Review of Impact Assessment Tools and Post Project Monitoring Guidance

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Clients

SEPA

Authors

Dr. Kevin Skinner
(Haycock Associates Limited)
Professor Colin Thorne
(Nottingham University Consultants Limited)

Tel; + 44 (0)1386 556004
Fax; + 44 (0)1386 556004
enquiries@haycock-associates.co.uk
www.haycock-associates.co.uk
Haycock Associates Limited,
Red Roof, Wick Road, Little Comberton
Pershore, WORCS, WR10 3EG
Reg. in England No. 03934665
Vat No. GB 658 1644 14

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1) INTRODUCTION

1.1) Background to project

The Water Framework Directive (WFD) has necessitated that a new set of requirements be developed for the management of rivers in all member states. SEPA's Engineering Task Team is working on the implementation of the new regulations to control building, engineering and other works in, or in the vicinity of, inland surface waters (including rivers, lochs, canals and wetlands). These new regulations will form part of the Water Environment and Water Services (Scotland) Act, which transposes the EU Water Framework Directive in Scot's law, and are due to come into force in April 2006. The appropriate level of regulatory control required for particular works is primarily dependent upon the risk of the proposed activity. Once a risk assessment of an activity is undertaken works will be classified accordingly. Three outcomes are possible at this stage. The first is that the works are simply registered. This category will encompass activities that are of low risk. The second possibility is that a simple licence will be provided that will incorporate a standard set of conditions. This category will include projects that have a slightly increased risk and may, potentially, require further impact assessments. Finally, a complex licence will be provided. These types of project will have higher risks and are likely to require further work to determine the level of impact of the proposed activity.

The main objective of this project is to review existing knowledge and provide guidance to SEPA staff on geomorphic impact assessment and post project monitoring methods. It aims to deliver the tools necessary to determine the potential risk of any proposed measures and thus aid in the determination of the appropriate level of control, focusing on activities that will require either a simple or complex licence. The specific aims of this project are thus to deliver:

1. A review of existing impact assessment tools and post project monitoring methods available in the field of river geomorphology;
2. an assessment of their appropriateness for use in a regulatory context, and
3. a scoping exercise of further work required to develop detailed staff guidance in the use of available tools and methods.

1.2 Role of geomorphology in river management in the UK

The need to account for geomorphology in river engineering and management in the UK emerged during the 1990s. This resulted through a combination of i) the outcomes of schemes that produced unexpected and unwelcome morphological impacts, ii) applied research in fluvial geomorphology at UK universities and, iii) the engagement of geomorphologists as consultants on a variety of project-related and strategic research and development investigations. The academic basis for geomorphological studies in the UK and the type of work performed during this period are exemplified in ' Applied Fluvial Geomorphology for River Engineering and Management' (Thorne et al. 1997). Experience in the UK has demonstrated that, not only do schemes that work with rather than against the natural processes and forms of a stream produce fewer negative impacts, but they may also require less intensive operational maintenance and are therefore generally more sustainable (Newson *et al.*, 1997).

Many of the methods and techniques developed to support standardised approaches to geomorphological investigations are detailed in the 'Guidebook of Applied Fluvial Geomorphology' (Sear *et al.*, 2003). Geomorphologic adjustments can occur over a variety of scales in time and space (Figure 1). As a result of this fact a particular characteristic of geomorphological investigations is that they may extend over substantial portions of the river catchment when the scale or extent of the proposed project is large and geomorphological responses are possible in the fluvial system that are wide scale or long-term.

Given the recognised importance of geomorphology it is essential that SEPA is able to judge the potential for engineering and management activities along or near rivers to generate geomorphological impacts. This requires that SEPA staff are cognisant with the necessary knowledge base and tools for geomorphic impact assessment and post project monitoring, so that they can determine the appropriate level of control for any proposed engineering or management project.

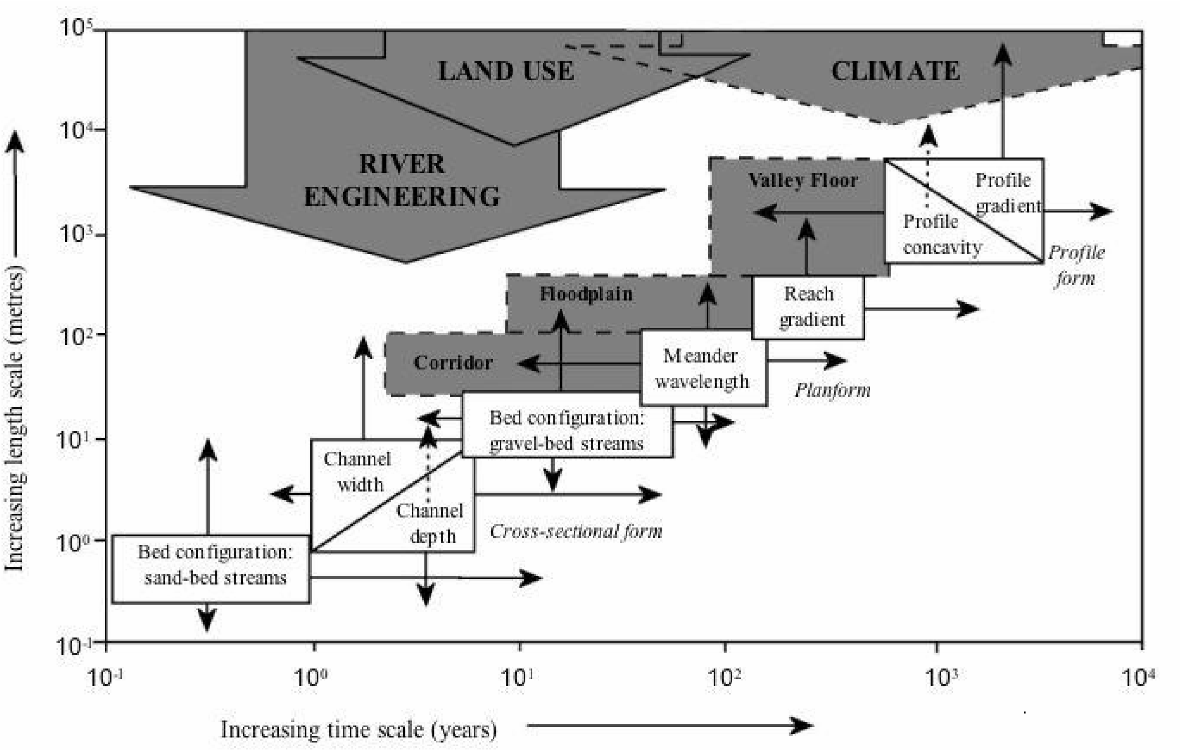


Figure 1: Time and space scales for adjustments of the fluvial system (adapted from Knighton, 1998)

Further Reading

Newson, M.D., Hey, R.D., Bathurst, J.C., Brookes, A., Carling, P.A., Petts, G.E. and Sear, D.A., 1997, Case Studies in the Application of Geomorphology to River Management, in Thorne, C.R., Hey, R.D. and Newson, M.D. (eds.), *Applied Fluvial Geomorphology for River Engineering and Management*, John Wiley and Sons, Chichester, UK, 311-363.

Sear, D.A., Newson, M.D., Thorne, C.R., 2004, Guidebook of Applied Geomorphology, Defra/Environment Agency Flood and Coastal Defence R&D Programme, R&D Technical Report FD1914, DEFRA, London. (Downloadable free from http://www2.defra.gov.uk/research/project_data/More.asp?I=FD1914&M=KWS&V=fd1914&SUBMIT1=Search&SCOPE=0)

Thorne, C.R., Hey, R.D. and Newson, M.D. (eds), 1997, *Applied Fluvial Geomorphology for River Engineering and Management*, John Wiley and Sons, Chichester, 384p.

2.0) APPRAISAL OF CURRENT PRACTICE IN SCOTLAND (CONTRIBUTION FROM DR DAVID GILVEAR, UNIVERSITY OF STIRLING)

2.1) The legislative framework for river engineering activities

Regulation of gravel removal, dredging, channel construction and diversion, re-sectioning, in-stream structures and bank protection for the most part has fallen on the local planning authorities. The current regulatory system is complicated and in many cases has been inadequate and failed to prevent, (and indeed in some cases encouraged) activities that have damaged the quality of physical habitats and, by inference, the ecology of natural watercourses in Scotland. Thus, dredging and re-sectioning, small-scale bank protection works and gravel removal have gone ahead unregulated and often noticed. It seems the only place where dredging, re-sectioning, bank protection works and gravel removal has been prevented is at SSSIs and, more recently, cSACs where SNH have taken a strong line. The level of regulation and awareness of the risk to nature associated with activities that are potentially damaging to river morphologies and habitats also vary considerably between regions, as Planning Authorities exercise their own judgements and on a case by case basis. Overall, the regulatory framework has been one of consultation rather than prescribing activities that are allowed or prohibited.

The following Acts and Regulations are those that have historically been directly relevant with regard to the regulation of river engineering and management activities in Scotland.

- The Town and Country Planning (Scotland) Act 1997
- The Town and Country Planning (General Permitted Development) (Scotland) Order 1992
- The Environmental Impact Assessment Regulations Scotland 1999
- Wildlife and Countryside Act 1981
- Environmental Protection Act 1990
- Flood Prevention and Land Drainage Act 1997
- The Conservation (Natural Habitats and Species) Regulations 1994
- The Salmon Fisheries (Scotland) Act 1868

Most recently, the Water Environment and Water Services Bill (2003) came into force, but the precise implications of this Bill for river engineering activities are still emerging. Interwoven with these various pieces of legislation is statutory and advisory consultation. The key players in with respect to consultation are the Planning Authorities (Development Control), Local Authorities (Nature Conservation and Flood Management), District Salmon Fisheries Boards, SEPA, SNH, Historic Scotland and adjacent landowners.

2.2) Current practice (gravel removal, dredging, channel construction and diversion, re-sectioning, in-stream structures and bank protection)

Generally, any river work in Scotland involving use of mechanical plant for excavation or construction will fall within the definition of ‘engineering operations’ and planning permission will be required unless the work is considered ‘permitted development’, as defined in the Town and Country Planning General permitted Development (Scotland) Order 1992. Recent examples of activities requiring planning permission include re-diversion of the River Nith, Ayrshire in 2004 and reinstatement of the Abbey Burn, Midlothian in 2005. The Local Authority should also be notified in connection with any other works which change the direction or speed of water flow, have the potential to generate scour (such as croys), involve river training, include bridge construction or where channelisation will reduce floodplain storage. Typically, assessment of these activities has been undertaken by engineering staff in “Transportation and Infrastructure”, whose main concern has been the free passage of water. The Scottish Executive has, however, now provided guidance to planning authorities on national policy with respect to watercourses. Consequently, Scottish NPPG

14 “Planning and the Natural Heritage” promotes watercourses as “both valuable landscape features and wildlife habitats” for which planning authorities should “seek to safeguard their natural heritage value”.

Local authorities often look to SEPA as the major consultee in the process of providing advice on whether a proposed activity will be damaging to the environment. For example, SEPA were consulted in connection with the River Nith re-diversion in 2004, and provided recommendations that the proposers were, in effect, required to accept in order to obtain planning permission. Often, however, SEPA’s main concern has been to determine whether or not a proposed activity is likely to cause pollution, with less attention being paid to the potential for morphological impacts and responses. The Control of Pollution Act (1974) has long given SEPA the power to protect rivers from pollution. However, following passage of the Water Environment and Water Services Bill, SEPA are now also the lead agency with statutory responsibility for overseeing river engineering activities. Under the Bill, Catchment Management Plans will also have to be drawn up. In this context, plans have already been drawn up for the Rivers Spey and Nith and these have gone out to the public for consultation.

Another key player in the consultation process is often the District Salmon Fisheries Board, since this organisation has powers to take action against anyone found to have caused the wilful destruction or disturbance of salmon spawning beds under the Salmon Fisheries (Scotland) Act 1868. The Salmon (Fish Pass and Screens) (Scotland) Regulations (1994) also require the land owners or occupiers to ensure free passage of migratory fish both upstream and downstream. Much of the legislation is wrapped around fisheries laws drawn up for individual catchments. For example, under the Tweed Fisheries Acts of 1857 and 1859 it is an offence to carry out works that will result in “the destruction, injury, disturbance of juvenile salmon, sea trout, fry and spawning beds”. Thus the guidance (Figure 2) given by the Tweed Forum for alteration to rivers and river banks in the Tweed catchment is:

a) Consult SEPA for advice on avoiding pollution

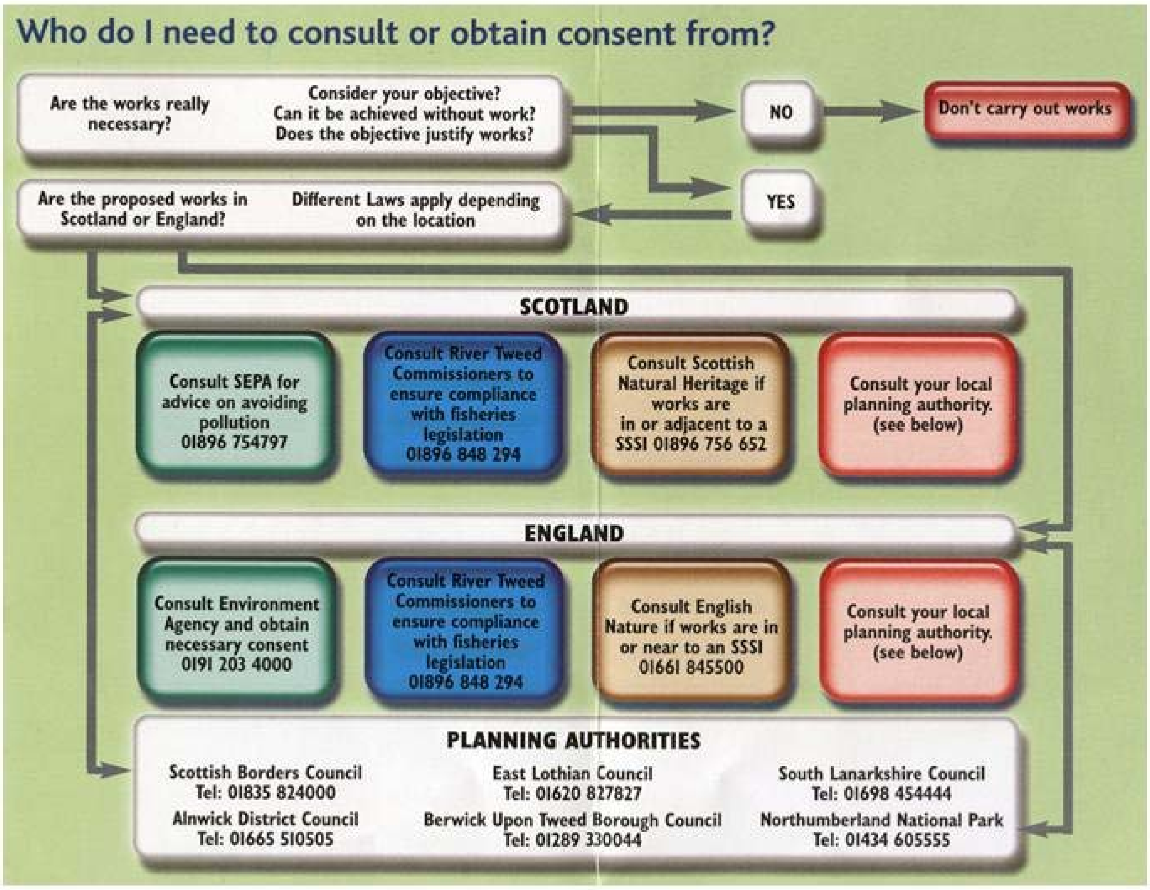
b) Consult Scottish Natural Heritage if works are in or adjacent to a SSSI

c) Consult Tweed Commissioners to ensure compliance with fisheries legislation.

Where a proposed engineering activity lies close to and may affect an SSSI, written consent must be obtained from SNH since it is highly likely the activity will be listed as a ‘Potentially Damaging Operation’. SNH would also need to be consulted on any works that may impact on a site with a designation or proposed European site (SAC or SPA) under European Union law and, often, there will be restrictions on activities permitted. Written consent is also required from Historic Scotland where river works may affect the integrity of a Scheduled Ancient Monument.

In Scotland the law regarding flooding is also significant in that it puts the prime responsibility for safeguarding land or property against flooding. Under the Flood Prevention and Land Drainage Act 1997 discretionary powers are given to Local Authorities to carry out, in non-agricultural areas, works of maintenance to reduce the likelihood of flooding. Indeed, this Act recognises that regular maintenance of water courses can contribute significantly to the prevention or mitigation of flooding. While local flood risk impacts at the location of a proposed activity are considered, the downstream consequences for flood risk are seldom considered. Instances of river engineering unsympathetic to the river environment following flooding have occurred, for example, on the River Tummel system in Perthshire as recently as 2003. SEERAD (Scottish Executive Environment and Rural Affairs) exercises control over non-agricultural areas, which are grant aided with the exception of emergency flood bank repairs. They, however, do not regulate non-grant aided works. In this regard, the Town and Country Planning (General Permitted Development)(Scotland) Order 1992 allows excavation and engineering in rural areas for agricultural purposes, including repair of river banks and any other works designed to prevent flooding and further erosion if this is necessary for the benefit of the agricultural use of the land. For example, dredging on the Allan Water near the village of Braco in Stirlingshire has occurred regularly to allow free passage of water from land drains. Given that undisturbed river banks and bank erosion are integral features of natural watercourses this Order of General Permitted Development could potentially be a serious impediment to rural streams and rivers achieving good ecological status. Indeed, part 6 class 20 permits *any* riparian owner to carry out works required in connection with the improvement or maintenance of the watercourse, with the Council determining what constitutes ‘improvement and maintenance'. The right of the owner to Permitted Development can, however, be lost if the Planning Authority so deems and then an Environmental Impact Assessment becomes necessary under the relevant Environment Impact Assessment Regulations (Scotland) 1999.

Figure 2: Guidance given in leaflet given by the Tweed Forum to riparian owners



2.3) Appraisal of the effects of river engineering activities

The use of river surveys, such as RHS and Fluvial Audit, prior to works and application of appraisal techniques following completion has been, to date, virtually unknown in Scotland. A national RHS inventory, together with more intensive surveys at locations such as Glen Clova and the River Tweed, has been undertaken, but not with any intention that the baseline information so established can be used to appraise the potential impacts of river engineering schemes. With respect to project-driven surveys, one of the first Fluvial Audits to be proposed has only recently gone out to tender for the River Clova, where over-grazing and engineering works have been cited as possible causes leading to degradation of Atlantic Salmon and freshwater pearl mussel habitats. The only examples of project-centred appraisals that can be cited are isolated cases such as an appraisal of the effects of dredging on the River Endrick for SNH performed by Dr Lindsey McEwan of University College Cheltenham, and appraisal of the River Nith diversion in 2000, by the School of Biological and Environmental Sciences at Stirling University. In the realm of computer modelling, iSIS and Mike 21 have both been employed by engineering consultants as aids to designing major river diversions and flood protection works. However, the context for use of these powerful computational techniques has been engineering design rather than morphological appraisal.

2.4) Geomorphic appraisal, channel typology and river engineering in Scotland

No standard approach has been adopted in Scotland with regard to assessing the geomorphic impacts of river engineering activities and information is also scarce on post-impact geomorphological appraisal. A good appraisal on environmentally sound river engineering in relation to the Scottish environment was produced by Hoey *et al.* (1995). The few good Scottish examples of post project appraisal include:

- A research study of the impact of dredging on a species is the study of the freshwater pearl mussel in relation to river management by Cosgrove and Hastie (2001).
- A research investigation by Gilvear (2004) to examine geomorphological changes below the Spey Dam. The primary approach here was to measure changes in water and active gravel width over time as depicted on aerial photographs.
- A case study by Gilvear and Bradley (1997) concerning geomorphic adjustment of a newly engineered river diversion following a large flood.

Werritty *et al.* (1994) identified river management and engineering as a threat to freshwater geomorphic heritage via destruction of active and relict landforms, disruption of active processes and potential for fundamental change in process regime. With regard to the degree of potentially damaging operations on individual, relict landforms and relict landform assemblages, increasing impacts were assigned to a scale of 1 (lowest) to 5 (highest). Werritty *et al.* (1994) also distinguished theoretically between fluvial systems that are robust and those that are likely to be sensitive to potentially damaging operations. This concept of channel sensitivity on Scottish streams was also taken up by Werritty and Leys (2001). In practice, identifying the sensitivity of a system is difficult and predicting (or even determining) the behaviour of sensitive systems is a complex undertaking.

Recently, Chris Soulsby at the University of Aberdeen produced a comprehensive but unpublished typology for SEPA, based on an earlier effort by Lindsey McEwan in 1998. This utilises the well known Montgomery and Buffington typology (1997), which can be used to appraise the sensitivity of differing channel types to river engineering threats. In this approach, eight river types were identified and the potential impacts of a range of river management activities suggested (Flood management; Fisheries management; Channelisation; River re-alignment; Gravel extraction; Road crossings and culverts; Riparian management and Impoundment). This approach could be further developed in order that much of the typology could be automated using GIS and remotely sensed data. Such an approach seems a sensible way forward for Scotland, where the Montgomery and Buffington (1997) approach is more suitable that other typologies, such as the river styles approach.

For non-specialists wishing to learn more about river typology for engineering and management, the Farming and Watercourse Management Handbook (produced in 1998 with support from WWF Scotland, FWAG, SAC and SEPA) provides a good summary of the linkage between geomorphology, river management activities and impacts on river channel behaviour.

2.5) Recommended Reading

Cosgrove, P.J. and Hastie, L.C., 2001, Conservation of threatened freshwater pearl mussel populations: river management, mussel translocation and conflict resolution, *Biological Conservation*, **99**, 183-190.

Gilvear, D.J., 2003, Spatial and temporal patterns of channel adjustment to impoundment on the Upper River Spey, Scotland (1942-2000), *River Research and Applications*, **19**, 34-49.

Gilvear, D.J. and Bradley, S., 1997, Geomorphic adjustment of a newly constructed ecologically sound river diversion on an upland gravel bed river; Evan Water, Scotland, *Regulated Rivers*, **13**, 1-13.

Hoey, T.B., Smart, D.W.J., Pender, G. and Metcalfe, N., 1995, *Alternative methods of river management for Scottish rivers,* SNH Report, SNH/045/95 ESB.

Montgomery, D.R. and Buffington, J.M., 1997, Channel reach morphology in mountain drainage basins. *Geological Society of America Bulletin,* **109**, 596-611.

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Werritty, A. and Leys, K., 2001, The sensitivity of Scottish rivers and upland valley floors to recent environmental change, *Catena*, **42**, 251-273.

Werritty, A. and Brazier, V., 1992, Geomorphic sensitivity and the conservation of fluvial geomorphology SSSIs. In Stevens, C., Gordon, J.E., Green, C.P. and Macklin, M.G. (Eds), *Conserving our Landscape*, Crewe, 100-110.

Werritty, A., Brazier, V. Gordon, J.E. and McManus, J., 1994, Geomorphology, In Maitland, P.S., Boon, P.J. and McClusky, D. (Eds), *The Freshwaters of Scotland,* Wiley, 65-88.

3) AN ASSESSMENT OF THE APPROPRIATENESS OF DETAILED GEOMORPHIC TECHNIQUES IN ASSESSING THE IMPACT OF VARIOUS ACTIVITIES

3.1) Introduction

SEPA have two key stages in the determination of an engineering authorisation proposed under the new WFD. The first is to undertake a risk assessment to determine the appropriate level of control (from simple registration to full licence). Secondly, an impact assessment should be undertaken to determine the likely risk associated with an application and set appropriate licence conditions. This would normally be reserved for high risk activities which will be subject to full licences.

There are a variety of geomorphological tools that could be used to determine potential impacts of any proposal. Each of these techniques are reviewed in detail in Appendix 1 and an evaluation of which techniques are most relevant to assess individual activities are reviewed below in section 3.2.

3.2 Review of geomorphic techniques and their suitability in assessing the impact of a variety of activities

The geomorphological techniques that can be used for impact assessment can be broadly split into four categories, namely those that are desk/field, field, field/modelling and modelling based. The techniques that will be reviewed in this report are detailed in Table 1. These different techniques can be used at various scales in the catchment. The appropriateness of the technique is related to the scale of the features that are being examined. A geomorphological assessment procedure was developed (see Figure 3) as part of the Environment Agency document detailing river geomorphology as early as 1998 (Environment Agency, 1998). This diagram (Figure 3) outlines several of techniques and illustrates how they can be used to fit different scales of assessment. In this report the desk-based approaches, like the RHS and the GeoRHS, are unlikely to be commissioned solely to assess the impact of an individual project. They are strategic rather than project-based tools, but would provide important background information on the state of the river at the location of interest. As a result they are largely used as a compliance tool and are often performed at a catchment level. The catchment baseline survey procedure has large desk and field based components and thus fits in between the desk and field based techniques. The catchment sediment budget uses a mixture of quantitative and qualitative techniques to estimate the amount of sediment eroded from the basin that drains to a river, the proportion of eroded material that is delivered to the drainage network (delivery ratio) and the proportion of the sediment load that is deposited on floodplain surfaces during overbank events. The fluvial audit is largely field based (but possesses a desk component) and focuses on developing a catchment level understanding of the sediment dynamics. Once the focus is narrowed to a reach scale other field-based techniques, such as the geomorphological dynamics assessment, river reconnaissance, gravel mining assessment and bank protection assessment methodologies can be more suitable. The modelling techniques (namely, SAM, SIAM, iSIS, iSIS sediment and MIKE 21) are all suitable at this level, although SIAM, iSiS and iSIS sediment have the potential to used at a larger scale.

Table 1: Geomorphological techniques that can be used to assess impacts

Category	Technique
Desk/Field	GeoRHS
	Catchment Baseline Survey
	Fluvial Audit
Field	River Habitat Survey
	River Reconnaissance
	Fluvial Dynamics Assessment
	Bank Assessment Methodology
	Sand/Gravel Mining Assessment
Field/ Modelling	Catchment sediment budget
Modelling	Stable Assessment Methodology (SAM)
	Sediment Impact Assessment Method (SIAM)
	One-dimensional flow modelling using iSIS
	One dimensional flow and sediment modelling using iSIS Sediment
	Two-dimensional flow and sediment modelling using MIKE 21
	Three-dimensional flow and sediment modelling

A series of spreadsheets has been prepared to document how applicable certain techniques are to various categories of activities in rivers in Scotland. The list of activity categories and types were provided by SEPA. The spreadsheets are illustrated in Tables 2-3. Of all the techniques reviewed there is a noticeable scaling/complexity issue with type of activity against the number of geomorphological techniques appropriate to assess the activity (see Figure 4). In small-scale activities, such as a ford crossing, the impacts are likely to be local and thus it is appropriate that a technique such as river reconnaissance is used to assess the issue. Conversely, if there were a proposal to design a reservoir impoundment, or a large channel diversion scheme, then it would be necessary to employ a range of geomorphological techniques which encompass larger scale work, such as the Fluvial Audit and ISIS modelling. It is important to note that as scale of the study increases certain techniques become more suitable. For example, the geomorphological reconnaissance technique is excellent for reach scale studies but if a large catchment scale assessment is required then the fluvial audit would be more appropriate methodology to use.

There is a need to balance the requirements of the registration/licensing procedure with the use of relevant geomorphological techniques to promote compliance with the new procedures. If the demands were set too high for particular activities then it is possible that applicants might choose to ignore the new permitting procedure. This is of increased risk in Scotland as a licensing procedure of this type has never been required previously.

A standardised approach was used for completing each of the spreadsheets. Three symbols were used, namely a tick, a cross and an asterisk. A tick indicates a technique that is relevant for use in assessing the impact of a particular activity. Conversely, a cross suggests that the technique is not useful for assessing the impact of a particular activity. If an asterisk is present then the technique could be useful for assessing a particular activity under some circumstances, for example if the proposed project were to be located in a particularly sensitive location or where the sediment-related issues are likely to be significant.

Figure 3: Geomorphological Assessment (adapted from Environment Agency, 1998)

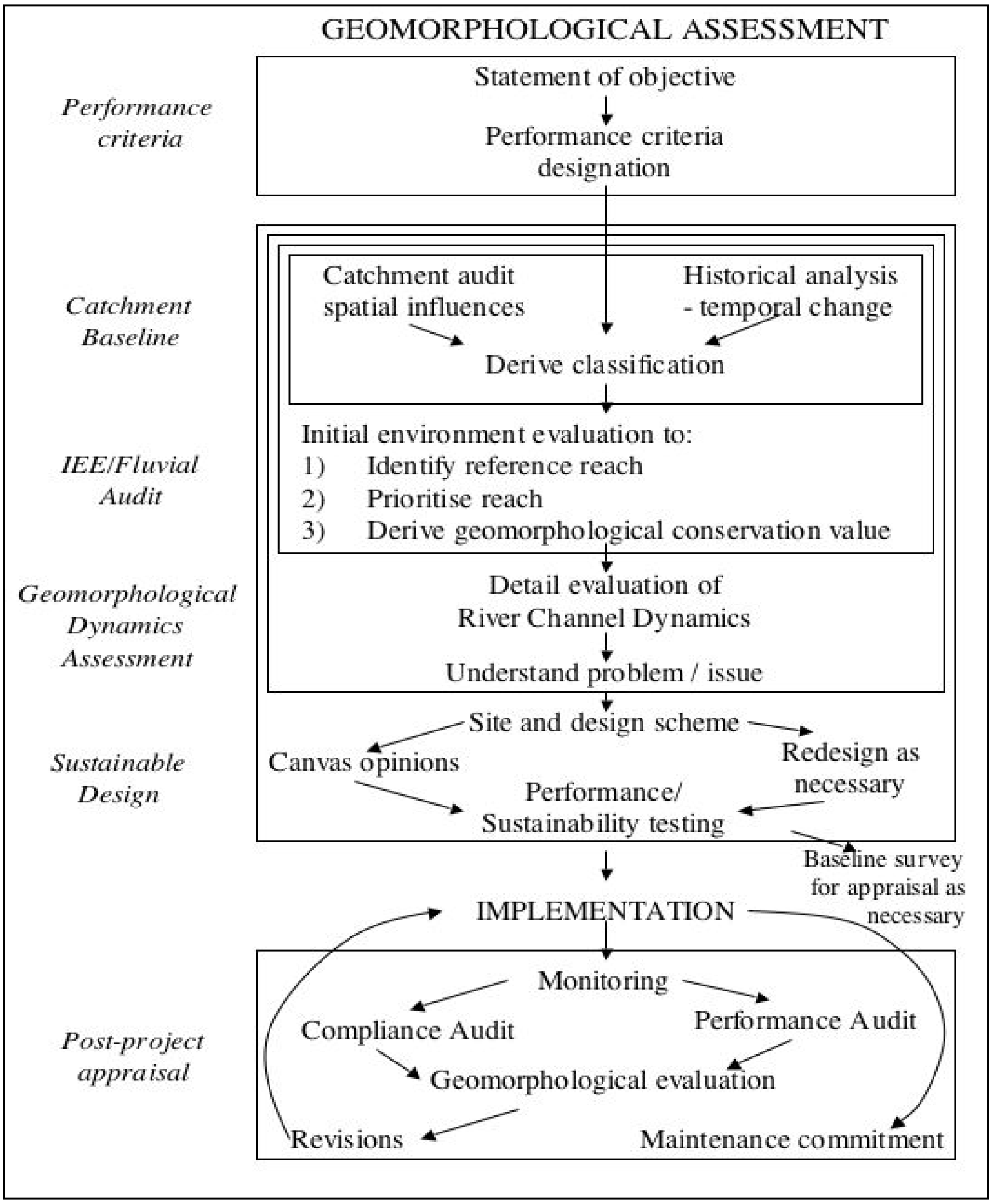

Figure 4: Scale of activity against number of geomorphological techniques available

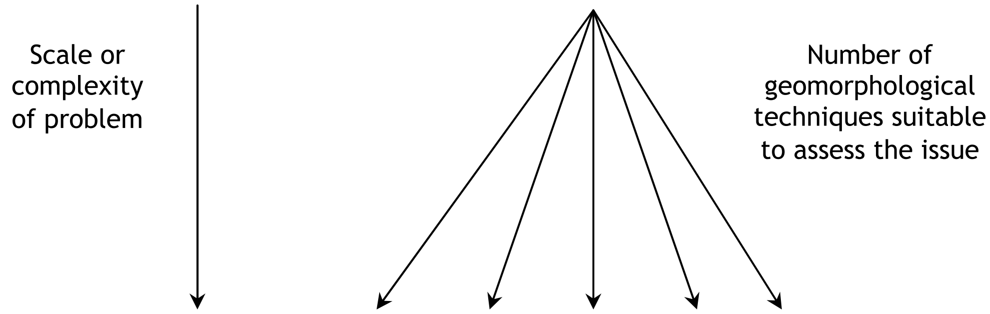

Table 2: Suitability of impact assessment techniques (Part 1)

		Technique					
		Desk/Field			Field		
Activity Category	Activity Type	GeoRHS	Catchment Baseline Survey	Fluvial Audit	River Habitat Survey	River reconnaissance	Fluvial Dynamics Assessment
River Crossings	Bridges	✓	✕	✕	✓	✓	*
	Bridging Culverts	✓	✕	✕	✓	✓	*
	Fords	✓	✕	✕	✓	✓	✕
	Pipelines/Cable crossings	✓	✕	✕	✓	✓	*
In-Stream Structures	Piers/Jetties/Platforms	✓	✕	✕	✓	✓	*
	Boat Slips	✓	✕	✕	✓	✓	*
	Boulder Placements	✓	✕	✕	✓	✓	✕
	Croys/Flow Deflectors	✓	✕	✕	✓	✓	✕
	Outfalls/Intakes	✓	✕	✕	✓	✓	✕
Impoundments	Un-managed Weirs	✓	✕	*	✓	✓	✕
	Managed Weirs	✓	✕	*	✓	✓	✕
	Reservoir Impoundments	✓	✓	✓	✓	✕	✕
	Flood Management Impoundments	✓	✓	✓	✓	✕	✕
Channel Modifications	Realignment	✓	✕	✓	✓	✕	✕
	Resectioning	✓	✕	✓	✓	✕	✕
	Culverting	✓	✕	✓	✓	✕	✕
	Permanent Diversions	✓	✕	✓	✓	✕	✕
	Straightening	✓	✕	✓	✓	✕	✕
	Remeandering	✓	✕	✓	✓	✕	✕
	By-Pass Channels	✓	✕	✓	✓	✕	✕
Sediment Management	Sediment Traps	✓	✕	✓	✓	✕	✕
	Dredging	✓	✕	*	✓	✓	✕
	Pool Maintenance	✓	✕	✕	✓	✓	✕
	Aggregate/Mineral Extraction	✓	✕	✓	✓	✕	✕
	Desilting	✓	✕	✕	✓	✓	✕
Bank Modifications	Bank Protection	✓	✕	✕	✓	✓	✕
	Outfalls/Intakes	✓	✕	✕	✓	✓	✕
	Side Weir	✓	✕	✕	✓	✓	✕
	Bank Re-profiling without Reinforcement	✓	✕	✕	✓	✓	✕
	Bank Re-profiling with Reinforcement	✓	✕	✕	✓	✓	✕
	Floodwalls	✓	✕	✕	✓	✓	✕
Developments in the vicinity of River	Set-back embankments	✓	✕	✕	✕	✓	✕
	Off-line Storage	✓	✕	✕	✕	✓	✕
	Pipelines	✓	✕	✕	✕	✓	✕
	Marinas	✓	✕	✕	✕	✗	✕
	Housing Developments	✓	✕	✕	✕	✗	✕
	Commercial Developments	✓	✕	✕	✕	✗	✕
	Infrastructure	✓	✕	✕	✕	✗	✕

Note: The bank assessment methodology is used specifically for assessing bank modifications and thus is the most suitable technique for this purpose. Likewise, the sand/gravel assessment mining assessment is the most suitable technique for assessing the impacts of aggregate/mineral extraction and dredging.

Table 3: Suitability of impact assessment techniques (Part 2)

		Technique					
		Field/Modelling	Modelling				
Activity Category	Activity Type	Catchment sediment budget	SAM	SIAM	1D Flow Modelling using iSIS	1D Flow and sediment Modelling using iSIS sediment	2D Flow and sediment modelling using MIKE 21
River Crossings	Bridges	✗	✗	✗	✗	*	✗
	Bridging Culverts	✗	✗	✗	✗	✗	✗
	Fords	✗	✗	✗	✗	✗	✗
	Pipelines/Cable crossings	✗	✗	✗	✗	*	✗
In-Stream Structures	Piers/Jetties/Platforms	✗	✗	✗	✗	✗	✗
	Boat Slips	✗	✗	✗	✗	✗	✗
	Boulder Placements	✗	✗	✗	✗	✗	✗
	Croys/Flow Deflectors	✗	✗	✗	✗	✗	✗
	Outfalls/Intakes	✗	✗	✗	✗	✗	*
Impoundments	Un-managed Weirs	*	✗	✗	*	✗	✗
	Managed Weirs	*	✗	✗	*	✗	✗
	Reservoir Impoundments	✓	✗	✓	✓	✓	✓
	Flood Management Impoundments	*	✗	✓	✓	✓	✓
Channel Modifications	Realignment	*	✓	✓	*	*	*
	Resectioning	*	✓	✓	*	*	*
	Culverting	*	✓	✓	*	*	*
	Permanent Diversions	*	✓	✓	*	*	*
	Straightening	*	✓	✓	*	*	*
	Remeandering	*	✗	✓	*	*	*
	By-Pass Channels	*	✓	✓	*	*	*
Sediment Management	Sediment Traps	✓	✗	✓	✗	*	✗
	Dredging	*	✗	✓	✗	*	*
	Pool Maintenance	✗	✗	✗	✗	✗	✗
	Aggregate/Mineral Extraction	✓	✗	✓	✗	*	*
	Desilting	✗	✗	✗	✗	✗	✗
Bank Modifications	Bank Protection	✗	✗	*	✗	✗	✗
	Outfalls/Intakes	✗	✗	✗	✗	✗	*
	Side Weir	✗	✗	✗	✗	✗	*
	Bank Re-profiling without Reinforcement	✗	✗	✗	✗	✗	✗
	Bank Re-profiling with Reinforcement	✗	✓	*	✗	✗	✗
	Floodwalls	✗	✗	✗	✗	✗	✗
Developments in the vicinity of River	Set-back embankments	✗	✓	✗	✗	✗	*
	Off-line Storage	✓	✗	✓	✓	*	*
	Pipelines	✗	✗	✗	✗	✗	✗
	Marinas	✗	✗	✗	✓	*	✗
	Housing Developments	*	✗	✗	✓	*	✗
	Commercial Developments	*	✗	✗	✓	*	✗
	Infrastructure	✗	✗	✗	✓	*	✗

3.2.1 River Crossings

River crossings are likely to have only local impacts and thus techniques such as the river reconnaissance survey would be most suitable for assessing the likely impacts that might occur. River Habitat Surveys and the GeoRHS could also be useful in providing background information on the state of the river system. However, river reconnaissance is likely to be the most suitable technique for a local survey as it offers the opportunity to record spatially referenced data over the reach in question and is adaptable to assess the specific aims and designs of a particular project. A fluvial dynamics assessment could be valuable in locations that are particularly sensitive relating to bridges, bridge culverts and pipeline/cable crossings. The only modelling technique that could prove useful in assessing impacts is ISIS sediment. However, this is limited to assessing bridges and pipelines/cable crossings.

3.2.2 In-stream Structures

In general, in-stream structures are likely to have only local scale effects and thus techniques such as the river reconnaissance survey are likely to be most suitable for assessing each of the activity types. As with the river crossings the RHS and the GeoRHS will provide useful background data but are unlikely to be commissioned in connection with a particular project-related issue. A fluvial dynamics assessment could be valuable in locations that are particularly sensitive to change with respect to the activities of piers/jetties/platforms and boat slips. Of the modelling techniques available, ISIS sediment can be used to assess impacts in sensitive locations. MIKE 21 can be used to assess the potential impacts on outfalls/intakes where complex flow patterns are expected and/or the sediment loading is likely to be high.

3.2.3 Impoundments

A variety of techniques can be used to assess the impact of impoundments. As impoundments are likely to have significant implications for the catchment sediment system, fluvial audits are generally recommended. However, in the case of small weirs (managed and unmanaged), where potential impacts are less significant, impacts could be assessed effectively using river reconnaissance. The RHS and GeoRHS can be valuable tools to aid an assessment, but are unlikely to be commissioned specifically for this purpose. A catchment baseline survey could be commissioned to assess both the impacts of reservoir impoundments and flood management impoundments. Specifically, the capability of the catchment baseline survey to assess the conservation of the channel will prove useful in assessing any proposed siting of the structure, but would generally need to be undertaken alongside a fluvial audit. Most of the modelling methods can be used to assess the impacts of reservoir impoundments and flood management impoundments. Only SAM does not have any use in this regard. In contrast, of the techniques included here, only ISIS can help to assess the impacts on managed or unmanaged weirs.

3.2.4 Channel Modifications

In the case of any significant channel modifications it is recommended that a fluvial audit is undertaken to assess impacts, rather than a river reconnaissance, since such an intervention of this type can have major impacts on the catchment sediment system. The RHS and the GeoRHS would be valuable in assessing the baseline conditions, but would be unlikely to be commissioned in response to a particular proposed channel modification. Of the modelling techniques, SAM (except for remeandering) and SIAM can be used effectively to assess morphological impacts. The other modelling procedures, such as ISIS, ISIS sediment and MIKE 21 could be used for all activities when the scheme justifies the necessary investment of time and effort because the scale is large or the sediment loading is significant.

3.2.5 Sediment Management

The range of applicable techniques that can be used to assess sediment management activities is largely dependent on the scale of the activity. The fluvial audit is recommended for assessing aggregate/mineral extraction and sediment traps because of their likely large-scale impacts. In contrast, river reconnaissance is recommended for assessing both pool maintenance and desilting as both are only likely to have local impacts. A fluvial audit or river reconnaissance is recommended for dredging and the choice of technique is dependent on the scale of activity. Both the RHS and the GeoRHS should be referred to if available although neither is likely to be commissioned independently. In addition, the NOAA Fisheries gravel mining assessment guide would be valuable for assessing the impacts both to dredging and aggregate/mineral extraction. Of the modelling techniques covered here, SAM can be used to assess dredging and aggregate/mineral extraction activities; SIAM for assessing sediment traps; as well as ISIS sediment and MIKE 21, where the sediment loading is high and sediment-related issues are significant.

3.2.6 Bank Modifications

Morphological impacts associated with bank works can be partially assessed using the bank assessment methodology. However, this is designed primarily to assist engineers in selecting appropriate bank protection solutions and only partly concerns assessment of the impacts of the scheme on channel morphology. River reconnaissance techniques could, therefore, also prove helpful. The bank guide does not deal specifically with assessment of the impact of a side weir and in such cases a river reconnaissance would certainly be needed. Both the RHS and GeoRHS can prove valuable in providing background information. Of the modelling techniques, SAM and SIAM (if sediment loadings are significant) can be used to assess the impact of bank re-profiling without reinforcement. MIKE 21 can be used to assess the impacts of both side weirs and outfalls/intakes if the scale or complexity of the scheme merits the necessary investment of time and effort.

3.2.7 Developments in the Vicinity of River

Only a few of the techniques reviewed are useful in assessing the potential impacts of developments in the vicinity of a river. In this case, the GeoRHS could potentially be used as it includes a floodplain component that could be used to review some of the potential implications with respect to location to the river and flooding risk. The river reconnaissance technique is valuable in assessing the impacts of set-bank embankments, off-line storage and pipelines. The RHS would not be applicable in any form in this circumstance. Of the modelling procedures available ISIS is perhaps the most adaptable and can be used to assess impacts in each activity except set-bank embankments and pipelines. ISIS with the sediment modelling component could also be effective with each of these activities if the sediment input was significant. SAM can be used to assess set-bank embankments and SIAM for off-line storage. MIKE 21 could also be effective in assessing the impacts of both the set-bank embankments and off-line storage.

4.0) A REVIEW OF THE SUITABILITY OF GEOMORPHIC TECHNIQUES IN MONITORING A VARIETY OF ACTIVITIES

4.1 Introduction

Monitoring of a scheme can be very useful not just for evaluating the scientific value, or success, of the project but it is increasingly necessary for compliance. The first stage in developing a monitoring programme is to determine what to measure in light of the objectives of the scheme and the potential for morphological impacts both on and off-site. This will help guide both the spatial and temporal resolution of the monitoring programme and what techniques to use. For example, if a morphological response involving accelerated bank erosion was anticipated and this was a particular concern than a strategy would need to be developed that could effectively monitor the rate of bank retreat. This might require several cross-sections along a reach to be measured to determine the spatial extent of this erosion. The additional component is to determine the frequency of the sampling that is required to adequately monitor changes through time. It would be expected that morphological response would occur soon after the implementation of a project as the system adjusts to the new conditions at the reach. As a result the frequency of monitoring might be high in the early stages after installation. Fluctuations would decrease over time as the system settles down following this initial perturbation. However, the river system will always respond to flow events, particularly those of high, or low, magnitude. As a result, a monitoring programme would need to be flexible enough to ensure that any large adjustments are recorded.

A third element that needs consideration is the issue of uncertainty and risk. If the outcomes of a particular project are likely to have a high level of uncertainty than it might be necessary to have an increased level of monitoring undertaken both on a more frequent time frame as well as at an increased resolution. Conversely, if standardised techniques are used and there is increased certainty in the outcome then the project might require less monitoring both on a temporal and spatial basis. Similar arguments may be applied to consideration of risk, with the intensity and extent of monitoring tailored to the severity of the consequences of any undesirable outcomes. The balance between the spatial and temporal resolution required in a monitoring programme is a fine one and is ultimately a case specific issue. This applies to all the possible techniques that can be used to monitor morphological change. As a result, it is important that any monitoring programme is based on sound scientific principles and is flexible enough to ensure that any adjustments in the system are adequately recorded.

Geomorphological monitoring techniques are less advanced than impact assessment tools as little monitoring of projects has been undertaken. The techniques outlined below (Table 4) are thus often quite basic since the resources made available for monitoring have historically been limited. The number of man days detailed below for each technique reflects the amount of time required to undertake survey work and any laboratory analysis that is associated with the technique. It does not allow for any report writing time since this is clearly a case specific issue and will depend upon the amount of monitoring undertaken and the level of analysis of data that is required.

4.2 Review of appropriate geomorphic monitoring techniques and their suitability in monitoring a variety of activities

As with the impact assessment techniques a series of spreadsheets were prepared to document how applicable certain monitoring techniques are for monitoring particular activity categories and types. This uses the same list as in 3.2, which was provided by SEPA, and the techniques outlined in Table 4. As with section 3.2, a standardised approach was used the spreadsheet and this is detailed in Table 5. Three symbols were used, namely a tick, a cross and an asterisk. A tick marks a technique that is relevant for use in assessing the impact of a particular activity. Conversely, a cross suggests that the technique is not useful for assessing the impact of a particular activity. If an asterisk is present than the technique could be useful for assessing a particular activity in a sensitive location or where the sediment loading is likely to be large.

Table 4: Geomorphological techniques that can be used to monitor changes

Techniques
Fixed-point photography
River reconnaissance survey
Cross-sections
Topographic Survey
Erosion pins/PEEPS
Bed substrate sampling
Sediment transport monitoring

4.2.1 River Crossings

Monitoring the effects if river crossings can largely be undertaken using river reconnaissance surveys and fixed-point photography. If there is a particular area of concern cross-section surveys could be

Table 5: Suitability of monitoring techniques

		Technique						
Activity Category	**Activity Type**	Fixed point photography	River reconnaissance survey	Cross-section surveys	Topographic survey	Erosion pins/ PEEPS	Bed sediment sampling	Sediment transport monitoring
River Crossings	Bridges	✓	✓	✓	*	✗	✗	✗
	Bridging Culverts	✓	✓	✓	*	✗	✗	✗
	Fords	✓	✓	✓	*	✗	✗	✗
	Pipelines/Cable crossings	✓	✓	✓	*	✗	✗	✗
In-Stream Structures	Sediment Traps	✓	✓	✓	*	✗	✓	✗
	Piers/Jetties/Platforms	✓	✓	✗	*	✗	✗	✗
	Boat Slips	✓	✓	✗	*	✗	✗	✗
	Boulder Placements	✓	✓	✓	*	✓	✓	✓
	Croys/Flow Deflectors	✓	✓	✓	*	✓	✓	✓
	Outfalls/Intakes	✓	✓	✓	*	✗	✗	✓
Impoundments	Un-managed Weirs	✓	✓	✓	*	✗	✓	✓
	Managed Weirs	✓	✓	✓	*	✗	✓	✓
	Reservoir Impoundments	✓	✗	✓	✓	✗	*	*
	Flood Management Impoundments	✓	✗	✓	✓	✗	*	*
Channel Modifications	Realignment	✓	✓	✓	*	✓	✓	✓
	Resectioning	✓	✓	✓	*	✓	✓	✓
	Culverting	✓	✓	✓	*	✗	✗	✗
	Permanent Diversions	✓	✓	✓	*	✓	✓	✓
	Straightening	✓	✓	✓	*	✓	✓	✓
	Remeandering	✓	✓	✓	*	✓	✓	✓
	By-Pass Channels	✓	✓	✓	*	✓	✓	✓
Sediment Management	Dredging	✓	✓	✓	*	✗	✓	✓
	Pool Maintenance	✓	✗	✓	*	✗	✓	✓
	Aggregate/Mineral Extraction	✓	✓	✓	*	✗	✓	✓
	Desilting	✓	✗	✓	*	✗	✓	✓
Bank Modifications	Bank Protection	✓	✓	✓	*	✗	✗	✗
	Outfalls/Intakes	✓	✓	✓	*	✗	✗	✗
	Side Weir	✓	✓	✓	*	✗	✗	✗
	Bank Re-profiling without Reinforcement	✓	✓	✓	*	✓	✗	✗
	Bank Re-profiling with Reinforcement	✓	✓	✓	*	✗	✗	✗
	Floodwalls	✓	✓	✓	*	✗	✗	✗
Developments in the vicinity of River	Set-back embankments	✓	✗	✗	✓	✗	✗	✗
	Off-line Storage	✓	✗	✗	✓	✗	✗	✗
	Pipelines	✓	✗	✗	✓	✗	✗	✗
	Marinas	✓	✗	✗	✗	✗	✗	✗
	Housing Developments	✓	✗	✗	✗	✗	✗	✗
	Commercial Developments	✓	✗	✗	✗	✗	✗	✗
	Infrastructure	✓	✗	✗	✗	✗	✗	✗

used to monitor any lateral or vertical adjustment. If this is likely to be in a particular sensitive area or of a large enough scale then a topographic survey might be required. More precise and intensive measurements such as the use of erosion pins, bed sediment sampling and sediment transport monitoring are largely not appropriate for these activities.

4.2.2 In-stream Structures

Both the fixed-point photography and river reconnaissance can be used to monitor the changes caused by in-stream activities. Cross-section surveys are appropriate in any area where the cross-section is likely to change as a result of an activity and thus can be effective in monitoring sediment traps, boulder placements, croys/deflectors and outfalls/intakes. The topographic survey would be required in either a sensitive area or if the project is of a large enough scale. Erosion pins/PEEPs, bed sampling and sediment transport monitoring could all be valuable in assessing change caused by boulder placements or croys/deflectors. Bed sampling will also be helpful for determining the calibre of material deposited in a sediment trap or around croys/deflectors. Sediment transport techniques could be used to monitor changes caused by outfalls/intakes particularly in relation to suspended sediment.

4.2.3 Impoundments

Fixed point photography and river reconnaissance could be used to monitor effects caused by impoundments but as a result of the scale of these features cross-section surveys and topographic surveys are likely to be more appropriate in examining channel change. Bed sediment sampling and sediment transport monitoring could also be effective in estimating changes in sediment flux caused by impoundments.

4.2.4 Channel Modifications

Virtually all the monitoring techniques are applicable for assessing the effects of channel modifications. A topographic survey would add increased data to survey and should be used for larger schemes or those that are in sensitive locations. The more intrusive techniques such as erosion pins, bed sediment sampling and sediment transport modelling are obviously limited when monitoring the impacts of culverts.

4.2.5 Sediment Management

As with the channel modifications many of the monitoring techniques can be used to assess the impacts of sediment management activities. Erosion pins/PEEPS are the only monitoring technique that is limited in this instance. River reconnaissance is restricted since it is not possible to easily observe in-channel changes and thus cannot adequately assess dredging or desilting activities effectively. The topographic survey would be beneficial in estimating volumetric changes at the sediment trap.

4.2.6 Bank Modifications

Bank modifications are best assessed using a combination of fixed-point surveys and river reconnaissance. Cross-section surveys can also be used to assess the extent of any lateral adjustment. A topographic survey could be used but will provide only limited beneficial information. Erosion pins/PEEPS could be used in areas where no re-enforcement is used in bank re-profiling since adjustment is possible and feasible to measure.

4.2.7 Developments in the vicinity of River

There are few monitoring techniques currently available in geomorphology that can adequately monitor developments in the vicinity of rivers. Of the techniques reviewed fixed-point photography could be beneficial at appropriate locations. In addition, topographic surveys could be beneficial in monitoring changes caused by pipelines, set-bank embankments and off-line storage.

5.0) EVALUATION OF WORK REQUIRED TO DEVELOP GUIDANCE FOR SEPA STAFF IN THE USE OF GEOMORPHIC TECHNIQUES

A variety of items of work could be performed/commissioned to benefit SEPA staff both in terms of geomorphological training and the development of best practice manuals that SEPA staff can use to aid the decision making process. Outlines of some of the proposed projects are detailed below:

1) Training courses in applied fluvial geomorphology and geomorphological river reconnaissance techniques

Those SEPA staff who deal with applications would benefit from being trained in basic geomorphological processes. In addition, training on the river reconnaissance technique would also be beneficial to support staff in their decision making.

2) To investigate the use of remote sensing technology in evaluating morphological change in large projects. This could be particularly relevant in the assessment of potential hazards of developments in the vicinity of rivers.

One of the key areas that few impact assessment or monitoring techniques can currently assess effectively is in the activity of assessing the effects of developments in the vicinity of rivers. Some of these activities, such as marinas, could have wide spatial consequences and as result a project that investigated the use of remote sensing technology, such as LiDAR and CASI, in assessing issues such as flood risk could prove beneficial.

3) Development of a best practice manual for small-scale projects that are likely to be undertaken under only a registration procedure.

A large number of projects are likely to be registered only and, therefore, not subject to the licensing procedure. As a result, many projects could be undertaken by landowners with little experience in river management. As a consequence of this, *ad-hoc* techniques will be used in many circumstances, with varying degrees of effectiveness. A project that developed a best practice procedure for small-scale projects that come under the registration procedure would prove to be beneficial. Indications of costs, applicability and effectiveness should be reviewed for techniques outlined.

4) Development of a standard format application document that will enable SEPA staff to make valued judgements on an application using the best information that is available to landowners.

In order, to make judgements on applications, SEPA staff would benefit from development of a standardised application form. This should detail key features that are easy for an applicant to provide such as a basic scaled map, geo-referenced photographs, history of site and notes on the perceived problem. This project would need to involve stakeholders to ensure that the devised form was not too onerous for an applicant. If this becomes too complex than there remains a risk that stakeholders would by-pass this procedure completely.

6.0) CONCLUDING REMARKS

A variety of geomorpholgically based techniques are available to assist in the assessment of the effects of a variety of activities both in the impact assessment stage and in monitoring post-installation. In the impact assessment phase, techniques largely fell into three headings namely, desk, field and monitoring based procedures. Of most relevant to assessing the likely impact of a particular activity were the field and modelling based techniques. The desk based techniques identified were valuable in providing background information and for compliance purposes but they were not very suitable to assessing the impacts of a particular activity. Of the field based techniques identified the river reconnaissance survey is perhaps the most widely applicable technique as it is the underlying tool for some of the more advanced geomorphological techniques. It is particularly useful for small-scale assessments that require an evaluation of a reach scale problem. Once the likely impacts increase in scale techniques such as the fluvial audit become more valuable. For example, if problems in instability have been identified at various locations or for prioritising restoration efforts within a catchment management strategy. Other specific techniques such as the bank assessment methodology and the gravel mining assessment are effective in assessing defined activities.

Of the computer-based modelling approaches detailed here, there is not a single one that would be appropriate for use in all cases. In general, the utility of these techniques is likely to be project-specific and the mode of application and parameterisation of each model will be linked directly to the likely morphological impacts of a particular intervention or in-stream activity.

Geomorphologically-based monitoring techniques remain less advanced than the impact assessment tools. These methods suffer from problems related to obtaining statistically relevant samples, as well as issues related to site accessibility and a variety of practically-based difficulties associated with all physically-based fieldwork. Statistical and sampling-based problems are greatest in relation to the direct measurement of sediment movement, bed sampling and bank retreat monitoring using erosion pins. Cross-sectional surveys and topographic surveys generally have fewer sampling problems. Of the less intrusive techniques, both the river reconnaissance survey and the fixed-point photography can be very useful tools.

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9.0) ACKNOWLEDGEMENTS

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10.0) APPENDICES

APPENDIX 1: Impact Assessment Techniques

1) GeoRHS (the Refined Geomorphological and Floodplain Component for the River Habitat Survey)

Technique

The GeoRHS 'add-on' module to the RHS is still its infancy. It has only been recently developed to supplement the RHS and is still undergoing further testing. The module itself is due to be brought into practice in 2006 (Jim Walker, National Geomorphologist, Environment Agency, *personal communication*, 2005).

Aim

The GeoRHS is an additional geomorphological module of the River Habitat Survey (see Environment Agency, 2003a and 2003b). It uses many of the same methodologies as the RHS to ensure consistency.

Methodology

The new GeoRHS component largely targets features and dimensions that relate to the processes of sediment transport in the channel and floodplain rather than purely their extent and quality that supports biodiversity (Environment Agency, 2003b). The GeoRHS further details in-channel geomorphological features but critically adds the floodplain component that is largely missing in the RHS. In addition to the field survey a desk study is also required. The desk study possesses a remote sensing component. In the field survey the sheets have been preliminary split into 4 sections:

A) Header information and cross-section dimensions

As with the RHS the initial header information details information about the location of the site (GPS located), the date of survey, surveyor and information regarding flow condition and practical problems experienced in the survey.

The cross-section dimensions section details 5 cross-sections (with GPS locations) where basic dimensions for width, depth, substrate and photograph reference and descriptions are required.

PART 1: Channel geomorphology

B) Erosion Features

The erosion feature section expands on that already within the RHS providing more detail on commonly occurring bank erosion features (river action), locally accelerated bank erosion features (biological or human) and channel bed scour. In particular, the modes of bank failure are detailed in the river action section (not in the RHS) with estimations of their lengths. The modes of accelerated bank erosion features occurring through biological or human action include fallen trees, burrowing, poaching, gravel extraction, access and failed revetments/groynes.

C) Deposition Features

The depositional feature section is broken down to 2 sections, namely, bars (active or stable) and other deposits/obstructions (mainly fines/disruption). The bar category details standard types of bar features. Other deposits include berms (vegetated/un-vegetated), bed drapes or deposition of fines up/downstream of structures. Disruption activities include waste disposal, ad-hoc revetment, sediment jams, macrophyte chokes and chaotic flood deposits.

PART 2: Floodplain geomorphology, flood conveyance and adjustment

D) Geomorphology of the floodplain

This section is split into two parts, namely, geomorphology of the floodplain and indicators of channel stability/adjustment. The geomorphology of the floodplain is examined using a further set of headings. These are 1) floodplain features/terraces, 2) channel to floodplain flow routes, 3) bank-floodplain zone, floodplain flow routes, drains, wetlands and finally 4) floodplain roughness features.

The indicators of channel stability/adjustment section provides a checklist of features that are indicative of either aggradation or degradation.

Note: As the sheets are still under development no survey forms have been included in this report.

The floodplain component of the GeoRHS involves a desk-based study. This largely is performed using remote sensing analysis with certain aspects being verified in the field. Proposed areas where information is required are:

1) channel planform eg Meander amplitude, radius of curvature, sinuosity and planform type

2) floodplain processes eg estimation of planform change, meander change and evidence of relic channels;

3) floodplain hydrology eg dominant soil type and evidence of extensive drainage systems

4) factors influencing floodplain inundation eg presence of embankments, roads, mineral extraction and floodplain lakes.

Deliverables

The deliverables for each reach is 3 page survey with a photograph section. In addition, the floodplain component involves the 1 page sheet of data and maps collected through the remote sensing analysis. This will be collected for each 500m reach.

Expertise

As with the RHS it is intended that will be compulsory training and accreditation in the usage of the GeoRHS procedure. The exact nature of this is still yet to be determined although early testing suggests that it could amount to 2 days with the RHS training being a pre-requisite to the GeoRHS training (information supplied by Joanne Barlow, River Habitat Survey team, Environment Agency, 2005, personal communication).

Man days

The number of man days required to undertake the GeoRHS is still yet to be determined. However, in early testing the field based component has undertaken anywhere between 1 and 2.5 hours (Joanne Barlow, River Habitat Survey team, Environment Agency, 2005, personal communication and Laura Russell, DEFRA, 2005, personal communication).

Activities that technique could be used for

The GeoRHS, like the RHS, is largely an inventory technique. In contrast to the RHS it focuses more on the features and their dimensions that relate to sediment transport. The survey provides a useful bolt-on to the RHS but as remains an inventory of features it is less suitable for project related activities. Thus as a result it remains an important compliance tool.

Further reading

Environment Agency, 2003a, A refined geomorphological and floodplain component – River Habitat Survey FD 1921, DEFRA/EA Joint R&D – Project 11793, prepared by GeoData Institute, Warrington.

Environment Agency, 2003b, A refined geomorphological and floodplain component – River Habitat Survey FD 1921, GeoRHS fieldwork survey form and guidance manual, DEFRA/EA Joint R&D – Project 11793, prepared by University of Newcastle, Warrington.

2) Catchment Baseline Survey

Technique

An early version of the catchment baseline survey was developed by Andrew Brookes (Gifford Consulting) and Peter Downs (Stillwater Sciences) for the National Rivers Authority, in the early 1990s. This was furthered in the Environment Agency's practical guide to River Geomorphology (1998) and DEFRA's latest Guidebook of Applied Fluvial Geomorphology (Sear *et al.*, 2004).

Aim

The aim of the catchment baseline survey is to provide a strategic overview of the geomorphological state of the rivers through the catchment (Environment Agency, 1998). The knowledge gleaned can be used to guide people on the geomorphological conservation status of the channel and thus determine how they are likely to affected by any development proposals, changes in maintenance operations or proposed capital works for flood defence or land drainage (Environment Agency, 1998).

Methodology

There are two main components to the catchment baseline survey. The first is a desk survey which is followed by a field survey. The desk survey involves the collation and examination of information on geology, soils, topography and land-use and any supplementary data available. This will be detailed in a 1-2 page summary and could be supplemented by site visits to 1 or 2 key locations. The field survey is the detailed, and time consuming, part of the survey. The field survey involves the collection of morphological data that is used to sub-divide the channel network into reaches of similar geomorphological character. The information is combined with the results of the desk study to classify reaches with respect to their geomorphological conservation value. The geomorphological conservation value reflects the likely susceptibility that the channel might be degraded by human activities (see Table 6).

The information obtained in the survey can be used to examine the extent to which individual reaches are natural, modified or recovering towards a natural state. This can be used to guide river management decisions as well as identifying areas that are in need of either restoration or rehabilitation.

Deliverables

The output from the catchment baseline survey includes:

1) Catchment geomorphological conservation map

2) Report detailing findings (for each reach), interpretations and recommendations (approx 5-10 pages). In addition, survey sheets could be included in the Appendix.

3) Geo-referenced photographs of the catchment

Bolt-on includes:

1) GIS based searchable map detailing the results of the geomorphological classification

Expertise

To undertake a catchment baseline survey a high level of training in geomorphology is required. It is recommended that a PhD level trained geomorphologist or, alternatively, someone who has shadowed someone of this level of experience for at least 4 years undertake this type of work. This is required since the interpretation of features and processes at a catchment level is a complex one.

Table 6: Summary of NRA (1990) scheme classifying river susceptibility to disturbance

Susceptibility to disturbance	Score	Description
High	8-10	Conforms most closely to natural, unaltered state and will often exhibit signs of free meandering and possesses well developed bedforms (point bars and pool-riffle sequences) and abundant bankside vegetation.
Moderate	5-7	Shows signs of previous alteration but still retains many natural features, or may be recovering towards conditions indicative of the higher category.
Low	2-4	Substantially modified by previous engineering works and likely to possess an artificial cross-section (eg trapezoidal) and will probably be deficient in bedforms and bankside vegetation.
Channelised	1	Awarded to reaches whose bed or banks have hard protection (eg concrete walls or sheet piling)
Culverted	0	Totally enclosed by hard protection.
Navigable	-	Classified separately due to their high degree of flow regulation and bankside vegetation, and their probable strategic need for maintenance dredging.

Man days

Man days for a catchment baseline survey can be broadly be separated into individual tasks. The level of work required is dependant upon the size of catchment that is to be surveyed. As with the river reconnaissance the distance of survey covered each day is dependant upon season and weather conditions. Broadly, around 4.5-5km of watercourse can be surveyed on a winters day with up to 8km being undertaken on a good summers day. The field survey probably amounts to around 50% of the man days required in the project. A further 30% is required for the report writing and production of maps and finally 20% for the initial desk study.

Costs in % of project for 'bolt-ons' are approximated at:

1) GIS based searchable map detailing the results of the geomorphological classification – 40-50% extra

Activities that technique could be used for

The catchment baseline survey like the RHS and the GeoRHS is not that suitable to project related activities as it largely provides baseline geomorphology data. More often than not a fluvial audit is more suitable as this catchment based technique provides an assessment of the sediment dynamics of the river system rather than the conservation value. However, the catchment baseline survey is useful in conjunction with a fluvial audit in assessing activities that could have a large-scale impacts on the river system such as reservoir or flood management impoundments.

Further reading

Sear, D.A., Newson, M.D., Thorne, C.R., 2004, Guidebook of Applied Geomorphology, Defra/Environment Agency Flood and Coastal Defence R&D Programme, R&D Technical Report FD1914, DEFRA, London.

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3) Fluvial Audit

Technique

The fluvial audit technique was developed by Malcolm Newson (University of Newcastle) and David Sear (University of Southampton) in the early 1990s. Details of the procedure are outlined further in the Environment Agency's practical guide to River Geomorphology (1998) and DEFRA's latest Guidebook of Applied Fluvial Geomorphology (Sear *et al.*, 2004).

Aim

The basis of the fluvial audit is to obtain an understanding of a broad qualitative sediment budget of a reach paying close attention to sediment transport processes, the impact of flood events and impacts of land use change (Environment Agency, 1998). The Fluvial Audit is a catchment based survey with each reach being defined by virtue of its geomorphological characteristics.

Methodology

The Fluvial Audit uses collectable information to assess the level and significance of adjustment in the current channel. The technique is often focused on a particular project reach but as a result of the likely impacts of a proposal a catchment scale assessment is necessary. This requires both documentary evidence on catchment and channel changes, as well as field evidence to assess the contemporary status of the river. Documented evidence includes a variety of sources such as flood defence, land drainage and maintenance operation records as well as historical maps and aerial photographs (Environment Agency, 1998). In addition, other reports written on the state of the river and alterations to the catchment can also prove to be valuable sources of information. An optional component of a fluvial audit is to overlay historic maps to establish a map of channel change over distinct time periods. This has proved to be very useful for determining the rate of channel adjustment as well as the influence of anthropogenic activities. Together, all this material is used to form a time chart of changes throughout the catchment (see Figure 5 for an example) and to provide a detailed assessment of Potential Destabilising Phenomena (PDPs). PDPs are particular activities, or processes, which could lead to a change in sediment supply (increase or decrease) either at a catchment or reach scale (see Table 7).

Field evidence can be used to verify/reject evidence of channel response to these PDPs. Field reconnaissance sheets have recently been adapted for fluvial audits and catchment baseline surveys for this purpose (Babtie, Brown and Root, 2005; Haycock Associates, 2004). Types of features that can indicate stability and instability within a catchment are detailed in Table 8. These indicators are key to understanding the status of individual reaches. Information collated in the survey sheets, the timechart and the historic maps are used to determine the contemporary geomorphological status of the individual reach. While no standardised reach class procedure exists a classification approach has been developed based on the dominant process that is occurring in the reach and this is detailed in Table 9 (Thorne and Skinner, 2002). In this example, a reach classified as a *Sediment Storage* area does not necessarily mean that sediment is not being generated or moving through the reach but that the predominant impact on the sediment dynamics of the system is one of deposition. A map showing the reach classes through the catchment should also be detailed (see Figure 6, for an example).

The reconnaissance results are also used alongside the time chart and historic maps to characterise the geomorphology of the channel classifying it on a reach-by-reach basis, and identifying trends and styles of morphological change. A series of grid-referenced photographs should also be undertaken to illustrate the various features observed.

Table 7: Potentially Destabilising Phenomena (PDP) within a sediment system

	Increase Sediment Supply	Decrease Sediment Supply
CATCHMENT SCALE	Climate change (>Rainfall) Upland drainage Afforestation Mining spoil inputs Urban development Agricultural drainage Soil erosion Deforestation	Climate change (<Rainfall) Dams/regulation Reduction in cropping Cessation of mining Vegetation of slopes/scars Sediment management
REACH SCALE	Upstream erosion Agricultural runoff Tributary input Bank collapse Tidal input Straightening Upstream embanking	Upstream deposition Sediment trapping Bank protection of erosion Vegetation of banks Dredging (Shoals/berms) Channel widening upstream Upstream weirs

(adapted from Sear *et al.*, 1995)

Figure 5: Example timechart of catchment changes (from Skinner and Haycock, 2004)

TIME →	PRE 1600	1600-1700	1700-1800	1800-1900	1900-2001
CLIMATE FLOODS ★					
CAPITAL WORKS					
RIVER MAINTENANCE Type (erosion or siltation), location and frequency				Channel straightening likely to have occurred between 1860 and 1899	
CHANNEL CHANGE (erosion / deposition) LOCATION (old maps, aerial photographs, flood defence surveys and records)					Extensive channel change occurred as the river recovered its braided/anabranching planform. Evidence from historic maps.
LAND USE CHANGE Urban development Agriculture Mining Forestry Reservoir construction Other	-12-13th Century Enclosure of Wasdale valley -First permanent settlement inWasdale in 14th Century	Localised Charcoal production in 17th Century	-Peat cutting -Localised Slate quarrying -Early paths installed in valley		
FISHERIES CHANGE Improvement / decline					

Table 8: Field indicators of instability and stability

CATEGORIES	UPLAND	TRANSFER	LOWLAND
EVIDENCE OF INCISION	Perched boulder berms Terraces Old channels Old slope failures Undermined structures Exposed tree roots Narrow/deep channel Bank failures, both banks Armoured/compacted bed Deep gravel exposure in banks that are topped with fines	Terraces Old channels Undermined structures Exposed tree roots Bank failures, both banks Armoured/compacted bed Deep gravel exposure in banks that are topped with fines	Old channels Undermined structures Exposed tree roots Narrow/deep channel Bank failures, both banks 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	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	Buried structures Buried soils Large silt/clay banks Eroding banks at shallows Contracting bridge space Deep fine sediment over coarse gravels in bank Many unvegetated point bars
EVIDENCE OF STABILITY	Vegetated bars and banks Compacted weed covered bed Bank erosion rare Old structures in position	Vegetated bars and banks Compacted weed covered bed Bank erosion rare Old structures in position	Vegetated bars and banks Weed covered bed Bank erosion rare Old structures in position

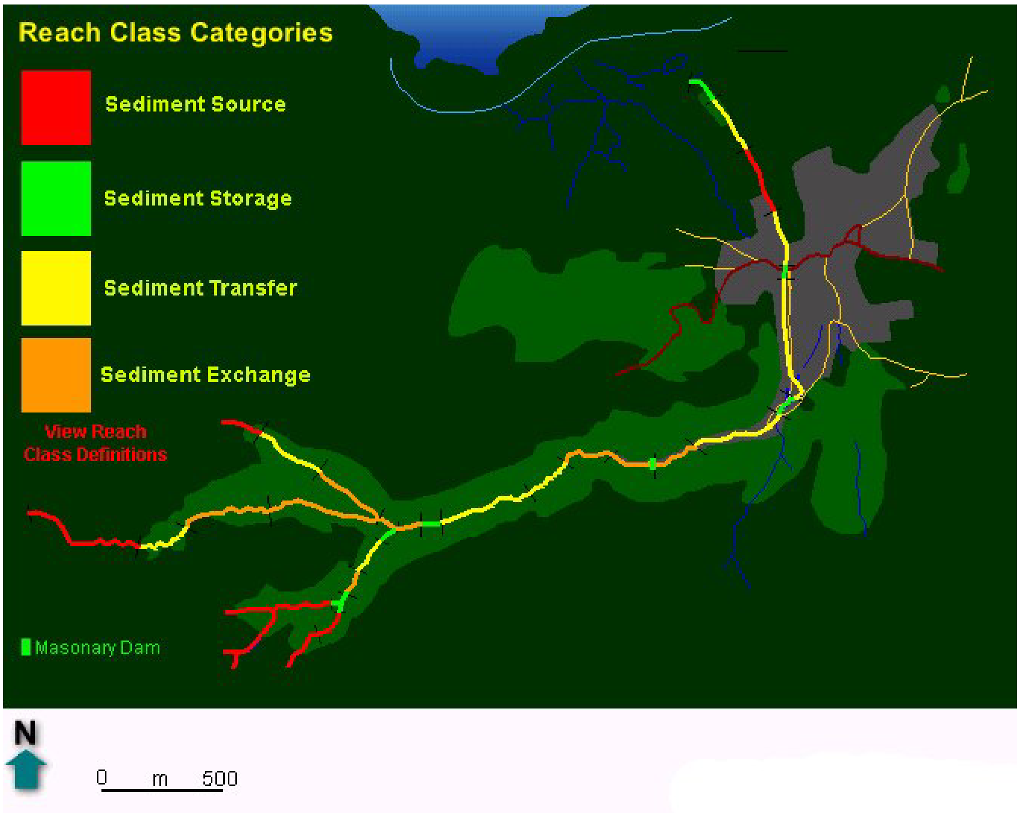
(Sear and Newson, 1994)

Table 9: Reach Classification Definitions

Class of Reach	Description
Sediment Source	Sediment output from the reach is greater than sediment supply from upstream.
Sediment Transfer	Sediment output is approximately equal to input from upstream. Sediment is transmitted through the reach, which features few sites of active erosion, or deposition either because the channel is adjusted and naturally stable or because the bed and banks have been stabilised artificially.
Sediment Exchange	Sediment output is approximately equal to input from upstream (as for a transfer reach), but incoming sediment is exchanged with that derived within the reach, which features active erosion and depositional sites.
Sediment Storage	Sediment input to the reach is greater than sediment output to the next reach downstream.

(adapted from Thorne and Skinner, 2002)

Figure 6: Example geomorphological classification map



(From Thorne and Skinner, 2002)

Deliverables

There are a variety of deliverables required in a fluvial audit with a series of optional extras. The main deliverables are:

1) Timechart of catchment changes

2) Geomorpological classification map (catchment)

3) Report detailing findings, interpretations and recommendations.

4) Geo-referenced photographs of the catchment

5) Detailed project reach map

Optional 'bolt-ons' include:

1) Historical map overlay showing channel change over distinct periods

2) GIS based searchable map detailing the results of the geomorphological classification

3) Interactive CD-Rom for examination

Expertise

To undertake a fluvial audit a high level of training in geomorphology is required. It is recommended that a PhD level trained geomorphologist or, alternatively, someone who has shadowed someone of this level of experience for at least 4 years undertake this type of work. This is required since the interpretation of features and processes at a catchment level is a complex one.

Man days

Man days for a fluvial audit can broadly be broken down into tasks. The level of work required is dependant upon the size of catchment that is to be surveyed. As with the river reconnaissance the distance of survey covered each day is dependant upon season and weather conditions. Broadly, around 4.5-5km of watercourse can be surveyed on a winters day with up to 8km being undertaken on a good summers day. The field survey probably amounts to around 40% of the man days required in the project. A further 40% is required for the report writing and the production of maps and finally 20% for the initial desk study.

Costs in % of project for optional extras are approximated at:

1) Historical map overlay showing channel change over distinct periods – 40% extra

2) GIS based searchable map detailing the results of the geomorphological classification – 50-60% extra

3) Interactive CD-Rom for examination – 50% extra

Activities that technique could be used for

The fluvial audit is suitable to assess the impacts of activities that are going to have significant effects on the catchment sediment dynamics. For example, issues such as a sediment trap, by the very nature require that a full catchment sediment assessment be undertaken.

Further reading

Sear, D.A., Newson, M.D., Thorne, C.R., 2004, Guidebook of Applied Geomorphology, Defra/Environment Agency Flood and Coastal Defence R&D Programme, R&D Technical Report FD1914, DEFRA, London.

Environment Agency, 1998, River Geomorphology: A practical guide, National Centre for Risk Analysis and Options Appraisal, Guidance Note 18, Bristol, UK.

4) River Habitat Survey (RHS)

Technique

The RHS has been designed, tested and used on UK rivers since 1994. An updated version was produced in 2003. To date, 17000 sites have been surveyed (Jim Walker, Environment Agency, *personal communication*, 2005).

Aim

The aim of the River Habitat Survey is to broadly characterise and assess the physical structure of freshwater streams and rivers (EA/SEPA/Environment Heritage Service, 2003).

Methodology

The whole survey is based upon a standardised inventory sheet to assess 500m reaches of river. Observations are made with spot checks spaced at every 10m. In addition, information on the land use and valley form is also provided (EA/SEPA/Environment Heritage Service, 2003). Consistency is a priority and thus training of surveyors is critical. Each RHS consists of 4 sheets with an additional two page spot-check key. Spot checks should be undertaken at every 50m and aim to record predominant channel, bank and river corridor features at 10 locations within the 500m reach.

Deliverables

The deliverable for each reach is 4 page survey with an additional 2 page spot-check. In addition, the latest version of the RHS allows for an expanded photograph section. Once the data has been collected it is inputted into a national database that allows the national state of rivers to be searched on a wider scale.

Expertise

People undertaking a RHS survey need to be nationally accredited to ensure the survey is carried out on a consistent basis. The training course requires the surveyor to go on a 3.5 days of training which involves approximately 30% theory and 70% fieldwork (information supplied by Joanne Barlow, River Habitat Survey team, Environment Agency, 2005, *personal communication*).

Man days

The length of time required to undertake an RHS survey of a 500m reach is dependent on weather and conditions but it is generally reckoned that each survey should take around an hour on average. Taking into account travel time between potential sights this should amount to 6 reaches on average being surveyed in a day (data from Joanne Barlow, River Habitat Survey team, Environment Agency, 2005, *personal communication*).

Activities that technique could be used for

The River Habitat Survey provides an excellent inventory of features of interest at a particular river reach. This is focused towards features and dimensions that determine biodiversity. The technique itself is only an inventory and thus unlikely to be commissioned as part of a project based survey. The most important role of the RHS is for compliance purposes.

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.

5) River Reconnaissance

Technique

The river reconnaissance method and sheets, that form a major part of the work, have gradually evolved in the field of geomorphology over the last 30 years. The work has been developed and tested by a variety of geomorphologists but the most detailed commentary of the technique, its uses and benefits is outlined by Thorne (1998).

Aim

River reconnaissance is a rapid geomorphological survey of a reach noting the contemporary morphological forms of interest and establishing an overview of geomorphic processes. It is perhaps the most standard and frequently used technique by practising geomorphologists and is central to many other geomorphic tools. The main purposes of the method 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)

Methodology

Central to the river reconnaissance technique lies a series of recording sheets (see below). The sheets detailed in Figure 7 (below) are those illustrated by Thorne (1998). These particular sheets focus in depth on the river bank but they have been adapted by various groups so that they are more suitable for larger scale studies such as the fluvial audit (see Babtie, Brown and Root, 2005; Haycock Associates, 2004). Despite any alterations, the basis for which the reconnaissance sheets are outlined remain the same. The sheets are split into a number of sections moving from the purpose of the survey through to noting the valley form down to analysis of the bed and bank features. The extent to which the bed and bank features are detailed is the main area that the different sheets alter.

The sheets detailed by Thorne (1998) have 5 main sections:

Section 1: Scope and Purpose

The first and very important part of the survey involves outlining details of the project such as the scope and purpose of the survey; name of river; location; number of reach; date; general notes of the reconnaissance trip.

Section 2: Region and Valley description

This section starts the morphological description but focuses on the geomorphological setting of the river within the wider environment. Of particular interest is the relationship between the river, the floodplain and the valley walls. The wider morphological features in the valley can significantly influence the morphological forms and processes within a channel and are thus important to document. Features of interest include drainage pattern; land use; vegetation; floodplain extent; terraces; levees; planform; floodplain features; lateral activity.

Section 3: Channel description

The third part of the survey narrows the focus on the river form. This examines the flow types, width controls (such as bridges, revetments etc) and bed controls (such as bedrock or grade contol structures) as well as bed sediment descriptors (material, forms, depth etc).

Section 4 and 5: Left and Right bank survey

Sections 4 and 5 detail surveys of the left and right bank surveys which form the central focus of the sheets detailed by Thorne (1998). The bank surveys are extensive and include the detailed examination of bank characteristics, vegetation, erosion, geotechnical failures and toe accumulation.

There are a variety of simple pieces of equipment that can aid the field survey but largely the river reconnaissance is based on observations of morphological forms and processes.

The reconnaissance sheets detailed by Thorne (1998) form the basis of many river reconnaissance surveys. In addition to the sheets, a sketch of the river (or a digital enlarged map for the field), grid referenced photographs and more extensive notes on field observations and interpretations are beneficial to the overall survey.

Deliverables

Often stream reconnaissance is undertaken on a project reach basis but should also encompass up and downstream reaches to determine whether there are any locally significant contemporary geomorphological processes that influence the project reach. A concerned client who perceives that something is 'wrong' with the river often initiates the survey. As a result the deliverables will often include:

i) Notes on problem

ii) Completed river reconnaissance forms for the reaches of interest

ii) Complete set of geo-referenced photographs

iv) Sketch map showing river and any significant issues

v) Interpretations

vi) Recommendations

Expertise

To undertake reconnaissance surveys some level of training in geomorphology is essential. Generally, geomorphology is taught in a number of undergraduate degree courses at a variety of levels. At this level of experience a basic geomorphological reconnaissance survey can be undertaken. However, the understanding of river systems is complex and thus the application of geomorphology in the real world requires both practical experience and academic qualifications. The more experienced the geomorphologist the more likely issues that affect the project reach can be adequately identified and addressed accordingly. Thus is it recommended that a PhD level trained geomorphologist or, alternatively, someone who has shadowed someone of this level of experience for at least 2 years undertake this type of survey.

Man days

The number of kilometres of river that can be surveyed per day using river reconnaissance is dependant on seasons and weather conditions. This can range from about 4.5-5km in the winter to about 8km in the summer. On a small size project the time required to write up the notes and order the photographs should not amount to more than 2-3 man days.

Activities that technique could be used for

The river reconnaissance is one of the most adaptable geomorphic tools. The technique can be used to assess the impact of a whole variety of project related activities particularly at a reach scale. As the scale of the potential impact increases, such as the construction of a reservoir or sediment traps it is recommended that a full catchment scale fluvial audit is undertaken instead.

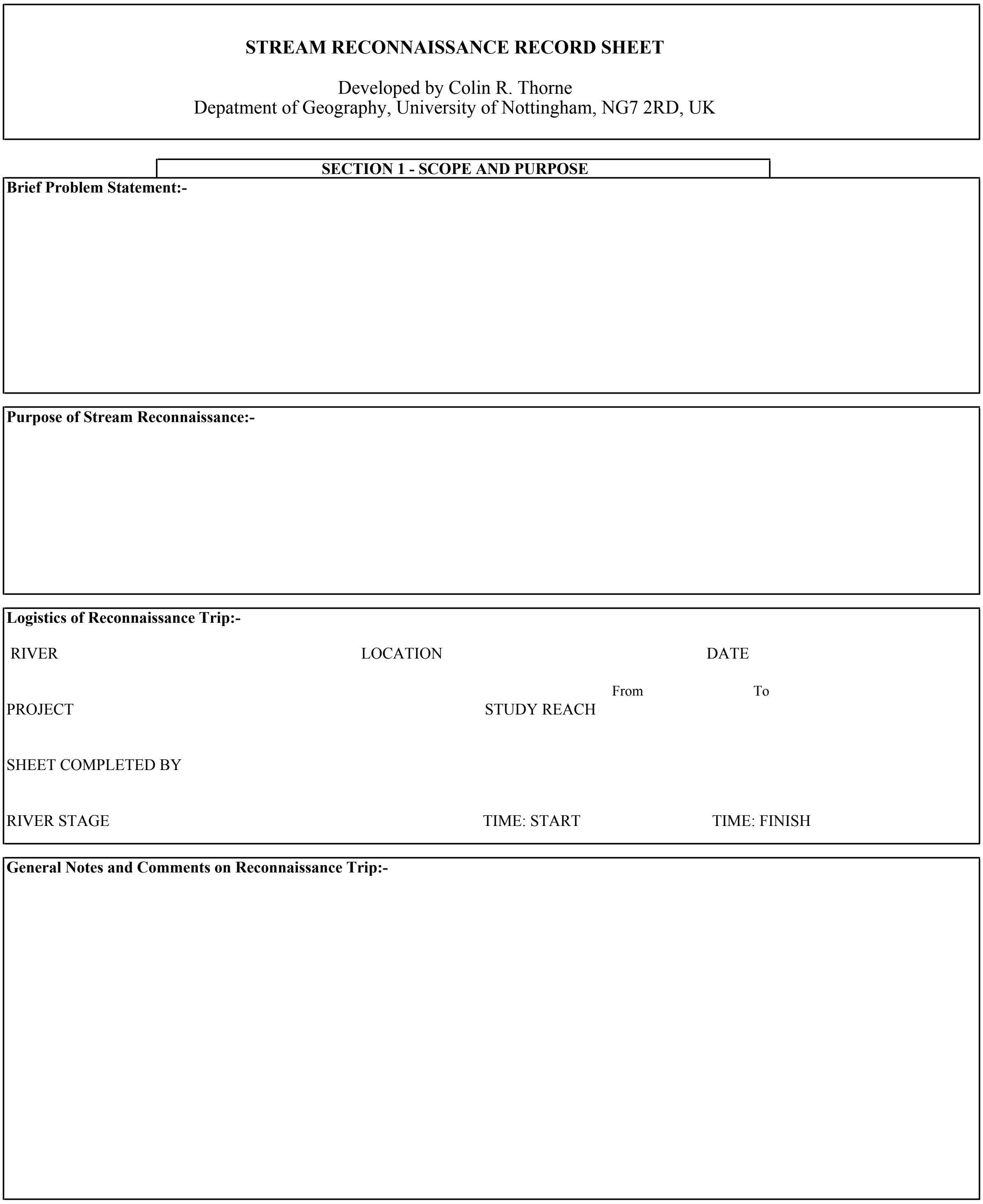
Further reading

Thorne, C.R., 1998, *Stream Reconnaissance Guidebook: Geomorphological Investigation and Analysis of River Channels*, J Wiley and Sons, Chichester, UK, ISBN 0-471-968560, 127p.

Downs, P.W and Thorne, C.R, 1996, A geomorphological justification of river channel reconnaissance surveys, Transactions of the Institute of British Geographers, New Series, 21, 455-468.

Thorne, C.R., Simon, A. and Allen, R., 1996, Geomorphological river channel reconnaissance for river analysis, engineering and management, Transactions of the Institute of British Geographers, New Series, 21, 469-483.

Figure 7: Stream reconnaissance record sheets developed by 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

From To

PROJECT STUDY REACH

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
Mountains ☐
Uplands ☐
Hills ☐
Plains ☐
Lowlands ☐

Drainage Pattern
Dendritic ☐
Parallel ☐
Trellis ☐
Rectangular ☐
Radial ☐
Annular ☐
Multi-Basin ☐
Contorted ☐

Surface Geology
Bed rock ☐
Weathered Soils ☐
Glacial Moraine ☐
Glacio/Fluvial ☐
Fluvial ☐
Lake Deposits ☐
Wind blown (loess) ☐

Rock Type
Sedimentary ☐
Metamorphic ☐
Igneous ☐
None ☐

Specific Rock Types (if known)
____
____
____

Land Use
Natural ☐
Managed ☐
Cultivated ☐
Urban ☐
Suburban ☐

Vegetation
Tropical forest ☐
Temperate forest ☐
Boreal forest ☐
Woodland ☐
Savanna ☐
Temperate grassland ☐
Desert scrub ☐
Extreme Desert ☐
Tundra or Alpine ☐
Agricultural land ☐

Notes and Comments:-

PART 2: RIVER VALLEY AND VALLEY SIDES

Location of River
In Valley ☐
On Alluvial Fan ☐
On Alluvial Plain ☐
In a Delta ☐
In Old Lake Bed ☐

Valley Shape
Symmetrical ☐
Asymmetrical ☐

Height
< 5 m ☐
5 - 10 m ☐
10 - 30 m ☐
30 - 60 m ☐
60 - 100 m ☐
> 100 m ☐

Side Slope Angle
< 5degrees ☐
5-10 degrees ☐
10-20 degrees ☐
20-50 degrees ☐
>50 degrees ☐

Valley Side Failures
None ☐
Occasional ☐
Frequent ☐

Failure Locations
None ☐
Away from river ☐
Along river (Undercut) ☐

Interpretative Observations

Material Type
Bedrock ☐
Soils ☐
Loose debris ☐

Failure Type
(see Sketches in Manual) ________

Severity of Problems
Insignificant ☐
Mild ☐
Significant ☐
Serious ☐
Catastrophic ☐

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
None ☐
Indefinite ☐
Fragmentary ☐
Continuous ☐

Valley Floor Data
None ☐
< 1 river width ☐
1 - 5 river widths ☐
5-10 river widths ☐
>10 river widths ☐

Flow Resistance*
Left Overbank Manning n value ___
Right Overbank Manning n value ___
(* note: n value for channel is recorded in Part 6)

Surface Geology
Bed rock ☐
Glacial Moraine ☐
Glacio/Fluvial ☐
Fluvial: Alluvium ☐
Fluvial: Backswamp ☐
Lake Deposits ☐
Wind Blown (Loess) ☐

Land Use
Natural ☐
Managed ☐
Cultivated ☐
Urban ☐
Suburban ☐
Industrial ☐

Vegetation
None ☐
Unimproved Grass ☐
Improved Pasture ☐
Orchards ☐
Arable Crops ☐
Shrubs ☐
Deciduous Forest ☐
Coniferous Forest ☐
Mixed Forest ☐

Riparian Buffer Strip
None ☐
Indefinite ☐
Fragmentary ☐
Continuous ☐

Strip Width
None ☐
< 1 river width ☐
1 - 5 river widths ☐
> 5 river widths ☐

Notes and Comments:-

SECTION 2 - REGION AND VALLEY DESCRIPTION (Continued)

PART 4: VERTICAL RELATION OF CHANNEL TO VALLEY

Terraces
None ☐
Indefinate ☐
Fragmentary ☐
Continuous ☐
Number of Terraces ___

Trash Lines
Absent ☐
Present ☐
Height above flood plain (m) ___

Overbank Deposits
None ☐
Silt ☐
Fine sand ☐
Medium sand ☐
Coarse sand ☐
Gravel ☐
Boulders ☐

Levees
None ☐
Natural ☐
Constructed ☐

Levee Description
None ☐
Indefinite ☐
Fragmentary ☐
Continuous ☐
Left Bank ☐
Right Bank ☐
Both Banks ☐

Levee Data
Height (m) ☐
Side Slope (o) ☐

Levee Condition
None ☐
Intact ☐
Local Failures ☐
Frequent failures ☐

Interpretative Observations

Present Status
Adjusted ☐
Incised ☐
Aggraded ☐

Instability Status
Stable ☐
Degrading ☐
Aggrading ☐

Problem Severity
Insignificant ☐
Moderate ☐
Serious ☐

Problem Extent
None ☐
Local ☐
General ☐
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
Straight ☐
Sinuous ☐
Irregular ☐
Regular meanders ☐
Irregular meanders ☐
Tortuous meanders ☐
Braided ☐
Anastomosed ☐

Planform Data
Bend Radius ___
Meander belt width ___
Wavelength ___
Meander Sinuosity ___

Location in Valley
Left ☐
Middle ☐
Right ☐

Lateral Activity
None ☐
Meander progression ☐
Increasing amplitude ☐
Progression+cut-offs ☐
Irregular erosion ☐
Avulsion ☐
Braiding ☐

Floodplain Features
None ☐
Meander scars ☐
Scroll bars+sloughs ☐
Oxbow lakes ☐
Irregular terrain ☐
Abandoned channel ☐
Braided Deposits ☐

Interpretative Observations

Present Status
Adjusted ☐
Over wide ☐
Too narrow ☐

Instability Status
Stable ☐
Widening ☐
Narrowing ☐

Problem Severity
Insignificant ☐
Moderate ☐
Serious ☐

Problem Extent
None ☐
Local ☐
General ☐
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**
		None ☐	None ☐	None ☐	None ☐
Av. top bank width (m) ___	None ☐	Occasional ☐	Solid Bedrock ☐	Occasional ☐	Bedrock ☐
Av. channel depth (m) ___	Uniform/Tranquil ☐	Frequent ☐	Weathered Bedrock ☐	Frequent ☐	Boulders ☐
Av. water width (m) ___	Uniform/Rapid ☐	Confined ☐	Boulders ☐	Confined ☐	Gravel armor ☐
Av. water depth (m) ___	Pool+Riffle ☐	Number of controls ___	Gravel armor ☐	Number of controls ___	Revetments ☐
Reach slope ___	Steep + Tumbling ☐		Cohesive Materials ☐		Cohesive Materials ☐
Mean velocity (m/s) ___	Steep + Step/pool ☐		Bridge protection ☐		Bridge abutments ☐
Manning's n value ___	(Note: Flow type on day of observation)		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
Noncohesive ☐
Cohesive ☐
Composite ☐
Layered ☐
Even Layers ☐
Thick+thin layers ☐
Number of layers ___

Protection Status
Unprotected ☐
Hard points ☐
Toe protection ☐
Revetments ☐
Dyke Fields ☐

Bank Materials
Silt/clay ☐
Sand/silt/clay ☐
Sand/silt ☐
Sand ☐
Sand/gravel ☐
Gravel ☐
Gravel/cobbles ☐
Cobbles ☐
Cobbles/boulders ☐
Boulders/bedrock ☐

Layer Thickness
Material 1 (m) ___
Material 2 (m) ___
Material 3 (m) ___
Material 4 (m) ___

Ave. Bank Height
Average height (m) ___

Ave. Bank Slope
angle (degrees) ___

Bank Profile Shape
(see sketches in manual)
☐

Tension Cracks
None ☐
Occasional ☐
Frequent ☐

Crack Depth
Proportion of bank height ___

Distribution and Description of Bank Materials in Bank Profile

Material Type 1
Toe ☐
Mid-Bank ☐
Upper Bank ☐
Whole Bank ☐
D50 (mm) ___
sorting coefficient ___

Material Type 2
Toe ☐
Mid-Bank ☐
Upper Bank ☐
Whole Bank ☐
D50 (mm) ___
sorting coefficient ___

Material Type 3
Toe ☐
Mid-Bank ☐
Upper Bank ☐
Whole Bank ☐
D50 (mm) ___
sorting coefficient ___

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

Notes and Comments:-

PART 9: LEFT BANK-FACE VEGETATION

Vegetation
None/fallow ☐
Artificially cleared ☐
Grass and flora ☐
Reeds and sedges ☐
Shrubs ☐
Saplings ☐
Trees ☐

Orientation
Angle of leaning (°) ___

Tree Types
None ☐
Deciduous ☐
Coniferous ☐
Mixed ☐

Tree species
(if known)
☐
☐
☐

Density + Spacing
None ☐
Sparse/clumps ☐
dense/clumps ☐
Sparce/continuous ☐
Dense/continuous ☐

Roots
Normal ☐
Exposed ☐
Adventitious ☐

Location
Whole bank ☐
Upper bank ☐
Mid-bank ☐
Lower bank ☐

Diversity
Mono-stand ☐
Mixed stand ☐
Climax-vegetation ☐

Health
Healthy ☐
Fair ☐
Poor ☐
Dead ☐

Age
Immature ☐
Mature ☐
Old ☐

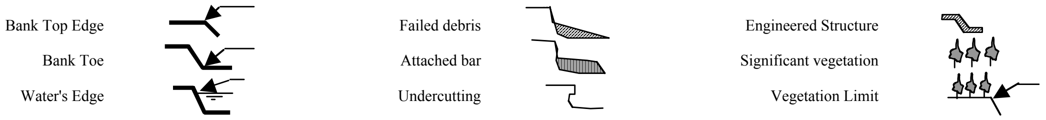
Height
Short ☐
Medium ☐
Tall ☐
Height (m) ___

Lateral Extent
Wide belt ☐
Narrow belt ☐
Single row ☐

Notes and Comments:-

Bank Profile Sketches

Profile Symbols



SECTION 4 - LEFT BANK SURVEY (Continued)

PART 10: LEFT BANK EROSION

Erosion Location
- General ☐
- Outside Meander ☐
- Inside Meander ☐
- Opposite a bar ☐
- Behind a bar ☐
- Opposite a structure ☐
- Adjacent to structure ☐
- Dstream of structure ☐
- Ustream of structure ☐
- Other (write in) ☐

Present Status
- Intact ☐
- Eroding:dormant ☐
- Eroding:active ☐
- Advancing:dormant ☐
- Advancing:active ☐

Rate of Retreat
m/yr (if applicable and known) ____

Rate of Advance
m/yr (if applicable and known) ____

Interpretative Observations

Severity of Erosion
- *Insignificant* ☐
- *Mild* ☐
- *Significant* ☐
- *Serious* ☐
- *Catastrophic* ☐

Extent of Erosion
- *None* ☐
- *Local* ☐
- *General* ☐
- *Reach Scale* ☐
- *System Wide* ☐

Processes
- *Parallel flow* ☐
- *Impinging flow* ☐
- *Piping* ☐
- *Freeze/thaw* ☐
- *Sheet erosion* ☐
- *Rilling + gullying* ☐
- *Wind waves* ☐
- *Vessel Forces* ☐
- *Ice rafting* ☐
- *Other (write in)* ☐

Distribution of Each Process on Bank

Process 1
- *Toe (undercut)* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Process 2
- *Toe (undercut)* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Process 3
- *Toe (undercut)* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Process 4
- *Toe (undercut)* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

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

Failure Location
- General ☐
- Outside Meander ☐
- Inside Meander ☐
- Opposite a bar ☐
- Behind a bar ☐
- Opposite a structure ☐
- Adjacent to structure ☐
- Dstream of structure ☐
- Ustream of structure ☐
- Other (write in) ☐

Present Status
- Stable ☐
- Unreliable ☐
- Unstable:dormant ☐
- Unstable:active ☐

Failure Scars+Blocks
- None ☐
- Old ☐
- Recent ☐
- Fresh ☐
- Contemporary ☐

Interpretative Observations

Instability:Severity
- *Insignificant* ☐
- *Mild* ☐
- *Significant* ☐
- *Serious* ☐
- *Catastrophic* ☐

Instability: Extent
- *None* ☐
- *Local* ☐
- *General* ☐
- *Reach Scale* ☐
- *System Wide* ☐

Failure Mode
- *Soil/rock fall* ☐
- *Shallow slide* ☐
- *Rotational slip* ☐
- *Slab-type block* ☐
- *Cantilever failure* ☐
- *Pop-out failure* ☐
- *Piping failure* ☐
- *Dry granular flow* ☐
- *Wet earth flow* ☐
- *Other (write in)* ☐

Distribution of Each Mode on Bank

Mode 1
- *Toe* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Mode 2
- *Toe* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Mode 3
- *Toe* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Mode 4
- *Toe* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

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

Stored Bank Debris
- None ☐
- Individual grains ☐
- Aggregates+crumbs ☐
- Root-bound clumps ☐
- Small soil blocks ☐
- Medium soil blocks ☐
- Large soil blocks ☐
- Cobbles/boulders ☐
- Boulders ☐

Vegetation
- None/fallow ☐
- Artificially cleared ☐
- Grass and flora ☐
- Reeds and sedges ☐
- Shrubs ☐
- Saplings ☐
- Trees ☐

Age
- Immature ☐
- Mature ☐
- Old ☐
- Age in Years ☐

Tree species
(if known) ____

Health
- Healthy ☐
- Unhealthy ☐
- Dead ☐

Roots
- Normal ☐
- Adventitious ☐
- Exposed ☐

Interpretative Observations

Toe Bank Profile
- *Planar* ☐
- *Concave upward* ☐
- *Convex upward* ☐

Present Debris Storage
- *No bank debris* ☐
- *Little bank debris* ☐
- *Some bank debris* ☐
- *Lots of bank debris* ☐

Sediment Balance
- *Accumulating* ☐
- *Steady State* ☐
- *Undercutting* ☐
- *Unknown* ☐

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
Noncohesive ☐
Cohesive ☐
Composite ☐
Layered ☐
Even Layers ☐
Thick+thin layers ☐
Number of layers ___

Protection Status
Unprotected ☐
Hard points ☐
Toe protection ☐
Revetments ☐
Dyke Fields ☐

Bank Materials
Silt/clay ☐
Sand/silt/clay ☐
Sand/silt ☐
Sand ☐
Sand/gravel ☐
Gravel ☐
Gravel/cobbles ☐
Cobbles ☐
Cobbles/boulders ☐
Boulders/bedrock ☐

Layer Thickness
Material 1 (m) ___
Material 2 (m) ___
Material 3 (m) ___
Material 4 (m) ___

Ave. Bank Height
Average height (m) ___

Ave. Bank Slope
Average angle (o) ___

Bank Profile Shape
(see sketches in manual) ☐

Tension Cracks
None ☐
Occasional ☐
Frequent ☐

Crack Depth
Proportion of bank height ___

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
None/fallow ☐
Artificially cleared ☐
Grass and flora ☐
Reeds and sedges ☐
Shrubs ☐
Saplings ☐
Trees ☐

Orientation
Angle of leaning (°) ___

Tree Types
None ☐
Deciduous ☐
Coniferous ☐
Mixed ☐

Tree species
(if known)
☐
☐
☐

Density + Spacing
None ☐
Sparse/clumps ☐
dense/clumps ☐
Sparce/continuous ☐
Dense/continuous ☐

Roots
Normal ☐
Exposed ☐
Adventitious ☐

Location
Whole bank ☐
Upper bank ☐
Mid-bank ☐
Lower bank ☐

Diversity
Mono-stand ☐
Mixed stand ☐
Climax-vegetation ☐

Health
Healthy ☐
Fair ☐
Poor ☐
Dead ☐

Age
Imature ☐
Mature ☐
Old ☐

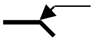
Height
Short ☐
Medium ☐
Tall ☐
Height (m) ___

Lateral Extent
Wide belt ☐
Narrow belt ☐
Single row ☐

Notes and Comments:-

Bank Profile Sketches

Profile Symbols

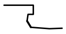
Bank Top Edge


Bank Toe


Water's Edge

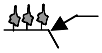

Failed debris

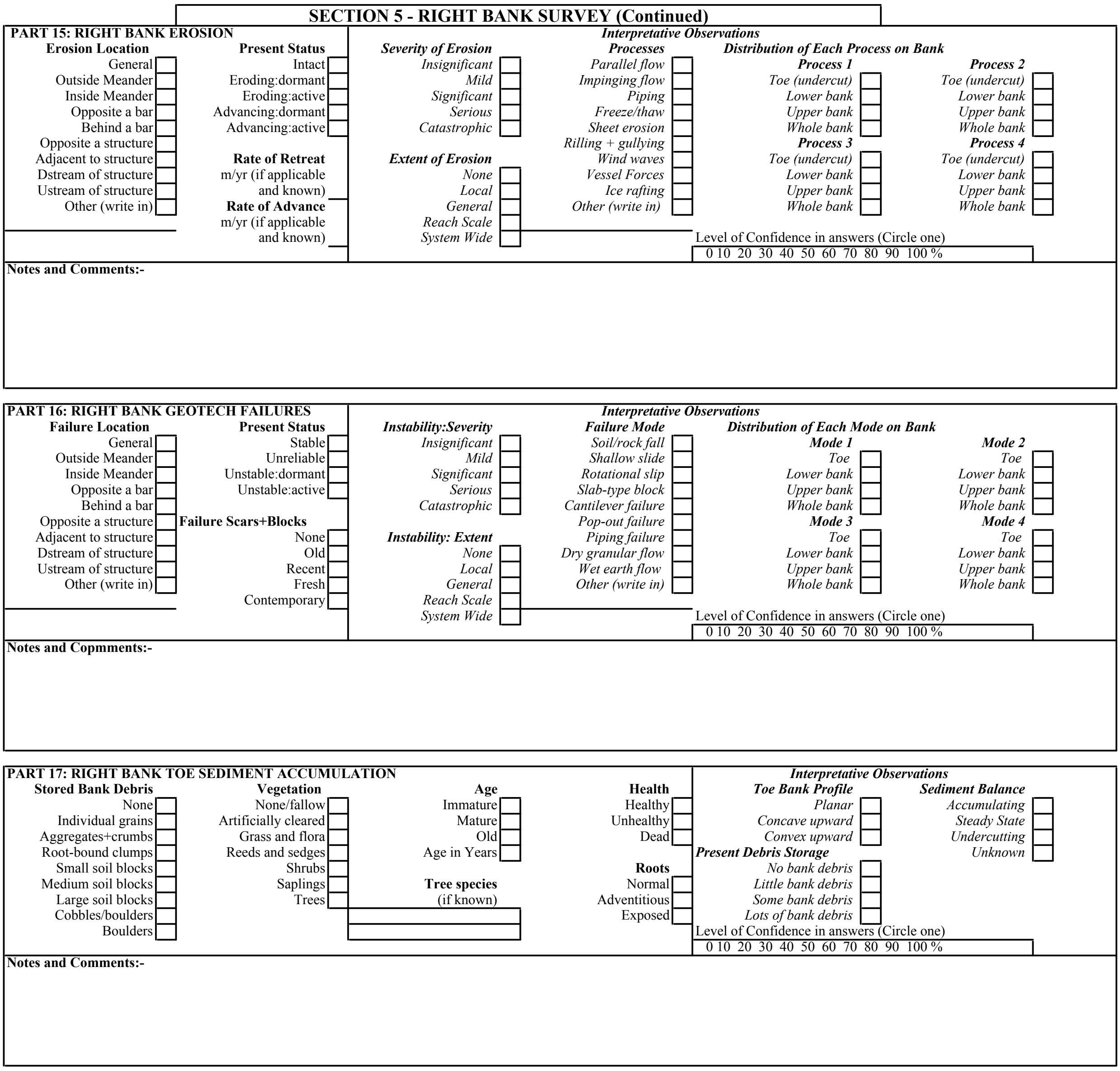

Attached bar


Undercutting


Engineered Structure


Significant vegetation


Vegetation Limit




SECTION 5 - RIGHT BANK SURVEY (Continued)

PART 15: RIGHT BANK EROSION

Erosion Location
- General ☐
- Outside Meander ☐
- Inside Meander ☐
- Opposite a bar ☐
- Behind a bar ☐
- Opposite a structure ☐
- Adjacent to structure ☐
- Dstream of structure ☐
- Ustream of structure ☐
- Other (write in) ☐

Present Status
- Intact ☐
- Eroding:dormant ☐
- Eroding:active ☐
- Advancing:dormant ☐
- Advancing:active ☐

Rate of Retreat
m/yr (if applicable and known)

Rate of Advance
m/yr (if applicable and known)

Interpretative Observations

Severity of Erosion
- *Insignificant* ☐
- *Mild* ☐
- *Significant* ☐
- *Serious* ☐
- *Catastrophic* ☐

Extent of Erosion
- *None* ☐
- *Local* ☐
- *General* ☐
- *Reach Scale* ☐
- *System Wide* ☐

Processes
- *Parallel flow* ☐
- *Impinging flow* ☐
- *Piping* ☐
- *Freeze/thaw* ☐
- *Sheet erosion* ☐
- *Rilling + gullying* ☐
- *Wind waves* ☐
- *Vessel Forces* ☐
- *Ice rafting* ☐
- *Other (write in)* ☐

Distribution of Each Process on Bank

Process 1
- *Toe (undercut)* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Process 2
- *Toe (undercut)* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Process 3
- *Toe (undercut)* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Process 4
- *Toe (undercut)* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole 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
- General ☐
- Outside Meander ☐
- Inside Meander ☐
- Opposite a bar ☐
- Behind a bar ☐
- Opposite a structure ☐
- Adjacent to structure ☐
- Dstream of structure ☐
- Ustream of structure ☐
- Other (write in) ☐

Present Status
- Stable ☐
- Unreliable ☐
- Unstable:dormant ☐
- Unstable:active ☐

Failure Scars+Blocks
- None ☐
- Old ☐
- Recent ☐
- Fresh ☐
- Contemporary ☐

Interpretative Observations

Instability:Severity
- *Insignificant* ☐
- *Mild* ☐
- *Significant* ☐
- *Serious* ☐
- *Catastrophic* ☐

Instability: Extent
- *None* ☐
- *Local* ☐
- *General* ☐
- *Reach Scale* ☐
- *System Wide* ☐

Failure Mode
- *Soil/rock fall* ☐
- *Shallow slide* ☐
- *Rotational slip* ☐
- *Slab-type block* ☐
- *Cantilever failure* ☐
- *Pop-out failure* ☐
- *Piping failure* ☐
- *Dry granular flow* ☐
- *Wet earth flow* ☐
- *Other (write in)* ☐

Distribution of Each Mode on Bank

Mode 1
- *Toe* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Mode 2
- *Toe* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Mode 3
- *Toe* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole bank* ☐

Mode 4
- *Toe* ☐
- *Lower bank* ☐
- *Upper bank* ☐
- *Whole 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
- None ☐
- Individual grains ☐
- Aggregates+crumbs ☐
- Root-bound clumps ☐
- Small soil blocks ☐
- Medium soil blocks ☐
- Large soil blocks ☐
- Cobbles/boulders ☐
- Boulders ☐

Vegetation
- None/fallow ☐
- Artificially cleared ☐
- Grass and flora ☐
- Reeds and sedges ☐
- Shrubs ☐
- Saplings ☐
- Trees ☐

Age
- Immature ☐
- Mature ☐
- Old ☐
- Age in Years ☐

Tree species
(if known)

Health
- Healthy ☐
- Unhealthy ☐
- Dead ☐

Roots
- Normal ☐
- Adventitious ☐
- Exposed ☐

Interpretative Observations

Toe Bank Profile
- *Planar* ☐
- *Concave upward* ☐
- *Convex upward* ☐

Present Debris Storage
- *No bank debris* ☐
- *Little bank debris* ☐
- *Some bank debris* ☐
- *Lots of bank debris* ☐

Sediment Balance
- *Accumulating* ☐
- *Steady State* ☐
- *Undercutting* ☐
- *Unknown* ☐

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

Notes and Comments:-

6) Fluvial Dynamics Assessment

Aim

The fluvial dynamics assessment is a detailed, intensive, small-scale assessment of the channel in an individual problem reach that would have likely to have been identified in the wider scale studies such as the catchment baseline survey or the fluvial audit. The method aims to provide a comprehensive assessment of geomorphological processes, channel forms and process-form interactions at a site or reach scale (Sear *et al.*, 2004). As a result of the nature of the work each case will be site specific and a period of monitoring might be required to fully understand the nature of the problem. The duration of the study will thus normally be for at least over 1 year to ensure that seasonal changes and geomorphologically significant flows can be covered effectively.

Methodology

The techniques for a fluvial dynamics assessment are largely developed from a research level and are tailored to the specific case in question. As a result, it is not possible to define a full brief for such an assessment. However guiding principles can be followed to determine techniques required and the investigation into the particular problem (from Sear *et al.*, 2004):

1) Assess the problem in the context of catchment based system. As it is likely that procedures such as the fluvial audit will have identified such a problem these should be used to establish a context for the reach in question.

2) Perform intensive period of survey, measurement and monitoring to identify cause of the problem.

3) Use the results from 1 and 2 to assess potential morphological evolution of the reach under a 'do-nothing' scenario. Identify possible solutions if risk of continued change is unacceptable.

4) If intervention is necessary use 1-3 to predict likely changes that would occur given a particular intervention strategy and devise an appropriate solution that would suit the cause(s), severity and extent of the problem.

Deliverables

1) Report detailing results of investigation and justification of options selected for any future management.

2) Monitoring results

Expertise

To undertake a fluvial dynamics assessment a high level of training in geomorphology is required. It is recommended that a PhD level trained geomorphologist or, alternatively, someone who has shadowed someone of this level of experience for at least 4 years undertake this type of work. This is required since the interpretation of features and processes at a catchment level is a complex one.

Man days

Highly variable as the GDA is case specific. Monitoring costs are likely to be significant as the survey might well last over a year.

Activities that technique could be used for

The fluvial dynamics assessment is most suitable for assessing the impacts of small-scale activities such as river crossings or instream works where the project is in a particularly sensitive location.

Further reading

Environment Agency, 1998, River Geomorphology: A practical guide, National Centre for Risk Analysis and Options Appraisal, Guidance Note 18, Bristol, UK.

Sear, D.A., Newson, M.D., Thorne, C.R., 2004, Guidebook of Applied Geomorphology, Defra/Environment Agency Flood and Coastal Defence R&D Programme, R&D Technical Report FD1914, DEFRA, London. (download free from http://www2.defra.gov.uk/research/project_data/More.asp?I=FD1914&M=KWS&V=fd1914&SUBMIT1=Search&SCOPE=0)

7) Bank Assessment Methodology (Environment Agency, 1999)

Technique

The bank assessment methodology was developed for the Environment Agency in 1999 by Cranfield University and is an example of a methodology that can be used within the Geomorphological Dynamics Assessment.

Aim

The guide to the bank assessment methodology details processes for bank erosion and procedures for assessing bank erosion as well as methodologies for determining appropriate solutions. Of key use is the field manual that details an iterative procedure for determining what type of bank erosion is occurring and what is the most appropriate solution for addressing the problem.

Methodology

The step by step procedure is summarised below:

Step 1: Survey the problem

The first part of the survey is to evaluate the problem and what type of system is being addressed (non tidal, tidal or canals). Of key importance is to establish the type of bank failure. A flowchart guide is provided to aid the surveyor to determine the likely type of failure.

Step 2: Assess the present state of the channel

An assessment of the channel status and potential actions is required in step 2. A list of diagnostic features is provided to aid the surveyor in determining the channel status.

Step 3: Evaluate the consequence of allowing the bank erosion to continue

A list of potential consequences is outlined and the surveyor is required to assess the risk to each class whether it is moderate, important or severe.

Step 4: Assess the major causes of erosion

As with step 2 a list of diagnostic features are outlined to establish the cause of the bank erosion. Once the cause is determined a list of potential solutions is provided for each cause.

Step 5: Assess the key properties of the bank and channel that will influence the choice of solution

Key properties that influence the type of solution required are detailed and assessed accordingly. These include measures of bank loading, bank height, bankfull velocity and bank slope.

Step 6: Set objectives of an erosion control strategy

Objectives for an erosion control strategy are determined in step 6 using all information gathered in the survey so far.

Step 7: Determine a strategy for erosion control

A strategy is developed using a flow chart detailing consequences of failure, causes of problem, issues to be addressed and type of bank failure.

Step 8: Select an appropriate solution to the strategy

Appropriate solutions are developed from a flow chart illustrating the various bank properties, how they interrelate and how this influences the type of solution.

Step 9: Final check before implementation

Prior to recommendation it is recommended that a quick survey of historic channel change is required in addition to an evaluation of the likely cost-benefits of the work. It is important that any individual measure takes into account the context of the erosion area in the wider scale fluvial processes. Finally, recommendations should be made as to the likely monitoring and evaluation requirements needed to assess whether the solution works.

Deliverables

1) Report detailing an assessment of the bank erosion, interpretations, recommendations for an appropriate solution accompanied by a series of geo-referenced photographs.

Expertise

To use a bank assessment methodology a high level of training in geomorphology is required. It is recommended that a PhD level trained geomorphologist or, alternatively, someone who has shadowed someone of this level of experience for at least 2 years undertake this type of work. This is required since the interpretation of features and processes is a complex one.

Man days

Time required for report depends upon the extent of bank erosion but presuming it is based on one reach the costs can be split into three areas, namely the desk study, field work and report production. The desk study can be undertaken in 1 day, the site survey in 1-2 days and the report in a further 3-4 days. Therefore the total time allowed for an individual to undertake the survey should be between 5-7 days.

Activities that technique could be used for

The bank assessment methodology was developed to primarily assess the causes of bank erosion and suggest appropriate methods for dealing with this issue. As a result, the methodology is obviously focused towards bank modification activities. The technique can be used to assess the causes of erosion and the most appropriate technique for addressing these issues.

Further reading

Environment Agency, 1999, *Waterway Bank protection: a guide to erosion and assessment and management* (project W5-635), Bristol. (Download for free at: http://publications.environment-agency.gov.uk/epages/eapublications.storefront/4216163d0007b1cc2740c0a802960610/Search/Run)

8) Sand/Gravel Mining Assessment

Technique

In the USA, the National Marine Fisheries Service (NOAA Fisheries) is responsible for protecting, managing, and conserving marine, estuarine, and anadromous fish resources and their habitats under various legal authorities. In 2003 a guidance document specific to in-stream sediment removal was developed, because sediment removal operations have the potential to adversely affect aquatic ecosystems and, particularly, all life stages of fish populations. The *Sediment Removal Guidelines* produced by NOAA Fisheries present thorough scientific information that may be used to conduct effects analyses of proposed removal of gravel from streams, either as part of commercial mining operations or as part of capital works or operational maintenance for flood defence.

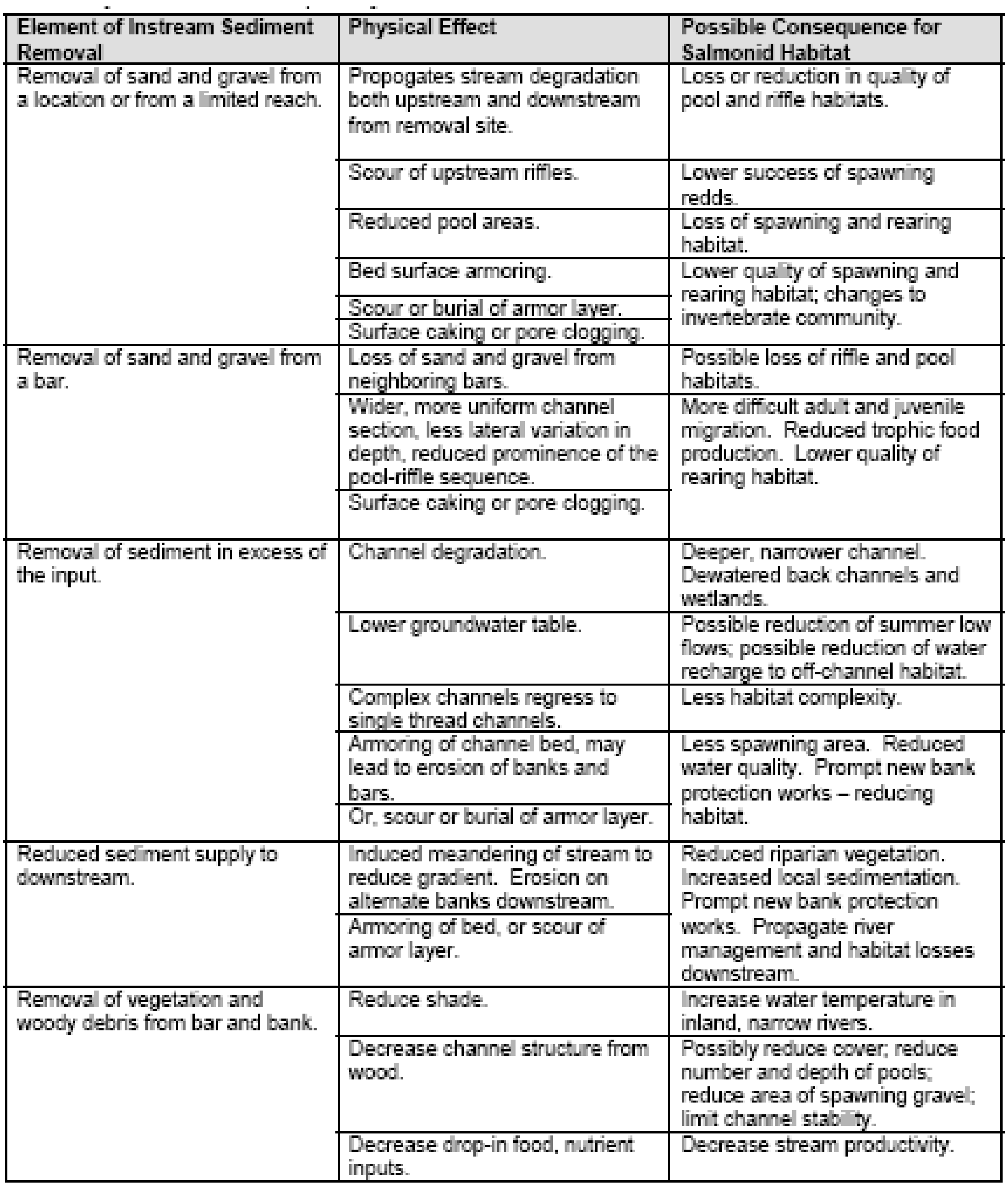
Aim

The aim of the Guidance Document is not to present parties proposing gravel removal activities with prescriptive measures that they must implement in order to gain permission to proceed. Consequently, the language used in the document does not seek to establish binding requirements for sand/gravel mining/removal operations. Instead, the document sets out, on a scientifically rigorous basis, the investigations and analyses necessary to predict the morphological and environmental impacts of a proposed operation and then uses the provisions of the NOAA Fisheries protection procedures to evaluate the consequences of sediment removal activities and determine the extent to which such activities might impair the ability of key species to survive and recover. Finally, the Guidelines suggest approaches for designing sediment removal activities in ways (locations, timing, and methods) that should minimize any adverse effects.

Methodology

The Guidance Document recognises that to predict the effects of a proposed sand/gravel removal operation from an alluvial stream or river, it is necessary to first understand the current functioning of geomorphological stream processes and how these relate to the associated aquatic habitats. Hence, the document presents an overview of the fundamentals of fluvial geomorphology as they relate to channel form and process. The document identifies how the removal of material from the streambed has direct effects on the stream's physical boundaries, on its ability to transport and sort sediment, and on numerous associated habitat qualities. These effects summarized in the Table 10 below.

Table 10: Impacts of gravel removal from alluvial streams (from NOAA Fisheries *Sediment Removal Guidelines*)

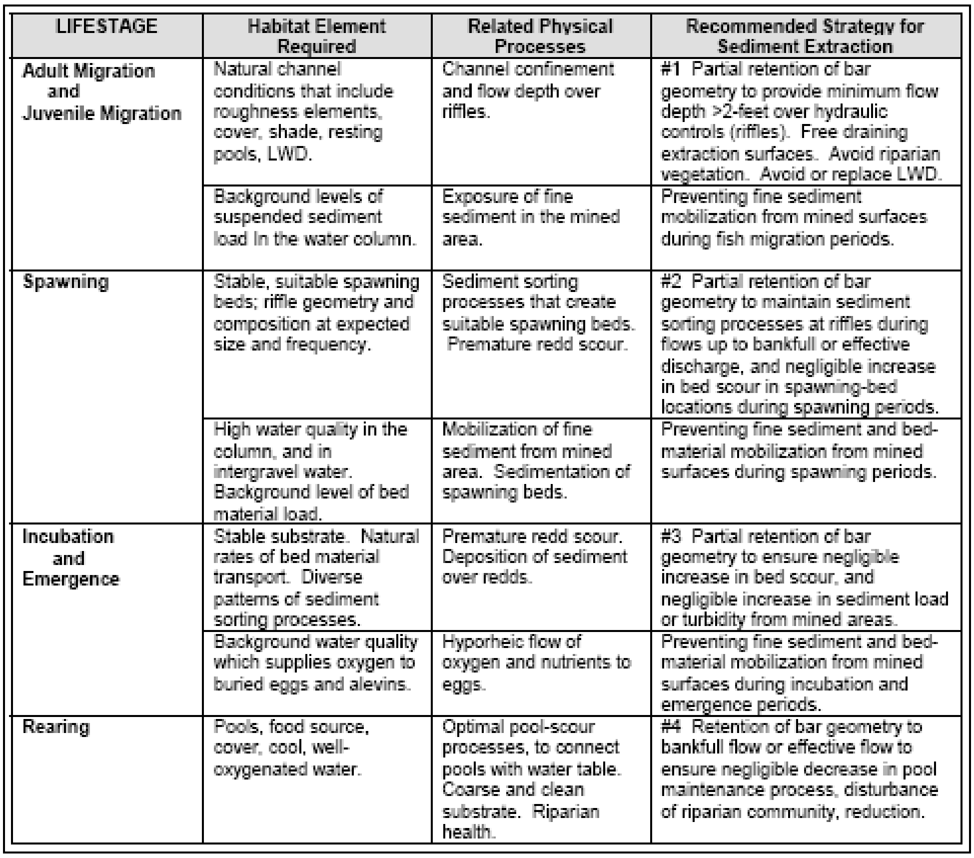


Element of Instream Sediment Removal	Physical Effect	Possible Consequence for Salmonid Habitat
Removal of sand and gravel from a location or from a limited reach.	Propogates stream degradation both upstream and downstream from removal site.	Loss or reduction in quality of pool and riffle habitats.
	Scour of upstream riffles.	Lower success of spawning redds.
	Reduced pool areas.	Loss of spawning and rearing habitat.
	Bed surface armoring.	Lower quality of spawning and rearing habitat; changes to invertebrate community.
	Scour or burial of armor layer.	
	Surface caking or pore clogging.	
Removal of sand and gravel from a bar.	Loss of sand and gravel from neighboring bars.	Possible loss of riffle and pool habitats.
	Wider, more uniform channel section, less lateral variation in depth, reduced prominence of the pool-riffle sequence.	More difficult adult and juvenile migration. Reduced trophic food production. Lower quality of rearing habitat.
	Surface caking or pore clogging.	
Removal of sediment in excess of the input.	Channel degradation.	Deeper, narrower channel. Dewatered back channels and wetlands.
	Lower groundwater table.	Possible reduction of summer low flows; possible reduction of water recharge to off-channel habitat.
	Complex channels regress to single thread channels.	Less habitat complexity.
	Armoring of channel bed, may lead to erosion of banks and bars.	Less spawning area. Reduced water quality. Prompt new bank protection works – reducing habitat.
	Or, scour or burial of armor layer.	
Reduced sediment supply to downstream.	Induced meandering of stream to reduce gradient. Erosion on alternate banks downstream.	Reduced riparian vegetation. Increased local sedimentation. Prompt new bank protection works. Propagate river management and habitat losses downstream.
	Armoring of bed, or scour of armor layer.	
Removal of vegetation and woody debris from bar and bank.	Reduce shade.	Increase water temperature in inland, narrow rivers.
	Decrease channel structure from wood.	Possibly reduce cover; reduce number and depth of pools; reduce area of spawning gravel; limit channel stability.
	Decrease drop-in food, nutrient inputs.	Decrease stream productivity.

Impacts are then considered at two *timescales*: (1) short-term (up to 3 yrs.), and (2) long-term (> 3 yrs) as, depending on the scale and method of removal, adverse effects can persist from as little as one year to several years or even decades if mining or dredging triggers significant channel instability. The effects of sediment removal are also considered at two *spatial scales*; the reach that is directly disturbed, and a much longer reach that has physical or biological connections to the disturbed reach. This is essential as large-scale sediment removal operations, or the combined effects of multiple operations in a given stream, can have far-reaching effects that extend both upstream and downstream for kilometres.

The guide lastly recommends strategies for protecting various stream habitat elements and these are summarised in the Table 11 below.

Table 11: Recommended sediment removal strategies to protect habitat, stream hydrology, and physical processes (from NOAA Fisheries Sediment Removal Guidelines).



LIFESTAGE	Habitat Element Required	Related Physical Processes	Recommended Strategy for Sediment Extraction
Adult Migration and Juvenile Migration	Natural channel conditions that include roughness elements, cover, shade, resting pools, LWD.	Channel confinement and flow depth over riffles.	#1 Partial retention of bar geometry to provide minimum flow depth >2-feet over hydraulic controls (riffles). Free draining extraction surfaces. Avoid riparian vegetation. Avoid or replace LWD.
	Background levels of suspended sediment load in the water column.	Exposure of fine sediment in the mined area.	Preventing fine sediment mobilization from mined surfaces during fish migration periods.
Spawning	Stable, suitable spawning beds; riffle geometry and composition at expected size and frequency.	Sediment sorting processes that create suitable spawning beds. Premature redd scour.	#2 Partial retention of bar geometry to maintain sediment sorting processes at riffles during flows up to bankfull or effective discharge, and negligible increase in bed scour in spawning-bed locations during spawning periods.
	High water quality in the column, and in intergravel water. Background level of bed material load.	Mobilization of fine sediment from mined area. Sedimentation of spawning beds.	Preventing fine sediment and bed-material mobilization from mined surfaces during spawning periods.
Incubation and Emergence	Stable substrate. Natural rates of bed material transport. Diverse patterns of sediment sorting processes.	Premature redd scour. Deposition of sediment over redds.	#3 Partial retention of bar geometry to ensure negligible increase in bed scour, and negligible increase in sediment load or turbidity from mined areas.
	Background water quality which supplies oxygen to buried eggs and alevins.	Hyporheic flow of oxygen and nutrients to eggs.	Preventing fine sediment and bed-material mobilization from mined surfaces during incubation and emergence periods.
Rearing	Pools, food source, cover, cool, well-oxygenated water.	Optimal pool-scour processes, to connect pools with water table. Coarse and clean substrate. Riparian health.	#4 Retention of bar geometry to bankfull flow or effective flow to ensure negligible decrease in pool maintenance process, disturbance of riparian community, reduction.

Deliverables

The NOAA Fisheries guidance document supports production of a sediment extraction evaluation report that contains four part assessment of the proposed sediment removal scheme. The parts are:
(1) Description of potential sediment removal locations,
(2) Evaluation of the habitat needs of aquatic ecosystems in general and fish species in particular,
(3) Identification of the fluvial processes that create or maintain those habitats, and
(4) Selection of an appropriate sediment removal strategy to protect those habitats and processes.

Expertise

The Guidelines are intended for use primarily by NOAA Fisheries staff in conducting effects analyses in response to project proposals in accordance with the US Federal Endangered Species Act (ESA). Hence, they require that the user has had education and training in the appropriate disciplines of fluvial geomorphology and aquatic/fisheries biology.

Man Days

Assuming that the necessary background information and input data are available, typical proposals can be evaluated within a few man days. In the case of more complex projects with multiple reaches or complicating factors, a NOAA Fisheries evaluation might take several weeks to perform.

Activities that technique could be used for

The NOAA Fisheries guidance on sediment extraction could be applied to evaluate the morphological and environmental impacts of any proposal involving sand and gravel mining, or plans to remove sediment from the channel for flood defence purposes.

Further reading

The complete guidelines are available for free download at: http://swr.nmfs.noaa.gov/hcd/policies/April19-2004.pdf or may be found by following the link from: http://swr.nmfs.noaa.gov/.

9) Catchment sediment budget

Technique

Construction of a catchment sediment budget relies on a mixture of quantitative and qualitative techniques to estimate the amount of sediment eroded from the basin that drains to a river, the proportion of eroded material that is delivered to the drainage network (delivery ratio) and the proportion of the sediment load that is deposited on floodplain surfaces during overbank events.

Aim

The primary aim of a catchment sediment budget is to identify whether a project reach receives a heavy sediment load due to catchment erosion and upstream sediment supply. This is important, as streams that are heavily charged with sediment are likely to develop adverse morphological responses to river management and engineering projects unless special measures are taken to deal with sediment moving thorough the catchment system. A subsidiary aim is to develop an understanding of the dynamics of sediment production, delivery and storage for a basin so that the quantities of both coarse and fine sediment input to the fluvial system (that is the channel drainage network) and lost to overbank storage can be accounted for in geomorphological assessment and monitoring studies. The proportion of sediment fluvially transported sediment that is derived from the catchment varies widely from system to system depending on catchment geology, relief, soils, vegetation and land use, and the stability of the channel system. In many streams, the yield of sediment from catchment erosion may constitute the bulk of the total load. Similarly, the proportion of sediment deposited during overbank flows depends on the degree of connectivity of the channel with its floodplain and this varies widely due to management and engineering for flood defence and land drainage, making it important to account for catchment sediment dynamics in geomorphological assessments.

Methodology

Approaches to catchment sediment budgeting combine methods developed in related sciences such as soil conservation, slope stability analysis and physical hydrology as well as those of geomorphology. A thorough review may be found in the book, ‘Rapid evaluation of sediment budgets’ by Reid and Dunne (1996). For larger projects, the use of isotope tracing provides the best basis for catchment sediment budgeting (see Walling 1999). Whatever techniques are involved, the basic steps are:

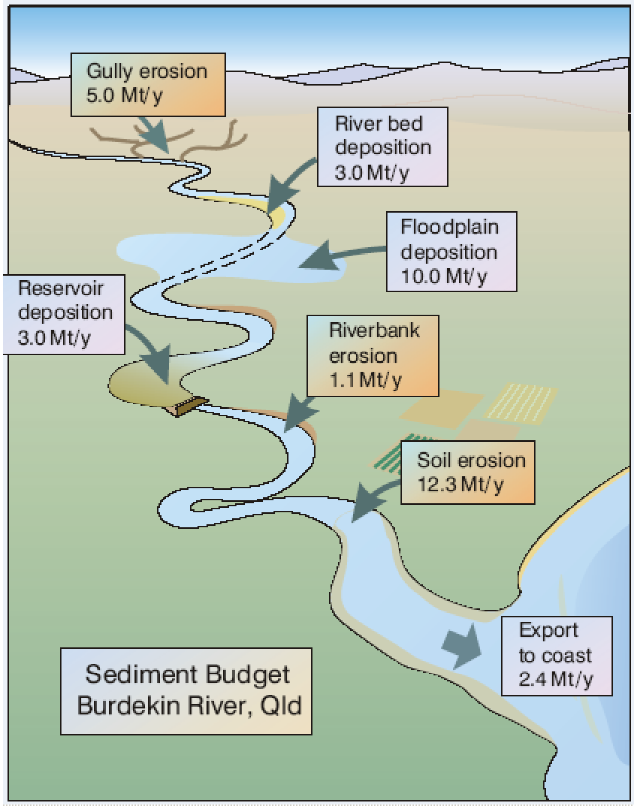
1. Define the project-related issue to be addressed.
2. Acquire background information from existing archives and past studies including catchment baseline surveys if these exist).
3. Divide the catchment into sub-basins with similar geomorphological characteristics.

4. Obtain and interpret aerial photographs and any other remotely-sensed imagery/data (satellite images, LiDAR, CASI etc.).
5. Conduct fieldwork (using appropriate methods and techniques) to identify and characterise key sediment sources, transfer pathways and stores.
6. Compile and analyse archival, remotely-sensed and field data to produce a sub-basin sediment budgets.
7. Assemble sub-basin results to construct a catchment sediment budget.
8. Check results and consider errors and uncertainties.

Deliverables

The outcomes of sediment budget exercise include a catchment map showing sub-basins, key sediment sources, transfer pathways and stores and tables listing sediment inputs, outputs and storage terms for sub-basins and other selected points in the fluvial system. A representation of a sediment budget is shown in Figure 8 below.

Figure 8. Schematic showing sediment budget for the Burdekin River, Queensland (from CSIRO website)



Expertise

The construction of a catchment sediment budget requires a wide range of expertise in geomorphology, hydrology and soil science. In addition, technical skills in the processing and analysis of remotely-sensed data, aerial photograph interpretation, field work and database management/display are all required. These heavy demands severely limit the numbers of people available to perform catchment sediment budgeting in the UK.

Man Days

Due to its catchment specific nature and the high level of skill and expertise required on the part of the scientist, no clear guidance on the man days required to construct a catchment sediment budget has been developed to date. For a small basin (say < 100 km^2) a budget could probably be derived within one or two weeks (assuming that the archival and remotely-sensed data sources outlined above were available) of office and field work. The time and effort required for larger basins would increase in a non-linear fashion with the basin area.

Activities that technique could be used for

Catchment sediment budgeting should be employed where the proposed scheme is likely to have a significant impact on sediment dynamics at the basin scale, either through interrupting or disconnecting some part of the fluvial sediment transfer system that is responsible for linking sediment sources and sinks. Examples would include construction of impoundments that trap sediment in substantial quantities and for long periods, flood defence embankments that disconnect channels from their floodplains and restoration or washland storage schemes that reconnect channels with significant off-line storage for water and sediment.

Further reading

www.clw.csiro.au/publications/ general2002/managing_regional_water_quality.pdf

Reid, L.M. and Dunne, T., 1996, Rapid Evaluation of Sediment Budgets, CATENA Verlag GMBH, 35447 Reiskirchen, Germany, ISBN 3-923381-39-5, 164p.

Walling, D.E., 1999, Linking land use, erosion and sediment yields in river basins, *Hydrobiologia*, **410**, 223 – 240.

10) Stable Alluvial Method (SAM)

Technique

The SAM Hydraulic Design Package for Channels was first developed by the US Army Corps of Engineers (USACE) at the Waterways Experiment Station, Vicksburg, Mississippi during the 1980s and it has been evolving ever since. In 2001, the USACE entered into an agreement with Owen Ayres & Associates, Inc., Ft. Collins, Colorado, to add a Windows interface to the DOS-based SAM. Ayres has exclusive rights to sell and support the resulting SAM.win package to the private sector and all government agencies except the USACE.

Aim

SAM is an integrated system of computer programs developed to support hydraulic analyses concerning the design, operation and maintenance of flood defence and stream restoration projects. The package was designed to provide a qualitative analytical method that could easily be used in preliminary screening of alternative solutions to channel instability problems where limited availability of funds precludes more sophisticated investigations.

Methodology

SAM provides hydraulic engineers with a seamless series of routines from which to progress from hydraulic calculations to calculating sediment transport capacity to determining sediment yield. This is achieved by using the three main modules of the package in series. First, SAM.hyd is used to calculate the width, depth, slope and n-value for a stable channel formed in the alluvial materials specified by the user. Next, SAM.sed is used to calculate sediment transport capacity according to a wide range of sediment transport functions, using the hydraulic parameters previously calculated in SAM.hyd. Finally, SED.yld is used to calculate the sediment yield based on the sediment transport capacity calculated using SAM.sed. In parallel, SAM.aid provides guidance in the selection of an appropriate sediment transport function to use in a given river, based on five screening parameters: D_{50}, slope, velocity, width, and depth.

SAM considers a single cross-section, rather than a reach of a river. However, the geometry of that cross-section can be defined in several ways. For trapezoidal channels, either a simple or compound channel can be input. Also, an irregular channel can be defined using distance and elevation coordinates for the cross-section.

The program operates interactively while saving the input data in ASCII files and using these files to pass data from one module to the next.

Deliverables

The output from SAM.hyd is a spreadsheet defining the normal depth and composite hydraulic parameters for a cross-section with variable roughness. The calculations can be made with a variety of bed roughness predictors. Stable channel dimensions (channel width, depth and slope) are also specified for a given discharge and sediment load in the form of a family of possible solutions that meet project constraints.

SAM.sed a bed material sediment rating curve by size class using hydraulic parameters calculated in SAM.hyd (other, user specified values may also be used). The sediment discharge rating curve can be specified as either sediment discharge versus water discharge or sediment concentration versus water discharge.

SAM.yld output consists of a sediment yield passing a cross-section during a specified period of time. The time period considered can be a single flood event or an entire year. In SAM.yld the flow can be represented either by a flow duration curve or a sediment hydrograph.

Expertise

The user manual notes that 'SAM will provide reasonable answers if the user is cognizant of the need for the careful prescribing of the bed material gradation'. This statement alone should be sufficient to caution potential users that they must be trained not only in open channel hydraulics, but also in sediment transport technology before using SAM in project-related applications. While SAM in its SAM.win form is simple to load and run, the reliability of the results is directly correlated with the skill and experience of the user under conditions pertaining to the particular application in hand.

Man Days

The SAM software runs very quickly and, assuming that the necessary input data are available, typical applications can be completed within 1 to 3 man days. In the case of more complex projects with multiple reaches or complicating factors, a SAM application might take up to one week to perform.

Activities that technique could be used for

SAM is not a one-dimensional model. It bases its calculations on a single cross-section and a single point in time. No provisions are made in any of the modules for simulating the effects of a hydrograph, nor for analysing a reach of a river, except in as much as a reach might be represented by an average cross-section. It follows that SAM could be used as part of low level assessment of relatively modest river works which do not affect long reaches of the fluvial system. SAM is a cost-efficient tool of limited applicability and application of SAM-based assessments to major projects would not be recommended.

Further reading

The SAM manual may be found at: http://www.ayresassociates.com/Web_SAMwin/Manual/Chapter-1.pdf

11) Sediment Impact Assessment Method (SIAM)

Technique

The Sediment Impact Assessment Method (SIAM) is a sediment budgeting tool that was first conceived in 2001 by David S. Biedenharn, Colin R. Thorne and Chester C. Watson during investigation of sediment dynamics in the Upper Missouri River, USA. In 2001-2003, a prototype SIAM was coded in joint research by developed by Colorado State University (CSU) and the US Army Corps of Engineers, Engineering and Research Development Centre, Mississippi, USA. In February 2004, the prototype (US-SIAM) was made available to the EPSRC/Defra/EA/Scottish Exec. Flood Risk Management Research Consortium for exploration or the concepts, user interface and potential for development of a UK-SIAM tool. The UK version is currently under development at the University of Nottingham, with assistance from Jeremy Benn and Associates (Atherstone Office) and will be rolled out in April 2006.

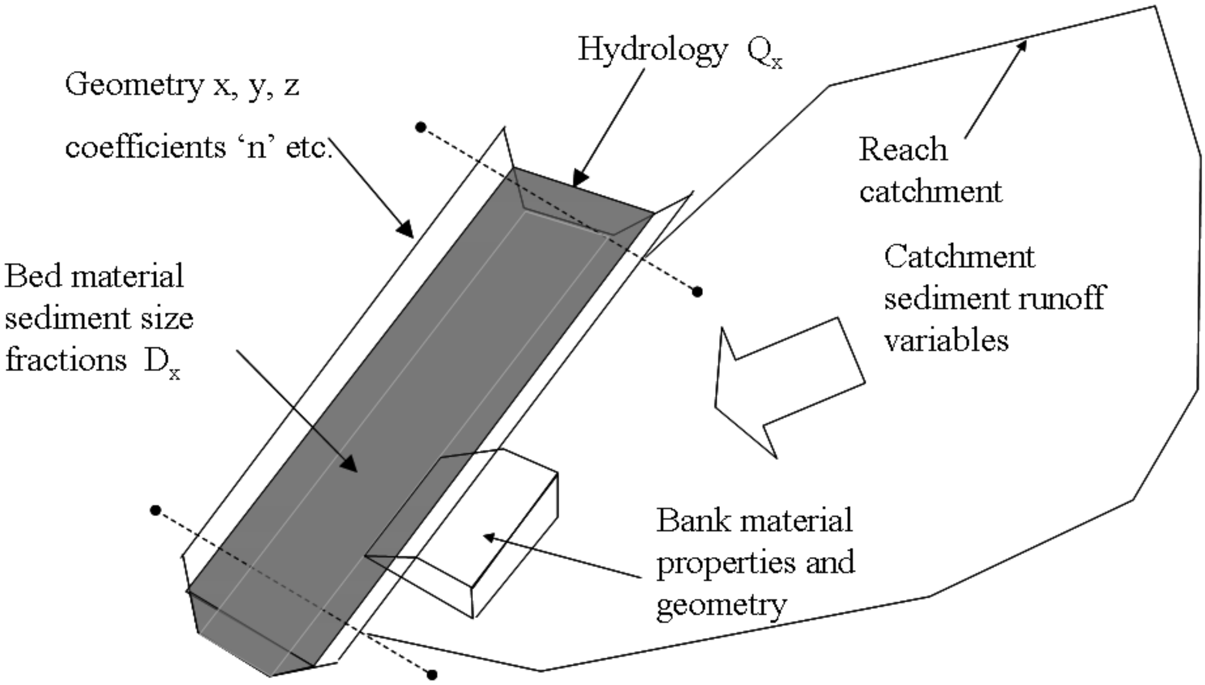
Aim

The aim of SIAM is to create a reach-scale sediment budget for the fluvial system being analysed that identifies reaches as sediment sources, transfer links or sinks and which indicates the magnitude of sediment imbalance in non-equilibrium reaches. SIAM differs from conventional sediment routing models (such as iSIS Sediment Transport) in that it aims to account explicitly for sediment in the fluvial system derived from erosion of the catchment, gullies and ditches, and the channel banks, as well as that sourced from the channel bed.

Methodology

SIAM uses the sediment continuity or Exner equation to create the reach-scale sediment budgets, based on the difference between the amount of sediment entering and leaving each reach as shown in Figure 9 below.

Figure 9: Schematic illustration of reach-scale sediment budget in SIAM

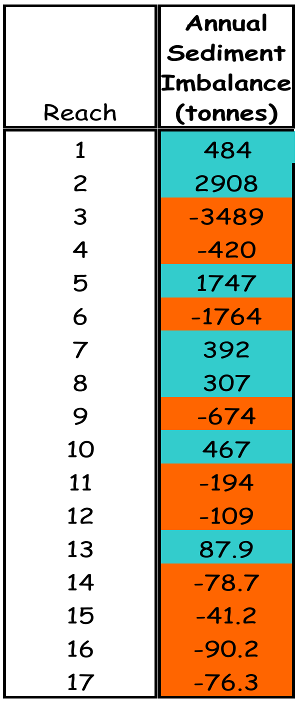


Wash load and bed material load components of the total load are handled separately. Wash load is relatively fine-grained material that is not found in significant quantities in the bed. The quantity of wash load carried by a river is usually limited by the supply available rather than the transport capacity of the flow. Bed material load is coarser material that is found in significant quantities in the bed. The transport of bed material load is usually limited by the capacity of the flow to carry it rather than the available supply. Hydrology is represented using a flow duration curve, so that SIAM integrates the sediment budget over the entire range of flows experienced in each reach. Once SIAM has established sediment budgets for current conditions, it can be used to investigate the impacts of engineering interventions, in-channel activities and catchment changes on the sediment budgets at reach and system scales.

Deliverables

The output from SIAM is presented as a table of reach-scale sediment budgets under current and 'with project' conditions. Reaches are identified as sediment sources, transfer links or sinks and the magnitude of sediment imbalance is listed for non-equilibrium reaches. An example results table for a gravel-bed stream in southwest England that has been analysed using 17 sediment reaches is shown below (Table 12). In the table, cells coloured orange indicate sediment source (where, over a representative range of flows, sediment transport capacity exceeds supply resulting in a negative sediment imbalance) reaches while those coloured green indicate sediment sinks (where, over a representative range of flows, sediment supply exceeds sediment transport capacity, resulting in a positive sediment imbalance).

Table 12: Example of the results table generated by SIAM using different sediment transport



Reach	Annual Sediment Imbalance (tonnes)
1	484
2	2908
3	-3489
4	-420
5	1747
6	-1764
7	392
8	307
9	-674
10	467
11	-194
12	-109
13	87.9
14	-78.7
15	-41.2
16	-90.2
17	-76.3

Expertise

Under the current FRMRC remit, SIAM-UK will be developed to proof-of-concept stage by April 2006. It will then be operationalised for general application and should be available later in 2006. It is anticipated that two versions will be released. An advanced version embedded within the Hydraulic Engineering Center – River Analysis System (HEC-RAS) will required expertise in hydrodynamic modelling and sediment transport technology. This version is intended for use on major river projects requiring advanced analysis of complex river environments. A simpler, entry level version will also be released, suitable for use by non-specialists following a 3-day short course and intended for use on smaller schemes and less sensitive rivers environments.

Man Days

While SIAM itself runs very quickly and efficiently on a modern PC, data assimilation and entry are time consuming. A great deal depends on what data are already available to characterise the river channel, its flows and its sediments. To date there have only been a few field applications of SIAM, but from available evidence it is estimated that a typical application to a small watercourse (say a river length of 10 km) may require about 1 man-month provided that the river has already been surveyed as part of flood defence or land drainage investigations. While it might not be feasible to construct a SIAM model for each proposed application, if a model for a given fluvial system were in place, using it to investigate the sediment impacts of any scheme or activity would be a quick and cost-effective way of checking the system-scale impacts.

Activities that technique could be used for

SIAM is intended for use in, first, characterising the present sediment balance and budgeting sediment in the fluvial system and then, second, allowing the user to play ‘what if’ games to investigate the sediment impacts of various alternative schemes for river engineering and sediment management. In the context of Impact Assessment and Post Project Monitoring, SIAM would allow the system-wide impacts of a proposed project or activity to be assessed and would support period ‘health checks’ on the operation of the fluvial system under post-project conditions.

Further reading

SIAM context, visit: http://www.floodrisk.org.uk

SIAM research and development contact: colin.thorne@nottingham.ac.uk

12) One-dimensional flow modelling using iSIS

Technique

iSIS was developed and is jointly owned, developed and supported by Wallingford Software Ltd. and Halcrow Group Ltd. and is an ‘industry standard’ 1-dimensional, fixed-boundary, hydrodynamic simulator that models flows and water levels in open channels and estuaries (http://www.wallingfordsoftware.com/products/isis/). It is able to model complex and branched channel networks, and includes methods for simulating floodplain as well as in-channel flows. Other models that employ similar (though not identical) techniques to iSIS and which could be employed as alternatives to iSIS in morphological investigations include the US Army Corps of Engineers, Hydraulic Engineering Center, River Analysis System (HEC-RAS) and Danish Hydraulics MIKE-11.

Aim

The aim of iSIS is to represent the flow in a river or estuary in one dimension, accounting for the movement of water as shear flow by using the governing equations of motion. Once calibrated for observed conditions, an iSIS model is often used to estimate inundation levels associated with extreme events. iSIS may also be used to investigate the hydrodynamic impacts of proposed engineering works, in-channel and/or floodplain activities or changes to catchment hydrology.

Methodology

The hydrodynamic equations in iSIS are closed using either unsteady and steady flow solvers, with options to use simple backwater methods, flow routing or full unsteady simulation. The model coding is designed to optimise run-time and enhance model stability. The software includes diagnostic error checks and a comprehensive on-line help system (see Figure 10 for example windows).

Deliverables

iSIS outputs fully interactive views of the model data and results using maps, plan views, long sections, form-based editing tools and time series plots as shown below. The results can also be reported in text and tabular formats (see Figure 11 below).

Figure 10: Example windows

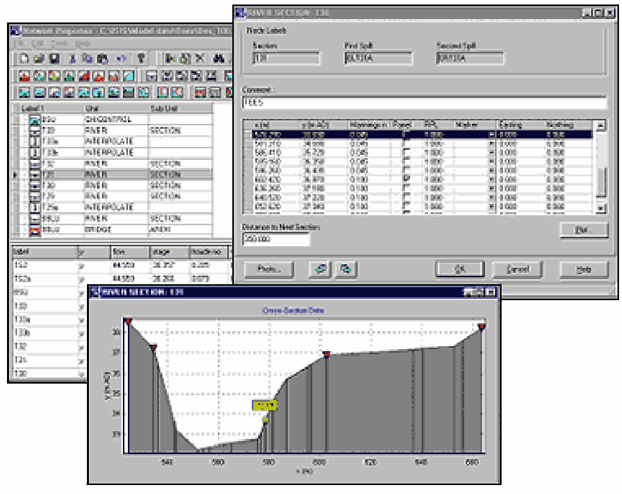
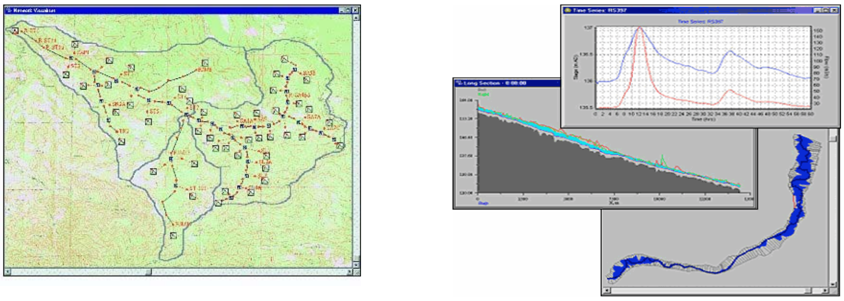


Figure 11: Example output



Expertise

One-dimensional hydraulic or hydrodynamic modelling should only be performed by specialists with a background in open channel hydraulics who have been trained in its use either as part of their Higher Education in Civil Engineering or via short courses offered by professional consultants. Advanced applications to complex situations are best performed by individuals with several years' experience in steady and/or unsteady flow modelling.

Man Days

It is difficult to generalise concerning the time and effort required to apply an iSIS model as each case tends to be different. However, for a typical small watercourse a calibrated and stable model can be produced within a man-week assuming that channel survey data and hydrology data are either available from a gauging station are can be generated acceptably using the FEH method (which is available as a front end in iSIS) for ungauged catchments.

Activities that technique could be used for

In the context of Impact Assessment, iSIS could be used to predict the hydrodynamic effects of any proposed works or activities in the channel or on the floodplain at reach and system scales. However, as it represents the river in one dimension only, iSIS would not be suitable to predict local hydrodynamic impacts. As iSIS Flow is a fixed-boundary model it is not able to predict morphological adjustments, although these may be inferred through consideration of the long-stream distributions of key variables such as mean velocity, bed shear stress and specific stream power. To predict morphological changes involving bed scour (incision) or deposition (aggradation) the sediment module in iSIS (or MIKE-11) must be used (see next section). It is intended that a version of HEC-RAS capable for modelling sediment transport will be released within a few months from now (March 2005).

Further reading

For iSIS visit:- http://www.wallingfordsoftware.com/products/isis/

For HEC-RAS visit:- http://www.hec.usace.army.mil/software/hec-ras/hecras-hecras.html

For MIKE-11 visit:- http://www.dhisoftware.com/mike11/

13) One dimensional flow and sediment modelling using iSIS Sediment

Technique

iSIS Sediment is a module in the iSIS Flow hydrodynamic model system that accounts for sediment transport and bed level changes through aggradation or degradation. The ownership and development of iSIS Sediment Transport is the same as that of the iSIS Flow model suite described above. Further details may be found at:

http://www.wallingfordsoftware.com/products/isis/sediment.asp

Other models that employ similar (though different) techniques to iSIS Sediment that could be employed as alternatives in morphological investigations include the US Army Corps of Engineers, Hydraulic Engineering Center, HEC-6 and Danish Hydraulics MIKE-11.

Aim

iSIS Sediment is designed to study channel morphology in a variety of fluvial settings and to be widely applicable to the study of sedimentation problems in rivers and major irrigation canals.

Methodology

Prediction of sediment transport rates, changes in bed elevation and amounts of erosion and deposition throughout the channel system are made by inputting the channel flow hydraulics calculated in iSIS Flow together with information on the bed material of the channel to a range of sediment transport prediction equations included within the sediment transport module. Available sediment transport functions include the Engelund-Hansen, Ackers-White and Westrich-Jurashek transport equations.

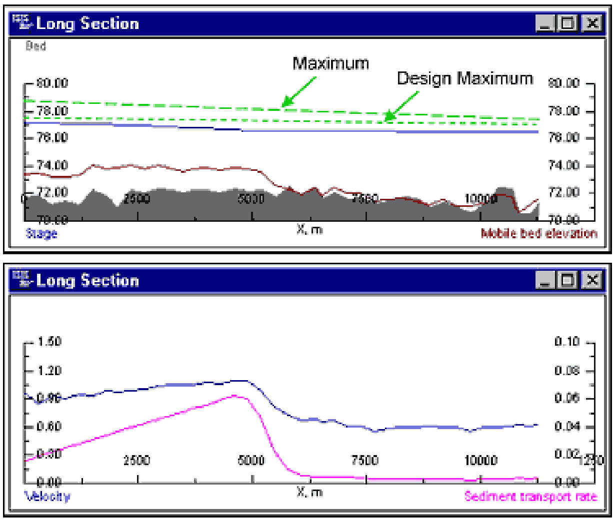
Deliverables

iSIS Sediment outputs fully interactive views of the model data and results using plan views, long sections, form-based editing tools and time series plots. The results can also be reported in text and tabular formats. A typical output graph showing bed level changes and sediment transport rate during a flood event is shown below (Figure 12).

Expertise

All of the requirements for one-dimensional flow modelling apply to use of iSIS Sediment Transport or any other aggradation/degradation model. In addition, sediment transport modelling should only be performed by specialists with a background in sediment transport technology and who have been trained in the use of iSIS Sediment Transport (or its alternatives) either as part of their Higher Education in Civil Engineering or via short courses offered by professional consultants. To obtain reliable results, applications are best performed by individuals with several years' experience in hydrodynamic and sediment transport modelling. In addition, in the case of HEC-6, direct experience with this model (which is DOS-based and which lacks a user-friendly graphical interface) is an essential prerequisite for reliable and cost-effective application.

Figure 12: Typical output graph



Man Days

While it might appear that utilisation of the sediment transport module represents a marginal additional amount of time and effort over and above that required for iSIS Flow modelling, in practice this is seldom the case. This is the case because iSIS Sediment Transport depends on comprehensive data on bed material size distributions in the modelled reach and because, usually, sediment modelling requires additional cross-sections to run successfully. Hence, a considerable investment in field data collection is likely to be needed in order to extend a study from application of iSIS Flow to use of iSIS Sediment Transport.

Activities that technique could be used for

iSIS Sediment Transport could only be used in morphological assessments associated with major capital works and projects. In such cases, the model has a powerful capability to perform long and short-term simulations of bed level changes associated with, for example, channel dredging, river training or the construction/operation of flood defence assets. The model's capabilities in dealing with sediment sorting and cohesive sediment transport make it particularly applicable to gravel-bed rivers and lowland rivers/estuaries. However, as it is a one-dimensional model, iSIS Sediment Transport is unable to simulate local or sub-reach scale morphological adjustments as these involve significant transverse (that is cross-channel) changes as well as long-channel (aggradation/degradation) changes.

Further reading

For iSIS Sediment visit:- http://www.wallingfordsoftware.com/products/isis/sediment.asp

For HEC-6 visit:- http://www.hec.usace.army.mil/software/legacysoftware/hec6/hec6.htm

For MIKE-11 visit:- http://www.dhisoftware.com/mike11/

14) Two-dimensional flow and sediment modelling using MIKE 21

Technique

MIKE 21 is a software package developed, owned and marketed by the Danish Hydraulics Institute (http://www.dhisoftware.com/mike21/). It is a numerical modelling system for free-surface flow in channels with deformable beds that is applicable to the simulation of rivers, lakes and estuaries, provided that stratification can be neglected. Mike 21 has a user-friendly interface that facilitates use of the model and is useful when communicating the results to non-specialists. A wide range of support software for use in data preparation, analysis of simulation results and graphical presentation are provided by the DHI. Another model that simulates complex river, estuarial and coastal flows and sediment dynamics in two dimensions, and which could be employed as alternatives to MIKE 21 in morphological investigations, is Telemac – which was developed by Electricité de France, Laboratoire National d'Hydraulique, in close partnership with HR Wallingford). SSIIM is another a multi-dimensional flow and sediment transport model applicable to rivers. It was developed by the Norwegian University of Science and Technology. An advantage compared to MIKE 21 and Telemac in that SSIIM is free-ware, but a disadvantage is that it lacks technical support as it has been developed by a university rather than a commercial software house.

Aim

MIKE 21 can be used to support investigations in many areas of hydraulics and sedimentation. The aim of the model is to allow users to model depth-averaged flows accounting for the effects of:

- currents and tidal flows
- storm surges
- dispersion and recirculation
- waves and seiches
- vessel motion
- sediment erosion, transport and deposition

Methodology

The latest generation of MIKE 21 is based on a fully Windows-integrated Graphical User Interface and is compiled as a true 32-bit application. The modelling system is constructed in a modular manner around the four main applications:

- coastal hydraulics and oceanography
- environmental hydraulics
- sediment processes
- waves

An inspection version of the program may be downloaded free from the DHI website given above.

Deliverables

A wide range of support software for use in data preparation, analysis of simulation results and graphical presentation of the findings of the model are provided by the DHI.

Expertise

MIKE 21 is a state-of-the-art computer model and can only be applied effectively and reliably by individuals with advanced training and experience in numerical modelling of fluid shear flows with mobile bed conditions. DHI offer training in the use of MIKE 21 but the number of people capable of using this model to simulate morphological responses to river/estuarial/coastal engineering and management in the UK is limited to a few academics and consultants.

Man Days

The man days required to construct and run a MIKE 21 model depend on the scale and complexity of the situation to be modelled and the skill and experience of the modeller. What is clear is that 2 dimensional modelling is not a task to be undertaken lightly due to the heavy data requirements (detailed surveys of bed topography and velocity fields are essential) and the time necessary to calibrate and validate the model prior to undertaking investigative model runs.

Activities that technique could be used for

A major investment of time and resources is required to apply MIKE 21 and this is bound to limit the range of activities that this approach could be used for. In the context of Impact Assessment for major schemes with large R&D budgets and long design study timescales, MIKE 21 could be used to predict the two dimensional hydrodynamic and morphological effects of any proposed works or activities in the channel or on the floodplain, at the sub-reach and reach scales. Applications specifically mentioned in DHI promotional literature are shown in the figure below (Figure 13).

However, as it represents the river in two dimensions only, MIKE 21 would not be suitable to predict local hydrodynamic and morphological impacts such as pier scour or toe scour adjacent to revetments at bends – which result from three dimensional flow phenomena that are poorly represented in this two dimensional simulation.

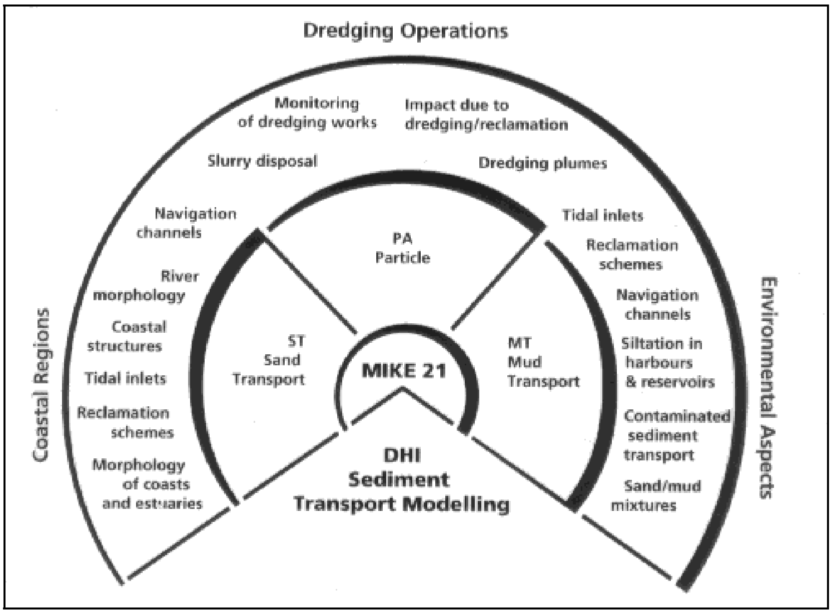
Further Reading

For MIKE-21 visit:- http://www.dhisoftware.com/mike21/

For Telemac visit:- http://www.hrwallingford.co.uk/software/telemac.html

For SSIIM visit:- http://www.bygg.ntnu.no/~nilsol/ssiimwin/

Figure 13: Applications for MIKE 21



15) Three-dimensional flow and sediment modelling

In reality, the flow of water and movement of sediment in rivers is a three-dimensional phenomenon. Ideally, numerical simulations should capture the dynamics of water and sediment motion all three dimensions by solving the full equations for open channel flow and sediment transport. Once this is established, it can be recognised that one or even two-dimensional models can never hope to simulate completely the complexities and nuances of how real flows of water and sediment in rivers interact with channel morphology to drive geomorphological evolution and change. However, at present (March 2005) while three-dimensional modelling of water movement can be undertaken routinely (see for example http://www.usbr.gov/pmts/sediment/model/u2rans/

modelling sediment dynamics in rivers in three dimensions is a research activity that is beyond the scope of the vast majority of project-centred or even strategic investigations.

This situation is likely to change within the next few years as our understanding of fluvial processes and the computational power of available machines both continue to grow and so further consideration should periodically be given to the practicality of adding three-dimensional modelling to the range of techniques recommended for morphological investigations of river response to engineering and management.

Further Reading

For advances in modelling visit:- http://hydra.cche.olemiss.edu/index.php?page=home

For an example of a current 3-D model visit:- http://www.usbr.gov/pmts/sediment/model/u2rans/

APPENDIX 2: MONITORING TECHNIQUES

1) Fixed-Point Photography

Aim

To provide a visual image at particular viewpoints within a reach and thus illustrating changes which occur through time.

Methodology

Fixed-point photography is performed at various locations in the reach at each time of survey. Each of the photographs will also need to be taken at the same bearing to ensure that the images are consistent and reproducible. To ensure that this happens it is useful to take the original set of photographs out into the field so that any new frames taken will cover the same details. A Global Positioning System (GPS) is also necessary to locate the point at which the initial photograph was taken.

Deliverables

Numerous site photographs at each time of visit. A map of the reach illustrating the location at which the various photographs were taken should also be included. At each photograph location, a direction arrow illustrating the angle at which the shot was taken should also be added.

Expertise

No geomorphological background is required to re-take photographs as long as a geomorphologist determines the initial photograph locations. This is important since a level of understanding of geomorphology is required to anticipate the parts of the reach that are most likely to change over time.

Man days

1 man day per site visit

Activities that technique could be used for

Repeat fixed-point photography provides a good visual representation of any changes that have occurred at a particular location and thus is useful in monitoring any activity.

Further reading

None

2) Cross-Section Surveys

Aim

To determine how the river has adjusted at specific locations.

Methodology

Cross-section surveys are undertaken in a single line perpendicular to the flow. These are generally concentrated at bends and riffles as these are often particular areas of interest. The survey should generally be undertaken with a total station so that all data points can be tied into a known ordnance datum. However, general level surveys could also be used. It is necessary to ensure that any repeat surveys can be tied to the same location and thus errors in measurement can be reduced. In each survey it is important to take measurements at any defined break in slope along the cross-section.

Deliverables

Cross-section diagrams which when overlaid can be used to calculate adjustments over time. Of particular interest is the monitoring of areas of erosion and deposition.

Expertise

Basic surveying training with a total station is required to undertake the work. The initial monitoring programme would need to be set up by a geomorphologist to ensure the spatial extent of the survey is adequate and all features of interest are included.

Man days

The number of cross-sections that can be surveyed in a day is largely dependent on the size of the river, season, vegetation density and weather conditions. However, it is anticipated that around 10-15 cross-sections could be surveyed on an average day, in a medium sized river of about 10m wide.

Activities that technique could be used for

Cross-section surveys are useful for providing an estimate of channel change at a particular cross-section in the channel. The technique is thus very adaptable and can be used to assess any activity where either lateral, or vertical, adjustment could be expected.

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)

3) Erosion Pins/PEEPS

Aim

Erosion pins or photo-electronic erosion pins (PEEPS) are used to measure the amount of erosion at a particular location.

Methodology

The erosion pins, or PEEPS, are driven into a bank face and used to measure lateral adjustment through time. The pins are periodically checked (preferably on an event driven basis) and the level of erosion is measured directly on the pin by noting the depth of pin that has become exposed at each location.

Deliverables

Reading of the amount of erosion, at each pin, at each survey date.

Expertise

Basic level of geomorphological training.

Man days

1 man day per site visit which could include the measurements of a number of pins which after installation only takes a few minutes to measure any adjustment.

Activities that technique could be used for

Erosion pins/PEEPS can only be used where lateral adjustment can be expected. Consequently, its applicability as a technique is limited to these situations.

Further reading

Couper P, Stott T, Maddock I. 2002. Insights into river bank erosion processes derived from analysis of negative erosion-pin recordings: observations from three recent UK studies. *Earth Surface Processes and Landforms* **27**: 59-79.

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 DM. 1992. Design and installation of a novel automatic erosion monitoring system. *Earth Surface Processes and Landforms* **17:** 455-463.

Lawler DM, Thorne CR, Hooke JM. 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.

4) Topographic Surveys

Aim

To measure enough points on the river and floodplain to build a 3D model of the river and floodplain system.

Methodology

Undertake a full topographic survey of the project reach using total station. A large number of points should be measured in the river, riparian corridor and floodplain. Points should be measured wherever there is a break of slope and enough points should be measured to develop a digitial terrain model. This requires a significant expansion in the number of points required compared to a simple cross-section survey.

Deliverables

3D map of reach with text files detailing x, y, and z co-ordinates.

Expertise

Skilled surveyor in the use of total station is required. It is recommended that a geomorphologist is used to guide the survey to ensure that all features of interest are included. This might only include a pre-survey meeting with the surveying team. Alternatively, a geomorphologist should be included as part of the survey team. A basic level of geomorphological training would be helpful for this purpose.

Man days

Clearly the number of man days required will be dependent on conditions at the site. If the vegetation is dense than a survey can take a significantly longer amount of time. Consequently, a general estimate of time for a survey is difficult to accurately provide and should be undertaken on a case by case basis. However, a good surveying team can take around 1000 points in a day. A further day, per day of fieldwork, should be included for the map production.

Activities that technique could be used for

Topographic surveys provide a very detailed set of data (x,y and z co-ordinates) and thus can be extremely valuable in determining channel change. The costs for undertaking such surveys have reduced in recent years and are thus suitable for monitoring an increasing number of activities, *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.

5) River Reconnaissance Survey

Aim

Perform a geomorphological assessment of a reach through detailing key morphological features and processes. This is noted on a standard survey sheet.

Methodology

To provide a rapid geomorphological survey of a reach noting the contemporary morphological forms of interest and to establish an overview of contemporary geomorphic processes. For further information see section Appendix 1, number 5.

Deliverables

Completed reconnaissance sheets, detailed annotated maps illustrating key geomorphological features, geo-referenced photographs and supplementary text.

Expertise

A PhD level trained geomorphologist or, alternatively, someone who has shadowed someone of this level of experience for at least 2 years should undertake these surveys.

Man days

1 man day per 4.5-8km depending upon season and conditions with additional time required for photograph cataloguing and supplementary text.

Activities that technique could be used for

River reconnaissance surveys are valuable in both impact assessment as well as post-project monitoring. They are most suited to reach scale assessments of change. As they are based on observations the technique is limited with respect to detailing precise data on channel adjustments.

Further reading

Thorne, C.R., 1998, *Stream Reconnaissance Guidebook: Geomorphological Investigation and Analysis of River Channels,* J Wiley and Sons, Chichester, UK, ISBN 0-471-968560, 127p.

Downs, P.W., and Thorne, C.R, 1996, A geomorphological justification of river channel reconnaissance surveys, *Transactions of the Institute of British Geographers,* New Series, **21**, 455-468.

Thorne, C.R., Simon, A. and Allen, R., 1996, Geomorphological river channel reconnaissance for river analysis, engineering and management, *Transactions of the Institute of British Geographers*, New Series, **21**, 469-483.

Downs. P.W., and Brookes, A., 1994, Developing a standard geomorphological approach for the appraisal of projects, in Kirkby, C. and White, W.R. (eds.), Integrated River Basin Management, John Wiley and Sons, Chichester, UK, 299-310.

6) Bed substrate sampling

Aim

The aim of bed substrate sampling is to determine the distribution of sediment sizes on the bed of the channel.

Methodology

There are several different approaches to measuring sediment calibre in the bed of the river. The two main types of methods are the surface sampling and the volumetric sampling techniques. The surface sampling techniques are fully undertaken in the field whereas the volumetric sampling techniques will also require an element of laboratory based work. For a full review of techniques please refer to Bunte and Abt (2001) and for a summary see Kondolf *et al.* (2003).

Deliverables

Sediment distribution curve for each site sampled.

Expertise

A PhD level trained geomorphologist or, alternatively, someone who has shadowed someone of this level of experience for at least 2 years should undertake these surveys.

Man days

Surface sampling: 1-2 hours per site.

Volumetric sampling

The amount of time required for volumetric sampling is difficult to define, as it is largely dependant on sample volume. Bunte and Abt (2001) suggest that for a statistical relevant sample 100kg would need to be obtained. Clearly this has a variety of practical problems particularly in small rivers where a volume of this magnitude could encompass the whole bed. As a result, a balance between statistical validity and practicalities of undertaking the work is required. For a small sample (say 5kg) the time required to obtain the sample is no more than about 10 minutes. In the laboratory, coarse samples of this size can be analysed in about 30-45 minutes each. However, if the percentage of silt and clay content in the sample is high a significantly longer preparation time would be required.

Activities that technique could be used for

Bed substrate sampling is useful in determining changes in the bed sediment as a consequence of a particular activity and thus is focused primarily on sediment management activities. This is particularly valuable for assessing potential implications on fisheries since fine sediment ingress into riffles can dramatically effect spawning success.

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.

7) Sediment Transport Monitoring

Aim

Sediment transport monitoring aims to monitor the level of sediment movement in a river.

Methodology

A variety of methods are available but as yet there is no standardised technique to measure either bedload or suspended load. In addition, the techniques available are fraught with technical difficulties of using them in the field in order to obtain a statistical relevant sample. Monitoring techniques for bedload are reviewed in Ryan and Troendle (1997), suspended load in Wren *et al.* (2000) and in general in Hicks and Gomez (2003).

Deliverables

Data on sediment movement in a defined reach over a period of time.

Expertise

A PhD level trained geomorphologist or, alternatively, someone who has shadowed someone of this level of experience for at least 2 years should undertake these surveys.

Man days

The number of man days is dependant upon whether the estimate of load is made remotely in the field or whether there is a need to take samples and provide estimations of load back in the laboratory. Specific field conditions, such as accessibility, will also be a key factor in determining time required to obtain readings. Certain, more remotely based, techniques can be expensive and thus could be a significant problem with respect to their widespread applicability. As a result, it is difficult to provide a general figure of effort required to obtain relevant data.

Activities that technique could be used for

Sediment transport monitoring tends to be expensive and thus is largely restricted to assessing activities that could dramatically affect sediment loading particularly in sensitive locations, such as a high quality fisheries system.

Further reading

Hicks, D.M and Gomez, B., 2003, Sediment transport, in Kondolf, G.M and Piégay (eds.) Tools in fluvial geomorphology, John Wiley and Sons Ltd, Chichester, England, 425-461.

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