PHASE 1
RIVER RESTORATION:

FEASIBILITY STUDY

The River Restoration Project

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the **River Restoration Project**

Executive Summary

The River Restoration Project (RRP) aims to implement a series of demonstration projects within the UK that apply state-of the art techniques to river restoration. This report evaluates the feasibility of that demonstration phase.

For the RRP to succeed:

- the demonstration projects cannot afford to fail
- they must break new ground
- the knowledge gained from the demonstration project must be applicable to other rivers and help establish a baseline for it to be used elsewhere.
- valuable technical results must be disseminated to educate and stimulate the public as well as the scientific community.

These targets are considered below in the framework of the current state of restoration, the benefits and disbenefits of the potential techniques and the general constraints and opportunities to and for the project. This forms the basis of the feasibility of the demonstration phase.

The nature of river restoration.

River restoration is the complete structural and functional return to the pre-disturbance and self -regulating state. Rivers and their floodplains are prime candidates for restoration as their high intrinsic value (ecological, sociological and economic) has been compromised by systematic degradation.

What is the purpose of restoration?

The primary purpose of restoration is to conserve and promote nature although there are occasions when other reasons (eg. landscape and amenity value) help determine the need for action. With multi-functional requirements (such as flood defence), the partial return to a pre-disturbance state, referred to as rehabilitation, becomes the pragmatic alternative to restoration. Critical evaluation of benefits/disbenefits of the various techniques and measures are limited by a lack of post-project appraisal, although there is a strong suggestion that restoration has many ecological benefits as well as improving landscape and amenity value, water quality, hydrological regime and channel stability.

The basic requirements of river restoration.

Restoration (or rehabilitation) can only be undertaken within the holistic framework of catchment planning. The use of multi-disciplinary teams (ecologists, geomorphologists, hydrologists, engineers etc) and rigorous design within this planning framework are critical. Sympathetic land-use is essential, and although there are opportunities in Britain through bringing land out of arable production, the available schemes for financial subsidy are only loosely applicable to rivers. Perhaps more importantly, much land is privately owned and is often divided between many people within a river catchment making complete control of land use difficult.

Most techniques for restoration involve reinstating physical habitat, the loss of which is often perceived to be the primary limiting factor. However, water quality and quantity are also of

prime consideration, and although improving physical parameters may have a beneficial influence upon water quantity and quality, the latter should generally be addressed, before physical restorative measures are implemented.

Plan of action

The most appropriate course of action towards the reinstatement of a natural river regime is to exploit the potential for natural recovery. Where potential is high, recovery may be enhanced by reducing the appropriate stresses. This may simply require non-structural techniques, such as changes in land-use. Where natural recovery potential is low, more direct intervention and the use of structural techniques may be required. However, this should only be undertaken to the level at which recovery of natural form and function within a suitable time-scale is likely. The choice of structural techniques for bank stabilisation and instream modification is wide, but, as a general rule, only local natural materials should be used, supplemented by artificial materials only where absolutely necessary.

British Coal Opencast

The River Restoration Project gratefully acknowledges the important contribution made by British Coal Opencast in sponsoring this Feasibility Study, which brings together existing knowledge of river restoration and enhancement work both in the United Kingdom and abroad.
The restoration of riverine environments represents a significant challenge, and the contribution made by British Coal Opencast is an excellent example of their commitment to environmental improvement through better knowledge and practice which will be of benefit to both wildlife and those whose livelihood or recreation depends on rivers.

The Opencast sector of British Coal has produced quality coal for over half a century from the shallow deposits found in the traditional mining areas of England, Scotland and Wales. Prior to the mining process surface features of natural interest may be conserved, translocated, or even enhanced. On restoration new features may be introduced adding diversity of topography and wildlife in landscapes greatly affected by past mining, intensive farming or industrial processes. Opencast's technical skill in land rehabilitation is now recognised as the finest in the world in terms of quality and variety.

Opencast works with a range of statutory bodies, research establishments and conservation groups in pursuit of improved knowledge, including county wildlife trusts, the Wildfowl and Wetlands Trust, the RSPB, Hawk and Owl Trust, Badger protection groups and the successor bodies to the Nature Conservancy Council, English Nature, the Countryside Council for Wales and the Scottish Natural Heritage.
Many new nature reserves have been created following surface mining. Where opencast mining requires the diversion and subsequent re

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1. AIM

To review, describe and assess current restoration projects, measures and techniques.
This to be accompanied by:

- a library of information (Appendix 3)
- a list of contacts (Appendix 2)
- recommendations for the next phase (Chapter 6)

2. INTRODUCTION

The River Restoration Project (RRP) has been set up by an independent group of river enthusiasts with the overall aim of setting up a series of demonstration projects within the UK that apply state-of-the-art techniques to river restoration. Knowledge gained from the experience will be disseminated to educate, to increase understanding and to promote further restoration attempts.

The RRP has a core group consisting of an executive of Jeremy Biggs, Lyndis Cole, Maureen Fordham, John Garland, Nigel Holmes, Anne Powell and Chris Spray and an National River Authority (NRA) technical group consisting of Andrew Brookes, Alistair Driver, Valerie Holt, John Steel and Richard Vivash. This is supported by a steering group of multi-disciplinary organisations concerned with the riverine environment.

Phase I of the RRP, this feasibility study has been supported by British Coal Opencast.

2.1 Information gathering

Information gathering for the feasibility study used three main methods:

- literature search
- contact with personnel involved in applicable projects
- site visits

2.1.1 Literature search

Published literature is inevitably somewhat out of date. However, it does provide a useful background on both in-channel, riparian zone and floodplain restoration schemes, measures and techniques.
Source material to aid the RRP in planning and successfully implementing Phase 2 was also gathered.

This included information on the need to restore rivers:

- the effects of channelization upon wildlife communities and channel form and function
- the effects of river catchment changes such as agricultural drainage
- the effects of river regulation
- evaluation of habitat requirements of particular groups

A little information on current thinking and techniques concerned with the study of rivers was also collected:

- recent concepts of river and floodplain processes and functioning
- methods for evaluating conservation, fisheries and recreational value
- methods for classifying rivers and floodplains
- catchment planning and legislative frameworks

The search was conducted in several ways:

- utilising the extensive library of information held by the River Environmental Engineering Group (REED) at the University of East Anglia (UEA)
- computerised data search using GEOBASE (through Geoabstracts) and the Bibliographic Information Data System (BIDS) at UEA
- exploiting extensive reviews of relevant literature undertaken for books (e.g. Brookes, 1988), conference proceedings (e.g. Boon *et al.*, 1992a, RIZA *et al.*, 1992) and recent influential papers (e.g. Petersen *et al.*, 1992)

2.1.2 Contact with practitioners

Communication with international workers was sought by letter or telephone call, building on a list supplied by Andrew Brookes. Personal contact was established with all conservation officers of all NRA regions.

2.1.3 Site visits

Site visits were undertaken to several restoration schemes in Sønderyllands amt (southern Jutland county) in Denmark via contact with Mogens Bjorn Nielsen. Visits to relevant schemes within the UK were arranged by Andrew Brookes, Alistair Driver, Valerie Holt and Richard Vivash of the RRP and Claire Redmond of NRA Anglian region.

3. BACKGROUND INFORMATION

Abstract

- Restoration is the complete structural and functional return to a pre-disturbance state and thus requires an appropriate and achievable time-scale.
- The naturalness of rivers and their riparian zones/floodplains has been severely compromised by human interference over a long time-scale, particularly through changes in land use such as urbanisation and agricultural intensification. This makes rivers likely targets for restoration.
- Understanding of the rate and pathways of restoration is limited, although the potential for the natural recovery of rivers is high and restoration of many may require only minimal intervention.

3.1 Introduction

This chapter considers some of the basic knowledge that is necessary before embarking on a programme of river restoration. The first step is to provide an exact definition of restoration itself, as well as other associated terms (such as rehabilitation and enhancement), to ensure everybody concerned has a clear idea of what is being undertaken. It is also beneficial to put the science of restoration ecology in context by describing some of the obvious constraints as well as some of the potentials of restoration. Secondly, it is necessary to consider what comprises a natural, fully functional river. This provides a baseline against which the current state of many rivers should be compared.

The scale of restoration can be broadly assessed with:

- insight into the reasons for, and extent of, any degradation that has occurred
- information on the nature of the resulting stresses
- knowledge of the potential for natural recovery

This section is thus divided into two parts:

- the context of restoration
- the restoration of rivers

3.2 The context of restoration

This section is set out in the following way:

- definition of terms
- restoration as the desired option

3.2.1 Definition of terms

Many terms are used to describe works involved in the improvement of the riverine environment, namely; restoration, rehabilitation, renovation, reconversion, renaturation, enhancement and even amelioration and mitigation. These are frequently interchanged but they all have distinct definitions.

These terms may firstly be split on the basis of the principal aim of the scheme in which they are employed. Those that have environmental benefit as the root of the proposed scheme, include restoration, rehabilitation (and its derivatives renovation, reconversion, renaturation) enhancement and creation.

Restoration

'is the complete structural and functional return to a pre-disturbance state' (modified from Cairns, 1982, 1991; NRC 1992).
This is intuitively the most desirable option for the environment. It is axiomatic that no restoration attempt can ever be perfect (Berger, 1990 op cit. NRC, 1992). This is simply because the geological, climatological, biological and chemical sequences responsible for the production of any river are unique (Cairns, 1991). The predisturbance state is therefore a viable option (Cairns, 1989).
Probably the best approximation to a pre-disturbance state is that exhibited during natural recovery. This process may be enhanced by minimal intervention tackling the appropriate stresses.

Rehabilitation

'is the partial structural and functional return to a pre-disturbance state' (Cairns, 1982).
Rehabilitation, 'the putting back to good order', also typically involves the selection of desirable features only (Cairns, 1982), whether or not some of these were present prior to disturbance. This is likely to be the most appealing option to planners and decision-makers, who are required to meet the needs of many user groups i.e., benefits must be measured in terms of wildlife, recreational and amenity value and flood defence requirements, and is therefore the pragmatic alternative. This may be self-maintaining but is more likely to require managing in some way.

Enhancement

'is any improvement of a structural or functional attribute' (NRC, 1992).
By definition this is usually conducted on a smaller-scale and does not refer to the pre-disturbance condition. Rather, desirable features are put into place to expand any current riverine attribute. Artificial structures, such as in-stream deflectors, which may mimic natural dynamics, are frequently used.

Creation

'is the birth of a new ecosystem that previously did not exist at the site' (NRC, 1992).
The concept of creation is not usually applied to rivers themselves, as these are not usually created where none existed, but more to habitats associated with rivers, such as wetlands. There is also an intrinsic suggestion that the new and altered use of the landscape is for some perceivable human gain (NRC, 1992), although wildlife may be the primary beneficiary.

Many projects have something other than environmental benefit as their primary objective. These schemes are only really of interest to the RRP where techniques that may be of wider application are employed.

Terms of relevance include mitigation, amelioration and reclamation.
Mitigation is defined as 'actions taken to avoid, reduce or compensate for the effects of environmental damage (potential or real) (NRC, 1992). Amelioration is often used in the context of avoiding damage and implies improvement is made.

The actions taken are often loss-reduction exercises, although it is possible that environmental gain (on the original condition) may become an intrinsic part of such schemes in the future. 'Sensitive river engineering', (Newbold *et al.*, 1983; Purseglove, 1988; IWEM, 1989) where the utilitarian goals of transmitting water from A to B as quickly and efficiently as possible are achieved, but the manner in which they are conducted may be less environmentally damaging than more 'traditional' engineering solutions, is a typical mitigation exercise.

Reclamation is 'the adaptation of a resource to fulfil a utilitarian human need' (NRC, 1992). Examples of reclamation e.g. the drainage of wetland for agriculture, often involve environmental loss, but, in certain circumstances, increases in conservation interest (perhaps habitat and/or species diversity) may occur. For example, where 'wasteland' or low-grade coastal systems are reclaimed for use in sustainable forms of agriculture or aquaculture.

3.2.2 Restoration as the desired option

This section considers the:

- constraints of restoration
- potential of restoration

The actual operations of restoration may be technical and dominated by engineering and financial operations but their underlying logic must be ecological (Bradshaw, 1987). As such, restoration has been described as the 'acid test of ecology' (Bradshaw, 1987), in that it provides an opportunity to test, in practice, our current understanding of ecosystem development and functioning, and perhaps, indicate where future efforts should be directed. In the process of restoration, individual functions or elements may be assessed alone or in combination, and their relative importance to the functioning of the system ranked. This may therefore combine the traditional reductionist approach of ecology (Diamond, 1987) with the basic synthetic approach of restoration, and may ultimately enhance the strength of ecological theory.

Constraints of restoration

There are several obvious constraints upon restoration, as modified from Cairns (1990):

- ecology has not yet matured as a hard, predictive science
- there is inadequate knowledge of:
  i) the functioning of the system
  ii) the direction in which restoration may proceed
  iii) the rate of restoration
  iv) the pre-disturbance state
- there are some pieces (ie species) of the ecosystem may no longer be present
- there are inadequate technical and financial resources

However, perhaps the greatest constraint is human attitude. Primarily, the recognition of the need to restore and the degree of willingness to attempt restoration. There are, clearly, human constraints of conflicting demands for the use of land, planning difficulties in satisfying the needs of many user groups, providing adequate finances and so on, but as has been shown by many groups (especially in other countries-see Appendix 1), these problems are surmountable if the desire to restore is strong. Analysis of the benefits and disbenefits of restoration can be attempted, but such is the complexity of ecological interactions, a relatively high level of unpredictability must be expected. Learning how to restore an ecosystem, therefore, often requires at least some trial and error.

Potential for restoration

Aquatic systems (apart from shorelines) have a higher potential for restoration than is predicted from the information that is available upon them (Table 1). As noted by Cairns (1990) this is especially true for rivers. Despite the lack of a robust theoretical support base, and with minimal intervention, some remarkable and rapid recoveries of rivers to a close approximation of the original condition have been made.

Table 1.
Evaluation of recovery characteristics of ecosystems. Ranked from 1 to 10 where 10 indicates most information or most potential. Cairns (1990) (from Cairns *et al.*, 1977).

type	information available	potential of restoration
aquatic		
freshwater flowing (lotic)	4	6
freshwater still (lentic)	5	7
estuary	3	4
marsh	6	8
shoreline	7	2
terrestrial		
arctic	8	5
temperate	10	10
tropical	2	1

3.3 The restoration of rivers

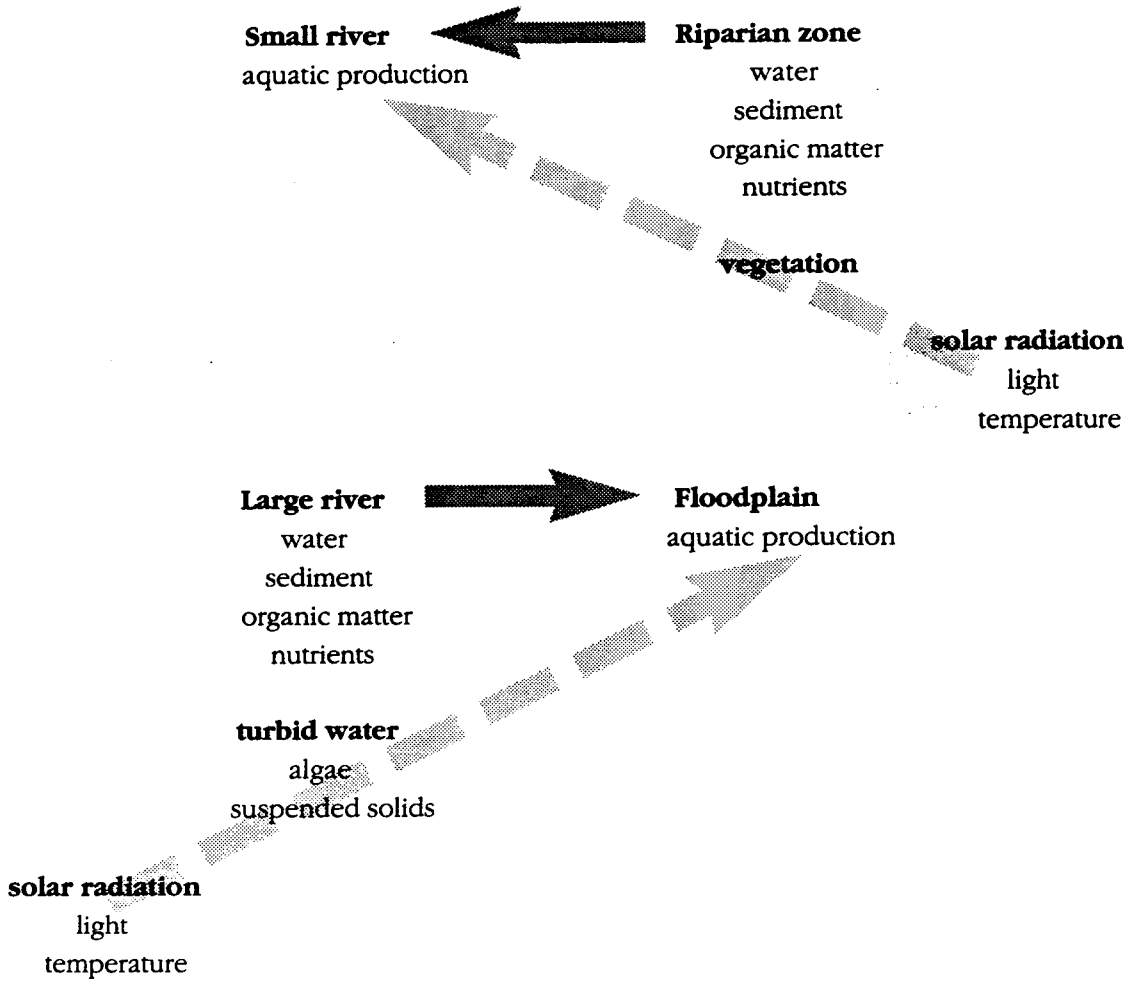
This section is divided into several parts:

- rivers and their floodplains
- river degradation
- the nature of the stresses
- the scope of natural recovery

3.3.1 Rivers and their floodplains

Any restoration must include the floodplain or riparian zone. This is because rivers are so intimately linked (hydrologically and ecologically, in food chain and nutrient cycling) with their floodplains or riparian zones, that they must be thought of as one functional unit (the Riverine-Riparian Ecosystem, NRC, 1992) (Fig.1).

Fig. 1.
Differences in the relationships between the channel and riparian zone or floodplain depending on the size of the watercourse (modified from Junk *et al.*, 1989; NRC,1992).



N.B. In a small watercourse, the riparian zone donates to the river, whereas in a large watercourse the river donates to the floodplain.

Rivers have several inherent properties that are crucial to their natural form and function:

- openness
- dynamism
- flow and retention
- patchiness
- resistance and resilience

These functions are best explained by the following description:

Rivers must be considered as open systems, a product of their drainage basins, with the riparian zone controlling the rate of exchange of materials (water, sediment, nutrients and consequently energy) between land and water.

The water itself characteristically flows in one-direction. However, its passage may be complex and should be considered in three dimensions; upstream-downstream; transversal - between main streams, side-arms, marshes etc; and vertically through the connection between epigean and ground waters. The rate of transport may be extremely variable, for example; according to tidal influence, on a seasonal basis or when comparing movement within the channel to that of the floodplain. Nutrients, sediments, pollutants and organisms are, therefore, always transported downstream, although they may be retained within the system by a variety of mechanisms, most notably by channel features such as organic debris. This will influence the rate of nutrient spiralling downstream. Continual mixing of the water column, characteristic of flowing water tends to increase the capacity of assimilation as well as dissolved oxygen levels.

The flow regimes of natural rivers may be relatively predictable. Peak flows may be viewed as perturbation events in which erosion and deposition destroy and create particular features. Although change on a local scale may be recognised, over a larger scale or longer time period the overall pattern (e.g. meandering) may remain constant in dynamic equilibrium.

This dynamic system is a heterogeneous environment with distinct habitats and patches to which organisms are adapted and form characteristic biotic communities. In turn, these habitats may be classified into functional units on the basis of those communities (Harper *et al.*, 1992). Patches may vary sequentially in a longitudinal fashion i.e. riffles and pools, as well as laterally i.e. channel, riparian vegetation, backwater, and even vertically into the hyporheic zone below the bed of the river (Amoros *et al.*, 1987). Patchiness is further complicated by seasonal variation, particularly in relation to flow regime.

This variability in flow regime and conditions means that communities have to be resistant to perturbation. This is a particularly valuable attribute when the stresses are artificial. The ability to recover from a number of those perturbation events, resilience, contributes to the potential natural recovery of the system (see 3.3.4).

For a river to be fully 'restored' these natural functions must be satisfied. As these are all at least partly dependent on a functional riparian zone and/or floodplain, reinstatement of this zone is of top priority.

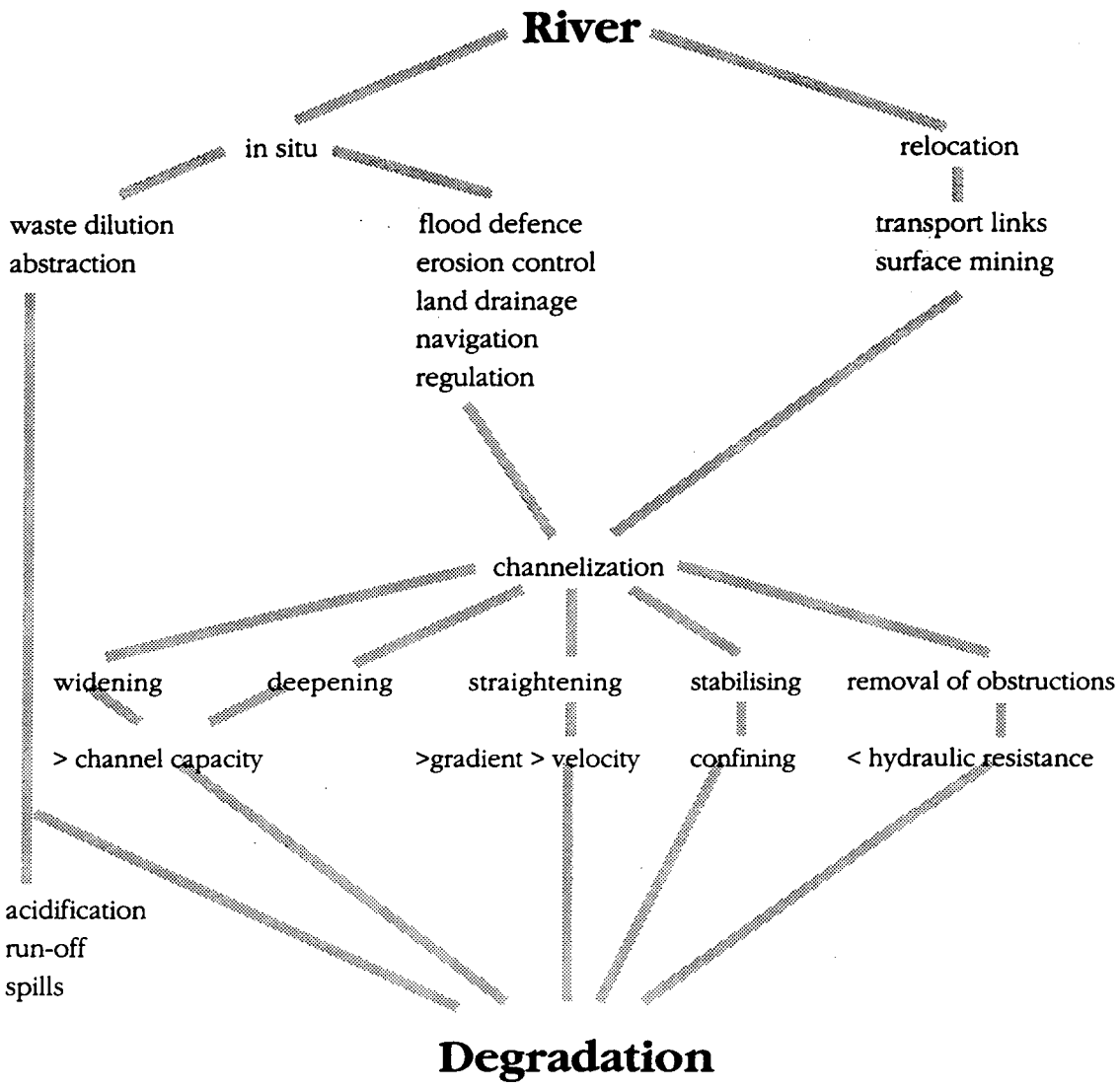
3.3.2 River degradation

This section is divided into:

- reasons for degradation
- extent of degradation

Some knowledge of these two factors will help in the selection of both suitable sites for restoration and the measures required in that restoration during Phase 2 of the RRP.

Fig. 2.
The pathways of riverine modification.



Reasons

Rivers may be subject to many factors that lead to their degradation. Although each of these factors may be present in a variety of river types and situations, a gross separation of the major factors may be made on the basis of whether the river has a lowland or upland catchment.

lowlands

- agricultural drainage and deforestation
- urbanization with a requirement for increased flood defence and erosion control
- pollution from anthropogenic eutrophication (an increase in rate of supply of nutrients) and industrial sources
- low flows through abstraction for water supply

uplands

- acidification
- afforestation and drainage of peatlands
- regulation through dam-building and interbasin transfer for public water supply

Rivers may be modified and perhaps degraded through several pathways (Fig.2). This may be because the river is required to adopt a specific function (eg water supply, land drainage), or prevents another function being fulfilled (eg exploitation of mineral resources, enhanced road and rail communication) which demands its relocation, or where modification is largely inadvertent (eg spillage of pollutants, agricultural run-off).

A recent questionnaire to NRA personnel (ECON & Pond Action, 1993; Appendix 1) revealed that physical habitat loss, principally through river engineering, is perceived to be the most important form of riverine degradation in England and Wales (Fig. 3). Of the specific reasons for river engineering, the requirement to defend land and property from the risk of flooding is the most important (Fig. 4), although land drainage and the relocation of rivers for transport links are also widespread. Whether in a rural or an urban setting there are two fundamental results of modification for such purposes:

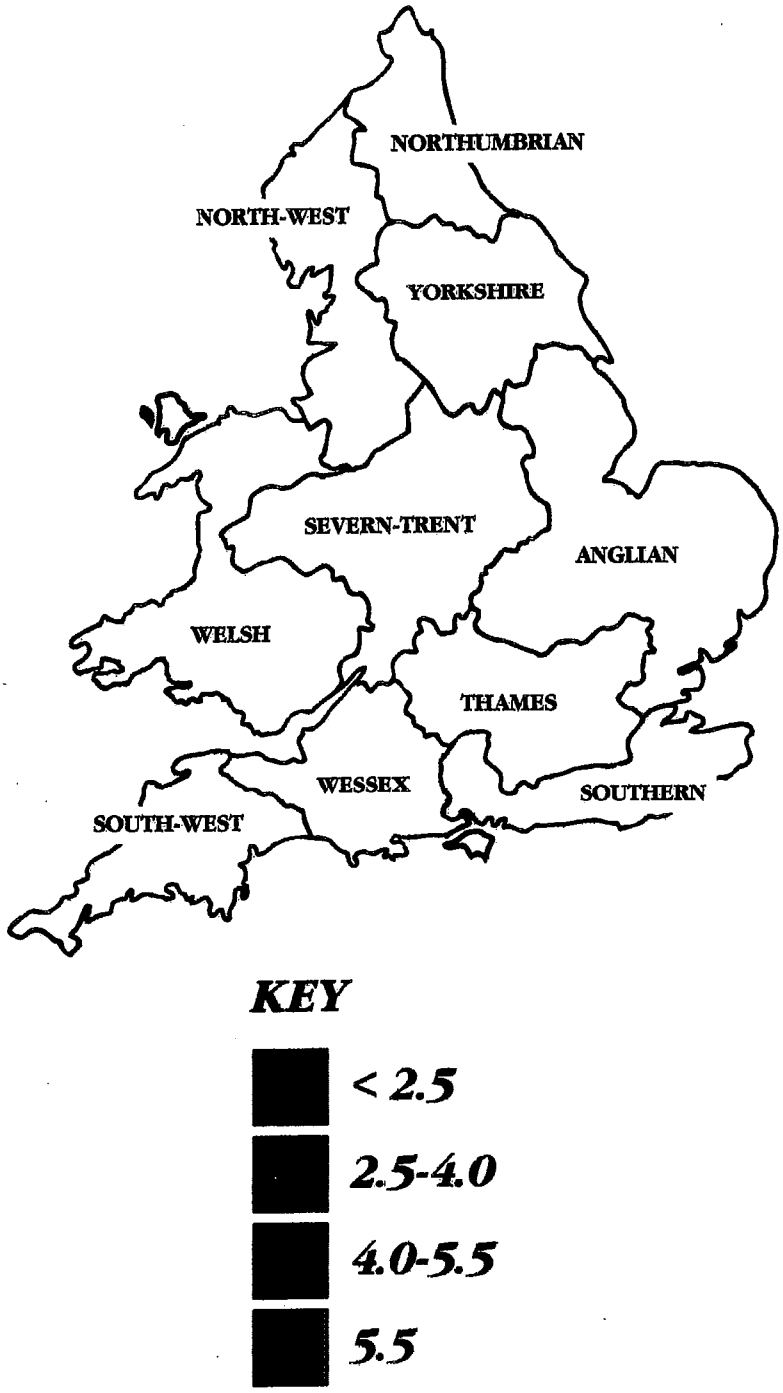
- the river is severed from its riparian zone
- water is confined to the channel, which is often considerably modified (channelization).

The latter often destroys the highly productive edges, which constitute a high proportion of the available habitat as a result of the long, thin shape of rivers.

Extent

There are 24 million hectares of land in the UK, which is crossed by almost 1500 discrete river systems (comprising 200 000 km in length) (NERC, 1990). All but a fraction of this land is now used for some purpose (Parry, 1991), which has consequently had a major impact upon rivers and streams. The extent of modification attributable to changes in land-use is summarised in Table 2.

Fig. 3.
The relative importance of physical, biological and chemical factors in river degradation as perceived by NRA personnel.
Means ranks for each of the factors are shown.



PHYSICAL
- HABITAT LOSS
CHANNELIZATION

WATER
QUANTITY

CHEMICAL
- WATER QUALITY

BIOLOGICAL
- SPECIES CHANGE

Table 2.
Summary of the extent of land use change affecting rivers

Woodland clearance

- the majority of Britain's rivers were probably originally wooded and clearance began some 5000 years ago for agriculture and settlement
- the few trees that remained in river valleys have been largely removed e.g., between 1879 and 1970, up to 70% of bankside trees were removed in eastern England, with 20% of this loss between 1960 and 1970
- afforestation has been extensively undertaken in much of upland Britain and now accounts for some 10% of the land use of the UK (Maitland *et al.*, 1990). Draining by ditching has caused peat shrinkage and major effects on the hydrological cycle (Petts, 1984)

Agriculture

- there are no absolute figures for the drainage of river dependent wetlands, but as very little of the original wetland resource remains, e.g., less than 1% in East Anglia (Williams & Bowers, 1987), this is likely to exceed 95%
- channelization is a typical method of drainage and in the principal lowland arable area, the Anglian region, over 2000 km of main river length has been channelized, around 33% of the total (Brookes *et al.*, 1983).
- intensive agriculture also contributes a massive nitrate load e.g., 71% of the mass nitrogen flow in the River Great Ouse in 1970 was from such sources (Mason, 1981)
- agricultural wastes represent a significant threat e.g. there were 4,141 reported pollution incidents from animal slurry and silage liquor in 1988, about a 1000 of which may be described as serious (NCC, 1991). Some 71 SSSIs were affected by such pollution between 1986 and 1990

Urbanization

- there are no figures for the amount of urbanization in river valleys but large increases in the last century are likely e.g., in the valley of the River Exe there was a 1300% increase between 1940 and 1980 (Countryside Commission, 1987)
- channelization is a typical method of flood protection and in the most urban areas much river will be channelized e.g., in London 41% of the main river has been channelized, by far the highest density in the UK (0.14 km/km^2) (Brookes *et al.* 1983)
- pollution from inputs of phosphate-rich sewage and industrial effluent is common in urban areas e.g., in 1975, there were 3,922 discharges of phosphate-rich sewage into the lower reaches of rivers, many of which were in towns

Regulation and damming

- 89% of rivers are regulated in the UK, (Petts, 1988) mostly for public water supply. 450 of the large dams in the UK are in upland regions, and in Wales the total area covered by reservoirs is 5600ha (Edwards & Howell, 1989)

3.3.3 The nature of the stresses

The stresses imposed upon rivers and streams that disrupt structural and functional patterns may be split into five classes (NRC, 1992):

- changes in the source of energy
- water quality
- water quantity and flow regime
- habitat quality
- biotic interactions

Each stress may produce many ramifying indirect effects about which there is scant knowledge.

For example, Webster *et al.* (1992) outline the dramatic changes that may occur if the nature of the riparian zone is altered, in their case, by removal of the riparian trees. Of prime importance, the very nature of energy flow will fundamentally change from being dominated by allochthonous (nutrients, organic material such as leaves) inputs from outside of the channel to autochthonous production (from primary production e.g. from algae) within the channel. In addition, the supply of organic debris such as wood, which helps retain sediment, aids nutrient cycling (by retention of organic matter and provision of biofilms) and shelters detritivorous macroinvertebrates, is cut off. In turn, the structure and functioning of the plant and animal communities may alter in a multitude of ways, typically producing a simple community of ubiquitous species rather than a species rich, diverse, productive, natural community. For this ideal community to be regained, a supply of woody debris and allochthonous production are basic prerequisites, processes that may take several millennia to be resumed naturally.

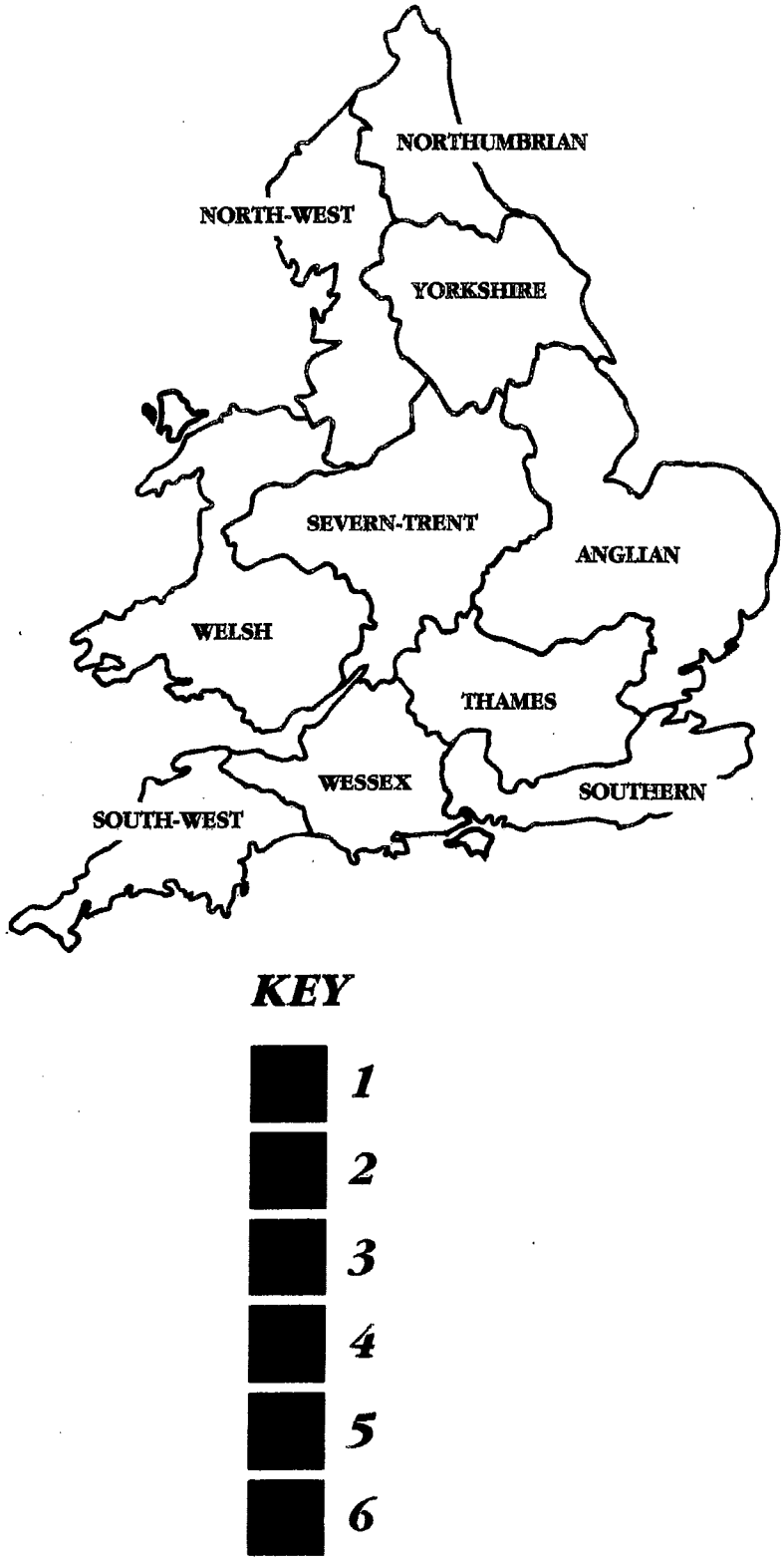
3.3.4 The scope of natural recovery

Rivers and streams often display considerably more resistance and resilience (the ability to recover) to and from chemical (Cairns *et al.*, 1971) and physical (Brookes, 1992) stresses than other aquatic environments. Resilience largely depends on the extent and condition of the structural and functional units after the stress, which is dependent on the nature, intensity and duration of the stress involved.

Several factors contribute to resistance and resilience:

- ability to change physical form
- continual flushing (eg of pollutants)
- organisms adapted to variable (patchy) environments
- high buffering capacity (eg chemical buffers in hard waters)
- high assimilative capacity
- a high degree of structural and functional redundancy in the ecological community (based on key or cornerstone species that disproportionately influence the functioning of ecosystem
- proximity of a source of potential colonists
- rate of colonisation

Fig. 4.
The relative importance of the reasons for river engineering as perceived by NRA personnel. Reasons are ranked on a scale of 1-6 in decreasing order of priority on a regional basis.



FLOOD DEFENCE

LAND DRAINAGE

EROSION CONTROL

NAVIGATION

TRANSPORT LINKS

OTHER

The ability to change physically and reinstate habitats that have been lost is of high priority as physical habitat loss is perceived to be the principal factor contributing to riverine degradation (Fig. 3). The scope and rate of physical change after disturbance is dependent upon two factors (Brookes, 1988, 1992)(Table 3):

- stream power
- sediment supply

Streams of higher energy, particularly those with a supply of sediment have a greater potential for recovery. This has important implications as to whether or not the simple removal of the physical stresses e.g., regrading banks and breaking out stabilising materials, is likely to lead to the recovery of the stream length in question.

Table 3.
Channel recovery characteristics according to stream power (after Brookes, 1992).

		Sediment available	None or limited sediment supply
High energy 35-1000 W m-2			
	a) resectioned	- deposition of sediment - perhaps bank slumping	- limited recovery - severe bank slumping
	b) straightened	- possible attempt to regain sinuosity - erosion with emergence of nickpoint	- limited recovery
Low energy under 35 W m-2			
	a) resectioned	- narrow to more natural low-flow width	- little or no recovery
	b) straightened	- limited adjustment	- no recovery

Summary

Restoration, by definition, requires detailed knowledge of the pre-disturbance state after setting an appropriate time-scale as well as understanding of the rate and pathways of change.This demands detailed ecological information and understanding, which is often lacking. Fortunately, rivers have great potential for natural recovery and so enhancing the ability of the river to recover, utilising geomporphological principles, perhaps through minimising the relevant stresses, may restore some rivers to their natural state.

At the present time, few rivers in the UK can be regarded as natural and many have been modified over a long time - scale (up to 5000 years), although physical habitat loss, in particular, has probably been accelerated over the last 50 years, with flood defence and agricultural drainage being important contributors. Perhaps the greatest shortfall of many rivers is the lack of a functional floodplain or riparian zone which is an integral component of a natural river. In this degraded condition, many rivers will require intervention using a multi-disciplinary approach combining ecology, geomorphology, hydrology engineering and planning.

The need to restore rivers as a result of their importance in ecological, sociological and economic terms has been recognised in many countries around the world (Appendix 1). Consequently, a variety of techniques have been developed and adapted (Chapter, 4) to help fulfil the goal of restoration and its pragmatic alternative, rehabilitation.

4. DESCRIPTION OF THE BROAD RANGE OF TECHNIQUES THAT MAY BE EMPLOYED IN RESTORATION

Abstract

- Restoration and rehabilitation demand a holistic approach comprising appropriate non-structural and perhaps structural techniques.
- Non-structural or planning measures, particularly in relation to land-use changes, may be all that is required to enhance natural recovery.
- Where some form of technical intervention is required, the range of suitable structural techniques, particularly for channel features (both bed and banks) is wide and includes many forms of biotechnical engineering using both natural and 'soft' artificial materials (e.g., geotextiles).
- Technical intervention should only be employed to reduce the appropriate stresses to a level at which natural recovery is likely to restore natural habitats

4.1 Introduction

The holistic approach demanded by restoration and rehabilitation is difficult to conceptualise easily, so it is beneficial to consider the structural and non-structural elements that make up a restoration project individually. These can then be built into a detailed holistic strategy.

The non-structural elements may include:

- planning and legislative framework
- land use
- species-centred restoration

The structural elements may include:

- channel features - both bed and banks
- riparian zone and floodplain

Selection of appropriate techniques will depend on many circumstances, although the level of degradation that has been suffered, the scope for natural recovery and the location of the river in question (i.e. in an urban or rural environment) are all critical considerations. Technical intervention should then concentrate on the limiting factors and reduce the stresses to a level within the scope (ability to recover in a suitable time-scale) of natural recovery. Appropriate form and function may then be restored naturally.

Consequently, not all restoration projects will require both non-structural and structural elements. It may be possible to fully restore a river to its natural state with non-structural elements alone through the relief of a particular stress and exploitation of the potential for natural recovery. For example a change in land use may reduce the need for flood protection, reduce nutrient inputs, relieve or introduce grazing pressure or, perhaps, simply give the river the space to move.

However, there are clearly many situations where intervention will be required to attain a more natural state, and a full range of structural techniques will be needed to supplement any non-structural measures.

For ease of reference, this chapter is structured in the manner illustrated in Fig. 5. Non-structural and structural techniques are considered and described in turn. Structural techniques may be required in the two major zones of a river, namely the channel/in-channel zone and the riparian zone/floodplain. These techniques may concentrate on reinstating natural features, such as an appropriate channel form with riffles and pools, or provide pragmatic alternatives to these natural features, such as the use of multi-stage channels with instream current deflectors. The latter may be used in urban areas where space is restricted and flood protection is of utmost priority. Each technique is considered individually in the text in terms of:

- principles
- description
- guidelines for implementation

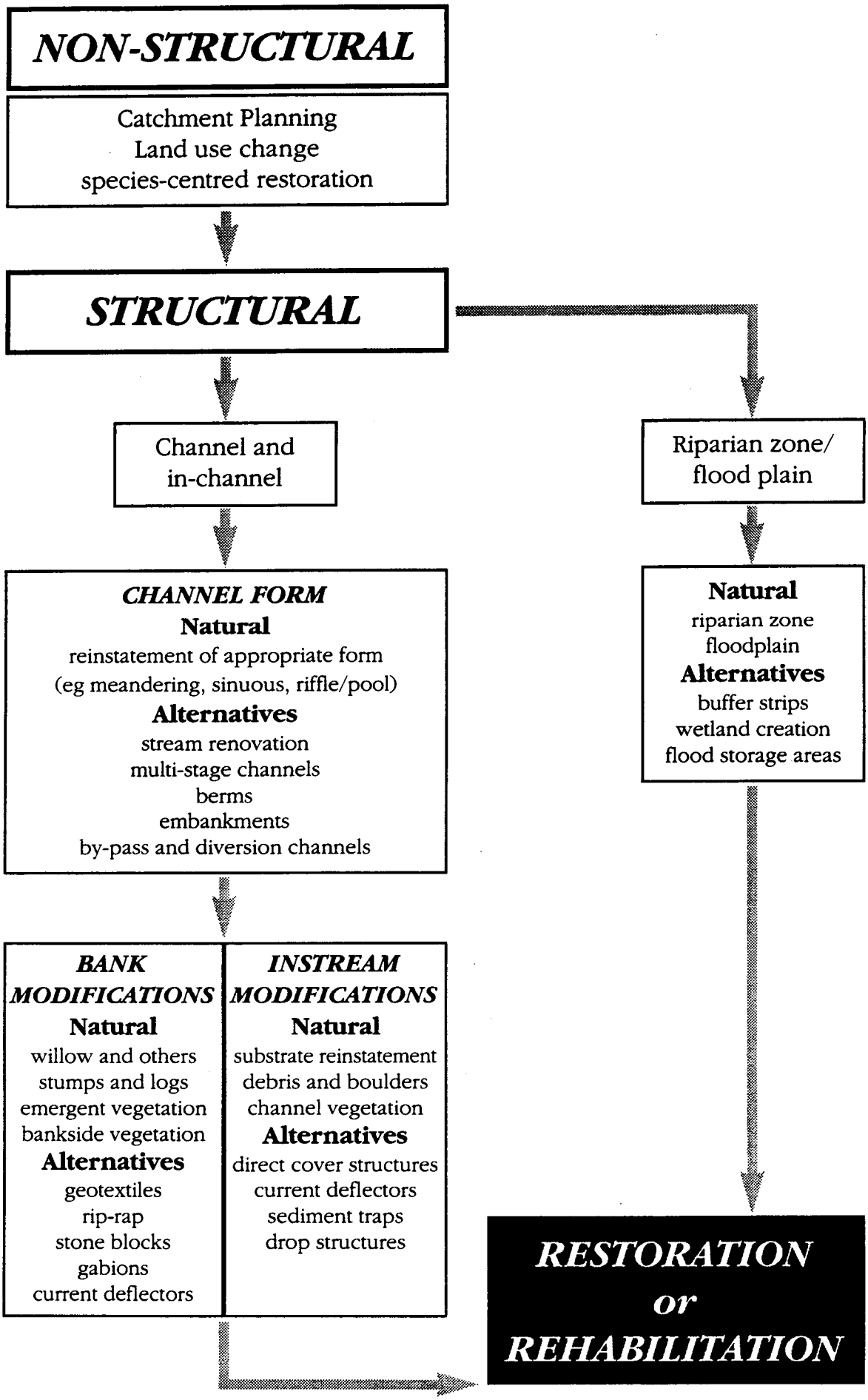
4.2 Non-structural techniques

This section is divided into:

- catchment planning
- land use change
- species reintroduction and species-centred restoration

4.2.1 Catchment planning

Catchment planning is a strategic approach that seeks to understand the catchment in terms of i) surface water ii) groundwater and iii) land use effects on the water cycle (Gardiner & Cole, 1992). This is based on the fundamental premise that land and water are a hydrological continuum and what is instigated in one part of the catchment will inevitably be manifested in other parts. Catchment planning may then be used to conserve, enhance and where appropriate restore the total river environment through effective land and resource planning across the total catchment planning area (Gardiner & Cole, 1992).


NON-STRUCTURAL
Catchment Planning
Land use change
species-centred restoration
STRUCTURAL
Channel and in-channel
Riparian zone/ flood plain
CHANNEL FORM
Natural
reinstatement of appropriate form
(eg meandering, sinuous, riffle/pool)
Alternatives
stream renovation
multi-stage channels
berms
embankments
by-pass and diversion channels
Natural
riparian zone
floodplain
Alternatives
buffer strips
wetland creation
flood storage areas
BANK MODIFICATIONS
Natural
willow and others
stumps and logs
emergent vegetation
bankside vegetation
Alternatives
geotextiles
rip-rap
stone blocks
gabions
current deflectors
INSTREAM MODIFICATIONS
Natural
substrate reinstatement
debris and boulders
channel vegetation
Alternatives
direct cover structures
current deflectors
sediment traps
drop structures
RESTORATION or REHABILITATION

The process of deriving a CMP as currently adopted by the NRA in England & Wales involves:

- setting up a multi-functional CMP group
- identifying and describing current and future catchment uses
- identifying environmental objectives and standards for individual catchment uses
- identifying catchment issues and options
- draft consultation report
- internal consultation
- external consultation
- final plan

This should allow decisions to be taken on (Gardiner & Cole, 1992):

- how to manage the existing situation
- how to approach and solve future problems

Catchment planning offers possibilities for changes of land-use within catchments, including development control, and will hopefully lead to the integrated management of water quantity, water quality, and the physical environment, with an emphasis on non-structural methods.

The adoption of the CMP ideals and framework is critical to further river restoration or rehabilitation (whichever is the most appropriate for user needs) in the UK. The NRA has begun to implement the CMP process, although, as recommended by ECON and Pond Action (1993) in a recent report to the NRA, the rationale and mechanism for river restoration/rehabilitation should be integrated fully into the CMP process, to ensure that rehabilitation receives the attention it deserves.

4.2.2 Land use change

Sympathetic land use is critical to allow the restoration of any river, which by definition includes a functional riparian zone and/or floodplain. There are currently opportunities to secure sympathetic land use in river corridors as a result of EC directives encouraging farmers to take areas of their farms out of production. Several schemes have been developed by a number of bodies to utilise this redundant land, and monies have been made available to compensate the farmer for the loss of income incurred.

The schemes include:

- Set-aside - organised by MAFF
- Countryside Premium Scheme - organised by the Countryside Commission
- Environmentally Sensitive Areas (ESA's) - organised by MAFF
- Countryside Stewardship Scheme - organised by the Countryside Commission

In addition, woodland grants are available from the Forestry Commission.

Set-aside

This MAFF scheme was set up specifically to promote changing land use as a result of the decrease in support prices for cereals and was agreed within the Common Agricultural Policy. One year and five-year set-aside schemes were initiated to take land out of production. These have now been superseded by an arable area payments scheme using set-aside land (MAFF, 1992a). This requires a minimum of 15% to be set-aside to be eligible for the scheme. This percentage is calculated from an individual farmers land receiving area payments for arable crops (cereals, oilseeds and proteins only) inclusive of the area to be set-aside. In addition, many crops can still be grown on set-aside land (including barley) provided they are for non-food use. There is some provision for environmental benefits under the scheme (for example managing land for overwintering geese), but this is largely limited to advice on good management practice (eg selection of sites bordering areas of high natural diversity, including watercourses). Therefore, set-aside land, *per se,* is currently limited in its application to riverine habitats, although if set-aside becomes compulsory then this may be of most relevance if applied to buffer strips (see 4.3.4) alongside watercourses.

Countryside Premium Scheme

This scheme, run by the Countryside Commission (CC), is available for set-aside land (under the five year set-aside scheme), and is at present only under operation in a limited number of English counties (Bedfordshire, Cambridgeshire, Essex, Hertfordshire, Norfolk, Northamptonshire and Suffolk). It has the advantage of requiring the sympathetic management of set-aside to fulfil a specific purpose including:

- wildlife fallow (£45/ha)
- wooded margins (£75/ha)
- pasture for Brent Geese (£80/ha)
- meadowland (£110/ha)
- habitat restoration

The latter option is potentially of value in river corridors as the creation of wetlands by raising water levels and reinstating washlands and other marshy areas, is a possibility (Countryside Commission, 1989). In addition, herb-rich meadows are also a suitable habitat for creation. The nature of the payments for this option are at the discretion of the project officer and the CC.

Environmentally Sensitive Areas (ESA's)

This scheme identifies areas of ecological value and pays farmers to create and/or maintain habitats in a manner in keeping with the natural environment (MAFF 1992b). Riverine landscapes form an integral part of some ESA schemes (eg Broadland, Suffolk River Valleys) and grassland is the habitat that forms the basis of the conservation interest. Payments are made on a tiered scale and the criteria for each tier are different according to the locality of the scheme (Table 4).

Table 4 Examples of the general criteria and payments for ESA schemes (after MAFF, 1992b).

Broadland ESA (Norfolk)

Tier 1	grassland
purpose:	to maintain the Broads ESA landscape and grassland
conditions:	enter all or part of grassland
payment:	£125/ha
criteria:	graze with livestock, avoid excess organic and inorganic fertiliser, do not use fungicides, insecticides or herbicides, do not use under-drainage, mole drainage or modify the existing system, maintain water levels, hedges, ponds and reedbeds, do not damage features of historic interest
Tier 2	conservation grassland
purpose:	enhance the ecological interest of grassland and dykes
conditions:	enter some grassland which has significant ecological interest or potential
payment:	£220/ha
criteria:	all conditions of tier 1 plus specific controls on water level and retention and the timing of grazing and mechanical operations, only cut for hay (not silage) within a restricted time period, do not apply organic manure or phosphate, potash, or anything that may reduce soil acidity, apply a plan of dyke maintenance for dyke flora and do not dig new foot drains and grips
Tier 3	conservation grassland
purpose:	to further enhance the ecological interest of grassland and dykes by the creation of wet winter and spring conditions on the grazing marshes
conditions:	enter some grassland where high water levels can be achieved
payment:	£250/ha
criteria:	all conditions of tier's 1 and 2 plus maintain water levels high enough to create shallow pools within a specified time period, do not apply organic or inorganic fertiliser, specific controls on the timing and intensity (density of animals) of grazing
Tier 4	arable reversion
purpose:	to revert arable land to permanent grassland
conditions:	enter all or part of arable (crops or ley grassland of less than 5 years) land
payment:	£200/ha
criteria:	in the first year certain practices will be allowed to enable a grass sward to be established but application of organic and inorganic fertiliser, substances to reduce acidity and pesticides requires prior approval, after this period all criteria in tier 1 must be followed

Suffolk River Valleys

Tier 1	grassland
payment:	£70/ha
criteria:	similar to tier 1 above but including some use of herbicides against nettles, docks and thistles, maintenance of dykes and ditches in rotation and by mechanical means, within two years accept advice on the management of woodland, scrub and reedbed
Tier 2	conservation grassland
payment:	£180/ha
criteria:	all conditions of tier 1 and similar to tier 2 above but including a restriction on filling low areas with river or ditch dredgings
Tier 3	reinstated grassland
payment:	£200/ha
criteria:	similar to tier 4 above

ESA's, are of long enough tenure (10 years) to allow significant environmental gain to be made, although there is an option of withdrawal after a shorter period (5 years). The current take-up of ESA schemes in both Broadland and the Suffolk River Valleys is reported to be encouraging.

Countryside Stewardship Scheme

This scheme originated from the 1990 White Paper, 'Our Common Heritage' and is run by the Countryside Commission. It is a ten year option, aimed to support those management practices that conserve, enhance or restore landscapes and wildlife habitat (Countryside Commission, 1991). This scheme is of direct application to rivers as it includes waterside landscapes as one of the options available for payments. Land that includes traditionally managed water meadows, grazing marshes and flood meadows, or is of high scenic and historical value is particularly suitable. Payments are made on two tiers, the first, of £70/ha for existing permanent grassland and of £225/ha for the re-creation of waterside grassland. Under both tiers sensitive management guidelines include light grazing, management of high water tables, maintenance of dykes, ditches and hedgerows and management of fen and reedbeds.

4.2.3 Species-centred restoration

Although containing both non-structural and structural elements, species-centred restoration is considered here, as it more of an approach to restoration. Species-centred restoration is geared to the needs of one (or occasionally a few) particular species. In the US especially, great efforts have been made to restore rivers as habitat for particular fish species, particularly, valuable commercial species such as salmonids. This may involve the reintroduction of eggs, larvae and adults, combined with attempts to improve habitat quality and water quality and quantity. However, the reintroduction of any species that have been lost must be regarded as the last stage in any restoration project and to be used only where natural recolonisation is unlikely or slow.

There are several guidelines available for such restoration attempts which may be applied to many fish species (Hunt, 1988 op cit. NRC, 1992):

- identify limiting factors and try to eliminate or depress those factors that reduce the carrying capacity of the habitat for the species concerned
- maintain or enhance base flow including riparian zone and entire watershed management activities
- consider species-specific and age-specific requirements of the species concerned including environmental suitability and social interactions with other fish species and/or age groups
- habitat improvement should be in a step-wise sequence, namely: examination of site, diagnosis of needs, prescriptions of remedies, planning and organisation of work, on-site treatment and development, evaluation of results and maintenance of development
- disguise artificial structures and restore aesthetic conditions as quickly as possible
- tailor management to the individual stream
- preserve, restore and accentuate the meandering channel profile and pool riffle sequence (where appropriate)

- work with the inherent capacity of rivers to recover naturally
- utilise stream flow and bring the main threads to flow close to refuge areas (especially salmonids)
- integrate habitat management in the channel with other management activities in the riparian zone and the larger watershed

The principle of concentrating on fish (although alien to most ecologists) may be of benefit as fish are often at the top of the food chain in riverine ecosystems, and, because of this, generally reflect the quality of the environment upon which they depend, including physical, chemical and biological features. Productive natural fisheries are usually only present in high quality biologically diverse rivers. The same principle has been used in Denmark where fish are used as indicators to prioritise sites for restoration (Nielsen, unpubl.)

In the UK, much attention has been directed at another top predator, the otter (*Lutra lutra*). Otters are dependent on good water quality and quantity (partly to provide habitat for their fish prey) as well as particular riparian habitat features as refuge and denning areas.These holt sites are typically in the root systems of trees such as ash and sycamore (Macdonald & Mason, 1983) as well as in the dense cover of scrub thickets. Planting of trees, piles of stumps and logs, and artificial holts have all been provided, and there is no doubt that use of a site by otters has the benefit of promoting more sensitive management of riparian zones, which, inevitably, also benefits other species.

4.3 Structural techniques

4.3.1 Channel and in-channel

The reconstruction of channel form is a basic element in any restoration or rehabilitation project. Although bank and instream modifications are an integral part of such reconstruction, channel form is considered in its own right here, in order to introduce some of the general principles of reinstating natural channels, and to consider some of the alternative channel designs that may be more appropriate where flood protection is of high priority.

Therefore, this section is divided into :

- reinstating natural channels-restoration
- alternative techniques and channel designs-rehabilitation

Reinstating natural channels

The reinstatement of natural channel form and function and consequent flow and sediment regime is based on the (not unreasonable) assumption that the natural river form is the most appropriate both in terms of stability (albeit dynamic), and in terms of faunal and floral composition. This may be applicable where the river is to remain in the same location, to be put back into its old channel, or to be relocated into a new channel.

Whichever is the case, design must take into consideration:

- channel capacity
- channel geometry
- bed and bank stability

Although rivers may be grossly divided into meandering, straight or braided, the high degree of variability within each of these categories makes it critical to consider each river individually, and establish an appropriate form and function. This may be achieved by:

- the use of historical information on channel course
- comparison with similar reaches or rivers in similar locations

Stream power and sediment supply will then determine the level of intervention required (see 3.3.4).

High energy

In high energy streams with a sediment supply, a natural form and function, (whether straight, meandering or braided) may be re-established with minimum intervention, perhaps requiring non-structural methods, e.g., securing the space for the river to manoeuvre. This is the basis of recovery enhancement. Understanding the natural regime in order to predict the rate and direction of recovery, perhaps through comparison with similar rivers is desirable. Design is critical, particularly where a premium of space limits lateral migration, (for example, in urban areas). Bank stabilisation will inevitably be needed and the promotion of flow diversity may require in-channel structures (see 4.3.3), although selection of both will be critical.

In disturbed catchments with an increase in bedload sediment delivery and where banks are erodible, an increase in width to depth ratio may be observed, resulting in a braided condition. Intervention in such circumstances is infrequent, although there are some notable successes (see Blanco river, Appendix 1; Jackson & Van Haveren, 1984). Bank stabilisation (particularly prior to the establishment of natural vegetation) and due consideration of sediment transport regime is of utmost importance, the latter benefiting from a properly designed floodplain.

Low energy

Many low-energy, lowland, alluvial rivers are incapable of regaining their natural channel form as this may have been cut in a period of higher discharge and sparser valley-floor vegetation, perhaps the early Holocene in many cases (Brookes, 1991). Therefore, intervention and full channel reconstruction is often required.

The reinstatement of meanders or sinuosity still requires adequate design. Where there is a sediment supply, e.g., in a highly disturbed catchment, sedimentation may occur as a result of the reduction in gradient through the reinstatement of sinuosity. In addition, where there is no sediment supply, self-adjustment is unlikely and mistakes may require further intervention.

Copying the original form or an appropriate form (in other reaches or other streams), both of which should be in equilibrium, is therefore necessary. The application of geomorphological principles may be aided by computer simulation models (as in Denmark, Nielsen unpubl.) or by building scale model replicas of the reach in question (see River Enz, Appendix 1).

Other appropriate actions include (Nielsen unpubl.):

- selection of depth and cross section in natural riffle pool sequence
- selection of bank form and slope
- substrate placement (see 4.3.3)
- raising bed levels and increasing roughness using plants and debris (see 4.3.3)
- removal of artificial structures
- placement of sand traps (see 4.3.3)

Riffle/pool structure is a common feature of many river types, particularly gravel-bed rivers, with slopes of 0.005 or less (Keller, 1978). Riffles and pools represent a natural means of energy dissipation whilst permitting the transport of sediment.

In meandering channels, pools naturally form on the outside of bends with diagonal riffles at the exit. In such channels the spacing of pools and riffles is 5-7x the width. In straight channels this is often 3-5x the width. Keller (1978) notes the width of the stream is critical in determining the spacing, more so than whether the stream is channelized or not. In addition, riffles are often 15% larger (in terms of area) than pools. This is a possible cause of width fluctuations within the channel, wider on the straights than the bends (Brookes, 1991).

Several guidelines are available on the design of pools and riffles (Brookes, 1988):

- whether pools and riffles are appropriate features must be determined
- spacing and size must be determined
- the size distribution of the bed material must be appropriate (see 4.3.3)
  i) for riffles to be dynamic and self-maintaining
  ii) as interstitial space size is critical for invertebrates and development of fish fry (see below)
- pools should have a minimum low water depth of 30cm
- riffles should not project from the bed by more than 30-50cm
- pools and riffles should be between 1-3 channel widths in length.

In rare cases, the re-establishment of the natural deltaic form of a river mouth may be required. Design is critical and may require the use of simulation models to predict the rate and extent of sediment transport and deposition. An example of such a scheme in which arms were systematically created in the straightened channel to supply sediment to the eroding shoreline is the River Reuss which runs into Lake Lucerne (Jaeggi, 1986).

Alternative techniques and channel designs

There is a demand on channels in urban areas or in areas of highly-intensive agriculture to maintain sufficient capacity to convey low occurrence floods (up to 1 in 100 years). Within such channels, it may be difficult to retain natural characteristics, such as pools and riffles, as the sediment transport regime is impaired and deposition may occur. The techniques listed below do however, allow the preservation of a more natural regime whilst maintaining or improving channel capacity and may therefore be viewed as rehabilitation or renovation.

Stream renovation

Renovation is a term used extensively in relation to urban streams in the US, to describe the techniques of utilising the natural morphological and hydraulic equilibria of the stream whilst retaining channel efficiency (Nunnally, 1978).

Four basic guidelines are followed:

- removal of urban debris, extensive growth of small trees and brush and removal of channel obstructions such as fallen trees to increase channel capacity
- straighten the channel and increase the slope as little as possible. This minimises the undesirable adjustments common in channelization
- promote bank stability by leaving as many trees as possible, minimize channel re-shaping, reseed disturbed areas promptly, use rip-rap (see 4.3.2) judiciously
- emulate nature in designing channel form

The latter point is illustrated by Keller & Hoffman (1977). The inside of bends is sloped to 3:1 or less to promote the formation of point sand bars. The outside of bends is steepened to 2:1 or greater. This asymmetric cross section promotes flow convergence at bends and divergence between a natural pool-riffle sequence. As noted by Keller & Hoffman (1976) the success of stream renovation depends upon a multifaceted approach to urban storm water problems including floodplain and sediment control regulations.

Similar measures are used in the 'Palmiter method' (NRC, 1992), where the hydraulic capacity of streams is restored by 'making the river do the work'. This has been applied primarily in low-gradient alluvial streams where debris reduces channel capacity and increases the risk of bank erosion.

The method involves:

- leaving and/or planting riparian trees to shade the channel to reduce plant growth and support banks
- obstructions and bars are made vulnerable to erosion by removal of the protective layer of debris and creating 'starter' channels to initiate scour
- centres of logjams are cut and allowed to float away, whilst the buried ends are left as flow deflectors to direct current away from the bank
- root wads and trees may be used to provide additional bank support

Multi-stage channels

Multi-stage channels are natural features in some upland rivers which are in the process of actively adjusting their relative position in the floodplain. This formation has been copied for use in lowland rivers. Design of this unnatural state needs careful attention and may be conventional, where the stages are opposite each other on both banks and unconventional where they alternate from bank to bank.

The general principles are:

- normal flows are contained within the original channel
- flood flows are contained within progressively larger cross-sectional areas

The lowermost part of the original channel is therefore undisturbed and the natural configuration is retained. Natural features such as shoals on the inside of bends effectively extend into low berms which represent the second stage of flood carriage. If the stream has sufficient power to migrate and cut into these berms then some stabilisation may be necessary. More stages may be added, often culminating in an embankment (see below) representing the final line of flood defence. Throughout the cross-section, the height of berm relative to water level determines which wetland plants are to prosper. Multi-stage channels may therefore lead to a wide range of groups and species (Brookes, 1991).

Berms

Shallow berms may be created in their own right in both urban or rural channels. The principle involves the re-distribution of material. Overwidened rivers typically deposit fine sediments. These may be removed from the original channel and spread along the channel edges or the river may be encouraged to deposit by using in-stream deflectors (for example see Wraysbury river, Appendix 1). A natural flow width is thus reestablished which may be in equilibrium, whilst the flood capacity of the channel is maintained. Marginal vegetation also protects the toe of the bank.

There are three main design points (Bonham, 1980):

- to maximise habitat diversity at least half the width of the berm should be submerged during low water flow.
- to encourage a range of aquatic plants at least 20 cm of water should be over the lowest edge of berm during low water flow
- effective bank protection from boat wash may be achieved by a 2m berm with slope 1 in 4 or less planted with emergents

Embankments

Embankments are essentially imitations of natural levees and are used to contain flood waters and protect land and property and may be used in both rural and urban catchments. They create the possibility of delineating a river corridor, whilst leaving the original course largely undisturbed.

Three situations commonly use embankments (Vivash in press):

- protection of land adjacent to large lowland rivers, especially in East Anglia where much land is below sea level
- protection of property on floodplains in towns and villages
- prevention of outflanking behind bridges, weirs and other obstructions

As a general rule, the further back the embankment the less disturbance for the original course and the reduction of maintenance and likelihood of damage to the embankment itself. The conservation value of embankments could undoubtably be improved with planting of native vegetation although this is unpopular as roots may undermine the structure and allow break-through of water.

Bypass and diversion channels

Bypass and diversion channels represent an opportunity to increase flood conveyance capacity whilst leaving the original channel relatively undisturbed. This is particularly pragmatic in urban areas where buildings restrict the options for movement. Depending on the circumstances, the by-pass channels may be used to take flood flows only, or any proportion of the normal flows. Weirs may be used in a variety of locations to control flows in the required manner (Lewis & Williams, 1984).

The channel (original or by-pass) that only conveys flood flows may form a valuable marshy habitat in normal flows. However, in urban channels particularly, a sweetening flow may be needed to prevent the stagnation of this channel should some water be retained.

4.3.2 Bank modifications

Any medium that is resistant to the forces of erosion is termed revetment. Natural revetments include hard materials such as rock, boulders, gravels and dense clays supplemented by the soft revetment supplied by consolidating vegetation such as trees, shrubs, herbs and grasses.

Revetment is clearly desirable to prevent lateral erosion and potential damage to land and property and the risk of banks being breached by flood waters. In addition, erosion may increase the sediment load of the river which may be undesirable for conservation and fisheries (Swales & O'Hara, 1980) as well as channel capacity.

It should be established whether additional protection is the most effective option. The reasons for erosion should be understood, and, if addressed, may represent a more long-term solution than tackling the effects of the problem.

Any form of engineered revetment effectively mimics the natural situation. Traditionally, hard materials have been used, including concrete, masonry, steel and wooden fascines. These may far exceed the required resistance in particular circumstances and are very costly.

More recently, the use of natural materials, 'biotechnical engineering' has received more attention. This requires more careful design although the costs of material are significantly cheaper (Hey *et al.*, 1991; NRC, 1992). As natural vegetation takes time to consolidate it is often necessary to use inanimate material in the preliminary stages.

Design should incorporate:

- what is naturally appropriate for the situation, including slope and composition of materials
- the establishment of geotechnical and fluvial limits

However, it is apparent that precise guidelines on the geotechnical and fluvial limits of each revetment type, and the cost-effectiveness of many types, is unavailable.

Current techniques for bank stabilisation are reviewed individually below in the sections:

- natural materials
- artificial alternatives

However it should be noted that some of the alternatives are also natural materials (eg some geotextiles). In addition, combinations of natural and artificial alternatives are often the most effective option

Natural materials

Willow and other trees

Willow, as a result of its ability to regenerate and develop secondary roots from cut stakes, can be used in a number of ways for bank protection.

General points on selection are as follows (Lewis & Williams, 1984):

- osier (*Salix viminalis*), goat willow and sallows (*S. caprea* and others) are the best types as they are bushy, relatively short, grow quickly and respond well to coppicing
- use willow from local sites to maintain local varieties
- tree willows are less useful as, without regular cutting, they tend to turn into a single trunked tree without regular cutting

Generally, willows are simply driven or staked into the bank to water level. Where bundles of green twigs are used, these must be fresh and not left exposed to the atmosphere. Additional protection may be afforded by wiring, wiring loose brashing, binding or supporting with natural rock ballast. Growth of shoots and the dense fibrous root system is generally rapid.

In higher energy situations, willow spiling is the practice of weaving willow withies around winter cut willow stakes into a fascine structure (Brookes, 1991). This is a traditional technique that is undertaken by a handful of practitioners in the UK. In very high energy situations, a continuous wall of willow stakes may be driven into the toe of the bank to provide immediate stability.

Alder (*Alnus glutinosa*) is a valuable bank protection agent with its dense vertically and laterally spreading root system that is capable of penetrating the water table and reinforcing bed as well as banks. Two year old saplings are the most appropriate for planting.

Both alder and willow may be cut halfway through the trunk and the tree laid on its side in the water pointing, in a downstream direction, and secured by staking to further protect eroding banks.

Other species of tree may be used as faggots which may be secured in place by pouring gravel over them. More substantial fascine hurdles may be constructed from hazel (*Corylus avellana*), which does not re-grow but degrades, during which time natural protective vegetation develops.

Stumps and logs

Stumps and logs may be removed from the river during routine clearance operations and secured to the banks with wire and stakes.

These may serve several purposes:

- absorb and dissipate energy
- provide habitat for invertebrates and where above water level for otters
- maintain biofilms and enhance nutrient spiralling properties

Emergent vegetation

Emergent vegetation such as reed (*Phragmites australis*), sedges (*Carex* spp.), bulrush (*Schoenoplectus* spp.), reedmace (*Typha* spp.), reed sweet grass (*Glyceria maxima*) and yellow flag iris (*Iris pseudacorus*) may all be used to protect banks. Though most are associated with lowland channels.

Several factors are important:

- roots bind the substrate preventing scour. Reed rhizomes in particular are strongly rooted and intertwined
- emergent stems absorb wave energy rather than reflect it. Sedges are capable of dissipating 70% of wave energy
- stems encourage sediment accumulation
- emergent vegetation regenerates and maintains its own stability and protects throughout all seasons

Being natural features they are of high value for wildlife.

Bankside vegetation

Traditionally, bank slopes have been sown with grasses to provide stability. However, a more appropriate wetland community (herbs, softwoods and hardwoods) may become established if the banks are left to colonise naturally, providing they can be protected.

This is likely to lead to:

- more complete bank protection by species adapted to the vagaries of water level, sediment chemistry etc.
- greater conservation value

Artificial alternatives

Several artificial alternatives are derived from natural materials including some geotextiles as well as natural rocks. The use of these in combination with natural materials is a common form of biotechnical engineering, which replaces the use of traditional materials such as sheet piling and concrete.

Geotextiles

Several geotextiles are currently available such as paraweb, asphalt matting, enkamat, nicospan, nicolon, jute and coconut fibre (as mats or rolls).

When selecting a geotextile the following should be considered:

- biodegradability
- breakdown products should be non-toxic and unobtrusive
- penetrability to root systems

Of the more widely used:
Nicospan and nicolon are black, flexible polyethylene geotextiles that have pockets in which large stones may be placed as additional ballast (Wraysbury river, Appendix 1; Lewis & Williams, 1984). Further pockets may be used as support for plants. The meshed structure is intended to allow root penetration.

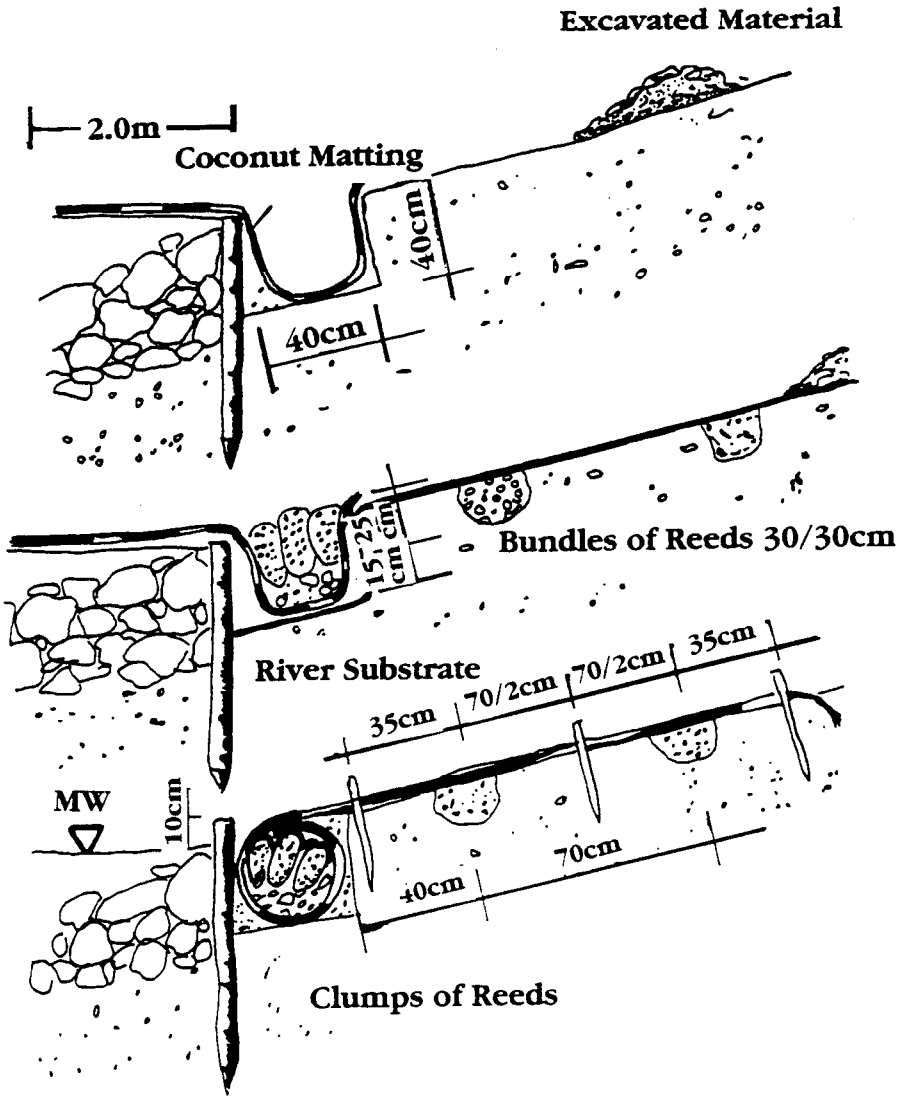
Enkamat consists of a mesh formed of nylon threads fused where they cross. Two forms are available. One of which is 90% air which can be filled and seeded. The other comes prefilled with gravel and bitumen but still allows plants to penetrate.

Coconut fibre is particularly useful because of the following properties:

- biodegradability (supposed to last 5 years but may be shorter)
- high tensile strength
- retains moisture
- protects plants whilst they grow

It is widely used as matting or rolls, particularly in Germany in combination with natural emergent plants (see Fig's. 6 &7) in current speeds of around 2m/s (Landenstalt fur Umweltschutz Baden-Wurttemberg, 1991)

Fig. 6
Technique for the installation of fibre matting to support plants (Redrawn from Landenstalt fur Umweltschutz Baden-Wurttemberg, 1991).

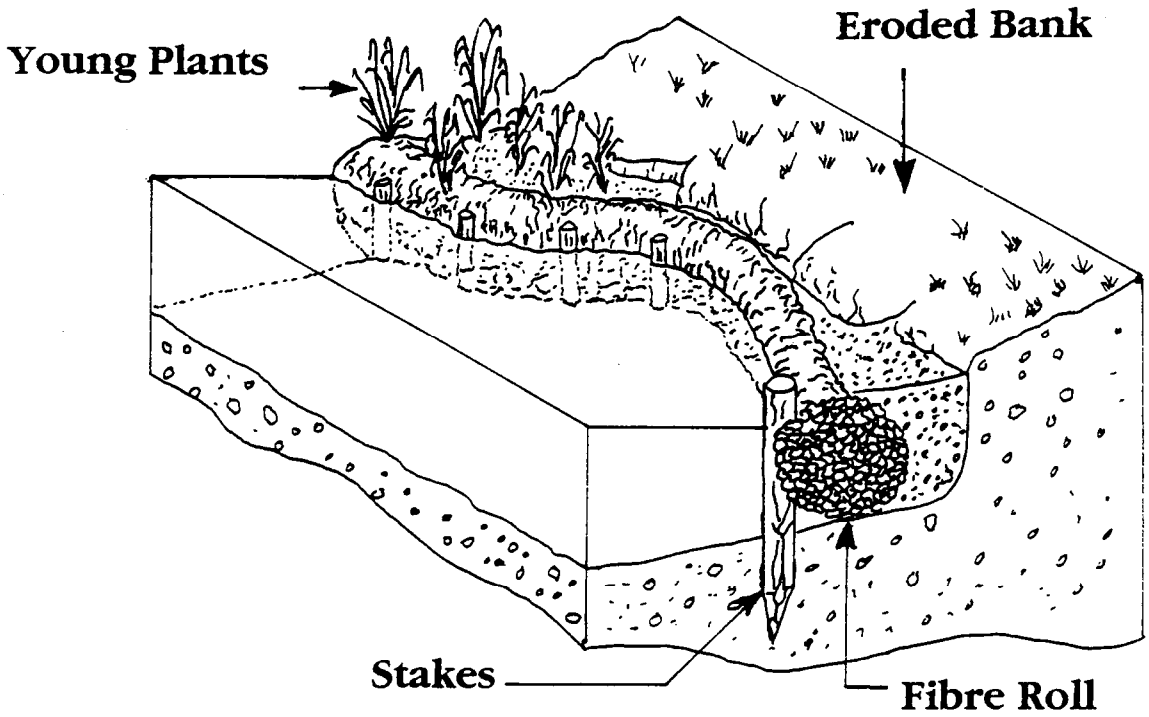


The procedure for installing matting is as follows:

- dig a ditch parallel to the bank at mean water level
- drive in stakes (5-10cm diameter, 1m in length) every 1-1.5m
- insert matting
- insert bundles of reeds using spoil to raise them to the required level
- plant clumps of reed at 50cm intervals along the bank
- fold matting back over entire bank and secure with stakes

The cost of this procedure is approximately £42/m (1991 prices).

Fig. 7
Technique for the installation of fibre rolls to support plants (Redrawn from Russell, 1992)



The procedure for installing rolls is as follows (Russell, 1992):

- Rolls are staked in along the river bank and filled behind with soil
- Plants are then planted directly into the fibre

Variations include the use of pre-planted plant pallets designed for heavier flows.

Rip-rap

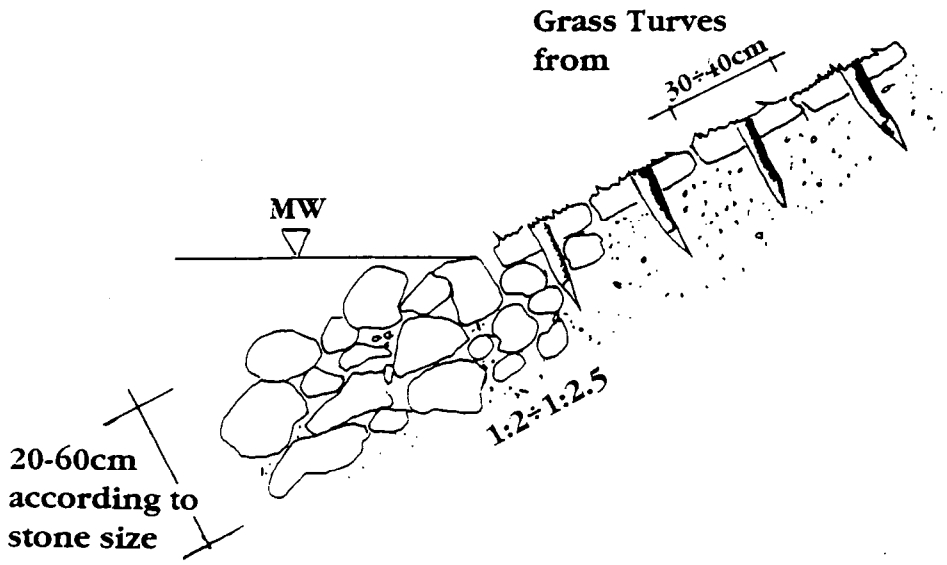
Laying out rip-rap of natural stone has been used widely in Denmark (see Gelså and Brede, Appendix 1) to consolidate reconstructed meandering channels and in Germany in a variety of channels.

Design guidelines are as follows:

- mixed natural stone of varying diameter is used (10-80 cm in Denmark, 20-60cm in Germany) according to drag
- machinery is used to tamp down material where streams are of higher power
- revegetation is often rapid, with a low patchy sward of herbs and grasses generally being present within a year
- opportunities for combining with different living materials (eg reed, willow and topsoil and grasses) and other natural materials (eg brushwood) although the diameter of the stone material may be varied

Rip-rap in combination with other materials provides very resistant structures. In Germany, combining rip-rap with willow, brushwood and turves are all commonplace (Landenstalt fur Umweltschutz Baden-Wurttemberg, 1991). In the case of the latter this can produce valuable amenity areas alongside rivers in an urban situation (see River Enz, Appendix 1) (Fig. 8).

Fig. 8.
Technique for the installation of rip-rap and turves to produce an amenity area (Redrawn from Landenstalt fur Umweltschutz Baden-Wurttemberg, 1991)



Combinations with brushwood (Fig. 9) and willow (Fig. 10) have inherent flexibility as well as strength and are used to resist very strong flows (median current speeds of 3.5m/s and 4 m/s respectively).

Fig. 9
Technique for the installation of brushwood with rip-rap, to resist strong flows (Redrawn from Landenstalt fur Umweltschutz Baden-Wurttemberg, 1991)

Design guidelines:

- create a fence of stakes (diameter 5cm) secured by wooden posts along the length of bank
- lay brushwood (2-3m long) overlapping at an angle of 60°
- drive in the stakes and posts
- stone (10-80cm in diameter dependent on stream power) is placed on top

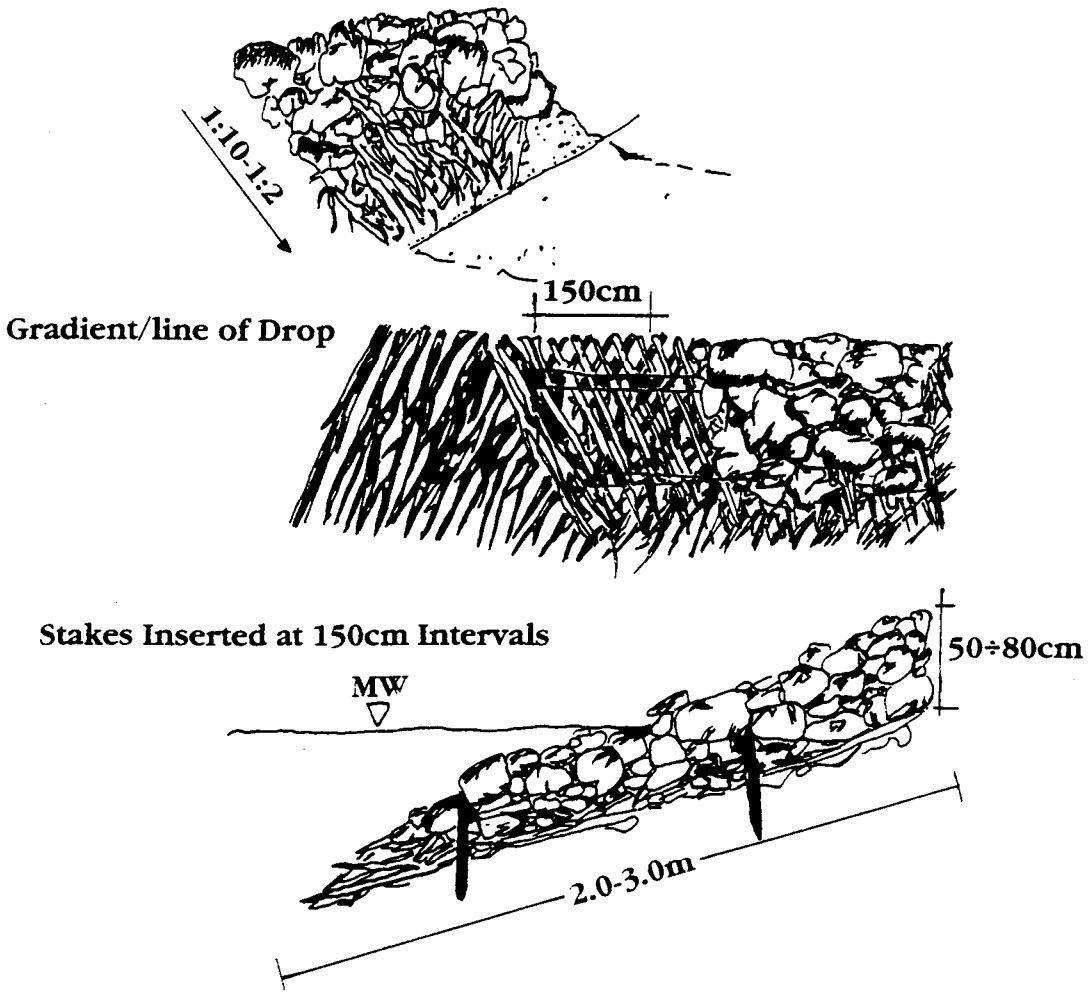
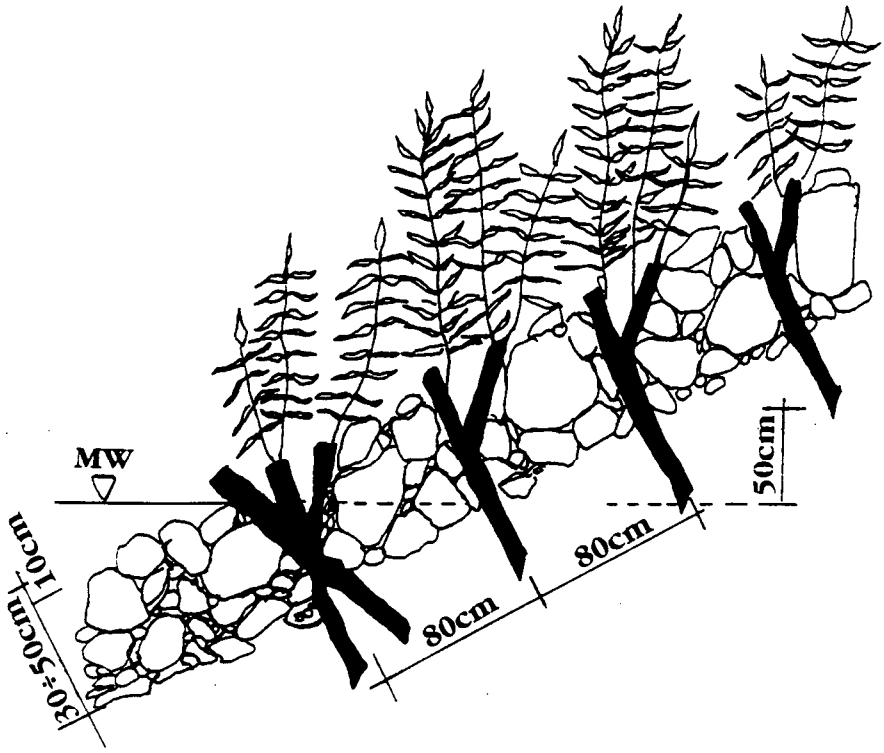
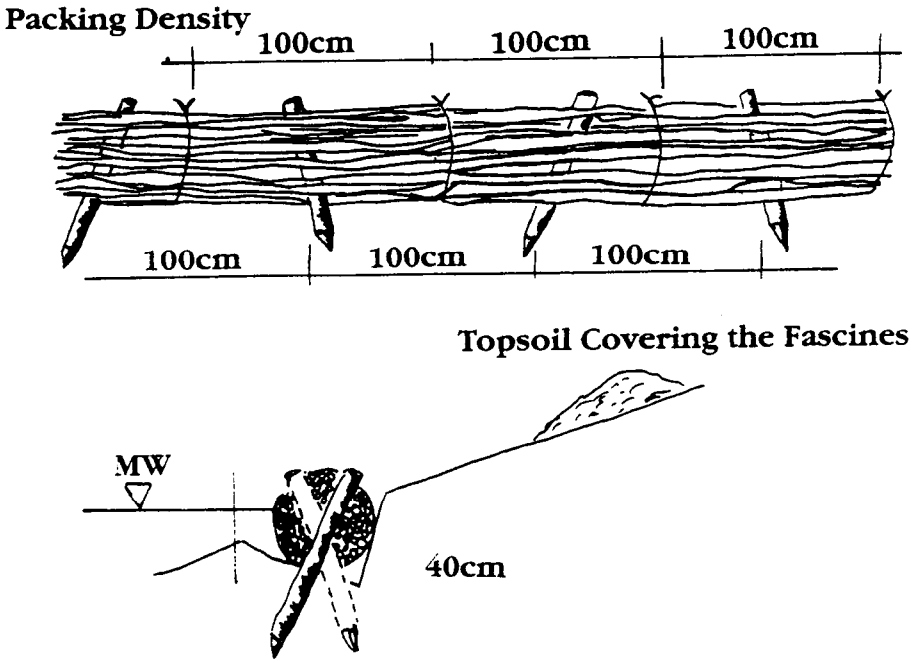


Fig. 10
Technique for the installation of a) willow with rip-rap, to resist strong flows and b) willow fascine (Redrawn from Landenstalt fur Umweltschutz Baden-Wurttemberg, 1991)

a)



b)



Blocks of natural stone

Large limestone blocks have been used in urban situations (see Wraysbury river, Appendix 1) as an aesthetically pleasing alternative to sheet piling and concrete, where protection of banks is of utmost importance. In keeping with the natural environment stone should be of local origin wherever possible.

Gabions

Gabions are rock-filled wire baskets which may be useful in the initial protection of reconstructed banks. A useful attribute is their porosity which allows for some movement of the rocks within. As these are unsightly, these need to be masked by for example, a geotextile filter and then hidden under a layer of soil (Brookes, 1991). Gabions may also be useful where vandalism of softer materials occurs and causes a problem.

However, where gabions do fail, perhaps as a result of scouring at the toe of the bank, the contents may spill out and the wire become exposed and create a nuisance.

Current deflectors

Deflectors may be used as a revetment technique but, by their very nature, create, as well as control, scour (see next section). Spurs and similar deflectors are most appropriate for revetment as they project into the river from the edge of the channel and create zones of slack water and, thus, deposition. They are frequently used in series around the outside of eroding bends and may be pervious or impervious. The most cost-effective structures are wooden (Fig. 11).

Some general points on installation particularly in gravel-bed rivers are provided by Hey & Heritage (1993):

- the length of spurs should be approximately one fifth of channel width
- spur height should extend up to the low flow depth
- angle of deflection should be 90° to the bank, apart from the first and last which should be angled more acutely into the bank
- spurs should be spaced at equivalent distances
- piling should be used to locate the spurs and material used to consolidate
- open planked structures that allow 35% of flow through are preferable, with the planks being keyed into the banks using slit trenches

Consolidation is especially important at the vulnerable toe of the bank with rip-rap and in-fill being used to prevent outflanking and isolation of the structure.

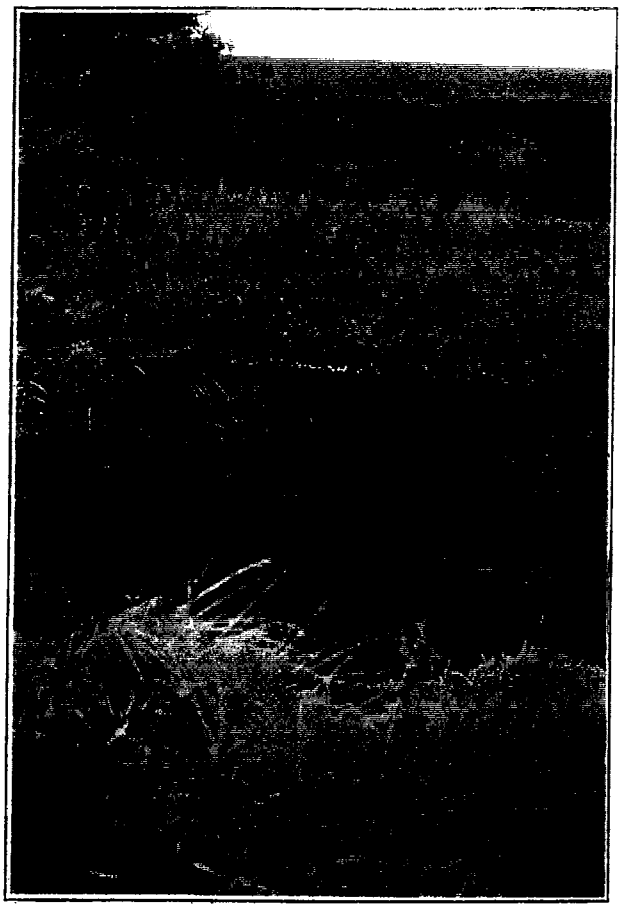


Fig. 11.
Using deposition and erosion for bank stabilisation and instream modification

The use of deflectors to stabilise banks -by enhancing deposition and development of emergent plants
River Arnå-Denmark

Log sill to promote current diversity -through scouring and pool formation
River Ash-England

4.3.3 In-stream modifications

The reinstatement of a suitable in-stream substrate is an essential element in many restoration schemes. Once substrate is in place, this may form desirable natural features such as riffles and pools (see 4.3.1) and provide the opportunity for colonisation of both flora and fauna. To enhance or mimic natural channel dynamics, in-stream modifications may then be used. These often artificial structures are powerful tools for the restoration or rehabilitation of rivers.

This section is set out in the following way:

- substrate reinstatement
- instream modification using natural materials
- instream modification using artificial means

Substrate reinstatement

The reinstatement of suitable substrate (where limiting) is essential to promote a stable sediment and flow regime as well as natural ecological structure and function. Benthic invertebrates, which are a critical link in the food web (e.g., as processors of organic matter and as food for many other organisms) are often identified as the primary beneficiaries of reinstatement of substrate as they show distinct preferences (Tarzwell, 1937; Chutter, 1969; Gore, 1985).

Disturbed gravel-bed streams which may have responded to channelisation by erosion of banks and beds to produce large amounts of deposited sediment, and urban streams where inactive armoured gravel beds have been produced (Brookes, 1991) are common targets.

There are several methods of reinstating substrate:

- reinstate natural channel form and function to expose natural gravels (see 4.3.1)
- mimic natural function to expose natural gravels (see current deflectors below)
- mechanical cleaning/disturbance of natural substrate
- physical reintroduction of natural substrate
- physical reintroduction of similar substrate

The above inevitably require some change in transport regime or further mitigating measures if deposition of fine sediments is not to re-occur (Hermansen & Krog, 1984) (see sediment and gravel traps below)

Cleaning of natural gravels

Natural gravels may be cleaned of sediment using a variety of methods:

- mechanical disturbance such as raking
- baffle gate
- hydraulic water jet - most efficient and economically feasible (Mih, 1978)
- water jet and suction pump

Physical reintroduction of substrate

There are four principle reasons for the physical reintroduction of substrate:

Physical reintroduction of substrate

There are four principle reasons for the physical reintroduction of substrate:

- ecological benefits associated with the substrate alone (eg to increase populations of invertebrates or spawning substrate for fish)
- to reinstate natural features such as riffles
- in conjunction with raising of bed and thus water levels to enhance communication with the riparian zone (eg River Rodå, Sappiston Brook, Appendix 1) (see ramps, and drop structures below)
- to reduce slope (eg River Sulzbach, River Metter, Appendix 1)

For ecological benefits to be maximised it is necessary to use appropriate-sized materials, particularly gravels. This is because the size of interstitial spaces is critical, both as living space for the natural invertebrate community, and as development space for fish eggs. Sediment deposition will occur if this is not in equilibrium with sediment regime, which may reduce the value of the substrate by:

- preventing free movement
- reducing oxygen levels
- preventing wash-out of metabolites

Naturally sorted river gravels from within the catchment are obviously the most desirable but these may be difficult and/or costly to acquire and will inevitably result in disturbance through their collection. Appropriate mixes are available commercially, but these may be costly and reject gravels are often used.

The thickness of substrate used depends on the principal objective of the substrate reinstatement and is likely to be thicker where bed levels are to be raised. Where it used just to provide a substrate, this should mirror the natural thickness as this is most likely to be in equilibrium with sediment and flow regime and communication with the hyporheic zone should be maintained.

There may also be additional constraints of high velocity and flood defence requirements for example in urban streams (Brookes, 1991). This may require the use of very angular or angular washed gravels and cobbles to form a permanent stable armoured layer than equivalent sized rounded gravels (Table 5):

Table 5 The mix used by Thames region of the NRA (Brookes, 1991) in urban streams

sieve size (mm)	% by weight passing through
75	100
37.5	50-85
20	30-55
5	0-5

If the shear stress is high then rolled angular cobbles may be used and the interstices filled with natural gravels. Alternatively mitigating measures such as low concrete sills may be used to locally retain gravels. This assumes that there is a supply from upstream but many urban channels (especially in London) carry limited amounts.

Where little can be done to alleviate catchment changes, artificial substrates such as crushed limestone and reject flint gravel (Spillet et al., 1984) have been used as substitutes for natural gravel and sand.

Substrate may be reintroduced specifically to create natural channel features, such as riffles (perhaps as spawning beds) and point bars. These must be appropriate and related to natural channel dynamics.

Riffle replacement is most appropriate on the site of natural riffles. This may still require a large amount of material (see Harper's Brook, Brede, Appendix 1) and stabilisation with wooden stakes driven into the bed on leading and trailing edges. In Denmark, this is necessary when the riffle is larger than $4m^3$ (Ottesen, pers comm).

Where the height of riffles is increased above natural low flow levels they become ramps which act as low weirs (see below) and raise water levels upstream (see Sappiston Brook, Appendix 1;.Geiger & Schroter, 1983). These will often require stabilisation.

In the highly artificial situation of lined channels there are a few techniques that may enhance flow and therefore habitat diversity. Pools and riffles may be created by simply modelling the substrate into appropriate forms with heavy machinery (see River Ash, Appendix 1). Design of such aspects as pool-riffle spacing in these situations is not critical (Brookes, 1988), as riffles in this situation are unlikely to be truly dynamic and subject to the processes of erosion and deposition. Artificial pools may also be created by lowering the concrete slabs by 400mm and coating with a 150mm thick bed rolled angular limestone cobbles (Brookes, 1991). These features may be connected by the creation of a sinuous path by forming recesses in the concrete lining (2.5m wide on bends and 3.5m wide on straights) (Brookes, 1991).

To reduce slope or raise bed levels, introduction of appropriate substrate is recommended to secure additional ecological benefits whilst fulfilling the specific aims of reducing flow velocity and enhancing communication with the riparian zone.

Instream modification using natural materials

Debris and boulders

Natural current deflection by the use of boulders and woody debris has been widely used in the USA (NRC, 1992). Boulders are of limited application in channels with high sediment supply and may promote bank instability where bars are formed (Rosgen & Fittante, 1986). If they are to be used they are best set as three in a line which reduces turbulence (Ottesen, pers comm.). As a general rule, materials that are natural to the stream and placed appropriately are more likely to be successful.

Channel vegetation

Channel vegetation is rarely introduced during restoration projects, although this may be a possibility during a species-centred restoration project (4.2.3) for rare plants such as the Loddon pondweed (*Potamogeton nodosus*) (Holmes, 1990). Rather, plants are left to colonise naturally after provision of suitable substrates and flow regime.

Many techniques do deliberately set-out to promote channel vegetation, for example, those structures (especially current deflectors) that encourage deposition aim to establish plants which aid in promoting natural low-flow width (eg Sapiston Brook, River Surbæk, Wraysbury river, Appendix 1) or increasing summer water levels by increasing roughness (eg River Surbæk, Appendix 1).

Instream modification using artificial means

Artificial structures have historically been used to enhance habitat for fish, typically salmonids. These practices are particularly well developed in the US. Fish are generally at the top of the food chain, and there is the assumption that where populations of fish are healthy, then ecological and geomorphological criteria upon which they are dependent must also be satisfied (see species restoration 4.2.3).

The application and success of these modifications is somewhat varied and implementation is frequently undertaken by trial and error. As a consequence, Rosgen & Fittante (1986) developed a selection guide for the installation of some commonly used habitat structures for fish by using stream type.

This uses the morphological criteria:

- gradient
- width/depth ratio
- sinuosity
- substrate type
- channel confinement/entrenchment
- landform-soils/stability

Where necessary, guidelines for individual in-channel modifications are discussed in relation to this classification system.

Direct cover structures

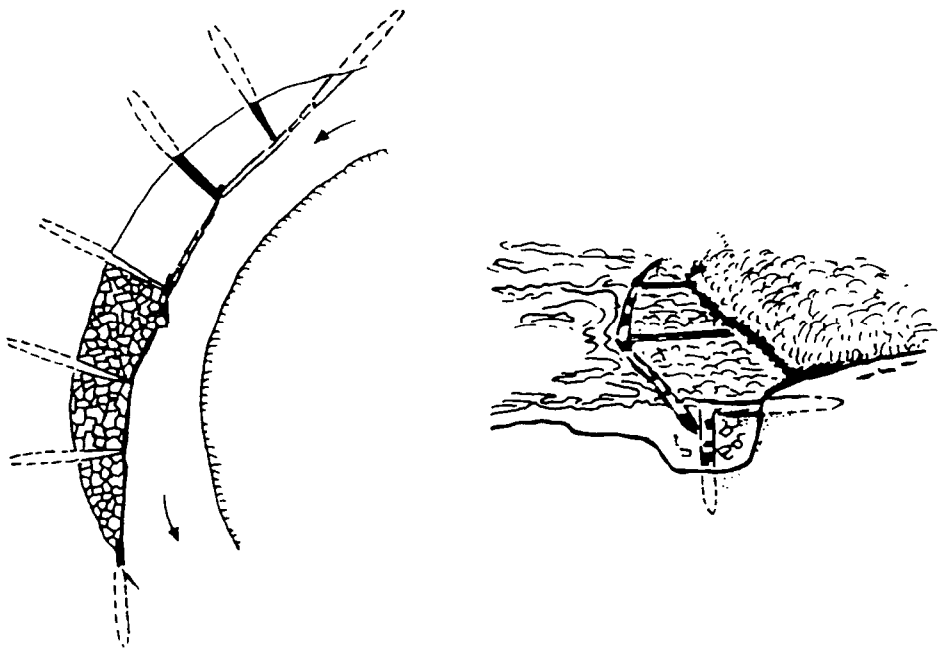
These structures (often wooden) overhang or sit on the surface of the water to form overhead cover for fish. They simply mimic the functions of natural bank vegetation (stabilising, shading and as direct habitat) and processes such as undercutting and the creation of overhangs. They may be an integral part of bank stabilisation techniques, typically on the outside of bends, which require greater elaboration and more careful design. The same principles outlined above (see bank modifications above) apply. This type (Fig.s 12 & 14) may be costly, and natural revetment techniques may provide greater benefit at reduced cost.

More simple structures, such as floating log covers (Fig.13) constructed of timber are of more widespread use for fisheries enhancement. They may be used on the outside of meanders in low energy situations or in straight sections with minimal cover.

Whatever the type used the following benefits for fish may accrue (Swales & O'Hara, 1980):

- concealment from predation
- shading providing lower temperatures especially in low flow conditions (especially for salmonids)
- helps natural spacing-territoriality (especially for salmonids)
- increased habitat for invertebrates prey

Fig. 12 Typical direct cover and bank protection structure



Current deflectors

There are many different types of current deflector (wing, straight, V type, Y type and A type) as well as groynes and vanes (Hey, 1992). Whatever the type, the principle is to mimic naturally variable flow patterns by restricting channel width and deflecting flow to a specific part of the channel. Natural features fulfilling this role are rocks, boulders and debris dams. The latter play an important role in the retention of nutrients and sediments within streams (Webster et al. 1992).

Current deflectors have traditionally been used as a tool to enhance fisheries in several ways:

- increase pool habitat for adult fish
- increase riffle habitat for young fish
- promote surface turbulence for use as cover
- improve water quality through increased aeration via turbulence
- expose spawning gravels
- enhance egg and juvenile survival in spawning gravels by removing sediment
- increase habitat suitability for invertebrate prey

However, they are undoubtably of wider application than merely for fisheries enhancement.

Artificial deflectors are suitable for a wide range of channel types and have been used in steep gravel bed rivers as well as lowland channels. They may generate riffle and pool characteristics in substrates of coarse sand upwards, but are most useful in gravel-bed rivers, by:

- increasing velocity downstream
- scouring sediment from the substrate
- moving the substrate and forming a pool
- material is transported downstream to form a riffle

Using deflectors on alternate banks creates a low flow sinuous channel. Deposition occurs behind the structures which may be colonised by plants (see Wraysbury river, Appendix 1). This is an attractive option where space is limited.

General guidelines:

- spacing of deflectors typically follows that of the natural pool/riffle spacing i.e. 5 to 7 stream widths typically alternating bank to bank with the thalweg (Swales & O'Hara 1980)
- sited below or part way down the natural riffle.
- strength of the structure should reflect stream power although gabions and timber are the typical materials, hazel hurdles (Brookes, 1991; Spillet et al., 1984), natural stone (Brookes, 1991; Spillet et al., 1984), natural bed materials (Warner & Porter, 1960) and sandbags (Spillet et al., 1984) have all been used.
- typical angle of installation is 45° (Swales & O'Hara, 1980), although this appears to be in need of quantification.
- height of installation should not be more than 25cm above normal flow level to allow high-stream flow to go over the top of the structure. If this is prevented, flood water may be concentrated behind the structure which will tend to erode the stream bed (Mills, 1986).

According to Rosgen & Fittante (1986) single and double deflectors (Fig. 14):

- are excellent in cobble-bed rivers of gradient 1.5-4%, with resistant banks (with double deflectors also include similar rivers with a lower gradient of 0.3-1%)
- may need bank stabilization in wider gravel-bed rivers of moderate gradient with erodible banks
- effectiveness is reduced in a wide range of types where channels are unstable and there is a high sediment supply from banks or bed, or where bedrock forms the bed
- extensive construction is needed in braided rivers in order to confine the active channel

Vanes are similar to deflectors but remain submerged even at low flows. These may be asymmetrical, symmetrical or simply straight (Hey, 1992). Vanes essentially consist of timber and/or rocks. Near bed flows are directed towards the centre channel whilst faster surface flows overspill the vane and create a pool adjacent to the bank.

Groynes are generally larger structures that may incorporate the objective of bank protection and deposition. Channel constrictors in the USA perform a similar function (Fig. 14). These are also of limited use in channels of high sediment supply and where bedrock forms the bed (Rosgen & Fittante, 1986).

Sediment and gravel traps

Simple sediment traps are created by overwidening and/or overdeepening the channel to reduce velocities and induce deposition of a variety of sediments from sand (Nielsen et al., 1990 (see Gelså in chapter 6)) to gravel (Hey & Winterbottom, 1990).

Sediment traps are of use in restoration projects particularly in the period after channel modification when the sediment transport regime is in disequilibrium or where introduction of substrate has occurred without changing the unfavourable sediment regime. Siting of the trap will be downstream in the former case and downstream in the latter. Traps will require regular maintenance.

Other types of sediment trap for use in gravel-bed rivers are illustrated in Fig.13. These are designed to concentrate gravel as a spawning medium for fish.

Drop structures

The principle of drop structures (weirs, dams and sills) is to raise water level and generate slower water upstream, whilst inducing scour pools below their crest and increasing flow velocity downstream. The magnitude of the effect is linked to the size of the structure, whereas shape may influence the location of scour downstream. Much energy may be dissipated where structures are used in series. These mimic natural waterfalls but are used in many river types with both resistant and erodible banks and a variety of substrate types.

Fig. 13 Examples of direct cover and drop structures and gravel traps.
After Rosgen & Fittante (1986).

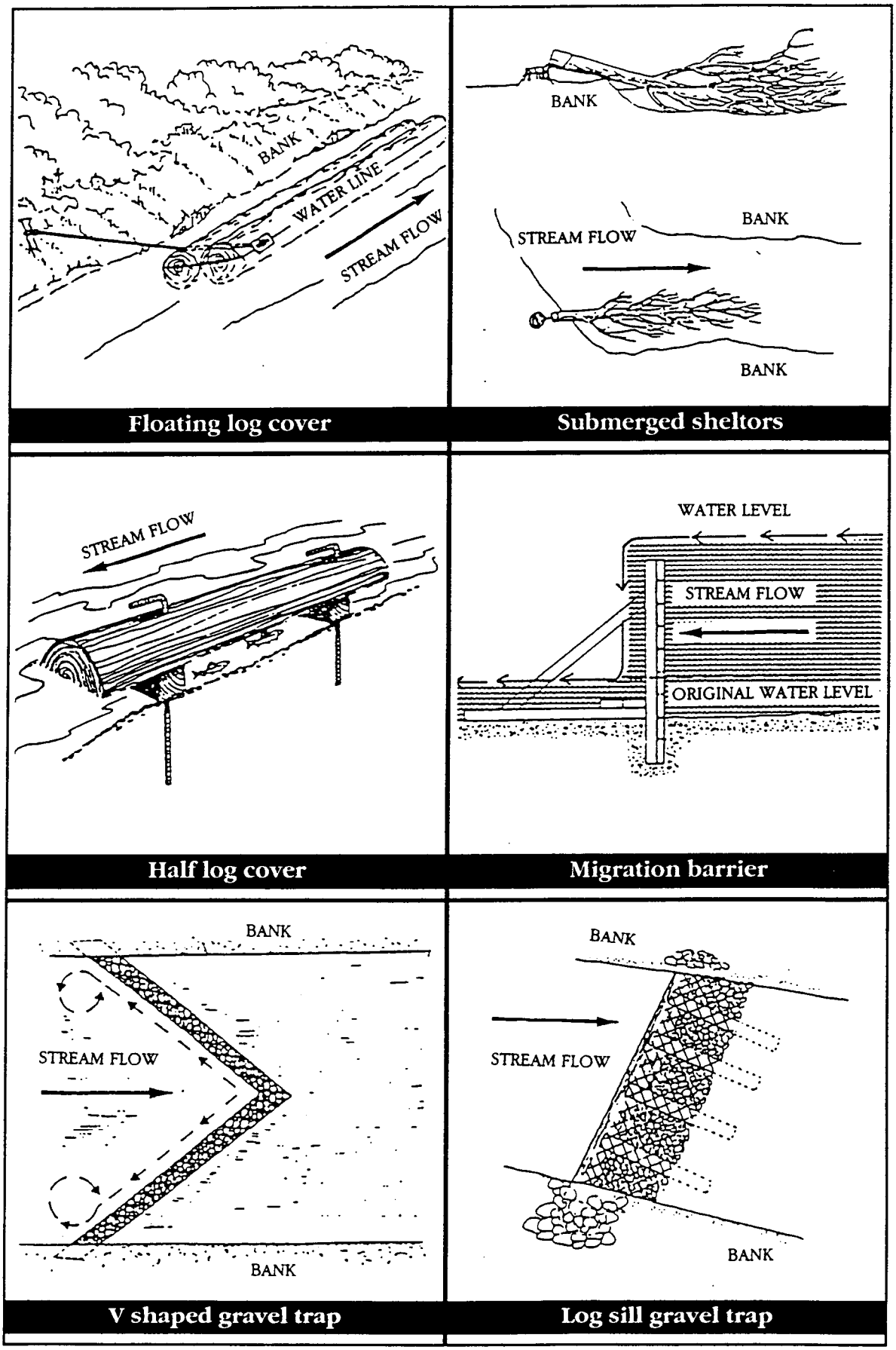
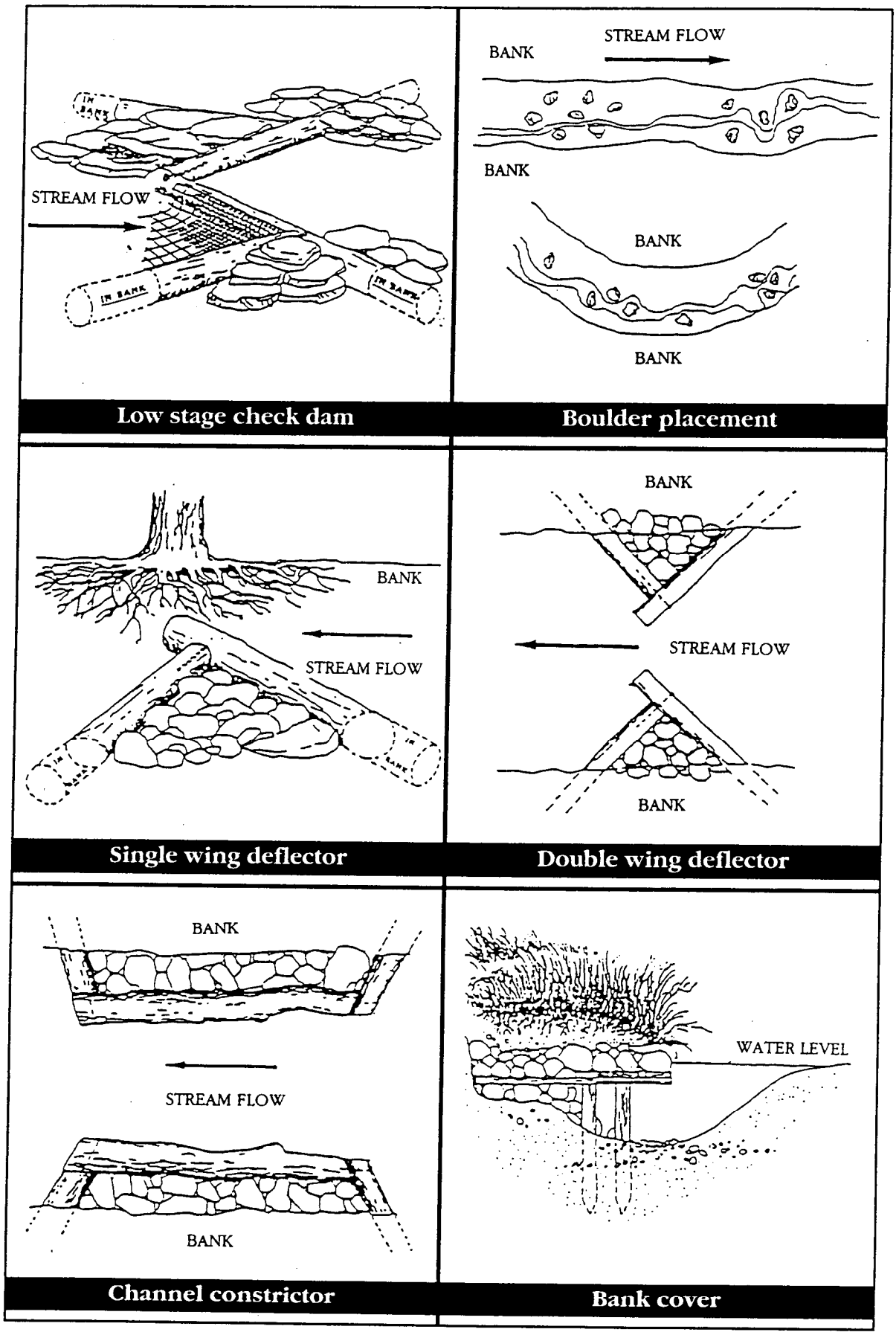


Fig. 14 Examples of deflectors and a direct cover structure. After Rosgen & Fittante (1986).



Several objectives exist:

- increase habitat diversity within channel (especially in upland rivers)
- increase habitat diversity by improved communication with riparian zone (especially in lowland rivers)
- improve water quality by increasing aeration downstream
- improve water quality by increasing deposition upstream

Drop structures for environmental improvement are typically smaller structures than those used for engineering objectives, although structures may be used in rivers up to 40m wide, with discharges up to 300m3/sec and velocities of 3m/sec. Greater stream power requires greater strength of material and rock, gabions and wood, especially logs, have been used.

Whatever the size, the construction method is similar (Hey & Heritage, 1993):

- excavate a depth twice that of the height of the structure
- key into the bank with slit trenches and reinforce with piles into the bed
- reinforcement of banks with rip-rap may be necessary to prevent outflanking
- angle the crest of the sill towards the centre to concentrate flows away from the bank
- crest height should not be greater than a third of the depth of normal flows

These structures are often sited on the upstream part of a riffle and should not be spaced more than every three pool lengths. Maintenance of deposition upstream will be necessary where there is a supply of sediment.

For fisheries enhancement, pools are often the desirable objective and small scale-log dams are recommended (Fig. 14).

For more general enhancement, larger scale structures may be employed and further opportunities exist with the creation of higher water levels upstream:

- creation or reinstatement of riparian wetland habitat (eg old backwater channels, see Geiger & Schroter, 1983)
- settling of sediments and pollutants in the riparian zone (see floodplain functions 4.3.4)
- a larger aquatic resource with the possibility of creating shallow bays for amphibia and fish (eg River Leen, Appendix 1)

Larger structures do have the disadvantage of being barriers to fish movement (Fig.13) and many have been removed to allow migration (of anadromous fish particularly) and to reestablish natural form and function.

4.3.4 Riparian zone and floodplain restoration

The reinstatement of functional riparian zones and/or floodplains is of critical importance in the restoration and rehabilitation of rivers as these zones play an intrinsic role in the natural functioning of the riverine system (see 3.3.1) (Fig.1).

Reinstatement of these habitats may be divided into:

- reinstatement of natural systems-restoration
- creation of alternative systems-rehabilitation

Reinstatement of natural systems

Riparian zones and floodplains

The difference between riparian zones and floodplains is largely one of size in relation to the channel (Fig.1), and, as they are effectively at either end of a continuum, they are considered together here. However, as riparian zones are smaller and apparently less complicated, their reestablishment appears to be easier. Few rivers are of sufficient size (only 25 4th order rivers, NERC, 1990) in the UK to have truly extensive floodplains.

Natural Rivers and their riparian zones and/or floodplains are intrinsically linked, with free exchange of materials (Fig.1). The maintenance of hydrological and geomorphological processes is critical to sustain a habitat mosaic (Large & Petts, 1992) which allows many organisms at all levels in the food chain to utilise river and floodplain as one functional unit.

These, include:

- invertebrates - (Newbold et al., 1980; Petts et al., 1992)
- fish - (Platts & Rinne, 1985; Copp, 1989; Williamson et al., 1990; Schiemer & Waidbacher, 1992)
- birds - (Anderson et al., 1978; Dister et al., 1990; Ormerod & Tyler, 1990)
- mammals (Mason & Macdonald, 1983; Anderson & Ohmart, 1985 Perrow et al., 1992)

Natural riparian zones and floodplains also perform the following functions:

- increase bank strength, reduce bank erosion, and reduce width and increase depth
- provide organic matter
- reduce weed growth and decrease water temperatures through shading
- reduce sediment inputs and sites for sediment storage when in flood
- improve water quality by reducing inputs of nutrients and pollutants
- increase water retention capacity

Restoration of floodplains, riparian zones and river-dependent wetlands is still largely in the experimental phase (NRC, 1992; RIZA, et al., 1992).

Techniques for restoring these habitats have concentrated on:

- increasing hydrological communication between river and floodplain which may be achieved by
  i) increasing riverine bed levels - for example, by the use of drop structures or substrate placement (eg River Rodå and Sapiston Brook, Appendix 1)
  ii) lowering land level - for example, by scraping (eg Sandbach, Appendix 1)
  iii) removing obstructions - by breaking embankments (eg River Ijssel, Appendix 1)
- eliminating and controlling contaminants (eg Hackensack meadows, Appendix 1
- reestablishing native biota (and perhaps controlling alien or nuisance species e.g., Hackensack meadows, Appendix 1)

It is clear that the reinstatement of riparian zones and floodplains relies heavily on non-structural techniques to secure favourable circumstances (e.g., sympathetic land use) to exploit the potential for natural recovery (recovery enhancement). In small riparian zones, this may simply require relieving grazing pressure to allow natural vegetation to recolonise and recover (Platts & Rinne, 1985) (see below).

Natural recovery has also been exploited in large floodplain systems such as the Kissimmee river system (Appendix 1), and the river Severn at Slimbridge (Heaton, pers comm). In the latter case, the pulling back of tidal defences led to the development of saltmarsh and other valuable habitats. This is only possible where the chances of colonisation are high from good innocula in other parts of the catchment. Fauna should be left to recolonise, with selective reintroduction of species that have become locally extinct, or are unlikely to colonise naturally (see species-centred restoration 4.2.3).

Where the scope for natural recovery is low, structural techniques will be required. The first step is often increasing water level through a variety of techniques (see above). Where innocula of suitable vegetation are scarce, or alien species are present, detailed selective replanting may be undertaken (Anderson & Ohmart, 1985; Baird, 1989).

In larger floodplain systems, contouring of the relief on the floodplain itself is often undertaken (eg Hackensack meadows, Appendix 1), as vegetation diversity is related to diversity of water levels and substrate type (Amoros et al. 1987). Some habitats such as depressions and ponds may be specifically created to increase habitat diversity (eg Agrico swamp west, Pinkhill meadows, Appendix 1). Riverine habitat may be also be diversified by creating such habitats as backwaters and side-arms.

A critical issue in the UK is that the majority of floodplains appear to be much less geomorphologically active than those in Europe (Large & Petts, 1992). In many cases the gravel layer of the floodplain is overlain by a layer of alluvial silt several metres thick. The movement of the river within its floodplain is thus often restricted and so much intervention may be needed. This may not be the problem it first appears as the lack of movement of the river may make it easier to integrate current irreversible land-use (eg settlement) (floodplains currently under intensive agricultural use may become available - see land use change 4.2.2) with restoration measures.

As the scale of floodplain rehabilitation is often very large, the design of projects is critical if the potentially serious consequences of uncontrolled flooding, threatening high-grade agricultural land and even human life, are to be avoided. Models must be developed and specific aims and targets established. It is in this phase that much work has been concentrated, particularly in the Netherlands (Aukes, 1989, 1992; Winand Staring Centre, 1991; Gerritsen, 1992; Havinga, 1992; Litgens, 1992; Marchand et al., 1992; Silva & Kerkhofs, 1992; Wolfert, 1992).

Much research is still needed. At present, there are few general guidelines, and restoration of these habitats is often a case of trial and error (NRC, 1992). In particular, although the reestablishment of riparian zones and river-dependent wetlands has been achieved, and these resemble natural systems, little is known of whether appropriate functions have been reestablished (NRC, 1992).

Livestock control

Simply controlling livestock, e.g., through fencing off riparian zones, has met with great success in the US in promoting habitat diversity in these habitats (NRC, 1992). This may also help in increasing bank stability, reducing width/depth ratios of the stream length in question, and thus providing more suitable habitat for aquatic invertebrates as well as fish (Platte & Rinne, 1985).

Creation of alternative systems

Buffer strips/zones

Buffer strips are, essentially, strips of land supporting appropriate vegetation alongside the river that have some of the natural functions of the riparian zone.

These include:

- filter nutrients and pollutants
- store sediments
- increase bank stability
- maintain in-channel species diversity
- maintain riparian species diversity

Buffer zones may be left as stands of natural vegetation but are more likely to be reinstated as few riparian zones are still intact in the UK.

Buffer strips are generally designed to prevent undesirable materials from diffuse sources entering the river and have little role, largely as a result of their relatively small size, in dealing with materials (water and sediments) transported to the riparian zone from the river itself. To be effective they have to cover all areas where inputs are likely.

In the control of water quality several factors are important:

- interception of nutrients, especially phosphorus, transported by surface run-off
- uptake by vegetation/soil microbes of soluble nutrients, especially nitrate
- absorption by organic and inorganic soil particles

The key parameter to the effectiveness of the buffer is the groundwater flow path beneath the riparian zone. The greater the retention time the better.

Wetland creation for biological pollution control

The self-purification capacity of natural systems has long been recognised and is now being exploited. Aquatic and semi-aquatic plants possess an outstanding ability to assimilate nutrients and create favourable conditions for microbial decomposition of organic matter. This involves a complex of biological, physical and chemical processes including (Brix & Schierup, 1989):

- direct uptake
- bacterial transformation
- sedimentation
- absorption to particles
- precipitation

Aquatic macrophyte-based wastewater treatment systems are generally used to treat point sources and may use:

- floating macrophytes
- submerged macrophytes
- emergent macrophytes in artificial and natural wetlands
- integrated systems

All of these systems have several advantages over conventional treatment systems

- low operating costs
- low energy requirements
- establishment on site
- more flexible and less susceptible to shock loading

The systems that have been most widely used in temperate zones, and are more appropriate for riverine systems, are natural and artificial wetlands with emergent macrophytes. Natural wetlands are extremely variable in their functional components, and the extent and efficiency of treatment is extremely difficult to predict and cannot be extrapolated to constructed wetlands (Brix & Schierup, 1989).

Artificial wetlands can be constructed with a greater degree of control and important variables include:

- type of vegetation
- composition of substrate
- flow pattern of water

Plants used include bulrush (*Schoenoplectus lacustris*) and most commonly, reed (*Phragmites australis*) on account of its deep roots and rhizomes. Reed has been widely used in Germany, Denmark and more recently Italy in the Root-Zone Process. This depends on a sub-surface horizontal flow of wastewater through the rhizosphere.

The reed itself has two important functions:

- supplies oxygen to the heterotrophic microorganisms in the rhizosphere
- increases and stabilizes the hydraulic conductivity of the soil

The performance is generally competitive with other treatment technologies. BOD and suspended solids are effectively removed but the removal efficiency for nitrogen and phosphorus is generally 20-50%. Hydraulic loading rate is the main determining variable, as this increases, so does surface run-off. Oxygen transport capacity of the macrophytes is also a limiting factor (Brix & Schierup, 1989).

Greater efficiency may be achieved by increasing the size of the system in relation to hydraulic loading and using a greater diversity of species in a more integrated system.

Flood storage areas

The provision of flood storage areas mimics the natural floodplain system where both water and sediments are stored and energy dissipated. The aim is to reduce the peak rate of flow to reduce the risk of flooding downstream.

By imitating the natural floodplain:

- the flows in the river downstream of the storage area will resemble the more natural situation
- wetland wildlife may benefit

Several situations lend themselves well to flood storage:

- lowland agricultural areas with the use of washlands
- tidal estuaries, also using washlands
- urban areas, perhaps using reservoirs or gravel pits

These off-stream areas may be combined with embankments or more rigorously controlled by the use of sluices and pumps.

Summary

Restoration and rehabilitation may require non-structural and structural techniques. However, it is clear that non-structural techniques, such as the framework of catchment planning and sympathetic land use, will always be required, and these measures alone may be used to restore rivers and their floodplains through recovery enhancement, particularly in high energy situations. However, where the scope for natural recovery is limited intervention and the use of structural techniques will be required.

Selection of these techniques will largely be determined by the nature of the limiting factors of the river in question and its location, more specifically, the level of the requirement for flood defence. There is no shortage of choice of techniques for channel (both bank and in-stream) restoration. With bank modifications it is clear that the choice of 'softer' engineering options, such as the use of natural materials, perhaps combined with geotextiles, is wide enough to eliminate the need for traditional engineering solutions.

The area for which techniques still have to be fully developed is natural riparian zone and floodplain reinstatement. General guidelines are not freely available, although such is the diverse nature of this suite of habitats, techniques are always likely to be partly site-specific and some trial and error is likely to be involved.

Technical intervention should only be undertaken to the level at which the recovery of appropriate form and function, within a suitable time-scale, is likely. The rate of this recovery will depend on physical characteristics such as stream power and sediment supply and the distance from suitable biological innocula.

5. IDENTIFICATION OF THE BENEFITS AND DISBENEFITS OF RIVER RESTORATION MEASURES

Abstract

- The critical evaluation of techniques and projects is limited by a lack of rigorous monitoring and so a subjective approach has been developed to assess the measures used in restoration and rehabilitation
- The ideal of catchment planning is the basis of any restoration project. Within this framework sympathetic land use must be guaranteed if any project is to be successful
- Ecological benefits appear to be greatest where natural channel form, flow and sediment regimes and natural floodplain or riparian zones are reinstated
- There appear to be few disbenefits of restoration, although this may be due to a reluctance to report failures
- Alternatives to natural features, although the pragmatic option in some situations, are generally of lesser ecological value

5.1 Introduction

Virtually none of the schemes reviewed during the extensive literature search, personal contact and site visits, appear to have undertaken rigorous post-project appraisal. This is similar to the findings of Holmes (1991) with respect to conservation enhancement as part of flood defence works in England and Wales. Consequently, consideration of the success of a technique can only be made by subjective assessment. A score has been assigned to each technique under a number of headings typically including:

- conservation
- recreation and amenity
- water quality
- hydrology
- channel stability
- river management

These functions above are displayed in matrices against the measures in question and using the subjective scoring system outlined below:

++ strong subjective evidence of a benefit (i.e. from a visual appraisal and/or limited monitoring)
+ suggested benefit (i.e. from the opinion of workers in the particular field)
0 neutral - neither success or benefit (i.e. no likely influence)
- suggested disbenefit (i.e. from the opinion of workers in the particular field)
- - strong subjective evidence of a disbenefit(i.e. from a visual appraisal and/or limited monitoring)

Scoring is based on the descriptions of the schemes in the literature and personal knowledge of actual schemes that have been undertaken, and does not consider potential benefits and disbenefits (or reflect likely benefit to particular species). The number of schemes utilising the technique is taken into account wherever possible. To help illustrate how the decision was reached notes on specific aspects are also provided. These refer to the case studies which are discussed in Chapter 6 and displayed in Appendix 1 unless stated otherwise.

Failures appear to be few in number but this may reflect a relutance to report failures.

This chapter is set-out in a similar manner to that of Chapter 4 (Fig. 5).

5.2 Non-structural techniques

It is clear that the ideal of catchment planning and sympathetic land use are essential to any restoration project. The latter is particularly important if reinstatement of a riparian zone/floodplain is to be attempted. There may be difficulties in securing sympathetic land use in the UK, where much land is under private ownership, and where the bodies, such as the NRA, that may implement restoration, or more likely rehabilitation, (see 3.2.1) have little or no control of the land in question. This is a very different situation to that in other European countries such as Denmark and Germany (see Chapter 6). However there are a number of opportunities to secure favourable land use (see 4.2.2 and Chapter 6).

5.3 Structural techniques

5.3.1 Channel and in-channel

This section is divided into :

- reinstating natural channels - restoration
- alternative techniques and channel design - rehabilitation

Reinstating natural channels

Although high energy channels present an ideal opportunity for recovery enhancement where sympathetic land use can be guaranteed, there are few detailed documented records of this being achieved. A notable exceptions is Bear valley creek, which was allowed to meander after construction of a suitable floodplain (see Appendix 1).

There are far more examples of restoration where technical intervention has been required to recover natural channel form and function. There are examples of this from a wide range of river types, from small lowland and upland streams, to braided upland rivers, to medium-sized low energy lowland alluvial channels, to large powerful lowland rivers. In addition, a high level of intervention has been required to release some rivers from pipes (Wiesenbachle, Rungsbachle) and breaking out concrete channels (Rungsbachle/Kleines Sulzbachle and Gutenbach). Breaking-out concrete channels probably represents the ultimate in channel reconstruction and this has been started in a small way in the UK on the Leen.

The majority of these examples have reinstated meandering/sinuous channel form and, where appropriate, the natural pool-riffle sequence.

	conservation	recreation & amenity	water quality	hydrology	channel stability	river management
meanders/sinousity	++	++	++	++	++	++

The appraisal for the above matrix was derived from the following examples: (unless otherwise stated these are illustrated in Appendix 1).

These include:

- lowland streams - Landeby baek, Stensbaek (Brookes, 1988)
- upland streams - Weisenbachle, Sulzbach, Steinbach, Siegentalbach, Gutenbach, Rungbachle,
- braided upland - Blanco
- medium sized lowland alluvial rivers - Birch Creek, Kammbach, Sandbach, Gelså, Brede, Alb, Kleines Sulzbachle and Gronå and Taps (Nielsen, unpubl)
- large lowland rivers - Enz

These schemes are more common in rural areas, but may be suburban or even urban providing sufficient space is available. In addition, all satisfy flood defence requirements, although full design capacity has not been tested on many, as insufficient time has elapsed since their implementation.

Post-project appraisal has not been conducted in detail to determine conservation benefits, although some of the more substantial evidence includes; an increase in that the number of macroinvertebrate and plant species in the Gelså, higher fish yield in the Blanco, evidence of a higher invertebrate diversity in the Alb, increased submerged plant growth in the Siegentalbach and strong recolonisation of marginal and bankside vegetation in the Sulzbach and Sandbach. There is a strong suggestion that landscape and amenity value (e.g., the Alb as green space) has increased dramatically on most schemes.

Water quality is often suggested to increase as a result of the reduction in suspended solids with the reinstatement of natural flow and sediment transport regimes. Improvement in water quality has been noted on the Siegentalbach although it is unclear if this is due to the buffer strips and/or the reinstatement of channel form.

Benefits to hydrology of the areas concerned may accrue from raising bed levels and ensuring flooding on a regular basis (every second year in the Gelså), increasing water retention through increases in channel length (17-63% increase in channel length in 5 projects in Denmark-Nielsen unpubl. data). In addition, the largest of the schemes reviewed, the Enz was undertaken to improve water retention and reduce the risk of flooding whilst making environmental gain.

The need for management is often reduced, particularly in terms of erosion control and sediment removal. For example, the sand trap on the Gelså has not been emptied (Ottesen, pers comm.). This contrasts with 12 disturbed danish streams from which 25 000m^3 of sand are removed annually.

There have been some reported drawbacks of the schemes in Germany, although these are design faults rather than disbenefits of restoring channel capacity (see Appendix 1 for more details):

- design inadequate to hold back the first flood event (Gutenbach) and some flood damage (Enz)
- inadequate sediment traps (Kammbach)
- excessive plant growth (Sulzbach)

Both Denmark and Germany in particular have concentrated on reinstating channel form through reinstatement of meanders and sinuosity and are therefore very experienced. Where these practices are still in an experimental phase failures may be more likely. For example, two schemes recently implemented in the Netherlands, the Vloedgraaf and the Esper loop (Wolfert pers. comm.), one (the Vloedgraaf) has been criticised as a result of its unnaturalness.

Careful and rigorous design within a multi-disciplinary team of ecologists, geomorphologists, hydrologists, engineers, planners etc, is clearly necessary.

Alternative techniques and channel design

Stream renovation

This technique is compared against channelization to which it is the typical alternative in urban areas in the US. The figures are derived from an assessment of the effects of channelization

recently undertaken by ECON and Pond Action (1993).

	conservation	recreation & amenity	water quality	hydrology	channel stability	river management
stream renovation	+	++	++	++	++	++
channelization	—	—	-	+	+	—

Stream renovation is documented in Keller (1976, 1978), Keller & Hoffman (1977), McConnell et al. (1980), Nunnally (1978ab, 1985) and Nunnally & Keller (1979ab). The main consideration is that costs are significantly reduced when compared to standard channelization techniques (see also NRC, 1992). Virtually no monitoring has been undertaken and so the results are purely subjective.

Multi-stage channels

Multi-stage channels are compared with standard channelization to which they are a viable alternative. The chief disadvantage of multi-stage channels is the amount of land that a hydraulically efficient channel requires. Excavation of the channel itself can also lead to considerable environmental damage. Some of this can be ameliorated by the use of water-borne excavators (Weeks, 1982).

	conservation	recreation & amenity	water quality	hydrology	channel stability	river management
multi-stage	++	++	+	+	++	-
channelization	—	—	-	+	+	—

The River Roding provides an excellent example of a multi-stage channel with rigorous post-project appraisal of conservation aspects (Raven, 1986abcd; Weeks, 1982). For example, for waterside vegetation, species frequency and mean number of species increased with berm construction compared to unbermed controls. Submerged vegetation (especially *Sparganium erectum*, *S. emersum* and *Sagittaria sagittifolia*), emergent vegetation (*S. erectum*, *Typha latifolia* and *Phragmites australis*) all increased as a result of reduced scour after berm creation. Some species (e.g., *Nuphar lutea* and *Schoenoplectus lacustris*) declined however. The avifauna of the site recolonised quickly after the works unlike the response to typical river engineering schemes. As the vegetation developed, species such as reed warbler (*Acrocephalus scirpaeus*) increased.

However, recent reports (Vivash in press) suggest that one of the notable conservation successes, the development of stands of emergent vegetation (especially reed) on the lowest berms (0.3m) has compromised channel efficiency and regular management is now needed.

Berms and channel narrowing

The creation of berms and the narrowing to a natural low-flow width is an excellent pragmatic alternative where channel capacity must be maintained, for example in urban situations. It is compared below with standard channelization.

	conservation	recreation & amenity	water quality	hydrology	channel stability	river management
berms/narrowing	++	++	++	++	++	++
channelization	—	—	-	+	+	—

Examples of the use of berms and channel narrowing include the River Stort (Brookes, 1991 using the cut and fill technique) the Metter, the Windrush and the Coln (Driver, pers comm), Wraysbury river and the Surbaek (see appendix 1).

In the case of the latter two examples, conservation value has increased with the development of extensive stands of marginal vegetation on the berms. A more natural channel width also appears to have improved fish stocks. In the case of the Wraysbury river, the area is now of considerably more landscape value and is used by local factory workers. Deposition of fine sediments that have been subsequently colonised by vegetation has improved water quality.

The success of such schemes frequently depends on the designer and the contractor (Brookes, 1991). In the latter case, berms may be cut too high or too low without proper supervision.

Containing and diverting flow

Embankments and by-pass channels are considered together briefly below. There are no well documented examples in the scientific literature and so assessment is based on more subjective accepted knowledge.

	conservation	recreation & amenity	water quality	hydrology	channel stability	river management
embankments	—	—	0	++	++	-
by-pass channels	+	+	-	++	++	+

Embankments require significant areas of land and although typically of little conservation value do create a green corridor enhancing landscape value and opportunities for recreation. Conservation value could be greatly improved by planting with appropriate vegetation and there is scope to create features within the area of the embankment (eg Lustrum Beck-Hogger, pers comm.).

By-pass channels may be landscaped for conservation (Purseglove, 1983; Brookes, 1991), although sweetening flow may be required. Re-routing water into old meanders has been achieved by White (1975) and Geiger & Schroter (1983) which presumably enhanced usage for fish and conservation value.

5.3.2 Bank modifications

The techniques for bank stabilisation are reviewed by subjective comparison with each other on the basis of their advantages and disadvantages. The same scoring system as outlined above, is adapted accordingly :

++ strong advantage
+ advantage
- disadvantage
— strong disadvantage

Biotechnical engineering, the use of natural materials perhaps combined with geotextiles, is particularly well advanced in Germany and all the restoration schemes outlined in Appendix 1 utilise such an approach in one way or another. This is further supplemented by British schemes where the approach has been used, including the Wraysbury, the Coln and Windrush (Appendix 1).

Information for the success of more traditional techniques was derived from literature outlining accepted knowledge (eg Lewis & Williams,1984; Hey et al. 1991; Vivash, in press).

	conservation	visual amenity	channel stability	cost
natural materials				
willow/alder	++	++	++	++
fascines/faggots	++	+	++	++
stumps/logs	++	++	+	++
emergent vegetation	++	++	++	++
bankside vegetation	++	++	++	++
artificial alternatives				
natural fibres	++	++	++*	+
other geotextiles	+	+	++	-
rip-rap	+	+	++	-
gabions	-	-	++	—
deflectors	+	-	+	-

* coconut matting reputedly takes 5 years to decay, although some reports suggest it may be as little as 6 months (Driver, pers comm)

In general, the scope for the use of softer techniques, particularly natural materials, is great, and there appears to be no need to consider any of the more traditional approaches to bank stabilisations, unless vandalism is likely to be a problem (Brookes, 1991). Where strong flows are encountered and flood defence is of high priority then combinations of natural materials with rip-rap and geotextiles may be used effectively.

Techniques and the materials used do vary according to the experiences of the country e.g., rip-rap in Denmark, willow in the UK, stumps (root wads) and logs in the US.

5.3.3 Instream modifications

This section considers:

- substrate reinstatement
- instream modification comparing natural and artificial structures

Substrate reinstatement

The physical reintroduction of substrate is an essential element of many restoration schemes. For example it has been used in the Weisenbachle, Siegentalbach, Rungsbachle and Kleines Sulzbachle, Gutenbach, Gelså, Brede, Landeby bæk, Rodå, Ash, and Birch Creek (Appendix 1). Substrate has also been introduced to improve invertebrate abundance (Spillet et al. 1984) and provide spawning habitat for fish, particularly salmonids (Hermansen & Krog, 1984; Afon Gwyrfai - Lewis & Williams, 1984; Coln and Windrush - Appendix 1).

Extensive riffle replacement has occurred at Harpers Brook, ramps have been created at Sapiston Brook and the River Sur (Geiger & Schroter, 1983) and slope reduction has been undertaken on the Weisenbache, Siegentalbach and Metter.

No information was found on the scientific comparison between introductions between different substrate types in the same river (this has been tried on the Sulzbach but the results are not available) although there have been comparisons between different substrate types in the same river (eg Tarzwell, 1937), and this has been used in the comparison below.

	conservation	fisheries	visual amenity	water quality	hydrology	channel stability	cost
types of substrate							
natural substrate	++	++	++	++	++	++	-
similar substrate	+	++	+	++	++	++	+
artificial substrate	+	+	-	++	+	++	++
natural features							
riffle reinstatement	++	++	++	+	++	++	-
ramp creation	++	++	++	++	++	++	-
slope reduction	+	+	++	++	++	++	

Reinstatement of the natural flow and sediment regime to remove excess sediment is clearly the best long-term option. Cleaning of natural gravels with the use of mitigating measures such as sediment traps is also likely to be cost-effective. If introduction of substrate is undertaken then natural gravels are preferred, although any substrate of better quality than the one present is likely to increase numbers of invertebrates.

Reinstatement of natural features such as riffles can bring many benefits, although care is needed to ensure these are sited correctly to be in equilibrium with flow and sediment regimes (this is less critical in lined channels). Using the site of natural riffles is obviously advantageous.

There may be problems in building substrate features too high, for example in the Steinbach (Appendix 1). This stream became a series of small pools after introduction of boulders and cobbles, which was atypical of its natural form. This was however, easily corrected by hammering the stakes that held the boulders in place further to reduce the height of the structures.

Instream modification

The techniques for instream modification are reviewed by subjective comparison of artificial structures with natural features on the basis of their advantages and disadvantages using the adapted scoring system above (5.3.1).

Those considered include:

- direct cover structures
- current deflectors
- drop structures

Direct cover structures

These structures are typically used for fisheries enhancement which may be part of a restoration project. Assessment of the success of these structures has been made by Tarzwell (1937), White & Brynildson (1967), Hunt (1976) and Rosgen & Fittante (1986). These are compared below with natural overhanging bankside vegetation.

	conservation	fisheries	visual amenity	water quality	channel stability	cost
direct cover	+	+	-	0	+	—
natural vegetation	++	++	++	++	++	++

Larger fish do associate with direct cover structures but the full benefits of these structures has not been quantified. Natural vegetation always appears to be superior, particularly with respect to potential filtering capacity of pollutants (thus improving water quality), and much reduced cost.

Current deflectors

Deflectors may be used for the general purposes of reinstating natural flow regimes as well as fisheries enhancement. In both cases, deflectors may take several forms and these are compared below with natural features such as riffles and pools.

The comparison uses information from the following studies on fish; Tarzwell (1937), Warner & Porter (1960), White (1975), Hunt (1976), Swales (1982), Lewis & Williams (1984), House & Boehne (1986), Rosgen & Fittante (1986), Jutila (1992).

	conservation	fisheries	visual amenity	channel stability	cost
wings	+	++	-	+	++
vanes	+	++	++	++	++
groynes	+	+	—	+	+
boulders/wood	++	++	++*	+	++
natural features	++	++	++	++	++

* this relies on appropriately sized boulders of local natural materials. Boulders that are too large or of non-local material are of reduced visual amenity value

Natural deflectors offer more benefits than artificial deflectors when used as enhancement for fisheries, although in both cases design and siting of structures is critical to avoid failure. In addition, many of the references cited above demonstrate that a high density of structures is needed before fisheries gains are made. In addition, only Hunt (1976) has monitored over a sufficient time-scale to demonstrate that it is abundance and not merely distribution of fish that is enhanced by the use of structures.

Artificial deflectors, particularly vanes, are excellent when used for general purposes such as narrowing of channels and creation of riffles and pools (eg Wraysbury river; Hey et al., 1992). Vanes are much more easily covered and become colonised by vegetation providing additional conservation benefits.

However, the creation of natural features as part of a more holistic approach is likely to lead to greater benefits for many functions.

Drop structures

The use of drop structures is common in fisheries enhancement and more general use. In the former case, these are usually smaller devices such as sills (Fig. 14), and assessment is made using the detailed works of Tarzwell, (1937), Warner & Porter (1960), Swales (1982) and Rosgen & Fittante (1986).

Some restoration schemes have used drop structures of varying sizes including the Leen, the Sur (Geiger & Schroter, 1983) and the Sulzbach. Suitably-sized drop structures in appropriate locations offer an excellent opportunity to reduce slope and increase communication with the riparian zone and promote shallow water marginal habitats (eg Leen; Geiger & Schroter, 1983).

	conservation	visual amenity	water quality	hydrology	channel stability	river management
drop structures	++	++	+	++	+	-

Possible disbenefits include the barrier that drop structures may represent to fish migration (eg river Sulzbach) and indeed much effort has been concentrated on removing such structures in Denmark (Sønderjyllands amt, 1991). In addition, deposition will inevitably occur behind drop structures and this will require periodic maintenance.

5.3.4 Riparian and floodplain restoration

This section is composed of:

- reinstatement of natural systems
- creation of alternative systems

Reinstatement of natural systems

The following subjective assessment of the benefits/disbenefits of riparian zones and floodplains has been made using information from the following schemes (further details are presented in Appendix 1 unless stated otherwise):

- riparian zones-Rodå, Sapiston, Sandbach, Lower Colorado (Anderson & Ohmart, 1985), San Luis Rey and San Diego rivers (Baird, 1989)
- floodplains- River Ijssel, Kissimee, Severn (Heaton, pers comm.), Hackensack meadows, Agrico Swamp west, Pinkhill meadows

However, the results of many of these schemes are often either not well documented or insufficient time has elapsed to make even a subjective assessment of the success of the scheme. The following assessment is thus based on just a few schemes.

	conservation	visual amenity	water quality	hydrology	channel stability	river management
riparian zones	++	++	++	++	++	+
floodplains	++	++	++	++	++	+

Conservation benefits are generally excellent. In the floodplain examples, the establishment of preferred plant species, a rich benthic community, and 83 species of bird have been reported from Agrico Swamp west. Pinkhill meadow after 3 years now supports 14 local and 1 nationally rare macroinvertebrate species, 49 species of wetland plant and several uncommon bird species. The Kissimmee river has much increased benthic invertebrate species diversity and fish populations.

With riparian zones, Anderson & Ohmart (1985) report increased abundance of small mammals after replanting of native vegetation. Platts & Rinne (1985) show fish yields are much greater in streams where riparian vegetation has been reinstated after livestock control.

Water quality is much improved at Agrico Swamp west and in the Kissimmee river (where sediment and organic debris that reduced oxygen levels have now been cleared from the now open backwaters). Moreover, the hydrologic regime of the Kissimmee, for example, is now close to the original condition.

Although the benefits of floodplain restoration are not fully quantified these are likely to be considerable. However, there are some obvious disbenefits. Firstly, with larger schemes the costs may be very high (eg $700 million for the Kissimmee, although the area covered by the scheme is far in excess of anything likely to be attempted in the UK). In addition, it may be difficult to rehydrate some soils after extensive draining of floodplains for agriculture has occurred. Substrate suitability may be increased with the use of mulch from other established wetlands (eg Agrico Swamp west).

However, the greatest constraint at the current time is that there are few general guidelines and much research and trial - and - error may be needed before success is achieved.

Creation of alternative systems

Buffer strips/zones

The literature on buffer zones largely refers to the functions of natural riparian strips. The performance of reinstated buffers is as yet largely unknown and will clearly demand time before full performance is achieved. Restoration schemes where buffer zones have been implemented include the Kammbach and the Siegentalbach (Appendix 1).

There is tremendous variability in the published literature on the size of buffers to perform specific functions (Fig. 15). This is related to differences in size of watercourse (Table 6), substrate type and permeability, vegetation type etc. In addition, monitoring has not been undertaken for long enough to establish if some pollutants e.g. phosphorus, remain in the buffer zone permanently or periodically become labile and are flushed out. It is clearly very difficult to recommend a buffer width for a specific river without detailed monitoring.

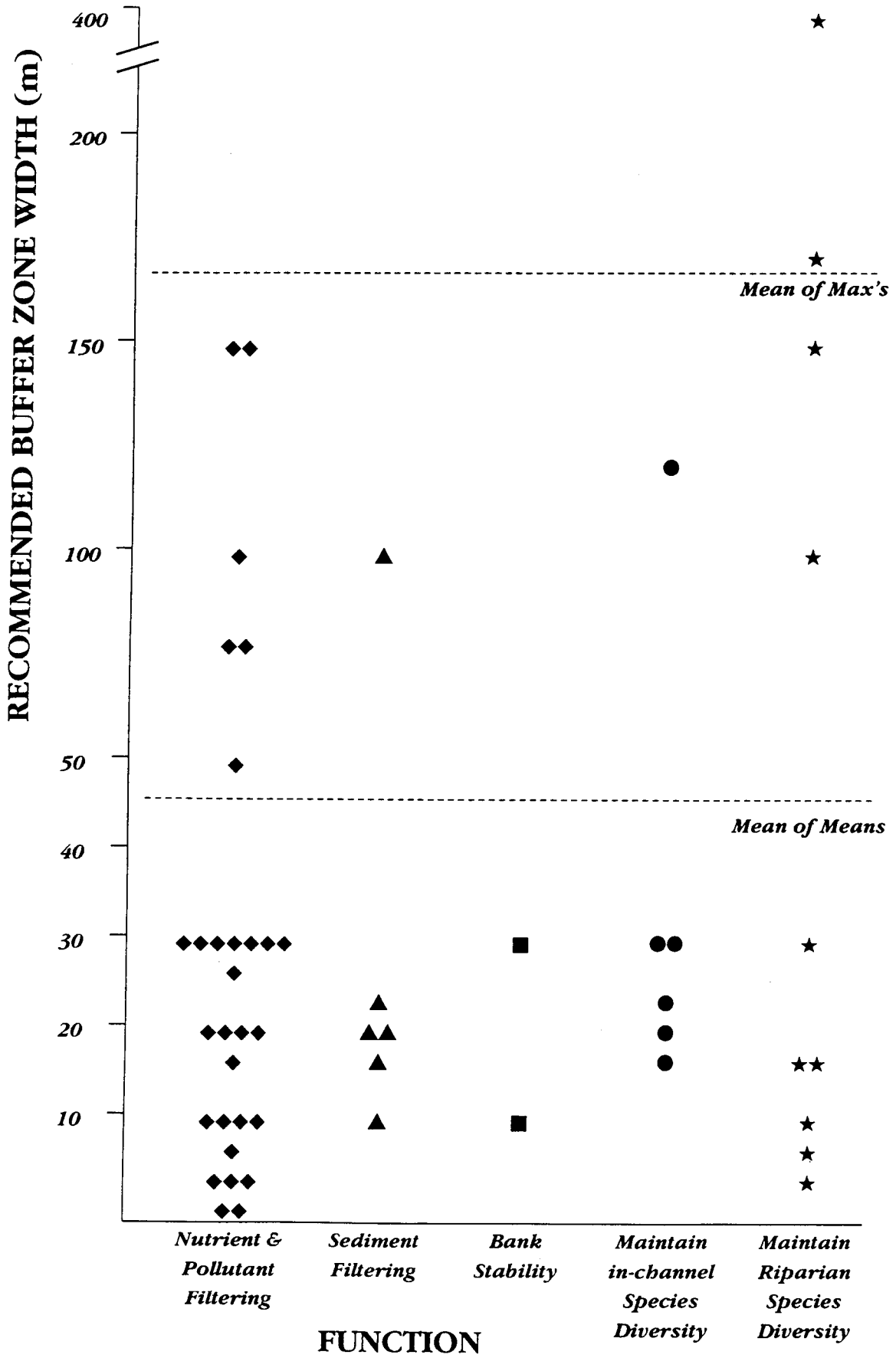
It is therefore recommended that the choice of buffer zone width be undertaken as follows:

- attempt to reinstate the appropriate riparian zone or floodplain
- establish a buffer zone 5x the width of the river
- negotiate for the maximum width attainable

Table 6 Summary of studies on buffer strips/zones

Buffer Function	Width (m)	Channel description	Location	Reference
Nutrient filter	1-2	small ditches	south Finland	Ahola (1989,1990)
	5-10	brooks		
	10-20	rivers		
	25	coastal plain	Georgia, USA	Lowrance et al. (1984)
	30	lowland river	France	Pinay & Dechamps (1988)
	15-80	coastal plain	Carolina, USA	Phillips (1989a)
	150	floodplain river	Netherlands	van der Hoek (1987)
Sediment filter	19	small stream	Maryland, USA	Peterjohn & Correll (1984)
Bank stability	30	low order streams	north California, USA	Erman et al. (1977)
Maintain in-channel species diversity	15	streams	Canada	Budd et al. (1987)
	20	streams	lowland UK	Dawson (1978)
	30	low order stream	California, USA	Erman et al. (1977)
	>30	streams from 950 to 1950m elevation	California USA	Newbold et al. (1980)
Maintain riparian species diversity	15	creeks from 240 to 430m elevation	Kentucky, USA	Triquet et al. (1990)
	99-169	lowland river	Florida, USA	Brown et al. (1990)
Multi-functional	150	mountain to lowland streams	Oregon, USA	Berger (1992)

Fig. 15
Variability in the recommended width of buffer zones between and within possible functions



Wetland creation for biological pollution control

Artificial wetlands incorporating emergent macrophytes, especially reed, have been used extensively in Germany and more recently Denmark. A full published assessment of the 'root-zone' technique has been made from the 25 operational sites in Denmark (Brix & Schierup, 1989).
The efficiency of treatment of waste-water is generally high but varies with respect to the nature of the pollutant (see 4.3.4). Tests at 32 sites in the UK have been extremely variable and there is some evidence to suggest that this is a result of inappropriate technique and reed stock rather than a fault of the technique itself (Aitken, pers comm).

In addition, there is some evidence that natural wetlands with a full range of emergent, submerged and semi-aquatic plants are likely to perform at a higher efficiency with additional benefits of conservation and reduced management (Schierup, pers comm.)

	conservation	recreation	water & amenity	hydrology quality	management
artificial wetland	+	+	+	+	—
natural wetland	++	++	++	++	0

Flood storage areas

There is little available scientific literature on the benefits and disbenefits of flood storage areas and so assessment relies on more anecdotal evidence.

	conservation	recreation & amenity	water quality	hydrology	channel stability	river management
flood storage areas	++	++	+	++	+	+

Flood storage areas may provide opportunities for recreation and amenity, for example at Milton Keynes (Vivash in press), Sandwell Valley Balancing Lake (Lewis & Williams 1984), Tone balancing lake (Jenkins, pers. comm.). With the provision of large water bodies, conservation value may be significantly increased particularly if a variety of water levels can be provided to simulate a natural wetland.

Summary

The critical evaluation of techniques used in schemes around the world is limited by a lack of rigorous monitoring and, even where this has occurred, by this information not being freely available. However, some general guidelines are emerging as to which techniques are the most effective in securing ecological and other benefits.

Catchment planning and securing sympathetic and appropriate land use are essential prerequisites to allow the restoration of a river and its riparian zone/floodplain. Exploiting and enhancing natural recovery is clearly the strategy most likely to succeed in reinstating a natural flow and sediment regime in equilibrium with its surroundings. This is also likely to be the most cost-effective.

It is possible that floodplain restoration in Britain will require structural intervention as many are geomorphologically inactive when compared to those in Europe. Many low energy lowland alluvial river channels will also require intervention. Where this is practised this should only go as far as necessary to exploit natural recovery. In all forms of channel, bank and riparian zone modification, local natural materials should be used as far as possible, not least because these are of greater ecological benefit.

In general, there is a strong suggestion that ecological benefits from restoration, particularly from riparian zone/floodplain restoration are high. Landscape and amenity value and the possibilities for recreation, water quality, hydrology, channel stability, may also be favoured. With the reinstatement of natural regimes, the requirement for river management may also be reduced.

Where flood defence requirements are high and space is limited to reinstate a natural floodplain, rehabilitation is a more pragmatic option. Techniques such as the use of berms to ensure a natural low-flow width are of benefit, although of lesser ecological value.

6. THE SCOPE FOR THE RIVER RESTORATION PROJECT

Abstract

- The RRP should aim at restoration (i.e. the full structural and functional return to pre-disturbance state) but adopt rehabilitation (the partial structural and functional return to pre-disturbance state) as a pragmatic alternative depending on the location and flood defence requirements of the sites involved
- As the RRP is aiming to break new ground, the principle roles of the group are to i) undertake full-scale monitoring and dissemination of the results ii) attempt riparian zone and/or floodplain restoration
- As the demonstration project(s) cannot afford to fail, the risks should be reduced by tackling low energy sites in both urban and rural settings. However, high energy rural sites provide a valuable opportunity to tackle recovery enhancement, and with careful design are attainable
- To be truly beneficial to the future of river restoration in the UK, i) the demonstration sites should be of widespread applications ii) the RRP should work to establish an appropriate framework for river restoration in the UK, as this appears to be inadequate at the present time

6.1 Introduction

This chapter reviews the scope of the demonstration phase (phase 2) of the RRP. The feasibility of phase 2 in relation to the basic targets of the RRP will be discussed. This depends on knowledge of the state-of-the-art techniques and measures for river restoration from around the world, and experience of the opportunities and constraints that may respectively aid or hinder its successful implementation. The selection of appropriate river types and sites for phase 2 must be incorporated within this framework.

This chapter is set out in the following way:

- targets of the RRP
- planning a restoration project
- site selection

6.2 Targets of the RRP

It is suggested that there are 5 basic targets of the next phase of the RRP:

- the demonstration project cannot afford to fail
- the demonstration project must break new ground (at least in the UK)
- to be truly useful the knowledge gained from the demonstration project must be applicable to other rivers within the UK and help establish a suitable framework for it to be copied
- knowledge gained from the experience must disseminate valuable scientific results
- knowledge gained from the experience must educate and stimulate the public and the scientific community

The future of river restoration in this country partly depends on the next phase of the RRP. For restoration in the UK to gain the attention it receives in other countries in Europe (eg Germany, Denmark, the Netherlands) and the rest of the world (eg USA), there must be notable and undeniable benefits. For this reason alone, the project cannot afford to fail as a result of inappropriate site selection, poor technique and planning framework etc.

Therefore, although the project has to break new ground in the UK (the current status of river restoration is illustrated in Appendix 1) it is suggested that the majority of the project should be within the accepted range of the technical expertise of workers in the UK and Europe. If the project overstretches the expertise of these workers (effectively the RRP) and mistakes are made, the consequences may be serious (eg flooding land and even jeopardising human life).

It is obviously beneficial for the demonstration project to reveal the full scope of river restoration and illustrate what the people of Britain have been missing, but, for the demonstration project to truly enhance the standing of river restoration, and the likelihood of it being implemented, the results of the demonstration project must be attainable by other workers and bodies (e.g., the NRA). This is especially true if the RRP does not work to enhance the nature of the future opportunities for restoration. For example, by opening negotiation with MAFF to include river restoration within policies for bringing land out of production.

Full-scale monitoring and post-project appraisal is lacking from many restoration schemes, which effectively reduces their effectiveness and limits the scope of future attempts. The RRP aims to disseminate all information for consumption by the scientific community as well as the public at large. Public support, which is enhanced through education, is vital to the future of river restoration, particularly as schemes get larger and more public money is spent. (ultimately for the benefit of the environment and the quality of life of everyone concerned.)

6.3 Planning a restoration project

This section discusses the components that are required in a successful restoration project and illustrates the opportunities and constraints for restoration in the UK whilst indicating the situation in other countries.

This section is divided into the following parts:

- reasons to restore
- planning and legislative framework
- structure of the technical group
- sympathetic land use
- techniques for restoration
- finances

6.3.1 Reasons to restore

It is clear that the primary reason to restore rivers in other countries is for the conservation of nature, including fisheries (Appendix 1). This does not mean that the benefits to other functions such as recreation, landscape and amenity value, hydrology and water supply, flood prevention, and possible financial benefits as a result of reductions in river maintenance through increased channel stability, reduced dredging requirements, (ECON & Pond Action, 1993) are insubstantial. In fact, there are occasions when restoration may be undertaken for any (one or more) of these functions (e.g., flood prevention on the Enz and the planned scheme on the Danube, Appendix 1).

Furthermore, restoration for landscape and amenity value is likely to be the primary reason in urban areas where green space and natural landscapes are at a premium.

However, these urban schemes are unlikely to contribute to national biodiversity which should be the primary aim of any restoration project and the reason for site selection in the first place (NRC, 1992). Prioritising sites for restoration should be undertaken on their potential to contribute to biodiversity and consequently, uncommon river types (as classified by the NCC-Holmes, 1991), large rivers (which by definition are uncommon - e.g. the Mississippi is the only twelfth order river in the US - Appendix 1, NRC, 1992; there are only 25 4th order rivers in the UK, NERC, 1990), rivers containing rare species (eg Loddon pondweed-Holmes 1990), and rivers containing rare habitat types. The latter group is potentially very large as much riverine-dependent wetland has been lost in the UK. Indeed it is the restoration of these habitats that attracts most attention in Germany (Kern, 1992).

In the UK, there are clearly problems in implementing river restoration for conservation purposes alone, as the chief body responsible for the riverine environment, the NRA, does not have conservation as one of its functions and so, therefore, monies are limited (see Table 7 in Appendix 1). Consequently, river improvement schemes for conservation alone are frequently small-scale (enhancements). Larger schemes are therefore undertaken in association with some of the functions of the NRA, most notably flood defence (Table 7, Appendix 1). A current project being undertaken by Richard Vivash (the RED programme) of NRA Anglian seeks to establish ways of co-operating with nature conservation organisations to provide suitable resources to undertake large-scale improvement. Rehabilitation is the most appropriate course of action for the NRA with its multi-functional proviso.

6.3.2 Planning and legislative framework

The ideal of catchment planning is an essential prerequisite for any restoration project. Catchment Management Plans are now being implemented by the NRA and provide the framework to implement restoration or rehabilitation. This would be further enhanced if rehabilitation, per se, was included within the framework of such plans (Econ & Pond Action, 1993).

It is clear that the involvement of many user groups at all planning stages, and setting up discussion groups and committees to disseminate knowledge and information, is essential, for large-scale projects in particular (NRC, 1992). A particularly successful planning design that may be referred to in this country is the German Leitbild concept (Fig. 16). This flexible framework provides an 'ideal' solution, which becomes an 'optimal' solution after the design phase, and finishes as a 'feasible' solution after public consultation.

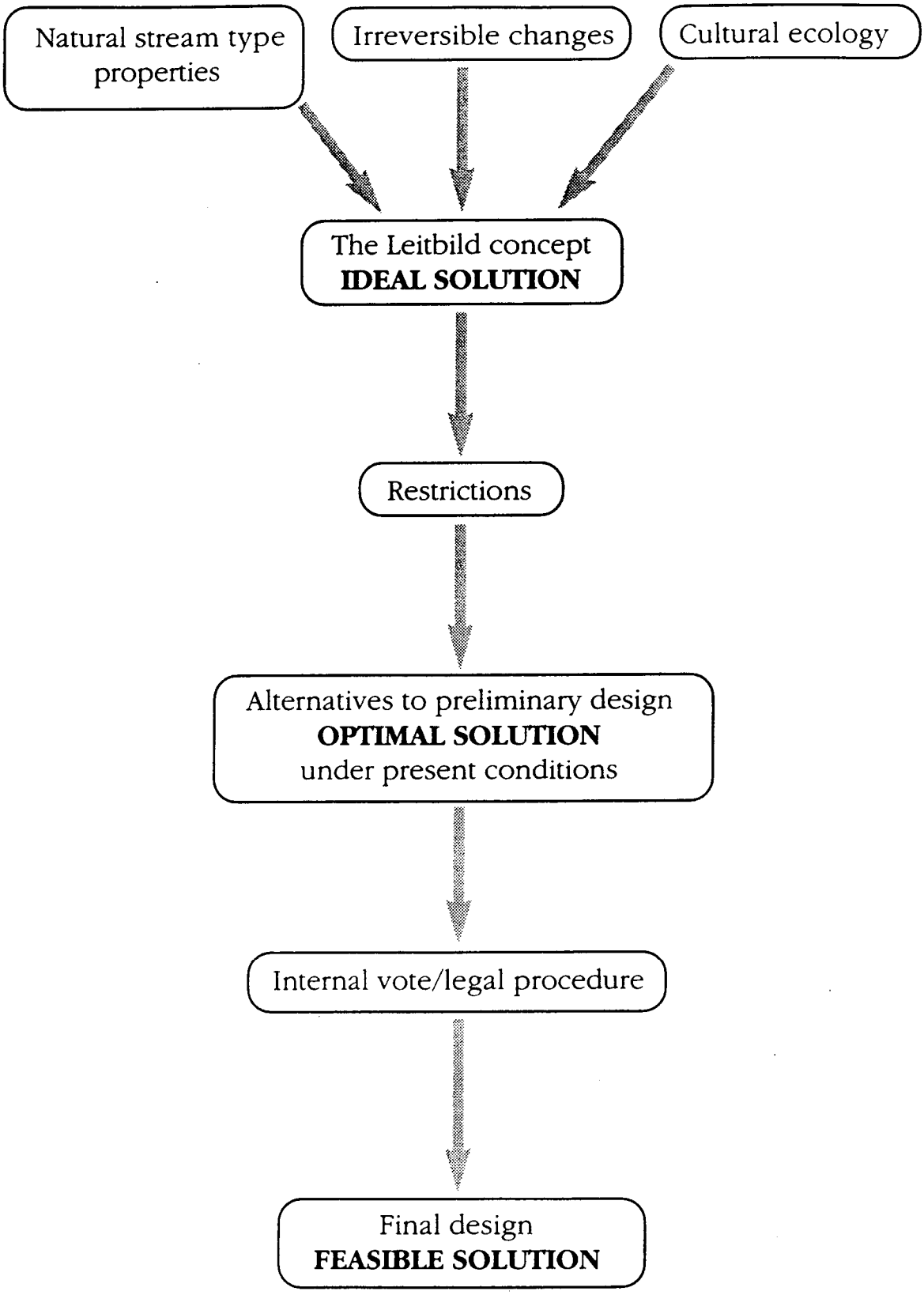
The legislative frameworks in other countries (eg Germany & Denmark) are particularly powerful, as one organisation is frequently responsible for, and has control of, the spectrum of water uses, making it easier to implement large-scale schemes. In addition, the environmental awareness of the public is high and this has provided the impetus to implement the restoration of physical habitat after water quality had first become acceptable (Kern, 1992).

6.3.3 Structure of the technical group

As a result of the scale and complexity of restoration projects, the groups responsible for such projects should have representatives from many disciplines, including ecologists, biologists, geomorphologists, hydrologists, engineers, landscape architects, planners etc. Design of projects is critical and scale replicas may be required in some cases (e.g., River Enz, Appendix 1) and simulation computer modelling is common (Nielsen pers. comm.).

It is also worthy of note that the success of any structural techniques that are required (see 6.3.5) is frequently dependent on the contractor who undertakes the work. Site supervision is needed and requirements should be clear. This may be facilitated by the personnel undertaking the scheme being part of the permanent staff of the organisation in question (eg Sønderjyllands amt in Denmark), although specialist contractors are frequently used (eg by Baden-Wurttemberg in Germany).

Fig. 16. The Leitbild concept as used in Germany (Redrawn from Kern, 1992)



6.3.4 Sympathetic land use

Sympathetic land use is essential to any restoration project, to allow the restoration of riparian zone/floodplain habitats or simply to give the river the space to move, without the potential problems of agricultural pollution for example.

In the UK, much land is under private ownership and so extensive negotiation is needed, often with numerous landowners. There are, however, several financial incentives to promote suitable rural land use, most notably through the ESA's (MAFF, 1992) and Countryside premium (Countryside Commission, 1989) and stewardship schemes (Countryside Commission, 1991). These are however of restricted distribution (ESA's and Premium) or of limited tenure (5 years for premium and stewardship, 10 for ESA's).

There is clearly much scope for a tailor-made land extensification scheme for river corridors and habitats. One of the future roles of the RRP may be to pursue such an option by negotiation with organisations such as MAFF. At present, species-specific options are available for set-aside land (typically through premium schemes). The species that could bring benefit to river restoration if it received such status is the otter.

In other countries in Europe, negotiation with land-owners to secure favourable land use is opened as early as possible in the project (Nielsen unpubl.). In Germany, the state of Baden-Wurttemberg seeks to purchase land wherever possible and this, and an equivalent organisation in Denmark, have the power of compulsory land purchase although this have never been used (Loffler, pers. comm.; Nielsen, pers. comm.).

6.3.5 Techniques for restoration

Restoration should focus on utilizing natural recovery wherever possible, partly because the knowledge of the rate and pathways of restoration is limited and therefore the system is more likely to restore natural flow and sediment regime, specific habitats and so on more efficiently than where such processes are controlled by humans. Therefore recovery enhancement should be conducted wherever possible, particularly if this simply involves non-structural methods i.e changing land use. Where structural techniques have to be used (eg in low energy streams) these should concentrate on reducing stresses to within the scope of natural recovery.

To be effective, restoration of a river requires suitable water quantity and quality as well as physical habitat. Typically, whichever of these factors is limiting receives most attention and as physical habitat is often the most tangible requirement (eg in straightened channels) and may be perceived to be the most deficient (eg as in England and Wales, Fig. 3), this is often the primary target for restoration (see Appendix 1).

However, if water quantity and quality are also limiting these should be tackled before measures addressing physical habitat quality are employed. Kern (1992), one of the more experienced restoration workers in Europe states that 'the structural rehabilitation of (the) most polluted rivers and streams is a waste of tax-payers' money '.

Water quantity and hydrological regime may often be adequately tackled by reinstating natural flow regimes. However, there is still insufficient information as to whether diffuse sources of pollution can be adequately controlled by, for example, the reinstatement of buffer strips. The recommended size of buffer strips is also highly variable (Fig.15). Control of point sources, e.g. from sewage works, may be effective, although retention of pollutants, particularly phosphorus,within large systems may lead to problems over a considerable time period (Broads Authority, 1987; Descy, 1992).

In addition, restoration of severely degraded sites may be extremely expensive, and require a long-time period, to correct. Only where this is likely to have great benefit to biodiversity and, possibly, to landscape and amenity is it worth the effort. It is far better to concentrate on more cost- and benefit - effective areas, particularly at the time when the ideal of restoration is still seeking acceptance in the UK.

6.3.6 Finances

Restoration may be an expensive process, particularly if full-scale monitoring is implemented as recommended (see 6.3.7). The size of the scheme and the level of technical intervention required including elaborate design in areas where flood defence requirements are a priority, (eg Enz, Alb Appendix 1) are common factors in determining such costs.

Projects illustrated in Appendix 1 vary from $700 million (Kissimee) to £5000 (Sapiston Brook). In Germany, of the 11 schemes illustrated, the mean cost per metre of reconstructing channels is £230. In Denmark, reconstruction of meandering channels normally costs between £30-50 000 per km. There is some suggestion that schemes in this country are more costly per unit. For example, the reinstatement of riffles and some berm construction on the Harpers Brook over a 2km stretch has cost £16000 (Redmond, pers. comm), whereas breaking out two small sections (one of which is illustrated in Appendix 1) of a bit of concrete on the Leen cost £5000 (Holt pers. comm). This may be due to the high costs of labour and materials as well as the advice of contractors.

To reduce costs, volunteer labour particularly of local residents (eg Mattole, Appendix 1) may be employed. This has the added benefit of involving the local community and helps facilitate negotiation cooperation with landowners within that community (Nielsen pers. comm). This approach has a long history in the US, particularly in relation to urban schemes and species-centred restoration projects involving fish. In the UK there is increasing evidence that such projects are being undertaken independently (eg Haines, 1990).

Furthermore, the costs of schemes may be reduced if an advisory service (from a multi-disciplinary team of experts) providing technical assistance to interested groups is available free or at-cost (NRC, 1992). It is suggested that the RRP undertake this role in the UK.

6.4 Site selection

The selection of a site(s) for the demonstration project of the RRP is a critical issue, as it is this choice that may ultimately determine the success (or otherwise) of the RRP, and perhaps even have some effect on the future of river restoration in the UK. The initial consideration for such a demonstration site should be the choice of river type, as different types require different techniques, some of which are better developed than others (see 4.3.1). Once this is decided, the selection of a site (effectively a river) and the areas within that river can then be undertaken.

To aid in the choice of sites for phase 2, this section is divided into:

- the selection of river type
- the selection of a suitable river and areas within it

6.4.1 The selection of river type

For the purposes of selecting a river type for the demonstration project, it is suggested that rivers should be divided into four gross categories:

- low energy rural
- low energy urban
- high energy rural
- high energy urban

To make a comparative assessment of the factors between the above categories, a subjective scoring system was devised:

++ strongly positive
+ positive
- negative
— strongly negative

This is displayed in relation to the targets of the RRP and the general opportunities and constraints for and against restoration in Table 8.

Table 8 Comparison of the opportunities and constraints of restoration according to river type.

	Rural		Urban	
	low energy	high energy	low energy	high energy
Targets of the RRP				
Likelihood of success	++	-	+	—
Breaking new ground [a]				
i) reinstating natural river forms	—	+	+	—
ii) the realistic scope for riparian/floodplain restoration	+	++	-	—
iii) ease of monitoring	++	-	++	-
Applicability [b]	++	-	++	+
Visual perception of results [c]	++	+	+	+
Opportunities				
scope for natural recovery	+	++	—	-
sympathetic land use				
i) likelihood of landowner concession	+	++	-	-
ii) incentives from extensification schemes	++	+	—	—
collaborative funding from conservation groups	++	++	—	—
collaborative funding from other groups (eg flood defence)	+	—	++	++
Constraints				
level of technical intervention	+	++	—	—
level of design needed	-	—	—	—
conflict with other priorities [d] (eg flood defence)	+	++	—	—
cost	-	++	—	—

explanatory notes:

a the scope for breaking new ground is greatest in urban areas as extreme measures such as de-settlement of floodplains or even simply offering higher insurance premiums has not has not been attempted

b applicability describes the likely scope of applying the experiences from the demonstration site to other sites. Where these are widespread and degraded the greater the applicability

c the difference between before and after restoration. Channel reconstruction and floodplain restoration are likely to score highly in terms of visual 'impressiveness' whereas subtle manipulation of instream features e.g., in urban situations is less meaningful to the public at large

d when conservation is the primary reason for restoration

From a visual appraisal of Table 8 it is apparent that there are three river types that are worthy of consideration as demonstration sites for the RRP:

- low energy rural
- low energy urban
- high energy rural

More specifically:

Low energy rural rivers are relatively easy to tackle and have the opportunity of reinstating a natural riparian zone/ floodplain. This scores well in terms of the likelihood of success, breaking new ground and achieving visually impressive results. They are also of widespread applicability particularly as arable land continues to come out of production. However, a relatively high level of structural intervention will be required at not insubstantial cost.

Low energy urban rivers are a pragmatic option in that rehabilitation rather than restoration will be tackled, largely as a result of lack of conflicting user demands. However, these may provide co-funding opportunities when centred upon public recreation and amenity, and flood defence requirements.

High energy rural rivers provide a great opportunity for recovery enhancement, although design is critical to avoid failure. Possibilities for co-funding may be more limited to conservation organisations although costs are likely to be relatively low.

To reduce the risks of restoration (see 6.2), the best policy seems to be to concentrate on river types that have received a lot of attention and for which techniques are available i.e. low energy systems in rural and urban environments (in that order). However, the recovery enhancement of a high energy situation is an attractive option that should be considered, perhaps as a second or even third choice option, if a suitable site, with low risk can be found.

Even within the framework of rivers that have received a lot of attention, there is still a great deal of scope for riparian zone/floodplain restoration (rehabilitation in urban areas). The scale of this will depend on the area of appropriate land that can be secured. Furthermore, the wholesale use of natural (combined with soft geotextiles where essential) materials as bank and instream modification (where necessary) has rarely been attempted in the UK (Appendix 1). Breaking-out concrete presents a further challenge that may also be attempted where the opportunity arises.

6.4.2 The selection of a suitable river and areas within it

Restoration is primarily conducted for nature conservation purposes and therefore should focus on those rivers that have potential to contribute to national and regional biodiversity (NRC, 1992; see 6.3.1). This is usually achieved by concentrating on habitats that have been dramatically reduced (eg riverine dependent wetlands - Kern, 1992). This general principle should be followed in the rural low and high energy situations.

In urban situations, as a general rule, rehabilitation should benefit the most number of people by benefiting the most user groups, whilst making significant environmental gain. This cannot be expected, however, to contribute significantly to biodiversity, except on a local scale.

The national prioritisation of rivers for restoration would be the most useful starting point (NRC, 1992) but whilst this is beyond the scope of the RRP, several classification systems for conservation (Boon et al., 1992b; Naiman et al., 1992) and one for rehabilitation (ECON & Pond Action, 1993) have been proposed, which may be of use.

For the RRP, the first level of selection is likely to be if rivers are offered to the RRP as demonstration sites. This may be combined with potentially suitable sites known to the executive and technical groups of the RRP. After a list is drawn up, comparison (eg by matrix analysis) should be made within each of the categories mentioned above (low energy rural and urban, high energy rural). The following questions should then be asked in order to prioritise sites.

- is water quality and quantity adequate to attempt the restoration of physical habitat?
- what is the scope for natural recovery? (i.e. the intensity of degradation)
- what is the time-scale of any recovery and how much technical intervention will be required?
- how much of the catchment can be restored? (see below)
- can sympathetic land use be guaranteed?
- what is the scope for riparian zone/floodplain restoration?
- what is the cost of the project?
- are there co-funding opportunities?

The size of the river must be offset against cost and the proportion of catchment that can be restored. It is suggested that a small river that can be restored over its whole length is of more value than a large river that can only be restored over a small length, as this decreases the likelihood of chance factors (eg pollution incidents from point or diffuse sources) affecting the restoration project. Moreover, the higher the site within the catchment, the lower the chances of such disruption.

In addition, other factors are worthy of consideration. These include the locality and accessibility of the site, a central location is more valuable as a national demonstration site and it must be accessible both to visitors and to the monitoring team. Furthermore, as monitoring will be an integral part of the project, sites that offer co-monitoring opportunities should also be considered (eg Little Ouse and the BTO, below).

British Coal Opencast

The activities of British Coal Opencast (BCO) offer a unique opportunity to practise restoration, and typically involve both low-energy and high-energy rural rivers (Appendix 1). There are some notable challenges in dealing with such sites, particularly the bank and bed instability of relocation in made-up ground. It is clear that a full understanding of geomorphological principles and bank shear stresses will be necessary, perhaps coupled with detailed computer simulation modelling. In addition, the experiences of Cairns (1983, 1985, 1986) in the US offer useful insight into some of the potential pollution problems in such restoration.

The RRP has already enjoyed a good working relationship with BCO and potential for BCO to provide further funding and/or a demonstration site that fulfils the roles of the RRP should be explored.

Potential sites

During this study, three sites have been identified that are worthy of consideration as demonstration sites(s) for Phase 2.

- the River Ock (Oxfordshire) a degraded rural lowland channel
- the Hermitage stream (Hampshire) a degraded urban and semi-urban channel
- part of the Little Ouse (Norfolk), a degraded rural lowland channel, in the grounds of the British Trust for Ornithology (BTO)

These present opportunities for two of the three river types under consideration. These sites are considered individually according to the above criteria in Table 9. This is achieved using the same scoring system as in 6.4.1 but it should be noted that detailed site visits are required to fully assess the sites in question.

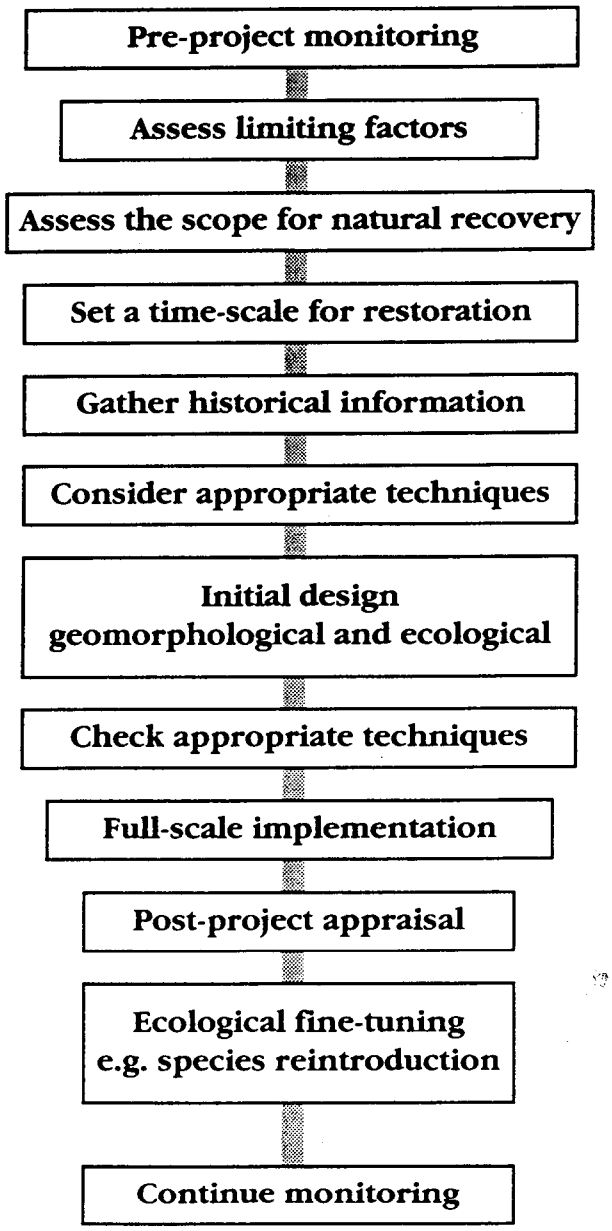
Table 9 Simple subjective consideration of three potential sites for the demonstration project of the RRP. Information is derived from discussion with relevant personnel (Ock - Alistair Driver, Hermitage - Hazel Long, and Little Ouse - Dr's Rowena Langston & Rob Fuller) and site visit (Little Ouse)

	Site		
Criterion	Ock	Hermitage	Little Ouse
contribution to biodiversity	+	-	+
contribution to amenity	-	++	++
adequate water quality and quantity	+	+	++
scope for natural recovery	+	-	+
the level of technical intervention	-	—	-
proportion of catchment	+	++	-
sympathetic land use	+	+	+
scope for riparian zone/floodplain restoration	+	+	++
co-funding opportunities	++	++	-
co-monitoring opportunities	+	-	++
location	++	-	+

6.3.7 The actual works

Once a suitable site(s) is chosen using the opportunities, constraints and general framework outlined above (6.3.1-6.3.6) the following plan (Fig. 17) of works is suggested. This is geared to the targets of the RRP and utilises the experiences of other countries.

Fig. 17. Plan for the works to be undertaken in a restoration project.



Summary

Within the framework of the targets of the RRP and the general opportunities and constraints to river restoration in the UK, it is recommended that the RRP should aim at restoration in a low energy rural site but adopt rehabilitation as a pragmatic alternative in a low energy urban site. This may be supplemented by recovery enhancement at a high energy rural site.

The combination of restoration (rehabilitation in urban areas) of the riparian zone/floodplain at each site, and the full-scale monitoring and dissemination of results, should break new ground in Europe. In addition, the wholesale use of natural materials where technical intervention is required.should also be demonstrated, and further challenges that may be taken on where the opportunity arises include:
i) breaking out concrete channels in urban areas and ii) reinstatement of rivers in 'made-up ground' (especially after surface mining).

Furthermore, the RRP should work to establish an appropriate framework for river restoration in the UK, both during and after the implementation of phase 2, and perhaps adopt an advisory capacity to encourage further restoration attempts.

APPENDIX 1

CASE STUDIES OF CURRENT RIVER RESTORATION PROJECTS

The following case studies were selected to :

- illustrate the range of restoration projects throughout the world
- be of direct relevance to British rivers

Schemes from Britain are illustrated alongside examples from Germany, Denmark, the Netherlands and USA. Other countries that have implemented restoration schemes include Austria, Switzerland, Hungary, France, Belgium and Australia.

BRITAIN

The following examples are included:

- Table of British schemes
- Wraysbury river
- River Ash
- River Coln
- River Windrush
- River Leen
- Sapiston Brook
- Harper's Brook
- Pinkhill meadows

BRITISH COAL OPENCAST

The following examples are included:

- Introduction to BCO
- River Rother
- Pigeon Brook
- River Erewash
- River Erewash at Smotherfly

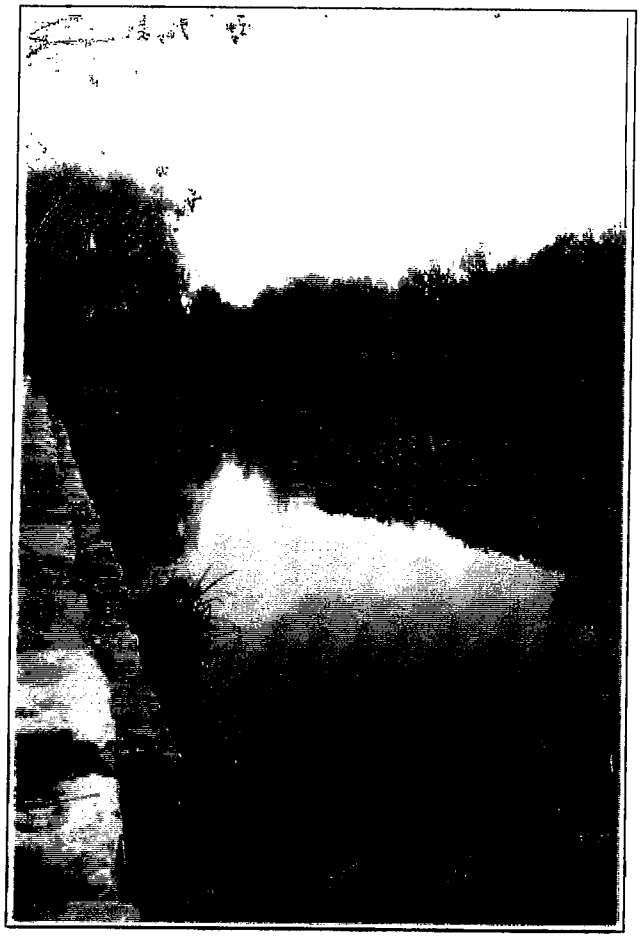
Table 7 Brief details of notable improvement schemes in seven regions of the NRA (ECON & Pond Action, 1993)

Region	River	width	length of scheme (km)	land use	reason	cost	conservation budget '92/'93	ppa
Anglian	Harper's Brook	4	2	rural	Cons	20	30	detailed visual
	Sapiston	6	1.5	rural	Cons	5		visual
Northumbrian	Lustrum	5	0.5	urban	Coms, FD	-	-	too early
	Leven	15pre 6post	0.4	urban	Cons, Am.	15		ongoing
	Till	20	-	rural	Cons	-		monitoring otters
Severn-Trent	Leen	4	15	urban	Rec, Cons	80	445	visual
	Rea Brook	3	5	urban	Cons, Arch, Rec	20		visual
	Severn	2500	5	rural	Cons	25		visual
Southern	Cray	1-2	3.5	urban	FD	700	5.2	visual
Thames	Ash	4	11.7	urban	FD, Cons, Rec	200	650	ongoing
	Coln	-	-	rural	Fish	31.5		monitoring fish
Windrush	8	1.5		rural	FD, Fish, Cons	150		ongoing monitoring
Welsh	Rhymney	-	34(10 sites)	urban	Cons	11	50	visual
	Cefni	10	2	rural	Cons	9		visual
	Gywrfai	6	0.6	rural	Fish	28		monitoring fish
Wessex	Brinkworth	1-2	2	rural	Con, Am, Fish	100	-	too early
	Tone	10	0.5	rural	FD	>1M		visual
	Wellow Brook	2-4	2	rural	FD, Fish, Cons	-		visual

Wraysbury River

The Wraysbury River, flows through an industrial area at Poyle (Thames Region). A flood alleviation scheme sought to use biotechnical alternatives to hard engineering methods. Large limestone blocks, willow spiling, and nicospan, rather than steel piling and concrete revetments, were used to stabilise banks.

Although channel capacity was maintained, a natural low flow width was created by the use of current deflectors to initiate the formation of berms, which were colonized by a variety of marginal plant species. An island and an extra high-flow channel were also incorporated to add further to the high instream diversity. As the area improved in appearance, it was increasingly utilized as an amenity area by the factory workers.



Creation of a more natural flow width and bank stabilisation with limestone blocks and willow spiling.

Name of river: **Ash**

Site: **Spelthorne Borough, NRA Thames Region** date: **1990-1991 phase 1**

River type: **lowland alluvial**
Form: **mostly straightened, some sinuosity and riffle/pool structure**
Substrate: **silty, especially where channel has been widened and deepened.**
Land use: **green corridor for urban area with some woodland, scrub, semi-improved pasture, amenity grassland, gardens and disturbed ground habitats**

Length of scheme: **11.7 km in total in a six phase plan**

Aims :

- **increase flow for greater dilution and aeration and decrease siltation of channel**
- **reinstate natural gravel bed, pool/riffle structure**
- **improve general habitat quality**
- **improve visual amenity**

Brief description of work in Phase one:

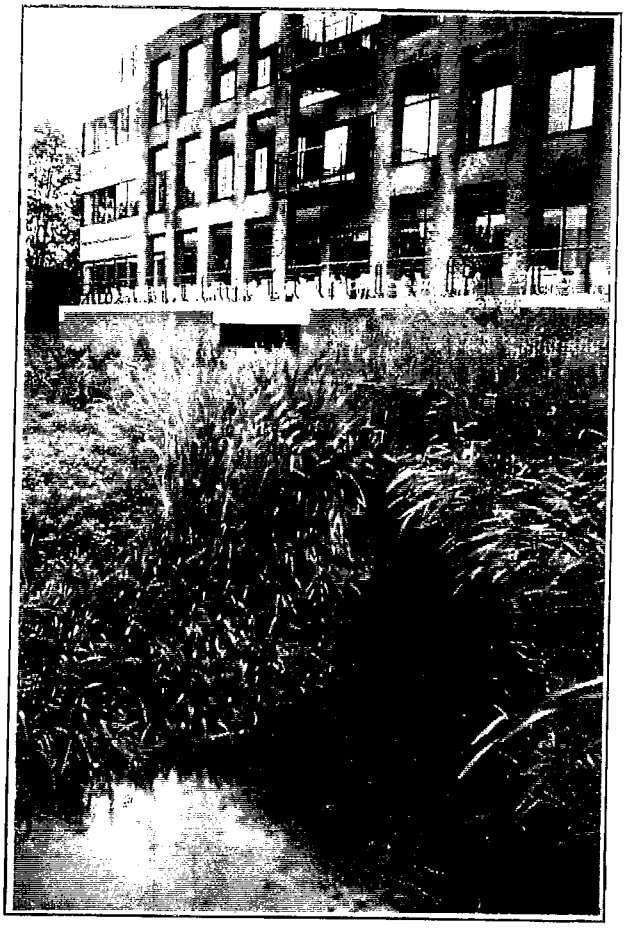
- **increase capacity by approximately 50% through work on outfall from the River Colne and de-silting of culverts**
- **de-silting of channel**
- **installation of flow deflectors**
- **creation of shelves for emergent vegetation**
- **tree planting**
- **pollarding/coppicing of existing trees**
- **walkway creation**

Funding: **Department of Transport, British Tobacco and NRA Flood Defence**
Cost: **Phase1 £200,000**

Post-project appraisal:

- **local residents and the project sponsors satisfied with improvement**
- **increases in populations of fish and waterfowl suggested**
- **invertebrate monitoring planned**

Contacts: **Alastair Driver, David van Beesten, Trevor Odell (NRA Thames region)**



Luxuriant emergent vegitation in an urban setting.

Creation of an island and a diversion channel

Boulder placement

Name of river: **Coln**

Site: **Coln St. Aldwyns, NRA Thames Region**

Aims:

- **to alleviate summer low flow caused by channel widening**
- **to reduce silt deposition and reinstate natural gravels**
- **to enhance the fishery through improving habitat quality for rooted macrophytes and macroinvertebrates**

Brief description of works:

- **a section of the river was narrowed using imported limestone blocks**
- **flint gravel rejects were spread throughout this section to increase substrate diversification**
- **individual limestone boulders were introduced into the mid stream area to create current variation**
- **deflector groynes were made from limestone blocks**
- **construction of a spawning weir**
- **a pond was created and lined with elastic polythene (90 x 12m) to provide material for backfilling**
- **pre-scheme monitoring of macroinvertebrates was carried out.**

Funding: **small contribution (£1500) from angling club**

Costs:

main work £25,000
pond lining £8,000
total £33,000

Post-project appraisal :

- **four year fisheries survey (carried out by Fisheries section)**
- **follow up surveys of biological factors, and fisheries to be continued**
- **moratorium to be placed on culling grayling stocks over a three year period so that the effects of the works can be assessed**

Contact: **Alastair Driver (NRA Thames Region)**

Name of river: **Windrush**

Site: nr **Oxford, NRA,Thames Region, U.K.** Date: **1991**

River type: **limestone river** Width: **8m**
Length of scheme: **1.5 km**
Land use: **agricultural**

Reasons for scheme:

- **low water flows resulting from drought and abstraction have caused a build-up of sediment and emergent macrophyte vegetation**
- **poor angling returns**

Aims :

- **narrow channel from 8 to 4.5 m**
- **recreation of pool-riffle bed for fish, brown trout in particular**

Brief description of works:

- **channel narrowing was achieved by stapling coir matting to 2m larch poles and driving these into the bed at 0.5 m intervals to create a meandering profile**
- **a two-stage channel was created by returning the bottom edge of matting to the bank and backfilling**
- **large limestone blocks (1x1x0.6m) placed in the upstream reaches to create a two stage channel**
- **600 tonnes of flint reject gravel was placed in new channel with large limestone blocks to create localized current variation**
- **two artificial 'trout spawning' weirs installed in which 10, 000 eyed eggs placed in Dec 1991**

Cost: **£ 50,000** Source: **the Upper Thames Water Flood Defence revenue**

Post-project appraisal:

Visual appraisal:

- ***Ranunculus* (water crowfoot), has begun to colonize the reach**
- **higher winter flows have begun to develop a pool-riffle regime**
- **backfilling behind matting and limestone blocks has consolidated and withstood the two periods of inundation by flood water**
- **further monitoring from environmental and flood defence aspect is planned**

Contacts: **Alastair Driver (NRA Thames Region)**

Name: **River Leen**

Location: **Nottingham, NRA Severn Trent Region** Date: **1988...**

Channel: **straight** Width: **4m** Substrate: **sandy**
Land use: **urban**
Length improved: **15 km (86% of catchment length)**

Reasons for scheme:

- **high profile location**
- **opportunity to collaborate with the the local council and wildlife trust**
- **to improve the ecological value of the river**

Brief description of works:

- **small weirs constructed**
- **watercourse widened, marginal features and ponds created**
- **battering of banks**

Funding: **£40,000 from NRA conservation fund, £40,000 from local authorities**
Cost: **£80,000**

visual appraisal:

- **aesthetically pleasing**
- **more diverse channel structure**

Contacts: **Val Holt, Andrew Heaton (NRA Severn Trent Region)**

The beginnings of breaking-out concrete

River Leen

Raising the bed level with a weir

The resulting shallow water embayment

Name: Sapiston Brook

Location: **Suffolk River Valleys, NRA Anglian Region** Date: **Feb-April 1992**

Channel: **meandering** Width: **6m.** Substrate: **gravel, silt and clay**
Land use: **rural, part of the Suffolk River Valley ESA scheme**
Length of scheme: **1.5 km (5% of total)**

Reasons for scheme:
- **opportunity to improve instream habitat and raise water levels of adjacent ESA grazing meadows**
- **landowner co-operation**

Brief description of works:
- **riffle reinstatement (using 20 tons of gravel per riffle)**

Funding: **80% conservation, 20% flood defence** Cost: **£ 5000**

Post project appraisal:
- **diversity of instream habitat increased**
- **water table increased on adjacent land due to raised water levels and backing up of connected dykes**
- **monitoring planned**

Name: Harpers Brook

Location: **Northants, NRA Anglian Region** Date: **March 1992-May 1993**
Channel: **straight, trapezoidal** Width: **4m** Substrate: **silt, gravel**

Length of scheme: **2 km, (5% of length)**
Land use: **rural, semi-improved pasture, a nature reserve**

Reasons for scheme:
- **poor quality instream habitat and excessive weed growth**
- **landowner co-operation (Northants. Wildlife Trust)**

Aims:
- **geomorphological improvement**
- **improve habitat diversity**
- **decrease need for flood defence maintenance**

Brief description of works:
- **riffle reinstatement using gravel at appropriate intervals**
- **bank re-profiling, to create slope variety**
- **tree planting**

Funding: **80% conservation, 20% flood defence** Cost: **£ 20,000**

Post project appraisal:
- **diversity of habitat increased through reinstatement of riffles**
- **formation of pools through natural scour and slight increase in sinuosity**

Contact: **Claire Redmond, NRA Anglian Region**

Sapiston Brook

Increasing bed levels by adding gravels

Colonisation of the ramps by marginal vegitation

Name: **Pinkhill Meadow**

Site: **adjacent to the River Thames & Farmoor Reservoir, nr. Oxford, NRA Thames Region**

Date: **1990-1992**

Area of wetland: **4 ha**

Land use:

- **nature reserve particularly for birds**
- **monitoring station for the Thames**

Land owned: **Thames Water Utilities Ltd.**

Reasons for scheme:

- **to create a wetland reserve between a meander of the Thames River and Farmoor Reservoir**

Aims:

- **to increase the variety of wetland habitats on the Farmoor site especially to enhance grazing meadows as survey had shown these to support a regionally valuable meadow plant community**
- **to provide shallow water habitats for wading birds as a complement to the deep water in the reservoir**
- **to monitor the colonisation of plant and animal species in seven experimental ponds**

Planning and Development:

- **project initiated as a Thames Water Authority habitat enhancement scheme. Which subsequently became a NRA Thames Region Operational Investigation (Thames Water was coordinator) and latterly a national NRA R&D Project in 1992**

Brief description of works:

- **project was in two stages**

Phase 1

- **four ponds of variable size created**

Phase 2

- **ponds extended to create various wetland habitats**
- **the 20 000m^3 of material excavated from the meadow was formed into a low hill near Pinkhill lock and planted with native trees and wildflowers**
- **a 4m wide belt of willow was planted around perimeter of the site to establish willow scrub habitats**
- **a variety of grassland habitats created with the use of traditional grazing and cutting regimes**

- **shallow pools were created by shallow excavation with sinuous edges to maximise edge habitats**
- **scrape created by excavation into alluvium above the water table the water level of which was controlled by a pipe linking it to the main pond**
- **a main pond was created by excavation into the gravel to 2.5m in places**
- **four gravel islands were created to encourage nesting birds especially terns whilst muddy islands were created as feeding areas for wading birds**

Post-project appraisal:
Monitoring:

- **plant colonisation was patchily distributed but 49 species were recorded in 1992, 4 of which are considered to have a 'local' national distribution**
- **the cumulative total of macroinvertebrate species from four ponds increased from 12 in the first season to 84 after three years**
- **14 species of macroinvertebrate are nationally local and 1, the water-beetle (*Coelambus nigrolineatus*) is listed as nationally notable A.**
- **34 wetland bird species have been recorded, 16 of which were waders**
- **more uncommon bird species included Temmincks Stint and Garganey**
- **breeding birds include Little Ringed Plover, Tufted Duck and Lapwing**

Contact: **Jeremy Biggs, Pond Action**

BRITISH COAL OPENCAST

- British Coal Opencast (BCO) covers four regions, Central, Northern, Scottish and South Wales.
- since 1942, BCO have reclaimed 80,000 ha of land, a new site (average 200ha) is required every month to satisfy requirements
- a variety of rivers (high energy and low energy) have been temporaily diverted or relocated to allow exploitation of coal resources
- these rivers are then often reinstated in their old channels and additional environmental benefits are hoped for
- various specialists are contracted to help fulfil this aim
- there is considerable scope to employ state-of-the-art restoration techniques as BCO continue to seek ways to make their operations as unobtrusive as possible and make a positive commitment to the environment

River Rother

Pictures here show the Rother at the Dixon site (note the massive scale of excavation).

Diversion of the River Rother - the Dixon Site

Upstream of the diversion channel

Low weirs in the diversion channel to increase oxygen levels.

Name of river: **Pigeon Brook**

Location: **Pithouse West, Central Region**

Length of scheme: **1200m, 200 of which have been completed**

Design: **ADAS**

Brief description of works:

- **development of a two-stage channel**
- **removal of some of channel from a culvert**
- **berm creation, some *Typha* plants have been transplanted**
- **in-stream flow diversity enhanced using large stone blocks**

Contact: Alan Batty, BCO Central Region (site manager)

Berm creation

Boulder placement

Bank instability in made up ground

Name: **River Erewash**

Location: **Shilo south site, Central Region**

Form: **strongly sinuous**
Substrate: **clay bed**
Water quality: **poor, due to the close proximity of three sewage works.**

Year of relocation: **1982**

Brief description of works:

- **on the advice of local naturalists groups and the Severn-Trent Water Authority, extensive washlands were reinstated**
- **these become flooded only once every ten years or so**
- **they are grazed or may be cut for hay**

Post-project appraisal:

Visual:
- **the river form with extensive washlands has been criticised as being atypical of the natural river which has vertical banks populated by trees and shrubs**

Monitoring:
- **some monitoring of invertebrates and plants has occurred**

Contact: **Ian Carolan, BCO HQ**

The reinstated river at Shilo south in extensive washlands

The natural river form downstream of the site.

Name of river: **River Erewash**

Location: **Smotherfly, Central Region, 20km NW of Nottingham**
River type: **stable, lowland alluvial** Form: **deeply incised, sinuous**
Channel: **steep banks with trees and shrubs in places**
Depth: **2-3m** Substrate: **sandy till**

Reasons for scheme:

- **BCO has planning permission for an opencast mine and is committed to reinstating the river to its original course**

Aims:

- **to create a wide range of habitats**
- **bank slopes and vegetation cover, capacity and distribution of flood plain to be reinstated**

Planning:

- **a Smotherfly environmental advisory group was set up comprising consulting engineers, NCC, NWT, Erewash valley wildlife project, BCO and DCC**

Plan of works:

- **temporary diversion channel for the River Erewash will commence at the end of 1993**
- **reinstatement of the river will begin in 1997 and continue for about four years, the diversion channel would become redundant after a further 3 years**
- **coaling contractor to carry out the basic site restoration**
- **specialists have been contracted to sculpture, build, and plant the new river**
- **methods will include, geojute for strengthening, bio-technical engineering instream devices to create habitats, meanders with high-flow relief channels, wetland and terrestrial plants or seeds from the site are to be saved in nurseries, Pye hill meadows are to be relocated for later replacement**

Contact: **Mike Greenwood, BCO Central Region**

Germany

The following examples are included:

- Wiesenbachle stream
- Kammbach stream
- Sulzbach stream
- Steinbach stream
- Siegentalbach stream
- River Sandbach
- Gutenbach stream
- Rungsbachle/Kleines Sulzbachle stream
- River Alb
- River Metter
- River Enz

Name of river : **Wiesenbachle Stream** date: **1991**

Site: **nr. Krumbach, Northern Baden-Wurrtemberg, SW Germany**
River type: **mountain**
Form: **3 springs, two of which were piped 30 years ago, the central connecting channel leads to a sewage works**
Discharge: **dependent on season and flow from springs**

Length of scheme: **800m**

Land use: **agricultural, traditional meadow**

Aims:

- **to remove two springs from pipes**
- **to dechannelize the third and remove the undercut banks**
- **to develop the range of habitats from nutrient poor to semi-fertilised**

Description of works:

- **800m of stream was recreated**
- **course excavated, filled with coarse gravel and the slope reduced**
- **restore channel form of the third stream**
- **branches and rocks were placed in to create habitat diversity**

Costs:

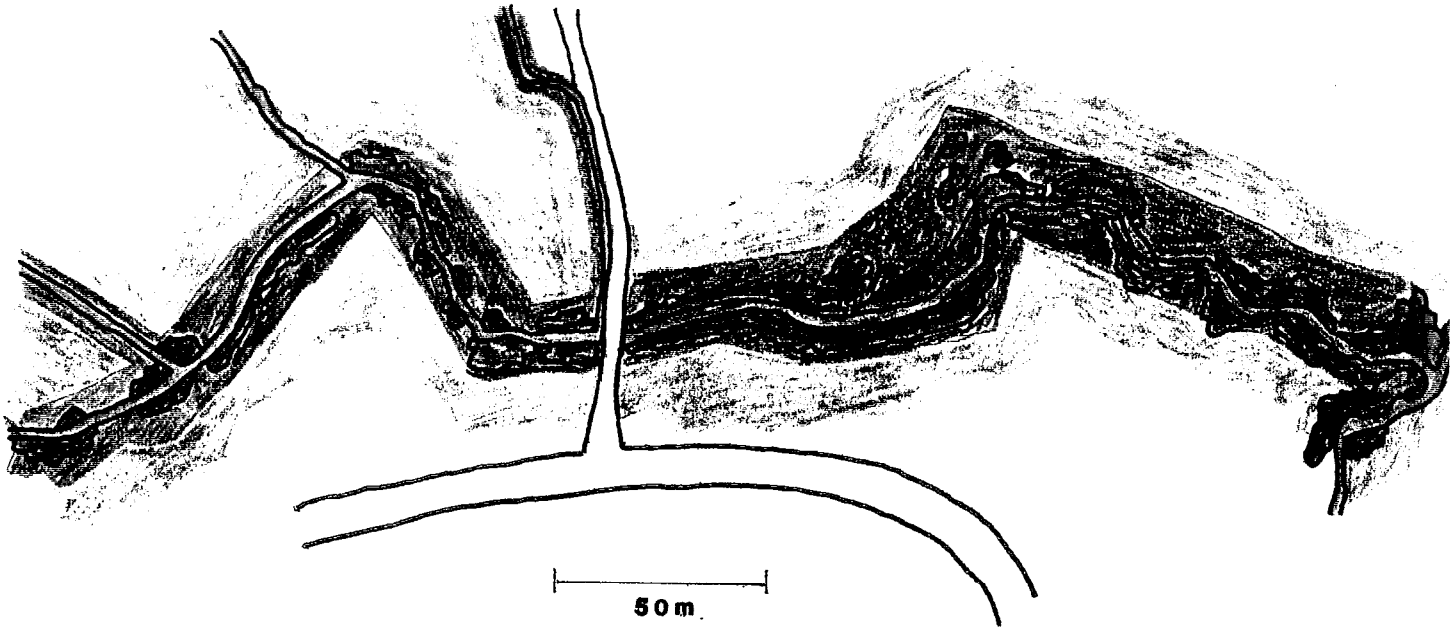
excavation £44 520
country lane crossings £3 424
planting £6 849
total £54 793
per metre £68

Post-project appraisal:
Visual:

- **completed parts of project showed evidence of strong plant colonization**

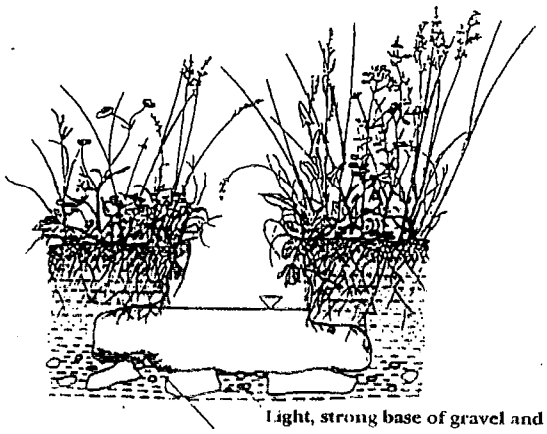
Contact: **Klaus Kern**
Reference: **Kern *et al*. (1992)**

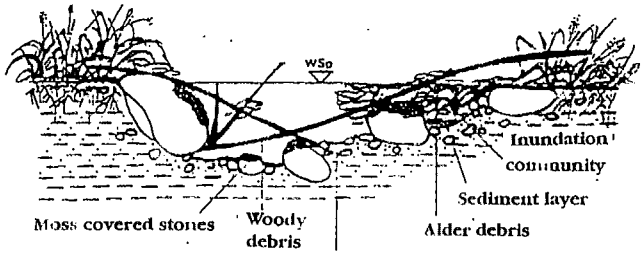
Photographs copied and plan redrawn from above



Before (8/87)

During (7/91)





Sandy loam with small flat stones with a covering of course sand.

Name of river: **Kammbach Stream**

Site: **nr. Strasbourg, West Baden-Wurrtemberg, Germany** Date: **1988**

River type: **lowland carbonate** Form: **straight**
Channel: **trapezoidal**
Substrate: **muddy alluvial sand over cobbles, prone to sedimentation**
Width: **6.5m** Depth: **1.6m** Discharge: **0.13 m3/s**

Length of scheme : **1700m**
Land use: **agricultural, 70% fields, 30% grassland**

Aims:

- **change channel morphology and improve stream dynamics**
- **reinstate ecological value of stream and floodplain**
- **development of riparian vegetation**

Brief description of works:

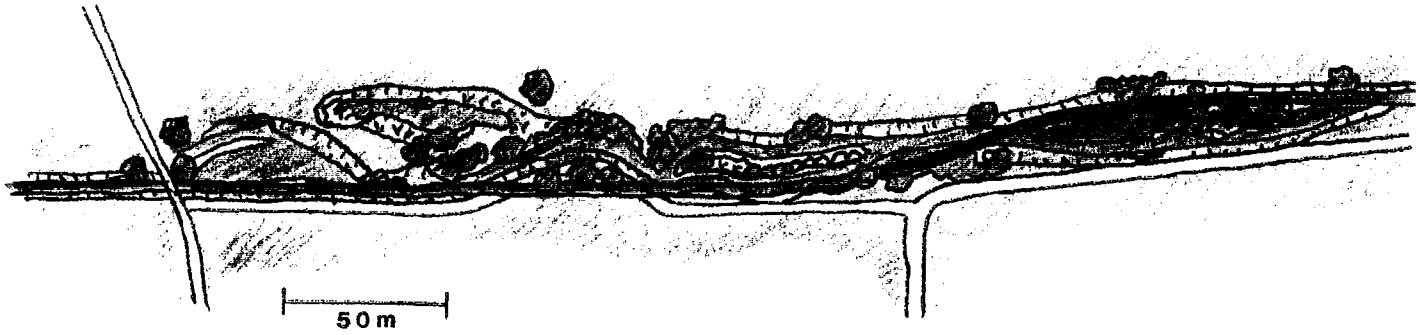
- **surveys of flora and fauna carried out before scheme started**
- **middle of bed was widened, islands created**
- **old cutoffs were modified to communicate with channel**
- **sand trap installed**
- **artificial oxbow lake created**
- **10 to 25m wide buffer zone established along both sides of the channel**
- **30% of bank planted with trees and shrubs**

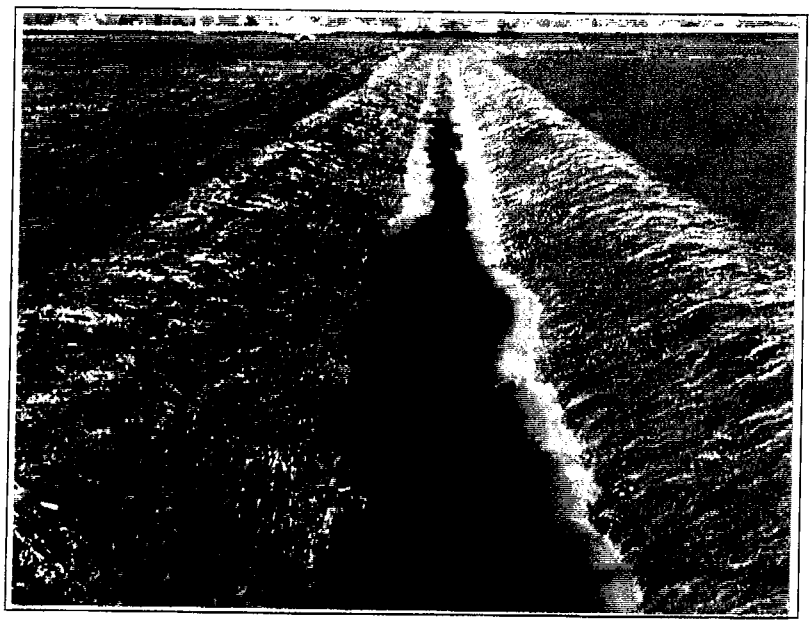
Costs: **total £99,200 £58 per metre**

Post-project appraisal:
Visual:

- **height of the islands and other features prevented flooding and hampered development of wetland vegetation**
- **more trees are needed**
- **sediment trap is currently inadequate**

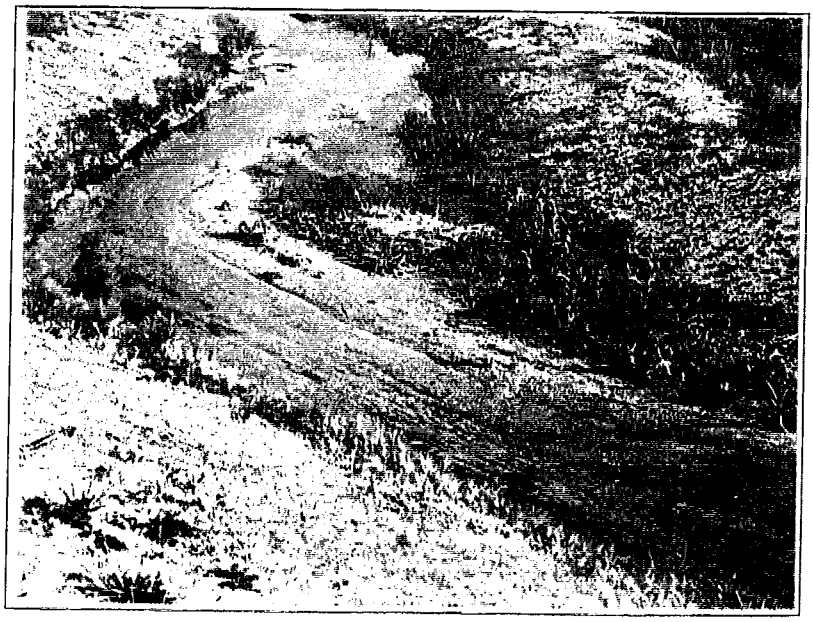
Contact: **Klaus Kern**
Reference: **Kern *et al*. (1992)**
Photographs copied and plan redrawn from above





Before (2/86)

Meander creation



After (9/88)

Name of river: **Sulzbach Stream**

Site: **Marbach, nr Steinheim, Baden-Wurrtemberg, SW Germany**
Date: **1986: 330m, 1989: 170m of scheme completed respectively**

River type: **mountain stream**
Form: **straight**
Width: **3m**

Channel: **trapezoidal channel, some in a pipe**
Substrate: **concrete**
Depth: **0.8m**

Length of scheme: **500m**
Land use: **agricultural - pasture**

Catchment: **42 km^2**

Aim:

- **to create a natural stream from an agricultural drainage ditch**

Organization of the Scheme:

- **scheme directed by the District Office for Nature Protection and Landscape Care in conjunction with the Water Office and the Fisheries Office**

First phase: **land owned by government.**
Second phase: **land purchased, input and practical work from citizens' groups**

Brief description of works:

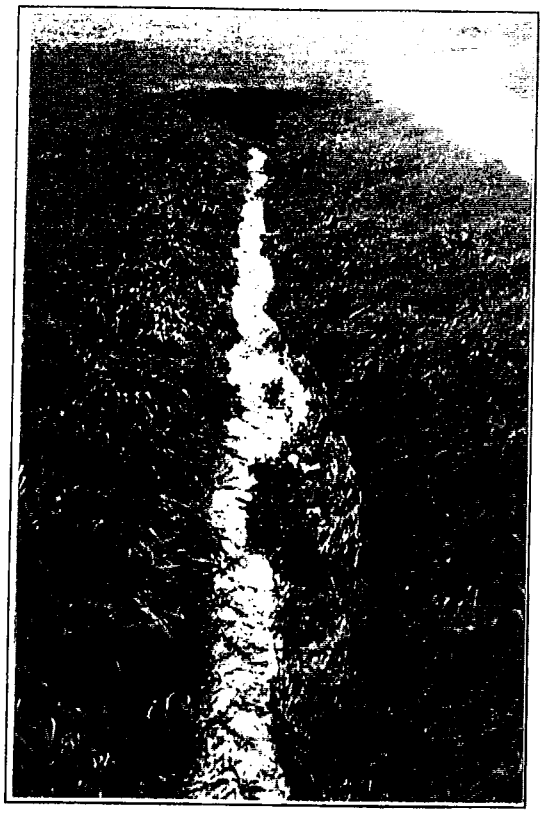
- **pipes by-passed**
- **short meanders created**
- **cobbles removed**
- **stream slope reduced with shell limestone steps**
- **bank re-profiling and willows and alders planted**
- **clumps of original bankside vegetation transplanted**
- **excavations made on nearby swamp to create dragonfly habitat**
- **actions carried out on a day to day basis as a result of voluntary help**

Costs: **£29 per metre (low cost achieved by use of voluntary help)**

Post-project appraisal:
Visual:

- **banks revegetated eg with *Mentha aquatica* and *Valeriana dioica***
- **channel choked with *Cardamine amara* future shading by trees should reduce this**
- **steps now invisible but have created barriers to fish migration**
- **great aesthetic improvement**

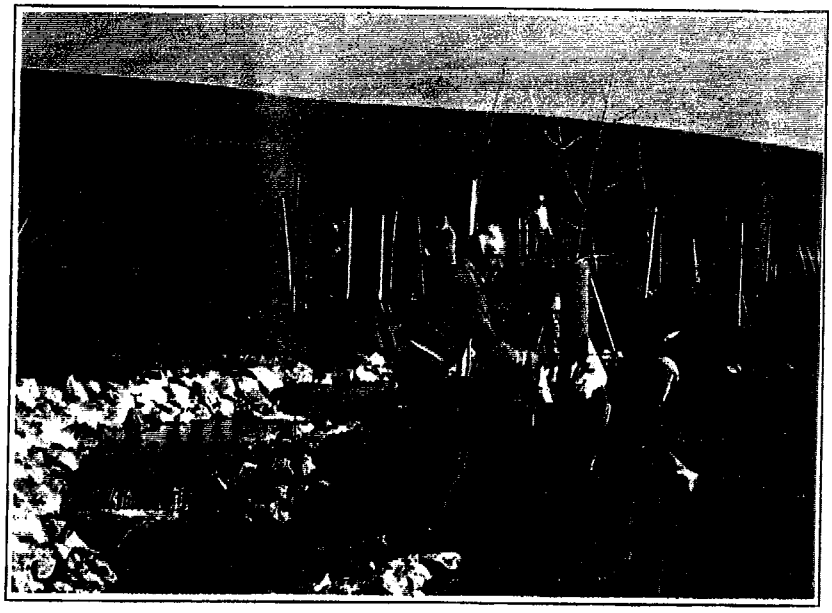
Contact: **Klaus Kern**
Reference: **Kern *et al*. (1992)** Photographs copied and plan redrawn



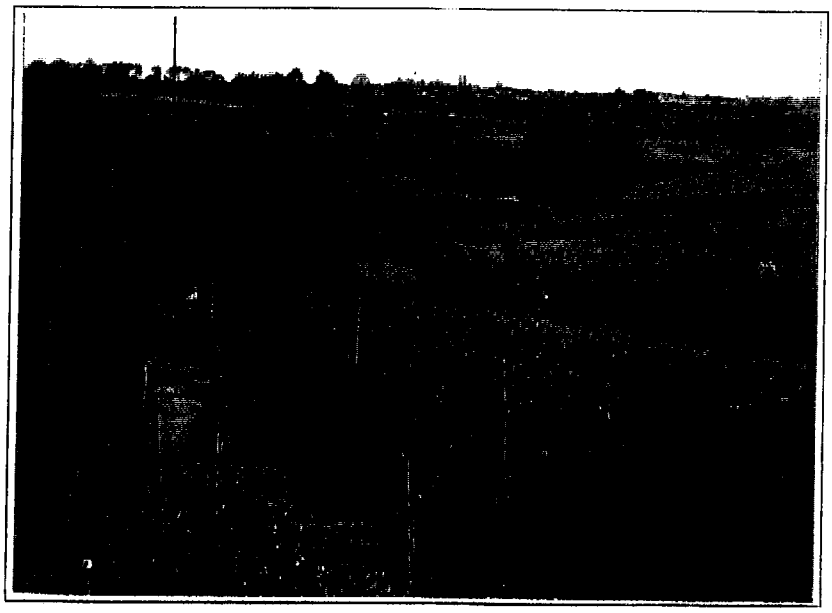
Before (10/86)

Digging the new course

Volunteers in action



After planting and sill placement



After (5/88)

Name of river: **Steinbach Stream**

Site: **Steinbach, north of Honhardt, Stuttgart District, Germany**
Date: **1988 (over 10 week period)**
River type: **mountain stream** Form: **straight, slope 5.8%**
Channel: **U shaped with some pools** Substrate: **firm loam**
Width: **1.8 - 5 m** Depth: **1.3m -2.3m** Discharge: **0.08m^3/s**

Length of scheme: **200m** Land use: **rural -mixed grassy farmland**

Organization:

- **land purchased from Frankenhardt local government**
- **contract to a landscaping firm (with the cheapest quote)**

Reason for choice:

- **regulation from the sewage plant at Honhardt had caused some reduction in water levels and eutrophication**

Aims:

- **stop erosion**
- **allow a wider area to be flooded**
- **create meanders**
- **increase landscape value**

Brief description of works:

- **meanders re-instated with technical bank protection measurements**
- **slope increased to 6.7%**
- **boulders/coarse gravel introduced, fixed with stake lines above and below water**
- **bed widened**
- **banks re-graded**
- **planting for shade and stabilization**

Costs :

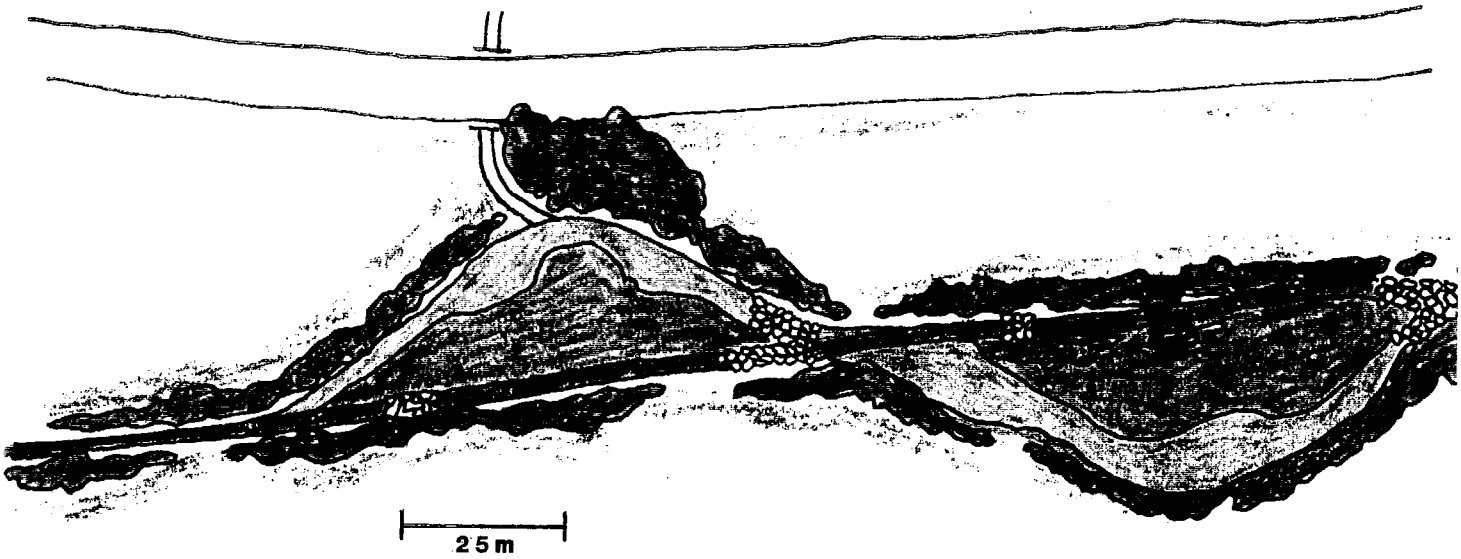
building work £54,336 **land purchase £6,250**
total cost £60,586 **£52 per meter**

Post-project appraisal:
Visual:

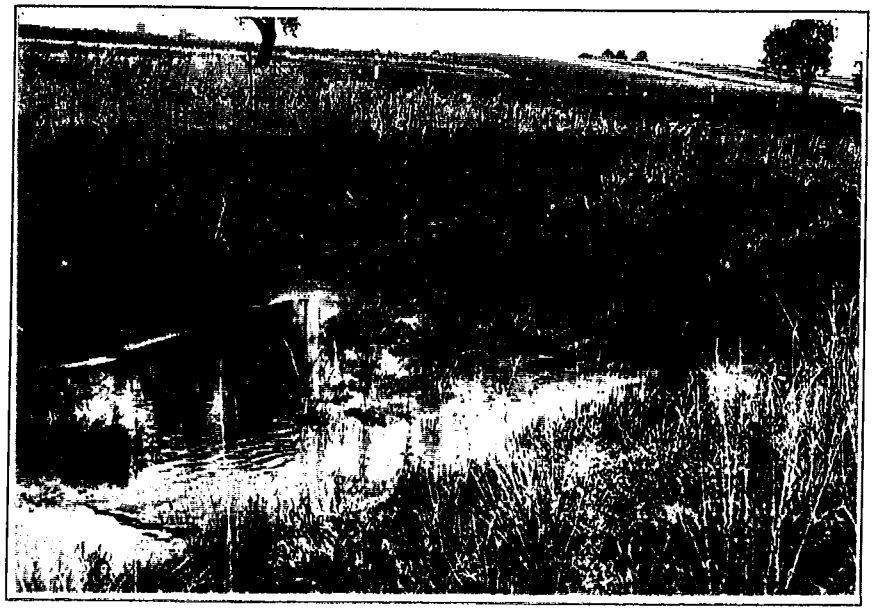
- **areas of boulder and cobble were built too high**
- **sand very unstable at high water**
- **at low flow the stream became a collection of small pools therefore stakes fixing the boulders were hammered in deeper**

Contact: **Klaus Kern**

Reference: **Kern *et al*. (1992)** Photographs copied and plan redrawn



Before (5/86)



After (8/89)

Name of river: **Siegentalbach Stream**

Site: **nr. Altheim, Aue Valley, Baden-Wurrtemberg, SW Germany**
Date: **1989**

River type: **mountain stream** Channel: **trapezoidal**
Form: **slightly sinuous** Substrate: **sand, gravel and mud**
Width: **2-3m** Depth: **1m** Discharge: **0.04m^3/s**

Length of scheme: **3 stretches, 250m, 270m & 350m spread along 3.9km**
Land use: **rural, predominately arable land**

Reason for choice:

- **ecological richness depleted by pollution**
- **valuable fisheries**

Aims:

- **reduce nutrient pollution and excessive sedimentation in Lake Schmiecher (an important wildlife area) downstream**
- **planting on one bank to reduce shade and temperature**
- **include the former upstream scheme carried out in 1987**
- **encourage extensification of agriculture in surrounding farmland to reduce nutrient load**

Supervised: **District Office for Nature Protection and the Water Office**
Funded: **Altheim council**

Brief description of works:

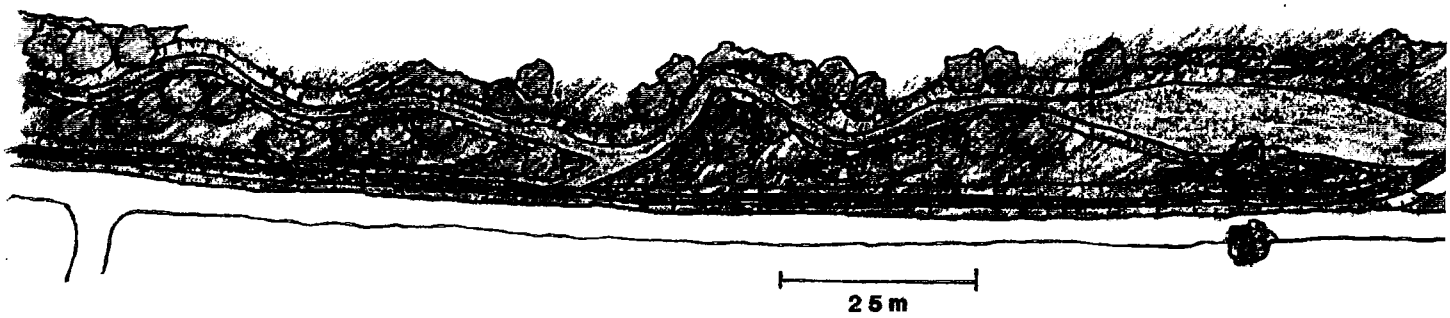
- **pre-project surveying to identify important habitats for wildlife**
- **creation of buffer strips**
- **some realignment of channel**
- **gravel placement**
- **slope reduction**
- **bank stabilization with jute mats and resowing**
- **reed-beds used to treat water at sewage works**

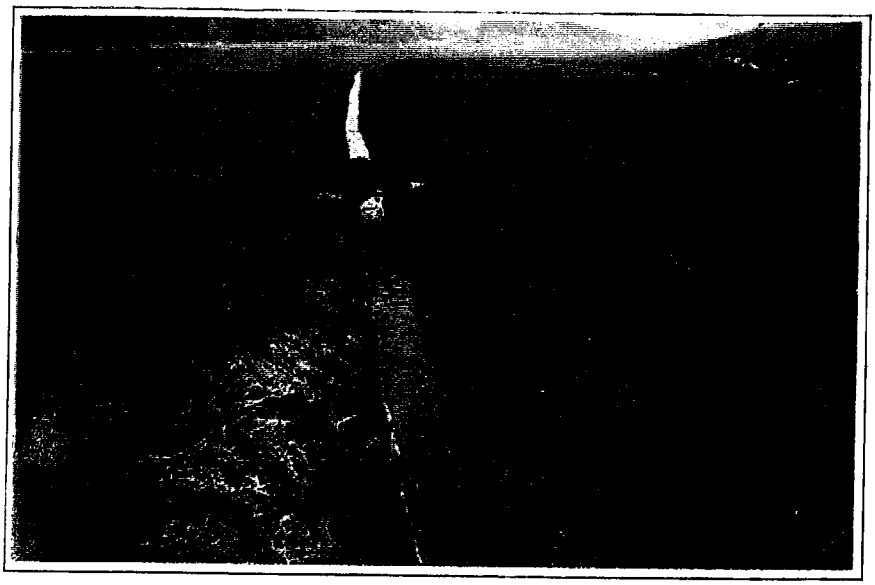
Costs: **£458,000**

Post-project appraisal:
Visual:

- **desirable plants established indicating that water quality has improved**

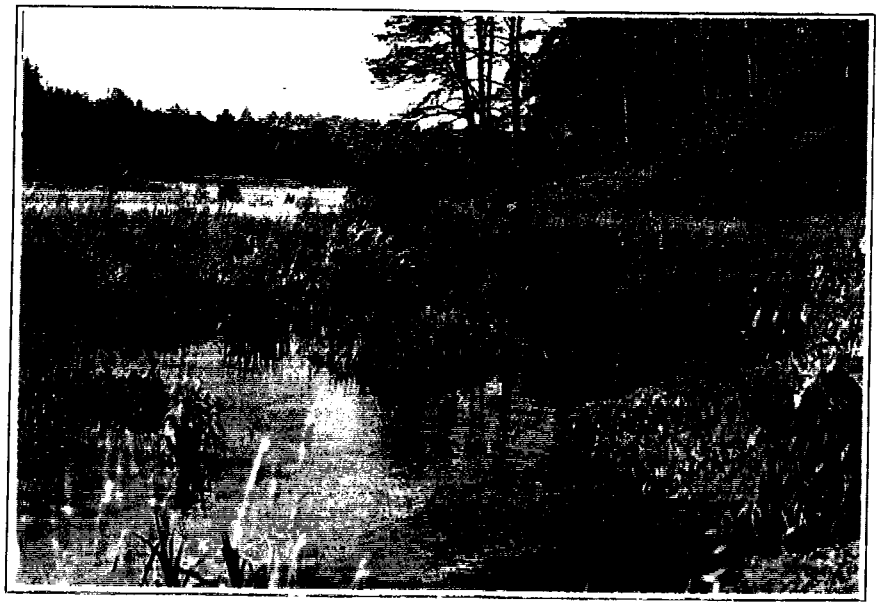
Contact: **Klaus Kern**
Reference: **Kern *et al.* (1992)** Photographs copied and plan redrawn





Before (4/88)

Recreating sinuosity



Sediment trap (8/89)

Name of river: **River Sandbach**

Site: **nr. Steinbach,west Baden-Wurrtemberg, SW Germany**
Date: **1987 (experimental section), full scheme started 1992**

River type: **lowland alluvial** Form: **straight, sewage collection pipes under river**
Substrate: **sandy** Channel: **trapezoidal, with 1m embankments for flood protection**
Width: **11-14m** Depth: **2-2.5m** Discharge: **0.5-1.5m^3**

Length of scheme: **2.6 km (plan to extend to 8km)**
Land use: **rural, agricultural with some residential**

Aims:

- **redress bank erosion and increase bank stability with tree and hedge planting**
- **ensure the channel could cope with increased runoff from the residential area**
- **increase flooding frequency to enhance wetland**

Brief description of works:

Experimental section:

- **stones and gravel section installed**
- **live willow and dead conifer fascines used for bank protection**
- **banks stabilised by planting stands of mixed trees in compost**

Full scheme:

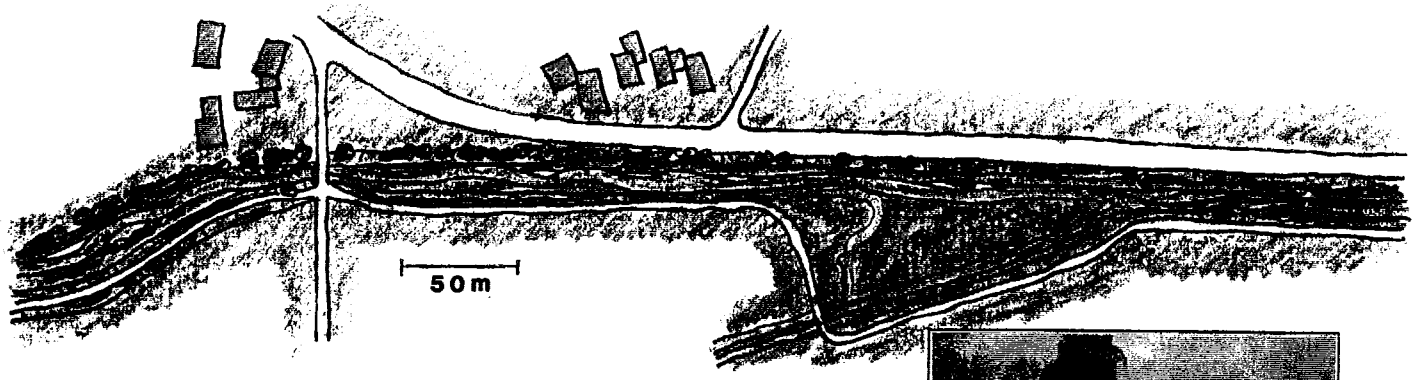
- **limited space in residential area meant work was undertaken on one bank only**
- **stone was used as a base for the bank and embankment was made higher**
- **1300 m length of channel was widened and meanders created**
- **some of land levelled to allow periodic flooding**
- **channel reconstructed to flow around both sides of this low lying area**
- **paths and bridges constructed**
- **pipes associated with residential area re-directed**

Cost of both phases: **£1 437,500**

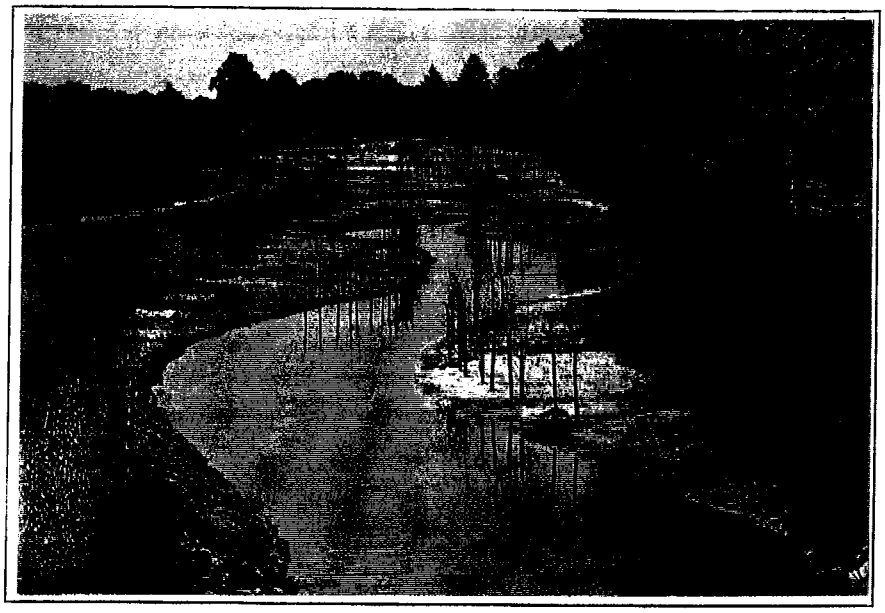
Post-project appraisal:
Visual:

- **major flood event caused no significant damage**
- **flooded area is developing a rich variety of wetland species**
- **channel has developed natural features**
- **landscape value of area has been enhanced**
- **further improvements would involve attempts to improve the water quality**

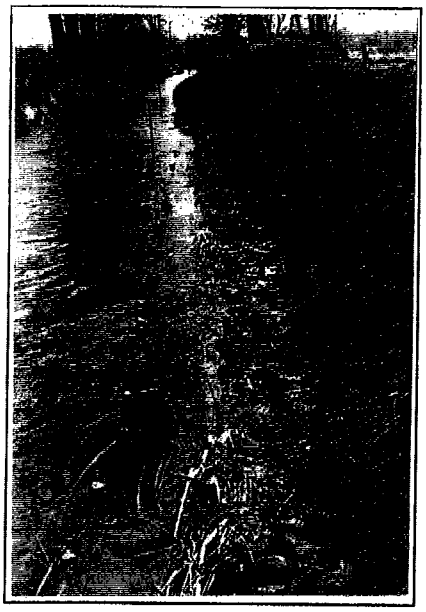
Contact: **Klaus Kern**
Reference: **Kern *et al.* (1992)** Photographs copied and plan redrawn



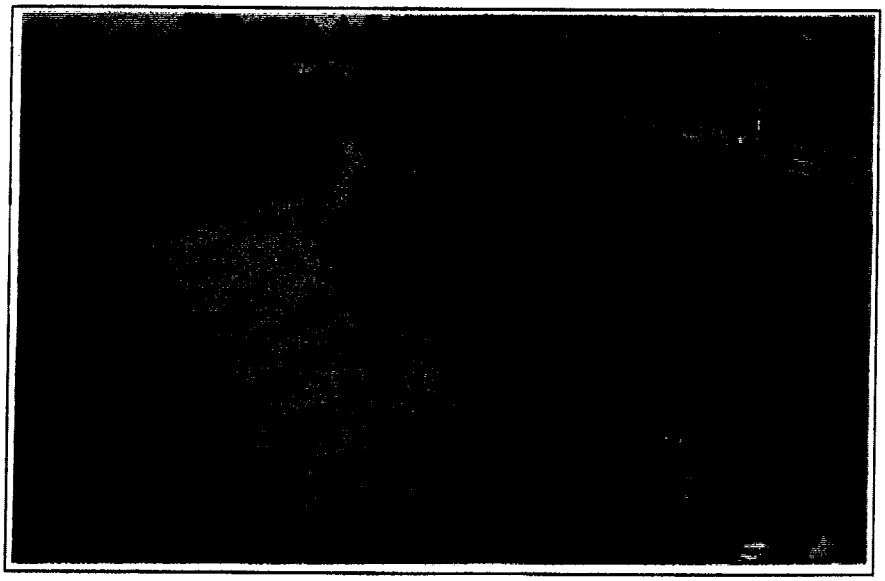
Willow spiling

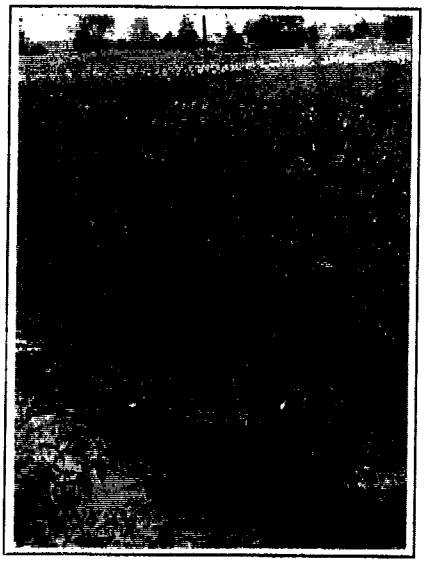


Meander creation (5/90)



Willow spiling after growth





After completion (8/90)

Name of river: **Gutenbach Stream**

Site: **Oberkochen, east of Stuttgart, Baden-Wurrtemberg, SW Germany**
Date: **1986-1988**

River type: **mountain stream** Form: **slightly sinuous**
Channel: **lined and channelized**
Substrate: **concrete paving tiles with alluvial clays sediments and eroded material**

Length of scheme: **840m**
Land use: **residential - formerly pasture**

Aims:
- **to create a more natural stream and surroundings**
- **to redirect (540m) of the course of the stream through a residential area**

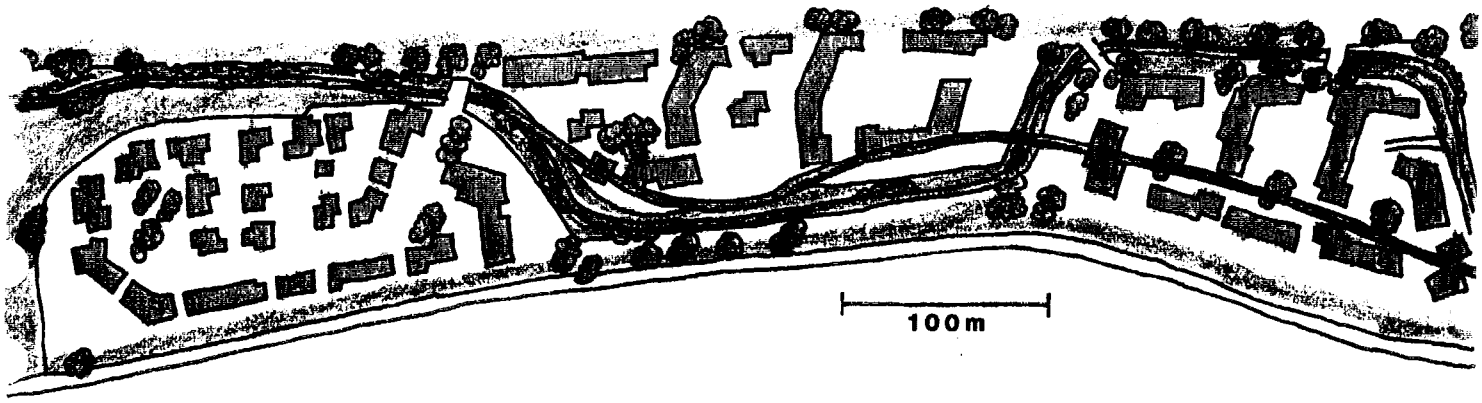
Brief description of works:
- **concrete removed**
- **the cross section was made irregular and variable in form**
- **relocated section has more pronounced meanders**
- **jurassic stone rockfill was used as channel reinforcement**
- **reeds were planted, and fascine used for further stabilization**
- **a 3m concrete wall has been created, with small natural banks where buildings are situated very close to the channel**
- **wetland habitats are situated at irregular intervals along the stream course**
- **pool was created, connected by a narrow channel to the stream, as a play and adventure area for children**
- **alder and willow were planted in copses on alternate sides of the stream**
- **open areas were sown with grass mixtures and plants typical of the region**

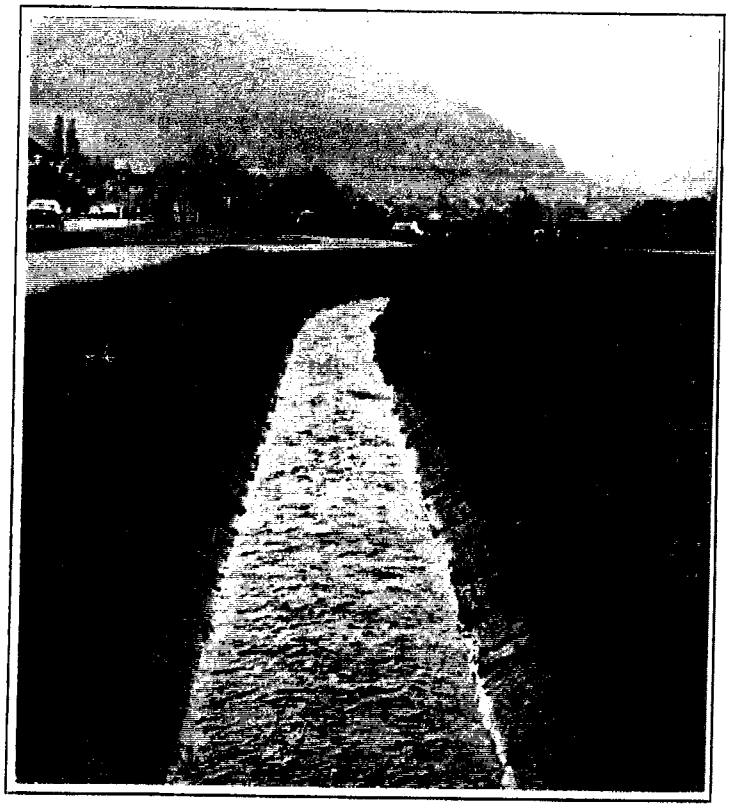
Costs: **£84,000 (without planting costs)** **£100 per metre**

Post project appraisal:
Visual:
- **a bankfull flood altered the stream bed and created a more natural morphology**
- **some poor quality drop structures were washed away**
- **embankments remained relatively intact due to the stable loam soil**
- **one year after the scheme grass was growing strongly where sown**
- **aesthetic and ecological value of the area improved**

Contact: **Klaus Kern**

Reference: **Kern *et al.* (1992)** Photographs copied and plan redrawn





Before (5/84)

After concrete removal (7/88)

Use of rocks to promote current diversity

After (4/89)

Name of river: **Rungsbachle and Kleines Sulzbachle Stream**

Site: **nr. Buhl, Western Baden Wurrtemberg, Germany** Date: **1990**

River type: **mountain stream**
Form: **Rungsbachle straight, realigned, enters a pipe, re-emerges as the straight Kleines Sulzbachle, slope gradually changes from 30% to 2%**
Channel: **Rungsbachle-trapezoidal**
Kleines Sulzbachle, V - shaped.
Substrate: **Rungsbachle-natural cobble, sand, slightly gravelly**
Kleines Sulzbachle-concrete tiles, sand and fine sediment
Width: **Rungsbachle-1.7m** **Kleines Sulzbachle-1.7m -6m**
Depth: **Rungsbachle-1.7m-1m,** **Kleines Sulzbachle-1.5m**
Discharge: **0.5-0.8m^3/s**

Land use: **residential and industrial area with some sports fields and agriculture**
Length of scheme: **475m experimental site**

Reasons for scheme:

- **valuable plant community including the rare *Leucojum vernum* in the surrounding damp meadows and swamps**
- **amphibian community includes endangered *Rana* and *Bufo* spp.**
- **rare dragonflies, butterflies and an endangered snail sp. in the area**

Funding:

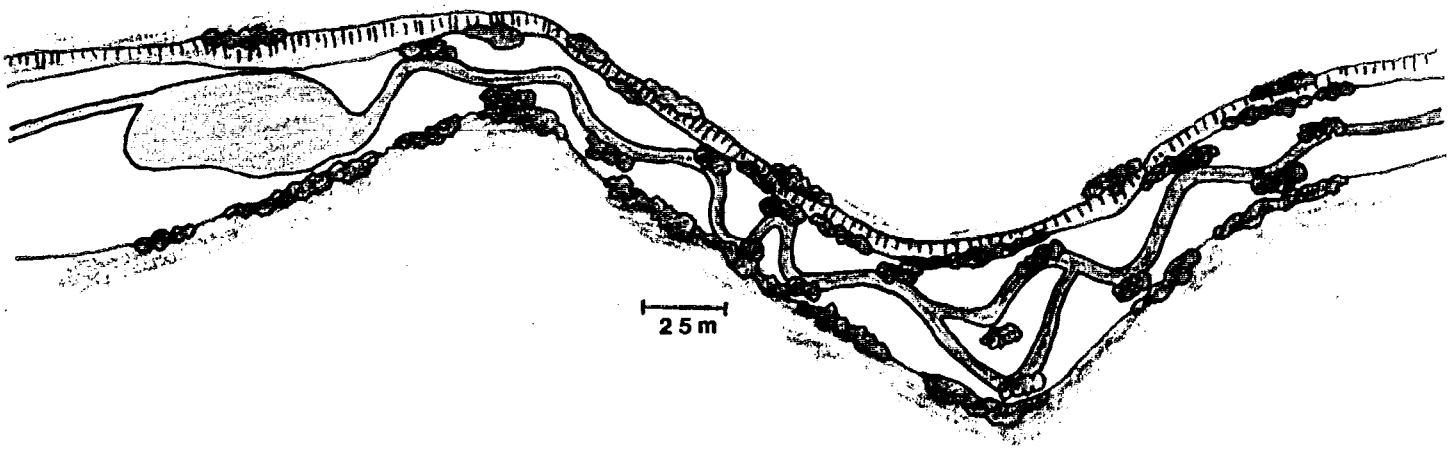
- **by the township of Buhl**

Aims:

- **to create a natural floodplain incorporating the meadows within the meanders**
- **re-divert the course around the sports field rather than entering a pipe**
- **narrow and deepen the upper reaches of the Rungsbachle**
- **remove concrete channel of Kleines Sulzbachle**
- **widen floodplain of the upper Kleine Sulzbachle to 50m**
- **change agricultural use of the area back to meadows as before**
- **re-establish hedges, ditches, and paths to lead walkers away from sensitive areas**
- **improve water quality**
- **improve fisheries**

Development and Planning:

- **the District engineers designed a scheme which was initially objected to by local citizens and conservation groups, as this was uncharacteristic of the waterway, therefore a small pilot scheme was developed to test alternatives**



Before (88)

Pre-works planning:

- **water quality and fauna assessed in several areas**
- **selection of a site with suitable soil conditions and outflow variation**

Brief description of works:

- **substrate reinstatement in two of the three areas, upper one coarse gravel (max. size 32mm), the middle one with fine gravel (6.3mm)**
- **substrate was adjusted so that it resembled the sand and gravel river bed clay/peat areas were retained for the floodplain areas**
- **some planting of endemic trees and bushes in compost on the embankment**

Costs: **excavation and stabilization £114,000** **planting £ 20,000**
property purchase £43 200
total £177,200

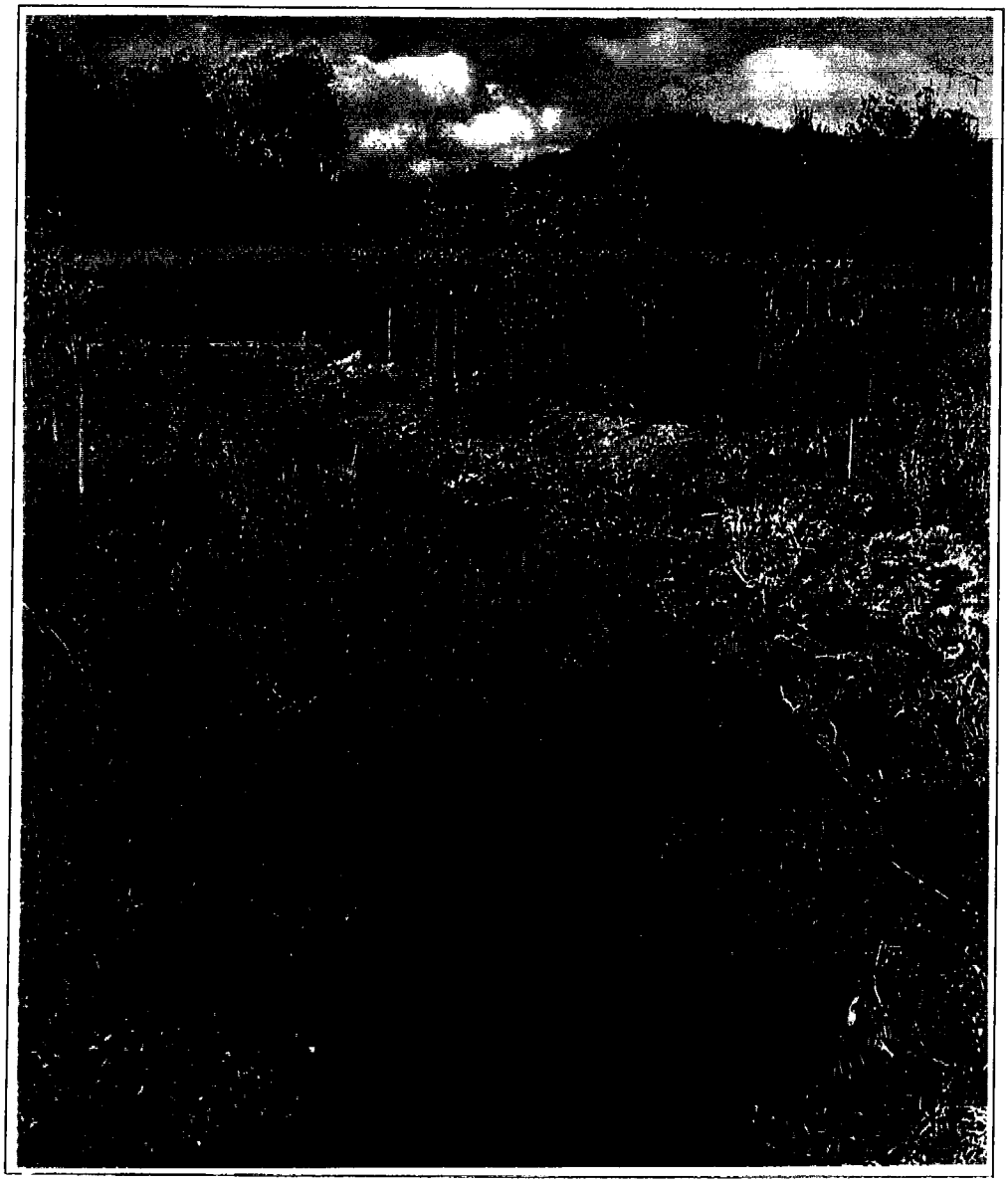
Post-project appraisal:
Monitoring:

- **additional protection structures are required in the future**
- **after two to three years of monitoring, it is expected that the scheme will be implemented on the whole river**

Contact: **Klaus Kern**

Reference: **Kern *et al.* (1992)** Photographs copied and plan redrawn

During the scheme (5/90)



After completion (9/90)

River Alb

Site: **Karlsruhe District, nr. Bierthe, Baden-Wurrtemberg SW Germany**
Date: **1988**

River type: **small lowland** Form: **slightly sinuous, slope 1.2%**
Channel: **severe trapezoidal** Substrate: **fine sand and gravel (<56 mm)**

Width: **14.5 m** Depth: **1.3m** Discharge: **2.94 m^3/sec**

Length of scheme: **500m (0.025% of catchment)**
Land use: **urban, river and valley area used as a "green place" for the town**

Planning: **Karlsruhe civil engineers, Dept. of Environment and Law, the Environmental Protection Officer, the Horticultural Dept. and the local fishing club**

Funded: **town of Karlsruhe** Maintained: **civil engineers**

Description of works:

- **concrete revetments removed**
- **widening of the stream bed, with gravel islands in the areas of low water**
- **narrowing of the middle section to create flow diversity**
- **protection and regrading of shore and banks with coarse gravel and riprap**
- **extensive planting of banks to the high water mark**
- **new islands were left to colonise naturally**

Costs: **riverbed works £92 916** **replanting £16 667**
total £109 583 **£219 per metre**

Post-project appraisal:
Visual

- **hydrologically sound after the first flood**
- **new islands were forming naturally**
- **naturally colonising trees were growing**
- **heavy use by the public in summer**

Monitoring:

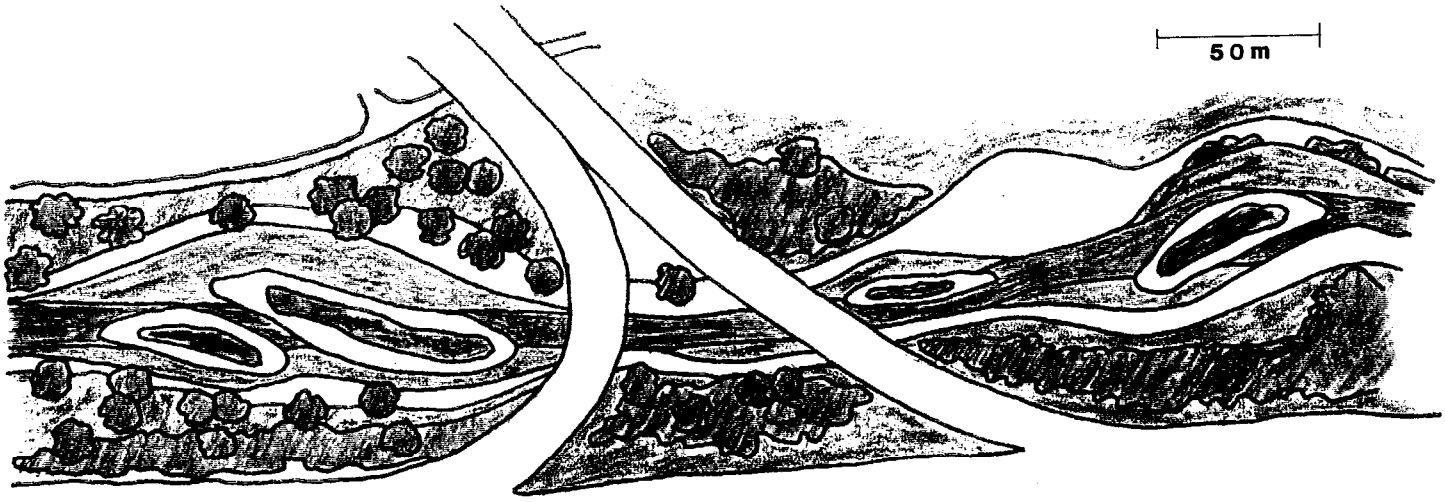
- **invertebrates show a higher species diversity in the altered areas**

Future plans:

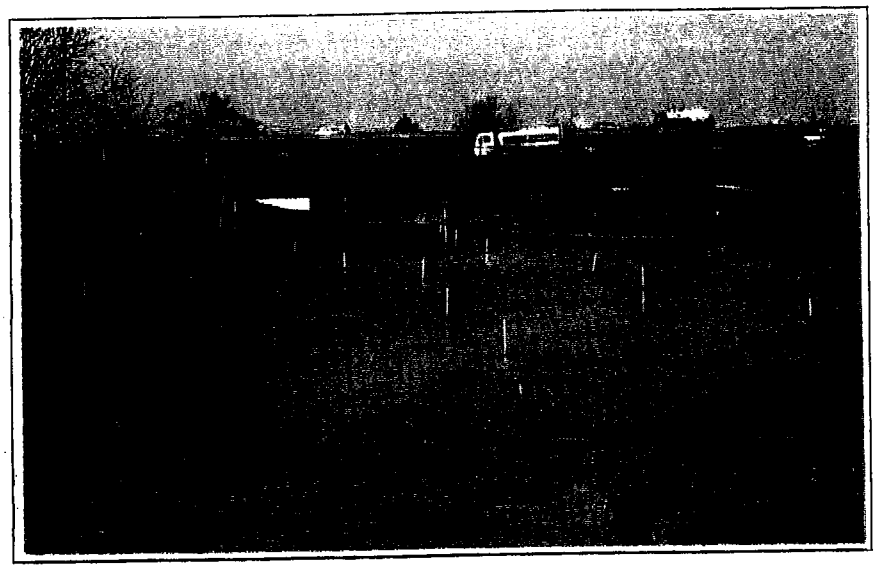
- **further improvements to the river bed**

Contact: **Klaus Kern**

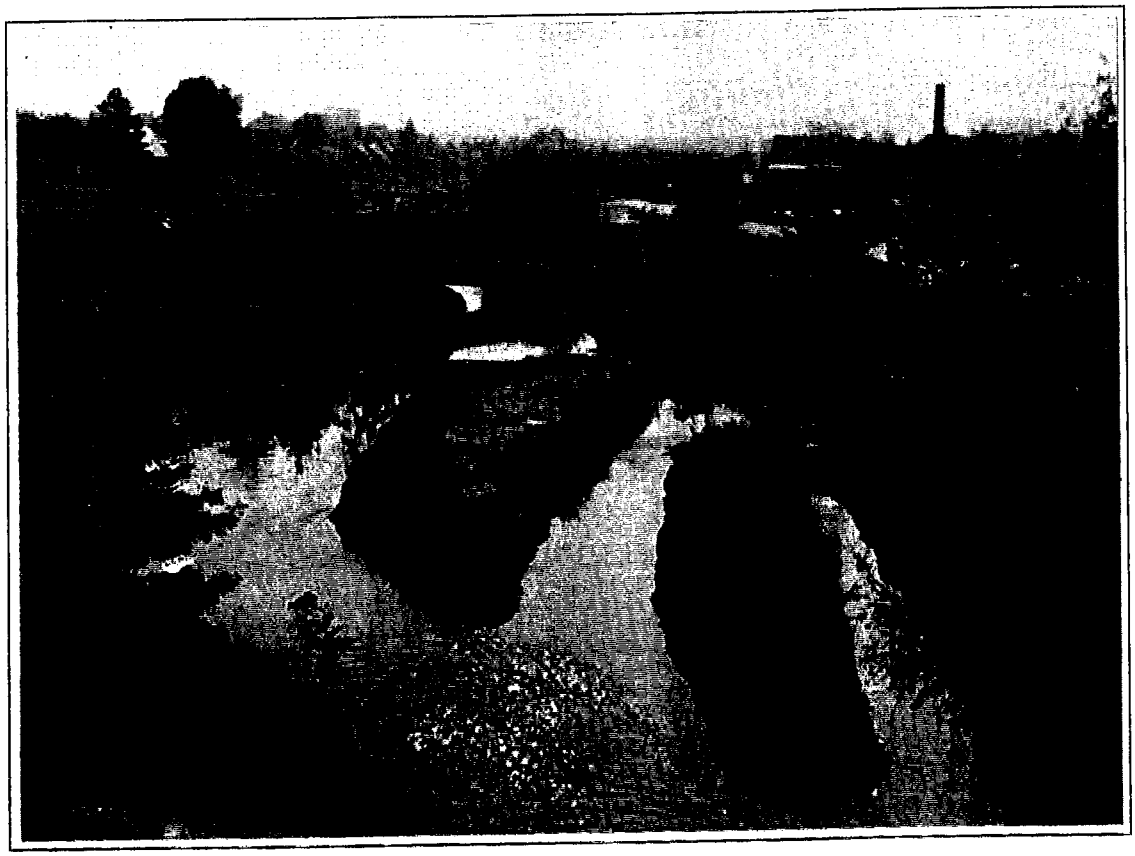
Reference: **Kern *et al.* (1992)** Photographs copied and plan redrawn



Before (10/87)



During (3/88)



After (10/89)

Name of river: **River Metter**

Site: **Bietgheim, north Baden-Wurrtemberg, S.W Germany** Date: **1988**

River type: **mountain**
Form: **straight** Channel: **rectangular, 3m high concrete walls**
Substrate: **muddy**
Width: **10m** Depth: **3m** Discharge: **0.8 m/s**

Length of scheme: **100 m**
Land use: **urban**

Reason for choice:

- **improve area for the 1989 Country Garden Festival**
- **poor water quality, slow currents, low oxygen content of water**

Planning: **designed by Bietingheim Water Office, specialist contractor employed**

Brief description of works:

- **reduction of the slope caused by two weirs**
- **1:10 ramp created with gravel (70-100mm) on flat areas, and large stones to bank up section immediately below weir to narrow the cross section.**
- **conifer branches and jute mats were used to stabilise the banks**
- **an extensive planting programme was undertaken using *Iris* and *Carex* spp., *Lythrum salicaria* and *Filipendula ulmaria*, reed beds are also planned**
- **seed rich soil was taken from the banks of the Enz**

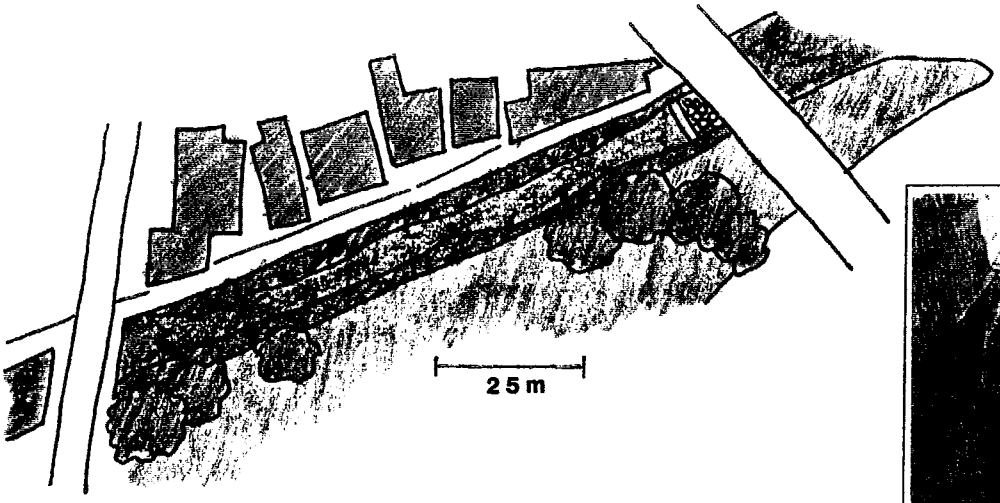
Cost: **£75 000 (the main cost being the stone material)**

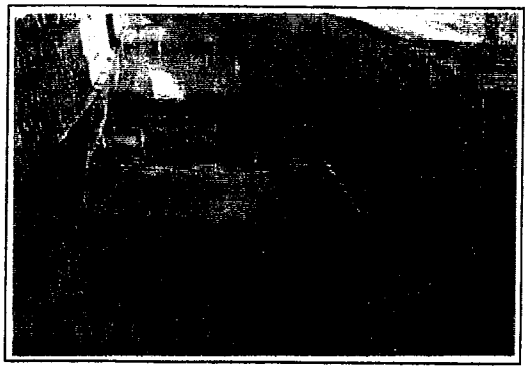
Post-project appraisal:
Visual:

- **one year after the scheme, vegetation has established over the whole area**
- **riffles, pools and slight meander formations are developing**

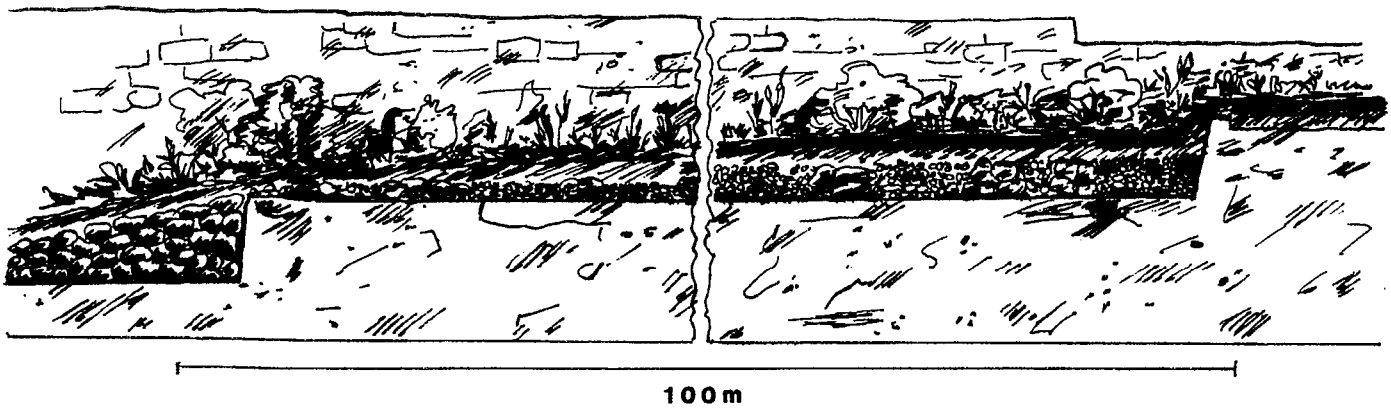
Contact: **Klaus Kern**

Reference: **Kern *et al.* (1992)** Photographs copied and plan redrawn





Before (5/88)



Decreasing the slope by substrate addition

During the scheme (11/88)

During the scheme (11/88)

After (7/89)

Name of river: **River Enz**

Site: **Pforzheim, west Baden-Wurrtemberg, SW Germany** Date: **1990**

River type: **mountain river, predominantly sandstone catchment**
Form: **straight** Channel: **trapezoidal**
Substrate: **sand and gravel with patches of stones**
Width: **90 m** Depth: **1.6m** Discharge: **16.7m^3/s**

Length of scheme: **1.5 km** Catchment: **1477km^2**
Land use: **urban, town, near factories and sewage works, river is a recreational area**

Aims:

- **to contain a 200 year flood**
- **improve areas appearance before the country garden festival (1992).**

Criteria to be satisfied:

- **levee to remain**
- **water pipes, gas pipes and electricity cables on river bed to remain untouched**
- **maintain a reliable source of cooling water for industry**

Brief description of works:

- **scale replica built to predict effects of scheme on flow and flooding regime**
- **more natural channel shape created by manipulation of channel substrate**
- **flow diversity increased by addition of 3 islands plus bays**
- **banks protected by local stone, willow piling, reed cylinders and turf**

Order of works:

- **reprofiling**
- **altered bed**
- **enforce erosion measures**
- **planting**

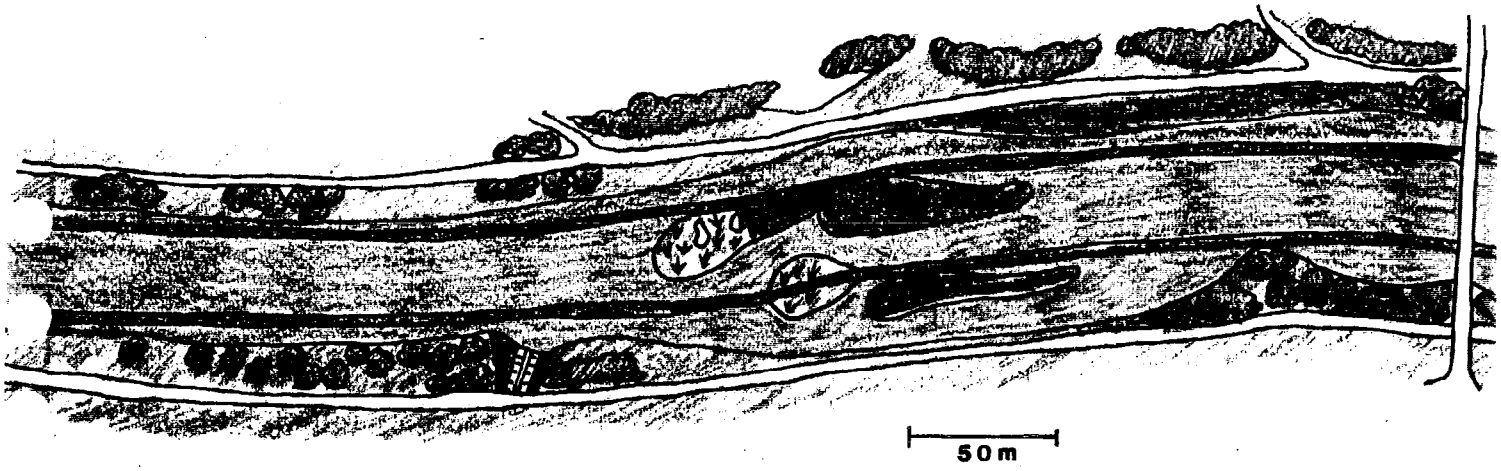
Cost: **£1 542,000** **£1,041 per metre**

Post-project appraisal:
Visual:

- **flood damaged some areas**
- **some ecological benefit**

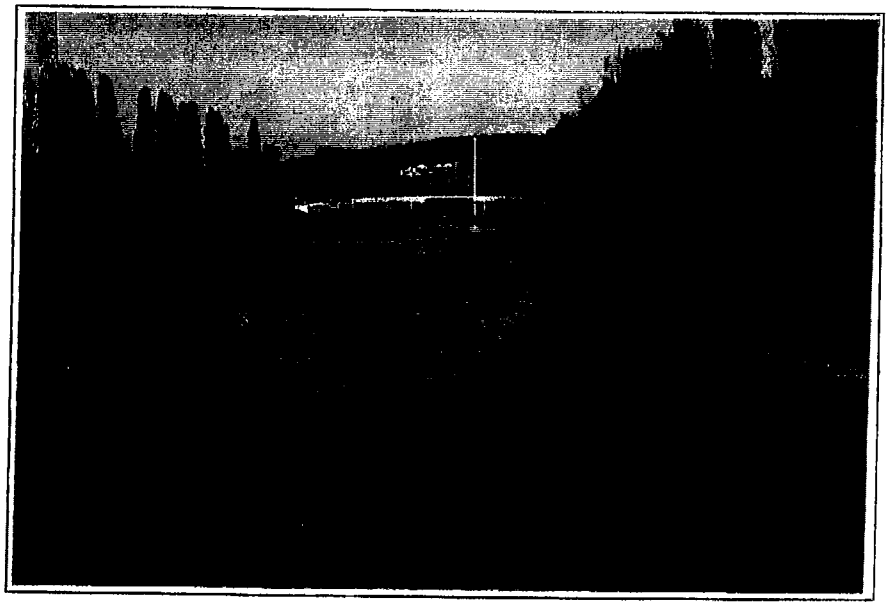
Contact: **Dr Herbert Loffler**

References: **Landestalt fur Umweltschutz Baden-Wurttemberg (1991)**
Kern *et al.* (1992) Photographs copied and plan redrawn



Before (3/90)

Detailed scale model



After (10/90)

Denmark

The following examples are included:

- River Gelså
- Landeby bæk
- River Brede
- River Rodå
- River Surbæk

The Netherlands

The following example is included:

- River Ijssel Floodplain-Duurse Waarden

Name of river: **River Gelså**

Site: **nr. Bevtoft, Southern Jutland, Denmark** Date: **1989**

River type: **lowland**
Form: **straight, was meandering until 1952, slope 0.9o/oo**
Channel: **trapezoidal** Substrate: **sand and gravel**
Width: **6-8m** Depth: **1.5m** Discharge: **5 m^3/sec**

Length of scheme: **1340m** Catchment: **113km^2**
Land use: **agricultural-pasture**

Aims:

- **restore meanders**
- **improve bed conditions**
- **create good buffer zones**
- **create aesthetically pleasing area for local residents**

Designed, funded & undertaken: **Sønderjyllands amt**

Description of works:

- **weir removed at Bevtoft mill**
- **gravel placement to raise bed level and promote flooding every second year**
- **16 meanders reinstated**
- **pools and riffles created**
- **bank reprofiling with natural stone**
- **flow diversity enhanced by large stones**
- **sediment trap installed downstream**

Costs: **1 mill. Kr** **$220 000**

Post-project appraisal:
Visual:

- **great aesthetic improvement**

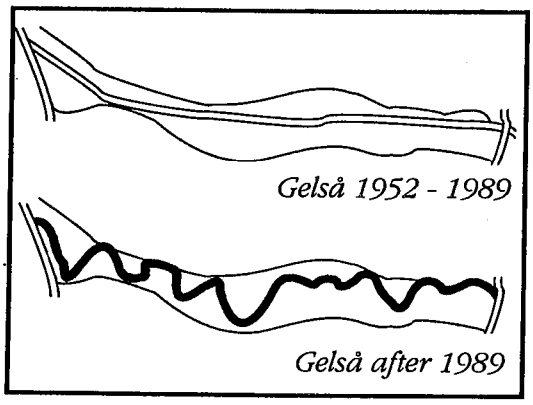
Monitoring:

- **13 new species of plant recorded**
- **75 species of macroinvertebrate (62 in a control stretch)**

Contact: **Mogens Bjorn Nielsen**

References: **Nielsen (unpubl.), Nielsen *et al.* (1990)**
Plan and top photograph copied from latter

Before



Plan

After

Name of river: **Landeby Baek**

Location: **nr. Logumkloster, southern Jutland, Denmark** Date: **1989**
River type: **lowland stream** Channel: **straight**
Width: **3-4m** Discharge: **3 m^3/s**

Land use: **agricultural, pastoral**
Length of scheme: **475m**

Brief description of works:

- **0.5 km restored to a meandering course**
- **four weirs removed**
- **two weirs evened out**
- **riffles created**
- **spawning gravel reinstated**
- **1.2 ha lake dug as amenity area**

Cost: **$ 300 000**

Name of river: **River Brede**

Location: **nr. Logumkloster, southern Jutland, Denmark** Date: **1991**
River type: **lowland** Channel: **straight**
Width: **10m** Discharge: **16m^3/s**

Land use: **agricultural, pastoral**
Length of scheme: **2.6 km.**

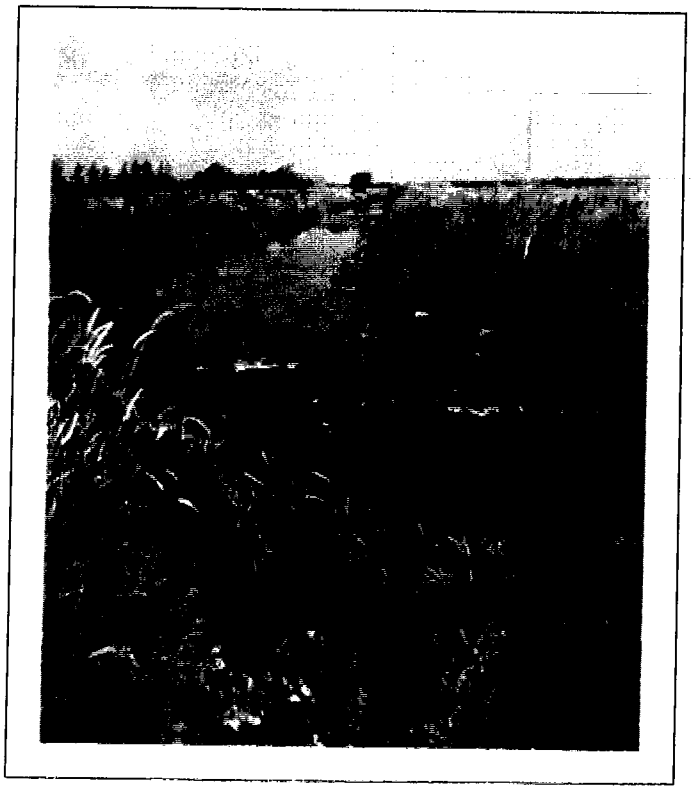
Brief description of works:

- **removal of a weir**
- **21 bends reinstated**
- **bottom elevated by 0.5m to create more river interaction with the floodplain**

Cost: **$ 250 000**
Contact: **Mogens Bjorn Nielsen, Sonderjyllands Amt**
Reference: **Nielsen (unpubl.)**

River Brede

Bank stabilisation with natural stone



Riffle creation

Landeby Baek

Before

After

Name of river: **River Rodå**

Location: **nr. Rodekro, southern Jutland, Denmark**

Length of Scheme: **5 km**

Aims:

- **to reduce iron content of stream water by flooding surrounding land (3.5ha) in winter to deposit iron on land**
- **raise summer water levels**
- **improve aesthetic value of surrounding area**

Brief description of works:

- **26 gravel riffles were positioned within reach**
- **large boulders placed within stream**
- **sluice installed to allow raising of water level to flood land**
- **channel installed to allow fish to move into flooded area when in flood**

Post-project appraisal:

- **too early to evaluate success**

Name of river: **River Surbaek**

Location: **southern Jutland, Denmark**

Brief history of the site:

- **experimental site for the testing of management regimes (1982)**
- **river left alone and subsequently developed natural flow width and depth variations**
- **plants and fish increased in number**
- **high populations of submerged plants increased summer water levels**
- **trees colonising the area provided shading which regulated the growth of aquatic plants**

Contact: **Ole Ottesen, Sønderjyllands Amt**

River Rodå

Increasing bed levels by adding gravel

River Surbæk

Recovery of a natural flow width

The land to be flooded over the winter

Name of river: **River Ijssel Floodplain**

Overview of river

Site: **nr. Zwolle, Provincie Overijssel, The Netherlands**

River type: **large lowland floodplain**

Upstream at Westervoort	Width **75m**	Velocity: **0.5-1.1m/s**
Downstream at Kampen	Width: **170m**	Velocity: **0.3-0.7m/s**

Floodplain: **around 10 000ha flooded annually, mainly in December to February**

Land use: **80% agricultural, 90% is grassland**

Reasons for choice:

- **ecological importance of river and floodplain was threatened by agricultural intensification and bank protection works with basalt stones**

Planning:

- **In 1989 provinces of Overijssel and Gelderland produced a plan of action, the Duurse Waarden project was initiated by the Ministry of Agriculture, Nature Management and Fisheries**

Aims:

- **agricultural extensification and ecological restoration of the floodplains**
- **ecological management of river dykes**
- **ecological restoration of the river banks**

Brief description of legislative change:

- **compensation scheme for extensification of agriculture on 3000ha of flood-plain or farmers can sell land to conservation organisations**
- **plan to increase amount of dykes managed ecologically from 25% to 60% by encouraging agricultural extensification in the area and river board involvement**
- **long term programme for ecological restoration of the river banks significance of 110ha northern area of the flood plain.**

Brief description of works:

- **a gap created in the dyke between river and reserve to increase amount of river water entering the reserve**
- **shallow water dredged**
- **density of grazing cattle was reduced to 0.5 animals/ha**

Post project appraisal:

Monitoring:

- **to early for there to be any significant changes but a decrease in macro-fauna, due to the increased influx of river water, has been noted**

Reference: **Gerritsen (1992)**

United States

The following examples are included:

- Upper Mississippi
- Kissimee floodplain system
- Bear Valley Creek
- River Mattole
- River Blanco
- Birch Creek
- Hackensack meadows
- Agrico swamp west

Name of river: **Upper Mississippi**

Site: **five US states** Date: **1986-1996**

Length of scheme: **throughout the 1300 mile length**
Land use : **National Fish and Wildlife Refuge, navigable area**

Planning: **input from the Upper Mississippi River Basin Commission, US Fish and Wildlife Services from all of the five states**

Problem: **prefer to select less degraded areas first (success and benefits likely to be greater), but only northern states fit this criterion, therefore sites selected over a larger geographic range**

Funded: **by the five states and federal funds, 11 member board oversees a Trust Fund for new constructions and rehabilitation within the inland navigation system.**

Maintenance: **US Army Corps of Engineers.**

Brief description of works:

Projects concentrated on habitat restoration, 6 complete by 1991, 6 underway, 41 designed/under review including:

- **sedimentation problems redressed in side channels and backwaters.**
- **enclosed levee systems with pumps for water level control.**
- **construction of island backwaters**
- **monitoring programmes established and field stations set up**
- **one to three year experimental studies to determine species population limits**

Cost: **$ 200 million, 97% for habitat restoration and long term monitoring**

Post-project appraisal:
Monitoring:

- **two to five years monitoring after completion of each section of the scheme**
- **each district has the capability of carrying out hydrographic surveys and studies of sedimentation rates**

Reference: **National Research Council (US) (1992)**

Name of river: **Kissimee Floodplain System**

Site: **Florida Everglades, USA** Date: **1976..**

Overview of system:
River Kissimee drains an upper basin containing a chain of lakes, to the Everglades (9000 square miles), with control of water levels by electric weirs
Form: **straight** Channel: **channelized in 1961**

Land use: **National park, wetlands (of considerable ecological value) and some residential and agricultural areas**
Aims:

- **recovery enhancements of natural ecological functions of the river system including the re-flooding of drained wetlands**
- **physical, biological and chemical integrity of the river to be maintained**
- **fill in drainage channels**
- **expand park area by 44600 ha**
- **proposal to restore Kissimee River to its meandering course**

Brief description of works:

- **test project initiated on 550 ha of drained wetland in river floodplain**
- **waterflow increased in remnant sections of the old river channels**
- **new flow fluctuation schedules adopted**
- **hydrologic and hydraulic modelling studies conducted**
- **monitoring carried out of impact of hydrologic changes on wetland vegetation, floodplain fish, secondary productivity, benthic invertebrates, and river channel habitat characteristics including bottom morphology, sediment characteristics, and community structure**

Cost: **$ 700 million, $422 million for the Kissimee Restoration (public funds)**

Post Project Appraisal:
Monitoring:

- **vegetation was able to recolonize reflooded areas as many seedlings had remained viable after decades**
- **riverine ecosystems responded favourably to resumption of natural flow regimes**
- **restoration of water flow to old river channels helped to re-establish natural substrate characteristics, channel morphology and benthic species diversity**
- **increased flow through remnant channels cleared organic debris**

Reference: **National Research Council (US) (1992)**

Name of river: **Bear Valley Creek**

Site: **Idaho, USA** Date: **1985/86**

Length of scheme: **3.2km**

Reason for choice: **seriously degraded by dredge mining in the1950's**

Aims:

- **reduce sediment recruitment from dredge mined areas**
- **improve water quality by minimizing turbidity**
- **stabilize channel and streambanks**
- **improve aesthetic qualities of mined area**
- **create or improve habitat for spawning and rearing of chinook salmon**

Brief description of works:

- **construction of 100m wide floodplain to allow the river the space to meander**
- **realignment of channel**
- **bank stabilization using geotextiles, erosion control blankets, vegetation and riprap**
- **willow seedlings treated with anti-transpirant to reduce evapotranspiration**

Cost: **$2.5 million**

Post-project appraisal:
Monitoring:

- **82-97% survival of willow seedlings**
- **redd counts of chinook salmon have increased (although this may be attributed to other factors)**

Reference: **Jensen & Platts (1990) in Kusler & Kentula (1990)**

Name of river: **River Mattole**

Site: **Humboldt County, North California, USA** Date: **1985...**

River type: **mountain stream, variable gradients from uplands to alluvial river valley**
Form: **variable, lower reaches meandering with bars and islands**
Channel: **variable, both natural and severely widened**
Substrate: **thick silt (produced by erosion)**
Discharge: **1340 ft^3/s**

Length: **62 miles** Watershed Area: **36 miles**
Land use: **agricultural and forestry**

Reason for choice :

- **tree-felling produced much erosion and increased the sediment loads to the river**
- **reduction in commercially important salmonids**

Aim: **to restore salmonid (predominantly king and silver salmon) habitat**

Planning: **species-centred restoration initiated by a small group of residents in the area, the Mattole Watershed Salmon Support Group**

Brief description of works:

- **local residents and geologists identified sources of erosion and measured siltation in the river channel**
- **alders and willows planted for bank stabilization and shading**
- **driftwood structures were attached to riverbanks for shade and fish shelter**
- **structures installed to scour out pools during winter flows**
- **enhancement plan for salmonids to be developed in the estuary area**

Costs: **$600 000 (raised by the Mattole Restoration Council)**

Post-project appraisal:

- **salmon populations establishing where released in new areas**
- **much public awareness and education concerning watershed processes generated**
- **regulatory agencies are now evaluating risks of extinction of species within their biological and hydrological management units**

Reference: **National Research Council (US) 1992**

Name of river: **River Blanco**

Site: **SW Colorado, USA** Date: **1987-90**

River type: **large 4th order**
Form: **braided, slope 1.5%**
Channel: **moderately entrenched**
Substrate: **heterogeneous, fine sand to very coarse cobbles**
Width: **125 m**
Depth: **1.1m**

Length of scheme: **4.3km**
Land use: **rural, agricultural**

Reason for choice: **previous channelization and levee construction methods failed and had been visually unattractive**

Aims:

- **stabilize river**
- **increase bank storage**
- **increase naturalness**

Brief description of works:

- **matched design with stable streams**
- **active channel field staked**
- **stream diverted into a bypass channel so work done dry**
- **channel narrowed to 20m, shaped with bulldozers and scrapers**
- **bank stabilization with logs, root wads and vegetation such as cottonwoods and willows**
- **vortex rocks to create current flow diversity**
- **sediment trap installed downstream**

Cost: **$400 000** **$30 per foot**

Post-project appraisal:
Visual:

- **landowner regained 170 acres of floodplain through channel narrowing**
- **high pool-riffle ratio**
- **fish abundant**

Reference: **National Research Council (US) (1992)**

Name of river: **Birch Creek**

Site: **Snake River sub-region of the Columbia River, Idaho** Date: **1987**

Length of scheme: **2km**

Aim: **to mitigate for losses of fish and riparian habitat due to stream diversion to supply a hydro-plant, taking into consideration the extremely permeable substrate**

Brief description of works:

- **new channel constructed with a sinuosity ratio of 1:25 (12 meanders in 2km)**
- **plastic liner installed and backfilled with gravel substrate to supply an artificial aquifer for the creation of riparian and instream habitats.**
- **topographic features created on riparian zones using topsoil**
- **a structure to control stream stage and a fish screen were placed at the downstream end of project area**
- **artificial bank overhangs and boulder placements used to enhance fish habitat**
- **establishment of riparian vegetation using an experimental approach, varying water levels and use of propagules or cuttings for willow and shrub species, transplanting or seeding of sedge, and broadcasting of native grass species.**
- **controlled flooding of the riparian zone used to create habitat diversity**

Cost: **$100,000**

Post-project appraisal:

Monitoring:

- **meandering pattern has developed**
- **fine sediment accumulation on convex points have formed point bars**
- **pool riffle sequence similar to natural stream**
- **fish populations 200% of target only 18 months after construction**

Problems:

- **contractor did not follow instructions given for stripping and stockpiling soil resulting in a shortage for construction of design features**
- **contractor had also failed to follow design plans of the in-stream structures**
- **unforeseen ice destroyed many young shrubs**

Reference: **Jensen & Platts (1990) in Kusler & Kentula (1990)**

Name of project: **Hackensack River Meadowlands**

Site: **New York, NE New Jersey metropolitan area**

Description: **8750 ha estuarine area of freshwater and saltwater marshes and meadows initially created by damming the Hackensack river**

Organisation:

- **Hackensack Meadowlands Development Commission (HMDC) was established in 1969 to improve management of the Meadowlands**
- **HMDC has overseen $1.5 billion worth of economic development whilst helping to bring about major environmental improvements**

Aims:

- **to mitigate the impacts of development on 53ha of brackish marsh**
- **enhance wildlife diversity and abundance on 26ha restoration site by converting the site from a reed dominated community to cordgrass and intertidal marsh**

Brief description of works:

- **site sprayed with RODEO to kill common reed**
- **marsh was sculptured into channels and open water, lower intertidal zones and berms**
- **cordgrass seed planted**

Post project appraisal:

Monitoring:

- **detailed monitoring carried out on the managed site and on 54ha control site**
- **plants on berms failed at first due to high salinity but this has now leached out**
- **80% of site inundated during part of mean tide cycle**
- **vigorous growth of cordgrass has become established on 75% of intertidal zones**
- **although early for site to have recovered from earth-moving, fish, benthic organisms and zooplankton similar to control site and birds have improved in number of species and equitability compared to control**

Reference: **National Research Council (US) (1992)**

Name of project: **Agrico Swamp West**

Site: **central Florida, US** Date: **1981**

Description: **reclamation site includes a 60 ha experimental wetland and a 87 ha of contiguous uplands in watershed**

Aim: **reclamation of high quality wetland ecosystem from phosphate mine area**

Brief description of works:

- **sand tailings pumped onto site provide backfill for planned elevations**
- **land contoured**
- **ponds and shallow depressions created to harbour fish during periods of low water**
- **revegetation, one marsh habitat created using mulch from a nearby marsh whilst the other was allowed to revegetate naturally**

Post-project appraisal:

Monitoring:

- **preferred plant species have rapidly established with the use of mulching**
- **rich benthic community has developed within site**
- **water quality excellent**
- **83 species of bird have been recorded**

Reference: **Erwin (1990) in Kusler & Kentula (1990)**

APPENDIX 2

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APPENDIX 3

LIBRARY OF INFORMATION

The references presented below forms the library of information for the RRP. Material referred to in the text is included.

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A DESCRIPTION OF THE PROJECT

1. Background to the River Restoration Project

The River Restoration Project (RRP) is a major conservation project, initiated in 1990, which aims to promote the restoration of rivers seriously damaged by intensive land-use by:

(i) Establishing a demonstration project which applies state-of-the-art restoration techniques to the re-establishment of natural ecosystems in badly damaged rivers.

(ii) Increasing understanding of the effects of restoration work on nature conservation value, water quality, visual amenity, recreation and public perception.

(iii) Dissemination of knowledge about effective river restoration methods and techniques.

A description of the organisation and objectives of the RRP are set out in the Planning Document (PD1.3) which is enclosed.

2. Summary of the Aims and Objectives of the Feasibility Study

The feasibility study forms part of Phase 1 of the River Restoration Project and is divided into three stages, its requirements are set out below.

2.1 Description and Assessment of Current River Restoration Measures

(i) A description of the broad range of restoration techniques that could be applied to British rivers

(ii) Identification of the benefits/successes and disbenefits/failures of river restoration measures in terms of ecology and conservation, water quality, channel stability, hydrology, river management, recreation and conservation and public amenity. In each case a clear distinction should be drawn between scientific evidence of success/failure and subjective impressions of success/failure obtained from the people involved.

The following subject headings are provided as a guide to the measures/techniques which could be discussed. However, they could be modified in consultation with the RRP Executive:

(a) In-channel modifications (including enhancements).

(b) Bank modifications (including enhancements).

(c) Channel re-shaping.

(d) Buffer strips.

(e) River corridor enhancement/habitat creation.

(f) Hydrological/flood water management.

(g) 'Reed-bed' and other biological methods of pollution control. This section should not include descriptions of other standard water pollution control measures (e.g. traditional sewage works, solids settling tanks in industrial complexes)

(h) Catchment planning/control (including agricultural land-use legislation). The report should include information about techniques applicable to both urban and rural rivers and main and non-main rivers.

(iii) Brief descriptions of current research and practical projects relevant to river restoration. This section will focus on projects undertaken in the UK which break new ground, have original ideas or are of large scope.\Major projects in Europe and the USA should also be included.

2.2 Application of River Restoration Techniques

Brief summaries of:

(i) Restoration techniques which are, and which are not, being applied in Britain (and elsewhere)

(ii) Techniques which seem to be the most fruitful or valuable for:

(a) immediate implementation in practical restoration work.

(b) monitoring or experimental work to assess their effectiveness.

(iii) The way forward for the RRP. The consultant is asked to assist in the process of investigation for Phase 2 of the RRP by describing any potential sites suitable for Phase 2 identified in the course of the Feasibility Study and indicating the nature and extent of the restoration works which could be undertaken at those sites.

2.3 Other Information

(i) A list of names and addresses of relevant contacts made during the Feasibility Study (cross-referenced to projects described in Section 2.1).

(ii) A library containing the papers and reports reviewed during the Study (this will provide source material for undertaking the detailed planning stages of Phase 2 of the RRP). Reports, papers and books for which copies are not obtained should be listed with an abstract (photocopies acceptable) or short summary of relevant contents.

3. **Recommended Primary Information Sources**

Information for the Feasibility Study should come from three main sources: (i)thorough literature reviews; (ii) discussion with practitioners; (iii) site visits. The consultant should note that work of members of the RRP Executive will provide a starting point for some of this work.

4. **Outcomes of the Feasibility Study**

The results of the Feasibility Study should be reported using the following format:

(i) A report on the assessment of river restoration measures (described in 2.1 and 2.2 above). Four hard copies of the final report should be provided and two copies on floppy disc, compatible with Apple Macintosh or IBM computers.

(ii) A list of contacts and library of documents (described in 2.3 above).

(iii) A non-technical summary (produced in the form of a non-glossy black and white A5 or A4 leaflet, illustrated as necessary) describing successful river restoration techniques and new ideas. This will be used to provide non-technical information about the project for BCO staff and by the RRP Executive to give preliminary information about Phase 2 of the River Restoration Project. The contractor should submit an initial draft report (two copies) for comments by the RRP Executive prior to the final report.

5. **Supervision of Feasibility Study**

The feasibility study will be undertaken by consultants appointed and supervised by the RRP Executive.