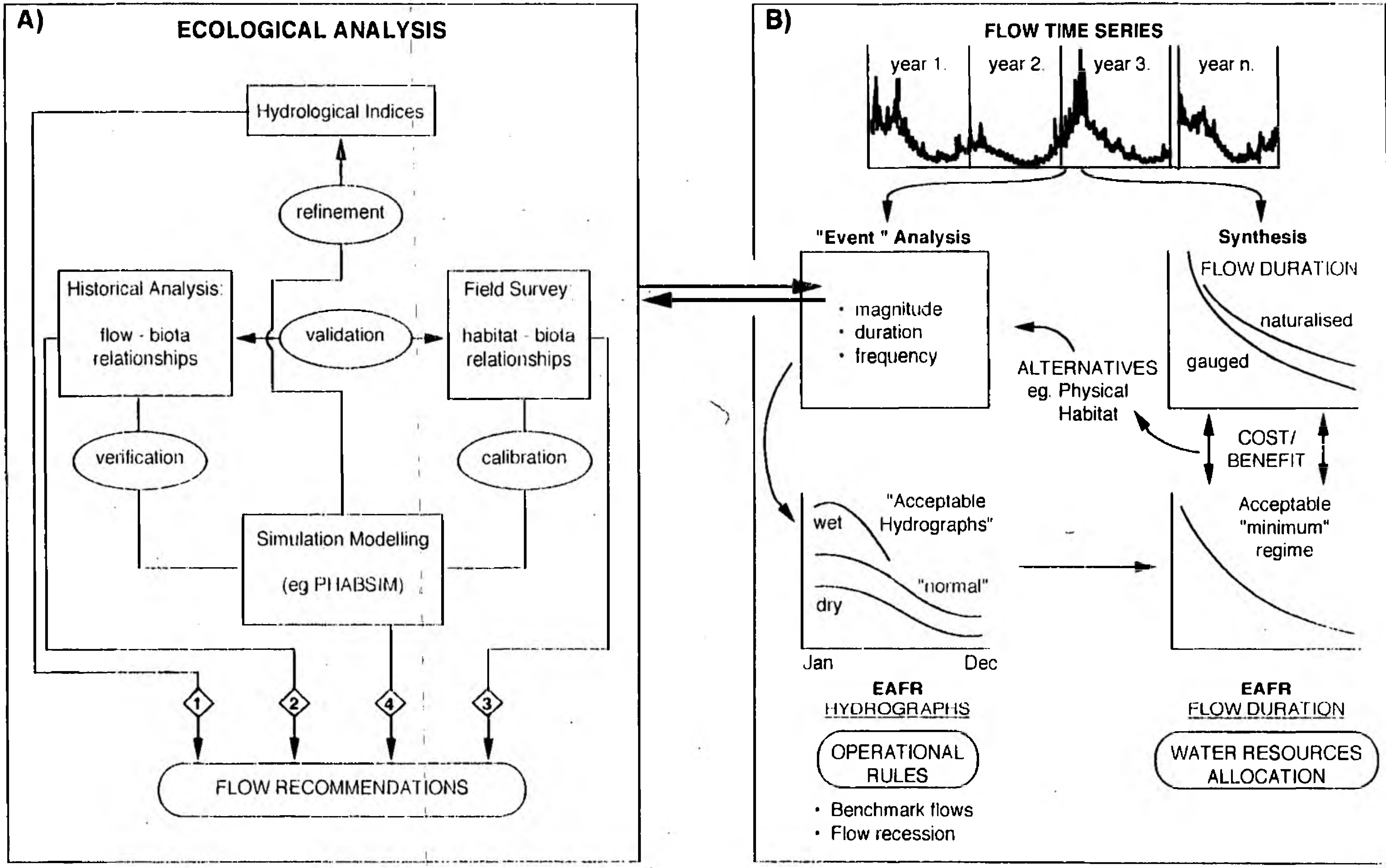

Figure 1 Methodology for the determination of Ecologically Acceptable Flow Regimes (EAFRs), based on integrated investigation of hydrology and ecology. A) The Wissey study and B) the input of the Wissey study to determining the Ecologically Acceptable Flow Regime (EAFR) following the Babingley recommendations (Petts, 1995).

Four groups of methods may be advanced to assess flow needs in these hydraulic-dependent streams (Figure 1A): (i) simple hydrological indices, (ii) analyses of relationships between long-term flow and biological data series, (iii) space-time substitution based on detailed field survey, and (iv) PHABSIM. Most established approaches are based on fish - usually a salmonid as the target species. However, an approach based upon macroinverterate data may have some advantages (Table 1).

Table 1 Reasons for advancing a macroinverterate-based, in-river, flow assessment methodology.

Macroinvertebrate communities play a vital role in the functioning of aquatic ecosystems, particularly in the processing of organic matter, and have a key role in food webs.
Macroinverterate communities are highly sensitive to the hydraulic conditions that are determined by flow and channel form.
Macroinvertebrates are present in most aquatic habitats; they are relatively abundant and easy and inexpensive to survey, and their taxonomy is well established.
Macroinvertebrate distributions reflect both regional and local environmental controls but at the meso-scale (within a reach) are representative of local conditions and often occupy narrow ranges of preferred habitat.
Most macroinvertebrates have a one- two-year life cycle but at the meso-scale are able to track suitable hydraulic conditions during flow recession under drought conditions.
In the UK, data on macroinvertebrates is collected routinely during biological water-quality assessment and there are records of invertebrate community composition over a period of 20-30 years on many rivers.

3. THE WAY FORWARD

This study advanced a two-stage process for determining in-river flow needs, following the recommendations of the Babingley Report:

i. The *description* of the river based on both the collation of existing information and field surveys; *classification* of the river system into sectors (Table 2) and reaches; and assessment of *ecological targets* (Table 3).

ii. The *experimental assessment* of relationships between biota and flows, using *representative* sites within each sector of interest. Given the lack of experience in using instream flow methods on UK rivers, an integrated and iterative approach was used (Figure 1A), involving a tool-box of methods.

Table 2 Sectors along the River Wissey

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 inverterate fauna. Channel is cut into non-alluvial clay.

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. Despite the poor quality of flows from the Watton Brook, this sector is particularly important (especially below Bodney Bridge) comprising a wide range of in-river and riparian habitats. 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. Another 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.

Table 3 Indicator Species and Ecological Targets for the River Wissey: Sectors 3 and 4.

Fish

Adult brown trout (*Salmo trutta*)
Juvenile brown trout
Adult dace (*Leuciscus leuciscus*)
Juvenile dace

Targets

To sustain suitable habitat within all reaches of both sectors (Desirable Ecological Flow)
To sustain suitable habitat within one reach type in each sector (Acceptable Ecological Flow).
To sustain suitable habitat within one reach type in one sector (Threshold Ecological Flow).

Flow-sensitive macroinvertebrate taxa

Baetidae
Ephemeridae
Elmidae
Simuliidae

Targets

To sustain suitable habitat for all four indicator taxa
To sustain suitable habitat for one indicator taxa

'Suitable habitat' has been defined as two-thirds of the habitat available under a 'standard' low flow - where the 'standard' low flow is defined as the historical gauged 7-day low-flow for the month concerned that is equaled or inceeded twice every three years.

3.1 Standard Methods

Hydrological indices can be obtained from the literature, mainly from work in USA (see Petts and Maddock, 1994). As experience increases, the scientific basis for hydrological indices will be strengthened. During the Wissey investigations, a range of indices was considered.

PHABSIM is a set of computer models, developed in the United States, that are used to relate changes in discharge to habitat availability for target species or life stages (see Petts and Maddock, 1994; Stalnaker, 1994). In the Wissey study, seven representative sites in sectors 3 and 4, and habitat suitability curves for brown trout, as published for UK conditions, but not specifically Chalk streams, were used.

3.2 An Approach based upon Macroinvertebrate Communities

Macroinvertebrate-flow relationships can be developed for each sector or river of interest. A Manual has been prepared, describing the recommended procedures, as an output from this study.

3.2.1 The River Wissey

Results of the Wissey study, based on data from 7 representative sites in sectors 3 and 4 (Table 2), and analyses of the abundance of the more frequent taxa (occuring in >20% of the samples) and environmental variables, revealed:

- both seasonally and between years, the primary variables explaining the distribution of invertebrate taxa were flow and macrophyte growth, these two variables determining the spatial pattern of velocities, depths and silt accumulation;
- season-specific relationships must be developed;
- data from a single spatial survey of a range of hydraulic habitats may be used to estimate changes with flow between years;
- family-level identification gives almost identical results to species level;
- methods for developing habitat preference curves (eg Figure 2A) have 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 2B) have been developed to provide a look-up guide to assess flow-related habitat quality based on point measurements of velocity and depth within a representative reach.

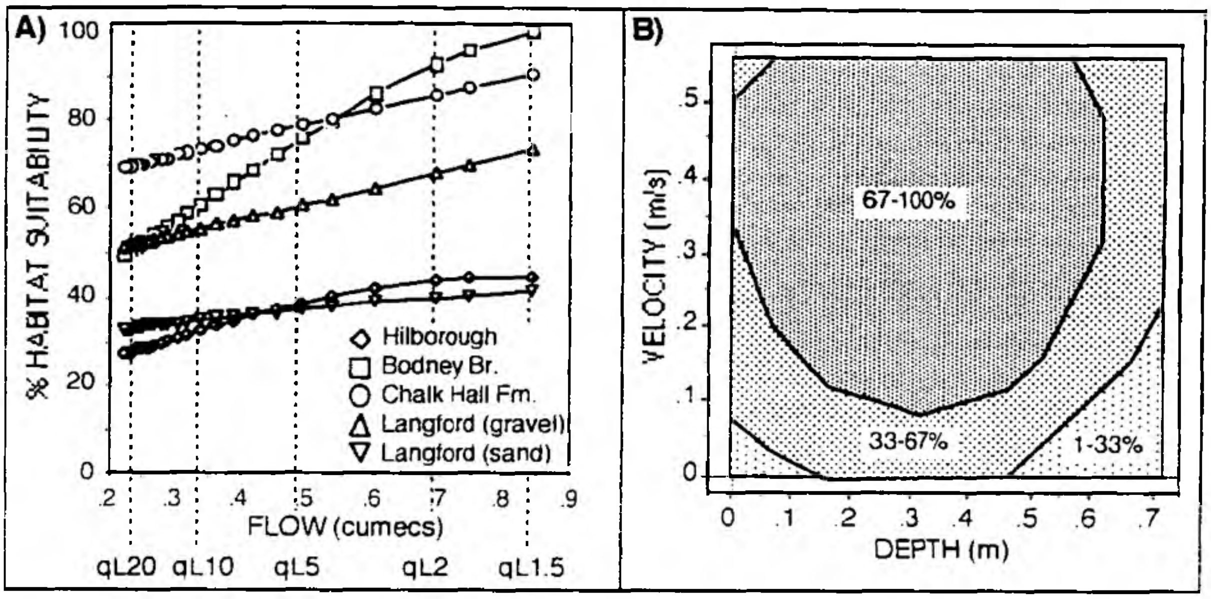

Figure 2 Habitat preference curves and surfaces for one indicator taxon (Baetidae) in the River Wissey, Sector 3. A) Habitat preference curves, showing habitat suitability with discharge relationships for 5 sites in Sector 3. B) Suitability surface, showing habitat suitability under different depth/velocity combinations.

3.2.2 Transferability of the Wissey Results

Flow-biota relationships established for the River Wissey were tested on a dataset comprising 9 other chalk streams: Cam, Gaywood, Heacham, Ingol, Kennett, Lark, Nar, Sapiston and Thet. At several sites, the hydaulic data was outside the range encountered on the Wissey whilst water-quality differences between rivers, especially with regard to trophic status, had a significant influence on the macroinvertebrate communities. Following a detailed analysis, it was concluded that:

- habitat suitability relationships for one river cannot (normally) be transferred to another river;
- habitat suitability relationships developed from a single spatial survey in one sector (based on a minimum of 20 samples) may be used to predict summer flow-related between-year changes of the fauna in that sector; such a spatial survey should include a range of representative mesohabitats covering a wide range of velocity-depth-macrophyte-substrate combinations - i.e. by focussing on representative reaches within each sector;
- difficulties arise in developing relationships for winter and spring because of sampling difficulties under high flows and the apparent weak partitioning of taxa between mesohabitats, resulting in weak or insignificant correlations.

4 APPLICATION OF INFORMATION TO SETTING MINIMUM FLOWS

4.1 Principles

Using the tool-box of methods (Figure 1A) a range of flows may be defined to meet different ecological targets for each sector. or series of sectors. of a river. Application of the results from any method involves subjectivity:

- the choice of target species;
- determination of the amount of habitat loss that is. or is not, acceptable; and
- the choice of acceptable frequencies of environmental stress.

This applies to both simple (hydrological indices) and more complex (PHABSIM) approaches. It must also be remembered that methods focus on suitable habitat and not abundance or biomass of biota. Nevertheless, the results of the approach (eg Table 4) inform the decision-making process and ensure that ecological impacts of hydrological change are fully considered.

The setting of an EAFR requires the determination of the typical dry-year flow recession for the catchment and consideration of four flows:

- winter flow to maintain channel form and habitat diversity;
- end-of-summer flow to protect aquatic biota (flow-sensitive invertebrates or juvenile trout being the recommended targets);
- spring flow to support spawning by cyprinids;
- autumn flow to support spawning by salmonids.

The winter flow must include the 'bankfull' or 'channel-forming' discharge as well as flushing flows to sustain in-channel and riparian habitats. In chalk catchments, the natural flow regime is naturally regulated and high-flows (higher than the 10th percentile flow) are not significantly influenced by groundwater abstractions. It is recommended that the gauged 5th percentile flow can be used as an index of high-flow needs.

The last three of the above seasonal flows may be defined as four benchmarks:

i) A **Threshold Ecological Flow (TEF)** to sustain refuges for biota. Below this value suitable habitat for the target species would be eliminated. This benchmark may be regarded as the exceptional minimum flow during rare droughts.

ii) An **Acceptable Ecological Flow (AEF)** is the normal low flow. The **AEF** will sustain suitable habitat for the ecological target within one reach type in each sector.

iii) A **Desirable Ecological Flow (DEF)** to sustain connectivity between the different reaches throughout the length of river under investigation sustaining suitable habitat within all reaches of the river under investigation.

iv) An **Optimum Ecological Flow (OEF)** to provide the maximum habitat for the target species or to maximize diversity. Under natural conditions this flow typically occurs infrequently but it is important in sustaining the ecological integrity of a river - many faunal populations may be dependent on an occassional strong year class (i.e. highly successful reproduction. recruitment, growth).

These flows define four types of annual flow regime: wet year regime (OEF + DEF): normal low-flow year (DEF + AEF): drought year (AEF): severe drought year (TEF). Acceptable frequencies must be given to each of these regimes which can then be combined to establish the EAFR and set control rules. In practice. the complexity of the procedure should be appropriate to the ecological target: a simple procedure for small streams of no special interest (using only an end-of-summer flow to protect invertebrates and the winter flow) and. at the other extreme. a more complex procedure for high-quality salmonid fisheries.

4.2 Application to the River Wissey

The aim of the Wissey study was to establish the in-river needs to protect the ecosystem which has special conservation value. Given the emphasis on environmental needs the precautionary principle was followed in establishing the benchmark flows (Table 4). Using these benchmark flows. three EAFRs have been defined (Table 5) to illustrate the effect of different Ecological Objectives. Each EAFR includes (a) the historical dry-year flow recession and (b) a wet-year regime. The latter is defined as the 7-day low-flow in October that is equalled or exceeded once in every three years linked to flows in previous months by the flow recession. with maximum flow in February supporting the habitat and channel maintenance flows. The frequencies given to the wet year. normal low-flow year. drought year. and severe drought year regimes are: 3.33 years. 2 years. 5 years and 20 years. The severe drought regime has a TEF of 0.3 cumecs. On the Wissey. severe drought with gauged flows falling to 0.3 cumecs and below has occured in four of the 38 years of record (1976. 1989. 1990. 1991).

4.2.1 The Ecologically Acceptable Flow Regimes

The three EAFRs (Table 5) are described below. They each comprise four annual-flow regimes: wet year with a frequency of 1:3. a normal low-flow year having a frequency of 1:2. a one-in-five year drought regime. and a severe drought regime having a frequency of 1:20 years.

a) To sustain the Sectors 3 and 4 as a self-maintaining system with a diverse invertebrate community. The EAFR combines the wet year. normal low-flow. drought and severe drought regimes defined using the flow recession and the DEF. AEF and TEF for inverterate habitat.

b) To sustain the Sectors 3 and 4 as a self-maintaining system with naturally reproducing dace populations. and a diverse invertebrate community. The EAFR uses the data for a) above plus the DEF. AEF and TEF to protect dace spawning habitat in May, and in determining the EAFR due regard was given to the flow requirements of adult dace.

c) To sustain the Sectors 3 and 4 as a self-maintaining system with naturally reproducing trout and dace populations, and a diverse invertebrate community. This EAFR is developed from the four regimes (wet year, normal low-flow, drought, severe drought) which incorporate the information used in a) and b) above plus the following benchmarks: adult trout DEF, AEF, TEF; spawning AEF; and juveniles AEF (as well as paying due regard to spawning DEF and TEF, and OEF for each.

Table 4 Summary of in-river flow determinations for end-of-summer flows at the Northwold gauging station.

Hydrological Indices:		
a)	10 and 20 % of mean daily flow -	
	Minimum flow to prevent marked habitat degradation:	0.19 cumecs
	Minimum flow to protect fish habitat	0.38 cumecs
b)	Aquatic baseflow index (September median flow)	0.79 cumecs
c)	95th %'ile flow (gauged 1956-88)	0.58 cumecs
PHABSIM:		
a)	Juvenile trout	
	Habitat significantly reduced throughout both sectors	0.20 cumecs
	Habitat significantly reduced in one sector	0.30 cumecs
	Optimum habitat occurs through the two sectors	0.85 cumecs
b)	Adult trout	
	Habitat eliminated throughout both sectors	0.30 cumecs
	Habitat available in one reach of both sectors	0.40 cumecs
	Habitat more than 67% of normal under low flow one reach of one sector	0.55 cumecs
	Habitat available in all reaches	0.90 cumecs
d)	Adult dace	
	Habitat more than 67% of normal under low flow in one reach of both sectors	0.40 cumecs
	Optimum habitat for adults	1.41 cumecs
HISTORICAL ANALYSES: Macroinvertebrates		
	15% loss of families	0.40 cumecs
	20% loss of families	0.30 cumecs
	>25% loss of families	0.20 cumecs
MACROINVERTEBRATE-FLOW RELATIONSHIPS:		
	Significant loss of habitat for most sensitive taxa (Simuliidae) in both sectors	0.53 cumecs
	Significant loss of habitat for all four indicator taxa (Simuliidae, Baetidae, Ephemeridae, Elmidae) in both sectors	0.34 cumecs

Table 5 EAFRs (flow duration percentiles) to meet different Ecological Objectives for the River Wissey. Percentiles - flows equal to or greater than. * Assumes high flows unaffected by abstractions but the duration of these flows would be reduced if winter surface-water abstractions are allowed; rules for such abstractions are given in the report, and the impact of maximum winter surface-water abstractions on the estimated mean flow is given in the last two rows of the table. T=trout, D=dace, ad=adult, spn=spawning, juv=juvenile, inerts.=invertebrates, inv.H.=historical analyses of inverterates.

Flow (cumecs)	Percentiles 1956-88 (gauged)	Invertebrates and Dace	Invertebrates, Dace, and Trout	Benchmark Flow
10*	0.1	0.1	0.1	CMF
4.33*	5	5	5	
3.5*	10	10	10	HMF OEF (T.ad.)
1.5		37	32	OEF (D.ad.) DEF (T.spn)
1.0	74	48	47	AEF (D.spn)
0.9		52	69	DEF (T.ad.) AEF (T.spn)
0.8		54	72	
0.7		64	78	AEF (D.ad.)
0.6	96	70	86	
0.5	92	86	93	DEF (Inverts.)
0.4		92	98	AEF (T.ad.) AEF (D.ad.) DEF (Inv.H.)
0.35		97.5	98.3	AEF (Inverts.) TEF (T.spn)
0.3		98	100	AEF (T.juv.) TEF (T.ad.) AEF (Inv.H.)
0.2		100		TEF (T.juv) TEF (Inv.H.)
Estimated mean (cumecs)	1.9	1.34	1.5	
Runoff (mm)	218	154	172	
* Mean (cumecs)		1.07	1.29	
* Runoff (mm)		123	150	

4.2.2 Hydrological Indices

The recommended flows provide support for the following hydrological indices:

- Flows at or below 10% of mean daily flow cause severe ecological degradation.

- The recommended Threshold Ecological Flow during rare (1:20-year drought) equates to 15% of the mean daily flow;

- The recommended Threshold Ecological Flow during a 1:5 year drought, equates to 20% of the mean daily flow;

- The recommended Acceptable Ecological Flow - the 'normal' summer low-flow having a frequency of 1:2 years - equates to 30% of the mean daily flow and the 95th percentile flow;

- The recommended Desirable Ecological Flow for end-of-summer approximates to 45% of the mean daily flow and the 7-day low-flow for October that is equalled or exceeded once every three years, on average (used here as the *standard flow* against which ecological impacts of lower flows have been assessed).

5 CONCLUSIONS

The Reports arising from the Wissey investigations provide a detailed insight into the links between river ecology and flows, and include a manual to guide future studies. Despite the lack of information from other rivers, and the lack of experience in applying EAFRs, the information gained enables the following conclusions and recommendations to be made.

- An Ecologically Acceptable Flow Regime (EAFR) can be defined and its derivation should be a building block for water resources planning and setting flow control rules.

- The benefits of achieving a River Flow Objective must be evaluated together with the potential benefits of water-quality improvements and physical habitat restoration as a central part of Catchment Managemenr Planning.

- The simplest approach for defining the EAFR is to use (i) the normal dry-summer flow recession, (ii) an end-of-summer minimum flow, and (iii) a wet-year (channel maintenance) flow. The end-of-summer minimum flow can be defined using hydrological indices, macroinverterate-flow relationships, or PHABSIM (for fish) as appropriate to the scale of the low-flow problem and the desired Ecological Objective. The more complex approaches incorporate flows to protect spawning habitat (in the autumn for salmonids and spring for cyprinids).

- Hydrological indices of the end-of summer flow have been defined for the Wissey and these provide a first approximation of in-river flow needs for other Chalk streams.

- Invertebrate data have been used to define the end-of-summer minimum flows, but invertebrate-flow relationships for one river cannot be transferred to other streams, even if apparently of similar type. Data may be obtained from historical records or from sector specific, primary data collection. Simple suitability surfaces may be used to assess in-river habitat during periods of low flow. More complex approaches have been developed to establish river/sector specific fauna-flow relationships. Such data are especially valuable for streams and rivers lacking a major fisheries interest.

- PHABSIM studies are shown to provide useful information on fish habitat and should be used where there are important fisheries.

- Comparison of the results obtained using the different methods (Table 6) provides the basis for guidelines on flow management for the Wissey and supports the wider application of the approach.

- The results allow determination of acceptable maximum abstractions (annual volumes):

  Runoff - Environmental needs = Maximum abstractions

Thus, for the Wissey if flows are to be sustained to protect trout, dace and invertebrates (1.5 cumecs or 172 mm)- **the acceptable maximum abstractions equate to about 46 mm of runoff** based upon historical gauged flows (average 218 mm).

For comparison, if flows are to be sustained to protect invertebrates and coarse fish, the acceptable maximum level of abstractions could be increased to an amount equivalent to about 65 mm of runoff.

Table 6 Comparison of benchmarks flows derived using different methods. Flow in cumecs. Figures in bold have been used to recommend control rules but note that for each benchmark flow the highest value has been taken, thereby protecting all interests.

	End-of- summer			
	DEF	AEF	TEF5	TEF20
Sector-based invertebrate-flow relationships	0.84	0.53	0.34	
Historical analyses of invertebrate records for sector		0.40	0.30	0.20
PHABSIM - dace	0.50	0.40	0.33	
PHABSIM - brown trout	**0.90**	**0.60**	**0.40**	**0.30**
Hydrological indices (45, 30, 20, and 15/10% of mean daily flow)	0.85	0.57	0.38	0.30/ 0.19

	Winter flows			
	OEF	DEF	AEF	TEF5
Sector-based invertebrate-flow relationships		2.50[2]	**1.50**[3]	0.90[3]
Historical analyses of invertebrate records for sector				
PHABSIM - dace			1.40[3]	**1.00**[3]
PHABSIM - brown trout	3.00[2]	2.00[2]	1.40[1]	0.90[1]
Hydrological indices (Q10: 100 and 45% of mean daily flow)	**3.50**[2]	1.90		0.85

[1] November [2] February [3] May

- The information (eg Table 6) may also 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. By incorporating flow-dependent rules, the volume available for abstraction may be increased above that defined using a simple "average" value of in-river needs.

The rules proposed for the River Wissey include:
(i) a winter HOF incorporating a special rule to protect channel maintenance flows,
(ii) a summer HOF;
(iii) drought year HOFs for both winter and summer; and
(iv) MFs to protect the river from rare severe low flows.
On average (based on the historical gauged flows), **the rules allocate 163 mm of runoff for in-river needs and allow 55 mm to be abstracted** (cf. 172 mm and 46 mm, respectively, ased upon "average" conditions).

- Current practice uses the 95th percentile flow statistic (Q95) for setting flows to protect in-river needs. This study has demonstrated that Q95 over-estimates in-river flow needs in drought years but grossly under-estimates the volumes required in 'normal' and wet years. **Q95 must not be used as an all-year-round minimum flow but may guide the setting of the end-of-summer minimum flow in 'normal' flow years.**

On the River Wissey: Q95 = 0.58 cumecs (equivalent to 67 mm of runoff). This is shown to approximate the minimum acceptable end-of-summer flow in a 'normal' year, but is higher than the recommended end-of summer minimum for the 1:5 low-flow year (0.40 cumecs) and lower than that required during the 1:3 wet year (0.90 cumecs).

- Further research is needed before the approach can be applied to different types of river, especially those with flashy regimes, but the results of the Wissey investigations suggest that the approach has wide application for defining EAFRs.