Final Report **Project WFD48**

DEVELOPMENT OF ENVIRONMENTAL STANDARDS (WATER RESOURCES)

STAGE 3: ENVIRONMENTAL STANDARDS

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SNIFFER
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This document was produced by:

Centre for Ecology & Hydrology
Crowmarsh Gifford
Maclean Building
WALLINGFORD OX10 8BB
UK

In collaboration with:
Environmental Systems Research Group
Department of Geography
University of Dundee
DUNDEE DD1 4HN
UK

Report authors: M C Acreman, M J Dunbar, J Hannaford (CEH), O M Bragg, A R Black and J S Rowan (Dundee University), J King (University of Cape Town)

SNIFFER's project manager

SNIFFER's project manager for this contract is:

Mike Briers, Environment Agency

SNIFFER's project steering group members are:

John Aldrick, Environment Agency
David Corbelli, Scottish Environment Protection Agency
David Crookall, Scottish Environment Protection Agency
Willie Duncan, Scottish Environment Protection Agency
Colin Gibney, Environment & Heritage Service (Northern Ireland)
Nigel Goody, Scottish Environment Protection Agency
Stuart Grieg, Scottish Environment Protection Agency
Kirsty Irving, SNIFFER
Geoff Phillips, Environment Agency
Hilary Smithers, Scottish Environment Protection Agency

SNIFFER
First Floor, Greenside House
25 Greenside Place
EDINBURGH EH1 3AA

www.sniffer.org.uk

Use of this report

The development of UK-wide classification methods and environmental standards that aim to meet the requirements of the Water Framework Directive (WFD) is being sponsored by UK Technical Advisory Group (UKTAG) for WFD on behalf its member and partners.

This technical document has been developed through a collaborative project, managed and facilitated by SNIFFER and has involved the members and partners of UKTAG. It provides background information to support the ongoing development of the standards and classification methods.

Whilst this document is considered to represent the best available scientific information and expert opinion available at the stage of completion of the report, it does not necessarily represent the final or policy positions of UKTAG or any of its partner agencies.

EXECUTIVE SUMMARY

The WFD 48 project carried-out the work necessary to revise water resource regulatory standards covering abstraction and impoundments for rivers and lakes, throughout the UK based upon ecological status. This report details the results of Stage 3 of WFD 48, which determines the appropriate environmental standards (i.e. the required thresholds) for water resources parameters for UK river and lake water bodies. The set of standards are appropriate to deliver the WFD and relate to the boundaries for all five WFD classification bands: high (HES), good (GES), moderate (MES), poor (PES) ecological status. The standards do not relate to other impacts on ecological status of rivers, such as physical obstructions to fish migration or temperature changes to riparian tree clearance. Stage 1 of WFD 48 reviewed the appropriateness of different parameters, such as river flow and lake level, as environmental standards. Stage 2 reviewed the potential typologies of rivers and lakes for defining water bodies in which different standards would be appropriate. Stage 3 produces the procedures for classifying any water body into the various types and defines the thresholds for the parameters within each type.

The UK has relatively few species and few people reliant directly on river resources for their livelihoods. Consequently, environmental standards for water resources can be quite simple. However, the resulting standards should not be used outside of the UK.

Developing a typology for river water bodies

The four elements of fish, macrophytes, macro-invertebrates and physical structure provide good indicators of river ecosystem status. The initial intention of the project was to adopt a typology for each element (*e.g.* RIVPACS for invertebrates). However, the only appropriate typology of UK rivers based on ecological data that can be used for water resources standards is that defined using macrophyte communities from 1500 sites (Holmes *et al.* 1998). This classification was simplified to give 8 generic river water body types (A1, A2, B1, B2, C1, C2, D1, D2). The types differentiate, for example, lowland, low gradient, clay substrate river water bodies (A1), lowland chalk streams (A2) and steep, upland, coarse-grained substrate river water bodies (D2). Chalk streams were further sub-divided into headwaters and downstream areas. Expert consensus was that this typology was suitable for setting standards for macro-invertebrates and macrophytes. The experts recommended the use of the 8 fish community types defined by Cowx *et al.* (2004) for setting standards for fish. In only one type (salmonid spawning and nursery areas), standards for fish exceeded those standards set for the 8 generic types (defined for macro-invertebrates and macrophytes). Consequently, only this fish type was used.

Physical river water body types

Since the environmental standards needed to be applicable to all river water bodies without any site visit, classification was based on variables that could be quantified using existing datasets. To understand the variables that differentiate UK river water body types, catchment characteristics were derived for a set of 781 river flow gauging stations, giving good geographical coverage over the UK. The catchment characteristics included topographical, climatological, soil, flow variables. Principal Components Analysis (PCA) was used to define uncorrelated linear combinations of these characteristics, which permitted the selection of a small number of dominant characteristics, that most strongly differentiated different river water body types. Rainfall, slope and altitude broadly differentiate north west UK (wet, steep, high) from south east UK (dry, low gradient, low altitude). Drainage area differentiated water bodies with catchments of different scale. Base flow index (BFI) differentiate flashy from base flow dominated water bodies. Together these three components account for 61% of the variance in UK water bodies and can be interpreted intuitively. From the PCA, rainfall (SAAR), altitude

(ALTBAR), slope (DPSBAR), drainage area (AREA) and baseflow index (BFI) were selected to characterise variation along the first three components and hence to provided a basis for discriminating between types.

Linking biology to physical river variability

The WFD System A catchment typology that uses altitude, catchment area and geology was examined, but the broad classes meant that it did not discriminate between the generic river water body types in the UK.

Recursive partitioning analysis (Rpart) was employed to classify the generic river water body types according to the physical characteristics selected from the PCA. Rpart constructs hierarchical binary classification trees, giving a series of splits based on cut-points in the explanatory variables. SAAR, AREA and BFI were able to predict membership of all classes except C1 and D1. Class C1 contains relatively few sites which have a wide geographical distribution and are not individually distinctive sites. Consequently it was of crucial importance for the model to differentiate this type. Class D1 sites have specific locations in English Lowland Heaths (e.g. New Forest), Scottish Flow Country and Western Isles and can thus be located geographically. Separate analysis was conducted for different hydro-eco-regions, but this did not improve predictive power in the model. The use of substrate data was also explored. Some general patterns emerged justifying future research, but no significant improvement in predictive power was gained. No method was available to define salmonid spawning and nursery areas, other than use of local knowledge.

Maps were produced to demonstrate how river water body generic types vary along major UK rivers from, for example, D2 in the headwaters to B2 near the mouth for the Rivers Tweed and Exe.

Defining environmental standards for river water bodies

Regulatory standards for each river water body type were defined through an expert consensus workshop approach. The experts were invited to define thresholds of flow alteration that would ensure good ecological status (GES) in water bodies, based on two scenarios: abstraction and impoundments. Experts in macrophytes and macro-invertebrates adopted the generic typology and defined thresholds for abstraction for each river water body type to achieve GES. The fish experts defined standards for fish community types. All standards were very precautionary based on indicating points at which experts could no longer be certain that GES would be achieved. The thresholds were broadly in the range of 10-20% permissible abstraction above flows of Q_{95} with hands-off below Q_{95}; these stringent levels reflected uncertainty in precise threshold levels. All experts felt that standards for impoundments should be the same as those for abstraction and that long periods of constant compensation flow releases from impoundments could achieve Good Ecological Potential (GEP) but would not achieve GES, which requires maintenance of flow variability.

No precise method was available to identify fish community types for UK river water bodies. A fish atlas is available for Great Britain at 10 km grid scale, but this does not include spawning and nursery areas. In general terms, fish community 1 (chalk river fish) relates to generic type A2 (chalk rivers); fish community 2 (eurytopic/limnophylic fish) relates to A1 (lowland clay-substrate rivers). The other fish communities cut across generic types; rheophilic cyprinids could occur in types B1, B2, C1, C2 and adult salmonids and salmonid spawning could occur in types B1, B2, C1, C2, D1 and D2. Future research is required to be able to predict these latter three fish community types in river water bodies. Recursive partitioning analysis (as used for the generic types) provides one possible approach.

Results of analysis of LIFE score data were not able confirm any variations in standards between river water body types so long as the flow regime was standardised by both mean and flow variation. Analysis of changes in physical character of river water bodies (based on wetted river width) reinforced the significance of Q_{95} as a threshold at which sensitivity to flow changes.

In all cases, except salmonid spawning and nursery areas, standards set for the generic types (based macro-invertebrate and macrophyte flow requirements) were more strict than those set for fish community types. Consequently, only the salmonid spawning and nursery area type was retained as an explicit river water body type for WFD 48, in addition to the 8 generic types.

Practical standards, less stringent than those precautionary standards defined by experts (which are likely to "guarantee" a particular status will be met), were derived by the project team by taking a risk-based approach. This approach accepts that with more relaxed standards, some river water bodies may fail to achieve the desired ecological status, but these would be identified by appropriate monitoring. In this way the team defined standards for the lower limits to achieve different levels of ecological status:

	% of flow	
	Lower limit for flow > Q_{95}	Lower limit for flow < Q_{95}
High Ecological Status	10	5
Good Ecological Status	15-35	7.5-20
Moderate Ecological Status	25-45	15-30

In general the strictest standards are those for steep upland rivers (D2) and chalk streams (A2) whilst the least stringent tend to be for lowland clay-substrate rivers (A1). All standards were defined in terms of % of flow on the day abstraction. The experts felt that it was not possible to specify a constant volume that could be abstracted at any flow and still achieve GES, except by defining the volume as a percentage of the very lowest flow. As a fail-safe, it was suggested that any abstraction should not reduce flow at Qn_{99} by more than 25%.

Although not strictly part of the project specification, the team analysed the experts' views on releases from impoundments that would achieve GEP. These included release of flood events at key times of the year and variations and fluctuations in compensations flows.

Defining a typology for lake water bodies

The fundamental approach to defining a typology for lake water bodies was to adopt the lake reporting typology adopted for Great Britain. This is based essentially on chemistry, in turn reflecting geology and salinity, and giving basic classes for peat, low, medium and high alkalinity, marl and brackish waters. It was recognised that the typology could allow for classes based on these types to be split or combined, in order to increase sensitivity to factors specifically relevant to the fundamental hydrological variable of water level, or to avoid duplication, respectively as appropriate. Such an approach offers the advantage that supporting biological data are now being collected and analysed.

Physical lake types

Further to the chemical basis of the typology reflecting geology and salinity, a second tier of the typology reflects lake depth (two classes for mean depth less than or greater than 3 m), and further lower tiers are based on altitude (three classes divided at 200 m and 800 m) and lake size (three classes divided at water area 10 ha and 50 ha). Strong control on the geographical distribution of these classes is exercised by geology: deep lakes are much more concentrated in the north while shallow lakes are much more abundant in the south. A further physical characteristic is basin form, whereby a further two-fold division of classes has been proposed following the work of Håkanson.

Linking biology to physical lake variability

The typology has been developed on the basis that water level alteration is the principal hydrological parameter to which aquatic communities are sensitive, while the degree of sensitivity is a function of many other lake characteristics, as identified above. The expert workshop identified that there were substantial deficiencies in the knowledge necessary to confidently predict the threshold hydrological alterations which would lead to changes in ecological status for lakes of various physical and chemical characters. The incorporation of effects was achieved by using the chemical types to define basic levels of sensitivity, located by reference to the limited opinions expressed at the expert workshop and as refined according to the literature, and then defining sensitivity modifiers according to each of the additional factors outlined above. Basic levels of sensitivity ranged from 10-20% deviation in naturally occurring lake levels. A sensitivity calendar was used to identify and collate the seasonal nature of sensitivity effects for different species and groups of organisms. A risk-based approach was developed, whereby the number of sensitivity-increasing factors applying to an individual lake in an individual season was used to identify the degree by which the basic sensitivity threshold should be reduced. The principal threshold of interest was that representing the boundary between Good and Moderate Ecological Status, and was initially expressed as a proportion of naturally-occurring lake level on any day, relative to the sill or control structure over which the outflow drains.

Defining environmental standards for lake water bodies

To provide environmental standards in terms of water flows, allowing regulators to work towards licences in volumetric or flow terms, it was necessary to relate water level deviations to flows. This was possible using the assumption that flow over a sill or other outflow is related to level by a rating relationship with a stage exponent greater than unity. This is as indicated theoretically by the Chezy equation and has been confirmed empirically in this study by reference to data from a necessarily small number of sites at which levels and flows are available. Assuming the Chezy exponent of 1.5, permitted abstraction fluxes were found to be more lenient than their corresponding (and more ecologically relevant) permitted water level deviations. Level restrictions ranged from a mere 5% for some peat lakes to 20% for some brackish lakes, corresponding to abstraction restrictions of 7% to 28% respectively.

This system of defining environmental thresholds provided for individual differences attributable to specific physical controls to be reflected through the concept of risk, but led to results with an unjustifiable level of apparent accuracy. As a means of addressing this concern, the final table of environmental standards, expressed in flow deviation terms, therefore introduces a rounding to the nearest 5%: the loss of unjustifiable minor differences in threshold is argued to compensate for possible exaggeration of threshold values in some cases where similar lakes fall just either side of a 5% boundary. The set of thresholds for the Good/Moderate Ecological Status boundary was then taken as a starting point to define threshold values for the other ecological status classes, while maintaining the assessments of relative difference in sensitivity.

By ultimately defining standards in flow terms, it becomes possible to assess the possible effects of a water use proposal not only in relation to the adjacent rivers but also any lakes on the same river system, and so therefore be able to identify whether the river or the lake provides the more stringent environmental requirement. Given the assumption of the Chezy equation applying to outflow ratings, it is likely that lakes will often require less stringent provisions than rivers.

Proposals for future work

Recommendations for future research are provided including: a method to predict which river fish community types occur in which water bodies; use of site variables such as channel geometry and substrate using RHS; applying environmental standards to licensing; involving researchers more closely with development of standards; and defining standards for flows to estuaries. For the proper setting of environmental standards for lake abstractions, further recommendations are made, especially in relation to increasing the amount of monitoring of lake levels and their associated outflows.

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1. BACKGROUND

1.1 Introduction

In order to deliver the ecological objectives of the Water Framework Directive (WFD), environmental standards are needed that will allow the agencies to determine the ecological flow requirements of UK surface freshwaters. Transitional and coastal waters are outside the scope of this project.

These standards must provide sufficient protection for the water environment so as to restore and maintain the ecological status of waters and so meet the WFD and other environmental objectives. To promote the sustainable use of water and allow water users to continue to operate without unnecessary restrictions, these standards must be set in relation to the ecological sensitivity of waters to changes in hydro-morphology.

The measures and parameters that typically affect the relative ecological sensitivity of surface waters to changes in the flow regime, and the thresholds for these parameters that are important in maintaining the ecological status of surface waters need to be identified. As a minimum, this project must consider all those parameters that are covered by the ecological, continuity and hydro-morphological quality elements set out in the WFD. The best current scientific understanding of the links between hydromorphology and ecology must be applied in order to justify the selected parameters and thresholds.

Other issues not included in the WFD quality elements, such as land use, may also be important in protecting the ecological status of waters and so would also need to be considered as part of this project.

Particular consideration should also be given to the protection of 'high status' waters where the hydromorphological quality elements are given specific protection in addition to the role they play in delivering the ecological quality elements.

1.2 Project aims

The aim of this project is to carry out the work necessary to revise water resource environmental standards covering abstraction and impoundments for rivers and lakes, throughout the UK based upon ecological status. This will be carried out in close liaison with the regulators. Closely linked to this work will be a separate project to develop new environmental standards for groundwater in Scotland, Northern Ireland and potentially also for Wales. The development of morphological standards is being carried out as a separate suite of projects, however the consultants will be expected to ensure that they are aware of this work and that the two are complimentary.

The programme shall be structured as follows:

Stage 1: A review of existing UK and international environmental and regulatory standards and the identification of all relevant parameters.

Stage 2: The creation of a typology for rivers and lochs / lakes and the identification of the ecological sensitivity of each 'type' to changes of the parameters defined in stage 1.

Stage 3: To develop the environmental standards (i.e. the thresholds for each of the parameters identified) by reference to the five categories of ecological status as defined in the WFD (High, Good, Moderate, Poor and Bad).

The project will be split into five main tasks for the purposes of project management (Table 1).

Table 1 Names of project tasks

Task	Project Stage and phase	Task Name
1	Stage 1, Phase 1a	Review of existing standards
2	Stage 1, Phase 1b	Identify all parameters
3	Stage 1, Phase 2	Environmental standards and gap analysis
4	Stage 2	Create Typology
5	Stage 3	Develop environmental standards

Other SNIFFER projects that will have close linkages with this work programme and that contractors will require to keep in close liaison with, include:

- WFD 53: A framework for setting abstraction limits from groundwater in Scotland and N. Ireland
- WFD 49: Development of decision making frameworks for managing alterations to the morphology of surface waters and
- WFD 44: Establishing the relationship between ecological and hydromorphological quality elements in rivers and lakes.

1.3 Project objectives

The UK agencies already employ a range of existing regulatory processes for controlling abstraction and impoundment of surface water. These are based primarily on the parameters of flow (in rivers) and level (in lakes). In addition, the parameters and thresholds that have been used to identify water bodies that are 'at risk' of failing to achieve WFD good status as part of the Characterisation process have been agreed by UKTAG and these can be viewed at the UKTAG website (http://wfduk.org/).

The agencies now require to augment these existing processes with a more comprehensive and ecologically driven set of parameters and thresholds that are needed to deliver the WFD and other ecological targets (e.g. Habitats Directive).

Stage 1 aims to identify those parameters to which aquatic ecology is sensitive. These will include hydrological parameters such as the flow (discharge), but also broader hydro-morphological parameters such as water velocity, water depth or level, channel form, or wetted area and may also include groundwater contribution (temperature, quality and/or quantity), seasonality etc. as appropriate.

The project aims to do this by carrying out a literature review to identify the full range of parameters for both rivers and lakes that may need to be controlled and the circumstances in which they are significant. Once identified, these parameters may, where appropriate, be grouped into generic sub-categories that allow those circumstances where they are of ecological importance to be defined. In tandem with this work, a review and appraisal of existing standards, both within the UK and internationally will be carried out to determine where there are any gaps – i.e. any parameters that have been identified as relevant but for which there are no existing UK or international standards available.

Stage 2 of the project aims to develop a meaningful typology to categorise the ecological sensitivity of rivers and lakes to the hydromorphological pressures that are created by abstraction and impoundment. This typology should then be used, along with the data collected as part of the literature review, to identify which specific parameters, from the full set identified in Stage 1, are relevant to the ecological requirements for each of the types.

Stage 3 aims to determine the appropriate environmental standards (i.e. the required thresholds) for those parameters included for each of the river and lake types identified in Stage 2. The set of regulatory thresholds that are developed must be appropriate to deliver the WFD and other objectives and should relate to the boundaries for all five WFD classification bands.

2. RIVER WATER BODY TYPOLOGY

2.1 Introduction

Stage 2 of the project aimed to identify a meaningful typology to categorise the ecological sensitivity of rivers water bodies and lakes to the hydromorphological pressures that are created by abstraction and impoundment. This typology would then be used, along with the data collected as part of the literature review, to identify which specific parameters, from the full set identified in Stage 1, are relevant to the ecological requirements for each of the types.

The results of Stage 2 were presented in a report whose main conclusions were:

- The four elements of fish, macrophytes, macro-invertebrates and physical structure are widely accepted as good indicators of the river ecosystem. The Resource Assessment and Management (RAM) framework typology fulfils many of the key requirements of a typology based on flow sensitivity. The RAM framework is, as its name suggests, a framework for setting flow targets, so its general principles are ecologically justifiable even if the reliance on flow duration curves and the sensitivity thresholds are matters for further research.
- Current or recent research has explored relationships between physical/chemical catchment characteristics and fish, invertebrates, macrophytes - fish classification of Cowx *et al.* (2004); RIVPACS (Wright *et al* 2000)/LIFE for macro-invertebrates; Holmes *et al* (1999) for macrophytes; and the CEH PHABSIM data for physical structure.
- There is an increasing recognition amongst hydro-ecologists that river ecology depends on a range of flow parameters, rather than just average flow or low flow parameters (Richter *et al.* 1996); for example, inter-annual flow variability and the duration and timing of flow events. The flow duration curve that forms the hydrological basis of RAM does not characterise all these parameters.
- Geomorphological classification schemes are of particular importance at the channel to reach scales, so are of less relevance to the development of a broad-scale typology.
- The WFD System A typology provides a rapid assessment tool, easily populated by digital datasets, which is primarily designed for reporting purposes. Whether the method has any utility beyond reporting depends on its ability to discriminate between types - in terms of ecological sensitivity to abstraction - relative to the within-type variability. This has yet to be tested, although preliminary work with RIVPACS has implied that the types have an ecological basis (UKTAG, 2003).

The main outcome of Stage 2 was that the typology for implementing environmental standards should be based on characterising each water body by four ecosystem elements: fish, macrophytes and macro-invertebrates communities and by its physical structure. Clearly, the typology would need to differentiate these communities on the basis of their sensitivity to changes in flow. Since the sensitivity to flow in this project is defined by expert consensus, the experts on each of the three biological communities would need to be able to set environmental standards for each type.

2.2 Selecting a typology

Criteria were established for a suitable typology for environmental standards. These were:

- there should be UK coverage
- the types must distinguish between rivers water bodies that have different sensitivity to flow change
- data must be available to validate the ecological integrity of the typology
- a means must be available to type all water bodies using readily definable variables,

without visiting the site or collecting significant new data, such as physical catchment characteristics slope, altitude, geology.

Following the review of typologies in Stage 2, two options were proposed:
Option 1, a single typology of water bodies is defined, such that each type indicates specific physical character of the river channel and specific fish, macrophyte and invertebrate communities
Option 2. separate typologies are defined for each of the four elements, so that physical character, fish, macrophyte and invertebrate communities are determined independently.

The former was the preferred route. The latter was acceptable if a single typology was not found.

Although considerable research has been undertaken on predicting macro-invertebrate communities in British rivers from physical and chemical characteristics culminating in the RIVPACS system (Wright *et al*, 2000, no simple typology of rivers has been developed based on their invertebrate fauna. Recent research by Cowx *et al.* (2004) has identified 8 fish community types and some indication of the physical characteristics of water bodies where there communities would be found. However, no definite method for predicting fish community types simply from knowledge of physical characteristics has been produced. Furthermore, the raw fish community data were not readily available for the project to undertake the analysis to define such relationships. This would need to be the subject of future research. Work on the RAPHSA project at CEH has recognised variations in physical sensitivity to flow change for different river reaches, but there was little consistent variation with catchment characteristics.

The most promising typology of river water bodies for use in environmental standards was developed using macrophyte data. British rivers were classified using macrophyte communities following extensive surveys carried out throughout the 1980s and early 1990s (Holmes *et al.* 1998). The classification is based on TWINSPAN analysis of macrophyte survey data gathered from a total of over 1500 sites. The classification yielded ten River Community Types (RCTs) in four groups, varying from lowland, eutrophic rivers (Group A) to torrential, oligotrophic streams. The groups are well differentiated by physical characteristics, with a between-type transition in terms of altitude and predominant geology in particular. The full classification is reproduced in Annex 3.

For the purposes of this study, the Holmes *et al* classification was simplified to give 8 generic river water body types to address option 1 above. These are presented in Table 2.

A major driver for the use of a macrophyte-based typology was an extensive dataset that is freely available. The data used by Holmes *et al* were obtained from the JNCC “conservation rivers” database, which contains data on the macrophyte communities of around 1500 river sites, many of which are in broadly good condition. The locations of the sites are shown in Figure 1. General descriptive relations with some physical catchment characteristics are described. Also, the surveys are based on two consecutive 500m reaches, and in the typology, these surveys are aggregated. Basing a typology on ecological data collected over 1km is likely to be more robust and more related to catchment characteristics (as opposed to local site-scale variables) than for ecological data collected over shorter lengths of river (e.g. 100m). The distribution of the 8 types is shown in Figure 2.

Table 2 Generic river water reach types based on Holmes *et al* (1998)

<table>
<tr><td colspan="2">Type A
clay and/or Chalk
low altitude;
low slope;
eutrophic;
silt-gravel bed;
smooth flow;
predominantly
C and SE England</td><td colspan="2">Type B
hard limestone and sandstone
low-medium altitude, low-medium slope; ?mesotrophic?;
gravel-boulder (predominantly pebble-cobble), mostly smooth flow, small turbulent areas
SW, NW, NE England, E Scotland, C and S. Wales</td><td colspan="2">Type C
non-calcareous shales, hard limestone and sandstone, medium altitude, medium slope, oligo-meso-trophic; pebble, cobble, boulder bed, smooth flow with abundant riffles and rapids;
SW, NE England, Lake District, W Wales, Southern Uplands, Grampians</td><td colspan="2">Type D
Granites and other hard rocks;
low and high altitudes;
gentle and steep slopes; ultraoligo – oligotrophic; cobble, boulder, bedrock, pebble;
smooth with turbulent areas – torrential;
C N and W Scotland, scattered in W Wales, SW, NW and S. England</td></tr>
<tr><td>Type A1
Lowest gradients (0.8 +/- 0.4 m/km) and altitudes (36 +/- 25 m), predominantly clay
SE England and East Anglia & Cheshire plain</td><td>Type A2
Slightly steeper (1.7 +/- 0.8 m/km), low altitude (55 +/- 38 m);
Chalk catchments; predominantly gravel beds base-rich;</td><td>Type B1
gradient (4.1 +/- 9.9 m/km), altitude 93 +/- 69 m; .
Hard sandstone, calcareous shales; predominantly S. & SW England and SW Wales</td><td>Type B2
shallower than B1 (2.7 +/- 10.7 m/km); altitude 71 +/- 58 m; predominantly NW England, E Scotland</td><td>Type C1
gradient 5.4 +/- 6.5 m/km;
altitude 101 +/- 84 m;
hard limestone; more silt and sand than C2; mesotrophic</td><td>Type C2
steeper than C1 (7.3 +/- 10.8 m/km); altitude 130 +/- 90 m; non-calcareous shales; pebble-bedrock;
oligo-mesotrophic</td><td>Type D1
medium gradient (11.3 +/- 15.6 m/km); low altitude (93 +/- 92 m), oligotrophic, substrate finer than D2 (incl silt & sand);
more slow flow areas than D2</td><td>Type D2
high gradient (25.5 +/- 33 m/km); high altitude (178 +/- 131 m);
stream order 1 & 2
bed rock and boulder;
ultra-oligo trophic torrential;.</td></tr>
<tr><td colspan="8">Example rivers where water body types (river reaches) can be found</td></tr>
<tr><td>Wissey, Lark, Nar, Wensum, Bure, Welland, Cherwell, Tame, Evenlode</td><td>Test, Piddle, Frome, Itchen, Mimram, Hull, headwaters of East Anglian rivers</td><td>Tamar, Torridge, Exe, Teifi, Monnow, Lugg, Dove</td><td>Ribble, Wharfe, Eden, Tweed, Lunan, Ythan</td><td>Scattered</td><td>Lower Findhorn, Spey, Dee, Esk, Ure, Derwent, Conwy, Dee, Cothi, Barle</td><td>English lowland acid heaths (New Forest), Scottish Flow Country, Western Isles</td><td>Dartmoor, Exmoor, Brecons, Snowdonia, Pennines, Cairngorms, NW Highlands</td></tr>
</table>

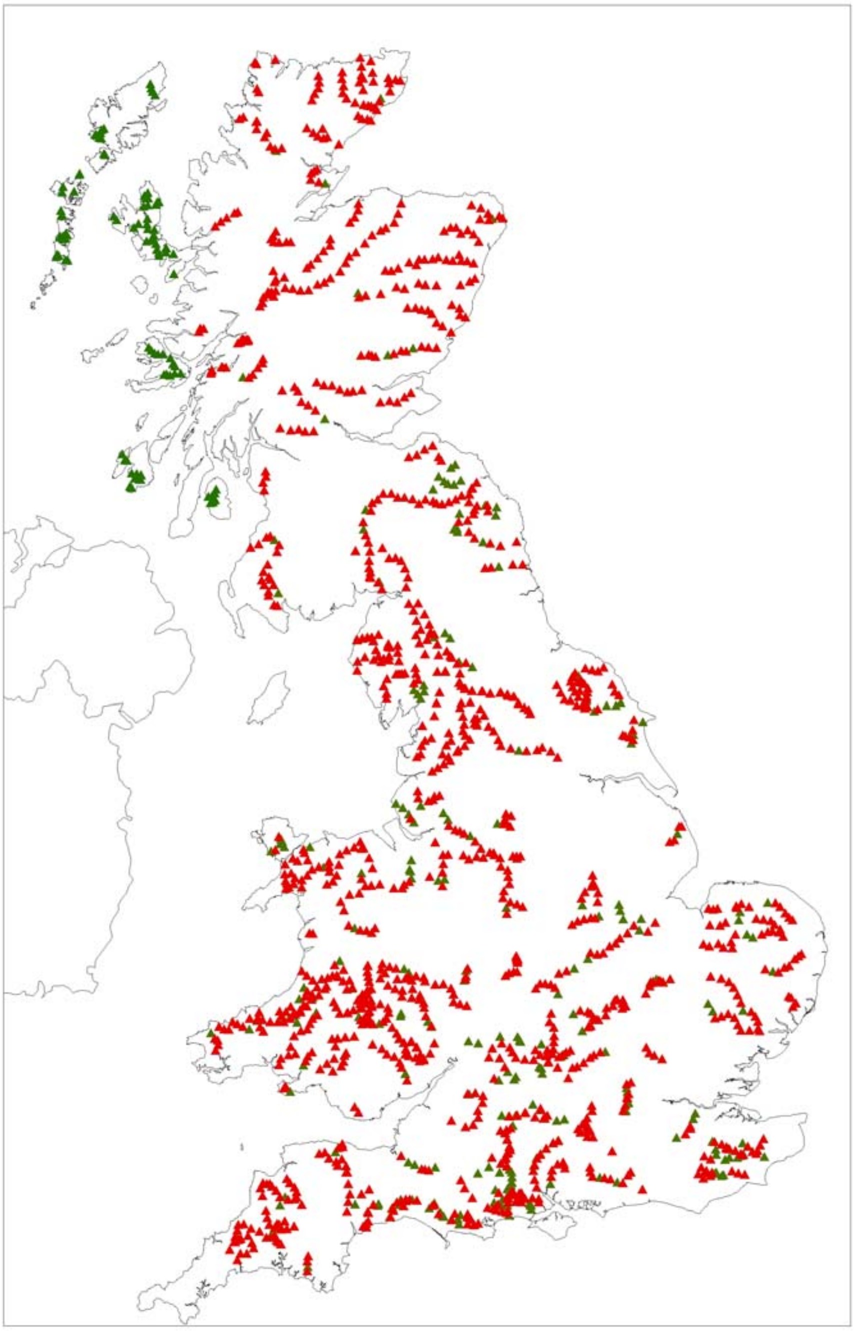


Figure 1 Distribution of JNCC Macrophyte sites. Sites for which catchment descriptors could be derived are coloured red, other sites green (note lack of data in Northern Ireland and Scottish Islands)

A second incentive for using the macrophyte-based typology was that it defined a reasonable number of river types that appeared meaningful from a physical, chemical and ecological viewpoint. With the addition of the time constraints within the project, a simplified version of the macrophyte typology was trailed at the Edinburgh workshop (see Annex 1). Macrophyte and macro-invertebrate experts at the workshop were broadly happy with using this typology. The fish experts felt that the variables used were appropriate for fish but the type boundaries made it difficult to differentiate fish communities with different sensitivity to flow change. Consequently, they felt that a fish-based classification would be more appropriate. After the Edinburgh workshop, we tested more formally the relationship between the macrophyte types and physical variables, and the utility of a model to classify sites according to their physical characteristics. This is detailed in Section 2.4.

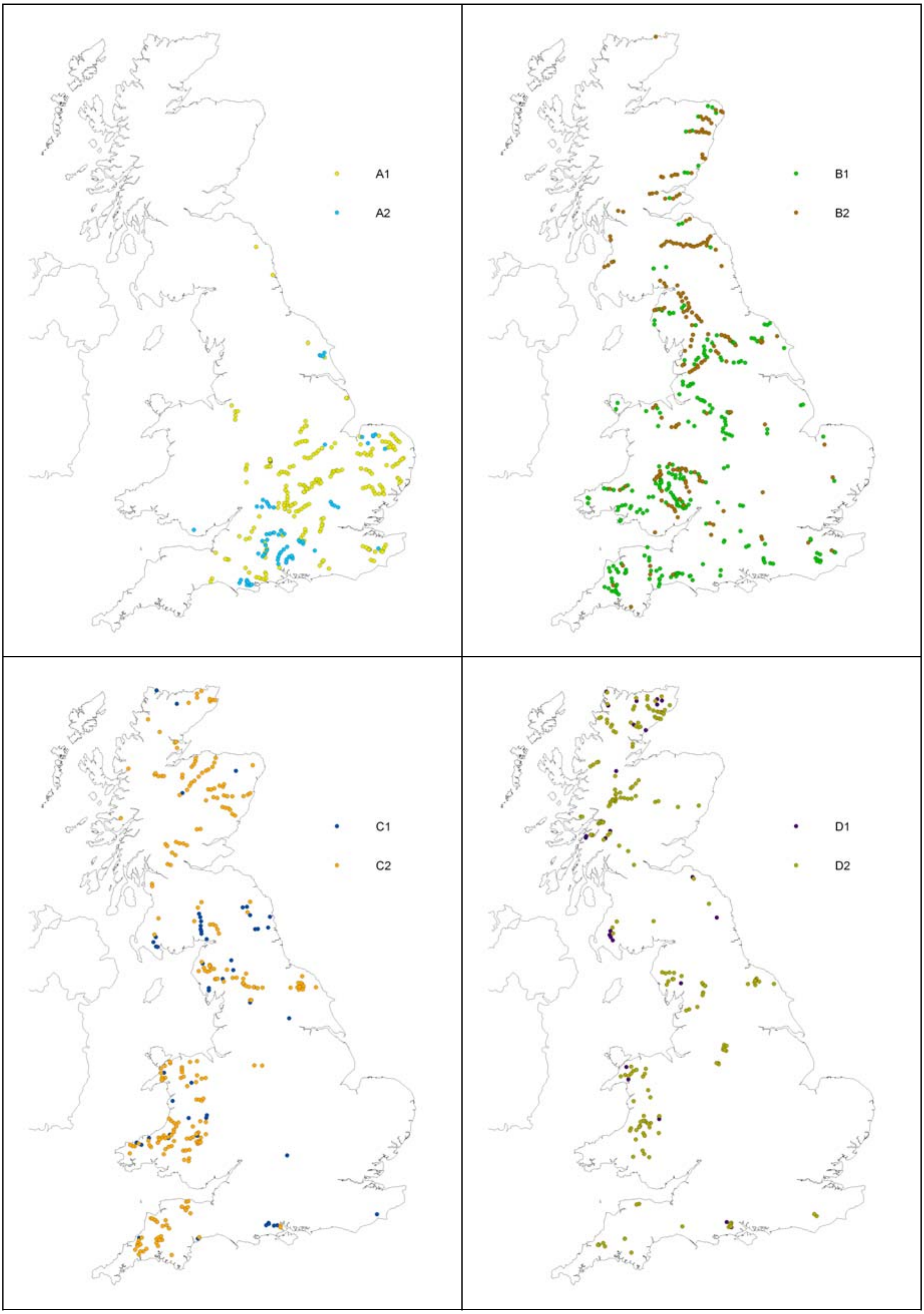


Figure 2 Maps showing geographical distribution of Generic River Types A1 - D2

2.3 Chalk rivers

The typology depicted in Figure 2 explicitly allows rivers to change type from its headwater (e.g. D2) to its estuary (e.g. A1), except in the case of Chalk rivers (A2) which covers the entire water course. Analysis of specific case studies, including the Rivers Itchen (Halcrow, 2004) and Wylye (Dunbar *et al,* 2000), was undertaken after the expert workshops. The results suggested that Chalk rivers should be further divided into two types, on the basis that their headwaters and downstream areas can exhibit different sensitivities to flow alteration. The threshold drainage area that divides these sub-types was set at 100 km^2. Consequently, the overall typology was extended to 9 types.

2.4 Physical river types

Following the decision to base identification of river water body types on physical catchment characteristics, a multivariate analysis was conducted to explore the relationships between various continuous-scale catchment characteristics, and hence to determine whether any dominant characteristics could be used to characterise variability between river types. This analysis could then inform the development of a new typology by ensuring that classification into types was based on physical variables that are effective in characterising variability across the range of UK catchments.

Selection of catchments for analysis

The catchment characteristics were derived for a set of 733 river flow gauging stations, giving good geographical coverage over the UK. These sites were selected on the basis of having readily available datasets of digital catchment characteristics, and were derived from a set of catchments selected following the work of Gustard *et al.* (1992), which graded stations held on the national river flow archive according to hydrometric performance and the degree of artificial influences. Catchments with significant artificial influences and poor hydrometric performance at low flows were thus excluded from the analysis. The distribution of the 733 catchments is shown in Figure 3. Catchments from Northern Ireland were excluded from the analysis owing to limited availability of some characteristics during the first phase of analysis. A subsequent analysis including 48 stations in Northern Ireland using a smaller number of characteristics was carried out, as reported below.

The catchment/site characteristics

The variables used in this part of the study can be grouped into four classes of catchment characteristics *per se,* and at-site characteristics measured at the actual catchment outlet but on a reach scale:

- Topographical characteristics
- Climatological characteristics
- HOST soils characteristics
- Flow regime variables
- Site Characteristics (reach scale)

These are described in the subsequent sub-sections.

<u>Topographical characteristics</u>

The topographical catchment characteristics were derived using the former Institute of Hydrology's Digital Terrain Model (DTM) (Morris and Flavin, 1990). This DTM consists of five

50m-resolution grids; the three that have been used to derive topographical characteristics are:

Altitude grid – the altitude of each node above mean sea level, derived from Ordnance Survey contour data using an interpolation procedure described by Morris and Flavin, (1990).

Drainage direction grid – from the altitude data the gradient between a node and its nearest eight neighbours is calculated and the drainage direction is taken as the steepest "down slope" gradient to its nearest neighbour.

Inflow grid – This grid identifies for each node, as an eight-bit code, the number of the eight nearest neighbour nodes that drains towards it, effectively defining a 50 m grid of drainage areas.

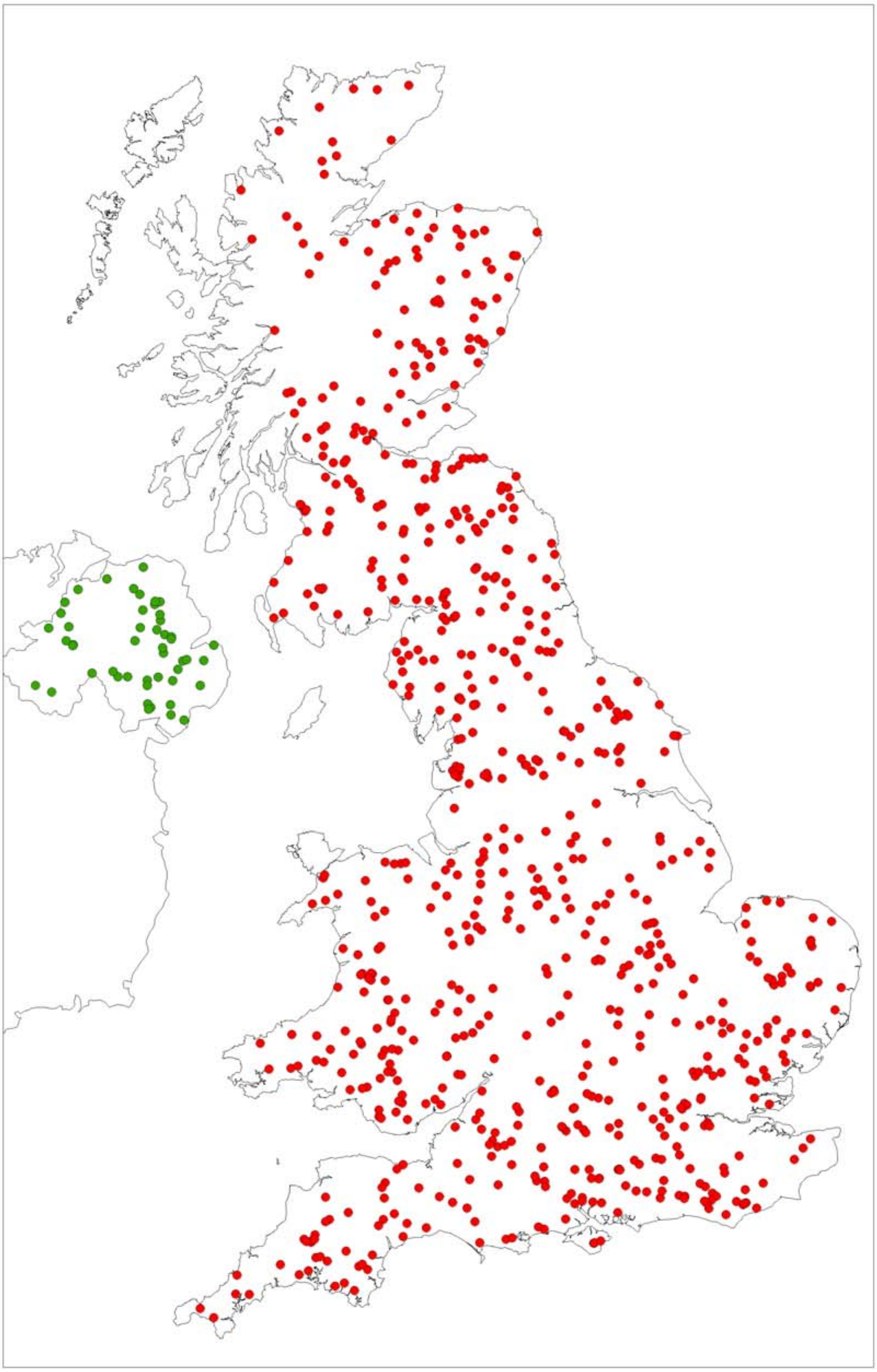


Figure 3 Map showing location of gauging stations used in the study. 733 GB stations shown in red, 48 Northern Ireland stations shown in green

Catchment area estimation

The accurate definition of the catchment boundary and hence the area draining to each catchment is extremely important. The boundary is used to identify the extent of each catchment characteristic grid within a catchment boundary. The drainage area values for the study catchments were derived from the DTM, which was used to generate catchment boundaries and areas using the method described by Morris and Heerdegen (1988). Previous work has compared these estimates of area derived using the DTM and the manually derived catchment area estimates held for most gauged catchments on the National River Flow Archive (A. Young, CEH Wallingford, pers.comm). The same exercise has been undertaken for the catchment data set used in the development of the Flood Estimation Handbook (FEH) by Bayliss (1999). Bayliss identified that only 5% of FEH catchments differed in area by 10% or more. Some of these catchments have boundaries that, through drainage diversion, do not always follow the topography, which the DTM-derived watershed must always do. In other cases, the generation of DTM flow paths has been flawed by difficulties encountered when using digitised rivers to fix the location of valleys (a key element of the generation of the DTM). Where initial estimates differed by more than 10% it was possible, for several catchments, to correct the DTM where it had chosen an incorrect stretch. Where the differences in catchment area were greater than 10% and could not be resolved the catchments were excluded from the initial data set. Therefore, for all of the catchments used in the study the error between DTM generated catchment areas and manually derived catchment areas is less than 10%.

Flood Estimation Handbook (FEH) catchment descriptors

A set of topographical catchment characteristics has been derived for the FEH. These are described fully by Bayliss (1999). Using FEH nomenclature these are called catchment descriptors. The catchment descriptors that were thought to be potentially important in controlling the variability in river flow regimes, and hence likely to be of importance in affecting the ecological sensitivity of rivers, were used for this study. The descriptors are summarised in Table 3.

Table 3 Glossary of FEH catchment descriptors

Catchment descriptor	Units	Description
ALTBAR	M	The mean altitude of the catchment
ASPBAR	Degrees (0,360=Nth)	The mean direction of all 50m slopes in the catchment. Represents the dominant aspect of catchment slopes
ASPVAR	None	The invariability of slope direction. Values approaching one indicate dominance of one direction
DPLBAR	Km	The mean of the distances measured between each node (on regular 50-m grid) and the catchment outlet. Characterizes catchment size and configuration.
DPLCV	Km	The coefficient of variation (CV) of the distances measured between each node and the catchment outlet. Descriptor of drainage path configuration
DPSBAR	m/km	The mean of all the inter-nodal slopes for the catchment. Characterizes the overall steepness within the catchment
LDP	Km	The longest drainage path defined by measuring the distance from each node to the defined catchment outlet. Principally a measure of catchment size but also reflects catchment configuration

Climatological characteristics (SAAR, SAARPE, PP)

Standard Average Annual Rainfall for the standard period 1961 - 1990 (SAAR6190) was provided by the Met Office on a 1km grid - the catchment boundaries were used to derive catchment values. The development of a 1km-resolution grid of Penman Monteith estimates for short grass was used to generate standard period PE estimates (SAARPE). These estimates were used in conjunction with the monthly rainfall statistics to derive the PP catchment characteristic.

Soil moisture deficits potentially occur in a catchment when the evaporative demand and drainage from the soil exceeds the incident precipitation. As significant soil moisture deficits build up the rate at which water evaporates reduces. The PP characteristic was developed to represent this process in a relatively crude way. The difference between the catchment average monthly rainfall and potential evaporation was calculated for each month within the year. The difference was summed for months in which it was negative (potential evaporation demand exceeds precipitation) and express as a fraction of the annual potential evaporation estimate. The interpretation of the PP statistic is that it represents that fraction of the potential evaporation demand that might occur when water availability is limited. The larger the value of PP for a catchment, the more likely there are to be significant soil moisture deficits occurring within the catchment.

Table 4 The HOST classification (Source: Boorman et al 1995)

<table>
<tr><th>SUBSTRATE HYDROGEOLOGY</th><th colspan="6">MINERAL SOILS</th><th colspan="2" rowspan="2">PEAT SOILS</th></tr>
<tr><th></th><th>Groundwater or aquifer</th><th>No impermeable or gleyed layer within 100 cm</th><th colspan="2">Impermeable layer within 100 cm OR gleyed layer within 40 cm</th><th colspan="2">Gleyed layer within 40 cm</th></tr>
<tr><td>Weakly consolidated, microporous, bypass flow uncommon (Chalk)</td><td rowspan="6">Normally present and at > 2m</td><td>1</td><td colspan="2" rowspan="6">12</td><td colspan="2" rowspan="6">13</td><td colspan="2" rowspan="6">14</td></tr>
<tr><td>Weakly consolidated, microporous, bypass flow uncommon (Limestone)</td><td>29</td></tr>
<tr><td>Weakly consolidated, macroporous, by-pass flow uncommon</td><td>2</td></tr>
<tr><td>Strongly consolidated, non or slightly porous. Bypass flow common</td><td>3</td></tr>
<tr><td>Unconsolidated, macroporous, bypass flow very uncommon</td><td>4</td></tr>
<tr><td>Unconsolidated, microporous, bypass flow common</td><td>5</td></tr>
<tr><td>Unconsolidated, macroporous, bypass flow very uncommon</td><td rowspan="2">Normally present and at < 2m</td><td colspan="3">6</td><td>IAC < 12.5 [< 1m day^{1}]</td><td>IAC > 12.5 [> 1m day^{1}]</td><td>Drained</td><td>Undrained</td></tr>
<tr><td>Unconsolidated, microporous, bypass flow common</td><td colspan="3">7</td><td>8</td><td>9</td><td>10</td><td>11</td></tr>
<tr><td>Slowly permeable</td><td rowspan="5">No significant groundwater or aquifer</td><td>15</td><td>IAC > 7.5
17</td><td>IAC < 7.5
20</td><td colspan="2">23</td><td colspan="2">25</td></tr>
<tr><td>Impermeable (hard)</td><td>16</td><td>18</td><td>21</td><td colspan="2"></td><td colspan="2">26</td></tr>
<tr><td>Impermeable (soft)</td><td></td><td>19</td><td>22</td><td colspan="2">24</td><td colspan="2"></td></tr>
<tr><td>Eroded Peat</td><td colspan="5" rowspan="2"></td><td colspan="2">27</td></tr>
<tr><td>Raw Peat</td><td colspan="2">28</td></tr>
</table>

<u>Hydrology of Soil Types Classification (BFIHOST, SPRHOST)</u>

The Hydrology of Soil Types (HOST) is a soil association-based hydrological response classification (Boorman *et al*, 1995) of soils across the United Kingdom. A brief description follows: The HOST classification was developed by grouping soil associations into self-similar groups based upon their physical properties. Simple conceptual models describing the flow paths of water provided a structure to the classification scheme. Initially the 969 soil series were analysed and those with similar flow paths (indicated by their physical properties) were grouped together into a single HOST class. This produced a more manageable data set for further analysis. The percentage cover of the reduced number of classes were then related to gauged Baseflow Index (BFI) values using multiple regression analysis, and by inspection of the response of individual catchments. The regression analysis provided further guidance on discriminating and grouping soil series. The process resulted in a final 29-class system. The classification is summarised in Table 4, in which classes are grouped by physical characteristics.

The BFI model developed by Boorman *et al* (1995) was used to generate the BFIHOST catchment characteristic for this study. Boorman *et al* (1995) also developed a model for estimating the Standard Percentage Runoff (a measure of the percentage of rainfall that generates runoff; NERC, 1975), which is the SPRHost characteristic.

Flow regime variables

In addition to thematic data which describe the properties of the catchment area, indices characterising the streamflow regime were included in the analysis. Flow regime indices are widely used to characterise anthropogenic impacts on flow regimes and the resultant impacts on aquatic ecology, and to establish sensitivity of rivers to modification - hence, they are of relevance to this study and should be considered in the development of new typologies.

The number of flow regime indices reported in the literature reflects the widespread contemporary interest in developing and applying metrics for quantifying changes to flow regimes. There has been a proliferation of indices, proposed by studies in a number of countries and describing various components of streamflow regimes. It is widely agreed that a number of indices are needed to characterise the different components of the regime which have relevance to stream ecology - e.g. averages and variability of monthly flows, numbers of floods, duration of pulses - as exemplified by the Richter *et al.* (1996,1998) suite of 'Indicators of Hydrologic Alteration' (IHA).

Clausen & Biggs (2000) and Poff & Ward (2003) performed multivariate analysis on a wide range of flow variables reported in the literature, to determine patterns of redundancy and suggest key groups of dominant indicators. Clausen & Biggs (2000) suggested one variable from four main groups could be used to characterise flow regimes in temperate streams:

1. Average flow magnitude
2. General flow variability and magnitude of high and low flows
3. Duration and volume of high flows
4. Frequency of high flow events

These main groups were provided the basis for selecting flow indices. At least one variable from each of these main groups were derived from the daily streamflow records for the 733 stations. Six flow indices were used, as presented in Table 5. Mean flow reflects the average flow magnitude, and Q_{95} (as a ratio of the median flow) is used to characterise low flow variability. Skewness also reflects average flow magnitude, and high flow magnitude - it is well correlated with the Q_{10} flow, a commonly used indicator of high flow magnitude. The duration, volume and frequency of high flows above a threshold of three times the median (DUR3, VOL3 and FRE3 from Clausen & Biggs, 2000) are used as indices to characterise the high flow components of the regime. This selection of indices covers the four main groups suggested by Clausen & Biggs (2000), and also agrees with the analysis of Poff & Ward (2003) - FRE3 and SK had among the highest loadings of the first principal components derived by these authors, and annual runoff (correlated with mean flow) and BFI (used in the present analysis via BFIhost as discussed above) scored highly on the second.

Other groups of variables, such as timings of events and rate of change, are also important for ecology. These were not considered for this part of the study, which is aimed primarily at broadly discriminating catchments rather than capturing specific impacts on flow regimes. Many of the indices used here can be derived for ungauged sites - mean flows and flow duration curves can be derived using the regionalisation procedures and mean flow estimation model provided by Low Flows 2000 (Holmes *et al.* 2002a, b).

Table 5 Flow characteristics used in the analysis

Flow Variable	Units	Description
MF	ms^{-3}	Catchment mean flow
Q95	ms^{-3}	Flow exceeded 95% of time, in this case expressed as a proportion of the median (Q50) flow - a common indicator of low flow magnitude (Gustard *et al.* 1992).
SK	ms^{-3}	Skewness - MF / Q50
FRE3*	Count	Average annual frequency of flow events three times the median (Q50) flow
DUR3*	Number of days	Average annual duration of flows 3 x Q50
VOL3*	ms^{-3}	Average annual volume of flows 3 x Q50

* high flow indices described by Clausen & Biggs, 2000

Other catchment characteristics and site characteristics

Whilst an emphasis on catchment-based characteristics is favoured for the development of a new typology, site-based variables should be included where they could be easily derived, in order that the analysis should be consistent with existing classification systems which utilise site based (reach scale) variables. The CEH Dorset Intelligent GIS was used to derive some RIVPACS at-site and catchment characteristics from the DTM, principally site altitude and slope and distance from source, and also altitude of source, which is used in RHS.

Other site characteristics used in existing typologies such as that in RIVPACS include water width and depth, and alkalinity. No consistent method is available to estimate these for all water body sites.

Hydro-eco-regions

Hydroecoregions are being defined for the whole of Europe (Figure 4), following the methods of Jean-Gabriel Wasson from Cemagref (Wasson et al., 2002). The variables used are very similar to those above: slope, rainfall and geology, but the result is a more spatially-based regional typology. Hydroecoregions could be used as an alternative top-level of any typology.

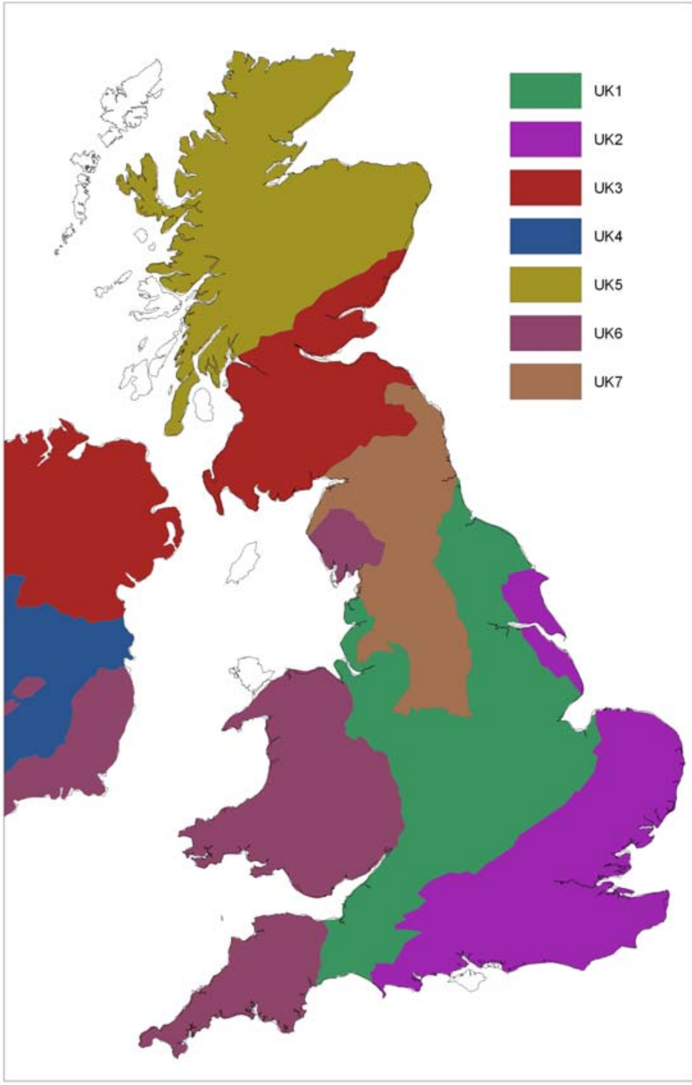


Figure 4 Hydroecoregions defined for the UK and Ireland as part of the REBECCA project. Data from Jean-Gabriel Wasson and Ana Garcia, Cemagref, Lyon.

Multivariate Analysis of Characteristics

Correlation between variables

Figure 5 shows a scatterplot matrix of FEH physical characteristics, HOST and climatological descriptors. The correlation matrix of these descriptors and the streamflow indices and site variables is presented in Table 6.

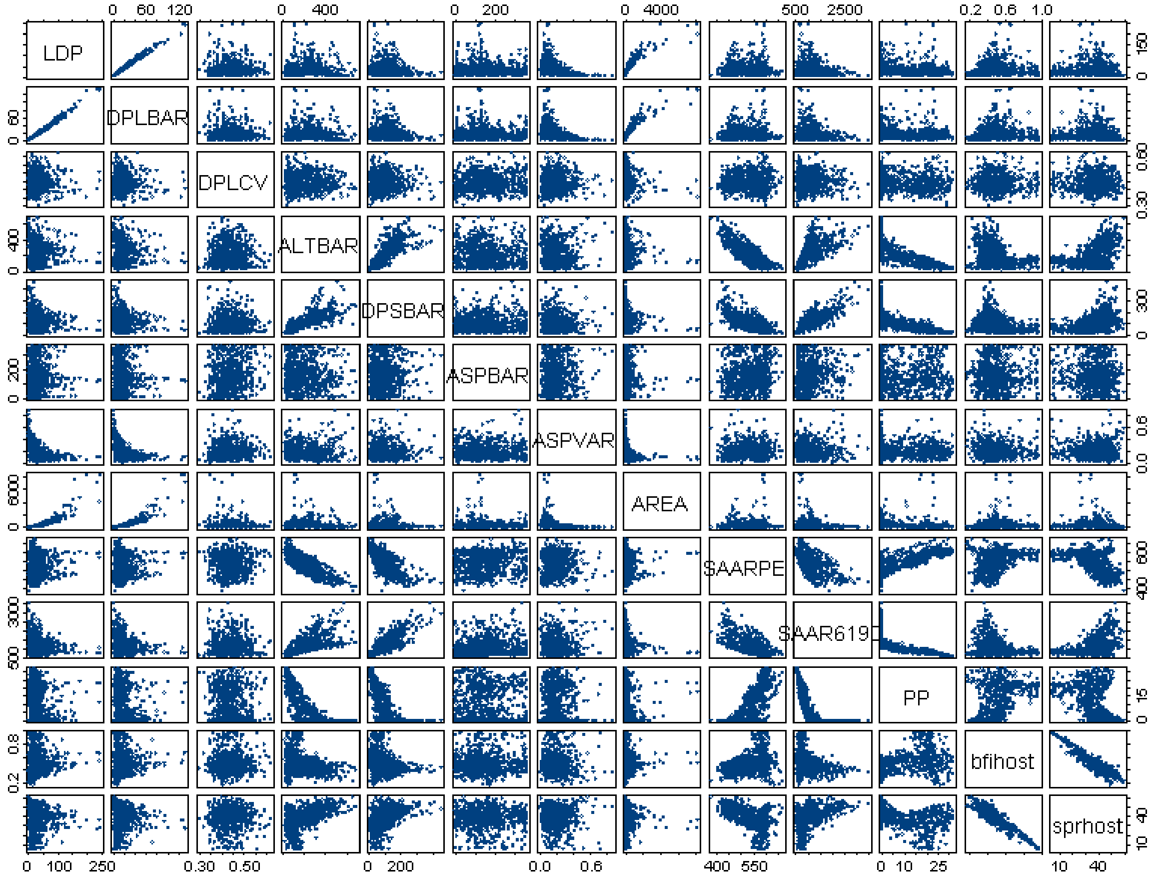


Figure 5 Scatterplot matrix for FEH and climatological and soils-based catchment descriptors

As would be expected, there is a high degree of inter-correlation amongst the variables, such as between the various topographical characteristics which express various components of basin configuration and size. Climatological characteristics are well correlated with elevation and steepness. HOST characteristics are correlated with each other and SPRhost is also correlated with SAARPE and ALTBAR. The flow regime indices are correlated with catchment properties which reflect influences on particular components of the regime - FRE3, a measure of flashiness, is correlated with HOST characteristics and climate, whereas mean flow and flood volume (VOL3) are correlated with catchment size/shape characteristics (AREA, LDP). It is notable that site slope is not particularly well correlated with catchment slope as defined by DPSBAR.

	LDP	DPL BAR	DPL CV	ALT BAR	DPS BAR	ASP BAR	ASP VAR	AREA	SAAR PE	SAAR 6190	PP	BFI HOST	SPR HOST	FRE3	DUR3	VOL3	MF	Q95	SK
LDP	1.00																		
DPLBAR	0.99	1.00																	
DPLCV	0.03	-0.04	1.00																
ALTBAR	0.07	0.06	0.03	1.00															
DPSBAR	-0.02	-0.02	0.00	0.79	1.00														
ASPBAR	-0.10	-0.10	0.05	-0.04	0.04	1.00													
ASPVAR	-0.44	-0.43	0.00	-0.01	-0.06	0.04	1.00												
AREA	0.86	0.87	-0.07	0.03	-0.03	-0.09	-0.28	1.00											
SAARPE	-0.07	-0.06	-0.01	-0.83	-0.73	0.09	0.03	-0.01	1.00										
SAAR619 0	-0.10	-0.11	0.03	0.69	0.82	0.12	0.06	-0.08	-0.64	1.00									
PP	-0.09	-0.07	-0.07	-0.78	-0.73	-0.04	0.01	-0.01	0.79	-0.75	1.00								
bfihost	0.07	0.07	-0.02	-0.37	-0.26	0.02	-0.07	0.05	0.38	-0.37	0.40	1.00							
sprhost	-0.04	-0.05	0.03	0.50	0.39	-0.03	0.03	-0.04	-0.53	0.47	-0.48	-0.94	1.00						
FRE3	-0.10	-0.11	0.05	0.46	0.39	0.03	0.09	-0.09	-0.49	0.57	-0.53	-0.70	0.70	1.00					
DUR3	-0.06	-0.05	-0.05	-0.12	-0.08	-0.02	0.02	-0.02	0.09	-0.11	0.13	0.31	-0.30	-0.25	1.00				
VOL3	0.84	0.84	-0.02	0.09	0.07	-0.07	-0.30	0.88	-0.08	0.04	-0.12	-0.01	0.03	-0.03	0.01	1.00			
MF	0.85	0.84	-0.02	0.23	0.18	-0.08	-0.36	0.84	-0.23	0.12	-0.26	-0.08	0.12	0.05	-0.07	0.82	1.00		
Q95	0.13	0.14	-0.06	-0.21	-0.26	0.02	-0.08	0.11	0.26	-0.36	0.33	0.35	-0.35	-0.36	-0.16	-0.03	0.01	1.00	
SK	-0.21	-0.21	0.03	-0.10	-0.13	-0.02	0.15	-0.13	0.04	-0.01	0.11	-0.35	0.29	0.25	0.05	-0.08	-0.15	-0.45	1.00
R.ALT	-0.24	-0.23	0	0.74	0.42	-0.01	0.22	-0.14	-0.52	0.41	-0.4	-0.27	0.35	0.17	0.29	-0.05	-0.14	-0.12	-0.11
R.SLOPE	-0.15	-0.15	-0.05	0.27	0.22	0.06	0.23	-0.08	-0.2	0.27	-0.16	-0.14	0.17	0.08	0.2	-0.02	-0.08	-0.09	-0.08
R.DSOU	0.96	0.96	0.05	0.08	-0.01	-0.1	-0.41	0.83	-0.07	-0.09	-0.11	0.03	-0.01	0.07	-0.07	-0.08	0.81	0.82	0.11
R.SALT	0.24	0.22	0.1	0.86	0.72	-0.01	-0.1	0.12	-0.76	0.62	-0.79	-0.39	0.5	0.24	0.45	-0.18	0.2	0.35	-0.21

Key - r values > 0.5 > 0.6 >0.8

Table 6 Correlation matrix for catchment characteristics used in multivariate analysis. Inter-correlation between site variables is not shown. Cells shaded according to correlation coefficients (r values, see key).

Principal component analysis

PCA Method

Principal Components Analysis (PCA) was used to explore how the continuous characteristics could be summarised to explain the variance within the data set. PCA can be viewed as a means of extracting uncorrelated linear combinations of variables which, by grouping related variables, permits the selection of a small number of dominant catchment characteristics. PCA is used to construct linear combinations Z_1, Z_2, $Z_3 \ldots Z_p$ of *p* variables X_1, X_2, $X_3 \ldots X_p$ (in this case 13 characteristics) that are uncorrelated where

$$Z_1 = a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + a_{14}X_4 + ... + a_{1p}X_p$$

$$a_{11}^2 + a_{12}^2 + a_{13}^2 + a_{14}^2 + ... + a_{1p}^2 = 1$$

As they are uncorrelated the combinations are measuring different dimensions within the data. The coefficients, a_{ip}, are a measure of the contribution of variable, X_p, to Z_i. A PCA involves finding the Eigenvalues of the sample covariance matrix for $X_{p.}$ For the PCA the normal practice of coding X_p so as they have means of zero and variance of one was adopted. This avoids one or more variables having an undue influence on the principal components as a result of scale effects.

Where two or more variables within a component analysis are correlated with one another, the coefficients, a, are not independent and are therefore not easily interpretable. To resolve this, it is common practice to look at the loading for component variables, X_i, with the principal component Z_i. The loading for a component variable is the correlation of that variable with the principal component. Plotting the component loadings may reveal that a variable has a sizeable loading for more than one principal component. One refinement is to use rotated loadings with the PCA, by performing a variance maximising (Varimax) rotation. In this analysis, if a variable has a sizeable loading for more than one PC, the plot axes for the PC are rotated with the aim of maximising the component loading for a variable with one PC and minimising it with respect to the others. This generally maximises the larger un-rotated loadings for a PC and minimises the smaller loadings, which aids in the interpretation of the loadings of the PCA.

Excluding PCs

The sum of Eigenvalues for all PC's is equal to the sum of the trace (diagonal) of the covariance matrix. As the diagonal of a covariance matrix contains the variance of each of the variables within the sample, the Eigenvalue for a PC is the variance of the PC. The scree plot (Eigenvalues plotted as a function of PC number) presented in Figure 6 for the PCA of catchment characteristics. The scree plots suggests a break between the third and fourth components. The first six PCs have eigenvalues greater than 1 - Kaiser's criterion for excluding eigenvalues (excluding those with eigenvalues less than 1) suggests excluding all but the first six PCs; hence these are retained in the loadings table, presented in Table 6. The first six PCs explain 76% of the variance in the dataset.

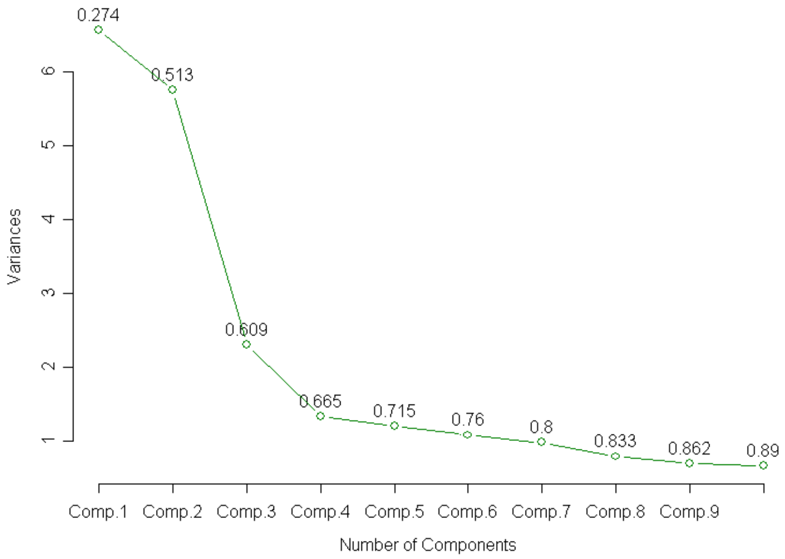


Figure 6 Scree plot for results of PCA

PCA Interpretation

The results suggest that a high degree of the variability within the dataset can be explained using the PCs retained in the analysis - in particular, the first three account for 61% of the variance and can be interpreted intuitively. The first encompasses climatological variables and altitude/steepness; as altitude and steepness increases, so do rainfall and Percentage Runoff, whereas PE and potential for developing SMDs decreases. This reflects the general association between these variables, and the variability is probably driven to a large extent by the broad NW/SE elevation and rainfall gradient across the UK which results from the interaction of predominant weather patterns and orography.

The second is a reflection of catchment size and related configuration variables such as mean drainage path length, so can be thought of as a scale component. In addition, as catchments get larger, the mean flow and also the volume of floods (as defined by VOL3) increases, as would be expected. The third PC is essentially a soils/geology component reflecting the measure of baseflow contribution relative to runoff - when BFI is high, SPR tends to be low, as these variables are strongly correlated. This could be described as a measure of 'flashiness' - when BFI is low, the frequency of flood events tends to be higher, but the duration is lower. The fourth PC is less easy to interpret, comprising some measure of magnitude of high flows relative to low flows beyond the relationships already characterised in the first three components. The fifth PC does not yield to an intuitive explanation other than that variability in aspect will tend to be high (low values of ASPVAR) when DPLCV is higher, reflecting drainage path configuration, and altitude and slope tend to be low, which may suggest this accounts for a tendency for catchments with a more 'open' configuration to be in lowland areas. PC6 is even more difficult to interpret owing to the use of circular statistics for ASPBAR. These last three components are not readily explainable and account for relatively little of the variance, hence they are not considered further.

The results of the analysis in terms of the first three PCs (Table 7) accord well with other multivariate analyses of catchment characteristics. A PCA undertaken during the NERC Flood Studies Report (NERC, 1975), based on a much smaller set of catchments, identified three groups of variables reflecting measures of size, steepness and permeability. Similarly, Demuth (1993) identified factors characterising scale, climate and relief in a factor analysis (closely related to PCA) of catchments in the Black Forest, Germany.

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6
LDP	0.007	**0.402**	-0.010	-0.040	0.062	0.000
DPLBAR	-0.002	**0.407**	-0.013	-0.042	0.028	0.021
DPLCV	0.072	-0.054	0.035	0.036	**0.351**	**-0.340**
ALTBAR	**0.378**	0.013	0.016	-0.046	-0.130	0.084
DPSBAR	**0.396**	-0.029	-0.055	0.040	0.018	-0.071
ASPBAR	-0.006	0.007	-0.015	-0.017	-0.061	**-0.846**
ASPVAR	-0.101	-0.092	0.041	0.048	**-0.462**	-0.098
AREA	-0.054	**0.423**	-0.005	0.013	-0.139	0.005
SAARPE	**-0.370**	0.004	-0.029	-0.031	0.007	-0.149
SAAR6190	**0.331**	-0.032	0.041	0.104	-0.032	-0.197
PP	**-0.356**	-0.012	-0.072	-0.038	-0.060	0.088
BFIHOST	0.006	-0.010	**-0.540**	-0.010	0.014	-0.055
SPRHOST	0.094	0.003	**0.450**	0.011	-0.002	0.098
FRE3	0.102	-0.019	**0.394**	0.046	-0.008	-0.066
DUR3	0.015	0.019	**-0.371**	**0.562**	-0.069	0.042
VOL3	-0.008	**0.411**	-0.002	0.117	-0.069	-0.046
MF	0.063	**0.385**	0.029	0.020	0.008	-0.012
Q_{95}	-0.070	0.003	-0.088	**-0.634**	-0.080	0.027
SK	-0.169	-0.011	0.247	**0.482**	-0.037	0.074
RIV.ALT	0.202	-0.059	0.004	-0.056	**-0.405**	0.133
RIV.SLOPE	0.011	0.049	-0.005	-0.011	**-0.649**	-0.139
RIV.D.SOURCE	0.011	**0.389**	0.014	-0.049	0.081	-0.005
RIV.SOURCE.ALT	**0.359**	0.060	0.072	-0.056	0.057	0.003
% Variance	27.4	24	9.6	5.6	5	4.5
% Cumulative variance	27.4	51.4	61	66.6	71.6	76.1
Eigenvalues	6.6	5.8	2.3	1.3	1.2	1.08

Table 7 Table of loadings for all variables on the first six principal components from the PCA. Loadings over 0.3 are highlighted yellow.

<u>Extension to Northern Ireland</u>

For confirmation, the analysis was extended to Northern Ireland by carrying out a separate PCA which included only the FEH descriptors which could be automatically derived. For 48 sites which could be located on the UK DTM grid, a reduced range of catchment descriptors was derived, and a PCA carried out following the same procedure as outlined above, including varimax rotation of the PCs.

Only the first three of these PCs had Eigenvalues greater than one. For these PCs, loadings are shown in Table 8. Clearly, the same gross pattern of variability is captured by the first three PCs, which suggests that the original PCA carried out with the full range of variables is likely to be valid in summarizing the variability across the UK as a whole, including Northern Ireland.

Table 8 Results of second PCA applied to entire UK including 48 sites from Northern Ireland

	PC1	PC2	PC3
LDP	0.002	**-0.559**	0.001
DPLBAR	-0.002	**-0.560**	0.002
ALTBAR	**0.528**	-0.049	-0.078
DPSBAR	**0.621**	-0.002	0.068
ASPBAR	0.122	0.079	0.143
ASPVAR	-0.059	**0.310**	-0.077
AREA	-0.018	**-0.517**	-0.021
SAAR6190	**0.558**	0.049	-0.030
BFIHOST	0.046	-0.007	**0.717**
SPRHOST	0.059	-0.009	**-0.669**
% Variance	33	30	13
% Cumulative Variance	33	63	76
Eigenvalues	3.19	2.98	1.27

Outcomes of analysis - selection of catchment descriptors

The results of the PCA applied to the 733 catchments suggest that three variables with high loadings on the first three PCs could be used to characterise variability in catchments across the UK. On the first PC, ALTBAR, DPSBAR and SAAR all have high loadings, and are well correlated with each other as would be expected - variability in this component reflects the broad NW/SE gradient of relief and rainfall across the UK, as shown by the maps of the distribution of ALTBAR and DPSBAR across the UK (Figure 7 and Figure 8). Evaporation decreases concomitantly, as expressed by its negative relationship with SAAR. This variable is not easily derived, so SAAR or ALTBAR, DPSBAR would be the most appropriate. Source altitude is the site-based variable that has the highest loading on this PC, being well correlated with catchment altitude.

Area has the highest loading on PC2. The catchment configuration variables LDP and DPLBAR also have high loadings, but as area is the most intuitive of these variables, being a direct measure of catchment scale and hence related to flow magnitude and variability, it is preferable as a classification variable rather than the other variables which also account for catchment configuration (also important in determining flow patterns, but in a less intuitive way). Mean flow could also be used to represent this axis, as Mean Flow estimates are also available for DTM grid points (LF2000). The high loading of VOL3 suggests that this PC axis captures variability in the magnitude of flood events, which is well correlated with gross mean flow. Area is plotted in Figure 9. Clearly, the distribution of area reflects the drainage network of the UK, with area values being nested down catchments and largest values for the major UK catchment areas such as the Thames, Severn, Trent, Wye and Tweed.

BFIhost has the highest loading on PC3, and is the most intuitive index to use, being effectively a measure of the contribution of stored sources to runoff, and hence a measure of permeability. The distribution of BFIHost over the UK is controlled to a large extent by the distribution of the major aquifers, as shown in Figure 10, with the highest BFI values being concentrated in the Chalk areas of the lowlands of Southern and Eastern England. BFI is also related to water chemistry through the influence of geology on, for example, alkalinity.

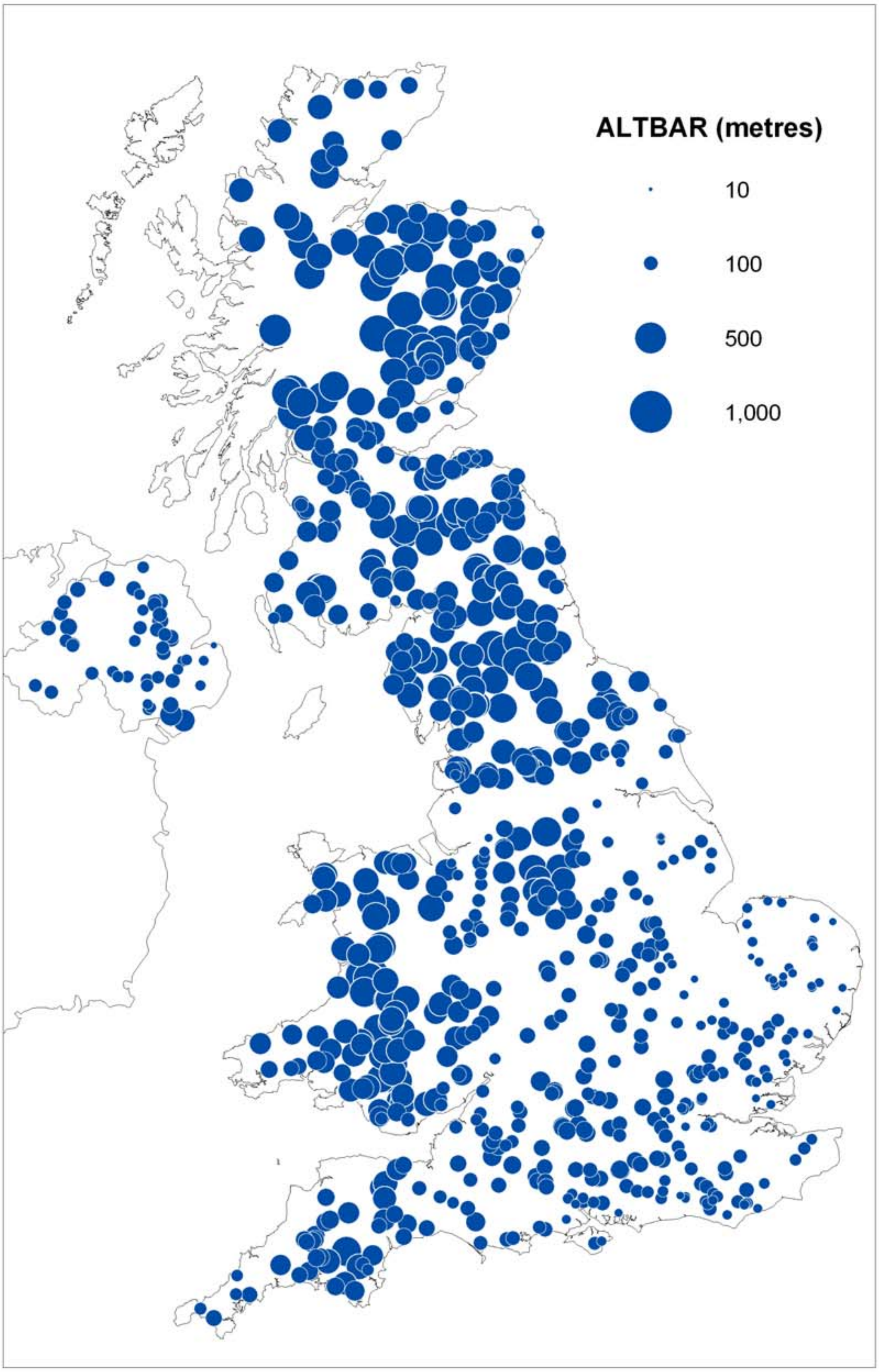


Figure 7 Distribution of ALTBAR over the UK using proportional symbols

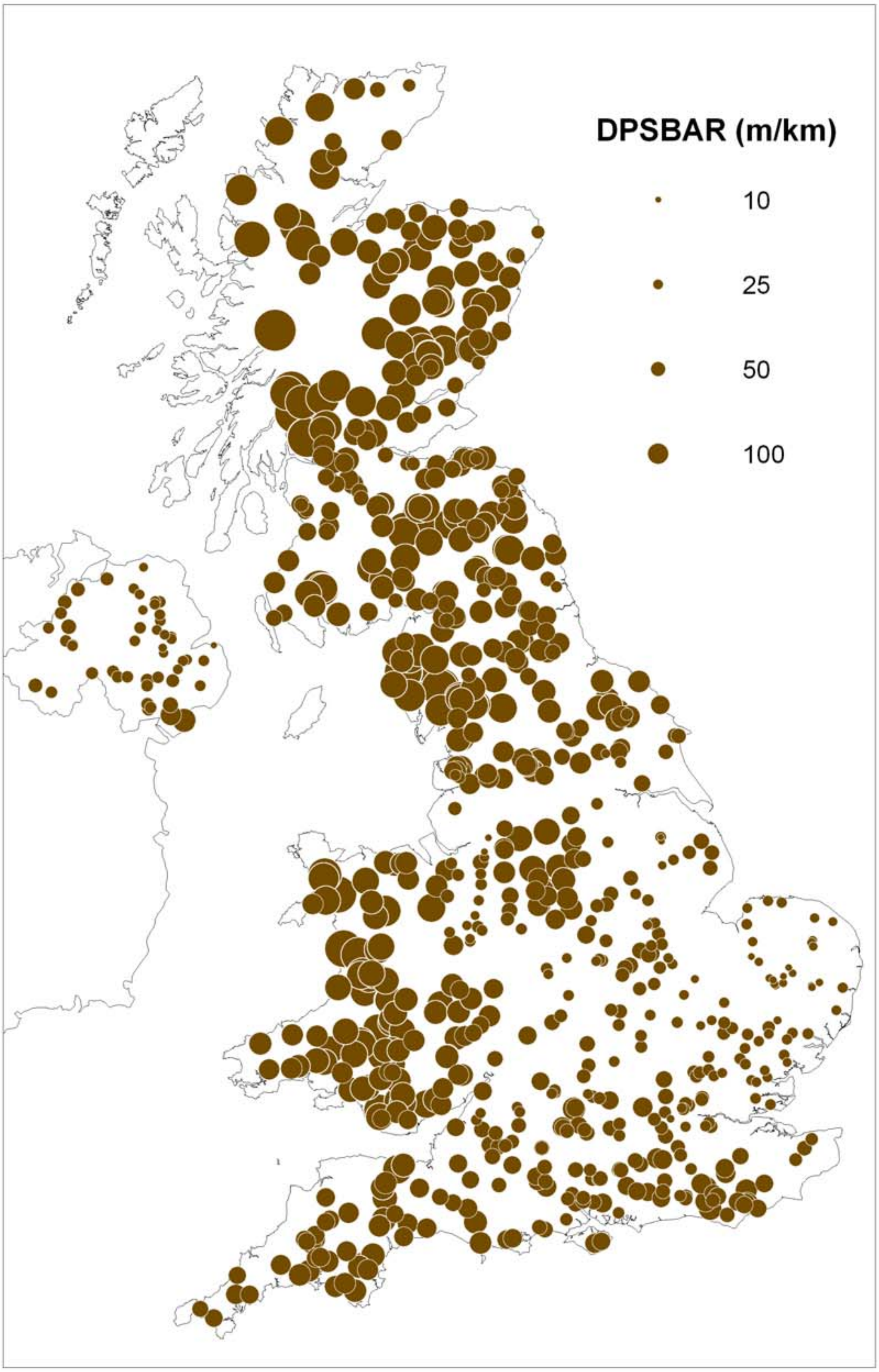


Figure 8 Distribution of DPSBAR across the UK using proportional symbols

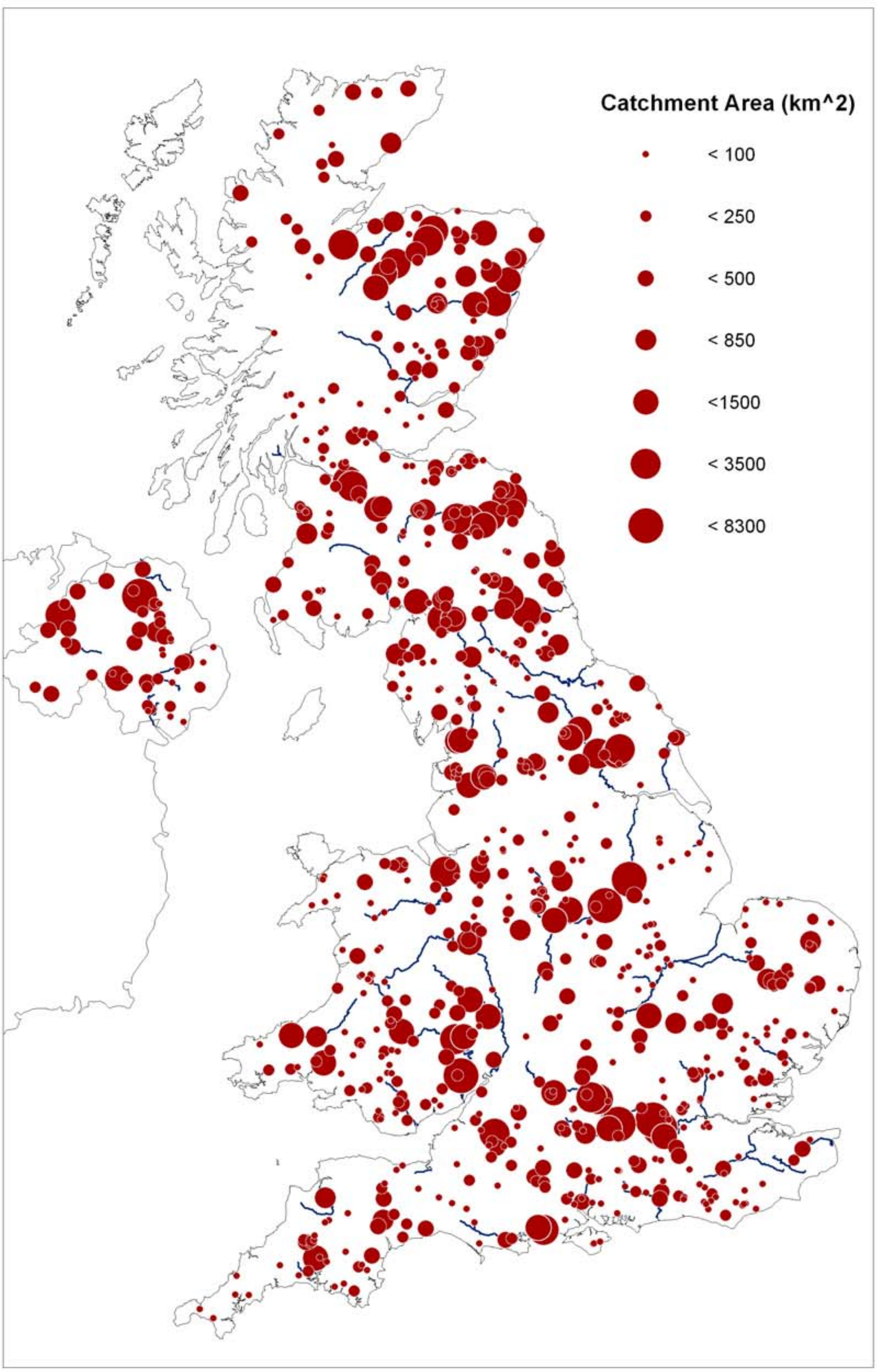


Figure 9 Distribution of AREA over UK using graduated symbols, showing selected major rivers

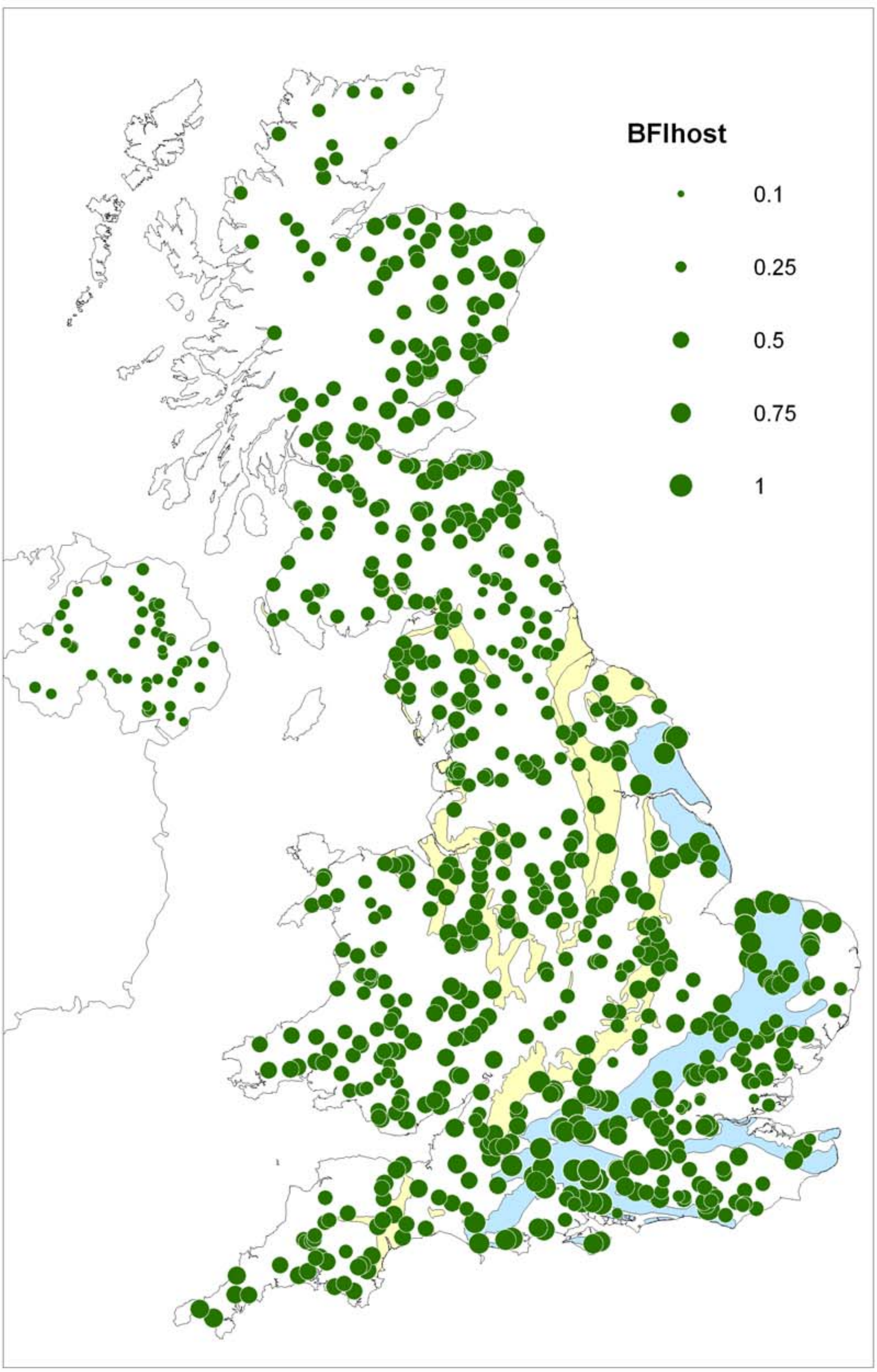


Figure 10 Distribution of BFIHost over UK using proportional symbols, showing location of chalk aquifer in blue and other major aquifers in yellow

2.5 Linking biology to physical variables

Hydrological catchment descriptors for predicting macrophyte types

The results of the PCA analysis were used to select a limited number of catchment characteristics to test for their predictive capability. These were SAAR, ALTBAR, AREA, DPSBAR and BFIHOST.

These catchment descriptors were then derived for the macrophyte sites used in this study. As there were no automatically available characteristics for the macrophyte sites, these had to be derived using the IHDTM, in the same manner as used to derive catchment characteristics for the gauging stations used in the PCA. However, the macrophyte sites first had to be 'snapped on' to the 50m DTM grid in order to be able to run the programs used to derive the characteristics. This was problematic, owing to the fact that the grid references used to locate macrophyte sites were derived from maps and subject to some uncertainty. Consequently, bespoke code was used to search for DTM gridpoints within a 500m^2 area of the macrophyte sites. The largest of these points in terms of catchment area was then selected, as this was most likely to be the main stream on which the macrophyte site was located. However, the matches frequently had to be manually checked on a GIS to avoid incorrectly assigning sites to the wrong stream branch at confluences. Hence, deriving this dataset was a laborious and time consuming task, although the methodology developed enables the derivation of catchment descriptors for future locations. The new set of macrophyte locations snapped on to the 50m grid was then used to derive the five characteristics described above, and additional validation was undertaken to check no spurious matches had affected the derivation of the data.

Altitude and slope at site were added to the list of five catchment characteristics. Altitude is recorded in the JNCC database, however there are a significant number of missing entries, recorded as zero. The CEH software tools (Dawson et al., 2002) were used to find the altitude of all sites and, where possible, the terrain slope at the sites. Substrate data were also extracted from the JNCC database, as it is known to be an important controlling variable. Finally, each site was assigned to a hydroecoregion.

Figure 11 shows box plots for ALTbar, DPSbar, SAAR and BHIhost. It can be seen that BFIhost differentiates river water body type 2 (Chalk rivers) and to a lesser extent types D1 and D2. SAAR values show a progression from dry A1 to wet D2. Maximum slope increases from A to D, but the minimum stays constant and the means are not significantly different. The box plot in Figure 12 for AREA shows that D2 are the water bodies with the smallest drainage areas, with A1 and B2 the largest, but AREA does not discriminate clearly between types.

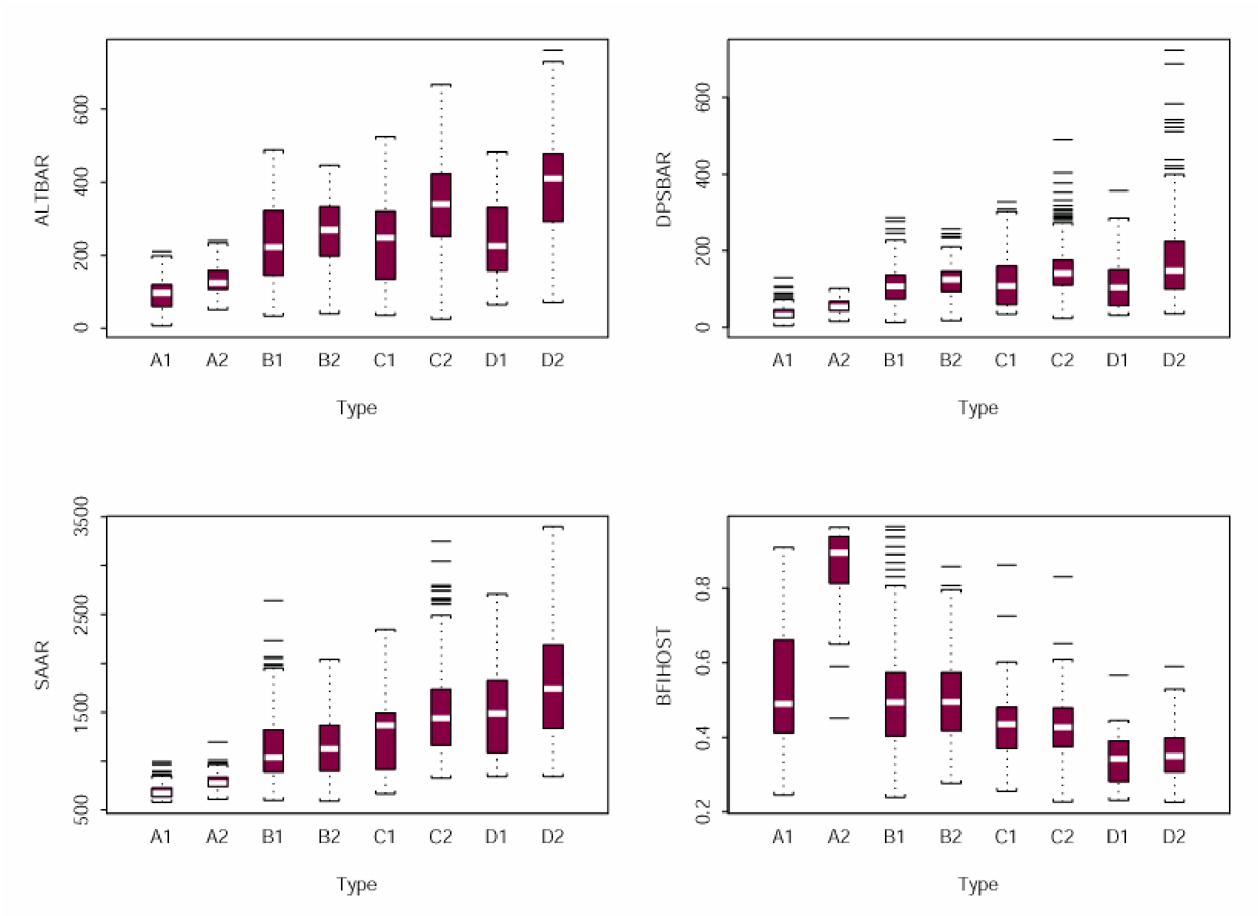


Figure 11 Boxplots showing distribution of key catchment descriptors for the eight Generic River Types. Boxes show inter-quartile range and whiskers show range, with outliers flagged as separate dashes.

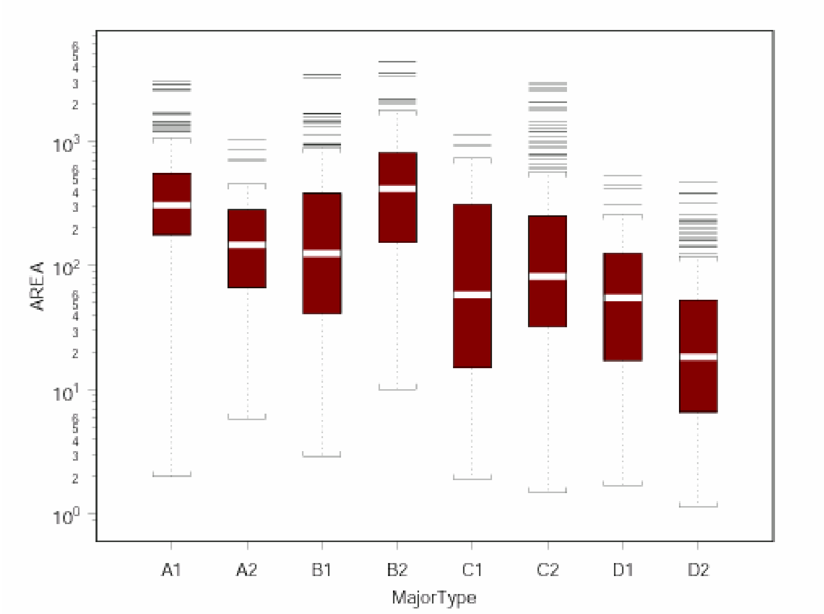


Figure 12 Boxplot showing distribution of catchment area for eight generic types on a log scale

Relating macrophyte types to WFD System A classes

The System A catchment typology has been developed for the reporting component of the Water Framework Directive (REFCOND, 2003; UKTAG, 2003), using three catchment properties and ranges (Table 9).

Table 9 Catchment parameters and ranges used in WFD System A typology, yielding 27 types

Altitude (mean catchment)	Catchment Size (km^2)	Dominant Geology
< 200m	10 – 100	Siliceous
200 - 800m	100 – 1000	Calcareous
< 800m	1000 - 10,000	Organic

.

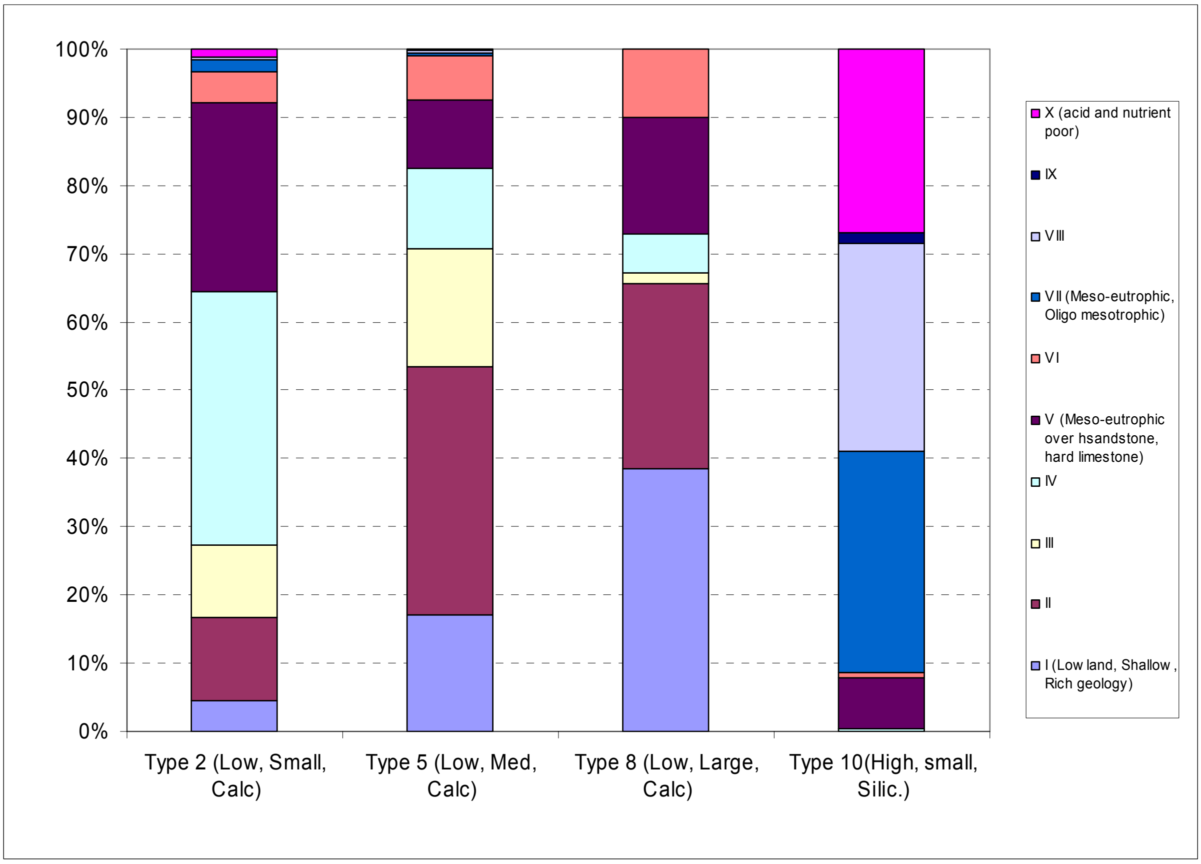


Figure 13 Percentages of macrophyte communities (from Holmes et al, 1998) occurring in 4 System A water body types

This typology has been applied to the river network of Great Britain, using catchments delineated between major nodes of the stream network; of the 27 types generated by this system, there are 18 types which are significantly populated (UKTAG, 2003). The WFD system A typology is thus based on *a priori* classification and yields discrete classes, and has the particular benefit of being based on only three parameters which are readily derived from existing spatial datasets. The typology can therefore be rapidly applied, for large areas, from a desktop setting. However, the classifying parameters and ranges used are relatively arbitrary and no conclusive assessment has been undertaken on the ecological relevance of the typology. Figure 13 shows the proportions of macrophyte community types occurring in 4 key water body types. It can be seen that each type contains a wide range of macrophyte communities and does not help in distinguishing water bodies according to their botany

Modelling macrophytes and catchment characteristics

Two statistical tools for classification were compared; recursive partitioning (rpart, Therneau and Atkinson, 1997) and linear discriminant analysis (lda, Venables and Ripley, 2000). In both cases the aim was the same, to predict some pre-defined class membership based on a set of explanatory variables. Both techniques can handle continuous explanatory variables; categorical explanatory variables (e.g. a code for type of geology) are better handled in rpart.

Lda finds linear combinations of the explanatory variables which maximise the differences between the classes. Rpart constructs hierarchical binary classification trees, giving a series of splits based on cut-points in the explanatory variables (e.g. SAAR >= 710mm). Rpart produces a more easily interpretable typology as it gives categories for the explanatory variables, it can also handle non-linearities in response. Lda is more suitable when the classes respond to smooth gradients in the explanatory variables.

Tree-based methods, as their name suggests, produce tree diagrams which depict the hierarchical relationship between the groups, with lengths of vertical lines proportional to the dissimilarity between sub-groups.

Any tree-based method needs to be used carefully as over-fitted models can easily be produced: ie they fit the data very well but lack general explanatory capability. There are many techniques for counteracting this, including cross-validation (testing the model on data not used to build it) and producing many trees on random subsets of the data. Because of time constraints, these methods have not been applied in this project.

In general, the tree-based models performed slightly better than the discriminant models, so only the results for the tree models are shown here.

Initial modelling was undertaken with eight classes, labelled A1, A2, B1, B2, C1, C2, D1, D2. Several sets of a reduced number of classes were tried:

A,B,C,D
A, BC1, C2D
A1, A2, BC, D
A1, A2, BCD1, D2

In addition the eight classes were also modelled separately for each hydro-eco-region (Figure 4) . The SAAR variable was excluded from these models as rainfall is a key variable in defining the hydro-eco-regions themselves. Results for eight classes are presented in Figure 14and Table 10, for eight classes with hydro-eco-regions in Figure 15 -Figure 17, and Table 11, plus compared in Table 12. Results for the four class model are presented in Table 12 and Figure 18.

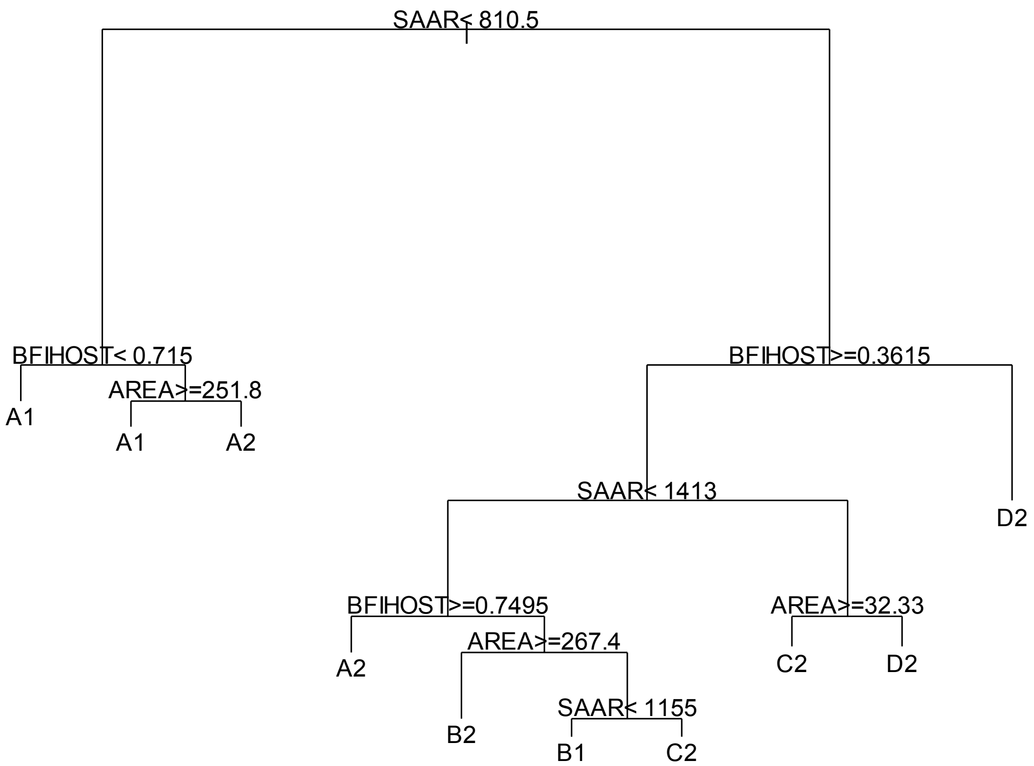


Figure 14 Tree-based model for 8 macrophyte classes (left branch = yes; right branch = no to the logical test stated at the top of the branch)

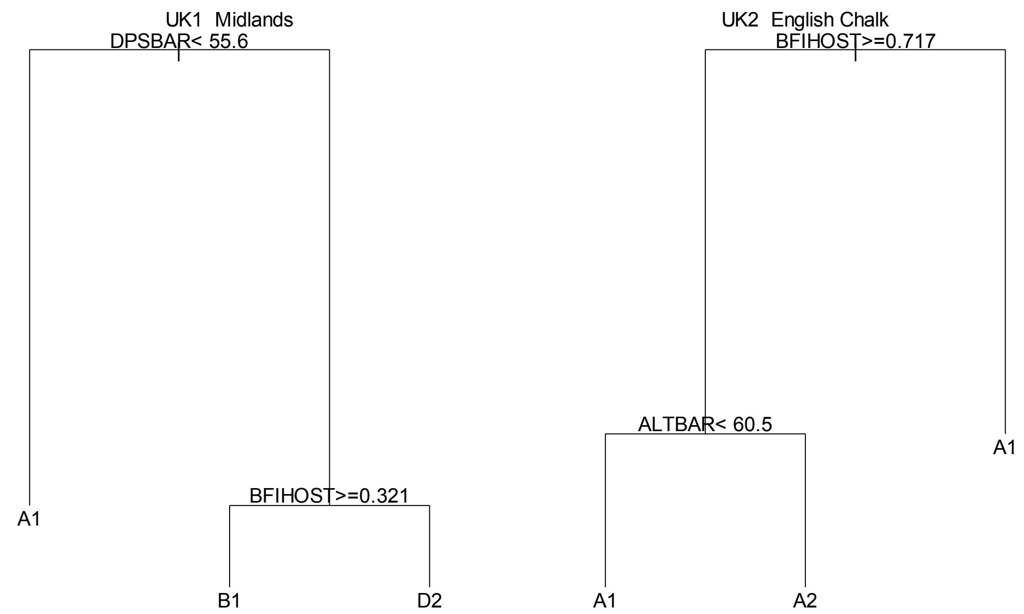


Figure 15 Tree models for hydro-eco-regions UK1 and UK2 (left branch = yes; right branch = no to the logical test stated at the top of the branch)

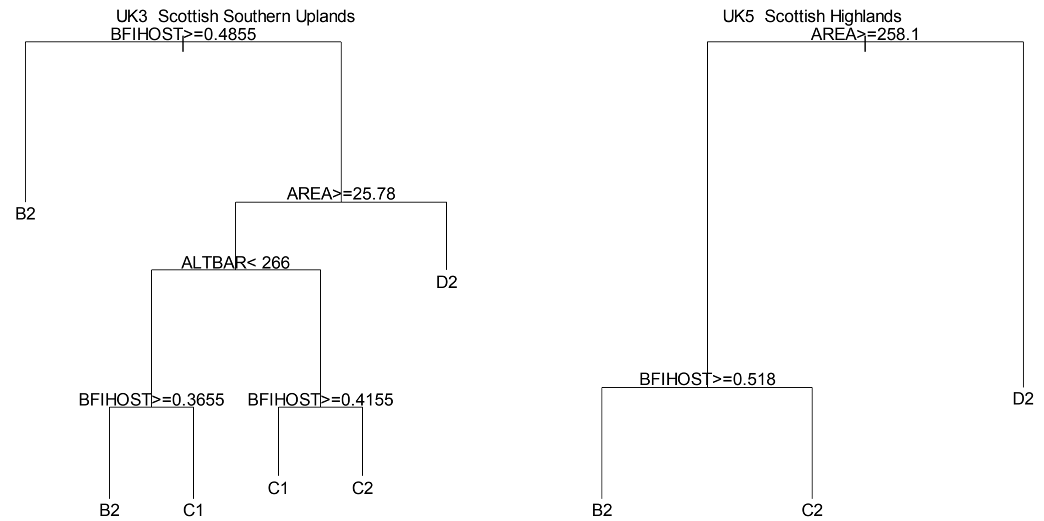


Figure 16 Tree models for hydro-eco-regions UK3 and UK5 (left branch = yes; right branch = no to the logical test stated at the top of the branch)

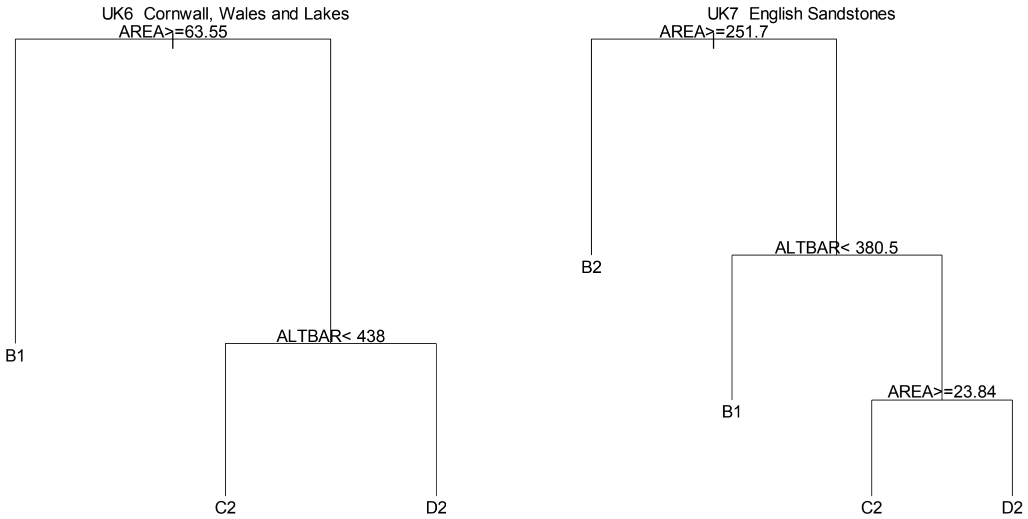


Figure 17 Tree models for hydro-eco-regions UK6 and UK7 (left branch = yes; right branch = no to the logical test stated at the top of the branch)

Table 10 Comparison of predictions for eight class model

	“True” site class Numbers of sites									Proportions of total number of sites							
Predicted class		A1	A2	B1	B2	C1	C2	D1	D2	A1	A2	B1	B2	C1	C2	D1	D2
	A1	**204**	12	19	14	5	0	0	0	**87**	16	7	7	9	0	0	0
	A2	16	**62**	15	4	1	1	0	0	7	**84**	5	2	2	0	0	0
	B1	2	0	**97**	34	10	27	2	5	1	0	**34**	17	19	10	7	3
	B2	13	0	66	**105**	5	40	0	0	6	0	23	**52**	9	15	0	0
	C1	0	0	0	0	**0**	0	0	0	0	0	0	0	**0**	0	0	0
	C2	0	0	59	35	18	**120**	4	29	0	0	21	18	33	**45**	14	15
	D1	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	**0**	0
	D2	0	0	27	8	15	76	22	**154**	0	0	10	4	28	29	79	**82**
Total		235	74	283	200	54	264	28	188								

Table 11 Comparison of predictions for eight class model with hydroecoregions at top level

	“True” site class Numbers of sites									Proportions of total number of sites							
Predicted class		A1	A2	B1	B2	C1	C2	D1	D2	A1	A2	B1	B2	C1	C2	D1	D2
	A1	**205**	5	30	9	7	2	2	8	**87**	7	11	5	13	1	8	4
	A2	19	**61**	12	2	0	0	0	0	8	**82**	4	1	0	0	0	0
	B1	9	7	**186**	80	14	82	2	8	4	9	**66**	40	26	31	8	4
	B2	2	0	18	**96**	5	7	0	0	1	0	6	**48**	9	3	0	0
	C1	0	0	0	1	**10**	5	3	1	0	0	0	1	**19**	2	12	1
	C2	0	1	24	8	14	**125**	9	34	0	1	9	4	26	**48**	35	18
	D1	0	0	0	0	0	0	**0**	0	0	0	0	0	0	0	**0**	0
	D2	0	0	10	4	4	40	10	**137**	0	0	4	2	7	15	38	**73**
		235	74	280	200	54	261	26	188								

Table 12 Comparison of % correctly classified for tree models with and without eco-region

Class	Without hydro-eco-region	With hydro-eco-region
A1	87	87
A2	84	82
B1	52	66
B2	52	48
C1	0	19
C2	48	48
D1	0	0
D2	82	73

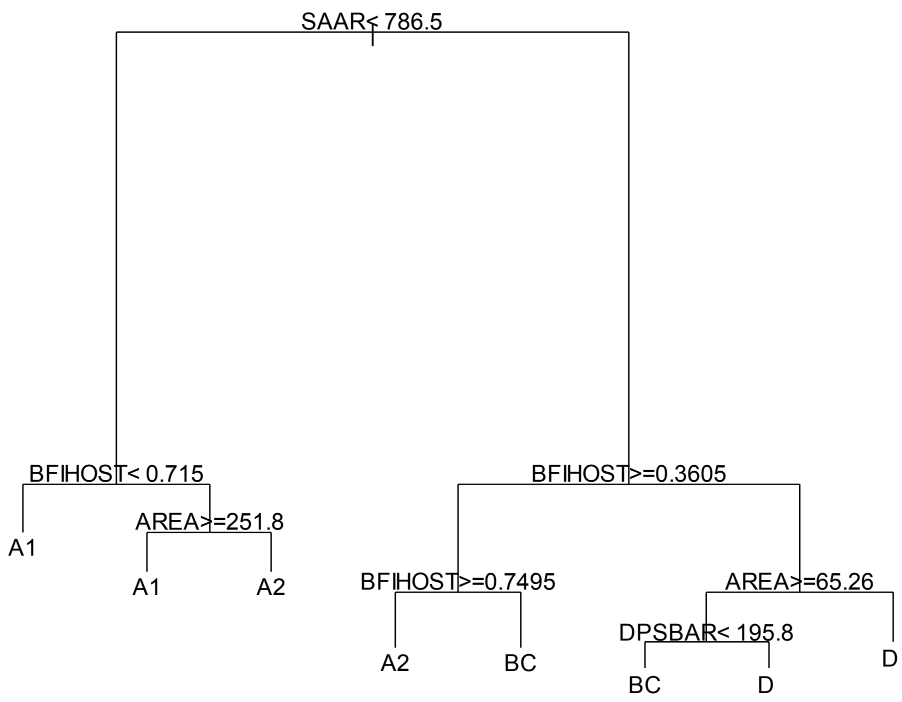


Figure 18 Tree model for four classes (left branch = yes; right branch = no to the logical test stated at the top of the branch)

Overall, whichever model is chosen, types A1, A2 and D2 are reasonably easy to define based on the chosen hydrological catchment descriptors. The other classes are much more difficult to separate, indeed the models above which do separate the B and C classes may not be very effective in assigning new sites to their correct class. This is because the classes are not discriminated very clearly using the physical characteristics available. Classes C1 and D1 are difficult in that they contain relatively few sites which have a wide geographical distribution.

Table 13 Comparison of predictions for four class model

	"True" site class Numbers of sites					Proportions of total number of sites				
		A1	A2	BC	D		A1	A2	BC	D
Predicted class	A1	195	8	26	0	A1	83	11	3	0
	A2	20	66	21	0	A2	9	89	3	0
	BC	20	0	714	106	BC	9	0	89	49
	D	0	0	40	110	D	0	0	5	51
Total		235	74	801	216					

Classes A1 and A2 are split based on rainfall (SAAR) if this is included in the model. This is most likely to reflect a geographical split as the A sites are generally in the south east.

ALTSITE and SLOPESITE variables did not add to the explanatory power of the FEH descriptors, neither did any substrate variables. This is not to say that these variables are not important, just that they are either correlated with other variables, or influence the community in more subtle ways that have not been revealed by the analytical techniques we have used. Further research in this area may produce more explanatory models.

The results for the model with the hydroecoregions for the top level suggest that these do enable a better discrimination of the B and C classes (although still not as good as the discrimination of A and D2 in any of the models). The discrimination of the A and D2 classes is slightly worse in the hydroecoregion model.

<u>Use of substrate data</u>

The only characteristic used in the analysis which reflects geology is BFIHOST. The PCA identified BFIHOST as an important control of variability, but this characteristic primarily reflects permeability and - whilst there will be some relationship between this variable and channel composition - it gives only a limited indication of geological characteristics which may be influential on site hydromorphology. It was thought that the composition of the substrate, as included in the JNCC survey database, is an existing site-based set of variables that have potential utility as an additional variable for discriminating between types.

The average breakdown of the percentage occurrence of each substrate type for the eight generic types is shown in Fig 18.

The graph shows some differentiation between substrate types. In general, the proportion of substrate coarser than pebbles increases dramatically between the A types and other types; accordingly, the proportion of Silt and Clay decreases between A types and the others. There is some indication of the transition from lowland to upland between these types, although this is far from smooth; D1 and C1 are more similar to each other than C2 or D2, and both generally reflect coarser characteristics than the B types. These contrasts suggest that substrate may improve the rpart predictions. In addition, A1 and A2 are discriminated by the amount of gravel, as would be expected from the chalk streams which comprise A2.

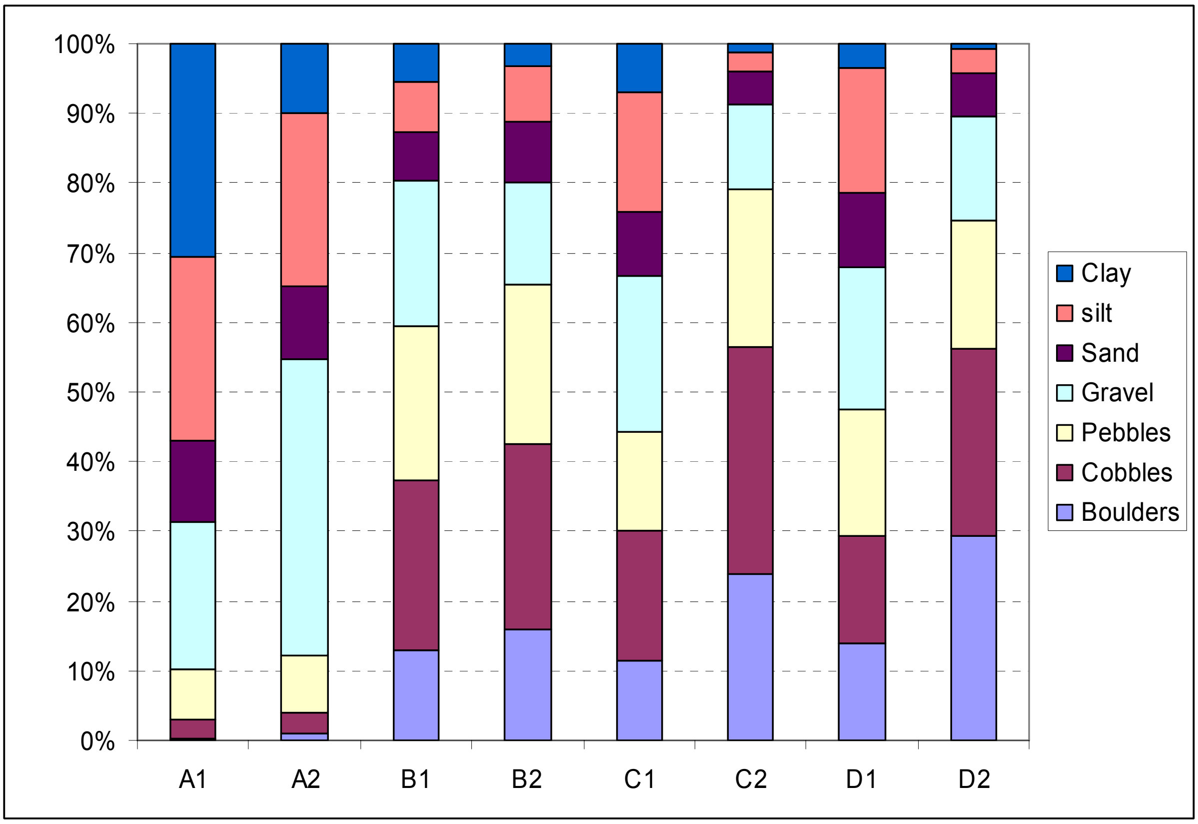


Figure 19 Substrate composition for the eight generic river types, using substrate data from the original JNCC survey

In order to derive a single index suitable for the rpart modelling, the substrate data were simplified into three variables: % > gravel and % sand, silt and clay, and then the dominant class, which was derived by extracting the class with the highest proportion at each site. The rpart models were run incorporating these data, but it was found that there was no significant improvement gained by using the substrate data.

Despite this outcome, it is quite possible that differences in substrate composition may be exerting some influence on the differing macrophyte communities in the middle range of types which are less well discriminated by catchment-based variables. Further work is needed to establish whether the existing data can be analysed in an appropriate manner to improve classification at this level. However, equally it must be remembered that substrate is a site variable, so any improvements in classification gained from its inclusion would have to be offset against the requirement for site based data in implementing the typology.

2.6 Recommended typology

The 8 class model for predicting to which type any water body will belong is reasonably successful. The major problem is its lack of ability to predict water bodies in types C1 and D1. Type 1 can be predicted according to geographical location, ie. the boundaries of the English Lowland Heath (e.g. New Forest), Scottish Flow Country and Western Isles will need to be defined.

Type C1 is widely scattered around Britain (Table 2, Figure 2) and thus readily determined by geographical location. Most type C1 river sites are classified mainly as C2 or D2 using the tree-based model, with which they have similar characteristics.

Use of hydro-eco-regions did not improve the performance of the model; only prediction of type B1 was improved, so this additional complexity was felt to be unnecessary.

Substrate has the potential provide additional discrimination between types, but considerable more assessment and analysis of the data would be required to take this forward.

The sib-division of class A2 into headwater and downstream areas could be based on a simple threshold of drainage area of 100 km^2.

3. DEVELOPING RIVER WATER BODY ENVIRONMENTAL STANDARDS

3.1 Defining indices of hydrological alteration

Stage 1 of the project reviewed environmental standards and parameters included a literature review to identify the full range of parameters for both rivers and lakes that may need to be controlled and the circumstances in which they are significant. In tandem with this work, a review and appraisal of existing standards, both within the UK and internationally was carried out to determine where there are any gaps – i.e. any parameters that have been identified as relevant but for which there are no existing UK or international standards available.

The results of Stage 1 were presented in a report, whose main conclusions were:

- Most countries have various methods of determining environmental flows, each defined for a different purpose, *e.g.* scoping or impact assessment.
- Licensing of reservoir releases and abstractions present quite different problems, and different methods have been developed to deal with these issues. With reservoir releases, the flow regime is likely to be subject to significant management (apart from very large floods that by-pass the dam), since it needs to be created. Abstractions, by and large, have no impact on high flows and so the focus is on low flow impacts.
- Where data are scarce, expert opinion is used, and increasingly a formal structured approach to getting consensus amongst a group of experts, including academics and practitioners, is favoured.
- There is wide acceptance that all parts of the flow regime have some ecological importance. As a result, there is a growing move away from single low flow indices towards environmental flows.
- Many methods determine environmental flows in relation to the natural flow regime of the river. Some methods define flow in terms of site characteristics, such as flow per unit width needed for salmon migration in Lancashire, but it has not been possible to examine the data or the basis of these derivations. Other methods define environmental requirements in terms of more direct hydromorphological elements, such as water depth and velocity.
- Small scale studies have shown that flow interacts with morphology to define physical habitat (such as width, depth, velocity and substrate) for specific organisms. These quality elements vary spatially; water is deep in pools and shallow on riffles; velocity is high in riffles and low in pools. Standards based on these quality elements at the broad water body scale cannot be readily defined. To implement standards at the reach scale, site data are essential.
- Implementation of the WFD will require that environmental standards are applied for all water bodies regardless of hydrological and ecological data available. Consequently, standards are required that can be applied without having to visit the water body or collect excessive data. This means that standards must be related to parameters that can be obtained from maps or digital databases, such as river flow, catchment area or geology. Any resulting standards will have less predictive power at a local scale and cannot be tested using site data.
- A hierarchical approach may be needed in which a broad scale approach, perhaps based on flow, is used as a screening tool to assess all water bodies. A more detailed approach, perhaps based on depth or velocity, may be applied to a smaller number of sites identified as requiring close attention.
- The natural flow regime is complex and is characterised by timing, magnitude, duration and frequency; all of which are important for different aspects of the river ecosystem. To produce operational standards, there is a need to identify a

small number of parameters that capture its most significant characteristics. For example the number of high flow events greater than three times the median flow has been shown to be related to the structure of macrophyte and macro-invertebrate communities in New Zealand (Clausen, 1997).

The main outcome of Stage 1 was that the regulatory parameter for environmental standards for rivers at a broad scale should be flow, since data on potentially more ecological meaningful parameters, such as depth and velocity are not widely monitored and cannot be determined without detailed surveys at all sites. Since flow varies greatly between water bodies, generic flow standards need to be expressed in dimensionless terms, such as proportions of natural flow or unit flow per drainage area or channel width. Nevertheless, UK agencies should develop a hierarchical approach to standards, where broad scale methods based on flow are used for screening, but detailed scale methods based on more directly ecologically meaningful parameters, such as depth and velocity, are used for site level impact assessment and license setting.

The flow regime of a river or level regime of a lake is often a complex time-series, rising and falling in response to precipitation, snowmelt, geology and catchment conditions. Many of the methods used around the world to set environmental standards for water resources are based on the premise that freshwater aquatic ecosystems are adapted to natural variations in the hydrological regime and are thus dependent upon them. For example, the Building Block Methodology (BBM) developed in South Africa (Tharme and King, 1998; King *et al.* 2000) recognises that river ecosystems are reliant on basic elements (building blocks) of the flow regime, including low flows (that provide a minimum habitat for species, and prevent invasive species), medium flows (that sort river sediments, and stimulate fish migration and spawning) and floods (that maintain channel structure and allow movement onto floodplain habitats). Richter *et al* (1996) analysed the magnitude (of both high and low flows), timing (indexed by monthly statistics), frequency (number of events), duration (indexed by moving average minima and maxima) and rate of change of natural flow regimes. They defined 32 parameters that were considered to be relevant to the river ecosystem. This was reduced to 8 key parameters in a redundancy analysis (Poff *et al*., 2000) as many of the 32 original indices were inter-correlated. Richter *et al* further suggested that initial flow management targets could be that all parameters should be within 1 standard deviation from the natural mean. The method has been adapted for analysis of Scottish rivers by Black *et al* (2000). However, precise ecological relevance of these parameters has not been defined and the 1 standard deviation threshold has never been tested.

Alterations to the hydrological regime due to abstractions, impoundments, diversions and river basin transfers can have very diverse impacts on any of these indices depending on their type, infrastructure and operation. To make the process of defining environmental standards for water resources manageable, it is necessary to organise all the possible hydrological alterations into a few scenarios for which ecosystem impacts can be analysed. The simplest approach is to consider two scenarios of hydrological alteration: (1) abstraction (directly from the river or aquifer supplying the river) and (2) impoundment where abstracted water is taken from a reservoir.

(1) Abstraction
Abstraction licenses may be complex, allowing different volumes to be taken at different times and according to different hydrological conditions. However, we will consider only a constant abstraction of a fixed volume of water, which will reduce the entire regime. Figure 20 shows a natural river regime (in blue) and the regime for the

same period given a constant abstraction of 0.06 m^3s^{-1}. It is evident that the abstraction is having a greater proportional impact at low flows; it is having no impact on timing of floods and very little impact on their magnitude. Because of this, the focus of environmental standards to manage abstractions is on low flows.

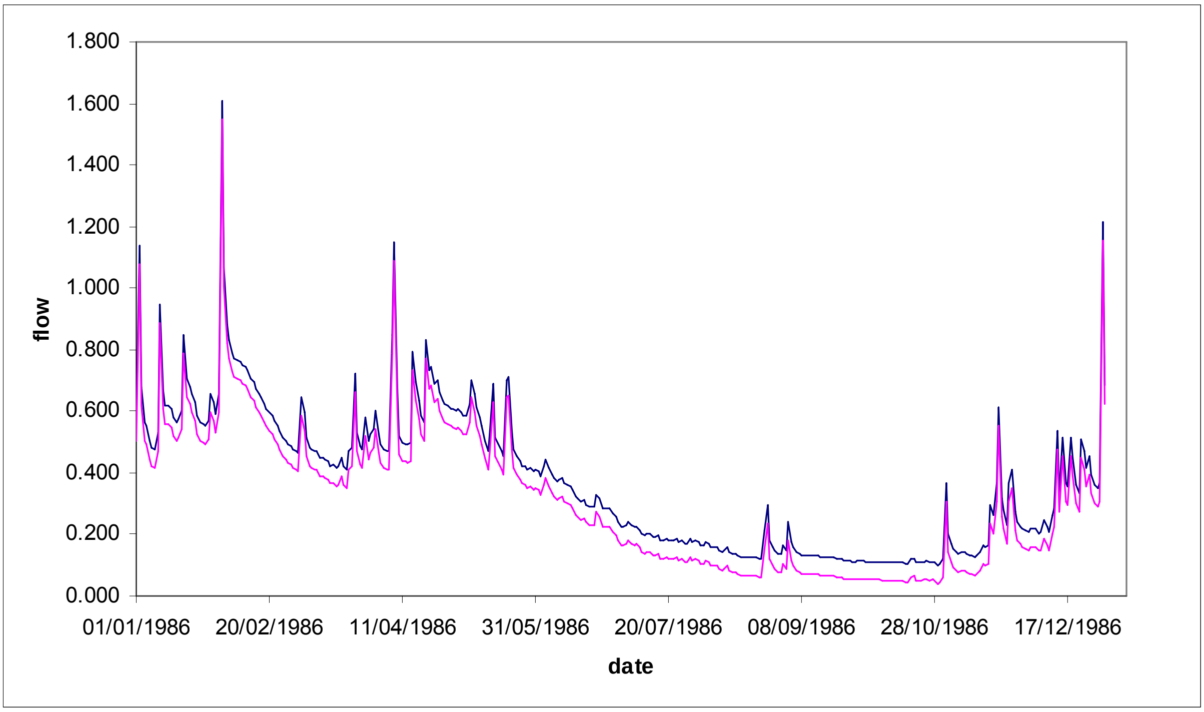


Figure 20 River flow regimes: natural (blue) and impacted by a constant abstraction of 0.06 m^3s^{-1} (pink)

(2) Impoundment
Impoundments can have even more complex impacts on the hydrological regime than abstractions depending on the size of the weir or dam, settings of sluice gates or release structures, level and size of spillways and dam operation. However, to make the exercise manageable we will consider a single impoundment scenario. Figure 21 shows the same natural flow regime (in blue) as Figure 20 and the regime for the same period with an impoundment in place. In this case, there is a constant compensation flow release from the dam of 0.13 m^3s^{-1}. It can be seen that in the late summer/early autumn the compensation flow is greater than the natural flow. Major floods in February, April and December pass the dam via the spillway. However, small floods in late Spring, Summer and Autumn disappear from the hydrograph as water is stored in the reservoir.

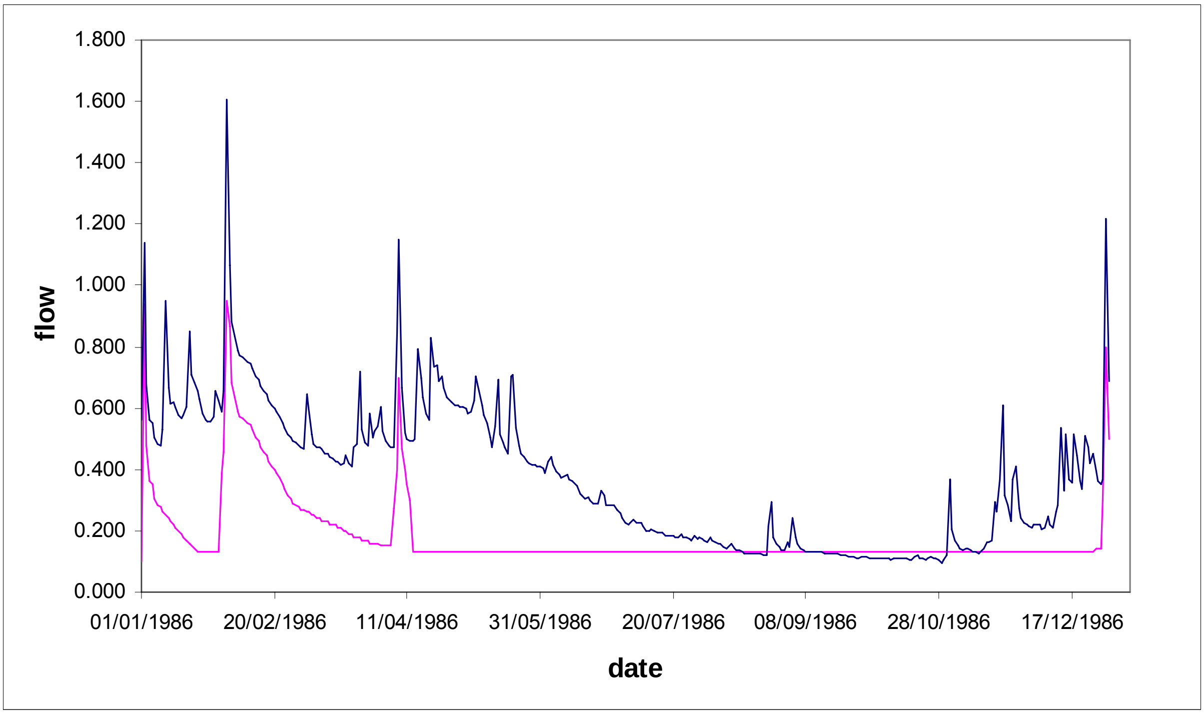


Figure 21 River flow regimes: natural (blue) and impacted by an impoundment with a constant compensation flow of 0.13 m^3s^{-1} (pink)

The two scenarios require different types of management: *restrictive and active* (Acreman and Dunbar, 2004). Abstraction needs *restrictive management*, in which environmental protection is achieved by restriction of practices by, for example, a “hands-off” flow (HOF) (Barker & Kirmond, 1998) where abstraction is permitted provided that the flow is above a certain critical value, but must reduce or cease when the flow falls below this value. The flow may continue to fall, but this will be at a natural rate governed by meteorological and geological conditions, not due to artificial influences. Reservoir control requires “*active management*” in which environmental protection is achieved by actively making releases from a reservoir.

Different levels of (compensation) flow releases could be made at various times of the year and for many dams (depending on the release gate structure) freshet or flood releases can be made such the various ecologically important elements of the flow regime can be generated (e.g. low flows in summer, higher flows in winter, spates in autumn) as in the Building Block Methodology.

It is recognised that the two scenarios do not include the operation of dams for hydro-power generation. This can have significant impacts on the hydrological regime of the river and its downstream ecosystem. In particular, the flow downstream of hydro-power dams reflects power demand, exhibiting very high rates of change over time; with sudden massive increases and decreases as turbines are turned on and off. There is currently insufficient knowledge on critical rates of change of flow to set generic standards on hydro-power operations.

3.2 Good Ecological Status or Good Ecological Potential

The Water Framework Directive requires member states to achieve good ecological status (GES) in all surface and ground waters. GES is defined qualitatively as slight deviation from the reference status, based on populations and communities of fish, macro-invertebrates, macrophytes and phytobenthos, and phytoplankton. Exceptions to the Directive are permitted for water bodies that are designated as heavily modified water bodies (HMWB). Most effort in identifying and designating HMWBs has focused on physical alterations to water bodies, such as dams, bridges, weirs and concrete embankments (Dunbar *et al*, 2002). For such water bodies, the aim is to achieve good ecological potential (GEP); a lower status than GES. HMWBs are beyond the scope of this project, so environmental standards for water bodies containing dams are not required. However, the impacts of a dam can be felt in water bodies some way downstream (often until the next significant tributary inflow) that are not themselves designated as HMWBs. These impacts may be in terms of flow regime or water quality. Work for the World Commission on Dams (Acreman *et al.*, 2000) identified a range of ecological impacts of dams including altered flow regime, reduced sediment load, reduced temperature and presence of chemical produced by stratification of water in the reservoir, such as hydrogen cyanide.

The Common Implementation Strategy for the WFD, Guidance note 4 "Identification and Designation of Heavily Modified and Artificial Water Bodies" states that "… substantial hydrological changes that are accompanied by subsequent non-substantial morphological changes would be sufficient to consider the water body for a provisional identification as HMWB." Furthermore, even if a water body is eventually designated as a HMWB, the flow regime to achieve GES is required as a part of the designation process.

It is important therefore to consider whether GES can be achieved by both restrictive and active management and whether their environmental standards must be identical. As stated abstractions reduce the entire flow regime but maintain natural variability, which is an ecologically important characteristic. In theory a dam could be operated such that its flow releases mimic natural patterns, although this would need a complex system that linked the flow signal in an unregulated reference catchment to the operations of the sluice gate which would need to be altered perhaps daily, called a translucent dam. In practice this would be difficult to achieve. A more realistic question is whether GES can be achieved by less frequent alterations to the gates settings through, for example, a building block approach (Figure 22); dispensing with short term natural variability. A major problem is that if the water body is heavily modified, even a natural flow may not achieve GES. For example, a dam may trap sediment and releasing naturally high flows below the dam may cause major erosion. Likewise naturally high flows in a concrete lined straight channel may create velocities beyond the swimming speed of fish which would be detrimental if sufficient refugia were not available. In such cases, the best that can be achieved is GEP; *i.e.* the flow regime that gives the ecological status given the limitation of other quality elements. Achieving GES may not be possible.

This issue is addressed below.

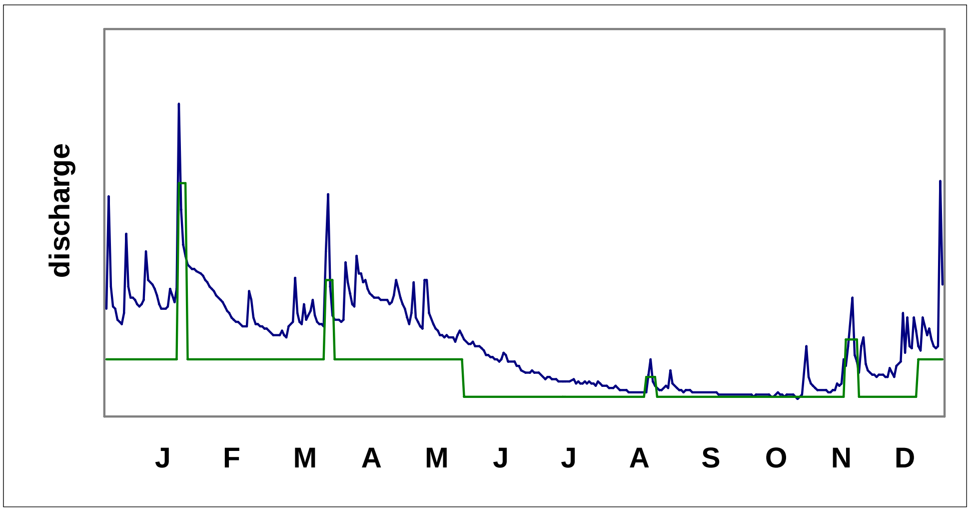


Figure 22 The Building Block Approach. The blue line shows one year of a natural regime for a catchment. The green line shows a flow release pattern from a reservoir that maintains some key elements of the flow regime (low flows in summer, higher flows in winter

3.3 Defining expert-based standards

To define the standards, a workshop was held in Edinburgh on 8 April 2005 at which experts on macrophytes, macro-invertebrates and fish were present, plus more general experts in river and lake management from Environment Agency of England and Wales, Scottish Environment Protection Agency and Environment and Heritage Service Northern Ireland. The workshop report is attached as Annex 1. The fish experts requested a subsequent meeting, which was held on 28 April 2005. The report of this meeting is given as Annex 2.

Workshop participants felt strongly that insufficient knowledge was available to define precise generic environmental standards. Instead their thinking was based on a precautionary approach by considering incrementally higher levels of flow alteration and deciding at what level of flow alteration we could no longer be certain that good status would be achieved.

A series of broad concepts emerged:

1. Standards derived from expert knowledge were the best available, but should be considered as first approximations. Wherever possible, local data and knowledge should be used to refine the standards. Major scheme might require an Environmental Impact Assessment. In most cases this would most likely lead to less stringent standards (i.e. allowing greater alteration of the hydrological regime), since the expert consensus reached at the workshops was precautionary.

2. Suitable conditions for river biota are controlled by many factors including water depth, flow velocity, temperature and light. River flow discharge is not a direct driving variable and only impacts indirectly through its interaction with channel geometry to create depth and velocity and through dilution effects. Ideally, environmental standards should be set on the basis of direct variables, but

insufficient data are available and these variables are not monitored widely or easy derivable. Broad standards can be set on the basis of flow discharge for river types in which channel geometry can be assume to be similar. Any follow-up detailed studies must consider the direct variables, such as depth and velocity, particularly in river water bodies where the channel geometry has been altered, for example by channel widening, deepening or construction of weirs or embankments.

3. In general standards are specified in terms of deviations from the natural flow regime. The reference natural flow regime considered would be the actual regime of the past 50 years or so, plus abstractions and minus discharges, or simulated from models such as Low Flows 2000. This would not account explicitly for changes in climate or land use. In exceptional circumstances the reference flow may be the gauged flow, for example where the flow has been augmented by major discharges for a long historical period, such as the River Don in Yorkshire.

4. With some variations, flow regimes should be within about 20% of natural to achieve GES. This is consistent with English Nature flow targets of 10% abstraction for rivers designated as Special Areas of Conservation (SACs) under the Habitats Directive which is broadly equivalent to high status.

5. In the restrictive management standards defined, there was wide support given for the idea of preserving Q_{95} flow by designating this as a “hands-off” flow. The concept being that when the river flow drops to and below Q_{95}, abstraction either stops or is significantly reduced.

6. Explicit seasonal variations in standards may not be required if the abstraction levels are defined in terms of seasonal flow statistics; e.g. hands-off flow is Q_{95} for that season.

7. It is difficult to define environmental standards for a simple screening approach to active management that are different from those for restrictive management; *i.e.* standards for GES can not be defined for “normal” infrequent operation of sluice gates which did not reproduce natural daily fluctuations of river flow. Such seasonal alterations in compensation flow releases plus occasional freshets and floods could achieve GEP.

8. If restrictive management standards for GES are applied to impoundments, then they will fail. The implication of this is that further detailed studies will be required for all impoundments beyond the screening approach.

3.4 Macrophytes

Details of expert standards defined for macrophytes are given in the workshop report in Annex 1. The standards are summarised in Table 14 below.

The river water body types relate to the generic typology based on Holmes *et al.* (1998) shown in Table 2.

The standards have a potential inconsistency implementation in that abstracting 20% of flow when the flow is just above Q_{95} will reduce the flow below the HOF of Q_{95}. In practice, abstraction will need to reduce gradually as the flow reaches HOF.

Table 14 Summary of expert standards defined for macrophytes

Restrictive flow management	(1) abstraction	For autumn and winter periods for all rivers types, permissible abstraction levels are 20% of total flow on the day. In spring/summer, for B2 and C1 types the critical level is also 20%; for other types critical level is 10%. HOF is Q_{95} in March – May period for all types.
Active flow management (GEP only - see restrictive management standards for GES)	(2) floods	For all river types floods events of 5-7 times the median flow are important and need to be maintained at 20-30% of natural occurrence (*e.g.* one day duration on small catchments).
	(3) compensation flow	For all river types continuous flow releases need to be maintained at Q_{95}. For types C2, D1 and D2 it is important to ensure that the flow (of around Q_{95}) fluctuates by + 100% / - 50% to maintain periodic inundation/drying of bryophytes.

3.5 Macro-invertebrates

Details of expert standards defined for macro-invertebrates are given in the workshop report in Annex 1. The standards are summarised in Table 15 below.

The river water body types relate to the generic typology based on Holmes *et al.* (1998) shown in Table 2.

Table 15 Summary of expert standards defined for macro-invertebrates

Restrictive flow management	(1) abstraction	For all seasons permissible abstraction levels are the same. A2, B1, C2 and D2 types require highest levels of protection with 10% permissible abstraction; A1 rivers require lowest level at 30%. For other types the critical level is 20%. HOF is seasonal Q_{97} for all river water body types.
Active flow management (GEP only - see restrictive management standards for GES)	(2) floods	For all periods flood requirements are the same. Lowest protection needed for A1 (40%) and D2 (50%) of natural flooding regime. A2 and D1 require highest protection at 80%. B1 and C2 require 60%, B2 and C1 require 70% of natural flooding regime.
	(3) compensation flow	For all periods continuous flow releases are the same. For good ecological status flows should be as (1) abstraction. For good ecological potential, highest requirements are for D2 rivers at Q_{60}. For B1, B2, C1, C2 rivers, flow release should be Q_{70}. For A2 and D1 Q_{80}. Lowest requirements are for A1 rivers at Q_{90}.

Modelling of the response of LIFE score to flow

The analysis in this section was undertaken by CEH as part of the EU Framework 6 project "REBECCA" (Relationships between the ecological and chemical status of surface waters), and is provided as a free contribution to project WFD48 in order to facilitate its dissemination.

In addition to the expert input to defining standards, analysis was undertaken of LIFE (Lotic Invertebrate index for Flow Evaluation) score data, calculated from according samples of macroinvertebrates according to the method of Extence *et al* ,1999. This analysis was based on a subset of the 290 sites collated for the Environment Agency LIFE GRC (Generalised Response Curves) project. This dataset only includes sites close to gauging stations which have not been subject to any chronic water quality problems. From this dataset, 29 sites were subsequently excluded for various reasons, principally that they had a habitat structure unsuitable for LIFE analysis, had intermittent water quality problems or had very low flow variability downstream of a reservoir. A further criterion was that there should be at least 5 autumn samples taken in the 14 year period of record (1990-2003). All these criteria together left 186 sites which were used in this analysis. This dataset has 1662 samplings, of which 1573 were lab sorted. Of the 186 sites, 144 are deemed broadly natural (following procedures undertaken in the CEH-Environment Agency Low Flows 2000 and generalised rainfall-runoff modelling projects) and 42 hydrologically impacted. Of the gauges linked to the 186 macroinvertebrate sampling sites, one is linked to 8 sites, three to 3 or 4 sites, 24 to 2 sites and the rest to 1 site.

A common set of catchment and site characteristics (hereafter termed environmental variables) was used in the analysis:

Variables calculated at gauge:

- Base flow index
- Mean flow for standard period (this effectively integrates catchment area and effective rainfall)

RIVPACS catchment variables (these can be calculated from GIS data, no missing values)

- Altitude of site
- Distance from source
- Slope (strictly a site variable, but it can be calculated from GIS data so is included here)

RIVPACS site variables (collected when sample taken, some values missing)

- Alkalinity
- Substrate
- Mean depth
- Mean width

Plus Expected LIFE score (ELIFE) from RIVPACS, which is determined from the suite of environmental variables.

The common hypothesis in these analyses was whether the slope of response to LIFE score to flow varied in any systematic fashion with any of the environmental variables. If it did, then this would be evidence for differing sensitivity to flow for different catchment or site types, and thus for differing sensitivity to abstraction or flow regulation.

In each of the following sequence of analyses, LIFE score was expressed in two alternative ways, observed / expected (O/E), where expected score is calculated by RIVPACS, and the raw unstandardised score. Two different formulations for standardising flow variables were chosen: standardised flows (flow divided by mean flow for period of record) and normalised flows ((flow-mean flow)/standard deviation of flow). The latter approach standardises all flows to a common range while the former allows gauges with greater variability around the mean (ie flashier catchments) to retain this variability. In each case, the between site variation in LIFE score is modelled using a two level random effects approach with flows as a fixed effect and environmental variables varying by site, assuming that deviations of site mean scores from an overall mean score can be modelled with a normal distribution with a variance determined from the data. A mean score from each site can be calculated, this is called a BLUP or best linear unbiased predictor.

Analysis 1. univariate relationship between site LIFE score and environmental variables, excluding any flow variables.

Results for raw LIFE score: ELIFE shows a clear relationship as one might expect, virtually all other variables show the expected relationships although the relationship with distance from source is unclear.

Results for LIFE O/E: Here as one might expect the relationships are far less distinct (indicating that RIVPACS is doing its job). BFI shows a positive relationship with LIFE O/E, this has been observed in the LIFE GRC project and is perhaps not surprising as it is not a variable in RIVPACS. This is possibly indicating the under-prediction of RIVPACS ELIFE on baseflow-dominated catchments. Other variables show fairly indistinct relationships aside from slope (slight positive relationship) and substrate (slight negative relationship). These latter two possibly reflect the formulation of the LIFE score to reflect velocity and siltation preferences.

Table 16 Visual assessment of LIFE score relationships with environmental variables (no flow covariates)

	Visual (non-statistical) assessment of relationship[1]
Variables calculated at gauge	
Base flow index	--
Mean flow for standard period	++
RIVPACS catchment variables	
Altitude of site	+++
Distance from source	0
Slope	+++
RIVPACS site variables	
Alkalinity	---
Substrate	---
Mean depth	--
Mean width	+
ELIFE	+++

[1] +++/--- very strong positive / negative; ++/-- strong or obvious; +/- weak, 0 no relationship

Analysis 2. Univariate relationships between raw and O/E LIFE and environmental variables, once within-site LIFE score is related to antecedent flow conditions

The antecedent flow conditions were indexed as the Q_{95} of all the flows in the six months before the sample was taken: this was chosen as it has been shown to be an important flow variable in previous analyses for the GRC project. Results are presented for the two methods of flow standardisation in Figure 23 and Table 17.

For intercept (*i.e*. overall mean LIFE score), the method of flow standardisation does not matter. However it does matter for slopes, flows standardised by mean flow give some positive relationships (Figure 23B), whereas normalised (z-score flows) give no clear relationships (Figure 23A). Note that in the case of comparing slopes, the intercept for the raw scores takes into account part of the “E”. Hence the slope graphs for O/E LIFE and raw LIFE look very similar, the results for O/E LIFE are not shown.

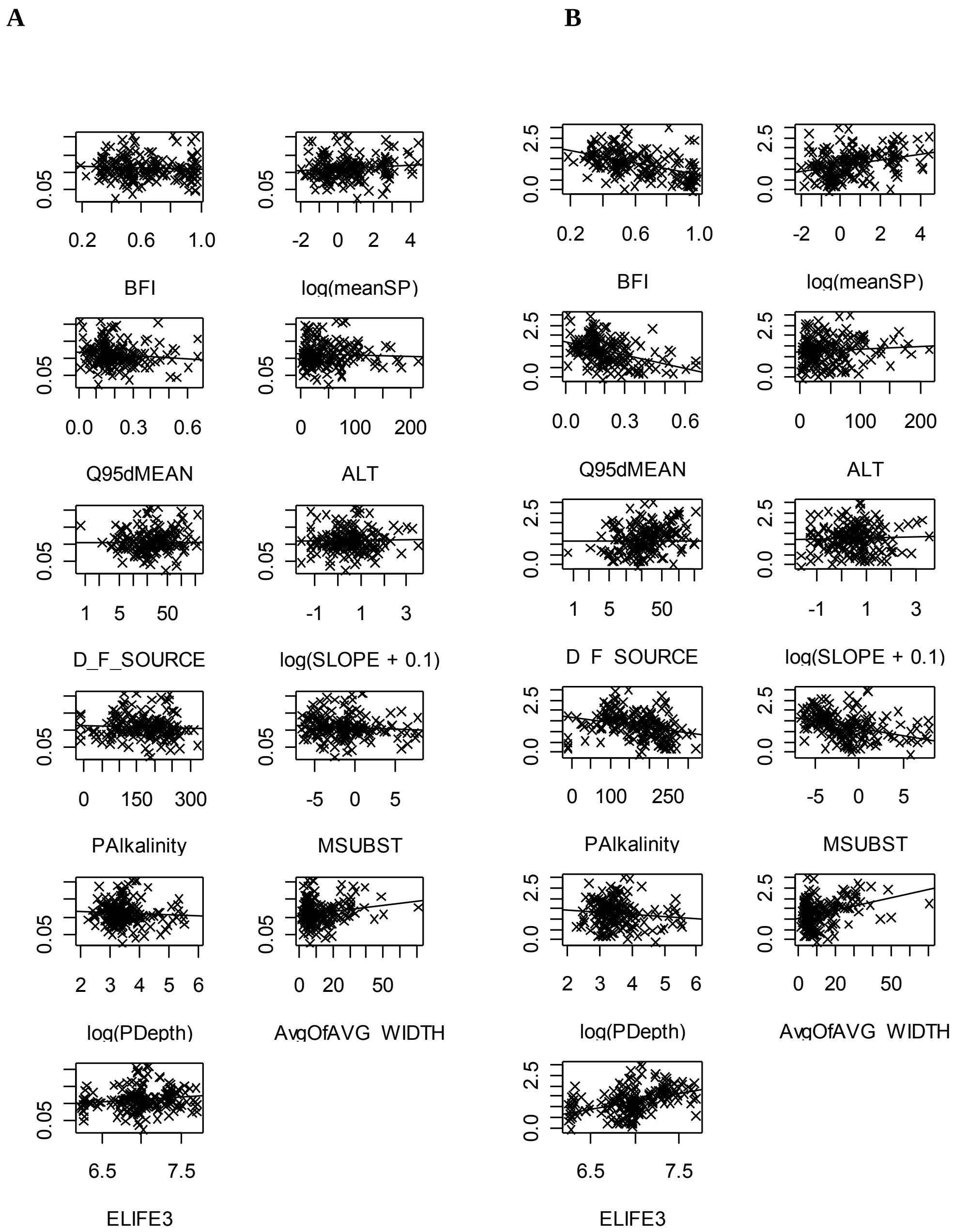


Figure 23 Univariate relationships between slope of LIFE response to flow and site/catchment predictors. A: Flows normalised as z-scores. B. Flows standardised by mean flow. Y axis is slope per unit change in flow, in raw LIFE score units.

Table 17 Visual assessment of LIFE score relationships with environmental variables (one flow covariate): Results for raw LIFE scores

	Intercept		Slope	
Variables calculated at gauge	Z score flows	dMean flows	Z score flows	dMean flows
Base flow index	-	-	0-	---
Mean flow for standard period	+	+	0+	+++
RIVPACS catchment variables				
Altitude of site	++	++	0	+
Distance from source	0	0	0	0
Slope	++	++	0+	+
RIVPACS site variables				
Alkalinity	--	--	0-	--
Substrate	---	---	-	--
Mean depth	--	--	-	-
Mean width	+	+	+	++
ELIFE	+++	+++	+	+++

Analysis 3. Results of multiple regression of raw LIFE scores vs slopes of LIFE to flow (standardised by mean flow).

In the case of flows divided by mean flows, there were several potentially important variables in the graphical analysis. Hence, a stepwise multiple regression was used to try to reduce to a few key variables. The variables retained are summarised in Table 18. ELIFE effectively summarises the entire suite of RIVPACS environmental variables and is retained. Site slope (which is included as a RIVPACS predictor) is not retained as having any extra predictive capability. Of the variables not in RIVPACS, overall long-term mean flow and long-term Q_{95}/mean flow are retained, whereas BFI is not. There is a positive relationship between mean flow and slope of LIFE response and a negative relationship between Q_{95}dMEAN and slope of LIFE response.

Table 18 Retained variables from multiple regression and their standard errors

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-2.0429	0.8031	-2.544	0.011864
log(meanSP)	0.102	0.0269	3.79	0.000209
Q_{95}dMEAN	-1.8103	0.3147	-5.753	4.03E-08
ELIFE3	0.5192	0.1131	4.591	8.57E-06

Overall Conclusions

In Analysis 3 the BFI term is not retained, but another index of flashiness (Q_{95}/mean flow) is. It is perhaps more obvious that ELIFE3 together summarises the effects of all the RIVPACS environmental variables. To recap, we are interpreting sensitivity to flow as change in LIFE score for a unit change in flow.

Thus:

- Sites with higher mean flow are *more* sensitive
- Sites with higher ELIFE are *more* sensitive

- Sites with lower long term Q_{95}/mean flow are *more* sensitive

These conclusions are for the case where flow is standardised between sites as a proportion of mean flow. This means that standardised flow will vary more for flashy rivers than for baseflow dominated rivers. Thus a unit change in flow is more significant in rivers whose Q_{95} is a lower proportion of the mean, in larger rivers, and sites with a higher expected LIFE score (*i.e.* generally more “upland” rivers.

However, when flows normalised as z-scores, i.e. the variability around the mean is standardised as well, none of the site-level explanatory variables are significant predictors. In effect the effects of the site-level hydrological predictor variables are removed.

Hence, if regulation is through licences based on a proportion of a low flow statistic like Q_{95}, there is an inherent compensatory mechanism, and all rivers behave essentially the same. In other words, the characteristics used do not differentiate between the sensitivity to flow change of the sites. This does not mean differences in sensitivity exist.

There are several caveats to this analysis. Firstly, that the ranges of altitudes looked at is not large, there are few sites in the dataset over 200m. This is partly limited by the fact that there are far fewer gauging stations at higher altitudes, but also because the analysis is for England only. Data for Scotland are available, and sample sites are being screened against gauging stations, however they were not available at the time of this report. Secondly, the analyses are based on samples identified to family level, which is the main approach used by the Agency. Species level data may show clearer patterns, although there would be far fewer sites available for analysis.

3.6 Fish

Details of expert standards defined for fish are given in the workshop report in Annex 2. The standards are summarised in Table 19 below.

The 5 river water body types in Table 19 relate to fish community types define at the expert workshop based on information from Cowx *et al.* (2004).

- Chalk stream communities
- eurytopic/limnophilic – roach, bream, tench, pike, bleak
- rheophilic cyprinids – dace, chub, adult resident trout
- salmonids – adult salmon
- salmonids – spawning and nursery areas

There is currently no precise method for defining which fish communities are expected in which river water bodies. Development of a method would need to be the subject of further study.

The definition of restrictive management standards for fish communities have been defined in a more complex way than for macrophytes and invertebrates to avoid the inconsistencies at HOFs. Calculation of permissible abstraction levels involves the addition of permissible takes below each critical point. For example, the standards for Chalk streams are

$< Q_{99}$ 5%, $< Q_{95}$ 10% $> Q_{95}$ 20%

thus permissible abstraction at Q_{90} would be: 5% Q_{99} + 10% (Q_{95} - Q_{99}) + 20% (Q_{90} - Q_{95}).

Table 19 Summary of expert standards defined for fish

Restrictive flow management	(1) abstraction	For Chalk streams (A2) < Q_{99} 5%, < Q_{95} 10% > Q_{95} 20% For eurytopic/limnophylic fish (A1) HOF of Q_{98}. Above HOF 20% abstraction May-June; 50% abstraction July-April. For rheophilic cyprinids (B/C/D) Feb – Jun HOF of Q_{90}, 50% abstraction of flow above HOF. Jul –Jan < Q_{90} 25% <Q_{95} 20% <Q_{99} HOF Adult salmon (B/C/D) HOF is Q_{95}, 50% abstraction of flow above HOF Salmonid spawning/nursery areas (B/C/D) HOF is Q_{95}. 25% abstraction of flow above HOF.
Active flow management (GEP only - see restrictive management standards for GES)	(2) floods	No significant impoundments on Chalk streams (A2) or lowland rivers with eurytopic/limnophylic fish (A1) For rheophilic cyprinids; a large flood (bankfull) November – January For adult salmon (B/C/D) 3 freshets September – November. For salmonid spawning/nursery areas (B/C/D) 3 small and 1 large flood (Q_2) during October – April period
	(3) compensation flow	No significant impoundments on Chalk streams (A2) or lowland rivers with eurytopic/limnophylic fish (A1) For rheophilic cyprinids: Q_{70} during May - July; Q_{95} August - April. For adult salmon: Q_{90} during December – April; Q_{95} May - November. For salmonid spawning/nursery areas (B/C/D): May –September Q_{95} during May – September, Q_{90} October – April.

3.7 Physical character

A project is currently underway, jointly funded by the Centre for Ecology and Hydrology and the Environment Agency, entitled Rapid Assessment of Physical Habitat Sensitivity to Abstraction (RAPHSA). The RAPHSA database contains 65 river sites at which detailed hydraulic data have been collected to undertaken habitat modelling studies, such as PHABSIM. These hydraulic data can be used to study the impact of flow changes on the physical character of river channels. As part of the RAPHSA project, each site was analysed to identify thresholds of change in hydraulic parameters with flow. Figure 24 shows 2 examples of the relationship between average width (for 7 or so cross sections at the site) and flow. Figure 24a shows the River Kennet at Axford, which exhibits a significant reduction in channel width as flows drop between Q_{95}. Figure 24b shows that for the Wissey at Langford the significant break point in the relationship is around Q_{85}.

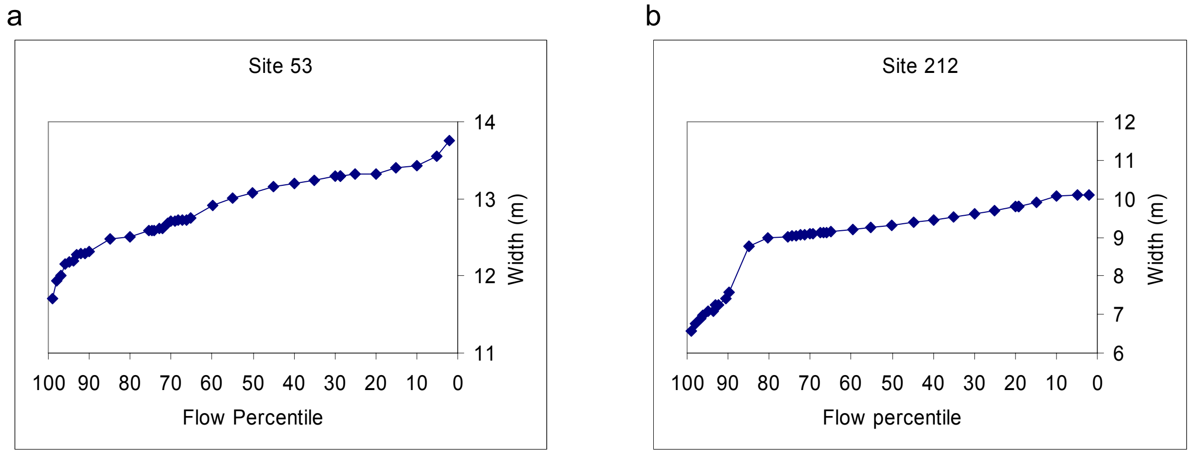


Figure 24 Relationships between flow and average cross-section width at two sites within the RAPHSA database

Each of the 65 RAPHSA sites was analysed to identify break points in these relationships. At many sites the relationship took the form of a smooth curve with no obvious break point. However, threshold points were identified at 36 sites. The range of break points is shown in Figure 25. It can be seen that the model value is around Q_{95} with a mean of Q_{92}. No obvious relationship was found between threshold level and river site type.

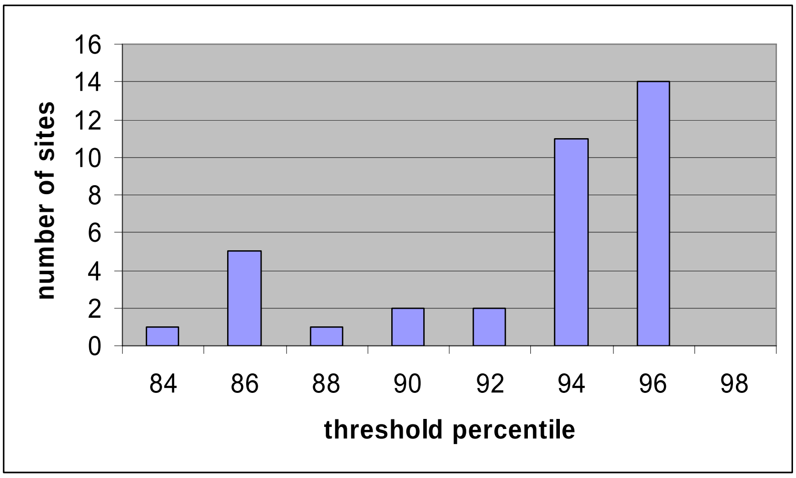


Figure 25 Distribution of threshold in the relationship between flow and width at RAPHSA sites

This analysis suggests that Q_{95} marks a significant point where below which conditions in the river change rapidly and hence the river is more sensitive to flow change. This provides justification for hands-off flows at Q_{95} in restrictive management and maintaining Q_{95} in active management.

Future work in the RAPHSA project will examine these break points at individual cross-sections within each site to assess the variability along river reaches.

3.8 Comparing standards for biotic and a-biotic elements

Sections 3.4 – 3.6 defined expert standards individually for macrophytes, macro-invertebrates and fish. These standards are summarised in Table 20 for comparison. It can be seen that standards for macrophytes and invertebrates are in broad agreement with the only exception being less stringent standards for invertebrates for A1 rivers. All experts felt strongly that protection of the natural low flow regime was very important; they argued forcefully for hands-off flows around Q_{95}). In addition, these two sets of standards vary very little between river types; either 10 or 20%. The experts clearly believe that invertebrate communities in different rivers have different sensitivity to flow change. Such differentiation was not found in the LIFE score analysis, but may be an attribute of the parameters used in the modelling.

Table 20 Comparing expert standards for macrophytes, invertebrates and fish

<table>
<tr><th></th><th colspan="2">Macrophytes</th><th colspan="2">Invertebrates</th><th colspan="2">Fish</th></tr>
<tr><th></th><th>%</th><th>Period</th><th>%</th><th>Period</th><th>% > Q_{95}</th><th>Period</th></tr>
<tr><td rowspan="2">A1</td><td>10</td><td>Mar – May</td><td rowspan="2">30</td><td rowspan="2">All year</td><td>50</td><td>Jul – Apr HOF Q_{98}</td></tr>
<tr><td>20</td><td>Jun – Feb</td><td>20</td><td>May - Jun HOF Q_{98}</td></tr>
<tr><td rowspan="2">A2</td><td>10</td><td>Mar – May</td><td rowspan="2">10</td><td rowspan="2">All year</td><td rowspan="2">20 >Q_{95}
10 <Q_{95}
5 <Q_{99}</td><td rowspan="2">All year</td></tr>
<tr><td>20</td><td>Jun – Feb</td></tr>
<tr><td rowspan="2">B1</td><td>10</td><td>Mar – May</td><td rowspan="2">10</td><td rowspan="2">All year</td><td rowspan="11">50 >Q_{90}
25 <Q_{90}
20 <Q_{95}

50

50

20

20</td><td rowspan="11">Rheophilic cyprinids
Jul - Jan
HOF Q_{99}

Feb - Jun
HOF Q_{90}

Adult salmonids
All year
HOF Q_{95}

Salmonid spawning and nursery
May–Sep HOF Q_{95}

Oct-Apr HOF Q_{80}</td></tr>
<tr><td>20</td><td>Jun – Feb</td></tr>
<tr><td>B2</td><td>20</td><td>All year</td><td>20</td><td>All year</td></tr>
<tr><td>C1</td><td>20</td><td>All year</td><td>20</td><td>All year</td></tr>
<tr><td rowspan="2">C2</td><td>10</td><td>Mar – May</td><td rowspan="2">10</td><td rowspan="2">All year</td></tr>
<tr><td>20</td><td>Jun – Feb</td></tr>
<tr><td rowspan="2">D1</td><td>10</td><td>Mar – May</td><td rowspan="2">20</td><td rowspan="2">All year</td></tr>
<tr><td>20</td><td>Jun - Feb</td></tr>
<tr><td rowspan="2">D2</td><td>10</td><td>Mar – May</td><td rowspan="2">10</td><td rowspan="2">All year</td></tr>
<tr><td>20</td><td>Jun– Feb</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Hands-Off flow is Q_{95} March – May</td><td></td><td>Hands-off flow Q_{97} All year</td><td></td><td></td></tr>
</table>

The comparison with fish standards is slightly more complex, for two reasons. First, the fish community types do not map directly to the 8-fold classification (A1 – D2). Chalk rivers appear in both typologies (A2) and eurytopic/limnophylic fish relate broadly to A1 rivers. However, rheophilic cyprinids could occur in types B1, B2, C1 and C2 whilst salmonids may occur in any river B1-D2.

A further research project is required to define which communities occur in which river water bodies; for example which water bodies would support spawning salmonids and nursery areas. This research could use tree models as in Figure 13 to define fish communities from physical characteristics of river water bodies and their catchments. Fish community data are held by University of Hull (Cowx *et al*, 2002).

The second difficulty arises because the experts defined standards in different ways for fish than for macrophytes and invertebrates. The fish experts provided standards in terms of % abstraction of flow left when Q_{95} has been protected *i.e.* % of residual flow (actual flow - Q_{95}). Figure 26 shows an example flow regime; for flows above Q_{82}, 50% of flow above Q_{95} (actual flow - Q_{95}) allows more abstraction than 10% of total flow; between Q_{82} and Q_{95} the opposite is true.

Overall it can be concluded that the fish standards are less stringent than those for invertebrates and macrophytes at higher flows (above Q_{82} in the example) but more stringent near to Q_{95}. For eurytopic/limnophylic fish (which relate broadly to A1 rivers), for rheophilic cyprinids and for adult salmonids.

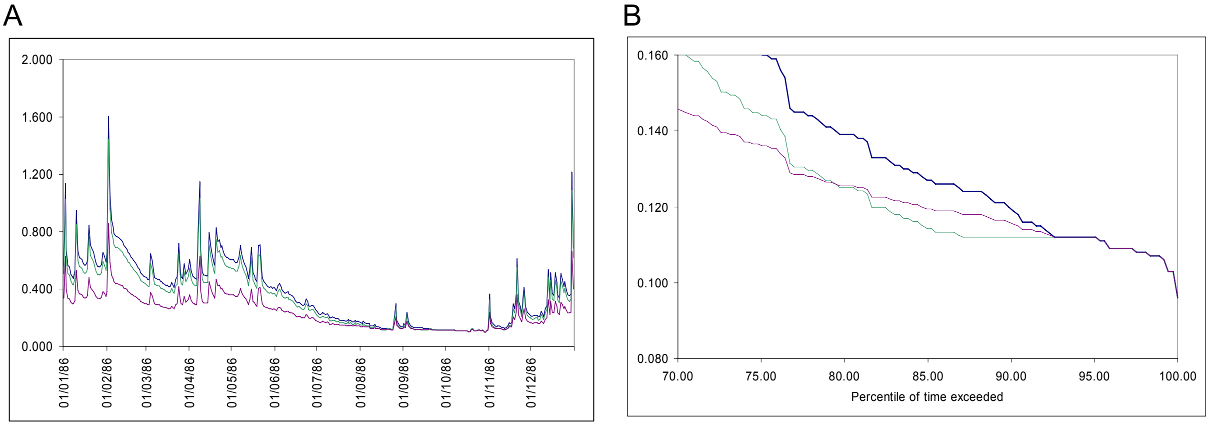


Figure 26 Comparison of natural flow (blue), flow with abstraction of 50% of flow exceeding Q95 (red) and 10% of total flow (green) both with a HOF of Q95. a. hydrograph; b. low flow duration curve.

Table 21 gives the proportion of Q_{95} that can be licensed under the RAM framework of CAMS (Environment Agency, 2002). It can be seen that at Q_{95}, values given by experts for GES are equivalent to moderate to low sensitivity. A major difference is that the RAM framework permits abstraction below Q_{95} whereas for GES no abstraction is permitted below Q_{95}.

Table 21 Abstraction standards from RAM framework (Environment Agency, 2002)

Abstraction flow sensitivity band	Very high	High	Moderate	Low	Very low
% of Q_{95} that can be abstracted	1 – 5	5 -10	10 – 15	15 - 25	25 - 30

It should be noted that the experts felt that good ecological status may not be achieved by making compensation flows (*i.e.* long periods of constant flow) from impoundments, so active management standards are probably only appropriate for good ecological potential (GEP).

The LIFE score analysis suggested that there if regulation is based on low flow statistics, such as Q_{95}, then sensitivity to flow change is not significant between types. However, data available for the analysis did not cover the more upland types. Hence we recommend that the expert consensus should be given highest priority. Nevertheless, the experts did not suggest widely differing standards for different rivers.

The use of Q_{95} as a critical flow point at which sensitivity to flow alteration changes, is supported by analysis of physical river structure from the RAPHSA database.

Table 22 shows the generic river thresholds (standards) proposed by English Nature for designated rivers (SSSI, SAC). These are examples of river water bodies that should be maintained at high ecological status (HES). It can be seen that the standards are in the range 10% reduction from natural flow for sensitive rivers (with 1-5 % below Q_{95}) which is the same as the experts view for rivers of type A2, C2, D2. For rivers of very low sensitivity (in which category A1 river water bodies would be place), reduction levels are 20% (with 1-5 % below Q_{95}).

Table 22 Generic river flow thresholds for designated rivers from English Nature

RAM Environmental Weighting band (sensitivity)	Maximum % reduction from daily naturalised flow		
	flow >Qn50 (average flows)	Flow Qn50-95	flow <Qn95 (low flows)
Very High	10	10	1-5
High	15	10	5-10
Moderate	20	15	10-15
Low	N/A	N/A	N/A
Very Low	20	20	15

4. RIVER WATER BODY RECOMMENDED STANDARDS

4.1 Identifying the type of river water body

In the project workshops, macrophyte and macro-invertebrate experts endorsed the generic 8 type classification of river water bodies based on Holmes *et al*. (1998). After the workshops, the analysis of specific studies, such as the Rivers Itchen (Halcrow, 2004) and Wylye (Dunbar *et al,* 2000), suggested that Chalk rivers should be further divided into two types, since the headwaters and downstream areas exhibited different sensitivities to flow alteration. A threshold drainage area of 100 km^2 was adopted as the division between the sub-types.

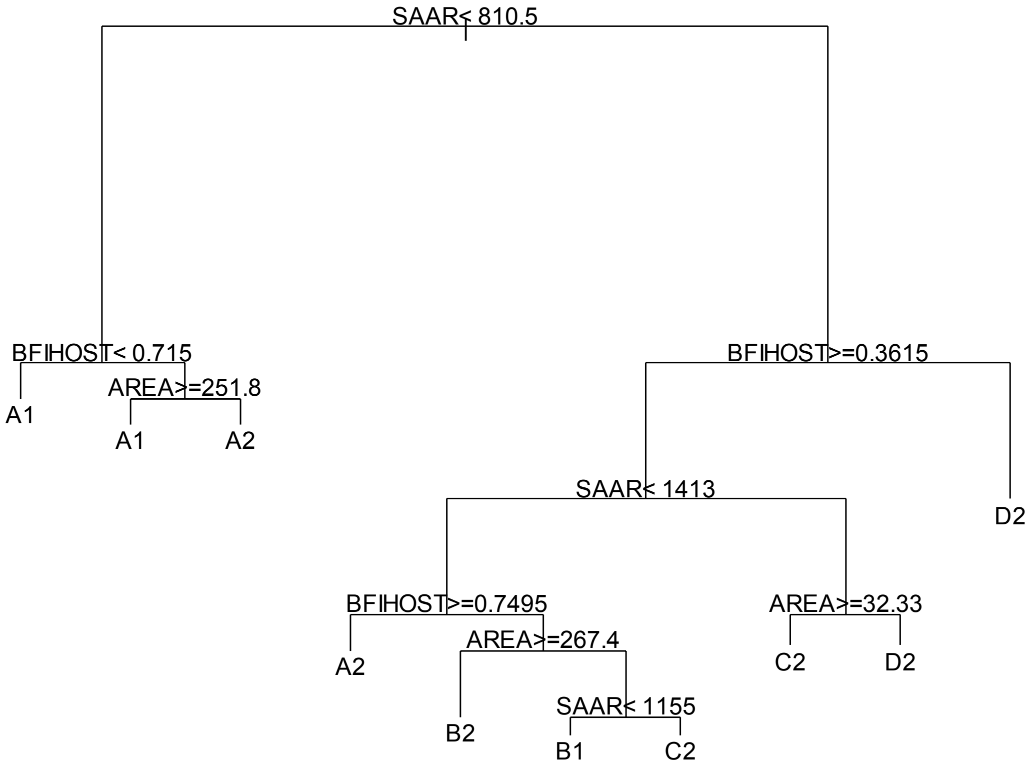
Fish experts recommended an alternative fish-specific typology based on Cowx *et al* (2004). Two of the fish types were equivalent to two of the generic types (A1 with eurytopic/limnophylic fish and A2 with Chalk stream fish). Expert standards for macrophytes and macro-invertebrates were broadly equal to or more stringent those for reheophillic cyprinids and adult salmon (Table 20) so separate types for these were not needed. The fish standards were more severe only for salmonid spawning and nursery areas. The Project Team thus concluded that standards were required for 10 river water body types; the 8 generic types with a sub-division of A2 (A1, A2(hw), A2(ds), B1, B2, C1, C2, D1, D2) plus salmonid spawning and nursery areas.

Table 23 Recommended method for classifying river water body types

river water body type	at site biological data	catchment data
A1 / eurytopic/limnophylic fish	macrophyte or fish data	tree model
A2 / Chalk river fish subtype hw – headwater subtype ds – downstream	macrophyte of fish data	tree model
B1	macrophyte data	tree model
B2	macrophyte data	tree model
C1	macrophyte data	no method
C2	macrophyte data	tree model
D1	macrophyte data	Geographical location
D2	macrophyte data	tree model
salmonid spawning and nursery areas	fish data	no method

Where local macrophytes surveys have been undertaken, such as at those sites in the JNCC database, generic river types can be identified from these data. Likewise, water bodies with known salmonid spawning and nursery areas could be classified as such. It is important to note that many water bodies in the UK have been altered to some extent by, for example weirs, sluices, dredging, straightening, pollution, loss of shading, even if they have not been formally classified as heavily modified water bodies. In such cases, observed riverine communities may be improverished versions of the natural community for the water body type. Where the communities are significantly different from natural, local fish, invertebrate or macrophyte data should not be used to define the water type, since this may lead to use of standards that permit abstraction that would preclude natural sensitive species from returning if other conditions are ameliorated.

For other sites, in the UK the tree-based model in Figure 27 provides a method for identifying the generic river water body types A1, A2, B1, B2, C2 and D2 from catchment data (Table 23). Type D1 river water body can be identified by geographical location (mainly the New Forest, Scottish Flow Country and Western Isles). The model does not distinguish type C1, so this type will only be identified where a macrophyte survey has been undertaken. There is currently no method for identifying salmonid spawning and nursery areas based on catchment data.



sub-type A2 (hw) AREA<100.0

sub-type A2 (ds) AREA>=100.0

Figure 27 Recommended tree-based model for 6 river types (left branch = yes; right branch = no to the logical test stated at the top of the branch)

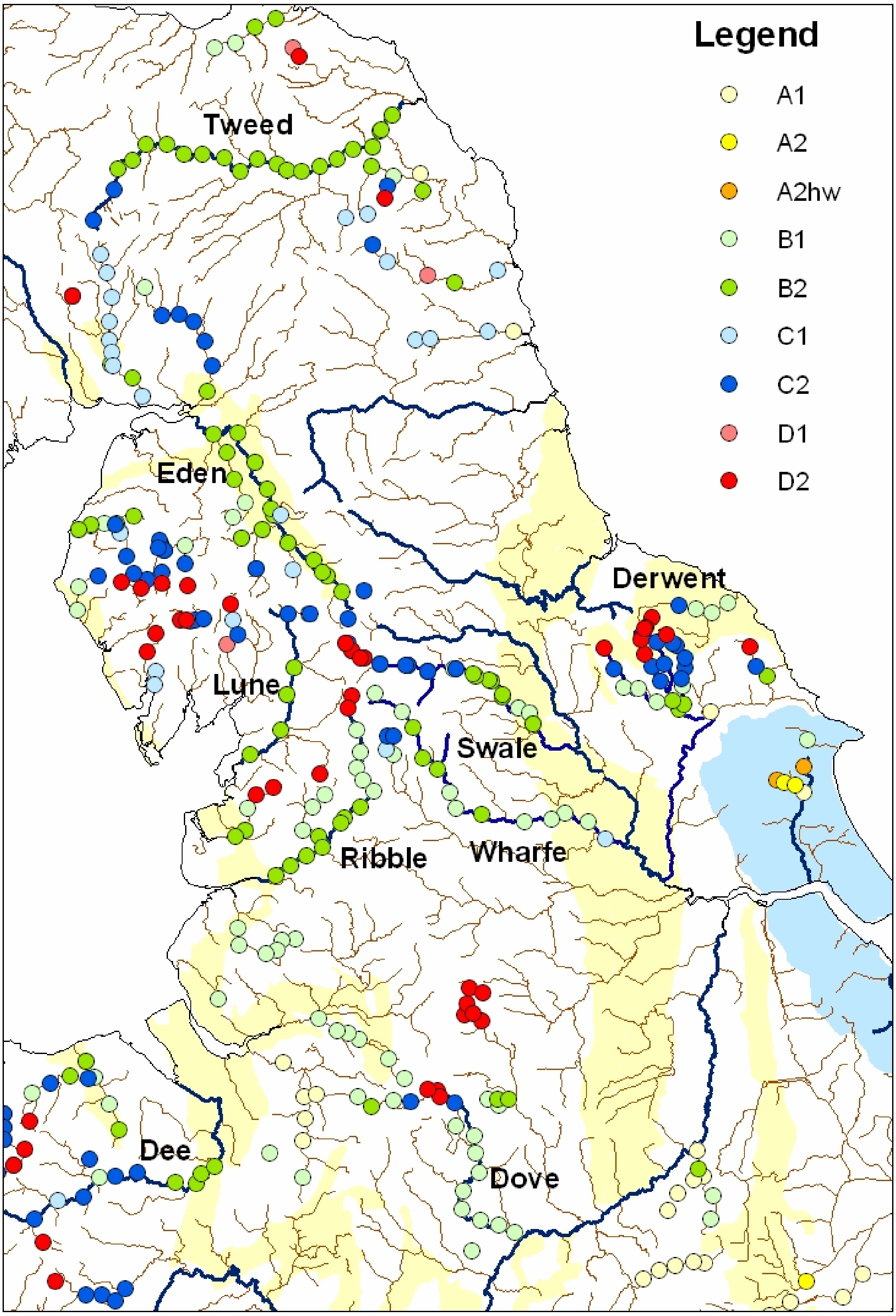


Figure 28 River water body types in North England and Southern Scotland predicted by the tree model in Figure 27

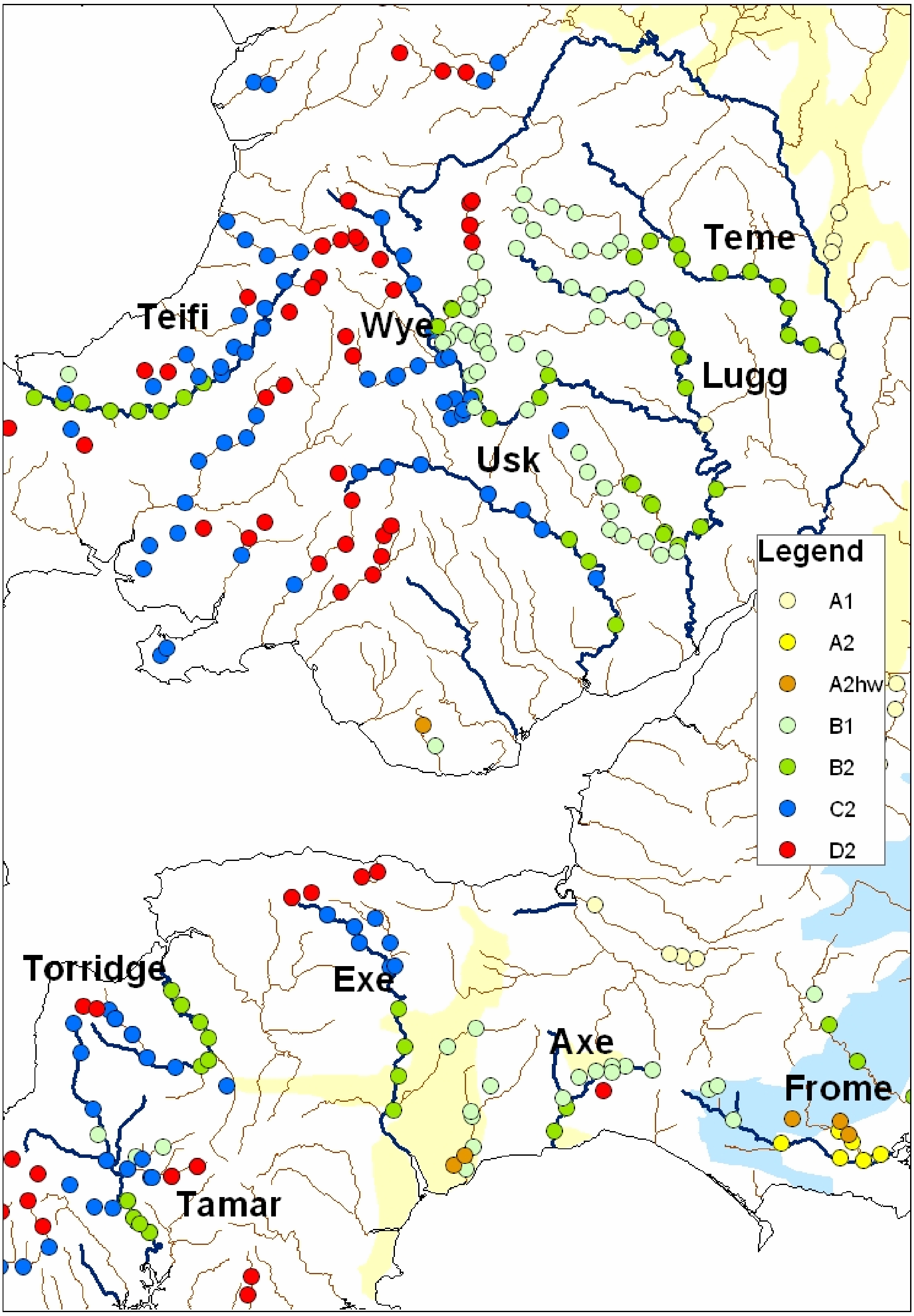


Figure 29 River water body types in south Wales and south west England predicted by the tree model in Figure 27

Figure 28 shows a map of rivers in northern England and southern Scotland together with the locations of macrophyte sample sites used to develop the recommended river typology. The sites are colour coded according to the river water body type predicted by the tree model in Figure 27. It can be seen, for example, that the headwaters of most rivers are classed as D1 becoming C2 downstream. The middle reaches are predominantly B2, particularly the Tweed.

Figure 29 shows a similar map to Figure 28, this time for south Wales and south west England.

A fish atlas has been published by CEH which shows the locations where different fish species have been recorded in Great Britain (Davis, 2004). Figure 30 shows records of Atlantic salmon *(Salmo salar)* within 10 km squares. However, the atlas does not provide maps of the spawning or nursery areas that could be used to locate this river water body type. Local knowledge of salmonid spawning and nursery areas provides the only method currently available.

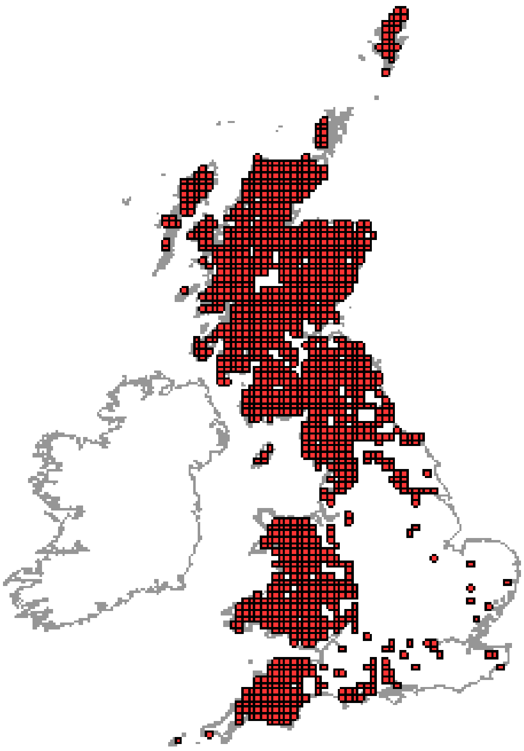


Figure 30 Locations in Great Britain where Atlantic salmon have been recorded (see http://www.searchnbn.net/gridMap/gridMap.jsp?allDs=1&srchSpKey=NBNSYS0000188606)

4.2 Standards for river water body types

In this step the expert advice from the project workshops was taken to define recommended environmental standards for UK agencies for restrictive flow management (abstraction). To achieve this, the following principles were adopted:

- Standards should be based on variations in flow from the natural hydrological regime of the river water body, signified as Qn. In exceptional circumstance an alternative baseline can be considered, such as where the flow regime has been altered significantly for many years so that the ecosystem has become adjusted and using the natural regime as the baseline would cause ecological degradation. An example of this could be the River Don, where at low flows more than half the flow may be contributed by discharges. In this case the historical gauged flow may be considered as the baseline.
- Standards should be based on the expert views as expressed at the project workshops. They identified protection of low flows as a key element in achieving GES, with Qn_{95} representing a critical threshold below which abstraction should be significantly reduced or stopped.
- Standards should vary between the river water body types to reflect the expert views of their sensitivity to flow change. However, expert views suggested that, in some cases, within the same river water body type different standards were appropriate for macrophytes, invertebrates and fish. It was considered that these needed to be combined into a single standard for each type; normally by taking the most stringent standard.
- Standards should vary with time of year. For example, March to May represents a critical time for river macrophytes and more stringent standards are required for this period than for June to February. Spawning time for fish and development of juveniles (May to June for cyprinids, October to April for salmonids) is the most critical time and more stringent standards are required for these periods.
- In defining critical flow statistics, e.g. Q_{95}, annual flow data should be used. This provides added protection to naturally low flow periods *i.e.* seasonal Q_{95} would be lower than annual Q_{95} during, for example, late summer. Clearly this approach gives less protection to period of low flows that occur during normally high flow periods.

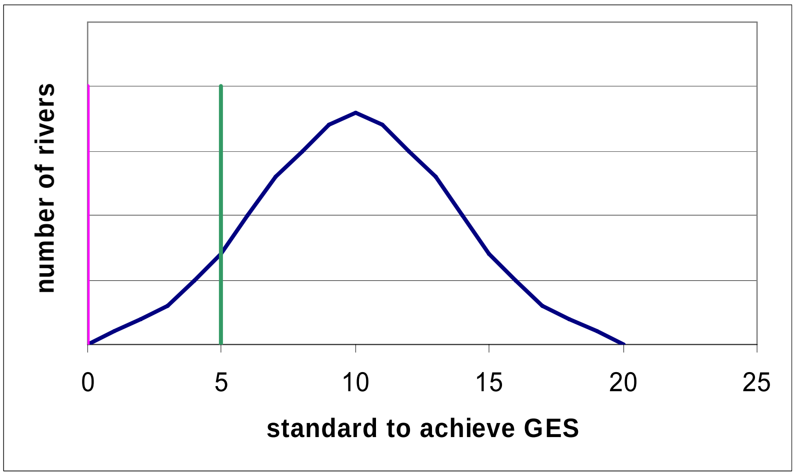


Figure 31 Histogram of maximum abstraction that can achieve GES for a set of rivers (blue curve), the standard that ensures all rivers achieve GES (purple line) and the risk-based standard that ensures GES will be achieved most of the time (yellow line)

- The Project Steering Group dictated that standards must follow a risk-based approach as adopted by UK regulatory agencies. It was taken that the standards recommended by the experts were those which ensure that all water bodies would achieve GES. In the risk-based approach slightly less stringent standards can be used if it is accepted that their application may lead in some cases to a river water body failing good status. Consequently, granting of abstraction licences must be associated with monitoring so that the status of the water bodies can be assessed and the conditions of the licence altered, if appropriate. This idea is show hypothetically in Figure 31, where the blue line represents a histogram of the distribution of actual maximum permissible abstractions rates for a range of rivers required to achieve GES. If the standard is set at 0% (no abstraction), all rivers achieve GES, if the standard is set at 5% most rivers achieve GES, but some fail. Unfortunately there are no data with which to define the precise form of Figure 31, the different between the risk-based standards and those of the experts remains subjective.

Table 23 Recommended standards for UK river types for achieving GES given as % allowable abstraction of natural flow (thresholds are for annual flow statistics)

Type	Season	flow > Qn_{60}	Flow > Qn_{70}	flow > Qn_{95}	flow < Qn_{95}
A1	Apr – Oct	30	25	20	15
	Nov – Mar	35	30	25	20
A2 (ds), B1, B2, C1, D1	Apr – Oct	25	20	15	10
	Nov – Mar	30	25	20	15
A2 (hw), C2, D2	Apr – Oct	20	15	10	7.5
	Nov – Mar	25	20	15	10
Salmonid spawning & nursery areas (not Chalk rivers)	Jun – Sep	25	20	15	10
	Oct – May	20	15	flow > Q_{80} 10	flow < Q_{80} 7.5

- The experts advocated that an absolute hands-off flow (HOF) restriction should be applied in many cases, with no abstraction below the threshold. It was the view of the Project Steering Group that alterations to the flow regime of the order of 5-10% were at the margin of hydrological measurement error and unlikely to have a significant impact on GES. Permitting 5-10% abstraction below the threshold would allow flexibility in applying the standards to water users with modest, but constant abstraction needs.
- Higher abstraction may be permitted at higher flows, above Qn_{70} and Qn_{60}.
- Standards for achieving moderate ecological status (MES) will be less stringent than for GES, of the order of 10% more permissible abstraction. In turn standards for achieving poor ecological status permit an additional 10% abstraction.
- A threshold level for the alteration of river hydraulics from natural needs to be set beyond which the general standards are not appropriate and site investigations are required.
- The English Nature 10% standard is set to maintain or restored favourable conservation status in Habitats Directive and other designated sites. The relationship with GES and HES needs to be noted.

Table 23 provides standards for UK river types for achieving good ecological status (GES) developed by the project team, following direction from the Project Steering Group to take a risk-based approach with the agencies undertaking monitoring at sites where the standards are applied to catch any that fail GES. As insufficient knowledge was available to define the form of the graph in Figure 31, *i.e.* how many rivers might fail GES by employing these standards to
Table 23, is recognised as the project team's expert experience. These standards are given in the form of the allowable abstraction as a percentage of the natural flow on any day. It assumes that Qn_{95} is a critical flow below which more stringent standards are required (or Qn_{80} in the case of salmonid spawning and nursery areas). All critical flows (*e.g.* Qn_{95}) are specified in terms of the annual flow duration. In addition, standards are more stringent for the period March to June (covering macrophyte reproduction and cyprinid spawning) for generic types A1 to D2. For salmonid spawning and nursery areas the critical period is October to April.

Table 24 Recommended standards for UK river types for achieving HES given as % allowable abstraction or discharge related to natural flow (thresholds are for annual flow statistics)

Type	Season	flow > Qn_{95}	flow < Qn_{95}
all river types	all seasons	10	5

Table 24 provides standards for UK river water body types for achieving high ecological status (HES). These are based on the Project Team's views of increased protection on the standards for GES. In setting these standards, only hydro-morphological conditions are considered and flows should be neither reduced by abstraction nor increased by discharges by more than the critical values given. In addition, the standards relate to gross alterations of the regime, not a net balance between abstraction and discharge *i.e.* HES would not be achieve where significant abstraction takes place even if abstracted water is returned to the river in the same quantity and quality. The standards were developed independently of the thresholds for designated rivers by English Nature (Table 22), but fall within the range of Very High and High sensitivity.

Table 25 Recommended standards for UK river types for achieving MES given as % allowable abstraction of natural flow (thresholds are for annual flow statistics)

Type	Season	Flow > Qn_{60}	flow > Qn_{70}	flow > Qn_{95}	flow < Qn_{95}
A1	Apr – Oct	40	35	30	25
	Nov – Mar	45	40	35	30
A2 (ds), B1, B2, C1, D1	Apr – Oct	35	30	25	20
	Nov – Mar	40	35	30	25
A2 (hw), C2, D2	Apr – Oct	30	25	20	15
	Nov – Mar	35	30	25	20
Salmonid spawning & nursery areas (not Chalk rivers)	Jun – Sep	35	30	25	20
	Oct – May	30	25	flow > Q_{80} 20	Flow < Q_{80} 15

Table **25** provides standards for UK river water body types for achieving moderate ecological status (MES) defined by the Project Team. These are given as the allowable abstraction as a percentage of the natural flow on any day. In the absence of ecological data to support a quantitative scientific analysis, these figures were derived by the Project Team using their judgement that MES was likely to be achieved in general with further reductions in flow of 10% from GES. River water bodies where abstraction greater than the standards for MES will only achieve Poor Ecological Status (PES).

Each of the above standards (GES Table 23; HES Table 24; MES Table 25) apply to river water bodies in which the hydraulic properties are not significantly altered from natural, for example by a major weir. “Significantly altered” here is defined as having an RHS modification score > 1496. In the RHS, such rivers are referred to as heavily modified, but this should be confused with the WFD HMWB classification. It is noteworthy that the definition of potential HMWBs under WFD is undertaken partly using RHS modification scores. Thus water bodies in the RHS heavily modified class may eventually be classed as HMWB and would thus fall outside the scope of the standards, and would need to achieve GEP. However, designation of a water body officially as HMWB is based on economic criteria*; i.e.* whether the modifications perform an economically important function. In theory, if the water body is not designated as HMWB, then the modifications may eventually be removed, thus the standards would be applicable.

4.3 Applying the river water body standards to licensing

Three characteristics of the environmental standards are noteworthy when considering their application to licensing:

1. the allowance percentage relates to flow at the time of abstraction, *i.e.* it can change continually
2. the allowances have hands-off flows at, for example, Qn_{95}
3. the allowances vary seasonally in some cases.

Application of these variations directly in a licence implies two things:

1. the licensee knows what the flow is on that day
2. the licensee can operate with different levels of abstraction at different times.

Water abstraction is essential to human life both directly for drinking and indirectly for growing food, power generation industrial processing and other uses. In managing water resources, UK regulatory agencies have a duty to balance the needs of the abstractor, the impact of the abstraction on the environment and the rights of other users. Some users, such as large water companies or canal owners, own storage reservoirs which provide flexibility; so that they could abstract more water during high flows and store this in the reservoir for use when less water is available during low flows. In addition, water companies may have licences for conjunctive use of surface and groundwater which also provides flexibility. In such cases, they may be able to manage with different abstraction allowances at different times. In addition, for major abstractions there may be a river flow gauging station near-by that can be used to define the allowance at any time. However, the agencies recognise that many water users (from fish farm owners to power station managers) need to be able to abstract a constant volume of water and they may be abstracting from a river water body where no flow gauging is undertaken. Thus, they may not be able cope operationally with a changing abstraction allowance and have no way of calculating the actual flow in the river. In these cases, simplified standards will be required to provide the licensees with appropriate water allowances.

One way of approaching the setting of single unvarying abstraction licenses is to consider the impact on flows at various frequency of occurrence. For example, if an abstraction allowance of 10% of Qn_{95} is set, the implications for flows at Qn_{99} need to be considered and the risk of failing the Qn_{99} standard assessed. This is illustrated in Figure 32 which shows for catchments in England and Wales, 10% of Qn_{95} as a percentage of Qn_{99}. Type D2 is not well represented in England and Wales, so data for the entire UK may show slightly different patterns. It is evident that for most catchments, 10% of Qn_{95} is, on average, equivalent to around 15 % of Qn_{99}. In exceptional circumstances, the river would be dry under such circumstances (*i.e.* where 10% of Qn_{95} is greater than or equal to 100% of Qn_{99}). Research used to develop Low Flows 2000 found that the steepness of the flow duration curve (and hence the ratio of Qn_{99} to Qn_{95}) is related to BFI. This is consistent with Figure 32, which shows that for Chalk rivers (high BFI - flatter flow duration curves) 10% of Qn_{95} is la lower % (around 13%) of Qn_{99}. Figure 32 also shows that this % value varies more within than between river water body types. Hence, we recommend that both Qn_{99} to Qn_{95} are calculated when setting licences, if the licensed amount is a fixed proportion of Qn_{95}, so that implications of the abstraction at Qn_{99} can be assessed.

In November 2005, a final workshop was held to report the draft standards to experts. The experts felt that it was not possible to specify a constant volume that could be abstracted at any flow and still achieve GES, except by defining the volume as a percentage of the very lowest flow. It was suggested that if a licence was granted for constant abstraction at any flow, then the abstraction should not reduce flow at Qn_{99} by more than 25%.

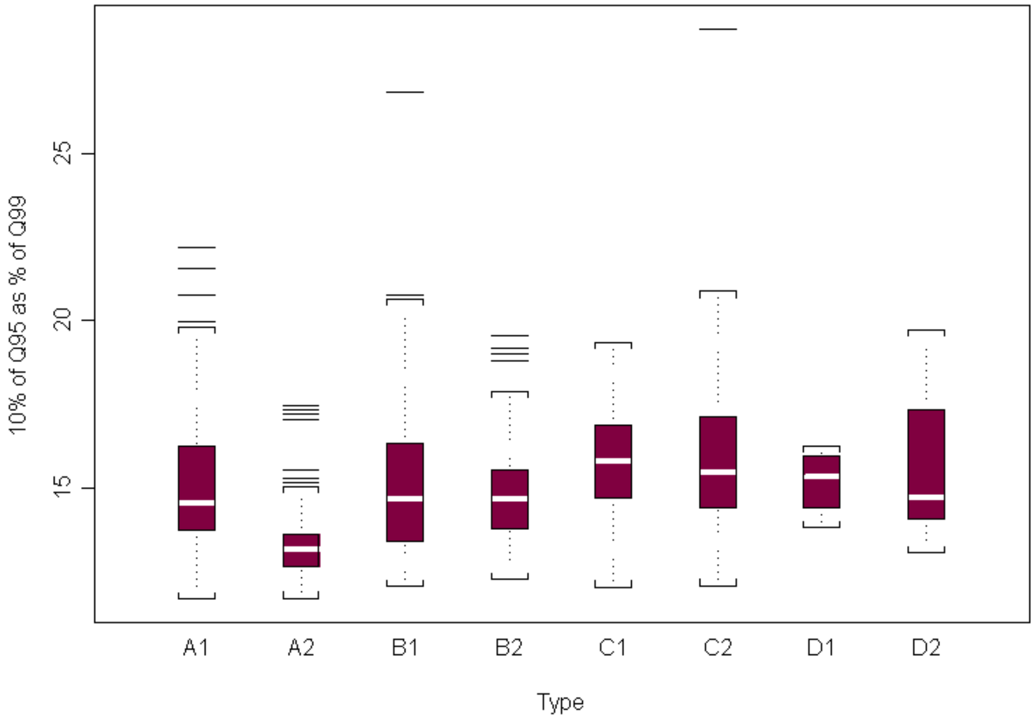


Figure 30 Box plot showing, for catchments in England and Wales, 10% of Qn_{95} as a percentage of Qn_{99}

One of the challenges of this WFD 48 project has been to satisfy both the broad requirements of the Water Framework Directive and practicalities of licensing water abstraction. The WFD requires the definition of thresholds to meet specific levels of ecological status. The WFD48 Project did not require any compromise between achieving ecological status and meeting water users' needs; as this balance is made by the UK regulatory agencies in deciding how to apply the environmental standards to regulation. At the expert workshop, the specialists highlighted they had had insufficient experience in setting standards; they were called upon at short notice to provide input within a few hours of workshop, then largely not contacted until a similar workshop several years later. The South African experience appeared to be one of more continuous interaction between scientists and implementing agencies with expert involvement in defining environmental flows in real case studies. This has built mutual understanding and led to better integration of research results and applications. We recommend that UK agencies develop better, longer-term and more consistent collaboration with UK scientists.

The standards can only be applied to river water bodies down to their tidal limit. Although flows to estuaries were mentioned in the fish workshop with regard to salmon migration, this topic was outside of the scope of the project. Nevertheless, flows to estuaries are an important element of environmental flows; even though estuaries and near-shore zones are saline, their ecosystems rely on freshwater inputs. This topic needs to be the subject of a separate research project.

Through this report standards have been related to the natural flow regime (Qn). However, it is recognise that the most appropriate baseline may be the gauged flow, and not the natural flow.

4.4 Heavily modified water bodies (HMWBs) and good ecological potential (GEP)

The WFD allows limited exceptions to achieving Good Ecological Status. In particular, certain water bodies will be required to achieve an alternate objective of at least "Good Ecological Potential". This objective takes account of the constraints imposed by physical modifications to the water body and is equivalent to achieving Good Ecological Status in unmodified water bodies. Such designation will either be as “Artificial” or “Heavily Modified” as appropriate, and will depend on the results of the two designation tests outlined in Section 4.3 of the WFD.

It is unclear whether hydrological modification alone would be grounds for designation as a heavily modified water body (HMWB), indeed there are conflicting views. On the one hand, there is some interpretation in the Common Implementation Strategy for the WFD that suggests that this is true, and it is thought that some countries which generate significant amounts of hydropower, such as Austria and Norway, are arguing for this. On the other hand, in the project “Guidelines for the Identification and Designation of Heavily Modified Water Bodies in England and Wales” (Dunbar *et al*. 2002) led by CEH was specifically asked to concentrate on morphological modifications rather than hydrological. In addition, some have the view that both hydrology/hydraulics and morphology need to be altered for HMWB to be applicable (Martin Mardsen, pers. comm.). Bearing the above in mind, rivers whose flow regime is heavily regulated will likely have non-natural morphologies because of this, so the debate could in part be superfluous. However, there could also be unclear borderline cases where morphology is not altered, but where the flow regulation is delivering significant economic benefit.

Whilst HMWBs are strictly outside of the scope of this project (i.e. the project was not required to define standards for HMWBs) the issues of HMWB and GEP were discussed at the expert workshops (see Annex 2, section 4), so it seems pertinent to summarise the outcomes here. The experts recognised that dams and other infrastructure may alter significantly the hydrological regimes of downstream water bodies but those water bodies may not themselves to designated as HMWB. The following general principles were concluded by the experts

1. the conventional mode of operating dams, with constant releases (compensations flows) for long periods would not achieve GES. Natural hydrological variability is an important element for maintaining healthy freshwater ecosystems
2. It does not make scientific sense to define two different sets of standards that can achieve GES i.e. one for abstractions and one for releases from

impoundments. To achieve GES below impoundments (active flow management), standards defined for abstraction (restrictive flow management) would need to be applied; i.e. whilst the whole flow regime may be reduced, natural variability should be maintained.

3. to achieve GEP, some basic elements of the natural regime need to be maintained, even if variability is not. In particular, floods competent to move gravel and stimulate migration are required at key times of the year and occasional larger floods to maintain channel form.
4. constant flow releases (compensation flows) need to be altered during the year for fish and for some macrophytes, releases should fluctuate around Q_{95} by +100 / -50% to maintain inundation/drying of bryophytes.

Table 26 Summary of expert views for achieving GEP in river water bodies downstream of impoundments

<table>
<tr><th></th><th colspan="3">Floods</th><th colspan="3">Compensation flows</th></tr>
<tr><th></th><th>macrophytes</th><th>Invertebrates</th><th>Fish</th><th>macrophytes</th><th>invertebrates</th><th>Fish</th></tr>
<tr><td>A1</td><td rowspan="2">20-30% natural floods 5-7 x Qn_{50}</td><td>40% natural floods</td><td rowspan="2"></td><td></td><td>Qn_{90}</td><td rowspan="2"></td></tr>
<tr><td>A2</td><td>80% natural floods</td><td></td><td>Qn_{80}</td></tr>
<tr><td>B1</td><td rowspan="3">As A1/A2 plus freshet 5 x Qn_{95} Mar-May</td><td rowspan="2">60% natural floods</td><td rowspan="6">Rheophilic cyprinids: May-July no major floods July – Jan bank-full flood

Adult salmonids: Sep-Nov 3 small freshets

Salmonid spawning: Oct-Apr 3 small floods to clean gravel and migrate adults; 1 large flood Qn_2</td><td rowspan="3">Qn_{95}</td><td rowspan="4">Qn_{70}</td><td rowspan="6">Rheophilic cyprinids: May-July Qn_{70} July – Jan Qn_{70}

Adult salmonids: Dec-Apr Qn_{90} May-Nov Qn_{95}

Salmonid spawning: Oct-Apr Qn_{90} May-Sep Qn_{95}</td></tr>
<tr><td>B2</td></tr>
<tr><td>C1</td><td>70% natural floods</td></tr>
<tr><td>C2</td><td rowspan="3">As A1/A2 plus freshet Qn_{50} Mar-May</td><td>60% natural floods</td><td rowspan="3">fluctuations around Qn_{95}</td></tr>
<tr><td>D1</td><td>80% natural floods</td><td>Qn_{80}</td></tr>
<tr><td>D2</td><td>50% natural floods</td><td>Qn_{60}</td></tr>
</table>

Table 26 provides a summary of the experts' views for achieving GEP in river water bodies. It can be seen that the experts felt that invertebrates in particular require a flooding regime close to natural. More work would be required to turn these views into standards for achieving since they represent broad-brush opinion of the experts within a project that was not focusing on HMWBs.

4.5 Expert feedback workshop

An addition workshop was held on 21 November 2005 to provide feedback on the recommended environmental standards to the experts that had been involved in the initial standard setting. Standards were sent to all invitees prior to the workshop. Unfortunately, many of the experts were unable to attend due to prior commitments. The report of the workshop is presented as Annex 4.

A major point of discussion was that for practical implementation, standards would be best presented as a constant quantity of water available for abstraction as a % of Q_{95} at the site. The experts argued that river ecosystems could only be protected by defining abstraction as a % of flow on the day. As a compromise, it was suggested that a rule of thumb should be that no abstraction greater than 25% of Q_{95} should be permitted.

Only minor suggestions were made for changes to the environmental standards (Tables 23, 24, 25). The seasons were re-defined to Nov-Mar and Apr-Oct. The standards for A1 rivers could be made less restrictive due to their low sensitivity to flow change.

Additional comments were received following the workshop. These comments included:

- Rheophilic cyprinids will not occur in type D1, D2.
- WFD 48 takes little account of importance of migration flows in summer for e.g. sea trout.
- More use could be made in future of RHS – enhanced version – which takes into account the geometry and substratum of the channel.
- Some fish experts questioned whether macrophytes and invertebrates are more sensitive to flow variation than fish.
- Any decision to replace HoFs with allowable abstraction below Q_{95} (the risk-based approach) is a political decision, not an ecological one. The onus of proof of lack of likelihood of ecological damage should fall on the abstractor rather than the regulator.
- In rivers that are currently impacted (pollution, weirs) and have no flow-sensitive species, a greater take is allowed, therefore the river will be kept in poor status.

5 LAKE WATER BODY TYPOLOGY

5.1 Introduction

As for the rivers part of the project, Stage 2 considered the choice of typology to be used for the development of environmental standards. A major influence was the System B reporting typology developed by UKTAG (2003) - this served the required purpose and no credible alternatives were thought to be available. However, the Stage 2 report left open the possibility for a final decision on the choice of typology to be delayed until Stage 3, and for the typology to be implemented in a way that most suited the needs of this project. Specifically, it was recognised that types used in the reporting typology may need to be combined or split, according to the evidence available regarding sensitivity to hydrological change and in the interests of avoiding unjustifiable complexity.

At the project workshop held in Edinburgh in April 2005, primary emphasis was placed on the sensitivity of lake ecosystems to changes in water level, which was identified in the Stage 1 report as the principal ecologically relevant hydrological parameter. A number of aspects of the lake level regime were identified for discussion, and proposals were made regarding allowable changes in hydrological parameters corresponding to the HES/GES and GES/MES boundaries (Table 27). Feedback at the workshop was reserved. There was no resistance to the proposed threshold values, nor to the selection of aspects of the regime. However, there was no strong consensus that the proposals were definitely appropriate, since the science base available as a foundation for such conclusions is weak.

Nonetheless, the expert-based approach has been taken forward from the workshop discussions, through reference to the literature and further consultation with individual experts, to the formulation of a sensitivity typology scheme for lakes as a modification of the UKTAG system.

Table 27 - Questionnaire addressing the sensitivity of the macrophyte/phytobenthos community of Type LA lakes to change in the hydrological regime. Similar tables were produced for all six lake types and for all macrophyte/phytobenthos, macro-invertebrate and fish communities described by UKTAG (2004), for completion during the expert workshop.

Type LA	Most typical species: *Juncus bulbosus, Littorella uniflora, Lobelia dortmanna, Myriophyllum alterniflorum, Juncus articulatus, Ranunculus flammula, Eriophorum angustifolium, Equisetum fluviatile, Carex rostrata, Sparganium angustifolium, Menyanthes trifoliata, Potamogeton polygonifolius, Potamogeton natans, Isoetes lacustris*				
	Eunotia incisa, Eunotia bilunaris, Frustulia rhomboides var. *saxonica, Tabellaria flocculosa, Brachysira brebisonnii, Cymbella hebridica, Cymbella perpusilla, Pinnularia* spp., *Brachysira vitrea, Fragilaria virescens* var. *exigua*				
	HES		GES		units
How much can the annual range be altered without compromising ecological status?					% or m
How much can the annual maximum level be raised without compromising ecological status?					% or m
How much can the annual minimum level be lowered without compromising ecological status?					% or m
How much can the degree of seasonality be changed without compromising ecological status?		±2		±4	no. weeks
How long can the community tolerate sub-aerial exposure?					no. days
How much can the hydraulic retention time be changed without compromising ecological status?					% of natural
How much can depth be reduced without compromising ecological status?		<5		<10	% of natural
How much can surface area change without compromising ecological status?		<5		<10	% of natural
Which is the most important periodicity of water level fluctuations to protect?	*daily*		*daily*		*please tick ONE*
	weekly		*weekly*		
	monthly		*monthly*		
	annual		*annual*		
Other important attributes of water level regime					
Lake-specific sensitivity					
How might community resilience vary between lakes with different physical attributes?	size				
	shape				
	depth				
	basin form				
	geographical location				
	altitude				
Comments					

Note: Greyed-out values indicate current UKTAG thresholds.
(HES/GES: High/Good Ecological Status)

5.2 Selection of basic typology

The lake reporting typology for Great Britain (UKTAG 2003) integrates the results of previous biologically based lake classifications specifically for the UK. It distinguishes six principal lake types reflecting a composite chemical signature associated with solid geology, soil and drift characteristics and saline influence; with subsidiary tiers based on depth, altitude and size. Thus it adopts a similar approach to the ECOFRAME typology (Moss *et al*. 2003) recently developed for application at pan-European level, although types probably cannot be mapped directly from one scheme to the other because they adopt different threshold levels. The principal deviation of the UK system from the ECOFRAME approach is that the influence of peat drift is placed at the same hierarchical level as the chemical differences between basins with different solid geology (reflected by alkalinity) and marine influence (reflected by conductivity). Some anomalies that have arisen in applying the UK scheme to lakes in peat-covered calcareous catchments (see basin features for type HA in Table 28) might be avoided by following the ECOFRAME hierarchy. However, the UK lakes reporting typology remains the current 'best-possible' reflection of biological variation of lakes within the UK, and has the additional advantage that supporting biological data are now being collected and analysed.

5.3 Physical lake types

The six lake types distinguished by (Tier 1) of the UK typology are Peat (P), Low Alkalinity (LA), Medium Alkalinity (MA), High Alkalinity (HA), Marl and Brackish (B). In Tier 2, each of the principal types is divided into two depth classes (mean depth less than or greater than 3 m). The lower tiers are based on altitude (three classes divided at 200 m and 800 m) and size (three classes divided at water area 10 ha and 50 ha). The experts' outline descriptions of the physical and biological characteristics of each of the UK core types at undisturbed reference condition are provided by UKTAG (2004). Physical characteristics for the Tier 1 types are summarised in Table 28. The distributions of Tier 1 and Tier 2 types in England, Scotland and Wales are shown in Figure 31 and Figure 32.

Table 28 - Some characteristics of lake types distinguished by Tier 1 of the UK reporting typology for lakes (UKTAG 2004)

Type	*Catchment land cover/geology*	*Basin features*	*Shoreline features*	*Water environment*
P (Peat)	>75% peat.	In mires or glacial troughs, often irregular.	Typically small peat bank, sand to boulder beach due to wave action; peaty littoral zone. Shore unstable if irregular.	Dystrophic; very low primary production, low light penetration due to humic content.
LA (Low Alkalinity)	Blanket peat, moorland/ heath, rock/scree; solid geology >90% siliceous .	Deep: steep-sided flat-floored glacial troughs, corries. Shallow: knock & lochan, kettle-hole, moraine dammed. Multi-basin if large.	Bedrock, boulder or eroded glacial till/earth/peat bank; beach narrow bedrock if exposed, wider cobble to sand if sheltered; boulder to sand littoral zone.	Oligotrophic with limited primary production. Clear water and good oxygenation at depth.
MA (Medium Alkalinity)	Often blanket peat if upland; solid geology >50-90% siliceous	Glacial troughs, knock and lochan, kettle hole, moraine dammed. Multi-basin if large.	Variable bedrock, boulder or eroded earth bank; narrow, stable pebble to sand beach (softer rocks than LA); sand-silt littoral zone.	Oligotrophic to mesotrophic with intermediate primary production. Seasonally restricted light penetration due to algal blooms.
HA (High Alkalinity)	Low gradients; glacially derived till drift; solid geology >50% calcareous rocks, e.g. limestone, chalk, red sandstones.	Formed by drift damming.	Often contiguous with base-rich mires. No bank; beach may be extensive gently sloping fine-grained sand-silt or high-energy gravel-cobble; soft muddy sub-littoral; fines susceptible to re-suspension especially if riparian vegetation cover is low.	Eutrophic with high primary production. Fine sediment resuspension critical in limiting light especially in large, exposed basins.
		Formed by 12^{th} and 14^{th} century peat cutting in fen peat (Norfolk Broads).	Often contiguous with base-rich mires; small peat bank.	Stable water level due to low catchment gradients.
M (Marl)	Soluble limestone and chalk; solid geology >65% limestone.	Formed by chemical weathering; variable form arising from solution and fracture of rock.	Bedrock-boulder bank, marl beach and sub-littoral.	A subset of HA lakes characterised by marl deposition and clear water. High nutrients, clear water because P, CO_2 and organic material removed. Macrophyte expansion limited by water depth only.
B (Brackish)	Variable; this lake type is characterised by saline influence (from sea spray, groundwater or seawater).	Variable.	Varies from gravel to soft mud.	Brackish; range of alkalinity.

Figure 31 - Distributions of lake types Low Alkalinity (LA), Medium Alkalinity (MA), High Alakalinity (HA) and Marl (all depths) derived from the GBLakes database

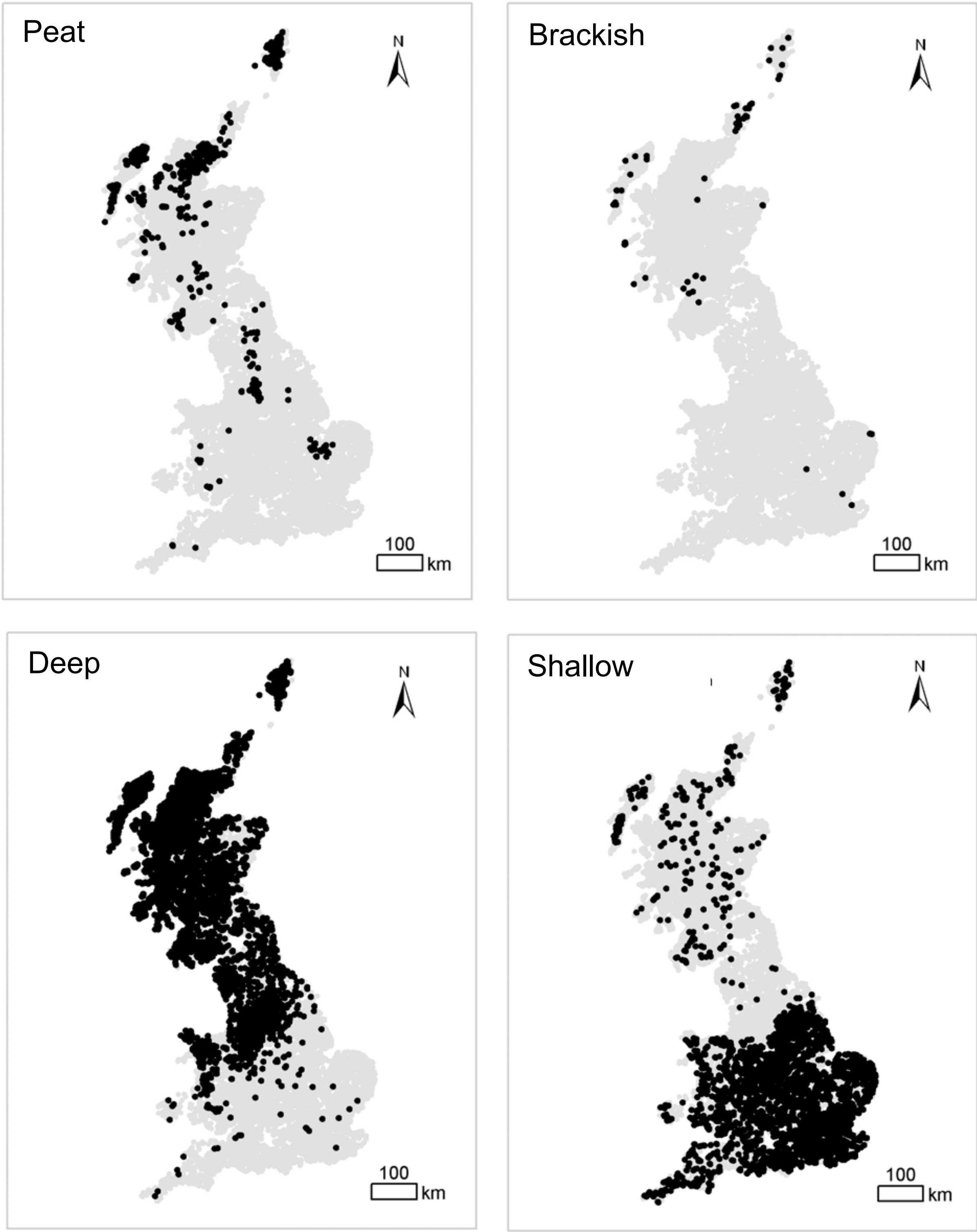


Figure 32 - Distributions of lake types Peat (P) and Brackish (B) (all depths) (above) and of types Deep (D) and Shallow (Sh) (all geological types) (below), derived from the GBLakes database

5.4 Linking biology to physical variables

5.4.1 Linkage mechanisms

The scientific literature gives a wide range of examples of the effects of hydrological change on the other WFD quality elements. The principal hydrological variable that has been related to biota is water level, and a number of ways in which water level change is linked to biological change are indicated in the literature reviewed in Appendix 2 of the Stage 2 report. These are summarised in Table 29, and the relationships between hydromorphological and ecological quality elements are indicated in Figure 33.

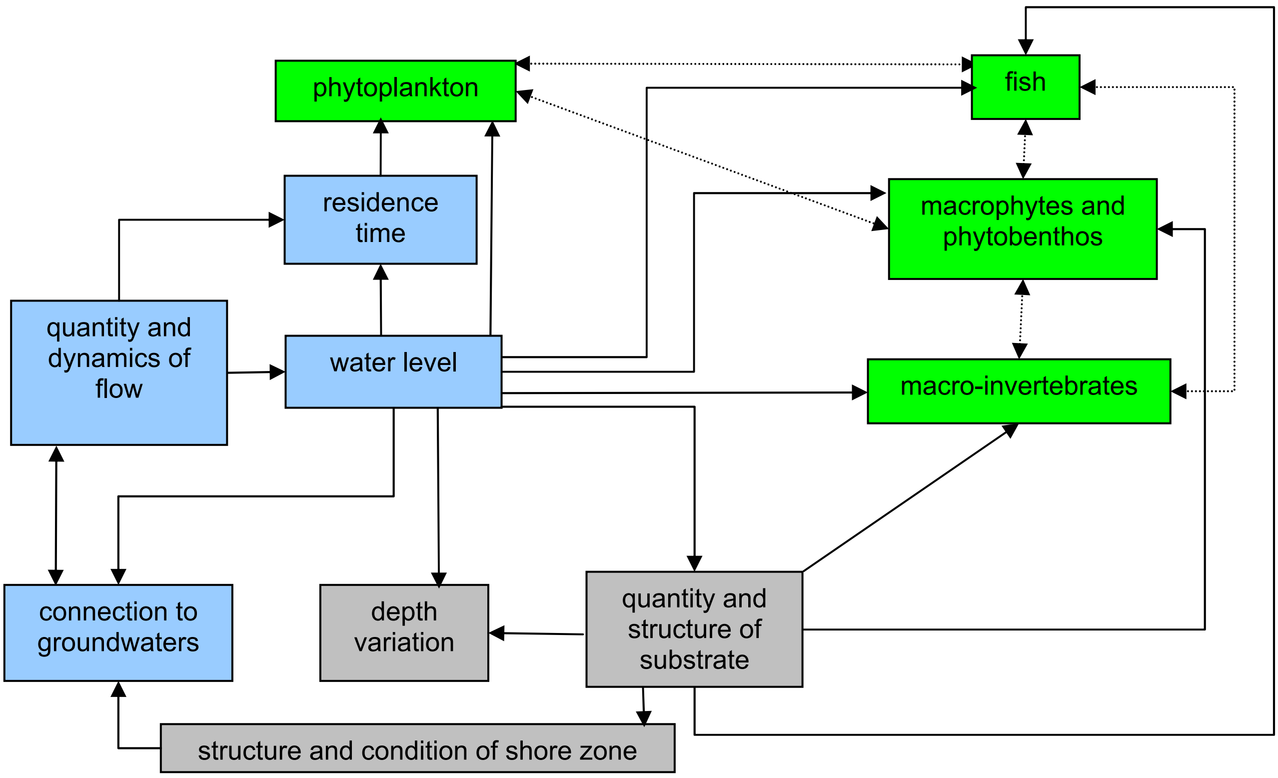


Figure 33 Relationships between WFD quality elements in lakes. Blue: hydrological quality elements; grey: morphological quality elements; green: biological quality elements (inter-relationships indicated by dotted arrows)

There is a web of interactions. The hydrological regime directly determines the rate of throughflow, driving the fluctuations of storage and thus the principal hydrological habitat variable, water level. Phytoplankton populations are influenced by throughflow and storage, through residence time. Otherwise, the water level regime exerts the principal hydrological influence on both biological and morphological quality elements.

Table 29 - Summary of effects of hydrological disturbance on WFD quality elements, based on literature review

Altered hydrological quality element	Receptor	Mechanism of effect
Water level regime	sediments	Wave erosion influenced by water level regime in conjunction with basin form
		Redistribution of underwater sediments
		Erosion of exposed sediments by water
		Erosion of exposed sediments by wind
		Ice-induced erosion of exposed sediments
		Wash-in of eroding peat from catchment
		Effects on water clarity and underwater light climate
	macrophytes and phytobenthos	Flooding/exposure of littoral zone: competition
		Flooding/exposure of littoral zone: germination
		Seed dispersal
		Light limitation by submergence
		Flood pulses for nutrient supply
		Range of fluctuations for submerged macrophytes
		Inter-annual variation in water level
		Range of fluctuations for shoreline vegetation
		Rate of rise and fall: migration/adaptation
		Freezing of littoral zone during winter drawdown
		Balance of shoreline and submerged species influenced by water level regime in conjunction with basin form
	macro-invertebrates	Freezing of littoral fauna during winter drawdown (fraction of littoral zone allowed to freeze)
		Desiccation during summer drawdown
		Rate of rise and fall for migration/adaptation
		Underwater light climate
		Abnormally low winter temperatures in profundal
		The performance of macrophytes affects invertebrate habitat and thus their abundance, richness and assemblage
		Balance of littoral and profundal species influenced by water level regime in conjunction with basin form
	fish	Flooding of littoral zone for spawning
		Rising water level for spawning
		Survival of eggs (wave damage, desiccation)
		Survival of larvae
		Flood pulses for nutrient inputs
		Migration to avoid stranding
		Balance of littoral and profundal habitat availability influenced by water level regime - basin form interaction
		Temperature effects on abundance/distribution of larvae
		Abnormally low winter temperatures in profundal
		Macrophytes for habitat
	phytoplankton	Alteration of hypolimnion nutrient levels (effect after autumn turnover)
Residence time		Proportion of “R” selected taxa
		Biomass (nutrient supply)
		Washout
		Autogenic succession during isolation phase (infinite residence time)

The linkages between physical and biological quality elements in the UK lake types form the foci of several current investigations, but none of these is sufficiently advanced to feed definitive results into this project. Therefore, the approach adopted is to employ the best evidence available to identify at least critical biotic sensitivities to change in the hydrological (principally water level) regime, through consultation with experts and reference to the literature. Issues identified for each of the biological quality elements are described below.

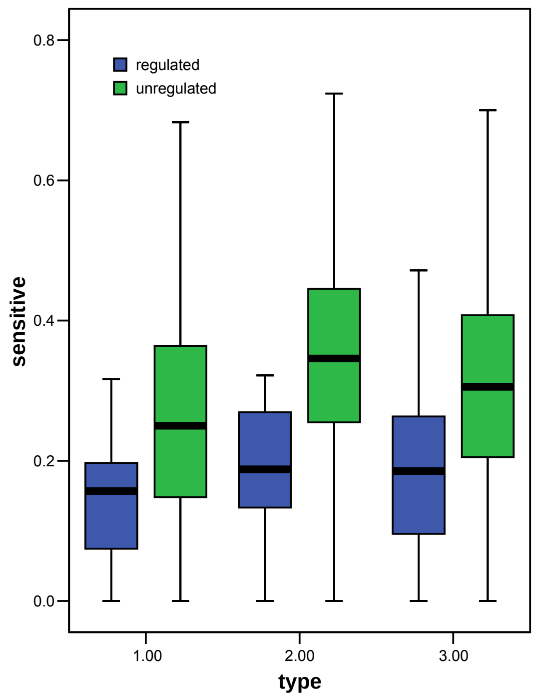
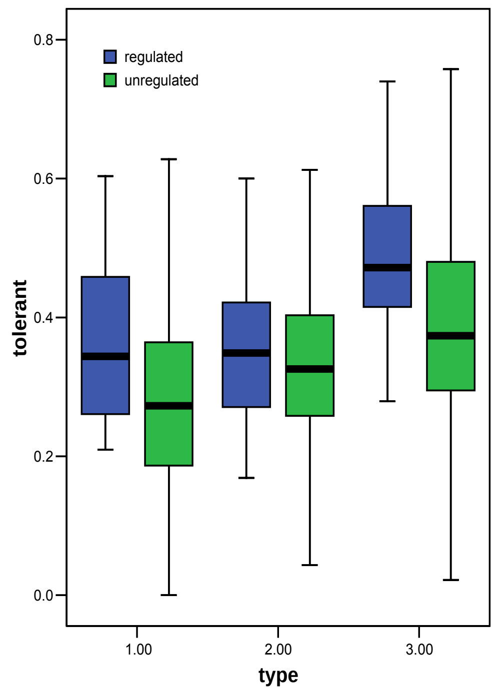
5.4.2 Macrophytes

Fairly comprehensive macrophyte species characterisations were prepared for all the UK reporting types (UKTAG 2004). These indicate similarities between P, LA and MA lakes, and significant floristic differences between this group and HA/Marl lakes on the one hand and B lakes on the other.

During the expert workshop, it was suggested that the sensitivity of these communities to alteration of the water level regime might vary for the following reasons:

- seasonally high sensitivity might be associated with flowering (March to May) and seed dispersal (late summer); and
- development of the vegetated zone is severely limited in peat (type P) lakes due to low light penetration, so this is likely to be the type that is most sensitive to alteration of the water level.

A systematic treatment of the sensitivity of macrophyte communities to water level regulation has been undertaken within SNIFFER project WFD39 (Dr Nigel Willby/University of Stirling). This is based on analyses of amalgamated data collected during conservation agency lake surveys, together with the results of some new surveys. The effects of species composition, cover of sensitive and tolerant species, and moisture affinity are summarised in Figure 34 and Figure 35. These data indicate that regulation (water management activity) enhances species richness, that the effect is greatest at moderate to low alkalinity, and that the differential between sensitive and tolerant species increases as alkalinity declines. In general, the macrophyte communities of LA lakes are more sensitive to water level regulation than those of HA lakes. MA vegetation occupies an intermediate position but its responses are more often similar to those of LA vegetation, as might be anticipated from the considerable overlap of LA and MA species complements noted above.

<table>
<tr>
<th>CHANGES IN COVER OF SENSITIVE SPECIES WITH REGULATION</th>
<th>CHANGES IN COVER OF TOLERANT SPECIES WITH REGULATION</th>
<th>DIFFERENTIAL BETWEEN SENSITIVE AND TOLERANT SPECIES</th>
</tr>
<tr>
<td>
</td>
<td>
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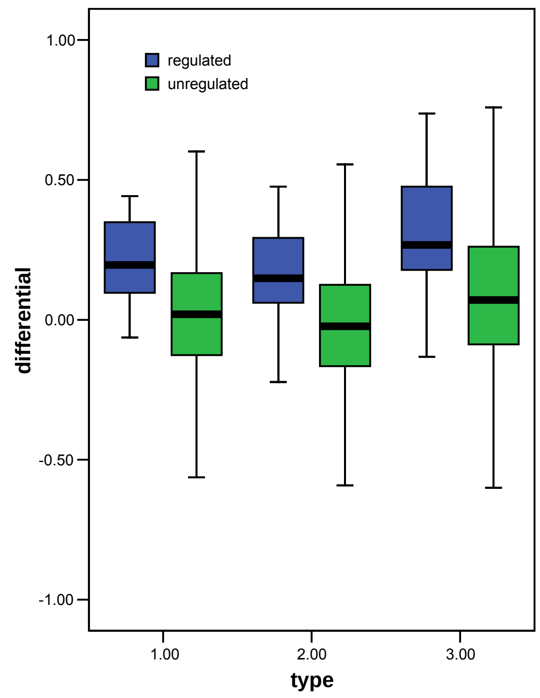
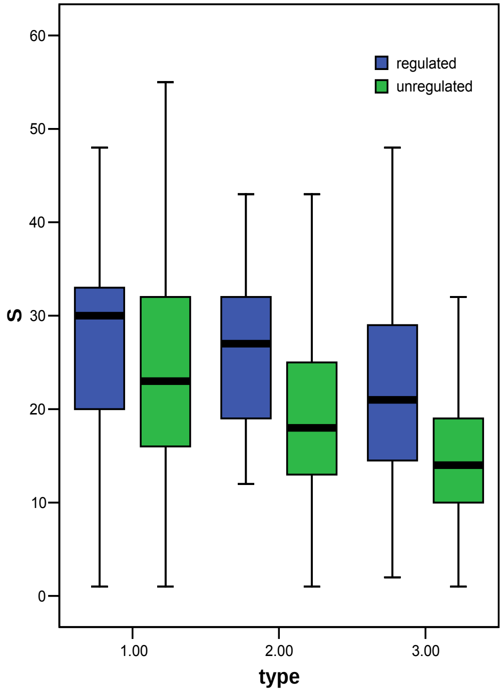
<td>
</td>
</tr>
<tr>
<td>Cover of sensitive species is dramatically reduced, especially in MA and LA lakes.</td>
<td>Less clear-cut pattern; the only marked difference is in LA lakes.</td>
<td></td>
</tr>
</table>

Figure 34 - Sensitivity of HA (left), MA (centre) and LA (right) vegetation to water level regulation, measured in terms of absolute and relative cover of sensitive and tolerant species (source N. Willby)

<table>
<tr>
<th>EFFECTS OF REGULATION ON SPECIES RICHNESS</th>
<th>COMPOSITIONAL EFFECTS OF REGULATION</th>
<th>EFFECT OF REGULATION ON MOISTURE AFFINITY OF VEGETATION</th>
</tr>
<tr>
<td>


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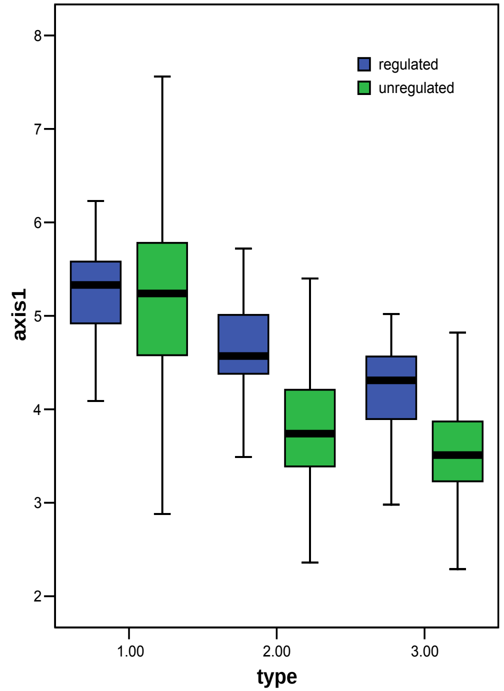
<td>


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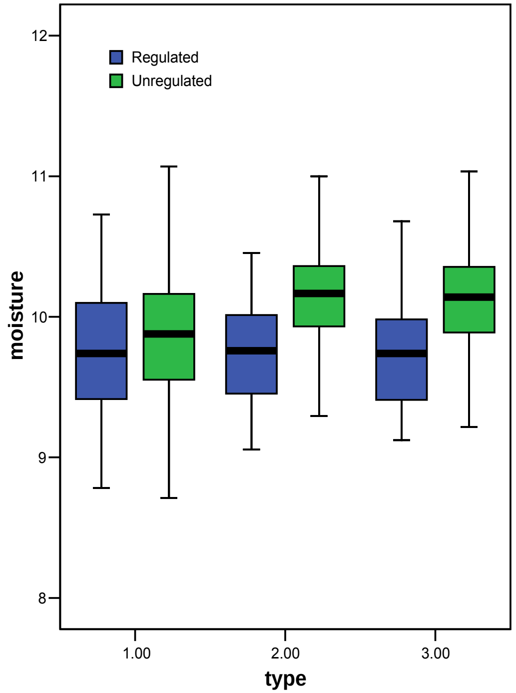
<td>


</td>
</tr>
<tr>
<td>Generally enhanced species richness; the greatest enhancement occurs in LA and MA lakes.</td>
<td></td>
<td>Loss of desiccation- intolerant species in MA and LA lakes.</td>
</tr>
</table>

Figure 35 - Sensitivity of HA (left), MA (centre) and LA (right) vegetation to water level regulation, measured in terms of species richness, community composition and moisture affinity (source N. Willby)

5.4.3 Macro-invertebrates

The UKTAG characterisation gives a fairly comprehensive account for LA lakes, but indicates only significant differences in invertebrate communities for the other types. The major macro-invertebrate groups (e.g. mayflies, stoneflies, molluscs and chironomids) probably occur across all lake types. The principal differences noted are the presence of:
dragonflies in most P lakes; and water boatmen, insects and crustacea in B lakes.

The view of the expert workshop was that too little is known about the ecology of lake macro-invertebrates to allow reliable prognoses with regard to their hydromorphological requirements (K. Irvine pers. comm.). A small quantity of information relating to the sensitivity of individual groups is available from James *et al*. (2002), indicating that:

- Invertebrate densities are reduced after 10-12 days' exposure to air.
- Chironomids can survive exposure for *ca*. 3 months if they can bury themselves to 20 cm depth in a muddy substrate.
- After exposure, recovery occurs within weeks from the time that the substrate is re-covered with water for some taxa (eg. chironomids, oligochaetes); but others (eg. caddisfly larvae and the snail *Potamopyrgus*) start recolonising only after up to three months. Thus, total abundance and species diversity can probably recover within three months during the summer period; and distribution and community composition generally reflect lake-level history at a scale of weeks to months.
- Mobile littoral invertebrates can keep pace with water level rises of 0.63 cm hr^{-1}, (15 cm per day) but are left behind at rates of 1.25 cm hr^{-1} (such rapid water level changes probably occur only in small hydro-electric schemes).
- Dragonfly nymphs migrate to shallow water in winter, in preparation for spring emergence; whereas nymphs of other insect taxa remain near the bottom until warm temperatures stimulate emergence.

5.4.4 Fish

Fish are enigmatic indicators of habitat change. On the one hand, being close to the top of the food chain and mobile, they integrate and indicate conditions across the whole lake. On the other hand, since they can move and the distributions of many species do not cover the whole of the British Isles, their absence does not necessarily indicate that there is a habitat problem.

The fish communities of each of the UK lake types are characterised by UKTAG (2004). The water level conditions for each type should be compatible with the general life requirements of the characteristic species, as well as for critical life stages. The critical life stage for fish is spawning, since the eggs must remain in one place until they hatch. Therefore information on both general (e.g. feeding) and spawning habits of the characteristic species was extracted from *Fishbase* (Froese and Pauly 2005) and other literature sources, and aspects with a bearing on sensitivity to hydrological disturbance and sensitivity differences between lake types identified.

The characteristic fish communities of P, LA and MA lakes comprise salmonids (brown trout, sea trout, Atlantic salmon, Arctic charr), lampreys (brook lamprey, sea lamprey), three-spined stickleback, eel, minnow and pike (UKTAG 2004). Most of these species prefer lotic conditions and use lakes opportunistically, moving on if conditions prove unsuitable. Thus the principal lake species appear to be pike, three-spined stickleback and eel (although eel do not breed in UK lakes). What does not emerge clearly from the UKTAG characterisation is the importance of oligotrophic lakes for isolated populations of lake-dwelling whitefish, vendace and endemic charr (Winfield 2004, Winfield *et al*. 2004). Most of these species feed on invertebrates and other fish; charr are also planktivorous. The top predator is pike. The littoral zone is important for feeding during the summer but less so in autumn and winter since sticklebacks and eel migrate to the profundal zone in autumn.

The species with the most demanding spawning requirement is pike which, in early spring, moves into the eulittoral zone of temporarily flooded vegetation to spawn in water less than 0.2 m deep. Lake-bound populations of charr, whitefish (*Coregonus lavaretus*) and vendace (*Coregonus albula*) typically spawn in clean gravel areas of the littoral zone during the early or mid winter, the eggs remaining there until hatching in the spring. In a detailed study of whitefish population dynamics in Haweswater (northwest England), Winfield (2004) suggested that a fall in water level in excess of 2 m during the egg incubation period would result in a total recruitment failure even though the spawning ground was around 4 m depth because any eggs incubating in less than 2 m of water were likely to be destroyed by winter storms. The other species for which littoral spawning conditions are of paramount importance is the three-spined stickleback, whose eggs incubate in nests built in vegetation and guarded by the male.

The characteristic fish communities of HA lakes include some of the species of less eutrophic lakes, although lake-bound salmonids and coregonids are probably absent (UKTAG 2004). Perch, ruffe (perch family) and the cyprinids bream, common carp, Crucian carp, gudgeon, roach, rudd, silver bream and tench are typical. However, the distribution of cyprinids does not extend to Scotland so that the fish communities of HA lakes in Scotland consequently resemble more closely the communities of less eutrophic lakes.

Gudgeon feed exclusively on invertebrates, whilst zooplankton are included in the diet of ruffe and form the principal food of juvenile bream and silver bream. The remaining (omnivorous) species consume both macro-invertebrates and plants. Whilst some species venture to 15 m depth, others such as bream, silver bream, tench and rudd live in very shallow (0-1 m depth) water. Apparent adaptations to living in shallow water include the ability of bream to survive for extended periods out of the water, and the burrowing behaviour of Crucian carp and tench in winter. None of these species migrates to spawn, all simply scattering sticky eggs that become attached to shallow vegetation and in some cases to the substratum. The spawning envelope is April to July, and the small amount of information available indicates that the eggs hatch within a few days.

Brackish lakes and HA water bodies in western Scotland and Orkney have a few additional characteristic species; namely goby, flounder, 9/10 (15) spined stickleback, saithe, bass and mullet spp. Flounder, mullet and saithe are essentially marine (and marine spawning) species that occasionally find their way into brackish waters. On the other hand, ninespine stickleback and goby show some adaptations to life in lakes, in that both exhibit nest-guarding behaviour and goby survives periods of low water level by burrowing.

5.4.5 Phytoplankton

It was pointed out at the expert workshop that conditions for plankton are important not only because they comprise a biological quality element in their own right, but also because planktivorous fish are dependent on them. Since they float freely in the water rather than being anchored to the substratum like macrophytes, phytoplankton are relatively insensitive to water level fluctuations[2] (A. Elliott pers. comm.) but highly sensitive to changes in the rate of throughflow because of the effect on nutrient availability. Allott (1990) identified a threshold

[2] There may be times when phytoplankton become associated with macrophytes, for example by being entrapped in macrophyte beds during periods of lower water level, but the relationship is not permanent.

of 20 days for the 'instantaneous residence time' (calculated by dividing lake volume by daily discharge at the outlet), below which phytoplankton populations were affected by washout. Current work (SNIFFER project WFD38) indicates significant differences in phytoplankton populations between lakes with annual average residence times above and below 20 days. Thus, hydrological disturbance is likely to affect phytoplankton populations if it results in a significant change in the annual range and distribution of daily residence time, and especially if it affects the distribution relative to the 20-day threshold. Residence time is a function of lake volume and rate of throughflow, so that it is uniquely related to water level; but its value also depends upon the metrics of the individual basin so that calculations of change relative to the 20-day threshold would be most appropriately carried out at that level. However, a preliminary analysis indicated that the sensitivity of residence time to changes in water level is a function of lake area, depth, outlet rating and basin form/shoreline slope, and it is three times more sensitive to alteration of through-flow/water level in a vertical-sided lake than in an (unstratified) conical lake of the same maximum depth.

5.4.6 Sensitivity calendar

The considerations outlined above indicate that many of the habitat requirements of biota vary seasonally. The implications for an ecologically acceptable water level regime are highlighted by the sensitivity calendar (Table 30).

Many of the life requirements of fish and invertebrates are intimately linked to the primary producer (macrophyte and phytoplankton) communities. For example, pike use vegetation for cover; sticklebacks, perch and eel migrate to the profundal zone as the end of the vegetative season approaches in autumn; perch also make rapid and flexible diel movements between the pelagic and littoral zones in order to balance the conflicting demands of feeding and avoiding predation; sticklebacks build their nests in vegetation; and many invertebrate distributions are linked to those of macrophytes. Phytoplankton are generally insensitive to water level fluctuations, so that a key aspect of the ecologically satisfactory water level regime is that it should provide conditions suitable for macrophytes. Obviously, this requirement will apply principally during the vegetation growth season, which is taken to last for eight months from March to September inclusive. Critical stages of invertebrate and fish life cycles occur at different times of year for different species, and it is possible that these will impose more stringent requirements than vegetation at some times, especially for species whose life cycles include critical stages during the winter months. The timing of all critical periods identified is indicated in the sensitivity calendar, and these are grouped according to the lake types for which the species involved are characteristic.

The principal indications of the sensitivity calendar are:

- sensitive life stages of biota may be in progress in all lakes from February to September inclusive;
- from October to January inclusive, no life stages that are critically sensitive to water level change are indicated for species typical of HA, Marl and B lakes; whereas
- sensitive stages are indicated during the winter months for species characteristic of P, LA and MA lakes.

Table 30 - Sensitivity calendar showing the duration of critical life stages for species characteristic of different lake types

			WINTER				SUMMER							
Lake type	Species/group	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jly	Aug	Sep
all	Macrophytes							growth, flowering and seed dispersal						
most	3-spined stickleback							nesting						
most	Pike						spawning in flooded eulittoral							
P	Dragonflies			nymphs in shallow water										
LA, MA	Charr	spawning and incubation												
LA, MA	whitefish, vendace						spawning and incubation							
HA	Ruffe								spawning					
HA	rudd, silver bream, gudgeon, roach, Crucian carp									spawning				
HA	bream, tench, common carp									spawning				
B	9-sp stickleback, rock bass								nesting					
HA, B	common goby								nesting					

5.5 Sensitivity modifiers

The information in Table 29 indicates that some attributes of a lake are likely to influence its physical response to water level alteration in ways that will affect the biota. Thus, whilst the basic sensitivity of each of the geological types will be determined by its characteristic plant and animal communities (the receptors), various sensitivity modifiers may or may not operate within each type. Such effects are explored below.

5.5.1 Underwater light climate

The development of vegetation in the sub-littoral zone will be determined by the depth to which light can penetrate below the water surface. Thus the same water level drawdown in lakes with clear and turbid water will expose different fractions of the sub-littoral vegetation. Since water clarity varies between the geological types (Table 28), this is likely to give rise to type-specific differences in sensitivity to alteration of the water level regime.

The water in type P (Peat) lakes is typically highly coloured by humic material, so that light penetration is severely restricted and sensitivity to water level alteration consequently high. Additional justification for the high sensitivity of this type arises from the likelihood that riparian vegetation in peat catchments will include a high cover of *Sphagnum* (bog moss), which requires high water table conditions; an observation made during the expert workshop suggested that survival of this genus can be jeopardised by water table drawdown of only a few centimetres. Where the lake water is actually contained by peat banks, an additional consequence of drawdown is the oxidation of dewatered peat along the shoreline. Since peat consists almost entirely of organic material, it will either disappear completely through oxidation, or suffer erosion with release of fine peat sediment into the lake. In either case, the structure of the shoreline will be irreversibly altered through such desiccation.

The least sensitive lake types in this respect should be LA and Marl, since they have clear water, and thus good light penetration, throughout the year.

An intermediate level of sensitivity can be anticipated for MA and HA lakes, where light penetration is seasonally restricted (in summer) by algal blooms. In these types, sediments tend to be finer (sand-silt) than in other types (Table 28) and thus susceptible to re-suspension through wave action in windy weather. Sediments in brackish lakes range from gravel to soft mud, so that in the absence of site-specific information, type B must be included in this category on the basis that individual examples may also have fine sediments that are readily re-suspended.

This effect is opposed, however, by the higher sensitivity of LA and MA vegetation to water level regulation (Section 5.4.2).

5.5.2 Altitude

The principal effects identified in Table 29 that might be influenced by altitude are those connected with cold winter temperatures, including:

- freezing of flora and fauna in the littoral zone during winter drawdown;
- ice-induced erosion of exposed sediments; and
- abnormally low winter temperatures in the profundal zone.

Lakes at higher altitudes are also likely to experience greater exposure to wind, with associated sediment and water clarity effects. Therefore, sensitivity to water level drawdown should increase with altitude, with the effect being felt mostly in winter.

5.5.3 Lake area

Area – in other words the size of the lake – influences the sensitivity of the system to water level drawdown in more than one way that is likely to affect biota.

The shallowest part of the lake floor is exposed to wave action, and so any sediment there is subject to frequent re-suspension. If the water level is altered, sediments on a different part of the lake floor that was previously not exposed to waves will be made available for re-suspension, with consequences for water clarity. The magnitude of the effect increases with wave base depth D_{wb}, which in turn increases with wind fetch over the lake, and thus with lake area.

Residence time is related to lake area (through volume) and water level (through flow), and its sensitivity to water level change increases with lake area.

The tendency of the lake to stratify in summer also increases with area. Since the development of a thermocline reduces the volume of water involved in throughflow, residence time will be more sensitive to changes in water supply when the lake is stratified, with consequences for nutrient dynamics, phytoplankton populations and planktivorous fish.

Whilst these effects indicate that sensitivity should increase with lake area, an opposing effect can also be identified. Larger lakes tend to offer greater diversity of habitats, so that their biota tend to be more resilient to alteration of the physical conditions.

5.5.4 Lake depth

The potential influence of lake depth on sensitivity to water level change is also multi-faceted.

The fraction of the lake floor where sediments are susceptible to re-suspension is a function not only of area but also of depth, the pertinent variable being the dynamic ratio $DR=\sqrt{A}/D_{mean}$ where A is the water surface area in km^2 and D_{mean} the mean depth in metres; thus shallow lakes should be more sensitive in this respect than deep ones.

Residence time is related to lake depth through volume, becoming less sensitive to water level change as depth increases; although this effect may be partially offset in summer by the fact that deeper lakes are more likely to stratify than shallow ones (Allott 1990), again with implications for summer residence time and nutrient dynamics.

5.5.5 Basin form

Basin form is expressed by the 'volume development' or 'form factor' V_d , which is defined by the relationship

$$V_d = 3D_{mean}/D_{max}$$

where D_{mean} and D_{max} are the mean and maximum depths respectively (Håkanson 1981). Small values of V_d indicate 'convex' basins, in which a large fraction of the lake floor is relatively shallow, so that alteration of the water level will involve proportionally larger lake floor impacts than in other basin types. There are implications for the sediment re-suspension effect described in the previous two Sections, since the area of the lake floor between the surface and the wave base will be proportionally large in convex basins. Also, the relative proportions of littoral and profundal habitats offered to organisms, as well as lake volume (relevant to residence time), will undergo comparatively large changes as the water level is altered in convex basins.

A recent analysis of data for the limited sample of lakes in the UK for which surveyed (rather than modelled) values for both D_{mean} and D_{max} are available (Table 31 and Figure 36) indicates that the characteristic basin form is 'linear' for types P, LA and MA, and 'concave' for type HA, and that 'convex' basins (V_d < 0.67) occur in 5% or fewer of the examples available for each of these types. This analysis also indicates that D_{mean} and D_{max} are highly correlated in all of the examples available.

Table 31 - Classification system for defining the form of lake hypsographic curves and corresponding probabilities based on standard deviations (SD), class limits and V_d values, modified from Håkanson (1981)

Lake form	Label	Probability (%)	Class Limits	V_d
Very convex	VCx	6.5	f(-3.0) to f(-1.5)	0.05-0.33
Convex	Cx	24.2	f(-1.5) to f(-0.5)	0.33-0.67
Slightly convex	SCx	38.3	f(0.5) to f(1.5)	0.67-1.00
Linear	L	24.2	f(0.5) to f(1.5)	1.00-1.33
Concave	C	6.5	f(1.5) to f(3.0)	1.33 to 2.00

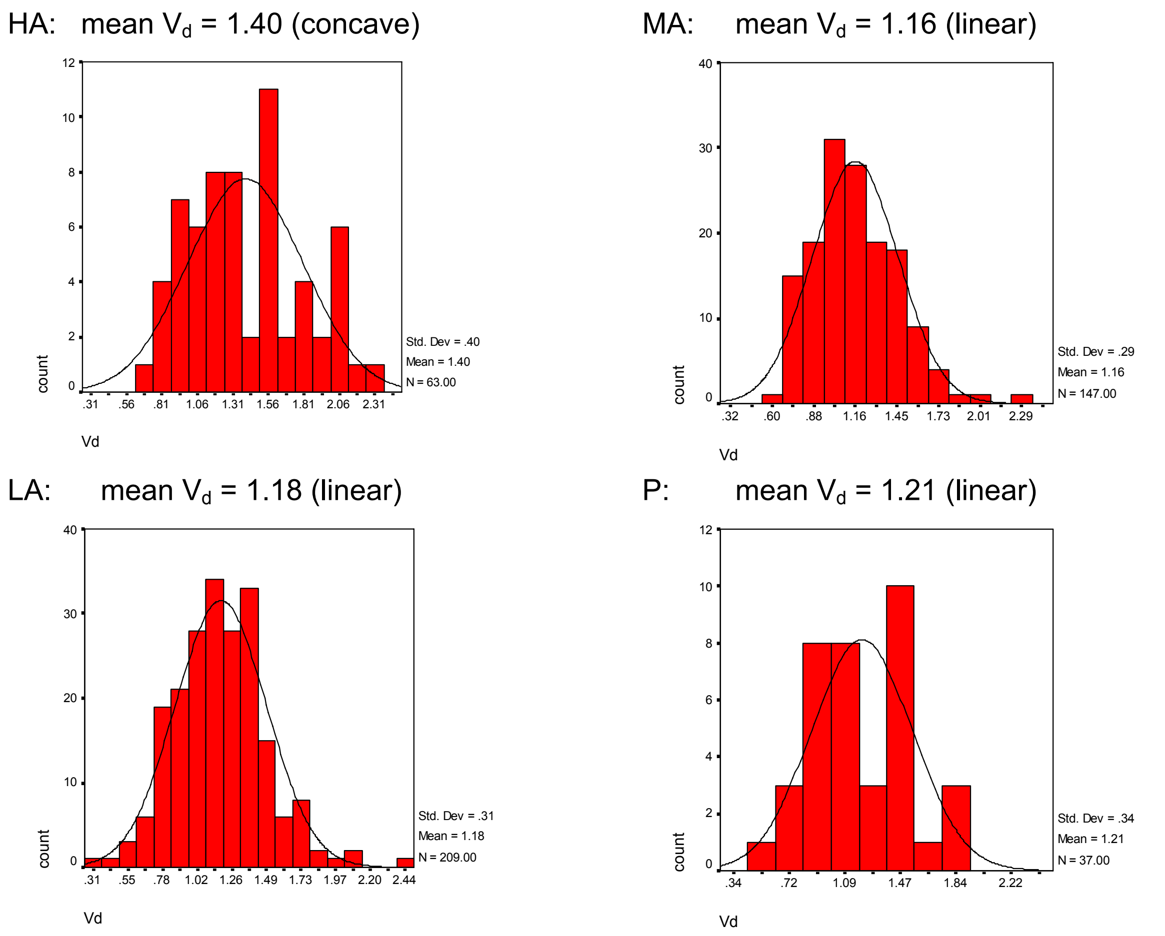


Figure 36 - Frequency distribution curves of V_d for surveyed lakes of types HA, MA, LA and P. Number of examples (N) varies between lake types. Data from GBLakes; analysis conducted within SNIFFER project WFD49a.

5.6 Sensitivity typology for lakes

The considerations outlined above (Sections 5.4.2 to 5.4.6 and 5.5.1 to 5.5.5) indicate that the factors that determine the sensitivity to hydrological alteration of the lake types defined in Tier 1 of the UK lakes typology can largely be related to the subsidiary tiers of that typology, but that the relationships are not straightforward in some cases. Moreover, the lack of scientific background makes it less than meaningful either to define sensitivity classes anew or to distinguish between all of the UK lakes typology classes for all variables. Aspects that are not covered by the UK typology are seasonality (note of course that this is not a characteristic of a lake per se, but is included here to aid the development of a sensitivity score method in the following sections) and basin form. The tiers of the sensitivity typology are summarised in Table 32. Criteria that deviate from those of the UK lakes typology are explained briefly below.

Size (Section 5.5.3)**:**
The UK reporting typology offers three size classes based on lake area, and a fourth class (VL) is now proposed[3]:

- Very small (VS): 1-<10 ha
- Small (S): 10-<50 ha
- Large (L): 50-<500 ha
- Very large (VL): >500 ha (5km^2).

In view of the opposing size-related sensitivity effects identified in Section 5.5.3, only two classes – VS/S (A < 50 ha) and L/VL (A ≥ 50 ha) - are distinguished.

Basin form (Section 5.5.5)**:**

Lakes whose basins fall into Håkanson's (1981) "very convex" and "convex" classes (V_d <0.67) are distinguished as being more sensitive than those in classes "slightly convex", "linear" and "concave" (V_d ≥0.67) (Table 31).

Season (Section 5.4.6 and Table 30)**:**

The eight-month (February to September) summer season represents the envelope of critical life stages that are common to all lake types, and is intended to incorporate the whole of the growth season for macrophytes which appear to be fundamental to habitat provision for other organisms. During the four-month (October to January) winter season, critical life stages are in progress in some lake types but apparently not in others.

5.7 A risk-based system for sensitivity assessment

The effects on lake sensitivity to hydrological change associated with the various chemical and physical attributes identified in the typology above are uncertain: there is a significant lack of calibration data to identify the effects in isolation or in combination. Accepting this uncertainty while seeking to make the best possible estimates of sensitivity, a risk-based system using a points-scoring system is proposed. In this, substantial weight is afforded to geological type, which is currently the best understood aspect of the typology in terms of relationships to biota; and limited weight is given to the sensitivity modifiers, for which only scant and circumstantial accounts of mechanisms are available to date. Thus the proposed system recognises the considerable inherent uncertainties, but nevertheless provides a mechanism for flagging sources of increased sensitivity and taking some account of their effects as the cumulative number of points scored increases.

[3] SNIFFER WFD49a; Development of decision making frameworks for lakes.

Table 32 - Outline of proposed tiered sensitivity typology for lakes reflecting sensitivity to alteration of water level

Tier	distinguishing variable(s); (units)	Class names and criteria					
Geological type	as UK lakes typology (UKTAG 2003)	P	LA	MA	HA	Marl	B
Depth	D_{mean} (m)	Very shallow (Sh)			Deep (D)		
		< 3 m			≥ 3 m		
Altitude	(m)	Lowland (Low)		Mid-altitude (Mid)		High-altitude (High)	
		< 200		200 – < 800		≥ 800	
Size (lake area)	A (ha)	VS/S			L/VL		
		1 - < 50			≥ 50		
Season	months	summer			winter		
		February to September			October to January		
Basin form	$V_d = 3D_{mean}/D_{max}$	vex (VCx/Cx)			lin (SCx/L/C)		
		< 0.67			≥ 0.67		

Note: the order of tiers reflects that of the UK lakes typology, and does not necessarily reflect order of importance in terms of sensitivity to alteration of the water level.

The sensitivity score indicates the minimum acceptable water level (relative to the natural water level) at GES. The water level must obviously be referred to a fixed datum. The datum chosen is the level of the sill at the outlet of the lake, and water levels are measured as heights above the sill. The sensitivity score is a positive integer that indicates the minimum height of the modified water level above datum at GES, as a percentage of the height that it would attain under natural conditions. Thus, if the water level can be lowered by 20% before the GES/MES boundary is reached, the sensitivity score is 80; whereas if it can be lowered by only 5%, the sensitivity score is 95.

A sensitivity base score f_{min} is awarded to each geological type for the 8-month summer season February to September and the 4-month winter season October to January. This is essentially an ‘expert-opinion’ score taking into account the factors identified in Section 5.5.1 (underwater light climate) and the critical life stages of biota identified in the sensitivity calendar (Table 30).

The summer base score is 80 for lake types with clear water (LA, Marl), 85 for types where light penetration is affected by plankton blooms and/or readily mobilised sediments (MA, B), and 90 for peat lakes where light penetration is permanently limited by water colour and there are additional issues of sensitivity of riparian peat and wetland plants to desiccation. Although HA lakes have seasonally limited light penetration, their summer base score is set at 80 in view of the relative insensitivity of their macrophyte communities to water level regulation.

The winter base score is 80 for lake types where the sensitivity calendar indicates no specific sensitivities to water level change during the winter period (HA, Marl and B), since the general issues of cold temperatures for invertebrates and sediment erosion initiated by freezing still apply in these cases. For LA and MA lakes, which can support winter-spawning charr, the winter base score is 85. Although charr are rare and certainly will not be present in all LA and MA lakes, their absence reflects existing disturbance to the water level regime in at least some cases (e.g. Loch Leven), and the capability of the type to support charr may well serve as an index of conditions for other biota[4]. The winter score for P lakes is 90 - the same as the summer score - in order to retain the same inundation of vegetation likely to support exposure-sensitive dragonfly nymphs at that time of year.

The remaining sensitivity modifiers are then applied by adding 1 (unity) to the base score for each case where additional sensitivity is indicated. This is done in all instances where mean depth is less than 3 m, where lake surface area (A) is $\geq$ 50 ha and/or where basin form is convex or very convex (V_d < 0.67). Only the winter sensitivity score is modified for altitude. For five types, one point is awarded if basin altitude is > 200 m a.s.l. and a second point is added if basin altitude is > 800 m a.s.l. For brackish lakes, a point is added only in the latter case to take into account the lower freezing temperature of salty water. The final total is the sensitivity score f. The maximum achievable scores f_{max} varies between types as shown in Table 33.

Table 33 - Scheme for award of sensitivity points

	Geological type	P		LA		MA		HA, Marl		B	
	months	F-S	O-Ja	F-S	O-Ja	F-S	O-Ja	F-S	O-Ja	F-S	O-Ja
	f_{min}	90	90	80	85	85	85	80	80	85	80
Modifier criteria	D_{mean} < 3 m	1	1	1	1	1	1	1	1	1	1
	A $\geq$ 50 ha (0.5 km^2)	1	1	1	1	1	1	1	1	1	1
	Basin altitude $\geq$ 200 m	0	1	0	1	0	1	0	1	0	0
	Basin altitude $\geq$ 800 m	0	1	0	1	0	1	0	1	0	1
	Basin form: V_d < 0.67	1	1	1	1	1	1	1	1	1	1
	f_{max}	93	95	83	90	88	90	83	85	88	84

[4] Given the limited information base available and the small quantity of biological information likely to be available before regulation requirements are set, it is proposed in general that the required water level conditions set for each lake type should be suitable for the characteristic species even if they are not actually present. This approach is justified on the basis that the requirements of these species reflect the characteristic water level regime for the type, which is highly likely to influence additional, more obscure, aspects of ecology.

6 LAKES RECOMMENDED STANDARDS

6.1 Standards for GES based on water level

The maximum permissible abstraction or withdrawal compatible with good ecological status can be defined in terms of the lowest acceptable water level on any day resulting from abstraction, since lake water level and outflow are related. That minimum acceptable water level H_{ac} is set as a function of H_{nat}, the water level without abstraction (anywhere in the upstream catchment) and f, as:

$$H_{ac} = \frac{f \times H_{nat}}{100}$$

H_{nat} and H_{ac} are measured in metres above the lake's sill level (sill datum, at which level flow ceases). Thus, the sensitivity scores awarded in Table 33 represent H_{ac} as percentages of H_{nat}.

For conformity with Table 20 for rivers, Table 34 shows the environmental standards for each lake type in terms of drawdown as %H_{nat}. Expressing environmental standards as a drawn-down proportion of natural level ensures that lake level variability is maintained.

Table 34 - Environmental standards expressed in terms of drawdown as % of H_{nat} for lake types and seasons

Geology		Altitude	Low				Mid				High			
range of drawdown permitted		Size	VS/S		L/VL		VS/S		L/VL		VS/S		L/VL	
		Basin form	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex
	Season	Depth												
P	summer	D	10	9	9	8	10	9	9	8	10	9	9	8
		Sh	9	8	8	7	9	8	8	7	9	8	8	7
5-10%	winter	D	10	9	9	8	9	8	8	7	8	7	7	6
		Sh	9	8	8	7	8	7	7	6	7	6	6	5
LA	summer	D	20	19	19	18	20	19	19	18	20	19	19	18
		Sh	19	18	18	17	19	18	18	17	19	18	18	17
10-20%	winter	D	15	14	14	13	14	13	13	12	13	12	12	11
		Sh	14	13	13	12	13	12	12	11	12	11	11	10
MA	summer	D	15	14	14	13	15	14	14	13	15	14	14	13
		Sh	14	13	13	12	14	13	13	12	14	13	13	12
10-15%	winter	D	15	14	14	13	14	13	13	12	13	12	12	11
		Sh	14	13	13	12	13	12	12	11	12	11	11	10
HA, Marl	summer	D	20	19	19	18	20	19	19	18	20	19	19	18
		Sh	19	18	18	17	19	18	18	17	19	18	18	17
15-20%	winter	D	20	19	19	18	19	18	18	17	18	17	17	16
		Sh	19	18	18	17	18	17	17	16	17	16	16	15
B	summer	D	15	14	14	13	15	14	14	13	15	14	14	13
	summer	Sh	14	13	13	12	14	13	13	12	14	13	13	12
12-20%	winter	D	20	19	19	18	20	19	19	18	19	18	18	17
	winter	Sh	19	18	18	17	19	18	18	17	18	17	17	16

Codes: VS: very small, S: small, L: large; lin: linear, vex: convex; Sh: shallow; D: deep. All terms as defined above.

6.2 Confidence and interpretation

Due to the lack of relevant data, this is of necessity a largely 'expert opinion' based scheme. Even experts are reluctant to offer numerical estimates. During the workshop, one ventured an opinion that a drawdown of "about a metre" would be the maximum permissible for lake macrophytes. When asked to estimate an acceptable drawdown as a percentage of H_{nat}, another expert later indicated that 30% drawdown would not be satisfactory for macrophytes, and that a precautionary estimate of acceptable drawdown would be "about 20%"; this estimate is used to set the sensitivity base score for summer at (100-20=) 80, equivalent to a water level drawdown of 20% of H_{nat}. The reticence of experts is hardly surprising in view of the fact that there is little information available even on the annual ranges of fluctuation of lake water levels. An energetic search made during this project yielded data for eight natural lakes (Table 35), which show annual ranges of 0.3-2.0 m. Casual observations indicate that lake sills are no more than one metre below normal-to-low water levels, so that a drawdown of 20% of H_{nat} would be 0.06 - 0.40 m in absolute terms, and thus well within the limit set by the first expert. Though the sensitivity scores may be difficult to justify precisely, the system does offer the benefit of being responsive to differences between lakes, according to the factors selected for inclusion in the scoring system.

6.3 Standards for GES based on flow

Consider the outflow from the lake. The natural water level is H (expressed in metres above sill datum), corresponding to outflow flux Q (m^3s^{-1}). If a rating curve for the outflow were available, this would show how water level H varied with outflow flux Q. In most cases, such rating curves are not available. However, the problem can be approached by adopting an equation of the form

$$Q = K(H + c)^a \qquad (1)$$

where K, c and a are constants that can be derived empirically, e.g. from flow series and water level data. Flow gauging stations located downstream of the outlets of lakes for which water level records are available were identified (Lochs Ness, Insh and Tay) and flow plotted against water level. Estimates of K, c and a, obtained using the Solver function of MS Excel and user choice of break-points, are given in Table 36. The results show reasonable consistency with Chezy's equation:

$$Q = bmH^{\frac{3}{2}} \qquad (2)$$

where the width of the sill is m (m) and the roughness coefficient[5] is b. Comparing with Equation 1, $bm=K$.

Discarding the stage datum correction c, Equation 1 can be written as

$$Q_{nat} = KH_{nat}{}^{a}$$

where water level H_{nat} corresponds to outflow flux Q_{nat} (m^3s^{-1}). It can then be used to explore a scenario with an abstraction flux.

[5] The width of the outlet of Loch Tay was measured on a 1:10560 Ordnance Survey map, and the corresponding roughness coefficient calculated at 1.8.

Table 35 - Water level statistics derived from daily data for eight lakes with relatively natural regimes; the only data resulting from exhaustive search and enquiry

	Coniston		Derwentwater		Rockland (Broad)		Quoich pre-hydro		Naver		Arkaig		Insh		Malham Tarn	
	Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev	Mean	St dev
annual range	1.341	0.097	1.985	0.209	1.667	0.068	2.048	0.369	1.363	0.168	1.295	0.312	1.969	0.494	0.238	0.105
max. daily rise (9am - 9am)	0.451	0.110	0.884	0.242	0.894	0.062	0.999	0.207	0.699	0.253	0.559	0.308	0.869	0.360		
max. daily fall (9am - 9am)	-0.137	0.025	-0.369	0.070	-0.793	0.180	-0.541	0.241	-0.287	0.064	-0.237	0.130	-0.468	0.125		
spring-range	0.816	0.239	1.187	0.390	0.979	0.049	1.289	0.355	0.972	0.244	0.838	0.051	1.016	0.574		
summer-range	0.573	0.264	0.735	0.293	0.860	0.075	1.261	0.229	0.534	0.212	0.720	0.187	0.453	0.307		
autumn-range	1.058	0.192	1.512	0.258	1.127	0.102	2.299	0.461	1.119	0.271	1.143	0.353	1.483	0.513		
winter-range	0.999	0.192	1.474	0.376	1.316	0.199	1.794	0.406	1.029	0.155	1.126	0.368	1.435	0.708		
15%ile weekly range	0.338	0.058	0.586	0.110	0.703	0.039	0.633	0.093	0.437	0.063	0.389	0.115	0.400	0.089		
Comment	Essentially natural		Essentially natural		Broad - tidal influence		Natural		Natural		Natural		Moderately natural; inflow regime affected by u/s hydro-power impoundments		Natural inflow regime; effect of sluice operation apparently very minor	

Table 36 - Rating coefficients obtained for lakes with level and outflow data, using Equation 1

Site	K	c	a
Outflow of Loch Tay at Kenmore	76.0	-0.480	1.65
Outflow of Loch Insh H<1.347m	31.79	0.132	1.40
Outflow of Loch Insh H≥1.347m	54.03	-0.329	1.50
Outflow of Loch Insh H>2.2m	148.3	-1.285	0.60
Outflow of Loch Ness H<1.84m	453.9	0.000	1.52
Outflow of Loch Ness H≥1.84m	154.3	0.000	1.42

If the maximum permitted abstraction flux Q_{abs} (m^3s^{-1}) is applied, the outflow flux will be reduced to ($Q_{nat} - Q_{abs}$) and the new (steady-state) water level will be H_{ac}. Then

$$Q_{nat} - Q_{abs} = KH_{ac}^{a}\text{; thus } Q_{abs} = Q_{nat} - K\left(fH_{nat}\right)^{a} \text{ and } Q_{abs} = Q_{nat}\left(1 - f^{a}\right)$$

Using the Chezy equation (K=bm, a=3/2), the corresponding expressions are:

$$Q_{abs} = Q_{nat} - bm\left(fH_{nat}\right)^{\frac{3}{2}} \text{ and } Q_{abs} = Q_{nat}\left(1 - f^{\frac{3}{2}}\right)$$

The environmental standards given in Table 34 can now be expressed in terms of flow, referring to permitted abstraction flux as a total abstraction expressed as a proportion of net natural inflow (all surface inflows plus direct precipitation and net groundwater flux, less evaporation) to the lake (Table 37).

Table 37 - Abstraction standards for GES as flows obtained as a function of net lake inflow

lake type		P		LA		MA		HA, Marl		B	
		min	max	min	max	min	max	min	max	min	max
permitted drawdown	$\%H_{nat}$	5	10	10	20	10	15	15	20	12	20
permitted abstraction flux	$\%Q_{nat}$	7	15	15	28	15	22	22	28	17	28

Recommendations for rivers are Q_{ac}/Q_{nat} = 0.8 and 0.9 for macrophytes and invertebrates (Table 20); these correspond to values of H_{ac}/H_{nat} of 0.86 and 0.93 respectively for the Chezy scenario. Thus the lake appears to be less sensitive than the river, although this relies upon the true value of a exceeding unity. This is found to be true throughout the stage range for the Ness and Tay sites, and for all except the highest stages at Loch Insh (if the Loch Insh rating is simplified to one curve, its exponent is in excess of 2) (Table 36).

Assuming the a exponent to be 1.5, Table 34 can be re-worked to show permitted abstraction flux for each lake type (Table 38).

Table 38 - Environmental standards for GES expressed in terms of abstraction as % of natural net inflow for lake types and seasons

Geology		Altitude	Low				Mid				High			
Range of abstraction permitted		Size	VS/S		L/VL		VS/S		L/VL		VS/S		L/VL	
		Basin form	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex
	Season	Depth												
P	summer	D	15	13	13	12	15	13	13	12	15	13	13	12
		Sh	13	12	12	10	13	12	12	10	13	12	12	10
7-15%	winter	D	15	13	13	12	13	12	12	10	12	10	10	9
		Sh	13	12	12	10	12	10	10	9	10	9	9	7
LA	summer	D	28	27	27	26	28	27	27	26	28	27	27	26
		Sh	27	26	26	24	27	26	26	24	27	26	26	24
15-28%	winter	D	22	20	20	19	20	19	19	17	19	17	17	16
		Sh	20	19	19	17	19	17	17	16	17	16	16	15
MA	summer	D	22	20	20	19	22	20	20	19	22	20	20	19
		Sh	20	19	19	17	20	19	19	17	20	19	19	17
15-22%	winter	D	22	20	20	19	20	19	19	17	19	17	17	16
		Sh	20	19	19	17	19	17	17	16	17	16	16	15
HA, Marl	summer	D	28	27	27	26	28	27	27	26	28	27	27	26
		Sh	27	26	26	24	27	26	26	24	27	26	26	24
22-28%	winter	D	28	27	27	26	27	26	26	24	26	24	24	23
		Sh	27	26	26	24	26	24	24	23	24	23	23	22
B	summer	D	22	20	20	19	22	20	20	19	22	20	20	19
		Sh	20	19	19	17	20	19	19	17	20	19	19	17
17-28%	winter	D	28	27	27	26	28	27	27	26	27	26	26	24
		Sh	27	26	26	24	27	26	26	24	26	24	24	23

Codes: VS: very small, S: small, L: large; lin: linear, vex: convex; Sh: shallow; D: deep. All terms as defined above.

The standards proposed in Table 38 take into account the various physical factors thought to be relevant to sensitivity, and draw on the concept of risk in using a points-based approach for combining influences in the process of setting standards. However, they suffer the disadvantage of suggesting a level of accuracy which cannot be justified empirically. Therefore, in order to make allowance for this, while still maintaining an appropriate level of discrimination, a rounding process has been undertaken – each of the standards in Table 38 has been rounded to the nearest 5% in Table 39. These are therefore the environmental standards proposed for use.

These threshold values are proposed to apply to inflows calculated on a daily time step. Available abstraction amounts will therefore theoretically be at a maximum at times of maximum inflow to a lake, although amounts abstracted in practice may well be limited by plant capacities.

Table 39 - Environmental standards for Good Ecological Status expressed in terms of abstraction as % of natural net inflow for lake types and seasons, rounded to the nearest 5%

Geology		Altitude	Low				Mid				High			
		Size	VS/S		L/VL		VS/S		L/VL		VS/S		L/VL	
		Basin form	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex
	Season	Depth												
P	summer	D	15	15	15	10	15	15	15	10	15	15	15	10
		Sh	15	10	10	10	15	10	10	10	15	10	10	10
	winter	D	15	15	15	10	15	10	10	10	12	10	10	10
		Sh	15	10	10	10	10	10	10	10	10	10	10	5
LA	summer	D	30	25	25	25	30	25	25	25	30	25	25	25
		Sh	25	25	25	25	25	25	25	25	25	25	25	25
	winter	D	20	20	20	20	20	20	20	15	20	15	15	15
		Sh	20	20	20	15	20	15	15	15	15	15	15	15
MA	summer	D	20	20	20	20	20	20	20	20	20	20	20	20
		Sh	20	20	20	15	20	20	20	15	20	20	20	15
	winter	D	20	20	20	20	20	20	20	15	20	15	15	15
		Sh	20	20	20	15	20	15	15	15	15	15	15	15
HA, Marl	summer	D	30	25	25	25	30	25	25	25	30	25	25	25
		Sh	25	25	25	25	25	25	25	25	25	25	25	25
	winter	D	30	25	25	25	25	25	25	25	25	25	25	25
		Sh	25	25	25	25	25	25	25	25	25	25	25	20
B	summer	D	20	20	20	20	20	20	20	20	20	20	20	20
		Sh	20	20	20	15	20	20	20	15	20	20	20	15
	winter	D	30	25	25	25	30	25	25	25	25	25	25	25
		Sh	25	25	25	25	25	25	25	25	25	25	25	25

Codes: VS: very small, S: small, L: large; lin: linear, vex: convex; Sh: shallow; D: deep. All terms as defined above. Shading indicates cases where the standard for the lake may be more rigorous than that of the connecting rivers.

As already noted, the abstraction standards set for macrophytes and invertebrates in rivers in Table 20 are 20% and 10% of natural flow. Thus, in practice, the river standard will always be more rigorous than those for HA and Marl lakes so that these require no further attention once they have been identified within a river system for which environmental standards are being derived. For other lake types, further typological information will be required in order to assess whether the presence of the lake is likely to constrain the standard for the whole system. For rivers where the environmental standard is set at 10% (e.g. A2, B1, C2, D2), the only lake type that could impose a more rigorous standard is a large, shallow, high-altitude peat lake with convex basin.

However, in all cases, measurement of lake levels will be highly desirable for the purposes of (a) gaining a better knowledge of lake hydrology and/or (b) developing some length of observations for individual water bodies thought to be particularly at risk, so that hands-off conditions may be declared in the context of a reasonable knowledge base in future. It is anticipated that once a few years of record have been developed for individual lakes, threshold levels corresponding to 95 and 99-percentile exceedance values will be defined for reduced abstraction and hands-off levels, in a manner analogous to that developed for rivers, and subject to learning more about river-lake-abstraction interactions in individual catchments.

6.4 Standards for High, Moderate and Poor Ecological Status based on flow

The project brief requires standards for the other ecological status boundaries in addition to the key ecological status boundary of good/moderate. The available literature provides no assistance in identifying the appropriate values for these thresholds, and similarly neither were the experts at the project workshop.

The generic river thresholds (standards) proposed by English Nature for designated rivers (SSSI, SAC) and shown in Table 22 of this report provide a helpful guide to the setting of thresholds for high ecological status (HES). The table provides thresholds according to flow condition (expressed on a percentile scale) and according to water body sensitivity. The lakes part of this report does not involve thresholds being altered according to flow condition, and so only the middle column of the table (for flows of between Q_{50} and Q_{95} on the natural flow duration curve) will be used for lakes.

A range of sensitivities is identified by Table 34, and it is considered to be desirable that differences in sensitivity are maintained in tables providing threshold values for other ecological status boundaries. For the good/high boundary, values of 10, 15 and 20% are provided by Table 28. These values appear to be suitable for adoption, providing discrimination between types, but with the one drawback that some lake types have good/moderate threshold abstraction values of 10%. It would not make sense for the good/high boundary to be co-located at 10%, so in this case, a 5% boundary is proposed for good/high. Otherwise, where the good/moderate boundary is set at 20% or less, a good/high boundary of 5% less flow is proposed, while for good/moderate boundaries of 25% or more, the good/high boundary may be set at 10% less flow, reflecting lower sensitivity.

Following the precedent of Section 4.2 for rivers, the moderate/poor boundary is set at 10% more flow than the good/moderate boundary, and the poor/bad boundary is set allowing an additional 10% flow abstraction. This scheme allows the size of gaps between boundaries to be the same between differing water bodies, except at the top of the status scale where (a) English Nature work for protected sites gives some guidance to the contrary, and (b) the limited range at the end of the scale demands adjustments to be made to the basic pattern of adjustments. The proposed standards in flow terms for each of the status boundaries beyond good/moderate are provided in the following

Table 40 - Table 42. Rounding to the nearest 5% is maintained.

As with the boundaries for good/moderate ecological status, it must be emphasised that the scientific basis for the threshold values shown in these tables is uncertain, and lake level and ecological monitoring will assist in the future refinement of threshold values. Also, for lakes in which the outflow ceases under some conditions, it may be worthwhile to consider the further development of standards to cater specifically for these situations.

Table 40 - Environmental standards for High Ecological Status expressed in terms of abstraction as % of natural net inflow for lake types and seasons, rounded to the nearest 5%

Geology	Altitude		Low				Mid				High			
	Size		VS/S		L/VL		VS/S		L/VL		VS/S		L/VL	
	Basin form		lin	vex	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex
	Depth	Season												
P	summer	D	10	10	10	5	10	10	10	5	10	10	10	5
		Sh	10	5	5	5	10	5	5	5	10	5	5	5
	winter	D	10	10	10	5	10	5	5	5	7	5	5	5
		Sh	10	5	5	5	5	5	5	5	5	5	5	*
LA	summer	D	20	15	15	15	20	15	15	15	20	15	15	15
	summer	Sh	15	15	15	15	15	15	15	15	15	15	15	15
	winter	D	15	15	15	15	15	15	15	10	15	10	10	10
	winter	Sh	15	15	15	10	15	10	10	10	10	10	10	10
MA	summer	D	15	15	15	15	15	15	15	15	15	15	15	15
		Sh	15	15	15	10	15	15	15	10	15	15	15	10
	winter	D	15	15	15	15	15	15	15	10	15	10	10	10
		Sh	15	15	15	10	15	10	10	10	10	10	10	10
HA, Marl	summer	D	20	15	15	15	20	15	15	15	20	15	15	15
		Sh	15	15	15	15	15	15	15	15	15	15	15	15
	winter	D	20	15	15	15	15	15	15	15	15	15	15	15
		Sh	15	15	15	15	15	15	15	15	15	15	15	15
B	summer	D	15	15	15	15	15	15	15	15	15	15	15	15
		Sh	15	15	15	10	15	15	15	10	15	15	15	10
	winter	D	20	15	15	15	20	15	15	15	15	15	15	15
		Sh	15	15	15	15	15	15	15	15	15	15	15	15

Codes: VS: very small, S: small, L: large; lin: linear, vex: convex; Sh: shallow; D: deep. All terms as defined above.
* No UK lakes of this type thought to exist

Table 41 - Environmental standards for Moderate Ecological Status expressed in terms of abstraction as % of natural net inflow for lake types and seasons, rounded to the nearest 5%

Geology		Altitude	Low				Mid				High			
		Size	VS/S		L/VL		VS/S		L/VL		VS/S		L/VL	
		Basin form	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex
	Depth	Season												
P	summer	D	25	25	25	20	25	25	25	20	25	25	25	20
		Sh	25	20	20	20	25	20	20	20	25	20	20	20
	winter	D	25	25	25	20	25	20	20	20	22	20	20	20
		Sh	25	20	20	20	20	20	20	20	20	20	20	*
LA	summer	D	40	35	35	35	40	35	35	35	40	35	35	35
	summer	Sh	35	35	35	35	35	35	35	35	35	35	35	35
	winter	D	30	30	30	30	30	30	30	25	30	25	25	25
	winter	Sh	30	30	30	25	30	25	25	25	25	25	25	25
MA	summer	D	30	30	30	30	30	30	30	30	30	30	30	30
		Sh	30	30	30	25	30	30	30	25	30	30	30	25
	winter	D	30	30	30	30	30	30	30	25	30	25	25	25
		Sh	30	30	30	25	30	25	25	25	25	25	25	25
HA, Marl	summer	D	40	35	35	35	40	35	35	35	40	35	35	35
		Sh	35	35	35	35	35	35	35	35	35	35	35	35
	winter	D	40	35	35	35	35	35	35	35	35	35	35	35
		Sh	35	35	35	35	35	35	35	35	35	35	35	30
B	summer	D	30	30	30	30	30	30	30	30	30	30	30	30
		Sh	30	30	30	25	30	30	30	25	30	30	30	25
	winter	D	40	35	35	35	40	35	35	35	35	35	35	35
		Sh	35	35	35	35	35	35	35	35	35	35	35	35

Codes: VS: very small, S: small, L: large; lin: linear, vex: convex; Sh: shallow; D: deep. All terms as defined above.
* No UK lakes of this type thought to exist

Table 42 - Environmental standards for Poor Ecological Status expressed in terms of abstraction as % of natural net inflow for lake types and seasons, rounded to the nearest 5%

Geology		Altitude	Low				Mid				High			
		Size	VS/S		L/VL		VS/S		L/VL		VS/S		L/VL	
		Basin form	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex	lin	vex
	Depth	Season												
P	summer	D	35	35	35	30	35	35	35	30	35	35	35	30
		Sh	35	30	30	30	35	30	30	30	35	30	30	30
	winter	D	35	35	35	30	35	30	30	30	32	30	30	30
		Sh	35	30	30	30	30	30	30	30	30	30	30	*
LA	summer	D	50	45	45	45	50	45	45	45	50	45	45	45
	summer	Sh	45	45	45	45	45	45	45	45	45	45	45	45
	winter	D	40	40	40	40	40	40	40	35	40	35	35	35
	winter	Sh	40	40	40	35	40	35	35	35	35	35	35	35
MA	summer	D	40	40	40	40	40	40	40	40	40	40	40	40
		Sh	40	40	40	35	40	40	40	35	40	40	40	35
	winter	D	40	40	40	40	40	40	40	35	40	35	35	35
		Sh	40	40	40	35	40	35	35	35	35	35	35	35
HA, Marl	summer	D	50	45	45	45	50	45	45	45	50	45	45	45
		Sh	45	45	45	45	45	45	45	45	45	45	45	45
	winter	D	50	45	45	45	45	45	45	45	45	45	45	45
		Sh	45	45	45	45	45	45	45	45	45	45	45	40
B	summer	D	40	40	40	40	40	40	40	40	40	40	40	40
		Sh	40	40	40	35	40	40	40	35	40	40	40	35
	winter	D	50	45	45	45	50	45	45	45	45	45	45	45
		Sh	45	45	45	45	45	45	45	45	45	45	45	45

Codes: VS: very small, S: small, L: large; lin: linear, vex: convex; Sh: shallow; D: deep. All terms as defined above.
* No UK lakes of this type thought to exist

7 INTEGRATING LAKE AND RIVER ENVIRONMENTAL STANDARDS

In applying the environmental standards developed for rivers and lakes, a fundamental consideration is that water uses will impact not only on the water bodies at which they take place, but also downstream. In the case of an abstraction from a river water body, for example, ecological impact would be expected typically to be greatest in the reach in which the abstraction occurs, since further downstream there will be tributary inflows which will lessen the effects of the abstraction. However there will be changes in water level in any lake downstream, as well as in other river water bodies between the abstraction point and sea level. Indeed in some extreme cases, abstraction from rivers may cause ecological effects in estuaries and the adjacent coastal environment also.

While the above sections have addressed rivers and lakes in turn, a particular concern is the choice of environmental standards for lakes since the most appropriate standard may be not that required by the lake itself but by the river immediately downstream. Section 6 illustrates the linkage expected between lake level and the flow from its outlet. The least stringent standards developed for GES in Section 4 for restrictive management are those set to allow 20% abstraction of the natural flow. If this is considered as the maximum impact permissible in a river downstream of a lake, then Table 34 and Table 38 together indicate that the commensurate maximum permissible reduction in lake level would be 14%. Given that separate typologies will be used to define the standards applicable to river and lake water bodies, and that the relative sensitivity of a river will not necessarily be influenced by the sensitivity of an adjacent lake, sensitivity assessments will have to be done separately and the results then compared before deciding on the correct course of regulatory action. In some cases, the lake may be the most sensitive environment, while in others the reverse may be true.

A simple model was developed to investigate the sensitivity of lake levels to lake abstractions resulting in reductions of downstream river flow of 10% and 20% as per the restrictive management element of Section 4. This model was based on the following assumptions :

- Daily lake levels and outflow rates available
- Rating obtained from the above data and no allowance made for hysteresis
- Lake area obtained from GBLakes
- Inflows obtained from change of storage (indicated by level change) and outflows
- Modelled outflow rate defined using rating equation and assuming that daily abstracted volume is reflected in lowered stage based on volume/lake area.

The results are shown in Table 43. It can be seen that so long as lake abstraction is regulated as a proportion of net lake inflow, then the largest absolute impacts will be those occurring in high flow conditions. However, if total abstraction rates are limited by plant capacities, e.g. pump or turbine capacities, then the maximum proportional changes will occur at flows at and below the limit of the abstracting capacity.

Table 43 also shows the results of adjusting the rating exponent and multiplier, lake area and abstraction fraction. While the range of data goes beyond the range of natural lake characteristics found in the UK, the general conclusions can be found that while downstream river flow abstraction is limited to an environmental standard expressed in fractional terms, lake level sensitivity in absolute terms increases as lake area decreases, as the rating multiplier (synonymous with the outflow width) decreases, and rapidly as the rating exponent falls below unity. An example plot showing level hydrographs representing with and without abstraction scenarios is provided in Figure 37, illustrating the maintenance of the temporal variability in the level data series.

Table 43 - Sensitivity of maximum absolute lake level change to controlling factors

Abstraction %	Rating 'a' exponent	Lake area (m^2 x10^6)	Rating multiplier	Level range before abstraction (m)	Max level change (m)	Note
0	1.65	10	76	2.5	0.000	Baseline data
20	1.65	10	76	2.5	0.611	
10	1.65	10	76	2.5	0.306	
20	1.65	20	76	2.5	0.313	
10	1.65	20	76	2.5	0.156	
20	1.65	7	76	2.5	0.867	Below 7km^2, rating inapplicable
20	1.50	7	76	2.7	0.870	
20	1.10	7	76	4.1	0.887	As rat exp falls <1, sensitivity increases rapidly
20	1.00	7	76	4.7	0.895	
20	0.90	7	76	5.6	0.948	These ranges seem implausibly high - multipliers too low.
20	0.80	7	76	7.0	1.051	
20	1.65	7	20	5.6	0.885	
20	1.65	7	10	8.5	0.924	
20	1.65	5	10	8.5	1.242	
20	1.65	2	10	8.5	3.035	

Baseline data (Row 1) for Loch Tay. Yellow identifies cells changed compared with row above.

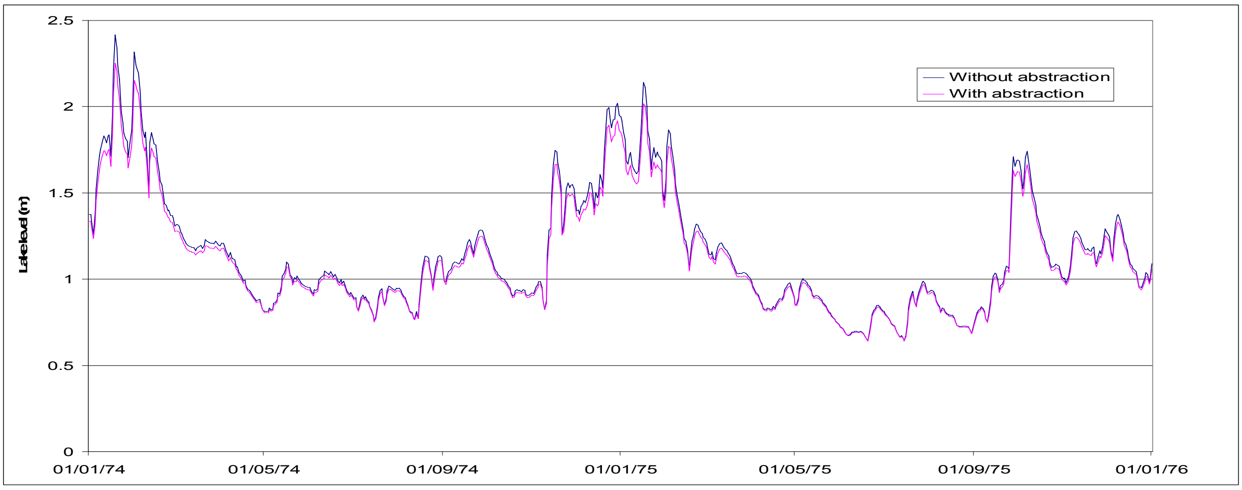


Figure 37 - Estimated water level effect of abstraction resulting in 20% reduction in outflow rate

The concept of hands-off flows and levels needs to be considered here also. While hands-off levels may be justified on the basis of specific protection for the lake, another case for ceasing any abstraction from the lake or the streams and rivers draining into it might be to allow retention of volumes of water which may be useful in protecting the downstream river in a later period, e.g. in the further development of a drought. The extent to which this would be viable seems to be an issue for modelling, since cessation of abstraction must, to some extent, lead to more outflow to the downstream river than would otherwise occur. This is an issue which therefore requires further work.

8. RECOMMENDATIONS

Experts involved in the project workshops need to be more regularly involved with the work of UK agencies to be in a good position to define regulatory standards. In the past experts have been invited at fairly short notice to help with SWALP, RAM and WFD with insufficient little time to prepare to be expected to define standards in a short workshop. There is often then little contact until the next standard setting project. The South African experience is that regular contact between agencies and experts has produced understanding of each others issues and points of view, trust between them and more robust standards.

Detailed long term study required to assess the impact of any standards that are set so that their effectiveness can be determined and revised standards can be defined. In particular the experience of all individual flow setting studies should be collated to accumulate experience of issues, best practice and outcomes.

Further research is required on the relationships between flow regime alteration and impacts on macro-invertebrates. Complete stages of the LIFE project have produced interesting results but these need to be verified over a wider range of catchments including those from Scotland and Northern Ireland.

A follow up project is required to development of a method for determining which fish community types (particularly salmonid spawning and nursery areas) occur in which water bodies, such as in the form of a map. Models that be used include the tree model used in this study to relate macrophyte communities to physical characteristics such as drainage area, slope, rainfall, altitude and geology or hydrological characteristics, such as mean flow or Base Flow Index, or site variables such as local channel width and substrate. The work of Cowx *et al.* has gone some way towards this, but results cannot be used directly for applying standards.

Additional research is required to define sensitivity to flow change of fish communities. Similar analysis to the LIFE project could be undertaken using fish datasets to determine which elements of the flow regime are most critical to achieve GES for fish. This would require improvements to the UK fish databases to permit easier access and analysis.

The use of site data such as bed substrate or river width may provide additional discrimination between river types and thus predictive power to assign new river water bodies. Whilst the standards defined in this report have, out of necessity, been based on flow (m^3/s), the physical impact of flow on in-river communities is driven by channel form and hydraulics. River Habitat Survey is the standard method for collecting river habitat data in the UK and is a huge data resource, but its consideration of channel geometry is limited: further research into the utility of RHS for water resource management is needed. Future River Habitat Surveys should include additional data collection on hydrological and hydraulic variables to assist future assessments of sensitivity to abstraction.

Further work is required to integrate the results of WFD 48 (water resources standards) with standards for water quality and morphology.

The active flow management used in this project does not include dam management for hydropower generation. There is insufficient knowledge for defining critical rates of change of flow from dams on which to set standards. This work requires a new separately funded project.

Further work is required to turn the continuous flow standards recommended in this report (ie. percentage of natural flow on any day) to fixed proportions of flow statistics that can be used where abstractions cannot be varied easily and or flow data are not available.

A follow up project is required to define more detailed regulatory standards for impounded water bodies. In particular, the optimum use of volumes of water available for release downstream. As a possible starting point, the Downstream Imposed Flow Transformation (DRIFT) method developed for Lesotho and now used in South Africa (King *et al*., 2003) contains a "solver" for defining release patterns that have most ecological benefit for the volume available.

The UKTAG should consider designating water bodies as HMWB on the basis of alterations to the flow regime. This designation should continue downstream until the modification to the hydrology is mitigated by accretion.

Attention should be directed to obtaining or developing a lake hydrological/hydraulic model capable of assessing lake level sensitivity to abstraction, and taking into account the geometry of its outflow and shores, and suitable to the needs of hydrological regulation. No such model is presently known.

A monitoring programme should be established to monitor water level fluctuations in a diverse range of lakes appropriate to current and expected patterns of abstraction activity, in conjunction with existing or new outflow measurement. This will support the modelling work in order that impacts of regulation can better be predicted in future.

Consideration should be given to establishing lake level monitoring programmes for lakes where current or anticipated abstraction is expected to give rise to particular concerns for lake ecology. This will be especially helpful in informing decisions to impose hands off conditions and may serve as a trial to help guide the establishment of future requirements for individual water users to establish lake level monitoring instrumentation.

Finally, consideration should also be given to the question of whether methods need to be developed to address the needs of lakes in which levels may naturally fall below the outflow level: it is not presently known whether any such lakes exist in the UK.

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Annex 1 Report of expert workshop report Edinburgh, 8 April 2005

DEVELOPMENT OF ENVIRONMENTAL STANDARDS (WATER RESOURCES) WFD48

Workshop 8 April 2005
SNIFFER offices, Edinburgh

1. Participants

Paul Wood (University of Loughborough), Chris Extence (Environment Agency), Nigel Willby (University of Stirling), Jackie King (university of Cape Town), John Aldrick (Environment Agency), Owen Mountford (CEH), Ian Winfield (CEH), Ian Cowx (University of Hull), Richard Noble (University of Hull), David Solomon (consultant), Peter Maitland (consultant), Colin Gibney (Environment and Heritage Service, NI), Iain Malcolm (Pitlochry Laboratory), Steve Axford (Environment Agency), Jo-Anne Pitt (Environment Agency), Doug Wilson (Environment Agency), Kirsty Irving (SNIFFER), Mike Briers (Environment Agency), David Crookall (SEPA), Stuart Greig (SEPA), Willie Duncan (SEPA), Mike Acreman (CEH), Andrew Black (University of Dundee), John Rowan (University of Dundee), Olivia Bragg (University of Dundee), Ken Irving (Trinity College, Dublin)

Apologies Phil Jordan (University of Ulster), Ian Fozzard (SEPA)

2. Guest speaker presentation

On Thursday evening, 7 April, Jackie King gave a presentation on the development and application of environmental flow methods in South Africa. Key conclusions of the talk were:

- A consistent approach had been applied in some 90 studies in South Africa with independent scientist working together with agency staff to address management needs
- Numerical definition of flow regimes had been made for ecosystem maintenance (environmental standards - Reserve).
- Threshold flows had been set to achieve given river condition classes
- River classes – mosaic of conditions across country
- Scientists had become accustomed to management –orientated approach
- A rapid approach had been developed based on many studies
- Monitoring was in its early stages; assessment of approach will follow
- Implementation way vital – if this fails it all fails

3. Introduction

On Friday 8 April, Mike Acreman thanked Kirsty Irvine and her team at SNIFFER for organising the workshop venue and Mike Briers for all the administration.

Participants introduced themselves giving a brief indication of their background and interest in the project.

David Crookall presented the background to the WFD 48 project stressing the need for an approach to address implementation of the Water Framework Directive across the UK. He explained that the resulting tool would be used for broad-scale assessing the impacts of small-scale abstractions and impoundments.

John Aldrick presented the history of Catchment Abstraction Management Strategies (CAMS) and application of the Resources Assessment and Management (RAM) framework in England and Wales. The results of the first CAMS were being analysed to determine whether the standards adopted had helped to achieved healthy river ecosystems.

4. River water bodies

4.1 Plenary session

Mike Acreman explained how the workshop was Stage 3 of the WFD 48 project held to define environmental standards based on hydro-morphological thresholds that separate good from less-than-good ecological status. Stage 1 had reviewed standards and regulatory parameters from UK and other countries around the world, whilst Stage 2 had reviewed typologies, including categorical classifications such as the WFD System A and continuous typologies such as RIVPACS and Low Flows 2000.

A single generic typology of 8 UK river water body types was presented based on Holmes *et al* (1998)[6] classification of macrophytes. The main axes defining the types were trophic status (nutrient level/alkalinity), river gradient and altitude; drainage area was a possible sub-type axis. In addition, separate typologies for fish, invertebrates and macrophytes were presented. The experts divided into working groups according to biotic communities (fish, invertebrates and macrophytes) to discuss the typology and to define standards.

Mike Acreman suggested that since flow estimation was only at best accurate to +/- 10%, standards at finer resolution would not be appropriate. He speculated that default values for standards for high ecological status might be around 10% of natural river flow parameters, with the good-less than good threshold being in the range 20-30%.

David Solomon presented a set of fish research data that showed how the critical flow to induce salmon migration increased (in absolute and percentile terms) with distance upstream from source on the River Exe. He concluded that the controls on fish migration are complex and vary between rivers, while accepting that data for the Exe are rarely available elsewhere.

Jo Pitt felt that trophic status should not be used as parameter for river water body types. She suggested that alkalinity, together with slope and maybe altitude were appropriate for differentiating between macrophyte communities. Willie Duncan added that for fish, altitude, alkalinity and slope were also key parameters. In some cases drainage area may be required.

4.2 Macrophytes

Nigel Willby explained that in the LEAFPACs project, detailed analysis of macrophyte data was being undertaken than would define an improved approach to relating macrophyte communities to river water body types that would overcome many of the limitations of the simple categorical classification system of Holmes *et al*. It was nevertheless recognised that the Holmes *et al*. classification provides a useful interim typology until LEAFPACs is completed.

The macrophyte experts were able to make recommendations for standards for some river water body types; these are presented in Appendix A1.1. The experts stressed that these were very approximate, based on broad knowledge and not on specific analysis of hydrological or ecological data. In many cases, the justification for the standards proposed was that they could not propose anything different from default values of around 20%, rather than being able to identify specific threshold values. They recommended that the WFD 48 team discuss all the standards with Nigel Holmes (who was invited to the workshop but could not attend) and specific standards for bryophytes with Mark Hill of CEH.

[6] Holmes, N.T.H., Boon, P.J., Rowell, T.A. 1998 A revised classification system for British Rivers based on their aquatic plant communities. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8. 555-578.

4.3 Macro-invertebrates

The invertebrate experts recognised the importance of the RIVPACs system for estimating the expected invertebrate taxa given physical and chemical characteristics of UK river water bodies. However, the form of the RIVPACs systems does not readily define broad river water types that have specific invertebrate communities. The only analysis available produced 3 broad types (upland, lowland and all others); the experts felt this was inadequate for defining environmental standards for water resources. However, the axes defining the generic typology, although originally for macrophytes, were also important for differentiating between invertebrate communities.

The group was uneasy about the processes of defining standards by expert judgement as data were lacking for steep upland streams and for reference conditions in lowland rivers. In general lowland river invertebrates may be less sensitive but they may require a flow regime closer to natural because the natural regime is less flashy.

Recognising the needs of the Water Framework Directive, the experts accepted the generic typology as a way forward for defining standards for invertebrates. These are presented as Appendix A1.2.

4.4 Fish

The fish working group felt that the most appropriate typology for fish currently available was the 8 fold classification produced by Cowx *et al* (2004)[7]. Equations developed as part of the FAME programme programme would allow WFD water bodies to be assigned to these fish community types. The experts agreed to try and identify standards for each type.

The group recognised the problem, but noted that it was something that various people had been wrestling with for the last 30 years or more with limited success, so expecting a large group to reach consensus in an hour was expecting too much.

The fish types had been derived from data across England & Wales as part of the FAME project, so there was little dissent, least of all from Ian Cowx and Richard Noble. The problem was seen to be as expressed by Mike Acreman and John Rowan, that although the fish were probably responding to such parameters as velocity and depth, these needed to be interpreted in terms that could be used for regulating abstractions.

Although it was accepted that measures that needed to be collected at site level could not be used, it was indicated that regulation would need to take place at the WFD water body level, therefore it might be possible to relate relevant parameters for fish to flow at the water body level on the basis of typical values found in a water body of that altitude, gradient, upstream catchment size, etc. However, it was noted that the project to develop such relationships was still in progress and the predictive abilities were uncertain.

It was recognised that very different problems for setting flow criteria are raised when considering abstractions, hydropower and impoundments and new ones are different to existing ones, to which the ecology may have adapted.

[7] Cowx, I.G., Noble, R.A., Nunn, A.D., Harvey, J.P. 2004. Flow and level criteria for coarse fish and conservation species. Environment Agency R & D report, W6-096, Bristol.

Seasonally varying flow criteria were desired. No one liked the rigid periods of Nov-Mar, etc, but thought these should be changed to reflect periods most relevant to the typical species in each water body. Thus, for Types 1-4, which relate mainly to salmonids, relevant periods would be for spawning, incubation and hatching of eggs, dispersion and feeding and migrations. The relevant periods involving each of these would need to be set for each water body or groups of water bodies and could thereby encompass local variations. Thus the spawning period might vary with latitude and the main species, salmonids mostly in autumn and cyprinids in spring.

The group was happy that the flow criteria would probably need elements to protect low flows, flow variability and high flows that would maintain channel structure. So the building block concept and that used in CAMS was OK. However, any procedures must come back to local checks to ensure that there are not obstructions to migration or geological features, such as sink holes or sub-gravel flow, that would make a nonsense of the supposed suitability of a flow threshold. The threshold criteria should be set so as to leave a suitable safety margin. Licences taking flows below the threshold would only be granted after a detailed environmental impact assessment.

The group finally started to think about the form of the expression of the flow criteria, using salmonid spawning as an example. The long-term Q_{95} was regarded as suitable as the absolute threshold for allowing abstraction, but even might be too low a flow in some environments and would need to be subject to local checks (winterbournes might be a problem depending on the timing of re-watering).

It was thought that abstractions would have little effect on the high flows needed to maintain channel structure in most river types, but this might not be true in spring-fed rivers with little contrast between the highest and lowest flows.

Reasons for maintaining flow variability patterns were less clear, but probably related to ensuring that flows essential for migrations occurred at some point in a relevant period and to some extent also for sediment sorting and other in-channel processes.

5. Lake water bodies

John Rowan made a presentation for the development of standards for lakes. Some necessary background was required before the questions for the day were introduced.

The typology forming the basis for regulation activities was recommended to be the UK (GB Ecoregion) Type B reporting typology. This hierarchical scheme comprises six lake types defined according to alkalinity/geology (as well as water clarity and salinity), each divided into two depth categories. Altitude and basin size form the next two levels of discrimination and lake basin form (based on bathymetric relations) and location were proposed as enhancements to the existing typology. Using UKTAG documentation a scheme was presented outlining the expected biological communities in each of the four biological quality elements of (phytoplankton, macrophytes/phytobenthos, macroinvertebrates and fish).

Jo Pitt (EA) explained that the provisional data compiled by UKTAG should be replaced as soon as possible with data emerging from the various classification projects on-going within the agencies and through associated research projects. Nigel Willby (Stirling) reported that for macrophytes this process has reached completion enabling discrimination of different lake types at reference condition. Ian Cowx and Richard Noble (Hull), expressed concern about the appropriateness of the existing typology with respect to lake fish communities, because biogeographical factors and introduced species posed particular problems. This prompted a general discussion leading to the consensus about the desirability of defining type-specific biological communities based on the reporting typology because it provides the common framework for assessing ecological status, for regulating hydromorphological modifications and for implementing appropriate programmes of measures.

The general lack of lake level data from around the UK was outlined: data are generally available from reservoirs operated under the Reservoir Safety Act, but not for lakes with natural regimes or for small lakes. Annual range data from 19 lakes were presented, showing two Scottish reservoirs to have ranges well in excess of 3 m with all others, including one Broad system, falling below this threshold. With this data availability, an understanding of the aquatic communities associated with reference hydrological conditions is bound to be limited.

Drawing on international literature, the interrelationships between form factor (bathymetry and hypsographic form), littoral sediments, residence time, groundwater connectivity and hydrological regime, as they affect lake habitat, were explained. Key aspects of the water level regime were explained to include range, seasonality and elements of frequency, duration and rate of change.

Two forms of questionnaire were presented. One presented a list of ecologically-relevant aspects of the hydrological regime, with some proposed threshold values to define boundaries between high/good and good/moderate ecological status. The other asked questions in a more open form, instead inviting participants to suggest which aspects of hydrological regime imposed controls on the ecology.

The audience of experts comprised researchers with lake expertise covering invertebrate, macrophytes and fish communities, though typically in small numbers for each group. Despite the presence of many leading authorities of lake ecology there was considerable uncertainty and a reluctance to establish regulatory thresholds in terms of lake water level regime manipulation. There was general approval of the types of hydrological effect which had been proposed in the detailed questionnaires, and a general unwillingness or inability to suggest revisions to the proposals. The proposed thresholds presented by the Dundee team were therefore left unaltered. This experience does not amount to an endorsement of the proposals, but is interpreted as an acceptance that the work completed to date does provide a platform for discussion and further development. On-going analysis in Dundee will lead to a refined set of thresholds (following on-going discussions with individuals e.g. Nigel Willby) which will be presented to the steering group. For implementing water resources regulation in practice, lake level monitoring will be essential because of the major uncertainties in modelling lake response to water abstractions. The costs of such monitoring can be offset against license fees or, in some cases, a regulator may require water users to undertake monitoring directly.

6. Summary and next steps

In general participants felt that it was important to be involved in the process of setting standards. However, as with development of the RAM framework, time was always too short, with project rushed through in a few months. Experts were called upon at short notice to provide input within a few hours of workshop. They were then largely not contacted until a similar workshop several years later. The South African experience appeared to be one of more continuous interaction between scientists and implementing agencies with expert involvement in defining environmental flows in real case studies. This has built mutual understanding and led to better integration of research and applications. Participants urged the UK agencies to develop better, longer-term and more consistent collaboration with UK scientists.

Good progress was made by the river invertebrate and macrophyte groups towards setting standards for water resources. Mike Acreman agreed to follow-up with Mark Hill (CEH) and Nigel Holmes, particularly on bryophytes.

The river fish experts made some conceptual progress with the issue, but had not been able to set standards in the short time permitted. They requested a 2nd workshop before the end of April. SNIFFER agreed that sufficient funds were available and Mike Acreman agreed to organise the workshop.

On lakes, an action was agreed to hold a further meeting with Nigel Willby to investigate the links which may be evident between macrophyte communities and hydrological regime disturbance. The next steps are:

- to draw on such possibilities as may exist in the macrophyte sphere to help inform the identification of thresholds,
- to resolve the precise form of typology to be used,
- to contact members of the steering group promptly for general feedback on the form of the final report before committing to greater detail.

7. Epilogue

Mike Acreman met with Nigel Holmes at follow-up meeting on 20 April. The focused particularly on setting standards for river water body types C2, D1 and D2 of the generic framework. These are included in Appendix A.

Mike Acreman spoke to Mark Hill at CEH, who was an expert on bryophyte physiology. However, after some discussion of the issues Mark felt that he could not contribute significantly on thresholds of river flow regimes required to maintain these plant communities.

John Rowan, Olivia Bragg and Andrew Black met with Nigel Willby on 18 April. A small number of lakes were identified for which researchers have complementary macrophyte and hydrological data – insufficient it was thought to permit meaningful analysis at this stage. It is intended that further hydrological data will be gathered from water supply reservoir operators and further macrophyte data be gathered by fieldwork in order that analysis may be carried out in future, subject to necessary resources being available. Discussions were also held with Alex Elliott (CEH), who suggested phytoplankton are highly insensitive to water level change and that instead, residence time is the key factor. A sensitivity threshold of 20-30 days was identified.

Appendix A1.1 Macrophyte standards

Restrictive management

Type *Generic A1*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun - Oct
(1) threshold abstraction level	*80% natural flow (Nov – Feb)*	*90% natural flow (Mar – May)* *hands-off at Q_{95}*	*80% natural flow (Jun-Oct)*
Comments			

Active management

Type *Generic A1*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(2) number of floods	*20-30% of natural events 5-7 times median flow*	*20-30% of natural events 5-7 times median flow*	*20-30% of natural events 5-7 times median flow*
(3) magnitude of compensation flow			
Comments *For large rivers high flows were particularly important in the Autumn for the distribution of propogules and seeds.*			

Restrictive management

Type *Generic A2*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(1) threshold abstraction level	*80% natural flow (Nov – Feb)*	*90% natural flow (Mar – May)* *hands-off at Q_{95}*	*80% natural flow (Jun-Oct)*
Comments			

Active management

Type *Generic A2*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(2) number of floods			
(3) magnitude of compensation flow			
Comments • *There are no major impoundments of A2 rivers requiring Active management* .			

Restrictive management

Type *Generic B1*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun - Oct
(1) threshold abstraction level	*80% natural flow (Nov – Feb)*	*90% natural flow (Mar – May)* *hands-off at Q_{95}*	*80% natural flow (Jun-Oct)*
Comments			

Active management

Type *Generic B1*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(2) number of floods	*20-30% of natural events 5-7 times median flow –* *floods should be competent to move gravel*	*20-30% of natural events 5-7 times median flow –* *feshets needed 5 x Q_{95} for 1 day*	*20-30% of natural events 5-7 times median flow –* *floods should be competent to move gravel*
(3) magnitude of compensation flow	Q_{95}	Q_{95}	Q_{95}
Comments *For large rivers high flows were particularly important in the Autumn for the distribution of propogules and seeds.*			

Restrictive management

Type *Generic B2*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun - Oct
(1) threshold abstraction level	*80% natural flow (Nov – Feb)*	*80% natural flow (Mar – May)* *hands-off at Q_{95}*	*80% natural flow (Jun-Oct)*
Comments			

Active management

Type *Generic B2*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(2) number of floods	*20-30% of natural events 5-7 times median flow -* *floods should be competent to move gravel*	*20-30% of natural events 5-7 times median flow -* *feshets needed 5 x Q_{95} for 1 day*	*20-30% of natural events 5-7 times median flow -* *floods should be competent to move gravel*
(3) magnitude of compensation flow	Q_{95}	Q_{95}	Q_{95}
Comments *For large rivers high flows were particularly important in the Autumn for the distribution of propogules and seeds.*			

Restrictive management

Type *Generic C1*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun - Oct
(1) threshold abstraction level	*80% natural flow (Nov – Feb)*	*80% natural flow (Mar – May)* *hands-off at Q_{95}*	*80% natural flow (Jun-Oct)*
Comments			

Active management

Type *Generic C1*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(2) number of floods	*20-30% of natural events 5-7 times median flow -* *floods should be competent to move gravel*	*20-30% of natural events 5-7 times median flow -* *feshets needed 5 x Q_{95} for 1 day*	*20-30% of natural events 5-7 times median flow -* *floods should be competent to move gravel*
(3) magnitude of compensation flow	Q_{95}	Q_{95}	Q_{95}
Comments *For large rivers high flows were particularly important in the Autumn for the distribution of propogules and seeds.*			

Restrictive management

Type *Generic C2*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(1) threshold abstraction level	*80% natural flow (Nov – Feb)*	*90% natural flow (Mar – May)* *hands-off at Q_{95}*	*80% natural flow (Jun-Oct)*
Comments *Desiccation of bryophytes is a particularly important problem in May-Aug.*			

Active management

Type *Generic C2*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(2) number of floods	*20-30% of natural events 5-7 times median flow*	*20-30% of natural events 5-7 times median flow (flood of Q_{50} 1 day duration)*	*20-30% of natural events 5-7 times median flow*
(3) magnitude of compensation flow	*Q_{95}*	*fluctuations flows around Q_{95} (+100 / -50%)*	*Q_{95}*
Comments *Need to maintain periodic inundation is summer*			

Restrictive management

Type *Generic D1*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(1) threshold abstraction level	*80% natural flow (Nov – Feb)*	*90% natural flow (Mar – May)* *hands-off at Q_{95}*	*80% natural flow (Jun-Oct)*
Comments *Desiccation of bryophytes is a particularly important problem in May-Aug.*			

Active management

Type *Generic D1*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(2) number of floods	*20-30% of natural events 5-7 times median flow*	*20-30% of natural events 5-7 times median flow (flood of Q_{50} 1 day duration)*	*20-30% of natural events 5-7 times median flow*
(3) magnitude of compensation flow	*Q_{95}*	*fluctuations flows around Q_{95} (+100 / -50%)*	*Q_{95}*
Comments *Need to maintain periodic inundation is summer*			

Restrictive management

Type *Generic D2*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(1) threshold abstraction level	*80% natural flow (Nov – Feb)*	*90% natural flow (Mar – May)* *hands-off at Q_{95}*	*80% natural flow (Jun-Oct)*
Comments *Desiccation of bryophytes is a particularly important problem in May-Aug.*			

Active management

Type *Generic D2*	Species *macrophytes*		
	Nov – Feb	Mar – May	Jun – Oct
(2) number of floods	*20-30% of natural events 5-7 times median flow*	*20-30% of natural events 5-7 times median flow (flood of Q_{50} 1 day duration)*	*20-30% of natural events 5-7 times median flow*
(3) magnitude of compensation flow	*Q_{95}*	*fluctuations flows around Q_{95} (+100 / -50%)*	*Q_{95}*
Comments *Need to maintain periodic inundation is summer*			

Appendix A1.2 Macro-invertebrates standards

Restrictive management

Type *Generic A1*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(1) threshold abstraction level	*70% natural flow (Nov – Mar)*	*70% natural flow (Apr – Jun)*	*70% natural flow (Jul-Oct)*

Comments

- *Use a daily value to protect variability*
- *Variability reflected means that dynamic nature of river is maintained*
- *HOF at Q_{97} for seasonal values*
- *Altitude & gradient were important factors generally*

Active management

Type *Generic A1*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods	*40% of natural events*	*40% of natural events*	*40% of natural events*
(3) magnitude of compensation flow	Q_{90}	Q_{90}	Q_{90}

Comments

- *If looking for "good ecological status" then use some values as for restrictive management approach*
- *NB magnitude and duration should be considered to mimic natural regime*

Restrictive management

Type *Generic A2*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(1) threshold abstraction level	*90% natural flow (Nov – Mar)*	*90% natural flow (Apr – Jun)*	*90% natural flow (Jul-Oct)*
Comments • *Need to reflect higher protection as required for Habitats Directive sites (SACs and SPAs)* • *As A1 comments*			

Active management

Type *Generic A2*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods			
(3) magnitude of compensation flow			
Comments • *There are no major impoundments of A2 rivers requiring Active management*			

Restrictive management

Type *Generic B1*	Species *invertebrates*		
	Nov – Mar	Apr – June	July – Oct
(1) threshold abstraction level	*90% natural flow (Nov – Mar)*	*90% natural flow (Apr – Jun)*	*90% natural flow (Jul-Oct)*
Comments • *As for A1 comments*			

Active management

Type *Generic B1*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods	*60% of natural events*	*60% of natural events*	*60% of natural events*
(3) magnitude of compensation flow	Q_{70}	Q_{70}	Q_{70}
Comments • *See notes for A1*			

Restrictive management

Type *Generic B2*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(1) threshold abstraction level	*80% natural flow (Nov – Mar)*	*80% natural flow (Apr – Jun)*	*80% natural flow (Jul-Oct)*
Comments • *As A1 comments*			

Active management

Type *Generic B2*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods	*70% of natural regime*	*70% of natural regime*	*70% of natural regime*
(3) magnitude of compensation flow	Q_{70}	Q_{70}	Q_{70}
Comments • *See notes for A1*			

Restrictive management

Type *Generic C1*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(1) threshold abstraction level	*80% natural flow (Nov – Mar)*	*80% natural flow (Apr – Jun)*	*80% natural flow (Jul-Oct)*

Comments

- *Because this is a disparate group need to be careful in generalisation. Difficult to visualise the kind of rivers, →assumed moderate sensitivity*

Active management

Type *Generic C1*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods	*70% of natural regime*	*70% of natural regime*	*70% of natural regime*
(3) magnitude of compensation flow	Q_{70}	Q_{70}	Q_{70}

Comments

- *See comments A1*
- *See comments C1 in above box*

Restrictive management

Type *Generic C2*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(1) threshold abstraction level	*90% natural flow (Nov – Mar)*	*90% natural flow (Apr – Jun)*	*90% natural flow (Jul-Oct)*
Comments • *As A1 comments*			

Active management

Type *Generic C2*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods	*60% of natural regime*	*60% of natural regime*	*60% of natural regime*
(3) magnitude of compensation flow	Q_{70}	Q_{70}	Q_{70}
Comments • *See comments A1*			

Restrictive management

Type *Generic D1*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(1) threshold abstraction level	*80% natural flow (Nov – Mar)*	*80% natural flow (Apr – Jun)*	*80% natural flow (Jul-Oct)*
Comments • *See A1 comments*			

Active management

Type *Generic D1*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods	*80% of natural regime*	*80% of natural regime*	*80% of natural regime*
(3) magnitude of compensation flow	Q_{80}	Q_{80}	Q_{80}
Comments • *See comments A1* • *The group has the potential for considerable ecological change*			

Restrictive management

Type *Generic D2*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(1) threshold abstraction level	*90% natural flow (Nov – Mar)*	*90% natural flow (Apr – Jun)*	*90% natural flow (Jul-Oct)*
Comments • *See A1 comments*			

Active management

Type *Generic D2*	Species *invertebrates*		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods	*50% of natural regime*	*50% of natural regime*	*50% of natural regime*
(3) magnitude of compensation flow	Q_{60}	Q_{60}	Q_{60}
Comments • *See comments A1*			

Annex 2 Report of expert workshop (fish 2) York, 28 April 2005

DEVELOPMENT OF ENVIRONMENTAL STANDARDS (WATER RESOURCES) WFD 48

2nd workshop on fish 28 April 2005
Environment Agency offices, York

1. Participants

Ian Cowx (University of Hull), Richard Noble (University of Hull), David Solomon (consultant), Steve Axford (Environment Agency), Mike Acreman (CEH), Robin Welcomme (consultant).

A written contribution was provided by Iain Malcolm based on discussion at the Fisheries Research Services, Pitlochry – see Appendix A2.1.

Apologies were received from Peter Maitland.

2. Introduction

Mike Acreman reminded participants of the background to project. The objectives of the workshop were to define environmental standards for fish communities for application to Water Framework Directive water bodies in the UK. Heavily modified water bodies were not included. Water bodies downstream of those containing impoundments may have their flow regimes significantly altered without being classed as heavily modified.

It was noted that defining appropriate flow regimes for fish could not be achieved without considering changes to channel structure since it is the combination of flow and morphology that define the ecologically relevant variables such as depth, velocity, presence of refugia and connectivity. It was agreed that setting standards could only be set at a generic level if the channel structure was assumed to be natural; otherwise standards would need to be set on a case by case basis.

It was recognised that the benchmark flow regime against which standards could be defined would not be the true natural flow regime, since this must account for catchment changes; it would be the actual regime plus abstractions and minus discharges, or simulated from models such as Low Flows 2000.

David Solomon presented a discussion paper that had been circulated to participants prior to the meeting. He explained the thinking behind SWALP which aimed to protect low flows, flow variations, high flows, as the three most important characteristics of the hydrograph.

There was agreement on the need to protect low flows whenever they occur during the year. However, the impact of low flows could be different at different times; for example in mid-summer reduced flow may lead to higher BOD or higher temperatures than in other seasons.

3. Definition of typology

Mike Acreman presented the river water body typology that was adopted for defining environmental standards for macro-invertebrates and macrophytes. The fish experts felt strongly that the typology was not appropriate for defining standards for fish communities since the types spanned across various fish communities and they could not relate their knowledge of flow requirements of fish to these types. However, participants felt that it may be possible to define standards for fish community types. They amalgamated the 8 types defined by Cowx *et* *al* (2004) into 5:

1. Chalk stream communities
2. eurytopic/limnophilic – roach, bream, tench, pike, bleak
3. rheophilic cyprinids – dace, chub, adult resident trout
4. salmonids – adult salmon
5. salmonids – spawning and nursery areas

Use of this typology would necessitate a method for defining the dominant fish community type in any river water body. The key variables that discriminated between these fish communities were river gradient, flow variability and river width. Additional analysis would need to be undertaken to produce a method that could employ available water body characteristics such as altitude, slope, drainage area, BFI used in other parts of the project. This could not be done within the current time and financial constraints of the WFD 48 project. Mike Acreman agreed to the request funding for this work as an addition to the project.

4. Relevant issues in standard setting

The Group noted the Common Implementation Strategy for the WFD, Guidance note 4 "Identification and Designation of Heavily Modified and Artificial Water Bodies" states that "… substantial hydrological changes that are accompanied by subsequent non-substantial morphological changes would be sufficient to consider the water body for a provisional identification as HMWB." It was however recognized that current UK interpretation of WFD is focused on defining HMWBs according to structural criteria such as dams, embankments and channel straightening. In such cases, water bodies may have their flow regimes modified by a dam upstream, but may not be designated as HMWBs themselves. Thus standards are required for dam operation outside of HMWBs. Even within HMWB, the flow regime to achieve good ecological status is required as a part of the designation process.

The Group recognised that HMWBs were required to achieve good ecological potential (GEP); i.e. making the best of heavy modification. A flow regime to achieve GEP may be different from that needed to achieve GES because a "natural" flow regime may have negative impacts on the ecosystem in a HMWB. For example, a dam may trap sediment and releasing naturally high flows below the dam may cause major erosion. Likewise naturally high flows in a concrete lined straight channel may create velocities beyond the swimming speed of fish if suitable refugia were not available.

The Group further recognised the very different flow regimes that would result from restrictive management (where the whole flow regime would be reduced, but natural fluctuations would be maintained) and active management (where, in practice[8], the flow regime is constant for long periods between changes to sluice gate settings, but where occasional freshets or small floods may be generate artificially). They concluded that GES could not be achieved by these very different flow regimes. Because natural variability was important, judicious restrictive management could achieve GES. However, active management would in practice[1] not achieve GES, but it may achieve GEP.

Good ecological status was taken to mean good composition, abundance and age structure of fish.

Participants felt strongly that insufficient knowledge was available to define precise generic

[8] Natural fluctuations could be maintained below an impoundment in theory by opening and closing sluice gates at very frequent intervals (daily or even hourly) trigger by the hydrological signal from an unregulated natural catchment nearby. However, this was considered as unlikely to be the case in practice.

environmental standards. Instead their thinking was based on a precautionary approach by considering incrementally higher levels of flow alteration and deciding at what level of flow alteration we could no longer be certain that good status would be achieved. The standards produced were only appropriate for a screening-level tool that would separate water bodies into two groups (1) potential problem needing further assessment, and (2) those requiring no further immediate assessment, unless some other factors suggest investigation. Where possible more precise standards should always be define for specific water bodies using detailed local data.

Threshold levels of abstraction were defined by considering a “hands-off” flow (HOF), below which reduced or no abstraction should be taking place, and a percentage take of the flow in excess of the HOF; i.e. % naturalised flow minus HOF. It was accepted that “naturalized” flow would mean recorded flow +/- abstractions and discharges and would not be adjusted for any land use or climate change. Flow percentiles are expressed in terms of the long term annual flow duration curve.

The time base over which to calculate indices would need to be considered, *e.g.* records that started in 1995/6 may have much lower figures for Q_{95} and Q_{99} than longer periods of flow. This is especially important if flows can vary rapidly, e.g. below dams. The representativeness of indices should also be checked since mean flow may not be representative of managed flow regimes that are either very low or very high.

Expected fish communities predicted by any model should always be checked against data or local knowledge of a water body before any standards are set.

In groundwater dominated catchments, it may not be easy to estimate the flow regimes in any water if there are substantial gaining or losing reaches between it and the nearest flow gauging station.

The implementing flow standards would need to start at the downstream end of a river basin and work upstream so that upstream standards do not compromise any downstream.

Inter-basin transfers represent a significant impact on the flow regime in some rivers, particularly in Scotland. In some cases these may act like an abstraction, *i.e.* a constant small flow is diverted but this does not impact on high flows or flow variability. In other cases, the diversion may be associated with an impoundment that may impact on the whole flow regime.

5. Definition of standards

Restrictive management (mainly applying to where water is abstracted from a river or immediately adjacent aquifer) was defined in terms of one parameter.
(1) the threshold abstraction level of abstraction below which high or good status will be achieved and above which status will be in moderate, poor or bad status. Whether this changes with time of year. This should be given as % of a low flow or other specified units, such as flow per unit width, an absolute flow or another parameter such as depth or velocity

Active flow management (mainly applying to where releases from dams are involved) was defined in terms of two parameters
(2) The number of floods (exceeding 3 times the median flow) above which high or good status will be achieved, below which status will be moderate, poor or bad. The duration of the flood can be specified if known.

(3) The magnitude of flow release (compensation flow) required to achieve high or good status, below or above which status will be moderate, poor or bad. This should be given as % of a low flow or other specified units, such as flow per unit width or an absolute value for a particular case.

1. Chalk river communities

Restrictive management

Type Chalk river communities	Species trout, grayling
	all year
(1) threshold abstraction level	20% any flow on the day < Q_{95} 10% < Q_{99} 5%
Comments	

Active management

Type Chalk streams	Species		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods released			
(3) magnitude of low flow released			
Comments No major dams on Chalk streams - local decisions needed in any significant cases			

2. Eurytopic/limnophylic fish communities

Restrictive management

Type Eurytopic/limnophylic	Species roach, bream, tench, pike, bleak	
	Jul – Apr	May – June
(1) threshold abstraction level	50% at medium high flows hands-off at Q_{98}	20% at medium high flows hands-off at Q_{98}
Comments		

Active management

Type Eurytopic/limnophylic	Species roach, bream, tench, pike, bleak		
	Nov – Mar	Apr – June	July - Oct
(2) number of floods released			
(3) magnitude of low flow released			
Comments No dams on large lowland rivers Critical issues is connecting backwater habitats and floodplain.			

3. Rheophilic cyprinid communities

Restrictive management

Type Rheophilic cyprinids	Species dace, chub	
	Feb – June	July – Jan
(1) threshold abstraction level	50 % annual Q_{90} hands off	50 % < Q_{90} 25% <Q_{95} 20% Q_{99} hands off
Comments If any physical barrier need local study to determine depth		

Active management

Type Rheophilic cyprinids	Species dace, chub, resident trout adults	
	May – July	Aug – Apr
(2) number of floods released	No major floods	Nov – January Large flood at bankfull, one day
(3) magnitude of low flow released	Q_{70}	Q_{95}
Comments Above standards for active management relate to GEP, they may not achieve GES. Q_{70} needs more research		

4. Adult salmonids (other than Chalk rivers)

Restrictive management

Type salmonids – adult (not Chalk rivers)	Species adult salmon
	All year
(1) threshold abstraction level	50% of flow above Q_{95} hands-off Q_{95}
Comments 50% take above HOF is proposed here to take account of a wide range of existing schemes; depletion of all flows above HOF by 50% is likely to be unacceptable, but in practice, the take in most schemes is limited such that the impact on medium to high flows is minimal. In a situation where significant takes from high flows may be possible, eg. inter-basin transfers and diversions for hydro-power generation, further restrictions on take are likely to be justified.	

Active management

Type salmonids (not Chalk streams)	Species: adult salmon		
	Dec – Apr	May – Aug	Sep – Nov
(2) number of floods released			3 small freshets
(3) magnitude of low flow released	Q_{90}	Q_{95}	Q_{95}
Comments Above standards for active management relate to GEP, they may not achieve GES. Local over-rides for obstructions Site specific number of freshets Avoid high flow releases during emergence (April-May) as possible to lose high % of recently emerged year class.			

5. Salmonid communties; spawning and nursery areas

Restrictive management

Type Salmonid	Species: spawning, nursery	
	Jun – Sep	Oct - May
(1) threshold abstraction level	20% abstraction of flow above Q_{95} Hands off Q_{95}	Hands off Q_{80}
Comments Abstraction level could be higher, but is site specific		

Active management

Type salmonid	Species: salmonid spawning, nursery	
	Apr – Sep	Oct – May
(2) number of floods released		3 small floods to clean gravel and migrate adults 1 large flood Q_2 bank-full one day
(3) magnitude of low flow released	Q_{95}	Q_{90}
Comments Above standards for active management relate to GEP, they may not achieve GES.		

6. Recommendations

Research by Cowx *et al* (2004) and within the EU FAME project identified at a broad level the typical physical characteristics of rivers which are correlated with differences in the types of fish community found. River gradient was the most important characteristics, this may be a surrogate for other more ecologically relevant factors such as bed substrate or flow velocity. These relationships need to be defined more specifically to be able to predict the fish communities for any target river. This will need to be undertaken in a separately funded new project.

The current scenario on active flow management does not include dam management for hydropower generation. There is insufficient knowledge for defining critical rates of change of flow from dams on which to set standards. This work requires a new separately funded project.

Inter-basin transfers may have a range of impacts similar to an abstraction or an impoundment. These need further research to define appropriate standards.

The group recommended that the UK considers designating water bodies as HMWB on the basis of alterations to the flow regime. This designation should continue downstream until the modification to the hydrology is mitigated by accretion.

Appendix A2.1 Written input from Fisheries Research Services, Pitlochry

General

There is a paucity of information on the effects of low flow and draught on salmonids. Additionally, the relationship between low flows and salmonids is often complicated by thermal regime. Because of the thermal capacity of water, low flows are often characterized by high diel temperature variability and extreme high temperatures. Nevertheless, it is clear that low flows should be protected, dry river beds and extreme high temperatures are both detrimental to fish. The question of where to set limits is less clear and likely to be largely arbitrary. As such this is a political decision, balancing water resources and ecology and not a question that can be answered by scientific consideration. Given the limitations of our knowledge Q95 appears a reasonable starting point for defining hands-off flows

There is the need for catchment by catchment consideration of flow requirements and in particular 'bottle necks' and there is a need for re-assurance that there will be an opportunity to incorporate local knowledge and to re-visit flow-setting limits where required.

Unlike many other geographical locations Scottish catchments often contain a number of salmon populations with differing adult and smolt run timing characteristics. Adult fish enter the rivers almost all year round, with a wide range of life strategies which can include long or short periods of freshwater residency. Any discussions should bear in mind the spatial and temporal implications of this biological diversity.

Fish populations (the fish themselves) and fisheries (exploitation) are separate issues. Their requirements are not necessarily the same.

Time periods

Nov-Mar would normally cover the period of time between spawning and hatch, although spawning in Scotland can take place between mid-October and Early February. Extreme low flows can prevent spawning adults from reaching headwater areas and impede up river migration. Excessive draw down between spawning and hatch can lead to stranding, desiccation and mortality of salmonid embryos.

Apr-June would normally approximate to fry emergence, first territory uptake and maximum growth.

July-Oct (more particularly July / August) is the period of time most susceptible to extreme high temperatures which can be detrimental or even lethal to salmonids. Low flow conditions exacerbate these effects as smaller volumes of water exhibit more marked thermal variability. Additionally, low flow conditions reduce wetted area and consequently territory with unknown consequences.

Annex 3 Classification of British rivers by macrophyte types (after Holmes et al, 1999)

Type I lowland low gradient rivers *e.g.* Avon, Wissey, Lark, Bure	Non-flowering species - *cladophera glomerata*, *Vacheria sp,* Common species – *carex riparia, Sparganium emersum, Potamogeton pectinatus, Sagittaria sagittifolia* Less common – *Pulicaria dysenterica, Berula erecta, Eupatorium cannabinum, Oenanthe fluviatilis, Iris pseudacorus, Phragmities australis*
Type II lowland clay-dominated rivers; low gradient *e.g.* Devon, Welland, Cherwell, Tame, Evenlode	Assemblage similar to type 1, greater variety, more occurrence of common species *Cladophora glomerata and Vaucheria sp*, more occurrence of less common species *Potamogeton natans, Juncus acutiflorus*
Type III Chalk rivers and other base-rich rivers with stable flows *e.g*. Frome, Test, Piddle Itchen, Hull, Minram	All rivers underlain by base-rich geology – 60% of type III rivers are on Chalk with high base flow and stable flow regime.
Type IV Impoverished lowland rivers; degraded through drainage and flood defence, depleted flows or pollution	Most typical species are all emergents or marginal species, none of common submerged aquatics of Type I-III occurring in more than 35% of sites
Type V Sandstone, mudstone and hard limestone rivers of England and Wales eg. Tamar, Exe, Teifi, Lugg, Dove	No submergent aquatics in over half type V sites, *Sparganium erectum* is the only emergent to occur. Submerged habitats dominated by mosses, most important being *Rhynchostegium riparioides, Fontinalis antipyretica* and *Amblystegium sp*. Of common species found in IV and V, *Oenanthe crocata, Solanum dulcamara, Conocephalum conicum* and *Vaucheria sp* are more frequent in type V. Of less common taxa, *Apium nodiflorum, Eupatorium cannabinum, Lythrum salicaria* and *Carex remota* are frequent.
Type VI Sandstone, mudstone and hard limestone rivers of Scotland and northern England. e.g. Ribble, Wharfe, Eden, Tweed, Ythan	Of common species in V and VI, *Myostosis scorpioides, Mentha aquatica, Mimulus guttatus, Equisetum arvense, Caltha palustris, Elodea canadensis* and filamentous algae are more prevalent in Type VI. This also applies to less common occurring species *Myriophyllum spicatum, Polygonum amphibium* and moss *Schistidium alpicola, Ranunculus fluitans* and *Eleocharis palustris.*
Type VII Mesotrophic rivers dominated by gravel, pebbles and cobbles. Sites well scattered around Britain	Wetland edge species characterise the assemblage with fewer bryophytes reflecting finer sediment. Of common species in VII and VIII, *Phalaris arundinacea* and *Myosotis scorpioides* are more common in type VII. Of less common species, *Callitriche stagnalis, C. hamulata, Equisetum fluviatile, Myriophyllum alterniflorum, Juncus articulatus, Potamogeton natans* and Rorippa nasturtium-aquaticum are far more prevalent
Type VIII Oligo-mesotrophic rivers. Shales, hard limestone and hard sandstone dominate, gradients steeper than VII *e.g.* lower Findhorn, Spey, Dee, Esk, Ure, Derwent, Conwy, Dee Cothi, Barle.	Higher proportion of rocky substrate, less base rich means wide variety of bryophytes. Species more common in VIII than VII include: *Rhynchostegium riparioides, Chiloscyphus polyanthus, Pellia epiphylla, Hygrohypnum ochraceum, Amblystegium fluviatile, Thamnobryum alopecurum,* and *Scapania undulate*. Less common bryophytes and lichens occur five time more frequently in VIII than VII including *Dermatocarpon fluviatile, Hyocomium amoricum, Dichodontium pellucidum* and *D. flavescens.*
Type IX Oligotrophic low altitude rivers. Rivers with	Because of relative scarcity of rock *Fontinais antipyretica and Sphagnum sp* are the only mosses among top 30 common species.

gentler slopes than in type X and located at lower altitude, more sand and silt, less cobbles, boulders. No single large rivers; English lowland acid heath (New Forest), Scottish Flow Country and Western Isles.	Vascular plants *Juncus bulbosus, Equisetum fluviatile, Myriophyllum alterniflorum, Potamogeton polygonifolius* and *P. Natans* are all much more common than in type X.
Type X Ultra-oligotrophic rivers. Type X communities on steeper gradients than IX and at higher altitudes *e.g.* upper reaches of rivers on Dartmoor, Exmoor, Brecon Beacons, Plynlimon, Snowdonia, Pennines, North York Moors, Cairngorms and north-west Highland.	Higher proportion of cobbles, boulders and bedrock and presence of blanket bogs and acid heath means that bryophytes are a major component of the flora and very dominant in submerged habitats. Common species, *Pellia epiphylla, Racomitrium aciculare, Scapania undulate, Hyocomium armoricum, Bryum pseudotriquetrum, Marupella emarginata* and *Jungermannia atrovirens* are 10 times more common in X than IX as are less frequently recorded *Nardia compressa, Hygrohypnum ochraceum* and *Schistidium alpicola*

Annex 4 Final rivers workshop 21 November 2005

Development of Environmental Standards (Water Resources)
Report of expert workshop 21st November 2005, Leeds

1. Participants

Attendees: Chris Extence (Environment Agency), John Aldrick (Environment Agency), Richard Noble (University of Hull), Doug Wilson (Environment Agency), Kirsty Irving (SNIFFER), Mike Briers (Environment Agency), David Crookall (SEPA), Willie Duncan (SEPA), Mike Acreman (CEH), Robin Welcomme (consultant), Nigel Holmes (consultant), Mike Dunbar (CEH), Mike Acreman (CEH), Ineke Jackson (Environment Agency), Natalie Howes (UKTAG).

Written comments from Iain Malcolm (Pitlochry Laboratory)

Apologies: Paul Wood (University of Loughborough), Owen Mountford (CEH), Ian Winfield (CEH), Ian Cowx (University of Hull), David Solomon (consultant), Peter Maitland (consultant), Colin Gibney (Environment and Heritage Service, NI), Steve Axford (Environment Agency), Jo-Anne Pitt (Environment Agency), Ken Irvine (Trinity College, Dublin), Phil Jordan (University of Ulster), Ian Fozzard (SEPA), Nigel Wilby (University of Stirling).

2. Introduction

Proposed water resource environmental standards have been developed via a research project (SNIFFER WFD48). The project was managed by a UKTAG steering group comprising staff from SEPA, EA and EHS. The consultants on the project were CEH for rivers and Dundee University for lakes. The proposed lakes standards are undergoing international peer review and this paper considers only the development of the river standards.

The project considers surface freshwater only. Standards for groundwater and transitional and coastal waters will be considered separately. The project aims to improve the links between the flow and level standards and the ecology. There is relatively sparse field data on which to base the standards and it is accepted that the standards will need to be refined over time as WFD monitoring programmes provide better data. The WFD framework allows for this iterative, ongoing learning approach by allowing for a six year planning cycle.

The proposed rivers standards were informed by expert workshops held as a key part of the research project and by dialogue between the project steering group and the UKTAG River's Task Team.

The workshops brought together experts on each of the three key biological quality elements: macrophytes; macro-invertebrates; and fish and resulted in the development of initial recommendations for standards and identification of the issues that needed to be considered. The steering group initially proposed standards that were based on these recommendations but which were less restrictive. This was due to the lack of existing monitoring data on which to justify significant changes from existing standards. Subsequent dialogue between the UKTAG River's Task Team and the project Steering Group resulted in a revision of the proposed standards which have sought to address the concerns of the RTT experts. The workshop on 21st of November aimed to allow the expert group who were involved in the April project workshop to review the revised version of the river standards.

Key questions asked of the workshop included the conditions where 'hands off' flows are required, the timing of seasonal standards and the necessary monitoring and research needed to refine standards for future basin planning rounds.

The outcome from this workshop will be taken into account in considering the final proposals to put forward for technical stakeholder review and in informing SNIFFER and the agencies research priorities over the next six years.

3. Outline of Day

Time	Agenda	Presenter
9:30 -10:20	Arrival and coffee	
10:20-10:50	Scene Setting	David Crookall (SEPA)
10:50 –11:35	WFD48: presentation of recommended standards	Mike Acreman (CEH)
11:35-11:50	COFFEE	
11:50 – 12:30	Implications of new standards	Rob Soley (Entec)
12:30 – 13:00	Discussion – points of clarification, identify issues for the afternoon session	Facilitated by Kirsty Irving (SNIFFER)
13:00 – 13:45	LUNCH	
13:45 – 16:30	Plenary discussion* o HOFs o Seasonality o Typology (salmonids & scale) o Monitoring o Research o Ongoing Expert involvement o Artificially High Flows	Facilitated by Kirsty Irving (SNIFFER)

* Due to a smaller than expected meeting, the group stayed together for the discussion, rather than splitting into breakout groups. Also, it had been hoped to include a discussion of High Ecological Status and whether only a-biotic indicators should be considered for this category; however there was no time for this discussion.

4. Outcomes

Hands off Flows and Interpretation of Standards

- It was discussed that the standards will need to be applied by the UK Agencies as a quantity available for abstraction, represented by the % flow at Q_{95}, rather than as the percentage flow on the day. This is currently not clear in the report and must be clarified. The ecologists were concerned that this would mean that at flows below Q_{95}, the percentage take could be a large percentage of actual flow on the day and thus provide little protection for the ecology. No consensus was reached but it was recognised that the views of the experts regarding standards based on %age of flow on the day could not be accommodated within a manageable regulatory system. As a compromise, it was suggested that a rule be set up that if the environmental standard (x% of Q_{95}) was more than 25% of Q_{98} then alternative measures, such as hands off flows should be implemented to protect flows less than Q_{95}.

Seasonality

- The original seasons were based primarily on the needs of macrophytes.

- It was agreed that the seasons of the standards should be changed to
    - Nov – March (higher take)
    - April – Oct (lower take)

This was to ensure protection of invertebrates during their growing season and to protect fisheries.

Standards

- It was agreed that the standards for A1 river types could be made less restrictive due to the low sensitivity of this river type. See table 1 below for revised standards.

Typology (salmonids and scale)

- The “type” of “spawning and nursery areas” was discussed, regarding how information defining this type could be captured across the UK. It was agreed that there was no UK dataset easily available to create this type; however, a good starting point would be the recently published CEH book on fish distribution (E&W) and information held by Peter Maitland. In other cases, local knowledge would be required.
- There were no independent data sets identified for Scotland or N. Ireland. This requires more investigation and possibly some additional research.

Monitoring and Research

- It was reported that the RivPacs and LeafPacs methodologies are already being revised to improve their ability to identify the ecological impacts of changes in flow regime.

- Research required to improve the understanding between ecology and hydrological and morphological pressures; cross links with the impact of water quality need to be made.

- Improved capture of fish data held within the agencies (especially the EA) to allow better analysis.

- Matching of environmental datasets to hydrological impact.

- Fish version of LIFE, especially with respect of flow (but there would be a need to build a consensus on how sensitive fish are to changes in flow before it was decided if this were useful research.)

- Comparison of similar river types with different abstraction pressures, to identify any ecological impacts.

Ongoing Expert Involvement

- There was agreement that there was a need for ongoing involvement and regular feedback on issues from the point of view of regulators, end users etc.

- It was agreed that the next time to meet could usefully be following the completion of “Leafpacs” classification tool in one year’s time to discuss the findings and how they could be taken forward. This could then be followed by further meetings on the completion of other major tools.

Artificially High Flows

- It was agreed that there needs to be a statement in the report that where a river has higher flows than natural (due, for example, to inter-catchment transfers) then the standards may be set against gauged flows rather than natural flows.

General

- It was agreed that the WFD48 report should contain a paragraph stating why (on a global scale) the UK standards can afford to be relatively simple (e.g. due to simple fish populations, no subsistence farming, etc.) – this is to ensure that in any future international peer review, the report is not misused or used out of the UK context.

- It was agreed that the WFD48 needs to have a clear statement that for Good Ecological Status and below, the hydrological standards are a surrogate for ecology as the links between hydrology (and morphology) and ecology are not well understood.

Table 1: Revised Standards 21/11/05

Type	Season	More than Q60	More Than Q70	More Than Q95	Less than Q95
A1	April -Sept Nov -March	30 35	25 30	20 25	15 20
A2 (ds), B1, B2, C1, D1	April -Sept Nov –March	25 30	20 25	15 20	10 15
A2 (hw), C2, D2	April -Sept Nov –March	20 25	15 20	10 15	7.5 10
Salmonid spawning and nursery areas	April -Sept Nov –March	25 20	20 15	15 10	10 7.5

5. Next Steps

- The project steering group will ask CEH to update the WFD48 report to take on board the above points of clarification and the revision to the standards.

- The revised standards will go forward through UKTAG for stakeholder review in the New Year, and submitted to Defra in April 2006.

- It will be acknowledged that consensus was not reached with regard to using flow on the day as opposed to the value of the % flow at Q_{95} for all flow conditions less than Q_{95}. The use of the rule of "further restrictions required if environmental standard> 25% of Q98" will mitigate this issue.

- SNIFFER and the agencies will discuss the best way to manage on going expert involvement in the process, and aim to hold a follow-up event in twelve months time.

Kirsty Irving
SNIFFER

23/11/05