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Key Recommendations for sediment management – A Synthesis of River Sediments & Habitats (Phase 2)

Project: SC040015/R2

Flood and Coastal Erosion Risk Management Research and Development Programme

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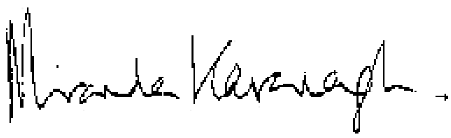

Miranda Kavanagh

Director of Evidence

Executive summary

The research aims to improve our understanding of the interactions between sediments, habitats and management of the watercourse in the context of delivering flood risk management (FRM) that is both cost effective and provides significant environmental benefits.

The process of sediment erosion, transport and deposition is important in forming habitat diversity in rivers and thereby influencing biodiversity. Sediments are the building blocks of discrete habitats, such as bars, which, depending on their character, are subsequently colonized by different species. Such features can also change the flow depth and velocity. In general, however, the more natural and varied the channel character, the higher the ecological value.

Deposition of sediment and vegetative debris along with growth of vegetation act to increase the chance of flooding through their influence on channel roughness and blockage potential (i.e. at structures such as culverts and bridges). This can act to reduce conveyance and increase afflux and associated in-river water level and hence flood risk. FRM staff may therefore need to plan and undertake sediment removal or other sediment-related activities to manage and reduce flood risk. The effects of these activities on the natural environment must be understood to ensure that protecting people and property from flooding can be achieved whilst also delivering the greatest possible environmental benefits.

The findings of this project are published in three main reports; (i) River sediments and habitats and the impact of maintenance operations and capital works, Report on Stage 1; (ii) River Sediments and Habitats Review of Maintenance and Capital Works: report on Stage 2 and (iii) this Key Recommendations report (which provides a synthesis of the work completed). These reports are further supported by an e-learning module titled Guide to Managing Sediments in Watercourses.

Five field study sites were selected during Stage1 to represent different channel types and sediment management interventions across a broad geographical range of particular relevance to FRM. The full Phase 2 technical report which, this report aims to summarise, details the data collected and its analysis from the five field sites. Field data were supplemented by desk studies of the historical and contemporary watercourse management at the study sites together with an evaluation of available Environment Agency guidance on channel maintenance policies and practices to address the following project objectives:

- To quantify the impacts, benefits and influences of management and maintenance on sediment and habitat features.
- Establish if, when and how sediment processes become self-regulatory negating the need for further maintenance or management.
- To determine the critical time at which intervention is required to manage geomorphically created sediment habitats in restored rivers for conveyance purposes.
- To test and validate new approaches to maintenance and channel design.
- To provide guidance on appropriate management, and when safe and desirable to allow river reaches to have no management.
- To supply the experimental basis for adaptive management of flood control and restored channels.

- Develop improved links between River Habitat Survey outputs and flood risk management, with the former providing a guide to when modifications to management would be desirable.

To aid in synthesis of this data and knowledge into recommendations for improved sediment management, it has been necessary to establish a framework of overarching premises and principles relating to sediment management that underpin the more detailed advice available in this project record. The Premises and Principles are designed to prompt those dealing with the management of sediment in watercourses to consider:

1. The cause of the sediment problem.
2. The range of different options for managing the sediment problem.
3. The implications of these options in relation to other watercourse management requirements including conservation, Water Framework Directive (WFD), and FRM/ Land Drainage.
4. To use these to inform the selection of the most appropriate option.
5. To ensure that a robust monitoring process is implemented to check the effectiveness, efficacy and environmental impact of the selected option.

An interim[1] typology for watercourses in England and Wales has also been developed so that the results can be readily extrapolated to other similar watercourses which form part of a flood risk management system. The typology developed brings together watercourses that (morphologically) behave in a similar way and that might reasonably be expected to response to sediment management activities in a similar way.

A number of useful recommendations for sediment management are developed. which are grouped under the following headings:

- Understand the geomorphological and land use processes
- Relationship of sediment and flood risk management
- Managing vegetation and sediment together
- Using local knowledge
- Design of channel works

It envisaged that this report will underpin the generation of future detailed guidance in this area, which will be relevant to those making decisions on flood risk management policy at the national level and the implementation of actions locally in terms of if, how, where and when sediment management may be necessary.

[1] Not withstanding the above, it is recognised that the applicability of this suggested typology is limited (an therefore, as described, only interim position).

Contents

1 Introduction

1.1 Project Overview

The overarching aim of this research has been to improve our understanding of the interactions between sediments, habitats and channel management actions to enable the optimal delivery of flood risk management (FRM) that seeks to be both, cost effective while also providing significant environmental benefits in line with the following aims of the Making Space for Water:

- to reduce the threat to people and their property; and
- to deliver the greatest environmental, social and economic benefit, consistent with the Government's sustainable development principles.

This work has been carried out under Project SC040015 - River Sediments and Habitats and the Impacts of Maintenance and Capital Works as part of Sustainable Asset Management Theme of the Joint Defra Environment Agency Flood and Coastal Erosion Risk Management R&D Programme.

The project has been delivered, via two specific phases:

Phase 1, focused on the selection of suitable field sites for survey, monitoring and future analysis. Watercourses were primarily selected on the geomorphological context (so as to cover a wider geographical range) and on the extent and type of sediment-removal management interventions of particular relevance to FRM.

Phase 2, has comprised of data collection using the 5 field sites selected in Phase 1, and the subsequent analysis to improve our scientific understanding of the effects of FRM maintenance activities and capital works on the processes of erosion, transport and sediment deposition and onward implications on sediment dependant habitats.

This report make useful recommendations aimed at practitioners (particular FRM staff) involved in sediment-related management of watercourses and channels. These recommendations have been developed based on the work outlined above and the general knowledge of the research team and understanding of the underlying science and good practice generally. This report doesn't try to recommend policy or set operational processes, rather it presents a synthesis of the evidence gathered during the River Sediment and Habitats Project in order to enable informed decision-making for sediment management.

The findings of this study have been framed by the development of six guiding principles which it is recommended be considered prior to any sediment related management action – see appendix 6. The extrapolation of the recommendations from the study sites to watercourses across England and Wales is possible via a suggested interim typology for watercourses and channels – see appendix 7. These Guiding Principals and some of the key recommendations arising from this study have been further articulated in an E-learning package. which can be found in http://learning.environment-agency.gov.uk/courses/sediment/launcher.html.

Although the recommendations of this report are of direct use to the practitioner, it is envisaged that this project be a precursor to the development of a more detailed suite of guidance aimed at the sustainable management of sediment in watercourses.

1.2 Target audience

This report is intended for all involved in sediment-related management of watercourses and channels, including capital works. It provides guidance relevant to those making decisions on flood risk management policy at the national level and the implementation of actions locally in terms of if, how, where and when sediment management may be necessary.

1.3 Managing sediments and habitats to reduce flood risk

The key reason for sediment management in a watercourse is to reduce flood risk to people and property where risk is deemed unacceptably high or needs to be maintained at the present level. The management of sediment may also be undertaken in response of other management objectives associated with the watercourse's function (e.g. land drainage, ecology, recreation and fisheries) and includes meeting statutory obligations for navigation rights.

From the perspective of a Flood Risk Manager, the channel, whether natural or artificial, is an asset which itself is set in a 'system' of assets. In terms of a typical watercourse, an asset system may comprise of a reach of a river or drainage network and the associated (if any) linear flood defences (man made or natural), culverts, bridges, sluices and pumping stations along its length. Together this system of assets function to reduce the chance of flooding and hence help protect people and property from the adverse consequences of flooding.

Sediment and vegetation can cause problems affecting the performance of an individual asset (at any point within the asset system, for example a culvert blockage or development of a sediment shoal) or similarly, problems associated with sediment and vegetation maybe symptomatic throughout the whole of the asset system. When such issues occur, the probability that the asset system fails to perform as specified increases, and, potentially, so does the probability of flooding. For example poor management of sediment and habitats may result in:

- The deterioration of a flood defence asset due to significant scour or channel movement (which could lead to an increased chance of breach)
- A reduction in channel capacity to convey floodwaters due to excessive siltation, blockage of a structure or a increase in roughness from excessive vegetative growth (which could increase in channel (stage) water levels for a given return period flow and hence potentially increase overtopping the system of defences.

FRM staff therefore plan and undertake sediment and vegetation removal or other sediment-related activities to manage and reduce flood risk. This work is prioritised on a risk basis to help ensure resources are targeted to those areas where the biggest reductions in risk can be made for the least cost.

Historically, in-channel sediment management work has been performed through channel stabilisation and/or sediment removal to maintain channel cross-section and conveyance capacity where affected by erosion or sediment deposition (Sear *et al*., 2003). However, the processes of erosion, transport and sediment deposition that are being managed for flood risk benefit, are the same critically important processes in forming habitat diversity in rivers and thereby influencing biodiversity. Sediments are the building blocks of discrete habitats, such as bars which, depending on their character, are colonized by different species. The formation of discrete sediment features also has an indirect effect on the rest of the river character locally by changing flow depth and velocity, as well as substrate. In general, the more natural and varied the channel character, the higher the ecological value (see also chapters 3 and 4)

It is clear that some balance needs to be achieved between the functional objectives of a watercourse when they are in conflict. The effects of FRM and sediment-related activities (which can range from one-off capital works to infrequent, small-scale, at-a-point sediment removal) of habitats and sediments must be understood.

1.4 Policy drivers for improvement Sediment Management

The Government's over arching strategy for the water in England 'Future Water' (Defra 2008) sets a policy vision of sustainably managed risks from flooding and coastal erosion which endorses the approach laid out in Making space for Water (with its commitment to deliver flood risk management so as to achieve the greatest environmental, social and economic benefit, consistent with the Government's sustainable development principles. This clearly articulates the need to manage the risk of flooding to people and property whilst balancing the needs of the environment.

The need for greater transparency by the Environment Agency during its channel management activities was called for during Sir Michael Pitt's Review of the Summer 2007 Floods (Pitt Review 2008), in particular, the review quoted the fact many of its responders noted that they'd never see the Environment Agency clearing rivers of vegetation or dredging; and, that a reduction in maintenance to restore a channel to its natural equilibrium can often be seen by the public as neglect rather than as a benefit.

Furthermore the review recommended that EA guidance should updated to explain how to carry out channel maintenance works in a safe manner and in compliance with environmental legislation. Specifically, the review recommended (Recommendation 27) that Defra, the EA and Natural England should work with partners to establish a programme through CFMPs and SMPs to achieve greater working with natural processes.

There are a number of key European Union policy drivers and environmental legislation which must be taken into account in the context of flood risk management activities. These include:

- The **Floods Directive** (2007/60/EC) which aims to reduce and manage the risks that floods pose to human health, the environment, cultural heritage and economic activity.
- The **Water Framework Directive** (2000/60/EC) requires member States to take actions to prevent the deterioration in the ecological status of surface water bodies. It aims to improve the ecological status so that all water bodies achieve good ecological status or good ecological potential in the future.
- The **Habitats Directive** (Conservation of Natural Habitats and of Wild Fauna and Flora, Council Directive 79/409/EEC) provides legalisation for the protection of rare or declining European-wide habitats and species (designated areas are Special Areas of Conservation (SACs)). There is a requirement to assess if management actions on their own, or in

combination with others, may have negative impacts on habitats, and hence feature interests of the sites.

- The **Birds Directives** (Conservation of Wild Birds, Council Directive 79/409/EEC) aims to protect wild birds and their habitats within Europe via designated Special Protection Areas (SPAs). Rivers and floodplains are included.

1.5 Flood Risk Management Context

Under the Water Framework Directive, River Basin Management Plans (RBMPs) have been drawn up for River Basin Districts covering England and Wales. RBMPs have been developed in consultation with stakeholder organisations and individuals. They describe the programme of measures to be implemented to improve the ecological status or ecological potential of each water body and form the basis for protecting and improving the water environment and must also take account of other aspects of water management planning, such as Water Resource and Water Utility plans.Within the Environment Agency, FRM activities take place within a hierarchy of wider considerations including land-use planning (both rural and urban) with the catchment-wide context which are captured in the Catchment Flood Management Plans (CFMPs). (see Figure 1.1 for linkages). Objectives laid out in CFMPs should be implemented through delivery of Strategy Plans which then support the development of System Asset Management Plans (SAMPs). These SAMPs identify the standard of service in terms of flood risk reduction an asset system will achieve. A minimum level of asset performance is specified to deliver the required level of risk reduction. Understanding linkages between sediments and habitats at all stages in the above process is of paramount importance in delivering sustainable and environmentally acceptable FRM activities. Of equal importance is that the planning of sediment management in watercourses for FRM purposes must be based on evidence and a rational process so as to be properly justified, and that the approach should be consistent across the country.

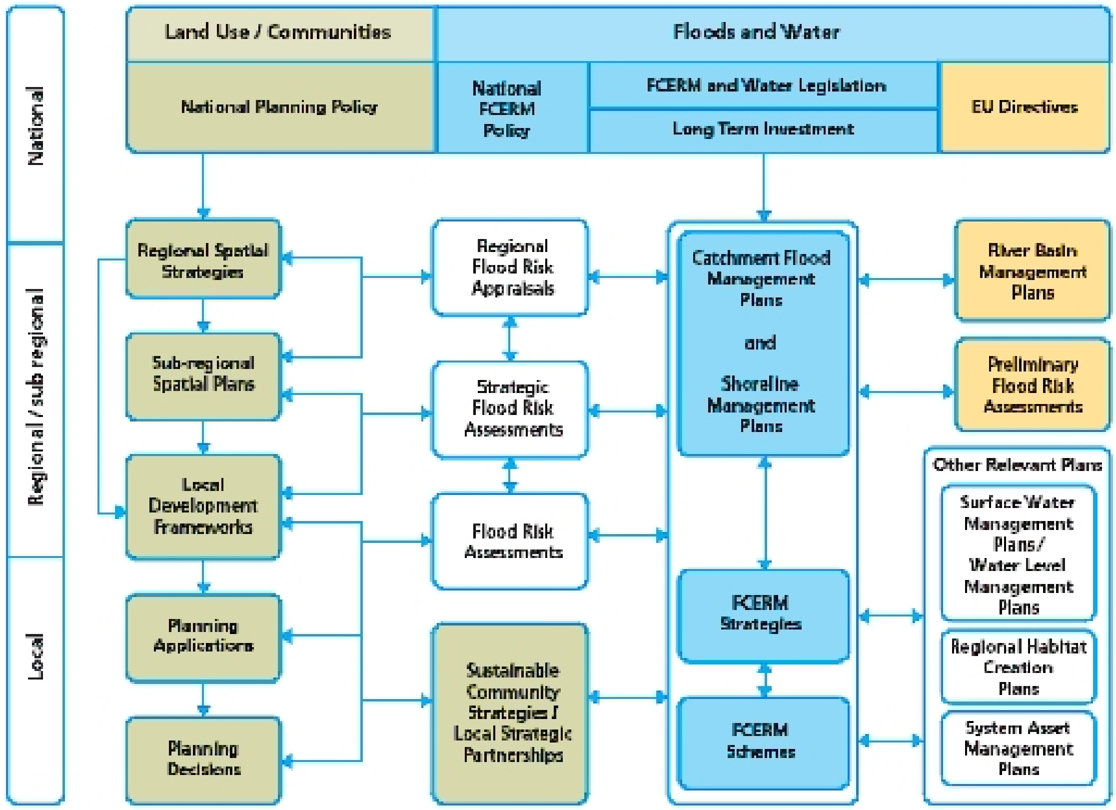

Figure 1.1 An Indicative Illustration of the Relationship between high level plans strategies, schemes and other planning initiatives (extracted from Defra 2009)

2 Phase 2 Work

2.1 Project objectives

The original objective of the project on Sediments and Habitats and the impact of capital and maintenance works was to improve the understanding of the interactions of sediments, habitats and conveyance as affected by Flood Defence (now Flood Risk Management) maintenance operations and capital works. The primary objective of Phase 2 was to carry out field studies and to interpret the results tp provide information on the self-regulatory nature of conveyance-response, effective river management and new approaches to maintenance and channel design, including adaptive management.

The objectives of the Phase 2 project were to:

- Quantify the impacts, benefits and influences of management and maintenance on sediment and habitat features
- Establish if, when and how sediment processes become self-regulatory negating the need for further maintenance or management, where appropriate
- Determine the critical time at which intervention is required to manage geomorphically created sediment habitats in restored rivers for conveyance purposes
- Test and validate new approaches to maintenance and channel design
- Provide guidance on appropriate management, and when safe and desirable to allow river reaches to have no management
- Supply the experimental basis for adaptive management of flood control and restored channels
- Develop improved links between RHS outputs and flood risk management, with the former providing a guide to when modifications to management would be desirable, and then as a monitoring tool to show benefits accrued

2.2 Field Studies

Sediments, habitats and the impacts of maintenance and capital works were studied using the data collected and its analysis from five field sites which were selected to represent different river types and sediment-removal management interventions relevant to Flood Risk Management across a broad geographical range. The locations of these sites are shown in Chapter 5 (Figure 5.1) and more details can found in Environment Agency (2010).

The study sites were:

- Long Eau: Lincolnshire
- Dearne: South Yorkshire
- Eden: Kent
- Harbourne: Devon

- Kent: Cumbria.

Data collection from the sites and associated analysis included:

- Hydrology and cross-section data (Appendix 1)
- River Habitat surveys (Appendix 3)
- Macrophyte surveys
- Invertebrate surveys
- Geomorphological surveys (Appendix 2)
- Hydraulic modelling (Appendix 4)
- Sediment surveys and modelling (Appendix 5)

Field data were supplemented by: desk studies of historical and contemporary river management at the study sites, the evaluation of available Environment Agency guidance on channel maintenance policies and practices and the general knowledge and understanding of the underlying science and good practice of the project team .

2.3 Additional studies (Phase 2 – part 2)

To support the practical application of the findings within the context of FRM activities, additional work with 5 key outputs was commissioned as shown below:

- Item 1: Identify programme of work to deliver improved sediment-related management in watercourses.
- Item 2: Deliver an interim typology to aid sediment-related river management processes
- Item 3: Produce Guiding Principles to help understand sediment-related management
- Item 4: Scope an e-Learning training package on sediment-related management
- Item 5: Outline Guidance Handbook content that focuses on sediment-related management and FRM requirements

The aim of this additional work was to help to translate and direct the key findings from the field sites and other knowledge into practical guidance for FRM activities. Together these five items represent steps towards achieving the goal of improved sediment-related management in watercourses. These items are part of a longer process that will focus on producing detailed guidance documents and an e-learning package that links science to practice for the benefit of delivering improved watercourse management which ultimately should help to better define short, medium and long-term watercourse sediment-related activities as outlined in Item 1.

Understanding river typology is beneficial since it provides the basis for selecting appropriate sediment-related management actions with respect to the geomorphological characteristics of the watercourse. The underlying assumption is that watercourses of a particular type will respond to sediment management in broadly similar ways; using a standard typology will assist in the selection of appropriate management actions for particular rivers. An interim typology has been identified (Item 2) that can be used, in the short-term, to assist FRM staff (appendix 7).

Guiding Principles and Founding Premises (see Chapter 3 and appendix 6 for details) have been drawn up (Item 3) that are designed to provide a consistent and logical rationale based on natural processes for those dealing with sediment management in watercourses. This prompts consideration of the following:

- Whether it is better to treat the cause rather than the symptoms of the sediment problem
- Identify the range of options for managing the sediment problem
- Ensure management options are appraised in relation to FRM/Land Drainage objectives and conservation, biodiversity and WFD water management goals
- Consider how best to apply options appraisal to help inform decision making processes with regard to the selection of the most appropriate management option
- Ensure monitoring is implemented that demonstrates that the selected option is cost effective, practically efficient and represents the most beneficial option environmentally.

Applying these new Guiding Principles in terms of sediment-related management will require understanding. To help facilitate this requirement an e-Learning package is being developed (Item 4) which builds on the already widely-used geomorphological e-learning package (http://e-learning.geodata.soton.ac.uk/EA/).

The final item (5) of this work is the scope of the contents for a Guidance Handbook that links together geomorphological, engineering and conservation aspects of sediment-related river management whilst recognising that the final product will need to take account of multiple audiences with a range of diverse requirements. It is envisaged that the recommendations of this Phase 2 report will be incorporated into this future Guidance Handbook, which will promote the application of best management practice.

3 Sediment management in watercourses

3.1 Why it is necessary to manage river sediments

The primary reason for sediment management is to reduce flood risk in watercourses where that risk is deemed unacceptably high. However, as noted in Chapter 1 (Section 1.2) it is also related to other watercourse functions (e.g. land drainage, ecology, recreation and fisheries) and includes meeting statutory obligations for navigation rights.

An increase in the probability of flooding may result either from the deterioration of an asset system due to significant scour or channel movement, or a reduction in the capacity to convey floodwaters due to excessive siltation. Most importantly, however, flood risk depends not only on the probability of flooding but also its consequences for people, property and key infrastructure in the area at risk. The benefits of sediment management in terms of risk reduction must justify the costs and so such activities may not be appropriate everywhere.

It is particularly important to manage sediment in urban areas, where the consequences of flooding can be large and watercourses are often confined. Where the watercourse has both a channel and a floodplain, it is only necessary for the channel to convey low to medium discharges, since during floods, water naturally spills onto the floodplain. Under such circumstances, sediment management is unlikely to be the most technically sound way to reduce flood risk.

Sediment management involving structural protection of the bed or banks, or the removal of sediment through dredging can be harmful to the environment. Thus, all work must be performed in the least environmentally damaging manner and must comply with the relevant environmental regulations (see Chapter 1, Section 1.4).

3.2 Founding Premises and Guiding Principles of Sediment Management

As noted in Chapter 2, underlying premises and principles have been developed to provide a consistent and logical rationale based on natural processes for those dealing with sediment management in watercourses. Based on current policy and practice in the UK, three Founding Premises that underpin the principles of sediment management were identified. These are that:

1. The erosion, movement and deposition of sediment in a watercourse is a natural regulating function of a watercourse. Action taken to manage flood risk should seek to protect or restore these processes.
2. Justification for removal or disturbance of sediment must be evidence-based.
3. Where justified, sediment management actions must follow best practice to minimise damage to the environment.

The six Guiding Principles based on these premises provide a rational basis for sediment management (see Table 3.1). These principles have a science base grounded in fluvial geomorphology (for more information on how to apply this science see Sear et al. (2003; 2009)).

It is important that all those involved in sediment management have an understanding of fluvial and sediment processes in watercourses in the context of FRM. Sediment related management must be planned and implemented based on an underlying understanding of the dominant natural fluvial processes at that location. It is only with such an understanding that appropriate management will be undertaken.

FRM staff need to appreciate that:

- A watercourse should be viewed as an ecosystem where sediment is as fundamental to the physical habitats as the flow regime and other aspects of water quality.
- Sediments in watercourses have a source, a transport pathway and a sink.
- The frequency and intensity of sediment-induced morphological change varies between watercourse type and position within the catchment (i.e. headwater, mid-basin or lowland reaches).
- Bed scour, bank erosion, sediment transport and accumulation are all natural processes, explicable through local and catchment-wide influences.
- Vegetation interacts with, and strongly influences, sediment processes.

Table 3.1 Guiding Principles of Sediment Management

Number	Guiding Principle	Issue being addressed
1	Identify why you are considering action	Why is sediment management being considered? What is the evidence that maintenance, refurbishment or capital works are necessary?
2	Treat the cause of the problem not its symptoms	What is the sediment-related problem here? Is it on-site, off-site, or systemic?
3	Identify and prioritize the functions of watercourses	In addition to FRM, what other functions of the river must be considered and in what order?
4	Identify and appraise management options based on risk analysis	What are the options for sediment management (including ‘doing nothing’)? What risks are associated with each one?
5	Balance multiple goals of channel management	How do the options identified in 4 relate to other river functions and stakeholder requirements?
6	Inspect channels and appraise maintenance outcomes with respect to targets set for all relevant functions.	Following implementation, how well is the selected option working in relation to goals for FRM and those of other functions and stakeholders?

3.3 Interim Typology for Sediment-related Management

Evidence gained during the field studies demonstrated the need to match the choice of sediment management options to the channel type. The nature of fluvial system at a particular location depends upon the dominant natural processes at work. In many cases the success or otherwise of particular management strategies depends upon the dominant processes in a reach. A simple way of understanding the nature of a particular reach and the dominant sediment processes in action within the reach is via a river typology. It is likely that appropriate sediment management will be similar for reaches within the same river typology. As a consequence the project has proposed an interim typology (see chapter 2 section 2.3) which aims to:

- Focus attention on the fluvial processes controlling sediment dynamics and morphological behaviour in different types of watercourse
- Help identify how a specific watercourse type may be expected to respond to dredging disturbance or a decision to delay or cease maintenance
- Guide the evidence-based identification of which sediment management options are most appropriate to particular watercourse types
- Enable development of policies and options for sediment management in different watercourse types that are sustainable and nationally consistent.

The interim typology has been modified from the approach of Montgomery and Buffington (1997) to take account of specific UK watercourses (particularly heavily modified and lowland cases). The typology is based on an understanding of the balance between sediment supply and transport capacity in a watercourse, and how this varies between the headwater and the lowland reaches (Table 3.2). This, in turn, has an impact on how channel morphology responds locally and helps to provide an understanding of watercourse sensitivity to sediment-related management.

Table 3.2 Modified Montgomery-Buffington typology for use in England and Wales

MMB Type	Channel Description
1	Steep Headwater Channels
2	Pool-riffle/Plan bed
3	Wandering
4	Braided
5	Active Meandering
6	Passive Meandering
7	Groundwater Dominated
8	Channelised High Energy (w = specific stream power > 35 Wm^{-2})
9	Channelised Medium Energy (35 Wm^{-2} > w > 10 Wm^{-2})
10	Channelised Low Energy (w < 10 Wm^{-2})
11	Armoured Channels (culverts, bed and bank protected)
12	Tide-Locked Channels

3.4 Options for sediment management (adapting the management)

The main types of sediment management performed in England and Wales are listed in Table 3.3

Table 3.3 Measures commonly used to manage sediment-related problems

Problem	Measure	Description
Erosion	Bed Control	Structure installed to stabilise the bed elevation.
	Bank Protection	Stabilisation or reconstruction of a retreating bank.
Sediment Transfer	Bed Regrading	Large-scale modification of the longitudinal bed profile.
	Channel Re-sectioning	Large-scale modification of channel cross-section.
	Gravel Trapping	Installation of structures to prevent downstream coarse sediment movement.
Deposition	Dredging	Underwater excavation, usually including removal of the excavated material
	Desilting	Removal of accumulated sediment from the bed of a channel, generally as a maintenance activity
	Shoal Removal	Selective removal of individual bars and riffles.
	Groynes/Deflectors	Structures installed to promote the spatial organisation of sediment storage.

Approaches to FRM assets (including channels) stress the advantages of adopting sustainable and adaptable solutions. In this context sediment-related maintenance should also be cost effective, technically justifiable and environmentally acceptable. Adaptive sediment management should be adopted wherever possible.

Adaptive management rests on monitoring the impacts of watercourse management and being prepared to alter existing practices as necessary to deliver optimal outcomes in terms of targets for FRM and other watercourse functions; these may include, for example, achieving good ecological status/potential under the Water Framework Directive, or favourable condition for an SSSI under the Habitats Directive.

3.5 Links to Vegetation Management

Vegetation and sediment together increase the diversity and quality of habitats in natural channels but, by impacting on both channel conveyance and hydraulic resistance, may have an adverse impact on channel conveyance. Sediment management in a reach cannot be considered independently of any vegetation management in that reach. For example, the growth of shrubby vegetation in in-channel bars may result in the stabilisation of otherwise mobile sediment features that could, subsequently, be detrimental to both flood conveyance and the extent of aquatic and riparian habitats. The removal of such vegetation, however, would ensure the continued mobility of the sediment. It is important that both sediment and vegetation management are considered as different tools that can be used to achieve the FRM objectives.

Actions to manage vegetation need to be understood in the context of sediment management. For example, the roots of plants that colonise shoals and bars bind the sediment, their stems and large wood can impede the flow to trap fine material and seeds and propagules promote further vegetation growth. The strong link between sediment management, vegetation and habitats must therefore not be overlooked.

4 Sediments and habitats

4.1 Sediment influence on river fauna

There are complex interactions at a reach and catchment scale that affect the movement of sediment and the creation of habitat types in watercourses. Channel shape and flow influence the movement of sediment and the composition and form of the river bed and banks. The composition of the sediment and the shape of the habitats they create, determines what wildlife a watercourse can support. Subtle differences in character determine what plants and animals will be present in each discrete habitat, as well as within whole reaches depending on whether narrow or broad mixtures of habitat types are present.

Most studies that illustrate the importance of sediment on biota have been carried out on fish and invertebrates. Different fish species require contrasting types of sediment for spawning, with adults needing different conditions to juveniles. Salmon and trout, for example, need clean, well aerated, gravel (free from silt) habitats for successful spawning. Such habitats may be present in low-gradient streams where sediment bars locally narrow the channel to increase water velocity over the remaining width, with the resultant cleansing of the bed of silt. Removal of such bars, or constrictions of the low-flow width, potentially leads to a loss of suitable habitat for salmonid fish.

A detailed study by Harper *et al.* (1998) highlights the influence that the diversity of vegetation types and the range of sediment-related habitats have on aquatic invertebrates in watercourses. This research showed that very different communities of invertebrates were found within contrasting physical environments; such discrete areas within survey areas were termed ‘functional habitats’. At a community level, it was shown that areas with silt substrates had very different communities of invertebrates compared with those with clean gravels, as did areas with emergent reeds compared with those with fine, submerged, dissected leaves. At a species level, they showed that in study reaches (of a standard length) with uniform character and only having a single ‘functional habitat’ present, on average just a single caddis species was present; with four discrete habitats, there would be four caddis, and if there were seven discrete habitats, seven caddis taxa would be expected.

4.2 Exposed Riverine Sediments (ERS)

Only recently has attention been focused on the communities of invertebrates associated with the discrete habitats formed by accumulations of sediments – referred to as ‘Exposed Riverine Sediments’ (ERS). The Environment Agency (2003) defines ERS as ‘the shoals, bars and spits present’ in watercourses and notes the importance of such habitats for nationally scarce and rare invertebrates. Key to the invertebrate interest is the shape, size and location within a watercourse, sediment composition, and degree of colonization by vegetation. All these factors are affected by the natural processes of erosion and deposition (as outlined in chapter 3) and the degree of impact due to catchment land-use, hydrological control measures and FRM interventions.

The mostly widely applied survey method to record the presence of sediment-related habitats in rivers is River Habitat Survey (EA; 2003a); for more details see 7.3. Such surveying is essential since it has been shown that in the UK, several hundred invertebrates are associated with marginal, sediment-related, habitats (Environment Agency 2003). Preventing their natural formation, or removing them, can have significant negative impacts.

5 Key Lessons from study sites

5.1 Site selection

The project looked at five field sites from around England. The selection of the field sites took into consideration: the watercourse and sediment type, the maintenance activity and potential impact on formation of habitats and the potential for scientific study related to the objectives of the project which included the enthusiasm of local staff to be involved. For site locations see Figure 5.1. With only five sites it was not possible to cover the full range of potential river types and management interventions.

Figure 5.1 Locations of field sites

The key sediment-related issues identified at these sites were as follows:

Long Eau, Lincolnshire: Fine silt accumulation with resultant vegetation and sediment removed historically.

Dearne, South Yorkshire: Modified channel with fine silt accumulation for drains and tributaries. Dredging and vegetation management (both banks and bed) has historically been carried out.

Eden, Kent: Fine sediment input from arable, pastureland, poaching and angler access with partial shoal removal carried out periodically.

Harbourne, Devon: Scheme designed to improve flood and sediment conveyance through the village and thus reduce maintenance.

Kent, Cumbria: 1970s flood alleviation scheme though Kendal requires periodic dredging of gravel.

Below is a summary of the key findings of each site together with the associated typology as outlined in chapter 3.

5.2 Long Eau: (Typology 10 – low gradient, channelised river)

The watercourse comprises a low gradient, clay-bed channel set predominately in agricultural area. Past capital works carried out for land drainage include re-alignment, deepening and widening, with little variation in the longitudinal and cross sectional form. Channel vegetation and silt has been removed on an annual basis. The presence of flood embankments further disconnects the river from its floodplain. These embankments may have some benefit in terms of buffering the river from agricultural sediment and run-off, but fine sediment (silt, sand and clay) enter the watercourse via land drains, sewer outfalls and ditches. As part of a rehabilitation scheme part of the embankment was removed to encourage some flooding adjacent to the river; some artificial riffles had been installed in the downstream part of the study reach.

Key Lessons

Prior to the project, the modified management of in-channel vegetation to reduce impacts on, or enhance habitat diversity for, wildlife and fisheries involved a maximum of two-thirds of the channel width of vegetation being cut in any one year. This represents the adoption of the recommended 'Best Practice' (Ward et al 1998) for managing in-channel vegetation when this is deemed necessary. There was evidence that the practice was adopted but there were limited signs of ecological gains in terms of sediment-related habitat development.

Observations suggest the reason for the limited evidence for ecological gain is because different parts of the channel width were cut in successive years. These changes in the location of the cutting meant that vegetation never became established in one location long enough to trap sediment and thereby create discrete sediment deposits and alter cross-sections and flow types across the channel width.

Figure 5.2 Vegetated section cut every year

Figure 5.3 Ponded section: little habitat

Where vegetation is cut in the same locations year after year (see Figure 5.2) these cleared areas have larger current velocities, becoming self-cleansing. Where sediment is trapped by the retained vegetation it starts to form discrete sediment bars. If vegetation is retained on the inside of meanders, point bars may develop opposite cliffs, with the formation of riffle and pool habitats. This had not happened on the Eau.

Discrete deposits of gravel have been added to the stream bed in some locations. The intention was to create a series of artificial 'riffles', providing fish spawning areas and habitat diversify for other biota. The study showed that because of the very low gradient in this watercourse, ponding of water occurs upstream of these features and sediment is deposited (see Figure 5.3), with little resultant variation in flow velocity except under high flows.

5.3 Dearne (Typology 9- moderate energy, channelized, over-widened, straightened and re-aligned)

This study reach consists of a medium energy, gravel-bed river that has been over-widened and disconnected from its floodplain through the construction of high embankments. The land-use in the catchment is a mixture of rural and urban, but predominately rural at the site location. Sediment inputs are primarily via drainage ditches and tributaries and comprise of silt, sand and clay. Previous dredging and vegetation clearance (both banks and bed) has now ceased.

Key Lessons

In 1995 a radical approach was taken to enhance fishery interests and reduce the extent of vegetation management in one reach. The low gradient, very wide, reach of the river previously had a low flow velocity throughout and the channel became choked with reeds, causing significant raising of water levels within the reach itself and upstream. The site was poor for fish recruitment and angling. As shown in Figure 5.4, the channel was narrowed by about 50%, with the low-flow channel constrained by rock revetment. Several small backwater habitats were also created.

Figure 5.4 Channel narrowed by rock revetment

Figure 5.5 Backwater pools filled with silt and vegetation

The work was very successful in creating a self-cleansing channel that now requires no vegetation management to keep clear of emergent vegetation. Fish recruitment and popularity with anglers has increased in line with project objectives. However, the backwater pools soon became filled with silt and choked with reeds (see Figure 5.5), and the ‘armouring’ of the edges of the narrowed channel means no sediment erosion or deposition has taken place along the channel margins, nor can in the future.

In the reach upstream no routine management has been carried out. A self-maintaining width, free of emergent reeds, has developed, illustrating that it is possible for the width of channels to adjust due to natural processes and thereby reduce the need for future channel management. Where shrubs occurred on the banks, these often act as flow deflectors, allowing discrete reed beds to develop, which trap silt and start the process of creating side bar habitats, Figure 5.6.

Figure 5.6 Vegetated section with shrubs and reeds

The impact of the cessation of maintenance is to raise water levels for a flood flow with a 1% annual probability of exceedence of 84 m^3/s. The main reason for the rise in water levels is the increased hydraulic roughness generated by the vegetation growth on bed and banks as shown in Figure 5.6 where there is tree and bush growth on the banks.

Figure 5.7 Floodplain vegetation

At present the floodplain vegetation growth (Figure 5.7) is restricted by common grazing of horses. If the grazing stopped then the bankside and floodplain vegetation would increase and the flood risk would be increased, based on modelled values, by raising water levels in a 1% flood by 0.15m.

5.4 River Eden: Typology 9 (Medium energy channelized river; over deepened but planform in-situ)

The River Eden flows through Wealden Clay and comprises a steep sided, single thread, mainly meandering river but with some sections of re-alignment. It has been over-deepened through past dredging, de-silting and vegetation removal and, as a result, exhibits limited morphological diversity (Figure 5.8). Glides, some pools and dead water zones are the prominent features with fine sediment trapped by in-channel vegetation and stored in berms and benches.

Figure 5.8 River Eden

The fine sediment load (sand, silt and clay) is relatively high in the river and whilst transported primarily via drainage ditches associated with arable land use and improved pastureland, poorly controlled stock access and angler activities increase sediment yield.

Key lessons

The River Eden represents a trial site for sensitive maintenance operations aimed at increasing flow and habitat diversity. The modified management of partial removal of shoals at specific sites along the River Eden, as opposed to the dredging the entire river bed as experienced historically, has resulted in the alteration of some cross-sections and flow types across the channel width. Observations show that these features are more extensive near heavily vegetated berms and benches, which have caused the accumulation of sediment immediately upstream and downstream. Reduced maintenance has allowed the natural growth of these berms and benches, resulting in channel narrowing and an increase in flow types and physical biotopes.

There is a reduction in channel conveyance locally where berms have started to formed and have narrowed the channel. The impact of this has been to increase water levels locally but there was no change in water levels further upstream. The study showed that where berms and shoals are beginning to form, see Figure 5.9, the section is more varied leading to greater variation in depth and velocity.

Figure 5.9 Shoals beginning to form in the river Eden

Despite this study site showing increased flow diversity and increased physical biotopes, due to channel narrowing and sediment accumulation, the site failed to show high ecological diversity in terms of invertebrate populations or river habitat scores resulting from the modified maintenance regime. This can be attributed to limited time for recovery at this site and is something which should improve now that the Environment Agency has ceased all in-channel maintenance on the River Eden study site.

5.5 River Harbourne: Typology 2 (Pool-riffle and plan bed channels)

This study area comprises a naturally incised, gravel-bed watercourse with a meandering planform that is, for much of its course, connected to a narrow floodplain. The river has been heavily modified historically, especially to harness energy to power mills. Land use is dominated by improved pasture which provides a source of fine sediments but gravels are also frequently transported within the channel. The more urbanised area of Harbertonford village was the subject of a capital works flood alleviation scheme in 2002 which had the intention of also providing potential habitat and aesthetic improvements whilst reducing river management requirements. A flood retention area and dam were also installed upstream as part of this work.

Key Lessons

Previously the sediment transfer system was punctuated by in-channel structures and loss of channel conveyance with channel plan form restrictions in the form of tight, meander bends, associated with urban development within the village. This resulted in extensive sediment accumulation during flood flows and the subsequent need to desilt on a regular basis. The site exhibited very poor in-channel features and ecological diversity.

The implementation of an upstream flood retention basin, alteration of in-channel structures and re-alignment of the river, has been very successful in not only reducing the flood risk to the village of Harbertonford, but also in creating a channel which requires little or minimal maintenance compared to the pre-construction era. The channel is now exhibiting a variety of different physical biotopes and functional habitats.

Figure 5.10 Bar at the downstream end of the reach

A bar or shoal towards the downstream end of the reach, Figure 5.10, was designed into the scheme on the assumption that sediment would deposit in that location. There is some evidence of sediment accumulation on the right bank with the channel narrowing in this area. Hydraulic modelling was undertaken to reflect what might happen if this shoal were to increase in size. The modelling showed that even if the depth of the shoal increased by 0.5m only a local rise in water levels would occur but no increase in further upstream.

This study site has provided a basis for demonstrating how new channel design approaches can be adapted to not only to maintain a standard of protection, but also to improve the ecological status of a watercourse, through reduced maintenance intervention, thereby improving links between FRM and environmental goals.

5.6 River Kent, Kendal - Typology 8 (High energy channelized river)

This gravel-bed river has been heavily modified historically especially since industrialisation including mining in the upstream sections, and weirs and other control structures in the middle and lower reach related to milling activities. In the 1970s a flood alleviation scheme was introduced through Kendal, resulting in the construction of artificial banks with the bed constrained by a number of weirs. Sediment yield is from range sources including over-grazing, poaching but also mining waste which contributes significant amount of coarse gravel material in some reaches. As a result of high coarse sediment loads, shoals continue to frequently develop through the flood alleviation scheme in Kendal which is routinely removed.

Key Lessons

Historically, the river has been managed on a reactive basis comprising of large gravel shoal (see Figure 5.11) removal at specific points throughout the urban phase of the River Kent. This removal has been done with little regard to its impact on downstream stability of the channel and the impact on ecological status.

Figure 5.11 Large gravel shoal in the River Kent

The sediment transfer system is complex with the majority of sediment accumulating in or around in-channel structures, such as bridges and weirs. Observations from field monitoring and detailed hydraulic sediment modelling revealed that bar growth within the channel does reach a point where it becomes self-regulating, without compromising the standard of defence. However, this is dependent on sufficient high flows to reduce the onset of vegetation colonisation which reduces sediment mobilisation. Despite the loss of conveyance and channel capacity for flood flows associated with in-channel bar growth, something which needs further investigation, the study site indicates that the sediment removal rate and volume could be adapted to improve the ecological status of the river. Furthermore, field observations showed that the removal of sediment in the upper reaches resulted in sediment starvation for reaches downstream. Sensitivity tests using hydraulic sediment modelling show that an adaptive management routine, through partial sediment removal at key points, can provide an opportunity for achieving a balance between improved ecological status, maintaining a standard of defence, and ensuring the integrity of flood defences in downstream reaches. This site provides a vehicle for advanced research into balancing social, economic and environmental needs during a time of rapid climate change, and recommending non-structural solutions to providing a more sustainable approach to FRM and achieving goals for environmental standards.

6 Key findings and recommendations

6.1 Introduction

A number of important aspects have been highlighted which relate to the project objectives, and these are discussed under the following headings:

1. The importance of sediment features in watercourses
2. What happens if we remove sediment?
3. What happens if we don't remove sediment?

It is essential to put this chapter into context. The Founding Premises (see chapter 3) are formed around a presumption against sediment removal in order to work with natural processes. In some situations though, sediment-related management may be necessary to maintain sufficient flow conveyance so as not to increase flood risk. Sections 6.2 to 6.4 here discuss the implications and potential consequences of removing (or not) sediment using the five case studies and other examples. Section 6.5 provides recommendations for future sediment management which should be considered in the context of the Founding Premises and Guiding Principles.

6.2 Sediment features in watercourses

6.2.1 Naturally occurring sediment-related features

Sediment features occur naturally in all alluvial channels, but their shape, composition and mobility can vary widely (Figure 6.1). These features contribute to the diversity and quality of the functional habitats.

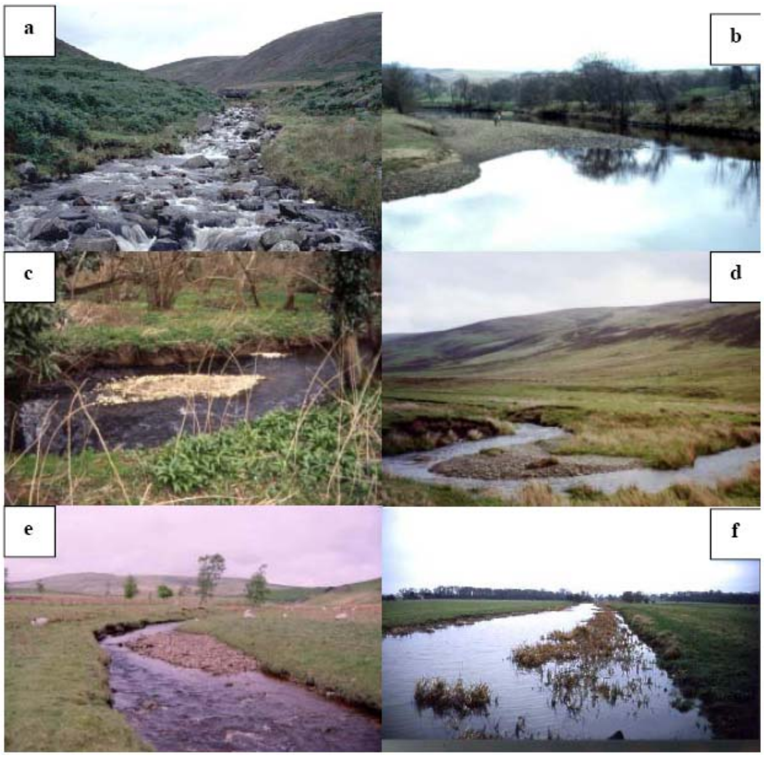

Figure 6.1 Sediment features in UK rivers: (a) Step-pool boulder accumulation (b) Tributary bar (c) Mid-channel bar (d) Point bar (e) Side bar (f) Fine sediment berm

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In dynamically stable reaches, bars and shoals store sediment between transport events, interacting naturally with bank erosion to drive plan form change and evolution. Where sediment supply exceeds local transport capacity, these features grow to raise bed elevations and reduce channel conveyance of flood flows that may compromise flood risk management function. This can trigger dredging or desilting measures but these activities must be balanced against retaining habitat diversity through cross-sectional depth, flow velocity, and sediment movement variability over a range of different spatial scales, as discussed in chapter 4.

6.2.2 Treating sediment source causes and predicting sediment movement

A more sustainable long-term option to at-a-point sediment removal is to address the sources and transport pathways of elevated sediment inputs to reduce sediment removal frequency.

For example, on the Eden, bank poaching by uncontrolled livestock access increases the fine sediment supply entering the channel. Fencing and the creation of a well-vegetated riparian corridor could reduce this source substantially. On the Long Eau, sediment derived from field erosion is delivered to the watercourse via drains and ditches. In this case set-back confluences with reed beds could trap sediment before any related perceived flood risk management problem occurs.

It is important to note, in the context of watercourse management, that sediment movement is highly unsteady, making sediment loads and deposition rate predictions highly uncertain. Sediment dynamics assessments can be carried out both via qualitative techniques such as the Fluvial Audit (Sear et al., 2003; 2010) and through quantitative modelling. Whilst beneficial in some instances, as demonstrated on the Long Eau (where modelling indicated that 90% of sediment movement takes place during the winter), it must be recognised that these assessments require substantial resources and expertise.

6.2.3 Influence of in-channel structures

Problems caused by deposition are often particularly severe around in-channel structures such as weirs, culverts and bridges (Figure 6.2). On the river Harbourne, shoaling downstream of the A391 road bridge in Harbertonford necessitated repeated and frequent dredging that was disruptive to both the aquatic environment and life in the village. Re-design of the flood control channel, including the installation of artificial riffle features in 2002, has successfully reduced and perhaps eliminated the requirement for on-going sediment management at this location.

Figure 6.2 Example of limited capacity of a bridge due to sediment deposition (water depth about 30 cm)

6.3 What happens if we remove sediment?

6.3.1 Impact of dredging on water levels and habitats

If sediment is dredged from a river channel, there is generally a reduction in water levels. Sediment features which were previously submerged may become exposed, whilst the activity itself results in a more uniform watercourse, both of which effects have a negative impact on in-channel habitat diversity. This was demonstrated on the River Eden, where analysis of topographic data, together with modelling, showed less variability in water depths and flow velocities where dredging had recently occurred, compared to those areas where it had not. The resultant changes included exposed bank-side benches which then became colonised by terrestrial plants and reduced habitat heterogeneity.

6.3.2 Sediment removal and the impact on sediment feature development.

Sediment removal may lead to reduced inputs downstream, preventing development of sediment-related features. If the amount of sediment removed is significant in terms of the overall yield then erosion or sediment starvation may result in the destruction or replenishment of features downstream, as shown on the River Kent (Figure 6.3)

Figure 6.3 Limited in-channel features due to the trapping/removal of sediment in River Kent

Flood retention reservoirs are one feature often associated with sediment trapping. Depending on their function though, they can be designed to allow sediment to pass through, thus reducing adverse impacts downstream. On the River Harbourne, a flood retention reservoir was constructed upstream of Harbertonford. This was designed to pass all sediment loads up to the 1 in 8 year flood event. Similarly, gravel traps can also result in downstream changes, including bed scour and alteration to the sedimentary structure and grain size. This in turn has implications for channel adjustment, provision of spawning gravels and the availability of other benthic habitats (see for example Sear et al 2010).

6.3.3 Dredging activity recovery rates

The rate of recovery from dredging activities depends upon the aspects that are being considered, the nature of the watercourse and the degree of dredging that has been carried out. Watercourses with large sediment loads may recover within one or two years but where low sediment loads prevail it may take decades for sediment features to re-develop fully. On the River Kent, the morphology of the river recovers rapidly from dredging. On the River Arun in E Sussex, a clay river of very similar character to the Eden, sediment-related features, however, have not completely developed 10 years after maintenance was withdrawn.

The time period between sediment-related management activities has an impact on what suites of habitats may or may not evolve. On the River Kent, frequent ‘scalping’ of the sediment bars promotes Exposed Riverine Sediments scenarios (see chapter 4) suitable for particular types of aquatic invertebrates. Less frequent sediment removal would allow colonisation of sediment bars by terrestrial vegetation. This could result in reduced channel conveyance and inhibit sediment movement whilst not necessarily affording the best option for aquatic invertebrates. This option should not always be seen as the best solution and the creation and/or retention of bars must be considered in the context of flood risk and river typology.

~~6.3.4~~ When not to remove sediment

The regular removal of sediment features, such as point bars, as soon as they have developed can inhibit sediment processes and may suppress natural channel plan form change, as illustrated on the River Eden. Here, regular sediment removal has inhibited bank erosion and lateral channel movement. In turn, this may affect the development of certain habitat types (e.g. steep bank cliffs used by the Kingfisher).

6.4 What happens if we don't remove sediment?

6.4.1 Sediment features and water levels

If sediment deposits over a significant length of a watercourse or in key locations, water levels can rise. In heavily developed urban areas where flood risk is a key concern, sediment may need to be removed to prevent reduction in sediment and flow conveyance, as demonstrated on the River Kent. However, in some cases (i.e. where there is space along the watercourse corridor) there may be opportunities to consider alternative measures to removing local in-channel sediment features that achieve a similar standard of protection and these should be considered wherever practicable. Such measures might include re-profiling channel banks to provide extra channel capacity, whilst allowing for the formation of in-channel features and managing the floodplain to increase conveyance or storage.

Where sediment management ceases, morphological and ecological diversity develop, although recovery rates differ in relation to typology. As shown on the River Arun (section 6.3.3), recovery can be slow even when most in-channel management has ceased. In this case, large wood has continued to be removed often by local landowners and this may be having a significant impact on recovery.

Generally, if isolated, local sediment features are left 'in situ' the impact on conveyance is not usually significant and sediment features and hence habitat diversity can be allowed to develop, as exemplified on the River Eden, where partial shoals were left at specific locations, resulting in an increase in physical biotope variability. This management approach may be particularly appropriate in areas of low flood risk. Such sediment features need to be monitored. If they increase in size to provide significant blockage of the channel or if the associated vegetation increases the hydraulic roughness significantly then further management may be required.

6.4.2 Backwaters zones

In some locations the primary influence on the water level may not be the conveyance of the channel, for example, upstream of structures where the water level is controlled by the stage discharge relationship for the structure. In such locations sediment removal may not reduce water levels. If sediment is not removed then there is unlikely to be a significant impact on water levels, as was illustrated through modelling studies on the River Eden, with outputs showing that there was no significant reduction in water levels as a result of sediment removal and consequential bed level reduction.

6.4.3 Bridges, culverts and conveyance

Sediment may deposit in and around bridges and culverts, reducing the discharge capacity of such structures. If this sediment is not removed, or the source of the sediment input from upstream reduced, then this deposition can impact on flood water levels upstream.

The River Harbourne, a high energy, gravel-bed river, had historically caused flooding problems through shoal formation at a bridge. A flood alleviation scheme was designed to solve those problems (section 6.5.5).

6.4.4 Self-cleansing channel formation

In the absence of sediment-related management, self-cleansing channels can develop with resultant good habitat potential. Sediment management was ceased on a section of the River Dearne, and analysis of cross-sectional surveys and other data collected confirmed that a self-maintaining watercourse width, free of emergent reeds, developed (see Section 5.3 for more information). This example has demonstrated that self-adjustment of channels due to natural processes may, for some channel types, reduce the need for future management.

6.5 Recommendations for sediment management

The following recommendations for sediment management are made within the context provided by the Founding Premises and the Guiding Principles and highlight the key areas of importance in terms of sediment-related management, using examples to illustrate the recommendations. The material in the shaded boxes draws out practical advice from the basis provided by the Founding Premises and the Guiding Proinciples.

6.5.1 Understand the geomorphological and land use processes

Whilst more details about understanding the implications of sediment-related problems and identifying the causes are highlighted in the Guiding Principles, most importantly:

> It is essential to look beyond the immediate area of deposition/erosion to *understand the geomorphological and land use processes* within the catchment, since this has implications for management decisions.
>
> Appreciating the differences in sediment transfer and sources related to river typology is essential for deciding upon appropriate management.

For example, on the River Kent in Kendal, coarse sediment transport is related to mining, poaching and tributary inputs. Channel modifications (weirs, channel widening downstream and engineered banks) in the urban areas then result in deposition and the formation of a shoal that creates habitat, but also may affect flood risk. In comparison, on the River Eden in Kent, a combination of diffuse catchment sources of fine material (drainage ditches, pasture and arable land) and point sources (cattle poaching and bank slips) increases the fine sediment load.

6.5.2 Sediment issues related and Flood Risk management

Where flood risk management dictates that the presumption against sediment removal cannot be applied it will be necessary to assess management options against all Guiding Principles.

> Where a sediment problem cannot be resolved at the catchment scale and *in-situ* management is necessary, the appropriate option needs to be considered in the context of location, typology and the amount and temporal variation of sediment load in the system.
>
> Any removal must depend upon the observed condition of the channel rather than on a fixed temporal programme of maintenance activities.

Vegetated shoals:

Vegetated shoals may increase flood risk if colonised by shrubs and trees. Where these develop in high flood risk areas, the most practical and environmentally sound approach (as adopted on the River Kent) may be to carry out adaptive management by regularly observing shoal growth and then responding with selective and partial removal when required (Figure 6.4).

Figure 6.4 Adaptive management allows for ecological and flood protection benefits

Removing individual shoal features:

Bank slips and local sediment deposition create discrete bar features which may encourage the formation of pools and riffles (Figure 6.5). Complete removal destroys the associated habitats and does not necessarily improve channel conveyance. Partial removal is a compromise that can reduce adverse environmental impacts and achieve the necessary flood risk conveyance, especially where previous interventions have resulted in an over-wide or deep watercourse, as shown from modelling work on the River Eden, where isolated sediment-related features have limited impact on conveyance and may actually improve it. Hydraulic modelling can help to identify how much of the shoal needs to be removed.

Figure 6.5 Bank slips and local sediment deposition can help create habitat diversity

Stopping sediment removal:

Increasingly, it is being shown that sediment frequently does not have to be removed to sustain adequate FRM standards, since watercourses can become self-cleansing. In ceasing sediment removal, the intention is to allow sediment accumulation, increase out-of-bank spills and deliberately allow floodplain inundation for flood risk benefit downstream. This is particularly likely to be a practical measure in locations where the Policy Option in the Catchment Flood Management Plan is to take action to increase the frequency of flooding (Option No 6).

On the River Arun in Sussex (see section 6.3.3 and 6.4.1), cessation of watercourse management has resulted in consistently higher River Habitat Survey diversity scores (Habitat Quality Assessment) than seen on currently (or recently) managed systems. However, recovery can be slow (especially in a low energy system such as this) where sediment supply is limited and further more as highlighted in 6.4.1, woody debris removal which continue probably also impinges on recovery.

River enhancement options to maintain conveyance:

Where sediment-related habitats are shown to cause unacceptable flood risk, it may still be possible to retain the bars and re-profile the banks to increase channel conveyance and improve marginal habitat. Modelling work on the River Rhee, Cambridgeshire (Janes et al 2005), has shown that even if excavated bank material is deposited in the river to form marginal shoals, flood levels are not increased. In this particular situation, the bank profile was altered to provide material for the ledge and extra conveyance capacity (Figure 6.6).

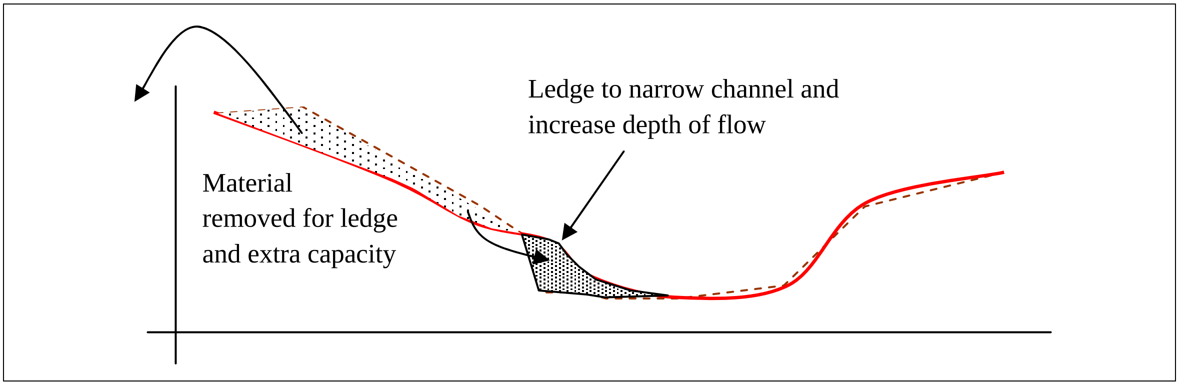

Figure 6.6 Re-profiling of a cross-section on the River Rhee

6.5.3 Managing vegetation and sediment together

Vegetation growth and control is intrinsically linked to sediment management, affecting erosion, transport and deposition, and channel conveyance. Recommendations below are illustrated by examples from the 5 principal study sites as well as other UK watercourses.

> The manner in which vegetation and associated sediment is managed is critical to the links between ecological diversity and FRM. Thinking about where sediment is removed and at what point during the year is critical to planning and achieving the optimum benefits.
>
> Where the vegetation remains, there are lower velocities and this encourages sediment deposition in the channel margins and the formation of sediment-related features.
>
> The impact of different vegetation management options on channel conveyance can be quantified by the application of models such as the Conveyance Estimation System (CES). These can be used to ensure that the management option adopted is appropriate to the flood risk and is justifiable. Generally, there is little difference in channel conveyance between cutting only 60% of the channel width (Environmental Option W9) and cutting the entire channel width (Environmental Option W1). The only exception may arise for narrow, steep-sided channels.

Retaining sediment features in the same location:

Vegetation management on the Long Eau now adopts EA-recommended best practice (Ward *et al.* 1998), by removing ‘weed’ from a maximum of two-thirds of the bed width. Only where the same third of the bed width is retained year-after-year are sediment-related discrete habitats able to form. The maximum habitat benefit therefore develops if the uncut areas reflect where a watercourse would most naturally deposit sediment (e.g. on the inside of meanders). Since the change in the management practices on the Long Eau discrete habitats have failed to materialise fully, but are developing. Despite this, some areas developed more rapid current velocities and self-cleansing of silt from the channel was occurring where it was narrowing. The modelling of this system, however, also demonstrated that during the summer period, the amount of sediment transport depends upon the vegetation cutting regime, with the transport rate increasing as a greater proportion of the channel width is cut (Figure 6.7). As outlined in Section 6.2.2, most sediment movement occurs during the winter period.

Figure 6.7 During summer periods sediment transport is low

Creating new features and improving conveyance:

On the River Darent in Kent, the strategy has been to remove vegetation from the same side of the river each year. The result is a narrow, self-cleansing channel with a gravel bed with silt being trapped by the reeds (Figure 6.8). No adverse impact on flood risk has been predicted by modelling of lowland channels (Fisher 1993), indicating over 95% improvement in conveyance being likely from just removing 60% of the vegetation.

Figure 6.8 Partial vegetation management results in natural sediment dynamics, improved habitats and conveyance

Similarly, hydraulic modelling undertaken on the Long Eau demonstrated that, in many circumstances, little increase in conveyance is achieved by cutting vegetation on the channel margins, and, even for the largest flows with an annual probability of exceedence of 0.5%, there was only about an 8% difference in water depths between a 50% and a 70% width cut. It should be noted, however, that these figures vary with channel shape and hence typology and, for example, in wider channels, one would expect even smaller changes in water depth.

Cutting weed to create a self-cleansing channel to reduce sediment management:

On the Darent, Kent, a narrowed channel cut through an over- wide, bur-reed choked watercourse resulted in the formation of a self-cleansing low flow channel that now requires no management and supports healthy crowfoot (see Figures 6.9 and 6.10).

Figure 6.9 Self-cleansing cleared channel (summer), with a gravel bed and crowfoot growth

Figure 6.10 Watercourse during spate: reeds die back and the full channel width is used to convey flow

On some watercourses, vegetation is extremely important since it forms the only variation in habitats, as is evident on the River Itchen in Hampshire. In-channel management has retained marginal vegetation that now traps silt because the velocity here is much reduced compared with the central area of the channel. The narrow cleared channel enables an aerated gravel bed to persist which is essential to supporting invertebrates and trout spawning habitat (Figure 6.11)

Figure 6.11 Vegetation on the River Itchen

Reducing or stopping sediment removal:

Reducing or stopping sediment removal may result in the channel tending towards being self-cleansing, thereby reducing the need for future sediment removal. The constraint on being able to do this is normally the associated flood risk. Reducing or stopping sediment removal may lead to changes to the channel which may increase in flood risk. In addition, some river types are more sensitive than others to such changes in sediment removal. Though the management option may be a reduction in sediment removal or complete cessation, it must be appreciated that there is an on-going management need to monitor the channel into the future.

Channel narrowing can help to create a self-cleansing channel and negate the need for sediment management, as demonstrated in a case-study of the lower reach of the River Dearne. The watercourse width was constrained through the installation of block-stone edges, resulting in a self-cleaning channel. Natural morphological processes, however, have been prevented and, hence, so have the development of sediment-related habitats (see Chapter 5), although some fisheries benefits have been observed mediated by velocity increases. So, while self-cleansing channels can improve conveyance, the delivery of these should be carefully considered. Softer engineering techniques using earth and vegetation are recommended, to allow for the development of marginal sediment deposition and macrophyte growth important for aquatic habitat generation, rather than the terrestrial vegetation encroachment that has occurred (Figures 6.12 and 6.13).

Figure 6.12 River Dearne with ceased watercourse management has resulted in a reeded fringe and not a choked system

Figure 6.13 Hard engineering at the banks do not allow for the development of marginal deposition

6.5.4 Using local knowledge

Local knowledge is important in assessing catchment-wide consequences that can allow for the retention of sediment-related habitats in watercourses. This can be particularly relevant in adopting measures of reduced or no management in upstream reaches of rivers, where there may be little or no infrastructure at risk from flooding, to achieve the Policy Option in many CFMPs of increasing the frequency of flooding upstream in order to reduce the flood risk downstream.

> Local knowledge can help in assessing whether or not the presence of shoals may pose unacceptable local flood risk.

The importance of local knowledge is demonstrated on the River Kent in Kendal, as illustrated in 6.5.1, where local information has been used as a factor in determining how much and how frequently the gravel shoals are reduced in size.

6.5.5 Design of channel works

It is possible to design capital works which reduce flood risk but do not generate significant sediment-related maintenance commitments thus optimising whole-life costs and benefits. This is seen as an important topic for up-dated channel management guidance.

> Channels should be designed to reduce maintenance and ensure that habitat benefits are included.
>
> It must be recognised that sediment loads entering a reach can vary significantly from season to season and from year to year, and so the potential for erosion or deposition remains even if no problems have been observed in a reach over a number of years.
>
> Such designed watercourses do not remove the need for future asset management works (monitoring and maintenance) but should help to reduce this to a minimum.

As outlined in Section 6.3.2, the high energy, gravel-bed River Harbourne historically caused flooding problems through shoal formation at a bridge. The flood alleviation scheme was designed to allow the movement of sediment through the system, has successfully reduced village flood risk, created a channel that now requires little or minimal maintenance and incorporates a range of physical biotopes and functional habitats (Figure 6.14).

Figure 6.14 River Harbourne

The same principles apply in low gradient, low energy, rivers where silt is the predominant sediment type. Channel design must allow both for self-cleansing and some adjustments in response to seasonal and annual variations in discharge and sediment load. Achieving this balance gives improved habitat for wildlife and reduced flood risk. A good example of this is a small river close to Warrington, designed to ensure a narrow low-flow channel is scoured to allow drainage of the adjacent sports field (Figure 6.15). The wide second-stage channel ensures only major floods spread onto the sports field, and the embankment to the left provides flood protection for properties. In the absence of the self-cleansing low-flow channel, the watercourse would rapidly silt up across its entire width, become choked with reeds, and drains from the playing field would be blocked.

Figure 6.15 Example of narrow low-flow channel close to Warrington

7 Conclusions and Next steps

Six Guiding Principles for Sediment Management have been identified and underpinned by three Founding Premises as follows:

1. Sediment management actions must be reasonable and justified
2. Understand the sediment related problem and identify its cause
3. Identify and prioritise the functions of the watercourse
4. Identify and appraise management options based on risk analysis
5. Balance multiple goals of channel management
6. Appraise maintenance outcomes by inspecting channel conditions with respect to targets set for all relevant functions

Application of these in FRM in the future is essential for good management of the sediments and habitats within a watercourse prompting those dealing with the management of sediment in watercourses to consider:

- treating the cause rather than the symptoms of the sediment problem being addressed;
- identifying the range of options for managing the sediment problem;
- appraising these management options in relation not only to FRM/Land Drainage objectives but also with respect to other watercourse management goals, including conservation, biodiversity and WFD;
- applying options appraisal to inform decision making with regard to selection of the most appropriate option;
- ensuring that a robust monitoring process is implemented to establish that the selected option is cost effective, practically efficient and represents the most beneficial option environmentally.

An interim typology has been completed to help assess best sediment management principles based on Montgomery and Buffington (1997). This typology has been tested under a wide range of UK watercourse conditions (see SNIFFER, 2008 for further information) but it is recognized that the interim typology now requires directed research to improve its application for lowland watercourses. A map-based GIS tool together with photographic examples of each typology to facilitate field identification will be developed.

Alongside this it has been identified that there is a need to ensure effective dissemination of information based on new research and understanding. An e-learning package has been produced to help practitioners understand sediment dynamics and management in watercourses (http://learning.environment-agency.gov.uk/courses/sediment/launcher.html). Further practical guidance, in the form of a 'Sediment Management Handbook' is planned with the scope of contents and format for this output forming part of a future R & D project.

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Appendices

Appendix 1 Physical Data

In order to undertake hydraulic assessments of the watercourse and associated floodplains some physical data relating to catchment, floodplain and channel will be required. Different amounts of data will be required for different levels of analysis. In some cases an analysis of a single cross-section, for example, using the Conveyance Estimation System may be appropriate but in some situations more complex modelling may be required. Typical data required for a 1 dimensional hydraulic model include:

- Cross section data through the reach of river to be modelled. It is suggested that the model extends to a distance above and below the reach of study outside of the influence of that reach. The cross-section spacing will depend upon the size and slope of the watercourse..
- LiDAR data can be used for the floodplain modelling where available. If no LiDAR data is available then the river sections can be extended across the floodplain or contour maps or spot heights could be used provided that vertical accuracy and spatial density of the data is appropriate to enable the floodplain to be modelled.
- Information on the downstream boundary chosen for the model should be specified. This is normally specified in the form of a a relationship between stage and discharge or between stage and time or between discharge and time. Such relationships might be derived from a flow gauging station, a bridge, a normal flow section or a tidal sluice.
- Data on hydraulic roughness characteristics –ideally from a range of photographs at different times of the year or from site visits - which can be compared with the roughness advisor in the Conveyance Estimation System (CES), see Appendix 4 on Hydraulic Assessment.
- The hydrology of the catchment will need to be assessed to provide estimates of flows for the model. Methods to assess the hydrology of the catchment are described in the Flood Estimation Handbook..

For calibration of the model it is best to have data from a number (ideally 3) of flood events. Depending upon the nature of the calibration exercise the data required for calibration might include:

- Flow and level data from a gauging station if available
- Rainfall data for the event and for a week prior to the event
- Water level data at points along the reach
- Flooded extents – either mapped or from photographic evidence
- Anecdotal evidence from the flood – where it went, how high was the water level.

Appendix 2 Geomorphological Assessments

2.1 Geomorphological assessment

A range of approaches is available to perform the geomorphological assessment necessary to support informed decision making in sediment management. Selection of the appropriate approach should be related to the level of risk associated with the sediment problem, the resources available, and the stakeholders involved. Themes common to all geomorphological assessments are the over-arching needs to:

1. Establish catchment context for the reach under consideration.
2. Explore links between the local reach and the wider sediment transfer system qualitatively and, if necessary to the purpose of the assessment, quantitatively.
3. Identify whether proposed sediment management actions are (a) sustainable in terms of the geomorphology of the problem reach and (b) likely to disrupt sediment dynamics in the fluvial system and so trigger new problems upstream or downstream.
4. Promote selection of sustainable sediment management options that preserve or restore local geomorphic forms and processes while promoting connectivity, continuity and balance in the sediment transfer system.

Geomorphological assessment in this project focused on the field identification of morphological features in the various study reaches at the five project sites, coupled with interpretation of the links between channel morphology, sediment dynamics and maintenance practices. The assessments identified the impacts of past and current maintenance regimes on channel morphology and supported evaluation of the potential for morphological features and sediment forms to recover if maintenance ceased or was modified to allow or even promote the development of sediment features and the physical biotopes they provide.

Assessment employed geomorphological the field reconnaissance method published by Thorne (1998) to assess the morphological features and forms in the watercourses. This involved filling-out check-sheets following stream inspection to gain a general overview of their morphologies and a detailed understanding of their sediment features. Sites were visited at least twice, with the more dynamic watercourses being inspected on multiple occasions. This was essential to establish seasonal changes and inter-annual trends in channel forms and sediment features.

Stream reconnaissance is just one of a suite of methods that may be used in geomorphological assessment. Methods range from broad-scale, qualitative appraisals such as the Catchment Baseline Survey, to more reach-focused investigations of sediment conditions in a particular problem reach in relation to those in the catchment as a whole (Fluvial Audit) that identify the credits (sources), debits (storage) and transfers (transport paths) of sediment in the catchment, in order to develop a semi-quantitative budget for sediment dynamics within the fluvial system. Where the seriousness and complexity of a sediment-related problem merits, quantitative evaluation of sediment forms and processes, a Geomorphological Dynamics Assessment (GDA) may be performed (Sear et al., 2003; 2010).

In summary, there are a wide range of practical methods that can be employed for geomorphological assessment and it is essential to match appropriate techniques to the nature, extent and risks of the sediment-related problem and as well as the management actions proposed to deal with it. Practical guidance on selecting appropriate techniques may be found in a user-focused report published by the Flood Risk Management Research Consortium (Thorne et al. 2006).

Appendix 3 The River Habitat Survey (RHS)

The River Habitat Survey (RHS) is a method developed in the UK to characterise and assess, in broad terms, the physical character of freshwater streams and rivers. The field survey is carried out along 500m lengths of river. Observations on channel features and modifications are made at 10 equally spaced cross-sections, together with an overall "sweep-up" summary for the whole site. Other information such as valley form and land-use in the river corridor is also collected. A Survey should follow the strict protocols given in the 2003 RHS Manual (EA, 2003a) and surveyors in the UK are required to be fully trained and accredited.

This field survey method was used in this project as a method of recording channel habitats and morphology, including the extent of modifications and presence of sediment-related features.

All RHS data are entered onto a dedicated database. This contains field observations, map-derived information and photographs from more than 22,000 surveys (in 2009) undertaken since 1994. A geographically representative baseline survey of streams and rivers across the UK established in the 1990s allows the national context of habitat quality and degree of modification to be determined.

Indices of habitat quality and channel modification can be derived from RHS data; for this study, they were used to assess habitat variety and degree of modification. The method worked well in recording 'significant' habitat features that contribute to the scoring system, but did not allow recording of small features, or sediment-related habitats in their formative stages.

Habitat Quality Assessment (HQA) is a broad indication of overall habitat diversity provided by natural features in the channel and river corridor. Points are awarded for the presence of scoring features such as point, side and mid-channel bars and cliffs (all fluvial habitat features) as well as marginal tree roots, woody debris, waterfalls, marginal reeds and floodplain wetlands. Additional points reflect the variety of substrate, flow-types, in-channel vegetation (affected by the presence of fluvial features), and also the extent of trees and semi-natural land-use adjacent to the river.

Habitat Modification Score (HMS) is an indication of the degree of modification that has taken place to the natural river channel morphology. To calculate HMS for sites, points are awarded for the presence of artificial features such as weirs and bank revetments, and modifications to the channel such as re-sectioned banks. The more severe the modification to the channel system then the higher is the score.

The RHS database allows sites of a similar nature to be grouped together for comparative purposes. Slope, distance from source, height of source and site altitude are used to cluster RHS sample sites for so-called "context analysis" based on principal component analysis (PCA) plots. This enables any site in the UK to be compared with other sites of a broadly similar nature, either nationally, regionally or locally. This enabled our study reaches to be compared with sites of a similar character nationally. This part of the study highlighted that the River Arun, a clay river of very similar character to the Eden (both in Southern Region) had HQA scores higher than the norm, and higher than the Eden. Subsequently it was determined that maintenance dredging of the Arun had ceased more than ten years previously.

RHS has also made an important contribution to the development of European standards for hydromorphological surveys of rivers, and has been adopted for use in

Poland, Spain and Portugal. It has been used in the UK to help identify reference conditions, “heavily modified” riverine water bodies, and hydromorphological pressures affecting river catchments, for implementation of the WFD. An adaptation of RHS – geo-RHS – has been developed to assist in interpreting the processes shaping river and floodplain character at a broader scale (Defra/EA, 2005).

Appendix 4 Hydraulic modelling

There are many different methods and models available for investigating the hydraulics of water courses and their associated floodplains.

In a capital scheme or where river management is proposed, the requirement for hydraulic modelling is often driven by Flood Risk Management. The requirement being to provide an assessment of the impact on the water levels through a reach and how the flows though a water course and across the associate floodplain may be affected. The level of risk will determine the complexity of the modelling required, for example, if the watercourse is through an urban area then the flood modelling required mayl be more detailed. Hydraulic modelling can be used to investigate the impact of river management at a range of flows and can inform ecological decisions by providing water level, velocity and shear stress information.

Selection of the appropriate approach and the extent of the river model should be related to the level of flood risk, the type of river management being proposed and the likely impact of the management on upstream and downstream reaches. If the impact is seen to be local then a short reach of river can be modelled. If the impact of maintenance may have a wider effect upstream or downstream either in increased water levels or changing the flow hydrograph then the model needs to extend beyond the areas of likely influence.

1 Dimensional Modelling

The outputs are flow, water levels and velocities in the one dimension along the channel at fixed cross-section points and can simulate either flow and/or storage of water on the floodplain. Models can be used in a *steady* or *unsteady* state depending upon the nature of the river and the management options being considered.

2 Dimensional modelling

Two dimensional models investigate the flow *along and across* the water course and associated floodplains. The watercourse and/or floodplain is represented by a two-dimensional grid along and across the channel rather than using cross-sections at regular intervals as in a 1D model. A combination of 1D and 2D modelling can be used with the 2D grid being used where a higher level of detail on flow patterns and velocities is required.

3 Dimensional modelling

Three dimensional models represent flow along and across the water course and floodplain and through the depth of the water column. They add a further level of detail, complexity, time and costs to modelling although give detailed results and are more commonly used to investigate detailed problems such as bridge scour.

Conveyance Estimation System

The Conveyance Estimation System is a one dimensional, steady state model developed by the Environment Agency to help investigate river management issues on a more local scale. It performs as a one dimensional, steady state model with good assessment of roughness and a facility to vary roughness through vegetation growth and simulate vegetation cutting. It can be linked to an ISIS or INFOWORKS model to simulate unsteady flows. The CES software can be downloaded free of charge at http://www.river-conveyance.net/

An assessment of the data requirements, indicative costs, applications and outputs of the different models can be found in RRC, 2005.

Glossary

Steady State is where it is assumed that the discharge and water level do not change or change only slowly in time and one flow condition is represented.

Unsteady State refers to conditions in which the flow varies over time. This type of modelling is used when changes to how the water is stored on the floodplain need to be simulated or when the impact of changes to the flood hydrograph might impact on conditions downstream.

Appendix 5 Sediment modelling

Mobile-bed numerical models can be used to simulate the movement of water and sediment through a reach of a river. If the sediment transport rate varies spatially along the reach then erosion or sedimentation will take place and the models can predict the amount and rate of such bed level change. By tracking different sediment size classes separately one can also predict changes in bed sediment composition. Such numerical models can be used for both short-term and long-term predictions. As the models require river discharges and upstream sediment loads to be specified as boundary conditions, predictions are subject to uncertainty due to uncertainties in the boundary conditions. Numerical models can be used to predict the impact of some maintenance activities. For example, the impact of dredging on future bed levels can be simulated by removing sediment from the river channel. The flow models used can be 1, 2 or 3-D depending upon the nature of the flow and the detail that is required.

Sediment modelling is carried out in order to make predictions of future morphological change as a result of changes to:

- the morphology of the river
- the upstream discharge and sediment load
- sediment disposal or removal.
- The models can predict changes in bed sediment composition.

Mobile-bed models predict both sediment transport rates and changes in bed level. The input data normally includes time-series data of discharge so that predictions will depend upon the nature of the time series used.

Sediment modelling must be undertaken within the context of an understanding of the geo-morphology of the fluvial system and it can provide quantitative predictions associated with identified geo-morphological processes. The sediment modelling has to be underpinned by a reliable understanding and model of the flow. Sediment modelling can be used to ensure that the impact of future morphological change is predicted and taken account of in any future maintenance or capital works.

The application of numerical morphological models is normally a specialist activity and if one is not familiar with this type of modelling it is recommended that specialist advice is sought before undertaking such a study.

Model results are dependent on the input data used and so there is always a risk that inappropriate data is used. Model results always need interpretation and so there is a risk that model results will be incorrectly interpreted. These risks can be reduced by ensuring that there is a full understanding of the geo-morphology of the system and nature of the flow.

Appendix 6 Guiding Principles for sediment management in watercourses

Summary

This report has been developed as an output of Item 3 of the River Sediments & Habitats Phase 2- Additional works Project by David Sear and Colin Thorne.

A range of stakeholders are affected by sediment issues including not only the Environment Agency but also DEFRA, IDB's, Local Authorities, riparian owners and land users, home and business owners in areas vulnerable to flooding, angling societies, etc. To date, the scientific information, analytical procedures and practical advice necessary to guide decision making with respect to sediment management actions has been provided in a piecemeal manner, through uncoordinated documents largely related to either the Flood Risk Management or conservation related to watercourses, but not both.

This report seeks to create an overarching set of principles that encourage a staged approach to decision making related to sediment management that provides an underpinning framework for: the more detailed advice available in existing reports, the reporting of River Sediments and Habitats Phase 2 and future up-dated and improved guidance on sediment management in watercourses for FRM.

Three policy-related premises provide the foundations that underpin the Guiding Principles for Sediment Management set out below. These are:

- the erosion, movement and deposition of sediment in a watercourse is a natural regulating function of a watercourse. Action taken to manage flood risk should seek to protect or restore these process;
- the justification to move or remove sediments must be evidence-based;
- when sediment actions are found to be justified best practice must be employed in performing the necessary work with the aim of maximizing benefits to habitats and ecosystems while avoiding or at least minimising damage to the environment.

These Founding Premises provide the basis for six Guiding Principles of sediment management:

- Sediment management actions must be reasonable and justified
- Understand the sediment related problem and identify its cause
- Identify and prioritise the functions of the watercourse
- Identify and appraise management options based on risk analysis
- Balance multiple goals of channel management

- Appraise maintenance outcomes by inspecting channel conditions with respect to targets set for all relevant functions

The Founding Premises and Guiding Principles are designed to prompt those dealing with the management of sediment in watercourses to consider:

- treating the cause rather than the symptoms of the sediment problem being addressed;
- identifying the range of options for managing the sediment problem;
- appraising these management options in relation not only to FRM/Land Drainage objectives but also with respect to other watercourse management goals, including conservation, biodiversity and WFD;
- applying options appraisal to inform decision making with regard to selection of the most appropriate option;
- ensuring that a robust monitoring process is implemented to establish that the selected option is cost effective, practically efficient and represents the most beneficial option environmentally.

1. *Introduction to sediment management issues in UK*

The management of sediment in watercourses within England & Wales is likely to become more important in the coming years and decades for a number of reasons:

1. Increasing flood risk arising from climate change and socio-economic development (Pitt Review 2007, Foresight Report 2004 and 2008)
2. Increasing delivery of sediment from upstream watercourses and catchments arising from increased rainfall intensity and flood frequency (Pitt Review 2007, Foresight Report 2004 and 2008; IGCP 2007)
3. Increased protection afforded hydromorphology and ecology as part of the Water Framework Directive, Habitats Directive.
4. Growing evidence base concerning interactions between sediment dynamics, sediment management, flood conveyance and river habitat (Reid et al. 2008; River Sediments and Habitats Phases 1 and 2).

A range of stakeholders are affected by sediment issues including not only the Environment Agency but also DEFRA, Internal Drainage Boards (IDB's), Local Authorities, Riparian owners and land users, home and business owners in areas vulnerable to flooding, angling societies, Natural England, Countryside Council for Wales (CCW), Royal Society for the protection of Birds (RSPB), Rivers Trusts and Wildlife Trusts. To date, the scientific information, analytical procedures and practical advice necessary to guide decision making with respect to sediment management actions has been provided in a piecemeal manner, through uncoordinated documents largely related to either the flood risk management or conservation functions of watercourses, but not both. Documentation developed for use by Environment Agency staff in Flood Risk Management (FRM) and Water Framework Directive (WFD) has failed to be taken up more broadly. Recently, a series of further reports have been developed that provide different levels of analysis and advice on sediment in watercourses. Reports relevant to sediment management include:

- Sediment Matters (Atkins 2009) a commissioned report from the hydromorphology group within the Environment Agency which aims to highlight the issues associated with sediment in rivers and streams, and which provides some initial checklist methods for understanding a specific sediment issue. There are extensive references to methods and techniques for measuring different aspects of coarse to fine sediments.

- Digital Design Manual Chapter 1: a document for works in the fluvial environment that sets out the legislative and design issues associated with undertaking flood management activity. It includes a set of eight design principles that are complementary to the principles for sediment management advocated below.

- Guidance for appraising options for FCERM in terms of WFD (Haskoning 2009). This report to DEFRA, sets out a series of stages for appraising the hydromorphological impacts of different FCERM (Flood and Coastal Erosion Risk Management) options including sediment management. The options are set out in a series of digital manuals for mitigation measures linked to a staged approach to identifying the impacts of different options on hydromorphology and ecology

- Guidebook of Applied Fluvial Geomorphology (Sear, Newson & Thorne 2003/2009) originally a DEFRA document produced under R&D 1914 and based on NRA/EA R&D performed in the 1990s, an updated version is shortly to be published by Thomas Telford. It contains a review of fluvial processes in UK river systems, and links these to river management and outcomes including sediment management activities performed for FRM, Conservation and WFD compliance purposes. The earlier version is still available on the DEFRA website and may be ordered in hard copy from the DEFRA printing office

- WFD 49 (Rivers): Environmental Standards to support river engineering regulations and WFD status classification (SNIFFER, 2006). A report that develops a methodology for screening river engineering options in terms of WFD requirements. The method is based on a river typology and an approach that links ecological impacts to the scale of river engineering.

- Development of guideline sediment targets to support management of sediment inputs into aquatic systems, Natural England Research Report NERR008 (2008). Applies to fine (< 1mm) sediments only. Uses existing evidence base to develop a catchment typology that links to catchment sediment yield. It also sets targets for these catchment types.

This report seeks to describe an overarching set of principles, laid out as a series of Founding Guiding Premises and Principles that lead to a staged approach to decision making that provides an underpinning framework for the more detailed advice available in these different reports, for the reporting of River Sediments & Habitats Phase 2 and for future updated and improved guidance on sediment management in watercourses for FRM. The Founding Premises and Guiding Principles are designed to prompt those dealing with the management of sediment in watercourses to consider:

1. treating the cause rather than the symptoms of the sediment problem being addressed;
2. identifying the range of options for managing the sediment problem;

3. appraising these management options in relation not only to FRM/Land Drainage objectives but also with respect to other watercourse management goals, including conservation, biodiversity and WFD;
4. applying options appraisal to inform decision making with regard to selection of the most appropriate option;
5. ensuring that a robust monitoring process is implemented to establish that the selected option is cost effective, practically efficient and represents the most beneficial option environmentally.

2. Founding Premises for future Sediment Management

Three policy-related premises provide the foundations that underpin the Guiding Principles for Sediment Management set out below. These are that:

a. the erosion, movement and deposition of sediment in a watercourse is a natural regulating function of a watercourse. Action taken to manage flood risk should seek to protect or restore these process.

b. The justification to move or remove sediments must be evidence-based.

c. When sediment actions are found to be justified, best practice must be employed in performing the necessary work with the aim of providing benefits to habitats and ecosystems while avoiding or reducing damage to the environment.

These Founding Premises provide the basis for six Guiding Principles of sediment management.

3. 1st Guiding Principle: Sediment management actions must be reasonable and justified

Given a general presumption against removing sediment from rivers and other watercourses, any decision to undertake a sediment management action must be based on clear reasoning and be fully justified. This requires that decision making be objective and evidence-based. The first Guiding Principle may be applied in three steps. These steps should:

a. <u>Establish the context for the proposed sediment action.</u> This is essential because it influences the route to action and the type of channel maintenance that may be required. For example, a sediment action might be planned as an intervention under an System Asset Management Plan or required to be implemented under a Catchment Flood Management Plan (CFMP) policy. The reasoning and justification for these kinds of actions differ markedly from those for emergency maintenance actions that might be necessary in responding to the sediment-related impacts of a recent, high magnitude flood (e.g. shoal development with adverse impacts on channel conveyance) or a sediment-related complaint received from a riparian property owner.

b. Evaluate the nature of the sediment-related problem. This requires assessment of the evidence base for the sediment problem (which may extend to quantitative analysis where the necessary data exists), coupled with evaluation of the quality of that evidence. For example, evidence based on repeat surveys of cross-sections would establish conclusively that a change in bed elevation has taken place. Conversely, evidence based on stakeholder opinions or qualitative observations of bed levels would, in isolation, be less conclusive. This step should conclude by assigning a confidence rating to the evidence base concerning the sediment problem. Where confidence in the evidence is low, uncertainty may unacceptably cloud the assessment of risk in step c). In such circumstances, additional investigations should be triggered to reduce uncertainty to the point that a risk-based decision can be made concerning the need for maintenance.

c. Assess the risks associated with allowing the sediment-related problem to persist. This step provides the basis for deciding whether maintenance is necessary because of an over-riding Public Interest (c.f. EA Briefing Note of 14/04/08). Where failure to address the sediment problem would produce unacceptable risks to people, property, asset performance or the environment action will always be justified. However, it will still be necessary to ensure that sediment management conforms to Best Practice and will be performed using the least environmentally damaging option applied in the most environmentally sensitive way possible.

4. 2nd Guiding Principle: Understand the sediment related problem and identify its cause

The foundation for managing sediment-related problems sustainably lies in identifying the cause of the problem prior to taking action. As long ago as 1992, the NRA highlighted this principle and demonstrated how, in the majority of cases, sediment-related maintenance was at the time undertaken as part of a rolling programme of routine work or in response to specific events (breakdown maintenance), rather than being targeted on producing long-term solutions to the root causes of the problem. This is important because:

a. Identifying the cause of a sediment related maintenance problem will reveal whether it is systemic (and therefore requires a broad-scale, long-term management commitment) or local (in which case the problem may be treated using actions that are spatially limited and short-term). The causes of sediment-related problems can be further sub-divided into those that are chronic (i.e. incremental build up of silt in arterial drains) or acute (rapid sedimentation or erosion during a large flood).

b. The key to identifying the cause of a sediment-related problem lies in understanding its relation to sediment dynamics in the fluvial system. Guidance here is available from geomorphology (Sear et al. 2009; FRMRC), but important points to note are that sedimentation or erosion problems do not always result from a locally generated imbalance in sediment transport capacity. Important off-site factors such as discontinuity in the supply of sediment from upstream, as a result of the presence of a dam, sediment trap, weir, culvert or a naturally occurring sedimentation zone, can result in bed erosion and/or bank collapse. The role of vegetation in moderating sediment transport through increased trapping of fine sediment or by decreasing energy for transport may also be the root cause of sedimentation. Vegetation can also provide a potential solution, however, through, for example the effect of riparian vegetation in helping to stabilize banks, and shade out of excessive in-channel vegetation. *Thus, it is important to consider the role of vegetation as both a potential cause of a sediment problem and a potential part of the solution.*

c. If some form of geomorphological assessment is required to understand and identify the cause of a sediment-related problem, the decision to do so should be taken at this stage.

5. 3rd Guiding Principle: Identify and prioritise the roles of the watercourse

All watercourses (defined pragmatically as the reach within which a particular operational activity is planned/specified) perform at least one and, typically, multiple roles. Identifying these roles is a critical component of planning maintenance because sediment-related actions taken to improve the performance of the reach with respect to one roles (e.g. flood conveyance) have unavoidable impacts on the other roles of that reach (such as conservation) that may be detrimental to that role. Further, because the project reach is part of the fluvial system, performing sediment-related actions there also runs the risk of inadvertently impairing the functionality of adjacent reaches. In following this guiding principle:

a. The roles of water courses broadly fall into two categories: 1) Ecosystem Services including Geomorphology (sediment supply, transfer and storage), Ecology/Habitat (specific to the stream type and biota), Hydrology (natural flood wave transmission/diffusion/storage, interactions with floodplain and groundwater); and 2) Societal roles, including Flood Risk Management, Land Drainage, Navigation, Conservation and Recreation. Some of these roles may impose constraints on the types of maintenance actions that are required, permitted or forbidden in the reach, and clearly these must be identified at this stage. For example, designation of the reach as an SSSI or SAC with regard to either its ecological interest or qualifying interest may severely limit the types and/or timings of maintenance actions that are allowed. Conversely, where the potential consequences of flooding would be severe, the over-riding public interest in flood risk management within a watercourse may result in a reach being designated as a Heavy Modified Watercourse Body (HMWB), in recognition that the geomorphological and ecological functions are subservient to flood risk management in this particular case. It should be noted that this a particular case. Designation as a HMWB may arise as a result of a wide range of pressures that cannot be lifted and which mean that Good Ecological Status is not achievable. However, even in a HMWB, the WFD stipulates that management of the waterbody should seek to achieve good ecological potential by ensuring that maintenance is performed in the least environmentally damaging manner.

b. When considering the many roles performed by a reach targets should be agreed, listed and prioritized using an appropriate method of ranking. The purpose is to support selection of maintenance options appropriate to solving sediment-related problems affecting the higher priority roles, while at the same time ensuring that the constraints imposed by other roles are properly taken account of in designing the management regime.

Given that the concept of ecosystem services is relatively new in river management, expert input will probably be required to assist Operational staff in identifying all of the geomorphic, habitat and ecological functions for a reach.

6. 4th Guiding Principle: Identify and appraise management options based on risk analysis

The basis for identifying and appraising options for managing a sediment-related problem should be analysis of the risks associated with the problem and with each of the management options identified as being potentially appropriate to solving it. Options appraisal must include consideration of off-site actions (e.g. sediment source control) as well as on-site actions such as sediment removal. The relevant questions include:

a. What are the risks of doing nothing? The most serious risk resulting from allowing the sediment-related problem to persist usually stems from the possibility that the flood risk may become unacceptable. If this risk is high then the option of doing nothing will be unacceptable and action will be required.

b. Is the problem self-limiting? This is an important question as there is the potential to save money and avoid disturbing the river environment if the sediment problem is self-limiting (that is, if allowed to adjust naturally, the need for management intervention will diminish with time rather than persisting or growing worse). However, identifying whether a given sediment problem is in fact self-limiting is difficult and may require expert input in many cases.

c. What risks are associated with each of the proposed management options? These risks include not only the possibility that an action may not meet the needs of flood risk management, but also that it might fail WFD criteria or be found to breach other environmental regulations. Risk analysis should include consideration of risks to neighbouring reaches up and downstream as well as those in the reach containing the proposed activity.

d. When analyzing options, the level of analysis should be proportional to the risks identified, with the aim of reducing uncertainties in decision making to levels that are acceptable, or at least tolerable.

e. What risks are associated with vegetation in the problem reach? Vegetation often interacts with sediment in watercourses to contribute to or mitigate sediment management problems. Hence, the influence of vegetation needs to be scoped at this stage. This allows the costs and benefits of managing riparian or aquatic vegetation to be compared to those of removing sediment. For example, management of riparian vegetation may provide the additional conveyance to achieve the desired level of flood risk without the need to remove sediment from the bed and bars.

If it is established that a sediment action is required, the risks associated with the sediment management options available to sediment managers will depend on a range of factors including:

a. Type of river including:

   - - calibre of sediment and transport mechanism (flood driven, coarse bedload, silt accumulation during low flows)
   - - style of channel adjustment (shoal/bar accumulation in an otherwise stable channel, lateral shifting through bank erosion, vertical adjustment involving incision or aggradation)
     - sensitivity to management intervention; ranging from highly sensitive (liable to respond disproportionately to any intervention), to insensitive (morphologically stable and resilient to perturbation)

b. Type of sediment management problem (local shoaling, reach-scale siltation, regional aggradation etc. see Table 1.)

c. Asset constraints (e.g. revetted banks, bridge abutments/aprons upstream, or outfall structures, etc.)

d. Ecological value and sensitivity of the site (e.g. Freshwater Pearl mussel beds, salmon spawning habitat especially at time of spawning etc.)

7. 5th Guiding Principle: Balance multiple goals of channel management

This guiding principle reflects the fact that sediment management requires multi-functional thinking based on multi-disciplinary approaches and advice. Most river reaches are multi-functional and this introduces the potential for conflict between different function-specific management goals and the maintenance actions taken to achieve them. However, while there may be multiple management goals, there is only one river, and conflicts between actions necessary to meet different goals have to be resolved. Ideally, the balancing of multiple management goals should be directed by policy and achieved strategically, but if this is not possible it falls to river managers to achieve a balance based on the practical way they maintain the channel. It follows that, in optimizing sediment related actions, it is essential to select options that allow the goals for river management with respect to, for example, ecology, flood risk and land drainage to be achieved, both in the project reach and those immediately up and downstream.

Attaining these goals may requires careful selection and coordination of sediment actions and to facilitate this options can be entered into an ‘Impact Table’ that presents a risk matrix for the functions of the river and the sediment related actions that might be taken in support of each function (Table 1). The table synthesizes information on how in-channel sediment management actions taken for one function will impact other functions and so provides the basis for balancing multiple goals for river management in such a way that: (1) no function is compromised unacceptably, (2) the sum of adverse impacts across functions is minimized, and (3) maintenance is performed sustainably.

Table 1: Example of an 'Impacts Table' that could be used to facilitate balancing multiple goals for channel management. H = High Impact, M = Moderate Impact, L = Low Impact of activity; * Refers to High and Good Ecological status sites or impacts on a site's ability to achieve Good Ecological Status/Good Ecological Potential; ^ Impact depends on style of protection (Bioengineering – Structural engineering)

Sediment-related Problem	**Sediment Management Options**	**FRM**	**Land Drainage**	**WFD***	**Statutorily Protected Sites**	**WLMP**	**etc…**
Erosion	Bed Control	L	L	H	M	M	
	Bank Protection	M	M	L-H^	L-H^	L	
Sediment Transfer	Bed Re-grading	H	H	H	H	H	
	Channel Re-sectioning	H	H	H	H	H	
	Gravel Trapping	M	M	H	H	L-M	
Deposition	Dredging	H	H	H	H	H	
	Desilting	H	H	H	H	H	
	Shoal Removal	H	M	H	H	L-M	
	Groynes/Deflectors	L-M	L-M	L-M	L-M	L-M	
	Off-site Sediment source control	H	H	L	L	L	
	Vegetation Management	H-M	H-M	H-M	H-M	H-M	

Level of impact in Table 1 is based on an expert assessment of the potential effects that a given sediment management action would have in relation to the goals for different river functions. For example, the use of deflectors for managing sediment deposition has a Low-Moderate impact on FRM since these structures are designed to be drowned out at medium discharges. However, each case should be assessed in its own right and this impact might change e.g. become High if the deflectors in a reach were colonized by woody vegetation so that they impeded flood flows

Examples of potential hydromorphological consequences of specific FRM and other river management activities are listed in DEFRA (2008) project report '9T1355: WFD and Expert Assessment Progress' prepared by Haskoning. In the context of multi-functional river maintenance, the data from this report should be used to compile guidance documents for decision support by staff responsible for implementing maintenance.

8. 6th Guiding Principle: Appraise maintenance outcomes by inspecting channel conditions with respect to targets set for all relevant functions.

Regular inspection is a feature of most channel management in the UK and provides the opportunity for appraising *the outcomes of maintenance actions*. Inspection is also required to support adaptive maintenance and is valuable not only for checking the performance of the channel and its response to past maintenance actions, but also enhancing the inspectors' understanding of the fluvial system under their management.

To be effective, inspection should include monitoring of post-maintenance changes set against specific, measurable targets for multiple river functions, rather than qualitative goals for maintenance or channel performance with respect to any single function. Monitoring must persist over timescales and extend over spatial scales that are relevant to the sediment problem. The results of monitoring may then be fed back into the management regime for that particular problem in that particular sub-reach, so that through time maintenance becomes tailored to the catchment context and local attributes of the sub-reach – which are to a degree unique. Clearly, this tailoring relies on a process of interpretation of the monitoring data, reviewing the maintenance actions and 'learning by doing'. Given the multiple functional goals for the reach identified according to Guiding Principle 5, monitoring must take account of all the functions for the reach, according to the priorities set according to Guiding Principle 3.

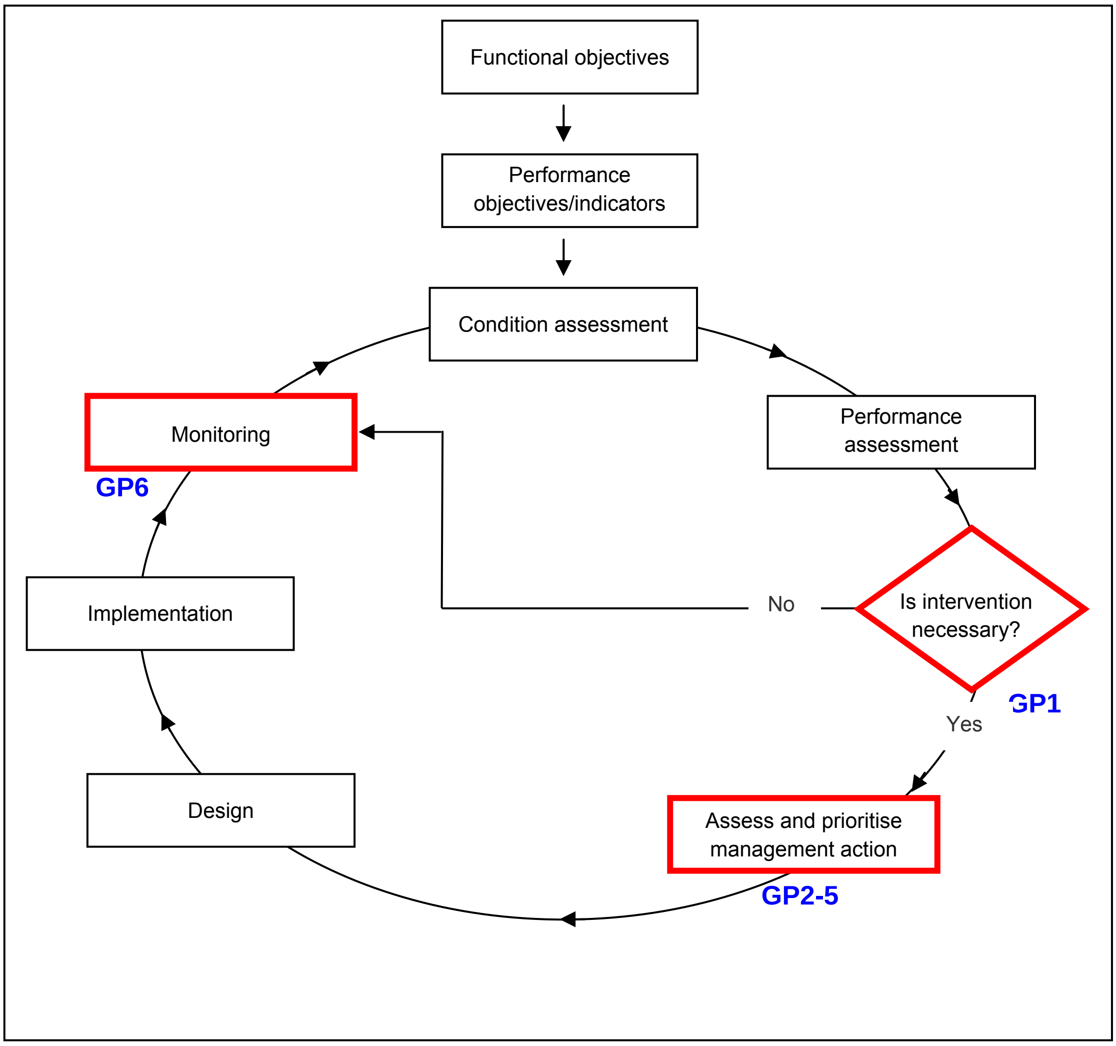

Figure 1: Guiding Principles (GP) nested within the Sustainable Asset Management System (SAMS) lifecycle (after Flickweert and Ogunyoye 2009).

Figure 1 shows where the Guiding Principles for sediment management nest within the Sustainable Asset Management System process (SAMS) (Flickweert & Ogunyoye 2009). The Guiding Principles process is based on an adaptive management approach that recognises the need for monitoring and adjustment as conditions change.

9. Implementation of improved operational sediment management: a staged approach

Implementation of sediment management based on the six Guiding Principles set out above will require training for EA staff and others engaged in management and maintenance of watercourses in England and Wales. Training in the new approach will require development of a training package that includes worked examples that are representative of (a) the broad river types encountered by Asset Managers and other stakeholders (e.g. tidal locked drainage channels) and (b) the range of sediment management issues dealt with by stakeholders (e.g. erosion, deposition, vegetation sediment interactions). Further detailed work will be needed to apply the 3rd Guiding Principle because at present, the practical basis for evaluating and prioritizing multiple watercourses functions is limited. This project will implement an initial e-learning package, see Item 4 of this study, but it is recognized that this will need further development, particularly to ensure that the examples it includes are appropriate to different EA and IDB regions. Item 1 of this study identified an overall strategy to providing the required tools to implement this approach to sediment management.

The most effective approach to implementing a staged approach to sediment management based on the Guiding Principles set out here would be to develop an on-line Decision Support Tool. Experience in this process strongly advocates that development is tailored to the needs and cultures of the different stakeholders – for example a different level of support would be needed by practitioners compared to that required by asset Managers. The advantage of this approach is that the information required to take a decision can be supplied to the end-user and the implications of their actions highlighted. Ultimately, however, the decision is made by the informed individual.

10. Insights regarding sediment management gained from Fluvial Geomorphology

Set alongside the Guiding Principles for sediment management are a series of insights which underpin the overall approach to sediment management. These are based on fluvial geomorphology and are set out below to inform the thinking of those involved in policy making with respect to watercourse management and maintenance. Understanding geomorphology influences the approach to river maintenance because it helps the river manager to focus on causality and process in the fluvial system, which ultimately improves the selection of an appropriate solution. These elements are supported by an on-line, e-learning package designed to inform river managers and practitioners. Several of these elements can be found in case studies in the Key Recommendations Phase 2 Report (Environment Agency 2010).

1. **A river should be understood as an ecosystem** within which water, sediment, wood and nutrients are continuously sourced, transported and stored. Sediment production, movement and accumulation are, therefore, important components of the river ecosystem, with sediment dynamics being largely responsible for creating and maintaining physical habitat. Within the ecosystem, the sediment system is strongly influenced by connectivity between the river and the wider catchment and by the production and transfer of sediment from the catchment to the sea via the

river network (including temporary storage in channel and floodplain deposits – see bullet point 2 below).

2. **Sediment accumulation** occurs where more sediment is transported to a location than can be transported away from it. This usually happens due to a local decrease in the stream power available to transport sediment. Typical locations for sediment accumulation include places where: a) flow resistance is increased – e.g. where there is an increase in vegetation density/extent, bed roughness or flow width, b) a decrease in the slope of the bed (increased sinuosity) or water surface (e.g. ponding behind weirs); or c) a reduction in water discharge (reservoir, abstraction, off-take). Sediment may also accumulate due to a local increase in sediment supply. Often this results primarily from a point source such as a landslide, sediment laden tributary or drain or an eroding bank.

3. **Bed scour** results from an excess of sediment transport capacity over the supply from upstream and local sources, the bed being eroded to balance the reach-scale sediment budget. The reason for scour is usually a local increase in stream power available to drive sediment transport. Typical locations for sediment accumulation include places where: a) flow resistance is decreased – e.g. where there is a reduction in vegetation density/extent, bed roughness or flow width, b) an increase in the slope of the bed (decreased sinuosity) or water surface (flow acceleration through or below a hydraulic structure); or c) an increase in water discharge (reservoir release, drainage outfall). Scour may also occur due to sediment starvation resulting primarily from sediment removal in an upstream reach that supplies material to the project reach, or trapping (e.g. gravel traps) in an intermediate reach that acts as a pathway for sediment. Bed scour is also likely where the banks of a river are artificially stabilized, preventing lateral erosion and shifting of the channel and focusing erosion processes forces on the bed.

4. **Bank erosion and deposition** are processes that occur naturally in all alluvial rivers and which are responsible for lateral migration and plan form development (meandering, braiding, anastomosing) and evolution. It is through bank line shifting that sediment is exchanged between the active channel and floodplain storage and, wherever possible, lateral connectivity between the channel and the floodplain should be sustained to allow the sediment transfer system to sort and exchange sediments naturally. However, accelerated bank accretion is likely in channels that have been widened unnaturally to control flood risk. Conversely, accelerated bank erosion is likely where the stream power available to transport sediment increases (for the reasons outlined in bullet point 3).

5. **The ability of a river to transport the sediment** derived from entrainment at the bed can be represented by the magnitude of the stream power (or boundary shear stress) available in excess of the critical stream power (or boundary shear stress) required to mobilize the bed material. In alluvial streams, the threshold of motion for bed sediment is influenced by the submerged weight of the particles (usually represented by their diameter) and inter-particle friction, which is proportional to the tightness with which bed grains are packed together. Fine sediment has an important role in this packing process. Any operation that loosens the bed (shoal removal, gravel cleaning) mayl increase the mobility of the sediment and the rate of sediment transport out of the disturbed area.

6. **Sediments have a source** and management of this source may, in many cases, be the best option for the long term solution to a sediment

accumulation problem. However, fine sediments (<1mm) that are able to be transported over long distances are frequently sourced from outside the channel, being derived from catchment erosion. These sediments enter the river via field drains, road ditches, farm tracks and un-surfaced roads that are poorly sited, constructed and/or managed. It follows that source control to reduce elevated yields of catchment-derived sediment may require the involvement of stakeholders acting outside the riparian corridor. However, fines may also be sourced from within the riparian corridor, from eroding banks. Consequently, bank stabilization can be an effective sediment management option, especially where bank erosion has been triggered or accelerated unnaturally. Coarse sediments (>1mm) are usually derived from scour of bed and bar materials.

7. **Vegetation influences sediment transport** by locally increasing flow resistance and thereby decreasing the energy available for transporting sediment. Vegetation can also be effective in physically trapping sediment within areas of closely spaced stems. The result is that clearance of vegetation may result in accelerated scour and elevated rates of sediment transport, while invasion of the channel by unnaturally dense vegetation can promote locally enhanced sedimentation, particularly at the channel margins. Wood in rivers is a natural part of the morphological and eco-systems that enhances both habitat and biodiversity. It also influences sediment dynamics significantly. Wood jams can result in both the accumulation of finer sediments where flow resistance is locally increased, and local scour that reveals coarser substrate sediments where the flow is concentrated. Evidence from heavily disturbed fluvial systems demonstrates that wood has a net stabilizing effect, with unstable channels that contain wood releasing less sediment and recovering their dynamic stability faster than those from which wood has been removed.

8. **Sediments in rivers are a fundamental element of the physical habitat** and have an important role in sustaining and supporting the biological communities that live within them. Examples include exposed riverine sediments on shoals that support diverse invertebrate communities and provide nesting sites for some bird species. Sediments provide the growing medium for many aquatic plants and the spawning habitat for many fish species such as Salmon (*Salmo salar*) and Lamprey (*Lampetra fluviatilis*). Sediment also provides the habitat for invertebrate species that provide the base of the food web. However, sediment can also be a limiting factor if concentrations are too high, resulting in excessive turbidity, reduced productivity and physical damage to organisms. Finally, sediment transport and accumulation create the physical habitat within which all in-stream biota live.

Our understanding of these various principles is partial and specific to particular river types. Hence the need for: a) an adaptive management approach and b) further underpinning science that will support river management agencies. Such R&D is particularly urgent in the areas of:

- Defining Ecosystem Functions and relating these to Ecosystem Services using methodologies applicable to both natural and modified channel-floodplain units.
- Understanding vegetation-sediment interactions in rivers of different types.

- Understanding the influence of floodplain-channel interactions on in-channel sediment transport and adjustment in order to justify decisions to deny permission for maintenance or construction activities that would risk disconnecting the channel from its floodplain and explain restore floodplain connectivity where past actions have artificially disrupted it.

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Appendix 7 Interim river typology for sediment management in watercourses

Summary

This report has been developed as an output of Item 2 of the River Sediments & Habitats Phase 2- Additional works Project by David Sear and Colin Thorne.

This interim river typology is proposed specifically to assist FCERM staff with decisions on sediment related management issues and should not be viewed as a new typology of UK rivers. A typology is useful because it aims to bring together watercourses that behave in a similar way and that might reasonably be expected to be managed in a similar fashion. The report presents the basics and specifications of a typology and details the one recommended as an interim typology, the modified Montgomery and Buffington.

1. What are the benefits of a typology?

This document proposes the use of a river typology for use within Flood Risk Management (FRM) to assist in selecting and implementing sediment management in watercourses. An understanding of river typology is beneficial since it provides the basis for selecting appropriate sediment-related management actions with respect to the geomorphological characteristics of the watercourse. The underlying assumption is that watercourses of a particular type will respond to sediment management in broadly similar ways; using a standard typology will assist in the selection of appropriate management actions for particular rivers. The use of a river typology will assist in classifying assets and asset management activities and provide a means of achieving a consistency of approach. A river typology provides a method for linking an understanding of sediment processes to the management activity in a water course. A key step in this is to provide guidance on the processes and issues that occur in different river types and the actions and solutions that are most appropriate for those river types. Such an approach will benefit operational and technical staff by providing confidence in decision making brought about through having a clear evidence base. However, no typology is perfect (see below) and case by case investigation such as outlined in the Guiding Principles will be necessary – aided by the ability to recognise a given channel Type.

The additional benefits of a typology aimed specifically at the management of sediment issues, is in the provision (alongside the Guiding Principles and E-Learning package- presented in the appendices of the report) of skills and learning for existing technical and operational staff. A key role for the typology in the medium term is to provide the linkage between the Science base (evidence base), Guiding Principles and practice of managing a sediment related issue.

A typology is useful because it aims to group together watercourses that behave in a physically and ecologically similar way and that might reasonably be expected to be managed in a similar fashion. It:

a. focuses users on the specific processes controlling the behaviour of a given watercourse type;

b. helps identify how a particular watercourse type can be expected to respond under certain pressures (e.g. dredging, non-intervention);

c. helps to select type-specific sediment management options, and;

d. enables geographically rational and consistent options to be undertaken, thereby reducing the risk of undertaking work that is inconsistent with the processes operating within a given river type (cost-saving) and reducing the risk of damaging the habitat and ecology (i.e. conforming with Water Framework Directive).

In undertaking this work we were guided by the following requirements:

- Do not invent a new typology unless necessary.
- The purpose of the typology is to provide a generic typology for FRM sediment managers that links the channel type to river processes and, therefore, the stages for sediment management, helping to decide on most appropriate sediment management plan.
- Requirement to link FRM Asset reaches to a typology that is relevant to different aspects of river management, including Water Framework Directive and the Habitats Directive..

2. River Channel Classification and Typology: basics

The desire to impose order onto complex natural systems is at the root of all scientific disciplines. The process by which this is achieved is generally termed classification. The rationale for classification is to simplify complexity in order to better understand the relationship between natural processes and resulting adaptations (be they morphological or ecological); to aid communication between scientists through employing standard protocols for interpreting observations; and for interfacing across disciplinary boundaries. Classification has been applied in a wide range of environmental management river conservation (Naiman et al., 1992; Raven et al., 1998; Thomson et al., 2001) and river management and restoration (Frissell, 1986; Rosgen, 1994;). The history of attempts to classify rivers into different types spans at least 125 years, a period over which more than a hundred different attempts to divide and categorise rivers have been made (Kondolf et al., 2003). In the context of river management in Europe, it is important to recognize that the term ‘classification’ should be reserved and applied only to classification according to ecological status under the WFD. To ignore this would create confusion about which classification system was being used in a particular management context and open the door to multiple channel classifications becoming involved in management decision making – both of which are unnecessary. In light of this, classification in this document refers exclusively to Ecological Status (High, Good etc.) in natural rivers and Ecological Potential in Heavily Modified Water Bodies. The term ‘typology’ is applied to the grouping of channels into different types based on their morphological attributes and trend of morphological change through time.

A typology should identify the boundaries between channel types using physical process based theory that is generally applicable across region of similar geology and hydrology. In river channel geomorphology these boundaries are often termed thresholds (Newson, 1992). Boundaries are often perceived as crisp divisions between states, however, this is rarely the case in relation to channel morphology. Rather, Newson (1992) recognises transitional forms – for example, the wandering gravel-bed river, whose channel displays characteristics associated with both braided and meandering plan form types. The association between sensitivity and channel behaviour at these transitions is an important process-response characteristic of the different channel types, but is rarely included in river channel typologies.

Typologies are broadly split into those that generate individual types for each river catchment (Special Typologies) and those that are generally applicable across all river catchments (General Typologies). Examples of Special Typologies include those developed for EA Climate Science by Environment Agency (2007), or Naura (on-going) for Fisheries Science. The benefits of special typologies are primarily that they recognize the importance of local factors in controlling processes and the resulting channel morphologies. Their disadvantages mainly relate to the lack of inter-comparison outside of the specific catchment for which they were developed. Examples of General typologies include that developed for SEPA based on modifying the general typology of Montgomery & Buffington (1997), and included in the **M**orphological **Im**pact **A**ssessment **S**ystem (MImAS) (Sniffer 2006); the RHS typology developed by Jeffers et al., (1998); and that developed by Newson et al. (1998) for UK rivers based on RHS data. The advantage of these general typologies is that they tend to be less data intensive and more widely applicable, providing river managers with a standardised framework within which to understand the links between river processes and resulting morphologies (Downs & Kondolf 1995; Thorne, 1997; Kondolf et al. 2003;).

Note of Caution

Universal (General) Typologies have only limited usefulness and are not a "panacea" that can replace the understanding of a river channel sediment system and physical habitat (Kondolf et al., 2003).

This statement, made by Kondolf et al., (2003) and generally accepted by the science community in geomorphology, is based on increasing experience of river management and restoration works that have been Typology-based and that have sometimes failed to deliver appropriate solutions. Typologies should be seen as a first stage in the process of selecting appropriate management actions, to be supported by more detailed analysis of site conditions where the high level of uncertainty concerning simple typology-based approaches is intolerable or the risks associated with miss-classifying the river are too high.

3. Specification for a Typology

The fundamental specification for a typology that aims to guide sediment managers towards the most appropriate actions for sediment management must be:

1. Based on an understanding of geomorphological process-form interactions that recognises the importance of perturbation and change and which includes definition of channel dynamics as well as morphology.
2. Strongly related to physical habitat and biota (WFD, Habitats Directive)
3. Applicable across all UK river channel/catchment conditions in which sediment management might be considered for the purposes of FRM (upland – lowland, permeable – impermeable, natural - modified)

4. Easily applied by sediment managers (can be supported by training)
5. Easily understood by all stakeholders (can be supported by training)
6. Clearly linked to the selection of appropriate sediment-related activity given the catchment context and local attributes of the sub-reach (links to Guiding Principles)

4. Candidate Typologies

With over 100 different river classification systems in existence a complete review would be a substantial undertaking that is beyond the scope of the additional work reported herein. Instead, the approach adopted has been to:

1. Screen the more recent literature for reviews of classification systems;
2. Focus on those which have a track record in operational as opposed to purely academic applications;
3. Focus on those typologies that were sufficiently generic to be applicable to the UK environment.

Table 1. lists those typologies that were drawn from the review literature.

5. Interim Typology for FRM

The application of the modified Montgomery and Buffington typology (SNIFFER 2006) is recommended as an interim typology for the following reasons:

1. It is based on a widely recognized and tested typology developed by Montgomery and Buffington (1997) which has generic application across montane rivers.
2. The typology has been tested under a wide range of UK river conditions.
3. The typology is supported by a national scale GIS tool for typing the river network based on map-derived variables (SNIFFER 2008 - WFD49e). This has been applied to Scotland and could be applied to the rest of the UK river network.
4. There is an explicit link between the typology and the impacts of a range of FRM activity embedded such that an initial screening of the impacts of FRM activity can be made in relation to the WFD requirements.
5. Limited (though evolving) field validation of the national typology tool and the ecological basis for the Typology are underway.

Notwithstanding these factors, the Typology is recognized as being limited due to:

1. The typology is currently based on the natural attributes of the channel, and does not recognize the features associated with past management and existing artificial modifications.

2. The typology is potentially insensitive to the variety of lowland rivers found in the UK (e.g. 'groundwater dominated' and 'passive meandering' types currently represent all lowland river types) – though these have been extended to include modified watercourse types
3. The typology is static and does not include any measure of channel dynamics or morphological adjustments that may be going on in a reach (this criticism is common to many typologies, however).

For these reasons we recommend that additional information is collected in order to enhance the application of the modified Montgomery and Buffington typology to the requirements of sediment managers.

1. Addition of a measure of the current trend of morphological adjustment to the typology to assist users in identifying whether sediment problems are associated with a particular style of morphological adjustment within a reach.
2. Development of a protocol for applying the typology to reaches, in particular coping with multiple types within a single reach.
3. Specific research to increase the resolution of the typology in lowland rivers and those that have been modified, both conditions being widespread in the UK.
4. Application of the Typology to not only the reach of interest but also to the reaches immediately upstream and downstream in order to provide information to assist users with evaluation of the risk of offsite impacts and the upstream context for the sediment management problem.

6. Available measures of channel adjustment

Three systems for quantifying the styles of adjustment of UK rivers are available;

1. Downs (1992) graphical model of UK river channel adjustment styles. This is visual and developed on lowland river systems in the Upper Thames catchment as part of PhD research. The principles are based on those developed by Brice (1981) and Brookes (1987). The advantages are that it is explicitly relevant to the lower energy systems of the UK, and is based on a set of diagrams rather than a textual description (Figure 1). The disadvantage is that there are uncertainties in translating the evidence that can be observed in the field into a given Downs class. Experience suggests that field visits are best done during winter at a time of low flow, when vegetation does not obscure bed and banks, so that erosive features and sediment forms in the channel can be clearly observed. However, in light of the limitations of the diagram-based approach developed by Downs, it is recommended that for sediment managers it be supplemented by the table-based method of Sear et al. (1995) that is described below.

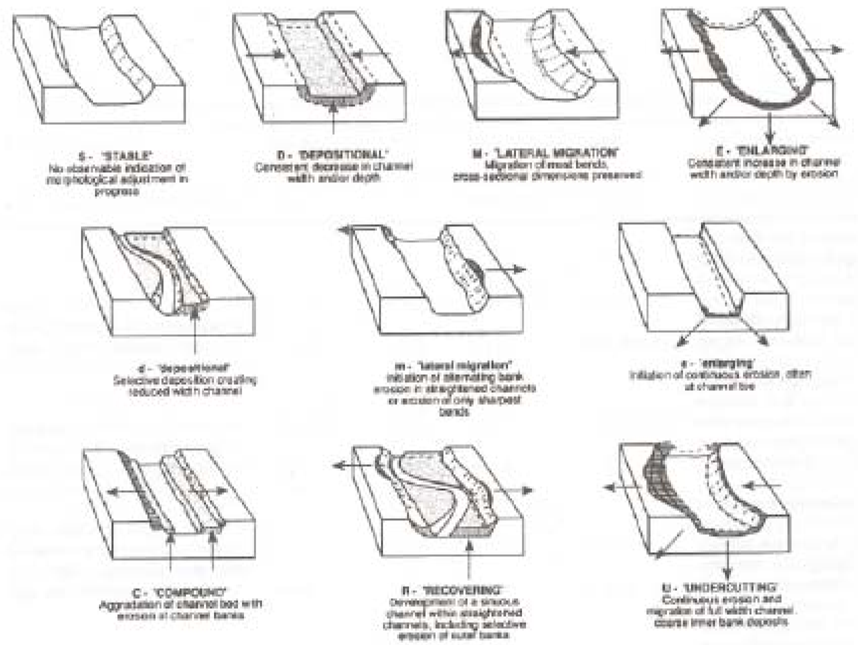

Figure 1: Downs (1992) Classification of channel adjustment types observed in low energy streams of the Upper Thames basin.

2. NRA (1994); Sear et al. (1995) indicators of channel adjustment (Table 2). These were developed for the NRA and subsequently embedded within the Fluvial Auditing framework for assessing sediment related river management problems in UK rivers. The information is field based and focused on the processes of vertical channel adjustment. Lateral channel adjustment would be assessed using aerial photography (e.g. Google Earth™ imagery) and evaluation of at least one historic map (OS 1st Edition 1:10560) compared to the most recent available mapping.

Table 2: Field-based symptoms of vertical channel adjustment (Sear et al., 1995)

Category	Upland (Source)	Middle (Transfer)	Lower (Sink)
Evidence of Incision	Perched boulder berms Old channels in floodplain Old slope failures Undermined structures Exposed tree roots Narrow/deep channel Bank failures both banks Armoured/compacted bed Thick gravel exposure in the banks overlain by fines	Terraces Old channels in floodplain Undermined structures Exposed tree roots Tree collapse (both banks) Trees leaning towards channel (both banks) Downed trees in channel Bank failures both banks Armoured/compacted bed Thick gravel exposure in the banks overlain by fines	Old channels in floodplain Undermined structures Narrow/deep channel Exposed tree roots Tree collapse (both banks) Trees leaning towards channel (both banks) Bank failures both banks Thick gravel exposure in the banks overlain by fines Compacted bed sediments

Category	Upland (Source)	Middle (Transfer)	Lower (Sink)
Evidence of Aggradation	Buried structures Buried soils Many uncompacted 'over loose' bars Eroding banks at shallows Contracting bridge openings Deep fine sediment overlying coarse particles in bed/banks Many unvegetated bars	Buried structures Buried soils Large, uncompacted bars Eroding banks at shallows Contracting bridge openings Deep fine sediment overlying coarse particles in bed banks Many unvegetated bars	Buried structures Buried soils Large, uncompacted, 'over loose' bars Eroding banks at shallows Contracting bridge openings Deep fine sediment overlying coarse particles in banks Many unvegetated bars
Evidence of Stability	Vegetated bars and banks Compacted, weed covered bed Bank erosion rare Old structures in position No evidence of change from old maps Well established trees on banks Little large woody debris	Vegetated bars and banks Compacted, weed covered bed Bank erosion rare Old structures in position No evidence of change from old maps Well established trees on banks Little large woody debris	Vegetated bars and banks Compacted, weed covered bed Bank erosion rare Old structures in position No evidence of change from old maps Well established trees on banks Little large woody debris

3. Typology adjustment characteristics

Tables 3 and 4 provide additional information on the likely adjustment response of the Montgomery and Buffington (1997) channel types to moderate changes in sediment and water discharge. Table 4 presents the types of channel adjustment typically observed in UK rivers within the modified Montgomery and Buffington classification. These do not present specific information on adjustment in modified channels, which remains a problem for this classification.

Table 3: Interpreted Montgomery and Buffington type response potential to moderate changes in sediment supply and discharge

TABLE 2.2. Interpreted reach-level channel response potential to moderate changes in sediment supply and discharge (+ = likely to change; p = possible to change: – = unlikely to change).

	Reach level morphology	Width	Depth	Roughness	Scour depth	Grain size	Slope	Sediment storage
Response	dune-ripple	+	+	+	+	–	+	+
	pool-riffle	+	+	+	+	+	+	+
	plane-bed	p	+	p	+	–	+	p
Transport	step-pool	–	p	p	p	p	p	p
	cascade		–	p	–	p	–	–
	bedrock		–	–	–		–	–
Source	colluvial	p	p	–	p	p	–	+

Modified from Montgomery and Buffington, 1997.

7. *Deploying the Interim Typology within the Environment Agency*

Within the Environment Agency the recommendation is that the interim typology is applied to existing National Flood and Coastal Defence Database (NFCDD) reaches and sub-reaches. This would be achieved in three phases:

1. Phase 1: Undertake specific UK based research to develop a more appropriate typology for low gradient modified watercourses, with an emphasis on those previously maintained for FRM or Land drainage. Particular evidence of adjustment styles in these watercourses can be derived from careful selection of channels from different stream power/lithology classes and for which the history of maintenance and works is well documented. Additional work is required to explicitly link the river typology to the options for sediment management and the Guiding Principles such that the typology can provide a first order screening of what options are not appropriate. The typology should be delivered using visual guides (photographs of different channel types) linked to clear guidance on most appropriate management solutions. An appendix of worked examples would be appropriate. This could be delivered to technical and operational staff as part of staff development and linked to the proposed future Sediment Management Handbook / Guiding Principles.
2. Phase 2: Map-based application of the typology based on the WFD49e programme to allocate Main River reaches broadly to Typology classes. This could be achieved nationally within perhaps 2 years (it was done for Scotland within such a period) and combined with the NFCDD reaches to define the morphological type for each NFCDD reach. The aim would be to provide interim guidance on the channel type, and associated styles of adjustment expected for that type (based on Table 4), to help inform selection of appropriate sediment-related management and maintenance actions. A second aim, based on screening, would be to identify reaches that are outside the expected typology and that, therefore, require field-based typing.
3. Phase 3: Field based typing through operational investigation to a) determine type in cases where this is not that expected based on the map-based exercise and b) to characterize the style of morphological adjustment displayed by NFCDD reaches. At this stage a combined Downs (1995) and Sear et al. (1995) assessment of morphological adjustment style should be undertaken and compared to the types developed in table 4 and expanded in Phase 1. This could be undertaken during routine inspection of NCFDD reaches by Ops Delivery staff, although if this process were to prove too slow, additional work would have to be commissioned.

A clear costed business case would need to be developed as part of Phase 1 and prior to Phase 2 in order to provide justification for the roll out to national level under these subsequent Phases.

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Table 1: Variables used to allocate rivers into specific types in classification systems used in humid-temperate climates
Shaded Columns are data that can be extracted from spatial datasets (Maps / Air Photos). The rest are only usefully derived from Air photos and field measurement.

	Adjacent Geology	Slope	Q	Sinuosity	Braiding index	Confinement	Grainsize	Relative roughness	Entrenchment	W:d ratio	Bedform Pattern	Sediment Source	Sediment storage	Flow Type	Pool-Spacing	Adjustment
Downs (1995)											**Y**					**Y**
Brookes (1987)		**Y**	**Y (bankfull)**							**Width**						
Montgomery & Bufington (1997) also VNRA (2003)	**Y**	**Y**				**Y**	**Y**	**Y**			**Y**	**Y**	**Y**		**Y**	**N**
NIWAS (1999)	**Y**	**Y**	**Y (Variability Index)**	**Y**	**Y**											**N**
MIMAS (2006)	**Y**	**Y**		**Y**		**Y**										**N**
RHS (Naura et al., 2005)							**Y**						**Y**	**Y**		**N**
Rosgen (1994)		**Y**	**Y**	**Y**			**Y**		**Y**	**Y**						**N**
Newson et al., (1998)	**Y**			**Y**			**Y**				**Y**	**Y**	**Y**			**N**
River Styles Brierley & Fryirs (2002)	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**

Table 4: Styles of Adjustment associated with the proposed channel typology (modified from Sear et al., in press)

Channel Type	**Morphological Description**	**Style of adjustment**
1) Steep headwater channels (0-2 order) 	Cascades, Step-pool, Poorly sorted grainsize with boulders and exposed bedrock. Confined by valley sides resulting in strong coupling. Absence of floodplain. Steep slopes (>0.03)	Limited lateral movement – commonly the result of avulsion. Channel bed elevations periodically aggrade and incise in response to slope-channel connecting events often in association with generation of a sediment wave. Bed morphology can be destroyed by high magnitude events but reform step-pools. Where present, woody debris contributes to aggradation and sediment accumulation creating steps in long profile.
2) Pool-Riffle and Plane bed channels  	Can exist in meandering partially confined and unconfined states. Characterised by lateral oscillating sequences of bars, pools and riffles. The gradient of such channels is low-moderate and the width depth ratio high. The bed is predominantly gravel, with occasional patches of cobbles and sand. Interactions between the stream and the riparian zone result in over bank flood flows and wetland areas.	The banks are typically resistant to erosion, and lateral migration of the channel is limited, resulting in relatively narrow and intermittently deep channels. Lateral channel adjustment occurs via avulsion and chute cut-offs across meander bends. Bar erosion and development coupled with pool-infilling and riffle erosion characterize the bed adjustment particularly in presence of a sediment wave. Where present, woody debris creates local scour and sedimentation and can force the formation of pools/ pool-riffle sequences.

Channel Type	Morphological Description	Style of adjustment
3 Wandering gravel-bed rivers 	Generally, they can be viewed as a transition channel type between braided and active meandering channels. These reaches exhibit characteristics of braided and meandering channels simultaneously, or, if studied over a number of years, display a switching between divided and undivided channel types. Wandering channels typically occur where a reduction of bed material size and channel slope is combined with a widening of the valley floor. Presence of lateral, point and mid-channel bars with pool and rifle sequences.	Wandering channels are susceptable to channel avulsions during high flow events, particularly where the channel can re-ocuppy an old channel. Bank erosion processes are active with lateral migration and channel widening forced by bend curvature and sediment accumulation into mid channel bars. Phases of incision and aggradation build sequences of terraces on the valley floor. Woody debris important part of island formation and flow deflection resulting in bank erosion and chanel migration.
2) Braided rivers 	Braided reaches can occur in a variety of settings. Typically characterised by relatively high gradients and/or abundant bedload with high width:depth ratio. Channel splits into a number of threads around instream bars. Nevertheless, poor bank strength renders them highly dynamic and channels will generally change even in relatively small flood events.	Braided channels are rare in the UK They are susceptable to channel avulsions, chute-cutoff and bar development during high flow events. Bank erosion processes are active with lateral migration and channel widening forced by sediment accumulation and flow deflection. Phases of incision and aggradation build sequences of terraces on the valley floor. Confluence-difluence processes of scour and aggradation maintain divided planform. Woody debris important part of island formation.

Channel Type	Morphological Description	Style of adjustment
3) Active Meandering alluvial channels 	Bordered by floodplains, the single channel is characterized by pool-riffle sequences and point bars. Counter-point bars occur at over-wide bends. Silt berms extend from point bars, often colonized by riparian vegetation. Wooded riparian corridors. Bed material typically gravel with fines.	Bank erosion and lateral migration of the channel dominated adjustment processes. Bends develop through a range of forms, leading in some cases to meander cut-off. Chute-cut-off processes also prevalent where channel is not incised. Sinuosity changes over time resulting in progressive reduction in slope, and accumulation of sediments on bars. Riffle-pool sequence is dynamic with addition riffles and pool units developing as channel length extends with bend migration. Laterally stable reaches often occur in between active bends. Large wood creates complex bar and flow structures that can influence bend, pool and bar development.
6) Passive Meandering 	Generally lower slopes, flowing through resistant materials, for instance boulder or marine clay deposits. They are generally sinuous – meandering. Channels are often incised and display low width depth ratios. The beds typically comprise shallow layer of armoured or paved gravels with fine sedimentary materials (sands and silts). Bars are typically low amplitude and have a high fines content. Fine sediment berms also prevalent where channel width increases. Pool and riffle sequences occur but often in association with other transitional bed forms such as glides and runs. Primary production is strong in these channels and, coupled with stable beds of with much fine sediment, allows extensive growth of macrophyte vegetation. Riparian corridor is typically wooded.	Combination of low slopes and resistant bank materials result in limited rates of lateral adjustment often characterized by widening or narrowing through deposition of fines. Woody debris important feature of adjustment processes, resulting in localized chute-cut-off channels at bends, widening around jams and local plunge and scour pools and upstream backwater pools at dams. Bar migration occurs but typically in response to large wood dynamics.

Channel Type	Morphological Description	Style of adjustment
7) Groundwater dominated rivers 	Groundwater-dominated rivers low gradient channels and are characterised by a stable flow regime; although limestone rivers with cave systems may display hydrological characteristics similar to freshet rivers. Typically, sediments are derived from catchment sources, although large macrophyte beds provide a source of in-stream organic detritus. Lack of bed disturbance promotes the accumulation of large quantities of fine sediment. Substrate generally comprises gravels. pebbles and sands, and glides and runs are the dominant flow types. Localised areas of riffle may be present, particularly where woody debris is available. Dense marcophtye beds and wooded riparian corridor.	Bed and bank migration is infrequent and sediments are predominantly transported in suspension. Lateral channel migration is absent or at very low rates. Bar development and gravel transport is highly localized resulting in stable channel morphology. Large wood is present in the channel for long periods and creates local scour and deposition and possibly avulsion where the main stream is blocked. Macrophyte development controls much of the flow and fine sediment transport. Development of marginal berms of fine sediment frequent where channels are over-widened.
8) Channelised high energy watercourses (>35 Wm^{-2}) 	Simplified cross-section and straightened planform, often with embankments. Typically incised, with bank protection necessary to maintain cross-section and prevent bank erosion. Bed can armoured especially where river is incised with coarse bed material. If the channel is over-widened then shoals of sediment will accumulate, especially if upstream reaches are more efficient at transporting sediment. Limited riparian vegetation due to mowing regime and wood management. Steep bank profiles with limited aquatic margins. Bed morphology typically simplified with shallow runs and glides, with occasional riffles. Pool habitats limited.	Bank erosion and undercutting in incised channels with armoured coarse stable beds. Reaches upstream of the channelised reach may be experiencing incision and active bank erosion. In widened reaches, adjustment will be through sediment accumulation in shoals and berms. These in turn will result in a meandering flow and the potential to initiate bank erosion.

Channel Type	Morphological Description	Style of adjustment
9) Channelised moderate-energy watercourses (11-34Wm^{-2}) 	Simplified cross-section and straightened planform, often with embankments. Typically incised, with some limited bank protection. Bed can be armoured especially where river is incised with coarse bed material. Generally absence of shoaling. Limited riparian vegetation due to mowing regime and wood management. Steep bank profiles with limited aquatic margins. Bed morphology typically simplified with shallow runs and glides, with occasional riffles. Pool habitats limited.	Limited erosion and depositional adjustment. Bed tends to be armoured and bank stable. What sediment transport occurs is in the form of small finer gravel shoals and marginal fine sediment berms. Overall the reach would be expected to be stable across most of the flow regime.
10) Channelised Low-energy watercourses (< 10 Wm^{-2}) 	Simplified cross-section and often a straightened planform. Often with embankments and often over-deepened by dredging. Often disconnected from floodplain, with flows contained within the channel and embankments. Bed material often dominated by fine sands and silts, with emergent vegetation and limited riparian vegetation due to mowing regime and wood management. Steep bank profiles with limited margins. Absence of regular or frequent pool-riffle sequences, and typically deeper glide, pool and ponded habitats dominate.	Adjustment is primarily by fine sediment processes, typically the formation of marginal silt berms that are colonized by emergent vegetation, and the trapping of fines on the bed by vegetation. Banks typically fail by geotechnical slippage due to over-deepening, otherwise banks tend to be stable. Over-widening promotes fine sediment berm development out into the channel to reduce capacity to normal low flows particularly on the inside of meander bends.

Channel Type	Morphological Description	Style of adjustment
11) Armoured Channels 	Simplified cross-section with artificial bank and or bed. At one extreme is the culvert, and the other is the reach in which one bank is armoured. Channel adjustment is therefore constrained in one or all dimensions. The presence of armouring (concrete, gabions etc.) impacts on the ecology by limiting vegetation development (steep margins) and providing poor quality substrates for aquatic organisms. Where the channel is over-widened and receives a sediment load from upstream, then the bed may have a residual layer of natural substrate including some bars. Where the bed is armoured, then pool development will be limited.	Adjustment will be dependent on the extent and success of armouring. At one end, adjustment can only occur through deposition on the bed. Where both banks are armoured, and the channel is not over-wide, then incision and erosion of the bed will be evident from undercutting of the bank protection, and the presence of a coarse, compact bed substrate. Upstream structures may also exhibit undercutting, while downstream may show evidence of sediment deposition. Where one bank is armoured, then the bed and opposite banks may show signs of undercutting and incision. Rates of adjustment will be conditioned by the power available to undertake sediment movement and bank erosion – lower stream power channels (<10Wm^{-2} bank full stream power) may not show evidence of erosional adjustment.
12) Tide Locked Watercourses 	Often straightened and embanked. Flows are contained within the channel. During flood tide, flows are stopped and flow velocity declines as water levels rise. On the ebb tide, water levels drop and flows increase in velocity. Bed and banks rapidly accumulate fine sediment. In freshwater sections of these transitional waters, marginal vegetation colonizes the fine sediments leading to extensive berms.	Adjustment is primarily by fine sediment accumulation on the bed and banks. The rate is dependant on the supply of fines from upstream. The bank processes are dependant on the tidal range. In systems where the tidal range if large and there are high levels of incoming fine sediment, accumulation on the banks occurs rapidly and adjustment is by bank slips and slides. Vegetation growth across the bed and on the margins can occur where tidal range is small and ponded freshwater flows occur.

Glossary

Accretion	Process by which particles carried by the flow of water or by the wind are deposited and accumulate (opposite is erosion).
Adaptive management	An approach to managing systems which have inherent uncertainties that involves learning from the system response to intervention, and using that learning to improve the next stage of management.
Afflux	Maximum increase in water surface elevation above that of an unstructured stream due to the presence, and the possible obstruction, of a structure such as a bridge or culvert in the stream. The afflux may also be described as the maximum change in water level that would occur, at a particular flow, if the structure were to be removed.
Aggradation	Regional rise in the bed level of a channel (opposite is degradation).
Asset	In Flood Defence or Coast Protection, any man-made or natural object - such as a raised defence, retaining structure, channel, pumping station, culvert or beach - that performs a Flood Defence, Land Drainage or Coast Protection function. Includes components owned by the Environment Agency or another body, whether or not flood defence is the primary function or is incidental to some other purpose, and components which may be detrimental to flood defence objectives.
Asset management	Systematic and co-ordinated activities through which an organisation optimally and sustainably manages its assets and asset systems - including their associated performance, risks and expenditures - over their life cycles for the purpose of achieving its strategic aims. This includes the performance of the assets and the associated risks and expenditures throughout their lifecycles.
Assessment	The process of understanding the state, performance or structural competence of an existing asset or asset system in order to inform the planning of future interventions.
Catchment, (catchment area)	The land (and its area) which drains to a give point on a river, drainage system or other body of water.
Catchment flood management plan (CFMP)	A large-scale strategic planning framework setting out policies for the integrated management of fluvial flood risks to people and the developed and natural environment in a sustainable manner.
Channel	Natural or man-made open passage designed to contain and convey water.

	The part of a body of water deep enough to be used for navigation through an area otherwise too shallow for navigation. The deepest part of a body of water through which the main volume of current passes.
Conveyance	Channel conveyance is a measure of the discharge carrying capacity of a channel.
Debris	Solid material (sediment or of vegetation or anthropogenic origin) transported in a watercourse particularly during flood events. Debris can move intermittently and has potential to cause blockages that impede the free flow of water.
Desilting	Removal of accumulated sediment from the bed of a channel, generally as a maintenance activity.
Discharge	Flow volume of a river, watercourse, drain or surface flood pathway as measured by volume per unit time. Often referred to as 'flow'.
Dredging	Underwater excavation, usually including removal of the excavated material.
Ecological Quality ratio	Ratio representing the relationship between the values of the biological parameters observed for a given body of surface water and values for these parameters in the reference conditions applicable to that body. The ratio shall be represented as a numerical value between zero and one, with high ecological status represented by values close to one and bad ecological status by values close to zero.
Ecosystem	System in which, by the interaction between the different organisms present and their environment, there is a cyclic interchange of materials and energy.
Environmental costs	Represent the costs of damage that water uses impose on the environment and ecosystems and those who use the environment (e.g. a reduction in the ecological quality of aquatic ecosystems or the salinisation and degradation of productive soils).
Erosion	Process by which particles are removed by the action of wind, flowing water or *waves* (opposite is *accretion*).
Flood Defence asset	An asset that by its failure would increase the likelihood of flooding from any Main River, watercourse and/or the sea to people, property or infrastructure.
Flood Defence system	A collection of flood defence works for a river catchment and/or estuary and/or coastal region in which individual components)or assets) depend upon each other for their overall effectiveness.
Flood Risk Management	The activity of understanding the probability and consequence of flooding, and seeking to modify these factors to manage flood risk

	to people, property and the environment in line with agreed policy objectives.
Flooding system	The broad social and physical domain within which risks arise and are managed. An understanding of the way a system behaves and, in particular, the mechanisms by which flooding might be propagated and receptors could be harmed, is an essential aspect of understanding risk. This is true for an organisational system like flood warning as well as for a physical system of assets.
Flow	General term used to describe movement of water in a particular direction (as distinct from specific descriptors such as discharge or velocity).
Frequent maintenance	Planned activities supporting the standard of service of an asset in a cost-effective manner by reducing its rate of deterioration (Frequent < 5 yearly interval).
Geomorphology (Fluvial)	The branch of geomorphology that describes the characteristics or river systems and examines the processes sustaining them..
Hydromorphology	The physical characteristics of the shape, the boundaries and the content of a water body.
Impact	The environmental effect of a pressure (e.g. fish killed, ecosystem modified).
Intermittent maintenance	Infrequent and one-off planned activities that support the standard of service of an asset.
Intervention	A planned activity designed to effect an improvement in an existing natural or engineered system (particularly with asset management).
Macrophyte	All aquatic higher plants, mosses and characin algae, but excluding single celled phytoplankton or diatoms.
Main River	Watercourses defined on a “Main River Map” designated by Defra. The Environment Agency has permissive powers to carry out flood defence works, maintenance and operational activities for Main Rivers.
Maintenance	Work that sustains the desired condition and intended performance of an asset.
Operating Authority	An organisation (Environment Agency, Local Authority or Internal Drainage Board) having powers under the Land Drainage or Water Resources Acts to operate, maintain or improve flood defence assets within its operating boundaries.
Operational inspection	Regular inspection of an asset to check it is in working order and in a safe condition.

Performance	The degree to which a process or activity succeeds when evaluated against some stated aim or objective.
Raised defence	Any raised structure that protects an area from flooding.
Reach	A length of channel or linear Flood Defence asset between set boundaries. For asset management purposes, each riverbank or flood defence system is divided into reaches of broadly similar length.
Refurbishment	The process of returning an asset to its original as-designed performance.
Resistance	As roughness but defined as flow-, form-, frictional or turbulent.
Risk	Risk can be considered as having two components - the probability that an event will occur and the consequence associated with that event to receptors. Risk = f (probability x consequence). Flood risk to a receptor can be indicated graphically by a PDF with probability and consequence as the x and y axes. The area under the curve is the overall risk.
Risk assessment	The process of identifying hazards and potential consequences, estimating the magnitude and probability of consequences, and assessing the significance of the risk(s). A 'tiered' approach can be used with the effort in assessing each risk proportionate to its importance in relation to other risks and likely consequences.
Risk management	The systematic process of risk assessment, options appraisal and implementation of any risk management measures to control or mitigate risk.
River basin management plan (RBMP)	A plan that describes the main issues to be addressed under the Water Framework Directive for each river basin district and highlights some key actions proposed for dealing with them.
Roughness	The effect of impeding the normal water flow of a channel by the presence of a natural or artificial body or bodies, biotic e.g. vegetation, abiotic/mineral e.g. bank, bed substrate.
Sediment	Material ranging from clay to gravel (or even larger) that is transported in flowing water and that settles or tends to settle in areas where the flow slows down.
Silting	Deposition of waterborne particles onto the bed of a body of water.
State	The condition of the water body resulting from both natural and anthropogenic factors (i.e. physical, chemical and biological characteristics).
Status	The physical, chemical, biological, or ecological behaviour of a water body.

System	Assembly of elements, and the interconnections between them, constituting a whole and generally characterised by its behaviour (e.g. elements in a structure; assets in an asset system). Concept also applied to social and human systems.
System Asset Management Plans (SAMPs)	Long term investment plans for Flood Defence and Coast Protection asset systems that identify the investment needed and the benefits they bring.
Trash screen	A screen on the upstream end of a structure, often a culvert, pumping station or weir, whose primary purpose is to prevent debris from entering the structure and causing blockage.
Typology	The study and interpretation of types.
Watercourse	Defined natural or man-made channel for the conveyance of drainage and flood water by gravity.
WFD, The Directive	Directive 2000/60/EC establishing a framework for Community action in the field of water policy.
Withdrawal of maintenance	Process of stopping maintenance of Flood Defence or Coast Protection assets that have previously been maintained because it is uneconomic to continue.

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