Stage 2 Report **Project WFD48**

DEVELOPMENT OF ENVIRONMENTAL STANDARDS (WATER RESOURCES)

STAGE 2: TYPOLOGY REVIEW

July 2005

SNIFFER
SCOTLAND & NORTHERN IRELAND
FORUM FOR ENVIRONMENTAL RESEARCH

Dissemination status
Unrestricted

Research contractor
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PART I – RIVERS

1.1 Introduction

In order to deliver the ecological objectives of the Water Framework Directive (WFD), regulatory standards are needed that will allow the agencies to determine the ecological flow requirements of UK surface freshwaters. The WFD requires member states to assign water bodies to each type and thence to assign reference conditions to each type, to be used as 'baseline' conditions against which management targets can be set.

The WFD System A typology has been established for the reporting elements of the WFD in the UK, and the UK Technical Advisory Group has begun to define associated reference conditions (UKTAG; 2003). However, there are also a number of existing typologies and classification systems which have been developed both in the UK and overseas, and applied in various river management settings.

The aim of this part of the project is to review typologies and classification systems of relevance to the setting and implementation of environmental flow standards. In this part of the report, some of the general principles behind typologies are discussed, followed by a review of particular typologies with specific consideration of their utility, and limitations, for the particular task of developing a new typology suitable for setting type-based environmental flows for UK rivers. Appendix 1 contains a table which provides a brief synopsis of the river typologies reviewed.

1.2 Context - relevance of typologies for the project

Typologies are reviewed with a view to several criteria which are regarded to be of particular importance for this project - these are listed and discussed briefly below, whilst a fuller discussion of the rationale behind these criteria are discussed more fully in the review. These criteria are partially based on scientific justification, but also reflect a necessary consideration of available resources, both in terms of the project lifetime and also in terms of the eventual implementation of the system.

The project team has established that a typology for environmental flow setting in the UK should be:

- Ecologically meaningful; thus, the typology should yield types that are ecologically distinct
- Readily amenable to the application of flow sensitivity targets; further to the above point, defensible sensitivity criteria should be applicable for these types
- Based on readily available datasets
- Applicable from a desktop setting - thus, based on parameters which do not necessitate field visits. Hence, preference is given towards methods which can be applied using a desktop analysis - in particular,

broad scale datasets available at a catchment level, which are readily applied in a GIS setting, rather than site-based parameters which require field observation.

- Hierarchical, to enable application across scales;
- Applicable alongside existing systems, which may cover different elements of the scale hierarchy - such as the RAM framework.

It is envisaged that the development of a new typology will probably be based on existing systems to some degree - it is unlikely that an 'off-the-shelf' solution will meet the above criteria, yet it is also unlikely that a completely new approach will be developed within the timescale of the project. It is the intention that, following this review of the theoretical basis of typologies, existing systems will be tested experimentally, and the outcomes will be used to guide and inform the development of a new typology.

1.3 General Principles of Classification and Typologies

Classification procedures such as typologies are used to group like-members into types which have particular characteristics in common. Whilst this is a common aim of most classification procedures, there are a diverse range of approaches to the actual mechanics of classification. A useful generic distinction drawn by Bailey (1994) is between *taxonomy*, which is an empirical procedure for allocating cases on the basis of similarity or difference, via some measured attributes, and *typology* which is based on *a priori* judgments of class definitions and boundaries[1]; both are cases of the more general procedure of *classification.* Both approaches have advantages and disadvantages, and many classification systems involve elements of both.

Typologies have found widespread application in the environmental sciences, although Naiman *et al.* (1992) point out that stream classification, whilst having existed in one form or another since the 19th Century, is still in a formative stage - partly because of the relatively recent recognition of rivers as ecological systems, and because of the complexities of the dynamic changes that occur over broad spatial and temporal scales. Notwithstanding these conceptual obstacles, in recent years, typologies have found increasingly widespread application in the management of hydrological resources and the typology is now a core element of many approaches to sustainable river management and conservation.

Firstly, some of the conceptual obstacles to constructing typologies will be considered. The requirement for classification and the resultant evolution of typologies has come about through a desire to organize the complexity of the natural world. The benefits of 'typing' entities into like units for management purposes is clear - management decisions (such as flow targets) can be developed and applied for particular types rather than individual water bodies. Building a typology is thus a process of simplification and abstraction; the

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[1] *Terminology:* Many of these terms are used interchangeably in the literature, so this convention of Bailey (1994) will not be adhered to here; the convention adopted in this report will be to refer to all the systems reviewed as *typologies*, and the general procedure for grouping into types as *classification*, although this distinction between *a priori* and *a posteriori* definition of class boundaries is an important and will be referred to throughout.

efficacy of a typology then hinges on the extent to which it permits simplification whilst still remaining meaningful. Juracek & Fitzpatrick (2003) point out that whilst simplification brings advantages for understanding, communication and management decisions, classification can oversimplify the complexities inherent in natural systems, and lead to misapplication and extension beyond the original constraints of the classification.

A central tenet of classification is the existence of discrete 'types' with distinct boundaries - however, the classification of streams is complicated by longitudinal and lateral linkages, changes over time, and by boundaries that are often indistinct (Naiman *et al.* 1992). In particular, as is well known in hydrological systems, natural variability occurs across a range of time and space scales, and different processes become important or dominant at various scales (Bloschl & Sivapalan, 1997), which creates an inherent complexity in constructing a widely-applicable typology. The dynamism of natural systems also means that changes will occur which may alter the state of the system to such a degree that typologies may cease to be applicable - this is particularly important in the context of anthropogenic disturbance. One possible approach to limitations imposed discrete boundaries is fuzzy set theory. This approach has potential as a tool for classification, allowing objects to have partial membership of categorical classes. Fuzzy set theory is being increasingly employed to hydreocological problems; for example in defining rules for habitat suitability for salmonid fish in Germany (Schneider *et al*., 2001). Hitherto, there have been no known applications orientated towards the construction of typologies.

In terms of the desirable attributes of a stream classification, Naiman *et al.* (1992) argue that a consensus has developed on the fundamental attributes of an enduring classification system, which should: encompass broad spatial and temporal scales; integrate structural and functional relationships under various disturbance regimes; accomplish this at low cost with a high level of understanding among resource managers (Figure 1). This conceptual model is particularly important in considering the impact of cost and available resources - any typology will represent some trade-off between the functionality and efficacy of the classification system and the available resources for conducting the classification and thence applying the system in a management context.

In the UK, the last twenty years has seen the development of a number of classification procedures (many reviewed here), many of which are based on similar principles and survey methods. Raven *et al.* (1998) reviewed a number of contemporary classification methods employed in the UK, and identified several important requirements for a more integrated approach in the development of future classification systems:

- Clear objectives
- Appropriate scale for classification
- Interpretation of data should not exceed inherent limitations of data
- Capabilities of the system must be made explicit

- Technical standards and use-related protocols need to be agreed to provide a robust rationale for data capture, analysis, archiving
- A common understanding of terminologies is needed to ensure consistency of use
- Quality assurance and control are needed to maintain standards for survey methods

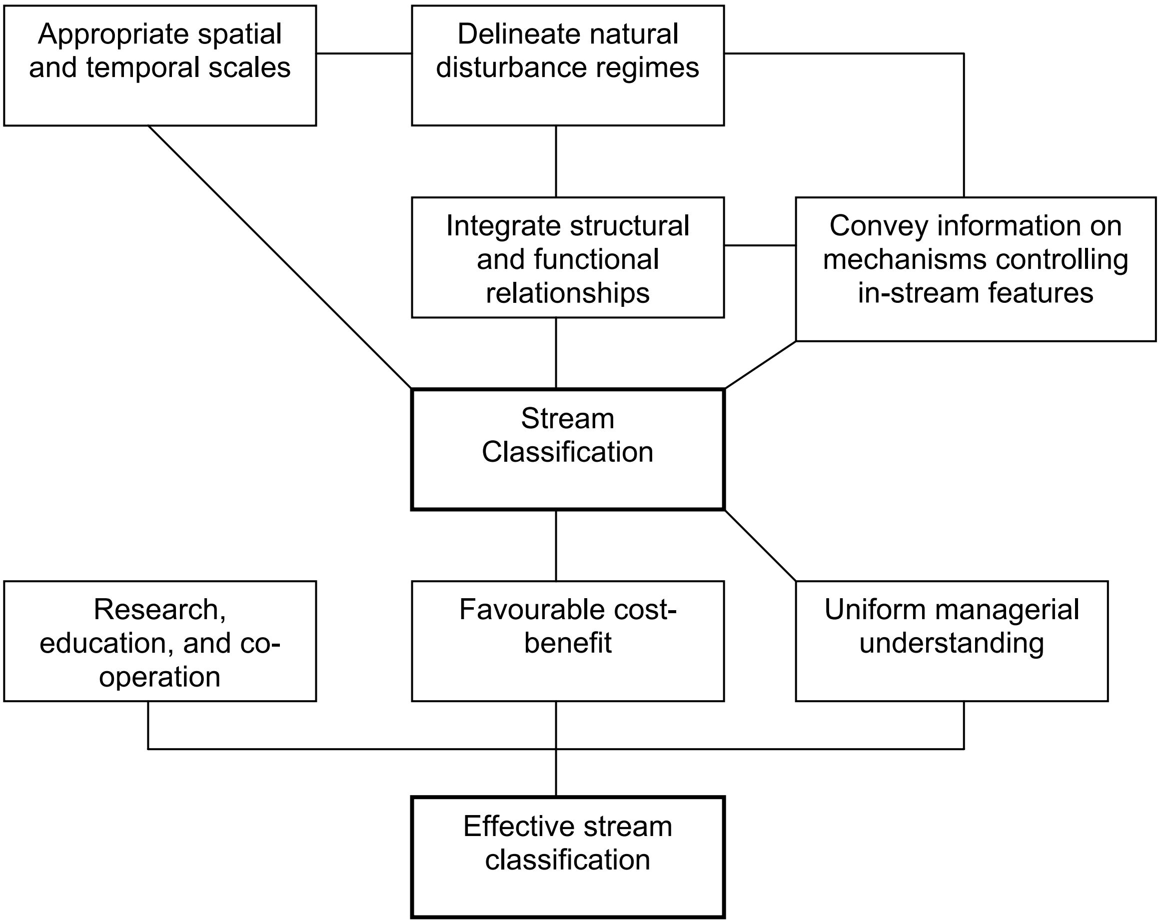

Figure 1 Relations between essential elements of an ideal stream classification system. (reproduced from Naiman *et al.*, 1992)

2. Use of typologies in characterizing ecological sensitivity and flow setting

Firstly, it is important to consider those typologies which share the main objective of this project, *i.e.* in defining a typology which is used to differentiate types on the basis of flow sensitivity and thence to establish targets for these types.

2.1 RAM Framework

The EW scoring system of the Environment Agency (EA) Resource Assessment and Management Framework (RAM; Environment Agency, 2002; Dunbar *et al.* 2004) is a typology designed to be sensitive to ecological considerations. The RAM Environmental Weighting (EW) bands are effectively river types, defined on the basis of ecological sensitivity to flow modification, and distinct River Flow Objectives (RFO) are defined for each EW band. The RAM framework is hierarchical, in the sense that overall EW scores are based on four distinct elements of ecological sensitivity: Physical characterisation, Fisheries, Macrophytes and Macroinvertebrates. The latter three are based on existing classification systems, and as such, can be viewed as individual typologies which will be discussed in the appropriate sections below. There are separate scoring systems (based on sensitivity to flow modification) for each element, and a river assessment point (AP) is typed into an overall EW band according to an aggregated score. Type-specific RFOs are then applied to the AP, and these are translated into percentages of the natural 'benchmark' flow which can be abstracted at various points on the flow duration curve. A second phase of RAM involves characterisation of current status based on sampled data for macroinvertebrates and macrophytes, and the comparison of derived metrics (LIFE and MFR) with expected scores.

Clearly, there are major parallels between the scope of the RAM typology and the present study. The principal advantage of the RAM typology is that it aims to type rivers on the basis of ecological sensitivity to flow modification, the key focus of this study. This is done for separate elements of the ecology, with scoring for each element being framed in terms of flow modification. The foundations of its typologies for macroinvertebrates and macrophytes are largely based on expected scores derived from map-based characteristics independent of site measurements. These use well-founded empirical models, widely used in the environment and conservation agencies of the UK such as RIVPACS and that of Holmes *et al.*, and flow sensitive metrics such at LIFE, developed by Extence *et al.* 1999 and the MFR system developed for RAM.

The limitations of the system are that there are still uncertainties as to the ecological justification of the EW system, and in its translation into flow bands. Whilst the aim of directly integrating sensitivity into the system is clearly laudable, the ecological justification for these sensitivity classifications (for example, the *a priori* physical characterisation) has not necessarily been validated. In addition, the concept that higher expected LIFE scores in the macroinvertebrate scoring system (see section 4.1) reflects greater sensitivity to abstraction, although plausible, is yet to be substantiated.

In terms of practicability, a potential limitation of the system is that it is designed for site-specific application as part of the EA Catchment Abstraction Management Strategies (CAMS). While much of the macroinvertebrate component, being based on RIVPACS catchment characteristics, can be easily automated, it is still dependent on some RIVPACS site variables, such as river width, depth and alkalinity. The predictor variables of the macrophyte component are not yet as well linked to communities as they are in RIVPACS, it uses three key map-based variables (geology, altitude and gradient), and both qualitative and quantitative guidance of how to assign a river to a type, this ideally needs to be done by a macrophyte ecologist with some knowledge of the sites to be typed.

The physical typology ideally requires a field visit or photographs and its conceptual basis is not justified and may go against thinking in other countries that steeper upland streams are less sensitive to flow modification.

RAM does not consider flow regime in its derivation of the environmental weighting, it could be that this is an important predictor variable. Although not specifically related to sensitivity to abstraction, work such as Clausen and Biggs (1997) and Riis and Biggs (2003) has demonstrated the controlling influence of flow regime on biota: it has also been suggested from an evolutionary standpoint that biota living in more predictable regimes could be more sensitive to flow alteration than those living in less predictable regimes.

2.2 Other systems

More recently, Cowx *et al.* (2004) developed a typology for UK fisheries, which is designed in order to allow flow targets to be set. This is discussed in section 4.3.

3. Characterisation of physical features and habitats

3.1 Geomorphological approaches to stream classification

Stream classification has been applied throughout the history of hydrology and fluvial geomorphology as disciplines, and has been reviewed extensively by Mosley (1987) and Naiman *et al.* (1992). Stream classifications have been applied across the scale hierarchy, covering a diversity of physical habitats from microhabitat to ecoregion (Naiman *et al.*, 1992). Most practical applications of stream classification appear to be focused on the channel to reach scales.

One typology widely used in management situations in the USA is the Rosgen (1994) system. The Rosgen system is applied at a reach scale, using a range of physical parameters (see Appendix 1) derived from field survey. The system is based on present stream characteristics, and thus is sensitive to perturbations (Naiman *et al.* 1992). However, the Rosgen system has been criticized for this very reason, as time dependence does not allow for natural variability. Other criticisms have been that the system lacks a process-based classification (Montgomery & Buffington, 1997) and for its limited applicability across physical environments (Juracek & Fitzpatrick, 2003). This latter point is particularly important, as the Rosgen system was designed following work on basins on the west coast of the USA.

Montgomery & Buffington (1997) proposed an alternative process-based classification for mountain channels (also based on work in the Pacific North West of the USA), with the types reflecting downstream changes in the balance between transport capacity and sediment supply. A process basis has utility in terms of advancing understanding and characterizing linkages across the scale hierarchy, although this typology shares similar limitations to the Rosgen system in, at least in its present incarnation, being limited in geographical transferability, in this case through its focus on a particular geomorphic domain.

An alternative hierarchical classification oriented towards the physical classification of channels is the 'River Styles' approach developed by Brierly & Fryirs. (2000). The River Styles approach was developed to address some of the criticisms directed towards previous classifications, and to provide a typology suitable for Australian environments. River Styles are characterised by distinctive sets of attributes, defined in terms of the channel geometry and planform, and the assemblage of geomorphic units that make up a river reach. The system is process-based and hierarchical, allowing linkages across the scale hierarchy. One of the main benefits of the system in the context of this study is that it is set within the context of river evolution; the approach permits an understanding of a river's capacity to adjust to pertubations, which enables an assessment of how far it is from its natural condition. In addition, the system is generic, in the sense that new variants can be applied in new environmental settings. A variant of the River Styles approach combined with the Montgomery and Buffington classification is being tested as part of a channel typology for WFD implementation in the UK (Grieg, 2004a).

The main benefit of stream classification based on physical characteristics is that it enables classification at a high level of detail, using features of importance as instream physical habitat. However, there appear to have been few attempts to quantify the extent to which these classifications have ecological justification based on ecological data. The River Styles approach has been tested against macroinvertebrate data from three river styles in Australia (Thomson *et al.* 2004) - macroinvertebrate assemblages were found to differ between river types, but the ability of the framework as a typology for discriminating rivers ecologically was found to be limited because large -scale drivers of local habitat conditions are not included in River Styles classification.

There are a number of common constraints inherent in these systems, such as whether the units of classification should be stable or dynamic (Naiman *et al.* 1992) and the limited applicability of systems in other environments. In terms of practical application in a UK setting, the latter issue is of particular importance. Nevertheless, whilst existing classification systems may not be directly transferable to a UK setting, it is important to consider the potential benefit of these typologies as conceptual tools for interpreting physical habitats. Juracek and Fitzpatrick (2003) argue that the limitations of stream classification systems such as the Rosgen system mean they should only be applied as a conceptual tool and therefore for communication purposes. The reach-based emphasis of these systems and the reliance on field survey data makes them less suitable for the development of a rapidly applicable classification tool; however, they may have considerable utility in appraising existing field survey data and also in attempting to link reach-based data to coarser scale catchment characteristics. There is a requirement to improve linkages across scales, particularly as different processes emerge at different scales in the hierarchy. An interesting issue with the use of physical feature and habitat based typologies is the relative role of local versus gross scale drivers for channel form and features. In the UK, the character of the physical riverine environment can be controlled by local scale drivers rather than the gross-scale geomorphic processes upon which the typologies are often based. For instance, Scotland’s glacial legacy can result in complex channel continuums that may not conform to generalities of channel form that would be suggested through a typology. However, this same issue may also have a positive implication within the context of the WFD. In England and Wales many local scale drivers of channel form are anthropogenic, thus the adoption of typology of the type outlined above may provide valuable indications of deviations from what would be expected under more natural landscape/channel conditions.

3.2 River Habitat Survey (RHS)

Of direct relevance to UK conditions is the extensive survey of the physical characteristics of rivers carried out for the River Habitat Survey (Raven *et al.*, 1997,1998), which - whilst not comprising a typology *per se* - provides a vast data resource which can be used to build classifications of river habitat features. Typologies can be constructed selecting particular groupings of RHS sites from the existing database, using bespoke queries applied to a range of physical parameters chosen according to the requirements of the typology. RHS data can also be used to assess habitat quality by reference to 'good' quality sites, through Habitat Quality Assessments (HQA), although there has been limited validation of the approach with ecological data.

Two existing classifications of physical characteristics using RHS data are those of Newson *et al.* (1998) and Jeffers (1998). Newson *et al.* (1998) sought to develop a geomorphological classification of UK river channel features (River Channel Typology, RCT) using multivariate analysis of RHS data. Jeffers (1998) applied ordination techniques to enable prediction of habitat features based on four map-derived variables: altitude, slope, distance from source and height of source. The ordination can thus be used to predict probabilities of occurrence of various habitats (such as substrate types) with only reference to spatial datasets. This categorization is potentially of very high utility for application in developing a UK based typology, by enabling rapid assessment using automatically derived data - particularly if facilitated by a GIS framework - yet being based on the extensive RHS database. There are limitations of the technique in that it still requires further validation against field data, and in particular, against biological response data.

4. Classification based on biotic elements

There have been many attempts to classify streams using biota - Naiman *et al.* (1992) provide a review of early developments in this field. Naiman *et al.* (1992) argue that classifications based on biotic elements may have their utility limited by the impact of several factors (zoogeography, disturbance regimes and biotic interactions) which affect species-habitat relationships.

In the UK, various systems have been developed in the recent past, which have typically involved empirical classification using multivariate analysis, coupled with a suite of environmental predictor variables which encompass various physical and chemical habitat features. In this sense, the typologies reviewed here can be viewed as coupling both biological and physical features.

4.1 Macroinvertebrates - RIVPACS and LIFE

The River InVertebrate Prediction and Classification System (RIVPACS) was developed in the UK in the 1980s and 1990s (Wright *et al.* 1998, 2000). It is designed to work at family level, and was developed using a TWINSPAN multivariate analysis of macroinvertebrate assemblages at good quality, representative 'reference' sites (Wright *et al.*, 1987). This leads to a 35-fold classification system for Great Britain (Wright *et al.* 1998), although simpler sub-groupings (9 and 4 categories) can also be used. RIVPACS enables prediction of a target assemblage which would be expected in the absence of environmental stress, which provides reference ‘baseline’ conditions for comparison with the observed fauna. Prediction is based on a suite of environmental indicator variables which feed into a multiple discriminant model, predicting probability of membership of each RIVPACS group, and thus probability of occurrence of each macroinvertebrate family. The indicators encompass map-based physical variables (*e.g.* distance from source), at-site physical variables (*e.g.* water width, depth) and at-site chemical predictors of water quality (*e.g.* Alkalinity, Total oxidised nitrogen). It should be noted that there are various options for the use of the variables (see Figure 2). RIVPACS is also able to include some elements of uncertainty in its calculation, primarily that of errors in the environmental variables and typical site sampling variation. Variation arising from coverage of reference sites, and not having the “best” set of reference sites or “best” model are not included.

Site Registration Data
National Grid Reference
Altitude
Distance from Source
Slope [1]
Discharge (mean) category
Mean air temperature [1]
Air temperature range [1]

Environmental Data
Stream width
Depth
Substrate characteristics (as phi value)
Water geochemistry (preferably alkalinity, but a surrogate: total hardness, calcium concentration or conductivity is acceptable) [1]
Water velocity category (only required if discharge category not available)

[1] These variables may optionally be used in the following combinations:

	Option				
Variable	1	2	3	4	5
Alkalinity	✓	✓		✓	
Slope	✓	✓	✓	✓	
Mean air temperature	✓	✓	✓		✓
Annual air temperature range	✓		✓		✓

Figure 2 Environmental predictor variables employed in RIVPACS

RIVPACS is used in the macroinvertebrate element of the RAM framework. In this setting, RIVPACS is used to derive predictions for 'benchmark' conditions for CAMS assessments points - more specifically, to predict expected LIFE scores using the Lotic Invertebrate Index for Flow Evaluation (LIFE) method (Extence *et al.*, 1999). It should be noted that there are two separate methods of calculating expected LIFE scores, the LIFE calculator, developed by the Agency, and the method developed in the “Putting LIFE into RIVPACS” project (Clarke *et al.*, 2003).

As a typology, the RIVPACS classification system has the advantage of being an empirical, statistically robust classification system applied to data from reference sites across the UK. It is also a well established system widely employed by UK environmental agencies, and supported by a software application (RIVPACS III+). The classification system can be readily employed to 'type' new sites on the basis of the environmental predictor variables, which can be gathered relatively easily in comparison with biological data. A further benefit of RIVPACS, in view of the aim of this study, is that flow sensitivity can be attributed to types through the LIFE method, as employed by the RAM framework (although see the caveat below on the logic of high expected LIFE scores being more sensitive to abstraction).

In the context of this study, disadvantages of RIVPACS include the fact that its view of a reference site was developed when the focus was primarily on pollution, particularly from sewage treatment works: less attention was paid to river flow and morphological river degradation. Clarke *et al.* 2003 reviewed flows in the years when all the reference data were collected, and identified a very small minority of sites which might have been influenced by low-flow stress. The issue of the interaction of any morphological and flow degradation has not been particularly explored using these national datasets, this has been hampered by the separate development paths of RIVPACS and RHS.

Another key issue is that there is no overall conceptual model of how the predictor variables influence the macroinvertebrate community, it is clear that some catchment variables, such as distance from source, are important, but to what extent are they surrogates for other more appropriate variables? Also, as all the predictor variables go into the model in one go, it is not possible to test the predictions of a purely catchment-characteristic based model, such as could be of great utility in this project. RIVPACS also includes a slightly mysterious “flow group” variable, whose categorical nature is rather artificial. In addition, some of the site-based variables, such as depth, width and substrate, are clearly not independent of flow or morphological stress. Finally, it has not kept pace with the development of GIS datasets and techniques. Although Hornby et al. 1999 demonstrate how some RIVPACS map-based variables (principally distance from source) can be derived using GIS techniques, the possibilities now exist for a wholesale re-appraisal of the RIVPACS predictor variables, including modelling site physical variables (*e.g*. river width, “characteristic” flow, *e.g.* mean flow, QMED) using GIS, modelling chemical variables (*i.e.* alkalinity) from digital geology datasets, and testing other map-based / catchment variables, *e.g*. slope, catchment area.

For the LIFE methodology, its overall utility cannot be underestimated, particularly as it is unique in Europe, it fulfils a need of the WFD, yet initial development predates the Directive. However, the manner in which LIFE is used within RAM, particularly the concept that higher LIFE scores equate to greater sensitivity to flow modification, whilst intuitive, is completely untested. In addition, when used at family level, the LIFE index has a limited range, which constrains its sensitivity.

For the purposes of this study, RIVPACS must be considered to be of particular importance. The method currently requires reach-based data, necessitating some field data collection. Whilst this precludes rapid assessment, there is considerable scope for further work using the predictor variables employed in RIVPACS (perhaps using existing physical data from the RHS database), along with existing RIVPACS predictions, to investigate the feasibility of linking reach based data with catchment level parameters.

4.2 Macrophytes - River Community Types and Mean Flow Ranking; LEAFPACS

British rivers have been 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, although unlike RIVPACS there is no easy to use model to predict group membership: expert judgement is required.

The RCT classification is used in the RAM framework, for the macrophyte element of the EW categorisation, as described in Section 2.1 above. EW scores are applied according to the class. The EW scores for each class were derived using the Mean Flow Ranking (MFR) method (Environment Agency, 2002), which assigns flow sensitivity to macrophyte species using a development of the Mean Trophic Rank (Holmes *et al*. 1999) method. In common with RIVPACS/LIFE, the RCT/MFR system has the main advantage of being based on statistical analysis of representative sites and enabling assignment of flow sensitivity to types. However, whilst the MFR system has been tested on some sites, the RAM framework guidance stipulates that adjustments to the MFR scoring system may be necessary as the understanding of the relationship between MFR scores and flow sensitivity increases.

Overall, the MFR system, whilst conceptually sound, is currently less-well validated than LIFE. The RCT classification is based on an extremely comprehensive dataset and community analysis, but the modelling of the predictor variables and community types is less well developed than in RIVPACS, and possibly RHS as well.

The EA LEAFPACS project is developing a predictive system to assess the ecological status of rivers and lakes using macrophytes, equivalent to RIVPACS. The system is still currently under development.

4.3 Fish

Fish have formed the basis of a number of stream classification systems - some historical applications have been reviewed by Naiman *et al.* (1992). One of the earliest approaches, which is still widely used as a conceptual tool, is the zonation theory of Huet (1954), which differentiates rivers longitudinally into four zones associated with the dominant species - trout, grayling, barbel and bream - defined on the basis of channel slope.

In the UK, the main fisheries typology currently used in practice is the fisheries element of the RAM framework. This employs a five-fold scoring system, based on sensitivity to flow modification (Table 1) of fish communities. Scoring is carried out using expert judgment supported by the outputs of predictive tools such as HABSCORE, which expresses the expected abundance of salmonid fish by reference to a database of pristine sites (Milner *et al.*, 1998).

A new typology based on fisheries has been developed recently by Cowx *et al* (2004). This system discriminates eight fish community types, using multivariate analysis of fisheries datasets from undisturbed rivers across the UK. Each of these assemblages are characterized by different physical characteristics and flow regimes - the statistical analysis indicated that the main abiotic factors influencing fish communities are river gradient, flow characteristic and water chemistry. The eight classes generally reflect the classical zonation theory from upland salmonid to lowland cyprinid reaches (Cowx *et al.*, 2004). The objective of the typology is to develop flow requirements for each of these fish assemblages, although these have not yet been developed as the study is still in progress. In common with the RIVPACS system, this typology has the advantages of being empirically-based and founded on robust multivariate analysis. However, at the time of writing the typology is still under development - the authors point towards potential biases in the dataset owing to a lack of data in some regions, and for certain river types. The system has not yet been fully developed into a decision-support framework, although it clearly holds potential as another coupled biological-physical classification system, which will eventually be translated into type-based flow requirements. An additional project of importance is the EU Fish-based Assessment Method for European Rivers (FAME) project. The final results are not available, but due for dissemination in spring 2005.

Table 1 Fisheries scoring scheme in the RAM framework

RAM score	Description
5	Salmonid fish – spawning/nursery area
4	Adult salmonid residents (wild) and/or rheophile coarse fish – barbell, grayling
3	Salmonid fish passage (smolts and adults) and/or flowing water cyprinid fish – dace, chub, gudgeon, bullhead and/or shad spawning/rearing/passage
2	Slow/still water cyprinid fish – roach, bream, tench, carp
1	Minimal fish community *e.g.* eels and stickleback only or no fish.

5. Typologies based on catchment properties

The typologies so far considered have mixed catchment, river network and channel-reach attributes, focusing on properties of the channel and instream environment, or stream network, rather than the catchment area. One of the main scale issues in classification is the complexity of linking fine-scale channel processes with coarse scale catchment properties (Naiman *et al.* 1992); however, the catchment is the main unit for integrated river management, so there are distinct advantages to a catchment-based approach.

5.1 Water Framework Directive Typologies

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 2).

Table 2 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

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). Initial reference conditions have been established for these types (UKTAG, 2004a). The System B typology of the WFD follows this typology framework, although it does not prescribe the specific altitude, size or geology classes and also permits the use of additional factors, providing they achieve the same degree of differentiation as the System A typology. System B is largely based on the RIVPACS predictor variables, but also including additional variables, so its inclusion in this section is largely for convenience.

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 - work is needed to validate the efficacy and meaningfulness of the classification system for differentiating catchments in terms of their hydrology and ecology - in particular, in comparing within-type variability with between type-variability. Whilst such a rapid assessment tool has clear benefits for reporting purposes, much further work is required to validate the parameters and ranges, and also to relate catchment scale types to reach based classification. The system B classification lacks the arbitrary classification, so has greater flexibility, enabling the integration of site-level predictor variables, however the problem still arises as to whether site-level predictors are themselves impacted.

5.2 Pooling group methods

There are several systems for grouping catchments on the basis of hydrological similarity as measured by catchment properties, which have found widespread application in decision support systems. The Flood Estimation Handbook (Institute of Hydrology, 1999) and LowFlows2000 (Young *et al.* 2003) use indices of hydrological similarity to form pooling groups of catchments, based on physical catchment descriptors. The FEH, for example, utilizes a three-dimensional size/soils/wetness space - requiring catchment area, baseflow index (BFI), and average annual rainfall. Such indices are based on a continuous scale, and are not designed for classification, so do not lend themselves automatically to the definition of types with discrete boundaries. However, the method undoubtedly has potential for application in this area - clearly the 'pooling group' concept is analogous to a type, and the dynamic typologies used in FEH and LowFlows2000 are analogous to that used in RIVPACS. The FEH catchment descriptors and the hydrology of soil types (HOST) data used in LowFows2000 could be used as classification parameters for an environmental flow standards tool.

The advantage of these methods is that they provide a rapid assessment of hydrological similarity, and are based on catchment scale parameters readily available as digital datasets. The methods have hydrological justification, as the indices and parameters were developed following extensive studies such as the low flows studies report (*e.g.* Gustard *et al.* 1992) which applied regression models to observed hydrological datasets to derive relationships between flow regimes and catchment descriptors. Wharton (1989) demonstrated relationships between flood statistics and channel form, her aim being an alternative method to estimate the flood statistics from measured site channel dimensions, but such relations could clearly be applicable in the reverse direction.

Hitherto, however, there have been few attempts to relate these hydrological catchment descriptors and hydrological similarity indices to ecological datasets, although BFI has shown some promise in exploratory analysis (Dunbar and Clarke, 2004; Mike Furse, CEH Dorset, personal communication). It is thought that flood statistics are being used in large-scale analysis of RHS data (Marc Naura, Environment Agency, personal communication), but no more information is available at present.

5.3 Catchment Representativeness Index

The Catchment Represenativeness Index (CRI) has been developed as a hydrometric network appraisal tool by Laize *et al.* (2004). The CRI is a method for assessing how representative a catchment is of a wider area (such as a hydrometric area, or any administrative region) using a comparison of digital datasets (currently elevation and land use, using the Land Cover map 2000, but with future extensions using geology). The CRI is designed as a tool for network appraisal, and as such does not have any inbuilt classification system. However, in common with pooling group methods, it provides a continuous-scale Index for assessing similarity of catchments. There is scope, therefore, for application of the CRI as a potential method for supporting catchment-scale classification in a UK context. The method is supported by a GIS toolkit, although it is still under development.

5.4. Geographical Region methods

The hydro-ecoregion approach (Jean-Gabriel Wasson, Cemagref, personal communication), aims to define relatively large-scale geographical regions, defined *a priori* from controlling abiotic variables, principally geology, relief and climate, which have relatively homogeneous responses to large-scale pressures (*e.g*. agricultural, urban extent and intensity). Site-scale attributes, such as river width, depth, can be used to fine-tune biotic response models when such data are available.

This typological approach has the advantage that it does completely separate catchment-scale and local scale attributes, but it is almost the opposite approach to that adopted in RIVPACS and WFD System B. It has been tested for macroinvertebrate data in France.

An analogous situation has occurred in hydrology in that initial attempts to regionalise flood statistics worked on a geographical region basis. For example the UK was divided into geographical regions that were assumed to be homogeneous with respect to flood frequency in the Flood Studies Report (NERC, 1975) and with respect to flow duration curves in the Low Flow Studies report (Institute of Hydrology, 1980). Acreman and Sinclair (1986) recognised that geographically proximate catchments were not necessarily the same hydrologically and proposed regions for Scotland based on physical catchment characteristics. Acreman and Wiltshire (1989) developed the idea that catchments should not be constrained to be unambiguously assigned to any region and assigned probability of member to regions. This led to the development of a more dynamic approach to classification where a region is defined for a site of interest using catchments that have similar catchment characteristics; called the region of influence approach (Burn, 1990). This in turn led to the pooling group procedures adopted in the Flood Estimation Handbook (Institute of Hydrology, 1999) and Low Flows 2000 (Holmes *et al*., 2002) – see 5.2. above.

Geographical region-based approaches probably have more potential in hydro-ecology than in hydrology alone, primarily because hydrology acts in one direction (*i.e*. upstream to downstream), but river ecology is more complex and is affected both by overall connectivity, and movements of biota in both directions.

Overall, the hydro-ecoregion approach is not tested in the UK, and its development for the UK would require more effort than is practical for this project, however, the importance of geographical regions should not be overlooked.

6. Review of main findings and recommendations

The sections above have reviewed a number of classification systems which have been applied in a range of river and catchment management settings. Whilst there are parallels between many of the systems, the diversity of approaches reflects the range of purposes for which typologies are designed: in particular, the spatial and temporal scales of application and the choice of classification parameters are influenced by the projected end use of the typology and the availability of resources for developing and applying the system.

The typologies considered here vary in scale and complexity from the RAM typology (actually a nested system of separate typologies), with an array of classification parameters and - for some elements - a relatively small (site-based) spatial scale, to the WFD System A typology with few parameters and a wide spatial coverage. The former is data- and resource-intensive, but (notwithstanding uncertainties in the assignment of ecological sensitivity) empirically based and therefore meaningful in terms of ecological sensitivity. Conversely, the latter is parsimonious and easily applied, yet based on *a priori* classification predicated on an intuitive, yet not necessarily meaningful, categorical system.

The RAM typology, based on four elements of the river ecosystem (fish, macrophytes, macro-invertebrates and physical structure), fulfils many of the key requirements of a typology based on flow sensitivity. It must be emphasised that 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. In the context of this project, the principal limitations of the system are:

1. Data intensive and site focused
2. Does not consider influence of flow regime
3. Flow sensitivity elements require justification
4. Inter-relationships between classification systems (particularly physical predictor variables).

The first point is a pragmatic constraint on the applicability of the method as a rapid assessment tool. The latter three are areas where further work could be carried out to improve our understanding of the relationship between flow sensitivity and the component classification schemes, in order to validate the flow sensitivity components of the framework.

The RAM classifications are constructed more or less independently of the influence of the flow regime, which is only considered at the RFO setting stage. Generally, the flow sensitivity mechanisms are predicated on a linear relationship between the ecological components and flow. However, 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. Work is needed to elucidate the extent to which flow regimes, and in particular flow variability, influence the ecological sensitivity components of the framework

Points 3 and 4 on the above list relate more directly to the separate classification systems employed by the RAM EW mechanism. Firstly, relating to the ecological justification of these systems. Whilst they share the common advantage of having been developed from field survey data, the systems employed to relate flow sensitivity (LIFE and the MFR system) to the ecological classification systems still require testing and development. In addition, when considering all three systems - 1) RIVPACS/LIFE, 2) RCT/MFR and 3) the fish classification of Cowx *et al.* (2004) - it is clear that there is considerable common ground, both in terms of the classification systems and the choices of predictor variables. All three classifications recognise a continuum of types which typically grade from upland to lowland reaches. Whilst the individual classifications vary, there is undoubtedly some correspondence between the ecological communities found at various locations. From an ecological standpoint, all of these systems may be necessary to give a full indication of flow sensitivity (this integrated approach being one of the principal advantages of the RAM framework). However, many of the same physical characteristics are used as predictor variables, and many of the relationships will be driven by the same spatial heterogeneity in relief, geology and climate observed over the UK. There is scope for a detailed analysis which attempts to pool together these predictor variables and examine their influence on the types as defined by the three systems.

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 channel scale is of importance for any detailed physical characterisation of habitat features, so there is scope for the incorporation of more sophisticated physical typologies in future developments of reach-based management frameworks, such as the physical characterisation element of RAM. This and a general need to refine the physical elements of the various biological classification systems (as discussed above) employed in the UK may be a worthwhile avenue for a more detailed analysis of the RHS database. There is also possible scope for linking across scales by deriving relationships between at-site physical characteristics and catchment parameters. It is possible that some GIS - derived parameters (*e.g.* slope and area) could be used as some surrogate for reach/channel morphology, perhaps by using some development of the Jeffers (1998) ordination, although considerable work is required before this could be achieved.

In terms of practicalities, there are clear advantages in adopting a catchment-scale focus to classification. 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). However, there is a need for much more detailed work to establish whether the relatively arbitrary *a priori* categorisation has a sound conceptual and statistical basis. Work is needed to establish whether the ranges used in the classification have any justification - particularly as they have been developed for Europe as a whole, resulting in a significant bias towards smaller catchments when the typology is applied to the UK. In addition, this bias towards smaller catchments means that, based on the initial characterisation, up to 50% of the waterbodies delineated by the typology are relatively natural (A. Young, CEH Wallinford pers. comm.) and thus less likely to be subject to resource pressures.

Beyond the testing of the WFD typologies, there is a more general need to investigate classification schemes based on catchment descriptors, which are typically easily derived and facilitate rapid manipulation in a GIS environment. In relation to the classification variables of WFD system A, there is scope for a wider multivariate analysis which employs the system A variables along with other catchment descriptors (including the FEH descriptors, Hydrology of Soil Types (HOST) categories, land use classes) to determine whether the system A classification could be improved. For example, the relatively simplistic geology classification in system A may be improved by reference to HOST data or, via its influence on flow regimes, Baseflow Index. Both the testing of the WFD typologies and any new system based on catchment descriptors would need to be validated against observed flow regime parameters and available ecological data.

7. Specific recommendations for project workplan

It is proposed that a typology for developing water resources standards for WFD water bodies should be based broadly on the four elements of the RAM framework. However, the steps relating the elements to water resources standards (permitted abstraction levels) need to be re-examined. In particular, there is a need to establish the extent to which the ecological sensitivity of the four elements can be classified on the basis of a more simplistic framework based on only catchment-based, desktop-derived parameters. Furthermore, this analysis should examine where there are parallels and redundancy between the various sets of predictor variables employed by the RAM framework.

To support this work, it is proposed that research be directed towards examining the efficacy of existing classifications based on catchment properties - in particular, the WFD system A classification should be tested for its validity in differentiating between waterbodies in terms of hydrology and ecology, and thence to establish how well this classification or any alternative system can be used to define ecological sensitivity for types. Consideration should also be given to the possibility of relating site-based physical data - perhaps from the RHS database - to catchment-based predictors, and to determine how such linkages across scales could be facilitated.

Activity 1:Ddevelopment of alternative physically-based typology

The basis of WFD System A is that area, altitude and geology and dominant are adequate to distinguish between catchment types. We will calculate physical characteristics (based on best hydrological and ecological knowledge from FEH, Low flows 2000, RIVPACS and RHS) for a representative set of catchments in the UK. We will perform redundancy analysis using multi-variate methods to define a new water body typology.

Activity 2 Comparison of water body types; WFD system A and alternative typology.

We will use three tests to compare System A and the new typology.

Test A
We will test the homogeneity[2] of water body types according to sensitivity to abstraction with respect to:

(1) physical river structure, using wetted area, depth and velocity from RAPHSA database
(2) macro-invertebrates, using slope of LIFE response to flow curves
(3) physical habitat for salmonid fish, using weighted usable area from RAPHSA database

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[2] Homogeneity means that water bodies of the same type are similar and water bodies of differing type are different

Test B

Results of applying the RAM framework provide a further basis for testing the WFD system A and an alternative. We will test the homogeneity of water body types using the physical structure and fish-based environmental weighting from completed RAM framework applications.

(1) physical river structure, using RAM class
(2) fish, using RAM class

Test C

Reference ecology databases exist for

(1) fish (Cowx *et al,* 2004)
(2) invertebrates (RIVPACS/LIFE) and
(3) macrophytes (Holmes/NCC).

Each of these involves a classification based on the taxa present. We will test the ecological relevance of System A and any new typology from Activity 1 using these data.

PART II – LAKES

8 Introduction

Despite the significance of lakes within the UK as important resources in environmental, social and economic terms, information regarding their extent and distribution remains only partial (for reviews see Smith and Lyle, 1979; Lyle and Smith, 1994; Bailey-Watts *et al.,* 2000). Hughes *et al.* (2004) presented the results of a major initiative to develop a GIS-based inventory of UK standing waters: the GBLakes database and associated website (http://ecrc.geog.ucl.ac.uk/gblakes/) was the product of an Environment Agency initiative, supported by funding from SEPA, SNH, CCW, EN and SNIFFER. The inventory incorporates 43,738 water bodies across Great Britain, and for lakes > 1 ha metadata such as catchment area and basin elevation are routinely provided. Other key parameters such as mean depth are provided where available. The key driver for this exercise was to provide scope to implement risk-based prioritisation protocols identifying water bodies likely to be at risk of failing to achieve good ecological status (initially in relation to acidification and eutrophication).

The scale of the challenge to characterise the UK's standing waters resource base is implicit in Table 3, which provides distribution statistics for standing waters throughout the UK and the Isle of Man. Excluding systems smaller than 1 ha still leaves more than 15,000 water bodies requiring classification, and even restricting the detailed reporting to lakes > 50 ha involves 774 sites on the mainland alone. In all parts of the UK small lakes predominate in terms of numbers. In Northern Ireland, around 75 % of the 1668 sites recognised by Smith *et al.* (1991) are less than 2 ha, even though the largest five lakes occupy over 90 % of the total lake surface area (e.g. Lough Neagh is the UK's largest lake with a surface area of 380 km^2).

Table 3 Number of standing waters classified according to size and location

	<1ha	1-5ha	5-10ha	10-50ha	50-100ha	>=100ha	Total
England	10738[a]	4260	710	625	64	51	16448
Scotland	17727[a]	5294	1195	1205	168	171	25760
N Ireland	1069[b]	459	115	122	14	10	1789
Wales	894[a]	394	88	90	10	17	1493
Isle of Man	26[a]	9	0	2	0	0	37

[a] dataset contains no water bodies <0.02ha and the number between 0.02 and 0.2ha are almost certainly under-represented.
[b] water bodies >=0.02ha.

(Hughes *et al.,*2004; Colin Gibney, *pers. comm.*, 2005)

Size is only one aspect of the diversity of UK lakes. Climate and catchment geology provide physical controls on the development of lake ecology, while size and form of lakes combine to affect such factors as the residence time of lake waters which, in turn, may also affect the ecology.

The particular focus of this project is the development of environmental standards for water resources. In this section addressing lakes, we focus on typologies for lake classification, with a view to the identification and/or modification of typologies which will support the development of methods for assessing the sensitivity of lakes to hydrological pressures. The section presents a review of existing typologies and discusses implications for the work of this project.

9 Rationale for Lake Classification

The classic work of Hutchinson (1957) identified eleven major processes responsible for building, excavation and damming of lake basins (Table 4), and on this basis distinguished 76 different types of lake basin. However, the vast majority of British lakes were formed by glacial activity and, as such, fall into only three of Hutchinson's categories; namely 4b (glacial rock basins), 4c (moraine and outwash basins) and 4d (drift basins). Lakes formed due to fluviatile action (category 6b) and associated with shore lines (category 8) are also present, and category 9 lakes may be more common than presently indicated by GBLakes, since many are very small.

Table 4 Classification of lake types

TYPE	DESCRIPTION
1.	Tectonic basins
2.	Lakes associated with volcanic activity
3.	Lakes formed by landslides
4.	Lakes formed by glacial activity:
	(a) Lakes held by ice or by moraine in contact with existing ice
	(b) Glacial rock basins
	(c) Moraine and outwash basins
	(d) Drift basins
5.	Solution basins
6.	Lakes due to fluviatile action:
	(a) Plunge-pool lakes
	(b) Fluviatile dams
	(c) Lakes of mature flood plains
7.	Lake basins formed by wind
8.	Lakes associated with shore lines
9.	Lakes formed by organic accumulation
10.	Lakes produced by the complex behaviour of higher organisms
11.	Lakes produced by meteorite impact

(after Hutchinson 1957).

Because of the wide range of formative processes in lakes (Leach and Herron, 1992) and the continuum that exists in terms of physical, chemical and biological characteristics, some form of classification into a discrete number of lake types is considered essential to nationally consistent management of the UK national standing water resource. Classifying lakes into distinct types (essentially a regionally-founded typology) is the first step towards defining type-specific reference conditions against which measures of change can be established. Classification of natural lakes should reflect inherent properties of lakes independent of human influences and should therefore be based on measurements not subject to anthropogenic disturbance (USEPA, 1998). Critically, the resultant classes must be ecologically relevant such that the biological quality elements, e.g., macrophyte or fish assemblages should be distinguishable at reference condition and help identify human modifications that result in biotic impairment.

USEPA (1998) recognised two kinds of variables. ‘Classification variables’ are attributes intrinsic to the system and relatively unaffected by human activities, e.g. geology, soils, lake and catchment morphology. ‘Assessment variables’ are attributes which are either direct indicators of human activity, e.g. land use and discharges; or influenced by human activity such as involves most water quality variables . Classification variables assist in placing the lake into one of the categories for which reference conditions have been determined. It is then possible to determine the deviation of attributes of the test lake from reference conditions, for both habitat and biological indicators. Assessment variables are used to assess whether catchment conditions might account for observed ecological status. Several operations may impact lake habitat through sediment loading, nutrient loading, contaminant loading, hydrologic changes, and direct habitat alteration through removal of wetlands.

10 International Approaches to Lake Classification

Conquest *et al.* (1994) state that classification systems should be hierarchical, commencing at the highest (regional) level and stratifying as far as necessary and practical. Whereas multiple classification levels can be attempted, it is important that the scheme should be robust and parsimonious i.e. avoiding excessive numbers of lake types that do not contribute to the assessment (USEPA, 1998). Miers (1994) advocated a hierarchical classification scheme employing the concepts of Ecoregion and Biogeoclimatic Zones. The former represent geographical areas where macroclimate and topography are sufficiently uniform (of variable size) to permit the development of characteristic types of ecological association. Northcote and Larkin (1956) used geology and climate (together influencing trophic status) to describe 10 distinct ‘limnological regions’ within British Columbia, Canada.

Håkanson and Lindström (1997) presented multi-parameter datasets for over 900 Swedish lakes. Water variables, including pH, total-P, colour and hardness (n = 19); catchment characteristics, including geology and soils (n = 13), lake morphometry, including size and form parameter (n = 17) were used to classify lake types and develop empirical models of lake productivity and functional characteristics. Håkanson (1997) argues classification variables such as basin area, mean depth, elevation, continentality and various morphometric parameters which prove effective in distinguishing lake types and ecological processes in Sweden should be more widely applicable, since glacial lakes are the most common lake type on Earth. The Swedish examples cover a wide range of geographical, geological and climatological characteristics. This work may well be relevant to the lakes of Scotland, the English Lake District and the Welsh uplands, since most lakes in these areas were formed as glacial rock basins, moraine and outwash basins and drift basins (*cf.* Hutchinson, 1957).

Amongst other variables, Håkanson (1997) determined a range of standard morphometric quantities from bathymetric maps, such as V, a, A, D_{mean}, B_{mean}, D_r, F (Table 5) and dynamic ratio ($D_R = (\sqrt{area})/D_r$), applied transformations to yield approximately normal frequency distributions where appropriate, and used a simple statistical analysis to test inter-relationships. Two relatively independent clusters of morphometric parameters were identified; those indicating size (e.g. volume and area) and those related to form (e.g. relative depth and dynamic ratio). A useful outcome of this work is a method by which mean depth, maximum depth and other morphometric parameters can be predicted using information that can be obtained from topographical maps, and this issue will be further explored in the next stage of the project using GBLakes database data supplied by Geoff Phillips (G. Phillips *pers. comm.*).

Table 5 Definitions and formulae for lake morphometric parameters

Parameter (units)	Abbreviation	Derivation
Lake area (km^2)	A	From topographical maps
Altitudinal range of drainage area (m)	dh	From topographical maps
Drainage area (km^2)	ADA	From topographical maps
Relief of drainage area (dimensionless)	RDA	$RDA = dh / (\sqrt{ADA})$
Lake volume (km^3)	V	$\text{Log}(1000*V) = 0.134 + 1.224*\log(A) + 0.332*\log(RDA)$
Mean depth (m)	D_{mean}	$D_{mean} = 1000 * V/A$
Maximum depth (m)	D_{max}	$\text{Log}(D_{max}) = -4.202 + 4.558*(1000*V)^{0.1} – 1.008*\log(A)$
Relative depth (dimensionless)	D_{rel}	$D_{rel} = (D_{max}*\sqrt{\pi}) / (20*\sqrt{A})$
Dynamic ratio (dimensionless)	D_R	$D_R = (\sqrt{A}) / D_{mean}$
Volume development (dimensionless)	V_d	$V_d = 3*D_{mean} / D_{max}$
Shoreline length (km)	l_o	From topographical maps
Shore development (dimensionless)	F	$F = l_o / (2*\sqrt{(\pi*A)})$
Specific runoff ($m\ yr^{-1}$)	SR	From hydrological measurements/topographical maps
Theoretical water discharge (m^3/year)	Q	$Q = ADA*SR$
Theoretical retention time (yr)	T	$T = V/Q$ (where V is in m^3)
Areas of erosion and transportation (%)	BET[3]	$BET = 25 * D_R * 41^{0.061/D_R}$ (if A>1 km^2)
Areas of accumulation (%)	BA	$BA = 100 - BET$

(after, Håkanson, (1997)

Similar approaches have been developed in the US, e.g. Riera *et al*. (2000) explored the utility of a lake's landscape position to constrain lake character using test data from north-central Wisconsin. Lake order was introduced as a variant of the Strahler stream-ordering concept (Strahler, 1964) where headwater systems obtain low numbers and further downstream as drainage area accumulated the lake order increases. Lake order and the degree of connectivity is established solely on geographical information, and was strongly related to lake size and shape, concentrations of major ions and three biological variables (chlorophyll-a concentration, crayfish abundance and fish richness). In particular, lake area, shoreline length and the shoreline

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[3] The bottom dynamic parameters are: BET (the percentage of the lake bottom where erosion and transportation of fine sediments occurs) and BA (the percentage of the lake bottom where fine sediments accumulate continuously). For lakes in five area classes less than 1 km^2, a series of water depths delimiting BET from BA is given.

development factor[4] SDF = P/ (2√(πA)), where P is lake perimeter and A is lake area, increased with lake order. Lakes high in the landscape tended to be numerous, small and circular; whilst lowland lakes were less common, large, and tended to have convoluted shorelines.

Hondzo and Stefan (1996) explored the Minnesota Lakes Fisheries Database, which contains lake survey data on 22 physical variables and all common fish species for 3,002 lakes. They ascertained that nine primary variables explained 80% of the variability amongst lakes; namely surface area A_s, volume, maximum depth H_{max}, alkalinity, Secchi Disk depth, lake shape, shoreline complexity, percent littoral area and length of growing season. They then divided the lakes into three classes according to lake geometry ratio, $A_s^{0.25}/H_{max}$. At lake geometry ratios above 8 the lakes were well-mixed or polymictic. At values below 2 they were seasonally stratified or dimictic and had low dissolved concentrations near the bottom in summer. There was a transition region between the two values.

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[4] Equivalent to Håkanson’s shore development parameter.

11 Review of lake typologies currently used in the UK

Stimulated by the requirements of the WFD various biologically-based classifications of lake types have been developed. However, these are in general unsuitable as the basis for a WFD typology suitable for hydrological pressure sensitivity due to the associated dangers of circularity (e.g. employing the same variable to define the reference condition as will later be used to validate it), exclusion of rare types (e.g. naturally nutrient poor, low diversity water bodies), and human bias (Wallin *et al*. 2002). They do, however, have a role in informing the development of typologies since these should be based on physical attributes that can ultimately be associated with biological variation.

Palmer *et al*. (1992) classified standing waters in Britain on the basis of an indicator species analysis of vegetation. The analysis yielded 10 site types and two variants, which were subjectively associated with different types of lakes with different distributions within the UK (Table 6). On this basis, the physical criteria of lakes that could be associated with variation in the composition of macrophyte assemblages appeared to be: nutrient status (oligotrophic, mesotrophic, eutrophic and saline influence); drift geology (peat); solid geology (base poor, slightly base-rich, calcareous); substrate texture (fine, coarse or rock), and size (small, large).

Lewis (2002) lists six UK standing water habitat types with significance for implementation of the European Habitats Directive, namely:

> 3110 Oligotrophic waters containing very few minerals of sandy plains (*Littorelletalia uniflorae*)
>
> 3130 Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*
>
> 3140 Hard oligo-mesotrophic waters with benthic vegetation of *Chara* spp.
>
> 3150 Natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation
>
> 3160 Natural dystrophic lakes and ponds
>
> 3180 Turloughs

Like the Palmer *et al*. classification, this list has a substantial focus on nutrient status, but is limited in extent and does not have sufficient scope to cover all of the features which are thought to be required in order to produce a typology which is sufficiently comprehensive for the purposes of a typology for water resources regulation in lakes.

Finally, Bennion *et al*. (2001) employed simple hierarchical clustering techniques to produce a six-group palaeoecological classification of 166 UK lakes on the basis of diatom assemblages from the year 1850 (i.e. prior to human disturbance). Discriminant analysis was then used to assess how well eight physical descriptors (altitude, surface area, maximum depth, fetch, stratification class, dominant freshwater sensitivity to acidification class (FWS), % calcareous geology, % peat) explained this grouping. Three of the descriptors were significant, explaining 17% of the diatom data distribution among the six groups indicated in Table 7. The strongest signal appeared to be related to water chemistry (FWS being a reflection of alkalinity), but some relationships were apparent between diatom assemblages and hydromorphological attributes especially altitude, size and depth, identifying these as potentially useful typological criteria.

By drawing on palaeoecology, the Bennion *et al*. (2001) classification draws directly on natural characteristics of lakes, so avoiding the effects of human activity from over the past 150 years. However, one drawback in utilising this method for routine application is that diatom data are available for only limited numbers of lakes in the UK, such that much empirical work would be needed before more widespread application would be possible.

In all cases, there appears to be a strong link between biological variation and water chemistry. The latter is influenced in turn by bedrock (solid) geology and soil characteristics because different minerals and rock types vary in their resistance to chemical weathering, and by the presence of wetlands due to the capacity of humic material to exchange ions and bind metals (Håkanson and Peters 1995).

Lakes have not yet been incorporated into either the Environment Agency's RAM procedure (EA 2002) or the SEPA engineering typology (Greig 2004b), but a WFD reporting typology for UK lakes (Phillips 2003) has been developed (UKTAG 2004b, c). This is a tiered System B typology (Table 8 illustrates the distinction between the two systems available), distinguishing and characterising 12 core types on the basis of geology and depth, with a maximum of 108 divisions within the full typology, which additionally takes into account altitude and size (Figure 3, Table 9). Whilst this is essentially an "expert-opinion" based system, e.g. in the sense that geology and depth have been given precedence, it clearly reflects the principal relationships highlighted by the biological classifications outlined above. However, many potential problems associated with such systems have been discussed by Willby (2004). Preliminary attempts to use the 12 core types to classify macrophyte data have thus far produced very uncertain results (WFD39 - Nigel Willby *pers. comm.*).

Table 6 Classification of standing waters in Britain

Type	Nutrient status	Dominant species	Lake characteristics
1	Dystrophic	Submerged Sphagnum, Juncus bulbosus	Pools and small lochs on blanket bog in northern Scotland; a few pools on acid substrates in southern Britain
2	Oligotrophic/ base poor	Juncus bulbosus, Potamogeton polygonifolius	Upland tarns in the English Lake District; peaty lochs in northern Scotland; pools on Lizard peninsula in Cornwall
3	Oligotrophic/ base poor	Myriophyllum alterniflorum, Isoetes lacustris, Fontinalis antipyretica	Larger and rockier than Type 2, on base-poor rocks in Scotland (Loch Lomond), the English lake District (Wastwater, Buttermere, Coniston), north Wales (Llyn Ogwen, Llyn Idwal, occasionally elsewhere (Oak Mere, Cheshire).
4	Mixture of influences	As Type 3 with Potamogeton filiformis, P. praelongus, Myriophyllum spicatum, Chara spp.	Coastal freshwater lochs of the Scottish islands
5	Mesotrophic	Var A: (species-rich): Littorella uniflora, Myriophyllum alterniflorum, Nitella spp., Potamogeton spp., Elodea canadensis Var B: (species-poor): Potamogeton natans, Nymphaea alba.	Lakes in Scotland and northern England, often on slightly base-rich rock (e.g. Bassenthwaite, Windermere, Esthwaite Water, Lake of Menteith)
6	Brackish	Potamogeton pectinatus, Ruppia and Fucus spp.	Brackish sea lochs on islands off the north and west coasts of Scotland
7	Eutrophic/ base rich	As Type 4 but lacking Myriophyllum alterniflorum, Juncus bulbosus	Lochs with a strong marine influence on shell sand, limestone and Old Red Sandstone in northern Scotland
8	Eutrophic/ base rich	Poor in open water species but rich in emergents; Lemna minor, Callitriche stagnalis, Polygonum amphibium.	Meres of glacial origin in the West Midlands, scattered sites elsewhere. All have fine substrates. Calthorpe Broad, Norfolk.
9	Eutrophic/ base rich	Nuphar lutea, Nymphaea alba	Scattered throughout England and Wales, very few in Scotland
10	Eutrophic/ base rich	Myriophyllum spicatum, Potamogeton pectinatus. Var A: Elodea canadensis, Lemna minor; Var B: Chara species	Lowland lakes on sedimentary rocks, often calcareous, with predominantly fine substrates. Artificial sites such as gravel pits and little-used canals, also Malham Tarn in Yorkshire

(after Palmer *et al.* 1992)

Table 7 Description of six diatom groups identified by according to physical descriptors

Diatom group	No. of lakes	Altitude	Size	Depth	Mixing	Nutrients/ acidification
1	19	Lowland	relatively large	range	stratified	Mostly low FWS (alkaline)
2	22	Lowland	relatively small	Mostly shallow	Stratified	high % calcareous geology, low FWS, highly alkaline
3	43	Mostly upland	relatively small	range	Mostly stratified	High FWS, acid
4	23	Mostly lowland	Large	deep	Stratified	Range of FWS, acid
5	24	range	Range	Relatively deep	Stratified	High FWS, acid
6	35	range	Range	range	-	Mostly med-high FWS, circumneutral
Total	166					

(after Bennion *et al*. (2001)

Table 8 Outline of "System A" and "System B" typology systems for lakes (WFD Annex II)

System A	System B	
DESCRIPTORS	OBLIGATORY FACTORS	OPTIONAL FACTORS
Ecoregion	Latitude and longitude	Hydrological regime: Water level fluctuation Residence time
Altitude category: High >800m Mid-altitude (200 – 800m) Lowland (<200m)	Altitude	Mixing characteristics (e.g. monomictic, dimictic, polymictic)
Depth category: < 3m 3m – 15m >15m	Depth	Morphology: Mean water depth Mean substratum composition Lake shape
Surface area category: 0.5 – 1 km^2 1 – 10 km^2 10 – 100 km^2 >100 km^2	Size (surface area)	Temperature: Mean air temperature Air temperature range
Geology: Calcareous Siliceous Organic	Geology	Chemical status: Acid neutralising capacity Background nutrient status

(from Bragg *et al,* 2003).

Whilst the System A typology is straightforward and simple to implement, there seems to be no guarantee that the results will be ecologically meaningful. Wallin *et al*. (2002) state that the objective of establishing typologies is to partition among-group variance in order to facilitate the detection of ecological change, and point out that the classes established using System A may not adequately fulfil this function. Given the inflexibility of System A, they consider that most Member States are likely to use System B as a basis for characterising water body types, delimiting them using grouping procedures based on commonly used clustering techniques or more intuitive (expert opinion) methods. Statistical methods might also be employed to determine whether or not groups differ from one another (e.g. using randomisation techniques) and whether among-group variance can be adequately explained (e.g. using discriminant analysis). For Ireland and Austria, "System B" typologies based on the obligatory factors, and incorporating some additional attributes that are considered appropriate for each country, have been proposed by Irvine *et al*. (2001) and ÖNORM (2001) respectively (Table 10); although neither appears to be based upon rigorous statistical analysis at this stage.

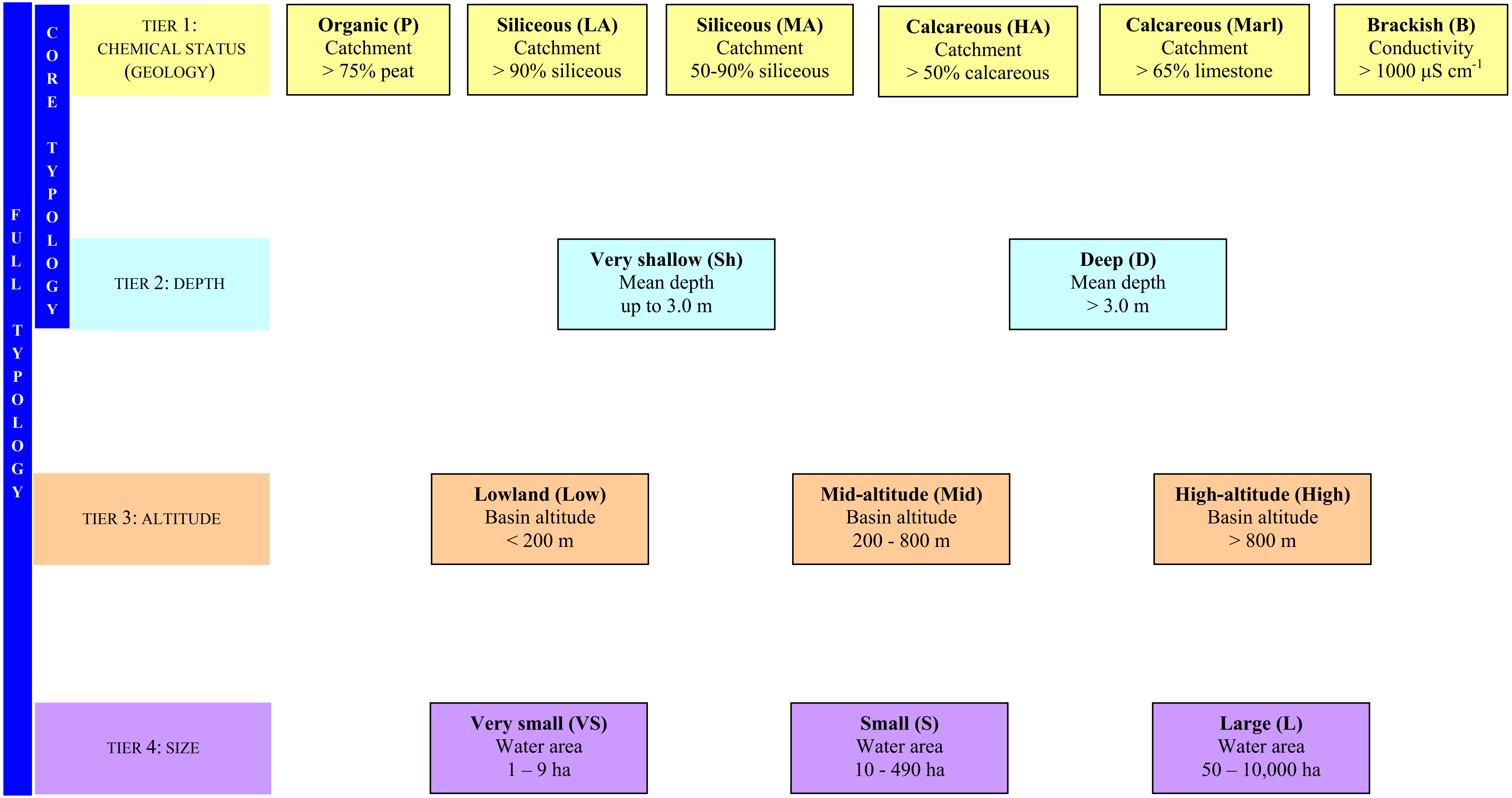

Figure 3 Outline of WFD lake reporting typology for the UK (after UKTAG 2004).

Table 9 Schematic classification of lakes in Great Britain

Ecoregion		18 Great Britain								
	Altitude	Low			Mid			High		
	Size	VS	S	L	VS	S	L	VS	S	L
Geology	Depth									
P	Sh	LVS	LS	LL	MVS	MS	ML	HVS	HS	HL
	D	LSB1	LCB1	LOB1	MSB1	MCB1	MOB1	HSB1	HCB1	HOB1
LA	Sh	LSC1	LCC1	LOC1	MSC1	MCC1	MOC1	HSC1	HCC1	HOC1
	D	LSD1	LCD1	LOD1	MSD1	MCD1	MOD1	HSD1	HCD1	HOD1
MA	Sh	LSA2	LCA2	LOA2	MSA2	MCA2	MOA2	HSA2	HCA2	HOA2
	D	LSB2	LCB2	LOB2	MSB2	MCB2	MOB2	HSB2	HCB2	HOB2
HA	Sh	LSC2	LCC2	LOC2	MSC2	MCC2	MOC2	HSC2	HCC2	HOC2
	D	LSD2	LCD2	LOD2	MSD2	MCD2	MOD2	HSD2	HCD2	HOD2
Marl	Sh	LSA3	LCA3	LOA3	MSA3	MCA3	MOA3	HSA3	HCA3	HOA3
	D	LSB3	LCB3	LOB3	MSB3	MCB3	MOB3	HSB3	HCB3	HOB3
B	Sh	LSC3	LCC3	LOC3	MSC3	MCC3	MOC3	HSC3	HCC3	HOC3
	D	LSD3	LCD3	LOD3	MSD3	MCD3	MOD3	HSD3	HCD3	HOD3

The principal (Tier 1) division is based on chemical status / geology (six types), each sub-divided (Tier 2) into two depth types to give the core typology. Further divisions on the basis of altitude (three classes L: lowland; M: mid-altitude; H: high) and size give the full 108-class typology.

Table 10 Proposed typological schemes and categories for Ireland and Austria

Descriptor	Ireland		Austria
Location	Latitude, longitude (relevance to be investigated through field trials and consideration of the recommendations of the EU and EPA reference conditions projects).		Latitude, longitude
Ecoregion	Ireland is covered by a single WFD ecoregion.		According to Illies (1978)
Altitude	High: > 800 m Mid-altitude: 200 – 800 m Lowland: < 200 m		Alpine: > 1000 m High: > 800 - 1000 m Mid-altitude 2: 500 – 800 m Mid-altitude 1: 200 – 500 m Lowland: < 200 m
Depth	Mean depth (data will need collation and/or models)		Mean depth < 3 m 3 – <15 m 15 - < 30 m > 30 m
Surface area	< 2 ha	< 0.02 km^2	
	2 - 50 ha	0.02 - 0.5 km^2	< 0.5 km^2
	51 - 100 ha	>0.5 – 1 km^2	> 0.5 - 1 km^2
	101 - 1000 ha	>1 – 10 km^2	> 1 – 10 km^2
	1001 - 10000 ha	>10 – 100 km^2	> 10 – 100 km^2
	>10000 ha	>100 km^2	> 100 km^2
Others	Residence time is likely to be critical for lakes and the absence of reliable residence time for many Irish lakes requires collaborative research to address this as a matter of priority.		Mean temperature
	Geology: conductivity defines mixed geology lakes and saline incursion.		Air temperature range
	Colour in Irish lakes is clearly important in defining typology, but may be covered by inclusion of drainage from peatlands.		Mixing characteristics (monomictic, dimictic, polymictic, meromictic)
	Specific lake types such as turloughs, spring-fed lakes, saline lakes, large lakes will need to be addressed separately in terms of hydromorphological typologies.		The above are examples of optional factors that might be included.
	There is a need to collate relevant hydromorphological data for lakes covering a wide geographical range with a view to statistical interrogation.		

(Adapted from Irvine *et al*., 2002; ÖNORM , 2001).

12 Discussion and conclusion

This review reinforces the view that lakes are diverse in terms of their various facets which are relevant in the context of the WFD, and it is therefore to be expected that it will be challenging for any typology to cover all aspects of lakes of potential utility to assessing sensitivity to hydrological change without becoming cumbersome and/or achieving a high level of redundancy in the classifications that it generates. The classifications reviewed have also been diverse, but with each reflecting the state of knowledge at its time of development and the intended purpose in each case. The intended purpose relevant to this review has not been addressed by previous authors.

The development of a new typology can certainly be considered. One ideal might be to use a cluster analysis of relevant lake characteristics to establish a number of discrete types. The sensitivity of each to hydrological pressure could then be assessed using such ecological data as are available in combination with expert judgement. However, resources within the project timescale are limited and there are some grounds for concern that a new typology may not yield any more efficient or relevant a structure than the use of an existing typology. Specifically, Willby (2004) observed problems in the ability of the UKTAG System B typology to offer explanation for the macrophyte assemblages which he has collated for lakes across the UK – although this could be a result of water quality, exotic species and/or hydromorphological influences.

Given the reservations expressed above, it is proposed to use the System A typology as modified by UKTAG (2004b, c) and further modified as required for the sake of this project. This offers the advantages of pragmatism and the avoidance of a potentially poorly justified new, different basis for this project’s typology. Geological classes may be split or combined as required. Geology, depth, altitude and size (the four tiers of Figure 3 above) all correlate in the UK to some extent, and it will be necessary to draw on at least one of these to provide additional differentiation for the purposes of the project.

In addition, form factor will also be relevant in representing sensitivity to water level regime change. It may be possible to find relationships based on available lake or catchment characteristics which allow a contribution to sensitivity assessment to be made. Finally, a further potential source of predictive ability is a system of assigning biogeoclimatic zones. No readily available system exists for immediate use, and so time and effort would be needed if this were to become a reality. Its use might also add undesirable complexity to the emergent typology. However, it is possible that other variables may not sufficiently differentiate lakes such that sensitivity is adequately predicted. Only in the event that this is thought to be the case will the use of such an additional variable be considered.

The precise form of the typology will be developed as the next task of the project.

PART III Conclusions

Rivers

- The four elements of fish, macrophytes, macro-invertebrates and physical structure are widely accepted as good indicators of the river ecosystem. The Resources 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* 1996)/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).

Lakes

- The WFD requires lakes to be allocated to ecologically distinct lake types, such that the ecological status of any given lake can be assessed in terms of 'type-specific' reference conditions. Classification parameters should reflect the inherent physical and chemical properties of lakes independent of human influences and thus should be based on measurements that are not subject to anthropogenic disturbance. Critically, the resultant classes must be ecologically relevant such that the biological quality elements, e.g., macrophyte or fish assemblages, should be distinguishable at reference condition and relatively consistent within the typological class.
- For Great Britain (Ecoregion 18), a tiered System B typology distinguishing 12 core lake types on the basis of geology and depth has been developed (UKTAG, 2004a). Further divisions, taking into account basin altitude and size, generate a maximum of 108 lake types. This '*a priori*' expert-opinion based system shows general agreement with previous biologically-based classification attempts (*cf.* Palmer *et al*. 1992; Lewis, 2002; Bennion *et al*., 2001). Preliminary attempts to explore the discriminating power of the GB core typology against macrophyte data have thus far had only limited success (WFD39, N. Willby *pers comm.*), but some of these difficulties could result

from the confounding effects of water quality and exotic species, as well as hydromorphological influences (both regime alteration and morphological alterations).

- In terms of ecological sensitivity, additional factors that are considered important are lake morphology, which further emphasises the role of lake form and size, and biogeographic zone (integrating factors such as mean annual precipitation, temperature and continentality).
- Expert judgement was used to characterise the biological communities expected at reference condition for the UK's geological lake types (UKTAG, 2004). These are not comprehensive descriptions, but for the purposes of the WFD48 workshop these communities provide a starting point to explore type-specific sensitivity to regime modification.
- The information provided on the species composition of macrophyte and phytobenthos, macro-invertebrate, fish and phytoplankton communities for each of the geological lake types incorporates distinct differences between the biota are reported for deep and shallow lakes, and/or for different geographical areas. Where this occurs, more than one community can be described for that lake type. In other cases, the same community can be reported for two lake types.

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APPENDIX: Table listing rivers typologies reviewed in this report

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
Water Framework Directive (WFD) - System A Typology • UKTAG, 2004	Catchment-based typology developed to enable reporting and characterisation of water body status as required by WFD. Typology comprises 27 types, 18 of which are significantly populated in GB. Reference conditions for WFD quality elements are established for each water body type, on the basis of: • Macrophytes and phytobenthos • Fish • Macroinvertebrates • Physico-chemistry • Hydrology • Morphology However, other mechanisms for defining reference conditions, *i.e*. RIVPACS and RHS PCA map are probably also being used by UK Agencies.	Catchment	• Altitude • Catchment area • Dominant geology (siliceous, calcareous, organic)	• DTM • Geology datasets • CEH flowgrid • River network • Supported by automated ArcGIS applications
	Positive • Chosen framework for WFD reporting - initial reference conditions established • Simple, parsimonious typology framework with few parameters • Catchment scale parameters derived from digital spatial datasets and supported by GIS - readily derived from desktop methods. • Discrete categories which enables rapid classification and simple allocation of new members to types; also enables straightforward 'lookup' method if assigning sensitivity to each type	*Negative* • Relatively arbitrary choice of classification parameters and classification boundaries: boundaries could be relevant at European scale but don't provide adequate discrimination within UK. • hydrological/ecological validation is required (*UKTAG indicates preliminary RIVPACS work supports ecological differentiation*) • Uncertainty as to within-type variability relative to between-type variability (see below) • Overly simplistic categorization? *e.g*. treatment of geology rendered in to three classes Types are not framed in terms of sensitivity to ecology although work is in progress		

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
WFD System B Typology (UKTAG)	Identical obligatory features as for system A, but without prescription of specific altitude/size intervals. Additional factors are permitted, but the WFD requires that system B must achieve the same degree of differentiation.	Catchment	As for type A, with optional additional parameters, such as those umpoyed by RIVPACS	
	Positive • Doesn't use arbitrary classes	*Negative* • Mixes catchment and site specific characteristics. Some of the latter could be impacted by human activities, which makes their use in defining reference conditions unsatisfactory.		
Environment Agency Resource Assessment and Management (RAM) Framework • Environment Agency 2002 Dunbar *et al.* 2004	EA Method for determining River Flow Objectives (RFOs) based on Environmental Weighting (EW) bands which reflect ecological sensitivity to flow modification. The EW scoring system can thus be viewed as a typology with ecological underpinning made explicit in the classification process; the types are defined in terms of ecological sensitivity. Ecological RFOs are set using a look-up table which gives the percentage of the natural 'benchmark' flow which can be abstracted at points on the flow duration curve. The RAM typology is nested - rivers are assigned to an overall EW type through appraisal of four distinct elements - each of which can be viewed as a separate typology with its own scoring system based on ecological sensitivity. The four elements are: 1) Physical Characterisation 2) Fisheries 3) Macroinvertebrates 4) Macrophytes	Assessment Point (AP) - sub-catchment/ catchment	EW sensitivity banding for each element - discrete scoring systems for each component, on 1- 5 scale **Scoring systems for regarding macrophytes based on Mean Flow Ranking system, and for macroinvertebrates based on LIFE (see below)**	• Site knowledge • RHS data • RCS data • visual appraisal (photographs) • Expert knowledge • HABSCORE • Physical characteristics • Visual appraisal • Macrophyte survey data (if available) • RIVPACS predictions of LIFE scores from environmental predictor variables • Macroinvertebrate survey data (if available), for current status
	Positive • Explicit treatment of ecology in classification system - ecological sensitivity is the primary basis of the classification system and type-specific RFOs are the end product • Ecological justification of classification systems - macrophyte (RCTs/MFR) and macroinvertebrate elements	*Negative* • Data intensive and time consuming to establish EW score - requires field visits (physical characteristics) and monitoring data (if available) for fisheries and to validate LIFE scores predicted from RIVPACS. • Requirement to assimilate a range of data sources and		

	(RIVPACS/LIFE) are based on widely-used classifications which were developed through robust statistical analysis of ecological data and environmental predictors for representative sites. • Scoring system incorporates interaction between ecology and flow regimes - through LIFE and MFR scores which respond to flow • Nested approach permits detailed consideration of several key elements of ecological sensitivity. How is it nested? • Employs 'benchmark' approach to establishing reference conditions • Scoring system incorporates interactions between ecology and physical habitat; both through physical characterisation and in macrophyte classification where vegetation communities are related to morphological characteristics of physical habitat through River Community Types • Flexibility - pragmatic approach whereby classification can be tailored according to data availability. Expert knowledge, available monitoring data are incorporated to strengthen rapid, default assessments	expert knowledge • Ecological justification of classification is not well established for physical characteristics which employs a fairly general qualitative scheme and does not consider morphology in detail • Similarly, how much is known about uncertainty regarding sensitivities to flow in the macrophyte and macroinvertebrate classification schemes. The concept that higher expected LIFE scores equates to greater sensitivity to abstraction is plausible but untested. The RIVPACS system uses both site and catchment-level characteristics: the site variables may be influenced by flow-related stress (although there is a warning not to use the variables measured in low flow years). • The LIFE index does not vary greatly, the difference between a RAM score of 1 and 5 is 1.5 LIFE units.

Typology	**Description - review of positive/negative attributes for present study**	**Scale**	**Parameters for Classification**	**Datasets required (available tools)**
River Community Types - Macrophyte classification scheme (Holmes *et al.* 1998, 1999)	Classification system for British rivers using macrophyte communities. Original classification system based on field survey of 1055 sites, 459 added to revised classification system (Holmes *et al.* 1998). Classification used TWINSPAN analysis of macrophyte survey data to yield ten River Community Types (RCTs) with related physical characteristics. In RAM framework, Macrophyte Flow Ranking, based on Mean Trophic Rank (MTR; Holmes, 1999x) survey, relates ecological sensitivity to RCTs.	Assessment point (reach/ catchment)	Macrophyte communities and physical characteristics: • geology • altitude • gradient • Substrates • Flow Types	• Physiographic data • Physical characteristics • Visual appraisal (photographs)
	Positive • Statistically based classification using ecological data from reference sites. • Physical characteristics can be used to 'type' new sites. • Employed in RAM framework macrophyte classification	*Negative* • Physical characteristics derived from field visits.		
River InVertebrate Prediction And Classification System (RIVPACS) • Wright *et al.* 1994)	Classification and prediction tool based on Macroinvertebrate assemblages at good quality, representative 'reference' sites. RIVPACS enables at-site prediction of a target assemblage which would be expected in the absence of environmental stress, which provides reference ‘baseline’ conditions for comparison with the observed fauna. Prediction is based on a suite of environmental indicator variables. A 35-group classification of UK rivers has been developed using the RIVPACS reference dataset of 614 sites (Wright *et al.* 1998). A simpler aggregation of 9 and 4 groups can also be used.	Reach (variable size)	Macroinvertebrate assemblages – occurrence data for major taxonomic groups. Prediction based on physical and chemical environmental variables (*e.g.*) • Distance from source • Total oxidized nitrogen • Gradient • Alkalinity Mean Air temperature	• MI data • Field survey data •
	Positive • Robust statistical basis for macroinvertebrate classification; thereby ecology is explicit in classification.	*Negative* • Requires both catchment and some field data - measurements of environmental data for classification of		

	• Enables prediction of reference conditions for sites; utility for establishing reference conditions for particular river types • Concept of WFD System B is based on RIVPACS • Flow sensitivity can be attributed to RIVPACS assemblages via LIFE score (as used in RAM framework, see above) • Widely used by Agencies with responsibilities for environmental protection, and in site classification for conservation	new sites, method not explicitly hierarchical. (But currently this is the same for all methods) • Flow-related stress was not the original rationale for RIVPACS, reference sites tend to be first and foremost reference sites for water quality.		

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
Fish Typology and flow and level criteria (Cowx et al. 2004)	Classification system for British rivers using fish communities. Typing of rivers based on modelling of fish community data from national fisheries monitoring programme, using cluster analysis. Eight major fish community types were defined, based on key species. Discriminant analysis was used to relate communities to physical and flow characteristics, although further work is needed to develop this into a predictive tool. It was concluded that the impact of flow modification should be considered within the context of these types, although no formal mechanism was developed within this project - several options for managing hydrological regimes were provided.	Site-based	Fish communities, related to physical characteristics:	• Fisheries data for initial classification; • Potential for predictive tool using physical and flow characteristics (not yet developed)
	Positive • Statistically based classification using fisheries data from reference sites. • Project aims to develop flow sensitivity criteria for fish community types.	*Negative* • Further work required to deveolop into a predictive tool for predicting assemblages based on flow characteristics, and eventual use in establishing flow sensitivity targets. • Important biases identified in dataset, in terms of regions and river types covered in dataset.		

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
River Habitat Survey (RHS) (Raven *et al*. 1998)	System for characterising physical habitat of UK rivers, enabling classification and assessment of habitat quality. Habitat quality can be assessed by comparing features at a site of interest with data recorded from sites of similar character; high quality is determined by habitat features occurring at unmodified sites. RHS does not explicitly classify or type rivers *per se*, but	Reach (500m)	Examples: • Geology • Channel slope • Distance from source • height of source	• Map-based data • Field data

	provides a framework for classification using the habitat feature data available on the RHS database. The choice of parameters for classification depends on purpose. Examples of existing classification projects using RHS data:		• Channel planform • BFI	
	1) River Channel Typology (Newson *et al.* 1998): TWINSPAN Classification of river channels using geomorphological features	Channel/ Reach	• substrate classes	• RHS Database
	2) Ordination clasiffication (Jeffers, 1998): Ordination of survey data based on PCA of RHS variables which enables prediction of habitat features	Reach	• Slope • Altitude • Distance from source • Height of source	• Map derived data (GIS) • RHS database
	Positive • Provides representative sample of UK rivers and associated habitat features, derived with standard field method and consistent sampling scheme • Large existing data resource on RHS database • Utility as a tool for classification - can construct a classification/typology in a bespoke fashion by querying RHS database, according to requirements of typology • RHS data can be used in characterizing reference conditions, and in describing or quantifying deviation from reference conditions in terms of physical habitat features (by reference to habitat features from high quality, viz. unmodified, sites) • Existing classification schemes such as Habitat-based characterisation of UK rivers is possible following PCA/ordination work of Jeffers (1998), using only map-derived data. • Habitat Quality Assessment (HQA) score used to quantify changes in habitat quality and to assess how change scenarios could affect habitat resources in a catchment. • Potential for integrating with macrophyte/macroinvertebrate classification schemes • Use in existing classification of physical habitats for conservation (SERCON) • Integration of site-based data to catchment scale? (Raven *et al.* 1998)	*Negative* • Primarily reach-based and reliant on field survey (although Jeffers work permits rapid map-based assessments) - requirement for site visits. • No classification framework for RHS data *per se* - typologies have to be constructed according to user re • Existing classification schemes based on geomorphology and physical features are not fully developed; Jeffers (1998) method allows prediction in a probabilistic framework but this requires further validation. • Use of physical characteristics as surrogate for ecological quality needs investigating • RHS PCA typology not tied in with RIVPACS or any biological data • HQA scoring is a very broad assessment of habitat quality agreed by experts, not related to real biological data • Reference conditions not fully defined, they tend to be the "best" sites in the database rather than true reference conditions.		

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
Rosgen Method (Rosgen, 1996)	Geomorphological classification of stream types based on channel form. Classification has a hierarchical structure; at Level 1, single-thread channels are differentiated from multiple thread channels and eight classification types are produced using morphological parameters; at Level 2, dominant substrate material is introduced to produce 41 stream types.	Reach	• Entrenchment ratio • Channel form • Width/Depth ratio • Sinuosity • Gradient • Substrate material	Morphological data - field survey based.
	Positive • High level of detail through reach-based approach. Enables classification based on physical characteristics on a scale which is important for habitat features • Useful for classification of morphological features at a reach scale, which may have potential for characterisation of reference conditions	*Negative* • Time consuming classification through reach/channel-based approach, relies on field survey methods for classification • Lack of a process-based method • Time-dependence; lack of stability of features used in classification (and impact on stability of reference conditions) Developed in Western USA: relevance to UK rivers?		

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
Montgomery and Buffington (1997)	Process-based classification based on channel-reach morphology for mountain channels. Differentiation of types is based on variations in bed morphology - types include cascade channels, step-pool channels, plane bed channels and pool-riffle channels which are generally found in a progression downstream through the long profile, reflecting specific roughness conditions adjusted to the relative influences of transport capacity and sediment supply.	Reach (10-20 times channel width)	• Typical bed material • Bedform pattern • Dominant roughness elements • Dominant sediment sources • Sediment storage elements	Morphological data - field survey based.

			• Confinement • Typical pool spacing	
	Positive • High level of detail through reach-based approach. Enables classification based on physical characteristics on a scale which is important for habitat features • Process-based framework for assessing channel conditions - links morphology to channel processes which has direct relevance for establishing relationships between morphology (thence habitat features) and flow • Utility as a conceptual framework for characterizing morphological elements of reference conditions	*Negative* • Primarily a conceptual tool aimed at improving understanding • Reach/channel based • Field survey emphasis • Specific domain, developed for mountain channels • Time dependence, though process basis would enable some dynamism to be accounted for		
Typology	**Description - review of positive/negative attributes for present study**	**Scale**	**Parameters for Classification**	**Datasets required (available tools)**
River Styles (Brierly & Fryirs, 2000)	'River Styles' is a conceptual geomorphic classification scheme for river channels developed in Australia. Reach-scale processes are explained within a catchment context.	Channel-reach focused but hierarchical conceptual basis.	• Valley setting (slope, shape, confinement) • Channel planform • Channel geometry • Assemblages of geomorphic units	• Physiographic data • Aerial photographs • Site-based data
	Positive • The system is process-based and hierarchical, allowing linkages across the scale hierarchy. • Set within the context of river evolution; the approach permits an assessment of how far it is from its natural condition. • Generic and open-ended - new variants can be applied in new environmental settings. • Work being undertaken in combinging river styles with Montgomery & Buffigton • Some validation against ecological data	***Negative*** • **Channel-based, focused on geomorphic features and setting** • **Data intensive - aerial photographs and field visits.** • **Requires high level of geomorphic expertise to modify for new environments and to establish reference conditions** • **Ecological validation so far limited - questions regarding the ability of the system to discriminate types and link across scales**		

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
Flood Estimation Handbook (FEH) Pooling Group Method (Robson and Reed, 1999)	Regionalisation method for selecting ‘pooling group’ of catchments for predicting a flood growth curve for flood frequency estimation at ungauged sites. A pooling group of catchments are selected using a continuous-scale measure of hydrological similarity based on 3-dimensional size/soils/wetness space (see parameter list). Also: Field investigations and statistical modelling have been undertaken to investigate the interaction of river regime and river channel geometry by Geraldene Wharton in collaboration with the Institute of Hydrology (CEH (UK)) and the United States Geological Survey. Channel-geometry equations for flood discharge estimation and a method for predicting flood frequencies in the UK have been published in a number of scientific journals and the most recent equations for the UK are included in Volume 3 of The Flood Estimation Handbook (1999) published by the Centre for Ecology and Hydrology Wharton, G., Arnell, N. W., Gregory, K. J. and Gurnell, A. M. (1989) River discharge estimated from river channel dimensions. Journal of Hydrology, 106, 365-376.	Catchment	• Catchment Area • BFIHost - Baseflow Index (BFI) estimated from Hydrology of Soil Types (HOST) classification (Boorman *et al.* 1995) • Standard Annual Average Rainfall, 1961 - 1990 (SAAR)	• Physiographic data (IHDTM, rivers network) • HOST soils data • 1km gridded SAAR data • WINFAP software
	Positive • Rapid assessment of hydrological similarity between catchments using existing algorithms (which can be automated) - statistical tools for assessing similarity • Catchment-scale parameters, readily derived from digital datasets • Parameters have hydrological justification - choice of parameters based on regression relationships developed during extensive projects; large number of sites, with assessment of data quality • Geological parameters also potentially correlated with water chemistry	*Negative* • Not a discrete categorization, although could be made discrete • No empirical ecological justification as yet: worthwhile investigating • No emphasis on seasonality, timing of flows		

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
Low Flows 2000 (LF2000) Region of Influence Method (Holmes *et al.*, 2002)	Regionalisation method for estimating flow duration curves for low flow estimation at ungauged sites in the UK. Hydrological similarity is assessed using distance in multi-dimensional HOST space, using fractional extent of HOST classes within catchments.	Catchment	• Fractional extent of HOST classes	• Physiographic data • HOST soils data • LF2000 software
	Positive • Rapid assessment of hydrological similarity for any group of catchments using existing algorithms • Catchment-scale parameters, derived from readily available digital soils data • Parameters have hydrological justification - regression relationships during original Low Flows work (Gustard *et al* 1992) which focused on catchments with limited artificial influences and good hydrometric performance. • Some emphasis on seasonality of flows (monthly FDCs)	*Negative* • Broad-scale • Not a discrete categorization • No empirical ecological justification as yet: worthwhile investigating •		

Typology	Description - review of positive/negative attributes for present study	Scale	Parameters for Classification	Datasets required (available tools)
Catchment Representativeness Index (CRI) (Laize, 2004)	Method for quantifying the representativeness of a particular catchment relative to a target area (*e.g.* hydrometric area, region). GIS method using overlays of elevation and land use data; current extension using geology.	Catchment	CRI score – weighted score based on occurrence of particular combinations of land use/elevation	- Gridded land Use data (LCM2000) - Physiographic data - Geology data
	Positive • Rapid assessment of hydrological similarity between catchments using available catchment datasets • Potential tool for typing catchments based on land use	*Negative* • Not a typology *per se*; would require development		