Environment Agency

enhancing... improving... cleaning... restoring...
changing... tackling... protecting... reducing...
create a better place... influencing... inspiring...
advising... managing... adapting...

Geomorphological Monitoring Guidelines for River Restoration Schemes

Final Report

February 2007

We are The Environment Agency. It's our job to look after your environment and make it **a better place** - for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

Published by:

Environment Agency
Rio House
Waterside Drive, Aztec West
Almondsbury, Bristol BS32 4UD
Tel: 0870 8506506
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Document History Record

Client: Environment Agency (Thames Region)
Project: Geomorphological Monitoring Guidelines Job No: B0435600

Title: Geomorphological Monitoring Guidelines for River Restoration Schemes

	Purpose of Issue	Prepared by	Checked by	Approved by
REVISION A01		NAME Kevin Skinner and Sally Kelday	NAME Kevin Skinner	NAME Andrew Brookes
DATE		SIGNATURE	SIGNATURE	SIGNATURE

	Purpose of Issue	Prepared by	Checked by	Approved by
REVISION		NAME	NAME	NAME
DATE		SIGNATURE	SIGNATURE	SIGNATURE

Environment Agency Client: **Thames Region**

Environment Agency Project Manager: **Judy England**

Consultants: **Jacobs**

Executive Summary

Monitoring is a key component of river restoration protocol. It enables an assessment of the success and failure of a scheme in terms of its vision, initial design objectives, specific success criteria and informs future post-project appraisal. To date monitoring procedure in river restoration is probably one of the least developed aspects of river restoration.

This report aims to provide some basic geomorphological guidelines for monitoring river restoration schemes. This report introduces key aspects of river restoration, monitoring and geomorphology before describing critical parameters that influence channel adjustment in a restored reach. These parameters need to be considered when formulating a monitoring programme so that monitoring focuses on areas where there is a geomorphological risk to the project or where key successes are anticipated. The report examines the main geomorphological variables that can be monitored in a restoration scheme before reviewing the most suitable techniques that can be used to measure them.

The report solely concentrates on geomorphological monitoring of river restoration schemes and does not detail any ecological or engineering guidance. The report is aimed at Environment Agency staff who are involved in restoration projects and practitioners who do likewise. A basic level of understanding in the principles of fluvial geomorphology is assumed.

Contents

Glossary

Acronyms	
PPA	Post-Project Appraisal
WFD	Water Framework Directive
SSSI	Special Site of Scientific Interest
Ramsar site	Wetland site protected under Ramsar convention of 1971

Glossary	
Adjustment	Alteration of the channel width, depth, slope or mean flow velocity through time as the stream evolves towards a condition of dynamic equilibrium.
Aggradation	Build up of sediment at a particular location often associated with processes of channel incision and widening.
Aeolian deposition	Wind blown sediment that is deposited in a river.
Buffer Strip	A vegetated strip of land adjacent to the top of the river bank. It can be used as a barrier to sediment movement into channels as well as protection to wind-born sediment inputs.
Channel Straightening	Engineered shortening of the length of a stream/ river artificially by removing meander bends. Often undertaken in historical times in conjunction with relocating a channel to the edge of the valley floor to improve utility of the land for farming or development.
Deposition:	Laying down of part, or all, of the sediment load of a stream on the bed, banks or floodplain. Mostly occurs towards the end of a high flow event. Forms various sediment features such as bars, berms and floodplain deposits.
Erosion:	Removal of sediment or bedrock from the bed or banks of a channel by flowing water. Mostly occurs during high flows and flood events. Forms various river features such as scour holes, cut banks and river cliffs.
FCFA method	Hydraulic model used to examine conveyance.
GeoRHS	GeoRHS is a recently developed method for collecting standardised and detailed information on the geomorphology of a 500m reach of river and adjacent floodplain. It is the geomorphological and floodplain component of the RHS.
Incision / Degradation:	Lowering of the elevation of a channel bed in a reach through time due to adjustment of the long profile by erosion.
Knickpoint	An abrupt change of slope in the bed of a river caused by instability within the system. It is usually marked by waterfalls or rapids and can migrate upstream until the channel has re-graded.
Monitoring Programme	A plan of intended procedure for the collection of data after the installation of a restoration project that can be used to assess the success of the project in a later Post-Project Appraisal.
Point bar:	Sediment feature formed by deposition at the inside of a meander bend.

Pool:	Area of deep water formed by local scour of bed at the outside of a meander bend or where the channel width is constricted (e.g. at a bridge).
Riffle:	Natural accumulation of course sediment (gravel or cobbles) in the bed of a channel to form an area of steep, shallow, highly turbulent flow. Typically found between meander bends.
Riparian Corridor:	Strip of land surrounding a stream channel that is directly affected by flow and sediment processes in the stream/ river.
Sedimentation:	Build up of sediment over time at a location due to supply that exceeds local transport capacity.
River Habitat Survey (RHS)	A standardised method for recording physical habitat and features in a river over 500m reaches.
Sediment Mat	Surface, such as a piece of astroturf, which is pegged to the floodplain at defined intervals to measure floodplain deposition.
Sinuosity:	Measure of channel planform when viewed from above. Defined by the ratio of channel length to straight line valley length. A straight line has a sinuosity of 1. A sinuous channel has a sinuosity between 1 and 1.3. A meandering channel has a sinuosity greater than 1.3.
Terrace:	Old bed level of a river located on the floodplain and formed before the channel incised.
Widening:	Increase in channel width through time at a site due to retreat of one or both banks, as part of adjustment of a channel through erosion.

1.0 Aim and Objectives

The aim of this report is to develop general guidance documentation for geomorphological monitoring of river restoration schemes. It is intended to be used by Environment Agency staff, or practitioners, who are involved in undertaking restoration projects. It is presumed that the end user has a basic understanding of fluvial geomorphology. It does not offer a 'cook' book approach to monitoring. For example, it does not provide the end user with a selection method for choosing particular techniques for use in different schemes. Instead, the report offers the end users sufficient information to make informed decisions on geomorphological monitoring.

The report outlines the main parameters that influence channel adjustment and how they need to be considered in the development of a restoration monitoring programme. Adjustment of the channel form could be a positive or negative outcome for a scheme but depends primarily upon the initial objectives that were defined. The report also outlines key geomorphological variables that can be measured and details key techniques that can be used to undertake this. The issues regarding the appropriate choice of techniques for use in monitoring different schemes is being considered on a national level and was the subject of a workshop in December 2006 hosted by the River Restoration Centre and sponsored by Environment Agency, Scottish Environment Protection Agency and Scottish Natural Heritage. This is currently being developed further and will be discussed at the River Restoration Centres annual conference in April 2007 in Chester.

The main objectives of the report are thus to:-

- introduce basic monitoring concepts;
- provide a general description of fluvial geomorphology;
- describe key parameters that might affect adjustment of a channel in a newly restored reach and discuss risks and uncertainties associated with these parameters;
- describe key parameters that can be measured when undertaking geomorphological monitoring;
- summarise commonly used geomorphological techniques suitable for monitoring.

These various objectives will be detailed in the following sections of the report.

2.0 Background to River Restoration and Monitoring

River restoration is used here as an umbrella term to describe river projects that seek to improve some aspect of the form and/or functioning of a river system. This incorporates a range from the more traditionally defined restoration schemes, which involve cutting a new channel form, to small scale in-stream enhancements. These projects could also include some form of floodplain restoration. The number of river restoration schemes undertaken in the UK has rapidly increased over the last 10 years (RRC, pers.com.). However, there remains no standardised approach despite the key criteria for successful river restoration projects being widely accepted. A restoration protocol is detailed below that highlights an idealised approach to undertaking such schemes (Figure 1).

All nine components of this restoration protocol are key aspects that need to be considered when undertaking a river restoration project from the initial design concepts through to installation, monitoring and Post-Project Appraisal (PPA). The first part of the procedure is the development of the restoration concept. This should take place once a potential location for a river restoration scheme is determined. Frequently, the location of a restoration project arises from an available opportunity rather than the preferred option, which is a co-ordinated catchment scale assessment. However, this is now slowly changing. The concepts developed through this scoping phase should be investigated further through the collection of baseline data. This information can be used to inform a preferred option. At this stage, it is important to establish key objectives for a scheme. For any particular scheme there are often multiple, diverse objectives such as improving the recreation value of an area (measured through public participation surveys) through to improving habitat value (commonly measured using geomorphological diversity or key ecological parameters). It is critical that these objectives are measurable, including the definition of targets and specific success criteria, so that monitoring programmes can be related back to them and ultimately the success of a scheme can be assessed in a post-project appraisal. The final part of the pre-installation phase of a restoration project should be detailed design work. This will provide drawings that are detailed enough for a contractor to cost the project. At this point, the original objectives should be re-assessed and amended accordingly as restoration is an iterative process. The scheme installation is a key part of the procedure and it is very beneficial for a ‘clerk of works’ or technical supervisor be present throughout the installation programme (or at least for part of the works). This is necessary so that the restoration concept/ vision is maintained throughout the course of the installation of the project.

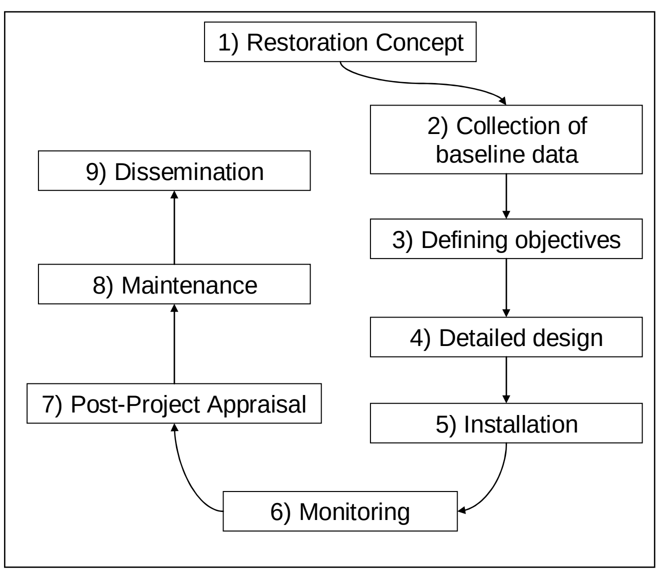


Figure 2: Idealised river restoration protocol (adapted from Skinner and Bruce-Burgess, 2005)

Of key importance for successful restoration projects and the development of the field in general, are the post-installation phases of the restoration protocol, namely monitoring post-project appraisals, maintenance and dissemination. These latter stages of the restoration protocol are less well developed. In many cases they are not as well resourced, partly due to the fact that restoration is frequently an opportunistic process (Skinner and Bruce-Burgess, 2005) and thus funds are often limited.

Monitoring is an important part of the restoration protocol. The main benefits for undertaking monitoring have been detailed in many articles previously (England et al., submitted; Kondolf and Micheli, 1995; Skinner and Bruce-Burgess, 2005; Skinner et al., in press) but are summarised below:-

- to provide a means of obtaining information and/or data on a scheme that can be used to evaluate its success in meeting initial objectives, targets and success criterial;
- to provide a means to be able to assess the changes in a scheme over time;
- to provide further evidence on the benefits of restoration schemes in achieving wider environmental objectives;
- to ensure legislative compliance

The broad aims of monitoring are similar for whatever aspect of a scheme is being assessed, whether it is looking at the general ecological recovery, specific fisheries aims or geomorphological changes to baseline conditions. The need for monitoring of such schemes is increasingly important as a consequence of the Water Framework Directive. This is an important piece of legislation that is likely to have significant effects on how rivers are managed in all member states. Key to this legislation is the need to achieve good ecological and chemical status in all surface waterbodies. It is also a requirement, to maintain the status once it is achieved. This provides significant potential for restoration projects as the structure of the channel planform is likely to be a significant factor that restricts achievement of good ecological status. If restoration projects are undertaken there is a clear need to then monitor what happens at the site to continue to measure parameters that would be used to determine whether this status is maintained. However, it is unlikely that monitoring will be undertaken on all schemes. It is probable that some form of screening tool will be developed to determine which projects should be monitored and to what degree. This is beyond the remit of this current project.

3.0 Background to Fluvial Geomorphology

Fluvial geomorphology is defined as the study of sediment sources, fluxes and storages within a river channel over short, medium and longer timescales and of the resultant floodplain morphology (Sear and Newson, 1993). To define the baseline conditions that exist at the site, it is necessary to measure a series of key geomorphological parameters. To understand how a restored reach responds to new channel conditions, particularly the flow and sediment regime, it is important to evaluate how geomorphological parameters at a site change through time to determine its success in meeting initial concept/vision, objectives, targets and criteria.

A key requirement for any end user is that they should have a basic level of understanding of fluvial geomorphology to make an informed decision about the most appropriate techniques and parameters to measure. The recently developed guidebook on applied fluvial geomorphology published by DEFRA (1993) details the experience that is necessary for making informed decisions on geomorphology (See Table 1 for adapted version). It is recommended that anyone working on determining levels of monitoring associated with geomorphology guidelines have the basic level (Level 1) of experience detailed in this table.

Table 1: Geomorphological experience

Level	Experience of Consultant	Expected Capabilities
4	Specialist fluvial geomorphologist (PhD) with extensive field experience and track record of working with river management agencies	Able to provide science based but practical solutions to most river management issues, clearly and in terms understandable to non-specialists. Could be used on more complex projects and as experts at Public Inquiries.
3	Specialist fluvial geomorphologist (PhD) with no, or limited, field experience of working with river management agencies	Sound on principles of fluvial geomorphology, but will have a steep learning curve on practical issues of river management. Advice on complex issues would be sound, and could be used in a supporting role at a Public Inquiry.
2	First degree in Geography/Environmental Science with Masters training in fluvial geomorphology. Limited field experience and no/limited experience in working with river management agencies	Will understand more complex issues and should be able to identify potential causes of most problems. Limited experience of providing solutions. Best working alongside experienced practitioners.
1	Trained non-specialist with field experience. Must have been on specialist workshops in geomorphology or undertaken e-learning courses in the subject.	Can identify potential problems and suggest solutions in straightforward cases. Able to make reliable decisions on when further expert advice is required.

4.0 Parameters that affect channel adjustment

4.1 Introduction

To meet the aim of developing guidance on geomorphological monitoring of river restoration projects it is necessary to consider what parameters influence the success or failure of a restoration scheme. Primarily, this involves understanding what parameters influence channel adjustment and taking these into consideration both in the designing of the scheme as well as in the development of a monitoring programme. The most important parameters for consideration in monitoring river restoration schemes are outlined in Table 3 and detailed in section 4.2. An example case study, on the River Idle, North Nottinghamshire, is illustrated in Appendix 1 to show how these factors can be considered in the design of a monitoring programme.

Table 3: Key parameters that influence channel adjustment

Key Parameter			Description
1	**Geology**		Underlying material
2	**Gradient**		Bed slope
3	**Planform**	Sinuosity (S)	S=channel length/straight line valley length for single thread channels (Knighton, 1998)
		Radius of Curvature	A measure of the relationship between channel form and flow. Describes bend geometry and channel curvature for single thread channels.
		Degree of braiding	B_r=sum of mid channel lengths of all primary channels in reach/mid channel length of widest channel in reach in braided channels (Knighton, 1998)
4	**Sediment Load**		Material transported through the fluvial system
5	**Scale**		The size of the river restoration scheme
6	**Land use**	Zone 1	0-2 times the channel width
		Zone 2	2-10 times the channel width
7	**Bank protection**		Artificial materials used to protect the channel banks from erosion
8	**Restoration type**		Separated to in-stream work, work that directly affects the channel form and floodplain restoration

4.2 Parameters affecting channel adjustment

This section provides a detailed discussion of the identified parameters that affect channel adjustment in a newly restored reach. These parameters directly affect the potential for geomorphological change and should directly influence what is included in a monitoring programme. It is important to note at the outset that while it is useful to define and describe these distinct parameters the interaction between them is a crucial part of the geomorphological process (see Appendix 1 for case study).

4.2.1 Geology

Background

Geology describes both the underlying geological rock unit and more recent superficial deposits (from the present time to 2 million years ago). In the UK glacial/ peri-glacial and fluvial processes lead to the deposition of superficial deposits that are generally discontinuous and rest in patches on the older underlying bedrock. Geology comprises the underlying bed and bank material of a river and it is one of the main controlling parameters in a fluvial system as it can either act as a constraint to channel adjustment, or alternatively, enable adjustment to readily occur.

For the purpose of monitoring river restoration schemes the geology in the restored section itself, rather than upstream or downstream, is generally the primary consideration. However, the geology upstream of the restored reach is also an important factor in determining the sediment supply to the reach. Table 4 details some common, basic geological types and the likely potential for geomorphological adjustment within these categories.

Table 4: Predominant Channel Material

Type	Description	Comments
Solid Bedrock (e.g. limestone)	Solid Rock.	A constraint to channel adjustment
Clay (e.g. London Clay)	Cohesive material.	Minimal potential for channel adjustment
Gravel/Cobble (e.g. Glacial Till)	Loose material. Ranging in size from cobbles to fine gravel. Often associated with fluvial and glacial deposits.	Potential for channel adjustment
Sand (e.g. Greensand)	Fine material often associated with fluvial and glacial deposits.	High potential for channel adjustment

In most systems channel material will change through the catchment. For instance there is often a gradation downstream from gravel and cobble bed river systems in the headwaters to predominantly clay and silt based systems in the middle and lower reaches (Schumm, 1977). It is also common for channel material to be layered, for example, superficial glacial or fluvial sand deposits are often layered on top of bedrock. This is an important concept to understand within the fluvial system but for the purpose of monitoring geomorphological change the most important consideration is the material forming the bed and bank material within the restored reach.

Assessing the parameter

To produce a monitoring programme there is generally little advantage in undertaking detailed geological classifications of the local area. Within the design phase of the restoration scheme the geology of the underlying the river should have been determined. Usually, this should have included digging trial pits or boreholes. This information can be used to inform the monitoring programme and determine what the likely affects could be on channel adjustment.

In the absence of more detailed information the British Geological Survey's GeoIndex http://www.bgs.ac.uk/geoindex/index.htm is a useful source of information. It provides a broad classification of geology for onshore Great Britain. While it is not detailed enough to provide accurate data within the restored river reaches it enables the broad bedrock and superficial deposits to be determined.

4.2.2 Gradient

Background

Gradient is a very important parameter in determining the types of features that are likely to be maintained within a river system as well the likely energy that exists within a particular reach. If the slope is greater than 3-5% (e.g. upland systems) step-pool features are common (Knighton, 1998). Steps are typically formed in boulder/cobbles based systems. Their development is dependent on the local supply of sediment and transport conditions. In channels with gentler slopes, riffle-pool sequences are typical. Riffles are typical in mixed bed channels with a gradient between 0.005 and 0.2 (Brookes and Sear, 1996). In the UK, the spacing of riffles generally varies between 3 and 10 channel widths (Brookes, 1988).

Gradient is a major driver of geomorphological change - the relationship is simple in that the higher the gradient the more energy the system is likely to have. Along with discharge, gradient is the other main parameter that determines stream power. Stream power (Ω) (per unit length of channel Wm^{-1}) is often defined as:

$$\Omega = \gamma Qs$$

where γ is the specific weight of water ($9810Nm^{-3}$), Q is the discharge (m^3s^{-1}) and s is the energy slope (mm^{-1}), often approximated by channel bed slope or bankfull discharge water surface slope.

Empirical studies have shown a strong relationship between stream power and geomorphological adjustment. For a specific dataset of channels in the UK Brookes (1990) demonstrated that above the threshold of 35 W m^{-2} channel adjustment, in the form of erosion, is common while below 35 W m^{-2} channels tend to be more stable. The work also suggested that below a stream power of 10 Wm^{-2} there is a tendency for deposition. This work is intended as a guide only and users must be cautious in extending it to other environments. For the purpose of these guidelines gradient is used as a surrogate for stream power as it is easier to measure.

Gradient is one of the main ways in which a channel responds to changing conditions and river schemes often directly affect channel gradient by altering a river's planform. For instance, straightening a channel will increase the channel gradient. This increase in slope could initiate channel incision through the development and progression of knickpoints. Knickpoints are one of the most common ways in which over steepened channel gradients are reduced (Brookes, 1988). These steps in the bed of the channel gradually move upstream causing lowering of the bed level. This will continue until the process of re-grading enables a dynamic equilibrium to be reached. These represent a form of instability within the river system. The incision process can lead to the redistribution of large quantities of material through bed incision, erosion and deposition. The manner in which a channel behaves after its gradient has been altered depends on the composition of the bed and bank material. The nature of the sediment load carried through the system is also important.

Alternatively, a decrease in gradient can lead to a reduction in energy. This can be achieved through increasing the sinuosity which can occur if a river channel is restored. Valley slope, which in itself reflects past sediment loads, and other controls such as geology also has a major influence the potential for gradient adjustment (Knighton, 1998).

Assessing the parameter

Channel gradient is often measured through calculating the bankfull discharge water surface slope over a specific distance. Alternatively, the change in bed gradient can be measured but it is important that the difference in elevation is calculated between similar fixed bed features (such as riffles, pools or the cross over points between bends). Care must be taken when locating points to measure on the ground. It is important that error is not introduced through measuring the difference between levels of different features. For example a riffle will have a higher bed level than a pool. To represent the gradient, bed level must be measured from feature to feature (i.e. riffle to riffle or pool to pool). Ideally, the gradient should be measured over a long enough distance to ensure that local variations in height in different features be averaged out over the full length measured.

4.2.3 Planform

Background

Rivers have traditionally been classified as braided, meandering or straight (Leopold and Wolman, 1957). In the 1980's Schumm identified 14 patterns according to the sediment load carried by a channel (Schumm, 1981, 1985). As such, while the Leopold and Wolman classification remains useful as a broad approach (with the additional category of anastomosing channels) a wider range of channel types is now recognised. A more recent approach is to examine the channel pattern as a continuum separated into two main categories of single channel and multi channel forms.

Single thread channels

The planform of single thread channels has been studied widely and there are numerous techniques for classifying and describing it. Measuring a combination of sinuosity and radius of curvature can suitably define the channel planform. Sinuosity is the ratio of the channel length to the valley length (Knighton, 1998) and provides an average value for the whole reach measured. The radius of curvature-width relationship (r_c/w) gives information for individual meander bends. Adjustments to the radius of curvature can alter flow pattern and associated erosion and deposition. Studies suggest that a channel can control the rate of migration and the pattern of erosion and deposition in meander bends through changing the channel curvature (Knighton, 1998). Typical radius of curvature values vary between river types. Wide, shallow channels are generally less sinuous than narrow, deep channels. If a threshold is reached such that the channel planform cannot be maintained (due to flow and bank material conditions) a cut-off can develop. Cut-offs form where the channel gradient has reduced to such an extent that a channel's energy has been reduced to a threshold where it can no longer transport the sediment load supplied from upstream (Knighton, 1998). If a channel has a high sinuosity and a high radius of curvature, there is a higher potential for geomorphological adjustment.

Multiple thread channels

Braided rivers are multi-channel systems separated by bars or islands. Braided channels can form through erosion or deposition and it is generally accepted that they have a relatively high stream power, erodible banks and a high bed load. In the United Kingdom these channel types are limited to upland systems, predominantly in Scotland. The restoration of these systems is rare but could be undertaken if restoration of former (ie palaeohydrological) features were wanted. When compared to single thread channels the geometric properties of braided systems are not as well understood. One of the reasons for this is that degree of braiding does not necessarily remain constant even in the short term - it generally decreases in high flows as bars are drowned out (Knighton, 1998). Restoration of braided channels to date has been very rare in the UK.

Anastomosed rivers also consist of multiple channels but are separated by stable islands such that in high flow events the channels remain distinct. As such the processes operating in adjacent channels are independent of one another. This contrasts to the functioning of braided rivers where there is interaction between channels - at bankfull a braided river consists of one channel. Planform in all types of system is closely linked to gradient and planform change is one of the main ways in which a channel responds to a change in gradient (see section 4.2.2).

Assessing the parameter

Single thread channels

Sinuosity is used to provide a distinction for the secondary classification for single thread channels (Knighton, 1998).

Sinuosity for a single thread channel is defined by Schumm (1977) as:-

$$\text{Sinuosity} = \text{channel length} / \text{straight line valley length}$$

If sinuosity is greater than 1.5 channels are classified as meandering. A channel can be straight, gently meandering through to tortuous. Regulatory of meanders is sometimes used as an additional classification.

Radius of curvature is calculated by measuring the radius of an individual meander bend and dividing by channel width. Hooke (1975) suggests that a radius of curvature of 2 to 3 represents a stable meander geometry. A meandering channel form is not an indicator of instability it is in fact a valid equilibrium form (Knighton, 1998). Even though meanders migrate a channel can maintain a consistent width.

Multiple thread channels

To monitor braided channels a useful measure of degree of braiding is given by Friend and Sinha (1993):

$$B_r = \frac{\text{sum of mid channel lengths of all primary channels in reach}}{\text{mid channel length of widest channel in reach}}$$

Using this approach B_r ranges from 1 (for a single thread channel) to more than 5 (for an intensively braided channel). Friend and Sinha (1993) suggest that values above 3.5 are rarely experienced in reality.

The most suitable approach to describe and assess potential for geomorphological change in an anastomosing river depends on the nature of restoration. In particular, it depends on whether a scheme is concentrated on an individual channel or if it affects several channels within an anastomosing system. If a scheme only affects one distinct channel it may be most appropriate to use the techniques adopted for single thread channels (i.e. sinuosity and radius of curvature). If itl is likely to impact more than one channel it may be more appropriate to consider the degree of braiding even though the geomorphological processes operating in braided and anastomosing rivers are clearly different.

Restoration of multi channel systems is very rare in the UK. As such there is a much higher associated risk and uncertainty when compared to restoration of a single thread channel. This should be reflected in the monitoring programme of a multi-channel restoration scheme.

4.2.4 Sediment

Background

Material that is transported through a fluvial system will have an impact on the success of a restoration project. The extent to which this parameter is important is dependent on the initial objectives, targets and specified success criteria defined in the scheme. For instance, if fisheries are a driving force in restoration, clean gravels for salmonid spawning is a likely desired outcome. It is important to consider whether there is a source of gravels upstream and whether any material imported as part of a scheme is likely to either be washed downstream or covered in fine material.

Material that is carried by rivers can be separated into: -

- The dissolved load (material transported in solution)
- The suspended load (fine particles <0.062mm). Particles travel at nearly the same speed as the flow and only settle out in reduced velocities.
- The bed load (larger material most commonly derived from the channel bed)

(Knighton, 1998)

Dissolved load has little influence on the geomorphological functioning of a fluvial system and is more of a water quality issue. Consequently, it has not been examined further in this report.

Assessing the parameter

Turbidity has been found to provide the best estimate of suspended sediment concentration (Lewis, 1996). Techniques that are available to measure bed load are varied. Sediment traps allow for repeat measurements and for comparisons to be made between sites. Sediment tracing is another technique that can be employed. Individual particles can be coloured (and sometimes numbered) and particle movement downstream tracked through field visits. An alternative means for monitoring is to measure distinct accumulations of sediment. For instance the location of riffle features can be monitored as part of a topographic survey.

To understand the potential geomorphological impact of material that is being transported through a system it is useful to classify the average particles by size. The Wentworth scale is the standard classification technique for sediment by particle size. It is given in Table 5. Note that the size of material transported as suspended sediment depends on stream power (the more energy in a channel the more potential to transport larger particles).

Table 5: The Wentworth sediment classification

Types	Wentworth (mm)
Boulder	More than 256
Cobble	256-64
Pebble	64-4
Granule	4-2

Very coarse sand	2-1
Coarse sand	1-0.5
Medium sand	0.5-0.25
Fine sand	0.25-0.125
Very fine sand	0.125-0.0625
Coarse silt	0.0625-0.0312
Medium silt	0.0312-0.0156
Fine silt	0.0156-0.0078
Very fine silt	0.0078-0.0039
Coarse clay	0.0039-0.00195
Medium clay	0.00195-0.00098

4.2.5 Scale

Background

The size of a restoration project influences potential for geomorphological adjustment through channel continuity. For example, in a large scheme there is more potential for change at one point to cause a knock-on effect and cause change at another point within the restored reach. A recent paper by England *et al.* (*submitted*) small scale schemes are determined as those that are lower than 100m in length. Medium size schemes are viewed as those that are between 100m and 500m in length, while large scale schemes are those that are over 500m. Channel length is viewed here to be the main parameter to determine the scale of the scheme. Channel width is also important for schemes but if a restoration project is over 500m long it is deemed to be large regardless of width. Equally, if scheme covers less than 100m in length it can also be viewed as being small regardless of width. It is uncommon for rivers with greater than 15m wide to be restored. Small scale restoration schemes are the most common in the UK. An example would be the re-profiling of one meander bend. Medium-sized schemes and large scale schemes are less common which means that there is more uncertainty associated with this type of work than there is with small scale schemes. Large schemes also have the highest potential for geomorphological change. Monitoring programmes should reflect these factors.

Assessing the parameter

A recent paper by England *et al*. (*submitted*) suggests that the following categories can be delineated with respect to scale:-

- A small restoration scheme is 0 to 100m in length
- A medium-sized restoration scheme is 100 to 500m in length
- A large restoration scheme is 500+m in length

4.2.6 Land use

Background

Land use is a major controlling parameter on the sediment yield that will enter a fluvial system. Different types of land use generate varying amounts of sediment being sourced into neighbouring rivers. (Geology is another key parameter influencing this.) Some of the worst types of land management are those that leave the soil bare, without vegetation cover, during the winter months. For example, a late cropping of maize can generate significant volumes of sediment that can be moved into nearby river systems. This is especially significant on certain types of soils (such as sandy loams) and on higher gradient fields. A significant controlling parameter at this point is the nature of the surrounding riparian margins of a river. If there is a significant buffer strip around the river banks the sediment yield generated in fields could be effectively prevented from entering the river system. In contrast, if a field is ploughed right up to the river bank there is no barrier to sediment movement with the likely result being a large sediment load entering the river system. Land use within urban areas is also a key factor in determining sediment loads. A dense road network could lead to high runoff into neighbouring rivers and a high input of suspended sediment into the river.

Assessing the parameter

For the purpose of assessing how likely channel adjustment is in a restoration scheme with respect to land use, two categories have been devised. The first category is where the predominant land use of concern is within 0 to 2 times the channel width from the edge of the channel. This category describes land that will have an immediate and direct effect on a river. It largely describes presence or absence of a buffer strip. This category gives information on any riparian corridor – the vegetated margins next to the channel bank that can reduce potential for channel adjustment. It can also be used to assess any land use at risk from geomorphological change, for example houses built close to the river that would be at risk from unwanted erosion.

The second category is the land use which lies with 2 to 10 times the channel width from the edge of the channel. This provides information on the wider catchment. As this category has more of an indirect effect on the channel, and is much less likely to be affected by any geomorphological adjustment, it should be given less consideration when determining a monitoring programme. This second land use category is included as it is an important parameter when considering sources of sediment particularly in larger scale restoration schemes.

Land use categories are broadly based on those used in the River Habitat Survey methodology (Table 6). The potential for channel adjustment associated with each of the land uses has been classified as L (low), M (medium) or H (high). These are indicative only and should be considered in the context of individual scheme and site conditions.

Table 6: Typical land use and likely potential for adjustment and sediment input

Land Use	Description	Comments	Potential for Channel Adjustment	Potential for Sediment Input
Woodland	Includes Broadleaf, Mixed and Coniferous woodland.	High habitat value. Woodland is a potentially suitable land use for restoration schemes.	L	L
Scrub, shrubs and herbs	Scrub and woody shrubs.	Low potential of increased sediment input due to increased roughness.	L	L
Plantation/ Orchard	Managed trees planted in lines. This category includes hop fields and vineyards.	Sediment input potentially higher than in natural woodlands due to ground drains.	L	M
Wetland	Bogs, marsh and fens.	River restoration schemes are sometimes associated with wetland and wetland restoration.	L	L
Moorland/ Heath	Typical vegetation types include heather, purple moor-grass and cotton grass.	Low potential of increased sediment input due to increased roughness.	L	L
Open water	Natural or artificial	Can be incorporated into restoration schemes.	L	L
Unimproved grassland	Usually herb rich and includes hay meadows.	This is a typical land use in which river restoration is undertaken.	L	L
Improved grassland	Agricultural grassland which has been re-seeded or artificially fertilised.	Potential for adjustment and sediment input are highly dependent on management. Presence of a riparian zone or poaching of channel banks reduces the likely adjustment and sediment input.	L/M	L/M
Suburban/ Urban	Includes buildings, roads, tracks, railways and landfill sites.	There is an increased likelihood of sediment input due to runoff.	H	M/H
Agricultural	Land on which crops are grown.	Potential for adjustment and sediment input are highly dependent on management. Presence of a riparian zone or poaching of channel banks reduces likely adjustment and sediment input.	M/H	M/H
Parkland and gardens	Includes parks, golf courses, public amenity spaces sports fields and gardens.	This is a typical land use in which river restoration is undertaken.	L	L

4.2.7 Artificial Materials

Background

This is generally related to river bank and bed protection. Precisely how artificial materials affect the success of a restoration project clearly depends on the type of material and the objectives of the scheme. However, for the purpose of geomorphological monitoring of such schemes artificial protection has two opposing influences.

In terms of habitat enhancement and contemporary thinking on *Making space for water* (DEFRA, 2005) the presence of artificial bed or bank protection is a negative impact. Constraining the channel through artificial means conflicts with DEFRA's initiative which aims to "*Make space for water* so that we can manage the adverse human and economic consequences of flooding and coastal erosion while achieving environmental and social benefits in line with wider Government objectives" (DEFRA, 2004). In many instances channel change caused by bank erosion will be a positive result; that is it is a successful result for a particular type of restoration scheme.

Conversely in terms of risk management, bed or bank protection could reduce risk associated with geomorphological change. For instance, an urban development on the bank of a river could potentially be at risk from lateral channel migration or erosion associated with a restoration scheme. Bank protection could reduce this risk.
Use of artificial materials in a restoration scheme needs very careful consideration. In some instances protection may be necessary, however there is a risk that its presence will hinder the success of a scheme (this should be given extra consideration if it is not clear whether the protection is necessary).

Assessing the parameter

The effect of and the need for bed or bank protection is a factor that can only be considered on a case by case basis. Key questions are:-

Is there a history of erosion in the restored reach?

What is the adjacent land use?

What are the scheme objectives?

What is the channel geology?

What is the channel gradient?

What is the channel planform?

Please refer to the sections above for more detailed information on how different types of geology (4.2.1), gradient (4.2.2) and planform (4.2.3) can affect the potential for geomorphological change and therefore the *potential* need for protection. This will be influenced by land use adjacent to a scheme and the objectives, targets and success criteria defined for a particular restoration project.

5.0 Other Considerations

While the parameters described above are critical to the type of geomorphological monitoring required for a river restoration scheme they cannot be considered in isolation. Based on experience a number of other parameters should be considered when developing a monitoring strategy. These are detailed below. This is not an exhaustive list but rather it is intended to highlight some of the more important variables that affect the need, scale and duration of a monitoring programme.

Geomorphological input at the design and implementation phases

Geomorphological input at the design and/or implementation stage of a restoration project would generally risks of unwanted geomorphological change. This would reduce the need for monitoring in particular situations. However, since the science of understanding the long-term effects of restoring rivers is still in its infancy, along with the general unique environment of each river system, some monitoring would be desirable.

Uniqueness of restoration design

As noted above, a classification of what constitutes a unique scheme is beyond the scope of these guidelines. However, a general consideration of the uniqueness of techniques being employed should be made when producing a monitoring programme. An assessment could be made through contacting the River Restoration Centre (RRC) http://www.therrc.co.uk/ who hold a database of restoration and enhancement schemes in the UK. The RRC is a non profit making organisation and is the national information and advisory centre on river restoration. The primary role of the RRC is to disseminate information relating to river restoration and enhancement.

Along with the uniqueness of individual restoration techniques a design needs to be considered in the context of particular river types. This would require an analysis of various river restoration schemes undertaken in the UK and on what river types they were undertaken. This would enable assessment of the effectiveness of particular techniques in different river types to be evaluated.

Particularly sensitive sites downstream of the river restoration scheme

The presence of designated sites (such as RAMSAR sites or SSSIs) downstream of a restoration project will influence the need for, and the comprehensiveness of (in terms of spatial and temporal resolution), a monitoring programme. The reason for designation should be taken into account, for instance if a Fresh Water Pearl Mussels or Depressed River Mussells are a feature of the site the mobilisation of fine sediments into the system as a result of a restoration scheme will be detrimental and monitoring would be essential.

Bankfull flows

It is generally accepted that bankfull flow (i.e. where the in channel flow reaches the top of the banks but does not spill over to the floodplain) is one of the most critical channel forming flows. The occurrence of bankfull flows will influence the results of a monitoring programme and it is often advisable for monitoring surveys to be repeated after these types of events so that any significant change can be evaluated.

Wider catchment land use (hydrology)

Any restored reach is affected by wider scale catchment processes. For example, floods with high return periods could lead to more than expected adjustment within a restored reach. Alternatively, periods of low flow could lead to significant deposition of fine material within a project reach. It is thus always important to understand the context of the restored reach within the wider catchment scale environment.

Soils

It is important to understand the context of soils in the surrounding area and to what risks might exist arising for surrounding soils. This primarily relates to how vulnerable the soil is to erosion. For example, if a restored reach was placed on a highly sandy soil then the risks of adjustment would be considerably higher than of the restored reach was located on a highly cohesive clay soil.

Floodplain connectivity

Floodplain connectivity is often a key aim in larger schemes that involve cutting a new channel. While this report has covered the measurement of fine sediment deposition on a floodplain it has not looked at how to measure the frequency of out of bank flows that flood the floodplain area. This is also an important parameter to measure and can be measured successfully using a variety of flow measurement techniques.

6.0 What to measure?

Once the potential for geomorphological adjustment is understood through an assessment of the above parameters a monitoring programme can be developed. As yet there is no simple way of defining how the combination of parameters becomes significant. There are a number of geomorphological variables that can be measured directly (See Table 7). Amongst the most important are: 1) bank erosion; 2) deposition (channel); 3) deposition (floodplain); 4) sediment transport; 5) gradient; 6) biotope changes. Each of these variables will be detailed below along with potential techniques that could be used to measure them. Detailed outlines of these techniques and their uses are given in Appendix 2.

Table 7: Main variables that can be monitored in a restoration programme

Variable		Description
1	**Bank Erosion**	Removal of sediment or bedrock from the bed or banks of a channel by flowing water.
2	**Deposition Channel**	Laying down of part, or all, of the sediment load of a stream on the bed or banks.
3	**Deposition (floodplain)**	Laying down of part, or all, of the sediment load of a stream on the floodplain.
4	**Sediment Transport**	Sediment movement through the reach
5	**Gradient**	The slope of the channel bed
6	**Biotope changes**	Alterations in habitat

6.1 Bank erosion

6.1.1 Background

Bank erosion has often been viewed as a problem in traditional river management. However, the role that a self-adjusting river has in creating valuable micro-habitats is now widely realised. It is thus important to put bank erosion that is occurring into context. The justification for bank protection should only be necessary if important assets are threatened at a particular location. Restoration projects should be aiming to produce more sustainable river management and thus the need for bank erosion protection measures should be carefully considered and used sparingly. However, there is still a need to monitor how much bank erosion occurs within schemes so that there can be increased certainty in allowing river channels to freely adjust without conflict to other important functions of river systems, such as flood management. Bank erosion rates can be measured in a variety of ways. The techniques that are possible to use are listed in section 6.1.2 and more information on the methods is detailed in Appendix 2.

6.1.2 Techniques to measure the variable

- Ground photography
- Aerial photography
- Channel cross section
- Topographic survey
- Erosion pins
- River reconnaissance survey
- GeoRHS

6.2 Deposition (channel)

6.2.1 Background

Deposition, in the form of bars or berms, is a natural feature of all river systems. The extent to which deposition occurs within a restored reach can be measured by various means. Deposition has also been previously identified as a major cause of failure amongst restoration schemes (Frissell and Nawa, 1992) and thus it is an important parameter to measure. The techniques that are possible to use to measure deposition are listed in section 6.2.2 and more information on the methods are detailed in Appendix 2.

6.2.2 Techniques to measure the variable

- Ground photography
- Aerial photography
- Channel cross section
- Topographic survey
- River reconnaissance survey
- GeoRHS

6.3 Deposition (floodplain)

6.3.1 Background

Deposition of fine sediment on a floodplain is a natural process of any river that still maintains connectivity with its floodplain. Unfortunately, many rivers have been modified to such an extent that this connectivity has been seriously curtailed. In schemes that are seeking to restore some natural connectivity between a river and floodplain the deposition of fine sediment on the floodplain (rather than in-channel) would be a key requirement for successful restoration. The techniques that are possible to use are listed in section 6.3.2 and more information on the methods is detailed in Appendix 2.

6.3.2 Techniques to measure the variable

- Ground photography
- Aerial photography
- Sediment mats

6.4 Sediment transport

6.4.1 Background

Sediment transport is a useful variable to measure as it enables the input and movement of sediment within a restored reach to be estimated. The techniques that are possible to use are listed in section 6.4.2 and more information on the methods is detailed in Appendix 2.

6.4.2 Techniques to measure the variable

- Sediment transport monitoring
- Sediment traps

6.5 Gradient

6.5.1 Background

If the gradient in the restored reach starts to change it could be an indication that instability is starting to occur within a reach through the initiation of channel incision process. The progression of knickpoints through the system could threaten the success of a scheme as processes could lead to the undermining of structures and initiate bank failures. Gradient is thus a critical parameter to measure particularly in larger, higher energy systems. The techniques that are possible to use are listed in section 6.5.2 and more information on the methods is detailed in Appendix 2.

6.5.2 Techniques to measure the variable

- Topographic survey

6.6 Physical habitat measurement

6.6.1 Background

Physical in-stream habitat is, perhaps, one of the most important monitoring parameters to measure within a restoration scheme. An increase in habitat is often a key objective in many restoration schemes and thus a method for measuring this parameter could be a valuable tool. The technique that is most applicable to measuring physical habitat is listed in section 6.5.2 and more information on the method is provided in Appendix 2. In addition, Appendix 4 details a case study on the River Misbourne on how the technique can be used to examine 'before and after' monitoring results.

6.6.2 Techniques to measure the variable

- River Habitat Survey (RHS)

7.0 Further Work

As stated in the introduction this report is a first attempt at the development of a set of guidelines to enable end users to make informed decisions when considering geomorphological monitoring of river restoration schemes. As such it could be taken forward in various forms. These include:-

- Adding further diagrams and photographs to make the document more accessible to a wider audience. However, the development of a monitoring programme would still strongly rely on the judgement of the individuals with ranging skills in geomorphology.
- Develop a matrix/decision tree approach for assessing which techniques can be best used under different scenarios based on professional judgement. Alternatively, a screening approach could be developed which will enable the user to determine which schemes would be in need of monitoring. This would provide more of a standardised approach that would be accessible but it would need to be statistically tested and peer reviewed. There is a risk that this approach could be considered "cook book" but to standardise geomorphological monitoring of river restoration schemes and to improve accessibility to non specialists this may be a good way forward.
- Ultimately, a database of techniques should be developed which includes detailing the success of techniques on different river types. With this in place it would be easier to judge the potential success of the techniques in different river environments.
- Assess the uniqueness of techniques under different conditions. This would provide background information allowing more informed decisions taking into account risks and levels of uncertainty. It could be conducted by analysing the RRC database.

8.0 Conclusions

Monitoring geomorphological changes following implementation of a river restoration scheme is important, but often neglected, part of the river restoration process. The importance of monitoring such schemes is likely to increase in the near future as a result of the Water Framework Directive. It is thus necessary to develop some guidelines that can be used by the various end users who are involved in river restoration projects.

This report has detailed key parameters that need to be considered when developing a geomorphological monitoring programme. It has also examined the most important variables to measure and what techniques currently exist that can be used to monitor these variables. Many applicable techniques already exist but the sophistication of the techniques is developing all the time making some of these now more cost effective and thus can be readily used in a greater number of schemes.

9.0 References

Branson, J., Hill, C., Hornby, D.D., Newson, M., and Sear, D. A. (2005); A refined geomorphological and floodplain component to River Habitat Survey (GeoRHS). R&D Technical Report SC020024/TR, Environment Agency, Bristol.

Brookes, A., 1988, *Channelised rivers: perspectives for environmental management* John Wiley & Sons, Chichester.

Brookes, A., 1990, Restoration and enhancement of engineered river channels: some European experiences, Regulated Rivers: Research and Management, **5**, 45-56.

Brookes, A. and Sear, D.A., 1996, Geomorphological principles for restoring channels, in Brookes, A. and Shields, F.D. Jr. (eds.), *River channel restoration: guiding principles for sustainable projects*, John Wiley and Sons Ltd., Chichester, UK, 75-101.

Bunte, K., Abt, S.R., 2001, Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring, USDA Forest Service, General Technical Report RMRS-GTR-74.

DEFRA, 2003, Guidebook of Applied Fluvial Geomorphology, DEFRA/Environment Agency Flood and Coastal Defence R&D Programme, R&D Technical Report FD1914.

DEFRA, 2004, Making space for water: Developing a new Government strategy for flood and coastal erosion risk management in England. A consultation exercise" *DEFRA publications,* London. Available at: http://www.defra.gov.uk/corporate/consult/waterspace/summary.pdf

DEFRA, 2005, "Making space for water: taking forward a new Government strategy for flood and coastal erosion risk management in England. First response to the autumn 2004 *making space for water* consultation exercise" *DEFRA publications,* London. Available at: http://www.defra.gov.uk/environ/fcd/policy/strategy/1stres.pdf

Downs, P.W. and Thorne, C.R., 1998, Design principles and suitability testing for rehabilitation in a flood defence channel: the River Idle, Nottinghamshire, UK, *Aquatic Conservation: Marine and Freshwater Ecosystems*, **8**, 17-38.

Downward, S.R., 1995, Information from topographic survey, In Gurnell, A.M., and Petts, G.E. (eds.), Changing River Channels, John Wiley and Sons, 303-323.

England, J., Skinner, K.S, and Carter, M., *submitted.*, Monitoring, river restoration and the Water Framework Directive, *Journal of the Charted Institution of Water and Environmental management*.

Environment Agency, 2003, *The State of England's Chalk Rivers.*

Environment Agency, 2003, River habitat survey: Field survey guidance manual.
for runoff-event load estimation" *Water resources research* 32 (7) 2299-2310.

Environment Agency/SEPA/Environment and Heritage Service, River Habitat Survey in Britain and Ireland, Field survey guidance manual- 2003 Version.

Friend, P.F. and Sinha, R., 1993, Braided and meandering parameters, in *Braided rivers. Special publication of the Geological Society of London* 75, 105-111.

Frissell, C.A. and Nawa, R., 1992, Incidences and Causes of Physical Failure of Artificial Habitat Structures in Streams of Western Oregon and Washington. *North American Journal of Fisheries Management,* **12**, 187-197.

Gurnell, A.M., Morrissey, I.P., Boitsidis, A.J., Clifford, N.J., Petts, G.E., Thompson, K. (2006) - Initial Adjustments within a New River Channel: Interactions between Fluvial Processes, Colonising Vegetation and Bank Profile Development. Environmental Management 38, 580-596.

Gurnell, A.M., Boitsidis, A.J., Thomson, K., and Clifford, N.J. (2006) - Seed bank, seed dispersal and vegetation cover: two years of vegetation colonisation along the margins of a newly-created river channel. Journal Of Vegetation Science. 17: 665-674.

Harrelson, C.C., Rawlins, C.L., Potyondy, J.P, 1994, Stream channel reference sites: An illustrated guide to field technique. General Technical report RM-245, Fort Collins, CO: United States Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 61p.

Hooke, R. Le. B., 1975, Distribution of sediment transport and shear stress in a meander bend, *Journal of Geology* 83, 543-566

Kondolf, G.M., Lisle, T.E. and Wolman, G.M., 2003, Bed sediment measurement, in Kondolf, G.M and Piégay, H. (eds.), Tools in fluvial geomorphology, John Wiley and Sons Ltd., Chichester, UK, 347-395.

Kondolf, G.M and Micheli, 1995, Evaluating stream restoration projects, Environmental Management, 19, 1-15.

Knighton, D., 1998, *Fluvial forms and processes: A new perspective* Arnold, London.

Lawler, D.M., Thorne, C.R., Hooke, J.M., 1997, Bank erosion and instability. In Thorne CR, Hey RD, Newson MD (eds). Applied Geomorphology for River Engineering and Management. John Wiley and Sons, Chichester: 137-172.

Leopold, L.B. and Wolman, M.G., 1957, River channel patterns – braided, meandering and straight, *United States Geological Survey Professional Paper* 282B, 39-85.

Lewis, J., 1996, Turbidity-controlled suspended sediment sampling for runoff-event load estimation, *Water Resources Research* 32(7) p2299

Raven, P.J., Fox, P., Everard, M., Holmes, N.T.H. and Dawson, F.H., 1997, River Habitat Survey: A new system for classifying rivers according to their habitat quality, in Boon P.J. and Howell (eds.), D.L., Freshwater quality: defining the indefinable, Scottish Natural Heritage, UK, 215-234.

Rice, S.P. and Church, M., 1996, Sampling fluvial gravels: bootstrapping and the precision of size distribution percentile estimates", Journal of Sedimentary Research, 66, p654-665

River Restoration Centre, 2001, *River Restoration and Chalk Streams,* RRC, Bedford.

Schumm, S.A., 1977, *The Fluvial System*. Wiley, New York,

Schumm, S.A., 1981, Evolution and response to the fluvial system, sedimentologic implications, *Society of Economic Paleontologists and Mineralogists Special Publication* 31, 19-29.

Schumm, S.A., 1985, Patterns of alluvial rivers" *Annual Review of Earth and Planetary Sciences* 13, 5-27.

Skinner, K.S., 1999, Geomorphological Post-Project Appraisal of river rehabilitation schemes in England, Unpublished PhD thesis, University of Nottingham, Nottingham, UK.

Skinner, K.S. and Bruce-Burgess, L., 2005, Strategic and project level river restoration protocols- key components for meeting the requirements of the Water Framework Directive, *Journal of the Charted Institution of Water and Environmental management*, 19, 2, 135-142.

Thorne, C.R. 1998, Stream Reconnaissance handbook, John Wiley and Sons, Chichester, England.

United States Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 61p.

Walker, J., Diamond, M. and Naura, M., 2002, The development of Physical Quality Objectives for rivers in England and Wales, Aquatic Conservation: Marine and Freshwater Ecosystems, 2002, 12, 381-390.

Appendix 1: Development of a Monitoring Programme

Section 4 has reviewed the main parameters that affect potential for adjustment occurring in a restored reach subsequent to restoration. In developing a monitoring programme it is important to understand inter-relationships that exist between these parameters. The monitoring programme needs to firstly set a list of objectives, targets and success criteria that the success of a scheme can be readily assessed against. This will need to be based on firstly, what does the scheme wish to achieve and secondly, given the location, the geology, gradient, planform, sediment, scale, land use, type of restoration project and artificial materials, what are the risks and uncertainties associated with the scheme that might affect the success of the project.

A case study on the River Idle is illustrated below to show how the various parameters were considered in the design of the rehabilitation scheme as well as how they influenced the monitoring programme. The River Idle (North Nottinghamshire) is a lowland, channelised, mixed gravel and sand-bedded river that has experienced substantial sedimentation following cross-section enlargement and resectioning for flood defence between 1978 and 1982. While the flood embankments were constructed over much of the course of the River Idle the sinuosity of the channel was largely maintained. The low gradient, and associated stream power, accompanied by overwidening, meant that extensive in-channel deposition had created a uniform bed topography and as a result a low habitat diversity. The soils in the catchment are amongst the most susceptible to aeolian erosion in the UK (Downs and Thorne, 1998). This was a major source of sediment moving into the channel.

Rehabilitation began in 1996 on a 1km section of the Idle following a broad assessment of morphology and sediment dynamics in the entire system (see Downs and Thorne, 1998). Land space for full scale restoration was limited and thus any work had to be undertaken in-channel (illustrated in Photograph 1). The main objectives were to create greater in-channel habitat diversity. This was to be achieved by creating an area of bed scour and deposition. It was also known that underlying the sand layer there were a series of gravel lenses that could be beneficial for spawning if uncovered. As a result, in-stream deflectors were used to locally alter flow patterns within the channel and thus ultimately change patterns of deposition and erosion around each of the deflector assemblages. Modelling work (BENDLFOW HMODEL2, FCFA method and HECRAS) was used to guide the location of deflectors so that they did not adversely affect the flood defence function and to ensure that natural deposition patterns associated with current sinuosity of the channel were maximised during rehabilitation of the reach.

Photograph 1: Three straight wing deflector assemblage on the River Idle

The project was funded by the Environment Agency and designed by Nottingham University Consultants Limited. The first stage of the scheme was installed in 1996.

A monitoring programme (Skinner, 1999) was developed to assess the effects of installing deflectors on in-channel scour and deposition. This included measuring six cross-sections around each deflector (2 upstream, 1 at the tip and 3 downstream) to measure changes in deposition and scour. It was anticipated that the installation of the hard structures (deflectors had to be made with stone gabion baskets) would create deposition zones upstream and downstream. Conversely, narrowing of the channel at the tip of the deflector would create bed scour (caused by an increase in shear stress). The effectiveness of each of the deflector assemblages in meeting these objectives was assessed in the monitoring programme. A baseline survey and as-built surveys were undertaken along with a series of surveys for 3 years post-installation. It was also considered likely that there would be significant change in the first couple of months following installation given the local bed conditions and the newly imposed channel structure. The temporal and spatial redistribution of sediment, and uncertainties associated with these assumptions could thus be investigated in the monitoring programme.

The findings of the monitoring programme suggest that various types of deflector assemblages trialled on the River Idle were successful at promoting deposition of sediment immediately upstream and downstream of the structures. The degree of success was dependent on the location of a deflector (relative to the channel planform), the degree of projection of the deflector into the channel and the shape of the deflector. The success of deflectors in creating scour pools in the narrowed section of the channel was less pronounced. While scour pools had developed in most locations they were subject to deposition of sand coming through the river on the falling limb of high flow events. To reduce this impact and to maintain the scour pool development the large amount of aeolian deposition from the surrounding environment needs to be addressed at a catchment scale.

Appendix 2: Monitoring Techniques

A) Ground Photography

Aim
The aim of ground photography is to provide a visual representation of change at a site. Photographs should be taken at a series of fixed locations as well as extra points of interest at the time of the survey.

Methodology
Ground photography is a simple technique using photographs of the site. For fixed point photography, consistency is a key issue. Each of the photographs needs to be taken at the same location (using a global positioning system) and at the same bearing (using a compass). It is also helpful to develop a set of photographs that can be taken on site to ensure repeat photographs have exactly the same frames. This is a straight forward process particularly when using digital cameras. Other photographs taken on different surveys should also have a GPS reference and bearing so that the location of each photograph can be readily identified on a map.

Deliverables
A series of photographs stored in a readily accessible manner with date information. A location map illustrating each photograph location, with a direction arrow showing the angle at which the picture was taken should also be included.

Time Requirements
This depends on the area to be covered but usually it is anticipated that only 1 day per site is usually required. Ground photography can be carried out at various times but it is recommended that this should be largely taken at regular intervals with additional sets after high flow events. Important sets of photographs that should be taken are a pre-restoration set, an 'as-built' set followed by a further set several months later to identify any initial adjustment (potentially around 3 months). After these initial sets of photographs the frequency at which they are taken can be reduced.

Appropriate Uses
Ground photography is one of the most useful monitoring tools for any restoration scheme as it provides a simple visual record of change over time.

Further Reading
None available.

B) Aerial Photography

Aim
The aim of aerial photography is to provide a visual representation of the land surface over time using air based techniques.

Methodology
Recently developed techniques can now enable aerial photographs to be easily obtained for many medium – large scale restoration schemes. New pieces of kit include helikites (Allsopp Helikites Limited) which consist of a balloon and kite which can fly up to 1000ft in height. A digital camera can be fixed on the helikite to provide aerial photography of the scheme.

Deliverables
A series of photographs stored with date information. A location map illustrating each photograph location should also be included.

Time Requirements
This depends on the area to be covered but no more than a couple of days per site should be required. Aerial photography should be carried out at regular intervals in time in a similar manner to ground photography.

Appropriate Uses
Aerial photography is a useful monitoring tool for any restoration scheme as it provides a good visual aerial record of change over time.

Further Reading
Helikites at http://allsopp.co.uk

C) Channel Cross Sections

Aim
The aim of this technique is to record channel adjustment at a particular location over time. Recording cross sections is an objective and repeatable methodology which provides quantitative data on both the level of deposition and erosion that has occurred between a two moments in time.

Methodology
Measurement of channel cross sections is taken across the width of the channel in a single line perpendicular to the flow. The survey may extend beyond the immediate channel width to include features such as terraces. In determining the location of cross sections it is useful to look for (adapted from Harrelson et al 1994):

- A straight section between bends
- Riffles
- Meander bends
- Clear indicators of the active floodplain or bankfull discharge
- Presence of terrace(s)
- Channel form typical of the river
- A reasonable view of geomorphological features

A total station is generally the most appropriate instrument for surveying cross sections as all data points can be tied into a known ordnance datum. As with fixed point photography it is essential that repeat surveys are carried out at the same location with marked endpoints. A vertically driven steel re-bar is often used to ensure this.
In taking measurements across the cross-section all significant breaks of slope should be marked to provide an accurate representation of change. It is necessary to have 'as-built' cross-section surveys to provide a baseline from which adjustment can be measured against. It is recommended that a further set of cross-sections are measured about 3 months after construction to provide an idea of how the river has adjusted to the new conditions at site. Surveys should be carried out on an annual basis and all after high flow events which drive geomorphological change.

Deliverables
The main deliverables are a series of cross section diagrams with estimations of adjustment (erosion or deposition). A location map of the cross-sections should also be included.

Time Requirements
This is very site specific. As an indication approximately 10-15 cross sections can be surveyed per day on a 10m wide channel.

Appropriate Uses
The measurement of cross-sections is particularly useful for monitoring areas of erosion and deposition at a fixed location. It is limited however by the fact that it only provides an estimation of change at fixed moments in time and does not examine changes between these periods. As a result fluctuations in deposition and erosion between these dates are not accounted for.

Further Reading
Harrelson, C.C., Rawlins, C.L., Potyondy, J.P, 1994, Stream channel reference sites: An illustrated guide to field technique. General Technical report RM-245, Fort Collins, CO: United States Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 61p.

(Downloadable for free at:
http://www.stream.fs.fed.us/publications/documentsStream.html)

D) Erosion Pins/Photo-Electronic Erosion Pins (PEEPS)

Aim
The aim of this technique is to provide a measure of the amount of erosion at a particular location. With careful placement of the erosion pins they can provide a good estimate lateral adjustment over time.

Methodology
This is a simple technique that comprises of driving erosion pins or PEEPS into the face of a river bank. While any material that will not decay is suitable, a small diameter metal pin is preferable as large pins may themselves lead to localised scour. The pin should be stable and perpendicular to the bank face. PEEPs offer a slight benefit over the

traditional erosion pin as they are generally linked to a data-logger so they can provide a near continuous measurement of adjustment at a bank face over time.

The section of the pin protruding from the bank is measured directly using a tape measure. This should be carried out periodically although, as outlined with previous techniques, a responsive approach should be adopted so that data is collected after high flow events.

Deliverables
The deliverables are readings of the length of each pin that is exposed at each individual location at each survey date. This will provide an estimate of the amount of erosion that has occurred at the location between two moments in time. A location map and or photographs should also be included.

Time Requirements
Once installed, measurement will take only a few minutes per pin.

Appropriate Uses
The erosion pins/PEEPS can be useful in detailing erosion at key areas of concern at particular bank locations. They provide an accurate method of measuring change at a particular point.

Further Reading
Harrelson CC, Rawlins CL, Potyondy JP. 1994. Stream channel reference sites: An illustrated guide to field technique. General Technical report RM-245, Fort Collins, CO:

United States Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 61p.
(Downloadable for free at:
http://www.stream.fs.fed.us/publications/documentsStream.html)

Lawler, D.M., Thorne, C.R., Hooke, J.M., 1997, Bank erosion and instability. In Thorne CR, Hey RD, Newson MD (eds). Applied Geomorphology for River Engineering and Management. John Wiley and Sons, Chichester: 137-172.

E) Topographic survey

Aim
The topographic survey aims to provide x,y and z co-ordinates of key points that will enable a digital terrain model to be constructed of the river and its floodplain.

Methodology
A total station is best used to take these types of measurements. It is important that the points recorded mark key breaks in slope to provide an accurate representation of the measured surface. A large number of points would be required to adequately represent a large scale restoration project. It is important that key geomorphological features such as zones of deposition and erosion, riffles (size and shape) are measured along with floodplain features such as terraces. In addition, other key features such as bank full markers and flow width at the time of the survey should also be detailed. A detailed resolution survey is required if adjustments over time are to be documented through repeat surveys.

Deliverables
The deliverable is the data (text file) and a digital terrain model.

Time Requirements
Time required for a full total station survey is dependent upon conditions at the site. In heavily vegetated areas the time required to undertaken a survey significantly increases. A good surveying team can undertake 1000 point per day but this is substantially reduced if a large area needs to be covered through the survey or in winter time when the daylight hours are less.

Appropriate Uses
The topographic survey is the best method for providing an accurate 3 dimensional representation of the surface of the river and floodplain. Key to the development of an accurate model is the need for a high scale resolution survey. The time required to undertake this significantly increases with size of project. It is necessary that someone who has been adequately trained in surveying does the work with the advice of a geomorphologist to ensure that all features required are picked up in the survey. In each survey, fixed markers are required to enable a repeat survey to be undertaken.

Further Reading
Downward, S.R., 1995, Information from topographic survey, In Gurnell, A.M., and Petts, G.E. (eds.), Changing River Channels, John Wiley and Sons, 303-323.

F) River reconnaissance survey

Aim
The river reconnaissance survey is a well established geomorphological technique which has evolved over the last 30 years. The main objectives of the technique are to:

- "supply a methodological basis for field studies of channel form and process;
- present a format for the collection of qualitative information and quantitative data on the fluvial system;
- provide a vehicle for progressive morphological studies that start with a broadly focused catchment baseline study, continue through a fluvial audit of the channel system, and culminate with a detailed investigation of geomorphological forms and processes in critical reaches;
- supply the data and input information to support techniques of geomorphological classification, analysis and prediction necessary to support sustainable river engineering, conservation and management."

(Thorne, 1998, p37)

The technique has been developed and tested by a variety of geomorphologists but is perhaps best documented in the Stream Reconnaissance Handbook written by Colin Thorne (1998).

Methodology
There are two central components of the procedure. The first is a set of recording sheets and the second, a detailed annotated map of the reach. The latter is perhaps the most useful tool when detailing monitoring of small scale projects. The first set of recording sheets detailed in Appendix 3 are those from Thorne (1998) and are most suited to detailed, small scale assessments of the river bank. These sheets have been adapted by other groups (eg Jacobs) to fit larger scale studies such as fluvial audits and catchment baseline surveys (For an example, see the second set of recording sheets in Appendix 2). The emphasis of these reconnaissance sheets is on sediment dynamics where key sediment sources and sinks are documented in more detail. Despite the differences in scale that these reconnaissance sheets are based upon, the principles behind the sheets remain the same. Each of the reconnaissance sheets provide similar descriptions of the valley form, before progressively decreasing in resolution of analysis to cover planform, boundary conditions, sediment sinks and sources.

The second set of survey sheets detailed has 9 main sections. A separate form should be completed for every geomorphologically defined reach. Unlike the River Habitat Survey each reach has no defined length. The reach length is dependent on the types of channel forms and processes observed within the reach. The start and end points of the reach can be defined through the identification of key changes to the dominant forms and processes operating within the river.

Section A: Details of survey

The first part of the survey involves providing details of the project such as the purpose of the survey; name of river; location; number of reach; client; date; time; upstream and downstream grid reference; reasons for upstream boundary; reach class.

Section B: Valley overview

This section focuses on the geomorphological setting of the river within the wider environment. The larger scale geomorphological setting can significantly impact the forms and processes in the channel and thus it is important to provide a broad description of the surrounding environment in the survey sheet. Key features of interest are valley form, land-use, floodplain; riparian corridor; terraces; levees; vegetation patterns.

Section C: Channel geometry

The third part of the survey focuses on the river form. Amongst others this examines planform, gradient, degree of modification, velocity variability, channel cross-section shape and flow width.

Section D: Boundary conditions

This section describes the boundary conditions of the channel detailing important information on the nature of the bed and banks of the river. In this section, natural materials and modifications are both noted.

Section E: Management operations

This part of the form details any obvious management operations, such as dredging (recent or historic), fisheries management and vegetation maintenance.

Section F: Channel flow

This section details the major flow types within the reach.

Section G: Sediment dynamics

This section is perhaps one of the most important components of the survey sheet as it directly records the sources and sinks of sediment within the reach. This can be adapted for the type of project but will at least record the locations of the sources and sinks of sediment within the reach in addition to a description of their form (eg point bar or medial bar). In more detailed studies, volumetric estimates of sediment sources and deposition have been made.

Section H: Channel dynamics

Channel dynamics describes the dominant types of process that are happening in each of the geomorphologically defined reaches through the identification of key field indicators. The dominant process in the channel is described as either being incising, widening, stable, laterally adjusting or narrowing. Key field indicators are outlined to help the user decide what the dominant channel process is operating within each reach. A space is available for the user to make comments and justify their answer.

Section I:

Section I provides a table for detailing the photograph identification number, the grid reference of the photograph and whether it was taken looking up or downstream. The table can also be used to detail the location of other key features such as major tributary junctions or weir locations.

Deliverables

The deliverable from the stream reconnaissance survey is both the recording sheets and the annotated map. This is often accompanied by a small report detailing a series of short notes on the perceived problem. In the case of monitoring of restoration schemes the stream reconnaissance technique can be used to document key changes over time (ie increase in the number of depositional features) which can be analysed through the comparison of the annotated maps. The survey should also encompass up and downstream of the restored reach to enable any locally significant contemporary geomorphological processes that influence the monitored reach to be detailed. The technique is suited to all scales of projects but is perhaps best suited to those projects that already have design and as-built plans. The survey needs to be repeated to determine changes over time. It is recommended that this could be used to illustrate the as-built scenario, 3 months after completion then on an annual basis to demonstrate how the restored reach changes over time.

Time Requirements
The number of kilometres of river that can be survey using river reconnaissance is dependant on seasons and weather conditions. This can range from about 5-6km in the winter to about 8km in the summer. It is also dependent on whether the user requires detailed annotated maps of the reach or whether survey sheets with additional information would suffice. Typically, for a small size project the time that is required to write up the notes and document the photographs would not amount to more than 2-3 man days.

Appropriate Uses
The river reconnaissance is a very adaptable technique and underlies many types of geomorphological survey. It is particularly suited to restoration schemes where the changes over time can be successfully detailed both with the survey sheets and detailed annotated maps.

Further Reading
Thorne, C.R. 1998, Stream Reconnaissance handbook, John Wiley and Sons, Chichester, England.

G) Bed substrate sampling

Aim
To provide information on the material that exists on the bed of the river. In particular, one of the most common aims is to determine the distribution of sediment sizes over a section of the river bed.

Methodology
There are a number of different techniques that can be used to determine the calibre of the material found on the river bed. The methods generally involve one of two techniques, namely surface sampling or volumetric sampling. Surface sampling largely involves sampling the surface of the river bed and working out the average size of the sediment. This usually requires a representative sample to be obtained and is best suited to gravel/cobble and boulder bed rivers. One of the initial sampling schemes was the Wolman sampling scheme developed by Gordon Wolman (Wolman, 1954). This involved stratified sampling of 100 particles (over 8mm in size). The sampling involves covering the bed surface of the river through pacing out at set intervals and sampling the particle at the toe of one's foot. The grain size is characterised by the measurement of the b axis (middle axis) and determining the number of particles in each range. Recent work by Rice and Church (1996) suggests that in fact you need 300-400 particles to adequately represent all particle ranges.

Volumetric sampling involves taking a volumetric sample of the river through the use of a sediment sampler and working out the dry weight of various particle ranges within your sample. This is best suited to channels that have more clay/silt/sand based systems.

Deliverables
For each sample a distribution curve will be produced that enables the user to determine the mean particle size.

Time Requirements
Time requirements are variable but for each surface sample a time of 1-2 hours in the field and 30 minutes in the office is required. Meanwhile for volumetric samples around 30 minutes fieldwork and 1.5-2 hours laboratory/office work is usually required.

Appropriate Uses
The need for bed material sampling is often linked to specific objectives of the restoration scheme. However, it is probably best reserved for projects where there is a concern on the nature of bed material movement such as though that have been led by fisheries spawning concerns.

Further Reading
Bunte, K., Abt, S.R., 2001, Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel- and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring, USDA Forest Service, General Technical Report RMRS-GTR-74.

(Downloadable free at: http://www.fs.fed.us/rm/pubs/rmrs_gtr74.html)

Kondolf, G.M., Lisle, T.E. and Wolman, G.M., 2003, Bed sediment measurement, in Kondolf, G.M and Piégay, H. (eds.), Tools in fluvial geomorphology, John Wiley and Sons Ltd., Chichester, UK, 347-395.

Rice, S.P. and Church, M., 1996, Sampling fluvial gravels: bootstrapping and the precision of size distribution percentile estimates", Journal of Sedimentary Research, 66, p654-665

H) Sediment transport monitoring

Aim
The aim of undertaking sediment transport monitoring is to investigate how sediment moves through the restored reach.

Methodology
There are several different methods for undertaking sediment monitoring and the choice of technique primarily depends upon whether the user wants to measure bed load movement or suspended sediment. Bed load monitoring is best undertaken using a series of bedload traps to investigate the volume of sediment that is moving as part of the bed load. Ideally, one would be constructed at the upstream limit of the restored reach and one at the downstream limit. This enables the background bed load to be determined against the amount moving through the project reach. This would help determine whether there is a net loss or gain of bedload to the restored reach.

The standard method for measuring suspended sediment is through collecting water samples in bottles and then calculating the weight of the sediment sample relative to the volume of water. These are often measured within in a reach at different flow stages to calculate how much suspended sediment is moving through the system at flows with different return periods. New instruments using acoustic loggers (to measure suspended sediment profile over a cross section) and optical backscatter equipment (to measure suspended sediment at a point location) offer significant potential for more automated recording. The costs for this kit are currently around £16,000-£20,000 for acoustic loggers and £2000-5000 for optical backscatter instruments. They have largely been used in oceanographic studies at the present time.

Deliverables
Calculated rate of sediment movement through a restored reach can be determined.
Time Requirements
The time required to construct sediment traps would vary according to the size of river but is unlikely to take more than a couple of days to install on smaller schemes. Time would be required for emptying and analysis which could take up to a week to undertake.

For suspended sediment sampling the time required for the traditional techniques would likely amount to 2-3 days per survey as the samples would need to be collected and then analysed. This is currently a labour intensive technique.

Appropriate Uses
The techniques are most suited to larger scale restoration projects or highly sensitive projects where the bedload and suspended sediment issues are more likely to be affordable part of the monitoring programme.

Further Reading
http://www.aquatecgroup.com

l) Sediment Mats

Aim
The aim of sediment mats is to provide a means of measuring sediment deposition on the floodplain.

Methodology
A series of sediment mats are cut from artificial turf (astroturf) and are pegged into the floodplain along cross-sections across the floodplain. The exact location of the mats would also need to be surveyed so their precise location is recorded. The weight of each turf is measured before being placed on the floodplain and once it is removed (at a late date) to measure the volume of sediment that has been deposited over the defined time period.

Deliverables
An amount of sediment deposition on the floodplain can be estimated using the sediment mats as representative samples.

Time Requirements
This depends on the area to be covered but would involve the placing of the mats (1 day), their collection (1 day) and then analysis of the weight of sediment collected in a laboratory (2 days). Thus for a small to medium sized scheme 4 days would need to be put aside for monitoring deposition of sediment on the floodplain over a specified time period.

Appropriate Uses
Sediment mats are a very good technique for monitoring deposition of sediment on the floodplain. They are therefore particularly useful in schemes that seek to restore river-floodplain connectivity.

Further Reading
Gurnell, A.M., Morrissey, I.P., Boitsidis, A.J., Clifford, N.J., Petts, G.E., Thompson, K. (2006) - Initial Adjustments within a New River Channel: Interactions between Fluvial Processes, Colonising Vegetation and Bank Profile Development. Environmental Management 38, 580-596.

Gurnell, A.M., Boitsidis, A.J., Thomson, K., and Clifford, N.J. (2006) - Seed bank, seed dispersal and vegetation cover: two years of vegetation colonisation along the margins of a newly-created river channel. Journal Of Vegetation Science. 17: 665-674.

J) GeoRHS (Geomorphological and Floodplain component for River Habitat Survey)

Aim
GeoRHS is a recently developed Environment Agency method for collecting standardised and detailed information on the geomorphology of a 500m reach of river and adjacent floodplain. It should usually be undertaken together with RHS, especially in the context of use in a restoration monitoring scheme. The benefit of this is to provide a link between the habitat data collected by RHS with more detailed geomorphological information, especially in situations where the restoration design involves re-establishing river-channel - floodplain connectivity.

Methodology
GeoRHS consists of two parts – a one-page desk study form which collects information on channel planform character, land use and historical river change. This is usually completed in advance of the field survey, which uses a 3-page form. In the field, five spot-checks are undertaken at 100m intervals along the 500m survey reach, collecting bed and bank sediment information, cross sectional measurements of the channel and floodplain and photographs at each point. The channel morphology section includes detail on bank engineering, erosion mechanisms and depositional features (including length/area of each occurrence). The third page includes floodplain geomorphology, conveyance and channel adjustment characteristics. The survey is undertaken by accredited surveyors, usually with a background in geomorphology.

Specific methods for data analysis have not yet been fully developed, but potentially include a number of classificatory and evaluative indicators which could be used for a pre-work baseline or for design, and for post project monitoring. For example, channel and floodplain connectivity (practicality of restoring floodplain, current connectivity, habitat/environmental value of floodplain) and ‘natural-state’ indicators (lateral connectivity, migration potential) have been suggested (Branson, J., Hill, C., Hornby, D.D., Newson, M., and Sear, D. A., 2005). There is a high degree of flexibility in use of the data collected, likely to require expert input to decide the most appropriate application.

Deliverables
A completed desk study and field form (4 pages total). Spot-check and general site photos and possibly a field sketch.

If data is to be provided electronically, data could either be entered into a hand-held device in the field if a suitable database is developed (a pilot has been as part of EA trials), or will be entered post-collection. It is likely that in most cases data would be analysed and a short report would be produced to interpret the data.

Time Requirements
Depending on the complexity of the site, and assuming data sets are easily available for the desk study element, around 1 hour for desk study and 1.5 hours for field survey. Additional time for data entry and analysis will vary for different projects.

The number of surveys undertaken will vary according to the length of the site and whether it is important to monitor possible downstream effects. The frequency of survey would be determined by the project 'risk' or by the energy (determining the likely rate of change/adjustment) of the river.

Appropriate Uses
Due to the volume and variety of data collected, a GeoRHS survey will satisfy a variety of uses, such as monitoring the location and extent of erosion and deposition between surveys, changes in bed material, and giving early warning of destabilising process occurring.

Bearing in mind the floodplain element of the survey, it is probably most applicable to relatively large scale restoration schemes (over 500m length) which involve an element of altering the river planform and/or connectivity between river and floodplain.

Further Reading
Branson, J., Hill, C., Hornby, D.D., Newson, M., and Sear, D. A. (2005); A refined geomorphological and floodplain component to River Habitat Survey (GeoRHS). R&D Technical Report SC020024/TR, Environment Agency, Bristol.

K) River Habitat Survey (RHS)

Aim
The River Habitat Survey procedure is a standardised method for recording physical habitat and features. It was developed from 1994 and currently 17,000 surveys have been undertaken (Environment Agency website, 2007) the results of which are stored on a national database.

Methodology
The survey uses standardised survey sheets to assess 500m of a river. A RHS involves using a four sheet survey, which has an additional two page spot check. At 50m intervals a series of spot checks are undertaken and record predominant channel and bank features in addition to immediate river corridor features. An example of how the RHS can be used for monitoring is shown in Appendix 4 on the River Misbourne.

Deliverables
Detailed 500m descriptions reaches based on standard field forms. Each form is four pages long, with a 2 page spot check, and requires information from both desk based resources and field data.

Time Requirements
A River Habitat Survey involves undertaking the survey over 500m reaches of channel. Experience suggests that 4-5 reaches can be completed on a standard day. Clearly this will vary between different times of year and conditions. For quality control purposes, each RHS surveyor has to go on a national training course which involves around 3.5 days of training with a mixture of desk based theory and fieldwork.

Appropriate Uses
The RHS is now a standardised methodology for collecting information on physical habitat and features and is an important tool for legislative compliance.

Further Reading
Environment Agency/SEPA/Environment and Heritage Service, River Habitat Survey in Britain and Ireland, Field survey guidance manual- 2003 Version.

Raven, P.J., Fox, P., Everard, M., Holmes, N.T.H. and Dawson, F.H., 1997, River Habitat Survey: A new system for classifying rivers according to their habitat quality, in Boon P.J. and Howell (eds.), D.L., Freshwater quality: defining the indefinable, Scottish Natural Heritage, UK, 215-234.

Walker, J., Diamond, M. and Naura, M., 2002, The development of Physical Quality Objectives for rivers in England and Wales, Aquatic Conservation: Marine and Freshwater Ecosystems, 2002, 12, 381-390.

Appendix 3: River Reconnaissance sheets

Recording sheets 1 (Thorne, 1998)

STREAM RECONNAISSANCE RECORD SHEET

Developed by Colin R. Thorne
Depatment of Geography, University of Nottingham, NG7 2RD, UK

SECTION 1 - SCOPE AND PURPOSE

Brief Problem Statement:-

Purpose of Stream Reconnaissance:-

Logistics of Reconnaissance Trip:-

RIVER LOCATION DATE

PROJECT STUDY REACH From To

SHEET COMPLETED BY

RIVER STAGE TIME: START TIME: FINISH

General Notes and Comments on Reconnaissance Trip:-

SECTION 2 - REGION AND VALLEY DESCRIPTION

PART 1: AREA AROUND RIVER VALLEY

Terrain	Drainage Pattern	Surface Geology	Rock Type	Land Use	Vegetation
Mountains	Dendritic	Bed rock	Sedimentary	Natural	Tropical forest
Uplands	Parallel	Weathered Soils	Metamorphic	Managed	Temperate forest
Hills	Trellis	Glacial Moraine	Igneous	Cultivated	Boreal forest
Plains	Rectangular	Glacio/Fluvial	None	Urban	Woodland
Lowlands	Radial	Fluvial		Suburban	Savanna
	Annular	Lake Deposits			Temperate grassland
	Multi-Basin	Wind blown (loess)	**Specific Rock Types (if known)**		Desert scrub
	Contorted				Extreme Desert
					Tundra or Alpine
					Agricultural land

Notes and Comments:-

PART 2: RIVER VALLEY AND VALLEY SIDES

Location of River	Height	Side Slope Angle	Valley Side Failures	*Interpretative Observations* *Material Type*	*Severity of Problems*
In Valley	< 5 m			*Bedrock*	
On Alluvial Fan	5 - 10 m	< 5degrees	None	*Soils*	*Insignificant*
On Alluvial Plain	10 - 30 m	5-10 degrees	Occasional	*Loose debris*	*Mild*
In a Delta	30 - 60 m	10-20 degrees	Frequent	***Failure Type***	*Significant*
In Old Lake Bed	60 - 100 m	20-50 degrees	**Failure Locations**	*(see Sketches in Manual)*	*Serious*
Valley Shape	> 100 m	>50 degrees	None		*Catastrophic*
Symmetrical			Away from river		
Asymmetrical			Along river (Undercut)	Level of Confidence in answers (Circle one)	
				0 10 20 30 40 50 60 70 80 90 100 %	

Notes and Comments:-

PART 3: FLOOD PLAIN (VALLEY FLOOR)

Valley Floor Type	Valley Floor Data	Surface Geology	Land Use	Vegetation	Riparian Buffer Strip
None	None	Bed rock	Natural	None	None
Indefinite	< 1 river width	Glacial Moraine	Managed	Unimproved Grass	Indefinite
Fragmentary	1 - 5 river widths	Glacio/Fluvial	Cultivated	Improved Pasture	Fragmentary
Continuous	5-10 river widths	Fluvial: Alluvium	Urban	Orchards	Continuous
	>10 river widths	Fluvial: Backswamp	Suburban	Arable Crops	**Strip Width**
	Flow Resistance*	Lake Deposits	Industrial	Shrubs	None
	Left Overbank Manning n value ___	Wind Blown (Loess)		Deciduous Forest	< 1 river width
	Right Overbank Manning n value ___			Coniferous Forest	1 - 5 river widths
	(* note: n value for channel is recorded in Part 6)			Mixed Forest	> 5 river widths

Notes and Comments:-

SECTION 2 - REGION AND VALLEY DESCRIPTION (Continued)

PART 4: VERTICAL RELATION OF CHANNEL TO VALLEY

Terraces	**Overbank Deposits**	**Levees**	**Levee Data**
None ☐	None ☐	None ☐	Height (m) ☐
Indefinate ☐	Silt ☐	Natural ☐	Side Slope (o) ☐
Fragmentary ☐	Fine sand ☐	Constructed ☐	
Continuous ☐	Medium sand ☐	**Levee Description**	**Levee Condition**
Number of Terraces ___	Coarse sand ☐	None ☐	None ☐
Trash Lines	Gravel ☐	Indefinite ☐	Intact ☐
Absent ☐	Boulders ☐	Fragmentary ☐	Local Failures ☐
Present ☐		Continuous ☐	Frequent failures ☐
Height above		Left Bank ☐	
flood plain (m) ___		Right Bank ☐	
		Both Banks ☐	

Interpretative Observations

Present Status	***Problem Severity***
Adjusted ☐	*Insignificant* ☐
Incised ☐	*Moderate* ☐
Aggraded ☐	*Serious* ☐
	Problem Extent
Instability Status	*None* ☐
Stable ☐	*Local* ☐
Degrading ☐	*General* ☐
Aggrading ☐	*Reach scale* ☐
	System wide ☐
	Regional ☐

Level of Confidence in answers (Circle one)

0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

PART 5: LATERAL RELATION OF CHANNEL TO VALLEY

Planform	**Planform Data**	**Lateral Activity**	**Floodplain Features**
Straight ☐	Bend Radius ___	None ☐	None ☐
Sinuous ☐	Meander belt width ___	Meander progression ☐	Meander scars ☐
Irregular ☐	Wavelength ___	Increasing amplitude ☐	Scroll bars+sloughs ☐
Regular meanders ☐	Meander Sinuosity ___	Progression+cut-offs ☐	Oxbow lakes ☐
Irregular meanders ☐		Irregular erosion ☐	Irregular terrain ☐
Tortuous meanders ☐	**Location in Valley**	Avulsion ☐	Abandoned channel ☐
Braided ☐	Left ☐	Braiding ☐	Braided Deposits ☐
Anastomosed ☐	Middle ☐		
	Right ☐		

Interpretative Observations

Present Status	***Problem Severity***
Adjusted ☐	*Insignificant* ☐
Over wide ☐	*Moderate* ☐
Too narrow ☐	*Serious* ☐
	Problem Extent
Instability Status	*None* ☐
Stable ☐	*Local* ☐
Widening ☐	*General* ☐
Narrowing ☐	*Reach scale* ☐
	System wide ☐
	Regional ☐

Level of Confidence in percent (Circle one)

0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

SECTION 3 - CHANNEL DESCRIPTION

PART 6: CHANNEL DESCRIPTION

Dimensions	**Flow Type**	**Bed Controls**	**Control Types**	**Width Controls**	**Control Types**
Av. top bank width (m) ___	None ☐	None ☐	None ☐	None ☐	None ☐
Av. channel depth (m) ___	Uniform/Tranquil ☐	Occasional ☐	Solid Bedrock ☐	Occasional ☐	Bedrock ☐
Av. water width (m) ___	Uniform/Rapid ☐	Frequent ☐	Weathered Bedrock ☐	Frequent ☐	Boulders ☐
Av. water depth (m) ___	Pool+Riffle ☐	Confined ☐	Boulders ☐	Confined ☐	Gravel armor ☐
Reach slope ___	Steep + Tumbling ☐	Number of controls ___	Gravel armor ☐	Number of controls ___	Revetments ☐
Mean velocity (m/s) ___	Steep + Step/pool ☐		Cohesive Materials ☐		Cohesive Materials ☐
Manning's n value ___	(Note: Flow type on day of observation)		Bridge protection ☐		Bridge abutments ☐
			Grade control structures ☐		Dykes or groynes ☐

Notes and Comments:-

PART 7: BED SEDIMENT DESCRIPTION

Bed Material	**Bed Armour**	**Surface Size Data**	**Bed Forms (Sand)**	**Bar Types**	**Bar Surface data**
Clay ☐	None ☐	D50 (mm) ___	Flat bed (None) ☐	None ☐	D50 (mm) ___
Silt ☐	Static-armour ☐	D84 (mm) ___	Ripples ☐	Pools and riffles ☐	D84 (mm) ___
Sand ☐	Mobile-armour ☐	D16 (mm) ___	Dunes ☐	Alternate bars ☐	D16 (mm) ___
Sand and gravel ☐			Bed form height (m) ___	Point bars ☐	
gravel and cobbles ☐	**Sediment Depth**	**Substrate Size Data**	**Island or Bars**	Mid-channel bars ☐	**Bar Substrate data**
cobbles + boulders ☐	Depth of loose	D50 (mm) ___	None ☐	Diagonal bars ☐	D50 (mm) ___
boulders + bedrock ☐	Sediment (cm) ___	D84 (mm) ___	Occasional ☐	Junction bars ☐	D84 (mm) ___
Bed rock ☐		D16 (mm) ___	Frequent ☐	Sand waves + dunes ☐	D16 (mm) ___

Notes and Comments:-

Channel Sketch Map

Map Symbols

Study reach limits — u/s, d/s	North point — N	Cut bank	Photo point — P1
Cross-section — A, A	flow direction	exposed island/bar	Sediment sampling point — S1
Bank profile — B3	impinging flow	structure	Significant vegetation

Representative Cross-section

SECTION 4 - LEFT BANK SURVEY

PART 8: LEFT BANK CHARACTERISTICS

Type	Bank Materials	Layer Thickness	Ave. Bank Height	Bank Profile Shape	Tension Cracks
Noncohesive ☐	Silt/clay ☐	Material 1 (m) ___	Average height (m) ___	(see sketches in manual)	None ☐
Cohesive ☐	Sand/silt/clay ☐	Material 2 (m) ___			Occasional ☐
Composite ☐	Sand/silt ☐	Material 3 (m) ___	**Ave. Bank Slope**		Frequent ☐
Layered ☐	Sand ☐	Material 4 (m) ___	angle (degrees) ___		**Crack Depth**
Even Layers ☐	Sand/gravel ☐				Proportion of
Thick+thin layers ☐	Gravel ☐				bank height ___
Number of layers ___	Gravel/cobbles ☐				
	Cobbles ☐				
Protection Status	Cobbles/boulders ☐				
Unprotected ☐	Boulders/bedrock ☐				
Hard points ☐					
Toe protection ☐					
Revetments ☐					
Dyke Fields ☐					

Distribution and Description of Bank Materials in Bank Profile

Material Type 1	Material Type 2	Material Type 3	Material Type 4
Toe ☐	Toe ☐	Toe ☐	Toe ☐
Mid-Bank ☐	Mid-Bank ☐	Mid-Bank ☐	Mid-Bank ☐
Upper Bank ☐	Upper Bank ☐	Upper Bank ☐	Upper Bank ☐
Whole Bank ☐	Whole Bank ☐	Whole Bank ☐	Whole Bank ☐
D50 (mm) ___	D50 (mm) ___	D50 (mm) ___	D50 (mm) ___
sorting coefficient ___	sorting coefficient ___	sorting coefficient ___	sorting coef. ___

Notes and Comments:-

PART 9: LEFT BANK-FACE VEGETATION

Vegetation	Tree Types	Density + Spacing	Location	Health	Height
None/fallow ☐	None ☐	None ☐	Whole bank ☐	Healthy ☐	Short ☐
Artificially cleared ☐	Deciduous ☐	Sparse/clumps ☐	Upper bank ☐	Fair ☐	Medium ☐
Grass and flora ☐	Coniferous ☐	dense/clumps ☐	Mid-bank ☐	Poor ☐	Tall ☐
Reeds and sedges ☐	Mixed ☐	Sparce/continuous ☐	Lower bank ☐	Dead ☐	Height (m) ___
Shrubs ☐	**Tree species**	Dense/continuous ☐			
Saplings ☐	(if known)	**Roots**	**Diversity**	**Age**	**Lateral Extent**
Trees ☐		Normal ☐	Mono-stand ☐	Immature ☐	Wide belt ☐
Orientation		Exposed ☐	Mixed stand ☐	Mature ☐	Narrow belt ☐
Angle of leaning (°) ___		Adventitious ☐	Climax-vegetation ☐	Old ☐	Single row ☐

Notes and Comments:-

Bank Profile Sketches

Profile Symbols

Bank Top Edge	Failed debris	Engineered Structure
Bank Toe	Attached bar	Significant vegetation
Water's Edge	Undercutting	Vegetation Limit

SECTION 4 - LEFT BANK SURVEY (Continued)

PART 10: LEFT BANK EROSION

Interpretative Observations

Erosion Location	Present Status	Severity of Erosion	Processes	Distribution of Each Process on Bank	
General	Intact	*Insignificant*	*Parallel flow*	***Process 1***	***Process 2***
Outside Meander	Eroding:dormant	*Mild*	*Impinging flow*	*Toe (undercut)*	*Toe (undercut)*
Inside Meander	Eroding:active	*Significant*	*Piping*	*Lower bank*	*Lower bank*
Opposite a bar	Advancing:dormant	*Serious*	*Freeze/thaw*	*Upper bank*	*Upper bank*
Behind a bar	Advancing:active	*Catastrophic*	*Sheet erosion*	*Whole bank*	*Whole bank*
Opposite a structure			*Rilling + gullying*	***Process 3***	***Process 4***
Adjacent to structure	**Rate of Retreat**	***Extent of Erosion***	*Wind waves*	*Toe (undercut)*	*Toe (undercut)*
Dstream of structure	m/yr (if applicable	*None*	*Vessel Forces*	*Lower bank*	*Lower bank*
Ustream of structure	and known)	*Local*	*Ice rafting*	*Upper bank*	*Upper bank*
Other (write in)	**Rate of Advance**	*General*	*Other (write in)*	*Whole bank*	*Whole bank*
	m/yr (if applicable	*Reach Scale*			
	and known)	*System Wide*		Level of Confidence in answers (Circle one)	
				0 10 20 30 40 50 60 70 80 90 100 %	

Notes and Comments:-

PART 11: LEFT BANK GEOTECH FAILURES

Interpretative Observations

Failure Location	Present Status	Instability:Severity	Failure Mode	Distribution of Each Mode on Bank	
General	Stable	*Insignificant*	*Soil/rock fall*	***Mode 1***	***Mode 2***
Outside Meander	Unreliable	*Mild*	*Shallow slide*	*Toe*	*Toe*
Inside Meander	Unstable:dormant	*Significant*	*Rotational slip*	*Lower bank*	*Lower bank*
Opposite a bar	Unstable:active	*Serious*	*Slab-type block*	*Upper bank*	*Upper bank*
Behind a bar		*Catastrophic*	*Cantilever failure*	*Whole bank*	*Whole bank*
Opposite a structure	**Failure Scars+Blocks**		*Pop-out failure*	***Mode 3***	***Mode 4***
Adjacent to structure	None	***Instability: Extent***	*Piping failure*	*Toe*	*Toe*
Dstream of structure	Old	*None*	*Dry granular flow*	*Lower bank*	*Lower bank*
Ustream of structure	Recent	*Local*	*Wet earth flow*	*Upper bank*	*Upper bank*
Other (write in)	Fresh	*General*	*Other (write in)*	*Whole bank*	*Whole bank*
	Contemporary	*Reach Scale*			
		System Wide		Level of Confidence in answers (Circle one)	
				0 10 20 30 40 50 60 70 80 90 100 %	

Notes and Copmments:-

PART 12: LEFT BANK TOE SEDIMENT ACCUMULATION

Interpretative Observations

Stored Bank Debris	Vegetation	Age	Health	Toe Bank Profile	Sediment Balance
None	None/fallow	Immature	Healthy	*Planar*	*Accumulating*
Individual grains	Artificially cleared	Mature	Unhealthy	*Concave upward*	*Steady State*
Aggregates+crumbs	Grass and flora	Old	Dead	*Convex upward*	*Undercutting*
Root-bound clumps	Reeds and sedges	Age in Years		***Present Debris Storage***	*Unknown*
Small soil blocks	Shrubs		**Roots**	*No bank debris*	
Medium soil blocks	Saplings	**Tree species**	Normal	*Little bank debris*	
Large soil blocks	Trees	(if known)	Adventitious	*Some bank debris*	
Cobbles/boulders			Exposed	*Lots of bank debris*	
Boulders				Level of Confidence in answers (Circle one)	
				0 10 20 30 40 50 60 70 80 90 100 %	

Notes and Comments:-

SECTION 5 - RIGHT BANK SURVEY

PART 13: RIGHT BANK CHARACTERISTICS

Type	**Bank Materials**	**Layer Thickness**	**Ave. Bank Height**	**Bank Profile Shape**	**Tension Cracks**
Noncohesive ☐	Silt/clay ☐	Material 1 (m) ___	Average height (m) ___	(see sketches in manual)	None ☐
Cohesive ☐	Sand/silt/clay ☐	Material 2 (m) ___		☐	Occasional ☐
Composite ☐	Sand/silt ☐	Material 3 (m) ___	**Ave. Bank Slope**		Frequent ☐
Layered ☐	Sand ☐	Material 4 (m) ___	Average angle (o) ___		**Crack Depth**
Even Layers ☐	Sand/gravel ☐				Proportion of
Thick+thin layers ☐	Gravel ☐				bank height ___
Number of layers ___	Gravel/cobbles ☐				
	Cobbles ☐				
Protection Status	Cobbles/boulders ☐				
Unprotected ☐	Boulders/bedrock ☐				
Hard points ☐					
Toe protection ☐					
Revetments ☐					
Dyke Fields ☐					

Distribution and Description of Bank Materials in Bank Profile

Material Type 1	**Material Type 2**	**Material Type 3**	**Material Type 4**
Toe ☐	Toe ☐	Toe ☐	Toe ☐
Mid-Bank ☐	Mid-Bank ☐	Mid-Bank ☐	Mid-Bank ☐
Upper Bank ☐	Upper Bank ☐	Upper Bank ☐	Upper Bank ☐
Whole Bank ☐	Whole Bank ☐	Whole Bank ☐	Whole Bank ☐
D50 (mm) ___	D50 (mm) ___	D50 (mm) ___	D50 (mm) ___
sorting coefficient ___	sorting coefficient ___	sorting coefficient ___	sorting coef. ___

Notes and Comments:-

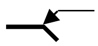
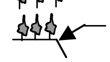
PART 14: RIGHT BANK-FACE VEGETATION

Vegetation	**Tree Types**	**Density + Spacing**	**Location**	**Health**	**Height**
None/fallow ☐	None ☐	None ☐	Whole bank ☐	Healthy ☐	Short ☐
Artificially cleared ☐	Deciduous ☐	Sparse/clumps ☐	Upper bank ☐	Fair ☐	Medium ☐
Grass and flora ☐	Coniferous ☐	dense/clumps ☐	Mid-bank ☐	Poor ☐	Tall ☐
Reeds and sedges ☐	Mixed ☐	Sparce/continuous ☐	Lower bank ☐	Dead ☐	Height (m) ___
Shrubs ☐	**Tree species**	Dense/continuous ☐			
Saplings ☐	(if known)	**Roots**	**Diversity**	**Age**	**Lateral Extent**
Trees ☐	☐	Normal ☐	Mono-stand ☐	Imature ☐	Wide belt ☐
Orientation	☐	Exposed ☐	Mixed stand ☐	Mature ☐	Narrow belt ☐
Angle of leaning (°) ___	☐	Adventitious ☐	Climax-vegetation ☐	Old ☐	Single row ☐

Notes and Comments:-

Bank Profile Sketches

Profile Symbols

Bank Top Edge		Failed debris		Engineered Structure	
Bank Toe		Attached bar		Significant vegetation	
Water's Edge		Undercutting		Vegetation Limit	

SECTION 5 - RIGHT BANK SURVEY (Continued)

PART 15: RIGHT BANK EROSION

Erosion Location	Present Status	*Severity of Erosion*	*Processes*	*Process 1*	*Process 2*
General	Intact	*Insignificant*	*Parallel flow*		
Outside Meander	Eroding:dormant	*Mild*	*Impinging flow*	*Toe (undercut)*	*Toe (undercut)*
Inside Meander	Eroding:active	*Significant*	*Piping*	*Lower bank*	*Lower bank*
Opposite a bar	Advancing:dormant	*Serious*	*Freeze/thaw*	*Upper bank*	*Upper bank*
Behind a bar	Advancing:active	*Catastrophic*	*Sheet erosion*	*Whole bank*	*Whole bank*
Opposite a structure			*Rilling + gullying*	***Process 3***	***Process 4***
Adjacent to structure	**Rate of Retreat**	***Extent of Erosion***	*Wind waves*	*Toe (undercut)*	*Toe (undercut)*
Dstream of structure	m/yr (if applicable	*None*	*Vessel Forces*	*Lower bank*	*Lower bank*
Ustream of structure	and known)	*Local*	*Ice rafting*	*Upper bank*	*Upper bank*
Other (write in)	**Rate of Advance**	*General*	*Other (write in)*	*Whole bank*	*Whole bank*
	m/yr (if applicable	*Reach Scale*			
	and known)	*System Wide*			

Interpretative Observations — *Distribution of Each Process on Bank*

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

PART 16: RIGHT BANK GEOTECH FAILURES

Failure Location	Present Status	*Instability:Severity*	*Failure Mode*	*Mode 1*	*Mode 2*
General	Stable	*Insignificant*	*Soil/rock fall*		
Outside Meander	Unreliable	*Mild*	*Shallow slide*	*Toe*	*Toe*
Inside Meander	Unstable:dormant	*Significant*	*Rotational slip*	*Lower bank*	*Lower bank*
Opposite a bar	Unstable:active	*Serious*	*Slab-type block*	*Upper bank*	*Upper bank*
Behind a bar		*Catastrophic*	*Cantilever failure*	*Whole bank*	*Whole bank*
Opposite a structure	**Failure Scars+Blocks**		*Pop-out failure*	***Mode 3***	***Mode 4***
Adjacent to structure	None	***Instability: Extent***	*Piping failure*	*Toe*	*Toe*
Dstream of structure	Old	*None*	*Dry granular flow*	*Lower bank*	*Lower bank*
Ustream of structure	Recent	*Local*	*Wet earth flow*	*Upper bank*	*Upper bank*
Other (write in)	Fresh	*General*	*Other (write in)*	*Whole bank*	*Whole bank*
	Contemporary	*Reach Scale*			
		System Wide			

Interpretative Observations — *Distribution of Each Mode on Bank*

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Copmments:-

PART 17: RIGHT BANK TOE SEDIMENT ACCUMULATION

Stored Bank Debris	Vegetation	Age	Health	*Toe Bank Profile*	*Sediment Balance*
None	None/fallow	Immature	Healthy	*Planar*	*Accumulating*
Individual grains	Artificially cleared	Mature	Unhealthy	*Concave upward*	*Steady State*
Aggregates+crumbs	Grass and flora	Old	Dead	*Convex upward*	*Undercutting*
Root-bound clumps	Reeds and sedges	Age in Years		***Present Debris Storage***	*Unknown*
Small soil blocks	Shrubs		**Roots**	*No bank debris*	
Medium soil blocks	Saplings	**Tree species**	Normal	*Little bank debris*	
Large soil blocks	Trees	(if known)	Adventitious	*Some bank debris*	
Cobbles/boulders			Exposed	*Lots of bank debris*	
Boulders					

Interpretative Observations

Level of Confidence in answers (Circle one)
0 10 20 30 40 50 60 70 80 90 100 %

Notes and Comments:-

Recording sheets 2

PART A: DETAILS OF SURVEY

Project:	Reach Number:	Client:
Purpose of Project:		
Date: / Time:	Surveyor (s):	
Catchment:	River:	Grid reference: Start:
Reasons for upstream boundary:	Conservation Status:	Grid reference: Finish:
		Reach Class Definition (Source, Sink, Transfer, Exchange) :

PART B: VALLEY OVERVIEW

Valley Form

	Tick Box
U or V Shaped (UV)	
Shallow Valley	
Deep Valley	
Gorge	
Lowland Floodplain	
Unknown	

Land-use

	0-5m	5m-10m	10m-50m
Left Bank			
Right Bank			

Floodplain

Floodplain (Tick box)		Left Bank	River Width	Right Bank
None			<1	
One			1-5	
Alternate			>5-10	
Both Banks			>10	

Riparian Corridor

None	Left Bank	Right Bank
Fragmentary		
Semi-Continuous		
Continuous		

Width of strip

	Left Bank	Right Bank
None		
< 1 River Width		
1-5 River Widths		
>5 River Widths		

Bank Top Vegetation

	Left Bank	Right Bank
None		
Unimproved Grassland		
Improved Pasture		
Arable		
Shrubs		
Deciduous woodland		
Coniferous woodland		
Mixed Woodland		
Orchards		

Tree lining

	Left bank	Right bank
None		
Isolated/ Scattered		
Regular		
Occasional clumps		
Semi-continuous		
Continuous		

Terraces

None	
Fragmentary	
Semi-Continuous	
Continuous	

Number

Levees

	Left Bank	Right Bank
None		
Natural		
Man Made		

Location

	Left bank	Right Bank
Fragmentary		
Semi-continuous		
Continuous		

PART C: CHANNEL GEOMETRY

Planform Description

Parameter	Class	Tick Box
Straight		
Meander	Irregular	
	Regular	
	Tortuous	
Braided		
Anabranching		

Channel Gradient (tick box)

High	
Medium	
Low	

Degree of modification through reach

High (>66%)	
Medium (>33<66%)	
Low (<33%)	

Velocity Variability

High	
Medium	
Low	

Channel Cross-Sectional Shape

	% of reach
Asymmetrical	
Symetrical	

Estimated flow width at date of survey: m

Other Notes:

PART D: BOUNDARY CONDITIONS

Bed Material

Obscured (Yes/No)

(complete table below if not obscured and mark with E if >33%)

Clay	
Silt	
Sand	
Gravel	
Cobbles	
Boulders	
Bedrock (type?)	
Artificial (Type?)	
D_{50} if calculated	

Bank Material

Obscured (Yes/No)

(complete table below if not obscured and mark with E if >33%)

	Left bank	Right bank
Clay		
Silt		
Sand		
Gravel		
Cobbles		
Boulders		
Bedrock (type?)		
Artificial		

Type of bank Modification

(tick if present and if over 33% mark as significant (E))

	Left bank	Right bank
None		
Rock wall		
Concrete		
Wooden		
Rip-rap		
Gabion baskets		
Block stone		
Sheet piling		
Willow Spiling		
Coir Rolls		
Geotextiles		
Other (please detail)		

In-Channel Vegetation
(in-channel or on depositional features)

Submerged in-channel vegetation	
Surface floating vegetation	
Emergent reeds/sedges/rushes	
Filamentous algae	
Mosses/lichens/liverworts	

Bank Face Vegetation
(tick if present and if over 33% mark as significant (E))

	Left bank	Right bank
None		
Grass		
Reeds/sedges/rushes		
Shrubs		
Trees		

Bank uniformity (through reach)

Uniform	
Variable	
Highly variable	

Bank Profile
(tick if present and if over 33% mark as significant (E))

	Left bank	Right bank
Cliff/Vertical		
Stepped		
Graded		

Bank Stratigraphy

Homogenous	
Variable	
Layered	
Number of layers	
Type:	

PART E:
MANAGEMENT OPERATIONS

(Tally accordingly)

Minor fish weirs	
Deflectors	
Dredged material	
Boulder placement	
Fisheries platforms	
Vegetation maintenance	
Other?	

PART F: CHANNEL FLOW TYPES
(tally numbers observed)

Waterfall	
Cascade	
Rapid	
Riffle	
Run	
Boil	
Glide	
Pool	
Marginal Deadwater	

Continued

Waterfall	
Cascade	
Rapid	
Riffle	
Run	
Boil	
Glide	
Pool	
Marginal Deadwater	

PART G: SEDIMENT DYNAMICS

Sediment Sources

Point Sources
(Tally inputs (either Course (C) or Fine (F) and mark * in location recording sheet)

	Left bank	Right bank
Tributaries *		
Drains *		
Mill leat *		
Tipped Material*		
Vehicle Access		
Scour at structure		
Footpath		
Burrowing in banks		
Poaching		

Diffuse sources
(Tally number of inputs)

	Micro (<5m long)	Meso (>5m <75m long)	Macro (>75m long)
Eroding Bank			
Colluvial Input (Valley Sides)			

Sediment Sinks

Point sinks

(Tally no. of sinks and sediment type)

	Fine	Course
Major weirs		
Dams		
Grade control structures		
Fords		
Bridge piers		
Large woody debris		

Floodplain deposits
(Tally number of deposits observed)

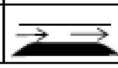
Fine deposits (Clays, silts and sands)	
Course deposits (gravels, cobbles and boulders)	
Woody Debris	

Comments:

Diffuse Sink

Types of Channel Deposit

(Tally number with letter ID for predominant calibre e.g. Boulder (B), Cobble (C), Gravel (G), Sands (S), Fines (F) or name two if they are of similar prominence

Deposit type	Illustration	Micro (<$25m^2$)	Meso (>$25m^2$<$150m^2$)	Macro (>$150m^2$)
Riffles				
Side bar				
Point bar				
Medial bar				
Tributary Junction bar				
Diagonal bar				
Berm				

Permanency of Deposits

	Permanent	Semi-permanent	Temporary
Approx % in reach			

PART H: CHANNEL DYNAMICS

Field indicators of instability and stability

(Tick indicators as appropriate)

Categories	Indicator	Tick	Categories	Indicator	Tick
Evidence of Incision	• Perched boulder berms • Terraces • Old channels • Old slope failures • Undermined structures • Exposed tree roots (both banks) • Narrow/deep channel • Bank failures, both banks • Armoured/compacted bed • Deep gravel exposure in banks that are topped with fines		Evidence of Aggradation	• Buried structures • Buried soils • Large uncompacted point bars • Eroding banks at shallows • Contracting bridge space • Deep fine sediment over coarse gravels in bank • Many unvegetated point bars • Large silt/clay banks	
Evidence of Widening	• Bank failure (both banks) • Vegetation falling in, or leaning towards, channel on both banks • Evolvement of new planform at lower elevation		Evidence of Lateral Adjustment	• A significant number of bank erosion areas • A significant number of bar formation areas • Channel cut-offs present	
Evidence of Stability	• Vegetated bars and banks • Compacted weed covered bed • Bank erosion rare • Old structures in position		Evidence of Narrowing	• Sedimentation on both channel margins	

(Adapted from Sear and Newson, 1994)

Dominant channel status

Status	Reasons
Laterally adjusting	
Stable	
Incising	
Widening	
Narrowing	
Aggrading	

Comments:

PART I: PHOTOGRAPH AND TRIBUTARY JUNCTION/DRAIN/OUTFLOW/LEAT/ WEIR LOCATIONS (Please record GPS location)

Photograph ID	Looking Upstream (U) or Downstream (D)	Location

Tributary (T)/ Drain (D)/ Outflow (O)/ Leat (L) Weir (W)	Fine (F) / Course (C) Sediment Input (if possible)	Location

Appendix 4: RHS Case Study on the River Misbourne

River Misbourne – Flow Restoration: Using River Habitat Survey (RHS) data to monitor changes in flow type and bed substrate diversity

Background – River Misbourne Low Flow problem and alleviation

The River Misbourne runs through a narrow chalk catchment from Great Missenden (Buckinghamshire) to its confluence with the River Colne in Uxbridge, West London. The river is a winterbourne, fed by a chalk aquifer, and is often subject to low flow problems in the summer months. In the mid 1990s, drought and unsustainable abstraction created a severe low flow problem in the river. Long stretches of the river were dry, even through winter and spring months when flow is usually sustained. In those sections where water was flowing, analysis revealed that the water was comprised of 95% Sewage Effluent (RRC 2001). The Alleviation of Low Flows programme (ALF), highlighted the need to reduce abstraction to sustain groundwater for natural flows and a reduced abstraction regime was developed by local water companies and the Environment Agency, and was implemented in 1997.

A river rehabilitation project has been completed in the lower reaches of the Misbourne through Denham Park (Site 5). Flow is maintained through the reach by discharges from a major Sewage Treatment Works. Historically, physical habitat has been degraded through a combination of channel widening, the installation of a 1.5m weir creating a ponded backwater, and the removal of natural gravels. The aims of channel rehabilitation work were to augment the gravel bed and improve flow variation, by removing the weir, importing gravel and narrowing the channel.

RHS was part of an extensive hydrological, biological and water quality monitoring programme undertaken along the Misbourne during the period of drought and subsequent recovery. The monitoring has found the flow restoration to be successful, restoring river habitats including pools and gravel runs, and indicating improvements in aquatic plant, bird and fish life (EA, 2003).

Aim of Physical Diversity analysis of RHS data

River Habitat Surveys have been undertaken between 1997 and 2005 (7 to 8 times), at approximately the same locations. The locations are; near the source of the river at Suffolk Bridge (Site 1); downstream of reservoir at Mantles Green (Site 2); Chalfont St Peter (Site 3); Gerrards Cross (Site 4); Higher Denham (Site 5); and upstream of River Colne confluence (Site 6).

Diversity indices are commonly employed in ecological studies to express how species rich a community is, and how even the distribution of the species is within that community. This study illustrates how repeat surveys can be used to compare the diversity of flow and substrates over time using a worked example. This type of analysis can be incorporated into monitoring programmes for river habitat or flow restoration projects, to investigate rates of natural recovery or responses to rehabilitation works. Ideally, it should be used as a simple method for setting basic objectives (e.g. aim to increase substrate diversity along a 500m reach) and evaluating success against a pre-project baseline. Furthermore, the same calculations can be applied to any physical habitat measurements and the ecological data (e.g. fisheries and macro-invertebrates) to allow direct comparisons between different components of the environment.

Calculation of Shannon index for flow type and substrate

What is the Shannon-Wiener index and what do values indicate?

The Shannon-Wiener index is a measure of the likelihood that the next sample (in this case a spot check substrate or flow type record) will be the same as the previous one. It can be used to indicate the diversity (H) and evenness (Ha) of the 'features' present. A value of H = 0 indicates that every record in a sample is the same, increasing with diversity to an infinite maximum value which is limited by the sample size. Ha = 1 if there is an even distribution (e.g. in a sample size of 10, there are two of each of five possible types present), and would decline if there were six of one and only one each of the other four possible types. Ha = 0 if there is only one type present.

Example calculation

RHS records a number of variables at 10 equally spaced transects (spot checks) along a reach. Data for Flow Type and Channel Substrate collected at these points is used in this study to create a flow diversity index and a substrate diversity index. The index values have been calculated for each of the 6 sites at every available survey date.

The Shannon-Wiener index is calculated using the equation:

$$H = -\sum_{i=1}^{\infty} pi \, \mathrm{LN} \, pi$$

Table 8 illustrates the calculation of the index for Channel Substrate using Excel.

Table 8: Calculation of SW index for channel substrate diversity

Channel Substrate	**No. spot checks where substrate present (frequency)**	***pi (frequency/N)***	**LN*(pi) (Natural Log of pi)***	***pi* LN*(pi)***
Artificial (AR)	0	0	0.00	0
Boulder (BO)	0	0	0.00	0
Cobble (CO)	1	0.1	-2.30	-0.23
Gravel/Pebble (GP)	4	0.4	-0.92	-0.37
Sand (SA)	1	0.1	-2.30	-0.230258509
Silt (SI)	3	0.3	-1.20	-0.361191841
Earth (EA)	0	0	0.00	0
Gravel (G)	0	0	0.00	0
Pebble (P)	1	0.1	-2.30	-0.230258509
N (number of spot check records, usually 10)	10	1	***H** (-Sum of pi LNpi)*	**1.42**
S (no. substrates possible to record)	9		***Ha** (H/LN(S))*	**0.65**
LN (*S*)	2.20			

N is the total number of records in a sample. In this case *N* = 10 as there are 10 spot check values in each sample. If 2 spot check values were missing (e.g. not visible in the field), *N* would = 8. Additional substrates which are not predominant at spot checks can also be recorded, so *N* could equal 11 or 12 or more, and the value in the calculation would need adjusting accordingly.

S is the total number of types that could be recorded in any one sample. There are 11 substrate types that are possible to record at RHS spot checks, but two of these were not recorded at any of the Misbourne sites. It was decided to eliminate types which were not considered relevant to the local situation. This was more significant for flow types as none of the high energy types (e.g. free fall, broken waves) were present. Therefore for substrate *S* = 9, unless there are fewer spot checks recorded (e.g. if 9 spot checks are recorded *S* = 9, if there were 2 values missing (8 spot checks recorded) *S* = 8). If there were less than 7 spot checks recorded the data should not be used.

It is difficult to know how best to deal with adjusting *S* to account for any additional substrates recorded. If no, or one, spot check values are missing it is not an issue; for 2 or more missing spot checks, increase *S* by one for each additional substrate recorded (up to the maximum for number of types possible). For the flow type calculation, *S* = 5 as only 5 flow types were present at any of the Misbourne sites. This value should be changed in a different study to account for the variety of flow types that are present in each case.

For this study, the maximum possible values for *H* are 1.61 for Flow Type and 2.16 for Substrate. For *Ha* maximums are 1 for Flow Type and 0.98 for Substrate.

Data Quality

RHS is a standard methodology which is undertaken by accredited surveyors trained by specialists in the Environment Agency. The data recorded on the forms is transferred into a central database held by the EA which is checked for data quality and consistency. However, several flaws in the methodology, data collection and data storage may affect the results.

RHS records only the predominant substrate or flow type at each spot check, so the diversity index is representative for the dominant types over a 500m reach scale. There may be additional substrates (often smaller size fractions) present in smaller quantities. Also, the combined gravel-pebble category presents problems as it inherently indicates a mixture of sediment sizes is present. It could potentially be weighted in the calculation of the index to take this into account. For example, the substrate can be converted into Phi units, which is based on the Wentworth Scale and a diversity index calculated from these. This would enable recordings to be categorised in favour of gravel or pebble.

RHS is undertaken by surveyors who are trained and accredited by specialists in the Environment Agency. Although this guarantees some level of consistent recording, surveyor variability and locational errors would be reduced if repeat surveys at a site were undertaken by the same person.

The surveys undertaken at the six sites on the Misbourne were not always consistent in the month of survey. This reduces the ability to directly compare values for different years, in particular for the flow types, which will change in response to rainfall events.

Only sites surveyed in 2003 and 2005 have been entered on the RHS database and thoroughly quality checked as part of that process. For all other surveys undertaken prior to 2003, only a basic check on valid entries was undertaken.

Results

Results for ***H*** are summarised for all sites in Figures 3 (Flow Diversity) and 4 (Substrate Diversity). Tables and graphs indicating results at each site are given in Tables 9 and 10 and Figure 5.

Figure 3: Flow Diversity at all sites, 1997-2005

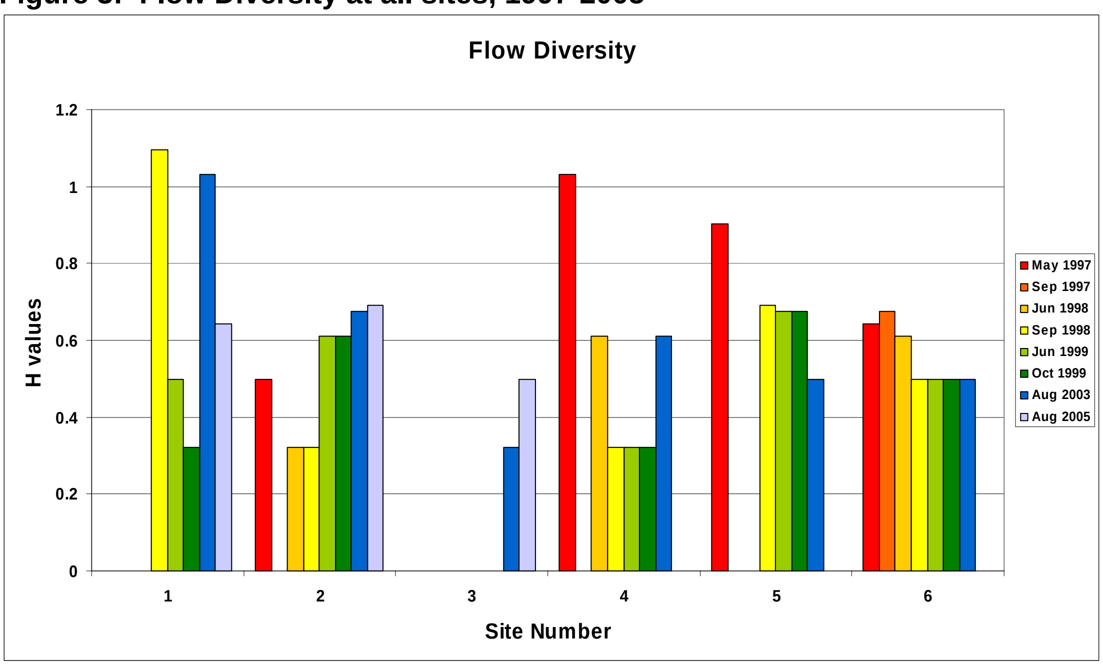
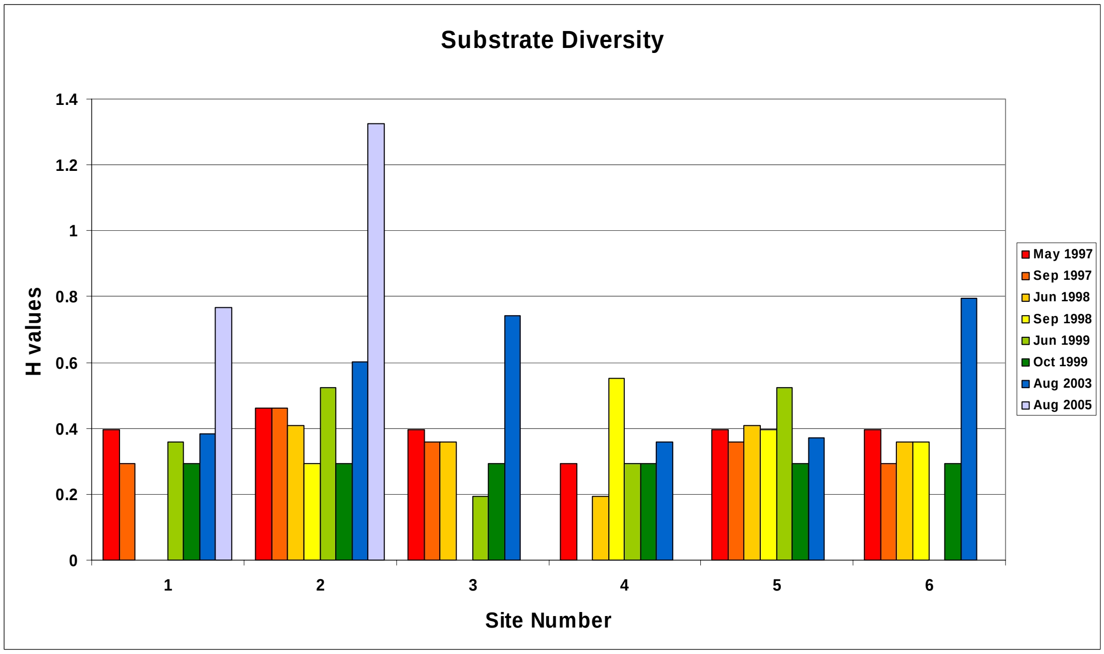


Figure 4: Substrate Diversity at all sites, 1997-2005



Site 1 (Headwaters): There is some recovery of flow approximately one year after being dry between 1997 and summer 1998. Some flow resumed in Sep 1998, giving a higher diversity value (1.09) due to patches of pooled water, some dry spot checks and others with a trickling run or glide. Diversity decreases in later years as smooth flows (glides) become more established. Substrate diversity was less varied, with a mixture of gravel, pebble and silt. The highest diversity in 2005 was due to the recording of some artificial substrate.

Site 2 (near Mantles Green): Flow diversity has remained quite steady (0.61) with a dominance of smooth and rippled flow (glides and runs). The site does have some dry spot checks in 2005, increasing the diversity but indicating a lack of maintained flow. Substrates are a mixture of gravel pebble, sand and silt with diversity values between 0.5 and 0.6. In 2005, earth was recorded as a substrate, perhaps at the dry spot checks, but only 7 of 10 records were completed.

Site 3 (Chalfont St. Peter): This site was persistently dry until the 2003 survey. The bed substrate is a mixture of gravel, pebble and silt, with silt completely dominant in Sep 1998. This suggests that silt is mobilised and transferred downstream, settling out in periods of very low flow. The later records indicate a gravel-pebble bed has been restored along with the improved flow.

Site 4 (Gerrards Cross): Flow types are generally smooth and rippled, sometimes with unbroken waves increasing the diversity value (1.03 in May 1997). Substrates are dominated by gravel and pebble, except in Sep 1997 when the bed was dry and silted.

Site 5 (Higher Denham): Flow diversity is generally moderate throughout this reach, except in the dry period of 1997-8. Flow is dominated by glides and runs which are controlled by the presence of a weir and over-widened channel. Substrate diversity is also moderate, with a change to more gravel substrate in 2003 and 2005, having previously been silty. This may be a result of channel rehabilitation works.

Site 6 (upstream of River Colne confluence): This could be considered a 'control site' as flow at this location is maintained through drought due to discharge from an upstream Sewage Treatment Works. Flow is moderately diverse (H = 0.5-0.6), as are substrates (H = 0.3-0.79).

Discussion

A basic review of the results indicates:

- The headwaters generally had a quicker response to the combined effects of reduced abstraction and recovery from drought. The gradual recharge of the aquifer meant that the river was unable to maintain flow through its middle reaches.
- Diversity in flow types in a low flow river can indicate 'patchy' flow, for example dry spots, puddles and trickles, rather than reflecting channel and bed morphology (riffles, runs and glides). A more consistent flow may be indicated by lower diversity in some cases. This highlights the need to set specific objectives for each site to measure against, with the aim of creating a more natural flow and substrate regime. For example, a winterbourne in the headwaters will often naturally run dry as the base flow fluctuates through the seasons, with spring being the wettest and late summer/autumn being the driest. Lower reaches can be wet all year round but with lower flows in summer and autumn.
- Some of the highest values may indicate unreliable data.
- In most cases, substrates appear to show relatively higher evenness (Ha) values than the flow index. Substrates are more evenly split between mixtures of gravel, pebble, sand and silt, while flow types were dominated by glides with a less even mixture of runs, ponded flow or unbroken waves adding diversity.
- The RHS data is not perfect for undertaking this type of analysis due to the way it records only dominant substrates, and groups gravel and pebble together. This will mask smaller scale diversity, which is important for supporting the ecological diversity of the system.
- A more complete analysis could be undertaken by using basic statistical tests (e.g. ANOVA – Analysis of Variance) to compare differences between sites and years. This type of analysis may also be used to look at interrelationships between the different components of the system.

References

Environment Agency (2003) *The State of England's Chalk Rivers*

River Restoration Centre (2001) *River Restoration and Chalk Streams*

Shannon Wiener Diversity Index Examples
http://teacherweb.capousd.org/custom/WMRedding/SHANNON%20WIENER%20DIVERSITY%20INDEX%20EXAMPLES.htm - accessed 17/01/07

Table 9: Flow Diversity Results

Site	Month	Year	RHS Database Survey No.	Dry	Ponded	Rippled	Smooth	Unbroken Waves	No. Spot Checks	H	Ha	Ha Class
1	Sep	1998		2	1	1	6	0	10	1.0948	0.68	4
4	May	1997		0	0	3	5	2	10	1.0304	0.64	4
3	Aug	2003	30223	0	0	3	5	2	10	1.0304	0.64	4
5	May	1997		0	0	1	6	3	10	0.9016	0.56	3
5	Sep	1998		0	0	5	5	0	10	0.6923	0.43	3
2	Oct	2005	31166	5	5	0	0	0	10	0.6923	0.43	3
6	Sep	1997		0	0	4	6	0	10	0.6762	0.42	3
5	Jun	1999		0	0	4	6	0	10	0.6762	0.42	3
5	Oct	1999		0	0	4	6	0	10	0.6762	0.42	3
4	Aug	2003	30225	0	0	6	4	0	10	0.6762	0.42	3
6	May	1997		0	1	1	8	0	10	0.644	0.4	3
1	Aug	2005	31165	0	0	1	8	1	10	0.644	0.4	3
4	Jun	1998		0	0	7	3	0	10	0.6118	0.38	2
6	Jun	1998		0	0	3	7	0	10	0.6118	0.38	2
2	Jun	1999		0	0	3	7	0	10	0.6118	0.38	2
2	Oct	1999		0	0	3	7	0	10	0.6118	0.38	2
2	Sep	2003	30222	0	0	3	7	0	10	0.6118	0.38	2
6	Aug	2003	30227	0	0	3	7	0	10	0.6118	0.38	2
2	May	1997		8	2	0	0	0	10	0.4991	0.31	2

Records more evenly distributed between types = more diverse

6	Sep	1998		0	0	2	8	0	10	0.4991	0.31	2
1	Jun	1999		0	0	2	8	0	10	0.4991	0.31	2
6	Jun	1999		0	0	2	8	0	10	0.4991	0.31	2
6	Oct	1999		0	0	2	8	0	10	0.4991	0.31	2
3a	Aug	2003	30224	0	0	2	8	0	10	0.4991	0.31	2
3	Oct	2005	31348	0	0	2	8	0	10	0.4991	0.31	2
2	Jun	1998		0	0	1	9	0	10	0.322	0.2	2
2	Sep	1998		0	0	1	9	0	10	0.322	0.2	2
4	Sep	1998		0	0	1	9	0	10	0.322	0.2	2
4	Jun	1999		0	0	9	1	0	10	0.322	0.2	2
1	Oct	1999		0	0	1	9	0	10	0.322	0.2	2
4	Oct	1999		0	0	0	9	1	10	0.322	0.2	2
1	Sep	2003	30221	0	1	0	9	0	10	0.322	0.2	2
5	Aug	2003	30226	0	0	1	9	0	10	0.322	0.2	2
1	May	1997		10	0	0	0	0	10	0	0	0
3	May	1997		10	0	0	0	0	10	0	0	0
1	Sep	1997		10	0	0	0	0	10	0	0	0
2	Sep	1997		10	0	0	0	0	10	0	0	0
3	Sep	1997		10	0	0	0	0	10	0	0	0
4	Sep	1997		10	0	0	0	0	10	0	0	0
5	Sep	1997		0	0	0	10	0	10	0	0	0
1	Jun	1998		0	0	0	9	0	9	0	0	0
3	Jun	1998		10	0	0	0	0	10	0	0	0
5	Jun	1998		0	0	0	10	0	10	0	0	0

Every record is the same -
no diversity

3	Sep	1998	10	0	0	0	0	10	0	0	0
3	Jun	1999	10	0	0	0	0	10	0	0	0
3	Oct	1999	10	0	0	0	0	10	0	0	0

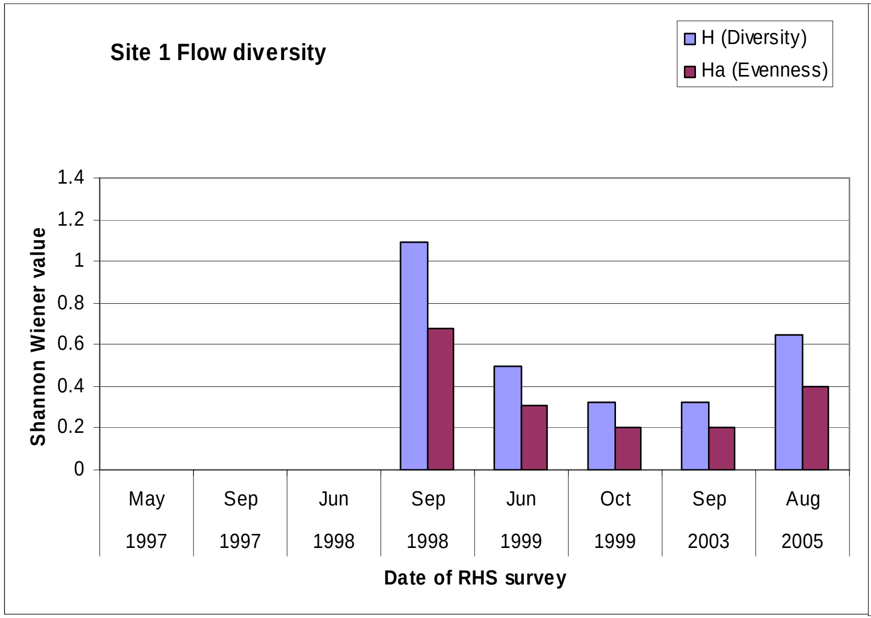
Table 10: Substrate Diversity Results

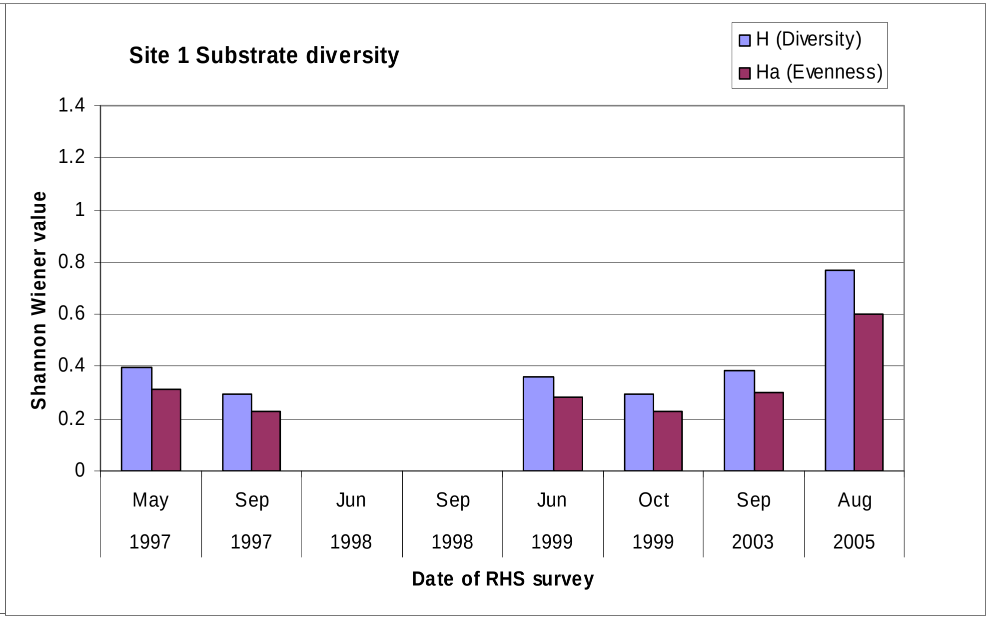
Site	Month	Year	RHS Database Survey No.	Artificial	Boulder	Earth	Gravel	Gravel/Pebble mixture	Pebble	Sand	Silt	Cobble	No. Spot Checks	H	Ha	Ha Class
2	Oct	2005	31166	0	0	2	4	0	0	0	1	0	7	1.326	0.68	4
6	Aug	2003	30227	0	0	0	5	2	1	1	1	0	10	0.7936	0.62	4
1	Aug	2005	31165	2	0	0	3	0	1	0	3	0	9	0.768	0.6	4
3	Aug	2003	30223	0	0	0	1	3	0	4	2	0	10	0.7424	0.58	3
3a	Aug	2003	30224	0	1	0	0	5	1	0	4	0	11	0.6784	0.53	3
2	Sep	2003	30222	0	0	0	0	5	0	2	3	0	10	0.6016	0.47	3
4	Sep	1998		0	0	0	0	4	0	1	5	0	10	0.5504	0.43	3
2	Jun	1999		0	0	0	0	3	0	1	6	0	10	0.5248	0.41	3
6	Jun	1999		0	0	0	0	6	0	1	3	0	10	0.5248	0.41	3
2	May	1997		0	0	0	0	2	0	0	7	1	10	0.4608	0.36	2
2	Sep	1997		0	0	0	0	2	0	0	7	1	10	0.4608	0.36	2
2	Jun	1998		0	0	0	0	5	0	0	5	0	10	0.4096	0.32	2
5	Jun	1998		0	0	0	0	5	0	0	5	0	10	0.4096	0.32	2
1	May	1997		0	0	0	0	4	0	0	6	0	10	0.3968	0.31	2

3	May	1997		0	0	0	0	6	0	0	4	0	10	0.3968	0.31	2
5	May	1997		0	0	0	0	6	0	0	4	0	10	0.3968	0.31	2
6	May	1997		0	0	0	0	6	0	0	4	0	10	0.3968	0.31	2
5	Sep	1998		0	0	0	0	6	0	0	4	0	10	0.3968	0.31	2
1	Sep	2003	30221	0	0	0	1	1	0	1	8	0	11	0.384	0.3	2
5	Aug	2003	30226	0	0	0	1	8	0	0	1	0	10	0.3712	0.29	2
3	Sep	1997		0	0	0	0	7	0	0	3	0	10	0.3584	0.28	2
5	Sep	1997		0	0	0	7	0	0	0	3	0	10	0.3584	0.28	2
3	Jun	1998		0	0	0	0	3	0	0	7	0	10	0.3584	0.28	2
6	Jun	1998		0	0	0	0	7	0	0	3	0	10	0.3584	0.28	2
6	Sep	1998		0	0	0	0	7	0	0	3	0	10	0.3584	0.28	2
1	Jun	1999		0	0	0	0	3	0	0	7	0	10	0.3584	0.28	2
4	Aug	2003	30225	0	0	0	0	7	0	3	0	0	10	0.3584	0.28	2
4	May	1997		0	0	0	0	8	0	0	2	0	10	0.2944	0.23	2
1	Sep	1997		0	0	0	0	8	0	0	2	0	10	0.2944	0.23	2
6	Sep	1997		0	0	0	0	8	0	0	2	0	10	0.2944	0.23	2
2	Sep	1998		0	0	0	0	2	0	0	8	0	10	0.2944	0.23	2
5	Jun	1999		0	0	0	0	8	0	0	2	0	10	0.2944	0.23	2
1	Oct	1999		0	0	0	0	2	0	0	8	0	10	0.2944	0.23	2
2	Oct	1999		0	0	0	0	2	0	0	8	0	10	0.2944	0.23	2
3	Oct	1999		0	0	0	0	2	0	0	8	0	10	0.2944	0.23	2
4	Oct	1999		0	0	0	0	2	0	0	8	0	10	0.2944	0.23	2
5	Oct	1999		0	0	0	0	8	0	0	2	0	10	0.2944	0.23	2
6	Oct	1999		0	0	0	0	8	0	0	2	0	10	0.2944	0.23	2

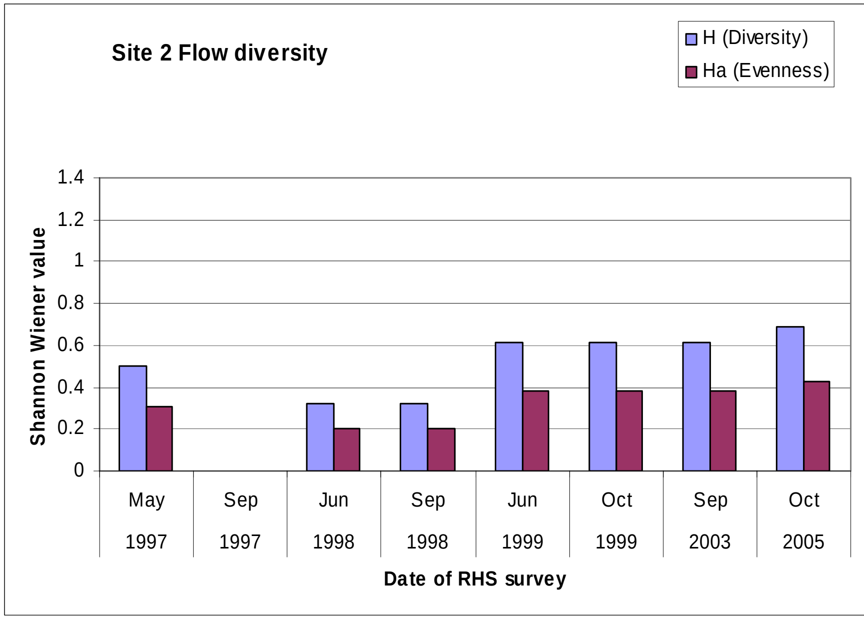
4	Jun	1998		0	0	0	0	9	0	0	1	0	10	0.192	0.15	1
4	Jun	1999		0	0	0	0	9	0	1	0	0	10	0.192	0.15	1
4	Sep	1997		0	0	0	0	0	0	0	10	0	10	0	0	0
1	Jun	1998		0	0	0	0	0	0	0	10	0	10	0	0	0
1	Sep	1998		0	0	0	0	0	0	0	10	0	10	0	0	0
3	Sep	1998		0	0	0	0	0	0	0	10	0	10	0	0	0
3	Oct	2005	31348	0	0	0	0	10	0	0	0	0	10	0	0	0
3	Jun	1999		0	0	0	0	0	0	0	0	0	0	0		

Figure 5 (a-l): Individual site Diversity and Evenness graphs

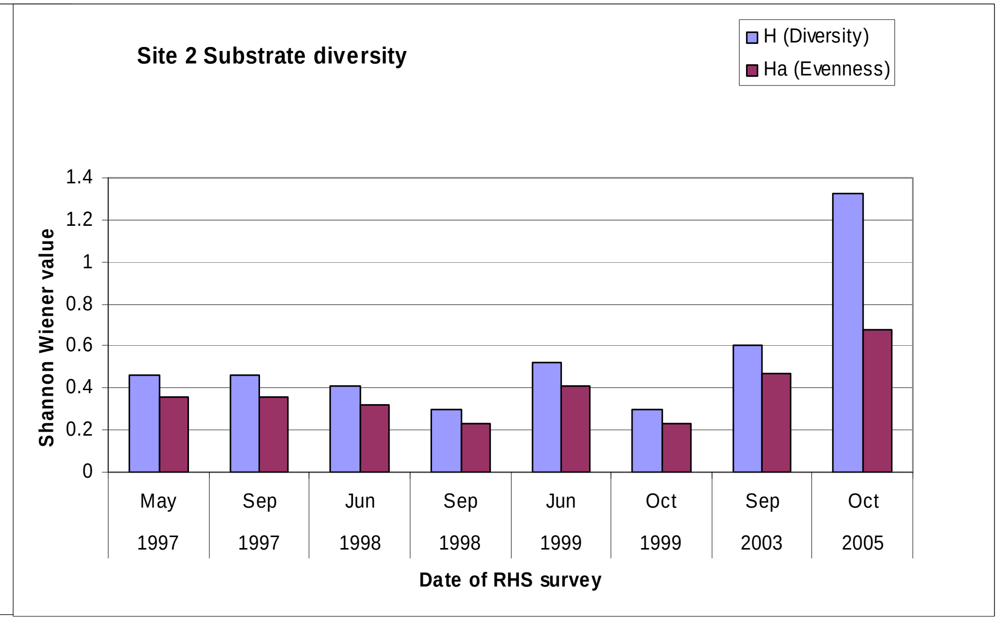




a.

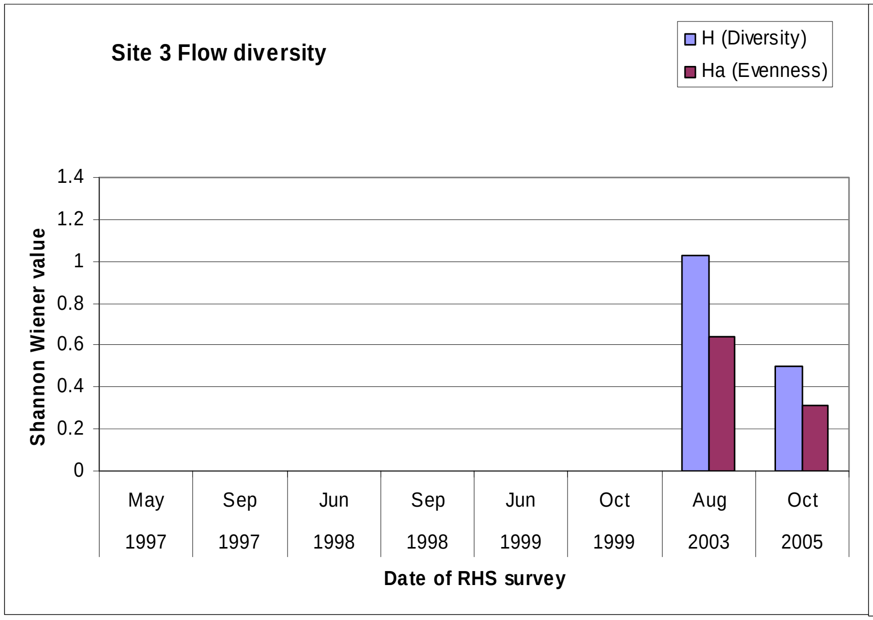

Site 2 Flow diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Sep 2003
Oct 2005
Date of RHS survey

b.

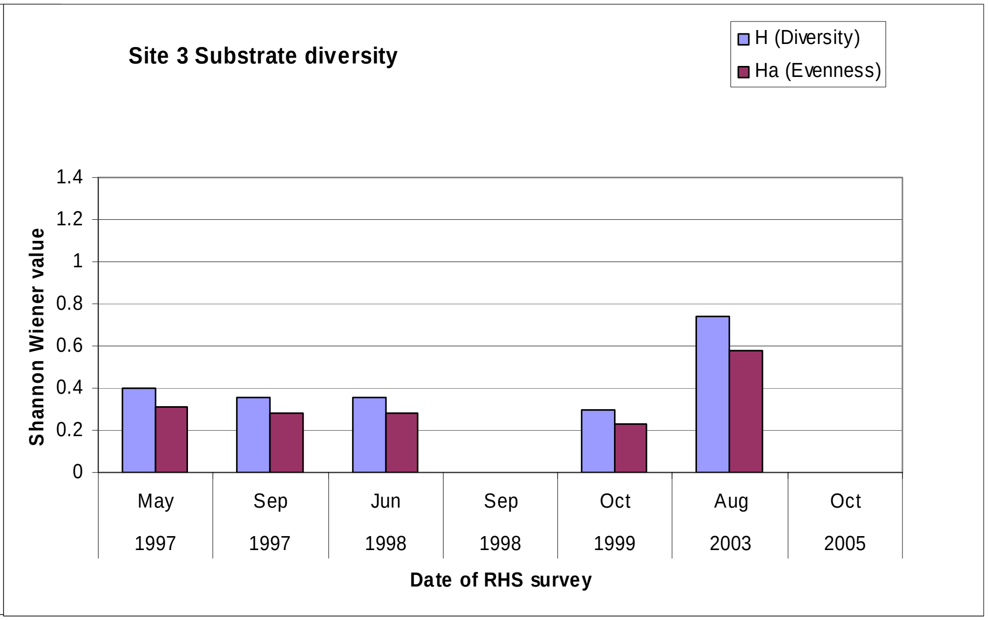

Site 2 Substrate diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Sep 2003
Oct 2005
Date of RHS survey

c.

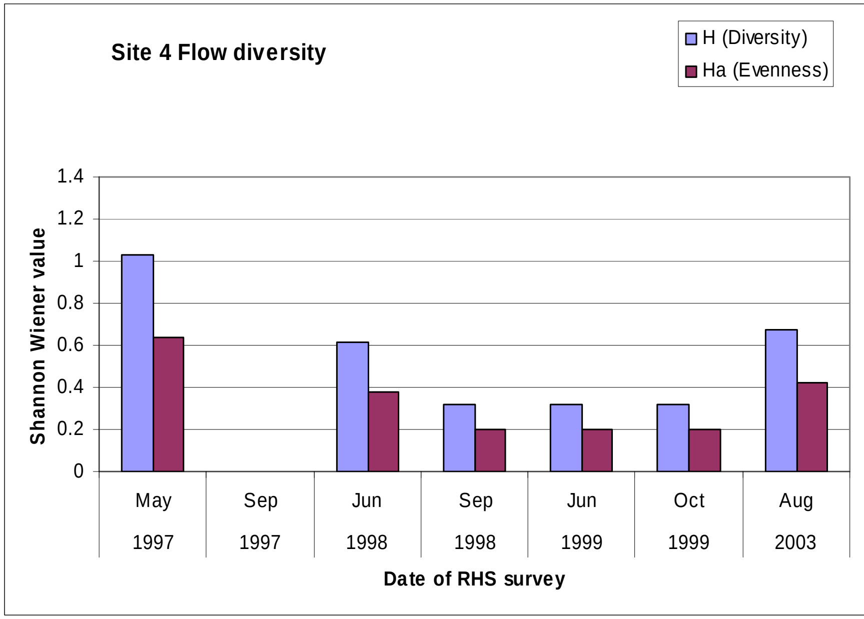
d.


Site 3 Flow diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
0
0.2
0.4
0.6
0.8
1
1.2
1.4
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Aug 2003
Oct 2005
Date of RHS survey

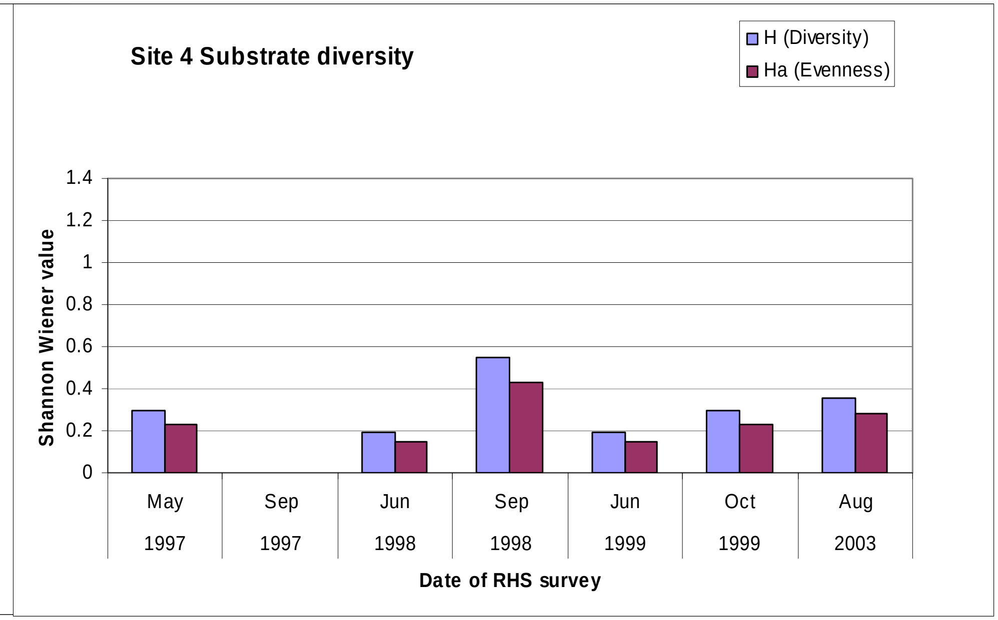
e.


Site 3 Substrate diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
0
0.2
0.4
0.6
0.8
1
1.2
1.4
May 1997
Sep 1997
Jun 1998
Sep 1998
Oct 1999
Aug 2003
Oct 2005
Date of RHS survey

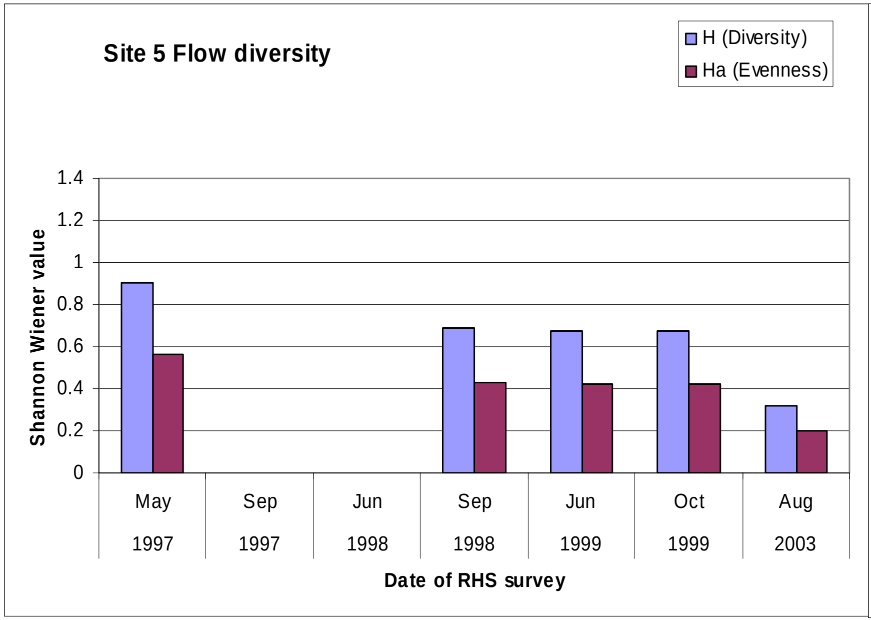
f.


Site 4 Flow diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Aug 2003
Date of RHS survey

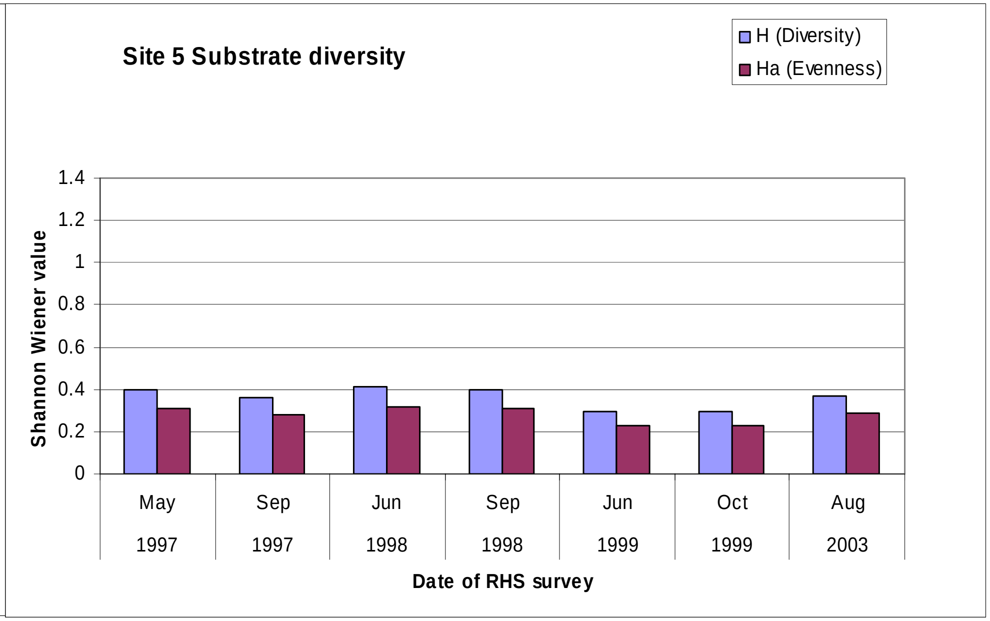
g.


Site 4 Substrate diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Aug 2003
Date of RHS survey

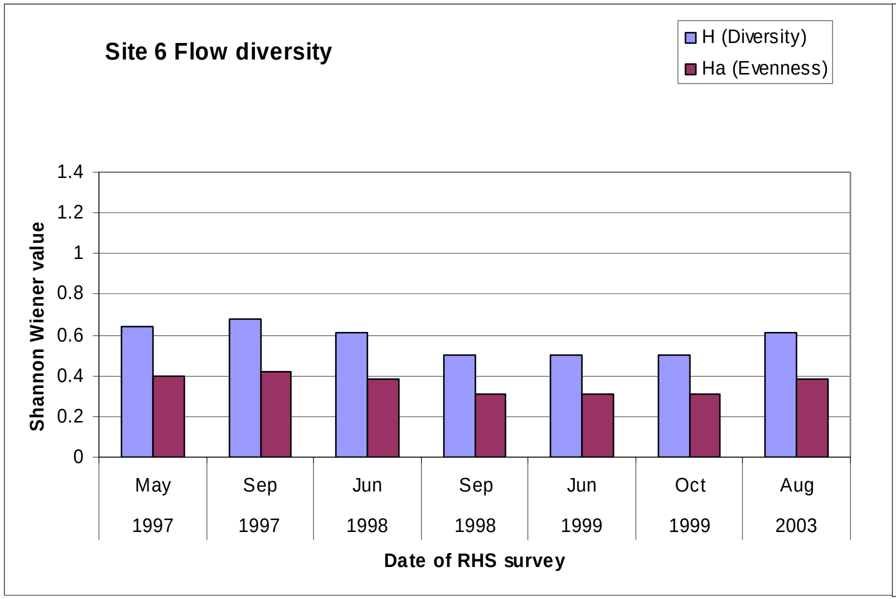
h.


Site 5 Flow diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Aug 2003
Date of RHS survey

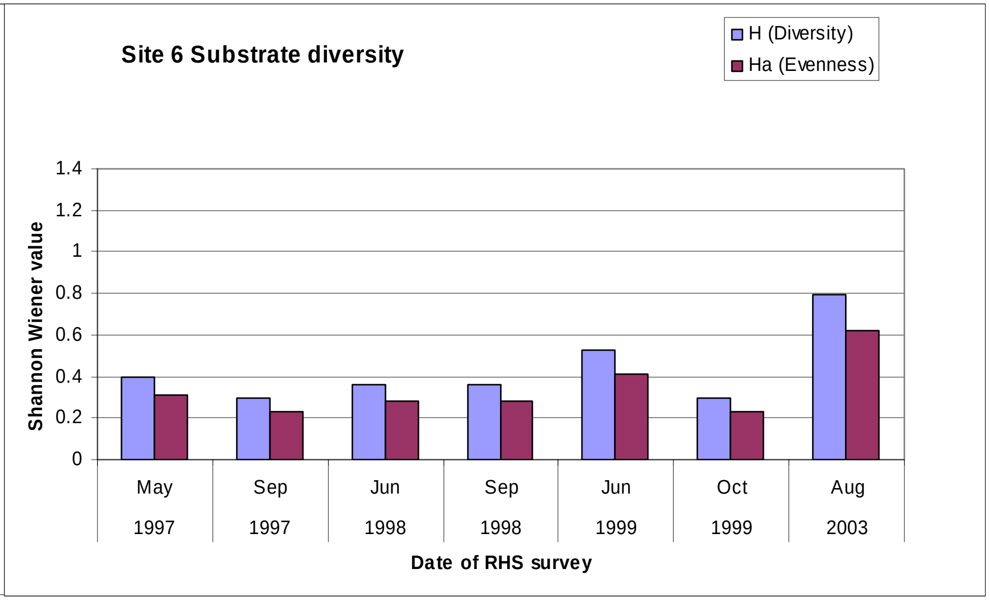
i.


Site 5 Substrate diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Aug 2003
Date of RHS survey

j.


Site 6 Flow diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Aug 2003
Date of RHS survey

k.


Site 6 Substrate diversity
H (Diversity)
Ha (Evenness)
Shannon Wiener value
1.4
1.2
1
0.8
0.6
0.4
0.2
0
May 1997
Sep 1997
Jun 1998
Sep 1998
Jun 1999
Oct 1999
Aug 2003
Date of RHS survey

l.