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

Digital Good Practice Manual: Phase 1 Report (review of techniques)

Science Report: SC060065/SR1



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Environment Agency

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Steve Killeen

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Executive summary

This report covers Phase 1 of a project to produce a Digital Good Practice Manual to assess whether a flood risk or land drainage scheme represents good environmental practice and, if not, what further mitigation measures/techniques could be applied. This work links to parallel initiatives prompted by the Water Framework Directive, including the Environment Agency's own Science Programme and the work of UKTAG on classification methods and environmental standards. The main component of Phase 1 has been assimilation of an evidence base (review of techniques) compiled for rivers, lakes, transitional waters and coasts. This is based on an extensive literature review (including internet searches) and telephone or face-to-face interviews with experts in river, lake and coastal water management from the UK and the reset of the world. This report includes a synthesis of the information collected, a description of the studies covered and an initial screening checklist. It also illustrates pan-European initiatives for tackling flood risk management (FRM) and land drainage (LD) issues.

There is considerable information on rivers, much less so for transitional waters and coasts and very little for lakes. For Phase 1 many hundreds of papers were obtained and reviewed from readily accessible sources. There is much previous experience to draw upon and the literature can be split into existing user manuals, grey (or unpublished) literature and published scientific papers. Over the last 20 years considerable progress has been made in mitigating the impacts of FRM activities (as a result of legislation, including the implementation of the EU EIA Directive in 1988). The European Centre for River Restoration (ERRC) and UK River Restoration Centre (RRC) have acted as catalysts since about 1990 to promote river restoration. This contrasts markedly with FRM activities over the last 50 years which generally paid scant attention to environmental constraints and opportunities, although there is now much optimism in Europe with the new Floods Directive (November 2007) and the development of Flood Management Plans exploring alternatives to enhance storage in floodplains, recreate wetlands and remove hard engineering structures on some rivers.

Whether a scientifically proven ecological benefit has arisen as a result of a measure/technique is a function here of publications in the scientific literature. This is distinct from the 'basis for use' of an individual measure/technique described in the checklists, which is a mix of user manuals and grey literature (reflecting more localised experiences) as well as scientific literature. Much data/information held by operational staff has never been published (indeed, many experts do not have the incentive to publish their experiences and monitoring results).   Interviews and questionnaires carried out for Phase 1 indicate that the depth and breadth of scientific monitoring and publications remains low compared to the large number of projects completed. This initial phase cannot hope to collect all available experiences and evaluate the scientific credibility of any evidence that exists.

Scientific information can be (cautiously) imported from other countries such as the USA. However, the number of papers remains low for many measures/techniques. For many physical environments, there will not be any directly applicable information. Lack of monitoring is a problem that has been flagged up by practitioners for more than two decades and remains a weakness (there is rarely any baseline data). Flood mitigation measures are most likely to be successful when properly designed and developed. For the majority of projects in Europe and the UK, there has been little or no monitoring. A project also needs to have a minimum combination of geomorphological, ecological and engineering expertise (and in urban areas, a contaminated land expert and landscape architect) to be successful.   It is also important to consider the opportunities and difficulties presented by mitigation measures and to arrive at a balanced view which inevitably will be site-specific. Thus, the Digital Good Practice Manual cannot be made prescriptive.

This report covers the following sections:

- Chapter 1 – Introduction to the project and report
- Chapters 2 and 3 – Methods used to compile the science evidence base in the UK and European contexts for the development of a manual
- Chapter 4 – Outline of how checklists were developed
- Chapter 5 – Details of the main mitigation measures/techniques, where they have been applied, their costs and potential effects on FRM/LD
- Chapter 6 – Conclusions of this interim report

Acknowledgements

We would like to thank members of the Steering Group as well as a number of individuals in other organisations in the UK who gave their time to our questionnaire interviews. Contributions made by contacts within Europe and the USA are also appreciated. Comments from members of the Steering Group substantially improved the draft report.

Contents

1 Introduction

1.1 Objective of project

To comply with the requirements of the EU Water Framework Directive (WFD), government agencies in the UK (including the Environment Agency) involved with flood risk management (FRM) and land drainage (LD) will need to show “good practice” to minimise the ecological impact of their ongoing activities. This project aims to develop such guidance for FRM and LD activities on rivers, lakes, transitional waters (estuaries) and coasts. The guidance is intended to be applicable across England, Wales, Scotland and Northern Ireland. The entire project will take until late 2009 to complete.

The project focuses on the most commonly used techniques applicable to the UK water environment. For each measure/technique, an assessment of the supporting scientific evidence is undertaken and, where this is lacking, expert opinion is used. It is important to ensure that all managers, across all water bodies and different organisations, share good practice and use consistent sources of advice. The outputs are used to identify the scope for reducing adverse impacts of FRM and LD schemes on the water environment. The final Digital Good Practice Manual is aimed both at the novice practitioner (whether they be a developer or a regulator) and experienced practitioners to enhance the information base available to them, thereby increasing their confidence in negotiating outcomes.

1.2 Scope of project

The scope of works to develop the Digital Good Practice Manual was divided into four main tasks (Jacobs, May 2007). Phase 1 (reported here) reviewed national and international best practice (including interviews/questionnaires) and the effectiveness of measures/techniques to improve biological quality (including hydromorphological and ecological linkages). Phase 1 also involved development of a rapid assessment tool for existing schemes to identify any scope to reduce adverse impacts.

Phase 2 helped build the checklists required for the Digital Good Practice Manual. These can be found in Appendix B of this report. A separate technical report covers the development of these checklists and proposes guidance for assessing whether a FRM or LD scheme represents good environmental practice and, if not, what further mitigation measures/techniques could be undertaken without significant adverse effects on the flood defence or LD objectives (Jacobs, 2008). This task involved undertaking trials for the FRM component of a UK-wide trial coordinated by UKTAG (Technical Advisory Group) covering all sectors (FRM, LD, ports, navigation, water resources, hydropower). This development relied on trialling in a number of Environment Agency offices which led to further iteration of the checklists.

Future work for the Digital Good Practice Manual (Phases 2 and 3) will produce a more detailed assessment tool for new FRM/LD schemes, with more detailed guidance sheets (Phase 2). A technical report will identify the cost-effectiveness of measures restoration and mitigation techniques.

Phase 3 will involve development of a Digital Good Practice Manual using a prescribed template for the internet. This will involve testing and trialling of the product on a number of case studies.

1.3 Purpose of this report

This report summarises the outcomes of Phase 1, undertaken between the initial commissioning of the work in May 2007 and December 2007. It assumes a basic understanding of the Water Framework Directive (WFD) (including terminology) by the reader. Phase 1 concerns reviews and initial assessment and covers the specific objectives set in the Scoping Report (Jacobs 2007) by:

- researching and compiling the scientific evidence base;
- describing the context;
- developing a checklist of FRM/LD measures/techniques;
- compiling an interim review of techniques;
- providing some general issues for discussion and pointers for the next phases.

The key output of this interim stage is a review of techniques covering national and international best practice and a rapid assessment tool for existing schemes to identify scope to reduce adverse effects. The checklists given for each mitigation measure in the review of techniques enable a rapid appraisal of those measures/techniques. The effectiveness of measures/techniques in improving biological quality (including hydromorphological and ecological links) is also referred to in the select literature review included in the text for each measure (where it exists). However it is important to note that this science is currently underway in a separate Environment Agency project tasked with eliciting eco-hydromorphological linkages.

1.4 Linking science initiatives

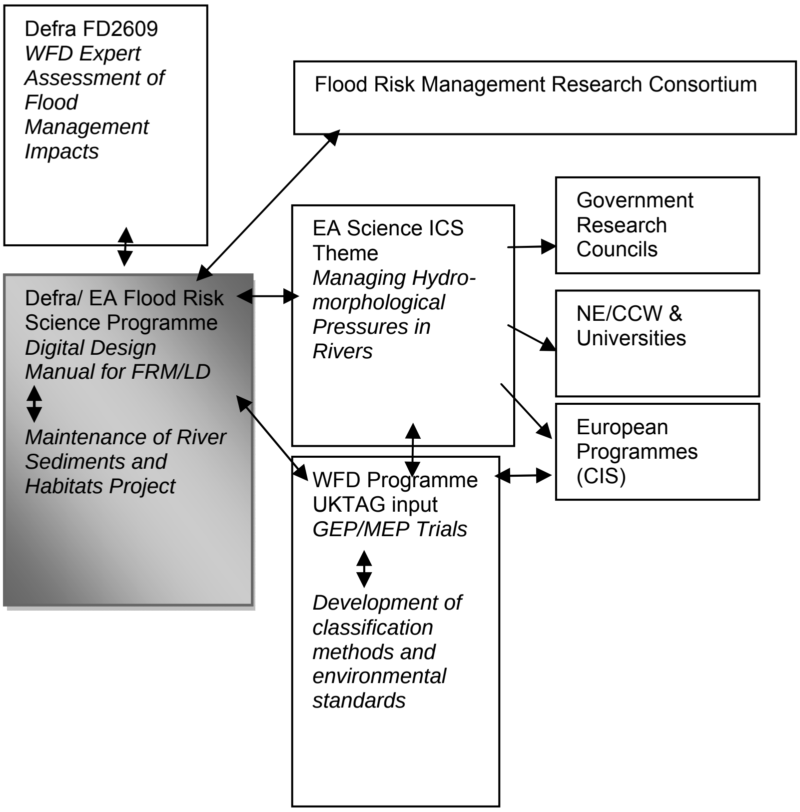
The link between this Digital Good Practice Manual and other key science initiatives is shown in Figure 1.1 below.

The Digital Good Practice Manual is under one theme of the joint Department for Environment, Food and Rural Affairs (Defra)/Environment Agency Flood Risk Science Programme. It has a key link with the *Maintenance of River Sediments and Habitats* project, which in turn links to Defra's project on *Expert Assessment of Flood Management Impacts*. The Digital Good Practice Manual also links to the Environment Agency's Intergrated Catchment Science (ICS) Theme, of which a sub-strategy is hydromorphology. The *Managing Hydromorphological Pressures in Rivers* project is part of a toolkit for river management addressing hydromorphological pressures affecting good ecological status/potential (GEP). This project aims to boost understanding of pressure-impact responses, and improve the use of existing data, information and science in support of restoration and mitigation programmes. It is envisaged that in the short term (2009-2015) quick-win proven measures will be used, whilst in the medium term piloting and monitoring will lead to the development of new measures and good practice. Wider measures will be adopted between 2015 and 2021.

Both the Digital Good Practice Manual and the hydromorphology sub-strategy of the ICS theme link to the UKTAG work. Two important links are with the Good Ecological Potential/Maximum Ecological Potential (GEP/MEP) trialling work to identify mitigation measures and develop UK-wide classification methods and environmental standards to meet the requirements of the Water Framework Directive (e.g. WFD SNIFFER 49 concerning *Trialling of MImAS and Proposed Environmental Standards*). This provides a direct link to work developing the MImAS tool.

The Flood Risk Management Research Consortium (FRMRC, www.floodrisk.org.uk) aims to run an integrated programme of research to support flood risk management.

Figure 1.1 Linking science initiatives



2 Researching and compiling the scientific evidence base

Along with drawing on the knowledge and experience of the authors and consultant team in the UK, EU and the USA, this task involved a fresh literature review (including online searches) and a questionnaire survey.

2.1 Literature search

This interim review of techniques relied on the expert judgement of consultant staff at Jacobs with extensive knowledge of the professional and scientific literature. The types of literature reviewed are listed in Table 2.1

Table 2.1 Literature reviewed.

Type	Description and use within this document
"How to do it" manuals and guidance	Manuals such as those of the River Restoration Centre which typically describe case studies of measures/techniques. In this report, this information (which typically includes problems and practical experiences) is used in the section *"What is the basis for its use?"*
Grey literature	A body of materials that cannot easily be found through conventional channels such as publishers. Examples include technical reports from government agencies, working papers, book chapters and unpublished conference proceedings. These may be internal sources from a particular organisation and although many are now published on the internet, this review cannot profess to have comprehensively searched for all this literature. This information is useful to the manual (particularly as there is so little literature generally), although its quality cannot be vouched for as it is not peer-reviewed. However it is worth noting that systematic reviews are often flawed because they do not adequately cover grey literature. In this report, the grey literature is used to illustrate the description of individual measures/techniques.
Published scientific papers	These are papers published in peer-reviewed journals and therefore have some merit. Because there are so few papers they are not ranked by scientific merit (such as the number of times they have been cited). Within this report (specifically the checklists) these papers have been used to form an expert view on whether there is scientific evidence of an ecological benefit.

More than 1,500 papers and reports were reviewed/assembled for this report. This included a review by Brookes (1988) on river channelization and a further one (Brookes and Shields, 1996) on river channel restoration (both considered at the time to be comprehensive reviews). One of the co-authors of this report (Dr Kevin Skinner) undertook his PhD research on river restoration and this covers many measures post-1996 (Skinner, 1999). Having access to these unique older sources of information was essential to this project as none of the internet-based sources (including Web of Science) were reliable for older papers*.* In carrying out these earlier reviews, Jacobs staff included a search of the Web of Science using their own accesses to licences. . For this interim review of techniques, Jacobs also sought information from several sources including the British Library, the River Restoration Centre and the Environment Agency/Scottish Environment Protection Agency. Members of the Steering Group were also consulted.

Compendiums of tools and techniques for river, lake, estuary and coastal management were examined, providing papers and handbooks as recent as 2007. Further key US papers (some only just in press) were provided by Douglas Shields, US Department of Agriculture. A good start was also made with evidence-based reviews by the Environment Agency and two initial reviews for in-stream deflectors and wood were checked.

Google Scholar was used to find other relevant or more recent articles. Google Scholar ranks articles according to the number of times they are cited by other authors. We examined the first 10 webpages of each (around 100 records) and any references found that were not in the original literature database (of which there were relatively few) were sourced from university libraries if the abstract found on the internet was not sufficient to indicate its worth. For example, there were over 6,000 records for the words "river restoration" and in the first 10 webpages only three references were judged to provide additional evidence.

In terms of screening the publications to include, we used our expert judgement. Internet-based searches tend to be biased towards articles that appear in the published literature. One of the guiding principles for this project set by the Steering Group was to provide a balance of pee- reviewed published papers and unpublished grey literature from organisations and networks; thus, expert judgement was regarded as the only realistic screening mechanism.

As far as possible, the literature review investigated and critically appraised strategies and methods adopted in various countries. This was almost entirely restricted to literature in the English language, although effort was devoted to finding English summaries of literature published in other languages.

Only those articles considered key to illustrating a measure/technique were listed (the aim was to describe the top ten where possible), although for a considerable number of measures/techniques there were less than two articles. As a result, each measure is illustrated by a mix of published and unpublished articles wherever possible. As discussed in Section 1.3 above, the effectiveness of measures/techniques in improving biological quality (including hydromorphological and ecological links) is also referred to for each technique (where it exists).

Within the checklists developed for the key measures/techniques there is a section entitled *"What is the basis for its use?*" Here, the reader can gain a quick impression of whether grey literature/professional guidelines exist. Further on in each checklist is a question on "*What is the scientific evidence to support an ecological benefit?"* Here, an evaluation is made of the science available with four questions about the 'evidence':

1) Are there any papers published on this measure in scientific journals?
2) Has a digest of results been produced?
3) Does a systematic review of the literature exist?
4) Overall, what is the quality of the scientific evidence base?

Scientific journals are those judged to be peer-reviewed, rather than unpublished proceedings of a conference or a technical manual. These were chosen irrespective of their citation rating. The number of papers unearthed by this interim review were less than two (quite often none) for the majority of techniques, and even for the most published there were usually no more than 10 articles worth quoting. These numbers are low in relation to the many types of biota that might be measured and many thousands of river types that might behave differently. The natural environment is complex. Even where there is some information, caution should be exercised in translating from one environment to another. For example, it would not be advisable to place soft-engineering structures in a high energy river as they would probably be washed out. Likewise, new gravel substrate placed in a lowland river with a very fine silt issue may be an unsustainable solution. An ecological benefit at one site might be a negative impact at another.

Digests are considered to useful in providing summaries, being based on critical evaluation of scientific studies and highlighting important messages. None have been produced to date for the measures/techniques described in this report.

Formal or systematic literature reviews use explicit and transparent quality criteria and standards for searching and appraisal. They seek to provide generalisations and account for the variability of similar studies and typically involve meta-analysis. Most authors recognise that formal or systematic reviews require time to develop. Systematic reviews can only look retrospectively and cannot per se develop new tools of the type required. They also tend to look at smaller-scale issues since these are most amenable to meta-analysis. To date, only three reviews of this type have been produced in this subject area.

These factors are combined to assess the overall quality of the evidence base for each measure/technique. The range spans non-existent, very poor, poor, moderate, good and very good to excellent. The highest evaluation achieved here is poor to moderate (for one technique). This is not untypical for environmental sciences, with little or no evidence to support a particular measure/technique in a specific geographic environment. This contrasts with medicine and other scientific disciplines where more rigorous evidence is collected (for example, before testing a new medicine on patients).

The types of pressures covered by this review are listed in Table 2.2 below, which also illustrates how these relate to the hydromorphological quality elements.

Table 2.2 Pressures covered for FRM/LD.

Pressure	Examples of relationship of pressures to UKTAG WFD hydromorphology quality elements
Rivers: Bed and bank reinforcement and in-channel structures	Potentially impacts on flow; connection to groundwater bodies; depth/width variations of channel; quantity, structure and substrate of bed; and structure of the riparian zone.
Rivers: Channel alteration	Potentially impacts on flow; depth/width variations of channel; quantity, structure and substrate of bed; and structure of the riparian zone.
Rivers: Floodplain modification	Potentially impacts on hydrology/flow; connection to groundwater bodies and structure of the riparian zone.
Rivers: Operations and maintenance	Potentially impacts on flow; depth/width variations of channel; quantity, structure and substrate of bed; and structure of the riparian zone.

Pressure	Examples of relationship of pressures to UKTAG WFD hydromorphology quality elements
Lakes: Bank and bed reinforcement and realignment	Potentially impacts on flow; connection to groundwater bodies; and structure of the riparian zone.
Lakes: Impounding	Potentially impacts on hydrology; connection to groundwater bodies; quantity, structure and substrate of bed; and structure of the riparian zone. Also affects residence time.
Lakes: Shoreline modification	Potentially impacts on connection to groundwater bodies and structure of the riparian zone.
Lakes: Operations and maintenance	Potentially impacts on quantity, structure and substrate of bed and structure of the riparian zone.
Transitional and coastal waters: Bank reinforcement	Potentially impacts on wave exposure; depth and width variations; quantity, structure and substrate of bed and structure of shore/intertidal zone.
Transitional and coastal waters: Channel dredging	Potentially impacts on flow; connection to groundwater bodies; quantity, structure and substrate of bed; and structure of the inter-tidal zone.
Transitional and coastal waters: Deposition of material	Potentially impacts on direction of dominant currents; quantity, structure and substrate of bed; and structure of the inter-tidal or shore zones. Potential impact on wave exposure.
Transitional and coastal waters: Tidal river alteration (e.g. channelization/realignment/ straightening)	Potentially impacts on flow/direction of dominant currents and wave exposure. Also, changes to the quantity, structure and substrate of bed; and structure of the inter-tidal zone.
Transitional and coastal waters: Impounding	Potentially impacts on hydrology/flow; connection to groundwater bodies; quantity, structure and substrate of bed; and structure of the inter-tidal zone.
Transitional and coastal waters: Manipulation of sediment transport	Potentially impacts on wave exposure; quantity, structure and substrate of bed; and structure of the shore zone.

2.2 Consultation

For this interim reporting stage of the project a number of experts in the UK, Europe and the USA were consulted. The purpose of this consultation was to fill in any information gaps that couldn't be filled by the literature search. Expert views and judgements should be treated in the same way as grey literature, by understanding their value in terms of observational evidence.

A questionnaire formed the basis of the consultation (see Appendix A). It was designed in two parts; the first included general approaches to FRM and LD activities, and understanding how the WFD might influence these activities. The second part collated detailed information in a case study format including: basic information; site descriptions; objectives and options; design and construction; and project appraisals.

The structure of these was roughly guided by a questionnaire by the National Rivers Authority, *Bank Erosion on Navigable Waterways* (1991), and the structure and content of case studies was informed by the River Restoration Centre (RRC) website project database 'data entry' form, and an unpublished Environment Agency report, *Investigating the use and long-term implications of 'soft' riverbank protection (30 Case Studies from the Thames Region)* (Environment Agency, 2003). This NRA questionnaire was a useful vehicle to elicit information on river engineering schemes. The draft questionnaire for the Digital Good Practice Manual was circulated to the Project Steering Group for comment prior to being finalised.

In practice the questionnaire was used as more of a prompt during the interviews. Interviews were face-to-face, by telephone, or in some cases (Europe and USA) by email. Those interviewed comprised those listed in Tables 2.3 and 2.4.

Table 2.3 UK Contacts.

Rivers	
Mark Diamond	Environment Agency
Alan Werritty	University of Dundee
Teg Jones	Environment Agency Wales
Jackie Banks	Environment Agency
Alvin Barber	City of Edinburgh Council
David Withrington	Natural England
Malcolm Newson	University of Newcastle
Roy Richardson	SEPA
David Sear	University of Southampton
Lakes	
Geoff Phillips	Environment Agency
John Rowan	University of Dundee
Transitional and Coastal (TraC) Waters	
Chris Vivian	CEFAS
Alan Brampton	HR Wallingford
Jan Brooke	Independent Consultant

Table 2.4 Contacts from Europe and other countries.

Name	Organisation
Walter Binder	Bavaria
Armin Peter	Swiss Federal Institute of Aquatic Science and Technology
Nikolai Friberg	Macaulay Land Use Research Institute (representing Denmark)
Mogens Bjorn Nielsen	Arhus Amtskommune (representing Denmark)
Henry Tolkamp	Waterschap Roer and Overmaas Regional Water Authority (WRO), Netherlands
Doug Shields	United States Department of Agriculture

Some consultees now advise on policy and strategy rather than carrying out river management projects. Valuable comments were gained in the consultation, but it was felt that more information could be gleaned in future project phases from current practitioners. A number of discussions were therefore held with practitioners from the Environment Agency and the River Restoration Centre and case studies including views on what constitutes success in the restoration field were sought.

During Phase 1 (up until December 2007) Jacobs staff attended the following events (Table 2.5) to collect information useful to the project.

Table 2.5 Additional meetings attended by Jacobs.

Event	Who attended from consultant team	Key information gleaned
La gestion physique des cours d'eau Bilan d'une decennie d'ingenierie ecologique (River Restoration Workshop in Belgium in October 2007)	Kevin Skinner	Practice in other European countries (including Belgium and the Netherlands).
AGM of the River Restoration Centre (in Northern Ireland) in Spring 2007	Andrew Brookes	Information about projects; also future contacts in NI Government and NGOs.
Annual Meeting of RRC	Kevin Skinner; Andrew Brookes and Suzie Hewitt	Information on latest WFD practice throughout UK.
Monitoring Workshop (convened by RRC)	Kevin Skinner	Latest developments for a monitoring protocol for the UK on river restoration in particular.
AGM of River Habitat Survey Group in December 2007	Andrew Brookes	Learned more of evidence-based review work and university-led studies on eco-hydromorphology (in particular a review by Professor Steve Ormerod).
CROCUS Seminar in November 2007	Andrew Brookes	Delivered a paper on 20 years of urban river restoration experience, emphasising lack of monitoring. Audience concluded that a way forward must be exchange of information.

Expert knowledge from practitioners and operational staff will need to continue to be captured throughout the next phases of the project. This source of information is also likely to be important for future updates of the Digital Good Practice Manual.

3 Context for the review of techniques

Key findings from consultees in the UK are reported in this section (first) before a broader assessment is made of initiatives in other European countries.

3.1 Findings from the consultation (UK specific)

3.1.1 Rivers

Consultees were selected to cover different aspects of FRM (and LD) with representatives from academic, policy and technical fields. Many good practice measures/techniques in sediment and vegetation management (both of marginal aquatic habitat and riparian corridor) are currently in place within statutory authorities such as the Environment Agency and the Scottish Environmental Protection Agency (SEPA). Guidance is available or currently being developed to allow for modifications. A large number of projects in the last two decades in the UK have been subject to formal processes such as environmental impact assessment or other good practice guidance. Compared to older "legacy" projects pre-dating more recent environmental protection legislation, newer and proposed modifications are more likely to be compliant with the requirements of the WFD. For example, both SEPA and the Environment Agency have policy statements on gravel management within river systems. Knowledge of the WFD is generally more limited amongst staff who carry out technical work even though the mitigation measures recommended in this document already constitute good practice in many procedures. Many interviewees thought that hydromorphology was still not actively embedded in FRM to the degree necessary for the WFD. FRM schemes frequently do not have advice from geomorphologists and whilst there are now geomorphologists within several consultancies in the UK, few are employed within regulatory agencies (particularly in England, Wales and Northern Ireland).

A number of FRM schemes now use set-back embankments to increase floodplain connectivity and enhance ecology. Defra's *Making Space for Water* initiative has been a key driver, though the benefits of this dual approach have yet to be adequately monitored. There has also been a push (particularly in central Europe) to explore the effect of replanting woodland in slowing down flood peaks. As yet, although this measure is now being tried in various locations, it has not yet been well documented. Many small impoundments, such as weirs, provide little FRM benefit and have been largely undertaken for other reasons, such as abstraction or navigation. However as with all mitigation measures it was felt that each site should be considered on its own merits. Modifying or removing weirs (for example) might be beneficial in the longer term in re-establishing continuity but there could be significant adverse short-term effects as stored sediment is released, as well as greater potential for erosion and undermining of structures. Similarly, allowing floodplain inundation on a more frequent basis could lead to undesirable distribution of brown (possibly contaminated) sediments on agricultural or ecologically-sensitive land. It is important to consider the pros and cons of mitigation measures/techniques and to come up with a balanced view which inevitably will be site-specific. The Digital Good Practice Manual thus cannot be made prescriptive.

The UK has regional differences in its implementation of the WFD. Policies in Scotland, such as the Controlled Activities Regulations and associated guidance are now having an impact on previous practice such as extensive gravel extraction from rivers and vegetation maintenance. Scotland also has an initiative on sustainable flood management (SFM), which has undertaken preparatory work for a Floods Bill to develop a modern sustainable approach to flood management. Such initiatives are starting to have a beneficial effect on habitat. The new arrangements in Scotland (with SEPA solely a regulator and not a developer) are an interesting model driving change. The Environment Agency is currently reviewing its own policies. One interviewee pointed out the potential for conflicts between the WFD and Floods Directive. However there is considerable effort through the Common Implementation Strategy to ensure (through a Floods Working Group) adequate integration. A core element of the new directive is to ensure ecological improvements under the WFD are not compromised by flood management measures implemented through the Floods Directive.

The majority of consultees felt that the lack of monitoring of such measures has been (and may continue to be) a hindrance. Baseline survey is often missing. Many felt that expert judgement would continue to play a key role in river management. Many successful projects have relied on proper options appraisal, design, implementation and adaptive management (combined with some form of monitoring if required). Lack of knowledge transfer of good practices was raised as a further issue.

3.1.2 Lakes

Few scientific papers cover the hydromorphological impact of FRM activities on lakes in the UK. More robust data may perhaps be found in the international community. Progress has been made in the UK (by SNIFFER) on developing a method for lake habitat survey (WFD42), environmental standards (WFD48) and a tool for assessing and managing alterations to lake morphology (WFD49f).

Outlet control structures and embankments are the main pressures (a particular concern for SEPA), but these have often been set up as a water resource function as well as for FRM. Llyn Tegid (Lake Bala) in the headwaters of the River Dee catchment has been modified with outlet sluices and embankments. At least one loch in Scotland has been considered for modification for flood storage. Perhaps the biggest morphological issue on lakes is the increased delivery of fine sediment from the upstream catchment.

One consultee highlighted the Broadlands Flood Alleviation Project website that describes activities and measures proposed and implemented on rivers and lakes in the region. Mitigation measures include replacing old bank protection with more environmentally acceptable protection and setting back embankments (it was presumed that lakes in the Norfolk Broads are heavily modified water bodies (HMWB) rather than artificial water bodies or AWB).

3.1.3 Transitional and coastal waters

Representatives with extensive experience in FRM and coastal protection were selected for consultation on transitional and coastal (TraC) waters. Good practice measures are in place for many activities relating to ports, navigation and construction within TraC waters.

Flood risk management and coastal protection activities in TraC waters now commonly include geomorphological input and advice. However, as with rivers few are employed within regulatory agencies and the majority of geomorphological input to proposed FRM/coastal protection schemes is currently provided by external consultants.

3.1.4 General findings

Consultation confirmed the following points.

The provisional list of FRM mitigation measures drawn up for rivers, lakes, coasts and estuaries is suitable and no techniques have been overlooked.

Few scientific papers provide robust data proving that mitigation (restoration) measures are ecologically effective. Few papers explore the hydromorphological impact of coastal FRM activities/measures from a UK perspective and none relate to lakes.

Measures/techniques are rarely used in isolation. As a result, it is difficult to attribute the overall success of a scheme to any one technique. In addition, stochastic variables, such as discharge or sediment loading, are highly variable making it difficult to compare different types of projects.

The consensus across sectors is that, due to the lack of scientific data, expert judgment is an essential alternative. However, one consultee pointed out that given the lack of scientific evidence and monitoring and poor recording of experiences, we should consider what this expert judgment is based on. It is also important for those offering ‘expert’ views to be aware of the scientific limitations of information that they may have at their disposal.

The majority of consultees agreed that monitoring should be integral to the project prior to, during and post-construction but it is rarely adequately funded at present. It is important to set project objectives and to have a clear idea of what represents a successful implementation of a measure or scheme.

Case studies documenting monitoring procedures and results provide some indication of how water ecology and hydromorphology have changed; however, it is difficult to evaluate the significance of such changes at the water body scale.

The need for a Digital Good Practice Manual was reinforced by consultation; however, at least one consultee suggested that to be effective this guidance would need to be regularly updated.

3.2 European context

A review of EU work was carried out with an extensive literature search (including use of the Google Scholar search engine based on keywords) and feedback received from the European experts contacted. For this report, the review covered key legislative and institutional frameworks, licensing procedures, lessons learnt from restoration, mitigation and management strategies, and collated information on national case studies. This review also explored authorisation procedures and the information and documentation typically required to support applications. A number of European initiatives will evolve in the course of this study, some salient points of which are summarised here.

3.2.1 European flood risk management and land drainage

A review of losses caused by flood events in the last ten to fifteen years indicates that in Europe economic losses are dramatically increasing, mainly because there has been a marked increase in the number of people and assets located in flood hazard zones. Extreme floods occurred on the Danube and Elbe and other major European river systems in 2002, in Romania, Bulgaria, Switzerland, Austria, Germany, Finland, Poland, Hungary, Czech Republic and Slovakia in 2005 and in Spain, Portugal, Greece, Romania and Bulgaria in 2006 (European Environment Agency, October 2007). It is likely that annual flood damage will increase (see Europa FD Website). Traditionally flood walls and embankments have been built in an attempt to control floods across Europe with consequent adverse ecological and social impacts. Flood risk mitigation can also be achieved by reducing vulnerability and/or hazard so as to reduce the total flood impact.

In terms of LD activities, perhaps nowhere is this more extensive than in Denmark where rivers have lost their natural physical properties due to deepening and dredging of watercourses "*which is among the most important causes of why two-thirds of all rivers do not fulfil …quality objectives*" (European Environment Agency, 1997). Whilst stable agricultural production has been achieved, the physical variability and hydraulic properties of the rivers have been severely reduced, affecting the macroinvertebrate and fish communities and strongly reducing habitat diversity.

3.2.2 EU Floods Directive

Recent devastating floods in several parts of Europe have prompted the European Directive on the Assessment and Management of Flood Risks (2007/60/EC of 23 October 2007), known simply as the Floods Directive. This is intended to help Member States prevent and limit floods and their damaging effects on human health, the environment, infrastructure and property. Development of the Digital Good Practice Manual should be informed by parallel initiatives such as this.

3.2.3 European research initiatives and example projects

Considerable research effort is being devoted to identifying alternative measures. Some examples of research frameworks are shown in Table 3.1 and projects in Table 3.2. These research initiatives and projects should be explored and fully integrated into the Digital Good Practice Manual as they come to fruition and develop further.

Table 3.1 Key European Research Frameworks.

Initiative	Description	Website
Flood Risk Management Research Consortium (FRMRC)	Within the context of future flooding in the UK the FRMRC aims to establish a programme of research, develop tools and techniques to improve FRM and run training initiatives.	www.floodrisk.org.uk
FLOODsite.	The FLOODsite consortium includes some 40 of Europe's leading institutes and the project involves managers and researchers from government, commercial and research bodies specialising in aspects of FRM.	www.floodsite.net

	FLOODsite covers the physical, environmental, ecological and socio-economic aspects of floods from rivers, estuaries and the sea. It considers flood risk as a combination of hazard sources, pathways and the consequences of flooding on people, property and the environment. Seven pilot study sites have been established within FLOODsite, including river, estuary and coastal locations with some river locations subject to flash floods. These are in Belgium, the Czech Republic, France, Germany, Hungary, Italy, the Netherlands, Spain, and the UK. These pilot sites offer a means of testing tools and research methods in real situations and also feeding back detailed operational requirements, issues and problems that require attention. FLOODsite is an integrated project in the Global Change and Ecosystems priority of the Sixth Framework Programme of the European Commission. It runs from 2004 to 2009.	
ERA-Net (CRUE)	CRUISE (CRUe Information System Europe) is a powerful new information resource that gives users instant access to the results of flooding research programmes worth more than €430 million. This is the first time that European countries have been able to exchange research experience on FRM. It provides a web-based starting point for users interested in finding out more about European flood-related research, both at the research programme level and individual project level. CRUISE is intended to benefit a broad range of users, including policy-makers, practitioners, research funders, and the research community.	http://www.crue-eranet.net/cruise.asp
PWM	PWM (International Water Management Portal) is an information tool for water management powered by the Universities of Nijmegen and Duisburg Essen. Includes information on flooding including on the River Rhine Dutch-German border.	http://www.portalwatermanagement.net/
Eurosion	Eurosion is a European initiative for sustainable coastal erosion management. Surveys have been undertaken of over 100,000 km of Europe's coastline. Results released in 2004 included: A cartographic assessment of European coasts' exposure to coastal erosion, based on spatial data and GIS analysis. A review of existing practices and experiences of coastal erosion management in local and	www.eurosion.org

	regional authorities. Guidelines to better incorporate coastal erosion issues into environmental assessment procedures, spatial planning and coastal hazard prevention, and into regional and local information decision-support systems. Policy recommendations to improve coastal erosion management in the future at the European, national, regional and local level.	

Table 3.2 Example projects.

Project	**Details**	**Reference**
Integrated River Engineering Project on the Danube in East Vienna	Concerned with sustainable conservation of the floodplain landscape in the Danube Floodplain National Park. Whilst taking into account the needs of water management and navigation, this project involves the removal of up to 30 kilometres of bank protection (stone armouring), allowing the river to re-naturalise. Allows shallow water zones to form; also allows side arms and backwaters to be reconnected to the main Danube (important as fish nurseries). Allowing gravel shoals to form at the margins and naturalised banks is important for nesting birds.	www.donau.bmvit.gv.at
Towards Natural Flood Reduction Strategies (EcoFlood)	The long-term aim of EcoFlood is to stimulate creation of floodplains that protect from floods and provide opportunities for restoration and development of highly valuable ecosystems. This requires an integrated vision. However, there is a knowledge gap.	http://levis.sggw.waw.pl/ecoflood/
Restoring river/floodplain interconnection on the Danube in Bavaria Germany	A project which started in October 2006 and aimed to be finished in spring 2009 when the first flow will occur through riparian forest. The Aueninstitut (Floodplain Institute) was founded in January 2006 to document the hydrological, morphological and biological changes in the project area.	http://www.auenzentrum-neuburg.de/Auenzentrum/index.php?id=5 (personal communication Walter Binder)
The Scheldt Pilot (Estuary)	This is located near the southwestern border of the Netherlands and Belgium and covers the tidally influenced part of the Scheldt River. The Dutch part of the river is called 'Westerschelde' and is a typical estuary with multiple river branches and inter-tidal mud flats. In Belgium the tide is felt many kilometres upstream as far as the village of Rupelmonde. This part of the river is called the Zeeschelde. This pilot site is a classic example of flood management for an	www.floodsite.net

	estuary along which many people live and work, with a valuable natural environment and navigation pressures. Both Dutch and Belgian governments have been working to improve understanding of risk (real and perceived) through a number of studies. The study involves new or improved evacuation measures which will help to reduce risks to people and property in the area of the estuary. The study involves regional management authorities, such as Rijkswaterstaat and the water board. In addition to these groups, local inhabitants along the Scheldt have been interviewed and have participated in workshops.	
Efficiency of non-structural flood mitigation measures: “room for the river” and “retaining water in the landscape”	This is part of a programme entitled First CRUE Funding Initiative on FRM research. The aim of this project is to examine the relative efficiency of non-structural flood mitigation measures. To do this, new scientific frameworks and technical tools integrating multidisciplinary approaches (meteorological, hydrological, hydraulics and socio-economical) on flood risk assessment will be used and tested in three different but complementary case study areas. Three study catchments will be selected, the semiarid Rambla del Poyo in Spain (380 km²), the humid/midland Kamp in Austria (1,500 km²), and the alpine/pre-alpine Iller in Germany-Austria (950 km²). The floods in these catchments cover a wide spectrum of processes to be expected in the European research area.	http://www.iiama.upv.es/roomfortheriver/home.html

3.2.4 Overview of river restoration experience in Europe

Whilst these projects will enhance our knowledge of mitigation measures for rivers, lakes, estuaries and coasts, a number of organisations in Europe are disseminating good practice on river restoration (Table 3.3). The term “restoration” is used in its broadest form throughout this report (see Brookes and Shields, 1996), but its purest definition is taken to be the return of an ecosystem to a close approximation of its original condition prior to disturbance. According to a definition by Berger (1990) in restoration, ecological damage is repaired and both the structure and functions of the ecosystem are recreated. Simply recreating the form without the biological functions, or creating an artificial system does not fall within this definition. This definition also fits well with the EU Water Framework Directive goals of maintaining on improving ‘good ecological status’ or ‘good ecological potential’.

Restoration in its purest sense has not been practised in the UK (or indeed elsewhere). What has actually been practised is rehabilitation or ‘partial restoration’, a logical and pragmatic approach based on the realisation that not all physical, biological and chemical components can be created at the same time or on the same project. All that can be monitored at present is partial restoration or rehabilitation. Perhaps a more workable definition for restoration is “*the return of a degraded ecosystem to a close approximation of its remaining natural potential* “(US Environmental Protection Agency USEPA). However, this definition assumes that causes of impairment have been correctly diagnosed and that ecological recovery will follow such a return.

The terms "creation" or "enhancement" (see definition in Brookes and Shields, 1996) have also been widely used (and, for example, are documented in the RRC Inventory). These terms imply putting a landscape to a new or altered use to serve a particular human purpose (creation or reclamation) (National Research Council (NRC) 1992) and are not primarily about improving ecological function. Some of these projects may have equally valid social drivers such as aesthetic improvement. Whilst it is not suggested that creation or enhancement projects should per se be the subject of monitoring for the WFD, all types of project will have some value in building guiding principles to advance knowledge of ecological outcomes under the WFD.

Even partial restoration and rehabilitation is highly complex and difficult to achieve. Projects are replete with uncertainty (see Darby and Sear, 2008) over multiple time-varying processes and responses. Restoring a river is far more complex to understand than previous impacts caused by the original use (such as a flood or arterial drainage channel).

Table 3.3 European organisations concerned with good practice on river restoration.

Organisation	Details	Web address
European Centre for River Restoration (ECRR)	One of key aims is to boost exchange of information on restoration of rivers and riparian areas and thereby advocate river restoration in as many European countries as possible.	www.ECRR.org
Danish Centre for River Restoration (DCVR)	Acts a network within Denmark (under umbrella of ECRR). Members of this network include those responsible for carrying out measures on rivers such as the Danish county authorities (Amtskommune) and local authorities (Kommune). The National European Research Institute (NERI) currently leads the Danish Centre, holding a database of Danish river restoration projects. Over 1,000 projects were carried out in Danish counties up to and including 1998.	www2.dmu.dk
River Restoration Centre (RRC)	RRC became the successor body to the River Restoration Project on 1st April 1998. It is a non-profit making organisation. The centre provides a focal point for exchange of information and expertise relating to river restoration and enhancement in the UK. Its primary role is to disseminate information on river restoration and enhancement projects and to provide advice on site-specific technical issues through a network of experienced river restoration practitioners.	http://www.therrc.co.uk/
Italian Centre for River Restoration (CIRF)	National coverage; established in 1999. Similar to UK centre in that it is non-political, and non-profit. Membership exceeds 100 from river management and engineering in private and public	http://www.cirf.org/

	organisations. Objectives include promotion of the restoration of river and floodplain processes and raising professional awareness of the need for sensitive river maintenance (rural and urban). Database of Italian projects currently being compiled. EU policy is implemented at regional government level; drainage authorities (Consorzi di Bonifica) are semi-autonomous within elected councils. CIRF recognises a range of actions: physical modification of rivers; new legislation and intervention of the public. CIRF feels that due to lack of information dissemination and resistance to new approaches is an obstacle to progress.	
The Netherlands Centre for River Studies (NCR)	Although NCR is different to ECRR (having wider objectives) there are many similarities: both organisations focus on transboundary river systems, integrated river management and river basin approaches. NCR is a cooperation of the major developers and users of expertise in the Netherlands in the area of rivers, with a view to: • achieving river expertise of sufficient breadth and depth in the Netherlands to meet societal requirements, both nationally and internationally; • establishing and reinforcing the position of Dutch scientific research into rivers, for instance for fundraising for such research, nationally and internationally; • strengthening partners' positions • enhancing education and scientific research at Dutch universities. NCR now functions as the Dutch river restoration network.	www.ncr-web.org

According to the ECRR website, other centres exist in Norway, Finland, Spain, Belgium and Romania.

An analysis was undertaken of publications and project databases on the European River Restoration Centre Website (www.ecrr.org) now based in Italy. This gave a snapshot (as at 28 December 2007) of where effort on restoration and enhancement (including rivers and transitional waters) has been focused. The criteria for selection of projects and publications by ECRR are not given on the website. However, it is understood that the database is biased towards Danish publications as the ECRR was formerly based there. Publications on the database date back to the early 1980s. There is a dearth of publications in other European languages, although it understood that an overhaul of the database will in due course make it more representative of Europe as whole. Currently, there is only limited funding to progress a European database. Also the extent to which it could cover all "good practice" articles published in other languages is unclear (the EEA published its 2007 State of the Environment Report in a total of 26 European languages).

From the current (limited) ECRR database, the majority of effort to date in Europe appears to have been expended in three countries, namely Denmark, the Netherlands and the UK (Table 3.4). Several scientific papers from Denmark and the UK are based on the three EU-LIFE funded river restoration projects (in the early 1990s).

Table 3.4 Papers held on ECRR Database (at 28 December 2007).

Country	Number of papers in refereed international scientific journals	Number of publications in books and reports
Europe (in general)	7	32
Denmark	9	22
Netherlands	5	5
United Kingdom	3	3
Austria	1	2
Germany	1	2
Finland	1	0
Italy	1	0
Switzerland	0	1
Russia	0	1

Table 3.5 lists the projects by country. Projects range from individual efforts on reaches of single water bodies to national research projects affecting many water bodies. Effort expended to date would appear from this information to be highest for Germany, Austria, the UK and Denmark. Projects listed in Germany and Austria include re-naturalisation of rivers and wetlands (including floodplain forests).

Table 3.5 ECRR projects database (at 28 December 2007).

Country	Number of projects
Europe (in general)	1
Germany	11
Austria	10
United Kingdom	8
Denmark	4
Netherlands	2
Spain	2
France	2
Latvia	2
Bosnia-Herzegovia	1
Italy	1
Finland	1
Romania	1
Hungary	1
Sweden	1

Table 3.6 shows some of the adjustments that have to be made in tackling FRM and LD activities in three European Countries. The literature reviews and questionnaires

indicate that some countries are more advanced in their thinking and practice than others. These countries have also developed good practice guidance on how to undertake such activities.

Table 3.6 Changes within Netherlands, Denmark and Germany.

Country	Organisations/Responsibilities	Changes
Netherlands	Has 27 water boards (Waterschappen) each of which is responsible for one or more polders or watersheds and covers: management and maintenance of water barriers (dunes, dikes, levees, quays); management of maintenance of waterways; maintenance of water levels in polders and waterways.	Each water board has a taxing authority – central government only contributes to cost of constructing and maintaining water barriers and main waterways; other activities funded locally on the 'polluter pays' principle. Run by a general administrative body (environmental organisations may be given the power to appoint members). Local taxes are a powerful mechanism for delivering benefits (considerable funds available in some water board areas for improving water bodies (Henry Tolkamp, personal communication).
Denmark	Danish EPA (Ministry of Environment) provides overall guidance. Has 13 regional authorities or county councils (Amtskommune) (under which there are 271 local authorities or Kommune) responsible overall for FRM and regulation of LD activities. Responsibilities for maintaining their rivers (whilst preserving the natural environment, flow and water quality).	Thirteen new administrative units proposed for integrated river basin planning and management. There should be cross-boundary cooperation between regional authorities who will maintain their river management functions. Also two rivers will be considered jointly with Germany (cross-border).
Germany	The Federal State (Bund) is responsible for legal frameworks and general WFD guidance. Sixteen German States (Lander) transform the federal guidelines into regional policies (through regional districts or Bezirksregierungen). Each State Department of Environment is key to regulation. Dike building and maintenance are the responsibility of public-private partnerships (Deichverbande).	Under a National Flood Act the states are prioritising polders, new or upgraded dikes and dams. Public money is being spent on traditional flood protection measures (such as on the River Elbe) but increasingly the floodplains are being used.

In this report, no information was uncovered on FRM and LD guidance driven by the WFD, either at pan-European or individual country levels. It was assumed for the purposes of this report that most EU countries are at a similar stage of development on

WFD and hydromorphology. For example, an EU seminar was held in Prague in October 2005 on the subject, and the workshops at this event produced some common understanding and recommendations on the way forward.

3.3 Future consultations

In terms of further disseminating awareness of and collecting feedback on this project, one option is to write an article in the River Restoration Centre newsletter or give a short presentation at the annual RRC conference. Other mechanisms of dissemination include a Chartered Institution of Water and Environmental Management CIWEM Rivers and Coastal mailshot and/or a leaflet distributed at the Winter Meeting of Rivers and Coastal (in February) or at the AGM in May. At the second Steering Group meeting in January 2008, it was agreed that a workshop should be held at the ECRR four-yearly conference in Venice in spring 2008.

Useful information could also be gained from consulting other bodies currently undertaking monitoring. This could, for example, include discussions with Avon LIFE project managers and contractors and further discussion with the University of Southampton which has been involved in long-term monitoring of the River Cole. At this stage of the project, preliminary discussions about the Cole have been held with Professor David Sear (at Southampton University). One area requiring development is better integration of geomorphological monitoring results with ecological ones (currently held in archive at the Pond Conservation Trust).

Further river restoration experts in the United States and Australia could also be contacted for information, although there could be transferability issues.

3.3.1 General findings from the European review

A preliminary review of the European literature was undertaken using searchable English-speaking summaries. This uncovered many European research initiatives and projects which will prove fruitful during River Basin Planning 1, 2 and 3 in providing evidence of the success (or otherwise) of measures. A review of river restoration experience in Europe was also undertaken, with the opportunity for further review as part of the ongoing development of the Digital Good Practice Manual. Overall, this review shows that whilst there is a diversity of useful knowledge, most European countries would appear “to be in the same boat” when it comes to recommending suitable measures/techniques for river, lake, estuarine and coastal environments. The same issues emerge such as lack of funding for monitoring. Experiences rely on expert judgement and inevitably the success of projects is determined by site-specific knowledge and (typically) the assemblage of a mixed team of experts.

4 Development of checklists

4.1 Proforma

Checklists of measures/techniques developed for the Digital Good Practice Manual are presented in this report (see Appendix B). They were also used to populate a proforma used for UKTAG trialling for FRM (see Jacobs, 2008 and Figure 1.1 of this report). The rivers and transitional and coastal (TraC) waters checklists were iterated as a result of the trialling. Trials were not undertaken for lakes per se. At this stage, checklists are still drafts for consultation and subject to iteration. They are based on a simple decision-tree approach (moving left to right) of: pressures; sub-pressures; potential impacts; and mitigation measures/techniques.

In looking at potential impacts, the two elements of hydromorphology (hydrology and morphology) were taken into consideration. Hydrology in this context is concerned with the characteristics of water flow (quantity, dynamics and water levels). Morphology is about the physical form of a water body, that is, the width, depth and structure of the river, lake or sea bed and the structure and condition of bed, banks and shores. Continuity is also a key element and in the context of the checklist was taken, for example, to mean continuity between upstream and downstream (in a river) and lateral continuity (such as between a river channel and its floodplain). Table 4.1 lists those hydrological aspects that should be considered for each water body type, whilst Table 4.2 lists the morphological aspects. Both tables are derived from Annex V of the WFD.

Table 4.1 Hydrological/tidal regime aspects.

Rivers	Lakes	Transitional waters	Coastal waters
Quantity of flow	Quantity of flow	Freshwater flow (and tidal flow)	Direction of dominant currents
Dynamics of flow	Dynamics of flow	Wave exposure	Wave exposure
Connection to groundwater bodies	Connection to groundwater body		
	Residence time		
Continuity			

Table 4.2 Morphological conditions.

Rivers	Lakes	Transitional waters	Coastal waters
Width variation			
Depth variation	Depth variation	Depth variation	Depth variation
Structure and substrate of the river bed	Quantity, structure and substrate of the bed	Quantity, structure and substrate of the bed	Structure and substrate of the coastal bed
Structure of the riparian zone	Structure of the lake shore	Structure of the inter-tidal zone	Structure of the inter-tidal zone

Pressures and sub-pressures were considered to be those potentially having a significant adverse impact on hydromorphology. Relevant activities (for FRM and LD) were considered to be those coming from (a) construction, maintenance or removal of structures in, on or near water bodies; and (b) maintenance and use of water bodies and their banks and shores.

Defra's consultation on mechanisms to meet WFD requirements on hydromorphology (Defra, February 2007) has also proved a useful source for development of the checklists. In particular, one table (originally developed by the Environment Agency) showed the potential impacts of sectors contributing to hydromorphological pressures on the four types of water body. Table 4.3 (below) is derived from this table to illustrate FRM (and LD) alone. Interestingly, FRM (and LD) is not regarded as a key pressure in lakes.

Table 4.3 FRM (and LD) and hydromorphological pressures.

	Rivers	Lakes	Transitional waters	Coastal waters
High contribution	FRM		FRM	FRM
Low contribution				

This table is considered to be typical for the rest of the EU.

The checklists were developed and trialled for FRM purposes and therefore, if they are to form the framework for the Digital Good Practice Manual (as proposed), they need to be extended to include LD (and pumped drainage systems). UKTAG has arranged a separate trial with the Association of Drainage Authorities, although this had not been reported in time to influence this report. Subsequent to the first draft of this report, Jacobs spoke with David Sissons of the Association of Drainage Authorities and added water level management plans (as a specific measure) to the checklists. Land drainage more generally is covered by the 'operations and maintenance' measures for rivers that already included in this report, for example sediment management strategies (5.1.19), maintenance strategies and techniques (5.1.20), vegetation control regime (5.1.22) and land management strategies (5.1.26).

Checklists were developed from existing lists/knowledge in response to a need to rapidly and simply classify previously designated HMWBs in the UK. The mitigation measures/techniques have therefore been "lumped" rather than "split". They are not intended to be prescriptive lists of measures/techniques to be applied at all sites.

Lists of measures developed for these initial checklists also tend to concentrate on physical changes (mitigation). Interestingly, at a seminar held by CIWEM on 9th November 2005 (entitled WFD: Hydromorphology – Challenges and Implications) 128 delegates were asked (amongst other things) what would be the best opportunities to improve the mitigation of hydromorphological impacts? Although this was not sector specific, the main thrust was as follows:

- provision of clear policy and guidance notes;
- regulation;
- economic instruments;
- better integration and communication;
- public and partner awareness;
- information.

The Digital Good Practice Manual aims to provide guidance for public and partner groups (including those who have membership of CIWEM and professional bodies).

4.2 Assessment of effectiveness of measures

In response to a request made in the scoping report (Jacobs 2007) a rapid assessment tool was developed for each mitigation measure as part of Phase 1. This was also informed by the UKTAG trials described in the parallel report (Jacobs, 2008). This tool is a simple checklist, shown as Table 4.4 below. This generic tool is applied (with some caution at this initial stage) in Section 5.0 (Review of Techniques) after each description of a measure/technique is given. Site-specific use will inevitably involve assessing the effectiveness of measures/techniques at the site.

Table 4.4 Proposed screening tool for rapid assessment.

Where has it been applied (geographically)?	
At what scale (reach, individual river, catchment)?	
To what type of environment has it been applied?	
What is the basis for its use?	
Was it successful? What criteria used?	
What were the potential environmental risks/benefits?	
What ecological impacts/improvements?	
Are there any other non-physical impacts?	
What monitoring is in place?	
What are the general learning lessons?	
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals?
	Has a digest of results been produced?
	Does a systematic review of the literature exist?
	Overall, what is the quality of the scientific evidence base?
Indication of order of costs	
Is there an impact to the key use?	

5 Findings: Interim review of techniques

The structure of this interim review of techniques is based on the development work for the checklists described in Section 4.0. The contents come from the literature reviews and interviews described earlier. Each mitigation measure/technique is assigned a number for ease of reference. These measures are discussed in the order that was finally agreed after the GEP/MEP trialling (see Jacobs 2008). Where the measure is considered for the first time, a provisional screening 'checklist' as set out in Table 4.4 is placed at the end of the review. Table 5.1 (below) provides a summary of the measures reviewed. These are all techniques that have been used at one or more locations around the world. Each measure/technique may apply to more than one pressure or sub-pressure. Some measures apply generically across all environments (rivers, lakes, transitional waters and coasts). Several rivers mitigation measures/techniques apply to FRM and land drainage activities.

Table 5.1 Summary of measures/techniques covered.

Reference Number Rivers	Reference Number Lakes	Reference Number TRAC	Measure/technique
1, 4	1, 6		Removal of existing hard bank reinforcement/ revetment or replacement with soft engineering scheme
2, 5	2		Protect and enhance ecological value of marginal aquatic habitat, banks and riparian zone
3, 6			Protect and restore aquatic habitats (through river restoration)
7			Operational and structural changes to dams, sluice and weirs
8	5	16	Install fish passes
9	6	14, 18	Removal of structure
10			Retain marginal aquatic and riparian habitats
11		12	Increase in-channel morphological diversity e.g. install in-stream features; two-stage channels and geometric variation
12, 14			Re-opening existing culverts
13, 15			Alteration of channel bed
16			Flood bunds
17	8		Set-back embankments
18, 19			Improve floodplain connectivity
20			Enhance aquatic and riparian habitats
21	9		Sediment management strategies
22			Channel maintenance strategies and techniques (minimise disturbance to channel bed and margins)
23			Channel maintenance strategies and techniques (remove wood only when in vicinity of urban area)
24			Vegetation control regime
25			Techniques to prevent transfer of invasive

Reference Number Rivers	Reference Number Lakes	Reference Number TRAC	Measure/technique
			species
26			Techniques to align and attenuate flow to limit detrimental effects of these features
27			Water level management
28	11		Land management strategies (develop and revise)
3, 10, 11	3		Amend design (re-naturalise) bed and banks
	4		Operational and structural changes to control structures
16	7		Remove flood banks/walls
	10		Release strategy (e.g. phased de-watering, small frequent release cycles)
		1	Removal of hard engineering (e.g. naturalisation)
		2	Modify existing structures
		3	Replacement with soft engineering solution
		4	Bank reprofiling
		5	Managed realignment of flood defence
		6, 11, 20	Restore/create/enhance aquatic and marginal habitats
		7, 9, 13, 17, 21	Indirect/ offsite mitigation (offsetting measures)
		8	Sediment management strategies (develop and/or revise)
		10	Material emplacement strategies (develop and/or revise)
		15	Operational and structural changes to locks, sluices and tidal barrages
		19	Modify structure design

5.1 Rivers

5.1.1 Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution

Pressure: Bank and bed reinforcement and in-channel structures	
Sub-pressure: Hard protection e.g. steel piling, vertical walls and gabion baskets. Includes hard bank protection in a state of disrepair.	Impact: Loss of riparian zone/marginal habitat/loss of lateral connectivity/loss of sediment input
Number:1	Mitigation measure: Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution,

The removal of hard bank reinforcement/revetment (for example where it is in a state of disrepair) and replacement with soft engineering solution, whilst possible, has historically not been carried out because of cost, practicality and wider impacts. In urban areas this could include lined channels. Such measures are not favoured in high-energy river systems such as in Edinburgh, Scotland (Alvin Barber, personal communication) and replacement with soft engineering may not be appropriate. Soft bank protection has been used in high-energy environments elsewhere, such as in Halltree on the Gala Water in the Scottish Borders.

Other mitigation measures/techniques are usually considered to be more viable options. The success of softer engineering solutions *per se* has been well documented over the last 50 years (Olschowy, 1957; Seibert, 1968; Miers, 1979; Binder *et al.*, 1983; Coppin and Richards, 1990; Hemphill and Bramley, 1989; Hey *et al.*, 1991; Gray and Sotir, 1996). A wide variety of good practice guides have evolved as a result, often as a consequence of wider restoration practice (Hey *et al.*, 1991; Environment Agency, 1999; Federal Interagency Stream Restoration Working Group (FISRWG) 1998; Hoag and Fripp, 2002; Schaff *et al.*, 2002: River Restoration Centre, 1999; SEPA, 2008). The use of living vegetation rather than artificial materials for bank protection has been practised for decades in the UK, Germany and Austria. Binder *et al.* (1983), for example, have shown that it is important to establish for each stream (and even for each part of a stream) a method that is both hydraulically and biologically correct. Bonham (1980) undertook experimental work on the River Thames at Wallingford in Oxfordshire to demonstrate the effectiveness of marginal plants in protecting against bank erosion.

Along with straight replacement of bank protection with softer solutions, trends in the past decade have been to reconstruct the inshore/riparian corridors to increase diversity and to develop a 'greenway' whilst maintaining protection. This has also increased the use of wood. Examples of long-term monitoring of such schemes include work on the River Danube (Chovanec *et al.*, 2000; Chovanec *et al.*, 2002) with the removal of up to 30 kilometres of bank armouring. This scheme was particularly successful in recreating habitat for dragonfly communities, reptiles, amphibians and fish. Bioengineering techniques have also been used to impede bank failure in highly incised systems such as north-west Mississippi, USA (Shields *et al.*, 1995). One of the historic concerns for the use of bioengineering techniques has been the risk of destabilising banks. Studies (Abernethy and Rutherfurd, 2000) on the use of silver wattle have shown that this is unlikely to be the case. Work by Lyons *et al.* (2000) has shown how grassy riparian areas can be important in preventing erosion, as can more wooded areas. More naturalised bank lines have also proved to be more effective at trapping large wood (Angradi *et al.*, 2004).

Table 5.2 Checklist: Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution.

Measure No.1. Removal of existing hard bank reinforcement/revetment, or replacement with soft engineering solution (on a new scheme, this might involve replacing an engineered bank with soft bank protection)	
Where has it been applied (geographically)?	Examples from UK, Europe and USA.
At what scale (reach, individual river, catchment)?	Local and reach scales.
To what type of environment has it been applied?	Predominantly lower energy river systems.
What is the basis for its use?	Widely practised (grey literature exists)
Was it successful? What criteria used?	Studies have adopted criteria such as recreating habitat and colonisation by flora and fauna (e.g. Danube example).
What were the potential environmental risks/ benefits?	Potential risk of destabilising banks through biotechnical engineering solutions (although only limited documented evidence).
What ecological impacts/improvements?	Considerable proven ecological advantages.
Are there any other non-physical impacts?	Increased roughness (e.g. from use of woody bank protection) may need to be taken into account in flood conveyance calculations.
What monitoring is in place?	Limited long-term monitoring (Danube is an exception).
What are the general lessons to be learnt?	If measures/techniques are properly designed, implemented and (if necessary) adaptively managed then more likely to be successful. These can be made applicable to the local characteristics of riverine water body.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Yes, more than 10 papers. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Removal of existing hard protection can be costly; however biotechnical solutions have been shown to be cheaper that conventional hard protection.
Is there an impact to the key use?	Cannot remove bank protection that is acting as an effective flood wall without considering alternative means of flood mitigation such as upstream storage.

5.1.2 Protect and enhance ecological value of marginal aquatic habitat, banks and riparian zone

<table>
<tr><td colspan="3">Pressure: Bank and bed reinforcement and in-channel structures</td></tr>
<tr><td colspan="2">Sub-pressure: Hard protection
e.g. steel piling, vertical walls and gabion baskets. Includes hard bank protection in a state of disrepair.</td><td>Impact: Loss of riparian zone/marginal habitat/ loss of lateral connectivity/loss of sediment input</td></tr>
<tr><td>Number:2</td><td colspan="2">Mitigation measure: Protect and enhance ecological value of marginal aquatic habitat, banks and riparian zone</td></tr>
</table>

The annual growth of aquatic plants has historically been a key issue in maintenance of channel capacity in highly productive rivers such as chalk rivers in Britain and North America (Haslam, 1978). LD activities can be severely impacted by vegetation growth (Westlake, 1968; Westlake and Dawson 1986). Maintaining a marginal aquatic habitat has long been recognised as important and alternative strategies such as partial cutting of vegetation (such as from the centre of a channel) developed (Brookes, 1988; Swales, 1982). Important papers have covered the benefits of altering the marginal habitat, particularly on flood defence projects where steep banks have been commonplace. For example, Clarke and Wharton (2000) show how macrophyte communities and wetland species diversity has been significantly enhanced through the reprofiling of channel banks to create narrow wetland shelves on the River Torne. Equally, Chovanec *et al.* (2002) show the positive effects on amphibians, dragonflies and fish of altering the bank profile on the River Danube to create a shelf feature. Larger scale restoration of riparian forests is more limited but a recent example is restoration work on the Sacramento River in California (Alpert *et al.*, 1999; Borders *et al.*, 2006; Gardali *et al.*, 2006). Initial monitoring results suggest that it is feasible to re-establish native trees and shrubs along regulated river systems (Alpert *et al.*, 1999) and restore the nutrient cycling process (Borders *et al.*, 2006). This can in turn have positive effects on the native fauna, such as land birds (Gardali *et al.*, 2006).

Good practice measures/techniques on the management of marginal vegetation have been developed for a variety of statutory organisations. In Denmark, guidelines were developed for small stream maintenance, targeting pinch points and only recommending a maximum of two-thirds of the width of a stream to be cleared of weeds (Madsen, 1995; Nielsen, 1996). National guidance on marginal habitats (and maintenance regimes in general) has been produced in conjunction with Natural and England and the Countryside Council for Wales (Environment Agency, 2002). The Rivers Agency (NI) have recently updated (2007) its Watercourse Maintenance Manual. As a further example, the Environment Agency (Welsh Region) good practice guidelines (courtesy of Teg Jones, Environment Agency Welsh Region) outline selective and seasonal vegetation management. In Scotland there is a ‘controlled activities’ general binding rule for maintenance of land drainage ditches (GBR5), including rules to protect marginal vegetation.

Table 5.3 Checklist: Marginal aquatic habitat, banks and riparian zone.

Measure No.2. Protect and enhance ecological value of marginal aquatic habitat, banks and riparian zone (on a new scheme, this might involve new planting)	
Where has it been applied (geographically)?	Examples from UK, Europe and USA
At what scale (reach, individual river, catchment)?	Local and reach scales, almost to entire catchment in some chalk rivers (on an annual basis).
To what type of environment has it been applied?	High to low energy river systems (widespread application).
What is the basis for its use?	Widely practised (grey literature exists)
Was it successful? What criteria used?	Studies have shown effectiveness of retaining marginal vegetation.
What were the potential environmental risks/ benefits?	Considerable benefits; no significant environmental risks.
What ecological impacts/improvements?	Considerable proven ecological advantages. Conversely, many scientific studies have shown negative impacts on fish of having insufficient cover/substrate.
Are there any other non-physical impacts?	Some risk is associated with calculating an accurate roughness value such that flow conveyance is not adversely affected by retaining vegetation. Particular types of vegetation cause most concern for flood risk.
What monitoring is in place?	Limited long-term monitoring (Danube is an exception). However, studies have monitored the inverse situation, the adverse impact of removing marginal channel vegetation.
What are the general lessons to be learnt?	Retaining marginal vegetation is a "quick hit" solution to improving the ecology of a reach.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Yes, greater than 10. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Relatively inexpensive solution
Is there an impact to the key use?	Low to negligible impact on use

5.1.3 Protect and restore aquatic habitats

<table>
<tr><td colspan="3">Pressure: Bank and bed reinforcement and in-channel structures</td></tr>
<tr><td colspan="2">Sub-pressure: Hard protection
e.g. steel piling, vertical walls and gabion baskets. Includes hard bank protection in a state of disrepair.</td><td>Impact: Loss of riparian zone/marginal habitat/ loss of lateral connectivity/loss of sediment input</td></tr>
<tr><td>Number:3</td><td colspan="2">Mitigation measure: Protect and restore aquatic habitats (through river restoration)</td></tr>
</table>

Preservation, and restoration, of aquatic habitats has been a growing trend over the last 30 years in the UK. There is a general presumption on protection of high quality habitats. Where habitats have already been degraded, there have been moves to restore these areas. A book by Brookes and Shields (1996) summarises experiences in the UK, Europe and USA in the previous decade. Early restoration practice in the 1980s in the UK evolved through two EU-driven demonstration projects by the River Restoration Project in 1996 (now the UK River Restoration Centre). One of these was on the River Cole, which is a rural location in lowland England, and the other an urban project on the River Skerne in Darlington, in the North East (see www.therrc.co.uk). A further project was undertaken on the River Brede in Denmark (a previously straightened channel which was re-meandered). The designs and monitoring results associated with the schemes were detailed in a series of papers (Biggs *et al.*, 1998; Holmes and Nielsen, 1998; Sear *et al.*, 1998; Vivash *et al.*, 1998).

A large number of restoration schemes have been undertaken around the world over the last 30 years. In the USA, since 1990 over $14 billion has been spent on 37,000 stream restoration projects around the country by a mixture of country, public, and private groups (Nagle, 2007). Evidence of habitat improvement in many of these projects has never reached scientific papers and thus a significant volume of grey literature and good practice guidelines exist. However, a number of scientific papers demonstrate general success of these types of measures/techniques in different environments. For example, restoration has been undertaken in rural environments (Akita *et al.*, 2006; Friberg *et al.*, 1998; Habersack and Nachtnebel, 1995; Klein *et al.*, 2007), woodlands (Millington and Sear, 2007) as well as urban settings (Nolan and Guthrie, 1998; Suren *et al.*, 2005).

In the earlier years of restoration practice, monitoring of the success of practice was largely absent with the focus on design and installation rather than monitoring and post-project appraisals (Beschta *et al.*, 1994). Recently, there has been an increase in the number of schemes monitored and thus the success of such practice in improving habitat quality is now becoming scientifically validated. A good example of such an approach is the restoration of the Lower Red River Meadow in Idaho, USA (Klein *et al.*, 2007). Success criteria has been an essential component of the design process and field monitoring and hydrodynamic modelling have been used to quantify post-restoration changes in 17 physical and biological performance indicators. Initial findings suggest that the project has led to improvements in a number of indicators notably quantity, quality and diversity of in-stream habitat and spawning substrate. A decline in native riparian cover was also picked up, which led to adaptive management (Klein *et al.*, 2007). Other indicators have yet to show statistically or ecologically significant changes such as groundwater depth, stream temperature and salmonid density. Projects of this kind have great potential for improvement in the science behind river restoration.

The emergence of restoration as a means of improving habitat has led to a number of different guidance documents over the last 15 years in the UK, USA and Australia (FISRWG; 1998; Hey and Heritage, 1993; NRCS, 2007; RRC, 1999; RRC, 2005).

These provide a wealth of guidance on approaches to restoration as well different types of techniques used and their appropriateness in different environments.

Table 5.4 Checklist: Protect and restore aquatic habitats (through river restoration).

Measure No.3. Protect and restore aquatic habitats (also known as restoration, rehabilitation, creation or enhancement)	
Where has it been applied (geographically)?	Examples from UK, Europe and USA and elsewhere (e.g. Australia)
At what scale (reach, individual river, catchment)?	Local and reach scales; extension to address catchment issues is almost entirely aspirational.
To what type of environment has it been applied?	Low to high energy river systems (widespread application) .
What is the basis for its use?	Widely practised (grey literature exists)
Was it successful? What criteria used?	Studies have shown effectiveness on the basis of a number of criteria.
What were the potential environmental risks/ benefits?	Considerable benefits including social issues (recreation; FRM; aesthetics; noise). Whilst there are no major environmental risks in emulating natural processes per se, known impacts can include increased flood levels (e.g. through increased channel roughness) and rise in groundwater levels (potentially flooding basements in urban areas). If properly planned, designed, implemented and adaptively managed, there is little evidence of destabilisation of river channels.
What ecological impacts/improvements?	Considerable proven ecological impacts such as increasing plant, fish and invertebrate biomass. Many projects are reach-scale and have not been proven to increase species diversity. Brookes (1988) summarises a wealth of literature that has examined the inverse situation (the impacts of removing morphological features).
Are there any other non-physical impacts?	Re-naturalisation of watercourses potentially increases roughness and may have an impact on flow routing and flood risk (which could be beneficial in certain environments where, for example, storage is to be enhanced; less so where conveyance is critical to use especially if flood risk is critical at a particular location). However, this can mitigated by providing more space for the river corridor.

What monitoring is in place?	A few cases of excellent short-term monitoring (e.g. River Cole (UK) and Brede (Denmark). Unfortunately, mainly due to costs intense monitoring has not been carried out over the longer-term.
What are the general lessons to be learnt?	Any approach which involves restoration, enhancement or creation of morphological features has some positive impact. To be successful, all schemes need a minimum of a geomorphologist, ecologist and engineer (and in urban areas a contaminated land specialist and landscape architect).
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Yes, greater than 10 papers. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Low to moderate costs.
Is there an impact to the key use?	Potentially an impact (could be positive if re-naturalised channels and floodplains retain water upstream of an urban area, for example). Care must be taken where flood risk and the protection of built assets is critical at a particular location.

5.1.4 Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution

Pressure: Bank and bed reinforcement and in-channel structures		
Sub-pressure: Hard protection e.g. steel piling, vertical walls and gabion baskets. Includes hard bank protection in a state of disrepair.		Impact: Loss of sediment continuity (lateral) - build up of sediment in the channel
Number:4	Mitigation measure: Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution	

Mitigation measure is the same as detailed in Section 5.1.1 above.

5.1.5 Protect and enhance ecological value of marginal aquatic habitat, banks and riparian zone

Pressure: Bank and bed reinforcement and in-channel structures	
Sub-pressure: Hard protection e.g. steel piling, vertical walls and gabion baskets. Includes hard bank protection in a state of disrepair.	Impact: Loss of sediment continuity (lateral) - build up of sediment in the channel
Number:5	Mitigation measure: Protect and enhance ecological value of marginal aquatic habitat, banks and riparian zone

Mitigation measure is the same as detailed in Section 5.1.2 above.

5.1.6 Protect and restore aquatic habitats

Pressure: Bank and bed reinforcement and in-channel structures	
Sub-pressure: Hard protection e.g. steel piling, vertical walls and gabion baskets. Includes hard bank protection in a state of disrepair.	Impact: Loss of sediment continuity (lateral) - build up of sediment in the channel
Number:6	Mitigation measure: Protect and restore aquatic habitats

Mitigation measure is the same as detailed in Section 5.1.3 above.

5.1.7 Operational and structural changes to sluices and weirs

Pressure: Bank and bed reinforcement and in-channel structures	
Sub-pressure: Dams, sluices and weirs	Impact: Loss of biological continuity - interference with fish population movements (also impacts to sediment continuity, substrate condition (upstream and downstream), lateral connectivity, flow diversity and complexity)
Number:7	Mitigation measure: Operational and structural changes to dams, sluices and weirs

The effects of dams on the biological continuity of rivers are well known and there is growing scientific literature on the effects of small dam removal (such as Heinz Centre, 2002), principally from the USA (including California), and some parallels on potential impacts can be drawn. However, this review has not come across any scientific papers on operational and structural changes to weirs as opposed to their removal. There are a growing number of examples on streams in southern and eastern England, including the Nadder, Witham and Chess. There is some literature on flushes from dams to promote fish movement (Ronnie Falconer, personal.communciation). The transfer of bedload across structures has been used in the Haweswater catchment, Cumbria to mitigate against degradation of salmonid spawning habitat downstream. The lack of scientific research (and other literature) is surprising given that this measure offers major ecological improvement in rivers at relatively low cost. The Environment Agency Management System Guidance for Flood Defence Regulation 217_03 covers fluvial erosion. There is a body of literature on the effectiveness of installing fish passes which also shows how biological continuity from upstream to downstream (and vice versa) can be improved (see Mitigation Measure 8, Section 5.1.8 below). Dam removal per se is dealt with under Measure 9 (see Section 5.1.9 below)

Table 5.5 Checklist: Operational and structural changes to dams, sluices and weirs.

Measure No.7. Operational and structural changes to dams, sluices and weirs (not installing a weir or sluice in the first place with a new scheme (by choosing an alternative option) could potentially have major advantages).	
Where has it been applied (geographically)?	Limited examples from Denmark; large number of small dam and weir removal projects from USA, particularly California, from which limited parallels (on potential impacts) may be drawn.
At what scale (reach, individual river, catchment)?	The measure/technique might be applied at a local (pinch point) scale but potentially altering one structure can have a catchment-wide benefit.
To what type of environment has it been applied?	Limited application but generally to low energy river systems (also weirs are more likely to cause erosion in high energy rivers).
What is the basis for its use?	Little information exists.
Was it successful? What criteria used?	No recorded evidence of criteria being used.
What were the potential environmental risks/ benefits?	Considerable benefits in terms of re-establishing continuity (potentially at relatively low cost). Risks include short-term release of sediments from impounded reach; potential for downstream (and upstream) erosion also and potential for undermining of structures. Lowering of average water level and adjacent groundwater levels could result in bank instability or structural instability especially if change is rapid (mainly short term). These are all short-term risks to be balanced with potentially significant long-term benefits.
What ecological impacts/improvements?	Intuitively this is a win-win solution but there is little or no scientific evidence on ecological impacts/improvements apart from those that can be inferred from the fish pass literature and/or small dam removal studies.
Are there any other non-physical impacts?	Altering FRM structures can have a significant adverse impact on use. To solve a flooding problem an alternative solution may be needed (e.g. increased use of storage in floodplains).
What monitoring is in place?	Some monitoring on the River Nadder at Fovant and a recent MSc thesis (RRC, personal communication).

What are the general lessons to be learnt?	Potentially a significant mitigation measure/technique under WFD; there is a need for research to fully understand the implications of altering structures.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? None found in this review (except for parallel papers in dam removal literature). Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor to non-existent.
Indication of order of costs	Could have a high cost if alternative FRM options have to be implemented. Could be cost-effective as part of a new structure or structural repair. Also the cost of a 'flush' depends on the value of the water used.
Is there an impact to the key use?	Potentially significant impact on use unless the FRM structure in its current form is regarded as 'not fit for purpose'.

5.1.8 Mitigation measure: Install fish passes

<table>
<tr><td colspan="3">Pressure: Bank and bed reinforcement and in-channel structures</td></tr>
<tr><td colspan="2">Sub-pressure: Dams, sluices and weirs</td><td>Impact: Loss of biological continuity - interference with fish population movements</td></tr>
<tr><td>Number:8</td><td colspan="2">Mitigation measure: Install fish passes</td></tr>
</table>

Fish passes are a well used and a successful way of mitigating the effects of a weir on fish passage (World Commission on Dams, 2000). However, there are restrictions on how successful this technique can be on different fish species. A variety of design guidance manuals for fish passes have been produced over the last 30 years. Early guidance included that provided by the former Ministry of Agriculture, Fisheries and Food (Beach, 1984). More recent guidance is detailed in Clay (1995), Jungwirth *et al.* (1998), Larnier (2000) and Larnier *et al.* (2002). For statutory authorities, the Environment Agency produced its own fish pass manual in 2004 (Armstrong *et al.*, 2004). The Environment Agency also has Management System Guidance Policy 606_06 on in-stream structures. In Scotland, the Scottish Government has published guidance for river crossings and migratory fish (Scottish Executive, 2000).

Table 5.6 Checklist: Install fish passes.

Measure No.8. Install fish passes	
Where has it been applied (geographically)?	Examples worldwide.
At what scale (reach, individual river, catchment)?	Local or multi-reach scale but intended to have catchment or sub-catchment impacts.
To what type of environment has it been applied?	All types of environment where dams are present.
What is the basis for its use?	Considerable professional;/ grey literature
Was it successful? What criteria used?	A wide range of criteria used (usually targeting one or more species of fish).
What were the potential environmental risks/ benefits?	Few identified wider environmental risks; can potentially benefit fish populations for a considerable distance upstream (and the headwaters can once again become spawning grounds for migratory fish).
What ecological impacts/improvements?	Considerable ecological advantages in terms of enhancing continuity (but mainly for fish species).
Are there any other non-physical impacts?	No significant impacts on FRM uses.
What monitoring is in place?	There have been long-term monitoring schemes (fish counters have typically been installed).
What are the general lessons to be learnt?	Fish passes not always successful, sometimes as a result of inappropriate design. Measure needs to be properly designed and implemented to be successful. Consideration needs to be given to upstream and downstream migration/movement.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Less than 10 papers were collated as part of this review. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	A fish pass (for example around a FRM online storage reservoir) can have a high cost. These costs may be relatively low compared to the benefit.
Is there an impact to the key use?	Should not have a significant adverse effect on use if properly design.

5.1.9 Removal of structure

Pressure: Bank and bed reinforcement and in-channel structures		
Sub-pressure: Dams, sluices and weirs		Impact: Loss of sediment continuity (longitudinal) - build up of sediment upstream, reduced bedload downstream
Number:9	Mitigation measure: Removal of structure	

Parallels can be drawn from the considerable work now being undertaken on small dam removal in the USA (particularly California) (Schuman, 1995). The decision to remove a small dam is complex and can have both positive and negative impacts (http://limnology.wisc.edu/personnel/emstan/DamRemoval.html). In particular, a key area of research aims to understand the relationship between hydromorphological and ecological responses downstream of the removed dam, principally as a result of sediments previously deposited in the reservoir. The Aspen Institute (http://www.aspeninst.org) convened a group of scientific experts in 2000 to assess the pros and cons of reservoir removal. One of the discussion groups weighed up short-term impacts (such as sediment release) versus longer term gains. There have been a limited number of scientific publications. Stanley *et al*. (2001) examined the short-term changes in channel form and macroinvertebrate communities following low-head dam removal. Within one year of removal, macroinvertebrate assemblages in the former impounded reaches did no differ significantly from those in the upstream reference sites or downstream. As only a small amount of sediment was released as a result of dam removal, downstream effects on macroinvertebrates were minimal. A limited number of "erosion check" weirs, identified as pinch points, were removed on watercourses in Denmark in the 1980s, with apparent immediate success at restoring continuity for fish (Nielsen, 1996). However this work has not, to the knowledge of the authors of this report, been written up. A large-scale weir removal project on the Tweed Catchment proved very successful (Roy Richardson, personal communication).

Complete removal of structures is still rare in the UK (as in many EU countries), although there are examples from the Thames Region of the Environment Agency (RRC, personal communication). The Wensum Physical River Restoration Plan produced in 2007 by Natural England and the Environment Agency covers a number of possible future examples. The geomorphological effects of weirs and dams are well known and documented in the scientific literature. This includes: a) deposition of sediment (which could be contaminated) upstream of the structure which is likely to cause bed levels to rise; b) reduced throughput of sediment downstream; c) potential problems of erosion upstream due to fluctuating water levels; d) increase in stream power immediately downstream of the structure which could lead to 'clear water' erosion (Downward and Skinner, 2005). Any removal of the structure would have to take into account these issues. Any general lowering of average water levels and adjacent groundwater levels should also be considered, as this could result in bank or structural instability especially if the change is rapid. Increased erosion potential associated with removal should also be considered. Further information on the issues associated with dam removal can be found in papers by Bushaw-Newton *et al.* (2002), Doyle *et al.* (2000), Hart *et al.* (2002) and Katopodis and Aadland (2006).

Table 5.7 Checklist: Removal of structure.

No.9. Removal of structure	
Where has it been applied (geographically)?	Examples from USA in particular but also Denmark.
At what scale (reach, individual river, catchment)?	Locally and usually one-off in a river catchment.
To what type of environment has it been applied?	Low to high energy systems (both lowland and upland).
What is the basis for its use?	Supported by a growing body of literature but is a developing area and most publications talk about future projects.
Was it successful? What criteria used?	Many initial 'dam removal' projects not comprehensively thought out in terms of criteria for success: most criteria have been for long-term benefits rather than potentially negative short-term effects.
What were the potential environmental risks benefits?	For an impounding structure there is the potential for short-term release of sediments (could be contaminated from industrial and other uses upstream; others high in nutrient status). Potential for downstream (and upstream) erosion and undermining of structures. Lowering of average water level and adjacent groundwater levels could result in bank or structural instability especially if change is rapid (mainly short term).
What ecological impacts/improvements?	Intuitively there would be long-term benefits (measure is the inverse of impounding a river in the first place, for which there are documented negative effects); however, as yet little monitoring to show response.
Are there any other non-physical impacts?	Changes of flow patterns immediately upstream and downstream of the removed structure; potential adverse impact on flood routing (unless modelled to prove otherwise).
What monitoring is in place?	A new technology which has attracted the attention of academics. Research programmes likely to yield results in the near future.

What are the general lessons to be learnt?	If measures are properly designed, implemented and adaptively managed can be made successful. Intuitively, a good thing to “right the wrongs” of the past by removing structures. But hydromorphologically, the river may have attained a new regime at the location of the structure, with potentially adverse impacts (particularly short-term) that need careful consideration.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Less than five scientific papers found (but observed to be a growing area of scientific interest owing to the number of projects now planned in the USA). Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Capital cost of demolition of a structure such as a weir could be moderate (cf Danish example). However, could be a high cost if associated with thorough studies of the potential impact, any associated mitigation measures/techniques and imposed monitoring costs. However benefits could be significant, and could be cheaper long-term than maintaining ageing structures.
Is there an impact to the key use?	Depends on local circumstances.

5.1.10 Retain marginal aquatic and riparian habitats

Pressure: Channel alteration	
Sub-pressure: Realignment/reprofiling/regrading	Impact: Loss of morphological diversity and habitat (also loss of substrate quality/condition, impact on sediment continuity, loss of erosion/deposition character, lateral connectivity, impact on flow diversity, loss of marginal/riparian habitats).
Number:10	Mitigation measure: Retain marginal aquatic and riparian habitats

The impacts of realignment (including channel straightening), reprofiling and regrading of watercourses are well understood and documented in the scientific literature (see reviews in Brookes 1988; Swales, 1982). Loss of morphological diversity is one of the key issues associated with this sub-pressure, as well as careful consideration of engineering aspects including any increase in erosion potential and stability issues. Anumber of recent projects have sought to restore this valuable habitat (Clark and Wharton, 2000 and Chovanec *et al.*, 2002 – see Section 5.1.2 above for more details). However, in areas where this habitat is already present, the focus should be on recognising this fact and preserving the habitat where at all possible.

Good practice guidelines have been developed by statutory authorities for retaining marginal aquatic habitats. National guidance on marginal habitats (and maintenance regimes in general) has been produced in conjunction with Natural England and the Countryside Council for Wales (Environment Agency, 2002). Welsh Region of the Environment Agency (courtesy of Teg Jones, Environment Agency Welsh Region) have produced the following guidelines for realignment/regrading and resectioning:

1. Resection least sensitive bank only; if this is not possible then the Biodiversity Officer should be made aware at an early stage.

2. Where water voles are present (see ESN1 & Conservation Constraint maps), small sections (centred on the core of the population) or nearby waterways or lateral channels should be left untouched to allow a refuge for individuals from which the local population can regenerate.

3. Where both banks are of interest, alternate bank reprofiling to accentuate sinuosity.

4. Bank reprofiling should incorporate slopes ranging from vertical cliffs to shallow margins.

5. Where possible, cross-sections should consist of a self-cleansing low-flow channel and a higher-level flood channel.

6. Regrading should retain or create bed diversity i.e. pools, riffles.

7. The Environment Agency's Pollution Prevention Guidelines should be complied with (PPG 5).

8. Where Japanese knotweed is present, care should be taken not to spread the plant, either through movement of spoil, or through tracking of vehicles.

9. Archaeological monitoring may be required (ESN 14)

Table 5.8 Checklist: Retain marginal aquatic and riparian habitats.

Measure No.10. Retain marginal and riparian habitats	
Where has it been applied (geographically)?	Examples from UK, Europe and USA.
At what scale (reach, individual river, catchment)?	Local, reach and multi-reach scales.
To what type of environment has it been applied?	High to low energy river systems (widespread application).
What is the basis for its use?	Supported predominantly by good practice guidelines.
Was it successful? What criteria used?	Effectiveness of retaining marginal vegetation demonstrated by various studies.
What were the potential environmental risks/ benefits?	Considerable benefits; no significant environmental risks.
What ecological impacts/improvements?	Considerable proven ecological advantages (conversely, many studies have shown negative ecological impacts of removal of marginal and riparian vegetation). Not least, water temperature increases and lack of cover for fish are serious issues supported by evidence.
Are there any other non-physical impacts?	Risk associated with calculating an accurate roughness value such that flow conveyance is not adversely affected by retaining vegetation.
What monitoring is in place?	Limited long-term monitoring (Danube is an exception). Studies have monitored the inverse situation, that is, the adverse impact of removing marginal and riparian vegetation.
What are the general lessons to be learnt?	Retaining marginal vegetation is potentially a "quick hit" solution to improving the ecology of a reach.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Less than five papers were found as part of this review. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Relatively inexpensive solution
Is there an impact to the key use?	Low to negligible impact on use

5.1.11 Increase in-channel morphological diversity

Pressure: Channel alteration		
Sub- pressure: Realignment/ reprofiling/regarding		Impact: Loss of morphological diversity and habitat
Number:11	Mitigation measure: Increase in-channel morphological diversity, e.g. install in-stream features; two-stage channels; geometric variation	

Loss of morphological diversity has long been recognised as a major effect of channelization and realignment of rivers (Brookes, 1988; Swales, 1982). As a consequence of the widespread loss of morphological diversity caused by these processes, there has been an increasing trend to remediate against these effects. In-stream devices are probably the most researched measure/technique (particularly in the USA) with papers first published in the 1950s (Brookes, 1998). In-stream measures are taken to include riffle construction (Harper *et al.*, 1998; Pretty *et al.*, 2003; Sear and Newson, 2004), bar construction, boulder placement (Brittain *et al.*, 1993; Gortz, 1998; Phillips *et al.*, 2000), wood (Champoux *et al.*, 2003) and deflectors (Champoux *et al.*, 2003; Gortz, 1998; Jungwirth *et al.*, 1993; Kelly and Bracken, 1998; Muhar, 1996; Muotka *et al*., 2002; Pretty *et al.*, 2003; RRC, 1999; Shields *et al.*, 1998; Shields *et al.*, 2003; Swales, 1982) as well as two-stage channels. They have been used to maintain the realigned/channelised form but offer the opportunity to improve the in-channel morphological diversity. A number of laboratory experiments have investigated the effectiveness of deflectors at changing channel morphology (Biron *et al.*, 2004; Kuhnle *et al.*, 1998). In-stream measures/techniques have also been placed to improve habitat for a variety of reasons including fish (see Champoux *et al.*, 2003) and macroinvertebrates (see Muotka *et al*., 2002). The use of such measures in rivers has been widespread (Nagle, 2007) but monitoring has been patchy and where it has occurred, has shown mixed results (see Frissell and Nawa, 1992; Pretty *et al.*, 2003).

For the USA, Thompson (2006) evaluated 79 pre-1980 publications and found relatively little evidence that in-stream structures improved fish populations. Thompson (2006) suggested, through statistical analysis, that many of the changes reported in the early publications were due to fishing pressure (that accompanies channel modifications). Thompson felt that many of the conclusions were not supported by data. He suggested that political pressure may have influenced reports of successful project outcomes. Thompson also suggested that more recent studies (after 1995) repeat some of the same mistakes made by earlier authors. However the author of this report has observed that Thompson fails to quote the extensive work of Doug Shields who has devoted a career to scientific studies in warm water streams. A 'systematic review' has now been commissioned by the Environment Agency into the effects of in-stream features in warm water streams (Mark Diamond, personal communication).

Evaluation of the success of such measures is difficult, since it is rare that schemes concentrate on one particular technique and thus it is difficult to determine the success or failure of a river attribute (fish population recovery) to one particular technique. Frissell and Nawa (1992), in their survey of 161 structures in 15 streams in southwest Oregon, suggest that many failed schemes occurred in streams with recent watershed disturbance, high sediment loads and unstable channels. Thus it is important that the use of techniques takes into account prevailing conditions at a site, particularly geomorphological controls such as sediment and discharge input into the reach (Kondolf, 2000; Miles, 1998). A SEPA publication provides design guidelines for engineered log-jams with good references on monitoring and success (http://www.sepa.org.uk/water/water_regulation/guidance/idoc.ashx?docid=3808b106-3a12-4e61-a7af-f6833c2078f7&version=-1)

Systematic reviews have the advantage of being repeatable, of discriminating between good and poor quality science (to a certain extent) and of testing specific hypotheses. A systematic review of literature with correspondence with some researchers (Stewart *et al.*, 2006) examined (for the UK in particular) the effects of in-stream measures solely on the abundance of salmonid species. This again revealed a mixture of findings. The review suggested that engineered in-stream measures resulted in a small, statistically significant increase in salmonid population abundance (increase in carrying capacity) when considering all data available (Stewart *et al.*, 2006). However, examining habitat preferences (redistribution of the population) showed no detectable effect although there was some evidence that measures provided preferential habitat at higher discharges (Stewart *et al.*, 2006). Habitat form is one of many factors that will affect the success of fish populations. Variables such as water quality are just as important and thus any systematic review of the effects of in-stream deflectors is limited by other stochastic variables which potentially differ between schemes.

Whilst the evidence of success of such measures/techniques is known to be variable the chances of a successful project are enhanced if in-stream features are properly planned, designed and constructed (Biron *et al.*, 2004). A variety of good practice guidelines have been developed to improve in-stream habitat (FISRWG, 1998; RRC, 1999; Rutherfurd *et al.*, 2000; Wesche, 1985). In Ireland such measures/techniques have been tried along considerable lengths in entire catchments adversely impacted by arterial drainage (O'Grady, 2006; 2008).

Table 5.9 Checklist: Increase in-channel morphological diversity.

Measure No.11. Increase in-channel morphological diversity, e.g. install in-stream features; two-stage channels; geometric variation.	
Where has it been applied (geographically)?	Examples from UK, Europe and (in abundance) the USA.
At what scale (reach, individual river, catchment)?	Local and reach scales but sometimes throughout a catchment impacted by channelization (e.g. Ireland).
To what type of environment has it been applied?	Predominantly lower energy river systems (although some examples in high energy systems in USA).
What is the basis for its use?	Supported by a range of guidance manuals. More literature to date than any other measure/technique.
Was it successful? What criteria used?	Studies have adopted a variety of success criteria; general observation is that there is a lack of baseline on which to measure success.
What were the potential environmental risks/ benefits?	Potential risk of destabilising river banks if not properly designed and implemented (need to work with river processes).
What ecological impacts/improvements?	Considerable proven ecological advantages: many studies to support return of migratory species and increased biomass in previously degraded reaches.

Are there any other non-physical impacts?	Increased roughness elements placed in channel may need to be taken into account in flood conveyance calculations and in reviewing flood risk for the reach where techniques are to be implemented and upstream; proven to be beneficial as a low flow mitigation measure.
What monitoring is in place?	Extensive literature based on monitoring (linking ecology and hydromorphology). Unfortunately the length of many studies is typically less than two years (e.g. the duration of someone's PhD research).
What are the general lessons to be learnt?	If measures are properly designed, implemented and adaptively managed, they can be successful.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? More than 10 publications found (several PhDs on associated topics). Has a digest of results been produced? No. Does a systematic review of the literature exist? Yes – Centre for Evidence Base Conservation in UK has done one on in-stream structures and their effects on salmonids. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	When applied at critical pinch points, costs may be low. Often these are built of relatively cheap (and natural) materials. However, as a measure to rectify extensive lengths of river previously subjected to FRM or LD (including arterial drainage), cost can range from low to moderate.
Is there an impact to the key use?	Not likely to have a significant impact on use as such structures drown out at high flows. Any impact on FRM would have to be assessed and considered. RRC has studied rehabilitation techniques for Eastern England and has addressed the question of the most cost-effective hydraulic modelling in a particular situation to show impact on use.

5.1.12 Opening existing culverts

Pressure: Channel alteration		
Sub-pressure: Culverts		Impact: Loss of morphological diversity and habitat (also sediment continuity, lateral connectively, fish passage, riparian/marginal habitats)
Number:12	Mitigation measure: Opening existing culverts	

Although not always practical, opening of existing culverts (also known as 'daylighting') is becoming more widespread. The science behind the method is still in its infancy but has many parallels with restoration of habitat since in many instances a new channel will be formed in the place of the previously culverted form. The most comprehensive review of this mitigation measure is detailed in Pinkham (2000). This illustrates a variety of case studies as well as problems encountered in this process. There is extensive experience in Denmark where streams 'piped' for agricultural purposes were 'broken out' (see Nielsen, 1996). However, there was little or no scientific monitoring behind this work, simply a belief that the "wrongs of the past were being rectified". A more recent example is the Niddrie Burn in the City of Edinburgh where parts of an urban stream are to be realigned away from a culverted course (Alvin Barber, personal communication). Other completed examples include the River Alt (Warrington), the Ravensbourne (Bromley), Bog Burn (at Bathgate) and Kyd Brook (Bromley). In addition there is a proposed scheme on the Brock Burn at Earlston. CIWEM recently prepared a position paper on deculverting – see http://www.ciwem.org/policy/policies/de-culverting_of_watercourses.asp. Another measure tried in the UK has been replacement of the existing structure with an over-sized culvert, allowing for the development of marginal habitat or even a two-stage channel form. A key document is the Environment Agency Management System DMS/150 Policy on culverting.

Table 5.10 Opening existing culverts.

Measure No.12. Opening existing culverts	
Where has it been applied (geographically)?	Limited examples from Denmark, UK and USA.
At what scale (reach, individual river, catchment)?	Local and reach scales (generally pinch points).
To what type of environment has it been applied?	Predominantly lower energy river systems.
What is the basis for its use?	Intuitively a logical solution and in excess of 10 good papers worldwide describing the measure and potential.
Was it successful? What criteria used?	Studies suggest success (nothing will grow in a dark pipe or culvert).
What were the potential environmental risks/ benefits?	Potential risk of replacing a culverted straightened watercourse with earth bed and banks, with potential for erosion. However, careful design should overcome such problems.
What ecological impacts/improvements?	Studies suggest ecological advantages.
Are there any other non-physical impacts?	Often culverts/pipes are removed because of blockages and flooding potential. However, removing a culvert which previously constrained flows could increase downstream flood risk.
What monitoring is in place?	Limited.
What are the general lessons to be learnt?	If measures are properly designed, implemented and adaptively managed then successful. Obviously a more naturalised channel should be created once the river is “daylighted”.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non-existent
Indication of order of costs	Removal of existing pipes and culverts could be viewed as costly; ideally a new earth channel (perhaps with improved sinuosity) should replace the culverted course.
Is there an impact to the key use?	Unlikely to have a significant impact on use. An option could be to leave the old culvert in situ (if a new course is created). This would also act as a ‘relief channel’ to convey flood flow (for example) although safety and blockage risks would need to be considered. In other circumstances, collapsing and burying the old culvert may be more appropriate.

5.1.13 Alteration of channel bed

Pressure: Channel alteration		
Sub-pressure: Culverts		Impact: Loss of morphological diversity and habitat
Number:13	Mitigation measure: Alteration of channel bed	

See Section 5.1.12 for good practice for the opening of existing culverts. Alteration of the channel bed is one of several issues associated with the installation of culverts. Where deculverting is not possible, depressed invert culverts are recommended to enable a natural bed to be maintained through the culvert, thus maintaining some degree of morphological diversity and habitat value. Lengths should be kept as short as possible. Please also refer to checklist in Table 5.10.

5.1.14 Opening existing culverts

Pressure: Channel alteration		
Sub-pressure: Culverts		Impact: Continuity
Number:14	Mitigation measure: Opening existing culverts	

See Section 5.1.12 for good practice for the opening of existing culverts. Please also refer to checklist in Table 5.10.

5.1.15 Alteration of channel bed

Pressure: Channel alteration		
Sub-pressure: Culverts		Impact: Continuity
Number:15	Mitigation measure: Alteration of channel bed	

See Section 5.1.12 for good practice for the opening of existing culverts. Alteration of the channel bed is one of several issues associated with the installation of culverts. Where deculverting is not possible, depressed invert culverts are recommended to enable both biological and sediment continuity to be maintained through the culvert to upstream and downstream reaches of the river. Also refer to checklist in Table 5.10.

5.1.16 Flood bunds

Pressure: Floodplain modification		
Sub-pressure: Flood banks and flood walls		Impact: Loss of riparian zone/marginal habitat/ loss of lateral connectivity/loss of sediment input (also sediment continuity, condition and quality of channel substrate)
Number:16	Mitigation measure: Flood bunds	

Flood bunds (earth embankments) are an alternative to 'hard' flood banks or revetments (usually with some form of hard erosion protection) and flood walls where space for construction of set-back embankments is limited. Strictly speaking, flood bunds could also be regarded as a less damaging engineering activity. However such features, whilst not being set-back (see Section 5.1.17 and Table 5.11 below), still enable ecological connectivity to evolve, allowing a marginal habitat to develop. As a result, they offer ecological benefits compared to hard flood banks or walls. A 'natural' and varied cross-section can allow the bund to blend with the landscape. Set-back embankments are, however, preferable.

5.1.17 Set-back embankments

Pressure: Floodplain modification		
Sub-pressure: Flood banks and flood walls		Impact: Loss of riparian zone/marginal habitat/ loss of lateral connectivity/loss of sediment input
Number:17	Mitigation measure: Set-back embankments	

Set-back embankments are becoming more frequently used to boost local river-floodplain connectivity whilst maintaining a flood defence function for the area. This has parallels with set-back embankments in coastal and transitional water mitigation measures. Antecedents of this type of work can be found, for example, in biotechnical engineering initiatives undertaken in southern Bavaria for more than 40 years (see summaries in Brookes, 1988). There are good examples from the Netherlands. A number of schemes have been planned or recently undertaken in the UK, involving the development of a flood storage area through set-bank embankments (such as River Thaw, upstream of Cowbridge, Wales – see questionnaire response). The RRC Manual also documents an example of the Long Eau in Lincolnshire. This type of project offers the opportunity to maintain a flood defence function while maximising ecological benefit. These projects are only possible where land is available to be set-aside for this purpose. A ‘natural’ and varied cross-section can allow the embankment to blend with the landscape and significantly reduce visual intrusion. Little scientific evidence or grey literature is available on their success in achieving ecological gains whilst maintaining their flood defence function. However, the value of floodplains and riparian corridors is well established in the literature.

Table 5.11 Checklist: Set-back embankments.

Measure No.17. Set-back embankments	
Where has it been applied (geographically)?	Extensively throughout Europe (good long-established examples in Bavaria and elsewhere in Central Europe); also USA.
At what scale (reach, individual river, catchment)?	Recent projects on multi-reach scales.
To what type of environment has it been applied?	Proved in low to high energy river systems.
What is the basis for its use?	Intuitively a logical alternative solution with some technical guidance.
Was it successful? What criteria used?	Studies indicate success.
What were the potential environmental risks/ benefits?	Potential risk of contaminated sediments from upstream catchment being deposited on the set-aside area. No specific studies. Some FRM benefits by using intermediate floodplains for storage.
What ecological impacts/improvements?	Studies suggest positive ecological impacts.
Are there any other non-physical impacts?	Benefits of attenuating flood flows to a certain extent. Typically, real enhancement for FRM requires an offline storage scheme.
What monitoring is in place?	Very little published.
What are the general lessons to be learnt?	Appears to be an accepted "engineering" alternative as the 'extended' flood channel provides greater flood conveyance and some additional flood storage is provided. Principal driver for this technique may not therefore be ecology.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non-existent
Indication of order of costs	Could be a high cost if land needs to be acquired (set-aside) for the measure to materialise. Value of floodplains and riparian corridors well known.
Is there an impact to the key use?	Unlikely to have a significant impact on use. More of a benefit.

5.1.18 Improve floodplain connectivity

Pressure: Floodplain modification	
Sub-pressure: Flood banks and flood walls	Impact: Loss of riparian zone/marginal habitat/loss of lateral connectivity/loss of sediment input
Number:18	Mitigation measure: Improve floodplain connectivity

Improving floodplain connectivity has been shown to have significant ecological gains. This measure can entail reconnecting old side channels and breaching of existing earth bunds. This measure emerged from West Germany (Bavaria) and Austria under the generic term “biotechnical engineering”. The first publications appeared more than 50 years ago (Brookes, 1988). Several large-scale projects on the Kissimmee River (Florida, USA), the River Danube (Austria), the River Rhône (France), the River Rhine (Netherlands) and the Cosumnes River (California, USA) carried out over the last 10 years are now beginning to show ecological benefits for river-floodplain connectivity and the reconnection of a river with former side channels. A large number of publications are associated with these projects as reviewed below.

The Kissimmee River is perhaps one of the largest schemes to date and has included the restoration of 24 km of previously channelised river (Colangelo, 2007; Shen *et al.*, 1994; Toth, 1996; Toth *et al.*, 1993; Toth *et al.*, 1998; Warne *et al.*, 2000). Prior to channelization the Kissimmee River had good connection with its floodplain and associated wetlands. Channelization degraded much of the fish and wildlife habitat (Toth *et al.*, 1993). The restoration sought to re-establish the river and floodplain links and started in 1994 with a series of demonstration projects (Toth *et al.*, 1998). Monitoring has been extensive, focusing on a wide variety of parameters. For example, an investigation of metabolism parameters in the restored channel showed that these levels are now similar to other blackwater river systems in southeast USA.

The River Danube restoration project is located between Vienna and Bratislava. The area which includes this length of the Danube was designated a National Park in 1996. The restoration project sought to restore sections of the channel in the Lobau and Regelsbrunn regions (Heiler *et al.*, 1995; Hein *et al.*, 1999; Scheimer *et al.*, 1999; Tockner *et al.*, 1999) through increasing river and floodplain connectivity with old side channels of the river. A pre and post-monitoring programme is based on monitoring hydrology, sediment load and nutrient load but also faunal changes (Heiler *et al.*, 1995; Hein *et al.*, 1999; Scheimer *et al.*, 1999; Tockner *et al.*, 1999). Afurther project is currently under construction on the Danube in Bavaria (see Section 3.0 above).

Other larger scale river-floodplain restoration projects include the River Rhine (Buijse *et al.*, 2002; Cals *et al.*, 1998; Simons *et al.*, 2001), the River Rhône (Henry *et al.*, 2002), and the Cosumnes River (Ahearn *et al.*, 2006). All projects are showing ecological gains ranging from improvements in fish populations to increases in macroinvertebrate densities, macrophyte numbers, algal biomass and numbers of wading birds. The evidence for ecological improvements offered by increase river-floodplain connectivity and reconnection of former side channels is thus steadily growing.

Smaller scale examples in the UK include floodplain lowering on the River Skerne (Northumbria) and a project on the River Parrett in Somerset.

Table 5.12 Checklist: Improve floodplain connectivity.

Measure No.18. Improve floodplain connectivity	
Where has it been applied (geographically)?	Extensively throughout Central Europe and USA.
At what scale (reach, individual river, catchment)?	Recent projects on multi-reach scales.
To what type of environment has it been applied?	Proved in low to high energy river systems.
What is the basis for its use?	Intuitively a logical solution with some technical guidance.
Was it successful? What criteria used?	Studies indicate success.
What were the potential environmental risks/ benefits?	Risk of contaminated sediments from upstream catchment being deposited on floodplain and in side-channels (including high nutrient loads). However the measure itself may not actually cause a problem. No specific studies. Good FRM benefits where measures result in enhancement of floodplain storage capacity. Using floodplains for storage is of no benefit unless the existing or natural capacity is enhanced or reactivated.
What ecological impacts/improvements?	Studies suggest considerable ecological advantages.
Are there any other non-physical impacts?	Potential benefits of attenuating flood flows where measures enhance or reactivate storage capacity.
What monitoring is in place?	Evidence from the last 50 years; monitoring particularly in the last 10 years. Ongoing studies.
What are the general lessons to be learnt?	Need proper design and implementation; flooding cannot just be allowed to happen – needs to be accompanied by monitoring of potential effects.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? More than 10 (particularly from central Europe). Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Could be a high cost if land needs to be acquired for the measure to materialise (and/or compensation paid to landowners).
Is there an impact to the key use?	This could have a significant impact on use as “flood bunds” would no longer serve their function. Implications for FRM need to be carefully considered on a case-by-case basis. Potentially a benefit.

5.1.19 Flood diversion channels

Pressure: Floodplain modification		
Sub pressure: Flood diversion channels		Impact: Loss of floodplain/riparian zone/ marginal habitat/loss of lateral connectivity/loss of sediment continuity through main channel
Number:19	Mitigation measure: Improve floodplain connectivity	

Flood diversion channels (also known as bypasses) have been constructed with the purpose of diverting flows away from an area to be protected, the existing channel carrying the normal flows (Brookes, 1988). The diversion channel can either be dry or wet (with a sweetening flow). There is considerable practice (for example, from the Thames Region of the Environment Agency). However, diversion channels can have an impact on the main channel (such as increased sediment deposition during flood flows as a consequence of reduced stream power) and on the floodplain. Whilst the hydraulic impacts of flood diversion channels can be modelled, there is a lack of modelling of subsequent ecological and hydrological impacts on the floodplain. This relies on an improved understanding of the interaction between river flows and floodplain ecology (Kingsford, 2000; Scruton *et al*., 2005).

5.1.20 Flood diversion channels

Pressure: Floodplain modification		
Sub-pressure: Flood diversion channels		Impact: Loss of floodplain/riparian zone/ marginal habitat/loss of lateral connectivity/loss of sediment continuity through main channel
Number:20	Mitigation measure: Enhance aquatic and riparian habitats	

A further measure for flood diversion channels is to enhance aquatic and riparian habitats in the river corridor. Enhancements should be detailed in the design phase of the diversion channel so that an appropriate level of roughness can be used to quantify their potential impact on flood conveyance (Kingsford, 2000; Scruton *et al.,* 2005).

5.1.21 Sediment management strategies

Pressure: Operations and maintenance		
Sub-pressure: Sediment management (including dredging)		Impact: a) Direct loss of/impact on aquatic habitats/hydromorphology; b) Transfer of fine sediment downstream; c) Bankside erosion and impacts on riparian habitats; d) Source of fine sediment (disposal of dredgings on banks)
Number:21	Mitigation measure: Sediment management strategies (develop and revise) which could include a) substrate reinstatement, b) sediment traps, c) allow natural recovery minimising maintenance, d) riffle construction, e) minimum management in flood risk areas	

This involves a diverse range of measures which might have different objectives. Sediment is problematic (such as fine silt) and beneficial (for example, deposited gravels may be important for fish spawning). There are many examples of sediment management strategies for river organisations in Europe and USA (and elsewhere in the world). A large amount of scientific literature (principally from the USA) assesses the inverse situation (impacts of sediment removal) and (some) ecological recovery following the initial dredge (see summary by Brookes, 1988).

Sediment management practices have evolved in good practice guidelines for various authorities in the UK such as the Environment Agency, SEPA, the Broads Authority and WWF Scotland. They are all based on understanding the vital role of gravels and deposition of sediment in maintaining habitat diversity in river systems. The Environment Agency has a national policy on the removal of gravel from rivers where the presumption is 'generally against gravel removal other than where specifically allowed for navigation or proven to be essential in specific locations for FRM or water supply purposes (Environment Agency, 2004).' The Environment Agency Management System Policy 359_04 encapsulates the removal of gravel from rivers and the best practice guidelines for modelling support this policy. There is also an Operational Instruction 218_03 Gravel extractions and other mineral workings (England). The System Asset Management Plans (part of Asset Management Review) initiative currently being pioneered by the Environment Agency is critical here. These plans aim to reduce maintenance on some 97 systems.

Equally SEPA have a statement on sediment management policy to support the Controlled Activities Regulations. This states that 'SEPA promotes the preservation of natural sediment budgets and resulting morphological features within surface waters. Any intervention with, or manipulation of, such sediment must be carefully considered, fully justified and sensitively managed within a catchment perspective' (www.sepa.org.uk/water/water_regulation/guidance/idoc.ashx?docid=660d8a75-54d6-454f-9ced-046a66a4947b&version=-1).Other parties such as the Broads Authority have a sediment management policy (http://www.broads-authority.gov.uk/managing/rivers-and-broads/sediment-management/sediment-strategy-action-plan.html). In addition, SEPA in its Farming and Watercourse Management handbook also offers good practice advice for gravel management (www.sepa.org.uk/water/habitat_enhancement/idoc.ashx?docid=dd5cb2a7-1489-4b3d-ba8d-32c0b880b694&version=-1). The University of Nottingham carries out sediment-related research and a current PhD student is examining sediment-related issues including those in FRM channels (personal communication Colin Thorne).

Table 5.13 Checklist: Sediment management strategies.

Measure No.21. Sediment management strategies	
Where has it been applied (geographically)?	Plenty of examples from throughout UK.
At what scale (reach, individual river, catchment)?	Reach basis (but needs a catchment assessment or fluvial audit)
To what type of environment has it been applied?	Wide range of sediment types from silt to gravel-bed.
What is the basis for its use?	Covered by many guidance manuals from around the world.
Was it successful? What criteria used?	Intuitively a good thing, as habitat features are allowed to return (thereby assisting ecological recovery).
What were the potential environmental risks/ benefits?	Intuitively the benefits outweigh the risks. However, the quality of sediments deposited could be an issue (e.g. in a urban area).
What ecological impacts/improvements?	Potentially a good thing: lack of maintenance may be a key factor in ecological recovery on many UK rivers. Invertebrates may no longer be directly removed and a retained substrate may provide further ecological habitat.
Are there any other non-physical impacts?	Potential impact on flow conveyance.
What monitoring is in place?	Little or no current monitoring.
What are the general lessons to be learnt?	Practice of allowing partial or complete return of sediment features to FRM channels varies considerably nationally. Removal of sediments often of limited or no FRM benefit.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No (although there are scientific papers on substrate removal and recovery). Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor to non-existent.
Indication of order of costs	Can be a low cost (or even a no cost option) as maintenance is reduced or eliminated.
Is there an impact to the key use?	Potentially yes, especially if blockages of structures remains a risk.

5.1.22 Channel maintenance strategies and techniques

<table>
<tr><td colspan="3">Pressure: Operations and maintenance</td></tr>
<tr><td colspan="2">Sub-pressure: Removal/clearance of urban trash and wood</td><td>Impact: a) Loss of aquatic habitats; b) Transfer of fine sediment downstream</td></tr>
<tr><td>Number:22</td><td colspan="2">Mitigation measure: Channel maintenance strategies and techniques e.g. minimise disturbance to channel bed and margins</td></tr>
</table>

The effects of channel maintenance on aquatic habitats from many countries have been well documented (see Brookes, 1988; Swales, 1982). Operations have been adapted to follow good practice guidelines over recent years. National guidance on maintenance regimes has been produced in conjunction with Natural England and the Countryside Council for Wales (Environment Agency, 2002). Welsh Region of the Environment Agency (courtesy of Teg Jones, Environment Agency Welsh Region) makes the following recommendations for access to channel and removal of materials:

1. No tree surgery to be undertaken mid-March to mid-July without checking for the presence of nests. If nests found, work should not be undertaken until mid-July.

2. Trees to be removed entirely to be limited to those either collapsed into the channel or those that have become isolated from the bank, and are now growing within the channel. Where appropriate trees should be pegged back to help consolidate the bank.

3. Limbs to be felled generally to be limited to those either causing an obstruction to flows or threatening the stability of the tree. Overhanging branches provide cover for fish and birds and should not be trimmed unless strictly necessary. In situations where trees or shrubs threaten to be undermined or be ripped out by high flows coppicing all limbs and branches may be appropriate. Pollarding should be used where grazing pressure is an issue and fencing cannot be undertaken.

4. Mature trees should not be managed (except for light trimming) without surveys for potential use by otters, bats or birds. Sites used by otters and bats are protected by law.

5. Landowner permission should be sought for large, unwanted timber to be stacked and secured if necessary, to provide deadwood habitat. In some places there may be opportunities for the creation of informal log-pile otter holts. It is recommended that the advice of Biodiversity Officers is sought for suitable locations. 'Live' material namely willows should be considered for enhancement works, such as bank stabilisation work within the vicinity.

6. If material is to be utilised for revetment, care should be taken to avoid infilling pools providing good fish cover, avoid earth cliffs suitable for nesting kingfishers and sand martins and earth cliffs with mosses and liverworts.

7. Ensure that scrub is not damaged in gaining access to the site.

8. Brush should be burnt at least 10 m from trees or shrubs and NEVER on vegetated shoals, rock slabs or any land of ecological interest. If in doubt, consult Biodiversity Officers. In woodland, brush should be stacked above the flood level to provide habitat piles, with the landowner's permission.

9. In narrow channels with overhanging trees and shrubs, trimming of vegetation should be generally directed to the lower most branches only to provide a tunnel effect. However, where weed growth is not a potential problem and the watercourse is important as a fish nursery then opening the channel to light may be appropriate. If in doubt Biodiversity Officers should be consulted.

Table 5.14 Checklist: Channel maintenance strategies and techniques.

Measure No.22. Channel maintenance strategies and techniques	
Where has it been applied (geographically)?	Widespread application
At what scale (reach, individual river, catchment)?	Usually applied at reach and multi-reach scales (e.g. maintenance through an urban area).
To what type of environment has it been applied?	All river types from upland to lowland.
What is the basis for its use?	Limited.
Was it successful? What criteria used?	Limited monitoring.
What were the potential environmental risks/ benefits?	Few negative impacts: however, stockpiled timber or that pinned to banks can be subject to vandalism (especially in urban areas); potential for flooding if material re-entrained in flow. Considerable benefits.
What ecological impacts/improvements?	Measure/technique is good practice aimed at minimising ecological impacts; potentially good ecological potential (habitat) of wood placed on banks
Are there any other non-physical impacts?	Few but loose material stored or pinned close to a river bank could become re-entrained during a flood.
What monitoring is in place?	None apparent from this review ,
What are the general lessons to be learnt?	Careful/select removal of vegetation is intuitively a good thing,
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non–existent.
Indication of order of costs	Low additional cost to practice of debris removal etc.
Is there an impact to the key use?	If correctly and sensibly carried out then little or no impact.

5.1.23 Channel maintenance strategies and techniques

Pressure: Operations and maintenance		
Sub-pressure: Removal/clearance of urban trash and wood		Impact: a) Loss of aquatic habitats; b) Transfer of fine sediment downstream
Number:23	Mitigation measure: Channel maintenance strategies and techniques e.g. remove wood only when in the vicinity of an urban area	

The presence of wood within rivers has ecological benefits through the creation of a diverse habitat for many species of invertebrates, fish, mammals and birds (Neumann and Wildman, 2002; RSPB *et al.*, 1994). Staffordshire Wildlife Trust produced a short booklet on the benefits of wood in rivers. In North America, engineered log jams are used in large river systems. SEPA is also looking at the value of wood in rivers. A recent systematic review examined literature on the impacts of wood on salmonid population and habitat preference. The review (Stewart *et al*., 2006) suggests that there is strong increase in salmonid population with the presence of wood. Evidence also showed that salmonid species had a preference for wood habitat (Stewart *et al.*, 2006). Overall, the number of papers demonstrating a positive benefit for salmonid species suggests that wood has a positive role for fish numbers. This can be attributed to the fact that wood can create local morphological diversity through scour and deposition around the feature (David Sear, personal communication*)*, but of equal importance is the cover that these woody features provide (Neumann and Wildman, 2002; RSPB, 1994). For similar reasons these features can be important for a variety of reptiles and mammals, such as the otter. The development of wood in channels is also important for vegetation colonisation, as the wood provides nursery logs upon which woody species colonise (Fetherston *et al.*, 1995). The features are also efficient at trapping sediment and vegetation parts and propagules. The decomposition of wood is in itself a valuable source of coarse particular organic matter (CPOM) into the river system (Tabacchi *et al.*, 2000).

Wood can have a long residency time in catchments, amounting to hundreds or even thousands of years (Nanson *et al.*, 1995; Webb and Erskine, 2003). Wood is also important for floodplain habitats as the development of wood piles can have significant ecological benefits (WWF, 2004). However, in the severely managed landscapes of Western Europe (Piegay and Gurnell, 1997; Piegay *et al*, 1999) and Australia (Cottingham *et al*, 2003; Erskine and Webb, 2003: MacNally *et al*., 2001), large-scale removal of wood within the river systems and their floodplains has removed the ecological benefits of such features. Historically, this has been done when clearing land for agriculture but more recently it has been undertaken as a part of FRM. Recent evidence suggests that wood is only a problem if it is within one km of an urban area (Environment Agency, 1999). The increasing weight of evidence on the beneficial aspects of wood for habitat has led to the development of riparian vegetation management rules to ensure the continued supply of vegetation to the river system (Gippel, 1995). In Australia this has been further advanced with some projects trying to restore the level of dead wood in the river and floodplain system (MacNally *et al.*, 2001; Webb and Erskine, 2003).

Table 5.15 Checklist: Channel maintenance strategies and techniques.

Measure No.23. Channel maintenance strategies and techniques	
Where has it been applied (geographically)?	Limited application
At what scale (reach, individual river, catchment)?	Generally reach scale only.
To what type of environment has it been applied?	Rural areas.
What is the basis for its use?	Several publications detailing technique and potential benefits.
Was it successful? What criteria used?	Yes.
What were the potential environmental risks/ benefits?	There are pros and cons for FRM. Where flood risk is not a threat (such as in urban areas) wood within channel and in floodplain can assist in slowing the flow and enhancing floodplain storage. However, debris blockage in urban areas can cause a flood risk and even threaten stability of bridges.
What ecological impacts/improvements?	A reasonable number of studies showing the importance of retaining wood for many species.
Are there any other non-physical impacts?	Key impact on flood flow (generally negative in urban areas; potentially positive in rural). There is also the potential for wood to be washed into urban areas from upstream, thereby causing blockages.
What monitoring is in place?	No evidence from this review.
What are the general lessons to be learnt?	Retaining wood is a good thing. Prior to 'pioneer tree clearances' in the 1930s wood was much more common in rivers
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Yes in excess of 10. Has a digest of results been produced? No. Does a systematic review of the literature exist? Yes (produced in UK by the Centre for Evidence Based Conservation). Overall, what is the quality of the scientific evidence base? Moderate.
Indication of order of costs	Low to moderate costs (could be a cost associated with pinning wood to channel bed/banks).
Is there an impact to the key use?	Yes (see above): especially urban areas.

5.1.24 Vegetation control regime

<table>
<tr><td colspan="3">Pressure: Operations and maintenance</td></tr>
<tr><td colspan="2">Sub-pressure: Vegetation control</td><td>Impact: Physical disturbance of bed and or bank- increased sediment input; sediment mobilisation and loss of marginal/riparian vegetation</td></tr>
<tr><td>Number:24</td><td colspan="2">Mitigation measure: Vegetation control regime e.g. a) minimise disturbance to channel bed and margins, b) selective vegetation management, for example only cutting from one side of the channel, c) providing/reducing shade</td></tr>
</table>

The effects of channel maintenance on aquatic habitats have been well documented (see Brookes, 1988; Swales, 1982). Guidance exists on good practice measures developed by competent authorities. National guidance on maintenance regimes has been produced in conjunction with Natural England and the Countryside Council for Wales (Environment Agency, 2002). The Rivers Agency (NI) have recently updated (2007) its Watercourse Maintenance Manual. More locally, the Environment Agency in Wales (courtesy of Teg Jones, Environment Agency Welsh Region) recommends:

1. *Vegetation to be removed from central part of the channel to maintain flow capacity.*
2. *A band of vegetation to be left unmanaged on both sides of channel, around 30 per cent of total channel width.*
3. *No excavation/resectioning of banks or marginal shelf without authorisation from Biodiversity Officers.*
4. *Brambles to be cut back hard.*
5. *Autumn cut – bankside vegetation can be trimmed to no less than 30 cm.*

Table 5.16 Checklist: Vegetation control regime.

Measure No.24. Vegetation control regime	
Where has it been applied (geographically)?	Widespread application in water management areas (e.g. Wales),
At what scale (reach, individual river, catchment)?	Multi-reach; entire individual river,
To what type of environment has it been applied?	Ubiquitous application ,
What is the basis for its use?	Significant amount of technical guidance but this is intuitively a good measure,
Was it successful? What criteria used?	Limited measurement of success.
What were the potential environmental risks/ benefits?	No wider environmental risks identified.
What ecological impacts/improvements?	Potentially considerable ecological benefits because of retained habitat; few if any wider impacts.
Are there any other non-physical impacts?	Can be negative. There is uncertainty in assessing hydraulic roughness in channels and therefore selective clearance could have impact.
What monitoring is in place?	None became apparent during this review.
What are the general lessons to be learnt?	Intuitively a good thing;
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Yes but less than five papers. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Could actually represent a saving (by limiting extent of vegetation clearance.
Is there an impact to the key use?	If properly implemented (in an adaptable way) there should not be a significant impact on use.

5.1.25 Techniques to prevent transfer of invasive species

Pressure: Operations and maintenance		
Sub-pressure: Vegetation control		Impact: Physical disturbance of bed and or bank- increased sediment input; sediment mobilisation and loss of marginal/riparian vegetation
Number:25	Mitigation measure: Techniques to prevent transfer of invasive species e.g. training of operational staff	

Good practice guidelines exist on invasive species. For example, the Environment Agency in Wales has developed guidelines on invasive species through a series of fact sheets (http://www.environment-agency.gov.uk/homeandleisure/wildlife/31350.aspx). A checklist has not been developed for this measure but will be produced at a later stage of the project if sufficient information becomes available.

5.1.26 Techniques to align and attenuate flow to limit detrimental effects of these features

Pressure: Operations and maintenance		
Sub pressure: Pipes, inlets, outlets and off-takes		Impact: Hydromorphological alterations of water and sediment inputs through artificial means
Number:26	Mitigation measure: Techniques to align and attenuate flow to limit detrimental effects of these features	

Although this mitigation measure is feasible, it has yet to be undertaken as part of general practice. A checklist has not been produced for this technique but will be produced at a later stage of the project if sufficient information becomes available.

5.1.27 Water level management

Pressure: Operations and maintenance		
Sub-pressure: Water level		Impact: Effect on aquatic habitat
Number:27	Mitigation measure: Water Level Management Plan (WLMP)	

Manipulation of water levels can lead to loss of habitats (with impacts on riparian habitats and vegetation at low water level and water logging at high water levels). Water Level Management Plans (WLMPs) were first introduced in 1991 and they impact on a wide range of water bodies. For example, WLMPs for Internal Drainage Boards need to carefully balance land drainage and conservation legislation by integrating water level management requirements. A WLMP can be ruled out where Natural England/CCW and the operating authority agree that groundwater levels are not affected by drainage or flood control within or outside the site. The water levels (hydrology) need to be obtained from factual data held by the operating authority, site inspection and assumption. Monitoring is a key component of water level management plans. Few papers have examined the potentially negative effects of raising water levels on rare grassland, for example (Swetnam *et al*., 1998).

Table 5.17 Checklist: Water Level Management Plan.

Measure No.27. Water Level Management Plan	
Where has it been applied (geographically)?	Application in water level management areas (including IDBs) in England and Wales. To date has been limited by availability of funding.
At what scale (reach, individual river, catchment)?	Usually the whole of an IDB (for example) but may be part of a water body in a fluvial system.
To what type of environment has it been applied?	Generally low-lying areas which are drained for farming or other purposes.
What is the basis for its use?	Considered to be a good thing intuitively.
Was it successful? What criteria used?	Limited measurement of success to date.
What were the potential environmental risks/ benefits?	Wider environmental risk includes detriment to farmland or other interests.
What ecological impacts/improvements?	Potentially considerable ecological benefits because of retained habitat.
Are there any other non-physical impacts?	Can be potentially negative, particularly if plan is not accurate first time round
What monitoring is in place?	Basic forms of monitoring in place with every agreed plan but little or no scientific analysis of data
What are the general lessons to be learnt?	Intuitively a good thing
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Only one found as part of this review. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Defra guidance suggests that costs are relatively low. Cost of producing a plan should be around £2,000.
Is there an impact to the key use?	If properly implemented (in an adaptable way) there should not be a significant impact on use

5.1.28 Land management strategies

Pressure: Land use		
Sub-pressure: Intensive land use		Impact: Changes to vegetation, hydrology and sediment supply
Number:28	Mitigation measure: Land management strategies (develop and revise), including SUDS and changes in farming practices and forest management	

Land management strategies are emerging as a mitigation measure for FRM (see Section 3 on floodplain measures). Potentially they could have significant impacts on the hydrology of a catchment. There is a distinction between rural land use management and urban spatial land use management, that is, minimising development in the floodplain. Land management strategies are now receiving a lot of attention as part of a portfolio of techniques under the sustainable flood management umbrella. There are potential long-term benefits on climate change timescales. General principles in the management of landscape in changing catchment hydrology and geomorphology is well understood (see Downs and Gregory, 2004; Newson, 1992). There is also a growing body of literature which advocates a catchment approach to restoration (Harper *et al.*, 1999). This includes an examination of land use (urban, forestry, agricultural) and its effects on biota within river and floodplain systems. For example, catchment-sensitive farming practices can reduce fine sediment input into river systems, which has significant effects on aquatic biota (Wood and Armitage, 1997). Likewise, appropriate management of our forests can have significant advantages for our aquatic systems, particularly in the development of a buffer zone around the river which maximises habitat diversity (Dobson and Cariss, 1999). Transverse forest strips on floodplains have been promoted for mitigation of flood risk in Dumfries (Ronnie Falconer, personal communication*)*. As this is not a direct FRM or LD measure, a checklist has not been developed at this stage of the project. Anti-livestock fencing is widely used and can prevent cattle poaching in a catchment, causing erosion of banks and increased sediment supply in the water body or water bodies downstream. There are several ongoing examples of projects in the UK where sediment management is an issue.

5.2 Lakes

The checklist developed for lakes is included in Appendix B. The mitigation measures are listed below and cross-referenced to the identical measures used for rivers (see Table 5.18 below and Section 5.1 above). Apart from two key FRM measures for natural lakes, it was not considered of value at this stage to produce an exhaustive review of techniques for lakes as this would be largely academic (there is no published evidence of these measures/techniques).

Table 5.18 Cross-references to rivers.

<table>
<tr><td colspan="3">Pressure: Bank and bed reinforcement/realignment</td><td rowspan="3">Refer to 5.1.1</td></tr>
<tr><td colspan="2">Sub-pressure: Hard protection
e.g. Steel piling, flood walls and gabion baskets</td><td>Impact: Modification to structure and condition of lake shore zone (loss of riparian zone/marginal habitat/loss of lateral connectivity)</td></tr>
<tr><td>Number: 1</td><td colspan="2">Mitigation measure: Remove hard reinforcement/ revetment, or replace with soft engineering solution</td></tr>
<tr><td colspan="3">Pressure: Bank and bed reinforcement/realignment</td><td rowspan="3">Refer to 5.1.2</td></tr>
<tr><td colspan="2">Sub-pressure: Hard protection
e.g. Steel piling, flood walls and gabion baskets</td><td>Impact: Modification to structure and condition of lake shore zone (loss of riparian zone/marginal habitat/loss of lateral connectivity)</td></tr>
<tr><td>Number: 2</td><td colspan="2">Mitigation measure: Preserve and enhance ecological value of marginal aquatic habitat, banks and riparian zone</td></tr>
<tr><td colspan="3">Pressure: Bank and bed reinforcement/realignment</td><td>Refer to 5.1.3;</td></tr>
</table>

Sub-pressure: Channelization of inflows and outlets		Impact: Straightening, widening, deepening of channel at approach to river mouths and outlets (modifications to flow dynamics, level, depth variation, quantity and structure of substrate, structure and conditions of lake shore zone)	5.1.10; 5.1.11
Number: 3	Mitigation measure: Amend design (re-naturalise) bed and banks		
Pressure: Impounding			See Section 5.2.1 below
Sub-pressure: Control structures on inflows and outlets		Impact: Changes in lake base level and alteration to flow regime downstream. Loss of continuity (sediment and biota)	
Number: 4	Mitigation measure: Undertake operational and structural changes to control structures		
Pressure: Impounding			Refer to 5.1.8
Sub-pressure: Control structures on inflows and outlets		Impact: Changes in lake base level and alteration to flow regime downstream. Loss of continuity (sediment and biota)	
Number: 5	Mitigation measure: Install fish pass		
Pressure: Impounding			Refer to 5.1.1; 5.1.9
Sub-pressure: Control structures on inflows and outlets		Impact: Changes in lake base level and alteration to flow regime downstream. Loss of continuity (sediment and biota)	
Number: 6	Mitigation measure: Remove hard reinforcement/ revetment, or replace with soft engineering solution		
Pressure: Shoreline modification			Refer to 5.1.16
Sub-pressure: Flood banks and flood walls		Impact: Modification to structure and condition of lake shore zone (loss riparian zone/marginal habitat/loss of lateral connectivity)	
Number: 7	Mitigation measure: Remove flood banks/walls		
Pressure: Shoreline modification			Refer to 5.1.17
Sub-pressure: Flood banks and flood walls		Impact: Modification to structure and condition of lake shore zone (loss riparian zone/marginal habitat/loss of lateral connectivity)	
Number: 8	Mitigation measure: Set-back flood banks		
Pressure: Operations and maintenance			Refer to 5.1.19
Sub-pressure: Sediment management (including dredging)		Impact: Direct loss of/impact on benthic habitats/hydromorphology. Alteration to bathymetry. Increase in turbidity and fine sediment transfer downstream.	
Number: 9	Mitigation measure: Do not dredge. Reduce the source of sediment entering the lake with good catchment and shoreline management practices (e.g. developing buffer strips alongside watercourses and lakes)		
Pressure: Operations and maintenance			See Section 5.2.2. below
Sub-pressure: Lowering/draining		Impact: Direct loss of/impact on benthic habitats/hydromorphology. Modification to flow regime.	
Number: 10	Mitigation measure: Adopt an appropriate release strategy (e.g. phased de-watering, small frequent release cycles)		

Pressure: Land use			Refer to 5.1.25
Sub-pressure: Intensive land use		Impact: Changes to vegetation, hydrology and sediment supply	
Number: 11	Mitigation measure: Land management strategies (develop and revise)		

5.2.1 Operational and structural changes to control structures

Pressure: Impounding		
Sub-pressure: Control structures on inflows and outlets		Impact: Changes in lake base level and alteration to flow regime downstream. Loss of continuity (sediment and biota)
Number: 4	Mitigation measure: Undertake operational and structural changes to control structures	

Some control structures are likely to have been developed or proposed at lake outlets for water resources use as well as FRM purposes. Modifications to the structure and/or operation could improve the longitudinal continuity (sediment and biota - the riverine benefits may be greater than the lacustrine benefits) and minimise the impact on lake outlet habitats and macroinvertebrates (Brunke, 2004). Control structures alter numerous parameters including water depth and oxygen levels. Constructing a fish pass (see 5.1.8) and removing or lowering the control structure (see 5.1.9) could be a mitigation measure. Drawdown issues (reducing the water level) are also important to consider (see below Measure No. 10) if operational changes are proposed.

Table 5.19 Checklist: Operational and structural changes to control structures.

Measure No.4. Undertake operational and structural changes to control structures	
Where has it been applied (geographically)?	No examples. Lake Bala has a large control structure for water resources and flood risk control but mitigation measures/techniques unlikely.
At what scale (reach, individual river, catchment)?	The measure might be applied at a local scale but altering one structure can sometimes have a wider benefit.
To what type of environment has it been applied?	Not applicable.
What is the basis for its use?	Practically no information in grey literature or good practice guidelines.
Was it successful? What criteria used?	No recorded evidence of criteria being used.
What were the potential environmental risks/ benefits?	Considerable benefits in terms of re-establishing continuity. Risks include short-term release of sediments from impounded reach; potential for downstream erosion and possible stability issues (see Table 5.5).
What ecological impacts/improvements?	More natural lake outlets and improved continuity.
Are there any other non-physical impacts?	Altering FRM structures can have a significant adverse impact on use. To solve a flooding problem an alternative solution may need to be sought (e.g. increased use of floodplain storage).
What monitoring is in place?	No monitoring studies were found.
What are the general lessons to be learnt?	Possibly few opportunities where modification to the control structure would be viable.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non-existent
Indication of order of costs	In itself a low cost option. However could have a high cost if alternative FRM options have to be implemented.
Is there an impact to the key use?	Potentially a significant impact on use unless the FRM structure in its current form is regarded as 'not fit for purpose'.

5.2.2 Release strategy

Pressure: Operations and maintenance		
Sub-pressure: Lowering/draining		Impact: Direct loss of/impact on benthic habitats/ hydromorphology. Modification to flow regime.
Number: 10	Mitigation measure: Adopt an appropriate release strategy (e.g. phased de-watering, small frequent release cycles)	

Some papers suggest that lake drawdown could have both positive and negative impacts. Positive impacts include the establishment of emergent plants, reducing turbidity and controlling macrophytes (Turner *et al*., 2005). There are also potential benefits for fish migration from controlled freshets. Negative impacts include stimulating invasive plants, nutrient release, algal blooms, reduction in some species and low dissolved oxygen (Cooke, 1980). Stability issues associated with rapid drawdown also need to be considered. The impacts are likely to be site-specific and to depend on the frequency and timing of the drawdown.

Table 5.20 Checklist: Release strategy.

Measure No.10 Adopt an appropriate release strategy (e.g. phased de-watering, small frequent release cycles)	
Where has it been applied (geographically)?	Example of drawdown impacts from Europe.
At what scale (reach, individual river, catchment)?	At local and downstream (reach or wider) scale.
To what type of environment has it been applied?	Boreal forest lake is one recent example where impacts have been tested.
What is the basis for its use?	A range of literature illustrating the mechanisms.
Was it successful? What criteria used?	No recorded evidence of phased dewatering or optimum release strategies being conducted.
What were the potential environmental risks/ benefits?	No significant environmental risks.
What ecological impacts/improvements?	Reduces adverse impact to lake habitats and river habitats.
Are there any other non-physical impacts?	May have an impact on FRM. Stability issues associated with rapid drawdown may need to be considered.
What monitoring is in place?	No monitoring studies were found.
What are the general lessons to be learnt?	Impacts are site-specific and vary with frequency and timing of release.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non-existent
Indication of order of costs	Low or no cost
Is there an impact to the key use?	Potentially a significant impact on use.

5.3 Transitional and coastal waters

Overall there is much less literature on transitional and coastal waters than on rivers. Some literature derived from riverine environments may be applicable to transitional waters.

5.3.1 Removal of hard engineering structures

Pressure: Shoreline/Bank reinforcement		
Description: Flood protection, erosion control or other bank elevation or strengthening using flood walls or embankments; bank protection using gabion baskets or blankets, boulders, sheet piling, wood, geotextiles etc.; road embankments		Impact: Coastal squeeze; disruption of tidal flow and channel interaction; disruption/alteration of estuarine process dynamics; modification of sediment dynamics; disruption of natural habitats; loss of faunal nursery, refuge and feeding areas
Number:1	Mitigation measure: Removal of hard engineering structures (e.g. naturalisation)	

The removal of hard engineering structures, for example a seawall, aims to eliminate their impact on natural processes so that through time, these processes will re-establish. Historically this has not been extensively undertaken, largely as a consequence of overriding public interest (through perceived risk and hazard: removal of hard defences significantly increases the frequency with which the formerly protected hinterland floods and potentially erodes) or financial cost (removal of seawalls and embankments is extremely expensive).

Abbotts Hall in the Blackwater Estuary, UK is an example of shoreline reinforcement removal. Whilst it is described as a managed realignment scheme, essentially the former flood protection, an earth seawall, has been removed and the new line of protection is now provided by the natural relief of the formerly protected/reclaimed hinterland (Nottage and Robertson, 2005).

Puget Sound in Washington, USA was armoured in the 1970s; since then, beach elevations in Seahurst Park have dropped three to four feet due to wave scouring and the disconnection of the beach from primary sediment sources. These changes have significantly degraded habitat quality for salmon and the organisms they depend on, particularly forage fish. From November 2004 to February 2005, some 1,400 feet of failing shoreline armouring was removed and the beach was restored to natural conditions in the south section of Seahurst Park. Through reconnection of the sediment supply, the beach will be naturally replenished, removing the sediment deficit in the area. The project goal is to restore self-sustaining nearshore habitats and ecological processes to avoid the need for ongoing human intervention (King County Department of Natural Resources and Parks, 2006, http://dnr.metrokc.gov/WRIAS/9/SRFB-seahurst-park-bulkhead-study.htm).

Table 5.21 Checklist: Removal of hard engineering structures.

Measure No.1. Removal of hard engineering structures (e.g. naturalisation)	
Where has it been applied (geographically)?	Very limited number of examples from UK and USA.
At what scale?	Very localised length of shoreline.
To what type of environment has it been applied?	Predominantly lower energy river systems.
What is the basis for its use?	Limited grey literature/professional guidance.
Was it successful? What criteria used?	Unknown at present.
What were the potential environmental risks/ benefits?	Potential risk of erosion of hinterland.
What ecological impacts/improvements?	Goal is to restore self-sustaining nearshore habitats and ecological processes.
Are there any other non-physical impacts?	Increased frequency of flooding.
What monitoring is in place?	Limited long-term monitoring (results not known).
What are the general lessons to be learnt?	If measures/techniques are properly designed, implemented and adaptively managed then successful.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non-existent.
Indication of order of costs	Can have low to moderate capital costs (removing structures); may be additional costs for adaptive management and monitoring
Is there an impact to the key use?	Cannot remove an effective flood wall without considering alternative means of flood protection (e.g. if urban area present).

5.3.2 Modify existing structures

Pressure: Shoreline/Bank reinforcement		
Description: Flood protection, erosion control or other bank elevation or strengthening using flood walls or embankments; bank protection using gabion baskets or blankets, boulders, sheet piling, wood, geotextiles, etc.; road embankments		Impact: Coastal squeeze; disruption of tidal flow and channel interaction; disruption/alteration of estuarine process dynamics; modification of sediment dynamics; disruption of natural habitats; loss of faunal nursery, refuge and feeding areas
Number:2	Mitigation measure: Modify existing structures	

This method of mitigation involves modifying the existing hard flood defence structure to enhance biodiversity. Within the scientific literature on coastal and transitional waters, there is little evidence of this type of measure/technique being used, or the level of mitigation it may provide. However, the report authors obtained anecdotal evidence of such schemes in the UK (see below) but to date there has been insufficient monitoring to substantiate any claims of mitigation/habitat enhancement.

Barking Creek, Essex was an area for redesign within the Environment Agency's London Tidal Flood Defences. The design of a new frontage for Barking Creek provided an opportunity to enhance the biodiversity of the area by modifying the existing defence structure. The proposed flood defence frontage was designed with this in mind, to encourage sensitive tidal habitats to increase botanical diversity, including the introduction of reed beds (a Biodiversity Action Plan habitat), at the face of the steel sheet piling. Options for improving the botanical diversity at the adjacent frontage were limited, but some improvements were incorporated into the design such as a terrace. This terrace has been filled with gravel and planted to encourage aquatic invertebrates and to act as a refuge for migratory fish species.

Table 5.22 Checklist: Modify existing structures.

Measure No.2. Modify existing structures	
Where has it been applied (geographically)?	Limited number of examples from UK.
At what scale?	Very localised length of shore.
To what type of environment has it been applied?	Barking Creek is low energy (transitional).
What is the basis for its use?	Little practical guidance available.
Was it successful? What criteria used?	Unknown.
What were the potential environmental risks/ benefits?	None ascertained.
What ecological impacts/improvements?	Goal is to encourage sensitive tidal habitats to increase botanical diversity.
Are there any other non-physical impacts?	Negligible effect.
What monitoring is in place?	Macroinvertebrate monitoring planned for 2008.
What are the general lessons to be learnt?	If measures/techniques are properly designed, implemented and adaptively managed then have a higher chance of being successful.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non-existent
Indication of order of costs	Can have low to moderate capital costs.
Is there an impact to the key use?	Cannot modify an effective flood barrier without considering implications.

5.3.3 Replacement with soft engineering solution

Pressure: Shoreline/Bank reinforcement	
Description: Flood protection, erosion control or other bank elevation or strengthening using flood walls or embankments; bank protection using gabion baskets or blankets, boulders, sheet piling, wood, geotextiles, etc.; road embankments	Impact: Coastal squeeze; disruption of tidal flow and channel interaction; disruption/alteration of estuarine process dynamics; modification of sediment dynamics; disruption of natural habitats; loss of faunal nursery, refuge and feeding areas
Number:3	Mitigation measure: Replacement with soft engineering solution

This mitigation measure involves the removal or modification of the shoreline/bank reinforcement and its replacement with a soft engineering solution. Within coastal and transitional waters this type of solution can cover a range of different options that include beach nourishment and inter-tidal sediment recharge (see also Section 5.3.10).

5.3.3.1 Beach nourishment

Beach nourishment or recharge is the process of directly increasing the volume of beach using imported material, usually to improve its capacity as a coastal defence (Brampton *et al*., 1996). It is now the principal option for shore protection in countries such as the USA and the Netherlands (Nordstrom, 2005). Speybroeck *et al*. (2006) describe beach nourishment as a better and more ecologically sound alternative to the construction of hard structures to protect a coast against detrimental erosive effects. However, Nordstrom (2005) considers that research is needed to improve the compatibility of schemes.

The use of beach nourishment as a means of coastal protection has a relatively short history, with the first large projects in Europe and North America executed within the last 50 years or so (Speybroeck *et al*., 2006). The majority of European projects have been undertaken in Spain, the Netherlands, France, Italy, Denmark and the UK.

Beach nourishment projects have been subject to, and have benefited from, studies in increasing numbers and scope (particularly in the USA) investigating their effects on ecology and habitat (Rakocinski *et al.,* 1996; Peterson *et al.*, 2000; Minerals Management Service, 2001; Greene, 2002; Peterson and Bishop, 2005).

In general, these projects and studies have shown that beach nourishment is not an entirely ecologically sound coastal defence alternative, but should be favoured over alternatives to nourishment (such as hard protection) which tend to be more damaging to shoreline ecology and habitats. Beach nourishment can have a negative effect in the short-term on crabs, surf fish and birds (which feed on invertebrates (Peterson *et al.,* 2000). Other studies have shown short-term negative effects on benthos (such as Miller *et al.,* 2002). Speybroeck *et al*. (2006) present guidelines for ecologically good practice of beach nourishment.

5.3.3.2 Inter-tidal sediment recharge

Muddy dredged material has been used for inter-tidal sediment recharge in the UK as a method for flood defence and habitat management. The Centre for Environment, Fisheries and Aquaculture Science (CEFAS) states that beneficial placement of maintenance-dredged material in the UK is currently limited to small-scale trials. The reasons for this are two-fold:

Current understanding of biological processes following sediment deposition is poor.

Lack of knowledge of the rates of invertebrate recovery limits our ability to predict indirect effects of sediment placement on bird and fish populations, which is of particular importance as the majority of beneficial use schemes are located on estuarine inter-tidal habitats, important for sustaining these populations.

Inter-tidal sediment recharge at Horsey Island, Hamford Water, Essex was the first application of dredged material for 'beneficial use' in the UK. In total, a volume of 18,000 m^3 of coarse dredged material was sprayed onto the mid inter-tidal area by rainbow discharge from a self-load, self-empty discharge vessel at high water on spring tides. The material was used to fill gaps between a line of disused Thames Lighter barges that were grounded on the foreshore and had previously provided protection.

Some scientific publications support the ecological impacts of this measure/technique. These derive from a six-year research programme by CEFAS. For example, Bolam *et al.* (2006) determined macro and meiofaunal recolonisation of dredged material. Other papers are Schratzberger *et al.* (2006) looking at colonisation by nematodes; Widdows *et al.* (2006) who examined changes in biota more generally and Bolam *et al*. (2003) who studied invertebrate recolonisation on fine-grained sediments.

Table 5.23 Checklist: Replacement with soft engineering solution.

Measure No.3. Replacement with soft engineering solution	
Where has it been applied (geographically)?	Various European countries including the UK and USA.
At what scale?	Very localised lengths of coast.
To what type of environment has it been applied?	High energy coasts and low energy estuaries.
What is the basis for its use?	Limited practical guidance (although understanding is improving all the time).
Was it successful? What criteria used?	Fifty years of experience of beach nourishment.
What were the potential environmental risks/ benefits?	Erosion of emplaced sand or silt but slows down erosion of coastline.
What ecological impacts/improvements?	Unproven; can be negative, but generally less damaging than hard protection.
Are there any other non-physical impacts?	Softer defences could be eroded and then breached.
What monitoring is in place?	Monitoring inherent in all schemes licensed in the UK.
What are the general lessons to be learnt?	If measures are properly designed, implemented and adaptively managed then higher chance of success. Caution is recommended for inter-tidal sediment recharge as ecological effects not well understood (to date only small trials have been carried out in UK).
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Yes. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor.
Indication of order of costs	Can have low to moderate capital costs. Can also be used as mitigation measure to offset impacts of navigation maintenance dredging.
Is there an impact to the key use?	Potentially yes if soft engineering solution is breached.

5.3.4 Bank reprofiling

Pressure: Shoreline/Bank reinforcement		
Description: Flood protection, erosion control or other bank elevation or strengthening using flood walls or embankments; bank protection using gabion baskets or blankets, boulders, sheet piling, wood, geotextiles, etc.; road embankments		Impact: Coastal squeeze; disruption of tidal flow and channel interaction; disruption/alteration of estuarine process dynamics; modification of sediment dynamics; disruption of natural habitats; loss of faunal nursery, refuge and feeding areas
Number:4	Mitigation measure: Bank reprofiling	

This mitigation measure involves the regrading/reprofiling of flood embankments to lower gradients, allowing the establishment of vegetation and more effective dissipation of wave energy. It is anticipated that this type of mitigation would probably only be used in upper estuaries where the channels remain more river-like.

The impacts of reprofiling of watercourses are well understood and documented in the scientific literature (see reviews in Brookes 1988; Swales, 1982) (see also Section 5.1.10 above). Loss of morphological diversity is one of the key issues associated with this sub-pressure. A number of recent projects have sought to restore this valuable habitat on rivers (Clark and Wharton, 2000 and Chovanec *et al.*, 2002). However, in areas where this habitat is already present the focus should recognise this fact and preserve the habitat. Statutory authorities (such as Welsh Region of the Environment Agency) have developed good practice for retaining marginal aquatic habitats on rivers.

On transitional waters, reprofiling can be undertaken as part of a managed realignment scheme. A separate checklist is not given here.

5.3.5 Managed realignment of flood defence

Pressure: Shoreline/Bank reinforcement		
Description: Flood protection, erosion control or other bank elevation or strengthening using flood walls or embankments; bank protection using gabion baskets or blankets, boulders, sheet piling, wood, geotextiles, etc.; road embankments		Impact: Coastal squeeze; disruption of tidal flow and channel interaction; disruption/alteration of estuarine process dynamics; modification of sediment dynamics; disruption of natural habitats; loss of faunal nursery, refuge and feeding areas
Number: 5	Mitigation measure: Managed realignment of flood defence	

Managed realignment most commonly involves the deliberate breaching or removal of existing seawalls, embankments or dikes in order to allow the waters of adjacent coasts, estuaries or rivers to inundate the land behind. It was previously known as managed retreat in the UK and in the Netherlands is known as de-polderisation. Depending upon the topography of the land behind the breached wall, there may be a need to build a new line of defence inland of the original wall. In most instances the newly flooded land is low-lying coastal floodplain and therefore a new line of defence is required to protect the hinterland behind. However, on areas with increasing elevation inland (such as at Abbotts Hall in the Blackwater Estuary, see Section 5.3.1 above) either no new line of defence or only a partial defence is required.

This landward movement of the primary sea defence line is generally used as a defining characteristic of managed realignment. However, the term 'managed realignment' can be applied to other coastal habitat creation methods that extend inter-tidal habitats in a seaward direction. For example, the new Shoreline Management Plan guidance for England and Wales (issued in 2006) defines managed realignment as '*the process of allowing the coastline to move backwards or forwards with management to control or limit that movement'*. This definition would also apply to activities such as sediment recharge (discussed above) which can be used to increase the areal extent of existing inter-tidal habitats.

Coastal and estuarine managed realignment – design issues by Leggett *et al*. (2004) is a document produced by the Construction Industry Research and Information Association (CIRIA) to disseminate guidance on design issues for managed realignment projects, providing information on design and management processes and reviewing schemes implemented in the UK. Similarly the Online Managed Realignment Guide compiled by Associated British Ports Marine Environmental Research (ABPmer, 2007) provides detailed information on eight selected case study managed realignment sites: six in the UK, one in Germany and one in the Netherlands. Other useful guides to managed realignment in the UK published over the last two decades have covered a number of aspects, including (following Pontee *et al.*, 2006):

- lessons learned on existing schemes (English Nature, 1995; ABP Research, 1998; Atkinson *et al.,* 2001);
- constraints and incentives to implementation (Defra, 2002);
- site selection (Parker *et al.,* 2004);
- monitoring requirements;
- design guides (Leggett *et al*., 2004).

Leggett *et al*. (2004) consider the majority of managed realignment schemes to require a monitoring system, the nature of which will vary according to the drivers for the site, the geomorphological and hydrodynamic assessment, and the requirements of consents and licenses. The greater the risks identified, the greater the monitoring requirements are likely to be. An outline of monitoring requirements is given in the CIRIA guidance document. A further example of these is given by Garbutt *et al*. (2006) who monitored the development of inter-tidal habitats on former agricultural land after managed realignment of coastal defences at Tollesbury, Essex.

Research into the impact of marsh vegetation on wind-wave height reduction has also indicated that the siting of tidal restoration (managed realignment) schemes within an estuary can play an important role in reducing tidal amplitude (Pethick, 2002). The results suggest that the reduction of tidal amplitude depends on the location of the site within the estuary and is of fundamental importance. Model predictions for a theoretical 300 hectare restoration (realigned) site demonstrated that as the location of the site was moved landward along the estuary, the impact on tidal maximum elevation increased (Pethick, 2002). If results of the modelling can be verified in the field, it would mean that managed realignment could reduce tidal flood risk by reducing tidal amplitudes and decreasing erosion rates by dissipating wind-wave energy.

Pontee *et al*. (2006) discuss the removal of fronting flood embankment and replacement with reprofiled banked realignment at Welwick in the Humber Estuary to improve physical and biological connectivity with the wider estuary compared with breached realignment schemes. They suggest that to date, breach realignments have been the most popular schemes adopted in the UK, the main reasons being that they promote higher accretion rates and more rapidly raise marsh bed levels, increasing marsh development. Pontee *et al*. (2006) suggest that in the future, breached realignment could be used as an intermediate step, prior to the wholesale removal of existing flood embankments once marsh vegetation has become established.

In terms of ecological impacts per se, there is limited (but growing) evidence. Maris *et al.* (2007) demonstrated the creation of ecological conditions for tidal marsh development. For the Sieperda Tidal Marsh in the Netherlands, Eertman *et al*. (2002) reported on morphological and ecological change ten years after the breaching of a dike. Within five years, salt marsh vegetation had recovered together with a macrofauna typical of estuarine mudflats. Birds characteristic of salt marsh were observed breeding or seen foraging in the marsh. In contrast, Wolters *et al*. (2005) showed that recovery may be constrained by limited diaspore dispersal locally. Establishment of species absent from the adjacent marsh may be dependent on birds and humans as the main dispersal agents. Paramor and Hughes (2005) found from experimental work that saltmarsh development was limited where accretion of sediment was rapid and buried seeds. These sites also showed rapid invertebrate colonisation.

Some examples of managed realignment schemes in the UK include:

Orplands, Essex: breached in April 1995. Landward realignment of existing sea defence; created 40 ha of saltmarsh (Nottage and Robertson, 2005). For the Orplands project, Atkinson *et al.* (2004) found that in the first year of inundation bird communities were dominated by terrestrial species and that water bird communities rapidly developed during the second and third years. After five years communities were similar to surrounding mudflats with some notable differences. For example, the Oystercatcher *Haematopus ostralegus* did not occur at the site due to the absence of large bivalves.

Abbotts Hall, Essex: regulated tidal exchange implemented in 1995, realignment carried out in 2002; 85 ha habitat created including mudflat, saltmarsh, transitional grassland, grazing marsh and freshwater (Nottage and Robertson, 2005).

Nigg Bay, Cromarty Firth, Scotland: breached in 2003; landward realignment of an existing line of sea defence through breaching of the seawall to create up to 25 ha of saltmarsh and mudflat; first planned managed realignment scheme in Scotland (Nottage and Robertson, 2005).

Freiston Shore, The Wash, Lincolnshire: landward realignment of existing line of sea defence implemented in August 2002; 66 ha of saltmarsh created and 15 ha saline lagoon landward of new defence alignment; £400,000 monitoring programme from one year before breaching to five years afterwards; detrimental impacts experienced by a nearby oyster farm (Nottage and Robertson, 2005).

A scheme currently in progress is the Wallasea Island Scheme www.abpmer.net/wallasea/.

Table 5.24 Checklist: Managed realignment of flood defence.

Measure No.5. Managed realignment of flood defence	
Where has it been applied (geographically)?	Considerable UK experience (a few examples in the remainder of Europe).
At what scale?	Generally less than 100 ha of saltmarsh creation.
To what type of environment has it been applied?	Predominantly lower energy transitional waters systems.
What is the basis for its use?	Considerable number of guidelines from UK and USA. Also considerable Dutch literature (not in English).
Was it successful? What criteria used?	Generally successful at creating marsh and inter-tidal habitat.
What were the potential environmental risks/ benefits?	Potential risk of erosion of hinterland; adverse impacts on other uses (e.g. silt release impacting an oyster farm).
What ecological impacts/improvements?	Example goal is to restore self-sustaining saltmarsh habitats and ecological processes.
Are there any other non-physical impacts?	Potential impact on tidal peak.
What monitoring is in place?	Generally not carried out unless some monitoring is in place. Freiston Shore (Lincolnshire) has involved monitoring before and for 5 years after breaching. Results now reaching the literature.
What are the general lessons to be learnt?	If measures are properly designed, implemented and adaptively managed then a higher chance of success. Monitoring is seen by experts as key to success (before and after breaching).
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? Yes (five key papers sourced). Has a digest of results been produced? No Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor to moderate.
Indication of order of costs	Can have low to moderate capital costs (e.g. removing embankments); may be additional high costs for adaptive management and monitoring (Freiston has cost £400,000 in monitoring costs).
Is there an impact to the key use?	Cannot remove an effective flood structure without considering alternative means of flood protection (e.g. if urban area present). However, this has not been an issue for the examples completed to date in the UK.

5.3.6 Restore/create/enhance aquatic and marginal habitats

<table>
<tr><td colspan="3">Pressure: Shoreline/Bank reinforcement</td></tr>
<tr><td colspan="2">Description: Flood protection, erosion control or other bank elevation or strengthening using flood walls or embankments; bank protection using gabion baskets or blankets, boulders, sheet piling, wood, geotextiles, etc.; road embankments</td><td>Impact: Coastal squeeze; disruption of tidal flow and channel interaction; disruption/alteration of estuarine process dynamics; modification of sediment dynamics; disruption of natural habitats; loss of faunal nursery, refuge and feeding areas</td></tr>
<tr><td>Number:6</td><td colspan="2">Mitigation measure: Restore/create/enhance aquatic and marginal habitats</td></tr>
</table>

One of the most common objectives of habitat creation and restoration schemes in transitional and coastal waters in the UK is to enhance flood defence effectiveness. Saltmarshes are widely recognised for their sea defence value (Moller *et al.,* 2001) demonstrated by their ability to dissipate wave energy and stabilise sediments, thereby reducing erosion whilst at the same time offering protection to seawalls and embankments from wave attack (ABP Research and Consultancy, 1998). Here in the UK, saltmarsh restoration has been increasingly recognised as a means of providing a long-term, sustainable approach to flood and sea defence with the added advantage of enhancing the conservation value of a natural habitat.

Saltmarsh and inter-tidal restoration/creation helps to meet the objectives of:

- Providing compensatory areas of saltmarsh habitat to make up for losses of saltmarsh habitat attributed to a ‘hold the line’ coastal flood management policy (Nottage and Robertson, 2005).
- Satisfying Defra’s requirement for managed realignment to be evaluated as an option whenever capital works are being considered for sea and coastal defences (Nottage and Robertson, 2005).
- Provision of socio-economic advantages: reduced length of flood defence, new defences requiring less maintenance and opportunities for the development of multi-functional schemes (Nottage and Robertson, 2005).
- A variety of guidebooks and good practice guidelines have been produced on the creation of inter-tidal and saltmarsh habitat (see Niedowski, 2000; Atkinson *et al.*, 2001; Nottage and Robinson, 2005).

A number of monitoring and research studies have been carried out to establish how successful inter-tidal and saltmarsh restoration schemes have been in enhancing and recreating habitat and biodiversity. Examples of these from the scientific literature include Lindig-Cisneros and Zedler (2004) and Roman *et al*. (2002) who investigated vegetation colonisation; Tupper and Able (2000), Gray *et al*. (2002), Jivoff and Able (2003) and Moseman *et al.* (2004) who looked at faunal responses; and Garbutt *et al*. (2006) who adopted a more ecosystem-based approach. Underwood (1997) looked specifically at microalgal colonization in a saltmarsh restoration scheme. Warren *et al.* (2002) examined saltmarsh restoration impacts after 20 years on vegetation, macroinvertebrates, fish and birds in Connecticut.

Table 5.25 Checklist: Restore/create/enhance aquatic and marginal habitats.

Measure No.6. Restore/create/enhance aquatic and marginal habitats	
Where has it been applied (geographically)?	Examples from UK, Europe and the USA.
At what scale?	Generally small-scale in comparison to water body size.
To what type of environment has it been applied?	Low to moderate energy transitional water (inter-tidal) environments.
What is the basis for its use?	Increasing understanding.
Was it successful? What criteria used?	Generally regarded as a successful approach (e.g. as an alternative to hard flood defence dissipating wave energy).
What were the potential environmental risks/ benefits?	Potentially wider socioeconomic benefits.
What ecological impacts/improvements?	Some studies have addressed vegetation colonisation and faunal responses.
Are there any other non-physical impacts?	None listed.
What monitoring is in place?	Significant number of monitoring and research studies.
What are the general lessons to be learnt?	In the UK saltmarsh restoration has been increasingly recognised as a means of providing a long-term, sustainable approach to flood and sea defence with the added advantage of enhancing the conservation value of a natural habitat. A number of guidance documents are now available for this well-established measure/technique.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? More than 10. Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Poor to moderate.
Indication of order of costs	Low to moderate costs; considerable benefits to vulnerable structures.
Is there an impact to the key use?	Can be beneficial to existing use by providing protection from wave attack on flood embankments and walls.

5.3.7 Indirect/offsite mitigation (offsetting measures/techniques)

<table>
<tr><td colspan="3">Pressure: Shoreline/Bank reinforcement</td></tr>
<tr><td colspan="2">Description: Flood protection, erosion control or other bank elevation or strengthening using flood walls or embankments; bank protection using gabion baskets or blankets, boulders, sheet piling, wood, geotextiles, etc.; road embankments</td><td>Impact: Coastal squeeze; disruption of tidal flow and channel interaction; disruption/alteration of estuarine process dynamics; modification of sediment dynamics; disruption of natural habitats; loss of faunal nursery, refuge and feeding areas</td></tr>
<tr><td>Number:7</td><td colspan="2">Mitigation measure: Indirect/offsite mitigation (offsetting measures/ techniques)</td></tr>
</table>

The US Army Corps of Engineers (USACE) consider the major form of indirect/offsite mitigation in the USA to be construction of compensatory habitat. Compensation is employed when resource loss (such as saltmarsh habitat) is unavoidable. The most common example is new wetland construction, to compensate for the wetland area lost due to project construction. Some US states require surplus wetland construction to create 'wetland banks' to compensate for planned and future wetlands loss. New and rebuilt dunes are replanted with grasses to compensate for any plants lost during construction. Mitigation by compensation methods is normally carried out and completed during project construction (USACE, 2006)

Morris *et al.* (2006) suggests that the creation of compensatory habitat can be problematic in terms of ecological outcome including in inter-tidal environments.

Paull Holme Strays in the Humber Estuary is a habitat creation scheme designed to offset or compensate for losses through the implementation of flood defence schemes in the Middle Humber Estuary, namely along the Thorngumbald Clough to Little Humber section of the north bank of the estuary to the east of Hull, and Barton Haven on the southern bank of the Humber. A substantial five-year environmental monitoring programme (on accretion/erosion, benthic invertebrates, saltmarsh vegetation and bird use) began in 2003 (Halcrow Group 2005, 2006, 2007). In 2005, consultation on the Draft Humber Estuary FRM Strategy commenced. The Strategy proposes a suite of managed realignment schemes with complementary objectives. Paull Holmes Strays counts as the first of the planned schemes and another is underway within the Humber at Alkborough. The design and monitoring of further managed realignment schemes is being informed by the lessons learned and successes at Paull Holmes Strays.

Another example (although not for FRM purposes) is the Humber compensation scheme for Immingham Outer Harbour (http://www.abpmer.net/humber/).

Table 5.26 Checklist: Indirect/offsite mitigation (offsetting measures/ techniques).

Measure No. 7. : Indirect/offsite mitigation (offsetting measures/techniques)	
Where has it been applied (geographically)?	USA in particular, some experience now from UK.
At what scale?	Tends to be localised.
To what type of environment has it been applied?	Transitional environments (lower energy).
What is the basis for its use?	Increasing amount of practical guidance.
Was it successful? What criteria used?	Overall regarded as a successful technique.
What were the potential environmental risks/ benefits?	Potential impacts on wider environment
What ecological impacts/improvements?	Compensates/offsets loss of habitat destroyed by development/construction.
Are there any other non-physical impacts?	Potential impacts
What monitoring is in place?	A substantial ongoing five-year monitoring programme began on the Humber in 2003. This is assessing accretion/erosion, benthic invertebrates, salt marsh vegetation and bird use.
What are the general lessons to be learnt?	If measures/techniques are properly designed, implemented and adaptively managed they have a greater potential to succeed.
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No (although there is potentially valuable data from the monitoring of Paull Holmes Strays, yet to be published). Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non existent.
Indication of order of costs	Capital and monitoring costs in line with managed realignment.
Is there an impact to the key use?	Not if site selection is appropriate.

5.3.8 Sediment management strategies (develop and/or revise)

Pressure: Channel dredging	
Description: Removal or displacement of substratum by dredging or related techniques to maintain flood conveyance	Impact: Alteration of bathymetry; disruption/ alteration of natural tidal and sediment dynamics; destruction and alteration of benthic habitats; mobilisation of contaminants; increased turbidity (periodically)
Number:8	Mitigation measure: Sediment management strategies (develop and/or revise)

Dredging in the UK and Europe is well regulated and any dredging work undertaken for FRM activities will be covered by dredging policies and guidelines already adopting good practice and inherently including mitigation. The North West European Countries Partnership New Delta Theme 6 presents a procedural framework to develop sustainable dredging strategies. The object of the framework is to provide an overall method to assess the impacts of a dredging (or development) project. It is also designed to help determine the best techniques, management and monitoring practices to keep to the tenet of sustainable development whilst complying with environmental regulations, thus delivering the Best Practical Environmental Option (BPEO). It is aimed at a number of audiences, including environmental groups, the dredging industry, the shipping industry, the port community and the EU Commission.

Discussion with experts within the field of transitional and coastal (TraC) FRM and protection have indicated that dredging in transitional and coastal waters for the purposes of flood conveyance is rarely, if ever, undertaken. Indeed, studies have confirmed that cessation of dredging activities would have no significant impact on FRM for specific situations. A separate checklist for this measure is not considered necessary, as little or no evidence for existence of the pressure within the UK was found.

5.3.9 Mitigation measure: Indirect/offsite mitigation (offsetting measures/techniques)

<table>
<tr><td colspan="3">Pressure: Channel dredging</td></tr>
<tr><td colspan="2">Description: Removal or displacement of substratum by dredging or related techniques to maintain flood conveyance</td><td>Impact: Alteration of bathymetry; disruption/ alteration of natural tidal and sediment dynamics; destruction and alteration of benthic habitats; mobilisation of contaminants; increased turbidity (periodically)</td></tr>
<tr><td>Number:9</td><td colspan="2">Mitigation measure: Indirect/offsite mitigation (offsetting measures/ techniques)</td></tr>
</table>

The Permanent International Association of Navigation Congresses (PIANC) have set out ecological and engineering guidelines for wetland restoration (indirect offsite mitigation) in the development, operation and maintenance of navigation infrastructures (PIANC, 2000). While no evidence of mitigation for channel dredging for FRM purposes was found, for such activities mitigation might follow similar guidance to that set out by PIANC.

The beneficial use of dredged material for flood and coastal defence purposes was discussed earlier. CEFAS (2007) also suggest that fine-grained dredged material can be used for habitat conservation and enhancement. Progressive inter-tidal habitat loss in the UK due to erosion and reclamation is of increasing concern. Dredged material emplacement has been shown to successfully protect against erosion and may even promote accretion and creation of saltmarshes and inter-tidal areas. The beneficial use of dredged material can have its own logistical, legal, economic and environmental limitations and each disposal case should be assessed on its own merits (CEFAS, 2007).

The options for dredge material use include: direct placement onto inter-tidal areas (confined or unconfined); sediment recycling and trickle charge; and placement on to managed realignment sites to build up surface elevations (Dearnley *et al*., 2007). Weinstein and Weishar (2002) and Dearnley *et al*. (2007) have reported successful ‘beneficial use’ of dredged material schemes in Delaware Bay, USA and in the Orwell Estuary, UK respectively. The scheme undertaken at Maldon, Essex is an example of small-scale restoration of an eroded saltmarsh through direct placement of dredged material to protect the remaining marsh from further erosion and raise foreshore levels. Initial works were carried out in 1993 and follow-up surveys have shown no further signs of erosion and signs of accretion prompting later material placements. Nottage and Robertson (2005) suggest that in the context of Maldon at least, the beneficial use of dredged material provides an ongoing management technique that can be employed to address erosion.

Indirect/offsite mitigation in terms of offsetting or compensatory measures is discussed in earlier sections; these would include the restoration and/or creation of habitat

5.3.10 Material emplacement strategies (develop and/or revise)

Pressure: Deposition of material		
Description: Deposition of dredged sediments or other material onto intertidal or subtidal bed for purposes of sediment nourishment or feeding		Impact: Smothering of existing floral and faunal and habitats; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry
Number:10	Mitigation measure: Material emplacement strategies (develop and/or revise)	

Deposition of material includes beach nourishment and inter-tidal sediment recharge (see also Section 5.3.3)

The United States Environmental Protection Agency (USEPA) and USACE have teamed up to construct a website entitled *Beneficial uses of dredged material* (http://el.erdc.usace.army.mil/dots/budm/budm.cfm). Here, uses of material are classified into three broad categories: engineered uses, agricultural and product uses, and environmental enhancement. Specific examples are listed for each category and case study projects are provided.

The American Society of Civil Engineers (ASCE) state that '*Dredged sediment is an invaluable resource that can be used to address sediment imbalances and to mitigate coastal land loss, and its coincident economic, environmental and safety consequences'* (ASCE, 2006). Similarly, Dearnley *et al*. (2007) have investigated the beneficial use of muddy dredged material for sustainable flood defence and habitat management in England and Wales.

DECODE (Determination of the Ecological Consequences of Dredged Material Emplacement) is a website created by CEFAS (http://www.cefas.co.uk/projects/determination-of-the-ecological-consequences-of-dredged-material-emplacement-(decode).aspx). The main aim is to harmonise efforts and increase information transfer between the many beneficial use-related research projects within the UK. Specifically, interests lie in the use of fine-grained dredged material for environmental enhancement, habitat sustainability and flood defence.

Examples of saltmarsh and inter-tidal recharge schemes include-

- Horsey Island, Hamford Water - Inter-tidal Recharge Scheme.
- Pewit Island, Blackwater Estuary - Inter-tidal Recharge Scheme.
- Trimley Marshes, Orwell Estuary - Inter-tidal Recharge Scheme.
- Parkstone Marshes, Stour Estuary - Inter-tidal Recharge Scheme.
- Funton Creek, Medway Estuary - Saltmarsh regeneration scheme.
- Saltmarsh creation. Horsey Island, Essex, UK.
- Saltmarsh creation. Suffolk Yacht Harbour, Levington, Orwell Estuary, Suffolk, UK.
- Saltmarsh creation, Titchmarsh Marina, Walton on the Naze, Essex, UK.

Table 5.27 : Material emplacement strategies (develop and/or revise).

Measure No.10. Material emplacement strategies (develop and/or revise)	
Where has it been applied (geographically)?	USA and Europe including the UK.
At what scale?	Localised in estuaries.
To what type of environment has it been applied?	Low energy estuarine.
What is the basis for its use?	Extensive experience around the world particularly in the USA.
Was it successful? What criteria used?	Many examples of success.
What were the potential environmental risks/ benefits?	Potentially improved flood defence/ coastal protection.
What ecological impacts/improvements?	Habitat creation, increased flood defence and coastal protection capacity. Emplacement of material reduces requirement for depositing material in licensed dumping grounds.
Are there any other non-physical impacts?	No.
What monitoring is in place?	Monitoring inherent in all schemes licensed in the UK.
What are the general lessons to be learnt?	If measures/techniques are properly designed, implemented and adaptively managed then higher chance of success. Caution is recommended for inter-tidal sediment recharge as ecological effects not well understood (to date only small trials have been undertaken in UK).
What is the scientific evidence to demonstrate an ecological benefit?	Are there any papers published on this measure in scientific journals? No (although data becoming available). Has a digest of results been produced? No. Does a systematic review of the literature exist? No. Overall, what is the quality of the scientific evidence base? Non-existent to very poor.
Indication of order of costs	Can have low to moderate capital costs. Can also be used as mitigation measure/ technique to offset impacts of navigation maintenance dredging.
Is there an impact to the key use?	Not aware of any.

5.3.11 Mitigation measure: Restore/create/enhance aquatic and marginal habitats

Pressure: Tidal river alteration e.g. channelization/realignment/straightening	
Description: In upper estuaries, where channel remains river-like, straightening, widening and deepening of channel, removal of meanders to increase channel gradient, flow velocity, flood capacity	Impact: Disruption of tidal flow and interaction; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry; loss of morphological diversity and habitat
Number:11	Mitigation measure: Restore/create/enhance aquatic and marginal habitats

The restoration/creation/enhancement of habitats was described in Section 5.3.6. Implementation of this type of measure/technique could provide mitigation for tidal river alteration. A separate checklist is not provided here.

5.3.12 Increase in-channel morphological diversity

Pressure: Tidal river alteration e.g. channelization/realignment/straightening	
Description: In upper estuaries, where channel remains river-like, straightening, widening and deepening of channel, removal of meanders to increase channel gradient, flow velocity, flood capacity	Impact: Disruption of tidal flow and interaction; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry; loss of morphological diversity and habitat
Number:12	Mitigation measure: Increase in-channel morphological diversity

A loss of morphological diversity has been long recognised as a major effect of channelization, realignment and straightening within riverine environments (Brookes, 1988; Swales, 1982). As a consequence of the widespread loss of morphological diversity caused by these processes, there has been an increasing trend to remediate against these effects. Mitigation measure Number 11 (see Section 5.1.11) describes the techniques implemented within rivers, some of which may be applicable to transitional and coastal waters where tidal rivers have been altered. However, to date no evidence of their use has been found. A separate checklist is not given here.

5.3.13 Indirect/offsite mitigation (offsetting measures/techniques)

Pressure: Tidal river alteration e.g. channelization/realignment/straightening	
Description: In upper estuaries, where channel remains river-like, straightening, widening and deepening of channel, removal of meanders to increase channel gradient, flow velocity, flood capacity	Impact: Disruption of tidal flow and interaction; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry; loss of morphological diversity and habitat
Number:13	Mitigation measure: Indirect/offsite mitigation (offsetting measures/ techniques)

See transitional and coastal mitigation measure Number 7 above. A separate checklist is not provided here.

5.3.14 Removal of structure

Pressure: Impounding		
Description: Backing-up of water through the construction of barrages, weirs and sluices		Impact: Alteration of bathymetry; disruption of tidal flow and interaction; alteration of natural sediment dynamics - loss of continuity; destruction and alteration of benthic habitats; mobilisation of contaminants; increased turbidity; loss of faunal nursery, refuge and feeding areas; disruption of habitat connectivity/continuity - interference with fish population movements
Number:14	Mitigation measure: Removal of structure	

While little or no scientific or anecdotal evidence has been found on the use of this measure in transitional and coastal waters, evidence for a similar type of mitigation measure within riverine environs would be applicable (see Section 5.1.9). A separate checklist is not provided here.

5.3.15 Operational and structural changes to locks, sluices and tidal barrages

Pressure: Impounding		
Description: Backing-up of water through the construction of barrages, weirs and sluices		Impact: Alteration of bathymetry; disruption of tidal flow and interaction; alteration of natural sediment dynamics - loss of continuity; destruction and alteration of benthic habitats; mobilisation of contaminants; increased turbidity; loss of faunal nursery, refuge and feeding areas; disruption of habitat connectivity/continuity - interference with fish population movements
Number:15	Mitigation measure: Operational and structural changes to locks, sluices and tidal barrages	

Whilst the effects of dams on biological continuity are well known, there is little evidence that this measure has been used to improve biological continuity. Little or no evidence has been found on whether this technique would be practical in transitional and coastal waters. However, evidence to support its implementation could be readily obtained by undertaking research studies. A separate checklist is not given here.

5.3.16 Install fish passes

Pressure: Impounding		
Description: Backing-up of water through the construction of barrages, weirs and sluices		Impact: Alteration of bathymetry; disruption of tidal flow and interaction; alteration of natural sediment dynamics - loss of continuity; destruction and alteration of benthic habitats; mobilisation of contaminants; increased turbidity; loss of faunal nursery, refuge and feeding areas; disruption of habitat connectivity/continuity - interference with fish population movements
Number:16	Mitigation measure: Install fish passes	

In order to sustain migratory fish populations, unrestricted access to spawning grounds must be ensured. Unfortunately, many man-made obstructions restrict this access to spawning area. The scientific evidence base supporting installation of fish passes in rivers to retain such migratory routes is well established. While little or no scientific or anecdotal evidence has been found on this measure's use in transitional and coastal waters, evidence for a similar type of measure implemented within riverine environs would be applicable (see Section 5.1.8). A separate checklist is not provided here.

5.3.17 Indirect/offsite mitigation (offsetting measures/techniques)

Pressure: Impounding	
Description: Backing-up of water through the construction of barrages, weirs and sluices	Impact: Alteration of bathymetry; disruption of tidal flow and interaction; alteration of natural sediment dynamics - loss of continuity; destruction and alteration of benthic habitats; mobilisation of contaminants; increased turbidity; loss of faunal nursery, refuge and feeding areas; disruption of habitat connectivity/continuity - interference with fish population movements
Number:17	Mitigation measure: Indirect/offsite mitigation (offsetting measures/ techniques)

See transitional and coastal mitigation measure Number 7 (Section 5.3.7) above. A separate checklist is not provided here.

5.3.18 Removal of structure

Pressure: Manipulation of sediment transport	
Description: Placement of piers, groynes and breakwaters etc. for controlling sediment distribution.	Impact: Disruption of tidal flow and interaction; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry; direct/indirect habitat loss
Number:18	Mitigation measure: Removal of structure

No published evidence was found to support the suggestion that removal of structures could provide mitigation. Removing sediment manipulation structures is possible; however, such schemes would probably only be practical if accompanied by substantial sediment nourishment of the shoreline to maintain protection, which would have its own environmental implications.

Ranasinghe and Turner (2006) conducted a review of shoreline response to submerged coastal structures. Submerged coastal structures are widely believed to provide beach protection without the adverse impacts associated with conventional structures such as revetments and groynes. However, the review by Ranasinghe and Turner (2006) reveals that contrary to expectations, the majority of submerged structures constructed to date have resulted in shoreline erosion in their lee. They suggest that before engineering design guidelines can be compiled for submerged coastal protection structures, fundamental research with numerical and physical modelling should be undertaken to improve structure design.

A separate checklist is not provided here.

5.3.19 Modify structure design

<table>
<tr><td colspan="3">Pressure: Manipulation of sediment transport</td></tr>
<tr><td colspan="2">Description: Placement of piers, groynes and breakwaters etc. for controlling sediment distribution.</td><td>Impact: Disruption of tidal flow and interaction; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry; direct/indirect habitat loss</td></tr>
<tr><td>Number:19</td><td colspan="2">Mitigation measure: Modify structure design</td></tr>
</table>

It is possible that a structure could be modified to enhance its ecological value. Bulleri and Chapman (2004) noted that breakwaters and inter-tidal seawalls in north-west Italy provided artificial habitat, albeit reduced in its value compared to natural rocky shores. Similarly, Bulleri *et al*. (2005) have undertaken comparative studies between the inter-tidal assemblages on (artificial) seawalls and (natural) vertical rock shores in Sydney Harbour, Australia with comparable results.

The second edition of *The Rock Manual* (CIRIA, CUR, CETMEF, 2007) was updated to provide guidance on good practice worldwide for the design and construction of rock structures in hydraulic engineering. It collates available research data and technical information with practical experience gained by practitioners.

A number of coastal engineering structure design guides, including the *Beach Management Manual* (Brampton *et al*., 1996) and the *Coastal Engineering Manual* (USACE, 2006), have produced procedural guidelines and set out best practice for the management of beaches based on the latest knowledge and results of research.

Airoldi *et al.* (2005), Moschella *et al.* (2005) and Martin *et al.* (2005) have investigated the effects and possible benefits to ecology and habitats of coastal defence structures, in particular low crested coastal defence structures (that protect sedimentary coastlines for erosion and flooding). Their results show that whilst in general the construction of low crested coastal defence structures has a negative impact on local habitats and native assemblages, they provide some ecological enhancement in particular in a nursery role.

To date, research on ecological enhancement by sediment manipulation structures has concentrated on understanding existing structures. Bulleri and Chapman (2004) and Bulleri *et al*. (2005) suggest that such work is a basis from which to understand and eventually to manage the development and design of artificial structures in coastal habitats to minimise their effects on, or even enhance, habitats and biodiversity. At present, little information exists on mitigation provided to structure design modification and therefore a separate checklist has not been provided.

5.3.20 Restore/create/enhance aquatic and marginal habitats

<table>
<tr><td colspan="3">Pressure: Manipulation of sediment transport</td></tr>
<tr><td colspan="2">Description: Placement of piers, groynes and breakwaters etc. for controlling sediment distribution.</td><td>Impact: Disruption of tidal flow and interaction; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry; direct/indirect habitat loss</td></tr>
<tr><td>Number:20</td><td colspan="2">Mitigation measure: Restore/create/enhance aquatic and marginal habitats</td></tr>
</table>

Restoration/creation/enhancement of habitats was discussed earlier (Section 5.3.6).

5.3.21 Mitigation measure: Indirect/offsite mitigation (offsetting measures/techniques)

<table>
<tr><td colspan="3">Pressure: Manipulation of sediment transport</td></tr>
<tr><td colspan="2">Description: Placement of piers, groynes and breakwaters etc. for controlling sediment distribution.</td><td>Impact: Disruption of tidal flow and interaction; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry; direct/indirect habitat loss</td></tr>
<tr><td>Number:21</td><td colspan="2">Mitigation measure: Indirect/offsite mitigation (offsetting measures/ techniques)</td></tr>
</table>

See Section 5.3.7 for mitigation measure Number 7 above.

6 Conclusions and recommendations

A number of interim conclusions emerge from this initial review, together with some recommendations for the next steps and future focus.

6.1 Interim conclusions

1. This review of techniques to respond to potential impacts arising from specific pressures and sub-pressures is highly diverse. Only measures that have been tried as mitigation, in some part of the world, have been put forward. The premise adopted is that there will always be a *"suitable horse for a particular course"*.
2. Measures range from those supported by scientific papers, guidance manuals and other grey literature (such as in-channel structures), to those (the majority) which have practically no documentation (such as catchment approaches). Some measures are more practical/feasible to implement in terms of limited (or less) impact on use, lower cost and (potentially) maximising wider environmental/ecological gains. Often these measures are those least supported by scientific literature and could be considered higher priorities for research in the context of the WFD.
3. Scientific evidence for the ecological benefit of such measures is generally poor to non-existent. This will make it difficult to develop digests or systematic reviews for the majority of measures, as there are relatively few studies on which to base a critical review. However further information is held by government agencies and the RRC that could be drawn upon.
4. Because many projects include a combination of measures, it is difficult to discern between the ecological impacts (potentially positive or negative) of the individual components.
5. Previous experience can be drawn upon. Over the past 20 years, considerable progress has been made in mitigating the impacts of FRM and LD activities (as a result of legislation, including the EU EIA Directive in 1988) and the RRC (for example) has acted as a catalyst since about 1990 to promote river restoration in the UK. This contrasts markedly with FRM activities over the previous 50 years, which generally gave scant attention to environmental constraints and opportunities.
6. A considerable number of experienced practitioners are expert at mitigating adverse impacts of FRM and LD activities, particularly for rivers. Unfortunately, many of their experiences are not written up in grey literature and even fewer in peer-reviewed scientific journals. Compared with academics in universities, most practitioners do not have the incentives (nor are confident of having the skills) to write a scientific paper. Equally, case study work undertaken by many practitioners is less well received by more academic journals. What is not clear (at the time of this review) is the quality of this unwritten/unpublished information/data.

7. Scientific papers (relevant to FRM or LD) collated for this review concern geomorphology, ecology and ecohydromorphology. An overwhelming majority of this literature concerns rivers; there is less on transitional waters (estuaries) and coasts and very little published on lakes.

8. A good start has been made on a number of evidence-based reviews in the UK. To date, these have only considered fluvial issues and for those where there is an established literature. There is also considerable professional and grey literature that has not been encapsulated in these initial reviews. There is, for example, much knowledge to be transferred from other countries (particularly from the USA).

9. Scientific literature on the original impact (such as substrate removal) is as pertinent as published work on the mitigation measure itself. Arguably, any measure that helps recreate the hydromorphology will, by default, have some kind of ecological gain (not necessarily quantified). However, there are potential risks that should be considered; for example reconnecting a channel to its floodplain could (in terms of groundwater) lead to flooding of basements in an urban area; contaminated urban sediments could be an issue where in-channel features are allowed to reform (see Environment Agency (2002) scoping guidance for projects).

10. Only a small sub-set of scientific papers have collected sufficient baseline data for comparison during and after implementation.The general lack of baseline data for projects is a handicap to progress. A typical PhD, for example, can at best only incorporate 18 months of data collection.

11. Despite pleas over the last 20 years (for example in the EU LIFE Demonstration Projects in the early 1990s), little monitoring has been undertaken (partly because routine funding has not been forthcoming) on rivers, lakes, transitional and coastal waters. Also the EIA legislation, for example, has not made monitoring compulsory for developers. An outstanding question remains unanswered: *Who should pay for monitoring?*

12. Few academic researchers have monitored mitigation measures. This community looks even smaller compared to the number of environments in which mitigation measures have been applied. Examples of success can be gleaned from the grey literature. For example, for rivers the RRC newsletter is replete with examples of restoration projects.

13. Where agencies have undertaken monitoring, this has rarely been documented in a readily accessible form. Generally speaking, there is ignorance of what measures have been monitored and to what extent.

14. UK interviews and questionnaires carried out for this project indicate that the depth and breadth of scientific monitoring and publications remains low (for some measures/techniques non-existent) compared to the large number of projects completed.

15. Optimistically, there are monitoring projects for certain types of measures in other parts of Europe (increasingly so). The driver for this work includes the WFD. There are now mechanisms at European level for rapid dissemination of research information in FRM and LD (such as ERANET CRUE).

16. The Environment Agency has been aware for sometime of the lack of monitoring of certain activities. In 2007, Jacobs was commissioned by Thames Region (Environment Agency) to produce a monitoring protocol for assessing the geomorphology of river restoration projects. This significant

'information gap' has been addressed as a topic by the RRC (including the Environment Agency, academics, consultants and other organisations) since 2002 and RRC held notable workshops in 2006 and again in 2007. The current initiative is development of a standard monitoring protocol for ecohydromorphology on river restoration projects. However, there is less attention in the UK on the monitoring of transitional and coastal waters.

17. Despite the limited scientific evidence, most people interviewed in the UK, Europe and USA for this report believe that projects can be successful if properly planned, designed, implemented and monitored (making allowance for some adaptive management if necessary). There are examples (few documented) of failure in river environments from the past 20 years where a simple multi-disciplinary team comprising an engineer, geomorphologist and ecologist (as a bare minimum) was not assembled. Equally, it could be argued that in urban areas there might be an additional call for a contaminated land specialist and landscape architect.

18. Simple criteria and tools have been developed to considerably increase the chances of a project's success. For rivers, this includes the fluvial audit tool.

19. However, simple criteria for success have often been lacking on projects despite calls for a more disciplined approach over the last 10 years or so.

6.2 Recommendations for next steps and future focus

The next steps are divided into recommendations for completion of the Digital Good Practice Manual in 2009 and medium to longer term recommendations for science.

6.2.1 Next steps for the Digital Good Practice Manual

The Digital Good Practice Manual is aimed at the novice practitioner (whether they be a developer or a regulator) but also aims to enhance the information base for existing practitioners, thereby increasing their confidence in negotiating outcomes. The manual will be developed to be useful at different levels of experience.

The overall conclusion of this report is that relatively little information is available, though there are sufficient manuals and guidance, grey literature and published science to produce detailed guidance sheets (as part of Phase 2). Information also exists on the costs of measures that will allow cost-effectiveness analysis to be undertaken. Further information can be drawn upon from the River Restoration Inventory and from operational staff in government agencies. However, it may be difficult to extract this information/data and to elicit sufficient information to determine the quality of the science supporting these unpublished studies.

Phase 2 of the project will therefore have to be heavily supported by expert judgement by convening a series of workshops of specialists. A preference elicitation process is recommended by which measures/techniques can be ranked and a value assigned to their cost-effectiveness. Because of the reliance on experts, this process needs to be adequately documented for the audit trail. Given the complexity of the environment the manual cannot be made too prescriptive. The measures/ echniques employed will inevitably involve the expert judgement of a balanced team of professionals working at a site-specific level. It will be important to explain the process, applicability and environments where an individual measure/technique cannot be applied. By 2009, the first digital version (Phase 3) of the manual will be built on a platform of scientific information mixed with the judgement of experts drawn from UK government agencies.

6.2.2 Recommendations for the medium to long term

Given the substantial gaps in knowledge (which will remain at the end of Phases 2 and 3) a strategy is needed for the medium to longer term. The Water Framework Directive is a 'learning directive' which allows evolution of knowledge and practice. One of the key links for this project is to the Environment Agency Science ICS Theme, specifically the *Managing Hydromorphological Pressures in Rivers* project (see Figure 1.1) which to date has included a position paper on understanding pressure-impacts on surface water systems, together with an overview of river restoration science and practice. The initial phase of the work has again shown a dearth of information and suggests that expert judgement will form a key component of decision-making, at least in the short-term. It is important to be precautionary but equally that precaution should not obviate the need for effort in mitigating the impact of ongoing FRM and LD activities. Recommendations have been made as part of Phase 1 on further monitoring required, as well as better use of existing data/information pertinent to ecohydromorphology.

The science programme offers the chance of links with research councils, other key government agencies and universities and European programmes (see Figure 1.1). This will be key to proving that individual measures/techniques have an ecological benefit (or otherwise). The Environment Agency and its partner organisations are currently prioritising future work for rivers.

Whilst a 'toolkit for river management' is being developed, less attention is being given to action for transitional and coastal waters, although (given the small number of incidences of management) lakes are perhaps a lower priority for action.

The following milestones are suggested in the medium (2009-2015) and longer terms (2015 to 2021 and beyond). These timescales are consistent with the first (2009), second (2015) and third (2021) cycles of river basin planning.

1. By 2009 a piloting and monitoring programme will be underway (for example, under the Environment Agency Science Programme)
2. From 2009 to 2015 quick-win proven measures will have to be provided, based on the first edition of the Digital Good Practice Manual and a combination of expert judgement (of a range of professionals) at site level. Current work on classifying water bodies on whether they are at or close to GEP will be particularly important in agreeing good practice measures. Clearly these techniques will only be applied where they are not disproportionately expensive or technically unfeasible. This experience will need to feed back to the Digital Good Practice Manual.
3. Following piloting and monitoring, new measures and good practice will be developed over the next decade and beyond. The results of this research will need to be built into regular updates of the Digital Good Practice Manual.
4. Wider measures such as restoration will begin to be delivered in RBP 2 (beyond 2015). Flood Management Plans will be developed to complement RBP2s.

The Digital Good Practice Manual will be useful to the land drainage consenting process, which also needs to take account of the Water Framework Directive.

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References are divided into: 7.1 General; 7.2 Rivers; 7.3 Lakes; and 7.4 Transitional and Coastal Waters.

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Appendix A: Questionnaire used in interviews

DOCUMENTING 'GOOD PRACTICE' FOR MITIGATION OF FLOOD RISK MANAGEMENT AND LAND DRAINAGE ACTIVITIES

PART 1 - GENERAL INFORMATION

This part includes contact information and questions on general approaches to Flood Risk Management and Land Drainage activities, and legislation focusing on how the Water Framework Directive (WFD) will influence activities.

SECTION 1: CONTACT INFORMATION

NAME:

OCCUPATION/ROLE:

ORGANISATION AND LOCATION:

QUALIFICATIONS:

NO. YEARS EXPERIENCE:

EMAIL AND/OR PHONE NUMBER:

SECTION 2: GENERAL FLOOD RISK MANAGEMENT (FRM) AND LAND DRAINAGE (LD) ACTIVITIES

WHAT IS YOUR ROLE IN FRM or LD ACTIVITIES? (e.g. modelling, design, options appraisal etc)

WHICH OTHER SPECIALISTS WOULD YOU USUALLY WORK WITH?

WHAT IS THE SCALE OF PLANNING/PRIORITISING OF FRM or LD ACTIVITIES IN WHICH YOU ARE INVOLVED? (e.g. regional, catchment)

HOW MUCH IS YOUR WORK PLANNED/STRATEGIC COMPARED TO BEING REACTIVE? (e.g. rough % of each and explanation)

WHAT TYPES OF ACTIVITIES ARE OFTEN UNDERTAKEN? (rank from most common to least frequent if possible) (e.g. dredging, reprofiling, flood alleviation channels, raising defences (e.g. walls), set back defences (e.g. embankments), flood storage, managed realignment/retreat, others - please state)

WHICH FACTORS ARE MOST IMPORTANT IN DETERMINING PREFERRED OPTIONS FOR FRM ACTIVITIES? (rank from most common to least frequent if possible) (e.g. cost, biodiversity, environmental impact, geomorphology, sustainability, low risk/assured design life, others - please state)

TO WHAT EXTENT IS EMPHASIS PLACED ON THE FOLLOWING:

PLANNING -

CONSTRUCTION -

OPERATION -

MAINTENANCE -

DECOMMISSIONING -

SUSTAINABILITY -

WHAT IMPORTANCE IS ATTACHED TO ACTIVITIES THAT MITIGATE POTENTIAL ENVIRONMENTAL IMPACTS?

WHAT PART DO ALTERNATIVES PLAY IN OPTIONS APPRAISAL?

WHAT PART DOES COST-EFFECTIVENESS PLAY?

WHAT SOURCES OF INFORMATION ARE REFERRED TO IN DECISION-MAKING FOR NEW ACTIVITIES? (e.g. does your organisation have existing ‘Good Practice’ manuals for activities?)

SECTION 3: YOUR WORK AND THE EU WATER FRAMEWORK DIRECTIVE

WHAT IS YOUR WORKING KNOWLEDGE OF THE WATER FRAMEWORK DIRECTIVE (e.g. very good, fair, poor, and details)?

HOW DO YOU FIND OUT UP TO DATE INFORMATION ON THE WFD?

WHICH ASPECTS OF THE WFD DIRECTLY OR INDIRECTLY RELATE TO YOUR ROLE?

HOW DO YOU THINK THE WFD FITS IN WITH EXISTING LEGISLATION GOVERNING FRM and/or LD ACTIVITIES? (e.g. EIA legislation, Habitats Directive, land drainage consents etc.)

HOW DO YOU ENVISAGE THAT THE WAY FRM/LD ACTIVITIES ARE UNDERTAKEN MIGHT CHANGE WITH THE REQUIREMENTS OF THE WFD?

ANY OTHER COMMENTS?

PLEASE CONTINUE TO PART 2 - SPECIFIC EXAMPLES OF MEASURES/PROJECT CASE STUDIES

DOCUMENTING 'GOOD PRACTICE' FOR MITIGATION OF FLOOD RISK MANAGEMENT AND LAND DRAINAGE ACTIVITIES

PART 2 - SPECIFIC EXAMPLES OF PREVIOUS PROJECTS

This part of the questionnaire aims to collate detailed information in a 'case study' format including: basic information; site descriptions; objectives and options; design and construction; project appraisal.

You may complete multiple copies of this part for different projects.

SECTION 1: BASIC SCHEME INFORMATION

WATERBODY TYPE: RIVER/WATERCOURSE LAKE

ESTUARY COASTAL

SITE LOCATION *(River/lake name, or coastal location by town):*

GRID REFERENCE:

IS THE SCHEME A *(state which):*

NEW ACTIVITY MAINTENANCE OPERATION

IMPROVEMENT TO EXISTING STRUCTURE/ACTIVITY

BASIC PROJECT OBJECTIVES (e.g. erosion prevention, flood risk management):

ACTIVITY TYPE(s) (e.g. bank protection, watercourse diversion, in-channel structures/impoundments, dredging, vegetation management etc):

ENVIRONMENTAL MITIGATION-TYPE MEASURES INCLUDED IN DESIGN/MAINTENANCE PROCESS:

OTHER PARTIES INVOLVED IN PROJECT AND THEIR ROLES:

COST (*Estimated or actual, capital or maintenance costs, please state)*:

ADDITIONAL SOURCES OF INFORMATION THAT CAN BE PROVIDED (e.g. design drawings, options reports):

SECTION 2: SITE DESCRIPTION

ENERGY/DYNAMICS:

LAND USE & VEGETATION:

BANK/BEACH MATERIALS AND FORMS:

EXISTING MODIFICATIONS:

ECOLOGICAL/CONSERVATION VALUE:

SECTION 3: OBJECTIVES AND OPTIONS

WHAT WAS THE ORIGINAL PROBLEM PROMPTING INTERVENTION/MANAGEMENT?

WHAT WERE THE REASONS FOR THE CHOICE OF MEASURES USED? (e.g. technical, environmental, economics)

WHAT ALTERNATIVES WERE CONSIDERED (AND WHY WERE THEY NOT USED)?

WAS AN ENVIRONMENTAL IMPACT ASSESSMENT (EIA) UNDERTAKEN? *(if so, how did findings influence the design, e.g. for mitigation measures?)*

SECTION 4: DETAILED DESIGN AND CONSTRUCTION (referring to any drawings etc made available - see Section 1)

WHAT WERE THE COMPONENTS OF THE DESIGN (TECHNIQUES, MATERIALS etc)?

WHAT CONSTRUCTION METHODS WERE USED?

HOW WERE CONSTRUCTION IMPACTS MITIGATED?

WAS A DESIGN/AS-BUILT COMPLIANCE CHECK UNDERTAKEN?

HOW WERE MAINTENANCE NEEDS CONSIDERED AT THE DESIGN STAGE?

SECTION 5: SUCCESS CRITERIA/PROJECT APPRAISAL

DO YOU CONSIDER THE MEASURES HAVE BEEN SUCCESSFUL IN MITIGATING HYDROMORPHOLOGICAL AND ECOLOGICAL IMPACTS?

ON WHAT EVIDENCE IS THIS BASED?

HAS ANY SPECIFIC MONITORING BEEN UNDERTAKEN (if so, of what and how frequently)?

HAS ANY UNPLANNED ADDITIONAL/REMEDIAL WORK BEEN REQUIRED?

IS THERE ANY EVIDENCE OF THE WORKS BEING COST-EFFECTIVE (OR NOT)?

IS THERE ANY EVIDENCE OF POSITIVE OR NEGATIVE ENVIRONMENTAL IMPACTS?

PLEASE ATTACH ANY FURTHER COMMENTS/INFORMATION

Appendix B: Checklists developed

River Checklist

Pressure	**Sub-pressure**	**Impact**	**No.**	**Mitigation measures**
Bank and bed reinforcement and in-channel structures	**Hard protection** e.g. Steel piling, vertical walls and gabion baskets. Includes hard bank protection in a state of disrepair.	Loss of riparian zone/ marginal habitat/loss of lateral connectivity/loss of sediment input	1	Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution
			2	Protect and enhance ecological value of marginal aquatic habitat, banks and riparian zone
			3	Protect and restore aquatic habitats
		Loss of sediment continuity (lateral) - build up of sediment in the channel	4	Removal of hard bank reinforcement/revetment, or replacement with soft engineering solution
			5	Protect and enhance ecological value of marginal aquatic habitat, banks and riparian zone
			6	Protect and restore aquatic habitats
	Dams, sluices and weirs	Loss of biological continuity - interference with fish population movements	7	Operational and structural changes to sluices and weirs
			8	Install fish passes
		Loss of sediment continuity (longitudinal) - build up of sediment upstream, reduced bedload downstream	9	Removal of structure
Channel alteration	Realignment/ reprofiling/regrading	Loss of morphological diversity and habitat	10	Retain marginal aquatic and riparian habitats
			11	Increase in-channel morphological diversity, e.g. install in-stream features; two-stage channels
	Culverts	Loss of morphological diversity and habitat	12	Opening existing culverts
			13	Alteration of channel bed
		Continuity	14	Opening existing culverts
			15	Alteration of channel bed

Pressure	Sub-pressure	Impact	No.	Mitigation measures
Floodplain modification	Flood banks and flood walls	Loss of riparian zone/ marginal habitat/loss of lateral connectivity/ loss of sediment input	16	Flood bunds
			17	Set-back embankments
			18	Improve floodplain connectivity
	Flood diversion channels	Loss of natural floodplain/riparian zone/marginal habitat/ loss of lateral connectivity and sediment throughput in main channel	19	Improve floodplain connectivity
			20	Enhance aquatic and riparian habitats
Operations and maintenance	Sediment management (including dredging)	Direct loss of/impact on aquatic habitats/ hydromorphology	21	Sediment management strategies (develop and revise) which could include a) substrate reinstatement, b) sediment traps, c) allow natural recovery minimising maintenance, d) riffle construction, e) reduce all bar necessary management in flood risk areas
		Transfer of fine sediment downstream		
		Bankside erosion and impacts on riparian habitats		
		Source of fine sediment (disposal of dredgings on banks)		
	Removal/clearance of urban trash and wood	Loss of aquatic habitats	22	Appropriate channel maintenance strategies and techniques e.g. minimise disturbance to channel bed and margins
		Transfer of fine sediment downstream	23	Appropriate channel maintenance strategies and techniques e.g. remove wood only when in the vicinity of an urban area

Pressure	Sub-pressure	Impact	No.	Mitigation measures
	Vegetation control	Physical disturbance of bed and or bank- increased sediment input; sediment mobilisation and loss of marginal/riparian vegetation	24	Appropriate vegetation control regime e.g. a) minimise disturbance to channel bed and margins, b) selective vegetation management, for example, only cutting from one side of the channel, c) providing/reducing shade
		Transfer and establishment of alien invasive species	25	Appropriate techniques to prevent transfer of invasive species e.g. appropriate training of operational staff
	Pipes, inlets, outlets and off-takes	Hydromorphological alterations of water and sediment inputs through artificial means	26	Appropriate techniques to align and attenuate flow to limit detrimental effects of these features
	Water level	Effect on aquatic habitats	27	Water level management plan
Land use (not, in itself, a sustainable flood management pressure)	Intensive land use	Changes to vegetation, hydrology and sediment supply	28	Land management strategies (develop and revise), including SUDS and changes in farming practices and forest management

Lake Checklist

Pressure	Sub- pressure	Impact	No.	Mitigation measures
Bank and bed reinforcement/ realignment	Hard protection	Modification to structure and condition of lake shore zone (loss of riparian zone/marginal habitat/ loss of lateral connectivity)	1	Remove hard reinforcement/revetment, or replace with soft engineering solution
			2	Preserve and enhance ecological value of marginal aquatic habitat, banks and riparian zone
	Channelization of inflows and outlets	Straightening, widening, deepening of channel at approach to river mouths and outlets (modifications to flow dynamics, level, depth variation, quantity and structure of substrate, structure and conditions of lake shore zone)	3	Amend design (re-naturalize) bed and banks
Impounding	Control structures on inflows and outlets	Changes in lake base level and alteration to flow regime downstream. Loss of continuity (sediment and biota)	4	Undertake operational and structural changes to control structures
			5	Install fish pass
			6	Remove hard reinforcement/revetment, or replace with soft engineering solution
Shoreline modification	Flood banks and flood walls	Modification to structure and condition of lake shore zone (loss riparian zone/marginal habitat/loss of lateral connectivity)	7	Remove flood banks/walls
			8	Set-back flood banks
Operations and maintenance	Sediment management (including dredging)	Direct loss of/impact on benthic habitats/hydromorphology	9	Do not dredge. Reduce the source of sediment entering the lake by implementing good catchment and shoreline management practices (e.g. developing buffer strips alongside watercourses and lakes)
		Alteration to bathymetry		
		Increase in turbidity and fine sediment transfer downstream		
		Source of fine sediment (disposal of dredgings on shoreline)		

Pressure	Sub- pressure	Impact	No.	Mitigation measures
	Lowering/draining	Direct loss of/impact on benthic habitats/hydromorphology	10	Adopt an appropriate release strategy (e.g. phased de-watering, small frequent release cycles)
		Modification to flow regime		
Land use	Intensive land use	Changes to vegetation, hydrology and sediment supply	11	Land management strategies (develop and revise)

Transitional & Coastal Waters Checklist

Pressure (physical modification or ongoing activity)	Description	Impact	No.	Mitigation measures
Bank reinforcement	Flood protection, erosion control or other bank elevation or strengthening using flood walls or embankments; bank protection using gabion baskets or blankets, boulders, sheet piling, wood, geotextiles, etc.; road embankments	Coastal squeeze; disruption of tidal flow and channel interaction; disruption/alteration of estuarine process dynamics; modification of sediment dynamics; disruption of natural habitats; loss of faunal nursery, refuge and feeding areas	1	Removal of hard engineering structures (e.g. naturalisation)
			2	Modify existing structures
			3	Replacement with soft engineering solution
			4	Bank reprofiling
			5	Managed realignment of flood defence
			6	Restore/create/enhance aquatic and marginal habitats
			7	Indirect/offsite mitigation (offsetting measures/techniques)
Channel dredging	Removal or displacement of substratum by dredging or related techniques to maintain flood conveyance	Alteration of bathymetry; disruption /alteration of natural tidal and sediment dynamics; destruction and alteration of benthic habitats; mobilisation of contaminants; increased turbidity (periodically)	8	Sediment management strategies (develop and/or revise)
			9	Indirect/offsite mitigation (offsetting measures/techniques)
Deposition of material	Deposit of dredged sediments or other material onto intertidal or subtidal bed for purposes of sediment nourishment or feeding	Smothering of existing floral and faunal and habitats; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry	10	Material emplacement strategies (develop and/or revise)
Tidal river alteration e.g. channelization/	In upper estuaries, where channel remains river-like, straightening, widening and	Disruption of tidal flow and interaction; alteration of estuarine	11	Restore/create/enhance aquatic and marginal habitats

Pressure (physical modification or ongoing activity)	Description	Impact	No.	Mitigation measures
realignment/straightening	deepening of channel, removal of meanders to increase channel gradient, flow velocity, flood capacity	processes; alteration of natural sediment dynamics; alteration of bathymetry; loss of morphological diversity and habitat	12	Increase in-channel morphological diversity
			13	Indirect/offsite mitigation (offsetting measures/techniques)
Impounding	Backing-up of water through the construction of barrages, weirs and sluices	Alteration of bathymetry; disruption of tidal flow and interaction; alteration of natural sediment dynamics - loss of continuity; destruction and alteration of benthic habitats; mobilisation of contaminants; increased turbidity; loss of faunal nursery, refuge and feeding areas; disruption of habitat connectivity/continuity - interference with fish population movements	14	Removal of structure
			15	Operational and structural changes to locks, sluices and tidal barrages
			16	Install fish passes
			17	Indirect/offsite mitigation (offsetting measures/techniques)
Manipulation of sediment transport	Placement of piers, groynes and breakwaters etc. for controlling sediment distribution.	Disruption of tidal flow and interaction; alteration of estuarine processes; alteration of natural sediment dynamics; alteration of bathymetry; direct/indirect habitat loss	18	Removal of structure
			19	Modify structure design
			20	Restore/create/enhance aquatic and marginal habitats
			21	Indirect/offsite mitigation (offsetting measures/techniques)

Glossary

It is assumed that the readership of this report have a firm grounding in flood risk management (FRM) and land drainage (LD) terminology, so unless considered peculiar or unique the terms which appear in the report are not defined in this glossary.

Artificial Water Body (AWB)

A specific WFD term which refers to a water body which is totally artificial (man-made) rather than with natural origins. Examples could include lakes and canals.

Asset management

The management of systems for flood defence assets over their whole life. Flood defence assets are recorded on the National Flood and Coastal Defence Database. Many of these assets are maintained by the Environment Agency, although a considerable number are the responsibility of others such as local authorities and private landowners. "System Asset Management Plans" is a specific term relating to an ongoing project within the Environment Agency to assess the maintenance needs of discrete systems of assets.

Best Practical Environmental Option (BPEO)

The option that minimises harm to the environment whilst considering cost and practicalities. Can be used as an informal term (as here) but also has a specific legal definition in UK legislation.

Biota

Biota is the total collection of organisms of a geographic region or a time period, from local geographic scales and instantaneous temporal scales all the way up to whole-planet and whole-timescale spatiotemporal scales.

Biotechnical engineering

Civil engineering methods incorporating organic materials to produce functional structures that are also aesthetically pleasing, provide wildlife habitat, and provide sites for re-vegetation.

Review of techniques (or compendium of measures)

The measures/techniques that have been identified in Phase 1 of the development of the Digital Good Practice Manual.

De facto structure

A structure which has been judged or proven to have flood risk management benefit but which is not within the specific ownership or responsibility of the FRM organisation.

Developer

A person or organisation (public or private) responsible for proposing modification to water bodies.

Ecohydromorphology

This is a term that links the biotic and abiotic attributes of water. Abiotic factors include geomorphology, hydrology and sediments.

Facilitated meeting

A meeting conducted (usually by a facilitator) to attain a consensus of expert views and judgement.

Fisheries, Recreation and Biology (FRB)

An Environment Agency term encompassing those disciplines responsible for the protection and conservation of water bodies.

Floods Directive

The European Directive on the Assessment and Management of Flood Risks (2007/60/EC of 23 October 2007) (the Floods Directive) is designed to help Member States prevent and limit floods and their damaging effects on human health, the environment, infrastructure and property. The Floods Directive came into force on 26 November 2007 and Member States have two years in which to transpose the Directive into domestic law.

Good chemical status (GCS)

This is one of the two components of good status (the other being good ecological status). GCS is defined in terms of compliance with all the quality standards established for chemical substances at the European level.

Good ecological potential (GEP)

By 2015 all artificial water bodies have to reach good ecological potential (GEP). GEP is set in relation to reference conditions. For HMWBs this reference condition is the MEP (maximum ecological potential).

Good ecological status (GES)

An expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters, classified in accordance with Annex V of the Water Framework Directive. GES is defined as "a state where the biological quality elements (for example benthic invertebrates or fish) of a water body deviate only slightly from conditions that would be present if the water body was undisturbed by human activity". To achieve GES in a HMWB would result in a significant adverse impact on use.

Heavily modified water body (HMWB)

In some cases, substantial alterations made for activities like navigation, water storage, flood defence and land drainage may mean that a surface water body cannot reach 'good' ecological status. Where certain criteria are met, the WFD allows such water bodies to be designated as heavily modified water bodies.

Hydromorphology

Used to describe in combination the hydrological and geomorphological forms and processes of rivers, lakes, estuaries and coastal waters. This includes the quantity and dynamics of flow or the tidal regime, associated sediment regime and size, shape and structure of the channel or foreshore. For rivers, hydromorphology not only includes the forma and function of the channel but also its connectivity (for example, the allowance of sediment movement or the migration/movement of organisms).

Impact

The environmental effect of a pressure (such as fish killed; ecosystems modified).

Macrophyte

Macrophytes are aquatic plants that are large enough to be apparent to the naked eye; in other words, they are larger than most algae.

Making Space for Water

Making Space for Water is the cross-government programme to develop a strategy for flood and coastal erosion risk management in England. There are similar strategies in other parts of Europe, one of which is known as 'Making Room for Water'.

Marginal aquatic vegetation

Vegetation found at the sides of a river channel rooted in the bed (not including the channel bank above the water line).

Maximum ecological potential (MEP)

Hydromorphological conditions mean the only impacts on the water body result from the artificial or heavily modified characteristics of the water body once all mitigation measures have been taken to ensure the best approximation to ecological continuum, in particular with respect to migration of fauna and spawning and breeding grounds.

Measure

Measures (or techniques) that can potentially be deployed to mitigate adverse impacts, thereby improving the ecological potential of a water body.

Pressure (sub-pressure)

The direct effect of a driver (an anthropogenic activity). For example, an effect that causes a change in flow.

Propagule

This is any plant material used for the purpose of plant propagation (such as a cutting, leaf section or seed).

Rapid Assessment Tool

A term specific to this report for a tool that enables the reader to quickly screen the effectiveness of a measure/technique based on a number of criteria.

Regulator

The organisation (or departments within an organisation) responsible for 'regulating' the works proposed by developers.

River restoration

In the context of this report, it is taken to include 'full restoration' (complete structural and functional return to a pre-disturbance state), rehabilitation (a partial return), enhancement (and improvement in environmental quality) and creation (development of a resource that did not exist previously).

Transitional and coastal waters (TraC)

A term coined to cover estuarine as well as coastal environments. In this report, both have been confined.

Transverse forest strips

A term peculiar to Scotland used to describe partial use of the floodplain to attenuate flood flows.

UK Technical Advisory Group (UKTAG)

The advisory group set up in the UK to implement the EU Water Framework Directive.

Use

The specific pressure which results in the water body being designated as "heavily modified". Uses may be singular (FRM, LD, navigation, water resources, HEP) or a combination of pressures.

Water body

A specific term used to define (for example) a length of watercourse or coastline. A river basin (catchment) may contain several water bodies.

Water Framework Directive (WFD)

Directive 2006/60/EC establishing a framework for EU Community action in the field of water policy.

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