Natural England Research Report NERR013

Geomorphological assessment of riverine SSSIs for the strategic planning of physical restoration

www.naturalengland.org.uk

NATURAL ENGLAND

Natural England Research Report NERR013

Geomorphological assessment of riverine SSSIs for the strategic planning of physical restoration

Sear, D.A., Hill, C.T. & Downes R.H.E

Published on 29 July 2008

ISSN 1754-1956

Project details

This report results from research commissioned by Natural England. The work was undertaken by GeoData Institute, University of Southampton.

A summary of the findings covered by this report, as well as Natural England's views on this research, can be found within Natural England Research Information Note RIN013 – Geomorphological assessment of riverine SSSIs for the strategic planning of physical restoration.

Project manager

Chris Mainstone
Natural England
Northminster House
Peterborough
PE1 1UA
chris.mainstone@naturalengland.org.uk

Contractor

GeoData Institute
University of Southampton
Southampton
SO17 1BJ
Tel: 023 8059 2719
Fax: 023 8059 2849
geodata@soton.ac.uk

Acknowledgments

We would like to acknowledge the help and assistance of a number of agencies and individuals in the provision of data, and those who commented on a draft of this report.

In particular, we are grateful for the comments from Chris Mainstone and David Withrington of Natural England. We are also grateful to the many surveyors and consultants who have undertaken fluvial audits for making copies of their surveys available to the project.

Summary

Natural England, in collaboration with the Environment Agency, has formulated guidelines for developing strategic plans for the physical restoration of SSSI rivers. This project was commissioned to help develop a generic specification for geomorphological assessment for use as part of the development of these plans.

Geodata has reviewed the extent and nature of past geomorphological surveys of rivers in England, and the specifications that have been employed in commissioning them. A list of these surveys is provided in Appendix 4 of this report. Such surveys have been commissioned for a variety of reasons and at carrying levels of analytical intensity. Only a few had similar objectives to those required for strategic planning of physical restoration.

Through the review of these surveys, and a reappraisal of the objectives of geomorphological evaluation processes collectively termed Fluvial Audit, a new generic specification has been devised that both reflects the theoretical underpinning of the methods and the objectives of whole-river restoration planning. The broad term 'Geomorphological Assessment' has been used to describe the work needed, to avoid the specific connotations of the term Fluvial Audit.

The generic specification is attached as Appendix 12. It describes:

- relevant sources of existing data;
- key aspects of field data capture;
- analysis and presentation;
- the development of a conceptual model of the sediment system and channel morphology;
- the mapping of historical modifications; and
- the specification of suitable management options to restore characteristic habitat form and function.

Importantly and for the first time in the definition of geomorphological assessment of rivers, the specification explicitly defines the need for ecological interpretation of geomorphological form and function, and characterisation of the ecological significance of both existing anthropogenic changes to geomorphology and recommended management options to restore the river. This integrated consideration of geomorphology and ecology is essential for the development of ecologically meaningful restoration plans.

The specification also provides guidelines for the standardised storage and provision of raw data arising from geomorphological assessment, which if followed would be useful for future collation of geomorphological data at a national scale.

Contents

Appendices

List of tables

List of figures

1 Introduction

Background

1.1 The Government has a Public Service Agreement (PSA) target for 95% of Sites of Special Scientific Importance (SSSIs) in England (by area) to achieve Favourable Condition (or Unfavourable Recovering Condition) by 2010. In the context of river SSSIs, favourable condition is currently only achieved on around 31% by area. Natural England is charged with overseeing activities to achieve the PSA target.

1.2 One of the reasons for the unfavourable condition of rivers is damage to physical, morphological status, resulting from past modifications including drainage, water abstraction, dredging, flood defence works, and construction of impoundments. The assumption here is that natural systems with low degrees of artificial modification allow the river to express its full characteristic diversity of habitats and hence biota.

1.3 A range of methods are used to assess the condition of SSSI rivers, based on UK-level 'Common Standards' guidance (JNCC 2005). Whilst use is made of the River Habitat Survey to provide quantitative information on the physical status of a SSSI river, such information is not sufficient to identify and plan any necessary physical restoration work, particularly at the whole-river scale.

1.4 In 2005, English Nature, in collaboration with the Environment Agency, drafted guidelines for the development of strategic physical restoration plans for SSSI rivers (English Nature / Environment Agency 2005). These guidelines aim to deal with the designated river as a whole and identify the most appropriate measures to bring the physical status of each reach of the SSSI into favourable condition. The term 'restoration' is used broadly to cover the more precise terminology of 'rehabilitation' and 'restoration'. The guidelines seek to provide a framework for planning measures at the whole-river scale for the whole biological community, shifting emphasis away from small-scale (short reach) planning that is often focused on a target species and does not consider larger scale geomorphological processes and anthropogenic impacts upon these processes. Detailed geomorphological evaluation is seen as essential underpinning for the development of these strategic plans.

1.5 Initial trialling of the guidelines revealed uncertainties and inconsistencies in the amount and nature of geomorphological information needed, and in the procedures by which this information should be collected, analysed and presented. Whilst guidance exists for geomorphological evaluation of rivers, a concise specification is required to ensure that the information generated is suitable and the procedures the most cost-effective for establishing whole-river physical restoration plans.

Project objectives

1.6 The objective of the project was:

- to generate a standard specification for geomorphological assessment that can be applied to any of the 35 river SSSIs in England. Its key attributes should be:

a) it is understandable and clear to the contractor and will lead to a tailored product; and
b) in addition to the geomorphological information generated in the audit, there should be an overall conclusion about the physical state of the river (degree of modification, functioning) and suitability for remedial action plus an outline set of options for each major reach.

1.7 An additional objective was to provide support to the development of a rationale for the physical restoration of SSSI rivers, being developed by Natural England (Mainstone 2007).

Approach

1.8 The approach adopted within this study has been to review the existing fluvial audit and geomorphological assessments that have been prepared around England and Wales, including those that have been conducted on the riverine SSSIs. Evaluation of practices, parameters surveyed and evaluated, and outputs generated have fed into the reappraisal of the use of geomorphological assessment in relation to meeting Favourable Condition.

1.9 Chapter 2 reviews the development of Fluvial Audit (FA) and other geomorphological survey methodologies to help set the context for a standard specification. In this sense it looks back at what was a standard specification in the early implementations of the FA methodology and how this has been changed over time, reflecting differing uses for the surveys.

1.10 Chapter 3 summarises the existing audits that have been undertaken, to assess how many of the SSSIs have already been addressed and the extent to which these datasets might fulfil the data requirements for the development of strategic restoration plans.

1.11 Chapter 4 reviews the specification requirements for geomorphological assessment in relation to SSSI river restoration, including the specification of the data and GIS layers that are likely to form outputs of the geomorphological surveys.

1.12 Chapter 5 introduces the draft specification for geomorphological assessment to support SSSI river restoration.

1.13 Chapter 6 briefly reviews the future developments in geomorphological assessment.

2 Fluvial geomorphological assessment in the UK: A review of developments

What is geomorphology?

2.1 Geomorphology is a natural or Earth Science that has its roots in Geology, Hydraulic Engineering and Physics. It differs from other natural sciences in that its focus is on the study of the processes of production, movement and storage of sediment within the landscape and on the characterisation of the features these processes produce. In its widest definition, geomorphology encompasses the study of glacial, coastal, slope, wind and fluvial processes of sediment movement across the surface of the Earth. This report is focussed on fluvial geomorphology.

2.2 Fluvial geomorphology is: "the study of sediment sources, fluxes and storage within the river catchment and channel over short, medium and longer timescales and of the resultant channel and floodplain morphology" (Newson and Sear 1993). Fluvial geomorphology draws on inputs from hydraulics, ecology and geology. It provides an explanation for the creation and dynamics of the physical habitat concerns of ecology/biology and nature conservation while providing explanations for the channel maintenance and channel instability concerns of flood risk management.

2.3 The term "morphology" is also used in UK river management. Morphology refers to the description of the features and form of the river channel (and increasingly the floodplain). Morphology has significance for nature conservation and flood protection interests through its links to physical habitat and conveyance respectively. Descriptions of channel morphology on their own, do not provide information on the processes of sediment transfer and channel adjustment; to do this requires additional interpretation. For example, an input to channel design that talks about "morphology" refers only to the description of features and river channel shape; it does not mean that the channel will have been designed with regard to sediment transport and channel stability.

2.4 With the advent of the EC Water Framework Directive (European Commission 2000) comes another term "hydromorphology". The 'hydromorphology' of a river channel includes consideration of:

1) the extent of modification to the flow regime;
2) the extent to which water flow, sediment transport and the migration of biota are impacted by artificial barriers; and
3) the extent to which the morphology of the river channel has been modified, including constraints to the free movement of a river across its floodplain.

2.5 Process and form information exists within the broad defining elements, and clearly fluvial geomorphology will be central both to the definition of hydromorphology, and to the design and implementation of emerging Pan-European monitoring methods (Raven and others 2002, Newson 2002).

Using geomorphological analysis to inform river management

2.6 Understanding river processes and form requires knowledge of the connectivity of the channel network to the surrounding catchment (Gregory & Walling 1976, Richards, 1982, Thorne and others 1998, Sear and others 2003). This is because the surrounding catchment provides the sources of water and sediment that are the fundamental drivers of channel form and adjustment. These in turn create the associated physical habitat of the channel. **Thus, any restoration plan that does not start by understanding the river as an interconnected system of channels, floodplain and slopes would be based on inadequate science (Sear 1994).**

2.7 To understand a river system in terms of processes and form requires us to understand:

1) How much of what we see is the result of past processes which will not be naturally replicated (we cannot rely on them to re-create themselves)?
2) How much of what we see is the result of current active processes?
3) How much of what we see is the result of processes that could operate but are currently constrained by human intervention?
4) How much of what we see is the result of past and current management activity of the landscape and channel?
5) How much of what we see is the result of interactions with ecological processes – either past or current?

2.8 To address these fundamental questions requires geomorphologists to use a variety of data collection methods and techniques that are characterised by three areas of information:

1) **The morphology or form of the river** which may involve a variety of scales including the catchment, river network, valley form, river channel size, shape and features.
2) **The materials associated with the morphology** – including measures of the sediment size range, vegetation composition, geology.
3) **The processes associated with the functioning of the fluvial system** – these may include slope processes (for example soil erosion, land sliding), bank erosion processes, processes of deposition and transport of sediment.

2.9 In addition, because river systems are often buffered by sediment storage in the landscape and river network, the relationship between process and form may not be clear when viewed over short timescales. Thus geomorphology requires information on the channel adjustment and landscape change over relatively long timescales.

2.10 Any specification for geomorphological survey that simply seeks to map features in isolation from understanding the processes responsible for them (and recognising that these may operate over long timescales) is a physical habitat inventory and will not provide sufficient information to design sustainable restoration projects.

Application of geomorphology in the UK: a review of developments

2.11 Over the last two decades, fluvial geomorphology has made increasing contributions to river management in the United Kingdom (UK) and, partly for reasons of professional accountability, it has become necessary to erect a terminology and equivalent standards for the procedures through which geomorphological expertise is applied (Sear and others 1995; Newson 2002). In increasing order of complexity and cost, but decreasing order of geographical scale, these standard methods are known as Catchment Baseline Survey, Fluvial Audit, Dynamic Assessment and Environmental Channel Design. Sear and others (2003), describe how these methods vary.

They are summarized in Table A. Appendix 1 provides a bibliography of references that chart the development of fluvial audit techniques in the UK.

2.12 Fluvial geomorphology is at heart a field-based science that aims to understand the processes and sequence of events that lead to the creation of landscapes and landforms. An important component of this process is the accurate mapping of river forms, materials and processes found within a landscape. Geomorphologists have therefore developed techniques to capture data on channel topography, bed and bank materials and associated vegetation communities (Kondolf & Piegay 2003). Early river reconnaissance approaches are covered by Kellerhals and others (1976) and subsequent variants have been devised to cover site, reach and catchment scales, for example, studies by Downs and Brookes (1994), National Rivers Authority (1994), Simon and others (1989), and Sear and Newson (2001). Reconnaissance surveys can be multi-functional and have been used for engineering-geomorphological analysis, stable channel design, assessment, modelling and control of bank retreat, to define the relationship between geomorphology and riparian ecology and as a component of statutory works assessments (Downs and Thorne, 1996). The main advantage of stream reconnaissance surveys is that they are a coherent way of collecting field data, which can be easily stored, analysed and interpreted using Geographical Information Systems (GIS).

2.13 The collection and interpretation of geomorphological data are dependent on the type of question that is being addressed. For example, the design of an environmentally aligned channel will require a different level of detail in the recording of channel sediments and the estimation of sediment flux, than a baseline survey in support of strategic catchment management planning, eg Catchment Flood Management Plans. Typically, a geomorphological project may include any or all of the following:

1) A desk study to collate historical / documentary evidence on river channel change, land management and channel management practices, hydrology, water quality and geomorphological datasets (for example, River Corridor Surveys, River Habitat Surveys, Geomorphological Surveys etc).
2) Field reconnaissance to audit the current river system in terms of materials, forms and processes.
3) A detailed survey of sediments and topography in specific reaches in order to calculate sediment transport, critical flows for sediment movement, sediment population available for transport.
4) Quantitative measures of morphological change using combinations of 1 and 2.
5) An interpretation of the geomorphological functioning of the river/reach.
6) A detailed channel design incorporating sediment transport issues.
7) A post-project appraisal of existing works in terms of channel stability, appropriateness of channel dimensions and morphology, and sediment conveyance.

2.14 Arguably, the most comprehensive and widely applied system for guiding clients on the application of fluvial geomorphology to river management within the UK is that developed under a series of research and development (R&D) contracts for the National Rivers Authority/Environment Agency and Scottish Natural Heritage (Table 1). The different methods were synthesised into a single set of procedures (EA 1998), which is now widely applied across a range of river management activities. Table 1 summarises the procedures and expected outputs under the title a Geomorphological Assessment Procedure (GAP). Guidance literature in support of each level of Geomorphological Assessment is given in Table 1. Copies of the relevant reports are available from the R&D publications office in each Agency.

2.15 Table 1 summarizes the main geomorphological methods used in UK river management. In practice the most frequently used is the Fluvial Audit. 'Fluvial audit' as a term was coined in a report on sedimentation problems in two upland catchments (Newson and others 1997). A Fluvial Audit is so named because it literally seeks to check for the credit (sources), debit (storage) and transfer routes of sediment in a river catchment, and attempts to link these to the morphology and sediments present within the river network. The concept of fluvial auditing was refined and developed into a standardized procedure for supporting Flood Defence sediment-related maintenance via a series of National Rivers Authority R&D projects (Sear et al. 1995). From the outset, fluvial audit was developed to answer specific questions relating to channel sedimentation and / or bed and bank erosion, in so far as they caused specific flood risk management maintenance issues. The method was founded on the basis that:

1) it is better to treat the cause of a sediment management issue (for example, an eroding reach) rather than the symptom (for example, dredging out a shoal);
2) catchments, rivers and floodplains should be understood as whole, connected systems, through which water and sediments are transported;
3) connectivity operates over a range of timescales depending on processes, grainsize, and the sequence of disturbance in the catchment; and
4) natural self-regulation functions are of equal value as river management actions for controlling sediment transport.

2.16 In practice, Fluvial Audit was deployed at three scales – the detailed analysis of the specific problem reach (of around 1-10km), and overview of the catchment in terms of sediment production and connectivity (<1000km2) and an assessment of disturbance within the catchment and reach over time (typically <500 years). These scales of investigation were used to identify the cause(s) of a sediment-related river management problem and used to develop specific engineering solutions that might involve restoration practices in order to manage sediment transfer (for example, Sear et al.1994; Sear and others1995).

2.17 In the mid-1990s, the role of Fluvial Audit changed, from specific problem solving, to encompass strategic reconnaissance at the catchment scale in support of a wider range of river management activity, including conservation. The aim of the auditing process was to understand the sediment system of a catchment, to map the sources and points of storage within the river network and surrounding catchment, and to associate these spatially within the GIS, with habitat features based on hydraulic biotopes (Newson & Newson 2000). The output from fluvial audits of this type was an interpretation of channel form and behaviour over time, together with an inventory of geomorphological and physical biotope features for the study reach. An implicit assumption in many of these studies was that they represented a baseline survey that could be re-evaluated in the future as part of a wider evaluation of river or catchment management. Data were, therefore, collected in digital format, accurately georeferenced and stored within a GIS and linked database.

2.18 The third iteration of the Fluvial Audit process was developed in the last 5 years in support of the restoration of degraded river habitats. Much of this development has been driven by the legislative requirements of the European Union Habitats Directive (92/43/EEC) and national legislation protecting SSSIs. It has been commissioned by English Nature, the Countryside Council for Wales and the Environment Agency. The aims of these fluvial audits are:

1) to develop an understanding of the geomorphological processes that are required to support the favourable condition of riverine SSSIs and Special Areas of Conservation (SAC), protected under the Wildlife and Countryside Act 1981 as amended and the Habitats Directive 1992 respectively;
2) to determine the extent and location of human modifications and their impact on favourable conditions; and
3) to use the information from (1) and (2) to identify reach-based management actions that would move the river into favourable condition.

2.19 New data analysis techniques (eg Sear and others, in review) have been developed to help address these aims.

2.20 An important part of understanding the current status of Fluvial Audit is also to recognize that, although much vaunted as a ‘standard procedure’; in practice it has been highly variable, although retaining commonalities of aim. Thus some fluvial audits are simple desk-based surveys with limited interpretation, whilst others integrate elements of modelling and high-level interpretation. Each approach has usually been selected by the contractor in consultation with the client as the best approach to delivering the project requirements; however, in the specifications for such work, the tendency remains to require Detailed Catchment Baseline Survey (DCBS), Fluvial Audit (FA) and often Geomorphological Dynamics Assessment (GDA), for example, surveys of the rivers Nar and Wensum SSSIs (Sear and others 2005). In practice, a Fluvial Audit already incorporates most elements of a DCBS and hence this is no longer a required part of a specification.

2.21 Importantly, specification of a Fluvial Audit must be based on individual requirements, and the contractor should be permitted to recommend the most appropriate techniques to achieve this. However, with an increasing number of geomorphologists within the consultancy and professional services, and the potential for a wide range of interpretations of what is required, there is a clear need for as standardised a specification as possible.

Table 1 Standard geomorphological approaches (Sear and others 2003)

Stage	**Planning / project**		**Project**	**Project**	**Project**
Procedure	**Geomorphological Assessment**		**Geomorphological dynamic assessment**	**Geomorphological channel design**	**Geomorphological post project appraisal**
	Catchment baseline study	**Fluvial audit**			
Aims	Overview of the river channel morphology and classification of geomorphological conservation value.	Overview of the river basin sediment system typically aimed at addressing specific sediment related management problems and identifying sediment source, transfer and storage reaches within in the river network.	To provide quantitative guidance on stream power, sediment transport and bank stability processes through a specific reach with the aim of understanding the relationships between reach dynamics and channel morphology.	To design channels within the context of the basin sediment system and local processes.	To assess the degree of compliance between design expectations and outcomes in terms of geomorphological processes, dimensions and morphology.
Scale	Catchment (size 25 - 300km^2)	Catchment (size 10 – 300 km^2) to channel segment.	Project and adjacent reach	Project reach	Project reach
Methods	Data collation, inc. **RHS/GeoRHS** Reconnaissance fieldwork at key points throughout catchment.	Detailed field studies of sediment sources, sinks, transport processes, floods and land use impacts on sediment system. Historical and contemporary data sets	Field survey of channel form and flows; hydrological and hydraulic data, bank materials, bed sediments (GA/FA if not available)	Quantitative description of channel dimensions and location of features, substrates, revetments etc. (GDA/FA/GA if not available)	Review of Project Aims/Expectations. Re-survey of project data sets. Field survey

Table continued…

Stage	Planning / project		Project	Project	Project
Procedure	**Geomorphological Assessment**		**Geomorphological dynamic assessment**	**Geomorphological channel design**	**Geomorphological post project appraisal**
	Catchment baseline study	**Fluvial audit**			
Core information	*Characterisation* of river lengths on basis of morphology and sensitivity to management intervention.	Identifies *range of options* and 'Potentially Destabilising Phenomena' (PDPs) for sediment-related river management problems	Sediment transport *rates* and morphological *stability/trends*. 'Regime' approach where appropriate.	The 'appropriate' *features* and their *dimensions* within a functionally-designed channel	*Extent of changes or conformity* to original project design and recommendations for mitigation options.
Outputs	15 – 30 page report; GIS including photographs.	GIS; Time chart of potentially destabilising phenomena; 25 – 50 page report including recommendations for further geomorphological input (GDA).	Quantitative guidance to intervention (or not) and predicted impacts on reach and beyond	Plans, drawings, tables and 15 – 50 page report suitable as input to Quantity Surveying and engineering costings.	Plans, tables, 10 – 30 page report.
Destination	Feasibility studies for rehab/restoration, Input to CFMPs, cSACs	Investment/management staff, Engineering managers or policy forums, Project steering groups, cSACs	Engineering managers and project steering groups	Engineering managers and project steering groups	Engineering managers and project steering groups

Table continued…

Stage	Planning / project		Project	Project	Project
Procedure	**Geomorphological Assessment**		**Geomorphological dynamic assessment**	**Geomorphological channel design**	**Geomorphological post project appraisal**
	Catchment baseline study	**Fluvial audit**			
Reference Material	**EA (1998) Geomorphology a Practical Guide**, EA National Centre for Risk Analysis and Options Appraisal, Steel House, London.	**EA 1998 Sediment & gravel transportation in rivers: a geomorphological approach to river maintenance**. EA National Centre for Risk Analysis and Options Appraisal, Steel House, London.	**Leys (1998) Engineering methods for Scottish gravel-bed rivers**, Report no. 47, SNH, Edinburgh. **EA (1999) Waterway bank protection: a guide to erosion assessment and management**, R&D Project W5-635.	**NRA(1993) Draft guidelines for the design and restoration of flood alleviation schemes**, R& D Note 154.EA Bristol. **NRA (1994) Development of Geomorphological Guidance notes for Use by Thames Region Fisheries & Conservation Staff**. Kings Meadow House, Reading.	**EA 1999 Geomorphological Post Project Appraisals of River Rehabilitation Schemes,** R&D Report, Bristol. **Briggs, A.R. (1999) The geomorphological Performance of river restoration projects**, Ph.D Thesis, University of Southampton.

3 Existing fluvial audits

Introduction

3.1 In order to define whether the Fluvial Audit can deliver geomorphological management options for riverine SSSIs, a review of existing survey methodologies was undertaken. Contact was made with leading experts in the geomorphological field and those organisations that are known to have undertaken fluvial audits in the past. A list of contacts is shown in Appendix 2.

Existing known fluvial audits

3.2 There are 45 riverine SSSIs; 25 of these are designated as whole river SSSIs and 20 have only a section of the river designated (Withrington 2006). 16 of these sites are also designated as Special Areas of Conservation (SAC) under the Habitats Directive. These river SSSI sites and their status are listed in Appendix 3. This list excludes those sections of rivers that may fall within an SSSI boundary, but to which the SSSI selection criteria for riverine SSSI status have not been applied.

3.3 A full list of known audited rivers is given in Appendix 4, including details of the client, contractor and report title where available. The locations of these surveys are shown in Figure 1. In total, 98 geomorphological audits have been undertaken on 95 different rivers in the UK. Of these, 29 surveys are on rivers designated as SSSIs.

3.4 The audits have used highly variable approaches, although retaining commonalities of aim. Some fluvial audits are simple desk-based surveys with limited interpretation, whilst others integrate field survey and analysis with elements of modelling and high-level interpretation. Table 2 summarises the approaches used by three different contractors, Babtie Brown and Root, GeoData Institute and Gifford, all of which have undertaken recent fluvial audits. These three survey methodologies were identified within the specification of this project to examine a sample of different approaches. A more detailed analysis of their approaches is given in Sections 4.11 – 4.19.

3.5 The extent to which existing fluvial audit on riverine SSSI could be used to drive the requirements of the favourable condition assessment and restoration planning has not been a specific target of this investigation, as not all the source data have been obtainable. It is recommended that all the field survey and digital data for these reaches should be assessed to establish the extent to which this information may meet these requirements, either on its own or with additional investigations, or whether new survey is required.

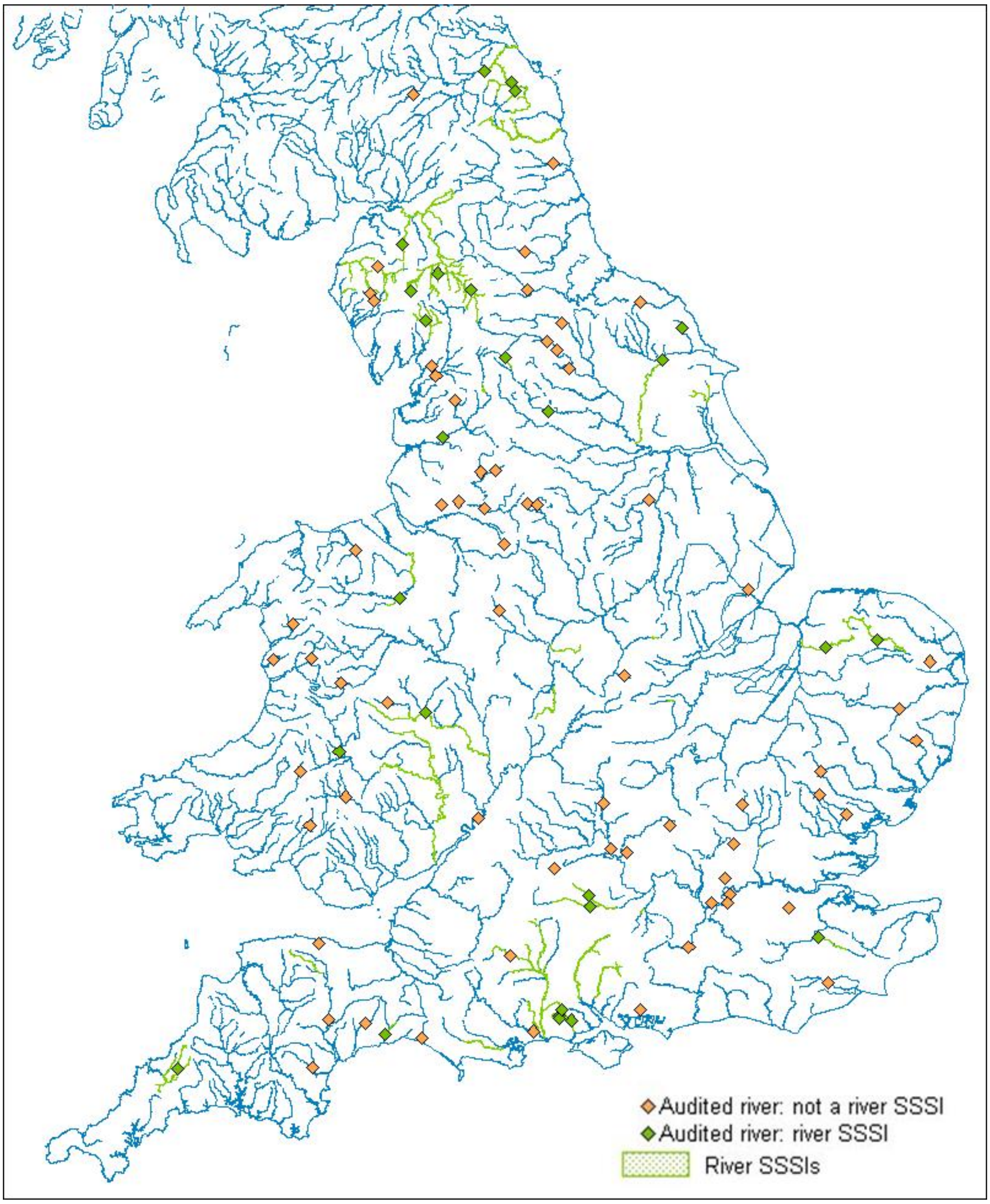

Figure 1 Location of known geomorphological surveys (1992-2006) and river SSSIs (GeoData 2006)

Table 2 Fluvial audit methodologies adopted for three case study contractors: Babtie, Brown and Root, GeoData and Gifford

Contractor	River	Inputs		Analysis	Outputs	
		Desk based	**Field survey**	**Processing**	**Information summaries**	**Format**
Gifford	eg Beult	Literature review; Historic analysis; consultation; data collection	Continuous field survey within homogeneous reaches	Historic channel changes; GIS based analysis; Geomorphological analysis.	Time chart; Catchment map; Geomorphological map; Management options	Report, photos linked to GIS, geomorphological GIS and MS Access database, map album
GeoData Institute	eg Wensum / Nar	Literature review; Historic analysis; consultation; data collection	Continuous field survey within homogeneous reaches, geomorphological dynamics assessment	Historic channel changes; GIS based analysis; Geomorphological analysis, Multi-criteria analysis of reaches	Time chart; Catchment scale recommendations; Geomorphological map; Reach-based management options	Report, photos linked to GIS, geomorphological GIS and MS Access database, map album.
Babtie Brown and Root	eg Tees	Literature review; Historic analysis; consultation; data collection	FA of the sub-catchment, homogenous reaches	GIS based analysis; Geomorphological analysis; linking field and desk-based findings	Geomorphological survey; watercourse summaries; catchment scale geomorphological; recommendations for future management	Report; web-based photo viewer, reach-based geomorphological database, geomorphological GIS data

4 Review of specification requirements for geomorphological assessment

Introduction

4.1 The project seeks to define the technical process of geomorphological assessment set within the wider context of the development of strategic physical restoration plans for SSSI rivers (Figure 2). We have views on the wider planning process, and how its development might be informed by the Shoreline Management Process – these are provided in Appendix 5 and are not considered further in this report.

4.2 The term Geomorphological assessment is used in preference to Fluvial Audit to remove the process from existing terminology and its associated connotations. Key issues associated with data and analytical requirements are discussed.

4.3 Critical to the assessment is an integrated approach to evaluating the geomorphological and ecological implications of anthropogenic changes to channel form and function. This requires a marriage of geomorphological and ecological disciplines that has not been apparent in river assessment to date. Only by analysing the ecological implications of artificial changes can appropriate restoration options be generated. This is not a task that geomorphologists can accomplish on their own.

4.4 In some ways it is unhelpful to try and define geomorphological assessment as a distinct specialist task, since as is evident from Figure 2 geomorphological thinking is required throughout the process. However, it is possible to identify certain activities associated with geomorphological survey, data collection/collation and information presentation/provision that can be specified in a useful way as part of a wider process of SSSI river restoration planning.

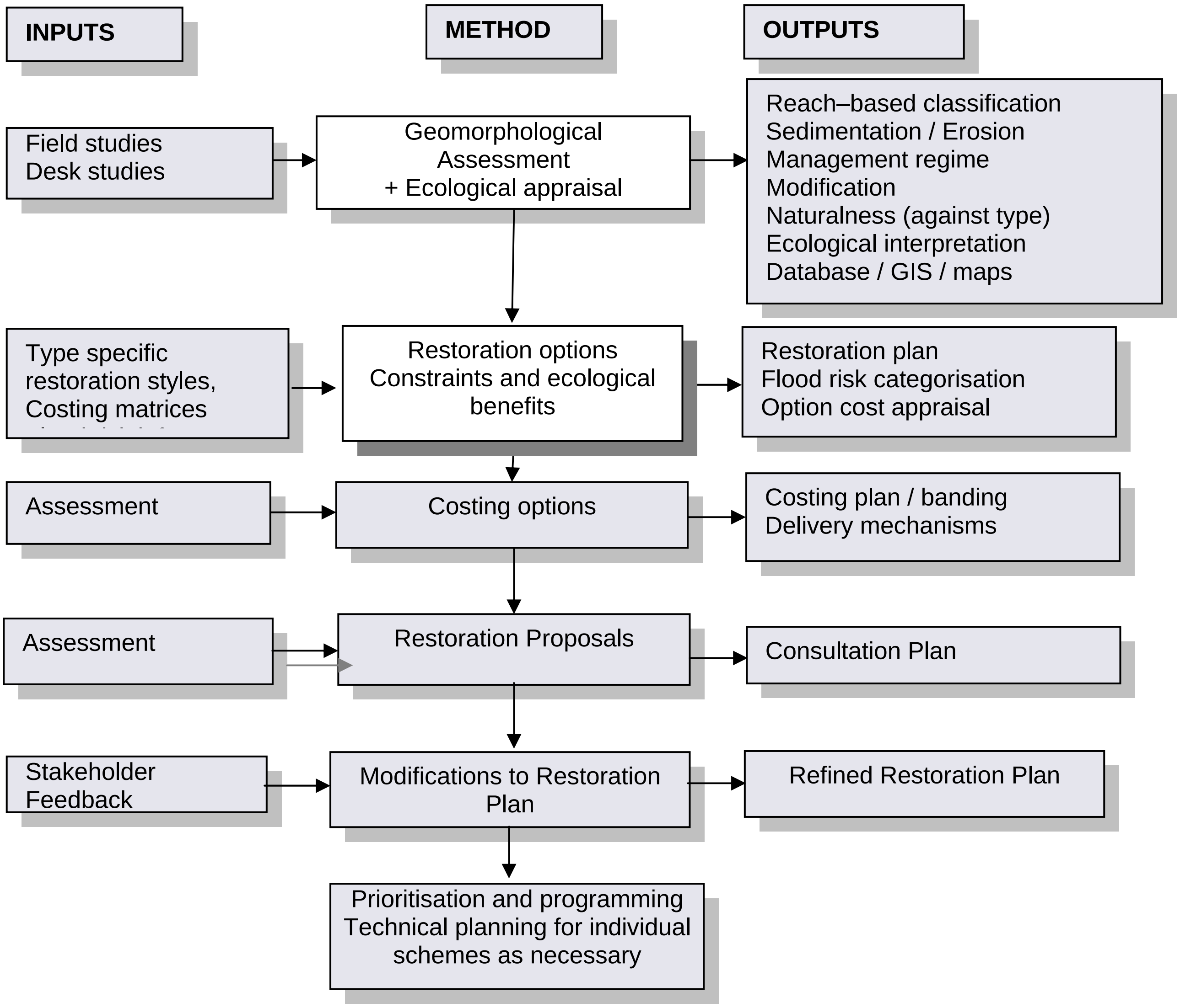

Figure 2 Geomorphological assessment (shaded in grey) in the context of the development of strategic restoration plans for riverine SSSIs

The content of recent specifications

4.5 Recent specifications for the Wensum, Nar and Beult, all aimed at underpinning strategic restoration plans, are based on essentially the same specification. The technical specifications are long, specifying DCBS, FA and GDA as described in the Environment Agency (1998) R&D report on approaches to applying geomorphology in river management. This report considered each component (DCBS/FA/GDA) to be part of an incremental process that provided different information at each stage.

4.6 It is clear that these specifications are too complex and overlapping to enable a contractor to separate out the work that is necessary from that which is simply an artefact of the text and context used in the original documentation (Environment Agency 1998). They are also too ambitious and unrealistic in terms of aims and objectives relative to the timescales and costs envisaged (6-8 months, <£30k).

Setting out the scope of the specification

4.7 In broad terms, the scope of the necessary technical work might be summarised as follows:

1) identify and report on the major geomorphological processes and features occurring in the SSSI (and its tributaries) and how they have been altered by human activities;
2) assess the ecological significance of the artificial alterations to channel form and function; and
3) identify practical measures, on a reach-by-reach basis, to restore characteristic geomorphological form and function, based on an understanding of the geomorphological characteristics of the river type, the ecological significance of these and an understanding of truly immovable constraints.

4.8 Note that no attempt is made here to separate out geomorphological appraisal from ecological interpretation, since these must be seen as closely integrated activities and not sequential and separate tasks.

4.9 Note also that the technical work is limited to geomorphological issues and does not extend to other aspects of river and catchment management such as water quality and water resource management. As such, it forms a contribution to a wider programme of evaluation and management aimed at securing the physical, chemical and hydrological integrity of the river in a way that amounts to Favourable Condition. However, it is recognised that water resource management can sometimes affect fluvial geomorphology and will have to be considered where necessary.

4.10 Appendix 6 takes a more detailed look at the relevance of geomorphological assessment to the full list of reasons for unfavourable condition of SSSIs. This gives useful context to the detailed consideration of geomorphological data in the following sections.

Attribute redundancy

4.11 Fluvial audits that have been undertaken to date differ widely in the variables that have been collected and the approaches used to represent features and analyse results and interpret the processes. At heart, they are largely based on the Sear and Newson (Sear and others 1995) approach, although most have now adopted the use of GIS and databases, introduced by GeoData, as a basis for presenting the locational material and the mapped outputs. The extent of the use of GIS mapping of actual locations of features (erosion, deposition, structures, embankments etc) is very variable, with most surveys tied solely to a 'geomorphic reach', a section of channel with broad homogeneous geomorphological characteristics. These differences reflect the different 'flavours' that have been developed by the range of consultants now undertaking geomorphological assessment.

4.12 Three fluvial audits have been assessed in detail in terms of parameters and measures employed and the outputs generated from this process (Appendix 7 and Appendix 8). This survey scope includes the inputs to the desk-based studies, field, analytical and assessment processes. It is clear that many components of these methodologies reflect the origins of the Fluvial Audit approach, but modifications to both the objectives and the approaches have slowly altered the nature of the geomorphological assessment from the original specification developed by Sear and Newson (1998).

4.13 This change in specification and components of the surveys is in part due to the interpretation of the Geomorphological Guidance Notes produced for the Environment Agency (Environment Agency 1998) that repeat the original concepts but which have incorporated GIS and databases within the audit process and a range of other geomorphological methods. These have driven a more formulaic approach to data management within the fluvial audits. Previously the Fluvial Audit approach was 'standardised' the methodological components (modules) were customisable to the issues identified and the data resources available. This is still the case to some extent; for any given river system the levels of information and past studies, topographic surveys will differ, affecting what is possible to assess from past survey records and the approaches that may be used within the GIS/database components. Often this is driven by the volumes of data available from past surveys, for example whether there are historic sectional and long profile surveys.

4.14 The River Beult follows the same data structure as the Rivers Nar and Wensum, based on the adoption of the same techniques, GIS and data management developed by GeoData and operating on very similar data capture field forms and field mapping components. Therefore, in order not to repeat the assessment, in looking at attributes we have also considered the next most frequently used data model for geomorphological assessment developed by the Environment Agency employing the Geomorphological Assessment 'add-on' to the River Habitat Survey (Walker 1999).

4.15 Fluvial audits for the River Nar and the River Beult are confused within this analysis by the requirement within the project specification to undertake Detailed Catchment Baseline Study, Fluvial Audit and Geomorphological Dynamics Assessment. This may have introduced additional datasets that would lie outside the normal fluvial audit spatial data requirements. However, the basic information collected by fluvial audit, and the approaches to displaying the data, has remained fairly constant between these surveys.

4.16 The approaches used in Fluvial Audit to generate the current restoration options have certain limitations. In particular, the 'standard' EA approach is not in fact a standardised approach. Other 'standards' are in principle standard but methodologically they may diverge. The 'standards' developed for the Wear, Tees and Esk (Babtie 2004) have been developed for species-focused surveys (salmonids spawning habitat), rather than the habitat-based, physical geomorphological evaluation process required for SSSI river restoration planning. The principle here is that the geomorphological and ecological systems are closely interrelated and that, assuming other environmental stressors are adequately controlled, channel form and processes and the channel and channel margin ecology are the result of interactions between the physical and biological elements.

4.17 The rationale for not adopting the EA standard (Babtie 2004) is as follows:

a) the data are not collected continuously, thus precluding reach-based specification of management options;
b) the data are only specific to certain species requirements; and
c) not all the information collected is relevant and some relevant information is missing from the survey.

4.18 A species-related approach was also adopted for the River Usk (GeoData 2005) utilising Multi-Criteria Assessment (MCA) techniques, but these techniques have subsequently been modified to develop prescriptions for restoration management of SSSI river habitat (Rivers Nar and Wensum) using physical criteria more relevant to restoration planning.

4.19 Many of the surveys that have lead to the development of restoration action plans have included more detailed studies than the fluvial audit, incorporating the geomorphological dynamics assessment. The broader scale whole watercourse summaries are generally not sufficiently targeted to provide restoration options at a reach or even a watercourse scale. More detailed studies using fluvial audit and geomorphological dynamics assessment (New Forest, River Wylye etc) have developed a conceptual model and developed a basis for specifying restoration options on a reach basis that cover the whole of the surveyed channel length and these may be closer to the targets required for defining the next stage of restoration plans.

The concept of Multi-Criteria Assessment (MCA) as an analytical tool

4.20 The concept of MCA has been employed by Geodata in recent Fluvial Audits, on the Rivers Nar, Wensum and Usk. This approach essentially allows data on a number of lines of evaluation to be drawn together in an integrated analysis that informs future management action, but it has been employed in different ways. On the Usk the approach was used to prioritise specific species/habitat requirements, whereas on the Nar and Wensum the MCA was problem-based and process-based, identifying features that indicated modification, naturalness, sediment sources and sinks.

4.21 MCA as applied here has incorporated a further process of ‘matrix reclassification’, where two MCA-derived indicators are combined to provide a third index of status combining positive attributes of naturalness and negative indicators of modification. This is intended to account for the fact that some highly modified systems, such as chalk streams, can nevertheless have high habitat quality. These techniques include considerable expert yet subjective judgement, as well as drawing on channel typologies and type-specific feature characterisations and restoration typologies.

4.22 The parameters used in MCA provide a useful summary of the field data that are relevant to SSSI river restoration planning (Appendix 9) - other information contributes to the MCA criteria from desk-based assessments.

Variables that might be modified within existing Fluvial Audit

4.23 From the analysis of the variables collected and run within the MCA there are ways of improving the quality and completeness of the information that contributes to the MCA approaches (as adopted within the River Nar and River Wensum implementation), both from the perspectives of the field and desk surveys. The following proposals for improvements are from the Nar/Wensum desk and field data capture; other survey systems (from other contractors) should also reconsider the attributes and measures of these attributes, whether or not they undertake MCA-type analyses:

- Bank sorting is a rather poorly completed dataset and one that often reflects rather local conditions rather than being representative of left and right banks. Where the extent of erosion is mapped within the GIS there is option to assess specific descriptions of the bank structure rather than a general description across each bank. For mapped erosion the nature of the bank erosion, its process and bank structure can be recorded.
- Clarification that the dominant erosion mechanism is recorded, even if the channel is predominantly stable. Introducing a stability class or reliance on the on mapped extents of stability of eroding banks would improve the quality.
- The extent of erosion is typically mapped (in some surveys) – this provides the basis for the extent of erosion and locational information to feed into remedial actions. Where this is not collected, alternative approaches would be needed to incorporate this influence into the assessment. Even though the measures of a parameter may vary between surveyors, there may be the potential to generate an equivalence of output and input to the MCA analysis.
- Floodplain features record the land cover types but are often not well matched to conservation objectives or the depiction of riparian vegetation types, especially where this is confined to a narrow width adjacent to the river. A proposed new structure should incorporate the land cover class and any management actions (mowing, grazing) as a class moderator. An indication of the width of managed and unmanaged riparian zone would help provide context for restoration plans. A suggested reclassification would be, pasture, tall herb, reedbed, other wetland, moor/heath, scrub, woodland, plantation, built bare rock/scree, bare ground, arable – this could be linked to the reporting categories used in the UK Common Standards rivers SSSI condition assessment process. Typically, categories should be recorded as dominant and present or some similar categorisation, given that the riparian vegetation will rarely define a reach break. The definition should be more strictly related to the riparian zone, with separate recording of the floodplain zone to clearly distinguish these influences.
- Stable or eroding areas should not be included within the erosion types; they would be better identified separately as a stability / instability class to enable a system-wide stability/instability assessment.

- Modification data are derived from both field- and desk-based assessments, identifying features from the field as well as past records of modification. Careful quality assurance is needed to ensure that the reach-based processing of the datasets captures all potential modifications, even though the field situation may show signs of recovery from past disturbance.

GIS and field data-capture models

4.24 Different approaches have been developed by different survey teams to describe the spatial model for the river reaches. This is driven in part by the survey methodology employed and also by the specific analytical approaches used. These differences also affect the presentation of outputs, although the important aspect is the equivalence of outcomes rather than the specific data model; unless it is an objective to collate all data.

4.25 Three basic spatial models have been used:

1) Line-based models, based on the centreline of the channel split into separate reaches and classified within the GIS by reference to a topologically correct but topographically generalised 'reach'. No channel centreline exists within the OS large scale mapping and this may have been created, or taken from other sources (such as the CEH river network). The river network is generated at 1:50,000 and is a very generalised dataset of the channel length and sinuosity, but may provide a suitable presentational model. A new river centreline spatial dataset is under discussion by the Ordnance Survey and is currently being developed by the Environment Agency.
2) Area-based models where field mapping and the form-based data have illustrated the channels by adding left and right banks and matching the mapping to real world locations. This model has been adopted also where the area of the channel within a reach has been estimated to provide the percentage values of sediment deposition or the channel bank length measurements. Typically the OS MM boundary is taken as the extent of the area, although this may be modified where additional information from field or aerial photography updates the channel margins depicted on Ordnance Survey mapping.
3) Point-based models – where the reach is represented as a point and the data are related to the point reference. This has typically been applied within the RHS based Geomorphological Audit datasets produced by the Environment Agency. Typically these are based on a partial survey or back-to-back RHS surveys on 500m reaches, which may not map well to homogeneous management reaches. There is no separate mapping of the channel features and channel adjacent features.

4.26 The selection of data models has also been affected by the survey objectives, such that where the three approaches (DCBS, FA and GDA) have been rolled together the detailed channel-based topographically-correct field mapping has been created as part of the contribution to the Geomorphic Dynamics Assessment. It is also influenced by the presentational requirements of the mapping that typically require both broad-scale representations as well as reach-specific information presentation.

4.27 Field-attribute data have generally been entered into a database (MS Access in all cases examined where a database has been developed), which may or may not be 'linked' to the GIS. Even where there has been no linkage it would be possible to create one from the reference to the unique reach reference numbers. There is no standard for this database and these are generally the proprietary products of the consultants undertaking the work. The volume of data collected and the complex data structure of many of the attributes mean that a relational model is needed and the mapping outputs are generated through database queries. This complexity tends to mean that the client recipients of the data rely on the paper mapped outputs rather than make effective, ongoing use of the raw datasets. Natural England's interpretation of the work will inevitably be largely based on the summary / mapped outputs, so the specification of these is probably more important operationally. Nevertheless, the transfer of the database, along with a description of its structure, is an important information resource that should form part of the deliverables of the Fluvial Audit.

4.28 This limitation has issues for the transfer of the data to the client, and also implies changes to the management of the spatial and attribute data to make them more amenable to wider use. Views and simplified queries and customisation of the database and GIS would assist here, as would client training to accompany the data handover.

4.29 GIS and data guidance in recent Fluvial Audit specifications is not well targeted at the nature of Fluvial Audit or indeed the DCMS and GDA surveys, having been derived from the survey guidance for collecting SSSI site boundaries. Guidance should be targeted to the data model used within geomorphological assessment, but can use generic statements for quality of data content and accuracy.

4.30 A number of other data layers are often employed within Fluvial Audit that help to describe the catchment parameters and characteristics. These are typically derived from a range of data sources, both from other GIS sources (soils, solid and drift geology, land use, relief) and data layers generated by the nature of the fluvial audit project (eg stream order classifications). For example, they may include pressures within the catchment, identification of areas of catchment erosion (rill and sheet wash, peat erosion), mining spoils. Within more analytical approaches to Fluvial Audit a series of derived spatial data may be generated, such as erosion risk maps and derived slope maps. Where the data are derived or created by the project these should be provided in GIS formats as part of the project deliverables.

4.31 Fluvial Audit may also suggest recommendations for management that are non-reach based and that reflect catchment-scale restoration or management proposals. Thus the data model needs to be sufficiently flexible to extend to the catchment, subject to the Fluvial Audit findings.

4.32 The collection of oblique photographs of the channel reaches, riparian and catchment areas is a component of the standard survey approach. These images can also be 'hot-linked' through the GIS to make them accessible within GIS. This approach is strongly recommended, so that the individual reach visualisations are enhanced and the images are easily accessible and referred to the reaches. Such linkage relies on having appropriate reference information associated with the photograph tables, including file location and name, reach number, direction and date.

4.33 In summary, the following recommendations are made in relation to GIS and field capture models:

1) Adopt a common data model for handling the spatial data within the fluvial audit. This may depend on the nature of the survey undertaken and the level of detail captured within topographic mapping. All models should allow for the explicit link between the database and the GIS data layers and image files. Recording the method used should form part of the reporting.
2) Define a common standard for the reach definitions mapping, based on the OS MasterMap derived area of the reaches, and where appropriate supplement this with a river centreline reach dataset for display purposes. This latter requirement could adopt the OS MasterMap river centreline, if this is developed in the future.
3) For field-based topographically represented spatial data, adopt a common structure, notation and annotation based on the limited features typically recorded. Include a key and classification within the reporting. The requirements for capture may vary with the Fluvial Audit requirements. These spatial layers typically include catchment-level mapping as well as bank and channel geographic layers, eg:

Channel

- erosion extents, type and severity;
- embankments;
- bank protection by type, material and face;

- sediment entry points, by type and dominant grade; and
- structures by type and influence.

Catchment

- bare ground/erosional scars; and
- soil erosion risk etc.

4) Although the focus of fluvial audit is channel and riparian, the additional catchment elements form part of the fluvial audit process, especially in relation to the development of the conceptual sediment and process model.
5) Derived datasets, from the analysis of the spatial and reach data, will vary with the nature of the fluvial audit processing. In many fluvial audits, the processing is the same, but it should respond to the nature of the inputs from the historic and field surveys. Where spatial data are generated as part of these analyses they should also be documented and supplied.

Scope of ecological interpretation

4.34 Fluvial Audit traditionally does not include an explicit ecological appraisal, but this is essential in the context of securing the Favourable Condition of SSSIs. Within the Geomorphological Assessment for SSSI rivers, it is critical to assess the biodiversity benefits of restoration options and to allow the assessment of appropriate restoration measures against these benefits.

4.35 Ecological interpretation is not intended to be based on a detailed review of available data on biological communities of the river. It simply seeks to make the connection between geomorphological changes to the river system and the provision of suitable habitat for biological communities characteristic of the river type. Some time may need to be spent understanding the nature of the community under conditions of low anthropogenic impact, but this should not be seen as a significant task. Whilst particular attention will need to be paid to any particular species or biological groups for which the site is formally designated, the primary focus should be on understanding the characteristic biological community through a geomorphological understanding of natural river form and function (as well as a basic understanding of water chemistry and flow regime).

4.36 The rationale for SSSI river restoration (Mainstone 2007) provides generic underpinning for the ecological analysis. This is based on the precept that a mosaic of habitats that is structurally and physically appropriate to the river type should support the type-specific communities, as long as other factors (eg water quality, abstraction stress, colonisation etc) do not constrain the biota. Local appreciation of characteristic flora and fauna, past and present, allows this generic, type-based understanding to be tailored to the river.

5 Proposed specification for geomorphological assessment of SSSI rivers

5.1 The proposed specification is included as Appendix 12. It includes sections on:

- relevant sources of existing data;
- key aspects of field data capture;
- analysis and presentation;
- the development of a conceptual model of the sediment system and channel morphology
- the mapping of historical modifications;
- the specification of suitable management options to restore characteristic habitat form and function;
- ecological appraisal of geomorphological findings and recommendations; and
- data capture and storage.

5.2 It is recommended that the specification is reviewed following a period of initial use.

6 Future developments in geomorphological assessment

6.1 Since the original Fluvial Audit methodology was developed there have been considerable advances made in the ability to model channel morphology and catchment erosion and deposition (see: Darby & van de Weil 2003; Coulthard & van de Weil 2006). Whilst the Fluvial Audit provides a framework for developing an understanding of the sediment transport and morphological response of a river catchment, the precise methods by which the aims and objectives are achieved should consider the application of some of these developing technologies:

- Use of remote sensing to support catchment-scale assessment of sediment production areas, in particular soil erosion (eg CASI, LiDAR). This links to other appraisals within the SSSI catchments that relate to sediment sources and care should be taken to avoid overlap.
- Use of geomorphological / soil erosion models to identify and refine understanding of the sediment system of a catchment or reach (eg Coulthard & Macklin 2001, PSYCHIC model).
- Use of 1-D sediment transport modeling to confirm locations of erosional / depositional reaches (eg SIAM / SIAM-UK).
- Collection of quantified grainsize data using standard particle size analysis.
- Explicit links with WFD River Channel Typologies, eg Sniffer Project WFD 49.

6.2 Appendix 10 lists some key catchment models that can potentially be linked to fluvial geomorphological appraisal to generate a holistic appraisal of the catchment sediment delivery system. Appendix 11 lists WFD channel types derived in WFD Project 49, and provides descriptions of them.

7 References

BATHURST, J.C., WICKS, J.M., & O'CONNELL, P.E. 1995. The SHE/SHESED Basin Scale Water Flow and Sediment Transport Modelling System. *In*: V.P. SINGH, ed. *Computer Models of Watershed Hydrology*, 563-594. Water Resources Publication. Colorado, United States.

BRIGGS, A.R. 1999. *The geomorphological performance of river restoration projects*. Ph.D. Thesis, University of Southampton.

COULTHARD, T.J. & MACKLIN, M.G. 2001. How sensitive are river systems to climate and land-use changes? A model based evaluation: *Journal of Quaternary Science*, 16, 346–351.

COULTHARD, T.J. & VAN DE WIEL, M.J. 2006. A cellular model of river meandering. *Earth Surface Processes and Landforms*, 31, 123-132

DARBY, S.E. & VAN DE WIEL, M.J. 2003. Models in fluvial geomorphology. *In*: M. KONDOLF & H. PIÉGAY, eds. *Tools in Fluvial Geomorphology*, 503-539. Chichester: John Wiley & Sons.

DAVISON, P.; WITHERS, P.; LORD, E.; BETSON, M.; STROMQVIST, J. (2008) PSYCHIC A process-based model of phosphorus and sediment mobilisation and delivery within agricultural catchments. Part 1: Model description and parameterisation. *Journal of Hydrology,* vol. 350, issue 3-4, pp. 290-302.

DE ROO, A.P.J., WESSELING, C.G. & RITSEMA, C.J. 1996. 'LISEM: a single event physically-based hydrologic and soil erosion model for drainage basins. I: Theory, input and output'. *Hydrological Processes*, 10-8, 1107-1117.

DOWNS, P.W. & BROOKES, A. 1994. Developing an standard geomorphological approach for appraisal of river projects. *In*: C. KIRBY & W.R. WHITE, eds. *Integrated River basin Development*, 299-313. J. Wiley & Sons.

DOWNS, P.W. & THORNE, C.R. 1996. The utility and justification of river reconnaissance surveys. *Transactions of the Institute of British Geographers, New Series*, 21, 455-468.

ENVIRONMENT AGENCY. 1998. *Geomorphology a Practical Guide*, No 18. EA National Centre for Risk Analysis and Options Appraisal, Steel House, London.

ENVIRONMENT AGENCY. 1998. *Sediment & gravel transportation in rivers: a geomorphological approach to river maintenance*. EA National Centre for Risk analysis and options appraisal, Steel House, London.

ENVIRONMENT AGENCY. 1999. *Geomorphological post project appraisals of river rehabilitation schemes*. Bristol: R&D Report.

ENVIRONMENT AGENCY. 1999. *Waterway bank protection: a guide to erosion assessment and management.* R&D Project W5-635.

EUROPEAN COMMISSION. 2000. Water Framework Directive. *Directive 2000/60/EC of the European Parliament and of the Council of 23rd October 2000.*

EWEN, J. 1995. Contaminant transport component of the catchment modelling system SHETRAN . *In*: S.T. TRUDGILL, ed. *Solute modelling in catchment systems*, 417-441. Chichester: John Wiley and Sons.

EWEN, J., PARKIN, G., O'CONNELL, E. 2000. SHETRAN: Distributed basin flow and transport modelling system. *Journal of Hydrologic Engineering*, 5(3), 250-258.

GREGORY, K.J., & WALLING, D.E. 1973. Drainage basin form and process: New York: Edward Arnold Ltd.

GREIG, S. RICHARDSON, R. & GIBSON, J. 2005. WFD49 (Rivers): *Environmental Standards to support river engineering regulations and WFD status classification.*

JETTEN, V., DE ROO, A.P.J. & FAVIS-MORTLOCK, D.T. 1999. Evaluation of field-scale and catchment-scale soil erosion models. *Catena* 37(3/4), 521-541.

JOINT NATURE CONSERVATION COMMITTEE. 2005. Common Standards Monitoring Guidance for Rivers, Version March 2005. URL: www.jncc.gov.uk/pdf/CSM_rivers_Mar05.pdf [Accessed July 2006]

KELLERHALLS, R., CHURCH, M. & BRAY, D.I. 1976. Classification and analysis of river processes. *Journal of Hydraulics Division, ASCE*, 102, 813-35.

KONDOLF, G.M. & PIEGAY, H., eds. 2003. *Tools in Geomorphology*. Chichester: J.Wiley & Sons.

LEYS, K. 1998. *Engineering methods for Scottish gravel-bed rivers*. Report no. 47. Edinburgh: SNH.

MAINSTONE, C. 2006. *Rationale for the physical restoration of the SSSI river series in England*. Draft V2.

MORGAN, R.P.C., QUINTON, J.N., SMITH, R.E., GOVERS, G., POESEN, J.W.A., AUERSWALD, K., CHISCI, G., TORRI, D. AND STYCZEN, M.E. 1998. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landforms,* 23: 527-544

NATIONAL RIVERS AUTHORITY. 1993. *Draft guidelines for the design and restoration of flood alleviation schemes*. R& D Note 154. Bristol: Environment Agency.

NATIONAL RIVERS AUTHORITY. 1994. *Development of geomorphological guidance notes for Use by Thames Region fisheries & conservation staff*. Kings Meadow House, Reading.

NATIONAL RIVERS AUTHORITY. 1994. *Sediment and gravel transportation in rivers, including the use of gravel traps.* R&D Project Record, C5/384/2, prepared by D.A. Sear and M.D. Newson, Bristol.

NEWSON, M.D. 2002. Geomorphological concepts and tools for sustainable river ecosystem management. *Aquatic Conservation*, 12, 4,365 - 381.

NEWSON, M.D. and others. 1997. Case studies in the application of geomorphology to river management. *In*: C.R. THORNE, R.D. HEY & M.D. NEWSON, eds. *Applied fluvial geomorphology for river engineering and management*, 311-363. Chichester: J.Wiley & Sons.

NEWSON, M.D. & NEWSON, C.L. 2000. Geomorphology, ecology and river channel habitat: mesoscale approaches to basin-scale challenges. *Progress in Physical Geography*, 24, 195 – 217.

NEWSON, M.D. & SEAR, D.A. 2001. Geomorphological procedures and river restoration: science, survey and sustainability. In: H.J. NIJLAND & M.J.R. CALS, eds. River restoration in Europe: practical approaches, 251-254. Silkeborg, DK, RIZA.

NEWSON, M.D. & SEAR, D.A. 1993. River conservation, river dynamics, river maintenance:contradictions? *In*: S. WHITE, J. GREEN & M.G. MACKLIN, eds. *Conserving our landscape*, 139-146. Joint Nature Conservation Committee.

RAVEN, P.J. and others. 2002. Towards a harmonised approach for hydromorphological assessment of rivers in Europe: A qualitative comparison of three survey methods. *Aquatic Conservation*, 12, 4, 405 – 424.

RICHARDS, K.S. 1982. *Rivers form and process in alluvial channels*. London: Methuen.

RIVER RESTORATION CENTRE. 2002. *Manual of River Restoration Techniques.*

SEAR, D A, and others. 2000. Channel modifications and impacts. *In*: M. ACREMAN, ed. *The changing hydrology of the UK*, 55-81. Routledge.

SEAR, D.A., DARBY, S. & THORNE, C.R. 1994. Geomorphological approach to stream stabilisation & restoration: Case study of the Mimmshall Brook, Hertfordshire, UK. *Regulated Rivers*, 9, 205-223.

SEAR, D.A., NEWSON, M.D. & BROOKES, A. 1995. Sediment related river maintenance: the role of fluvial geomorphology. *Earth Surface Processes & Landforms*, 20,629 - 647.

SEAR, D.A. & NEWSON, M.D. 2003. Environmental change in river channels: a neglected element: Towards geomorphological typologies, standards and monitoring. *Sci. Total Environ*., 2003 Jul 1; 310(1-3):17-23.

SEAR, D.A., NEWSON, M.D. & THORNE, C.R. 2003. *Guidebook of Applied Fluvial Geomorphology*. Swindon: WRc,.

SEAR, D.A., HILL, C.T. & BRANSON, J. 2005. *Geomorphological Audit for supporting river restoration on the River Nar, Norfolk*. Peterborough: English Nature.

SEAR, D.A., HILL, C.T. & BRANSON, J. 2005. *Geomorphological Audit for supporting river restoration on the River Wensum, Norfolk*. Peterborough: English Nature.

SEAR, D.A. and others (in review). Applying geomorphology for assessing the physical condition of riverine habitats in support of the Habitats Directive. *Aquatic Conservation*.

SIMON, A., OUTLAW, G.S. & THOMAS, R. 1989. *Evaluation, modelling and mapping of potential bridge scour, West Tennessee*. Proc. National Bridge Scour symposium, Washington D.C. Federal Highways Agency, 112-39.

SMITH, R.E., GOODRICH, D.C. & QUINTON, J.N. 1995. Dynamic, distributed simulation of watershed erosion: The KINEROS2 and EUROSEM models. *Journal of Soil and Water Conservation*, 50(5):517-520.

THORNE, C.R., HEY, R. & NEWSON, M.D., eds. 1997. *Applied geomorphology for river engineering and management*. Chichester: Wiley.

YOUNG, R.A. & OTHERS. 1989. AGNPS: A non-point-source pollution model for evaluating agricultural watersheds. *J. Soil Water Cons*., 3:168—173.

Appendix 1 Fluvial Audit development reports

NATIONAL RIVERS AUTHORITY. 1991. *Sediment & gravel transport in rivers including the use of gravel traps*. Project Record, C5.02, prepared by M.D. Newson & D.A. Sear, NRA Bristol.

NATIONAL RIVERS AUTHORITY. 1994. *Sediment and gravel transportation in rivers, including the use of gravel traps*. R&D Project Record, C5/384/2, prepared by D. A. Sear and M.D. Newson, Bristol.

NATIONAL RIVERS AUTHORITY. 1994. *Sediment and gravel transportation in rivers: a geomorphological approach to river maintenance. Policy and implementation recommendations.* R & D Note 315, prepared by D.A. Sear and M.D. Newson, NRA: Bristol.

NATIONAL RIVERS AUTHORITY. 1994. *Sediment and gravel transport in rivers: A procedure for incorporating geomorphology in river maintenance.* Project Record 384, prepared by D.A. Sear & M.D. Newson, NRA Bristol.

NATIONAL RIVERS AUTHORITY. 1994. *Sediment and gravel transportation in rivers: A procedure for incorporating geomorphology in river maintenance*. R & D Report, prepared by M.D. Newson and D.A. Sear.

ENVIRONMENT AGENCY. 1998. *Geomorphological Approaches to River Management.* Project Record W5A/i661/1, prepared by Thorne, C.R., Downs, P.W., Newson, M.D., Clarke, M.J., and Sear D. A., Environment Agency, Bristol.

ENVIRONMENT AGENCY. 1998. *Geomorphological Approaches to River Management,* R&D Technical Report W89, prepared by Thorne, C.R., Downs, P.W., Newson, M.D., Clark, M.J., and Sear, D.A., Environment Agency, Bristol.

ENVIRONMENT AGENCY. 1998. *River Geomorphology: A Practical Guide. Environment Agency*, Guidance Note 18, prepared by Thorne, C.R., Downs, P.W., Newson, M.D., Sear, D. A. and Clark, M. J., National Centre for Risk Analysis and Options Appraisal, Steel House, 11 Tothill Street, London SW1H 9NF.

WALKER, J. 2000. *A fluvial audit procedure for use in the Environment Agency's Flood Defence function.* Unpublished M.Phil. Thesis, University of Southampton.

Appendix 2

Table A Geomorphological contacts

Contact	Organisation	Contacted?
GeoData	Southampton University	Y
Dave Sear	Southampton University	Y
Dave Withrington	English Nature	Y
Jim Walker	EA	Y
David Brown	EA - NW regional geomorphologist	Y
Richard Copas	EA - Thames	N
Jim Heslop	EA - Newcastle	Y
Dave Bartrum	EA - Nottingham	Y
Matt Hazelwood	EA - Bangor	Y
Chris Tidridge	EA - Shrewsbury	N
Malcolm Newson	Newcastle University	Y
Mike Williams	EA SW	N
Nigel Reader	EA SW	Y
Jo Old	EA contact (ex GeoData)	Y
Harriet Orr	Lancaster University/ EA	N
Dave Gilvear	Stirling University	N
Tristan Hatten-Ellis	CCW	Y
Rhian Thomas	CCW	Y
Helen Dangerfield	Royal Haskoning (formerly Babties)	Y
Susannah Hewitt	Babties	Y
Andrew Brooks	Babties	N
Jo Shanahan	Exeter Halcrow	N
Kevin Skinner	Haycock Associates	Y
Colin Thorne	Nottingham University (Prof Geog)	N
Phil Soar	Jeremy Ben Associates (Skipton Office)	N
Jenny Mant	River Restoration Centre	Y
Sophie Milner	National Trust (East Midlands)	Y
Richard Palmer	National Trust (NW)	Y
Sally German	Gifford	Y

N = contact unavailable

Appendix 3

Table B River SSSIs and SAC status

SSSI ID	SSSI name	Master list river	SAC status
1003495	Cornmill Stream and Old River Lea	Cornmill Stream	
1002787	Dove Valley to Biggin Dale (units 40,41 & 42)	Dove	
1002148	Halsdon	Torridge	
1002911	Hamps and Manifold Valleys	River Hamps, River Manifold	
1003711	Lathkill Dale	Lathkill	SAC
2000203	Lymington River	Lymington	
1002913	Malham-Arncliffe	Malham/Arncliffe streams	SAC
1004461	**Moors river system**	Moors	
1000503	Ouse Washes	Old Bedford	SAC
1003629	Ripon Parks	Ure	
2000183	**River Avon system**	Avon	**SAC**
2000139	River Axe	Axe (lower)	SAC
2000143	**River Barle**	Barle	
1005993	**River Beult**	**Beult**	
1001772	**River Blythe**	**Blythe**	
2000151	**River Camel Valley and tributaries**	**Camel**	SAC
2000052	**River Coquet and Coquet Valley Woodlands**	**Coquet**	
2000452	**River Dee (England)**	**Dee**	SAC
1003398	**River Derwent**	**Derwent**	SAC
2000214	**River Derwent and tributaries**	**Derwent**	SAC
2000215	**River Eden and tributaries**	Eden	**SAC**
2000147	River Ehen (Ennerdale Water to Keekle Confluence)	Ehen	SAC
1001178	River Eye	Eye	
2000220	River Frome	Frome (lower)	
1003424	**River Hull Headwaters**	Hull headwaters	
1004261	River Ise and Meadows	Ise	
2000227	**River Itchen**	Itchen	**SAC**
2000164	**River Kennet**	**Kennet**	
2000335	**River Kent and tributaries**	**Kent**	
2000155	**River Lambourn**	**Lambourn**	
1006616	**River Lugg**	Lugg	

Table continued…

SSSI ID	SSSI name	Master list river	SAC status
2000416	**River Mease**	**Mease**	SAC
1006323	**River Nar**	**Nar**	
1003025	River Ribble (Long Preston Deeps)	Ribble	
2000102	**River Teme**	Teme	
2000170	**River Test**	**Test**	
2000431	River Till	Till	
1006328	**River Wensum**	Wensum	**SAC**
1003045	River Wharfe	Wharfe	
1006327	**River Wye**	Wye	
1001128	Sandwich Bay to Hacklinge Marshes	North Stream	
1002963	Stanford End Mill and River Loddon	Loddon	
1003036	The New Forest	New Forest Streams	
2000455	**Tweed catchment rivers - England: Lower Tweed and Whiteadder**	**Tweed**	SAC
2000288	**Tweed catchment rivers - England: Till catchment**	**Tweed**	SAC

(Source: David Withrington, English Nature 23/02/2006)

Bold type = whole river SSSIs. Ordinary type = sections of river

Appendix 4

Table C Known audited rivers (March 2006)

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
1	Alport	X	2004	National Trust	Haycock Associates		River Alport - Fluvial Audit
2	Axe	Section		Environment Agency			
3	Bassenthwaite Lake	X	2004	Environment Agency	Lancaster University	Fluvial Audit for lake restoration	Bassenthwaite Lake Geomorphological Assessment
4	Beane	X	1995	Environment Agency			River Beane Geomorphological Evaluation
5	Bear Brook	X	1996	Environment Agency		DCBS for identifying opportunities for habitat enhancements	Geomorphological Assessment of the Re-meandered Bear Brook
6	Beult	Whole	2005	English Nature	Gifford	SSSI Fluvial Audit for restoration	River Beult Geomorphological Assessment Report
7	Beverley Brook	X		Environment Agency	Portsmouth University		
8	Blackwater	Section	2002	EU Life Funded	GeoData Institute	SSSI Fluvial Audit for restoration	Geomorphological baseline assessment of the Highland Water and Blackwater catchments in the New Forest
9	Blackwater (Essex)	X	2002	Environment Agency	Lancaster/ Newcastle Universities	Fluvial Audit for conservation management	Fluvial Audit of the River Blackwater
10	Bollin (Mersey)	X				Fluvial Audit / GDA for river rehabilitation.	
11	Brent and Crane	X	1996		Jim Walker	DCBS for identifying opportunities for habitat enhancements	Catchment Audit of the Rivers Brent and Crane

Table continued…

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
12	Brit	X	2003	Environment Agency	GeoData Institute		Geomorphological Audit of the River Brit catchment
13	Caldew	Whole	2001	Environment Agency	GeoData Institute	Fluvial Audit for conservation and flood defence management	
14	Camel	Whole	2000	Environment Agency	Portsmouth University	Geomorph Dynamics Assessment of Croys.	Geomorphological Guidelines on Bankside Erosion Structures, River Camel cSAC
15	Chalgrove Brook	X		Environment Agency	Birmingham University		Using a Fluvial Audit of the Chalgrove Brook to Analyse Geomorphology of the Thame River and Catchment
16	Chalvey Ditch	X	1996	Environment Agency	Walker, Sear	DCBS for identifying opportunities for habitat enhancements	Channel stability on the Chalvey Ditch
17	Cherwell Catchment	X	1996/7	Environment Agency	Nottingham University Consultants/ Atkins		Geomorphological Audit of the Cherwell Catchment
18	Clun	X		Environment Agency			
19	Clwyd (SAP pre assessment)	X	ongoing	Environment Agency		SAP pre-assessment	
20	Cole	X	1994	River Restoration Centre	Sear, White	Geomorphological Assessment for restoration	Geomorphological Assessment of the River Cole
21	Darent	X	2003	Environment Agency	Gifford	Fluvial Audit for River restoration	
22	Deben	X	2001	Environment Agency	Newcastle University	Fluvial Audit for conservation management	Fluvial Audit of the Upper River Deben
23	Dee or Dyfrdwy	Whole	2004	CCW	GeoData Institute	SSSI Fluvial Audit for Restoration	

Table continued…

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
24	Derwent (Yorkshire)	Whole	ongoing				
25	Derwent (Yorkshire)	Whole	1992	Environment Agency	Sear	Fluvial Audit for Flood Defence Sediment maintenance management	Channel Siltation and catchment processes at the confluence of the Rivers Derwent and Rye
26	Dovey/ Dyfi	X	2000	Environment Agency	GeoData Institute		A Geomorphological Approach to the Strategic Management of River Bank Erosion: A Case Study of the Afon Dyfi (linked PhD)
27	Dovey/ Dyfi	X	ongoing	Environment Agency		SAP pre assessment	
28	Dovey/ Dyfi	X	1999	Environment Agency	GeoData Institute		
29	Dunsop	X	1988	North West Water	Newcastle University	Rapid appraisal for sediment management	Sediment Movement in Gravel Bed Rivers: application to water supply and catchment management problems, River Dunsop, Forest of Bowland, Lancs
30	Dysynni	X	ongoing	Environment Agency		SAP pre assessment	
31	Eden	Whole	2001	Environment Agency, Eden Rivers Trust, English Nature	Environment Agency, Centre for Ecology and Hydrology		River Eden RHS and Geomorphological Evaluation
32	Esk	X	2004	Environment Agency	Babtie Brown & Root	Fluvial Audit for salmon habitat assessment	Catchment Geomorphological Audit of the Esk Catchment. Detailed Geomorphological Survey (Report B)
33	Ettrick Water	X	2004	Scottish Environment Protection Agency / Scottish Natural Heritage	GeoData Institute		RHS based back to back surveys

Table continued…

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
34	Exe	X		Environment Agency	Babtie Brown & Root		
35	Glaze Brook	X	2002	Environment Agency	Liverpool University (ERC)		River Habitat Survey and Geomorphological Evaluation of the Glaze Brook Catchment
36	Goldrill Beck	Whole	2003	Environment Agency	Environment Agency (field data by Babtie Brown & Root)	Fluvial Audit for Sediment management	Goldrill Beck RHS and Geomorphological Evaluation
37	Hawkcombe	X		Environment Agency	Nottingham University Consultants	Fluvial Audit for sediment management	
38	Hermitage Stream	X	1995	Havant Borough Council	GeoData Institute	Fluvial Audit for restoration	River Restoration feasibility study: Hermitage Stream
39	Highland Water	Section	2002	EU Life Funded	GeoData Institute	SSSI Fluvial Audit for restoration	Geomorphological baseline assessment of the Highland Water and Blackwater catchments in the New Forest
40	Hogsmill	X	1993	Environment Agency	GeoData Institute	Geomorphological Assessment for river management	Hogsmill Stream Geomorphological Evaluation - Preliminary Report
41	Idle	X	1993	Environment Agency	Sear	Fluvial Audit for Flood Defence sediment maintenance management	Siltation and sediment transport in the River Idle
42	Keer	X	1997	Environment Agency	Jim Walker EA		Fine Sediment Deposition in the River Keer. Geomorphological Assessment
43	Kennet	Whole	2000	Environment Agency	GeoData Institute	Fluvial Audit for River Restoration	Detailed Catchment Baseline survey of the River Kennet
44	Kent	Whole	2001	Environment Agency	Lancaster University	Fluvial Audit for Flood Defence sediment management	Kent Catchment Geomorphological Assessment
45	Lambourn	Whole	2000	Environment Agency	GeoData Institute	Fluvial Audit for River Restoration	River Lambourn and Kennet Geomorphological Audit

Table continued…

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
46	Leith	Whole	1998	Environment Agency	Lancaster University		River Leith Fluvial Audit
47	Lingmell Beck and Mosedale Beck	X	2004	National Trust	Haycock Associates	Fluvial Audit for sediment management	Wasdale - Fluvial Audit of the Lingmell Beck and Mosedale Beck Systems
48	Liza	X	1996	Environment Agency	Environment Agency: Jim Walker		River Liza, Ennerdale, Modelling of Irish Bridge. Fluvial Geomorphological Considerations
49	Lune	X	1999	Environment Agency	Lancaster University	Geomorph. Audit plus Geomorph Dynamics Assessment for flood defence management	River Lune Processes. A study of change in the River Lune catchment and recommendations for flood defence management
50	Lymington	Section	2002	EU Life Funded	GeoData Institute	SSSI Fluvial Audit for River Restoration	
51	Mawddach and Wnion	X	1994	Environment Agency	Sear, Gurnell	Fluvial Audit for flood defence sediment management	Channel dynamics at the confluence of the Afon Mawddach and Afon Wnion
52	Mimmshall Brook	X	1992	Environment Agency	Newcastle University	Fluvial Audit for flood defence sediment maintenance management	Mimmshall Brook Geomorphological Assessment
53	Nar	Whole	2005	English Nature	GeoData Institute	SSSI Fluvial Audit for River Restoration	River Nar SSSI Geomorphological Audit
54	Ober Water	Section	2005	Forestry Commission	GeoData Institute	SSSI Fluvial Audit for River Restoration	
55	Otter	X	2003	Environment Agency	GeoData Institute	Fluvial Audit for Flood Defence sediment maintenance management	Geomorphological Assessment of the River Otter
56	Pant	X	2002	Environment Agency	Lancaster/ Newcastle Universities	Fluvial Audit for Conservation management	Fluvial Audit of the River Pant

Table continued…

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
57	Ribble	Section				Unknown	
58	Roch	X	2005	Environment Agency	Babtie Brown & Root	Geomorphological bolt-on for flood defence sediment management	River Roch Gravel Management Plan. Report 1 - Detailed Geomorphological Survey; Report 2 - Catchment Geomorphological Action Plan
59	Roch	X	?	Environment Agency	Environment Agency: Jim Walker	Geomorph Bolt-on survey for flood defence management	River Roch Comprehensive Flood Alleviation Scheme
60	Sankey Brook	X	2002	Environment Agency	Atkins	unknown	Sankey Brook. Geomorphic Assessment of Flood Defence in Sankey Brook Catchment
61	Scotch Brook	X		Environment Agency	Babtie Brown & Root	unknown	
62	Sence	X	1993	Environment Agency	Newcastle University	Fluvial Audit for Flood Defence sediment maintenance management	Siltation and Bank Instability on the River Sence, Leicestershire
63	Severn	X		Environment Agency	Pete Downs	unknown	
64	Shelf Brook	X	1999	Environment Agency	Environment Agency: Jim Walker	Fluvial Audit for Flood Defence sediment maintenance management	Sediment Transfer and Gravel Trap Performance: Shelf Brook, Glossop. Geomorphological Assessment
65	Skell	X		Environment Agency	Newcastle University	Fluvial Audit for Flood Defence sediment maintenance management	Sediment Accumulation Upstream of Alma Weir, Ripon
66	Stort	X	1990	Environment Agency		DCBS for flood defence management	Stort Catchment Morphological Survey: Appraisal Report and Watercourse summaries
67	Stour	X	2005	Bournemouth Borough Council	GeoData Institute	SSSI Fluvial Audit for channel management	Fluvial Audit of the Lower River Stour

Table continued…

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
68	Swale	X	2001	York Dales National Park Authority	GeoData Institute	SSSI Fluvial Audit for restoration	
69	Tawe	X	1993	Environment Agency	Newcastle University	Fluvial Audit for Flood Defence sediment maintenance management	Siltation and the Sediment System of the River Tawe Upstream of Ystalyfera
70	Tees	X	2004	Environment Agency	Babtie Brown & Root	Fluvial Audit for salmon habitat assessment	Catchment Geomorphological Audit of the Tees Catchment. Detailed Geomorphological Survey (Report B)
71	Teign	X		Environment Agency		unknown	
72	Teme	Whole	ongoing	Environment Agency		unknown	
73	Till (Tweed)	Whole	2004	Environment Agency	Lancaster/ Newcastle Universities	unknown	Tools for Applying the EU Habitats Directive to the English River Tweed cSAC. Hydromorphological Study of the River Till
74	Trannon	X		Environment Agency	Jim Walker EA	unknown	Short Geomorphological Evaluation of River Trannon Focus Site
75	Tweed	Whole	2004	Scottish Environment Protection Agency / Scottish National Heritage	GeoData Institute	Condition assessment	
76	Tywi	X		Countryside Council for Wales		unknown	
77	Upper Irwell	X	2004	Environment Agency	Babtie Brown & Root	Sediment management	Upper Irwell Fluvial Audit (2004), Upper Irwell Gravel Management Plan. Catchment Geomorphological Action Plan (2006)
78	Upper Mersey	X	1998	Environment Agency	Jim Walker EA	Unknown	Upper Mersey Catchment Draft Geomorphological survey

Table continued…

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
79	Upper Stour	X	2002	Environment Agency	Lancaster/ Newcastle Universities	Unknown	Geomorphological impacts of Ely-Ouse transfers: Stour receiving channel, Sipsey Bridge to Clare
80	Upper Thames Catchment	X	1996			Unknown	Geomorphological Audit of the Upper Thames Catchment
81	Upper Wharfe	Section	1997		Newcastle University	Fluvial Audit for strategic environmental management	Geomorphological Audit of the Upper Wharfe
82	Ure	X	2000	Environment Agency	GeoData Institute	Fluvial Audit for strategic environmental management	River Ure: Geomorphological Audit
83	Ure	X	1991	Environment Agency	Newcastle University	Fluvial Audit for Flood Defence sediment maintenance management	Bank Erosion on the River Ure at the Jervaulx Park Estate: Geomorphological Assessment
84	Usk Tributaries	X	2004	Countryside Council for Wales	GeoData Institute	SSSI Fluvial Audit for restoration	
85	Wansbeck	X	1992	Environment Agency	Newcastle University	Fluvial Audit for flood defence sediment management	Siltation in the River Wansbeck at Morpeth Geomorphological Assessment
86	Waveney	X		Environment Agency	Southampton/ Newcastle/ Salford Universities	Fluvial Audit for fisheries management	Rehabilitation of selected sub-reaches of the River Waveney, Anglia Region, Environment Agency
87	Wear	X	2004	Environment Agency	Babtie Brown & Root	Fluvial Audit for salmon habitat assessment	Catchment Fluvial Geomorphological Audit of the Wear Catchment. Detailed Geomorphological Survey (Report B)
88	Wensum	Whole	2005	English Nature	GeoData Institute	SSSI Fluvial Audit for restoration	Geomorphological Audit for supporting river restoration on the River Wensum
89	Western Rother	X	1996	Environment Agency	Sear	Fluvial Audit for fisheries management	Fine sediment transport in the River Rother

Table continued…

ID	River	SSSI?	Date of audit	Client	Contractor	Survey type	Report title
90	Wey	X	2001	Environment Agency	University of Portsmouth	unknown	River Wey Catchment Geomorphological Survey and Assessment
91	Wharfe	Section	2001	Environment Agency	GeoData Institute	SSSI Fluvial Audit for restoration	
92	Wharfe	Section	1998		Newcastle University	Geomorphic Dynamics Assessment of gravel trap impacts.	Dynamic Assessment of the Gravel Trap on the River Wharfe Upstream of Buckden
93	Witham	X				Fluvial Audit for Flood Defence sediment maintenance management	
94	Wooler Water	Whole			Newson and Sear		
95	Wye	Whole	ongoing	Countryside Council for Wales	Gifford	Fluvial Audit	
96	Wye	Whole			Nottingham University Consultants/ Atkins		
97	Wylye	X	2002	English Nature	GeoData Institute	SSSI Fluvial Audit for restoration	River Wylye Geomorphological Audit
98	Yare	X		Environment Agency	Babtie Brown & Root		

Some records of date and contractor are missing where records have not been received.

Appendix 5 Lessons from Shoreline Management Plans

The approach to the high level specification of survey to fit favourable condition can potentially learn from other approaches used in horizontal applications seeking to achieve sustainable and integrated approaches to environmental management. In particular, the development and evolution of the shoreline management planning approach has been instructive in developing a series of modules for fluvial audit approaches and in adopting MCA based decision support tools.

The approach adopted within Shoreline Management Planning (Figure A) is part of a series of survey, strategy and policy developments through to design options and stakeholder involvement. The objectives of the SMP process are somewhat different and broader (including stakeholders), but essentially they start with the identification and justification of sediment cells boundaries and process trends, rates and predictions within them. They are also based on parallel lines of evidence of geomorphology, from historic analysis, field status surveys and prediction of change to derive a management units and policy objectives for geomorphologically defined reaches (management units). They also escalate to modelling and survey where there are data gaps and uncertainties. This leads to establishment of management options that are subject to consultation and that are taken forward into later stages of strategic studies and design options.

The stages are illustrated below, Figure B. The SMP approach uses a range of data inputs, including historic, process and boundary conditions. The approaches have adopted GIS-based, multi criteria approaches and modelling (social and coastal trend prediction) to develop scenarios. The stages build on one another to define the appropriate intervention (if any) and justify non-intervention where this is the chosen strategy; from do nothing to various forms of intervention. The strategy plans consider processes in more detail to develop preferred generic forms of management solutions. The process also incorporates a series of stages of consultation that are also relevant to the development of restoration plans.

Scheme Appraisal provides the optimisation of the generic management approach to propose a detailed plan – suitable for submission for planning permission.

The SMP approach is more mature than fluvial audit in that it has been applied nationally and has developed though a consensus-based approach through to a second phase with a refined approach to encourage standardisation. The evolution of the SMP approach from stages 1 and 2 has also introduced a series of national scale programmes of survey, analysis and modelling to introduce some levels of consistency into the approach. For example, the predictive coastal evolution modelling from FutureCoast has nationally surveyed change and predicted coastal evolution rates, and the development of the Multi-criteria Decision Support Framework tool integrates GIS and costs and social vulnerability models to the SMP process. This has not happened (yet) within Fluvial Audit methods, although many of the objectives are the same.

These same stages are applied within the use of fluvial audit for the setting of restoration activities and favourable condition actions, identifying appropriate management options that reflect the process rates and trends, recognise the natural conditions or what might anticipate these being from analogues (without artificial interventions). The subsequent stages to the fluvial audit assessment are also similar to SMP requirements; on the Nar the restoration and rehabilitation targets (the management options) are being taken forward through strategic options for restoration and thence to develop design options for costing of restoration schemes.

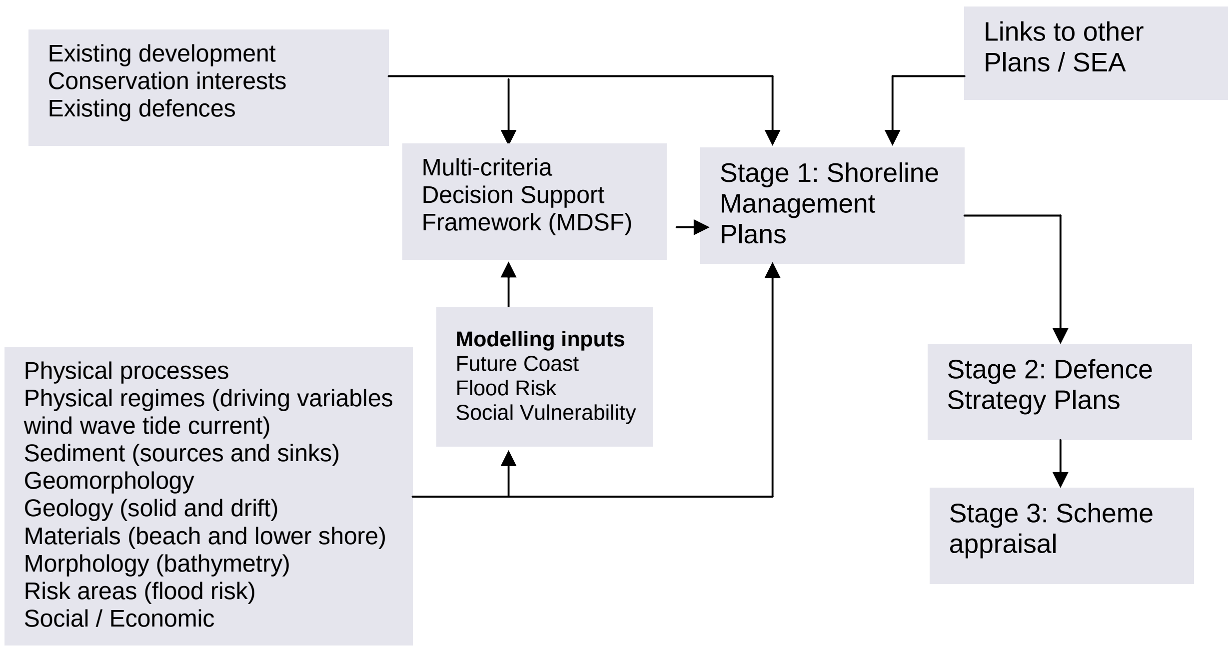

Figure A The Shoreline Management Planning development of management options (consultation stages are not shown)

Reflecting these approaches within the proposals for Fluvial Audit extension to Favourable Condition a similar diagrammatic approach can be constructed to illustrate the inputs, modules and outputs and potential next stages in proposal development (Figure B). The later stages are not yet effectively defined within any standard approach to fluvial assessment.

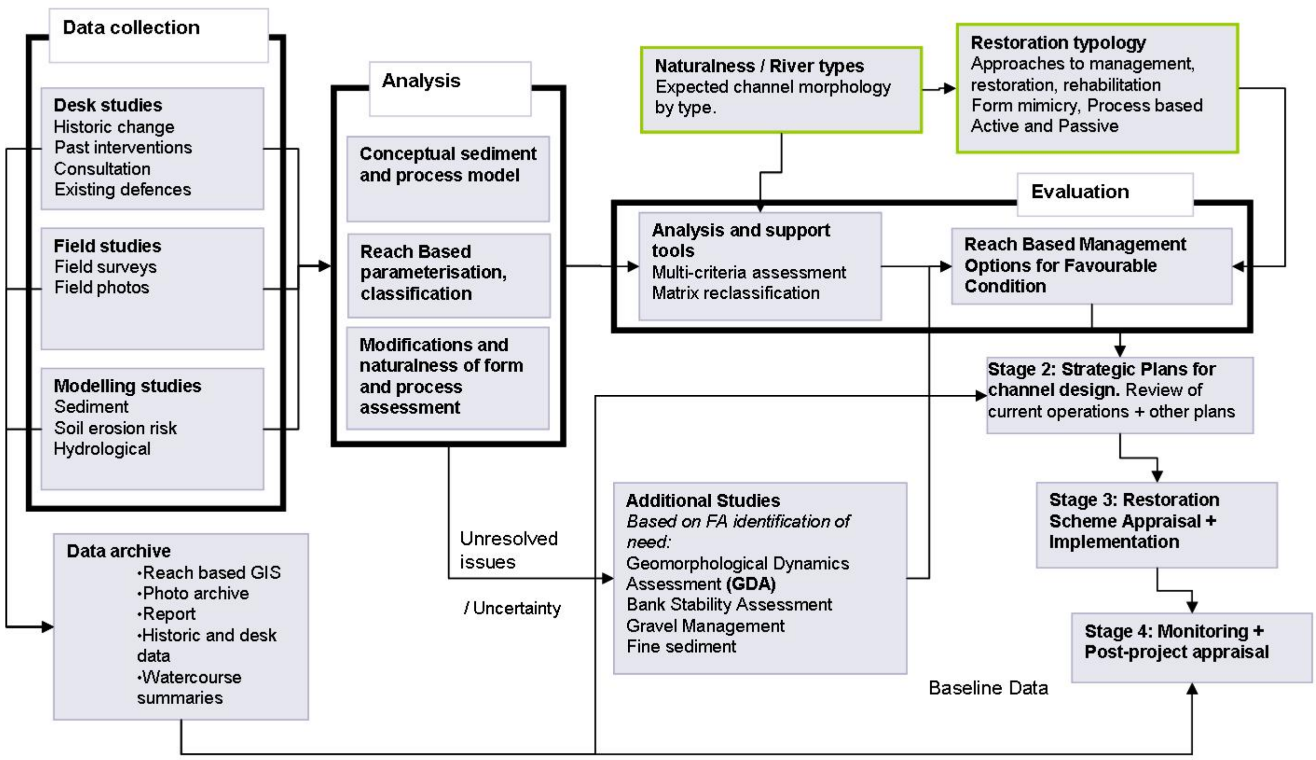

Figure B Proposed parallel approach to fluvial audit and subsequent stages of development of favourable condition planning and restoration. Green areas are external to the audit process

The results of this comparison suggest that the SMP model provides some useful 'best practice' in terms of process-based studies feeding into management options and visions integrated at large scales (sediment cell) that are consulted on to develop subsequent stages of planning, design and implementation.

Of particular relevance is the common need to establish a conceptual model of how the system is working, in both cases in terms of flow, sediment, supply, transport and sinks. This conceptual model provides the basis for the interpretation and assessment of the appropriateness of the management options. Developing the conceptual model relies on a range of data, and not necessarily consistent data sources for each reach or system, but responsive to the information available and its quality.

Modelling has formed an important element in improving the interpretation and quantification of the conceptual models. A number of these modelling exercises have followed the first round of SMPs where it was recognised that nationally consistent modelling was both more efficient and cost-effective and developed as ‘modules’ for subsequent stages. The FutureCoast, predictive erosion modelling, provides the basis for risk ‘module’ across all subsequent SMPs. Similar national (or SSSI-wide) mapping and modelling options may provide suitable ‘modules’ for the inclusion is subsequent fluvial audits for favourable condition proposals.

In addition, the inclusion of a decision support framework has helped to collate and interpret the multi-criterion based evaluation of the defence needs (in SMP terms). These have used the outputs from some of the national modelling activities and vulnerability assessments within a GIS framework. Similar approaches have been used within a few recent fluvial audits (Usk and Nar/Wensum), although the process and data formats and implementation need additional development.

Within the SMP process a series of defence options are proposed based on the broad approaches relevant to the process-based circumstances and the coastal configuration and process rates and risks imposed and constraints. These proposals are subject to consultation, often supported by stakeholder information materials. Similar issues affect the adoption of restoration and management options for river channels and catchments based on typologies of rivers and the approaches appropriate to the characteristics of the reach. Equally, it is recognised that coastal management may respond to near- and far-field influences, equivalent to the channel scale interventions and catchment-scale management.

Appendix 6

Table D Summary of the reasons for unfavourable status across all English Nature SSSIs and an assessment to the relevance to geomorphology

Pressure	Contribution from geomorphology
1. Water quality	
Discharge from STW and industrial works.	NONE
Discharge/diffuse pollution from cress farm.	Evidence of excessive siltation
Diffuse pollution from Agriculture	Evidence of excessive siltation
Siltation - turbidity.	Evidence of excessive siltation
Use of chemicals at golf club.	NONE
Road/urban run-off.	Presence of sediment routeways
Fertiliser use.	NONE
2. Channel management	
Bankside management (close mowing, removal of riparian habitat)	Evidence of impacts on bank erosion
Public access/disturbance to spawning beds.	Evidence of disturbance to gravel bed structure.
Inappropriate scrub control.	NONE
Inappropriate weed control.	NONE
Himalayan Balsam and Japanese Knotweed invasion.	Evidence of impacts on bank erosion processes (winter)
Weed cutting - >50% of channel plants removed.	Evidence of bed disturbance / siltation
Channel management – not allowing *Ranunculus* to flower.	NONE
Inappropriate pest control.	NONE
Presence of mink.	NONE
High numbers of signal crayfish causing bank damage (over-widening channel, removing marginal habitat and silt introduction).	Evidence of excessive bank erosion, over-widening and excessive siltation
High trout stocking affect salmon.	NONE
Tipping.	NONE

Table continued…

Pressure	Contribution from geomorphology
3. Channel structure	
Channelisation and channel enlargement for flood defence, land drainage.	Evidence of modification to channel planform, long profile, cross-section form and substrate.
Bed lowering and straightened.	Evidence of modification to channel planform, long profile, cross-section form and substrate.
Poor habitat structure.	Evidence of modification to channel planform, long profile, cross-section form and substrate.
Dredging.	Evidence of modification to long profile, cross-section form and substrate.
Degraded channel morphology – removal of river gravel shoals and islets.	Evidence of modification to channel planform, long profile, cross-section form and substrate.
Extensive channel revetment.	Evidence of modification to channel planform, long profile, cross-section form, substrate and bank erosion processes.
Presence of groynes.	Evidence of modification to channel planform, long profile, cross-section form and substrate. Channel form
Bank erosion.	Evidence of excessive bank erosion and nature of erosion process.
4. Land use management	
Urban impacts.	Evidence of modification to runoff regime.
No riparian buffer zone – no fencing schemes.	Evidence of excessive bank erosion / siltation. Evidence of modification to channel form.
Herbicide spraying and burning of adjacent fields to bank edge.	NONE
Silt inputs due to arable and intensive grass cultivation up to river bank.	Evidence of excessive siltation
Widespread stock access (and high stocking rates) causing bank erosion (poaching).	Evidence of excessive bank erosion dues to trampling / poaching.
Bankside vegetation overgrazed or under-grazed.	Evidence of excessive bank erosion and loss of riparian vegetation.
Forestry and woodland management-over shading.	NONE
Mineral planning permission breach (sediment pulses from mines).	Evidence of siltation / extraction of gravel.
Drainage.	Evidence of modified flow regime.
5. Flow regime (Low flow / low velocity / inappropriate water levels due to):	
Water abstraction and diversion of flow through weirs for fisheries	Evidence of modification to cross-section and long-profile. Evidence for excessive siltation.
Weirs barriers to fish migration.	Evidence of impact on sediment transport continuity
Inappropriate water levels.	Impacts on bank stability / floodplain inundation/sedimentation.

Appendix 7

Table E Parameters collected by the fluvial audit approaches for the Nar, Tees and the Goldrill Beck fluvial audits

River Nar Parameters	Measure	River Tees Parameters	Measure	Goldrill Beck Parameters (includes full RHS at site)	Measure
Form-based data				**Site information (a)**	
Catchment	name	Catchment	Name	Catchment	Text
Date		Watercourse	Name	Watercourse	Text
Time		Reach_ID	Code	Site Number	Number
		NGR-start	Num	Grid ref	Text
Reach code	code	NGR end	Num	Date	Date
Surveyor	code	Surveyor	Code	Surveyor	Text
Photo code	code	No of photos	number	Photo Number	Number
Reason for change	class	Reason for U/s boundary	text	Surveyed from bank	Text
Description	text			Additional notes	text
Condition	text	Condition	text	Adverse conditions	Text
Flow condition	class	Flow *level*	class	Water Width	m
Planform	class			Water depth	m
Modification	class	Valley form		**Erosion Features (B/C)** **Natural (b)** By sediment type,	MMM
Bankfull height	m L+R	Land use L+R (5m)	class	Wasting features	Tally + class
Bankfull width	m L+R	Land use L+R (50m)	class	Attrition features	Tally + class
Floodplain width	m L+R	Floodplain (presence)	class	**Accelerated features (c)**	
Water width	m	Floodplain widths class	class	Direct alteration	Tally + class
X-section	Sym/asym	Riparian Buffer strip (L+R)	class	Indirect alteration	Tally + class
Water depth	m	Width of strip (L+R)	class	**Deposition Features (d1)**	

Table continued…

River Nar Parameters	Measure	River Tees Parameters	Measure	Goldrill Beck Parameters (includes full RHS at site)	Measure
		Banktop vegetation (L+R)	class	Point bars	Tally + class
Bank vegn	% L+R	Connectivity	Y/N	Side bars	Tally + class
Woody	% L+R	Terraces L+R	Class	Mid channel bars	Tally + class
Embanking	% L+R	Terraces	Num	Structure associated bars	Tally + class
Embank height	m L+R	Levees (L+R)	Class	**Other features (d2)**	
		Trashlines	Y/N	Berm deposits	Tally + class
Bank material	**D/✓**	Trashlines height	M	Floodplain deposits	Tally + class
Bank cohesiveness	**D/✓** L+R	**Channel geometry**		Waste debris	
Bank sorting	**D/✓** L+R	Planform	Class	Organic debris	
Dominant erosion pro’	**D/✓** L+R	Realigned	Y/N	**Bed material (e)**	Tally + class
Dominant erosion mechanism	**D/✓** L+R	Cross-section	Class	**Engineering (f)**	M by class
		Resectioned	Y/N	**Other features (h)**	
Condition of toe	L+R	Culverted	Y/N	Weirs	MMM
Vegetation at toe	L+R	Length of culvert	M	Dams	MMM
Age of vegn at toe	L+R	Channel width	Class	Debris Dams	MMM
Acceleration of process	Y/N	Channel depth	Class	**Sediment from floodplain (g)**	
Evidence of incision	Y/N	Symmetry	Class	Left + Right land use	Class (tick and E)
Evidence aggradation	Y/N	Qbf min	m	Effect on sediment budget	Class (tick and E)
Evidence of stability	Y/N	Qbf Max	m	**Relict channels (i)**	Number
		Qbf Mean	m		Length

Table continued…

River Nar Parameters	Measure	River Tees Parameters	Measure	Goldrill Beck Parameters (includes full RHS at site)	Measure
Dominant bed material	**D/✓**	Low flow	m		Photo
Channel marginal silt	APE	Gradient	class	**Grazing and human access (j)**	
Bed vegetation cover	% length	Velocity	class	Grazing	Class
		Bed material	Tick / E	Fencing	Class
Berms length	% length	**Bed characteristics**		Access	Class
Ranunculus cover	**D/✓**	sorting	Class		
Dom species community	**D/✓**	Debris	Class	**Overall view (k)** Source, sink, transfer	Class
Deposition stable Micro, meso, macro	Tally (MMM)	Sphericity	Class		
Deposition unstable	Tally (MMM)	Imbrication	Class		
Flow type	**D/✓**	Diversity	Class		
Marginal waters	D U/NU	Channel vegetation	% cover		
Riffles and rapids	number	Channel vegetation type	class		
Significant Wood debris	tally	Banks (L+R) material	Class tock/E		
Hydraulic controls	impact	Banks (cohesive)	Y/N		
Hydraulic controls	scour	Profile (L+R)	Class tick/E		
Hydraulic controls	ponding	Protection (L+R)	Class tick/E		
Invasive species	Y/N	Tree lining (L+R)	Class		
Sediment sources	class	Bank face vegetation (L+R)	class		
Rank order	rank	**Sediment transport** = flow type	Tally + total		
		Channel deposits – Permanent	Tally MM		
Floodplain features	**D/✓**	Channel deposits – semi-permanent	Tally MM		

Table continued…

River Nar Parameters	Measure	River Tees Parameters	Measure	Goldrill Beck Parameters (includes full RHS at site)	Measure
		Channel deposits - temporary	Tally MM		
		Type of storage	class		
		Sediment sources			
		Point sources (fine)	Tally		
		Point sources (course)	Tally		
		Diffuse sources (fine)	Tally		
		Diffuse sources (course)	Tally		
		Sediment sinks			
		Sediment sinks (fine)	Tally		
		Sediment sinks (coarse)	Tally		
		Diffuse sinks – permanent Semi-permanent Temporary	Tally		
		Recent flood chaos	Y/N		
		Ad hoc fisheries improvements categories	Tally		
Field mapping (GIS)					
Erosion Length	m				
Erosion Type	class, cause, severity				
Embanking	length				
Sediment sources	point	Sediment sources	Point		
Bank protection lengths	m				
Photo locations	point	Photo locations	Point		

Measures of parameters include a range of classes (APE = Absent, Present, Extensive), dominant/present (D/tick) and

Appendix 8

Table F Fluvial Audit parameters used within the Nar and Wensum evaluations from the total set of parameters collated during field surveys

Parameter	Measure	MCA Process	Parameter	Measure	MCA Process	Parameter	Measure	MCA Process
			Bank material	**D/**✓		Deposition stable	tally	Nat, Sink, Sor
Reach code	code		Bank cohesiveness	**D/**✓ L+R		Deposition unstable	tally	Nat, Sink, Sor
Surveyor	code		Bank sorting	**D/**✓ L+R		Flow type	**D/**✓	Nat, Mod
Photo code	code		Dominant erosion pro’	**D/**✓ L+R		Marginal waters	D U/NU	
Reason for change	class		Dominant erosion mech	**D/**✓ L+R		Riffles and rapids	number	
Description	text					Significant Wood debris	tally	Nat
			Condition of toe	L+R		Hydraulic controls	impact	Mod
Flow condition	class		Vegetation at toe	L+R			scour	Nat
Planform	class	Nat	Age of vegn at toe	L+R			ponding	Mod
Modification	class	Nat, Mod	Acceleration of process	Y/N	Mod	Invasive species	Y/N	Nat, Mod
Bankfull height	m L+R	Nat, Mod, Sink, Sor	Evidence of incision	Y/N		Sediment sources	class	Sor
Bankfull width	m L+R	Nat, Mod, Sink, Sor	Evidence aggradation	Y/N		Rank order	rank	Sor
Floodplain width	m L+R	Nat, Mod, Sink, Sor	Evidence of stability	Y/N				

Table continued…

Parameter	Measure	MCA Process	Parameter	Measure	MCA Process	Parameter	Measure	MCA Process
Water width	m	Nat				Floodplain features	**D/✓**	Nat, Mod, Sink, Sor
X section	Sym/asym		Dominant bed material	**D/✓**		**Field mapping**		
Water depth	m	Nat	Channel marginal silt	APE		Erosion Length	m	Sor
			Bed vegetation cover	% length	Mod	Erosion Type	type	
Bank vegn	% L+R					Embanking	length	Mod
Woody	% L+R		Berms length	% length	Nat, Sink	Sediment sources	point	Sor
Embanking	% L+R	Mod	*Ranunculus* cover	**D/✓**		Bank protection lengths	m	Mod
Embank height	m L+R	Mod	Dom species community	**D/✓**				

Nat Naturalness, Mod Modification, Sink Sediment sink, Sor Sediment source

Appendix 9

Table G Parameters employed within the River Wensum MCA: Chalk Stream Multi-criteria (MCA) parameters used within the assessment of status and matrix reclassifications for the Nar and Wensum fluvial audit

GIS Field	Score field	Description						Values		
			Source	Sink	Naturalness	Modif	Class	From	To	Weight
Reach		Unique reach code								
SedBar	scSedBar	Barriers to sediment movement upstream					0	None		1
					Y		1	Minor		
							3	Major		
FineSedt	*scFineSed*	% fine sediment (silt and clay)	**Y**	**Y**	**Y**		1	0	4.9	4.5
							3	30	49.9	
							5	50	74.9	
							10	75	100	
							2	5	29.9	
MinHeight	*scHeight*	Minimum bank height			**Y**		0	0	1	3
							1	1.1	1.3	
							3	1.4	100	
WDRatio	*scWDRatio*	Width-depth ratio			**Y**		0	5	15.9	4
							1	16	24.9	
							3	0	4.9	

Table continued…

GIS Field	Score field	Description						Values		
			Source	Sink	Naturalness	Modif	Class	From	To	Weight
							3	25	1000	
PlanMod	*scPlan*	Plan modifcation			**Y**		0	Unmodified		3.75
							3	Modified		
FlowType	scFlow	Type of flow - glide, ponded, run			Y		0	Run		2
							0	Riffle		
							1	Glide		
							5	Ponded		
PrpBrmAr	*scBerm*	Proportion of reach area that is covered by berms		**Y**	**Y**		0	0	24.9	2
							3	25	10000	
Modif	*scModif*	Modification level				**Y**	0	1		4
							2	2		
							3	3		
							4	4		
							5	5		
PondPer	*scPond*	% ponded				**Y**	0	0	24.9	3
							5	25	100	
Ingress	*scIngress*	No. of ingress points	**Y**				0	0		3
							3	1		
							3	2		

Table continued…

GIS Field	Score field	Description						Values		
			Source	Sink	Naturalness	Modif	Class	From	To	Weight
							3	3		
BedVgPer	scBedVeg	Bed veg %				Y	0	0	79.9	2
							3	80	100	
PpErsnLn	scErosion	Proportion of erosion by bank length	Y				0	0	4.9	5
							1	5	9.9	
							2	10	49.9	
							3	50	100	

Appendix 10 Models for supporting Geomorphological Assessment of SSSI rivers: a review

A huge range of hydro-geomorphological models has been published in the scientific and engineering literature and various reviews exist (Jetten and others, 1999, Darby & van de Wiel 2003). For fluvial audit of SSSI rivers, the modelling support must be centred on identifying:

1) The location and magnitude of sediment production from the land surface;
2) The location and magnitude of sediment production from the channel bed and banks;
3) The location and magnitude of sediment deposition within the river network;
4) The characteristics and styles of change of channel morphology and sedimentology; and
5) Able to simulate 1-5 through time in response to management and environmental changes.

In practice, risk-based models of sediment production at the catchment scale can provide supporting information in the form of areas sensitive to soil erosion of land sliding. However they do not typically provide the locations of sediment input into he river network unless sediment routing algorithms are available.

A review of numerical models of water and sediment movement across catchments and through alluvial channels has been undertaken for a previous climate change project (EA 2000). This has been updated here and succinctly summarised to provide guidance on models that are or have the potential to support the Fluvial Audit process. To address the objectives of this research, the scope of this review is limited strictly to catchment and channel models that have the potential to simulate both the movement of water and the erosion, transport and deposition of sediment. An exception to this is the PSYCHIC soil erosion and nutrient model that is a static risk-based model.

Table H summarises the models identified as supporting the fluvial audit process.

Table H Catchment models capable of supporting Geomorphological Assessment

Model	Brief description	Key References
AGNPS	AGNPS is an event based model that can simulate runoff characteristics and transport processes of sediments, nutrients and chemical oxygen demand within agricultural catchments. A key feature of AGNPS is its ability to account for in-channel structures and a wide range of land use 'treatments'. The AGNPS code also has the ability to interface with other USDA models to explore (for example) reach-scale channel evolution and salmonid spawning habitat.	Young and others (1989)
EUROSEM	EUROSEM is an event based dynamic distributed model that can simulate sediment movement over land surfaces by rill and interill processes. Compared with other models it simulates both rill and interill flow, plant cover effects on interception and rainfall energy, and changes in rill dimensions through erosion and deposition.	Morgan and others (1998)
KINEROS	The kinematic runoff and erosion model (KINEROS) is an event oriented, physically-based model describing the processes of interception, infiltration, surface runoff and erosion from small agricultural and urban watersheds. The watershed is represented by a cascade of planes and channels; the partial differential equations describing overland flow, channel flow, erosion and sediment transport are solved by finite difference techniques. Spatial variation of rainfall, infiltration, runoff, and erosion parameters can be accommodated. KINEROS may be used to determine the effects of various artificial features such as urban developments, small detention reservoirs, or lined channels on flood hydrographs and sediment yield.	Smith and others (1995)
LISEM	The Limburg Soil Erosion Model (LISEM) is a physically-based soil erosion model, which simulates processes such as interception, infiltration and percolation, overland flow, channel flow, and detachment and sedimentation of soil particles. Soil and land use features often found in agricultural catchments can be incorporated: the influence of tractor wheelings, small paved roads, stones and surface crusts.	De Roo and others (1996)
SHETRAN	SHETRAN is a 3D, coupled surface/subsurface, physically-based, spatially-distributed, finite-difference model for coupled water flow, multi-fraction sediment transport and multiple, reactive solute transport in river basins.	Bathurst and others (1995) Ewen (1995) Ewen and others (2000)
CAESAR / ooCAESAR	CAESAR / ooCAESAR is a raster-based coupled catchment and channel evolution model. It is a grid-based, cellular automata model that routes surface runoff and multiple sediment sizes over the catchment surface and into and through the river network. It updates the topography and grainsize and is therefore capable of simulating morphology and sedimentology over event-millennial timescales. It is spatially distributed.	Coulthard 2001, http://www.joewheaton.org.uk/Research/Projects/ooCAESAR.asp

Table continued…

Model	Brief description	Key References
PSYCHIC	The precise methods used in this model are currently unknown and inaccessible. However they are believed to be empirical, providing a one-off assessment of sediment yield and associated P load from surrounding farmland to the watercourse. It is spatially distributed, and enables assessment of the impacts of different land use and farm management practices on total loads supplied to watercourses.	Davison et al., 2008

The availability of each of these models is given in Table H. Most of them represent spatial variability, which is an attempt to account for spatial variations in runoff and sediment dynamics that occur in large scale heterogeneous catchments. Spatially distributed modelling offers considerable advantages in that it is possible to identify source and sink areas of water, sediment and associated chemicals within the catchment (Jetten et. al., 1999). This is important in the context of this research, because this allows these models to be used as tools in designing management methods and techniques that aim to minimise undesirable impacts. Spatially explicit modelling does, however, imply considerable data and computational requirements. These are typically handled within a GIS environment.

Table I Software and documentation availability of various catchment models

Model	Availability of software, manuals and other support documentation	Cost
AGNPS	http://www.ars.usda.gov/Research/docs.htm?docid=5199	Free
EUROSEM	Morgan et al. (1998)	Free
KINEROS	www.tucson.ars.ag.gov/kineros	Free
LISEM	www.frw.ruu.nl/lisem/index.html	Free
SHETRAN	Software Via: Prof P.E. O'Connell, Dept. Of Civil Engineering, University of Newcastle-Upon-Tyne. E-mail: P.E.O'Connell@ncl.ac.uk	Not known
CHILD	www.colorado.edu/geolsci/gtucker/child	Free
CAESAR	www.coulthard.org.uk/downloads/downloads.htm	Free
PSYCHIC	Davison et al. 2008	Not Known

EA (2000) identified the AGNPS model as providing the most flexible and comprehensive representation of physical processes and management interventions. The PSYCHIC model is apparently simpler to implement and provides risk-based assessments of soil loss under a range of different land and farm management scenarios. The simplified approach is attractive and might represent a suitable means of identifying sediment production areas within the catchment under changing land management scenarios.

The CAESAR and ooCAESAR models provide a method for coupling sediment transport processes at the catchment scale, to the evolution of channel morphology and grainsize and hence physical habitat at the reach scale. However they are currently unable to simulate catchments with substantial groundwater flows.

The Flood Risk Management Consortium (FRMC) is currently developing a Sediment modelling tool for identifying the relative contributions of catchment and upstream sources to the local reach sediment budget. The model is based on one developed for the USDA called SIAM (Sediment Impact Assessment Method). SIAM provides an intermediate level of analysis more quantitative than fluvial audit, but less specific than a numerical, mobile-boundary simulation. The quick setup and run times provide the opportunity to run many simulations to explore operational scenarios, perform sensitivity studies, and create risk analysis information. Further details are available from David Mooney at Colorado State

University who is developing SIAM for the U. S. Army Corps of Engineers under the Regional Sediment Management program (http://www.wes.army.mil/rsm) and is continuing development at the Bureau of Reclamation.

Appendix 11

Table J WFD 49 Geomorphological reach classification

WFD49 Channel type	Description
Bedrock channel	Most commonly found in upland areas, though bedrock lined reaches can occur in certain lowland environments. They generally contain little, if any, bed sediment and have limited hydraulic connection with the riparian zone. Channel gradients tend to be high, resulting in a high transport capacity but limited sediment supply. These factors, together with the high degree of bank strength, result in quite stable channels.
Cascades	Are restricted to upland areas with steep slopes and are characterised by disorganised bed material typically consisting of cobbles and boulders constrained by confining valley walls. The riparian zone is usually extremely small in extent and interactions with the channel are limited. The large size of bed and bank material, together with high levels of energy dissipation due to the bed roughness, dictates that the largest bed load only becomes mobile in extreme floods (ca. >25 year return interval). Bedrock outcrops are common, and small pools may be present among the boulders.
Step pool channels	Has a steep gradient and consists of large boulder clasts which form discrete sediment accumulations across the channel, forming a series of “steps” which are separated by intervening pools containing finer sediment (typical spacing 1-4 channel widths). The stepped channel morphology results in zones of turbulence interspersed by more tranquil flows. As with cascade reaches, the high degree of channel roughness, and large sediment on the channel bed and banks results in stable channels that respond only in very large flood events. The stream is generally confined by the valley sides, and there is little/limited development of terraces or floodplain.
Plane bed channels	Generally moderate gradient streams with relatively featureless gravel/cobble beds, but include units ranging from glides, riffles and rapids. Sediment size and channel gradients are smaller than step-pool channels and deeper pool sections tend to be lacking. The river bed is generally armoured and, thus, mobilized in larger floods. Although channels are typically stable, they are more prone to channel change than any of the preceding channel types. Thus, with relatively more frequent bedload movement, they represent transitional channels between the more stable types listed above and the following more dynamic types of channel. Channels are generally straight and may be confined or unconfined by the valley sides. However, the banks- which generally comprise material resistant to lateral migration- constrain the channel from migrating laterally and developing alternate bars/riffles.

Table continued…

WFD49 Channel type	Description
Pool riffle and plane riffle channels	Meandering and unconfined channel that, during low flow, are characterised by lateral oscillating sequences of bars, pools and riffles, resulting from oscillations in hydraulic conditions from convergent (erosive) to divergent (depositional) flow environments (typical spacing 5-15 channel widths). The gradient of such channels is low-moderate and the width depth ratio high. The bed is predominantly gravel, with occasional patches of cobbles and sand. Accumulation of sediments in gravel bars indicates increasingly transport-limited conditions, though most large floods will produce some bedload movement on an annual basis, thus reducing the stability of the channel. In such channels, interactions between the stream and the riparian zone become more obvious with extensive over bank flood flows and wetland areas often characterising the riparian zone. The banks are typically resistant to erosion, and lateral migration of the channel is limited, resulting in relatively narrow and intermittently deep channels. Plane-riffle channels form an intermediate channel form between plane-bed and pool riffle channels. The retain many of the attributes of pool-riffle channels, however, they generally have less defined pools, coarser (armoured) substrate and less extensive bar features. They are a common channel form in UK, although it is unclear whether their presence is natural or whether they represent a degraded form of the pool-riffle channel. For management purposes, it is suggested that they are treated as a pool-riffle channel type.
Braided channels	Braided reaches can occur in a variety of settings. They are characterised by relatively high gradients (but ones that are less than upstream reaches) and/or abundant bedload. Sediment transport is usually limited under most conditions and the channel splits into a number of threads around instream bars. Nevertheless, poor bank strength renders them highly dynamic and channels will generally change even in relatively small flood events.
Wandering channels	These reaches exhibit characteristics of braided and meandering channels simultaneously, or, if studies over a number of years, display a switching between divided and undivided channel types. Wandering channels may also be susceptible to channel avulsions during high flow events, where the channel switches to a historical planform. Wandering channels typically occur where a reduction of bed material size and channel slope is combined with a widening of the valley floor. In sediment transport terms such reaches are bedload channels, but the number of competent transport events in any year will vary greatly according to bed material size and the associated entrainment function. Generally, they can be viewed as a transition channel type between braided and lowland meandering channels.
Low gradient actively meandering	Are unconfined low-gradient meandering channels with a bedload dominated by sand and fine gravel. Hence, the channel bed has marked fine sediment accumulations that are mobile in most flood events. These occur in higher order (ie typically lowland) channels exhibiting more laminar flow hydraulics, with turbulent flows being uncommon. The fine bed sediment erodible banks and unconfined settings means that such channels are dynamic and prone to change, they also often have extensive riparian zones and floodplains which are linked to the channel. Bars and pools may be present, and are associated with bends and crossing of the meander pattern.

Table continued…

WFD49 Channel type	Description
Groundwater dominated channels	Groundwater-dominated rivers low gradient channels and are characterised by a stable flow regime; although limestone rivers with cave systems may display hydrological characteristics similar to freshet rivers (Sear et al., 1999). This stable regime is a product of the pervious catchment geology, and consequent reduction in overland flow that characterises groundwater-dominated streams (Burt 1992; Sear et al., 1999). Bed movement is infrequent and sediments are predominantly transported in suspension (Sear et al., 1999; Walling and Amos 1999). Typically, sediments are derived from catchment sources, although large macrophyte beds provide a source of in-stream organic detritus (Burt 1992; Sear et al., 1999). As bed disturbance is infrequent, deposited sediments may remain in the gravel for extended periods, promoting the accumulation of large quantities of fine sediment. Substrate generally comprises gravels. pebbles and sands, and glides and runs are the dominant flow types (or morphological units. Localised areas of riffle may be present, particularly where woody debris is available.
Low gradient passively meandering	These channels are typically found at lower extremities of the channel system. Generally they flow through high resistant materials, for instance clay's and coarse deposits. They are generally sinuous; however, as the banks comprise materials that are resistant to erosion, they are typically 'fixed' in their planform geometry. Thus, these channels are often incised and display low width depth ratios. The beds typically comprise fine sedimentary materials (sands and silts), although pockets of gravel can be present, particularly in poorly formed bar deposits. These channels are typically deep and flows are dominated by glides, although runs may be associated with meander bends. Riparian vegetation is influenced by the clay soils and is often more sparse than in other channel types, fairly comprising grasses shrubbery and smaller pockets of woody growth. Primary production is strong in these channels and, coupled with stable beds, allows extensive growth of macrophyte vegetation.

Source: Greig, Richardson and Gibson (2005) WFD49 (Rivers): Environmental Standards to support river engineering regulations and WFD status classification.

Appendix 12 Draft Specification for geomorphological assessment to support strategic physical restoration of river SSSIs

Overall objective

To generate evidence-based recommendations for restoration measures necessary to restore the SSSI to favourable condition, through geomorphological assessment and analysis and associated ecological interpretation.

Specific objectives

1) To develop and present a conceptual model of the evolution of the channel and floodplain geomorphology highlighting the main controls on channel and valley form that have created the boundary conditions for the current river system.
2) To develop and present a model of the current functioning of the sediment transport system within the river network and surrounding catchment including supply, transport and storage.
3) To develop a specific understanding of the impacts of river and land management activity on the geomorphological processes and associated channel form identified in objectives 1 and 2 and outline the ecological consequences.
4) To apply this knowledge to identify specific channel and catchment management actions designed to alleviate the impacts identified in 3 as part of a river restoration plan and describe the benefits to biological communities characteristic of the river and its type.
5) To present a catchment-scale management plan for restoring the natural geomorphic processes and / or form of the channel to a level that can be considered to represent the favourable condition of the river habitat to support characteristic biological communities.

Scope of assessment

The Geomorphological Assessment is restricted in scope to those aspects of river and catchment management that critically affect the geomorphological form and function of the river. The following points are stressed:

1) It should be assumed that where excessive fine sediment delivery is part of the reason for failure to achieve favourable condition, measures will be identified and undertaken to treat this pressure. The role of Geomorphological Assessment is restricted to an evaluation of sediment ingress points to the river network, as a contribution to understanding sediment supply.
2) It is assumed that where modifications to hydrological regime are part of the reason for failure to achieve favourable condition, measures will be identified and undertaken to treat this pressure. The role of Geomorphological Assessment is restricted to identifying and evaluating those aspects of hydrological modification that are relevant to geomorphological condition.

In the likely situation whereby some of these pressures are newly identified by the Geomorphological Assessment then reference to the need to define and mitigate these as part of a wider catchment management plan should be made.

Desk studies

Desk studies are an important part of the Geomorphological Assessment. They are used to:

- Establish trends and styles of catchment land use, driving variables (rainfall and or discharge);
- Identify location, date and type of modifications made to river channel processes and form (eg channelisation, gravel mining, conversion to intensive arable agriculture, regulation of flow regime); and
- Quantify change in channel form (eg planform, width, depth, gradient from X-sections) and river network (eg increase in drainage network).

The historical data should be summarised in a TIMECHART that is used to identify potential cause and effect from the sequencing of events and responses in the river network. Historical and channel modification data may also be spatially referenced and visualised within a GIS. This information is used to establish the relationship between channel and catchment modifications and the current channel morphology and grain size. Modification data can also be used to establish an index of modification severity.

The desk study is also used to assemble information on the catchment and channel from the range of published and unpublished data sources including scientific papers and reports and datasets such as RHS/GeoRHS. This desk study process is used to:

- develop a conceptual model of the longer term evolution of the river and the nature of the controls on existing floodplain and channel form inherited from past processes; and
- develop the data necessary for identification of natural channel characteristics that are used to develop the index of channel naturalness.

These desk study data are recorded as a conceptual model and as a set of criteria which are used in the development of a natural channel template.

Desk study inputs will include, but may not be limited to the sources outlined in Table K. Where other sources exist these should be evaluated. Collation of this information may also be relevant to later stages of the restoration planning where more detail is required. The analysis of this information typically takes two weeks. The collation of this information is constrained by the rate at which it is delivered by external bodies. The contractor must keep the client informed of delays in data transfer.

Table K Data sources contributing to geomorphological assessment desk study

Data sources that are used within Geomorphological Assessment desk study	Information Base
Existing engineering records (flood alleviation schemes, channel modifications etc.)	Used to build database / GIS of channel modification. Essential to understand when, where and what type of modification in order to be able to interpret field morphology. For example a reach that was modified in the past may have recovered naturally. This capability in a river system is important to recognise with regard to restoration planning. Knowing the time taken to recover enables planning timescales to be defined.
Contemporary and historic cross sections and long profiles of bed and water levels	Used to identify scale of modification and / or channel adjustment. This information is used to identify reaches that have undergone incision / aggradation / widening etc. Mapped within the GIS helps to establish natural channel behaviour and / or response to modifications.
Academic literature on the site and similar riverine systems	Essential to understand what processes and forms to expect, and how the system might adjust to modification / restoration. Can be used to define "naturalness" under undisturbed conditions.
Historic mapping and historic aerial images that indicate channel and catchment scale, condition, modifications and change	Used to identify scales of change in catchment (eg land use, urban areas) that might influence current channel processes (Sear 1994). Used to identify styles and rates of planform change, provide evidence of planform modification. Used to define channel characteristics (meandering, braided etc.) for comparison with other studies or with reaches within the catchment.
Hydrological records, time series and records of floods and droughts	Review existing information to highlight dates of geomorphologically significant events that are required as boundary conditions for the interpretation of channel form and adjustment. For example, if the survey has been conducted following a rare, high magnitude flood then much of the geomorphology may reflect this event. Equally understanding channel planform or cross-section changes require prior understanding of hydrological events.
Contemporary and historic flood extents	Where available, these highlight the active floodplain. This is to include the extents of the flood risk zones available form the Environment Agency – to help identify where restoration options may be constrained by flood risk.
Records of channel management and maintenance	Used to build database / GIS of channel modification. Essential to understand when, where and what type of modification in order to be able to interpret field morphology.
Existing modelling study outputs	Where appropriate – for example, sediment models, catchment sediment modelling (eg PSYCHIC), and hydrological models. The review of these is used to understand the characteristics and behaviour of the drivers of river channel morphology and adjustment.

Table continued…

Data sources that are used within Geomorphological Assessment desk study	Information Base
Consultations with other EA functions (eg Fisheries, Recreation and Biodiversity, Water Resources, and other relevant organisations	Necessary as part of he wider understanding of the river system. Short structured interviews are the most efficient format after information review.
Catchment surveys of potentially destabilising phenomena	Where these exist.
Flood defences (National Flood and Coastal Defence Database) NFCDD	Used to build database / GIS of channel modification. Essential to understand when, where and what type of modification in order to be able to interpret field morphology.

Field studies

Field studies should be based on reach-based categorisation (Table L) and attribution and, where appropriate, topographic mapping of features of the channel, riparian area and floodplain environment. The field data collection is both an inventory and quantification of features and character and a geomorphological assessment of evidence of process and change. The approach to data capture should be proposed by the consultant, but should recognise the output requirements and their formats.

Table L Field studies and mapping and reach based summary information

Parameter	Scale of data collection (Continuously Mapped (CM) Reach Summary Data (RSM))
Reach start and end points	RSM + CM
Channel type (as per WFD 49 classes) – see Appendix 12	CSM
Morphology and flow conditions	
Cross sectional morphology	RSM
Sediment	
Source (diffuse and point based, ingress points)	CM
Storage (bars, berms, spreads)	CM
Erosion: process, cause, quantification severity	CM + RSM
Boundary conditions	
Bed material and condition	RSM
Bank material, form and condition	RSM
Bank protection	CM
Flood control features (embankments etc)	RSM
River continuity	

Table continued…

Parameter	Scale of data collection (Continuously Mapped (CM) Reach Summary Data (RSM))
Water level controls (sluices, weirs etc)	CM
Hydraulic influences (bridges, woody debris etc) Extent of artificial impoundment	CM
Floodplain connectivity	CM
Aggradation and degradation evidence	RSM
Evidence of process acceleration	RSM
Evidence of modifications (including restoration / rehabilitation actions)	CM
Photographic record of reaches, specific features and influences	RSM
Riparian	
Riparian vegetation characterisation	RSM

A common GIS / database model should be used for the reach-based data to allow the data to be effectively linked and queried on the reach. For field-based, topographically represented spatial data, a common structure and notation should be adopted, based on the limited features typically recorded. The requirements for capture may vary with circumstance and may be point, line or area based. These spatial layers typically include catchment-level mapping as well and bank and channel features. Examples of relevant data are given below:

Channel

- Erosion extents, type and severity;
- Embankments;
- Bank protection by type, material and face;
- Sediment entry points, by type and dominant grade; and
- Structures and modifications (eg impoundments) by type and influence.

Catchment

- Bare ground / erosional scars; and
- Soil erosion risk etc.

Geomorphic reaches should be identified wherever possible prior to field work. Various criteria may be used, including those in the Water Framework Directive hydromorphological channel typology (WFD49), and the sediment “cell” principle of net sediment storage, supply or transfer. Relevant data include existing mapped/GIS and Remote Sensed data, modelling (eg SIAM-UK/ISIS-Sediment-) where this already exists, and air-photos/historic maps. If such reach definition is not possible prior to survey, then it can be undertaken as part of field data collection.

Reaches can be defined on the basis of:

- Change in WFD-49 River Type (eg Cascade, Step Pool, pool-riffle etc).
- Changes in channel width:depth ratio (major changes defined as >20% difference).
- Change in channel planform (straight, sinuous, meandering, braided, anastomosed).
- Change in sediment storage (>20% change).
- Change in dominant substrate type.

- Change in dominant erosion process and/or major change (>20%) in erosion length.
- Change in field evidence of vertical reach behaviour (aggrading/degrading/stable).
- Change in modification (eg presence of bank protection, structures etc).

These factors should be combined to create specific geomorphic reach types throughout the river. Reaches should be uniquely referenced and associated with the tables of attributes. The specific GIS data model adopted should be justified and recorded within the report.

Where specific features are spatially mapped (eg point source sediment inputs, erosion, water level controls etc) these should be mapped and provided as categorised GIS data layers.

Data Analysis Phase

Describe and map key geomorphological features/processes

A series of maps should be generated of the key geomorphological features and processes. These may be reach-based generalisations or spatially explicit depending on the presentation requirements.

The mapped outputs will help to produce and describe the conceptual model and should include:

- Geomorphic reaches;
- Sediment (sources, storage and transfer);
- Erosion;
- WFD-49 morphological reach types (if used);
- Substrate and flow types (including impounded reaches etc);
- Potentially destabilising phenomena (catchment scale);
- Modifications & structures; and
- Flood risk zones (as defined by EA flood risk datasets).

The precise approach to mapping is not prescribed as the complexity of the information may allow multiple spatial layers to be represented within a single map set.

Develop conceptual model of the evolution of channel/valley floor

The best available conceptual model of channel evolution should be constructed based on:

- existing scientific and unpublished literature for the specific river / catchment or similar river/catchment types;
- historical trend analysis – in particular morphological change;
- field evidence of past channel type/behaviour; and
- geomorphic theory.

The purpose of the conceptual model is to identify those processes, forms and habitats that are the result of past geomorphic action and those that are currently active or potentially active. The explicit derivation of a conceptual model provides a transparent framework and set of assumptions that can be modified in the future as more information becomes available. The conceptual model should list assumptions, data limitations and should visualise the evolution of the river channel and valley form.

Develop conceptual model of the current sediment system

The best available conceptual model of the current sediment system should be constructed based on:

- existing scientific and unpublished literature for the specific river / catchment or similar river/catchment types;

- historical trend analysis – in particular morphological change;
- field evidence; and
- geomorphic theory.

The purpose of the conceptual model is to identify those sediment transport processes and associated forms and habitats that are the result of current geomorphic activity. The explicit derivation of a conceptual model provides a transparent framework and set of assumptions that can be modified in the future as more information becomes available (additional studies module). The conceptual model should list assumptions, data limitations and should visualise the sediment system as a set of reaches with specified function (sediment storage, sediment supply, sediment transfer). The channel morphological types associated with these reaches should be identified and linked to the functionality of the reaches and / or modification history of each reach.

Categorisation and mapping of modification and habitat quality

Categorisation of channel modification and habitat quality provides a means of identifying reaches that are most likely to represent a desirable geomorphological state for the river, and of identifying reaches in most need of restoration attention. Both categorisations are necessary since some river reaches can have suffered significant modification but nevertheless possess high habitat quality, either due to natural recovery or ecologically sympathetic engineering. In the case of the latter, engineering can modify what is considered characteristic of the river in a complex way (eg chalk streams). The two categorisations are combined in a two-way matrix to reflect this (Table M).

Those reaches with the lowest modification (highest naturalness) should be considered as possible '**analogue**' reaches that might be used to design restoration action for other reaches. In the absence of sufficiently natural sites within the river catchment, the RHS national dataset may be analysed to search for suitable analogue sites on similar rivers. The RHS sites chosen should have similar Principal Component Analysis scores to the sites on the study river, but low Habitat Modification Scores. The relevance of geomorphological features of predominantly unmodified reaches to other reaches must take account of natural longitudinal geomorphological changes inherent in most catchments – the characteristics of most analogue reaches are likely to be reach type-specific.

Table L indicates the categories that should be used and how they might be interpreted in broad terms. Although this task is reach-based, it should broadly reflect the process of assigning modification and habitat quality scores to RHS sites, which will be used for quantifying current and future physical condition of the SSSI. Reaches should be classified for modification on the basis of the field- and desk-based data available. The basis for the categorisation (which criteria were used and how) should be described.

The term 'restoration' is used in its widest sense, ranging from assisted natural recovery to major re-engineering works, and from fundamental restoration or river and floodplain form to less ambitious rehabilitation where immovable constraints associated with eg flood risk to people and infrastructure exist.

Table M Two-way matrix of channel modification and physical habitat quality, including possible interpretations

			Modification		
Physical habitat quality	**Unmodified**	**Predom. unmodified**	**Partially unmodified**	**Significantly modified**	**Severely modified**
Very high	Analogue site	Possible analogue site if nothing better	May be a result of natural recovery. If not, consider whether habitat quality is characteristic. If so, restoration may not be necessary.	May be a result of natural recovery. If not, consider whether habitat quality is characteristic. If so, restoration may not be necessary.	Unlikely scenario unless a result of extensive natural recovery.
Reasonably high	Possible analogue site if nothing better	Consider whether habitat quality is characteristic. If so, restoration may not be necessary.	May be a result of natural recovery. If not, consider whether habitat quality is characteristic. If so, restoration may not be necessary.	May be a result of natural recovery. If not, consider whether habitat quality is characteristic. If so, restoration may not be necessary.	Unlikely scenario unless a result of extensive natural recovery.
Intermediate	Investigate whether habitat quality is really natural	Consider if habitat quality is truly natural. If not, restoration is the focus	Restoration likely to be the focus	Restoration is the focus	Restoration is the focus
Low	Unlikely scenario	Unlikely scenario	Unlikely scenario	Restoration is the focus	Restoration is the focus
Very low	Unlikely scenario	Unlikely scenario	Unlikely scenario	Restoration is the focus	Restoration is the focus

Ecological appraisal of existing modifications

A broad understanding of the characteristic flora and fauna of the river, and the habitat niches that they occupy, should be developed from available information on the river and an expert knowledge of the relationships between riverine biota and geomorphological features. Generic information is also available in Mainstone (2007). Key aspects of the biological community likely to have been lost or disadvantaged by the physical modifications and resulting loss of habitat quality observed should be identified.

Map and/or tabular representation of the likely ecological consequences of the modifications observed should be made at an appropriate spatial scale.

Specifying management options

Management options should be identified for each reach considering modifications, habitat quality and naturalness, as outlined in Table M. The following issues should be properly considered and explained:

- Precise cause of loss of naturalness (eg planform modification, oversizing of the channel, impoundment, siltation).

- Potential for natural recovery based on conceptual models of channel and floodplain evolution/processes (artefact or active processes).
- Network and catchment-scale controls on reach behaviour (soil erosion source, presence of barrier to sediment supply, river regulation etc).
- Implications of modifications on features/process for characteristic biological communities, with reference to generic rationale for SSSI river restoration. Identification of benefits of different management options to characteristic biological communities.
- Consideration of major constraints on restoration (eg large urban centres, important strategic infrastructure).

The appropriateness of specific classes of management action will vary with the nature of the modifications, the river type and the specific factors that are affecting characteristic biological communities. Selection will be guided by the characteristics of river types under conditions of low anthropogenic impact (Mainstone 2007). Management action can be broadly divided into four categories:

- **Maintain** – reach considered to be consistent with Favourable Condition;
- **Assist natural recovery** – reach requires change of maintenance regime and/or minor works to allow self-healing;
- **Rehabilitate** – reach requires significant modification of form to re-create lost physical habitats and reintroduce semi-natural form and function; and
- **Restore** – reach requires fundamental restoration to re-create a pre-disturbance state.

Mainstone (2007) provides a brief guide to the types of specific measures that might be appropriate for different river types, but consideration of measures should not be restricted in any way. Measures may need to be used in combination; and channel and floodplain based restoration measures may rely on catchment scale interventions and restoration (eg diffuse sediment control, soil erosion measures) to be successful. The sequencing of measures may be critical and if so should be fully explained.

The management options derived from the geomorphological and ecological appraisals will provide the basis for consultations with relevant parties. Note that any detailed design specifications for works that might be necessary would be generated at a later date and do not form part of this contract.

Identifying monitoring sites

Monitoring quantitative change in physical habitat conditions is a key component of river restoration. It is intended that this will be undertaken through periodic RHS assessment at strategic locations. On the basis of the management measures identified, suitable sites for RHS monitoring should be suggested. Locations should be selected on the basis of their ability to reflect overall changes in physical status as a result of proposed restoration measures. Control and active restoration sites should be included, covering all SSSI condition reporting units. Note that this monitoring is to support basic reporting of SSSI condition – other more detailed (research) monitoring may be undertaken, but this is a separate issue and not relevant to this project specification.

Outputs

Standard outputs should be provided in digital and hard copy format.

1) A **technical report** with associated maps will be provided as Word .doc format and .pdf documents covering:

- the conceptual model of natural channel processes and form expected for the natural boundary conditions together with a model of the contemporary sediment system (the latter can be conceptual or numerical);

- the history of modifications within the river / catchment that have or are expected to have influenced the natural processes of sediment transfer and the resulting morphology of the river channel and floodplain;
- a description of the expected form and adjustment styles typical of the study river;
- a description of the extent and type of modification of each reach and how this modification has altered the channel relative to the expected natural channel morphology and habitats;
- an ecological interpretation of how these changes are likely to have affected the biological communities characteristic of the river channel and associated habitats; and
- reach-based identification of the best management options available for restoring the river to a physical condition consistent with Favourable Condition, and summary of ecological benefits to characteristic biological communities.

2) A **report summary** and **MS Powerpoint presentation** should be provided to support the consultation process. Allowance should be made for generating artwork to depict the vision for selected parts of the river post-restoration, comparing this with its existing state.
3) A **GIS-linked Database** of all field and archival data collection should be provided, including all **digital photographs** with appropriate georeferencing.

Detailed guidance on GIS and database outputs
The method and IT systems used to generate all outputs should be documented in the technical report or associated annexes.

General data issues

All spatial data generated as part of the project should be provided in GIS format. The data supply should be documented, to include the versions of software used and the base layers used in the mapping.

Data on parameters developed from the desk studies (eg catchment sediment sources, diffuse sediment sources, past modifications) should be treated in the same way as the field surveys and provided as part of the GIS outputs.

GIS data should conform to standards for GIS data capture, in having no digitising errors (dangles, overshoots and bowties etc). A spatial resolution is not specified within this document but data capture should be at such resolution to provide sufficient vertices to follow the natural form of the line at 1:10,000 scale. Where data are captured to OS MasterMap and the feature represents a feature within the base mapping, the digitisation should be snapped to the feature on the basemap.

All spatial data layers should have a spatial metadata record within the database that conforms to the standards adopted by Natural England.

Maps

Mapped output will be at sufficient scale to represent the features. Typically this will be at 1:5,000 or greater scale for reach-specific presentation. Where appropriate, overview maps at smaller scales should be provided. Catchment-scale mapping should be used to help characterise the river system. Mapped outputs should be generated from the GIS and also created as .pdf files at a suitable resolution for printing.

Photographs

Where photographs are produced within the field surveys they should be referenced to the reach number and to their grid coordinates. Photographic attributes should include the date, compass direction, reach number and direction of flow (‘us’ or ‘ds’). A GIS point file should be provided that locates the photographs suitable for use within MapInfo, to provide hotlink capabilities.

Natural England works for people, places and nature to conserve and enhance biodiversity, landscapes and wildlife in rural, urban, coastal and marine areas.

www.naturalengland.org.uk