Joint Defra / Environment Agency Flood and Coastal Erosion Risk Management R&D Programme

A refined geomorphological and floodpodplain component River Habitat Survey (GeoRHS)

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Steve Killeen

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Executive Summary

GeoData Institute and collaborator organisations have developed a series of survey and assessment procedures which add geomorphological variables of the river, floodplain and catchment to the river habitat survey methodologies to provide a basis for enhanced indices of fluvial status.

Geomorphology is inherent within River Habitat Survey (RHS) methodologies, but is limited in scope and does not extend to the floodplain environment or consider the catchment within which the reach is situated. This two-phase project has reviewed the potential, and provided a proof of concept, for extension of the survey approach to a range of riverine and floodplain applications that use more detailed or targeted geomorphological information. Phase I of the project developed the concepts and assessed parameters for inclusion within the survey approaches, including field and desk-based survey methodologies.

Phase II has further refined these approaches, providing updated field survey based on feedback and the results of two training exercises. The desk study elements have been built into an operational methodology collating spatial data from SEPA and the Environment Agency. A GIS-based application (ArcGIS) has been developed and customised for separate Environment Agency and the Scottish Environment Protection Agency implementations and installed within the Environment Agency and SEPA offices. This application has been used to generate a spatial database of morphological attributes for test sites. Separate MS Access databases have been developed to support the entry and analysis of the GeoRHS and RHS field survey records.

GeoRHS Phase II has undertaken field survey (using both GeoRHS and RHS methods) on a series of reference conditions sites and selected catchments across England, Scotland and Wales to test the methodology and provide a dataset from which to examine the development of indices. A series of sites on the River Laver have also been used to test the effectiveness and potential range of attributes. The information will be used, typically in tandem with RHS data, to develop indicators of channel and floodplain naturalness, modification for classification, evaluative and monitoring applications. The information will help set river channel and floodplain reaches in the context of reference conditions and provide a basis of monitoring.

Two broad indices, drawn from a wider list of potential indices, have been developed within the scope of this programme. These focus on flood risk management (assessment of the connectivity and potential and value of reconnection of floodplains) and Water Framework Directive (naturalness of the channel system) application areas. These indices are derived via a scoring and weighting based approach, similar to the HMA and HQI within RHS.

Future potential development and implementation stages of the GeoRHS methodology are discussed.

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1 GeoRHS – Developing indices

1.1 Background

Phase 1 of the GeoRHS study identified the potential user requirements that GeoRHS derived datasets, in association with RHS variables, would seek to address. The range of variables collected within GeoRHS reflected a number of potential application areas, WFD, Flood Risk Management, Conservation, Broad Scale Modelling, Catchment Flood Management Plans, channel and floodplain restoration etc. The requirements identified applications into two main areas (Tables 1.1 and 1.2), those measures that act as general support and those that provide a standard dataset or tool to the application domain. This approach is taken forward in Phase 2 of the GeoRHS programme.

Many of these objectives are reflected in the Environment Agency Vision and corporate strategy (EA 2003). Although the indicators suggested within GeoRHS are not ‘headline indicators’ proposed by the vision they help to deliver the objectives, in particular adapting to climate change and reducing flood risk; which have been key drivers for the development of the three classes of indices proposed by GeoRHS; classificatory, evaluative and monitoring. In particular, the addition of the floodplain and connectivity aspects of GeoRHS reflects the potential to use restoration of rivers and floodplains to help deliver multiple objectives (managing flood risks, benefiting wildlife and accommodating natural flooding).

Phase 2 of the GeoRHS programme refined the specification of the use of the data generated within the GeoRHS field and desk studies. An overview of the procedures developer through Phase I and Phase II are illustrated within figure 1-1.

Within the scope of Phase 2 the application areas (clients) that have been highlighted for initial development of analysis tools and indices are the Water Framework Directive and the Flood Risk Management. Reviewing the user requirements for these domains from Phase 1. Table 1-1and Table 1-2 provide an overview of the application areas.

Table 1-1 Application and data support areas from GeoRHS data within the implementation of the Water Framework Directive

GeoRHS as a general support to WFD		GeoRHS as a WFD standard dataset and tool	
GeoRHS support for developing water body typology	Channel descriptors Floodplain descriptors	GeoRHS data as baseline indicators and current status of sites	Channel Descriptors Ecological potential
GeoRHS as tool to help identify Heavily Modified Water Bodies (HMWB) and Artificial Water Bodies (AWB)	Modifications in floodplain and channel, and human activity	GeoRHS support detailed risk assessment Sensitivity / stability	Channel quality input Floodplain quality
GeoRHS support for identifying pressures and impacts	Identification of pressures Identification of impacts	GeoRHS identifying restoration opportunities Recovery potential Adjustment trajectory	e.g. Disconnected floodplains Relic channel / wetlands State of modified reaches
GeoRHS support for establishing Reference Conditions	Semi-natural and natural river and floodplain characterisation	GeoRHS monitoring to check the effectiveness of adopted measures (operational and investigative monitoring	Repeat survey sampling of hydromorphic condition Post project appraisal tool Impact monitoring tool

Figure 1-1

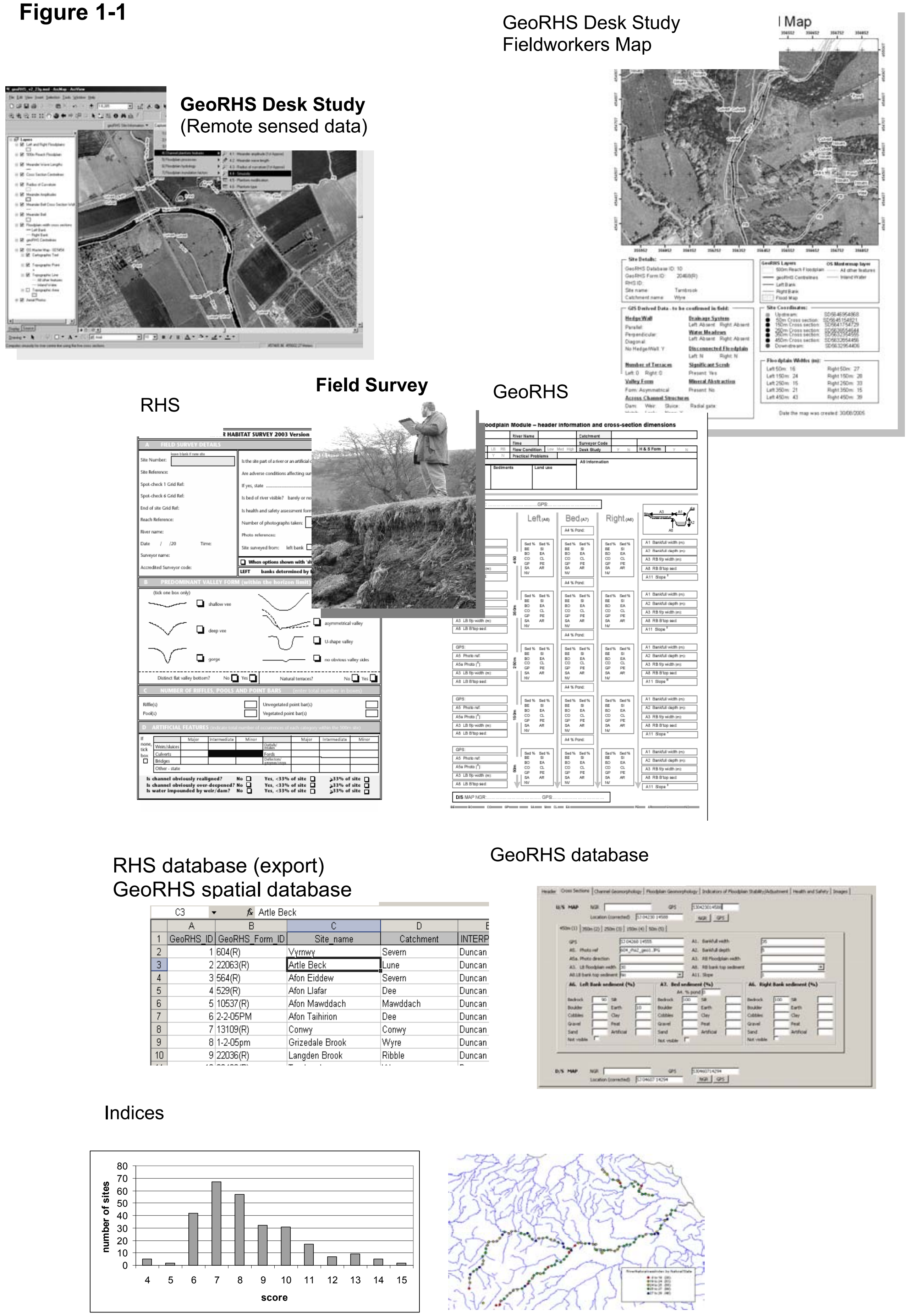

GeoRHS Desk Study
Fieldworkers Map
GeoRHS Desk Study
(Remote sensed data)
Field Survey
RHS
GeoRHS
RHS database (export)
GeoRHS spatial database
GeoRHS database
Indices
number of sites
score

Figure 1-1 Overview of the GeoRHS programme and data flows.

The sampling within Phase 2 GeoRHS surveys has put greater emphasis on the role of GeoRHS to contribute to areas originally conceived as being more general, in particular classificatory uses such as defining the typologies and defining the type-specific features of Reference Conditions. This has included benchmark sites, expert identified sites considered to be near natural and back-to-back surveys of the River Tweed. Evaluation within Phase 2 has highlighted certain roles for GeoRHS, specifically within monitoring within WFD, and in addressing Flood Risk Management and channel management in terms of processes, stability/instability, channel capacity to adjust and floodplain conditions and connectivity.

Table 1-2 GeoRHS and Flood Risk Management operational requirements

GeoRHS as a Flood Risk Management support		GeoRHS as a Flood Risk Management Operational Tool	
GeoRHS support for identifying the requirement for Fluvial Audit	Evaluation of need based on indicators of stability / instability	GeoRHS data as baseline attributes –	Conveyance factors – floodplain roughness Channel instability index Land cover characteristics contribution to MDSF
GeoRHS as tool to identify mitigation sites (e.g. response to Habitats Directive)	Catchment scale location options for mitigation Evaluation of sustainability of mitigation opportunity	GeoRHS sustainability screening FD strategy / options – WFD 49 Engineering assessments	Channel quality input Instability hotspots
GeoRHS linking FD to biodiversity potential	Floodplain wetland potential / priority habitats Washlands as a linked biodiversity and flood relief option, WLMPs	GeoRHS identifying restoration options	Floodplain restoration Reconnection of disconnected floodplain
GeoRHS impact assessment of FD actions on value of geomorphology	Valued geomorphic components / semi-natural classification Monitoring of impacts	GeoRHS contribution to environmental sensitivity of management projects	Monitoring of CFMP policies

The operational support areas of these two application areas form the basis for the development of the metrics, indicators and indices developed within this phase of the GeoRHS programme. Some application areas have come out more strongly as initial targets and some of the supporting roles are now more evidently operational applications, such as assisting with the characterisation of the reference condition of water bodies.

The approaches used for GeoRHS surveys (whether surveyed back-to-back, as individual sites, collected on a stratified random, 'expert' reference site selection or whether surveyed in relation to specified site problems or applications) will influence the nature and value of the indicators generated from the derived datasets.

There are still many questions to resolve, beyond the scope of the R&D, in implementing the GeoRHS approach:

- its association (both technical and methodologically) with the desk-GeoRHS and RHS field survey data;
- which indices can be generated for individual sites and which need to be compared with Baseline / Reference Condition data? (section 3)
- the practical operation of the indices and implementation of GeoRHS with RHS data structures and the implementation of the desk study in Scotland, Northern Ireland and in England and Wales (section 5).

The outputs of Phase II of the study (in addition to this report) are a series of technical products, reports and datasets, itemised below, but delivered as separate data sets or reports:

- Revised field forms and manuals for the GeoRHS field survey (updated from Phase I);
- GeoRHS GIS Tool operations manual;
- GeoRHS Database manual;
- MS Access databases for GeoRHS and RHS datasets and field photographs (databases were designed within Phase 1 to run on field laptops but have been further developed in Phase II)
- RS desk study data exported from the geospatial database and site location maps for the surveyed sites
- Field survey data of 'Reference Condition' sites in England Scotland and Wales – held within the databases (field survey 2004/05) and including the
- Field training support materials, presentations and testing schedules (revised within Phase II) from the EA training delivery.

Copies of the field forms and field 'crib sheet' are included within this report (Appendix A) to allow cross reference to the development of the indices. These versions are those which have been used to generate most of the field survey data, although the separate periods of field survey were undertaken through the period of form and survey protocol development and thus there are some differences between these data.

2 Fluvial indices

2.1 Introduction

GeoRHS surveys will, when completed for a large number of sites, particularly within one river basin, constitute a substantial increase in the number of simple, untransformed, numerical predictors of environmental quality and flood wave routing. In the same way as the British Isles Flood Study of the 1970's (NERC, 1975) set up an entirely new database of catchment characteristics to predict the mean annual flood and unit hydrograph dimensions, the new database will, without modification, contribute more information to this task, improve the downstream translation of flood estimation and add innovative environmental quality and change variables - without constructing any composite indices whatsoever. For example, the dimensions of the floodplain, contact between the channel and the floodplain, other issues of conveyance and indicators of progressive channel change – all influence the predictability (or monitoring) of floods and ecosystem quality. However, the design of the GeoRHS survey protocols, both desk-based and field implied a duty to manipulate basic data in the same way as RHS survey data has been challenged to yield composite parameters of quality and modification: the challenge is to add value to the basic numbers in the direction of management-relevant composites such as 'river health', defined and calculated from a deeper understanding of driving and response properties.

Boulton (1999) has examined the practice and philosophies of what he terms 'river health assessment', as indicators of channel condition, from ecological, physical and functional perspectives. Boulton identifies some of the issues that affect, and qualities that determine good river indicators: sampling, measurability, data quality, sensitivity, interpretability and resonance. He also notes the critical choices of spatial and temporal scales for these measures, issues that are picked up by the other research papers in this 1999 Freshwater Biology special edition on river classification methodologies. Thus, whilst many indicators are based around single point or reach measurements they may act as surrogates for process and change, whether ecological or geomorphological. Most typically this change dimension is introduced through reference to surveyed, near natural, states (reference conditions or reference sites) or predictions of these benchmark or reference conditions. Hence most indicators attempt to show the vector of change and evolution in the system either away from or towards defined, measured or predicted semi-natural states. Similar approaches are taken across many application domains, Flood Risk Management assessment, restoration potential etc.
Indices development has tended to adopt three methodological approaches:

- identified in the field through a general appreciation of the ecological or geomorphic character and or processes operating within the system;

- through enumeration and integration of assemblages of river (riparian and sometimes floodplain) features,
- and, increasingly, through integrating feature scores within multi-criteria and expert system approaches.

Comparative approaches are examined below (section 3) to evaluate the potential for use of existing methods and analytical approaches for integrating geomorphic parameters collected within the scope of the GeoRHS programme. Four systems have been looked at in some greater detail to assess this role: 1) River Habitat Survey (Raven et al 1997), 2) Physical Quality Objectives, (Walker et. al. 2002) 3) Fluvial Audit (Sear and Newson 1995), 4) Geomorphic river condition (Fryirs 2003), and the Index of Stream Condition (Ladson et. al. 1999). All these approaches have attempted to distil the river condition, state or health to a limited number of indices and a restricted number of scales (good, moderate, poor) or to allow resulting scores to be categorised. These approaches have been based on a series of parameter values collected from the field and from desk study, by combining sub-indices or by developing matrix reclassifications or multi-criteria analyses of the survey variables.

These other indices have varying levels of data input, both at a technical level and duration of surveys. One of the parameters of a good indicator may be the ability to measure the variables accurately, allow repetition and cost-effectively, without expert input to the surveys. The approaches vary in this regard, with many approaches assuming expert fluvial geomorphologist survey. For many of the indices used the expertise required comes both at the data collection and field interpretation point and in scoring and categorising the scores generated for the indices. Often this expert judgement is operated during the development of the methodology, without the opportunity to test and evaluate the outcomes for type specific situations; whether the measures are appropriate across river types is uncertain. Such approaches are perhaps understandable, since the tools for expert interaction with the allocation of scores do not encourage scenario building or review across a wide range of river types. The approaches adopted within RHS have used accredited surveyors and the same approach is assumed with GeoRHS, and whilst collected by trained surveyors and validated the data is not necessarily generated by specialists. This may be an important distinction, especially when assuming that the surveys may contribute to both operational and surveillance monitoring.

2.1.1 Rationale for process indices

RHS gathers a relatively modest array of information about geomorphology, necessarily because physical habitat was not, at its inception, of paramount significance to the survey system and inevitably because of time constraints involved with every extra element of detail (e.g. using clinometers or Abney levels instead of map slopes). An extra dimension of enquiry implicit in RHS is, however, the obvious added value of re-survey; every survey system should incorporate variables whose true value lies in repetition and the designers of GeoRHS are also driven by optimism that a huge added value comes from monitoring re-survey (especially relevant to WFD uses).

GeoRHS has evolved out of RHS and its geomorphological ‘add on’ to attempt to meet a range of needs and in the recognition that RHS could not be expected to meet all the targets for describing processes or extending its role to WFD and Flood Risk Management requirements, based on its habitat-centred objectives.

Quality measures for channels, such as those currently derived from RHS (HMS, HQI) (Raven et al 1998, revised in Walker et al 2002) are both based on the records of physical and habitat features and although the RHQ reassesses these within the context of a matrix reclassification it is apparent that disturbance processes generating diversity might score inappropriately high. This is equivalent to the species diversity dilemma, where disturbed sites may hold a greater species diversity (the number of different features weighted by their abundance) than well established communities or seres. Within ecology this issue is accommodated by a range of other indices that help to resolve this uncertainty, including richness (the number of different species/features in an area) and by evenness (the relative abundance with which each species are represented in an area). These approaches may be hard to apply to geomorphological descriptors without the reference condition against which to compare what is ‘natural’ for a particular area or type. Thus high diversity of features may equally imply high quality in some locations and deviation from high quality where there is naturally low feature or habitat diversity. WFD applications and those directed at Flood Risk Management both try to establish, for particular situations, the complement of features indicative of quality and the departure from a ‘natural’ condition.

WFD stresses within CEN the disruption of ‘natural processes’ for hydromorphological quality’ rather than just the habitat diversity. Whilst hydromorphological quality has a role at high ecological status and merely needs to be sufficient to support the biological quality elements within lower ecological quality (WFD Annex V, table 1.2.1)[1] hydrological and morphological parameters still play an important part of the monitoring requirements, to determine the parameters that need adjustment to improve the status and to focus on the system pressures. Thus particular targets for GeoRHS and RHS combined indices are the ‘naturalness of processes’.

Within RHS and GeoRHS (desk and field surveys) processes are not themselves measured, and process indicators rely on temporal and spatial distributions, that these survey methods cannot provide. Even within fluvial geomorphological audit methods, where catchment, floodplain and continuity can be measured the description of natural process still relies on indicators of change. Thus GeoRHS/RHS process measures are inferred from the parameters collected, especially in terms of the sediment supply and transport attributes and lateral connectivity values. Within GeoRHS there are a number of measures directly targeted at ‘process’ understanding, using professional judgement to indicate aggradation or degradation (section J and K of the GeoRHS field form) and inclusion of historic data (within the desk study and floodplain survey) which seek to describe a process. These include diagnostics of vertical adjustment (aggradation and degradation) and stability of the bed, banks and floodplain (Sear, Newson and

[1] For ecological status classes other than ‘high’ the hydromorphological elements are required to have “conditions consistent with the achievement of the values specified for the biological quality elements.” (WFD Annex V, table 1.2.1).

Brookes 1995). The measures within GeoRHS (field and desk) can thus be seen as indicators of adjustment, indicators of natural lack of adjustment and indicators of disruption.

GeoRHS has therefore added parameters as 'process' surrogates, such as width, depth and slope and in particular the floodplain connectivity, which may be used as a surrogate for the potential for the channel to adjust. The inclusion of remote sensing (aerial photographic) parameters to complement the RHS and GeoRHS field surveys allows greater scope for temporal adjustment measures to be included in process assessments through planform changes and artificial modifications that affect process rates (e.g. slope / stream power modifications).

2.2 Reference conditions and typologies

The geomorphological concepts of Reference Condition / Baseline / Benchmark underpin a wide range of responses and uses in terms of channel sensitivity, resilience and restoration potential (Sear et. al. 2004) by reference to control sections, literature-based and often historic parameters, in the absence of a full understanding of the undisturbed, 'natural' condition of a site. The relevance of reference conditions and river typologies to GeoRHS indices development is based on both a role for GeoRHS in helping to identify the parameters that constitute that reference condition, establishing the typology of channels and in assigning reaches and potentially water bodies to a typology and the scale of deviation from reference conditions.

The approach recognises that the processes of adjustment may be ongoing, that morphology is dynamic and that in many situations, especially within those systems with sufficient stream power, that channels will readjust and move towards a more 'natural' form, which may be morphologically adjusted to changed sediment and flow characteristics. Newson has defined morphological 'Reference Conditions (or 'natural') within the Guidebook of Applied Fluvial Geomorphology R&D Technical Report FD1914 (Sear et. al. 2003) as 'rivers with planform/sectional geometry and features which represent the full interplay of water and sediment fluxes with local boundary conditions. 'Natural' rivers are free to adjust their form and features (by aggradation/degradation and lateral migration across floodplain/valley floor) to both system-scale drivers and local conditions'. Thus what constitutes 'pristine' does not imply a static system.

Departure from the reference condition represents the 'damage' to the system, although readjustment may have progressed far enough to reflect near-natural form and dynamics, whist still being classed as modified from natural. The question is whether sites that have progressed far enough to reflect near natural conditions should be treated in the same way as un-adjusted sites; which is perhaps a target for the indicators. This may be especially true where 'natural readjustment' and 'assisted recovery' are selected management and restoration responses. The Guidebook of Applied Fluvial Geomorphology R&D technical report FD1914 (Sear et. al. 2003) provides a useful geomorphologic categorisation of the sediment and flow related 'damage' classes, although a wide range of other pressures may affect the channel and floodplain response:

- Flow manipulations which distort the spatial or temporal regime of water level variation in relation to key form elements;

- Flow manipulations which distort the broad spatial or temporal workings of the sediment system, both in-channel and in relation to the floodplain, particularly through lateral and vertical channel change (depending on local dynamics);

- Flow manipulations which impact on the detail of river bedforms such as the sorting of sediment sizes, both laterally and vertically;

- Direct 'river training' to create artificial planforms (including floodplain modifications), sections and dimensions which relate to society's conventional development needs of the river (e.g. flood protection, embankments, water meadows);

- Sediment-related 'maintenance' which tends to distort channel dimensions and reduces the diversity of sediment sizes and forms at all scales;

- The sediment impacts of catchment and river management, particularly of dam construction, sediment trapping, land use changes;

- A variety of secondary impacts from changes to the vital ecotones between channel and floodplain, notably the riparian vegetation zone.

2.2.1 Reference conditions and the Water Framework Directive (WFD)

The application areas to which existing systems (RHS) have been applied have covered restoration, flood risk management, ecological and conservation management. Many of these systems are now being re-appraised in relation to the WFD with its more explicit requirement for condition assessment, to determine 'high' status. Specific questions are raised by these methodologies since they necessarily set standards against a benchmark or reference condition. A major challenge is how to assess what constitutes reference condition for a particular type of stream (type-specific reference conditions), within the context of its catchment; thus combining the roles of typology and reference condition. The same questions are central to establishing appropriate baselines against which monitoring will be conducted, especially where the baseline itself may be dynamic and changing. Reference or control sites, reference condition and river-type specific results thus become central to many application areas of GeoRHS.

Many measures may be of little relevance unless the indices can be related to river type, or catchment area or discharge (or a combination of these variables) in order to compare like with like when selecting reference conditions. This is especially true in lowland situations where the high status sites that are close to reference condition may be scarce, by virtue of a long history of modifications and changes to boundary conditions. Predictive, literature and palaeo-environmental surrogates have been employed in these situations (Brown, 2002, Thoms 1996); and stressing the value of cartographic and historical studies for the reach surveys. Such measures are specifically identified within the GeoRHS programme in adding process / form relationships (river and floodplain evolution).

Locally-derived geomorphic descriptors or typologically similar geomorphologies can be used in support of river restoration and channel design; where sufficient semi-natural channels (and floodplains) can be found to provide the necessary data and relationships determined. These benchmark and predictive approaches are common in other areas of freshwater ecology, for example RIVPACS (Wright 2000) compares field sample data to RIVPACS predictions of community under non-anthropogenically influenced sites (based on reference condition site surveys). The challenge in these procedures is to determine what is natural, unmodified, or in locations where there are few natural sites what the conditions should be within a particular typology.

Although not explicit in these classes, the status of the floodplain and its connectivity to the channel are important parameters. The approaches used have varied and recognise, at least in passing, the continuum of channel diversity adjusted to local conditions. Reference condition may thus be defined from existing sampled sites (as in RHS), by reference to the literature or a combination of these approaches. The methods for reference condition evaluation are in some senses similar to assessment of favourable condition for species, where specific habitat conditions are defined as “preferred”, but at a local level other factors (biotic, chemical) may influence the diversity and whether a target species is present. Defining what is natural or semi-natural within a particular catchment or sub-catchment and establishing the applicability of reference conditions to particular typologies and geographic locations becomes central to making effective comparison for evaluation sites.

The European Committee for Standardisation (CEN 2003) lists reference conditions for hydromorphological quality in rivers as:

- Reflecting ‘totally’ or ‘nearly totally’, undisturbed conditions;
- Lacking any artificial in-stream and bank structures that disrupt natural hydromorphological processes, and/or unaffected by any such structures outside the site;
- Bed and bank composed of natural materials;
- Planform and river profile: not modified by human activities;
- Lateral connectivity and freedom of lateral movement: lacking any structural modification that hinders the flow of water between the channel and the floodplain, or prevent the migration of a channel across the floodplain;
- Lacking any in-stream structural works that affect the natural movement of sediment, water and biota;
- Having adjacent natural vegetation appropriate to the type and geographical location of the channel.

The development of WFD 49 has advanced a new, sensitivity-based, channel characterisation rather than a typology that is now being used to underpin the development of the Scottish engineering regulatory regime and provides a model for the UK environmental standards and managing modification to channels. Within this project the development of the morphological environmental standards set a typology defined using secondary map-based datasets. The assignment and categorisation may be improved or validated by GeoRHS datasets, especially where the WFD49 classification incorporates confinement parameters (SEPA 2005) based on the extended geomorphic descriptions of Montgomery and Buffington (1997). These recommendations for a hydromorphology condition class have important implications for the roles of reference conditions; setting bio-geomorphic attributes in setting and identifying the environmental standards and deviations from them. If GeoRHS is able to collect and calculate these environmental standards or the component bio-geomorphic parameters then it forms a basis for validating standards, monitoring the condition and achievement of the standards. The inclusion of the floodplain environment within WFD49 environmental standards reflects the WFD requirement for hydromorphological quality elements and CEN guidance standards for morphology, by the inclusion of river continuity (lateral connectivity).

It should be remembered that the use of empirical river channel information to objectively classify UK rivers has never been successful, even up to the coverage achieved by RHS (Newson et al., 1998). The whole RHS evaluation system for habitat quality is now, instead, based upon a multivariate statistical presentation of the driving variables (e.g. altitude and gradient), rather than the response variables. In the emergency conditions of implementing the WFD, however, an *ad hoc* national typology is vital.

Typologies for WFD may fulfil particular classificatory roles, but the nature of the classifications may not address the full range of applications required, beyond WFD. GeoRHS assumes that a number of parallel typologies may be acceptable, based on the application domain required. It may be asking too much of the varied, dependent and independent variables to establish a single, universal classification system. Rosgen (1994) river channel types goes a long way in this respect, but does not evaluate the process or channel response that is suggested by the Montgomery and Buffington (1997) approaches. Equally, the Montgomery and Buffington (1997) types whilst incorporating confinement stresses bed morphologies and mountain systems, which may not reflect the floodplain channel types. Thus a typology for ‘naturalness’ may be developed from; a typology for process and response, typology for floodplain and floodplain modification and energy types (Nanson and Croke 1992). In this sense the floodplain typology might be considered as a sub-division of the Montgomery and Buffington (1997) classification, applied to alluvial channel forms adjusting floodplain dimensions.

The development of typologies based on field surveys inevitably includes taxonomic assessments of the natural situations and the modifications from the reference typologies. Similar to ecological classifications a series of characteristics (abiotic) and features (biotic/species) attributes enable the matching of samples to nationally established classes. Nevertheless the classifications show variable percentage confidence limits in assigning to a single class. Similar situations may be apparent in river / water body classifications where continuity occurs between classes. Mixed classes are especially likely to be evident if the reach surveyed is non-homogeneous – as may be the case in RHS and GeoRHS reaches. Thus it would be possible to establish a channel response classification based on the principles of Montgomery and Buffington, based on sediment and response whilst also establishing a floodplain classification that extended the class into the floodplain response.

3 Comparative assessment of river indices

3.1 Introduction

The new information/data yielded by GeoRHS partly fills in direct numerical descriptions previously missing from the river scientist's toolbox – these numbers can be used directly for predictive studies and applications. Some may need combining, to form new indices, with other numbers from this or other surveys and databases. However, perhaps the major challenge at this stage of the GeoRHS system is to weave the information disaggregated for the purpose of efficient, repeatable data collection back into more holistic and more descriptive indices. This is particularly the need in respect of potential uses for management of the WFD where these indices may be targeted at decision support rather than conventional predictive models.

This section briefly examines, therefore some of the other indices and metrics used to identify habitat modification and geomorphological condition of rivers, as a basis for assessing the contribution these approaches may make to GeoRHS indices development. The section examines the rationale and methodologies for combining measures of riverine (primarily channel and riparian) features to derive synthesised classifications of naturalness, modification and overall / general quality.

The analytical requirements of the GeoRHS applications are more specific, targeted at particular 'clients' or application areas (e.g. floodplain connectivity, conveyance, naturalness of process) related to core business areas. This section reviews the Fluvial Audit, River Habitat Survey, River Styles, river geomorphologic typology and Index of Stream Condition. Whilst this is not an exhaustive review it provides some insight into the challenges of deriving variables and the core role of measures of naturalness or benchmark conditions in delivering the objectives of these measures.

3.1.1 Indices derivable from Fluvial Audit

Fluvial Audit represents as full a picture of the dimensions, features, processes and current state of fluvial geomorphology in a river channel as is currently collected within standardised river survey in the UK (EA 1998). We therefore present a brief selection of the way in which Audit might provide a 'gold plated' source of both simple descriptive numerical data, derived parametric descriptors and form the input substrate for decision-support tools concerned with e.g. river restoration. The simple uses and contributions from Fluvial Audit are described by Sear et al. (2003) but the survey system has evolved rapidly, tackling new challenges since the preparation of the Guidebook.

Fluvial audit has recently been developed to introduce habitat quality criteria, based on multiple criteria analysis developed utilising database and GIS components. The scope of the data collection for fluvial audit includes field and desk study and the scope of the data varies between rivers, where there are varied levels of background information. These approaches have been developed on the River Nar and River Wensum to provide targets for management across the whole catchment (Appendix A). This approach uses a series of attributes of the channel morphology and historic modification data from secondary sources to develop indices of modification and naturalness from which a re-classification is used to categorise the reach status from natural to heavily-modified. This same matrix can be reinterpreted in terms of the potential broad management response (protection to restoration).

The RHS and to some extent the GeoRHS do not have the range of attributes derived from secondary sources. The Fluvial Audit datasets are not specified or standardised, although the field surveys associated with FA are largely standardised and the GIS related data (where these are generated within a FA) offer the opportunity to develop multi-criteria analysis (MCA) based assessments. Recent Fluvial Audits, specifically directed at habitat assessments for the Countryside Council for Wales and English Nature have started to develop MCA based approaches to assess the favourable condition. Similar multi-criteria approaches, based on width / depth and shear stress have been used to discriminate pristine sites from modified Alaskan reaches (Wood-Smith and Buffington 1996).

3.1.2 Indices derivable from River Habitat Survey

Two indices have been developed from the RHS survey techniques and a number of other habitat suitability assessments and reference condition site selections have been driven by the collected RHS dataset analysis. The Habitat Quality Assessment (HQA) and the Habitat Modification Scores (HMS) based largely on the data within the spot checks. Table 3-1 summaries the attributes from the forms that are employed within the indices.

The scoring approach within both the HMS and HQA is based on the assignment of scores depending on the presence of or number of features associated with a 500m survey reach. The score in both cases were derived from expert judgement. (Raven 1998). The Habitat Modification Score calculation has been updated (Walker 2004) to allow for additional measures of resilience and potential for recovery and on a measure of the extent of the channel that has been modified. These measures are now defined in terms of the location of modification, lateral and vertical extents. The sum of the modifications still provides the overall HMS, but assigned to new 5 part classes with 1 assigned to the least modified and 5 the most modified. The factors are all scored, additive, positive and the higher score the more natural or more modified respectively.

Table 3-1 Parameters employed within the RHS metrics

HQA	Source	HMS	Source
Flow Type	Spot + sweep up	Modifications	Spot
Channel substrate	Spot	Modifications	Sweep
Channel features (natural)	Spot and sweep up	Features	Sweep
Bank features (LB + RB)	Spot and sweep up	Resilience and extent	
Banktop vegetation structure (LB + RB)	Spot		
Bankface vegetation structure (LB + RB)	Spot		
Total bars	Sweep		
In stream vegetation	Spot		
Landuse within 50m (LB + RB)	Spot		
Trees	Sweep up		
Associated features	Sweep up		
Special features	Sweep up		

In a similar fashion to reference conditions, the application of the HQA is designed for comparative purposes within a typological grouping, although the nature of these groups is not defined (e.g. mountainous streams) , but rather calculated from principal components analysis.

The approach to measuring naturalness used within RHS is based on accumulation of scores related to features present within and adjacent to the channel. The risk of using this approach is that a heavily disturbed site may exhibit high levels of diversity (see section 1.2.1). As with all indices they may only be as good as the ability of the field surveyors to identify features consistently in the field. River habitat surveys collect features in the channel and immediate riparian area. The measures do not attempt to understand the historical context, associations with the catchment or the historical and predictive evolution of the channel. Limiting the data within the channel focuses on the morphological features and processes and the lack of recording of features in the floodplain have underlain the requirements to enhance the methods through GeoRHS. This has also promoted the use of the same sampling framework for GeoRHS and RHS based on the 500m reach.

Physical quality objectives (Walker 2002, 2004), a derivative from RHS sub-indices, take the similar approach of matrix reclassification as described in 2.1.2, based on the combination of habitat modification and habitat quality – to deliver an index of habitat improvement objectives. The approach categorises the scores for HQA and HMS reclassifies the matrix to set 5 classes based on the assignment of modification scope categories and quality assessment categories. Whilst the HMS is based on the category of the value, the quality assessment is based on the percentage relative to the overall population. Thus the low modification scores and the top 20% of the habitat quality assessment scores are assigned as 'benchmark'.

What the method does not do is take into account the river type and type-specific reference conditions, and thus can be used as a universal measure.

Hydromorphological quality assessment needs evaluation of the departure from the reference condition in order to set habitat improvement objectives tailored to the local situation. The type-specific reference conditions, potentially developed with analysis of the RHS database used in conjunction with this approach offer a broader basis for setting specific objectives. Thus taking the top quality sites and assigning these, through PCA analysis or using expert judgement, to reference conditions sites offers a method for ensuring RHS sites establish appropriate indices.

3.1.3 River Styles and geomorphic river condition

River Styles® (Brierly and Fryirs 2000) adopt ecological approaches to classify or categorise rivers in terms of their likely response to change and restoration potential. This approach has many similarities to the requirements of the WFD objectives, river restoration and the flood risk management applications of GeoRHS. Fryirs (2003), within the context of River Styles in New South Wales, has developed a procedure for assessing geomorphic "condition". Condition, in this respect relates to the capacity for adjustment, irreversible changes and by relating the river sections to reference conditions.

The approach has been tested within alluvial and confined river sections in N.S. Wales and comprises identification of the River Style, assessment of river evolution and evaluation of the geomorphic condition of each reach within the catchment context. This is a wide-ranging approach that relies as much on geomorphic and field-based landform interpretation. The approach utilises a wide body of data, both field and historic information and incorporates floodplain characteristics.

The output of the semi-quantitative geomorphic condition assessment is a classification into good, moderate or poor geomorphic condition (against reference condition). The assessment also allows interpretation of the cause of the condition status. The method adopted is applied at a homogeneous reach level (rather than the standard reach length) and is applied throughout the catchment. The reaches are defined at the macro-scale based on the floodplain and confinement extents that indicate the extent to which the channel is able to adjust, its 'degrees of freedom' (Graf 1996).

3.1.4 Index of Stream Condition (ISC)

Index of Stream Condition (ISC) (Ladson et.al. 1999) is based on 5 sub-indices of condition, hydrology, physical form, streamside zone, water quality and aquatic life. This approach uses many of the same indicators as other metrics, but attempts to be more integrative using physical, habitat quality and biology sub-indices. The physical indices are developed through the hydrologic deviations and barriers, for the physical form, bank stability, bed aggradation and degradation, presence and influence of artificial barriers, density and origin of coarse woody debris (CWD). Also the width and structural intactness of the vegetation are included that describe some aspects of the non-biological influence of vegetation.

ISC does not measure some of the modification parameters that other indices have used, notably there is no modification index. In the case of modification it is assumed that the modification is readily assessed by the impacts on bed and bank stability measures. If these are not affected by the modification they are considered to be of low significance to stream condition, which may not be an appropriate decision where lateral connectivity is a ‘quality’ parameter. No assessment is made of the flow conditions (equivalent to flow biotopes) but are considered to be localised indicators (Raven et. al. 1997).

The procedures assign ratings (scores) to the identified conditions developed through the indicators for the component sub indexes, through subjective evaluation for the reach. These are similar to the assignment of scores within PQO and other metric approaches. Chosen reaches are geomorphologically homogeneous – with reaches decided by desk study. The ISC component scores are collected, summed and rated for sub-index scores to lie between 0-10, with the overall ISC score between 0-50 based on the five sub-indices. These scores are then graded to the 0-4 scales. The overall ISC score is based on a five point scale 4 = natural, 3= near natural, 2 = minor modification, 1 = major modification, 0 = highly modified.

Table 3-2 Rating of indicators for the physical form sub-index (from Ladson et al 1999).

Bank stability	Bed aggradation and degradation	Density and origin of coarse woody debris	Influence of artificial barriers	Rating
Stable (erosion resistant soils; no undermining; usually gentle batter, good vegetative cover; no significant damage to bank structure or vegetation)	Nil bed aggradation or degradation (no evidence of aggradation or degradation)	Essentially ideal: abundant debris from indigenous species. Site probably never desnagged and streamside vegetation probably never cleared	No artificial barriers in basin affect this reach	4
Limited erosion (good vegetative cover; some minor isolated erosion; no continuous damage to bank structure or vegetation)		Near ideal: numerous pieces of coarse woody debris from indigenous species. Perhaps limited coarse woody debris from exotic species present also. Limited impact of desnagging or streamside vegetation clearing		3
Moderate erosion (banks held by discontinuous vegetation; some obvious damage to bank structure and vegetation; generally stable toe)	Moderate bed degradation (steep bed; absence of alluvial material; narrow low flow course; bank erosion; evidence of recent minor deepening) or moderate bed aggradation (accumulations of material at obstructions; bed tending to flat; same size material on bed as bars; evidence of minor overbank siltation)	Moderate modification from ideal: moderate visible pieces of coarse woody debris from indigenous species in channel, or abundant pieces of exotic coarse woody debris in channel. Moderate impact of desnagging or streamside vegetation clearing	All artificial barriers in basin downstream of this reach are drowned out at least once per year	2
Extensive erosion (little effective vegetation; recent bank movement; mostly unstable toe)		Highly modified from ideal: few visible pieces of coarse woody debris in channel (either from indigenous or from exotic species)		1
Extreme erosion (evidence of rapid unchecked erosion; little effective vegetation; unstable toe)	Extreme bed degradation (low width to depth ratio; evidence of recent severe deepening; bare banks; bank erosion; possible erosion heads) or extreme bed aggradation (high width/depth ratio; flat bed; channel largely blocked; verbank siltation evident; adjacent water logging)	Not present: no coarse woody debris is visible	At least one artificial barrier in basin downstream of this reach is not drowned out at least once per year	0

3.1.5 Complexity measures

Few existing measures extend to the floodplain, although Brown (2002) examines the role of palaeohydrology and palaeoecology in determining what is natural in the context of river floodplains, how can they be defined and modelled and can they be recreated. For example, the palaeoecological evidence of the lowland streams is one of multithread rather than single thread braided, anatomosing or anabranching. Lowland rivers would have been largely forested and subject to disturbance, through wind throw, beavers, presence of CWD. Brown introduces an index of floodplain complexity based on hydromorphological variables. He argues that the floodplain geomorphology can provide models for the natural range of channel conditions, sensitivity to external change and potential for restoration. However, a number of Holocene influences have declined and in many locations irreversible, loss of species, deforestation, floodplain drainage, and sedimentation level have declined. However, the process form relationships may be relevant to reference condition and restoration goals. He uses channel sinuosity as a measure of complexity related to channel pattern. A complexity measure is proposed based on the sinuosity and the number of junctions within the reach R= S(1-J) where sinuosity is the total channel length / reach length, J is the number of junctions within the reach. This index has been modified to include palaeochannel forms that will increase the sinuosity levels where the sinuosity is the total length of channels including palaeochannels / reach length.

Sinuosity is closely related to the habitat area – at least within natural systems and with heterogeneity diversity and connectivity. As sinuosity increases in a natural channel the edge length increases, and greater sinuosity is related to the presence of channel features, erosion, bars, flow variation etc. Such features are also related to biological diversity and ecological stability. The role of GeoRHS in mapping the former channel form provides a measure of potential naturalness within the reach – based on the desk study variables, and has some parallels with the Brown (2002) approaches in incorporating floodplains into hydromorphological quality.

3.1.6 A comparative assessment of the candidate systems of index (with special emphasis on application to the WFD)

Table 3-3 provides a summary of the indicator approaches described above. Key distinctions between other geomorphic river condition surveys and GeoRHS/RHS assessment are the spatial sampling framework, based on standard geomorphically homogeneous reaches, and the level of expertise needed to complete the assessment. The introduction within the GeoRHS of much greater links to floodplain and measures or inference of process when interpreting the field parameters, associated with historic data and other desk-based study, introduces interpretation of potential system evolution and deviation from reference. This makes GeoRHS more akin to the channel reach morphology classifications of Montgomery and Buffington (1997) and provides both the basis for classification of the reaches to extend to condition assessment relative to a reference framework and the impact of pressures and disturbance on the channel and floodplain condition. Such approaches also allow for the assessment of the possible responses to natural or imposed changes or disturbance, such as increased sediment loads.

Most of the other classifications and indices attempt to develop a single, overall classification of condition, whilst within RHS and with GeoRHS there is the potential to develop multiple indices and the use of combinations of indices appear to offer ways of classifying the status for different system components (e.g. river channel and floodplain). The matrix reclassification approach offers the opportunity to being together floodplain and channel metrics that have been scored separately, yet is still a subjective allocation process based on reference to river types. This approach appears to have a lot to offer the WFD quality measures as well as being able to address the management responses.

Whether the broad interpretation of the nature of change drawn from expert field interpretation can be translated by the field-based methods adopted by GeoRHS desk study are debateable, but perhaps leads to the added role for a geomorphological interpretation of the desk study records (that allow for some understanding of the channel history) and supports their development in advance of the field programme.

Table 3-3 Summary of the characteristics of geomorphic survey methodologies used to generate catchment, floodplain and channel metrics.

Specification	River Styles	RHS	GeoRHS	DCBS	Fluvial audit
Methods	Extensive field evaluation and historic data	Field forms with limited desk parameters	Field and desk study (inc historic and RS)	Field data	Field data and secondary data
Outputs	Single classification and geomorphic river condition	Wide range of outputs including HMI and HQA	Multiple indices for different application domains	Mapping – more recent introduction of GIS approaches	GIS/database
Scales	Catchment, floodplain and reach based	Reach based	Floodplain and reach based	Catchment and reach based	Catchment, floodplain and reach based
Visualisation Interpretation	3 point classification linked to reaches. Mappable	Indices for reach Back-to-back surveys offer mapping based approaches	Indices for reach Back-to-back surveys offer mapping based approaches	Single thematic map of classification	Thematic mapping and ratios (w:d) channel:floodplain etc.
Indices and metrics	Single metric of condition	HMI Habitat Modification Index HQA Habitat Quality Assessment and derivative indices Physical Quality Objectives PQO	Under development for WFD and Flood risk management applications	Broad classification of propensity and capacity for change	Derivation of indices based on study requirements – e.g. w:d ratio, sediment status, modification, natualness,
Reach structure	Reach based (not defined)	Section based – 500m	Section based – 500m	Geomorphic reach based	Geomorphic reach based
Reference condition relationship	Relation to reference condition explicit	Benchmark sites established from database	Benchmark sites from RHS data	None – not explicit internal catchment levels quality	Relation to reference condition not explicit

Make reference to the investment in RHS/GeoRHS sites as a basis rather than River styles or DCBS.

4 Deriving indices from GeoRHS

4.1 Survey parameters

GeoRHS, together with RHS data and map-derived data in both systems aims to generate and maintain an information base of descriptive, classificatory and quantitative survey parameters with the objective to deliver a wide range of applications, indicators and monitoring requirements, at varied spatial scales (catchment, floodplain, waterbody and reach).

Within the scope of GeoRHS, and incorporating the variables from RHS, parameters may be considered as being of two types: 1) those parameters that help to characterise or classify the reaches on their own, setting sites within WFD derived typologies or other, more detailed reference typologies (such as the UK typology of morphological sensitivity under development by SNIFFER in WFD49) 2) those parameters that are directed towards calculations of metrics and indices or direct measures of features within their reference condition framework. Parameters may also be considered as both positive and negative factors, indicating the presence or absence of features, for example , the presence of modifications (A10 on the field form).

Table 4-1 provides a listing, excluding the survey header information, available for the construction of the indices – subject to availability of information at all sites. Some spatial datasets are not currently available (e.g. NFCDD) and may not be available for Scotland or are in different formats. Equally, some field data may also be missing by obscuring of features in the field. Thus, indices may need to be responsive to missing data values, for example where not all reaches can be accessed for cross-sectional data or where specific features cannot be seen (e.g. due to seasonal vegetation cover).

Sections 4.2 and 4.3 discusses potential indices for the two domains (WFD and Flood risk management) respectively, parameter use and limitations of their application.

Table 4-1 Attributes of the survey approaches contributing to the GeoRHS / RHS site records for use within characterisation, classification and indices development. Those items in red are used within the HMS those in blue are used within the HQA indices.

Attributes of the component surveys in GeoRHS and RHS (field and desk studies)			
GeoRHS	**GeoRHS Desk**	**RHS**	**RHS Desk Study**
CHANNEL	**Valley Form**	**B** Valley form	
A1 Bankfull width	Geology	**C** No of riffles	Altitude
A2 Bankfull depth	No of terraces LB/RB	**C** No of pools	Slope
A3 RB / LB floodplain width	Width of floodplain LB/RB	**C** No unvegetated point bars	Flow category
A4 Ponding (%)	Evidence of disconnected floodplain LB/RB	**C** Vegetated point bars	Solid Geology code
A5 Photo ref	Width of meander belt	**D Artificial Features**	Drift geology code
A6 RB/LB Material (%)	Width of recently active floodplain	Realignment	Planform category
A7 Bed material (%)	**Channel planform**	Over-deepening	Distance from source
A8 RB/LB Banktop sediment (dominant size class)	Meander amplitude	Impoundment	Significant tributary
A9 Information (txt)	Radius of curvature	**SPOT CHECK**	Navigation
A11 Slope (degrees)	Meander wavelength	**E Physical attributes**	Height of sources
	Total sinuosity	Bank material	Water quality class
BANK FEATURES	Planform modification	Bank modification	Stream order ?
A10 Engineering	Planform type	Bank features	
EROSION	Floodplain processes	Channel substrate	
B1 Basal Bank Scour	Planform change	Flow type	
B2 Full Bank scour	Channel meander change type	Channel modification	
B3 Cliffs / scree	Presence of relic channels	Channel features	
B4 cantilever	Width of relic channel	Braided sub-channels	
B5 Slabs	Planform of relic channel	**F Banktop land-use and vegetation structure**	
B6 slides / flows	Floodplain hydrology	Land use within 5 m	
B7 Accumulating	Dominant floodplain soil	Banktop veg type	
B8 Fallen tree	Presence of water meadows	Bank face veg type	
B9 Burrowing	Presence of extensive drainage systems	G Channel vegetation types	
B10 Poaching	Floodplain inundation	**SWEEP UP**	
B11 Gravel extraction	Presence of embankments	**H** Land use within 50m	
B12 Access	Embanked adjacent	**I** Bank profiles (natural and artificial)	
B13 Failed revetment	Embanked setback	**J** Extent of trees and associated features	
B14 Bend scour (Length)	Status of defences	**K** Extent of channel + bank features	
B15 mid-channel scour	Floodplain Level of Service	Flow types	
DEPOSITIONAL FEATURES	Distance of channel structure ds of reach	Marginal deadwaters	
C1 Point bars	Floodplain hedges and walls	Eroding cliffs	
C2 Side bars	Presence of significant scrub on FP	Stable cliffs	
C3 Mid channel bars	Presence of significant Urban on FP	Exposed bedrock	
C4 tributary bars	Presence of road rail canal	Exposed boulders	
C5 Point bars	Presence of mineral extraction	Vegetated bedrock/boulders	
C6 Side bars	Presence of OW/AW	Unvegetated mid channel bars	
C7 Mid channel bars	Dominant floodplain land cover LB/RB (LCM2000 derived)	Vegetated mid channel bars	
C8 tributary bars		Mature islands	
C9 mature island		Unvegetated side bars	
C10 Berms nat unveg		Vegetated side bars	
C11 Berms nat veg		Vegetated point bars	
C12 Berms artificial		Unvegetated point bars	
C13 Bed drapes		Unvegetated silt deposit	

C14 u/s of structures		Discrete gravel deposits	
C15 d/s of structures		Discrete sand deposits	
C16 waste disposal		**L Channel dimensions**	
C17 sediment jams/dams		Banktop height	
C18 macrophyte chokes		Bankfull width	
C19 CWD jams/dams		Is banktop also bankfull	
C20 chaotic flood deposits		Water width	
FLOODPLAIN GEOMORPHOLOGY		Embanked height	
D1 Floodplain		Water depth	
D2 External boundary to FP		Trash line height above water	
D3 Relict palaeochannels		Bed material stability	
D4 No of relic channels		**M Features of special Interest**	
D5 Relic channel planform		Braided channels	
D6 FP slope		Side channels	
D7 Height of FP relief		Natural waterfall <5m	
D8 Terraces above floodplain		Natural waterfall > 5m	
D9 Number of terraces		Natural cascades	
D10 Est height of first terrace		Very large bounders	
E1 Direct uniform spill		Debris dam	
E2 Eroded low points		Leafy debris	
E3 Active side channels		Fringing reed bed	
E4 Relic channels water filled		Quaking banks	
E5 Relic channels nat veg		Sink holes	
E6 Relic channel used		Backwater	
E7 No of embankments		Floodplain boulder deposit	
E8 Length of embankments		Water meadow	
E9 EM crest to BT		Fen	
E110 max Height EM above FP		Bog	
E11 natural levees and dredging		Wet woodland	
F1 Channel migration		Marsh	
F2 Trees continuity		Flush	
F3 Trees root spacing		Natural open water	
F4 Plantation conifers		Other (state)	
F5 Tree condition		**N** Choked channel	
F6 Washout at roots		O Notable nuisance species	
F7 Buffer zone		**P Overall characteristic keywords**	
F8 Buffer zone width		Major impacts	
G1 Trash marks		Recent management (specify)	
G2 recorded flood marks		Animals	
G3 Crop damage		Other	
G4 FP deposits		Alders extent	
G5 damaged walls/fences		Alders diseased	
G6 River fed FP storages			
G7 Artificial drainage on FP			
G8 No of FP drainage channels inside EM			
G9 length of drainage inside EM			
G10 No of floodplain drainage channels outside EM			
G11 length of channels outside EM			
G12 Flap valves through EM			
H1 Permeable boundaries			
H2 impermeable boundaries			
H3 RP (rough pasture)			
H4 IG (improved grassland)			
H5 TL (tilled land)			

H6 SH (shrub)			
H7 WU (woodland, plantation with understorey)			
H8 WW (woodland without understorey)			
H9 PG (parkland, gardens)			
H10 MH (moor and heath)			
H11 SU (suburban/urban)			
H12 WL (wetland)			
H13 OW/AW (open/artificial water)			
INDICATORS OF ADJUSTMENT			
J1 Buried artificial structures			
J2 Buried soils			
J3 Extensive coarse sediment shadows			
J4 Elevated bars, wandering and braided			
J5 Extensive floodplain splays			
J6 Eroding banks in shallow reaches			
J7 Contracted channel at bridges			
J8 Recent and extensive dredging/desilting			
K1 Recent terraces			
K2 recently abandoned channels			
K3 Recent cut-offs			
K4 narrow deep channel exposing roots			
K5 Extensive slumping of both banks			
K6 Undermined bridge piers			
K7 Paved (coarsened) bed materials			
K8 Artificial bed stabilisation (e.g. weirs)			

4.2 Selecting indices

A wide range of potential indices have been proposed for the GeoRHS using both the desk and the field survey records. At this stage this is specifically for the Water Framework Directive and Flood risk management domains, although it is recognised that there is significant overlap between these and extension to other business areas.

Proposed indicators / metrics fall into three classes:

- Classificatory, typing and descriptive (including at a site quantitative estimates for some parameters)
- Evaluative (against Reference Conditions / Benchmark)
- Monitoring (against Baseline or prior GeoRHS surveys)

Initial targets for channel and floodplain indicators for WFD and Flood risk management include:

- Geomorphological character of channel and floodplain
- Sensitivity / Resilience and Dynamic Change indicators

- Geomorphological adjustment and recovery
- Channel - Floodplain connectivity
- Floodplain energy type (e.g. Nanson and Croke 1992)
- Floodplain habitat features and quality
- Floodplain storage potential
- Geomorphic ‘health check’ vs natural state
- Overall erosion and deposition (e.g. classify reach as eroding, depositing, transfer or exchange)

Once the initial indicators are proposed Table 3.3 assigns the indices to the classificatory, evaluative and monitoring classes.

In many instances it is assumed that the floodplain and channel scores would remain separate, although some indices will be appropriate to combine. Further reclassification becomes possible where the indices are retained separate, although there is an issue of where no floodplain exists, in separately flagging these sites or identifying floodplains as a specific attribute of the typology.
RHS indices are also seen as being part of the applications with links, for example between RHS derived HMI and floodplain connectivity score, and between channel HQA and floodplain quality, although it is recognised that some of these RHS scores may need to be re-visited to better reflect naturalness. This may be particularly relevant where RHS survey is undertaken in summer and GeoRHS is undertaken in winter.

4.3 Water Framework Directive (WFD) implementation

Hydromorphology, within the context of the Water Framework Directive, helps:

- Define reference conditions
- Set ecological class boundaries
- Delineate water bodies and typologies
- Designation of Heavily Modified Water Bodies and Artificial Water Bodies
- Identify pressures

In addition, the hydromorphology assessment will form part of the sustainability assessments to be undertaken for new works as required by Article 4(7) of the WFD – although this aspect is considered within section 4.4 (Flood risk management applications).

WFD defines the hydromorphological elements to be monitored for which guidance has been prepared (CEN 2003). Annex V/1 sets out these morphological condition quality elements for the classification of ecological status:

- Hydromorphological elements supporting the biological elements
- Hydrological regime: quantity and dynamics of water flow and connection to groundwater
- Connection to ground water bodies
- River continuity
- River depth and width variation

- Structure and substrate of the river bed
- Structure of the riparian zone

WFD high hydromorphological status implies ‘nearly totally undisturbed’ conditions and considers ‘damage’ to mean ‘disruption of natural processes’ rather than just non-natural form; Other values for naturalness include: natural materials of bed and bank, planform, profile (and vegetation) and connectivity – both lateral and downstream.
Within Heavily Modified Water Bodies (HMWB) the ecological status may not be achieved by virtue of the modifications to the hydromorphological condition/pressures. The definition and reasons for designation of HMWB and the derogation from ecological status is required to be recorded in the River Basin Management Plan and this is to be reviewed every 6 years. This timescale also sets the timescale and needs for hydromorphological element monitoring on HMWB/AWBs.

Water Framework Directive indices must reflect ‘hydromorphological quality’ and departures therefrom. Within the WFD this implies:

- sets of reference conditions must be established. Annex II/ 1.3 establishes the requirement for this to be type-specific
- that compliance with the CEN definitions employs mandatory quality elements and both the Common Implementation Strategy and CEN have recommended quality elements even through the diagnostic and response variables are selectable. CEN is advisory and not statutory, but a consistency of approach will be needed.

Annex II / 1.3 assumes that reference conditions do indeed vary with river types, although the river types currently defined are based on broad scale characteristics (altitude, basin size and geology). It may be possible to both define types more closely, and have regional ‘types’ within the broad typology. Refining the criteria that constitute reference conditions inevitably depends on identifying the river type context. CEN only mentions location in terms of ‘appropriate adjacent vegetation’; however, the variability of sensitivity and resilience between rivers may need to be incorporated in defining ‘nearly totally undisturbed’. An alternative is to have a uniform reference condition *a la* CEN and score departures from it differently for different river type. However, this approach is considered unwieldy and would be difficult to establish a single reference condition that would work as the baseline since the typological characteristics are so variable.

RHS use of HMI and HQA did not attempt to establish these type-specific reference conditions , despite a number of channel typology programmes (Newson *et. al.* 1998), and so modifications and quality criteria were based on total values and variation within the whole population. RHS established ‘benchmark sites’ through expert judgement, both impressionistic and by carrying out the survey for them. Reference conditions sites have been selected through an extensive analysis of the RHS database to identify those sites with least or no modifications (Parsons and Syme in press). These reference condition sites that are forming the first tier of the GeoRHS site surveys. The benchmark sites cover a range of river types but a typology is not needed for the development of scoring systems – these are universal for features recorded by RHS. The derivation of HQO and HMS also relied on expert judgement of ‘desirable habitat features’ and the degree and seriousness of modification – neither metric explicitly involved geomorphic process.

Although there are currently too few sites with GeoRHS / RHS data gathered to operate the same approach as RHS and a need for trialling a range of indices on the available data for which it is evident that multiple indices can be derived from the parameters. A large number of potential indices are required by WFD – typing, quality (including floodplains), stability, sensitivity, adjustment trajectory, recovery potential. Many of these potential indices stress form, process and response associations and although we have inferred process drivers in the design of the survey it is only inference. Thus there are some inherent limitations and uncertainty in applying these geomorphic form-based approaches, although there is no scope or resource for more detailed and longer term process studies. Such associations rely to some extent on the space / time substitution with a large database able to represent a wider range of reference conditions and deviation from them. Given the importance of reference conditions, as near natural sites, it has been appropriate to add sites selected through expert opinion. RHS site survey may often miss modifications and adjustments that are complex to identify in the field and especially during the summer when the evidence may be cloaked by vegetation, and where the surveyors are not looking into the floodplain or seeking specific evidence of morphological changes in the field.

A current assumption is that RHS will always be conducted alongside the GeoRHS assessments, or at least within the selected reference condition sites. Longer term operation independent of RHS is not precluded; the inclusion of certain overlaps between the systems would permit certain indices to be derived independent of RHS. GeoRHS is a young methodology in comparison to RHS and further evolution may be anticipated through testing.

GeoRHS attempts to infer process, but relating this to reference conditions to derive hydromorphological quality is problematic since it is difficult to build form and process into reference conditions assessments. Regime form can only be predicted from flow or catchment area, the energy (stream power) for process can only be predicted from local slope and entrainment can only be predicted from detailed bank/bed particle size. Further evaluation is needed to assess the potential to add further, desk-based datasets, to assist with these parameters.

Hydromorphological ‘high’ quality relies on identifying nearly totally undisturbed’ conditions, although it is apparent from RHS record, and likely to occur within GeoRHS, that adjustments within processes are often re-establishing ‘semi-natural’ forms. The stage of evolution of these adjustments may make it difficult to assess the degree of modification and the position on the modified / recovered continuum. So, even where it is evident that the channel is modified the form and processes may be semi-natural. Further problems arise from of building ‘disturbance to process’ as a basis for measures of departure from reference conditions. Examples pose questions as to whether these features represent ‘departures from reference’: bridges without support in the water, road/railway within the floodplain, coarse woody debris resulting from poor grazing control, failed revetments – e.g. where the former spiling is in mid-stream, cattle and farm vehicle access points? Rule based approaches are likely to be needed to allocate disturbance classes since not all ‘damage’ factors will have equal weighting.

4.3.1 Characterising the waterbody

Hydromorphological quality relates to the water body, and not an individual site recorded through RHS and GeoRHS or other survey technique, which introduces issues of the scale by which GeoRHS/RHS data can describe these longer reaches. Perhaps multiple surveys within a surface water body will provide the necessary descriptors with averaging of the measures of departure from natural / reference condition. Given the waterbody classification it is assumed that all the 500m must be ‘natural’ or nearly natural to qualify for high quality. In addition, there is potential for a GeoRHS/RHS survey site to cross waterbody boundaries by the nature of the site selection, and further consideration of constraining the locations of reaches to fit within waterbodies may help avoid such complications.

Experience of building similar geomorphological indices comes from RHS data in developing geomorphic typologies (Newson et al., 1998). In these cases indices were grouped into LOCATION-DIMENSIONS-PATTERN, ENERGY-RESISTANCE and DYNAMICS (stability). Many of the parameters used within the process-based classifications were imported, additional to RHS data records – e.g. flow and catchment area derived from map data. The resulting classifications for attributes, such as stability came from rule-based approaches to bank material, substrate, bank features and channel features. Similar approaches are judged to be applicable to the implementation of GeoRHS.

Rationalising this within the scope of the Water Framework Directive monitoring requirements three targets for indicators / indices are suggested, based on the parameters within GeoRHS / RHS records:

1) Quality of channel and floodplain – scored departures from reference conditions (Sections A & D-F of GeoRHS);
2) Stability and sensitivity – Sections J&K of the GeoRHS and a re-run of rule-based approaches employed ;
3) Adjustment and recovery: rule-based combinations of Section B (bank features) of the GeoRHS survey.

The case studies within the Wensum and Nar catchments provide examples of the reference condition related, rule-based assessments. These indices, although derived from fluvial audit information could equally have employed GeoRHS parameters of quality (naturalness) such as barriers, % fines in channel, minimum bank height, width-depth ratio, planform modifications, flow types and berms as well as desk based data. Although these are specific to chalk streams of high conservation interest GeoRHS uses surrogates for the audit information and is discontinuous. The primary requirement in applying this approach is to broaden the reference information base for all river types to add geomorphic variables.

4.3.2 Geomorphological character / quality of channel and floodplain

RHS already scores for quality and modification (of the channel), although there is potential to re-examine these to target 'naturalness' values and to extend into the floodplain. RHS scores for Habitat Quality/ Modification through:

- 'Natural' channel/ bank features and substrates are scored for their occurrence, without subjective judgements about typicality or process inferences;
- Flow types, substrates and bank vegetation are scored for diversity and complexity;
- Modifications to banks, bed, long profile and vegetation are scored by subjective severity and extent, with most severe reserved for culverts and realignments.

Quality indicators have been examined as separate targets for the channel and the floodplain. This has been a pragmatic decision in putting a larger number of parameters together, but would appear to have added advantages of dealing with the issues of where no floodplain exists without degrading the quality classification and offering an opportunity to apply a matrix based approach to the floodplain and channel combined classes, similar to RHQ / Fluvial Audit approaches.

Quality for the **Channel**:

- A10 (extent of engineering structures for channel and banks), B9-13 (acceleration of erosion process), C16 (waste disposal) entries can be scored according to interference with process and their lengths divided by 500m;
- erosion and deposition lengths (areas) can be expressed by a diversity index (although this may need to be tested and related to the river-type);
- Width-depth ratios (A2/A3) may be of little use without discharge or catchment area or river type, although this variable may be definable from secondary data sourcing and from RHS desk based measures.
- % ponded useful on its own as a variable (derived from the cross sectional GeoRHS data A4).

The evaluation for the floodplain will depend on whether the floodplain is present and whether this accords with the reference condition. Clearly, a lack of floodplain recorded where none exists naturally should not be allowed to downgrade a site's quality. If channel and floodplain metrics are combined then in these situations (through a matrix reclassification) the role of the floodplain element will need to be neutral in developing the character assessment, but where a floodplain does naturally occur it can influence the overall assessment.

Quality for the **Floodplain**, where present:

- Connectivity with channel via scores for E4&5 (relic channels), H3,10&11(natural and semi-natural floodplain land cover classes) and negative scores for modifications like E9 (width to embankment) (qualified by E10&11) (constraints on the floodplain width due to defences and levees);

- G1-G6 (evidence of connection to the floodplain during flood flows) capable of (low) additional scores to show FP works – to provide a confirmation of operation of the floodplain in a natural way enhances the hydromorphological quality ranking.

4.3.3 Stability / Instability and sensitivity

Where RHS data is also available it is possible to use the Newson et. al. (1998) River Channel Typology rules (or the information from the GeoRHS transect) to evaluate stability / instability or equilibrium / dynamics. This approach may be complementary to the use of GeoRHS data and was a classification based on bank materials, substrates, bank and channel features. The results using the RHS variables indicated that 'natural' sites typically have unstable boundaries (either bank or bed unstable). The RCT / RHS approach was a classificatory programme that paired unstable with stable combinations of bed and bank and thereby inferred process or stability classes and from these inferred appropriate management response. Continued contribution of the RHS parameters would appear to be necessary to characterise the bank and bed substrate variables.

Stability and instability in this context are the measures of the dimensions of change whether lateral, vertical and longitudinal. Stability/instability may be separated into vertical and lateral if bed scour and degradation parameters are employed to distinguish vertical adjustments using the GeoRHS.

From GeoRHS a suite of parameters can be employed;

- from GeoRHS use a length score for B1-B6 (erosion extents), modified modestly by B7 (whether the toe of the erosion length is accumulating). Of B8-B13 (external erosion factors and acceleration), only B8 (fallen trees) is likely to be 'natural' instability, but it may not be appropriate to differentiate these for the stability/instability index.

- C5-C8 (extent of stable bars) as total area, compared to area of C1-C4 (unstable bars) and divided by the area of the survey reach (500xA1).

- C17,19 & 20 (evidence of sediment jams, chaotic flood deposits and CWD jams and dams), J8 and K8 also have relevance (recent and extensive dredging/desilting , artificial bed stabilisation (e.g. weirs)).

Once again the stability classes will be difficult to consider without reference to river types and type-specific reference conditions that describe 'natural' erosion and deposition rates. It is perhaps the causes and the lack of evidence of acceleration of processes (B10 – 13) that will help distinguish natural instability from artificial instability. Where RHS is run in tandem it is possible to add other sweep up classes (such as L Bed material at site if consolidated) although these values are from a single location on a riffle which may mislead overall reach classification.

Sensitivity or susceptibility to change is again a channel-related value, rather than one that can be applied for the floodplain, although floodplain measures may be included. The sensitivity is interpreted as the potential for instability (due to external influences) to shift the channel / reach to a different classification, relative again to the reference condition. Clearly, for this to operate the channel classifications / types need to be separately identifiable and sufficiently distinct. Some classes may be easier to envisage being more sensitive and responsive than others, typically driven by the power, sediment and water loads. For example, sediment input from mining tailings may shift a channel from a meandering to braided morphologic pattern, and from a v-shaped valley to one with coarse floodplain materials.

These concepts of thresholds and potential for changes would need further assessment, although the adjustment index may help to identify the spatial distribution of such responses. It is obviously difficult to identify the natural induced changes from the anthropogenic-induced dynamics and the resulting natural and un-natural disturbance patterns. Inertia within channels - 'resilience' and the ability of systems to reach an equilibrium form are important concepts to appreciate if trying to develop a measure of sensitivity and channel behaviour. Rare, large events may undermine the confidence of building relationships with these variables, but the importance of such an event on the morphology and the subsequent 'natural' readjustment (potentially crossing threshold and form boundaries) may be suitable targets for natural river channel sensitivity assessments.

Inclusions of parameters for chaotic flood deposits (C10) may help distinguish causes of instability (and higher sensitivity) of channels.

Testing the sensitivity of the channels will require a larger GeoRHS database and assessment of the ability to discriminate sensitivity classes. The concept, following from Schumm (1977), Montgomery and Buffington (1997) of channel disturbance and response potential, provides a process-related model of change to external (anthropogenic or natural). Once again, the potential for a sensitivity index would be type-specific and may require additional typology variables to those identified in table 2 (catchment size, relief and geology) to include gradient. (or surrogates, such as form ratios or relief ratios). Thresholds also suggest equilibrium and disequilibrium conditions; with channels in disequilibrium acting sensitively to impose changes (promoting lateral and possibly vertical change). Fuller et. al. (2003) illustrates this in relation to cut-offs of the River Coquet and subsequent channel adjustments in wandering gravel bed systems.

It is difficult to conceive of a 'floodplain stability' index and therefore the index here is limited to the channel.

4.3.4 Adjustment and recovery

Adjustments and recovery were key targets for the development of GeoRHS within the family of RHS survey methods, specifically to address the process and channel response. The nature of adjustment and recovery is that it takes place over time and responds to both natural and artificial changes (subject to the flow (power) and sediment delivery).

Adjustment (over longer periods) deliberately targeted in J and K (evidence of aggradation and degradation): scoring could simply be E=2, P=1,A=0 and total the entries in J1-K8; Where there is no evidence of such adjustments there are potential for further variables to contribute to the stability / instability index, although this needs to be carefully assessed as to whether to give weight to absence of evidence. If this is the case it emphasises the need for careful form filling, diligent identification of evidence and validation – although the photos should help here.

Shorter-term adjustment targeted in B14&15 (bend scour and mid-channel scour) and C10&11, C13 (stable / unstable berms and bed drapes). The experience of the field testing is that may of these feature of adjustment are obscured or harder to interpret in the summer, when taller emergent and marginal vegetation (*Phragmites/ Phalaris* etc) obscure the features. There is also a tendency to mis-classify the berms, and GeoRHS berms should be used rather than RHS, since the later are described as 'rare', when in specific situations they may common and may be dominant. Further advice has been created to assist field surveyors with the identification.

The combination of aerial photographic and historic map evidence also enables adjustment and recovery to be validated, although currently the vector data that would be needed to auto-generate change maps is not available. Aerial photographs are typically taken in summer and in colour so may not provide the best evidence of change although in lowland alluvial rivers classes of change are often evident (where for example 'benches' occur) with marginal tall vegetation and young willow are often diagnostic of lateral adjustment), (Shi et. al. 1999).

'Recovery' could be approached (as on Nar example in section 2.1.2) by adding a score for habitat quality to a score for modification (equivalent to the process for Physical Quality Objectives - PQOs).

The example of the Nar illustrates that this could be linked to type-specific domains rather than the national approach adopted within PQOs.

Many of the variables collected within the GeoRHS / desk study are included as classificatory (e.g. sinuosity, radius of curvature etc), where their value comes from the collation of a large database of sites, allowing categorisation of channel and floodplain forms and geometric relationships. Measures of sensitivity, adjustment and recovery may therefore be dependent on a large database from which to determine type-specific reference conditions that are hydromorphologically meaningful.

4.3.5 Monitoring for WFD

CEN (2003) establishes the standard for assessing the hydromorphological features of rivers, which is being translated into the operational procedures within Britain and the CIS (2003) establishes guidance on the requirements for monitoring. Monitoring protocols and the draft protocol for scoring river quality on physical features (CEN TC/WG 2/TG 5: N46), developing through workshops in Milan and Helsinki relies on a range of variable derived from a broad range of data sources (hydromorphological surveys, local knowledge, existing records, aerial photos). These data sources , which may not be available in all cases, have been used as the basis for proposed reporting structures based on a 3 figure code to score for channel, banks and floodplain. Ten parameter sets are proposed within the CEN 2003:

- Hydrological regime
    - Flow

- River Continuity
    - Longitudinal continuity affected by artificial structures
    - Lateral connectivity and lateral movement of channel
    - Adjacent land use

- Morphology
    - Substrates
    - Channel vegetation and CWD organic debris
    - Channel geometry
    - Erosion and deposition character
    - Bank structure and modifications
    - Vegetation type /structure

The status of a surface water body is determined by the biological quality elements or physico chemical element most affected by a pressure, therefore operational monitoring can rely on the monitoring of the condition of the quality elements most sensitive to the imposed pressures.

Monitoring can be divided into three classes

- Surveillance – ongoing survey to test compliance with standards to supplement and validate the risk assessment and assess long term trends
- Operational – monitoring based on indicators sensitive to pressures, focused on water bodies at risk of failing environmental objectives
- Investigative - cause and effect monitoring to devise/advise on management decisions

Monitoring across all the WFD relevant elements requires a range of indicators, and although surveillance monitoring may only need indicators for a specific pressure wider monitoring is needed to pick up other environmental changes within the risk assessments. EA suggests innovative monitoring techniques are needed, specifically that aerial surveys may provide a basis for morphological quality element monitoring.

Water quality indicators are most widely used but it is recognised that morphological monitoring will be needed to assess pressures on surface waters and defining:

- Monitoring systems
- Suitable indicators
- Reference conditions

It should be noted that, in contrast to the UK TAG reference condition, the draft protocol for scoring river quality on physical features does not apply the concept of river type (type specific reference conditions) and thus seeks to identify broad scales of modification. The proposed GIS implementation strategy Water Framework Directive (WFD) Common Implementation Strategy Guidance Document on Implementing the GIS Elements of the WFD Working Group GIS (2002) suggests a different data structure and recording format for the file and table structures (Table 4-2). As CEN No 46 indicates there is no WFD requirement for hydromorphology to be assigned to 5 classes and therefore the High – Bad classes may be misleading, hence a proposed classification based on the degree of modification, although the GIS classes retain the High – Bad classes.

Table 4-2 CEN guidance on monitoring file structures for hydromorphology

Attribute	Field Name	Definition	Type	Length	Restrictions
Hydrological Regime	HYDRO_REG	Annex V 1.2.1/1.2.2	String	1	Mandatory {H = High G = Good M = Moderate P = Poor B = Bad}
River Continuity	RIV_CONT	Annex V 1.2.1 Rivers only	String	1	Mandatory if waterbody is River {H = High G = Good M = Moderate P = Poor B = Bad}
Morphological Conditions	MORPH_COND	Annex V 1.2.1 / 1.2.2	String	1	Mandatory {H = High G = Good M = Moderate P = Poor B = Bad}

The limitations of these approaches seem to stem from the lack of a type-specific assessment of the parameters that may indicate deviation from natural, for example whether morphological features are natural components of a river type or situation. GeoRHS will provide many of the monitoring requirements in association with the RHS and desk study records.

4.4 Flood risk management implementation

The second key area of application envisaged for the GeoRHS is within the fluvial flood risk management domain. However, there is a clear and increasing overlap with the objectives of the Water Framework Directive and specifically within the requirements for sustainability appraisals for new engineering works to ensure compliance with the WFD objectives. Flood defences, both in-channel and on the floodplain, represent modifications to the hydromorphology often affecting the three principal WFD hydromorphology components of the status, hydrology (storage), continuity (hydrologic pathways) and morphology. The catchment level perspective of flooding is recognised by the Catchment Flood Management Plans (in England

and Wales) and now within the integrated role of River Basin Management Plans under WFD.

Indicators are being promoted elsewhere within the flood risk management planning; a series of indicators have been assessed for environmental change within the flood risk management R+D FD2311 (Law et. al. 2003) related to warnings for fluvial flooding and coastal erosion within the Risk Evaluation and Understanding Uncertainty theme. The indicators here were all derived from secondary information and many flood risk management indicators, especially those related to flow parameters, are subject to the need for sites with long records at gauging stations. Peak over Threshold (POT) parameters are selected as key indicators, but rely heavily on good records. Other indicators considered by Law et al (2004) and within the GeoRHS have been constrained by availability of suitable datasets with national coverage, although the dataset situation is changing, for example the HiFlow project and better maintained asset inventories (within NFCDD) offer wider indicator opportunities in the future.

The main indicator targets for the GeoRHS in flood risk management fields are on:

- Engineering sustainability assessments and Monitoring impacts of schemes
- Floodplain connectivity (both lateral and downstream)
- Conveyance estimation
- Natural process dynamics (e.g. managing sediment)
- Strategic options (flood risk management in relation to conservation objectives – based on flow biotopes and ability of morphology to support ecology, floodplain restoration)

The WFD and flood risk management are now integrated through the WFD requirements for sustainability appraisals affecting both flood risk management policies and flood risk management actions. This may require the restoration of river hydromorphology negatively affected by flood risk management and land drainage other than where certain derogations can be justified as HMWB or AWB or other overriding public and socioeconomic considerations. WFD also allows for closer integration of flood risk management with other river basin management objectives.

Within the scope of the GeoRHS application for flood risk management the survey is more typically operated as a back-to-back assessment or at-a-site assessment, responding to specific survey requirements rather than the random national site assessment. Nevertheless, the national database of sites helps to place a surveyed site within its associated context – within RHS through Principle Components Analysis (PCA). This approach parallels the operation of the RHS and geomorphological add-on (Walker 2000) application areas (e.g. River Eden, Sankey Brook etc).These examples established a strong role for catchment scale management of flood and sediment – which fits well within the catchment flood management planning programme. These approaches have been focused on the rapid site evaluation which can be set within the context of other similar sites.

The applications of the survey methodology to flood risk management may be less reliant on the type-specific reference condition, but where the surveys are for site environmental baseline for flood risk management strategies such a reference provides a valuable context. Increasingly flood risk management projects are being seen as multi objective projects (MOP) and integrated projects (with conservation and floodplain restoration). The Rivers Ripon, Laver and Skell have been selected as pilots for these MOP objectives; GeoRHS has been used within the Ripon survey as part of the geomorphological assessment methodology. These projects recognise the need for river flood management at a catchment scale within the context of Catchment Flood Management Plans (CFMPs) as well as the inclusion of river habitat and geomorphological options within flood risk management planning and design option. Section 3.5 evaluates the role of GeoRHS within this MOP flood alleviation scheme.

4.4.1 Conveyance

Conveyance estimation is heavily reliant on the estimation of the roughness, typically through Manning's 'n' or Colebrook White equations. Modelling of flows contribute to a wide range of flood risk management users for planning, flood forecasting, design and river maintenance. However, there are significant uncertainties in the estimation and calculation of these reach-scale and floodplain-scale hydraulic parameters that makes conveyance estimation uncertain (Samuels et. al. 2003). The uncertainty is the subject of a Defra/EA Flood and Coastal Defence R&D programme W5A-057, which sets out some of the limitations of the parameter estimations. A number of these limitations relate to the estimation of appropriate roughness values and the validation of these values.

The uncertainties in these estimates relevant to potential field approach improvements include:

- Seasonal impacts of vegetation on hydraulic roughness
- Variation of roughness along channels and across floodplains
- Effects of floodplain and channel features (e.g. hedges, permeable and impermeable barriers) on flow levels
- Interaction between channel and floodplains (flow pathways, storages and embanking)

Modelling, for simplicity, makes assumptions on the roughness elements that may not hold true and there is appreciation that reach-based integrated estimates need to consider:

- Conveyance is a 3D property which may be poorly represented by typically derived sectional roughness estimates. Hydraulic and geometric roughness elements need to be considered together with vegetation roughness. Whilst many current modelling approaches make assumptions about vegetation across a section there is little consideration of the full vegetation and structure influence within the reach.

- of permeability (H1-H2), floodplain – to help characterise flow through features and vegetation
- hydrologic pathways G6, and G7-G12; and desk based records of floodplain drainage, water meadows etc
- reach-based estimations of the vegetation cover from both field and desk based cover assessments (H4-H13)

GeoRHS's use of common data capture approaches across the floodplain offers a potential approach to recording the information that the conveyance modelling research identifies as currently missing. The understanding of the measures and the field methodology for collection within GeoRHS will be important to improving the variable inputs into the flood conveyance models, and both field and desk based measurements may be of value.

RHS collected at the same time records the riparian and bank face vegetation that GeoRHS does not include, so there is strength in including both techniques. GeoRHS does include the record of channel buffer zones (F7) and their width (F8) which may form significant roughness elements within the riparian zone. Other RHS measures of the channel form (e.g. artificial two stage bank profile).

In both survey cases the photo records from RHS and GeoRHS would provide a valuable observational context for setting a reach-based Manning's n and relating any improved estimates to observational approaches currently employed. Obviously there are some cautions here as GeoRHS is best undertaken during early spring or winter, before major vegetation growth (particularly tall herb vegetation), but RHS prefers later spring and summer. The value for flood conveyance modelling might wish to cover records for both seasons as vegetation growth will have a significant influence on the seasonal roughness figures.

GeoRHS Desk studies in particular offer standard, and automated ways of collecting information particularly on form roughness variables and vegetation cover:

- Channel sinuosity, meander amplitude, wavelength
- Presence of terraces
- Disconnected floodplains

Some of these variables are treated at a section in modelling terms and may be inherent in the topographic survey, but are not considered at the reach level.

However, in relative terms, when surveys are conducted within the context of a flood risk management operation or a flood alleviation scheme the floodplain measures become more useful even if cause and effect cannot be clearly established. In order to advance the value of the GeoRHS/RHS data in this application closer integration with the programmes on reducing uncertainty in floodplain systems is required.

4.4.2 Engineering assessments (at-a-site assessments / flood risk management EIA, project appraisals and strategy)

Under Article 4(7) of the Water Framework Directive for sustainable development derogations for the ecological objectives may be permitted, but subject to assessment. Flood risk management proposals (or other development), which would result in modifications to the physical characteristics of water bodies, will be required to be appraised against criteria and conditions:

- the development is set out in the river basin management plan and reviewed every six years
- all practical mitigation measures are taken to limit negative impacts on the water body,
- the development is required for reasons of overriding public interest, and
- there are no technically feasible alternative solutions or significantly better environmental options.

WFD ensures that, in future, the hydromorphological quality of the waterbody will have a higher profile in such assessments as a primary focus for monitoring and establishing the support for ecological status (both within the channel and on the floodplain).

How should GeoRHS be used in designing / assessing various types of project which may impact negatively on channel/floodplain, or are designed to rehabilitate or restore? It is likely that different details (and GeoRHS parameters) would be needed for each individual situation, based on the programme objectives and FD options, but GeoRHS/RHS offers a potential for some kind of standard approach.

Frequently, where strategy studies are prepared for Main River there is comprehensive modelling undertaken, but little appreciation of the geomorphological context or the processes operating or that are likely to be affected negatively or positively by the considered options. For example, the Upper Wensum strategy, a document that stretches to 3 volumes, and where the catchment supply of fine sediments and conflicts with nature conservation objectives exist, only refers to geomorphologic survey once (Babtie, 2003). More recent programmes, including the Ripon FAS MOP have included geomorphologic survey from the outset; and in this case are testing the role of GeoRHS. The results of these pilot projects will help define how these programmes can effectively use the GeoRHS data.

4.4.3 Channel - Floodplain connectivity

Floodplains (where they exist) are an integral part of the flood risk management mechanism, reducing the conveyance of the flood and storing water on the floodplain and within floodplain depressions. Connectivity obviously depends on the type-specific character where no floodplain may occur in some classes. Where a floodplain does occur the attributes within D – H of GeoRHS provide characteristics of the floodplain environment.

Floodplain connectivity is also relevant to the WFD application; where there is significant modification the channel processes deviate from the natural situation and therefore the hydromorphological quality elements will be degraded. The same (or similar) measures may be equally valuable to the FD applications at EIA and strategic levels in identifying the potential for floodplain reconnection, implications of Flood Alleviation Scheme actions.

- Key variable from the desk and field study provide the basis for describing this connectivity and interruptions to it. Section D – H;
- Variables are both positive indicators of connectivity (E1- E6) and indicators of divorcing of channel from floodplain (E7-E10 descriptors of embanking)
- Connection with the floodplain through other hydrological pathways (E4 relic channels water filled, G6 river fed floodplain storages, G7 – G12 artificial and natural drainage on floodplain)
- Also related to the connectivity, but also reflecting conveyance is the records of permeable and impermeable boundaries (H1-H2) and floodplain land cover classes (H3-H13).

The section G1-G5 are indicators of the confirmation of the functional connectivity of the floodplain, through trash marks, floodplain deposits etc.

Factors within the survey should be complemented by the desk study variables, in terms of the existing floodplain maps, presence of channels and routes within the floodplain, embanking locations and presence of floodplain storages. The National Flood and Coastal Defence Database (for England and Wales) derived variables envisaged by the user specification for the GIS analysis tool has yet to be implemented. The lack of availability of either a data model or the system precludes this data form the analysis at this stage. It is anticipated that once this becomes available and is populated by both attribute and spatial data that it will complement significantly the site surveyed parameters. There is strong potential for this nationally consistent dataset’s parameters to be auto-extracted, and this should form a target for future GIS tool development. It is currently unlikely that a similar approach would be possible in Scotland by virtue of the distributed and variable nature of the defence data sources.

4.4.4 Repeatable measurements of sediment and erosion

Erosion and deposition as indicators of the channel dynamics offer inference of process dynamics and channel adjustment. GeoRHS specific records of depositional features (C1 – 20) and extents of erosion and acceleration processes (B1-B15) provide a semi-quantitative assessment of the extent of bank features. B14 and B15 within ‘channel features’ extends the assessment to the channel bed erosion.

Combining these measures of erosion and deposition within the survey reach provides some estimate of the nature of changes evident in the system or channel stability. Operated back-to-back the techniques offer a similar approach to the RHS geomorphological add-on (Walker 2000) which surveyed or sampled whole channel or catchment-based sediment assessment using a standard form. The recording of active and stable sediment depositional features (C1- C9) and other deposited fines (C10-C15) and disruptions in sediment deposition (C16-C20) follow from the earlier RHS ‘geomorphological add-on’ and thus will aim to offer a similar level of quantitative assessment of sediment within the reach. Reach by reach analysis and mapping permits a whole catchment scale channel depositional picture to be provided and at least partially categorised on broad sediment sizes.

4.4.5 River design and floodplain restoration

River design is an activity that covers a number of SEPA / EA domains, flood risk management in managing flood risk; conservation in attempting to achieve more favourable habitat conditions and WFD in terms of attempting to meet ecological status objectives. Key issues are whether the quality of the resulting channel is in accord with the hydrological and morphological objectives for the site, the effectiveness of the channel designs, including its relationship with the floodplain. Similarly, floodplain restoration is increasingly being viewed from the engineering domain as a flood risk management strategy, as evidenced by the programme on the Wise Use of Floodplains examining the options for the R. Cherwell. The results of this study illustrate the potential for floodplain restoration (through embankment removal or reducing channel dimensions to pre-engineered dimensions), to contribute to the catchment's flood management strategy.

RHS data has long been used for evaluating the quality of a design reach in relation both to adjacent sites where back-to-back survey has been collected, but also through the PCA based analysis of the RHS records. The inventory based approaches of both RHS and GeoRHS and its desk-based counterparts suggests that survey records can contribute to establishing ‘what is missing’ in physical (hydromorphological) terms from equivalent semi-natural or ‘pristine’ sites as a basis for assisting with natural channel design

4.4.6 Energy classification of floodplains

Classification of floodplain environments has not had the level of attention nor the volumes of data that characterise the river channel environment. Many of the existing classifications of the floodplain are merely descriptive of the land cover classes. Nanson and Croke (1992), working in NS Wales, developed an energy based classification, that attempts to relate channel and floodplain environments through sediment cohesiveness and stream power. Such classification need evaluation within the UK, but may provide valuable classificatory parameters that inform about the ability of the channel to adjust within the floodplain.

Classification of the floodplains and their associated floodplain features also offers the opportunity to associate floodplain features with particular floodplain classifications to identify what is natural or semi-natural within the floodplain context. Such assessments would be based on the analysis of the GeoRHS database once a volume of site data had been accumulated. Many of the current reference sites are in upland areas or cloughs by virtue of the selection process for benchmark sites. Additional surveys of both upland and lowland floodplain rivers are necessary to provide a database of reference condition sites.

4.4.7 Maintenance activity and monitoring

Channel Maintenance and monitoring activity is similar to the hydromorphological quality assessment methods required by WFD (section 3.3.5). The approaches and variable used will reflect the needs of a specific situation, but GeoRHS offers opportunities to monitor response to engineering actions in a standards way. This would relate to at-a-site individual surveys but might be associated with pre-development baseline data or control site and reference conditions site surveys.

4.5 Summary

Section 3.2 to 3.4 and Table 4-3 provide the basis for discussion on the potential indices and classificatory parameters derived from the GeoRHS an RHS combined data, and section 3.6 evaluates the use of GeoRHS as a benchmark survey for the River Laver (Yorkshire) in relation to both an EA Flood Alleviation Scheme and a Defra floodplain land use pilot project.

The extent to which we can develop indices directly from map-based tools and other nationally collated datasets is currently untested. Certainly the role of channel and floodplain geometric, relationships is receiving increased interest, especially in attempting to relate geomorphic and biotic values and longitudinal variation in relation to channel change. Extending the range of shape, planform and channel floodplain geometric relations through remote and map based automation appears to offer an interesting research avenue.

Role of the national database of GeoRHS / RHS variables was conceived as delivering a wide range of other applications, habitat quality assessments and restoration objectives. Other application domains need to be considered in greater detail, especially to assess whether one application can address a number of data requirements – for example floodplain connectivity may address WFD, FD and restoration strategy development.

It is apparent that the range of parameters within the collected information base offers a wide range of potential evaluation and monitoring indicators, that may be applied at a national or river type-specific level. However, whilst the parameters can be used at an individual site level, there is a need to assess the survey requirements against the specific problem under investigation; for which more detailed geomorphological surveys may be required. A range of other geomorphological survey tools are available through the *River Geomorphology: a practical guide, (Guidance Note 18, R +D 661 (1988), Universities of Nottingham, Newcastle and Southampton*) to address such specific requirements. For example, where there is a bank erosion issue geomorphic dynamics assessment or bank stability surveys may be appropriate. At the more strategic level GeoRHS may well provide the most cost effective approach for placing the survey site within the context of similar types of rivers – to indicate what is ‘missing’ and what works in management terms.

There are a range of other data developed by the GeoRHS surveys that contribute to the management and monitoring of channels and floodplains. In particular the geo-located site photographs provide a validation dataset for the survey itself, but the bar sediment photos provide a visual basis for estimation of form roughness that is not widely available. This approach operated within the Thames region (GeoData 1994) went further to undertake particle size analysis for riffle sites as the basis for substrates for restoration works. A similar, albeit photographic assessment, based on exposed bar sediment within GeoRHS offers a similar approach for estimating D50 sediment size parameters that may add to the attribute records for roughness and contribute to site understanding for biological and fisheries habitat assessments.

Table 4-3 A 'menu' of the more direct parameterisations and indices available from GeoRHS + additional support available from RHS (*refer to the field manual for the list of parameter values or to Table 3.1*).

CLASS OF INDEX/METRIC	TARGET FOR CHANNEL & FLOODPLAIN INDICES	INDICES AVIALABLE FROM GeoRHS ALONE	POTENTIAL IMPROVEMENTS BY INCORPORATING RHS DATA
CLASSIFICATORY, TYPING AND DESCRIPTIVE	**Geomorphological summary of channel/floodplain**	Bankfull dimensions A1, A2 Channel slope A11 Channel bed/bank sediments A6, A7 Backwater impacts A4	10 spot checks permit W&D variance index Overlap: suggests GeoRHS do Wolman? Flow types extend the energy snapshot
		THE ABOVE PERMIT STREAM POWER CALCULATIONS OF SEDIMENT MOBILITY	Bank profiles may assist in detailed hydraulics
		Floodplain presence/absence D1 Floodplain width A3 Floodplain relief D7 Floodplain roughness H1 – H13 Floodplain slope D6 Embankments & channels inside E7 – E11; G8, G9 Two-stage channel A10 Macrophyte/CWD/sediment obstruction C17 – C19	n/a
		WITH DESK STUDY DATA, THE ABOVE IMPROVE FLOOD CONVEYANCE ESTIMATION	channel vegetation for detailed hydraulics
			Section D includes bridges; GeoRHS not

CLASS OF INDEX/METRIC	TARGET FOR CHANNEL & FLOODPLAIN INDICES	INDICES AVIALABLE FROM GeoRHS ALONE	POTENTIAL IMPROVEMENTS BY INCORPORATING RHS DATA
	Dynamic change indicators: sensitivity and resilience	Palaeochannels and terraces D3-5, D8-10 Recent flood activity G3, G5, C20 Recent floodplain deposition A8, G4 In-channel local deposition of fines C14 – C15 Channel migration F1 Widespread accumulation of bank erosion B7	n/a
		Pressures in riparian zone B8 – B13	Bank face and bank top information
		Tree condition and spacing (resilience) F2, F3, F5	Overlap: GeoRHS should focus on roots
		SENSITIVITY MAY ALSO BE COMPARED BETWEEN SITES e.g. total bank erosion per unit stream power	
	Channel-floodplain connectivity: local flood hazard	Existing protection E7 – E11 (A10 also refers) Flooding routes E1 – E3 Heights reached by floods G1, G2 Storage of flood waters G6 Return of flood flows G7, G10 - G12	n/a
		DESK STUDY AND INDICATIVE MAPS CAPABLE OF GROUND-TRUTHING WITH THESE DATA	

CLASS OF INDEX/METRIC	TARGET FOR CHANNEL & FLOODPLAIN INDICES	INDICES AVIALABLE FROM GeoRHS ALONE	POTENTIAL IMPROVEMENTS BY INCORPORATING RHS DATA
EVALUATIVE	**Geomorphological 'health check' vs 'natural' state**	A crude ratio of (B+C)/A lengths, scaled by A1 Diversity & distribution of erosion & deposition B & C tallies (scaled, perhaps by stream power but, more vitally, typed to planform) Modify form to make A9 a tentative surveyor-assigned score?	Numbers of riffles and pools Features of special interest Planform information now restricted: suggests need to bring into GeoRHS
	Channel quality and modification	'Natural' materials on bed/banks (not AR) at transects W/D ratio appropriate to bank materials Condition of riparian zone F2, F5, B8 – B10, B12 – B13 Coarse woody debris C19 Modification includes A10 but also B11 – B13, C12, C16, J8, K8 HQI & HMS A MODEL FROM RHS BUT MAY NEED TO REFLECT THE ADOPTED TYPOLOGY + BE SPECIFIC TO GEOMORPHOLOGICAL FACTORS LIKE STREAM POWER & SEDIMENT CALIBRE	Braiding – channel numbers Bank structure and 5m riparian land use Overlap but RHS does not quantify Channel and bank modification by transect Empirical experience

CLASS OF INDEX/METRIC	TARGET FOR CHANNEL & FLOODPLAIN INDICES	INDICES AVIALABLE FROM GeoRHS ALONE	POTENTIAL IMPROVEMENTS BY INCORPORATING RHS DATA
	Floodplain quality and modification	Presence/absence and width D1 & A3 (latter cf A1?) Storage of flood waters G6 Wetlands H12 (good) – H11 (poor) Floodplain land use from e.g. H3/H6/H10 to H9 & H11 Embankments etc – modifying 'flood pulse' A10 & E7 INITIALLY REQUIRES FIXING OF 'IDEAL': HQI AND THEN SCORES FOR MODS: HMS	n/a
MONITORING	**Geomorphological adjustment/recovery**	At a broad (system) scale, all of sections J and K Locally, adjustment signalled by e.g. area of C10 'Stable' bars vs 'active' bars C5-C8/C1-C4 Other signs can include balance of B15 & C13 or C17 Trees are often good indicators B8, F6 ACTION REQUIRED TO 'SCORE' THESE ALONG THE LINES OF NEWSON et al., 1998)	APE scores – no quantification Occur as marginal/bank features only Empirical 'stability' via materials & features (Newson et al., 1998)

CLASS OF INDEX/METRIC	TARGET FOR CHANNEL & FLOODPLAIN INDICES	INDICES AVIALABLE FROM GeoRHS ALONE	POTENTIAL IMPROVEMENTS BY INCORPORATING RHS DATA
	Physical habitat processes	(Changes in…..) W/D ratio (indicates gross erosion/deposition) A1 – A2 Sediment sources (total tally B1 – B13 x mean A2?) Sediment sinks (total tally of C1 – C9 Fine sediment problems C10 – C11 & C13 (needs more explicit entries on form)	 Sweep-up only Sweep-up only Discrete gravel, sand, silt deposits: GeoRHS to improve
	Response to management actions	(Changes in……) Failed revetments B13 Buffer zone F7 – F8 (related to bank erosion tally) Local impacts such as B14 or B15 cf A10 actions Regular impacts such as B7 cf J8 Bank erosion impacts of K8	

4.6 A field test of the relevance and meaning of a selection of GeoRHS indices (with implications for survey design)

4.6.1 General

This section provides an evaluation from Malcolm Newson's implementation of GeoRHS for the River Laver as part of a flood attenuation dam scheme and the separate Ripon Multiple Objective Pilot (MOP). It raises some issue for the scope of the GeoRHS surveys and the form. The section should be read in association with the field form as it refers to the alphanumeric codes allocated within the GeoRHS field form.

Whilst it is clear that there are clients for GeoRHS indices, principally FRM and WFD scientists and regulators, previous effort has expended in 'fit-for-purpose' arguments, rather than giving the data yielded by the current GeoRHS field forms a geomorphological grilling. The spirit of this section, encouraged by the need to summarise Malcolm Newson's field data from the River Laver, is simply to characterise the 500m surveyed such that a fellow geomorphologist could take generic interpretation further.

4.6.2 Assessment of GeoRHS and candidate indices: River Laver

The GeoRHS system has many precursors, but as a nationally-adopted technique it remains transitional between R&D and routine application as part of sustainable river management. The survey form evolved subtly (within the national R&D) during the application to the Laver and so the format used here is now dated in its detail; it is nevertheless fit-for-purpose.

Initially, there a number of comments related to the deployment of GeoRHS, such as to facilitate the range of 'normal' applications for the technique and to reduce uncertainty in the meaning and validity of the derived indices. The first element of note in the application of GeoRHS to the Laver (both Flood Alleviation Scheme and Multiple Objective Pilot) was that it is to be used as a monitoring technique; hence sites were chosen with a view to impacts and successful re-location at a future date is vital. Whilst we have taken care to triple mark each transect (peg, photo, GPS) we would have benefited from extra space on the survey form to describe landmarks in terms of trees, posts etc. and to add the flow type (biotope) crossed by the transect.

Secondly, the Laver application has continued from February through May; the impact of the growth of a riparian herb/scrub cover on access and the ability to observe features/dimensions/sediments confirms the view that GeoRHS is best carried out in winter. The principle errors resulting from a heavy vegetation cover are likely to be in estimating the length of bank erosion, typing it and assigning deposits to a stability category. However, at discharges higher than baseflow there can also be errors in detecting subtler deposits such as berms. Since GeoRHS and RHS are being scripted to be carried out side-by-side (with good reason – see below) one or other may suffer lower quality as a result.

Transect observations relating to bank materials currently allow only a mineral material whereas, particularly in the Laver, the relevant bank material is organic – especially dense root covers. This information might be available from RHS but, as a precaution, should be permitted as an option on the GeoRHS form. Another relevant observation in this 'overlap' area between the two surveys concerns the pool-riffle sequence. Long recognised as diagnostic for geomorphological 'health', we have added it as a comment in available space: again an optional entry in sweep-up for GeoRHS may be useful.

GeoRHS training has identified the problem of identifying bankfull dimensions in channels where there are transitional depositional features between stable bars and the 'true' floodplain. It has been proposed that these be termed 'inset benches' but we have added these to notes for the Laver surveys because there is as yet no national decision.

Finally, there are two potential upstream impacts of the Ripon FAS that GeoRHS is currently not structured to monitor and which may be worth adding to the form in future: infiltration of fines to a gravel matrix (would need a standard method of disturbing bed materials) and widespread deposition on a floodplain (needing optional boxes to complete for recently flooded sites).

4.6.3 Header information

The maximum possible information to characterise a river length (and therefore to enter into other indices when comparisons are made) comes from the hydraulic geometry variables of width, depth and slope. Users are going to need these for stream power, for regime dimensions and departures and to scale other indices for the channel in question. It is worth considering, albeit belatedly, whether we need slightly more information in the field: wetted perimeter at bankfull to get hydraulic mean depth? It would also be interesting to try an index like the coefficient of variation of width, depth and slope, since these now seem to be useful hydraulic geometry characteristics (Stewardson, 2005); such calculations would currently rely on a sample of 5! It would also be useful to know whether the banks at each transect are eroding or not.

Great care is needed (for use in FRM) to reconcile the bankfull width with entries under A3, A10 ('embanked') and E7-E11. Some form of visual check – e.g. cartoon cross-section to look for nonsense – may save those routing channel flows huge headaches as users.

For the Laver sites the application requires repeat surveys for monitoring and surveyors have used pegs and landmark information. The desk study outputs will give a much more visual impression of the whole survey lay-out but it might still be a useful addition to have a succinct textual entry for each transect; the use of biotope information might serve this purpose e.g. 'top end of pool below prominent riffle'.

There are points about the transect information that are worrying, particularly the state of bank vegetation (dense leads to NV, but roots are a virtual sediment type) and bed material size. IF RHS is applied at every GeoRHS site, the vegetation, bank profile etc. will be available (the latter perhaps helping with wetted perimeter) but the RHS bed material categories are the same as ours. Rhetorical question therefore: a Wolman sample for every site? – even by photo-sieve methods which are optional at present.

Again, revealed by the Laver study, an index deriving from bed armouring and one describing the infiltration of fines would have great benefit to FRM and WFD users, respectively. It seems very hard to take the transect categorical data forward to characterisation.

4.6.4 Part One: Channel morphology

Indices derived from A10 entries are vital to both FRM and WFD users but that their state holds vital clues. Since geomorphologists argue that process is the best guide to 'natural' it would be desirable to indicate the balance between process and the constraints offered by the engineering; currently we only have B13 'failed revetment' to help with this. Clearly, categories B and C will help considerably to indicate erosion and deposition processes there is no spatial reality in relation to structures. On the Laver it is important that users know that 'ad hoc revetment' has no real process impact because it is associated with a continuous tree cover; there is bank erosion in such reaches, but not of the revetment lengths! Recent critiques of HMS have focussed on the need to both order and score human impacts extremely carefully.

Experienced surveyors have moaned slightly that the time taken to tally dimensions for channel features outweighs its usefulness compared with the simpler 'A/P/E' (or Jim Walker's original categories) but, in line with stressing the value of width, depth and slope, the number and variability of the tally entries will be the basis of powerful indices. Many indices derived from page 2 of the survey should be scaled by a choice of header variables – width is probably best – to compare between sites. This reasoning comes from the 'riffle-diagnostic' and may carry a deal of geomorphological assumption: maybe sites can be compared 'raw' and after standardising by bankfull width. Clearly, indices involving erosion length and deposition area carry their own scaling – every site has a potential 1000m of bank erosion and big rivers have bigger bars!

The Laver has shown that B8 may need development. Potentially one of the most tree-clad meso-scale channels in the UK, the Laver indicates a complex interplay of CWD and standing trees, as well as 'fallen trees' on channel morphology. There is a form of bank erosion associated with riparian tree lines that is not covered well by F6 (but might include washout at roots): tree-lined channels are 30% narrower than grass-lined channels in the UK but they carry the same flows – hence those flows are deeper! The result is that the trees at 'bankfull' will be partitioning the flow and creating impressive local turbulence; this results in erosion by both the cells and the re-entering flows downstream of the trunk. It would be good to accommodate this form of adjustment – suggested term tree bank scour?

Using indices based upon the area of depositional features makes their accuracy highly dependent on the flow on the day of survey (just as bank erosion indices are dependent on the season of survey): would it be possible, in the former case, to convert the Header information on flow conditions into a precautionary asterisk or even to risk a calibrated increase in areas to reflect base flow?

4.6.5 Part Two: Floodplain Geomorphology

It seems daunting to derive numerical indices here when the balance has switched dramatically to categorical – there are clearly appropriate statistical options and precautions available. Obviously, the 'H' group need to go into a roughness calculator and E7 – E11 directly relate to the hydraulics of flood flows via width and depth. In this connection, we have only gone for maximum height of embankment (E10); to indicate spilling might not the minimum also figure? E9 can also be an unstable number – but the Desk Study would be very useful for this index.

Considering the need, especially in WFD, for some indices to characterise adjustment within different river types, the F1 'Channel migration' is uninspiring on the Laver! It produces more information when combined with K3 and perhaps should be moved to the J & K area of the form. These two were derived from Sear et. al. (1995) signs of instability (but get nowhere near the segmentation of 'upland, transfer and lowland' river types in Sear's original table). For the River Laver there would be great value in ticking one of Downs' channel adjustment categories (Downs 1995) or Hooke's meander types (Hooke 1977): maybe there should be a kind of 'archive sweep up' attached to the site data but it is the field observer who spots these things; or alternatively use interpretation from the RS data.

The adequate identification of adjustment may become an ultimate test for GeoRHS, especially if there becomes a tendency to use GeoRHS data rather than commission Fluvial Audits. It is for this reason that we must consider the berm and 'inset bench' controversies. The latter also takes us back to the accurate identification of bankfull and hence the basic driving parameters of the whole index set. Unlike the RHS definition of berm, geomorphologists associate it with (a) width adjustment in the sorter term and (b) fines. It cannot be a floodplain in the forming – but that is the role of the inset bench where meander cut-off is the characteristic adjustment, both of planform and elevation. The cut-off locally increases gradient; the extra stream power causes local incision and the bars abandoned by the cut-off become highly stable, even tree covered, but are inundated before 'true' bankfull is reached. It requires several phases of such adjustment before the benches start to join up and function as floodplain – this is when the former one appears to be a terrace.

4.6.6 A trial calculation of the candidate channel indices for 12 sites in the Laver catchment

Throughout this report, the emphasis has been on the potential of the GeoRHS system to yield particular indices and the potential of those indices to characterise the river and floodplain. It is, however, desirable at an early stage to 'see what they look like' in terms of statistical robustness and as a record of differences between sites. The 12 Laver sites in some ways form a good test because they are drawn from a relatively homogenous population – a generally stable channel system with highly characteristic forms of adjustment within the confines of a prominent riparian vegetation belt. Two tables are included here – to simply list the calculations to 'see what they look like' (Table 4-4) and a definition table which also contains an initial verdict on success or failure (Table 4-5).

Table 4-4 Summary of indices calculated for the River Laver.

Index	K1	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	11
SLOPE	n/a	n/a	0.011	0.015	n/a	n/a	n/a	n/a	n/a	n/a	0.009	n/a
Mean w	6.6	14.1	12.3	15.2	7.0	8.6	12.8	12.8	13.0	13.1	12.6	18.8
Cv w	38	42	65	86	43	58	39	63	54	(23)	56	(106)
Mean d	1.1	1.6	1.3	1.4	1.36	1.28	1.36	1.34	1.39	1.35	1.5	1.8
Cv d	55	75	23	50	22	39	96	45	54	15	33	28
W/D ratio	6	9	10	11	5	7	9	10	9	10	8	10
Modal bed	gp	gp	gp	gp	gp	gp	co	co	co/gp	gp	co	Co
Modal bank	Ea/roots	Ea	Ea/roots	Ea/roots	Ea/roots	Ea/roots	Ea/roots	Ea/roots	Ea/ro/he/sh	Ea/roots	Ea/he	Ea/he
AR bank	0	0	0	0	30	0	0	0	0	0	40	10
A10 occ	0	6	1	2	17	7	1	1	3	0	2	5
A10 %	0	1	6	4	15	3	1	.2	.8	0	8	7
Erosion occ	4/9	8/11	1/1	3/5	6/25	18/40	7/10	13/19	13/14	13/16	2/2	4/5
Erosion %	5/6	1/2	4/4	10/11	7/21	3/5	1/2	3/4	2/2	1/1	6/6	8/8
Scour %	.2	0	0	0	0	2	1	1	0	0	0	0
Active dep. Occ	13/17	5/5	4/4	6/6	2/4	6/8	18/24	17/22	6/7	5/8	6/8	4/4
Active dep %	3	4	1	1	3	2	4	5	3	2	1	2
Stable dep. Occ	0/0	0/0	0/0	4/4	0/0	1/1	3/3	7/8	½	4/6	2/2	5/5
Stable dep %	0	0	0	12	0	.1	3	4	2	3	4	7
Riffles	17/4.5	16/2.2	7/5.8	7/4.7	14/5.1	13/4.5	10/3.9	8/4.9	10/3.8	10/3.8	8/5.0	7/3.8
CWD occ	0	0	0	0	6	5	5	5	3	6	2	3
CWD %	0	0	0	0	1	.2	.4	.3	.2	.3	.1	.3
W + em	6.6	14.1	12.3	15.2	17.0	8.6	12.8	12.8	15.0	16.6	12.6	18.8
D50	n/a	45mm	n/a	n/a	28-37mm	n/a	30mm	32mm	n/a	n/a	n/a	50mm
J/K entries	n/a	n/a	n/a	n/a	0	0	K2&K3	K2&K3	K1-K4	K1-K4	n/a	n/a
Inset bench %	0	0	0	0	0	0	0	0	18	.6	3	3

Table 4-5 Evaluation of index values from the River Laver

Index	definition	Indicator class	Laver test verdict
SLOPE	Abney/clinometer – in the field	Driver	Vital – FAS design will use (stream power)
Mean w	Bankfull width, average of five	Driver	“
Cv w	Range of widths/average	Diversity	Sample of five unstable but may link to diversity or river type
Mean d	Bankfull depth, average of five	Driver	Vital – FAS design will use (stream power)
Cv d	Range of widths/average	Diversity	Interesting range here, suggests spill levels never uniform for 500m?
W/D ratio	Width/depth ratio (bankfull)	Type/condition	Limited discrimination, 5-10 what you might expect of highly wooded banks
Modal bed	Largest class over five transects (bed)	Driver	Discrepancy with Wolman where done
Modal bank	Largest class over five transects (bank)	Driver	Earth predominates – tells little on its own!
AR bank	% of the 10 bank entries = ‘AR’	Condition	Best ‘instant index’ in this sample – demarcates the agricultural response
A10 occ	Number of entries in A10	Condition	Shows there’s more to consider than ‘AR’
A10 %	Length of A10 as % of 2x500m	Condition	L4 really is the most interfered with
Erosion occ	Number of entries in erosion (+ biological)	‘stability’	L5 badly affected by poaching/burrowing; L4 by isolated tree scour
Erosion %	Length of both erosions as % of 2x500m	‘stability’	Compare with Fluvial Audit national erosion table? L4 & L5 again show
Scour %	Area of scour as % of mean w x 500m	‘stability’	Too rare and too small to help in this sample
Active dep. Occ	# active deposition entries (+ berms)	‘stability’	Large bars not a characteristic of low W/D. Kex, L6 & L7 have sand berms
Active dep %	Area of active deposition as % of wx500m	‘stability’	National RHS knowledge on this?
Stable dep. Occ	As active	‘recovery’	Tree cover largely prevents stabilisation of all bar raised benches
Stable dep %	As active	‘recovery’	National RHS knowledge of this?
Riffles	Riffle count and spacing (ratio to w)	Type/condition	Very riffly channels, all below ‘standard’ of 7 x w spacing
CWD occ	Number of entries for CWD	Type/condition	Little information here – maybe area of largest occurrence better?
CWD %	CWD area as % of wx500m	Roughness	Use of this for Manning links to on floodplain calculus for Manning
W + em	Check on embankment mod to w	Driver mod	Simply to alert those using stream power of the need to consider
D50	Wolman where carried out	Driver	Inherently ‘feels better’ and will be used for FAS design
J/K entries	(Where page 3 completed)	‘stability’	L6 – L9 definitely the most graphic adjustment sites
Inset bench %	New category indicating adjustment	‘stability’	Useful to indicate local, rapidly vegetated adjustments – not in J or K entry

5 Prioritising the indices development and testing

5.1 Introduction

The table of indices (Table 3.3) sets out the subsets of variables that might contribute to the indices, and specific targets which need to be prioritised. This selection of priority indices was undertaken by the Project advisory group to select two indices, from the many originally proposed, to take forward and test based on the GeoRHS and RHS data collected within the scope of the project.

Certain principles for the generation of indices were discussed, and at least some were agreed within the meeting, that have a bearing on how variables are selected and combined within the programme. Similar approaches have been proposed within the draft protocol for scoring river quality based on physical features, and these are relevant to cross-reference to any GeoRHS/RHS derived indices. In particular, it was considered that indices should be constructed in a uni-directional way, such that positive or negative factors are scored and weighted; rather than attempting to integrate both positive and negative elements within the same index. The recording of the ‘absence’ of a feature may be treated as both a positive and a negative variable depending on the context and the index being generated. For example, the absence of a form of channel modifications may be treated as positive in terms of naturalness and as a negative in an index of modifications. The second principle was that selected attributes (from GeoRHS, RS and RHS) would be scored and combined but that weightings were more likely to be applicable at the river type-specific level.

A number of key issues remain that will affect the validity and confidence in the indices:

- Whether individual measured values can be effectively mixed with categorisations - such as ‘absent, present or extensive’.
- Dealing with missing values within the development of indices will be a particularly difficult issue – does this limit the value of the site if data are not available, or the confidence which one has in the index?
- Should banks be treated as separate or combined for the purposes of developing an index, and how reliant on the individual index is this.
- Is there potential for combining indices to generate reclassifications, similar to the approach used in the PQO and the MCA analysis proposed in section 3.1.2.
- How should breakpoints in the scoring categories be defined where the values have been recorded – or should this await the acquisition of sufficient data from a range of sites to allow these breakpoints to be set on ‘real data’?
- Should all values within an index be uni-directional (all positive or all negative; or is it possible to derive indices by combining these)?
- The degree to which scaling factors are used, e.g. bankfull width, stream power etc as a means of characterising the scale or the river system; and the potential to add

scaling factors from ‘external’ data sources (such as FEH derived discharge estimates).

- Assignment of weights to scored parameters and the development of appropriate river type-specific values.
- How an index could be used for different river types – whether the index scoring method remains the same, whether attributes are added or dropped in the index for certain river types, or whether feature weightings are applied after the scoring or whether the comparison should be restricted to the same river type (as proposed by RHS).
- Issues of ground-truthing of indices and the setting of criteria for testing the quality of the indices

Dealing with missing values is probably best tackled, at least at this stage, by flagging the information with levels of confidence. Where a feature is not visible (NV) this also implies a missing value for which it may not be possible to resolve an answer and the assignment of a 0 score. The storage within the database queries of the individual score values for each parameter for each site within the database when creating the index allows the individual sites to be interrogated, to see why a site may score differently to what is anticipated. Checking of the index, the individual scores and the photos can help categorise the quality and confidence levels and provide an explanation of the resultant index anomaly. RHS approaches to missing values confidence limits may not be appropriate if a feature is not used in a particular index and thus should only be applied where the features are actually components of the index.

Alternative strategies to missing values may be relevant subject to further testing and a wider range of sites. The complexity of mapping floodplain elements in the field may suggest replacement of some field parameters by GeoRHS desk based or RHS based parameters. Additionally, the actual recording of a feature and the consistency of that record, based on a frequency analysis of missing values for particular attributes may help to refine the nature of the field survey or replace a feature record to minimise the occurrence of missing values.

However, the combination of surveys (RHS, GEORHS and desk study) and potentially a range of other secondary data variables may allow gaps to be partially filled (subject to modification of the scorings). For example, GeoRHS’ inclusion of information on berms as a numeric value might be replaced by the RHS spot check record of berms (as bank modifications or marginal and bank features for artificial and natural berms respectively). However, and to use berms as an example, great care is needed in such circumstances due to the differing survey ontologies (berms in RHS are seen as bank modifications and rare features). In GeoRHS berms are recognised as common, fine sediment and often as natural readjustments to channel change (whether natural or man induced) and deposits of the bed not the banks, and allows for artificial berms that may be closer to the RHS definitions of bank profile adjustments and channel narrowing modifications. Separate advice on berms has been provided within GeoRHS. Where the presence of berms in RHS is therefore given a score at each bank, and each section where it occurs, the scale and naturalness of the feature is uncertain, especially where the berm is a natural response to channel change or a readjustment to past modification – essentially a naturalness feature rather than a modification feature. The river type-specific categorisations may help to determine the appropriate use in these circumstances. In Scotland the association with the proposed morphological alterations database (WFD 74) would provide a basis for appropriate use of the feature attribute within the index.

The assignment of the index types was based on a categorisation: classificatory, evaluative and monitoring indices. The decisions made in selecting priorities for indicator development were:

a) Classificatory index: Channel and floodplain connectivity index (5.3)
b) Evaluative index: Naturalness, or natural state indicator (5.4)

These index selections have been based on the testing of selected attributes ability to discriminate classes on the R. Laver (section 4.6) and by the project board and lead end users. The procedure for developing indices has been similar to the development adopted for the RHS indices, which now incorporate the potential for weightings of the attributes as well as scorings. The new scoring systems for RHS Habitat Quality Assessment and Habitat Modification Scores have not been replicated and it is envisaged that these approaches would be run together given the integration (eventual) of the databases. Scoring are applied within the attributes and weightings are applied between different attributes, thus the width of floodplain attribute may score highly for larger widths, but relative to the presence of embankments have a low weight when calculating the between attribute influence.

5.2 Implementation of indices

The implementation of the indices has been undertaken as a series of queries within the GeoRHS database. Where values from the desk study and RHS parameters for the surveyed sites are used the database links to these databases based on the allocated site number to derive complex queries. Currently, the scoring tables within the queries are set up separately, such that the scoring can be refined and the index re-run, however this element has not been programmed as a ‘user friendly’ interface or slider-bar type interface, which would help exploration of the sensitivity of the generated indices.

The testing of the indices here will inevitably be influenced by the GeoRHS site selection (section 5.6) that emphasised sites close to or at reference condition based on the RHS data. Thus those indices that seek to identify naturalness, lack of modification and floodplain conditions and connectivity are likely to all score highly, since the impacts at the selected sites should be small, subject to RHS criteria.

No attempt has been made to score for the different forms collected during the GeoRHS development process. Since the field form was changing significantly the available suite of attributes or the measures of those attributes was also changing. These legacy sites may still be of value but are not treated as GeoRHS sites for index development.

5.2.1 Future index refinement

It is proposed that, subject to the approach being refined with a broader range of sites, especially with sites with higher degrees of modifications and a wider range of the Reference Condition sites, that the scores would be refined and that the river type-specific aspects would be picked up by type specific-weightings. Thus the surveyed sites may need to be classified (assigned to a typology) before index values are compared. Hence, where a channel vegetation measure is used, the relative importance of the attribute is influenced by the baseline vegetation status indicator for the river system, which may be type-specific. To take another example, where the degree of ponding is seen as a negative factor for naturalness a type-specific weighting may be applied where the channel is tidally influenced to allow the score to act positively in such circumstances (as a 'natural' feature of such reaches).

The weighting system has not been applied to these indices at present and an interface to both the scoring and weighting should be developed on the existing database structure to allow exploration of the index scores and weights. The scoring and weighting could be integrated within the GIS application to provide a mappable interface to the index.

Not all the attributes collected within the GeoRHS and RHS datasets have been used within the scope of these two prioritised indices, and there are opportunities to add more parameters to a specific index. For example, 'C13' bed drapes of fines, may be a specific negative naturalness indicator, but one that only applied in certain river-types. Consideration should be given to whether type-specific attributes are also added to the calculation of indices as well as type-specific weightings, through a database interface that allows selection of the variables to be scored. If applied on a section of records based on a river type-specific selection criterion (e.g. WFD typology) then comparison between sites would remain consistent.

The GeoRHS methodology was recognised as having a great potential for future linkage to other data sources (section 4.3), and in particular to the Flood Estimation Handbook (FEH) estimations of flood discharge levels at the location of the GeoRHS surveys. Such extensions, potentially with the automation of data extraction could provide valuable additional component attributes to GeoRHS to provide estimates of power and predict processes.

Currently, the calculation of indices is a complex database query that does not promote the interactive exploration of the scores, weights or the resulting values generated; an interface that allows greater user manipulation is needed. Integration of the different host IS systems (for SEPA and the Environment Agency) will be important in ensuring that the GeoRHS data are used effectively and integrated into existing working approaches and indices interfaces. Without the development of GeoRHS within RHS database and the lack of implementation of the RHS database within Scotland an interim measure would be the development of a front-end based on the database / GIS systems created for this R+D programme; allowing refinement of the index rules to be implemented in the RHS database if adopted.

5.3 Channel and floodplain connectivity

The channel and floodplain connectivity index was envisaged as a contributor to Flood Risk Management (FRM), and as a basis for assessing the value of natural flooding as a flood risk management strategy. The index is proposed as using data from desk and field survey and dividing the categorisation into three sub-indices:

a) Existing connectivity status
b) Habitat and environmental value of the floodplain
c) Practicality of restoration of connectivity.

The approach is only used if there is a floodplain or a disconnected floodplain. If there is naturally no floodplain in the river survey reach the site is excluded from further analysis and assigned values for the three sub-indices.

The objectives discussed also included the potential to evaluate the degree of favourability for connection, through the reclassification of the resultant measures based on the degree of connectivity and the value of re-connection. Thus there is a low connectivity but high value in doing so there is a target for restoration. A low connectivity and a low value may be less favourable target for restoration of connection, although the favourable condition may suggest these are higher level targets.

Thus all three sub-indices will use the presence of floodplain as a trigger for the further assessment of a site.

The scoring approaches are indicated in Table 5-1. There are significant issues that need to be considered in the longer term as to how to manage the information in relation to left and right banks. In this pilot the left and right bank has largely been combined, on the assumption that the connectivity to the floodplain does not matter whether it is LB or RB. However, a number of the measures used need to be evaluated on the LB and RB separately, as the influence on the index will vary. For example, the length of embankment of 500m would imply on average 250m on each bank if there is a floodplain on both banks but a full embanking of the floodplain if there is only a floodplain on one bank side. Therefore the index will score each bank separately and then add the values.

Essentially, the index seeks to indicate the connectivity, the higher the value the higher the level of existing connectivity of the river with the floodplain. The connectivity value is proportional to the extent of the functional floodplain.

Width to depth ratios may be able to indicate reduced connectivity due to channel modification influences, but there are problems with the accuracy of the field measurements of depth within the surveys and uncertainty of the river type-specific values that are ‘natural’. As an alternative the record of A10 ‘resectioned’ and straightened may be used a surrogates for reduced connectivity by virtue of channel modifications.

Table 5-1 Channel and floodplain connectivity sub-indices (better formatting)

Existing connectivity			
Parameter	**Description**	**Measure / Comments**	**Score**
D1	Floodplain - must be continuous or intermittent to allow connectivity.	A/I/C	If A record as no floodplain. If I or C calculate metrics.
A10	Embankments Set back embankments	Tally – setback embankments only (A10 partially duplicates E7) Culverted, straightened and resectioned should only apply to the channel not separate banks but metre tally will clarify this. Sections may be straightened and resectioned and the effect on connectivity is likely to be additive.	A10 Setback embankments (scored for each bank then summed) 0-125 3 125 -250 2 >250 1 A10 straightened 0-250 3 250-500 2 >500 1 A10 resectioned 0-250 3 250-500 2 >500 1

Existing connectivity			
Parameter	**Description**	**Measure / Comments**	**Score**
E7 – E10 (A10 also refers)	Existing disconnection of the floodplain. If no embankment no ratio and assigned 5.	E7 No of embankments Duplicates value of length of embankment. E9 Distance EM crest to bank top Greater distance to embankment indicates greater residual connectivity - as proportion of floodplain width (A3) proportional width). Functional/geographic floodplain ratio E10 Max EM height above FP Use lowest maximum height in LB and RB as limiting value E11Natural levees and dredgings Natural levees and dredgings difficult to use if levees are natural and dredgings are artificial – different indicators may suggest changes to form.	Score for both banks. E7 Embankments (scored for each bank then summed) 1-125 3 125 -250 2 >250 1 E9 Distance to embankment crest Max LB/RB value / average width A3 0.1 1 <0.25 2 0.25-0.5 3 0.5-1 5 E10 Max EM height: <1m 3 1-1.9 2 >2 m 1

Existing connectivity			
Parameter	**Description**	**Measure / Comments**	**Score**
E1 – E3	Flooding routes	E1 Direct uniform spill (APE) - implies connection E2 Eroded low points (APE) low points promote access E3 Active side channels (APE) If nothing entered the sites will be allocated A – this needs to be clarified in training.	Combine LB and RB data – so if occurs on either LB or RB allocate score. E1 Direct uniform spill A 0 P 1 E 2 E2 Eroded low points: A 1 P 2 E 2 E3 Active Side Channels: A 1 P 2 E 2
H2	Impermeable boundaries, parallel / cross floodplain	APE / IIX Most surveys do not indicate whether parallel or cross the floodplain – a training issue.	H2 impermeable boundaries E 1 P 2 A 3

Existing connectivity			
Parameter	**Description**	**Measure / Comments**	**Score**
G1, G2	Heights reached by floods	Height above floodplain (m) Recorded flood marks (date and m) Difficult to score and may be absent yet not imply lack of connection. Extreme flood events only are recorded by flood marks so may not indicate effective connection of lower flows. Affected by historic bias. **Propose to leave out of the index.**	
G7, G10 – G12	Return of flood flows	G7 Artificial drainage networks on FP (APE) G10 No of floodplain channels outside EM (#) G11 length of channel outside EM (m) G12 Flap valves through embankment (#) Needs further evaluation of use within this metric (is now used within 'impracticality of restoration').	Combine for L and R banks, if factor exists on one bank score. Networks on FP are only relevant to existing connectivity if inside EM.
G6	Storage of flood waters	APE Dropped from current evaluation	
DESK STUDY AND INDICATIVE MAPS CAPABLE OF GROUND-TRUTHING WITH THESE DATA			

Habitat and environmental value of the floodplain parameter scores are shown in Table 5-2.
The higher the value the higher the habitat and environmental value of the floodplain. Left and right bank values are combined. Only positive factors are used, therefore land use types that do not contribute to increased environmental value are not scored. If it is necessary to incorporate negative factors these could be considered as a separate environmental constraints layer.

Table 5-2 Habitat and environmental value of the floodplain

Habitat and environmental value of the floodplain Potential to weight the value based on the presence of floodplain on both banks, but this is subject to natural position of channel in floodplain and the relationship of the geographic floodplain to the functional floodplain.			
Parameter	**Description**	**Measure / Comments**	**Score**
D1	Floodplain	AIC If absent no environmental value of floodplain.	D1 Floodplain presence A -99 I 1 C 3

Habitat and environmental value of the floodplain Potential to weight the value based on the presence of floodplain on both banks, but this is subject to natural position of channel in floodplain and the relationship of the geographic floodplain to the functional floodplain.			
A3 (latter cf. A1?) Or use RS data.	Width of floodplain Left and Right Bank values	Width (m) Could be done as multiples of channel width or of valley width.	Cross check with the RS data or use RS data directly. Sum for LB+RB / 5 = average width FP in 5 sections A3 Floodplain width (average) 1-10m 1 11-50 m 2 51-100+ m 3
G6	Storage of flood waters – river fed low areas – potential restoration or wetland areas	APE	G6 Storage of flood waters A 0 P 2 E 3
E4 – E6 or	Relic channels (NB Width of relic channels in RS data as a surrogate)	APE Treat LB and RB together. Recommend dropping E6 (E6 is relic channels used – which have lower potential value and lower practicality of restoration).	E4 Water filled - relic channels A 0 P 2 E 3 E5 Natural vegetation - relic channels A 0 P 2 E 3

Habitat and environmental value of the floodplain Potential to weight the value based on the presence of floodplain on both banks, but this is subject to natural position of channel in floodplain and the relationship of the geographic floodplain to the functional floodplain.			
H12	Land use classes H12 Wetlands H3 rough pasture H10 moor H6 scrub H9 parkland	APE Options to use RS data with % cover values (GeoRHS records APE at present). Include whether occurring on RB or LB and weight evenly. Negative land uses not included	H Land use H12 (P/E) 3 H3 (P/E) 2 H10 (P/E) 2 H6 (P/E) 1 H9 (P/E) 1
A10	Embankments etc – modifying 'flood pulse' None and limited setback provides best habitat and environmental.	Tally – for both LB and RB Omit E7 as this duplicates A10 values in this metric.	A10 Engineering Embanked (0) 3 Embanked -setback (0) 3 Embanked -setback (1) 1
INITIALLY REQUIRES FIXING OF 'IDEAL': HQI AND THEN SCORES FOR MODS: HMS			

Practicality, of the restoration of the floodplain parameters are shown in Table 5-3 and impracticality Table 5-4. Practicality of restoration of floodplain employs a number of the same attributes as the defining connectivity, but scored differently and in combination with other attributes. The parameters that influence the practicality of restoration include a number of positive factors and negative factors. Here the positive factors are evaluated. The higher the value of the index the greater the scope (and practicality) of restoration. Again, there is potential to treat the positive and negative factors as separate indices and then combine through a matrix reclassification technique to provide a synthesis of the overall opportunities and constraints of reconnecting and restoration. Other indices might be used to establish the most appropriate mechanisms for such restoration activities.

Table 5-3 Practicality of the restoration of the floodplain

Practicality of restoration of floodplains			
Parameter	**Description**	**Measure / Comments**	**Score**
D1	Floodplain	AICD Absent, Intermittent, Continuous, Disconnected	D1 Floodplain presence (for both banks) A -99 I /D 1 C 3
A3	Width of floodplain Or use averaged value from the RS data.	M	A3 Floodplain width 1-10m 1 11-50 m 2 51-100+ m 3
D4 / D5	Number of relic channels and relic channel planform	Number Planform not recorded here.	D4 relic channels 0 0 I 2 >1 3

Practicality of restoration of floodplains			
Parameter	**Description**	**Measure / Comments**	**Score**
E9 /A3 ratio	Distance to crest top. Batter on embankment is small in comparison to distance and therefore has not been accommodated.	M Greater area of floodplain provides greater potential for restoration.	E9 Distance to embankment crest Max LB/RB value / average width A3 <0.1 1 <0.25 2 0.25-0.5 3 0.5-0.9 4 1 5
H12 (good)	Wetlands – and land use classes	APE Wetlands P/E are positive all other classes are (potentially) negative but are excluded from the classification.	H Land use H12 (P/E) 3
E3	Active side channels	APE LB+ RB (include both banks)	E3 Active side channels A 0 P 1 E 3
G7 –G12	Drainage on floodplain	Negative factors Not included in this metric. These are measures of getting water onto the floodplain but not necessarily compatible with restoration as they also reflect drainage of former wet floodplains.	

Other remote sensing datasets that may be of value here, but which have not been included within the current index development due to data availability, are dominant floodplain soil type, where the relationship between type and restoration potential needs to be evaluated. Presence of water meadows may also be a valuable indicator of potential to restore wetland habitats, derived from RS data (air photos and historic maps) – which may be picked up from drainage channels/ ditches and wetland community types within the floodplain.

Table 5-4 Impracticality of restoration of floodplains

Impracticality of restoration of floodplains Constraints on floodplain restoration – other than merely poor existing connectivity (that is reflected in the positive based estimators of existing connectivity). These are factors that will influence the restoration potential not the value of that restoration and have been limited to factors in the floodplain (e.g. road, rail and urban areas). High value is high impracticality.			
Parameter	**Description**	**Measure / Comments**	**Score**
RS data	Presence of significant urban area on FP	% of floodplain area	RS urban area constraints 0 -0.5 1 0.5-5 2 5-30 3 31-100 5
RS data	Presence of road rail or canal	% of floodplain area	Road and rail constraints 0 -0.5 1 0.5-5 2 6-30 3 31-100 5
H5 H9	Tilled land Parkland / gardens	APE/NV	Land use constraints A / NV 0 P 2 E 5

Impracticality of restoration of floodplains Constraints on floodplain restoration – other than merely poor existing connectivity (that is reflected in the positive based estimators of existing connectivity). These are factors that will influence the restoration potential not the value of that restoration and have been limited to factors in the floodplain (e.g. road, rail and urban areas). High value is high impracticality.			
Parameter	**Description**	**Measure / Comments**	**Score**
G7, G10 – G12	Return of flood flows Artificial drainage network sufficient indication of negative impact on the floodplain restoration potential, other factors are enumeration of these and would double count.	G7 Artificial drainage networks on FP (APE) (G10 No of floodplain channels outside EM (#) G11 length of channel outside EM (m) G12 Flap valves through embankment (#) Needs further evaluation of use within this metric (is now used within 'impracticality of restoration')	Combine for Land R banks, if factor exists on one bank score. Networks on FP are only relevant to existing connectivity if inside EM G7 Artificial drainage networks A 0 P 2 E 3

There are limitations in using the index of impracticality of the restoration, in that the records of the % of the floodplain affected do not record where within the floodplain these features are, thus low percentage urban areas close to the channel may be a much higher constraint than the same area more distant from the channel. The presence of road, rail and canal is also affected by the fact that there is no way of demarcating mapped tracks from roads, so they may artificially affect the level of impracticality calculated.

Similar tests could be run using the GeoRHS desk study data, and some of the parameters are equivalent to the field surveys, for validation purposes. In this instance these would be seen as corroboratory tests on field surveyed information, and a quality judgement may be needed to adopt either system, based on factors such as complexity of the field site and missing values from field survey. More generally, it was considered the field survey would predominate over the desk survey variables.

5.4 WFD Naturalness, or 'natural state' indicator

This index was described as evaluative, of the current condition of the channel versus the anticipated 'natural state' of the channel. This has similarities therefore with the HQA of the RHS methodology and index and also with the CEN proposals river quality scoring, based on physical features. This index was seen as being fundamentally channel-based, although within the context of WFD and, in particular, the potential use within morphological state assessment for SEPA implementation as a floodplain, riparian and channel index (or sub-indices). The Habitat Quality Assessment rules within RHS are predominantly 'diversity' based, with the risk that disturbed sites score highly and therefore need to be moderated by the modification levels, for example a weir plunge pool will introduce features that could score positively for 'naturalness' and in ecological and physical terms contribute to diversity.

Whilst it may be relevant to include some parameters of floodplain ‘naturalness’, these may be seen as replicative, in part, of the channel floodplain connectivity index. In the proposed index the value of the connectivity of the floodplain is an input value to the naturalness. The index will also need to reflect the adopted typology, and the approach adopted in Scotland currently differs from the England and Wales approach. Alternative approaches to weighting the site-specific elements may be through stream power and dominant sediment character (themselves surrogate typologies). This offers the opportunity to cross-reference channel naturalness against the floodplain naturalness to provide additional characterisation of sites. An alternative approach, and one where the type-specific attributes are unknown or uncertain, is to treat the index as ‘geomorphological diversity’ rather than ‘naturalness’. At least some attributes will be site type-specific and the high diversity of features may be exhibited by disturbed or readjusting sites more than natural/un-modified sites. Ultimately, with sufficient reference or near reference conditions sites the potential to use PCA to identify the components of naturalness for types,

The inclusion of naturalness attributes, particularly of channels is very river type-specific, but the types have yet to be refined and the parameters of naturalness and the deviations from naturalness and their significance still need to be defined. The guidance for the development of this index comes from the parameter selections envisaged within the CEN guidance ‘A guidance standard for assessing hydromorphological features of rivers’ (CEN TC 230/WG 2/TG 5: N32). SNIFFER (2005) have also reviewed the role of these attributes in establishing baselines against which to assess engineering regulations under WFD49 Environmental Standards to support river engineering regulations. This later programme has also developed a more refined categorisation/typology of rivers that reflects the fluvial process and morphology attributes; and may form the basis for a type-specific allocation of scores or weights within the index. Thus it is anticipated that either the scores or their weightings may vary with the river types, based on more catchment-specific definition of river types. The challenge in adopting this index at the current time is the lack of a reference typology around which to base the comparison of the sites.

Under WFD, the key attributes of hydromorphological condition include flow, connectivity and form variables (regime, continuity and morphological elements). Assuming that the hydrological regime elements are not covered within this index (although impacts on flow are) the variables under WFD that define Hydromorphological Quality Elements (Table 5-5) and that can potentially be derived from GeoRHS field and RS data are shown in Table 5-6. If additional information on flow modification at a catchment scale is available then this would be relevant to the naturalness index.

The proposals are again to keep the index to positive quality attributes, rather than negative derogations from naturalness. A separate modification index would be proposed to pick these negative naturalness features, the existing RHS Habitat Modification Score (HMS) offers part of this requirement although may not specifically pick up on the hydromorphological drivers of WFD.
The assessment of health indicators could be generated as three separate indices for river, riparian and floodplain. The indicator measures are included here within the context of a single index, but could equally be separated into distinct elements. Although the field survey datasets are important to this assessment there are also values in assessing the parameters based solely on the remote sensed datasets to allow the potential for a national site assessment. The development of separate data layers or datasets for

morphological alteration proposed by SNIFFER (WFD74) would assist within this WFD process, although similar data are not likely to be available for England and Wales. Once these data are available within Scotland automated procedures within the GeoRHS desk study could be implemented to attribute the RS database and incorporate them within a modification and/or naturalness index. The NFCDD data for England and Wales are inadequate currently to provide an alternative source to the morphological alterations database used in Scotland. The NFCDD records do not include gross modifications to the channels (realignment, resectioning etc) and do not form part of the data structure.

Naturalness of vegetation within and adjacent to the channel within the GeoRHS attributes will be limited by the proposed period of the survey (winter early spring), and would have to be incorporated from RHS data if required – although use of the HQA alongside the GeoRHS index may be more appropriate. The underlying uncertainty of the aquatic vegetation structure as a physical quality attribute, whilst clearly important in habitat terms, suggests that any scoring is very subjective and the values recorded very season dependent.

A number of the Habitat Quality Assessment measures used within the sub-scoring, such as the flow type sub-score, channel feature sub-score and the bank and in-channel vegetation sub-scores could be integrated within a composite index if the sub-scores within RHS are retained separate from the final score within the database.

Table 5-5 Hydromorphological Quality Elements under WFD

Hydrological Regime	**Continuity**	**Morphological Elements**
Quantity and dynamics of flow Connection to groundwater	Sediment transport Migration of biota Floodplain continuity	Channel pattern Width and depth variation Flow velocities Structure and Substrate conditions of the bed Structure and condition of riparian zone

Table 5-6 The parameters collected by the GeoRHS/ desk study and RHS

Natural state indicators positive indicators (or lack of negative factors)			
Parameter	**Description**	**Measure / Comments**	**Score**
Floodplain continuity (lateral connectivity) – river type-specific issues will need to weight on the natural absence of a floodplain)			
Floodplain connectivity	Degree of connection between floodplain and channel	Value derived from connectivity index above	Floodplain connectivity 1-3 1 4-8 2 9-12 3

Natural state indicators positive indicators (or lack of negative factors)			
Parameter	**Description**	**Measure / Comments**	**Score**
A3	Width of floodplain	metres Or use averaged value from the RS data. Note site may naturally have no floodplain, so only apply where appropriate.	A3 Floodplain width 1-10m 1 11-50 m 2 51-100+ m 3
H12	Wetlands hydrological continuity via wetlands	APE Wetlands P/E are positive all other classes are (potentially) negative but are excluded from the classification. RS alternative could be used based on LCM2000 class	H Land use H12 (P/E) 3
CHANNEL ZONE			
(**RS / RHS**) cross channel structures Sediment / migratory transport	Lack of impediment / barriers to flow – weirs etc) upstream. RHS has Artificial features with major, intermediate, minor	If present indicate barrier Issues of scale of features and whether they are an impediment to biota migration need to be considered. Significance is indicated by size and impoundment.	Major 1 Intermediate / minor 2 None 5
A4	% of reach ponded from 5 X-sections low % ponded is high naturalness feature, but is influenced by the barriers to flow. However, a reach may be ponded by a feature outside the reach.	High % = low naturalness of flow. Needs to be weighted for type-specific variance in lower reaches and tidally influenced reaches. Note also RHS water impoundment as absent, < 33%, >33 % could also be used as simpler to apply.	A4 % ponded / 5 (cross sections) 0 -5 5 6 – 10 3 >10 1

Natural state indicators positive indicators (or lack of negative factors)			
Parameter	**Description**	**Measure / Comments**	**Score**
A10 Engineering features GeoRHS	Presence of a range of engineering features in channel and on floodplain that affect naturalness of flow, ability to migrate (laterally). Options: to weight on values for 1 or both banks – but not applied here. Options: to score each type of engineering differently (like RHS) where culvert is high score. Additional levels could be defined.	Negative factor – engineering modification of channel therefore treat as negative Tally for both banks across all features / reach (bank) length. i.e. Length of A10 as % of 2x500m Where extent of impact is >100m on one bank – 10 %.	Absence of A10 classes LB and RB 0 -1 5 0.1-5 3 6 – 10 1 > 10 0
RS Planform modification	Assessed over reach 500m	Multiple types for natural and artificial can be resolved to natural and artificial Not used due to current lack of historic data – but potential to add variable once available.	RS Planform modification Natural / semi-natural type 5 Modified type (resections, realigned, dams, weirs and sluices) 1 Culvert 0
RS Planform type	Assessed over longer reach (2.5 km)	Uses broad categories of natural and modified categories, however, there is risk that a resectioned channel whilst being modified will not be picked up as such where there is no planform change. Anastomosing channels may be particularly difficult to assign as 'natural'.	RS Planform type Natural / semi-natural type *Straight, sinuous, irregular meanders, regular meanders, multi-thread anastamosing, braided.* 5 Modified - *straightened, navigation, mill channel, water meadow* 1
Migration potential (Longitudinal connectivity)			
RS channel change	Channel planform change using historic data	Change of channel as a basis for lateral adjustment – natural process change	RS Planform change Change 5 No change 1 No data 0

Natural state indicators positive indicators (or lack of negative factors)			
Parameter	**Description**	**Measure / Comments**	**Score**
A6	AR banks Presence of artificial banks LB/RB – partially replicates A10 but latter includes other engineering modifications	% , 10 values from GeoRHS data	A6 Artificial banks 0 5 1 -10 3 >10 1
A7 AR bed	Artificial bed materials	% of 5 values (issue of when channel bed not visible – impacts metric values)	A7 Artificial materials on bed 0 5 1 -10 3 >10 1
C10 and C11	Channel pattern Berms – indicator of existing adjustment process. Natural berms - treat as natural features of adjustment. C12 indicates artificial. Other HMS will pick up the degree of modification and potential for berms to be associated with past disturbance.	Area of berms (m^2). Berms on one bank imply channel adjustment by lateral migration, berms on both banks may imply a narrowing (response to reduced flow / over-widening). Calculate as sum of C10 and C11. Potential to average A1*500 to give percentage of channel area affected by natural berms. Percentage values are likely to be very low and the metric will be sensitive to channel width therefore use actual extent. Potential to add width of berms to datasheet.	C10+C11 berms extent 0 – 25 m^2 1 >25 – 100m^2 2 >100 – 500 m^2 3 >500 m^2 1
In channel vegetation	Aquatic vegetation RHS based variables – not colleted by (winter) GeoRHS.	Variable and difficult to establish positive or negative scores based on structure – where type-specific representation is an important weighting. Not used here – too complex to state what represents natural conditions, although very high % bed cover may indicate modifications	

Natural state indicators positive indicators (or lack of negative factors)			
Parameter	**Description**	**Measure / Comments**	**Score**
C19	In channel OM / CWD	Presence of CWD – difficult to assign May be influenced by negative factors, such as barriers. Area in channel as a proportion of channel area. Potentially a negative feature at small values and very large values?	C19 CWD dams 0 -1 % 1 1-10 % 5 11-25 3 >25 % 1
Erosion	Lateral rate of adjustment Other indicators may include indicators of degradation e.g. K7, K8	Variable not created due to lack of EA data supply, Features are very type-dependent and therefore their presence and extent need to be scored in type-specific ways. Not used at present – scoring needs to be type –specific sufficient to identify both the semi-natural conditions and disturbed conditions	.
Depositional features	Bar character	Not used at present.	
A1/A2 at 5 cross sections	W/D ratio	Not used at present.	
RIPARIAN ZONE			
F2	Riparian vegetation Continuity of trees	Subject to some limitations where trees do not occur, but this is likely to be due to management and grazing (indicators of modification). Subject to site-specifics that may be weighted.	F2 Tree continuity N (none) 1 I (intermittent) 1 R (rare) 1 OC (occasional) 1 SC (semi-continuous) 3 C (continuous) 5

Natural state indicators positive indicators (or lack of negative factors)			
Parameter	**Description**	**Measure / Comments**	**Score**
Naturalness of vegetation	Land use in the riparian zone GeoRHS RS has RHS has banktop (within 5m) vegetation at x-sections for LB and RB Sum for each occurrence at X section 0.1. Thus if 10 LB sections have TL = 1, then * by score. i.e. if both sides are natural vegetation max score is 10.	Land classes present on LB and RB. More natural land uses score more highly, but categories may be poorly defined (as natural) e.g. TH may be natural community or invasive. Alternative: to score separately for separate banks (distance within 500m), so that if the vegetation is natural on one bank and not the other this will be evident and can be weighted accordingly. TL tilled land, SU urban, IG improved grassland CP coniferous plantation, OR Orchard, RP rough pasture, TH Tall herbs, SC scrub, BL broadleaved wood RS rock and scree, OW open water, WL wetland, MH moor and heath	RHS riparian vegetation TL, SU, IG 1 x occurrence CP, OR, RP 2 x occurrence TH, SC, BL 3 x occurrence RS, OW, WL, MH 5 x occurrence .

Channel modifications can be taken from the HMS of the RHS rules, although the GeoRHS adds certain process related measures that may help quantify the modification level and add to index development. In particular, the addition of planform change information from the desk study component of the GeoRHS adds a historical context to the modification and therefore a potential to assess degree of recovery from modification.

In testing the sub-indices for floodplains and WFD applications the results of the database queries have retained the values of the scores allocated to each contributory attribute, as a basis for reviewing the implications of the final score. These can be checked against the photo sets for the individual reaches as a 'reality check'.

Table 5-7 shows the retention of the separate scores of the attributes within the floodplain connectivity assessment.

Table 5-7 Site based connectivity Index value for floodplains within the GeoRHS surveys and individual parameter scores.

QryIndexConn : Select Query

Survey ID	Site no	ConnectivityIndex	Setback	EMHeight	ActiveSide	ErodedLo	DirectSpill	ImpBound	EM length index	Crest index	Straightened
88	20094	14	3	3	1		0	3	1	1	2
248	TWD13	16	3	3	1		1	3	1	1	3
247	TWD15	17	3	3	1		2	2	1	2	3
119	22472	17	3	3	2		1	2	2	1	3
224	TWD14	18	3	3	1		2	2	3	1	3
213	TWD29	18	3	3	1		2	3	1	2	3
116	20912	18	3	3	2		1	2	3	1	3
114	22534	19	3	3	2		1	3	3	1	3
68	22334	19	3	3	1		2	3	3	1	3
246	TWD16	19	3	3	1		2	1	1	5	3
152	23470	19	3	3	2		1	3	3	1	3
214	TWD30	19	3	3	1		2	3	1	3	3
103	4362	20	3	3	2		0	3	1	5	3
11	10537(R)	20	3	3	2		2	3	3	1	3
133	4491	20	2	3	2		1	3	1	5	3
212	TWD22	20	3	3	1		2	2	1	5	3
153	20643	20	3	3	1		1	3	3	3	3
154	20940	20	3	3	2		1	3	3	2	3

Testing against the datasets for the surveyed sites the range is small, but this may be explained on the basis that the samples taken have been those sites that have low modification of the channel and the floodplain. The site selection criteria, based on RHS HMS and HQA scores tend to stress the channel and riparian areas, and thus where floodplain modification is concerned it is not surprising that some sites show lower connectivity than might be anticipated by higher quality RHS sites used for the survey. Of the sites surveyed (297) 15 have no floodplain on either bank and 39 have a floodplain on only one side of the channel. Site 20094 has the lowest score primarily because it is straightened (a low score impact on the metric) and because it has embankments along both banks close to the channel margin. The minimum value possible within this index would be 8 with the maximum connectivity at 25.

Sites on the Tweed (TWD 13 and TWD14) come out as poorly connected, with evidence of straightening of the channels and cross-section change divorcing the channel from its floodplain. Best examples (most connected sections) of the sites have no structures preventing reconnection, but also have features within the floodplain that promote connection, such as palaeochannels.

Figure 5-1 shows a predominance of high floodplain connectivity sites for the sites sampled within the GeoRHS field programme. This is anticipated by the site selection criteria. Further modified sites will need to be surveyed to ensure that the metric is separating sites effectively and the scoring may need to be ‘stretched’ to cover a connectivity range. Figure 5-2 show two reaches with high (left) and low (right) connectivity scores, where the low score (19) has embanking along one bank, disconnecting a wide floodplain.

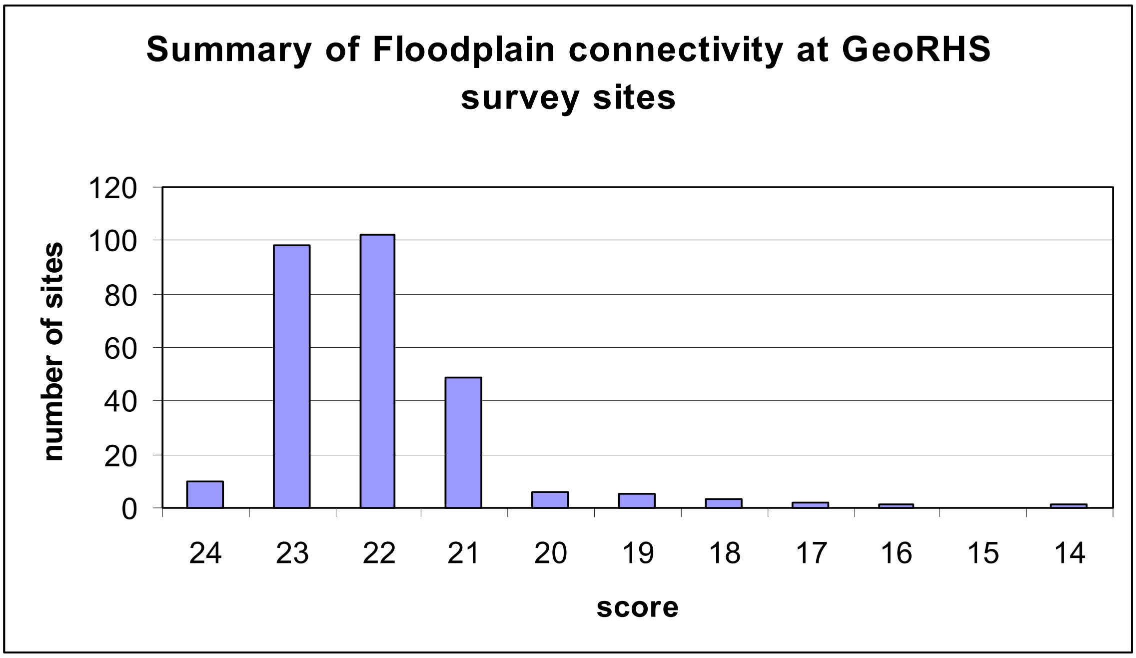


Figure 5-1 Floodplain connectivity values for sample sites

Figure 5-2 Examples of connectivity; Tributary of Bodgwo, Devon (reach 14560) and lower Tweed (TWD 29)

Floodplain value index, Figure 5-3, indicates the ecological value of the floodplain based on existing floodplain land cover classes, existing water storage, and palaeochannels in the floodplain and is designed as a current state variable. The distribution of site values stresses those sites with existing good connectivity and recent past flooding and channel migration zones that have retained their links with the channel. The large number (44) of sites scoring 0 is due to missing values and changes in the data capture values for the surveys undertaken at different dates, using different forms and the number of sites without a floodplain (predominance of upland streams and clough woodland sites etc) within the sample. The components of the index need to be reconsidered for this metric along with the wider distribution of sites with natural and affected floodplains to assess whether altered scorings are needed.

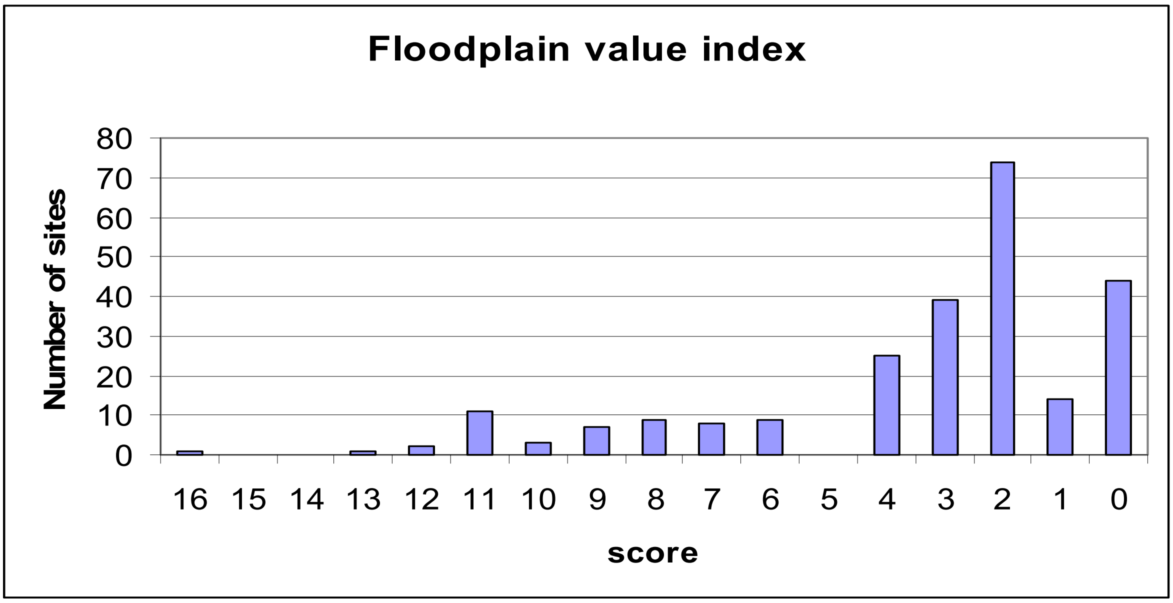


Figure 5-3 Floodplain value index

Figure 5-4 Floodplain value scores; sites with no floodplain score 0, high floodplain quality on Bowder (12)

Assessment of the individual sites and with evidence from the photographs of the channel sections and overviews suggests that the measures need to be reassessed to separate higher and lower sites, especially where the floodplain is narrow, yet with wetland coverage. A number of the reaches fell within this category by virtue of the reference condition selection with a high proportion of upland reaches. This measure does not effectively separate some of these narrow sites from more lowland sites with heavily modified land uses on the floodplain.

Floodplain restoration potential

Figure **5-5** is based on the overall resource capacity in terms of floodplain extent and the level of existing routes for flood waters to get onto the floodplain, through flow routes and relic channels. The relationship between connected and disconnected floodplain needs further investigation and enhancing as a metric component. In-channel effects on restoration potential also need to be factored into the metric, and although dredging and straightening modifications are included within the connectivity metric the potential to add factors that provide a feasibility of channel /floodplain reconnection should be considered.

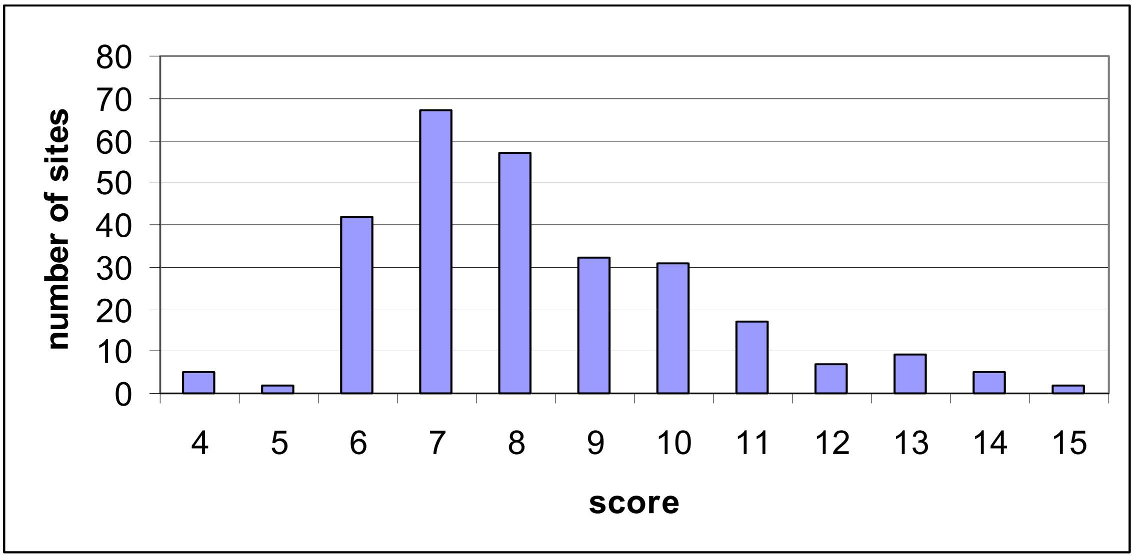


Figure 5-5 Floodplain restoration potential

Effectively, the score range should be from 1- 17, with 0 indicating that there is no floodplain. With the examples shown below (Figure 5-6) the Bre has a high connectivity, albeit on one bank, and features in the floodplain that promote restoration (relic channels, wetlands, active side channel and a significant width of floodplain). In contrast site the River Allen reach has only a moderate / low practicality score based on the limitations of the direct spill of floodwaters, the relatively narrow floodplain and a lack of wetlands and absence of relic features.

Figure 5-6 Examples of practicality of restoration, Bre 1 Brerachen Water (R. Tay) (scoring 14) and site 22534, River Allen (Cornwall) (scoring 4).

The practicality of floodplain restoration could encompass other factors (such as conservation values, physical constraints, specific land use types such as woodlands etc) but the current index concentrates primarily on the morphological practicalities and structure.

Some indices are perhaps not functional on their own – for example, the practicality of restoration of floodplain function is only really relevant if the floodplain is not already functioning effectively. In this sub-index, and by virtue of the attributes selected, the highest scoring sites are those that are already well connected and functioning effectively. When taken in parallel with the level of modification and floodplain connectivity the potential role for restoration becomes clearer. Taking an example, for the River Shee (Shee 1) reach has the highest practicality score and also a high connectivity score. The matrix reclassification of restoration and connectivity would be to interpret this as a site that was functioning effectively as a floodplain already. The floodplain scores for this reach are summarised in Table 5-8. The low impracticality score suggests that there are few constraints, and in this instance the score relates to the presence of artificial drainage channels on the otherwise near natural floodplain.

Table 5-8 Summary of floodplain quality scores within GeoRHS

Floodplain	Connectivity	Value	Practicality	Impracticality
River Shee1 site	High (23)	Moderate (11)	High (15)	Low (2)

This result indicates that out of a maximum score of 17 within this index the sites practicability score is 15, being slightly reduced, by the lack of active side channels that provide a route for the water onto the floodplain. The deficits within the separate scores calculated when developing the indices may also help determine appropriate restoration or enhancement actions.

By attempting to keep the attributes of the floodplain restoration potential positive there are attributes that would indicate against the potential for restoration. Hence these factors have been used within another sub-index of impracticality for restoration (Figure **5-7**) in order to keep the attributes separate and thereby facilitate an approach to developing a matrix based classification of overall practicality, subject to removal of constraints.

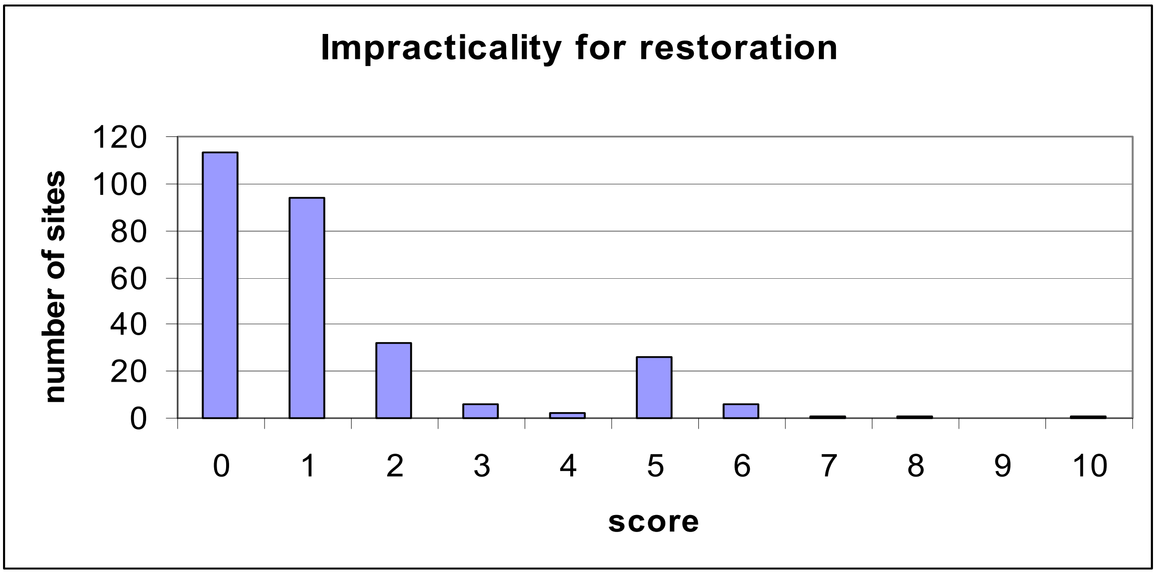


Figure 5-7 Impracticality for floodplain restoration

Naturalness scores under the WFD index are lowered where there is no floodplain, so the indices need to adopt a typology that scores within valley types where not floodplain is anticipated or where a compensation figure is allocated within the scoring or the 'no floodplain' result is weighted accordingly. The data has been separately run on those sites within the Tweed for the floodplain component of the naturalness index and the results are illustrated in Figure 5-8.

Many of the other sub-indices are misleading here as they utilise RS data from the GeoRHS desk study, which within Scotland the data were not available to derive all the parameters. The final index in the case of the WFD naturalness score is envisaged as a total score, summing the separate elements of the floodplain, riparian and channel components.

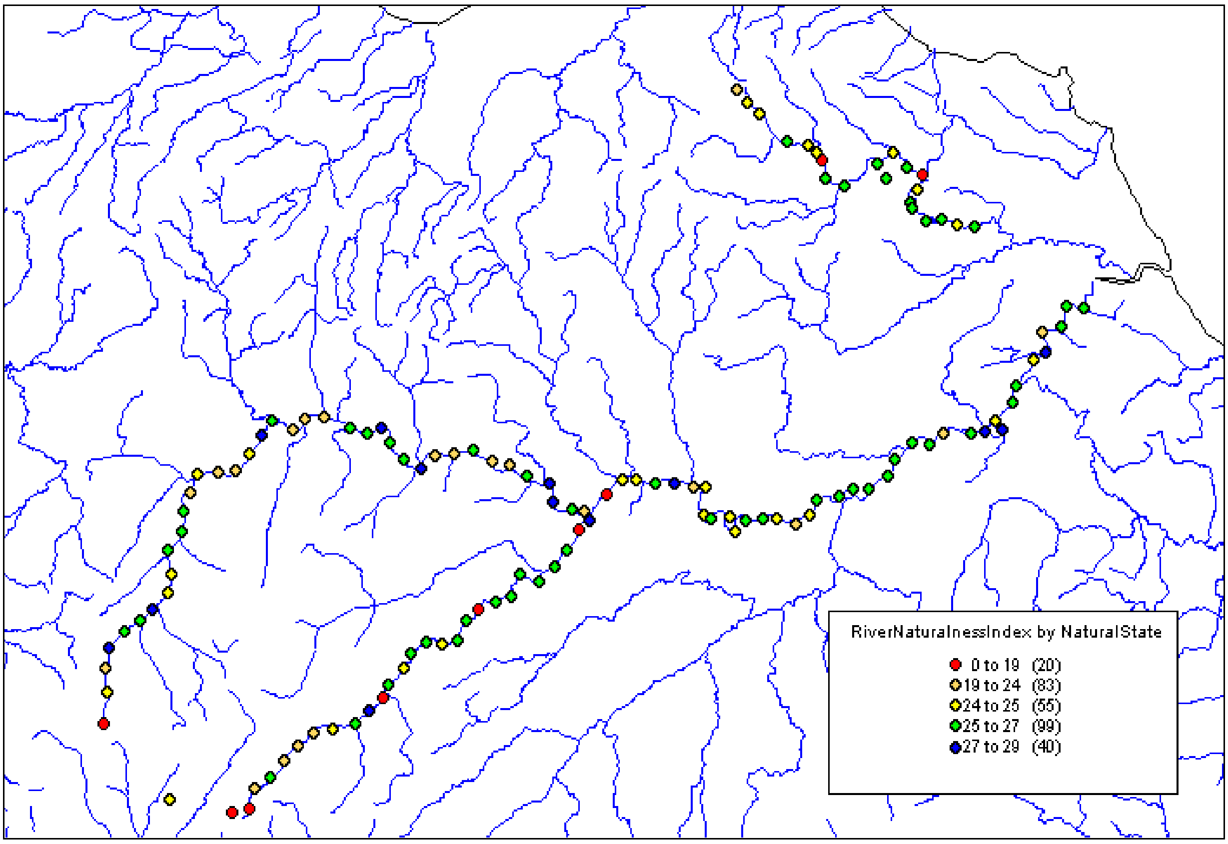


Figure 5-8 Naturalness index for the River Tweed sites based on the analysis of the lateral connectivity scale.

5.4.1 How the indices will be used?

It is anticipated that the attributes and indices will be used to help allocate reaches to a typology (as refined through WFD49), to identify type-specific variation and to characterise the status of reaches. The indices of connectivity and restoration potential for the floodplain may be used both to characterise the connectivity (reported separately) but also within a matrix reclassification to help determine management priorities (combined with other indices). For example, a matrix of connectivity and floodplain quality may be used to help target floodplain restoration evaluated against restoration potential. For such assessment the values of the indices would need to be assessed in terms of the class boundaries allocated 1-5 ranking. For this example, values of a highly connected floodplain of high floodplain quality appropriate responses might be to protect and monitor. At the other extreme high quality floodplain but moderately disconnected are targets for restoration, whereas low quality and highly disconnected floodplain may be a longer term target for rehabilitation or enhancements.

The naturalness index is also comprised of a number of sub-indices representing the different elements that contribute to naturalness relevant to the WFD; within the floodplain, channel and riparian zone. As with the connectivity index the sub-indices may be reported separately, used within the scope of a matrix reclassification or used to sum o an overall index for a site. The disadvantage of the latter approach is that detail of the separate features of morphological quality is lost, but the index would allow overall site quality comparison. Within the scope of WFD 49 environmental standards to support river engineering regulations GeoRHS (and RHS) provide tools for morphological monitoring; it is likely that the individual attributes as well as indices combining attributes will be relevant.

The indices explored above form only part of the range of anticipated indices that would use more of the attributes collected within the GeoRHS /RS forms and databases. For example, the lack of use of the erosion and deposition variables within the connectivity, modification and naturalness indices does not imply that they will not be valuable in other applications or used to distinguish between sites. In particular these attributes have been targeted at the development of an instability / stability index/indices (4.3.3).

5.5 Coverage of the GeoRHS – map of sites

The indices have been tested on the datasets collected within the ‘reference condition’ sites and those sites collected within Scotland for the Tweed. The data captured at each site included the RHS and GeoRHS data. In addition, for those sites were it was possible to obtain base topographic and thematic data for the GeoRHS desk based data collection the information was collected. A number of datasets were not forthcoming and therefore there are some missing blocks of information that affect the validity of the resulting scores where these are included within the indices. The distribution of sites is shown in Figure 5-9, and this emphasises the basis for site selection, being natural and semi-natural sites with a predominance of sites, at least in England and Wales, being outside the lowland areas – where few previous RHS sites indicated unmodified reaches.

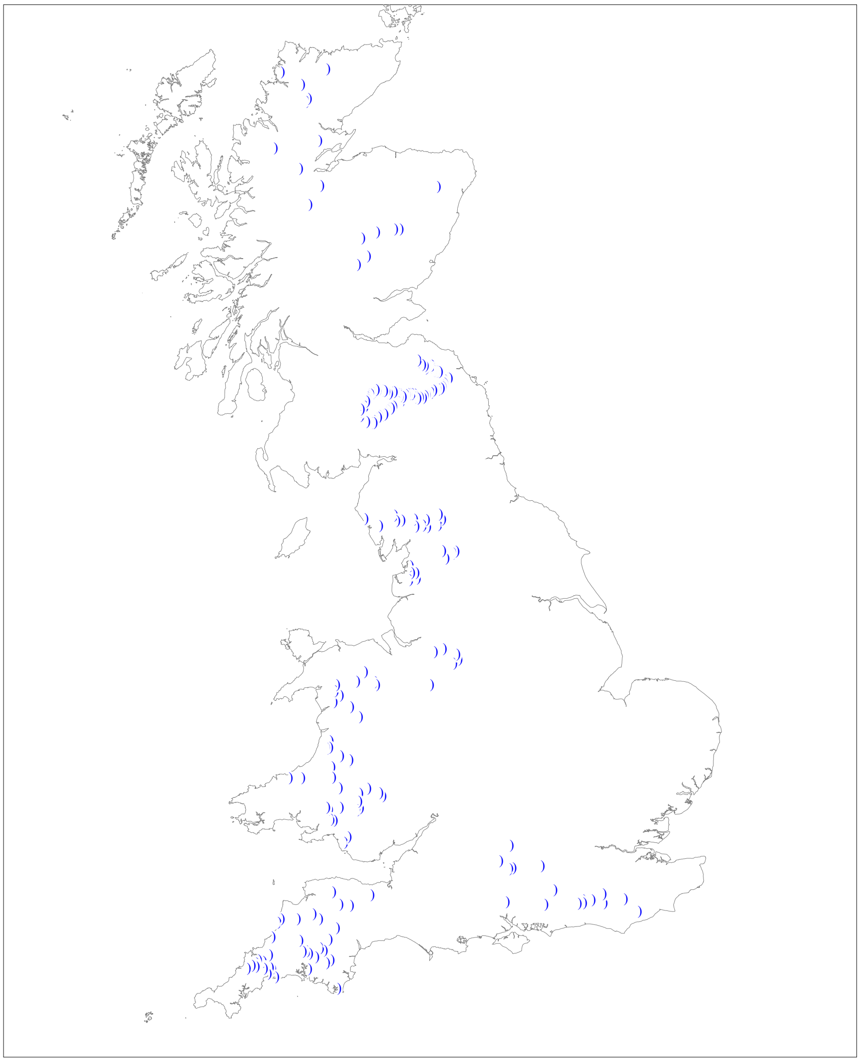


Figure 5-9 Location of GeoRHS/RHS sites surveyed (2004/2005).

6 GeoRHS – Operational and implementation issues

6.1 Introduction

Having developed the GeoRHS recording formats, their associated databases, help files and indices there are a number of remaining implementation issues to be resolved in collecting and managing the information to finally deliver the range of geomorphological indices.

Within this R+D report it has not been appropriate to fully address all these issues or to test the indices nationally; the scope of the R+D project was to develop and provide proof of concept for the GeoRHS methods, rather than full implementation. It is relevant to flag the key areas that will be necessary to address within a national implementation and to look at the next steps from technical, data, operational and training-related standpoints.

6.2 Technical issues

The databases in which the field survey data are entered and stored are based on MS Access version 97 and 2000, whilst the data collected from the remote sensed (desk study) is stored in an ArcGIS geodatabase. At an R+D level this is not a significant issue, but implementation suggests that different solutions may be required. The parameters collected using the GIS tool currently need to be exported from the geodatabase for analysis alongside the Access data (although SEPA are proposing collating all parameter data in a central Oracle enterprise database). Although this solution developed within the R+D programme relies on multiple systems the evolution of the database systems, within the EA in particular, do not encourage making other choices at present. Within the context of an R+D programme it is acknowledged that the actual systems for implementation are liable to change, the important dimension for this programme is that the specification and coding of the applications have already been achieved; translation is therefore relatively straightforward. Any new systems will need to be able to support the analytical requirements of the project and provide spatial outputs, but these are not limited by proprietary formats or systems.

Development in England and Wales is seen ultimately as integrating with the re-engineered IT developments supporting the current applications of RHS. These requirements have changed throughout the life of the GeoRHS programme, but are currently indicated as being developed within the context of EcoSys, a web-based database. This approach replaces earlier MS Access databases and the current RHS 2003 spreadsheet. No similar system has been implemented within SEPA or NI, although it is understood that the potential for SEPA / NI to access EcoSys is being evaluated. It currently seems likely that a parallel system would operate for GeoRHS in Scotland and Northern Ireland.

As EcoSys is still being tested, and is not widely available it has not been possible, or appropriate, to develop a fixed physical link between the GeoRHS and the RHS data. It is necessary to be able to reference RHS sites to know that an RHS survey has been undertaken at the same time / location as the GeoRHS field and desk study. A survey number for RHS, rather than a grid reference, would provide a unique reference, and within the R+D programme the RHS / GeoRHS / Remote sensing datasets have been linked using the RHS survey number. However, in normal operations the RHS number is allocated only when the data are entered into the EA RHS database. In the case of GeoRHS, where desk study is seen as being undertaken prior to RHS and GeoRHS field surveys there is an option to generate the unique survey reference within the desk study elements – each region could be allocated a distinct sequence of numbers. Potential modification to the databases to reference other surveys undertaken at the same time would help ensure that the data were analysed together if they are not held in a single data system. There is a risk of the need for some double data entry or export from RHS to run indices that use all the survey data streams if a physical link is not established with the RHS database.

The GeoRHS field survey databases have been delivered in MS Access 97 and MS Access 2000, but may need to be translated to the MS Access 2003, subject to the development plans within the Environment Agency. The code has been supplied so that this application can be translated by the Agency using standard MS Access functionality. The GeoRHS and RHS databases use very simple data models with most fields within a single table, so that conversion and export of the data to another database system such as ORACLE would be a simple process take around half a day, although the interface would need to be rewritten.

Ideally (as far as the application development, training and implementation is concerned) Scotland, England and Wales and NI would be operating the same database systems, have the same file structures and operational access procedures and be running the same versions of the software. This is not the case and hence an R+D development is unlikely to meet the demands of all these operating environments. We have attempted to modularise or allow user-entered parameters to reduce the mismatch between environments as much as possible. There are, however, remaining differences that will require further development.

6.3 Data issues

There are a number of datasets that are specified within the development that have not been obtained within the scope of the project. These shortfalls have occurred for various reasons, but highlight problems with availability of some sources which may continue to affect implementation, different data formats held or supplied by different groups and different approaches to holding and accessing data within different organisations. Dealing with missing datasets may require modification of the metrics from the collected parameters. This should only affect the desk-based information and may not affect all geographic areas. Options to fill some of these gaps or to enhance the availability of datasets for desk studies may be considered; for example the planned development of a national channel change dataset within Scotland for WFD purposes could be incorporated within the GeoRHS desk study and potentially replace the need for historic maps data (this would be dependent on the specification of the change information layer).

In Scotland certain datasets are not available that were available within England and Wales (for example the floodplain datasets, aerial photographic coverage) and others are available in both but are managed in different formats (e.g. geology coverage). In developing the implementation strategy it will be necessary to reflect the data management within each organisation, unless it was possible to coordinate information acquisition, storage and access for the whole of Great Britain and NI. The data shortages that affected this phase of the project has a number of potential impacts in the implementation: it may limit the parameters that can be extracted, may require other data sources to be used in their place or may limit the ability to calculate a variable at all. The use of different datasets in different organisations also place an overhead on the application development and the training requirements that will need to be separate. In some instances there are plans to add new datasets that may be drawn into the applications once these are available.

The lack of certain datasets within Scotland limits data capture tasks within the GIS application. Most critically the missing data are:

- lack of a national floodplain map (although this is being addressed). This also partially affects England and Wales as the dataset quality is inadequate in some areas.
- lack of ortho-rectified aerial photographic coverage (England and Wales datasets have been acquired although there is missing data). Options for capture for some areas are being considered
- lack of historic map data (this also affects England and Wales – although the data area available they have not been able to be copied). Options for data from Landmark or from the National Library of Scotland are being considered.

Certain approaches used within the development of the GIS application have been based on the format in which the data are managed at a national level by the Environment Agency. This has produced a situation where essentially the same data source is managed in two different ways and hence the need for different applications. This is evident with the arrangements for storing Geological data, where in England the files have been broken into tiles whereas in Scotland the system references to a single file. Resolution of these differences would help make the application more UK consistent.

Data supply arrangements also differ, with more efficient access in Scotland through a single spatial database. Current supply to the Environment Agency is as individual data requests that are time consuming and rely on standalone applications rather than server side access. A more efficient supply and access mechanism to the source data for external and internal clients would greatly enhance the ability to efficiently collect the desk study data.

6.4 Operational procedures

Training has been delivered to England and Wales Environment Agency and to consultants working in these fields. A further course is planned for Scotland and NI, based solely on the field surveys.

Training has been provided on the GIS application to EA and to SEPA, although it seems likely that further operational support would be needed to establish an effective system within each country. The requirements for support may depend on the configuration used for the capture of the GeoRHS desk study data. There are options for the desk study parameter acquisition:

- Data capture by a single centre
- Data capture by individual country centres
- Distributed data capture – (by surveyors, or consultants)

A single (Scotland, England, Wales and Northern Ireland combined) data capture centre suffers from the same limitations as a distributed data capture, in that it would require data for all countries, GIS applications that would run in all organisations' systems and potentially accept data updates. The advantages are in the consistency of data capture, reduced training requirements and the single support arrangement needed. Licensing issues may affect the supply of data between countries. The single centre approach would also allow all data to be integrated into a single system more effectively. The current management of the RHS recording within the Environment Agency may suggest the site as a centre for the GeoRHS desk study, and potentially integration with the RHS desk study components. However, many of these requirements are driven by MasterMap that the Agency has yet to adopt. There are significant processing requirements that imply that bringing this approach up to date within the Environment Agency and integration with proposed IT systems (EcoSys) would be both very costly and protracted.

Single country centres has advantages in allowing the specific operating and source data and derived parameter file management environments to operate with the GIS application, but requires some tailoring of the application to meet these demands. The same issues for deployment within the EA as within a single centre exist, long development timescales and limitations due to lack of integration with existing IT development plans. Critically, the lack of MasterMap implementation would affect the integration. The current solution would be to operate the system independently of the EA EcoSys system, but to enable integration of the derived data. The GIS application is, in any case, too complex to be implemented directly within EcoSys, which has limited GIS analytical capability.

The data supply limitations may suggest that distributed data capture is less effective than some centralised system. At this level the individuals would need to have been trained, have access to large data storage capacity, be aware of the differences between different countries data sources, require some form of data consistency comparison or checking.

On balance, based on source data, data acquisition differences, system and application specific requirements it seems appropriate to develop national centres to extract the relevant parameters.

An alternative, at least as an interim measure is to use the established systems within GeoData Institute to extract the required data for individual sites. This approach has the advantages of no further training requirements, support or maintenance and consistency of data capture. Such an approach could operate as an interim measure whilst the data provision and national centres are established. Although GeoData now holds many of the required datasets for a national system delivery within England and Wales, further data access would be needed within Scotland and Northern Ireland.

6.4.1 Quality and validation

Data capture for GeoRHS (field and desk study) are based on surveyor interpretation and are therefore partially subjective. This leads to the requirements for some form of quality assessment and repeatability assessment. Surveyors are formally accredited following similar procedures to those adopted for the RHS training, but further work is needed to establish a more robust test of performance once the methodology is stable. To date no formal training and accreditation procedure exists for the desk based assessments, but specific training has been provided to SEPA and the EA and the programme application is supported by a user manual.

RHS uses validation procedures to check the accuracy of the surveyors' data through a series of logical checks and error checking for omissions. This approach uses the associated photos to assist with validation. A similar approach may be required for the GeoRHS, both the desk and field based assessments. The desk based data is provided to the field surveyors, both as an aid to survey and as a basis for confirming the desk calculations and parameters. It is proposed that the field surveyor values would take precedence over the desk based data, and the forms would be marked accordingly.

6.4.2 Intercalibration

To date, no intercalibration between surveyors has been tested or attempted for GeoRHS as the targets for the data capture have been broad to take in reference sites. Further evaluation by multiple surveyors at a range of individual sites is needed to test the sensitivity of the measures within GeoRHS and the desk study. These studies may form part of the protocol for the field assessments within the accreditation process, whereby the individual accredited surveyors assess the same site and the results are both compared internally and with a reference completed form.

6.4.3 Survey timing

The R+D programme has been predicated on the assumption that the desk study will be operated in advance of the RHS or GeoRHS data capture in the field. This has significant advantages:

- allowing the precise specification of the locations of a survey, start and end points and reducing
- access to site specific information that will help the surveyors and help validate that information where otherwise it may be difficult to collect (e.g. floodplain widths)

Season of survey is the major issue that needs to be considered further. Initial assessment, based largely on the desire not to replicate the role of parameter collection in RHS and the assumption that RHS would normally be run alongside GeoRHS emphasised the spring and summer seasons for the survey, for channel vegetation measures. Testing of GeoRHS on the Ripon FAS and within the data collection undertaken within the winter of 2004/05 and into the Spring clearly recommends that survey GeoRHS before the main bank and bed vegetation growth is necessary to best describe the hydromorphology. If this timing were chosen it would narrow the period over which RHS and GeoRHS could be run together if the Spring / Summer period is essential for the RHS surveys.

Critical features often masked vegetation are the features that show channel adjustment of bed and banks, such as berms and benches. This was evident from the test sites when winter surveys on the R. Dane clearly showed up channel adjustment features and floodplain channels and cut-offs within the floodplain which were not evident or easily interpretable within the summer period. Whilst the desk study may help to fill these gaps to some extent the preference is still to undertake the GeoRHS surveys prior to annual vegetation growth. The variables within the RHS survey that rely on vegetation are cross section surveys (G) Channel vegetation types, notable nuisance plants, choked channels and vegetated point bars (which may only be annual vegetation growth and therefore still classed as unstable). These shortfalls would only partially be addressed by the use of aerial photography. Survey season is a difficult compromise that may only be resolved by the purpose of the survey, which may encourage one season or another.

6.4.4 Training

Training materials have been developed as the basis for the accreditation testing for field surveyors, equivalent to the developments within RHS. The GeoRHS programme currently assumes that the surveyors would all have been RHS accredited prior to undertaking the GeoRHS training or at least be familiar with the basic field survey protocols and procedures within RHS surveys. However, the precise procedure will depend on:

- whether the surveys are conducted together or whether GeoRHS can be run separately.
- whether the desk study is always conducted prior to the field surveys (for both RHS and GeoRHS)
- the extent to which field surveys and RS surveys are outsourced to consultants to undertake.

The current lack of trained geomorphological consultants will limit the ability of the Agencies to outsource any field survey work.

RS (desk study) training has been provided to the EA and for SEPA on the operation of the GeoRHS GIS application. No standalone training materials have been developed for the EA/SEPA to offer the training internally, although those already trained (and using the system) should have the necessary skills to train others. This is generally subject to the trainees having at least a basic knowledge of the workings GIS and of ArcGIS in particular. The different implementations and data sources in EA and SEPA suggest that future training courses for the RS components are likely to be separate. It seems likely that further support will be needed to permit the users to become confident in its set-up and operation. The training requirement for the desk study will depend on the implementation of this element of GeoRHS. Currently, the outsourcing of the RS data acquisition would be ineffective, as the system relies on significant data acquisition and set-up procedures that are best operated once. There is also a lack of trained consultant staff to undertake the RS component.

6.4.5 Future training requirements

From the review of the past training and the development of the other aspects (desk study and indices development) a range of future training requirements have been identified:

- Training materials need to emphasise the data quality and completeness issues
- Training needs to also address in more detail the role of the RS elements – such that field surveyors use the RS maps to help QA the data more effectively
- Training should explain the role and development of the indices to ensure that the field surveyors can more clearly understand the significance of quality and consistency in deriving the results of index operation.

A series of other factors affecting the implementation may also be picked up by training and improved procedures, and QA of the resulting data. These processes should be used to improve consistency of data and reduce missing values. There is however, a reluctance to add to the changes to the field form by virtue of the impacts on the support materials, forms and databases – and on to the data parameters themselves. However, one residual change is proposed to ensure that grid references are recorded as 12 figure references to facilitate the mapping in GIS, which has no impact on the functionality of the data. Other consistency and training issues are:

- Where a floodplain is absent guidance should be given on whether any adjacent features should be collected.
- Photo recording guidance should be improved to ensure that consistency of file-naming is achieved; this is likely to be improved by the specification of a site numbering system for surveys where desk study is conducted in advance of the field survey.
- The order of the reaches in GeoRHS (from upstream to downstream) needs to be confirmed with the surveyors and through the training to ensure consistency.
- Dealing with NV where the records are recording % values – in these instances 100% should be entered.
- Where a floodplain is not visible (as occurred in only 1 location) the RS data should be used in the field. Field maps from the RS elements were not available in the first survey round due to data deficiencies.
- Data quality checks, similar to RHS need to be performed and the potential to collect data in the field digitally should be readdressed, based on the results of the database development within Phase 1 of the GeoRHS project that developed the database for field data entry.

6.4.6 Indices and rules for assessment

The development of an appropriate rubric for assessment of the quality of the indices and contributory parameters is necessary within the use of GeoRHS (and RHS). The GeoRHS implementation is still ‘ young’, especially when compared to the development timescales for RHS indices and GeoRHS is still largely untested, particularly with modified sites and sets of scoring guidelines (criteria) for evaluating the performance or a product) and for giving feedback are needed.

Incorporating the GeoRHS features into PCA-based assessments, together with the RHS data, as used to identify similar river types, will be important in developing the appropriate contexts for analysis, although these will also need to cross-reference to the WFD typologies in establishing anticipated morphological features and processes.

6.5 Implementation options

An outline implementation plan within SEPA was discussed with IT team and Figure 6-1 illustrates the possible system architecture and data flows proposed within the SEPA implementation. Figure 6-2 illustrates the likely implementation within the Environment Agency considered by the Project Steering Group in April 2005. Both of these architectures are subject to change and may be influenced by the re-engineering of the RHS database within EcoSys, which might for a natural repository for the data.

Currently, GeoRHS data is not part of the EA EcoSys implementation, although early discussions with the EA indicated that it could accommodate the development of the GeoRHS parameters. Equally, EcoSys will not inherently have the capacity to work with spatial datasets as envisaged within the GeoRHS desk study requiring the use of ArcGIS and extensions regardless of where the data eventually reside. This implies that the implementation will require a hybrid of systems, although this is not atypical of such complex developments where data capture tools may differ from the resulting data management system.

Whilst all the derived data can be stored in a single multi-user access database within SEPA’s implementation it seems likely that the initial EA implementation would require separate spatial databases and field databases with import to an analytical environment to run combined SQL queries and provide GIS map based outputs. The analytical components are envisaged being operated through the databases rather than having any spatial interface; although mapped outputs are envisaged.

Both implementations will require upload of the data developed in the field to the analytical database and the import of the RHS database from the RHS excel spreadsheet or other EcoSys once this goes live, unless the capacity to store GeoRHS and GeoRHS desk study elements are also incorporated within the development.

Figure 6-1 Proposed multi-user implementation within SEPA.

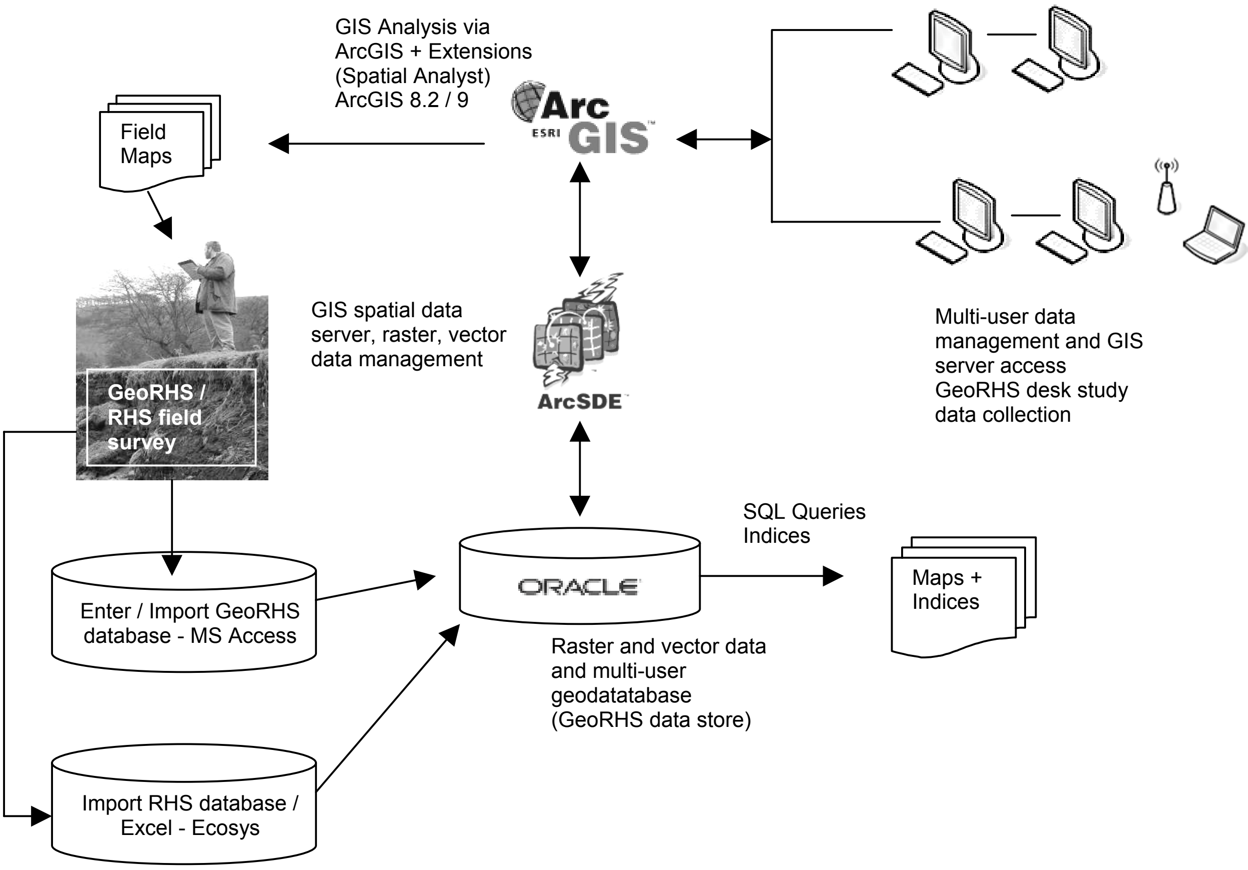
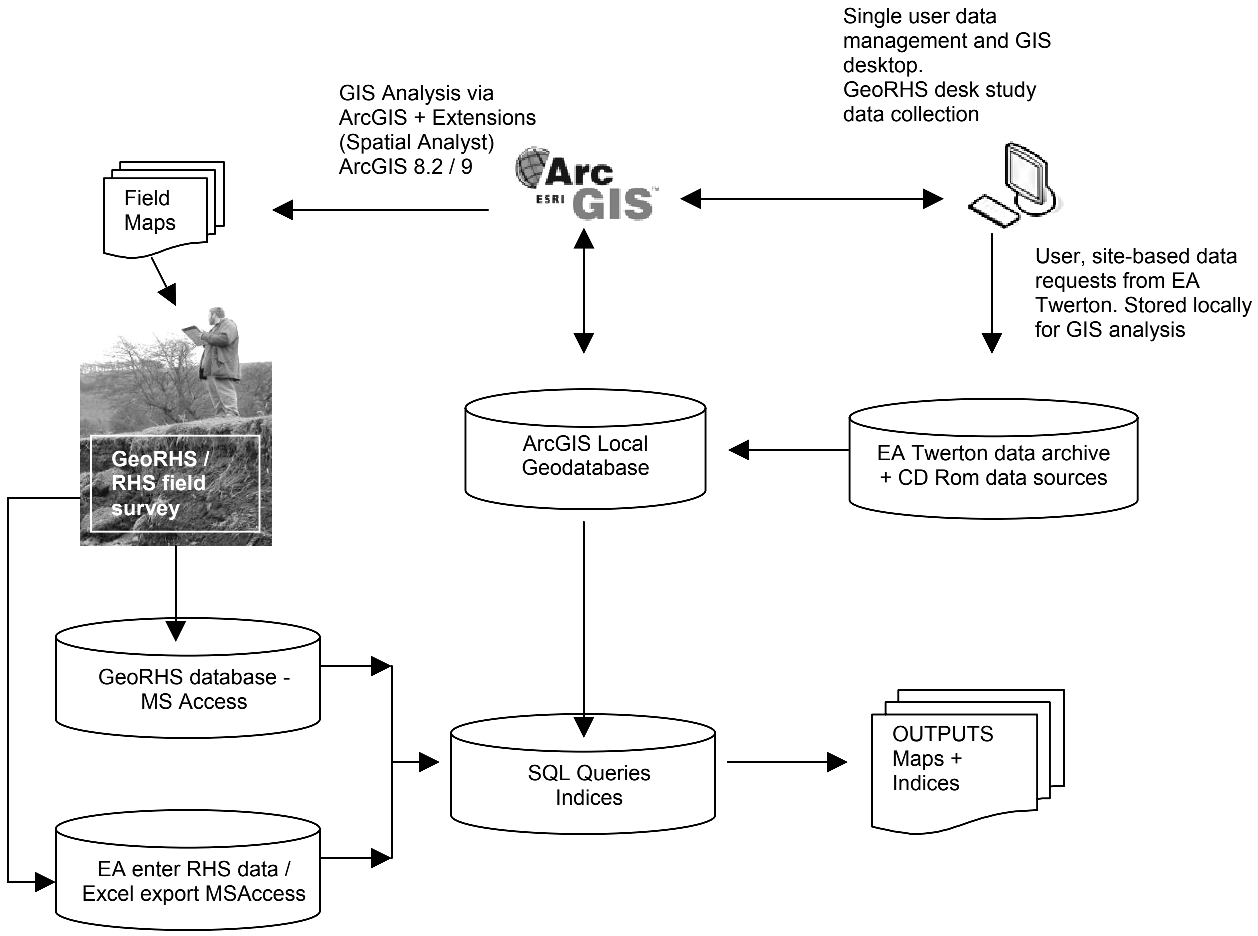


Figure 6-2 Proposed single-user implementation within EA.



A full implementation plan for Northern Ireland has not been developed at present as further evaluation of the datasets will be required and the IT implementation issues resolved. It seems likely that NI implementation would be more similar to that of SEPA's and may be used at present to estimate the development tasks.

6.6 GeoRHS GIS Tool – Future Challenges

6.6.1 Overview

The GeoRHS desk study component is now maturing into a GIS tool required by 2 organisations (EA and SEPA) and potentially a third (NI). Each organisation has been visited to examine the approaches for handling the data sources and outputs within their disparate IT systems. It is clear from this evaluation that a unified GIS, whilst not impossible to build will have issues for future maintenance and upgrades and responsibilities across the groups. The original concept for the GeoRHS GIS tool was of a system located in the EA with data requests passed from the other agencies and potentially outside organisations. The licensing issues of source data (especially Ordnance Survey information) makes this an ineffective model.

Table 6-1 shows the differences between the organisations and includes GeoData's (the software developer) implementation as an illustration of how external organisations may manage information.

Table 6-1 The different system versions and storage methods employed by the 4 organisations.

Organisation	ArcGIS Version	Networked PC	Storage method	Coordinates
GeoData	9.1	Y	File System	OS GB
EA	8.3	N	File System	OS GB
SEPA	9.0	Y	Oracle ArcSDE	OS GB
NI	9.0	Y	SQL ArcSDE	OS NI

The current version of the GeoRHS GIS Tool includes code that is capable of recognising if it is running as a GIS in the EA or SEPA. Not all functionality for the "SEPA" system is enabled, and further work is needed to implement the full data model within SEPA's offices. No code has been developed for the NI system.

The EA/SEPA system uses the same coordinate system although Northern Ireland has very different issues and would require considerable additional development that is beyond the scope of the R+D, although the principles of the development are transferable.

Table 6-2 shows the different data availability between the organisations. It does not indicate how the data is stored or the data currency; which will need to be determined in any future development.

Table 6-2 The availability of data between the different organisations.

Data set	GeoData	EA	SEPA	NI
Master Map	Y	Y	Y	Y*
Geology	Y**	Y**	Y	Y***
LCM2000	Y	Y	N	Y
Aerial photos	Y	Y	N	Not known
Flood map	Y	Y	N	N
Historical maps	N	N	N	N

* = has different fields to GB OS MasterMap and poorly built topology.
** = partial coverage.
*** = 1:250,000 scale.

Whilst some of the data missing from the Scottish implementation are crucial to the effective implementation of the GeoRHS GIS tool it is understood that these datasets are in the process of being acquired for other WFD related purposes. The aerial photography is currently not available for the whole of Scotland, with an estimated 80% coverage at the end of the 2005 flying season.

The EA have 'road tested' the system and produced a final list of improvements, some of these are simply amendments to the GIS Tool manual (see separate document) to improve definitions and give advice on how to handle "what if" situations.

The amendments list included:

- genuine bugs identified
- cosmetic changes to the interface
- amendments to the manual
- requests for additional features
- requests for operational changes (i.e. how the GIS operates)

Additional features added to the system are a bulk export button and zoom to NGR (SEPA only).
Other developments would alter the table structures and this would have ramifications on the database component of the GeoRHS and have not been implemented at the present time.

Table 6-3 shows where output is currently stored. This will affect how data is extracted and stored within the GeoRHS MS Access database. The storage solutions developed for the R+D project are recognised as a potential expedient that will be replaced by EA and SEPA systems, but provide the functional solution at the present time. The limitation of the EA development for accommodating new systems relies on storage on local drives, and will need to be replaced by a more secure system as soon as possible.

Table 6-3 Format and location of output data.

Organisation	Format	Output Location
GeoData	Personal GeoDatabase	Server
EA	Personal GeoDatabase	C:\ Drive
SEPA	Oracle Database	stir-app-gis01 server
NI	? – mostly like SQL Database	Network

6.6.2 Future updates and improvements to the GIS tool

This section reviews the current implementation of the GIS tool developed within the scope of the R+D programme. It looks forward to the stages and development options if the GIS tool is adopted within the agencies and its analytical role is enhanced. By the nature of the data sources and the systems environment there is no one system that meets the requirements of each partner agency. New datasets and new attributes may influence the development of indices and the application areas to which GeoRHS can be applied. Somewhat inevitably with such development, and as seen by the refinements in RHS implementation it is anticipated that further changes may affect the operation of GeoRHS.

If the project development demands new “must have” variables the differing data availabilities across the 3 organisations needs to be borne in mind. Even where data are available it will often be stored in different formats and scales requiring different implementation and customisations strategies. Significant changes to the attributes collected would be bound to influence how the GIS tool will function. For example, it has been suggested that multiple meander amplitudes would be a more useful data capture than a single value, collected in the current system (by manual and automated actions).

Any such additions would be likely to have ramifications for the spatial table structure, the code that accesses the data and the database that the information is exported to; as well as the time taken to extract the information. Changes will also affect the ability to use legacy data, without the new attributes, in any later processing and indicator developments.

The Environment Agency implementation is the ‘most complete’ system which the SEPA and NI should mimic in functionality depending upon source data availability, having been modified consequent on comments from users within the EA. Currently, although the EA implementation is as a standalone platform the potential migration of the EA IT systems, to Oracle and SDE with a central data store, may influence the longer terms structure. Current lack of implementation of OS MasterMap by the Environment Agency limits the integration of the GeoRHS GIS tool.

The SEPA system requires additional development to integrate into the Oracle database. This is estimated at an additional 5 days. This task would be used to integrate the remaining functionality and test the code. SEPA have additional requirements of a GIS Tool, over and above those currently required by the EA implementation. These are administrative requirements on controlling access rights to SEPA’s Oracle server and new functionality that is specific to SEPA; including the spatial extraction of catchment name from SEPA’s catchment layer, a process which is currently a textbox entry. Similar functionality could be added to both EA and SEPA and additional automated spatial layer attribution may be relevant (e.g. river basin attribution). SEPA’s more integrated IT structure demand that everything is held within their Oracle database. This makes development more bespoke to their individual set up and requires direct access to their system. This implies that further GIS Tool development should be undertaken in liaison with the SEPA IS team.

EHS Northern Ireland source data differs substantially from that of OS MasterMap; the basis for much of the current tool automation and data collection. Their data is projected into the NI national grid and has considerable topology issues that would affect tool implementation. There appears to be no consistent rule to what was a polygon/polylines within the data making application development more likely to adopt non-automated, interpretative processes. It may be many months before this dataset is in a consistent format that can used to develop with, and any further development should await the resolution of the data formats. The recent load of OS NI data into their SQL Server database will require further evaluation before it is possible to develop a GeoRHS GIS tool.

Future programmed data source development has the potential to streamline some of the data generation tasks for the GeoRHS GIS tool. These anticipated data source improvements include: floodplain maps in Scotland, OS MasterMap based river centrelines, NFCDD improvements, and morphological alterations data in Scotland. Once available the GIS Tool will need to be updated to extract the relevant attributes. For example, if soils data is made available, the GIS should be programmed to extract this automatically to take advantage of the advanced spatial processing capabilities of a GIS, instead of remaining as an error prone, uncontrolled free-form textbox entry.

The Atlantis development (OS pers. comm.) plans include the generation of a river centreline based on the OS MasterMap which could replace the need for the generation of the layer within the GIS tool. The development timescales for Atlantis centreline have not allowed for this to be integrated within the current tool.

Some of the procedures are currently free-form text box entries as no sample data was supplied to develop the tool (e.g. NFCDD). The current NFCDD database is largely non-transportable and the data structure has not been available. Nevertheless, when this data is finally released an improved automated data collection should be developed which would reduce/remove human error and enhance the collection of channel modifications. However, there are significant shortfalls in the accurate spatial representation of defence structures and assets and the level of attribution of the data within NFCDD that may limit its usefulness when compared with the potential to collect data during the field surveys (Halcrow 2005).

There is significant potential for RHS and GeoRHS based information to be used to validate the NFCDD data quality (completeness and accuracy) contained within the NFCDD at regional / area level. Within SEPA's development of the morphological alterations database (GeoData 2005) GeoRHS and the RS data could be used to validate the records and the GIS tool functionality used to help develop the alterations database.

With the upgrade to ArcGIS version 9.1, GeoData can now save a project file as Arc8.3 format. Whilst this significantly reduces development time where backwards compatibility is required there are likely to always be some compatibility issues due to different code libraries. Due to the EA having only Arc8.3 GeoData have developed at the "lowest level" to ensure backward compatibility. This does mean that more sophisticated raster catalogues cannot be implemented within this version as such data structures do not exist in 8.3. 'Work-arounds' for such issues are usually possible, but longer-term maintenance should be allowed for update of the underlying model to accommodate these features and enhancements.

6.6.3 Summary of next steps

Through the development of the GeoRHS R+D a number of additional tasks have been identified as the 'next steps' and implementation issues. Many of these are dependent on the business case and the routes for development. These next steps are reported within the individual sections but are drawn together in this section, in tabular form (Table 6-4).

Table 6-4 summary of implementation tasks and potential 'next steps'

Theme	Task
Form and data capture procedures	• Potential upgrade and attribute additions/alterations to the survey forms and field procedures following further evaluation. • Improved access to source data within the Environment Agency; including access to key resources such as OS MasterMap. • Establish a closer link between RHS data and the GeoRHS data, ideally through an RHS survey number rather than through a grid reference to ensure that the coverage of surveys of different types can be drawn together effectively. • Data quality and consistency checks are needed, similar to those operated for RHS data entry – or a system of in field digital data entry adopted. The desk study data created prior allows for some elements of field survey to be validated.
Indices	• Testing of indices and sensitivity assessment of indices based on a broader range of sites and against specific typologies. • Development of further indices based on a prioritisation, likely to include indices of stability and instability, aggradation and degradation indices. • Evaluation of the range of the indices scores to enable the sites to be 'stretching' of the scores to represent the range of site types within the index domain. • The database developments to run indices are currently not targeted at non-expert users, additional development should be undertaken to front-end the allocation of scores and weightings for attributes and their values.
Training	• Additional training courses to allow other EA/SEPA and contractor accreditation • Emphasis within training of items that have affected the consistency of data collection – most notably standardisation of direction, photographs and referencing and procedures for site data collection in the absence of a floodplain Part II form).
Implementation	• Greater integration of the attributes from RHS RS and GeoRHS datasets in EcoSys • Reimplementation of databases to match EA adopted software (MS Access 2003) to cover duration of implementation in EcoSys. • Access and integration of historic map data within SEPA and Environment Agency applications. • It is recommended that the interface include the ability to extract data for particular rivers and catchments (river basin districts, typologies etc).
GIS Tool	• NFCDD structure implementation within EA version of GIS tools • Morphological alterations database implementation within SEPA version of GIS tools • Potential to use new data streams, such as the river centreline based on the OS MasterMap.

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Glossary of terms

CEN The European Committee for Standardization (CEN) is the Technical Committee responsible for standardization of biological, chemical and microbiological methods in water.

CIS Common Implementation Strategy. Strategy developed by member state representatives and stakeholders supporting in the implementation of the WFD, by developing a common understanding and guidance on key elements of this Directive.

FAS Flood Alleviation Scheme. Combined actions within a comprehensive scheme to alleviate the risk of riverine flooding.

GeoRHS Geomorphological River Habitat Survey.

HQA Habitat Quality Assessment. An index of river habitat quality based on the in categories drawn from the River Habitat Survey data attributes.

HMS Habitat Modification Score. An index of river habitat modification based the total of all the component scores indicating modification to the channel and riparian area from River Habitat Survey data attributes.

HMWB Heavily Modified Waterbody. A body of surface water which as a result of physical alterations by human activity is substantially changed in character; designated by the Member State in accordance with the provisions of Annex II of the Water Framework Directive.

Hydromorphology Under the WFD the physical characteristics of the shape, the boundaries and the content of a water body. The hydromorphological quality elements for classification of ecological status are listed in Annex V.1.1 and are further defined in Annex V.1.2 of the Water Framework Directive.

Reference conditions For any surface water body type reference conditions is a state in the present or in the past where there are no, or only very minor, changes to the values of the hydromorphological, physico-chemical, and biological quality elements which would be found in the absence of anthropogenic disturbance.

RHQ River Habitat Quality. A reclassification matrix developed by employing the habitat modification scores and the river habitat quality indices derived from RHS survey data.

RIVPACS (**R**iver **Inv**ertebrate **P**rediction **a**nd **C**lassification **S**ystem). A biological classification of unpolluted running water sites in Great Britain based on the macroinvertebrate fauna.

UKTAG United Kingdom Technical Advisory Group. Group supporting the implementation of WFD within the UK. UKTAG consists of experts from the UK conservation and environment agencies and the Department of Environment and Local Government for the Republic of Ireland.

WFD Water Framework Directive European framework legislation (Directive 2000/60/EC) for achieving environmental standards for surface and ground waters through an approach of River Basin Management.

WFD49 Development of Environmental Standards (Morphology) SEPA /EA project investigating the Environmental Standards classification system based on channel sensitivity and capacity based on ecological and morphological sensitivity and activity extent.

WFD74 Morphological alterations database (Scotland) Sniffer programme for the development of a database of morphological alternations of the surface water bodies.

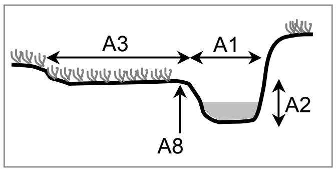
Appendix A: Field forms and field crib sheet

GeoRHS Floodplain Module – header information and cross-section dimensions

Site No.		**River Name**		**Catchment**			
Date		**Time**		**Surveyor Code**			
Surveyed bank	LB RB	**Flow Condition**	Low Med High	**Desk Study**	Y N	**H & S Form**	Y N
500 consistent	Y N	**Practical Problems**					

Transitions:			**A9 Information**
Morphology	**Sediments**	**Land use**	

U/S MAP NGR: …………………….........GPS:………………….……….



	Left (A6)	Bed (A7)	Right (A6)	
		A4 % Pond:		

450

GPS:	Sed % Sed %	Sed % Sed %	Sed % Sed %	A1 Bankfull width (m):
A5 Photo ref:	BE SI	BE SI	BE SI	A2 Bankfull depth (m):
A5a Photo (°):	BO EA	BO EA	BO EA	A3 RB f/p width (m):
A3 LB f/p width (m):	CO CL	CO CL	CO CL	A8 RB B'top sed:
A8 LB B'top sed:	GP PE	GP PE	GP PE	A11 Slope °
	SA AR	SA AR	SA AR	
	NV	NV	NV	
		A4 % Pond:		

350m

GPS:	Sed % Sed %	Sed % Sed %	Sed % Sed %	A1 Bankfull width (m):
A5 Photo ref:	BE SI	BE SI	BE SI	A2 Bankfull depth (m):
A5a Photo (°):	BO EA	BO EA	BO EA	A3 RB f/p width (m):
A3 LB f/p width (m):	CO CL	CO CL	CO CL	A8 RB B'top sed:
A8 LB B'top sed:	GP PE	GP PE	GP PE	A11 Slope °
	SA AR	SA AR	SA AR	
	NV	NV	NV	
		A4 % Pond:		

250m

GPS:	Sed % Sed %	Sed % Sed %	Sed % Sed %	A1 Bankfull width (m):
A5 Photo ref:	BE SI	BE SI	BE SI	A2 Bankfull depth (m):
A5a Photo (°):	BO EA	BO EA	BO EA	A3 RB f/p width (m):
A3 LB f/p width (m):	CO CL	CO CL	CO CL	A8 RB B'top sed:
A8 LB B'top sed:	GP PE	GP PE	GP PE	A11 Slope °
	SA AR	SA AR	SA AR	
	NV	NV	NV	
		A4 % Pond:		

150m

GPS:	Sed % Sed %	Sed % Sed %	Sed % Sed %	A1 Bankfull width (m):
A5 Photo ref:	BE SI	BE SI	BE SI	A2 Bankfull depth (m):
A5a Photo (°):	BO EA	BO EA	BO EA	A3 RB f/p width (m):
A3 LB f/p width (m):	CO CL	CO CL	CO CL	A8 RB B'top sed:
A8 LB B'top sed:	GP PE	GP PE	GP PE	A11 Slope °
	SA AR	SA AR	SA AR	
	NV	NV	NV	
		A4 % Pond:		

50m

GPS:	Sed % Sed %	Sed % Sed %	Sed % Sed %	A1 Bankfull width (m):
A5 Photo ref:	BE SI	BE SI	BE SI	A2 Bankfull depth (m):
A5a Photo (°):	BO EA	BO EA	BO EA	A3 RB f/p width (m):
A3 LB f/p width (m):	CO CL	CO CL	CO CL	A8 RB B'top sed:
A8 LB B'top sed:	GP PE	GP PE	GP PE	A11 Slope °
	SA AR	SA AR	SA AR	
	NV	NV	NV	

D/S MAP NGR:………..…………………….. GPS:……..………………………

BE bedrock **BO** boulders **CO** cobbles **GP** gravel/ pebble **SA** sand **SI** silt **CL** clay **EA** earth (i.e. bed of ephemeral channels when dry) **PE** peat **AR** artificial **NV** not visible **NO** = None

PART ONE: CHANNEL MORPHOLOGY

SITE No.	

BANK FEATURES	Left bank		Right bank	
A10 ENGINEERING	Tally (m)	Total	Tally (m)	Total
Culverted				
Straightened				
Resectioned				
Reinforced – whole bank				
Reinforced – toe				
Soft engineering (Bioeng)				
Soft engineering (Fabric)				
Ad hoc revetment				
Embanked				
Embanked – set back				
Artificial two-stage				

B EROSION	COMMONLY OCCURING BANK EROSION FEATURES (accumulated length for both banks: m in 500m)			
B1 Basal bank scour				
B2 Full bank scour				
B3 Cliffs / screes				
B4 Cantilevers				
B5 Slabs				
B6 Slides / flows				
B7 Accumulating?				

BIOLOGICAL	LOCALLY ACCELERATED BANK EROSION FEATURES (accumulated length for both banks: m in 500m)			
B8 Fallen tree				
B9 Burrowing				
B10 Poaching				
B11 Gravel extraction				
B12 Access - foot/vehicle				
B13 Failed revetment				

CHANNEL FEATURES	BED		BED & BANKS		
CHANNEL BED SCOUR	Tally Length (m in 500m)	Total	**OTHER DEPOSITS (FINES)**	Tally Area (m^2)	Total
B14 Bend scour			C10 Berms (Unveg)		
B15 Mid-channel scour			C11 Berms (Veg)		
C DEPOSITIONAL FEATURES	Tally Area (m^2 in 500m)	Total	C12 Berms (Artificial)		
ACTIVE (Unveg.) C1 Point bars			C13 Bed drapes (fines)		
C2 Side bars			C14 u/s of structures		
C3 Mid- channel			C15 d/s of structures		
C4 Tributary bars			**DISRUPTION**		
STABLE (Veg.) C5 Point bars			C16 waste disposal		
C6 Side bars			C17 sediment jams / dams		
C7 Mid-channel			C18 macrophyte chokes		
C8 Tributary			C19 CWD jams / dams		
C9 Mature Island			C20 chaotic flood deposits		

SKETCH MAP / NOTES	(rough sketch illustrating planform, bank profiles, floodplain palaeochannels etc.)

PART TWO: FLOODPLAIN (FP) GEOMORPHOLOGY, CONVEYANCE & ADJUSTMENT

SITE No.	

FLOODPLAIN GEOMORPHOLOGY

Floodplain Absent	

D FP FEATURES / TERRACES	Left	Right		Left	Right
D1 Floodplain (A/I/C/D)			D6 FP slope (1 = to channel, 2 = away, 0 = flat)		
D2 External boundary to FP flows (feature)			D7 Height of FP relief (relict channels)		
D3 Relict (palaeo) channels on FP (A/P/E)			D8 Number of terraces above floodplain		
D4 Number of relict channels			D9 Estimated height of terraces (m)		
D5 Relict channel planform (An/Br/Me/St)					

E CHANNEL / FP FLOW ROUTES	Left	Right		Left	Right
E1 Direct uniform spill (A/P/E)			E7 Number of Embankments (EM)		
E2 Eroded low points (A/P/E)			E8 Length of EM (m)		
E3 Active side channels (A/P/E)			E9 Distance: EM crest to bank top (m)		
E4 Relict channels - water filled (A/P/E)			E10 Max. EM height above FP (m)		
E5 Relict channels - natural veg (A/P/E)			E11 Natural levees and dredgings (A/P/E)		
E6 Relict channels - used (covered) (A/P/E)					

F BANK – FP ZONE	Left	Right		Left	Right
F1 Channel migration (A/P/E)			F5 Washout at roots (A/P/E)		
F2 Trees - continuity (A/I/R/OC/SC/C)			F6 Buffer zone (A/P/E)		
F3 Plantation conifers (A/P/E)			F7 Buffer zone - average width (m)		
F4 Tree condition (G/D/Dg)					

G FP FLOW ROUTES	Left	Right		Left	Right
G1 Trash marks (APE) & (height rel. to FP)			G7 Artificial drainage networks on FP (A/P/E)		
G2 Recorded flood marks (date & height)			G8 No. FP drainage channels inside EM		
G3 Crop damage (A/P/E)			G9 Length FP drainage channels inside EM (m)		
G4 FP deposits (A/P/E)			G10 No. FP drainage channels outside EM		
G5 Damaged walls/fences (A/P/E)			G11 Length FP drainage channels outside EM		
G6 River fed FP storages: leat, lakes (A/P/E)			G12 Flap valves through Embankments (no.)		

H FP ROUGHNESS FEATURES	Left	Right	*(add * if land use impacting morphology)*	Left	Right
H1 Permeable boundaries (A/P/E & II,X)			H7 WU (woods/plantation – with understorey)		
H2 Impermeable boundaries (A/P/E & II,X)			H8 WW (woods – ***without*** understorey)		
FLOODPLAIN LAND USE (A/P/E & *)			H9 PG (parkland/gardens)		
H3 RP (rough pasture, unimproved grass)			H10 MH (moor + heath)		
H4 IG (improved grassland)			H11 SU (suburban/urban)		
H5 TL (arable)			H12 WL (wetland)		
H6 SH (shrub/scrub)			H13 OW/AW (open water, artificial water)		

INDICATORS OF CHANNEL FLOODPLAIN STABILITY / ADJUSTMENT

J AGGRADATION	A/P/E	K DEGRADATION	A/P/E
J1 Buried artificial structures		K1 Recent terraces (<1m)	
J2 Buried soils		K2 Recently-abandoned palaeochannels	
J3 Extensive coarse sediment shadows		K3 Recent cut-offs (dry or wetland)	
J4 Elevated bars/wandering and braiding		K4 Narrow/deep channel, exposing tree roots	
J5 Extensive floodplain splays		K5 Extensive slumping of both banks	
J6 Eroding banks in shallow reaches		K6 Undermined bridge piers – recent repairs	
J7 Contracted channel at bridges		K7 'Paved' (coarsened) bed material	
J8 Recent and extensive dredging/desilting		K8 Artificial bed stabilisation structures (weirs etc)	

SUPPORT PHOTOS - Features of note, bank/bed/bar sediments, indicators of stability/adjustment, FP deposits/obstructions

DESCRIPTION	Bearing	GPS ref (x + y)	DESCRIPTION	Bearing	GPS ref (x + y)

RP/MH Rough Pasture Moorland Heath, IG improved grassland, TL Tilled land, SH scrub, SU suburban / urban, PG parkland grassland, WL wetland, OW/AW open water artificial water.

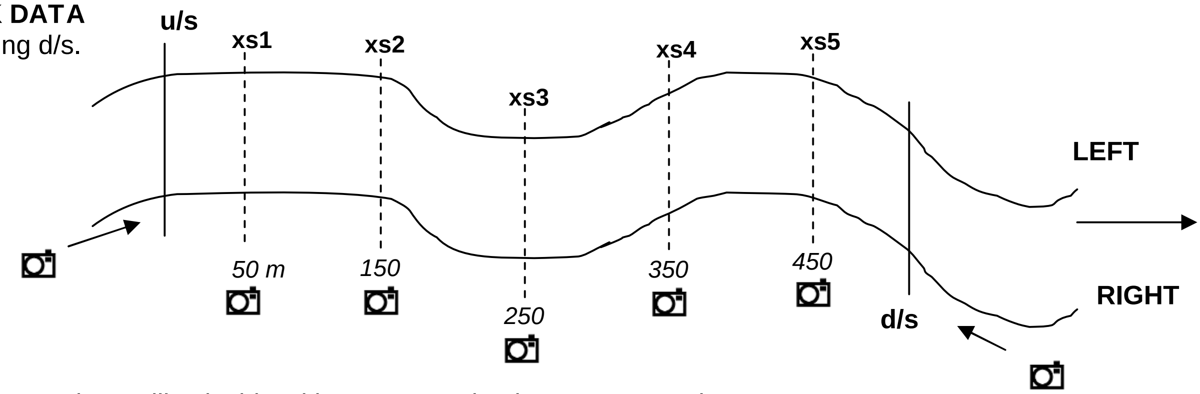
PAGE 1 HEADER INFORMATION + CROSS SECTIONS

A9 Information - describe the reach morphology e.g. deeply entrenched meandering section in non-cohesive sediments, wide floodplain with evidence of former channels.

Transitions = to what extent is the channel 500m reach uniform – what changes occur within the reach.

NGR: record all grid references as 12 figure reference (i.e. to the 1m resolution) – **not** as per RHS (which records to 10 m resolution). Record **NO** for none where there is no record**.**

SPOT CHECK DATA
Left = left looking d/s.



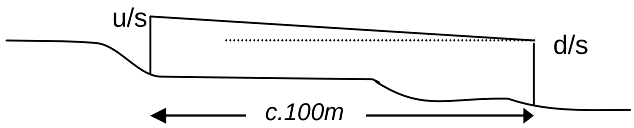
The GeoRHS X-Sections will coincide with RHS spot checks 2, 4, 6, 8 and 10.
Photos: one at each X-S, a reach overview looking d/s and looking u/s. **Supporting photos**: that note morphological features, eroding banks, bars, pressures and for areas of uncertainty etc.

A6, A7, A8 (Bed and Bank Materials)
% Data (to the nearest 10%)

BE	Bedrock	solid rock.
BO	Boulder	>= 256mm.
CO	Cobble	64-256mm.
GP	Gravel/Pebble	2-64mm.
SA	Sand	<2mm.
SI	Silt	<0.0625mm.
EA	Earth / Loam	sand/silt/clay
CL	Clay	cohesive.
PE	Peat	organic matter.
AR	Artificial	
NV	Not Visible	
NO	None	(only for A8)

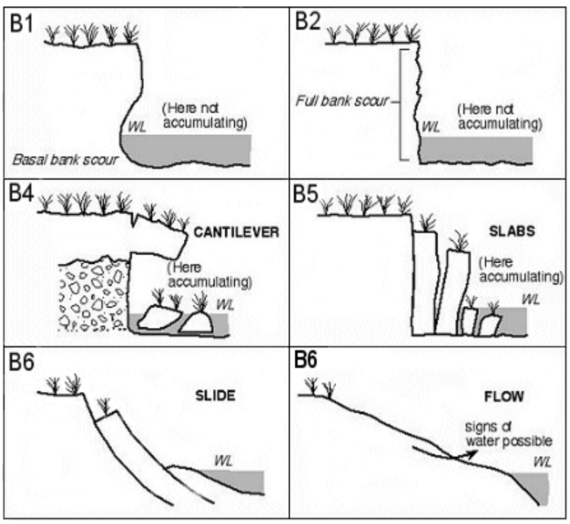
A11 (Slope)
Degrees (to 0.5 ^{o}) or **NO** (no measurement possible).

Record slope at each X-Section using a Clinometer. At each X-S measure looking u/s to the next section. Do not make measurements across inflexion points. Ignore waterfalls (slope = u/s and d/s of major breaks).

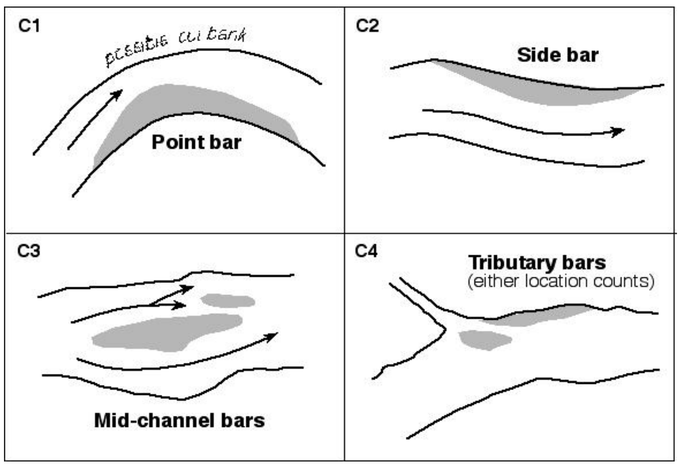


PAGE 2 CHANNEL MORPHOLOGY

Erosion



Deposition

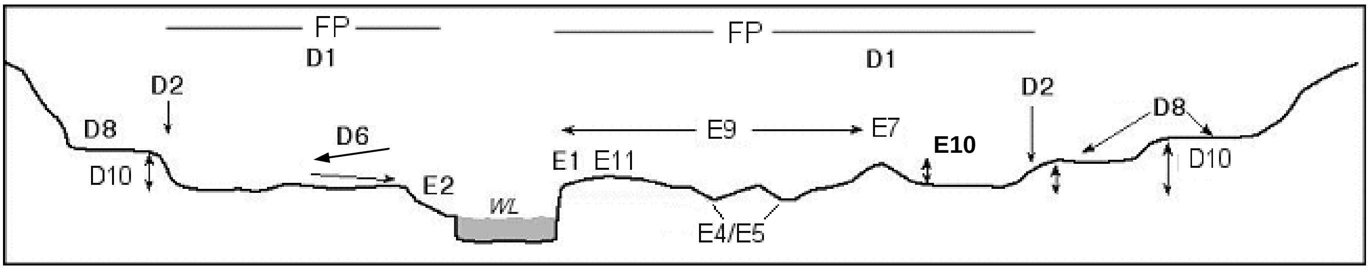


Estimate **Area** (m^2) of each depositional feature

Berm = GeoRHS definition differs from RHS – may be frequent, width adjustment mechanism, at base of bank but surface raised above low flow level, most frequently of silt and/or sand, low angle to flow, prone to vegetation colonisation (C11). Artificial berms (C12) may be constructed to narrow channel.

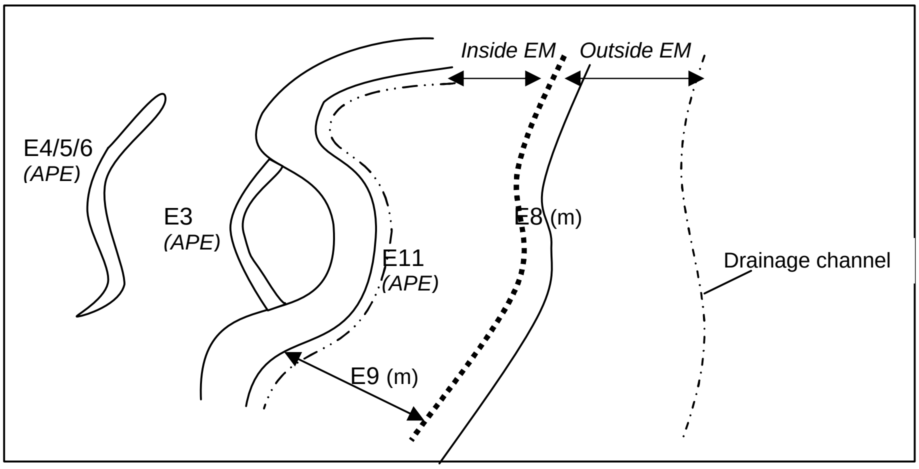
PAGE 3 FLOODPLAIN MORPHOLOGY, CONVEYANCE AND ADJUSTMENT

If floodplain absent TICK box and leave rest of form blank. Record for Left and Right banks separately. Record dominant features for each attribute.



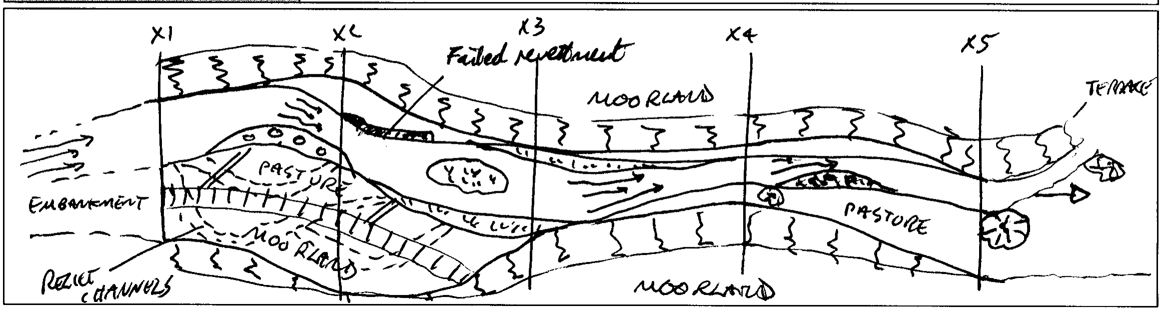
Codes

D1	A = Absent I = Intermittent C = Continuous D = Disconnected
D5	An = Anastomosing Br= Braided Me = Meandering St = Straight
D6	Most floodplains are flat (0), 1 = slopes towards river, 2 = slopes away from river.
E1-E6	A = Absent P = Present E = Extensive (>33% of floodplain)
F2	A = Absent I = Isolated R = Regular OC = Clumps SC = Semi-continuous C = Continuous
F5	G = Good D = Damaged Dg = Dying
G1 Trash marks	Record APE and height in m relative to floodplain.
G2 Recorded flood marks	Record date and height of mark (where it is possible to establish).
H1/H2	A = Absent P = Present E = Extensive II = Parallel X = Normal to flow
H3-H11	Record * if land use is contributing or has the potential to contribute sediment to the channel.



Example sketch: – use to indicate locations of X-sections relative to features, tansitions and u/s and d/s influences, useful for validation

SKETCH MAP / NOTES	(rough sketch illustrating planform, bank profiles, floodplain palaeochannels etc.)



Quality Assurance (Ensure the following items have been completed before leaving site)
Where you have been provided with pre-survey RS data check the validity of the information and locational information.

RHS Form (✓)							
Photo Reference (✓)	Photos at each X-Section		u/s		d/s		

Appendix B:

Examples of matrix based indices developed for the River Nar /River Wensum fluvial audit.

Fluvial Audit, as a broad scale methodology, has similarities to the section based surveys (RHS/GeoRHS), being form-based, but accommodates data integration from desk study, historic surveys etc (similar in this regard to the formal GeoRHS desk study extension). Thus the datasets that contribute to a geomorphic evaluation will vary from site to site, based on the levels of past survey of the river system, although often a common GIS/database dataset is derived from field surveys and historic maps.

Fluvial Audit data have been used recently within the Wensum and Nar catchments on lowland chalk river systems and provide a useful case study of combining scored data within a reclassification matrix to derive indices suitable for river management strategic purposes. Viewed as a whole, the Rivers Nar and Wensum are not in good hydromorphological quality condition according to the CEN definitions. However, some reaches may be closer to these attributes of a high quality site than others. In this instance the attributes collected may be treated from two directions; factors indicating modification and factors indicating naturalness. A third factor was included within the analysis, sediment flux based on sediment storage and sediment supply – and in these lowland river systems the issue is fine sediment load.

Reference conditions must clearly be defined within the context of naturalness for particular local conditions. Whilst WFD has defined an interim typology this is based on relatively simple measures and the local variation relevant to reference condition may underlie this typology. It is difficult to establish Reference Condition in lowland chalk catchments, which have been subject to extensive hydromorphological impacts.

In the case of the Nar and Wensum a literature and RHS database approach has been used to examine in more detail the attributes that would typically define a pristine chalk river in the Anglian context (equivalent to Reference Condition). This differs from the variation that may be seen in Southern English chalk systems, particularly related to past management activities and post glacial evolution. The Nar is distinguished by two main forms: groundwater dominated rivers flowing from chalk geology with overlying glacial deposits, and low gradient semi-tidal channels.

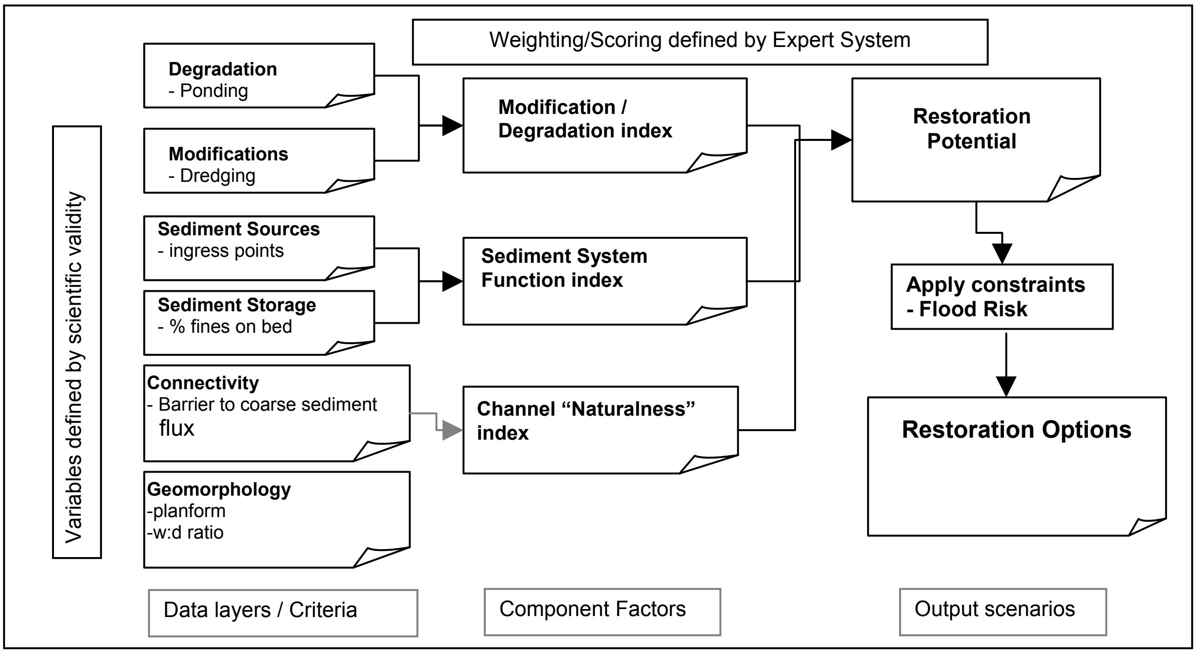


Figure A-0-1 Flowline of the analysis process for the derivation of matrix reclassification to develop condition classes and restoration options.

The physical attributes derived from these data sources have been combined into a table for each river type. Not all values are available from existing data. Those that are available have been used accordingly to derive classed 'Naturalness', 'modification' and 'sediment function' indexes for each reach within Multi-criteria (MCA) tables (the sediment function index was not used further within this analysis). It is recognised that the attributes, scores and weights are subjective. The MCA process enables discussion and modification of these according to expert or local understanding and could form the basis of decision-support and stakeholder involvement since the process is transparent.

The naturalness index was derived for each reach identified from fluvial audit data. The lower the index score the higher the naturalness of the reach as defined by the attributes used. The existing modification index was enhanced by including two other categories, presence of ponded flow upstream of structures, and > 80% bed cover by macrophytes. Again these were factors that the Fluvial Audit provided and were specifically relevant to the nature of modifications within the geographic location and within the context of the historic use of the river. The naturalness index and modification index were then overlaid in the GIS and both visualised. The resulting reaches are coloured according to the degree of naturalness and modification. This provides a set of potential classes for each reach – in principle similar to the RHS Physical Quality Objectives (Walker et. al. 2002) only derived from continuous, survey-based and locally applicable datasets. **Figure A-0-2** illustrates the potential classes arising from the combination of naturalness and modification indices. These classes embody, at least in part the trajectory of changes to the system (from HMWB to natural rivers within a restoration assessment context).

	0 Natural	1 Predominantly natural	2 Partially natural	3 Practically Un-natural	4 Un-natural
0 Unmodified	Natural	Semi-Natural	Damaged	Damaged	Damaged
1 Predominantly Unmodified	Semi-Natural	Semi Natural	Damaged	Damaged	Damaged
2 Obviously Modified	Recovered	Recovering	Degraded	Degraded	Degraded
3 Significantly Modified	Recovered	Recovering	Degraded	Severely Degraded	Severely Degraded
4 Severely Modified	Recovered	Recovering	Degraded	Severely Degraded	Artificial

Figure A-0-2 Classification of reach types arising from the combination of Modification and Naturalness indices.

Taking this approach further, each reach class can be allocated a management action required to move the river towards an improved condition. Such allocations may again be site-specific (or potentially within the WFD context type-specific) and the simple translation and ***matrix reclassification*** may be catchment specific and conditional on scales, extent of degradation etc. In the simplest case of a natural river reach the action would be to protect and monitor status. For the artificial river reach it is most likely a case of do nothing as there is very little that can be achieved.
Figure A-0-3 details the management options for each river class, which form the basis for the restoration vision for the River Nar. The approach does no rely on resolving to a single classification.

	0 Natural	1 Predominantly natural	2 Partially natural	3 Practically Un-natural	4 Un-Natural
0 Unmodified	Protect & Monitor	Protect & Monitor	Assist Natural Recovery	Restoration	Restoration
1 Predominantly Unmodified	Protect & monitor	Protect & Monitor	Assist Natural Recovery	Restoration	Restoration
2 Obviously Modified	Conserve & Monitor	Assist Natural Recovery	Rehabilitation	Rehabilitation	Enhancement
3 Significantly Modified	Conserve & Monitor	Assist Natural Recovery	Rehabilitation	Rehabilitation	Enhancement
4 Severely Modified	Conserve & Monitor	Assist Natural Recovery	Rehabilitation	Rehabilitation	HMWB

Figure A-0-3 Management action associated with each reach class.