River Restoration '96
– Session Lectures Proceedings

International Conference arranged by the European Centre for River Restoration

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Foreword

The international conference River Restoration '96, joined by 124 participants from all over the world, was held in Silkeborg, Denmark September 9-13, 1996. The conference was organized by the European Centre for River Restoration at the National Environmental Research Institute, Department of Streams and Riparian areas, Danish Ministry of Environment and Energy.

The main theme of the conference was the physical aspects of restoration of rivers and their riparian zones, reflecting the increasing attention currently being focused on this dimension of river quality in many parts of the world.

The four-day scientific programme comprised a series of plenary sessions together with 9 sessions of oral papers, posters and a full day excursion to selected Danish stream restoration sites covering many aspects of restoration and management of lowland river and catchment ecosystems.

This publication contains the proceedings from the 9 sessions as well as from the poster presentations.

The papers in these proceedings have been printed as received from the authors with only slight unifying adjustments made by the editors.

References to other works in the papers have been made using numerals in brackets, e.g.: (1). Each number represents a single reference in the order in which they appear in the text. The references are gathered in numerical order at the end of each paper.

The manuscripts of the plenary sessions have previously been published in an earlier proceedings (1). The plenary speakers included Professor Brian Moss, Dr. Nigel Holmes and Dr. Philip Boon (UK), Dr. Robert Newbury (Canada), Torben Moth Iversen, Mogens Bjørn Nielsen and Bent Lauge Madsen (Denmark).

In addition a number of papers from the oral presentations have been reviewed by two referees. Accepted papers have subsequently been published in a special River Restoration '96 conference issue of the scientific journal *Aquatic Conservation: Marine and Freshwater Ecosystems* (2). In agreement with the journal a number of the these papers are also to be found in these proceedings in a shortened version.

The organizers gratefully acknowledge the support they have received in arranging and running the conference, including the financial support from the Danish Environmental Protection Agency, Ministry of Environment and Energy and from Sønderjylland County, and for practical assistance from the technical staff at the National Environmental Research Institute and the Freshwater Centre before, during and after the conference. Furthermore, we thank the environmental officers of the Jutlandish Counties for the excellent planning and guiding of the excursions. Finally, a special thanks to all participants, whose enthusiasm ensured an exciting and warm atmosphere during all the events.

The editors.

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European Centre for River Restoration (ECRR)

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River restoration, European Centre for River Restoration, organisation.

Abstract
Restoration of rivers and their adjacent areas have been acknowledged by the EU during the last decades, and EU has already funded a number of isolated river restoration projects. To learn and act according to already gained knowledge and experience on river restoration EU has also acknowledged the need for an international organ collecting such knowledge and experience. As a consequence EU co-funded the establishment of a European Centre for River Restoration.

Background
European rivers and their riparian areas are used for many purposes and are among those habitats most severely affected by human activity. As a consequence, both the water quality and the river quality have been seriously degraded in numerous European rivers throughout this century.

For many years focus has been on degradation of water quality, but physical degradation of rivers and their riparian areas is common all over Europe. In Belgium, England, Wales and Denmark less than 20% of the rivers are still in a natural physical state. Engineering works in European rivers have significantly changed water retention capacity and flooding regimes. Similarly the natural nutrient retention capacity has been reduced resulting in increased loads of nutrients and eutrophication of downstream lakes and marine areas.

One way of improving both the physical river quality and the water quality is by an active programme of river restoration. Enabling rivers to flood their natural floodplains has a positive influence on the hydrological conditions in downstream reaches as a surplus of water can be stored on the floodplains. Thus allowing rivers to flood its immediate surroundings reduces the risk of flooding further downstream, where the consequences can be more severe.

Reinstatement of naturally functioning rivers and floodplains often obtain immediate environmental benefits. These often include: increased nutrient retention, increased floodwater storage capacity, better habitats, larger biodiversity, continuity between river reaches, a larger river area over the same direct distance, reducing river maintenance costs, provide higher aesthetic value and better amenity and recreation facilities, etc.

Restoration of rivers and adjacent riparian areas can improve water quality by reducing downstream nutrient loading of surface waters through increased removal of nitrogen in wet meadows and retention of particulate matter and associated nutrients during flooding of riparian land. This reduction makes use of the natural processes in rivers and floodplains.

The uniformity of channelized and deepened rivers provides poor conditions for aquatic life, whereas a restored watercourse provides more and better habitats for the flora and fauna. The more diverse the physical and environmental conditions are, the higher biodiversity will be found.

Biodiversity is high on the political agenda reflected in the Convention on Biological Diversity. In the EU 5th Environmental Action Programme biodiversity is also given high priority and nature restoration has been identified as one of the measures to maintain or even improve European biodiversity. This also includes restoration of rivers and their adjacent areas.

River restoration will also increase ecological quality, which is a significant goal of the proposed EU Framework Directive on Water. No doubt river restoration could be an efficient tool in future improvements of the aquatic environment and following the ideas of the proposed EU Framework Directive on Water, river restoration should become an integrated part of European water management.

The European Centre for River Restoration

During the last 10-20 years many river restoration projects have been carried out throughout Europe achieving wide environmental benefits. However, river restoration is often costly. In Europe as a whole several million ECU are spent per year on river restoration.

It is therefore of vital importance to gain knowledge and experience on the subject, and to assess whether the restoration measures do indeed result in the desired physical and ecological benefits. However, the exchange of information and experience nationally and not least internationally has so far been inadequate. At national level central points of contacts for information on national achievements, proposals and dissemination for technical information to practitioners have recently been established in a few countries (Denmark and UK), but at European level such an institution did not exist.

As a consequence the European Centre for River Restoration (ECRR) was established at the National Environmental Research Institute in Denmark in 1995 in connection with a EU Life-funded demonstration project on river restoration in Denmark and UK (described in (1)). One of the major benefits of the ECRR will be to increase cost efficiency in river restoration with clear benefits for the ecological quality. The Centre will ensure that already gained knowledge and experience, good or bad, will be available for coming projects so that project planners will be able to use practicable experience and avoid unfortunate measures . thereby insuring best value for money.

Objectives

The overall objective of the ECRR is to support the development of river restoration as an integral part of sustainable water management in as many European countries as possible.

The means to do so will be by dissemination of information (technical, environmental, cost-effectiveness) achieved through:

- newsletters;
- www (internet home page[s]);
- centres/demonstration project sites for visitors;
- workshops, meetings, conferences (planned intervals);
- advisory – putting people in contact with each other in addition to guiding them to suitable reference project sites, etc.;
- databases - of key people, institutions, specialists, project types, literature, success, failure long-term assessment of performance;
- research and monitoring – provision of reference to documents and people, but not directly undertaking either;
- education and teaching – refer enquiries to appropriate bodies, systems and people;
- provision of comparable reporting mechanisms - assist internal and external assessment of performance on meeting biodiversity objectives, production of objective state of the environment reports.

Activities of the ECRR so far

Since its establishment the Centre has so far had the following activities:

- In September 1996 the Centre organized its first international conference 'River Restoration '96' in Silkeborg, Denmark. 124 scientists from 21 countries participated in the conference. A special issue of the scientific journal Aquatic Conservation (2), two proceedings books (3)(4) and a number of papers have been published from the conference.
- The Centre has produced a technical handbook combining restoration and design techniques as well as a code of practice (5).
- A classification system and a database on river restoration projects has been developed (described in (5) and (6).
- An international network of 160 members from 34 countries has been established under the Centre. Publications and other communications from the Centre have been distributed to the members.
- The Centre has produced a demonstration video showing the main methods of river restoration work in Denmark (available in Danish, English and Italian). The English version of the video earned several international awards including the Merit Award at the International Wildlife Film Festival in Montana USA in 1997.
- Answering many enquiries from several European countries, and being visited by many scientists.
- A newsletter in English has been distributed.

Organisational structure

The aims of the ECRR will be achieved through the development of a European Network of relevant national institutions. This network is being developed at present (at the beginning of 1998) and is expected to be established and working during the summer of 1998.

It is envisaged that at least 20 European countries will have institutions or river management authorities which will wish to participate.

Ideally, an attempt will be made to appoint one institution in each country as member state representative having the superior contact to the ECRR and to the national level. However, this will not be a demand, and the member state representative will not act as a filter on the contact to and from ECRR, but will alone act in a pro-active way dealing with the more administrative parts of the Network. At all event everybody will be allowed to contact the ECRR or other participating institutions directly without going through the member state representative. There will be no limit on the number of participating institutions in the national network (Fig. 1).

A Management Board elected by the member state representatives will take care of the daily management, the ECRR structure, organise meetings and conferences, etc. Refinement and development of the organisational structure would be expected in early 1998, involving all interested-/participating countries. The Management Board should meet at least twice a year. Meetings should be held in different countries so that demonstration of national systems and restoration sites can be included where appropriate.

A secretariat elected by the management board should represent ECRR externally and function as the contact centre.

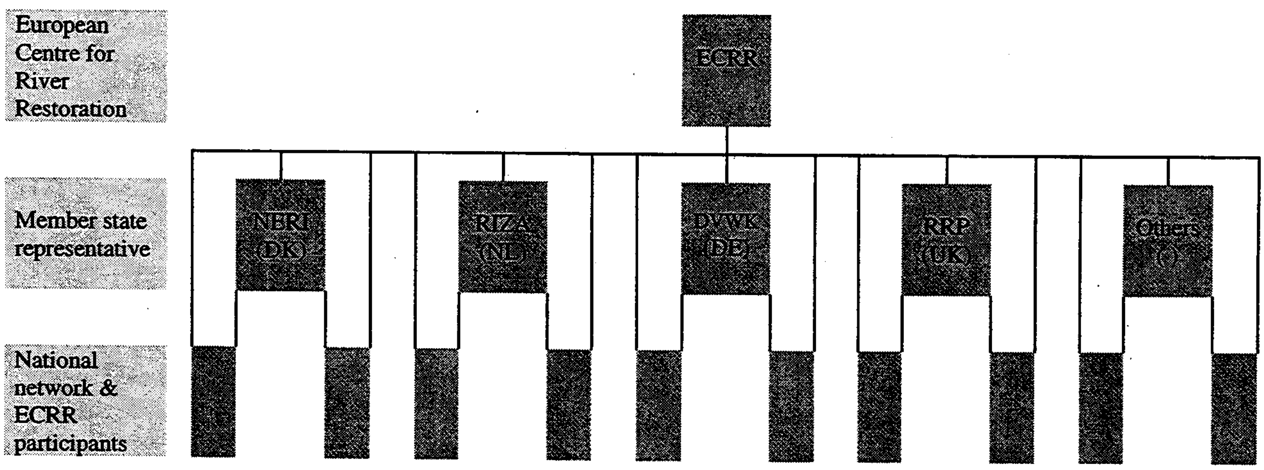

Figure 1. The European Centre for River Restoration (ECRR) and the future European River Restoration Network.

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Session proceedings

Habitat restoration along the River Rhine in the Netherlands; putting ideas into practise

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Abstract

1 Ecological rehabilitation of the River Rhine initially focused on the improvement of water quality. Protection and restoration of habitats became a target in the Rhine Action Programme in 1992.

2 In the Netherlands, Non Governmental Organisations (N.G.O.'s) made two visionary plans, "Black Stork" and "Living Rivers", which sketched a riverine landscape structured by dynamic hydrological and morphological processes. These plans have been worked out in several steps and targets for feasible nature rehabilitation have been specified. Targets will be improved by the results of the study "Rhine Econet", an instrument to evaluate ecological networks under various restoration scenarios.

3 In a densely populated country as The Netherlands every action influences other functions. Therefore, compatible combinations of measures are needed to neutralize undesirable side-effects of restoration measures.

4 Since 1989, theory has been put into practice in pilot projects for nature development. Such "learning-by-doing" projects are intended to provide insight in the physical design principles and ecological perspectives within the context of a strongly regulated river. Ecological monitoring, for which a cost-effective strategy has been developed, is used to evaluate and optimise these projects.

5 Future initiatives will be challenged to bridge the gap between restoration plans on a local level and rehabilitation strategies on a national and international scale.

Introduction

For the River Rhine, improvement of the water quality has been an issue since the early 1950's. Agreements made in the International Rhine Commission have resulted in a clear change for the better, but further effort was still needed. Only several decades later, it became clear that for further ecological improvement, restoration of habitats was required.

This paper focuses on strategies for habitat rehabilitation along the River Rhine in the Netherlands.

Characteristics of the River Rhine

The Rhine is an intensively used river for transport of water and sediment, shipping, drinking-water, agriculture, recreation and urbanisation. With more than 54 million inhabitants and about 10% of the world's chemicals industry, the Rhine catchment area is the most densely populated and industrialised river basin in Western Europe.

The Rhine has a total length of about 1320 km and drains a catchment area of about 185,000 km^2 (1) (Fig. 1). With an average discharge of 2200 $m^3 s^{-1}$ at the bifurcation of the Bovenrijn in the Netherlands, this combined glacier and rainfed river ranks high among European rivers in total discharge (2). River reaches have different hydrological characteristics. Therefor the discharge of the Rhine is less prone to fluctuations than that of other European rivers of comparable dimensions.

The history of a regulated river

As in many other streams and rivers (3)(4)(5) floodplains of the Rhine have changed drastically during past centuries. The river has changed from a meandering stream, with an extensive floodplain up to 10 km from the riverbed, into an almost completely canalised and controlled river (2)(6)(7). Dikes have constrained the river into a narrow strip of land and the regularly flooded area has been reduced to several hundred metres. Minor dikes caused stagnation of water after flooding which resulted in deposition of clayey sediments (Fig. 2). This has resulted in loss of the original variety in sediment types and relief structures in the area between the major and minor dikes (6).

The river bed has changed as well. The river bed has been deepened to improve navigability by dredging and construction of groynes. As a result, the original river bed characterised by sand and gravel banks has changed into a deep river bed with steep shore faces. In the period 1950-1970 water quality deteriorated to such an extent (8) that the River Rhine got the dubious reputation of being "the largest sewer of Europe".

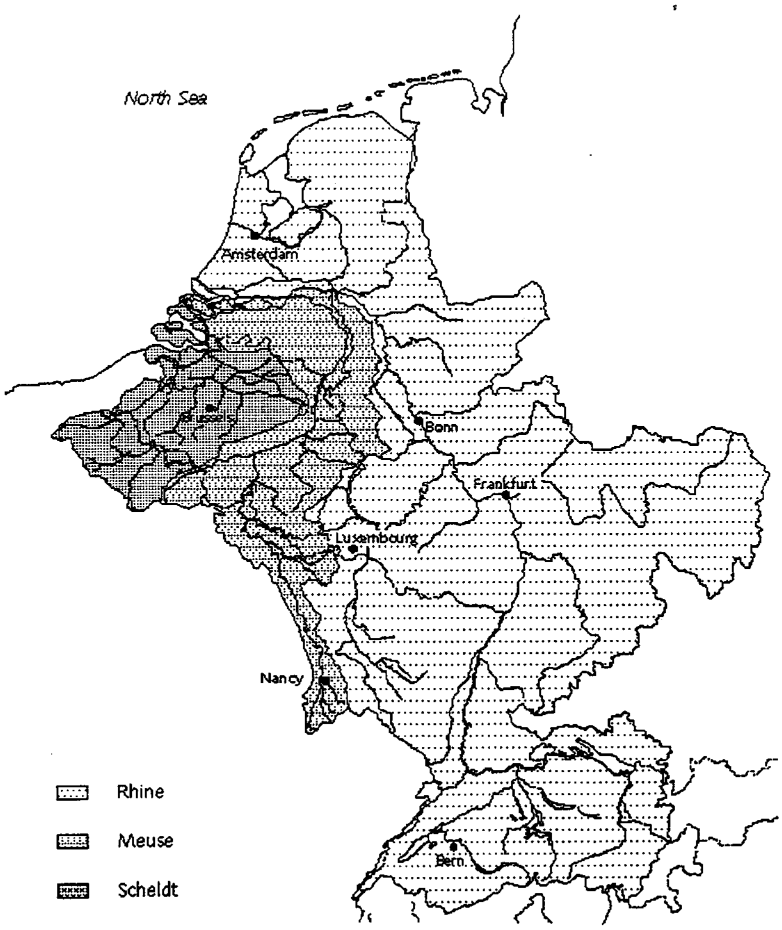

Figure 1. Map of the River Rhine basin.

Coping with pollution
Water quality declined to such an extent that the states bordering the River Rhine were committed to international cooperation, resulting in 1963 in the Convention of the International Commission for the Protection of the Rhine (ICPR). In 1987, the Rhine Action Programme (9) was established. It was the first time that a major transboundary river was considered for an action programme on international level with a specific ecological goal as the return of higher trophic level species. Each participating country in the ICPR is responsible for realisation of its own targets, applying its own national legal statutes and instruments. This procedure has been proven to be very effective. In the Netherlands targets for ecological rehabilitation of the Rhine were identified in national policy plans (10).

The Rhine Action Programme initially focused on the improvement of water quality. Although additional improvement is necessary, early signs of water quality improvements and recovery of the river's biological communities are promising (11). Currently water quality is no longer considered the limiting factor for the return of many species (12)(13)(14). Sediment quality however still creates serious problems. Since the mid 1980's it is clear that ecological rehabilitation requires not only improvement in water and sediment quality but also improvements in physical habitat conditions.

Habitat restoration: ideas, plans, policies

Salmon 2000
To facilitate an integrated ecosystem approach, the ICPR established the "Ecological Master Plan for the River Rhine" (15)(16) with the following targets:

1. Restoration of the mainstream as the backbone of the complex River Rhine ecosystem, together with its main tributaries, as habitats for migratory fish;
2. Protection, preservation and improvement of ecologically important reaches of the Rhine and the Rhine valley for a greater variety of indigenous plants and animals.

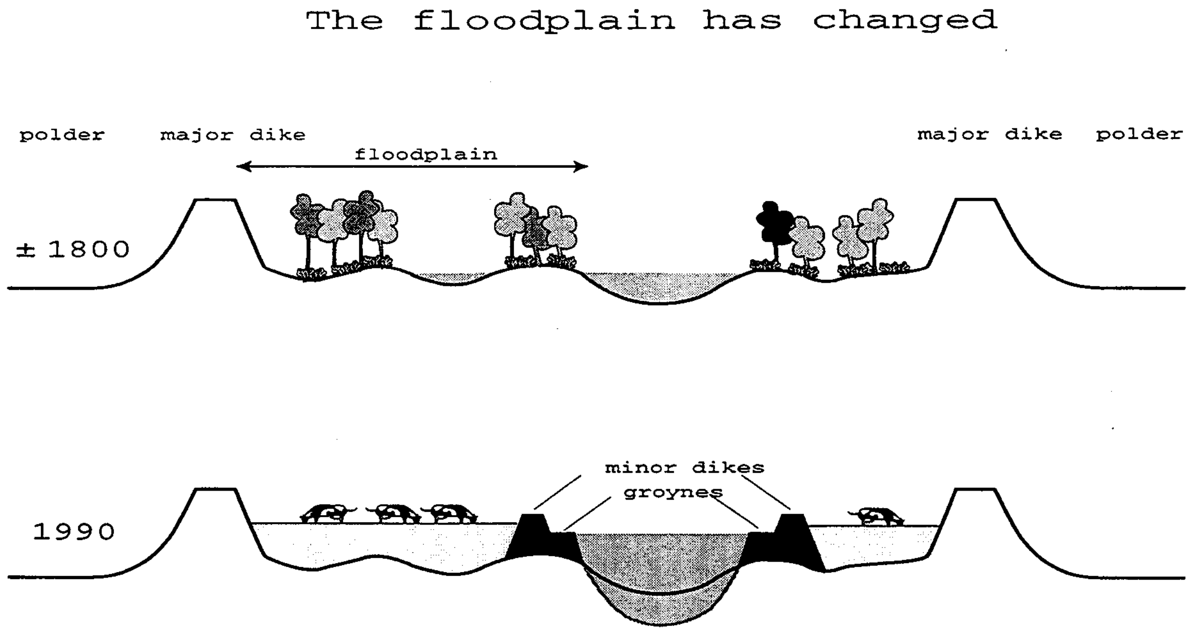

Figure 2. Changes in the river bed and floodplains.

Atlantic Salmon (*Salmo salar*), being a most highly valued species and in former times abundant in the River Rhine, became the symbol for the Ecological Master Plan that is also known as "Salmon 2000". Actions to be undertaken are:

- to make the existing barrage weirs which disrupt migration passable for migratory fish;
- to identify and restore spawning and nursery grounds and to re-stock these areas with juvenile salmon.

It was recognized in the IRC that not only the river itself, but also related areas, such as river banks and floodplains, are important for the return of indigenous riverine species. A variety of habitats is prerequisite for the development of a diverse species community. The loss of habitats along the Rhine has been significant, especially along the Upper and Lower Rhine. Protection, preservation and restoration of ecologically important reaches is necessary to regain an ecologically sound network of biotopes.

Black Stork

In the Netherlands, in 1987 a landscaping design contest was won by the report "Black Stork", made by a Non Governmental Organisation (N.G.O.) (17). It resulted in a breakthrough in the vision of the riverine landscape (6). The report launched the idea to shift agriculture activities to inland areas to provide more room for natural processes such as erosion and sedimentation in the floodplains. Isolated lakes were to be connected to the riverbed by a breach in minor dikes and floodplain forests were to play a key role in the ecosystem. It was a first and important step from nature conservation and protection towards ecological river rehabilitation. "Black Stork" remains the conceptual basis for many restoration projects along Dutch rivers.

Living rivers

In 1992, the World Wide Fund for Nature, in cooperation with several Dutch NGO's, further elaborated the principles of "Black Stork" in a report entitled "Living Rivers" (18). "Living Rivers" stressed that re-establishment of species is dependent on restoration of lost habitats such as shallow, flowing biotopes and large woody debris. These habitats were prevalent in former times when there was a close interaction between the hydrodynamics of the river and the highly productive floodplain. In natural river systems, most invertebrate biomass, the base of the foodchain, is derived from production in the floodplain (19) and on snag habitat (20). In the main channel of the Rhine, these typical riverine habitats are not compatible with functions such as navigation and transport of water and ice (6). "Living Rivers" therefore focused attention on secondary channels. These are side channels that pass through the floodplains and are linked to the main channel. They offer the opportunity to restore the interaction between the floodplain and main channel (21). For many aquatic organisms, the secondary and main channels are providing important interrelated habitats including the breeding and nursing grounds respectively.

The most inspiring aspect of "Living Rivers" was the integration of conflicting functions. Firstly, it was recognised that secondary channels could be created through clay mining. The clay extracted for secondary channels could be used for brick production and dike improvement; consequently ecological restoration could be accomplished budgetary neutral. A second advantage of this concept was that lowering of the floodplain would reduce high water levels. From this perspective, secondary channels provide both ecological and economical benefits.

Research: nuances in ideas, plans and policies

Nature targets

RIZA being responsible for the ecological functioning of the large rivers, felt the need to set targets for nature rehabilitation and monitor progress (10). Every five or ten year, targets and progress will be evaluated and described in policy documents. Therefore, the rather generally formulated visions had to be translated into quantitative targets, expressed in measurable units. The question arose where these quantitative targets could be derived from: both historical and geographical situations differ too much from any achievable situation to be a fair reference for the evaluation of nature rehabilitation measures. Therefor, a method was developed to trace feasible nature targets for large rivers (22)(23).

The target situation was defined as the ability to develop in a natural process under the hydrological and morphological conditions that are currently still feasible. The nature targets have been expressed in terms of areas of ecotopes. These are spatial ecological units with uniform morphodynamical and hydrodynamical characteristics and a certain vegetation structure as a result of landuse (e.g. grazing or mowing) or natural development (24). In a natural process, the larger part of the floodplain would be covered by floodplain forests. The presence of secondary channels in the floodplain as a compensation for natural ecotopes with running water, was emphasized once more. Based on the hydrological and morphological processes, regional differences in target ecotopes could be distinguished.

Ecological networks

The target situation, as defined above, has been described for the total area of floodplain. In reality, only part of the floodplain will be designated for nature restoration. At present, agriculture land in the floodplains only becomes available for nature restoration on a voluntary base. The spatial pattern of reaches intended for nature restoration is dependant on farmers who are willing to sell their land. Research has been conducted to determine whether there are ecological demands that should be steering the pattern of ecotopes that is desirable. In the study Rhine-Econet, a method has been developed to evaluate the habitat suitability for several species in different network configurations (25). The study focused on three habitat types: macrophyte marshes, floodplain forest and secondary channels. Nature rehabilitation plans for the River Rhine focus on these habitat types as these are very small and strongly fragmented at present.

To evaluate the network function, nine vertebrate animal species (e.g. Black Stork (*Ciconia nigra*), Barbel (*Barbus barbus*), Beaver (*Castor fiber*) and Night Heron (*Nycticorax nycticorax*)) were selected which are characteristic for one or a combination of these habitat types. Effects of three different river management scenarios, resulting in variations in planning for 10,000 ha of new nature areas, were evaluated. This quantity of habitat is consistent with the policy aims for nature rehabilitation of the River Rhine system in both Germany and The Netherlands.

Each river management scenario was evaluated by determining the effect of the spatial habitat distribution for viable populations of the selected species. Although some aspects require further elaboration, the method presented in this case-study appeared useful to compare scenarios. The preliminary results illustrated that areas linked in certain networks are ecologically more efficient. On the investigated scale, development of the new nature areas only resulted in viable network populations for species with small area demands such as Beaver, Great Reed Warbler (*Acrocephalus arundinaceus*) and Bittern (*Botaurus stellaris*). For all selected species, the amount of habitat in the surrounding area largely determined the population viability. Thus, when developing strategies for nature rehabilitation, these areas and their linkages should be taken into account. Species such as White-tailed Eagle (*Haliaeetus albicilla*), with large area demands however, only seem to persist if the amount of habitat and its distribution is part of a network on sub-European scale.

Integrated approach

In a densely populated country as The Netherlands, every activity influences other functions. For example, the construction of nature restoration projects can induce morphological and hydrological side-effects, that can be negative for safety against flooding or navigation. The Dutch Ministry of Transport, Public Works and Water management, responsible for policy and management of rivers, evaluated "Living Rivers" (26). Analyses showed that budgetary neutral development is only possible in 10%, and floodplain forest development only in 20%, of the floodplains. Possibilities for large scale development of secondary channels in the floodplains are limited because of undesired morphological side-effects. "Living Rivers" was determined to be too optimistic, however the general principle was concluded to be feasible (26).

A Decision Support System (DSS) was developed to further explore these analyses (27). The basis of the DSS consists of a Geographical Information System (GIS) in combination with a one-dimensional hydrological-morphological numerical model. Different landscape scenarios for the three Rhine branches were evaluated with respect to their consequences for a series of aspects using the DSS. Results of the DSS demonstrated that measures can have far reaching effects: i.e. nature restoration projects in one Rhine branche can influence the hydrological and morphological conditions of the other branches. Furthermore, combinations of different measures are needed to neutralize unwished side-effects of restoration measures.

Putting ideas into practise

Pilot projects

Since 1989, the general plans and ideas presented in "Black Stork", "Living Rivers" and policy documents have been put into practise in pilot projects. The first project, based on the concepts identified in "Black Stork" started in 1989. This project "Duursche Waarden" (52°22'N, 6°06'E) along the river IJssel, was located on the most northern branch of the River Rhine (28). The main objective was to improve ecological values by increasing river dynamics. Prior to the project intervention, the approximately 120 has area consisted of grasslands, an oxbow lake and some pits (Fig. 3).

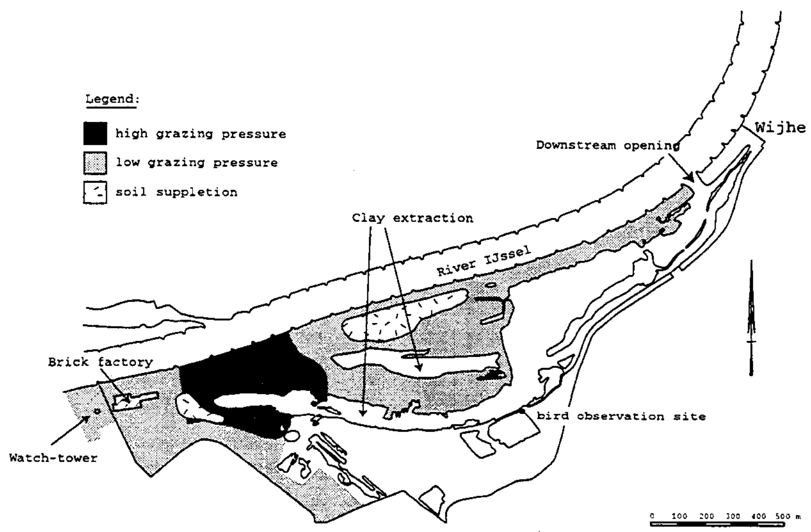

Figure 3: Map of nature restoration project "Duursche Waarden" along the River IJssel in the Netherlands.

The primary tactic for rehabilitation of aquatic habitat consisted of digging two water bodies. The first one was a small oxbow lake connected with the river at high water only. The second was a larger channel permanently connected with the IJssel downstream as a result of a breach in the minor dike. Year-round livestock grazing was also applied to generate habitat diversity and to slow down floodplain forest development. Initial monitoring results (28) demonstrated that developments in the terrestrial part were positive. Plant diversity and vegetation structure increased in the first few years. However, some of the results of the aquatic intervention were less positive. Riverine lotic biotopes did not develop. The aquatic macro-invertebrates were negatively affected by deteriorating water quality owing to increased river influence (14).

Pilot projects like "Duursche Waarden" not only are important as sources of experience but also to secure public support for nature restoration. Strong public interest was apparent as thousands of people visit these areas every year. Since 1989, additional projects of differing scales have been accomplished including rehabilitation of river banks and littoral zones, nature rehabilitation projects in floodplains similar to "Duursche Waarden" (14) and recently the first secondary channels (21).

Monitoring

In the projects undertaken, monitoring has been used to determine whether targets are achieved and to provide feedback to optimise future projects. Intensive monitoring of all projects (some hundreds within 5-10 years) is neither feasible nor desired. For this reason a strategy for monitoring of nature rehabilitation projects has been developed (29). Restoration projects are characterized as to landscape measures (design or management) for intended ecotopes, by geographical location and as to scale and year of realisation. Choices are made where, when, what and how to monitor. Monitoring includes risk assessment (safety, navigation, contamination), general ecological evaluation and in-depth ecological analysis. Through this top-down approach information exchange between projects is optimised and unnecessary duplication prevented.

Issues for the future

Over the years river restoration has shifted from a sectoral to an integral approach. Research has specified the more general plans and concepts. In pilot projects, theory and ideas have been put into practise. However, public and political support for river restoration was not only influenced by these new ideas, research and pilot projects but also by the floods that struck The Netherlands in December 1993 and January 1995.

These events emphasized that nature might be given certain priority however public safety comes first. A special emergency law was installed to accelerate dike reinforcements. A short-term beneficial consequence was that at several places, realisation of river restoration projects was accelerated significantly because excavation measures provided materials for dike reinforcements.

In the longer term, the floods stressed the need to combine actions on behalf of a variety of functions and to approach river restoration on a national or even international scale. An integrated approach combining ecological and other riverine functions therefor will have high priority. This complicates and might delay the implementation of restoration measures (11). However, effectiveness of projects may be considerably enhanced if measures not only improve the ecological state but also provide flood control during high discharges. Compatible combinations of approaches with a net neutral effect will be needed. This integrated approach to ecological restoration of large rivers in The Netherlands still is in its infancy, as it is elsewhere. To fill the gaps in knowledge, theory has to be put into practise. Monitoring and objective evaluation of projects will be absolutely necessary to assist in planning and optimization of future projects (29)(30).

Rehabilitation plans were initially implimented on a local scale. It will be a challenge for ecologists to bridge the gap between designs of local restoration projects and objectives on a national and international scale. For ecological rehabilitation, both the type of nature and function as stepping stone in ecological networks are prerequisites for successful strategies. This also strongly supports the need for large scale approaches such as river basin rehabilitation and transboundary river management.

Another point of attention for future action is the question whether or not polluted sediments pose restrictions to ecological rehabilitation (31). Present knowledge suggests that current levels of contamination in sediments have no dramatic effects on ecological rehabilitation and, in that sense, they form no restriction. Little is however known about chronic effects of accumulation or combined effects of several contaminants, so these potential concerns cannot be excluded. Further research is absolutely required to improve risk assessment on ecological impact of contaminants.

Realisation of many projects requires acquisition of land. Currently, sale or exchange of land is on a voluntary basis. Special attention to the approach of land acquisition or change of instruments, will be required to prevent a practical but serious bottleneck for many restoration projects.

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Secondary channels as a basis for the ecological rehabilitation of Dutch rivers

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Abstract

Over the centuries the ecological function of the large rivers in the Netherlands has gradually deteriorated. Although water quality is now much better than it was some years ago, more measures are needed to attain ecological restoration. One such measure is the excavation of secondary channels in the floodplain. These channels provide living conditions for organisms that are no longer present in the summer bed. Design studies, carried out in close cooperation between ecologists and engineers, show that secondary channels do not necessarily interfere with existing functions and interests. Along the Waal two pilot channels will be opened in the near future. By closely monitoring these projects the design of future channels can be improved.

Introduction

The economy of the Netherlands is greatly indebted to the rivers Rhine and Meuse. They constitute major transport arteries between the port of Rotterdam and the hinterland. The strong position of inland navigation could only be achieved thanks to large-scale river training works that have been undertaken over the past 150 years. The many parallel channels that once existed were confined to just a single one.

As early as the Middle Ages the construction of dykes was taken up, thus gradually reducing the floodplain area. The continuing deforestation of the remaining floodplain made the land suitable for agricultural use, and also facilitated the flow of water during floods.

As of the 19th century water quality deteriorated as a consequence of industrial, agricultural and household waste water disposal. All these developments have led to a widespread degradation of the Rhine and Meuse ecosystems.

The 1970s saw a turning point in the approach towards the use of rivers. Over the past two decades a gradual improvement of the quality of Rhine water has been achieved through close international co-operation. In recent years however, the understanding has gained ground that 'simply' improving the water quality is not enough to create a viable river ecosystem. Ecological rehabilitation also calls for the return of ecotopes that were prevalent in centuries past, when there was a close interaction between the hydrodynamics of the river and the highly productive floodplain. In unaltered river systems most invertebrate biomass, the base of the food chain, is derived from production in the floodplain (1) and on snag habitats (2). The main channel with its great depths and high flow velocities is not suitable for developing snag and other substrates in shallow flowing water. One possibility to create these ecotopes is the excavation of so-called secondary channels in the floodplain (3). This way the interaction between floodplain and summer bed and the variation in ecotopes that could be found along the rivers in the past, can be restored in the future. In this paper we will give a description of what secondary channels actually are, and of the state of affairs in developing secondary channels in the Netherlands.

Methods in designing secondary channels

The course of the river Meuse and the river Rhine and its branches is given in (Fig. 1). A characterization of both rivers is given in table 1. (Fig. 2) gives a typical cross section of a river in the Netherlands. A relatively deep, narrow and fast flowing summer bed is bordered on both sides by summer dykes and floodplains. Winter dykes or high grounds mark the edge of the floodplain.

Secondary channels are supposed to offer living conditions for riverine organisms, conditions that are no longer present in the summer bed of the river. Here, processes of sedimentation, erosion, growth of vegetation and forestation can take place. This will lead to the formation of specific habitats such as shallow flowing water on gravel, sand, clay and organic materials (e.g. snag). Flowing water guarantees an uninterrupted supply of oxygen, food and sediment. In this respect the ecological design criteria can be summed up as follows:

- shallow water
- permanent flow of water
- moderate flow velocities
- heterogeneity of substrate
- ecological interaction with surrounding area

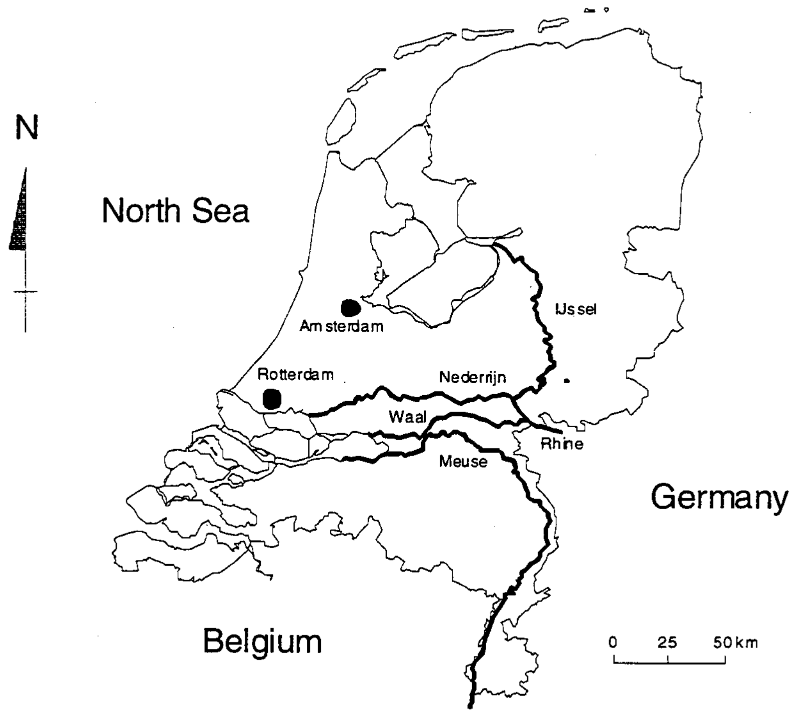

Figure 1. Large rivers in the Netherlands.

Table 1. Characteristics of Rhine and Meuse in the Netherlands.

Parameter	Rhine	Meuse	Unit
Discharge			
- average	2300	230	$m^3\ s^{-1}$
- highest	12600	3000	$m^3\ s^{-1}$
- lowest	575	0	$m^3\ s^{-1}$
Width			
- summer bed	80 - 340	100	m
- winter bed	80 - 2500	100 - 2500	m
Slope	11	15 - 30	$cm\ km^{-1}$
Suspended load	$35 \cdot 10^{-3}$	$15 \cdot 10^{-3}$	$kg\ m^{-3}$

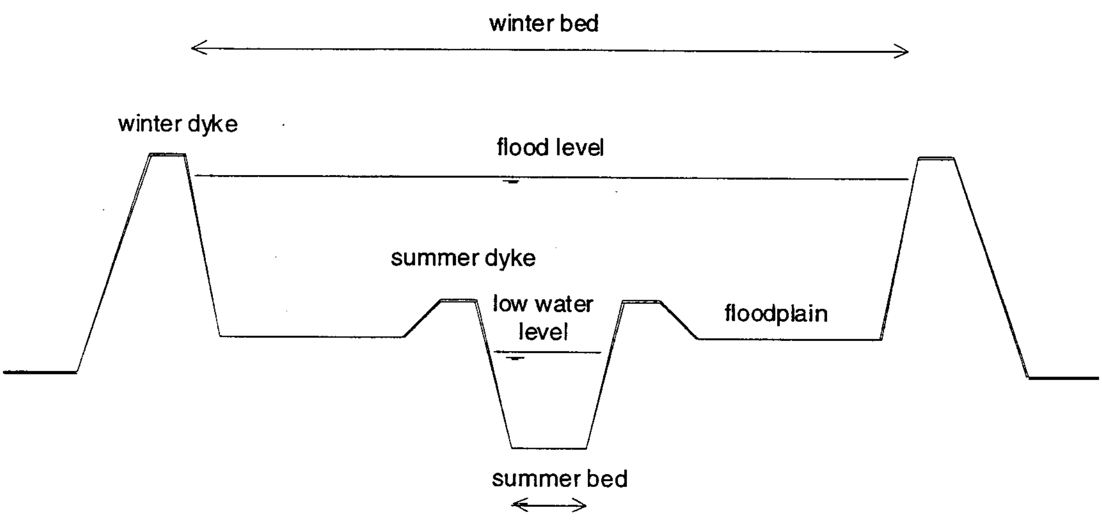

Figure 2. Cross section of a river in the Netherlands.

The secondary channel has to fit in the landscape, designed in proportion to the floodplain or river stretch where it is located. In this way it is the basis for the development of ecotopes and river processes resembling a natural river. In order to attain this ecological interaction and to realize permanent flow and gentle slopes with shallow water, the dimensions of the secondary channel have to be quite extensive. Typical sizes for the Waal are a length in the order of 2 kilometres and a width between 100 and 200 metres.

A threat to the proper working of a secondary channel is the deposition of suspended load. High flow velocities that keep the silt and fine sands in suspension in the summer bed, do not occur in a secondary channel. Although the suspended sediment concentration is not extremely high, the constant supply causes a load to the secondary channel of several tens of thousands cubic metres per year. To make maintenance easier, a sediment trap at the beginning of a secondary channel is incorporated in most designs. This does not solve the entire problem, since most of the silt will be chemically contaminated, and can only be disposed of at high costs. It is expected however, that the silt quality will improve over the coming years.

Recently the suitability of the Rhine floodplains for secondary channels has been investigated with the help of a GIS (4). The study showed that not on all locations secondary channels are feasible or even desirable. In view of the demand for permanent flow, secondary channels on impounded river stretches are less attractive, unless the channel runs around a weir. Since the Nederrijn and a large stretch of the Meuse are impounded, most attention in planning secondary channels has gone out to the Waal and the IJssel.

Secondary channels have to fit in with the existing environment. This means that vested functions and interests, such as the use of the river as a transport route for inland navigation and the protection against flooding, are not to be affected. Withdrawing water from the main channel leads to aggradation of the summer bed, which may cause draught restrictions for shipping. Therefore, the discharge available for the secondary channel is limited. The protection against flooding is at risk when nature development projects in floodplains entail the growth of extensive river forests. The hydraulic friction generated by vegetation will cause flood levels to rise. On the other hand, the increase of the cross-sectional area by the secondary channel itself reduces the flood levels. There is also the danger of secondary channels meandering freely in the floodplain. Therefore a safety margin of about 100 metres between the channel and nearby dykes has to observed.

The only exception to the rule of not interfering with existing interests, is the line of policy that has been set out in the Netherlands to take about 80 km^2 of floodplain out of agricultural use in the coming decades, in favour of nature development projects. In these projects secondary channels will play an important role.

Some functions of the river actually agree very well with the excavation of secondary channels. Rivers have always served as a source of sand, clay and gravel, and especially in the floodplains mining of these sediments has left some unattractive scars. The completion of a concession in the shape of a secondary channel can serve both an economical and an ecological purpose. In that case financing the excavation of secondary channels is no longer a problem, but maintenance, especially with regard to the deposition of suspended sediment, still will be.

Though on the basis of existing hydraulic and morphological knowledge fairly detailed designs can be made, some questions still remain. Will the deposition of silt actually occur in the quantities predicted, or will the silt be flushed out during floods? Are the measures to prevent bed load from entering the secondary channel effective? And does the aggradation of the summer bed take place on the spots the models point out to us? Also in the field of ecology there are some questions to be answered. Do target-ecotopes develop and are they accessible for riverine organisms. Are the dimensions of the new ecotopes sufficiently large for developing viable populations? How many secondary channels make a viable river ecosystem?

To deal with these uncertainties a 'no regret' policy is followed in the design and implementation of secondary channels. This means that during the whole process conservative assumptions are made as to how the system will react, and that all interventions have to be flexible and as much reversible as possible. Monitoring results of the first few projects will hopefully lead to more advanced designs. More details about how secondary channels are designed can be found in (5).

Preliminary results

In the Netherlands the concept of secondary channels occurred about ten years ago, and they feature in many restoration plans and policy documents on the subject of rivers that have been published since. Quite a few detailed designs of secondary channels have been drawn up by now, and the first ones are in the implementation phase. (Fig. 3) gives an overview of locations where secondary channels are planned or under construction. Presently, two small secondary channels are in operation along the Waal. Although the first results are promising, the scale of these projects is too small to draw final conclusions.

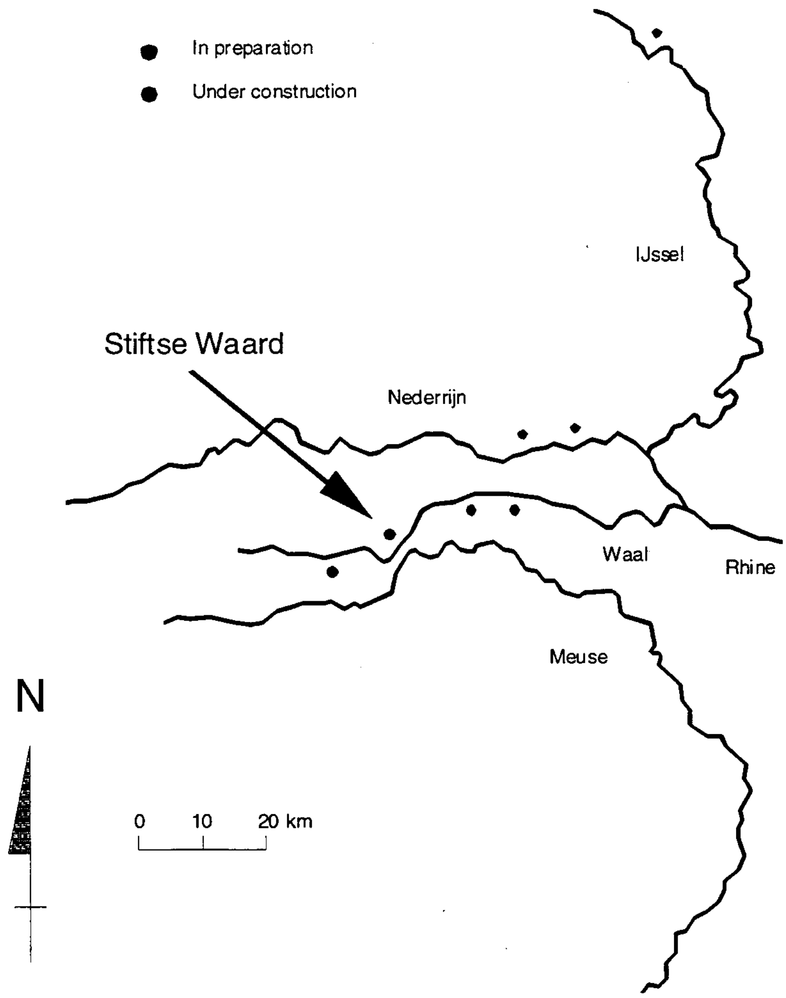

Figure 3. Locations of secondary channels.

To illustrate the development process of a secondary channel we will focus on one in particular, in the Stiftse Waard floodplain along the Waal (Fig. 3). On the basis of a landscaping plan for the whole area, in which a secondary channel was incorporated, RIZA has drawn up a basic design (6). It consisted of a channel of approximately 2900 metres long (Fig. 4), with successively an intake structure, a sediment trap, a group of islands, a discharge control structure and an outflow structure. The channel has long stretches with gently sloping banks, where riparian forest and plants can germinate. Some steep banks edge the higher natural grassland of the large central island, forming a habitat for birds like the sand martin. The group of islands provides a variety of flow velocities and water depths, where a heterogeneity of substrate will develop. The channel will carry a discharge of 30 $m^3 s^{-1}$ on average, which is about 2% of the average Waal discharge.

In consultation with all parties involved the basic design went through several adaptions. An implementation scheme was drawn up, based on two existing concessions for the mining of clay. These concessions will be completed as parts of the secondary channel instead of rectangular pits, which had been the plan up to then. The general idea is to start at the downstream end of the secondary channel and work in upstream direction. This way the relatively costly intake structure and the sediment trap would be built last, allowing extra time for optimizing the design and for the silt quality to improve. The completion of the entire channel is anticipated around the year 2005.

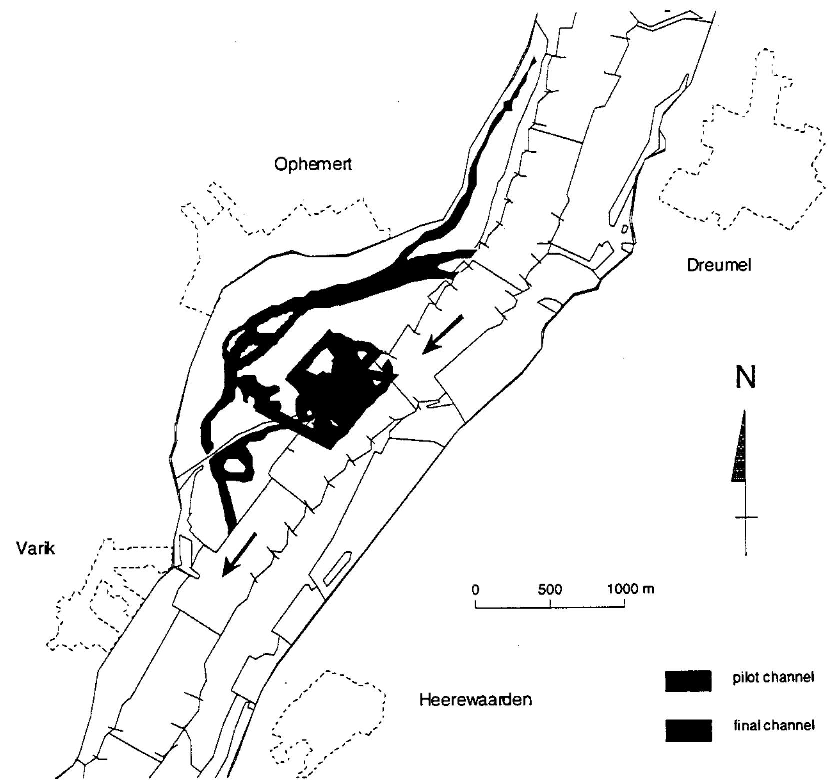

Figure 4. The stiftse waard secondary channel.

Early 1995 the Netherlands were struck by floods of Rhine and Meuse. As a result the implementation of the ongoing dyke reinforcement programme was accelerated. The need for sand and clay also proved beneficial for the progress of secondary channel projects. Several kilometres of secondary channel were excavated in meeting the demand. In the Stiftse Waard an extra clay mining concession was issued, creating the opportunity to initiate a pilot channel of about 1000 metres long. The downstream end of this channel coincides with the original plan, the upstream end is new and follows the course of an abandoned Waal channel. Most of the pilot channel has been excavated by now, and it will be opened in the course of 1997. Although shorter than the original channel, it has the same characteristics in terms of discharge withdrawal, width, depth and bank slope. Together with two other pilot projects along the Waal, it will be closely monitored and the results will be incorporated in future designs of secondary channels.

Discussion

Secondary channels can make a valuable contribution to the ecological rehabilitation of Dutch rivers. However, regarding the development in time of secondary channels some questions still remain, especially in the fields of morphology and ecology. The monitoring of pilot projects will provide the knowledge to fill these gaps. In spite of the lack of knowledge, there seems to be however no fundamental impediment to the construction of secondary channels. We therefore believe that secondary channels can also be of significance for rivers abroad that are similar to Rhine and Meuse.

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Ecological restoration in the Netherlands: a cost-effective monitoring strategy for nature rehabilitation projects.

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Abstract

The total area of large rivers including floodplains in the Netherlands encloses 683 km^2. At present, many plans are being developed for ecological restoration of which most are restricted to areas of not more than several square km's. Furthermore many organisations (GO's, NGO's and mining industries) dedicate themselves to restoration, which all together requires a current need for tuning. Uncertainty exists with regard to the ecological success or failure of restoration measures taken as well as the potential risks for safety, navigation and contamination. Monitoring therefore includes risk assessment, ecological evaluation and research and depends on the restoration measures taken. The presented monitoring strategy uses the following approach: rehabilitation projects are characterised by landscaping measures (design or management), geographical location, scale and year of realisation. Through this top-down approach information exchange between projects is optimised and unnecessary duplication is prevented. The monitoring programme helps to keep an overview over the relative small-scale rehabilitation projects along the large rivers in the Netherlands. A case study of an integrated monitoring programme for one project is described.

Restoration of large freshwater bodies

The Netherlands roughly have 3500 km^2 of freshwater bodies such as rivers, natural and man-made lakes and deltas (Fig. 1). These water bodies have suffered from poor water quality and habitat destruction during the last two centuries. Since the mid seventies water quality has improved much (e.g. (1)(2)). As a consequence it is presumed that at present the lack of habitat diversity is a main bottleneck for ecological restoration (3)(4). Ambitious visions, "Plan Ooievaar" (5) and "Living Rivers" (6), on river restoration, were launched to create "new nature". According to (6) 2000 km^2 can be realised along the River Rhine in the Netherlands before the year 2050. The Netherlands Ministry of Transport, Public Works and Water Management, responsible for policy and management of rivers, evaluated these ideas and concluded that they are feasible (7). Present policy aims at 70 km^2 in 2001 (8). "Duursche Waarden" was the first rehabilitation project in line of De Bruijn *et al.* (5) in the Netherlands. No question with regard to monitoring such an experiment intensively (Fig. 2).

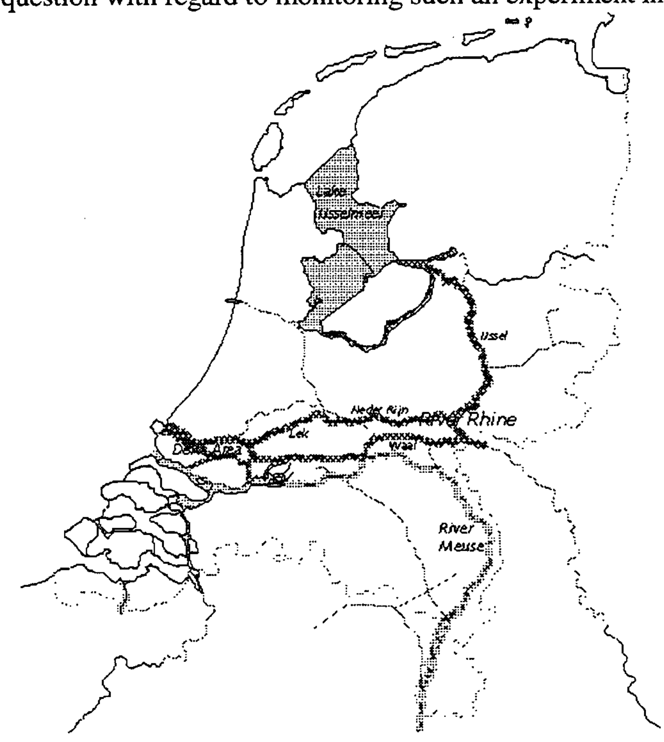

Figure 1. Large freshwater bodies in The Netherlands where many rather small-scale rehabilitation projects are foreseen and for which a monitoring strategy is desired.

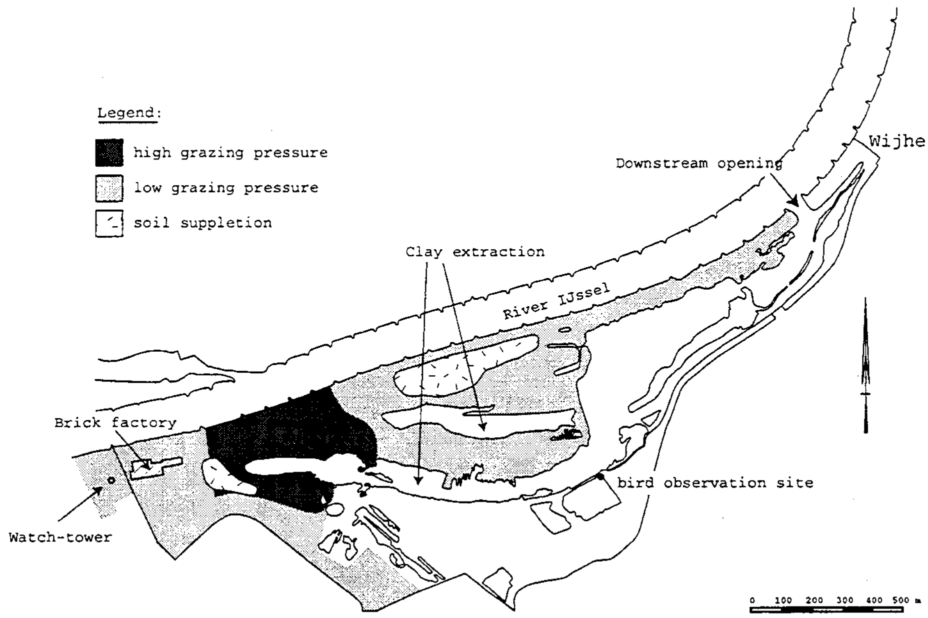

Figure 2. Design (clay extraction, soil suppletion, downstream opening) and management (grazing) measures in the restoration project 'Duursche Waarden' 52°22'N, 6°06'E (adapted after (9)), which has been accomplished in 1989. The main objective is to improve ecological values by increasing river dynamics. It covers a 120 ha floodplain area with open water, floodplain forest and herbaceous vegetation along the River IJssel, the most northern branch of the River Rhine (Fig. 1). The downstream opening results in water level fluctuations in the floodplain similar to those in the river. Furthermore cattle (Scottish Highland cattle and Icelandic horses) is used for year-round grazing to generate habitat diversity and to slow down floodplain forest development. Both the abiotic and biotic changes are monitored by an integrated programme covering water quality, morphology, vegetation, macro-invertebrates, fish, amphibians and birds as well as the recreational use and experience. The monitoring programme covers most essential aspects, but has had some teething troubles. The starting-point of the fish community and aquatic vegetation was not inventoried. Furthermore for some parameters the methodology has been adjusted over time. Since the project was the first of its kind, there was no question with regard to monitor its changes

To date many rehabilitation projects are foreseen in the floodplains of the rivers Rhine and Meuse, which have a total area of 542 km^2 (Table 1). Costs for restoration are estimated at DFL 5,000,000 per km^2, which include land acquisition, design and management measures (7). Since river restoration is still in its infancy, the success or failure of rehabilitation projects is unknown. Ideally monitoring should follow developments over a number of years or even decades requiring commitment for the long term (10). This asks for a strategy to select the most appropriate projects for monitoring. By prognosticating costs of different monitoring scenarios it is possible to make a rational choice on the basis of available funds or to indicate whether available funds are insufficient to cover all required monitoring.

Table 1. Characterisation of the branches of River Rhine and reaches of the River Meuse in the Netherlands by their length, total area, number and area of floodplains (adjusted after (11) and (12)).

	River bed		Floodplain		
River branch	Length (km)	Total area	Number	Area	% of
Bovenrijn & Waal	100	149	47	100	67
Nederrijn/Lek down to Schoonhoven	105	101	33*	75	74
IJssel	117	119	49	103	86
Rhine (total)	322	370	129	278	75
Grensmaas	49	33		27	83
Canalised Meuse	165	212		187	88
Tidal Meuse	69	67		50	74
Meuse (total)	283	313		264	85
Total (Rhine and Meuse)	605	683		542	

* number of floodplains are given for the stretch down to Hagestein only

Rehabilitation projects: benefits and risks

Each project constitutes an experiment and evaluation of project success is crucial to the advancement of ecological restoration (10). Restoring river dynamics might jeopardise safety and navigation. Monitoring is required to evaluate and learn from restoration both for ecological as well as risk assessment. Generally spoken restoration aims at spontaneous development of flora and fauna under morphological and hydrological processes that are currently feasible thereby restoring typical riverine ecotopes such as shallow river bed i.e. secondary channels, natural pastures, herbaceous floodplains and floodplain forest (4).

Normalisation of rivers of the centuries was to benefit mankind. Dykes protect the hinterland against flooding and rivers have become navigable and as such major transport routes. Ecological restoration might jeopardise safety and navigation; e.g. secondary channels could result in local sedimentation in the main channel, which requires a minimum depth for remain navigable and extensive floodplain forest development will result in a further rise of water levels during high discharge thereby jeopardising safety of people living in the hinterland (12)(13). Therefore, monitoring has to include risk assessment. Through "learning by doing" it should be evaluated whether any increase in river dynamics has undesired or even unacceptable side effects or on the contrary, more dynamics can be allowed: the first pilot rehabilitation projects meet many conditions imposed by river managers. Favourable risk assessment might extend "the scope for naturalness" for future projects.

Risk assessment also includes contamination. Floodplains along the rivers Rhine and Meuse have contaminated sediments with heavy metals and organo-chlorines. Restoration often includes large quantities of soil replacement. Present regulation allow transportation and storage of polluted sediment only under strict conditions, resulting in an enormous rise in costs for ecological restoration. On the other hand, it is unknown whether present levels of contamination hamper ecological rehabilitation.

Monitoring strategy

Before making choices for cost-effective monitoring programmes for rehabilitation projects, it is necessary to bridge the gap between high order motivation such as "increasing river dynamics in the floodplains" and identification of measurable restoration indicators. One of the first aspects is thus to define ecological restoration in measurable terms, which have a strong indicative value. For this the total area of fresh water is divided into unambiguously defined water bodies (14). For each water body a description is given of the present ecological state and the presumed pristine state or target ecological state, which is the best possible taking into account limiting conditions imposed by mainly safety and navigation (4). Differences between present state and target state are described in terms of ecotopes (Fig. 3). Ecotopes are defined as spatial ecological units which differ in morphodynamics, hydrodynamics and land use dynamics (15). For each ecotope measures to rehabilitate them are described e.g. clay or sand extraction or grazing (12).

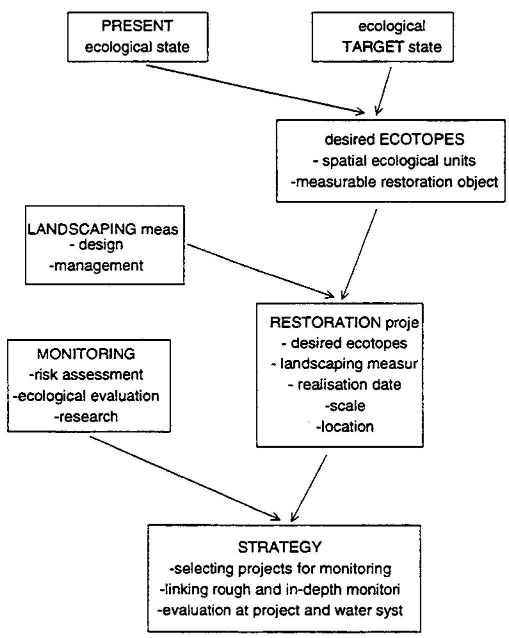

Figure 3. The step-wise strategy for selecting rehabilitation projects for monitoring.

Each rehabilitation project is described in terms of landscaping measures and desired ecotopes. Clear objectives are essential to identify potential incompatibilities among project objectives and provide a framework for design of project evaluation (10). By doing so it is possible to compare projects. For each ecotope the required monitoring is defined e.g. morphology, vegetation, invertebrates and fish.

The monitoring of various rehabilitation projects has to be complementary and redundancy avoided to be information- and cost-effective. In our opinion three scenarios could be selected:

- low-budget rough monitoring of every project;
- in-depth thorough monitoring of a few pilot study rehabilitation projects;
- a compromise between those two.

Without any in-depth analysis it was decided to choose the latter, which joins detail and overview.

The Ministry of Transport, Public Works and Water Management is responsible for the maintenance of safe navigable rivers and protection against floods. Furthermore it has a joint responsibility together with the Ministry of Agriculture, Nature Conservation and Fisheries to improve and restore aquatic ecosystems. Based on these responsibilities the following monitoring objectives of rehabilitation projects are identified: 1: risk assessment; 2: ecological evaluation; and 3: research related to those two. Risk assessment and ecological evaluation are considered to be rough monitoring, while research in this study is synonymous for in-depth monitoring. Coupling those joins detail and overview.

Table 2. The presence of ecotopes (P) and intended realisation through ecological restoration (I) for the Rivers Rhine and Meuse and their delta. Classification of ecotopes according to Rademakers and Wolfert (15).

		River Rhine		River Meuse		Delta of Rhine and Meuse	
ECOTOPE		P	I	P	I	P	I
River bed	deep	+		+	+	+	
	shallow	+	+	+	+	+	+
Bar/beach/bank		+	+	+	+	+	+
Secondary channel			+		+	+	+
Floodplain channel		+	+	+	+	+	+
Lake		+	+	+	+		
High-water free terrace	forested	+	+	+	+	+	
	herbaceous	+	+	+	+	+	
	grassed	+	+	+	+	+	+
Natural levee	forested	+	+	+	+	+	+
	herbaceous	+	+	+	+	+	+
	grassed	+	+	+	+	+	+
Floodplain	forested	+	+	+	+	+	+
	herbaceous	+	+	+	+	+	+
	grassed	+	+	+	+	+	+
Marshy floodplain	forested	+	+	+	+	+	+
	herbaceous	+	+		+	+	+
	grassed	+	+	+	+	+	+

Ecotopes and rehabilitation measures

As spatial ecological units ecotopes are relatively easy to map through aerial surveys. Furthermore they integrate abiotic and floristic characteristics. Mapping ecotopes is considered an efficient way of characterising restoration. Eighteen ecotopes have been defined to characterise the large rivers Rhine and Meuse and their floodplains (Table 2). Nature restoration aims at increasing areas of those ecotopes which contribute to achieving the target state of the river ecosystem and which are nowadays very small or fragmented (Table 3). As a consequence the total area of industrial, urban and agricultural ecotopes is expected to decline over time.

These ecotopes can be realised through either design or management measures. Design measures concentrate on reestablishing the original relief in the floodplain through clay extraction or shallow mining pits; the more important are desbribed in Table 3. Management measures include e.g. sluice management allowing tidal influence and brackish water into the delta area, utilisation by large grazers or through mowing of terrestrial floodplains and last but not least natural succession ("do nothing").

Table 3. Major aims of and design measures to achieve river restoration (in arbitrary order).

Aims
1 Establishing aquatic vegetation in the river bed;
2 Increasing the aquatic terrestrial transition zone resulting in secondary channels and floodplain channels;
3 Softwood and hardwood floodplain forest on highwater free terraces, natural levees and floodplains;
4 River dune formation and pastures on natural levees;
5 Reducing human use (agriculture, industry, urbanisation) of floodplains except for ecotourism.

Measures
1 Selective extraction of clay from the floodplains, thereby restoring the original relief;
2 Creation of secondary channels and floodplain channels through openings in summer dykes, which are situated between main stream and floodplain or riverbed widening;
3 Shallowing unnatural deep sand and gravel pits either through natural sedimentation or artificial suppletion;
4 Stimulation of river dune development;
5 Fish passages preferably in combination with secondary channels;
6 Marsh development through shallowing of deep pits or clay extraction of presently for the greater part of the terrestrial floodplains.

Criteria for selecting projects for monitoring

The required number of projects, where the various types of monitoring (risk assessment, ecological evaluation and research) should be conducted, differ: risk assessment is required at every site which could jeopardise safety and navigation, because direct intervention should be possible in case of risks. Research and evaluation is restricted to a few pilot projects. Selecting projects for monitoring thus mirrors the required number of sites (depending on the monitoring objective and associated undertainties) with the realised number. More projects does not imply more monitoring except for obligatory risk assessment. The pilot projects are selected by their

- year of realisation;
- scale ("representative");
- efficiency ("number of measures");
- spatial distribution.

The measures are described in terms of the per cent of the area of the project. Landscaping measures should result in desired ecotopes (Fig. 4). Monitoring should show the change in ecological character as result of measures taken. For monitoring, it is most effective to select projects where a large number of measures is taken. Spatial distribution is also taking into account, since measures could differ in their outcome along the various river reaches.

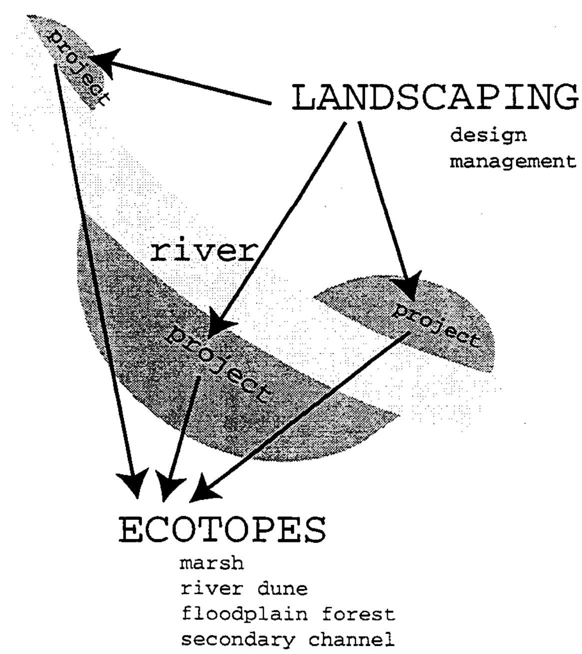

Figure 4. Rehabilitation projects along the large rivers are characterised by the geographical location, scale, landscaping measures, desired ecotopes and year of realisation.

Monitoring scenarios for the Rhine branches

The monitoring strategy for rehabilitation projects along the large water bodies in the Netherlands has been worked out for the River Rhine. For this river, risk assessment involves morphodynamics of secondary channels and floodplain forest development. Ecological evaluation includes aerial mapping of ecotopes and low-budget monitoring of flora and fauna. Research concentrates on important themes for restoration and for which little is known:

1: sediment transport in secondary channels;
2: rheophilic fishes and macroinvertebrates in secondary channels;
3: hydrodynamics and marsh vegetation development;
4: grazing pressure and floodplain forest development;
5: effects of contamination for ecological restoration;
6: rehabilitation projects as stepping stones.

Per measure the required number of sites for evaluation is determined. This is - at this stage - a best guess: measures which have a more uncertain outcome require more sites to be monitored. Also the number of sites differs based on the objective (risk assessment, ecological evaluation and research) for monitoring: most projects include risk assessment and aerial mapping of ecotopes, several projects rough monitoring of flora and fauna and only one or a few research. The latter are regarded as pilot 'learning-by-doing' projects.

All the projects which are foreseen until 2050 are characterised by their expected year of realisation, number of landscaping measures, scale and spatial distribution at the level of a river branch (IJssel, Nederrijn/Lek and Waal). Projects which are already realised or expected to be in the next five years are considered in the selection procedure, while other projects queue. The latter will be considered later, since the monitoring programme will be adapted every five years. The motivation for using a time horizon is the result of having to choose between a small insignificant project which has been realised knowing larger and more significant projects will be ready soon. Monitoring programmes are designed to follow developments over a number of years or even decades. Selecting small projects now will evidently lead to a discussion of

- interrupting the short time-series thereby making it rather useless later on;
- not monitoring the large and significant project, thereby missing the point;
- expanding the monitoring programme, which it regarded as unnecessary duplication and too costly.

As a result an overview is created of all projects with all required monitoring activities.

In total 45 projects, covering a total area of roughly 66 km^2, have been identified to be realised within the next five years distributed equally along the three river branches. Of those 45, 14 are classified as so-called 'A' projects: larger than 0.5 km^2 and more than 5 landscaping measures (Fig. 5). Based on the strategy for a cost-effective monitoring programme, it is most efficient that some of these become pilot projects, where research is concentrated both for risk assessment and ecology. Large scale projects with many measures, which are realised before long are the best sites for monitoring, while small scale projects with only one or few measures may be develop without much attention.

Three scenarios, which vary in total costs, have been compiled, and the expected benefits and a preliminary estimate for the yearly costs for each scenario is given (Table 4). The primary task of the Ministry of Transport, Public Works and Water Management is to safeguard navigation and protection against flooding. Nature development, especially the creation of secondary channels and the development of floodplain forest could jeopardise navigation and safety. So every scenario includes risk assessment. Scenario 1 monitors the consequences for safety, navigation and contamination in every project where appropriate. Ecological evaluation include solely an integral mapping of ecotopes; research concentrates on river management, navigation and contamination. It is the cheapest scenario with the shortcoming that it does not supply any information of the quality of ecotopes. It allows adjustment for risky developments and yields the effect of restoration incompletely: development of ecotopes, thereby characterising the potential for species, but not their actual presence.

Since restoration is still in its infancy, in-depth research at selected sites is at present more required than overall rough monitoring. Scenario 2 expands by monitoring flora and fauna in several projects per river branch and measures taken. Additional research concentrates on ecological themes for which little known. This scenario yields detailed information on the effect of the more important rehabilitation measures and desired ecotopes (secondary channels, floodplain forest, river dunes).

Scenario 3 expands with regard to rough monitoring of flora and fauna in every project and research on effects of every rehabilitation measure. It not only yields insight in changes, but also more knowledge on the driving processes which allows future improvement of all measures.

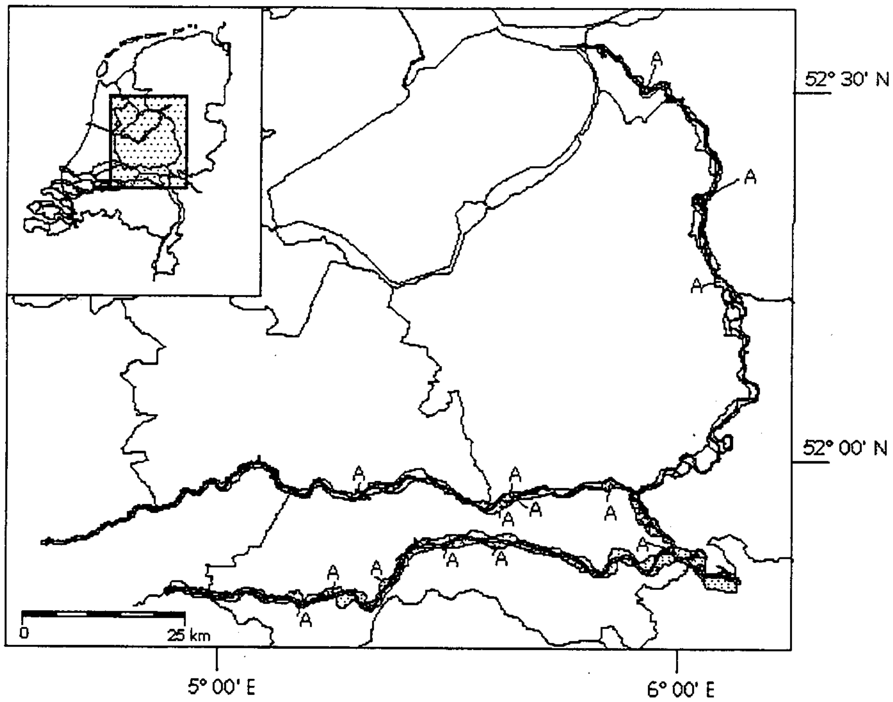

Figure 5. Restoration projects (in grey bordered by black lines) along the branches of the River Rhine which are expected to be realised before 2010 (adapted from (12)). 14 so-called 'A' projects, which are large with six or more landscaping measures and will be realised within five years, are the best sites for in-depth monitoring.

Table 4. Scenarios, benefits and yearly costs (preliminary figures between brackets) for monitoring. ++++ = high priority; +++ = medium high; ++ = medium low; + = low. Benefits for scenario II & III are described as extensions to scenario I.

Scenario	Risk assessment	Ecological evaluation	Research	Costs (x 1000 DFL.yr^{-1})
I	++++ safety, navigation and contamination in every relevant project	+ integral aerial mapping of ecotopes	+ themes: safety, navigation and contamination	low (700)
II	++++ no extension	++ monitoring flora and fauna in three projects per measure and river branch	+++ themes: uncertain ecological effects of measures	intermediate (2 000)
III	++++ no extension	++++ monitoring flora and fauna in every project	++++ all relevant ecological effects of measures	high (3 300)

Discussion

Ecological restoration of large rivers in The Netherlands is still in its infancy as it is elsewhere e.g. Kissimmee River (16)(17). "Learning by doing", "large scale experiments" and "self-design" is the strategy (18). At present each restoration project constitutes an experiment and requires an objective scientific evaluation (10). Restoration along the large rivers, which have an enormous economical function, will be a long-term process with many small-scale projects in a large area. Such projects should be evaluated at its own scale as well as on a regional, e.g. a river branch, scale in combination with national large scale monitoring programmes i.e. restoration requires a strategy for an adaptive cost-effective monitoring programme. Adaptive because new projects will be realised and insights will increase. A first and large obstacle is to translate general characterisations for ecological restoration into operational monitoring programmes. Without explicit hypotheses with regard to ecotope development, species diversity and abundance or risks, it simply is impossible to dimension a monitoring programme. Monitoring programme without explicit hypotheses are doomed to remain descriptive, while "learning by doing" requires a predictive approach.

We further noticed that in-depth evaluation, which is not a year-to-year occurring practice, is often omitted as an essential element of monitoring programme. Monitoring programmes should follow an adaptive approach and be adjusted if necessary at regular intervals e.g. every 5 or 10 years based on post-project evaluations.

For sure the presented strategy is only a first step to optimise monitoring of restoration. Although statistical techniques like random stratified sampling procedures are known to optimise data collection in a highly varied environment, at the level of selecting projects i.e. sites, we were at this stage unable to use statistics as a tool. The present strategy helps to compare projects making rational choices taking costs and benefits into account, but at some points it simply is merely a best guess.

Rehabilitation projects are characterised by the desired ecotopes, which is a rather static approach. Especially in a highly dynamic riverine setting - although much of its dynamics is lost due to normalisation - ecotopes will emerge and disappear. There will be repetitive rejuvenation as well as succession with ecotopes developing into others. Monitoring programmes have to take into account the change in character and also the time-scale at which recovery take place (18)(19). This for example requires sampling at irregular intervals (year 0, 1, 2, 5 and 10) for long term processes such as forest development or even changes in monitoring in case e.g. water bodies terrestrialise or grazers are introduced or removed.

The strategy does help to bridge the gap between general description of restoration and operational monitoring programmes. Making rather unique rehabilitation projects comparable required an intermediate level of abstraction (landscaping measures, ecotopes, planning and spatial distribution). Such abstraction often is subject for discussion itself. At last the strategy achieved in describing restoration in terms of objectives and to make choices for rehabilitation for any project.

In the future the strategy will help to standardise monitoring methodology, data storage and analysis. There will be an overview of projects and monitoring. Nowadays project monitoring is not tuned with other projects and not with regional or national monitoring programmes as described by Noordhuis *et al.* (20). The strategy into operation will generate a database and protocols for project monitoring which will allow comparison among projects and evaluation of small-scale rehabilitation projects in a larger context e.g. as an ecological network or as stepping-stones (21). Aspects which have been neglected at this stage, e.g. statistics, can then be used to further optimise monitoring.

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The 5-S-Model, an integrated approach for rehabilitation

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Abstract

1. Stream management needs tools to handle the complexity for an effective rehabilitation planning.
2. A representation of stream ecology is simplified through the 5-S-model. The 5-S-model is a simple ecological approach to describe the complex processes in stream ecosystems and their catchments.
3. Five groups of controlling and response factors are recognized in the stream ecosystem: System conditions, Stream hydrology, Structures, Substances and Species.
4. Species and their communities are the actual goal of ecological stream rehabilitation.
5. In order to make the proper choices in stream restoration, one has to understand the functioning and interactions of the controlling factors, all comprised and hierachically ordered by the 5-S-model. The major objective of the 5-S-model is to provide an easily understandable ecological tool for stream management practice.
6. The application of the 5-S-model is illustrated by means of an example. The development of a plan to protect and enhance the population of the noble crayfish (*Astacus astacus*) in The Netherlands shows the simple but effective use of the model.

Introduction

Streams are considered as arteries of catchment ecosystems. Many of the problems for stream management today relate to agricultural land use, urbanization and groundwater extraction. All these human activities increased over the last decennia. They strongly altered the quantity and quality of the water composing the stream and therefore changed the stream communities. Only recently the ecological importance of streams became apparent (1)(2)(3). Here, stream rehabilitation is one of the answers (among others (4)). In order to make the proper choices in stream rehabilitation, one has to understand the complex interactions between physical, chemical and biological components that occur in space and time in a stream. Furthermore, stream management needs tools to handle this complexity for an effective rehabilitation planning (5). Therefore, we will combine the major concepts in stream ecology in an applicable model.

Ward (6) introduced the concept of the four dimensional nature of stream ecosystems with a longitudinal, lateral, vertical and temporal component. At least for 40 years, attention was focused on the longitudinal component of a stream as a sequence of interlinked zones (7)(8)(9) or as a longitudinal continuum (10)(11)(12). Hynes (13) widened the view on the longitudinal component and included the catchment (1). More recently, the lateral component, the interaction between stream, riparian zone and floodplain, got more attention (1)(14)(15). The vertical component includes the groundwater flow and the hyporheic community (16). The temporal component includes the length of the organisms life histories as well as for example morphological changes in meander patterns over long periods of time or abrupt changes through channalization (17). All these concepts try to identify the controlling processes functioning in a stream and a catchment. Also within a stream the processes in space and time are conceptualized, such as in the patch dynamics concept (18). Frisell *et al.* (19) ordered the controlling factors from catchment to habitat in a hierarchical framework. Knowledge of the hierarchy in factors and processes acting in space and time in streams, allows us to infer the direction and magnitude of potential changes due to human activities (20). Changes which refer to disturbance as well as to restoration, and the time involved/needed (21).

All these considerations provide a conceptual basis for catchment ecology. In this article we will take catchment ecology as a starting point and use it in practical stream management. Therefore, a simple model is formulated from which guidelines are deduced to restore a stream. As an example, this model is used to improve conditions for an endangered population of *Astacus astacus* (Limm. 1758)..

The 5-S-model

In order to make the proper choices in management, one has to understand the functioning and interactions (dominance and feed back) of the controlling factors. To simplify this ecological complexity, large scale/long term and small scale/short term controlling factors and their interactions are comprised and hierarchically ordered by the *5-S-model*. The main structure of this model is shown in Fig. 1. The five main components are:

1. **System conditions** comprise the processes related to climate (temperature, rainfall), geology and geomorphology (like slope, soil composition). System conditions are composed of ultimate controlling factors and are boundary conditions for a stream. The system conditions set the possibilities and limits for stream ecosystem functioning. Ultimate controlling factors continuously interact with a stream at a high hierarchical scale level in space (the catchment), as well as in time (+/- 100 years). Generally, system conditions can not be changed by management. Human activities influence this level through, for example, atmospheric deposition and climate change. Stream rehabilitation does not focus on these factors but one has to consider the effects of these boundary conditions as well as the long term effects of change.
2. **Stream hydrology** characteristics are set by the system conditions. Stream hydrology comprises, at the scale level of catchment, the hydrological processes, like infiltration, ground water flow, seepage, run off and discharge. At the level of stream and habitat stream hydrology comprises hydraulic processes, like current velocity and turbulence. Stream hydrology refers to the water quantity parameters. The direction of the water flow strongely influences the direction of all other parameters in the system. The two main directions of flow are one running from the boundary of the catchment towards the stream (lateral) and one running from source to mouth of the stream (longitudinal).
3. **Structures** of the stream valley and the stream itself are strongely determined by the hydrological and hydraulic processes of stream hydrology. Structures imply the morphological features of the longitudinal and transversal shape of the stream bottom, banks and bed, as well as the substrate patterns within. Structures also refer to cut off meanders, terrestrialization, sand deposits and others in the stream valley. The dynamics of these structures directly relate to the dynamics in hydrology and hydraulics.
4. **Substances** comprise the dissolved components like nutrients, organic matter, oxygen, major ions and contaminants. Substances directly follow the water flow. From catchment boundary towards the stream the amount of dissolved substances increases. Also from source to mouth this increase is visible. Substances refer to the water quality parameters.
   Stream hydrology, structures and substances together compose the group of controlling factors that directly determine how the stream community functions. These controlling factors take an intermediate position in between the high scale and low scale levels, and include the latter.
5. **Species** are the response to the functioning of all above mentioned groups of controlling factors. Species and their communities are the actual goal of ecological stream management and rehabilitation.
   Controlling and response characteristics are not solely related to one of the mentioned groups of factors. There are mutual interactions. Structures, for example, can respond to the action of stream hydrology but can also reduce discharge fluctuations. Or species can be adapted to stream hydrology but, for example, trees can operate on stream hydrology and morphology. Despite a dominant hierarchical effect, a feed back is always present. Thus, factors interact on different hierarchical scale levels and with different intensity.

Example

Introduction

The noble crayfish, *Astacus astacus* is globally threatened and listed as an endangered species. This native species is severely affected by the plague fungus (*Aphanomyces astaci* Schikora), as well as by channalization, dredging and pollution (22). Only a few isolated populations remained in the Netherlands (23). The last ten years several projects have been developed to restore the decimated crayfish population. These projects were related to reduce respectively, sewer pollution, fish predation, habitat loss, eutrophication and loss of water plants, use of herbicides, and siltation. None, focused on the whole catchment and related the abiotic and biotic preferences of *A. astacus* to the abiotic and biotic characteristics of the stream ecosystem.

Study area

Two streams arise on a south-eastern slope (1.0 %) of a glacial hill-ridge at an elevation of 45 m above sea level (Rozendaalse and Beekhuizense stream). Both are spring-fed lowland streams flowing through artificial ponds. The streams are about 3-4 km long before they enter the river Rhine. The catchment (4-6 km^2) is located above an impermeable clay-layer. The groundwater above this layer feeds the streams through more concentrated (in the spring areas) and more diffuse seepage in the upper reaches and ponds. The average discharge of both streams is about 0.02 $m^3\ s^{-1}$. The bottom material consists of fluvio-glacial deposits (sand and loam). Over the last centuries, both streams were several times adapted for recreational and industrial purposes. Nowadays, the upper part of the catchment is forested (> 95 %), and the lower part is mainly urbanized or in agricultural use. Populations of *Astacus astacus* are known to occur in the Rozendaalse stream, already centuries ago. In the mid-eighties the population density show a marked decrease. The presence of the noble crayfish in the Beekhuizense stream is never reported.

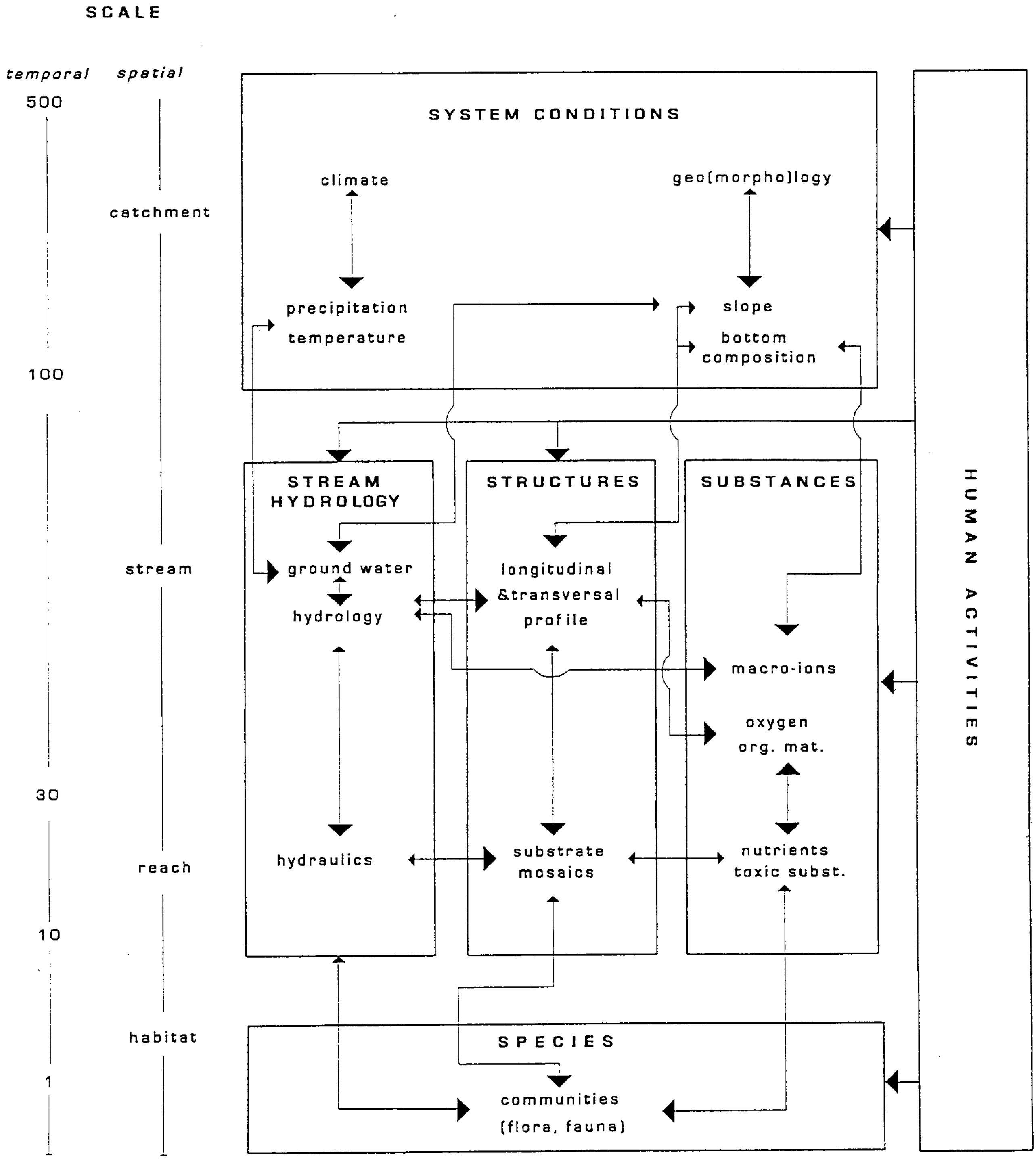

Figure 1. Interaction scheme of controlling factors and hierarchical scale levels of the 5-S-model.

Objectives

The questions from water and nature management institutions to improve the population of *A. astacus* are:

1. How can we protect and increase the *A. astacus* population in the Rozendaalse stream?
2. Are there possibilities to introduce and establish an *A. astacus* population in the Beekhuizense stream?

To answer these questions the 5-S-model is used.

Application of the 5-S-model

In order to generate the proper answers, the controlling factors and their hierarchy according to the 5-S-model, acting in both streams are weighted against the abiotic and biotic demands of *A. astacus*. To simplify this weighing process only those factors important to the crayfish are taken into account.

System conditions

All, important controlling factors with respect to *A. astacus*, at the level of system conditions are given in table 1. *A. astacus* mainly inhabits larger lowland streams and small rivers. Both streams under study are small spring-fed upper courses. Thus, both streams would be too cold in summer because of the continously in-flow of relatively cold groundwater (+/- 9-10 °C). But, both streams flow through larger ponds in which the water warms up in summer, thus meeting the demands for reproduction and growth of the crayfish. Furthermore, the continuous flow prevents these ponds to freeze in winter. Both streams are permanent and the loamy-sandy soil allows the crayfish to construct burrows.

Table 1. Suitability of the Rozendaalse and Beekhuizense stream for A. astacus with respect to system conditions.

SYSTEM CONDITIONS	Con-- trolling factors	*Parameters*	*Habitat conditions A. astacus*	*References*	*Rozendaalse stream*	*Beekhuizen-se stream*	*Suitability Rozendaalse stream*	*Suitability Beekhuizense stream*
	Cli-mate	Temperature Summer	3 months > 15 °C, max. 26 °C	24	+/- 3 months 15-18 °C	Few observations > 15°C	Suited	Insufficient information
		Winter	No complete freezing	25	No complete freezing	No complete freezing	Suited	Suited
		Precipitation		26				
		pH	6.5-9.0	27	7.0-8.8	7.1-7.9	Suited	Suited
		Drought	- - -		- -	- - -	Suited	Suited
	Geo- (mor pho-) logy	Water type Lowland streams	+++	28	+++ (upper course)	+++ (upper course)	Suited	Suited
		Ponds	++	25	+++	++	Suited	Suited
		Slope	< 4.4 %	24	1.0 %	0.8 %	Suited	Suited
		Bottom composition Loam	+++	24, 26	+++	++	Suited	Suited
		Sand	++		++	+++	Suited	Suited
		Gravel	++		+	++	Suited	Suited
		Stones	++		+	+	Suited	Suited

Legend: +++/- - - strong (positive or negative) preference, ++/- - (positive or negative) preference, + low preference with respect to A. astacus and respectivel, abundant/never present/incidental and occurring with respect to the streams.

Stream hydrology

The relation between *A. astacus* and stream hydrology is summed up in table 2. The ground water supply is large enough to overcome dry periods and to guarantee a permanent discharge throughout the year. Only, in very dry successive years the upper most part of the Rozendaalse stream dries up. The development of coniferi-ous forest in the catchment could be a cause of reduction of water supply. *A. astacus* inhabits slow flowing waters (current speed < 30 cm s^{-1}), which is related to a suitable oxygen regime. This condition is met in both streams.

Table 2. Suitability of the Rozendaalse and Beekhuizense stream for A. astacus with respect to stream hydrology.

	Controlling factors	*Parameters*	*Habitat conditions A. astacus*	*References*	*Rozendaalse stream*	*Beekhuizense stream*	*Suitability Rozendaalse stream*	*Suitability Beekhuizense stream*
STREAM HYDROLOGY	Ground water	*Supply*	Continous	24	Continuous	Continuous	Suited	Suited
	Hydrology	*Maximum depth (m)*	< 30	24	0.80	0.95	Suited	Suited
		Surface (ha)	< 50	24	ponds < 50	ponds < 50	Suited	Suited
	Hydraulics	*Current (cm/s)*	< 30	26	10-30	5-45	Suited	Suited
		Running	+++	29	+++	+++	Suited	Suited
		Stagnant	+++	29	+++	++	Suited	Suited

Legend: +++strong positive preference, ++ positive preference + low positive preference with respect to A. astacus and respectively, abundant/never, present/incidental and occurring with respect to the streams.

Structures

The presence of weirs in the streams prevent crayfish to migrate upstream, but also isolate the remaining population and prevent competitors (and the crayfish plague fungus) to move in table 3. The weirs also prevent a natural colonisation of the Beekhuizense stream, which would be possible because both streams join downstream. *A. astacus* is often found in meandering streams, with a large variation in current patterns and substrates mosaics to provide shelter and food for all life stages. A structured bank profile offers crayfish places to hide and a loamy bank is preferred to dig burrows. An undercut loamy bank with roots, branches, fallen trees and stones offers optimal habitat conditions. *A. astacus* also prefers shaded banks. Vegetation both serves as food and offers shelter, especially for young stages. Both, the Rozendaalse and Beekhuizense stream have a quite straight longitudinal profile and an often fixed, especially in the Rozendaalse stream, transversal profile. The substrate diversity is low in both streams. Also, trees lack for the larger part of the Rozendaalse stream and vegetation is scarcely developed. The Beekhuizense stream is more suited. It is more shaded and the banks offer a more diverse mosaic of structures. Still, the lack of vegetation and the sparse amount of structures in the latter stream again offer a less optimal habitat condition for the crayfish.

Substances

Both streams meet the high oxygen demand of the crayfish (Table 4). The load of organic matter, expressed in ammonium and nitrite content, will not stress the population. Silt and siltation do not hamper *A. astacus* as long as it does not reduce oxygen levels too much, nor will it prevent the crayfish to move around if the layer is not too thick. Neither should the silt be too fine to affect the crayfish gills. Only the lower reach of the Rozendaalse stream contains too much silt. Nutrient levels are less important as long as eutrophication does not affect other parameters, like excessive algae growth. Calcium is a vital substance in the exoskeleton of *A. astacus*. Both streams only just meet the minimal calcium need of the crayfish. The measured concentrations of iron and chloride are probably not hampering the animal. Knowledge on toxic substances is very limited. Especially, in the Rozendaalse stream the concentration of some toxic substances like PAC, copper, zinc, mercury and nickel are raised.

Species

A. astacus needs aquatic vegetation as food and to find shelter. Due to shading, aquatic vegetation will be scarce in the small streams (Table 5). Though vegetation could be well developed in the ponds. Yet, vegetation is scarce, probably due to a increased turbidity of the water caused by bottom dwelling fishes or by a too frequent maintenance. In both streams, the macrofauna provides enough food for the crayfish. Predation by large macroevertebrates and fish is most probably limited. The presence of *Orconectus limosus* in the Rozendaalse stream could have disastrous effects, if those individuals are contaminated with the crayfish plague fungus.

Table 3. Suitability of the Rozendaalse and Beekhuizense stream for A. astacus with respect to structures.

	Controlling factors	Parameters	Habitat conditions A. astacus	References	Rozendaalse stream	Beekhuizense stream	Suitability Rozendaalse stream	Suitability Beekhuizense stream
STRUCTURES	**Longitudinal profile**	*Meandering*	+++	24	+	+	Insufficient	Insufficient
	Transversal profile	*Bank variability*	+++	26	-	+	Very insufficient	Insufficient
		Undercut banks	+++	26	-	+/-	Very insufficient	Locally suited
		Shade	+++	26	-	+/-	Very insufficient	Insufficient
		Burrows	+++	30	+/-	++	Very insufficient	Very insufficient
		Shelter	+++	31	+/-	++/-	Very insufficient	Locally sufficient
	Substrate mosaics	*Silt*	+	26	+/+++	++/+	Locally insufficient	Suited
		Stones	+++	25	+	+	Insufficient	Insufficient
		Gravel	+++	30	+	+	Insufficient	Insufficient
		Sand	+++	26	++	+++	Suited	Suited
		Leaves	+++	26	+++	+++	Suited	Suited
		Roots	+++	32	-	+/-	Very insufficient	Very insufficient
		Wood	+++	26	-	+	Very insufficient	Insufficient
		Vegetation	30-80%	24	< 5%	< 10%	Very insufficient	Insufficient
		Detritus	+++	31	+	+/-	Insufficient	Insufficient

Legend: +++ strong positive preference, ++ positive preference, + /- low positive or negative preference with respect to A. astacus and respectively, abundant/never, present/incidental and occurring with respect to the streams.

Conclusions

Structures in the Rozendaalse stream are very insufficient to provide an optimal amount of hiding places for the noble crayfish. The longitudinal profile is too straight and the transversal profile too often fixed. Also shading is limited. Locally, the bottom contains too much silt. Therefore, the following measures are by means of the 5-S-model, deduced:

- prevent drying up (and in the long term stimulate the development of deciduous in stead of coniferous forest in the catchment),
- remove artificial bank stabilization,
- install artificial structures by means of natural materials on the short term and plant elders (*Alnus glutinosa*) to stimulate the development of structures in the long term,
- prevent the removal of vegetation and organic structures like debris dams, branches and leaf packages by omitting maintenance,
- stimulate vegetation development in the ponds by removing bottom dwelling fishes, omitting removal of vegetation and locally reducing input of fertilizers,
- prevent the inflow of sewer and toxic substances, and
- monitor the crayfish population as well as its abiotic and biotic habitat conditions.

Concerning introduction of *A. astacus* in the Beekhuizense stream should, according to the use of the 5-S-model, the following be considered:

- introduction can only take place in isolated systems like the Beekhuizense stream above the weirs to prevent contamination with the plague fungus,
- introduction is only allowed when abiotic and biotic conditions are suited, for the Beekhuizense stream this implies: - further improvement of natural structures, especially in the ponds.

By using the 5-S-model we were forced to figure out all controlling factors relevant for the long term survival of *A. astacus*. The study was based on literature data on the ecology of the noble crayfish as well as available data on the ecological status of both streams. Despite certain lacks of knowledge on the ecological demands of the crayfish as well as the sometimes limited knowledge of both streams, we were able to identify the major controlling factors to be managed. Not only those factors which decide on a sustainable population of the noble crayfish but also those controlling factors in both streams which directly and indirectly provide these conditions. We experienced the 5-S-model as a tool that systematically guides the user through the hierarchy of controlling factors in space and time. The model revealed the most important bottle-necks for a long-term survival of *A. astacus*. Based on expert judgement, the most important and effective measures were deduced. A monitoring and evaluation program is necessary to make a rehabilitation succesful. One should be careful in using only one species to construct a stream rehabilitation plan. A stream should be considered as an ecosystem with a number of inhabitants. Each inhabiting species puts its own demand to the stream. Thus, also in protecting a sustainable crayfish population one should not forget all other inhabtants. Measures to be taken should therefore be weighted against the stream type and its community. Only, when the complete stream ecosystem becomes sustainable, the crayfish is optimally protected.

Table 4. Suitability of the Rozendaalse and Beekhuizense stream for A. astacus with respect to substances.

	Controlling factors	*Parameters*	*Habitat conditions A. astacus*	*References*	*Rozendaalse stream*	*Beekhuizense stream*	*Suitability Rozendaalse stream*	*Suitability Beekhuizense stream*
SUBSTANCES	**Macro-ions**	EC mys/cm	80-700	33	150-330	180-220	Suited	Suited
		Ca^{++} mg/l	> 20	24	23-27	19,2-32	Suited	Minimal
		Cl^{-} mg/l	< 16,7	33	10-28	13,3-18,3	Acceptable	Acceptable
		Fe mg/l	< 1,2	33	0,2-0,5	0,04-0,94	Suited	Suited
	Oxygen	O_2 mg/l	6-12	26	5,5-13,7	8,9-12,6	Auited	Suited
	Organic matter	Saprobic index	8-meso-saprobic	26	Oligo-8-mesosaprobic	8-mesosaprobic	Suited	Suited
		Siltation	+	28	+/+++	+	Locally insufficient	Suited
		NH_4 mgN/l	0,0-1,58	26	0-0,6	0,1	Suited	Suited
		NO_2 mgN/l	0,0-0,68	26	0-0,44	0-0,03	Suited	Suited
		Dung	- - -	34	?	?	No data	No data
		Sewer	- - -	25	+	-	Less suited	Suited
	Nutrients	Ortho-P mgP/l	0,0-0,22	26	0,01-0,23	0,01-0,04	Incidentally too high	Suited
		NO_3 mgN/l	0,15-30	26	0-1,8	0,35-1,9	Suited	Suited
		Fertilizers	- - -	34	(+)	?	Insufficient data	No data
	Toxic substances	Herbicides, Insecticides, Fungicides	- - -	24	(+)?	?	Insufficient data	No data
		Industrial chemical wastes	- - -	34	?	?	No data	No data

Legend: ++ +/- - - strong positive or negative preference, +/- low positive or negative preference with respect to A. astacus and respectively, abundant/never, present/incidental and occurring with respect to the streams.

Table 5. Suitability of the Rozendaalse and Beekhuizense stream for A. astacus with respect to species.

	Controlling factors	*Parameters*	*Habitat conditions A. astacus*	*References*	*Rozendaalse stream*	*Beekhuizense stream*	*Suitability Rozendaalse stream*	*Suitability Beekhuizense stream*
SPECIES	**Micro-phytes**		35-45 mg/m^3	24	?	?	Insufficient data	Insufficient data
	Macro-phytes	Emergent	++	27	+	+	Insufficient	Insufficient
		Submerse	+++	35	+	+	Very insuf-ficient	Very insuffi-cient
		Calcium-rich	++	24	+	+	Insufficient	Insufficient
	Macro-fauna	Food organ-isms	++	25	++	++	Suited	Suited
		Predators	- - -	36	+	-	Suited	Suited
	Fishes	Predators	- - -	37, 38	+	?	Intermediate	Insufficient data
	Cray-fishes	*Orconectus limosus*	- - -	22	+ (some individuals)	?	Not infected	Insufficient data
		Astacus leptodactylus	-	22	?	?	Insufficient data	Insufficient data
		Pacifastacus leniusculus	- -	22	?	?	Insufficient data	Insufficient data
		Procambarus clakii	- - -	22	+ (1 individual)	?	Insufficient data	Insufficient data

Legend: +++/- - - strong positive or negative preference, ++/- - positive or negative preference, +/- low positive or negative preference with respect to A. astacus and respectively, abundant/never, present/incidental and occurring with respect to the streams.

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Bottlenecks of Dutch stream restoration projects

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Abstract

Recovery of stream systems is a recent topic in Dutch water managment and nature policy, especially since the appearance of the Third National Water management Plan in 1989 and the National Nature Plan in 1990. Many efforts by waterboards and other agencies have been made about restoration of streams in the Netherlands. Nowadays many stream restoration projects are in progress. These projects are distributed over the southern and eastern parts of the Netherlands.

The lowland stream restoration projects vary in size and objectives, but a lot of these projects suffer from administrative and technical bottlenecks in the development and execution phases of a project. The consequences are often a delay in time and a concern whether the objectives of the project will be achieved.

Several factors seems to be important to make stream restoration projects a success. Identification of these factors is a major objective in our research, carried out by researchers of Civil Engieering and Management of the University of Twente. For the purpose of our research, many stream restoration projects in the Netherlands have been studied. The results indicate that some bottlenecks are of more importance than others and the most important bottlenecks can be considered as factors of success and failure.

Introduction

In the Netherlands most lowland streams have been regulated for the purpose of land reclamation and drainage. Meanders were cut off, bends were straightened, channels were widened and deepened, bank vegetation was removed and weirs were placed to regulate flow, to reduce flooding and sediment transport, and to retain minimum water levels in summer for irrigation purposes. At present, 96 % of all stream kilometres in the Netherlands are degraded to some degree (1).

The Third National Water Management Plan describes the objectives of the functioning of Dutch streams. The main objectives are that the streams should meander, should be fed by groundwater and groundwater tables should be high enough to maintain a certain flow. In the National Nature Plan streams are also given the function of ecological corridors within the Ecological Main Structure.

Nowadays, many joint efforts stream systems are undertaken bywaterboards and other actors to rehabilitate or to restore stream systems. As a result of these efforts many restoration projects have started in the Netherlands. As water boards undertake most of the restoration measures, they play an important role in the projects. For water boards as river managers, who are primarily responsible for the quantity and quality of the surface water, this is a new role.

The first experiences with stream restoration projects showed that many projects suffered from time delays. Project evaluations showed a wide range of causes for these time delays ranging from land acquisition, lack of man power, a lack of co-operation or financial costs of the projects (2)(3)(4). Land acquisition for example is necessary for the purpose of re-meandering substantial lengths of watercourse and for the purpose of bufferstrips along watercourses.

In an evaluation study of the Dutch water policy in 1994, it was stated that due to the low availability of land along streams the objectives for stream restoration were not yet met (5). The low availability of land caused a delay in time of some projects or even cancellation of projects (3). The present study aims at obtaining an overall view on the causes ans related time delays in stream restoration projects. The research question is: 'What are the most important bottlenecks in stream restoration projects and what is the amount of time delay of these projects caused by the bottlenecks?'.

Theoretical framework

Early experiences with stream restoration learned that different projects often suffer from the same bottlenecks. For example implementation of stream restoration measures was delayed because some legal procedures were necessary, or the participants in a project could agree about the stream restoration measures.

Phases in stream restoration projects

From one evaluation study, it followed that the appearance of bottlenecks differed for several project phases (2). There are several subdivisions of project phases possible (6)(7)(8)(9). In this study five project phases are distinquished (Table 1).

Table 1 The five project phases (After (6)).

Project phase:	**Characteristics:**
Initiative	Problem will be explored No detailed information Vague objectives
Preparation and design	Formulation of the demanded and desired project results Development of technical solutions/measures Select a solution Settlement of procedures Preparation of implementation: translation of the selected solution into a realistic end result Put out a contract
Implementation	Implement the porposed technical measures to meet the project results
Maintenance	After-care Maintenance

Types of bottlenecks

The evaluation studies showed that different types of bottlenecks can be distinquished, such as economical or legal bottlenecks (2)(3)(10). Furthermore, stream restoration projects have impact in the socio-economic, administrative and legal systems and these impacts cause sometimes bottlenecks. For this reason in the study six types of bottlenecks are distinquished: technical, administrative, economical, legal, economical, social and organisational bottlenecks.

Framework of analysis

Combining the project phases with the six different types of bottlenecks the following framework of analysis appears (Table 2). The same subdivision in project phases was also used to reveal the amount of time delay in each project phase. Acoording to (11) the amount of time delay is sometimes an important indication of the success of a project, because 'The projects success is judged solely by whether or not the deadline is met'.

Table 2 Framework of analysis.

		Project	**phases**			
		Initiative	Preparation	Design	Implementation	Maintenance
Administrative bottlenecks	bottleneck 1 bottleneck 2					
Organisational bottlenecks	bottleneck 1 bottleneck 2					
Economical bottlenecks	bottleneck 1 bottleneck 2					
Legal bottle-necks	bottleneck 1 bottleneck 2					
Social bottle-necks	bottleneck 1 bottleneck 2					
Technical bottlenecks	bottleneck 1 bottleneck 2					

A list of bottlenecks

For the purpose of the study a list of bottlenecks was prepared. The main reason to prepare a list of bottlenecks was to avoid a time-consuming process of ex post analysis of the mentioned bottlenecks by respondents of the water boards. For obvious reasons (see the introduction) the respondents were officials of the waterboards. After a literature study the list consisted of a total of 52 different potential bottlenecks, divided among the six types of bottlenecks. (Potential bottlenecks means that there is a chance they will appear in one or more project phases).

Results

For the purpose of the study a questionnaire was developed and was presented to all water boards who undertake restoration projects. From a total of 78 questionnaires 52 were sent back with data from 50 projects. A setback was the fact that from one province there was no reply. Another setback was that the amount a time delay in each project phase only in a few cases could be recovered. Two main reasons were that many projects did not have a clear time table and that some follow-up projects interfere with the original project. The main results of the study are presented in Fig. 1 and Table 3.

Table 3. Delays and accelerations of some restoration projects in the Netherlands.
Accelerations of a project are printed in *italics*.

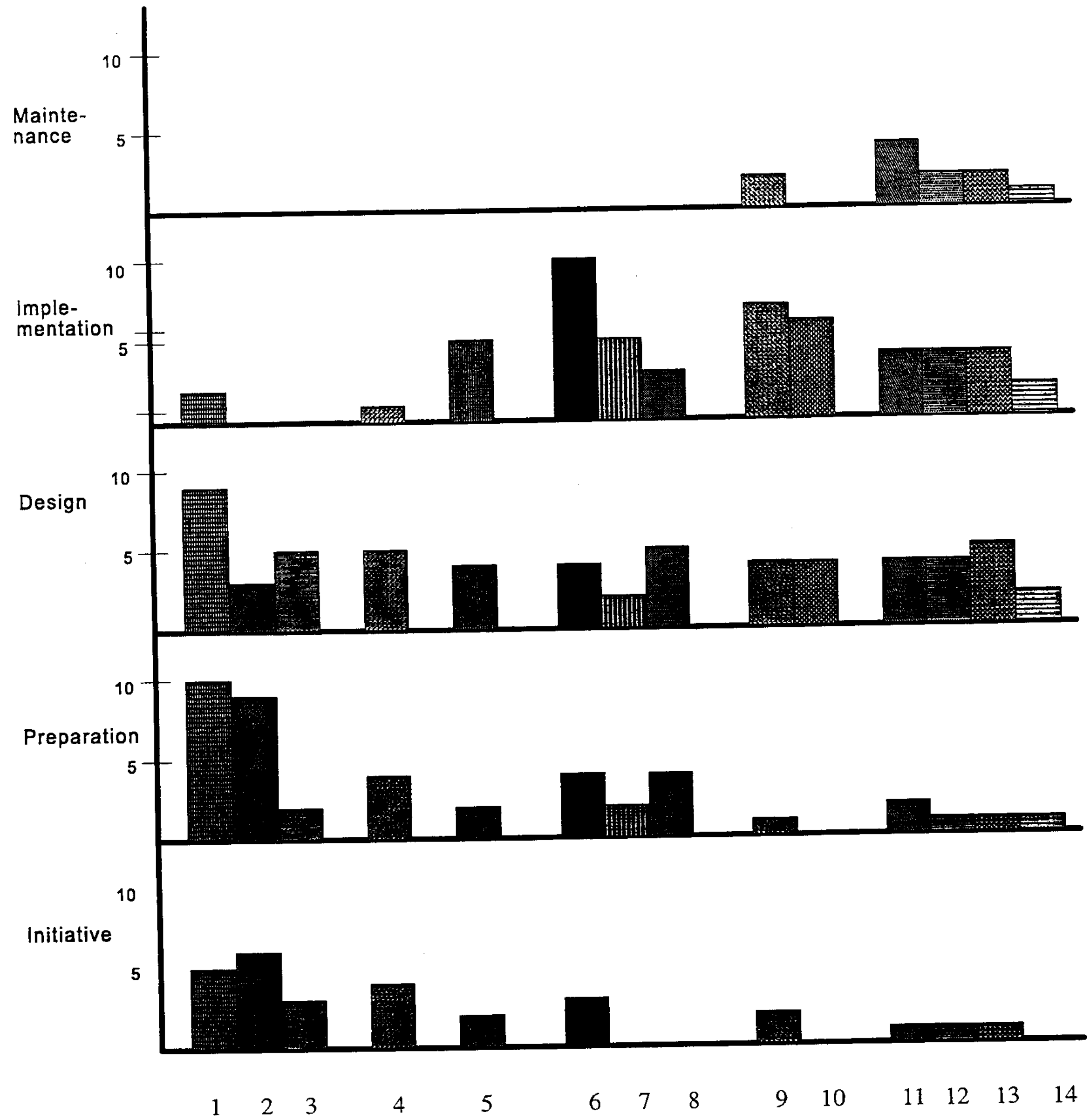
Project name	Initiative	Preparation	Design	Implementation	Maintenance
Boven-Slinge	?	-	-	2 months	?
Achelse Kluis	1 month	1 months	8 months	-	3 years
Drentsche A	4 years	17 months	-	?	?
Drentsche A	-	1 month	*½ month*	*2 ½ months*	4 months
Strijper A	-	10 months	1 month	-	-
Keersop(De Vloeten/	-	-	*6 months*	?	?
Ruiten A	-	-	6 months	1 year	?
Cluster Heer derbeken	2 years	-	-	-	-
Dalemstroompje	-	-	-	1½ months	?
Hierdense beek	19 months	5 months	4 months	1 month	?

The data did show the types of bottlenecks the officials of the water boards had experienced in the stream restoration projects. In Fig. 1 the bottlenecks as a function of the project phase are presented. It is clear the appearance of the administrative bottlenecks is concentrated in the first three project phases. It these project phases they play an important role and at the end of de design phase, which marked the end of the polital decision making, the administrative bottlenecks are solved. The lack of a clear predictability of the effects of restoration is considered by the respondents as a less important bottleneck.

The most mentioned organisational bottleneck was a lack of man power. This bottleneck is present in the first stages of a project. In those stages a water board plays an important role in the preparation of the project and most officials, who are involved within the project, have also other tasks.

Financial problems remain relevant even in the implemenation phase, but there is no sign of becoming a very important problem. The legal bottlenecks are dominant in the implementation phases. The land acquisition is already recognized as a problem in the initiative phase but becomes a major problem in the implementation phase of a project. Legal procedures are a problem in the design phase. Such procedures are an essential condition to implement the proposed stream restoration measures.

The social problems concern the voluntary participation and goodwill of farmers and landowners. It is believed that the problem of the voluntary participation is linked up with the problem of land acquisition. It is said that it is due to a (supposed) lack of legal instruments to force landowners to give their land for the project (see for example (12)). Voluntary participation of landowners and other civilians seems to be the only way to success, but the water board depends heavily on the voluntary co-operation of the landowners and civilians. In that case it is uncertain whether the project objectives will be met. The technical problems appear in every phase. The main technical problem remains the water quality of the surface water and the waterbed. In the projects were this problem remained, it is doubtful whether there will be an ecological recovery of the restored stream. The other technical bottlenecks, the natural characteristics of the stream channel and the possibilities of fish migrating are mainly a problem in the design and implementation phases of a project. These problems seems to be caused by the lack of knowledge. Although some general theoretical principles of stream restoration exist, re-creating natural characteristics is very complex, and therefore most restoration projects are based on trial and error and can be considered as experiments. Inundations became a bottleneck in cases where one of the objectives was a controlled inundation, but the water quality of the stream was still eutrophic. At least in one project a by-pass was needed parallel to the restored watercourse



Administrative bottlenecks
1. Difficult political decision making
2. Changes of objectives
3. Lack of clear predictability of effects

Organisational bottlenecks
4. Lack of man power

Economical bottlenecks
5. Availability of finances

Legal bottlenecks
6. Land acquisition
7. Lack of forcing instruments
8. Long term procedures

Social bottlenecks
9. Dependence on volutary co-operation
10. Lack of co-operation of landowners

Technical bottlenecks
11. Water quality of surface water and waterbed
12. Natural characteristics of the watercourse
13. Fish migrating works
14. Undesired inundations

Figure 1. Bottlenecks as a function of project phases.

In Table 3 some of the results about the delays or accelerations in Dutch stream restoration projects are presented. Although Table 3 is incomplete, it is obvious that the delays in the projects vary widely. In most cases restoration projects suffer from a long delay. A delay of years is possible, but delays are restricted mostly to several months. The longest delays occurs mostly in the initiative phase. A possible explanation is

the appearance of the administrative bottlenecks at the same moment. An accelaration of projects is very rare.
From the available is was concluded that average project lifetime is approximatively 7 years. One project had a lifetime of 10 years and 1 project had a lifetime of only 3 years. As the respondents in general mentioned at least two bottlenecks as an explanation for a delay in a project phase, it was not possible to relate the time delay to each bottleneck.

Discussion

In this study the bottlenecks in stream restoration projects are investigated. One of the major bottlenecks in Dutch stream restoration projects is land reclamation, confirming earlier studies. It is believed that the main cause for the problem of land acquisition is the (supposed) lack of legal instruments for water boards to force landowners to give up their land for a restoration project. The second cause is that water boards can depend only on the voluntary co-operation of landowners if they want to meet their objectives of restoration. Whether indeed the water boards lack the legal instruments to acquire the land is not clear. Legally the water board seems to be in a strong position, but in most cases landowners show a lack of goodwill and co-operation. It is possible that water boards do not make use of available instruments at all or they do not make use of the possibilities of available instruments or it is even possible they do not really know these possibilities. It is also possible that water boards do not use instruments in a proper way in relation with the civilians or landowners. It is also possible that the lack of legal procedures when using the instrument of buying land is an argument for choosing that instrument. Maybe instruments to force landowners are not very popular. A further study about these aspects will concentrate around two research questions. Firstly, which legal instruments do the Dutch water boards have for land acquisition, and secondly how do the Dutch water boards use their legal instruments to meet the objective of land acquisition.

Conclusions

Not all bottlenecks appear in every project phase. There is a clear shift in the intensity of the appearance of bottlenecks in the project phases. In the early phases of the project the administrative bottlenecks are the most important bottlenecks. In the implementation phase the land acquisition has become a major bottleneck. In the same phase social bottlenecks become also dominant. The intensity of economical and organisational bottlenecks is in all project phases merely constant. The technical bottlenecks still appear in the maintenance phase and these problems are not solved in the project.
Although there is a lack a data about the time delays of the Dutch restoration projects, is seems evident that in most cases restoration projects suffer from a long delay in time. A delay of years is possible, but most delays are restricted to several months. The largest delays appears in the initiative phase of the projects. An accelaration of projects is very rare. The average project lifetime is approximatively 7 years. One project had a lifetime of 10 years and 1 project had a lifetime of only 3 years.

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Scale analysis of bank stability: targeting river reaches for riparian revegetation

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Abstract

Riparian vegetation has different impacts on stream processes depending upon its position in a catchment. This paper illustrates a structured approach for assessing the role of vegetation in stream bank erosion. Using the Latrobe River in SE Australia as an example, we match the suite of riparian vegetation in a catchment to the erosion processes operating at different points in the catchment.

We find that in reaches where bank slumping is the dominant erosion process, increased bank shear strength due to root reinforcement is the major role of vegetation in stabilising banks. In mid-basin reaches of the Latrobe River, slumping is not important. Here, the dominant erosion process is fluvial entrainment, and flow resistance due to vegetation becomes crucial. In uppermost reaches, bank erosion is largely the result of subaerial processes: vegetative influences include the transfer of bank sediment directly to the flow by windthrown trees and damming by large woody debris.

Considering the interactions between vegetation and bank processes we are able to define those river reaches in which vegetation will be most effective in reducing bank erosion. On the Latrobe River, this critical zone occurs in that portion of the floodplain where it first leaves the mountain front and meanders across a broad floodplain. This information, combined with other scale analyses (e.g. ecological, hydrological), enables managers to plan physically-based riparian revegetation strategies.

Introduction

Native revegetation schemes are increasingly being used to manage stream erosion in Australia. (1) concluded that riparian vegetation has different impacts on stream processes depending upon its position in the catchment. But where, along a stream network, will vegetation be most effective in countering bank erosion? This paper describes an approach to answer this question by considering downstream changes in channel scale, the effects of those changes on bank erosion processes, and the influence of vegetation over the erosion processes along the river length.

Many authors have suggested that tree roots enhance bank shear strength and reduce the occurrence of mass movement (e.g. (2)). Moreover, a root permeated soil is markedly more resistant to direct erosion by fluvial entrainment. Experiments by (3) suggested that bank sediments reinforced by roots were some 20,000 times more resistant to erosion than non-reinforced sediments. On some river banks subaerial processes may result in either direct transfer of bank material to the flow or conditioning of bank material for removal by fluvial entrainment (4). (5) discusses a number of these processes, including rainsplash, rill erosion and frost action; the binding action of roots tends to resist these processes.

From these general observations it is difficult to decide where vegetation should be planted to control erosion. This is largely because observations about the effectiveness of vegetation have not been related to channel scale. In order to understand the role of vegetation in stream bank erosion, one must: understand the erosion processes; consider how each of the processes may be influenced by vegetation; determine the salient properties of the vegetation that affect the processes; and try to quantify the effect of vegetation on the processes acting in different parts of the river system. By considering the significant interactions between vegetation and erosion processes, future river management procedures will include native vegetation as a prerequisite for healthy, stable stream systems.

Following a description of the erosion processes and vegetation characteristics of the Latrobe, we present an analysis of the various mechanisms by which vegetation is purported to influence erosion. Our study was undertaken as part of the Australian National Riparian Zone Research Project which aims to define the role of vegetation in bank stability, nutrient and sediment buffering and other stream processes.

Latrobe River

The Latrobe proved to be ideal for this study because there are reasonably long flow records from six gauges along the length of the river, the banks are actively eroding, and there is a reasonable body of literature describing the river and its environs (6). The Latrobe River is 230 km long and drains a catchment of 4,700 km^2 (Fig. 1). The river is almost entirely alluvial, with few bedrock reaches. Headwaters remain forested, dominated by *Eucalyptus regnans*, whilst the floodplain is cleared for cattle grazing. Riparian vegetation in the lower floodplain tract was originally open forest: river red gum (*E. Camaldulensis*) and silver wattle (*Acacia dealbata*), but today is dominated by the exotic basket willow (*Salix rubens*), and wattles.

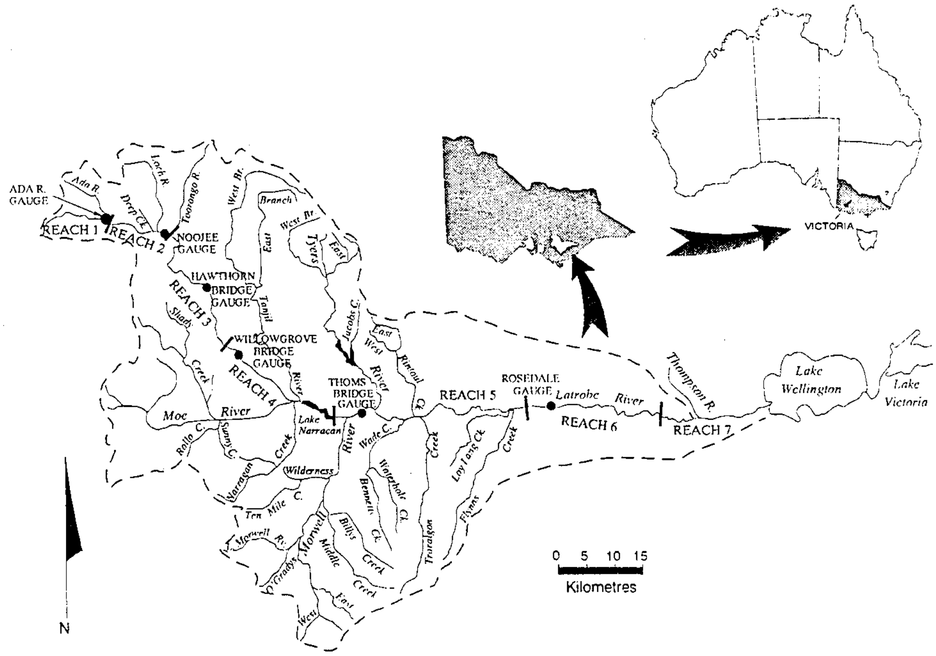

Figure 1. Latrobe River catchment.

To assess the changing role of vegetation in channel erosion we have divided the river into seven reaches, each having a characteristic relationship between riparian vegetation and erosion process. Three cross-sections were surveyed in each reach (except Reach 3 and Reach 7) providing channel data from seventeen sites, in total, along the river. The results of the survey work are briefly presented in Table 1. We also made use of some sixty additional cross-sections that had been previously surveyed in Reaches 5, 6, and 7. During the course of the channel survey, bank sediments were also sampled for laboratory determination of the geotechnical properties of each identifiable bank unit at surveyed sections in Reaches 4, 5 and 6.

Table 1. Latrobe River reach characteristics.

Reach No.	1	2	3†	4	5	6	7†
Distance downstream (km)	<15	15-30	30-60	60-90	90-160	160-200	200-230
Catchment area (km^2)	65	375	525	1895	3880	4425	4670
Cross-sectional area (m^2)	0-11	8-17	33	33-39	161-258	74-102	110
Bankfull width (m)	0-15	12-20	30	18-26	44-74	25-32	29
Maximum depth (m)	0.0-1.2	1.0-1.5	1.6	2.7-2.9	5.7-6.9	3.8-5.7	5.6
Riparian vegetation	Ferns, Sedges	Paper Barks	Paper Barks	Wattles, Red Gums	Wattles, Red Gums	Wattles, Red Gums	Wattles, Red Gums
Vegetation height (m)	~1	~10	~8	10-20	10-20	10-20	10-20

† *Data from one cross-section only.*

Reach descriptions

Vegetation has a profound effect on erosion processes in Reach 1. Fallen trees, or large woody debris (LWD), span and choke the channel and the bank is often undercut below the 0.3-0.5 m root-zone. Falling trees transfer large amounts of bank sediment to the flow and this appears to be the dominant erosion mechanism.

Banks in Reach 2 are vertical and too low to sustain trees on the bank face. Treefall remains the dominant erosion process and flow is significantly affected by the presence of LWD within the channel. The floodplain, where it is apparent, is narrow and generally only developed on one side of the river.

Major changes occur in Reach 3. Trees now grow on the bank face and the channel is broader than the trees are tall. LWD tends to be swept against the bank at an angle of about 30° and does not particularly divert flow onto the banks. Erosion begins to be concentrated on the outer bank of bends.

Meandering commences in Reach 4 as the river flows out of the confined upper reaches into the broad alluvial floodplain; levees are also developed in this reach. The dominant erosion process is bank slumping. Slump blocks are smaller than the average size of wattle rootballs and tree roots extend through potential shear planes, increasing bank shear strength.

The river attains its largest dimensions in Reach 5 and erosion is most pronounced on near vertical concave banks where slumping occurs. On these bank sections, roots of bank-top trees do not extend to the mean water level; outer banks with trees are often undercut by up to two metres. Slump blocks in this reach are over twice as large as those in Reach 4 and are often larger than the typical wattle rootball.

As the river moves into Reach 6 the channel contracts to almost half the size of Reach 5. Slumping remains the dominant erosion process but the incidence of mass failure is reduced. Artificial meander cutoffs have shortened the river substantially through this reach and there is intensive localised erosion immediately below some of these.

Reach 7 is located in the backwater of Lake Wellington. Here, the channel widens and stage varies by only 0.5 m. Water logged sediments limit root depth to about 1 m deep and, as in Reaches 1-3, erosion is by undercutting below the root-zone. There is little slumping.

Erosion processes

Riverbank erosion is a complex phenomenon in which many factors play a role, but in general it is flow, sediment transport, and bank properties that determine rates of bank retreat. Bank/flow interactions fall into three broad categories of bank erosion processes: subaerial preparation; fluvial entrainment of bank sediment; and mass failure mechanisms (4). A number of vegetative influences act upon these processes and, in most cases, reduce the amount of erosion.

All erosion processes act in concert with one another down the length of rivers but typically one mechanism tends to dominate over the others at any given point. Because the nature of erosion changes downstream in a river system, it does not seem unreasonable to expect that the suite of riparian vegetation established at a particular point might influence bank erosion differently to the same suite of vegetation established elsewhere on the river. To investigate this last point, we now present data for the Latrobe River for both the case of fully vegetated banks and entirely bare banks.

Subaerial preparation

Subaerial processes are active on stream banks throughout catchments but are particularly apparent in upper reaches. Channel form and size are greatly influenced in these reaches by the bank destabilising mechanisms of windthrow of stream-side trees, damming by LWD, frost heave, desiccation processes, rainsplash and micro-rill development on exposed banks (5)(7)(8)(9).

Data pertaining to rates of bank retreat due to the various subaerial preparation mechanisms are rare in the literature. However, observations of the Latrobe River lead us to believe that, with the exception of windthrow in upper reaches, subaerial preparation processes occur sporadically, display high seasonality and are at best of second order significance. Windthrow and LWD flow redirection appear to be the dominant form of bank instability in Reach 1 and the removal of trees from this reach may even reduce the potential for bank erosion.

Fluvial entrainment

Downstream changes in flow erosivity often results in fluvial entrainment dominating bank erosion processes in mid-basin reaches (4). Variations in the erosivity of flow may be approximated by considering downstream variations in mean streampower, ω, (W m^{-2}):

$$\omega = \rho g R V S \tag{1}$$

where ρ is the density of water (1000 kg m^{-3}), g is acceleration due to gravity (9.81 m s^{-2}), R is the hydraulic radius (m), V is the flow velocity (m s^{-1}) and S is the local energy slope ($\tan\Theta$). Following Lawler (4), and setting ρ and g as constant, mean streampower can be calculated as a function of individual functions of RV and S with distance downstream from the catchment divide (km).

The variables, V and R are strongly influenced by the hydraulic resistance imposed by LWD and standing vegetation within the channel, and some account must be made for these roughness elements. The hydraulic effects of vegetation in the flow are complex, so we assume here (after (10)) that the hydraulic effect is proportional to the area that the vegetation projects into the bankfull flow (the blockage ratio, B).

By reducing the surveyed bankfull cross-sectional area by a factor indicated by B, we can set R for both the bare and fully vegetated case. To derive mean bankfull velocities, U, at each of the gauge sites we use a combination of the blockage ratio, the gauged bankfull discharge and the Darcy-Weisbach friction factor. Total friction loss, f_t, through a river reach is the sum of the resistance due to vegetation, f_v, and the resistance due to all other roughness elements, f_b. We have adopted the method proposed by (10) to find reach averaged values of f_v. Values for hydraulic variables are presented in Table 2.

Table 2. Hydraulic variables by reach.

Reach	$L^{\dagger}$	B	R_b	R_v	f_b	f_v	f_t	U_b	U_v	S
1	10.7	0.208	0.66	0.52	4.50	0.58	5.09	0.39	0.32	0.0129
2	26.5	0.067	0.77	0.72	0.07	0.15	0.22	1.57	0.86	0.0029
3	43.4	0.051	1.05	1.00	0.19	0.15	0.34	1.17	0.85	0.0031
4	74.2	0.004	1.62	1.61	0.09	0.02	0.10	1.40	1.29	0.0014
5	107.6	0.004	3.14	3.13	0.21	0.03	0.24	1.02	0.96	0.0009
6	163.5	0.004	2.51	2.50	0.02	0.02	0.05	1.49	1.01	0.0002

† At gauge sites

Plotting the product of RU ($m^2 s^{-1}$) with and without vegetation, at each of the gauges, against chainage (L) yields the relationships:

$$(RU)_v = 0.0027L^{0.95} \qquad R^2 = 0.89, \tag{2}$$

and

$$(RU)_b = 0.0337L^{0.96} \qquad R^2 = 0.95. \tag{3}$$

We have no data to adequately describe the local energy slope at each cross-section, so we use local channel slope as a surrogate for the energy slope at bankfull discharges. Plotting the local channel slope (obtained from topographic maps) at each of the gauge sites against chainage yields:

$$S = 0.0090e^{-0.02L} \qquad R^2 = 0.92. \tag{4}$$

Substituting equations (2) or (3) and (4) in (1) allows us to express w as a function of chainage:

$$\omega = \rho g\left(kL^m\right)\left(S_0 e^{-rL}\right) \tag{5}$$

where k, m, S_0 and r are constants as derived above. Equation (5) is plotted in Fig. 2 for both the bare and fully vegetated channel cases. Also shown in Fig. 2 are the values of mean streampower calculated for the individual gauge sites. These known data points show good correlation with our idealised model.

Fig. 2 indicates that Reach 3 is the zone where bed slope and discharge combine to produce peak values of flow-erosivity. Fig. 2 also suggests that revegetating a bare channel and reintroducing a pre-disturbance load of LWD to the flow will have the greatest effect on the flow's capacity for fluvial entrainment of bank sediments in upper reaches. At the top of the river, ω is reduced by some 55%, peak values are reduced by 30% in Reach 3, and at the bottom of the catchment revegetation reduces ω by about 15%. While the impact of reducing mean streampower on bank erosion will depend on the actual threshold for fluvial entrainment of the bank sediments we assume here that the erosion rate is simply linearly related to mean streampower.

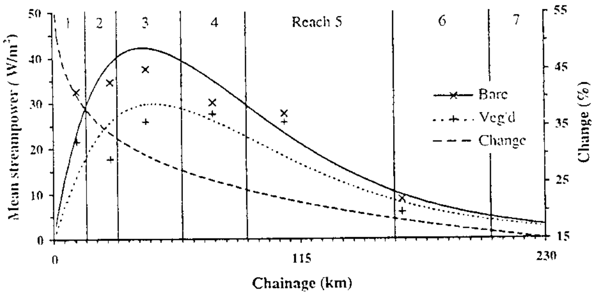

Figure 2: Mean streampower as a function of distance downstream for the cases of fully vegetated and bare banks on the Latrobe River. Also shown is the percentage change between the two plots.

Mass failure

The literature suggests a number of potential influences of vegetation on mass failure of river banks. They are: buttressing; bank hydrology modification; surcharge; and root reinforcement (2). However field investigations suggest that the main role of vegetation in mass stability of the Latrobe River banks is reinforcement due to roots.

Theories of slope stability, as expounded by (11), state that a bank will collapse under its own weight if, for any assumed failure mechanism, the rate of work done by the weight of the bank material exceeds the internal rate of dissipation. Accounting for the external and internal energies at failure, (11), release of tension in the bank material via cracking developed to its maximum depth of half the critical bank height (12), and the reinforcement of roots (2), the threshold bank height for failure, H_c (m), can be calculated:

$$H_c = \frac{2(c + c_r)}{3\gamma} N_s \tag{6}$$

where c is material cohesion (kPa), c_r is the component of bank cohesion due to root reinforcement (kPa), γ is the material's bulk unit weight (kN m^{-3}) and N_s is a dimensionless stability factor. N_s is a function of both the bank angle, β (degrees), and the internal angle of friction of the bank material, ϕ (degrees). (11) presents values of N_s for rotational discontinuities that occur along a logarithmic-spiral failure plane passing through the toe of the slope for a range of β, ϕ combinations. Using data reported by (2) we believe that an appropriate value of c_r for vegetated Latrobe River banks lies somewhere in the range of 5-10 kPa; for comparison we treat $c_r = 0$ as a fully degraded bare bank.

Bank shear strength γ parameters, c and ϕ, were determined by quick undrained triaxial compression tests of undisturbed samples from each identifiable bank unit at each of the nine cross-sections in Reaches 4-6. The lowest values of c and f and the highest values of saturated g from each reach were averaged to simulate a worst-case bank stability condition. We regard values of c_r as being representative of average conditions of root strength over the whole bank profile and have assumed that the bank material can be represented as a homogenous mass.

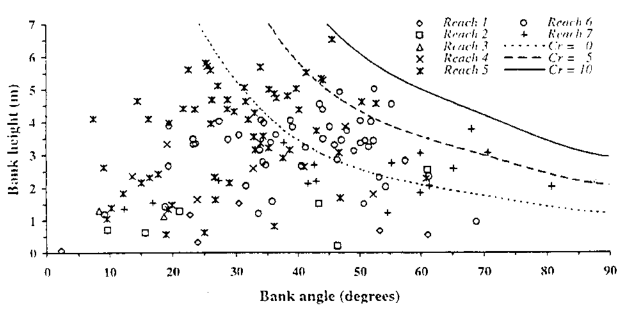

Figure 3. Latrobe River bank stability, defined by log-spiral failure analysis in terms of bank height (H) *and bank angle* (b)*. The crosses mark the height and slope of banks surveyed in each reach. The lines represent critical combinations of* H *and* b *for bank failure with measured bank cohesion* (c) *and internal angle of friction* (f) *and the addition of 5 and 10 kPa of cohesion to represent the role of vegetation in bank stability.*

Using our laboratory results, as obtained above, we set the soil strength parameters of equation (6) to c = 7.2 kPa, ϕ = 15.4° and γ_s = 19.7 kN m^{-3}. By interpolating N_s for various values of β, we have drawn equation (6) as a family of stability curves in Fig. 3, with c_r ranging from 0 to 10 kPa, through a plot of surveyed bank heights against bank angles. Latrobe bank data plotting below and left of the curve of a given vegetation treatment are predicted as stable against mass failure. For stable bank sections, under a given vegetation treatment, to become unstable, an increase in bank height through bed degradation or an increase in bank angle through toe erosion must occur. Although there are a number of different mass failure mechanisms occurring on the Latrobe, the slab failure along a log-spiral failure plane modelled here seems to be a reasonable surrogate for all. The results presented in Fig. 3 generally comply with observations of bank failure in the field. Failures usually occur on degraded bank sections, but steep and high banks are prone to mass failure even with a good cover of vegetation. We have seen occasional bank slumps in well vegetated locations of Reach 5 so it may be that the assumptions with which we apply c_r = 10 throughout the bank profile produce an overestimate of fully vegetated conditions, particularly on higher sections.

The channel is cutting into a high terrace in some parts of Reach 4 and in general, bank sections in this reach are probably somewhat higher and steeper than those points plotted for Reach 4 in Fig. 3. It is likely that with more data for this section the spread of bank geometries would overlap with the unstable regions, particularly that of c_r = 0. Fig. 3 suggest that many bank sections in Reach 7 are unstable with respect to mass failure. This is not strictly the case as field inspection of this reach reveals no incidence of mass failure at all. A possible explanation for this spurious result is that the stage in Reach 7, located in the backwater of Lake Wellington, is almost always very high. The hydrostatic pressure exerted against the banks by the water in the channel probably does much to hold the banks up against mass failure.

Discussion

As (4) correctly hypothesises, there exist spatial zoning of the dominance of the three erosion process groups. Our interpretation of the spatial patterns of erosion process efficacy for the Latrobe River is shown schematically in Fig. 4. In upstream reaches of low bank height and low mean streampower, subaerial preparation mechanisms are the prevalent bank erosion processes. Moving downstream, increasing discharge causes a rise in mean streampower and fluvial entrainment assumes dominance over subaerial preparation in mid-basin reaches. In lower reaches, bank heights pass through a threshold of critical height and mass failure eclipses the other erosion processes.

According to our analysis, revegetation of denuded Latrobe River banks will reduce the efficacy of erosion processes everywhere except Reach 1 (Fig. 4). Revegetation may actually increase the potential for bank erosion in Reach 1 due to the additional transfer of bank material to the flow via windthrown trees. The potential rooting depth of trees quickly increases downstream and any increased bank erosion due to revegetation is restricted to the top few kilometres of river length.

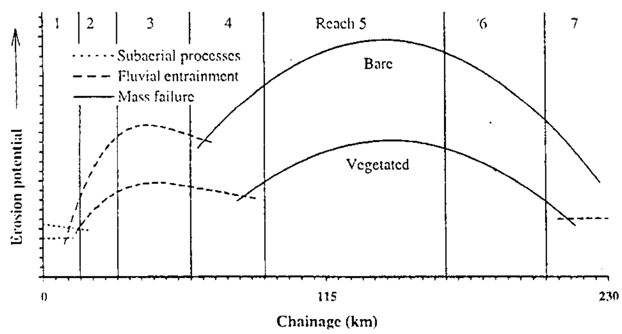

Figure 4. Spatial zoning and efficacy of erosion process for the vegetated and bare banks on the Latrobe River.

All that remains now is to identify the reach where vegetation is likely to have the greatest effect on the erosion process operating in that part of the river. On the Latrobe we believe that Reach 4 can be afforded the most protection by the introduction of vegetation. Vegetation in this reach will mitigate the effects of subaerial preparation processes, suppress fluvial entrainment efficacy by up to one quarter and protect all bank sections from erosion by mass failure (the last ~10 km is flooded by Lake Narracan). We feel that this last point is extremely important. Minor slab type failure in Reach 4 is a ubiquitous and continuous process at present in Reach 4. Any management strategy that can attack this problem will almost entirely stabilise this reach.

In summary, a manager faced with the task of controlling bank erosion problems in the Latrobe River, would be tempted to revegetate Reach 5. The large slumps in this reach are highly visible and intuition would dictate that bank stability in this reach should be treated as a priority. Our scale analysis, by matching vegetation to the erosion processes indicates a different management strategy. Whilst revegetating Reach 5 will ameliorate much of the erosion problem through this part of the river it is unlikely that anything like full stability can be achieved. In contrast, a riparian revegetation programme that explicitly targets Reach 4 as a first priority will stabilise the banks and slow erosion rates back to their former natural levels.

Conclusions

The interaction between bank erosion process and vegetation varies as a function of changing channel scale. We have identified the three important channel scale variables as: slope, cross-section size and shape, and discharge. The channel scale variables change with distance from the divide.

Three erosion process groups are responsible for bank retreat. These are, subaerial preparation, fluvial entrainment, and mass failure processes. We find that although these processes act on banks throughout the catchment, there exists spatial zoning in the dominance of each process group over the others. Bank erosion in upper reaches is dominated by subaerial preparation, in mid-basin reaches by fluvial entrainment, and in the lower reaches by mass failure.

Vegetation influences the erosion processes in different ways as channel scale changes downstream. The most important influences of vegetation are transfer of bank sediment to the flow by windthrown trees, hydraulic resistance (LWD and standing vegetation) and root strength.

Because channel scale changes downstream, matching the influence of vegetation to the erosion process allows managers to identify zones within the river system where the bank stabilising effects of vegetation can be maximised. On the Latrobe River, this critical zone occurs in that portion of the river where it first leaves the mountain front and meanders across a broad floodplain. Further research will improve the precision of predictions made by the scale analysis model and provide for its easy application to other rivers.

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Nutrient transformation in wet meadows

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Introduction

This paper is a very short presentation of an investigation project about nutrient transformation in a re-established wet meadow flooded by drainage from cultivated fields. The investigations are going on along the watercourse named Storå situated on the island Funen in Denmark. The Funen County Council in Denmark has through investigations found out that there are great perspectives in nitrate transformation in wet meadows. Wet meadows, corresponding to an area of just 2% of the farm land on Funen, have a potential to reduce the nitrogen run-off from farm land to the Funen watercourses with 25%. It demands that the wet meadows are correctly established as uncultivated meadows flooded by drainage water from cultivated fields. And - it is only realistic to establish wet meadows along watercourses with a distinct valley. To re-establish wet meadows is very important in relation to reduce the nitrogen leaching to the surface water, but it does not solve problems about nitrate leaching to the ground water. These problems can be solved by measures on the cultivated fields, only. To find out how realistic it is to use wet meadows in nitrate control in a larger scale, the Funen County Council has started a full scale demonstration project about wet meadows.

Objective of the investigation project

The objective of the investigation project is to investigate the capacity of wet meadows along watercourses to reduce nutrient leaching from cultivated farm land.

Study area and experimental design

The study area which is 0.8 ha was cultivated until the summer of 1989. In autumn 1989 the study area was flooded by drain water and vegetated in grasses and herbs gradually. The monitoring programme started at the beginning of 1990 and is expected to run until the year 2000. The study area is surrounded by a sheet piling to facilitate monitoring of surface run-off and determination of the water balance. Inflow of drain water and outflow of surface run-off from the study area are measured continuously by electromagnetic flowmeters. To ensure that drain water flows and seeps evenly into as much of the study area as possible a ditch is constructed along the upslope part of the study area (Fig. 1).

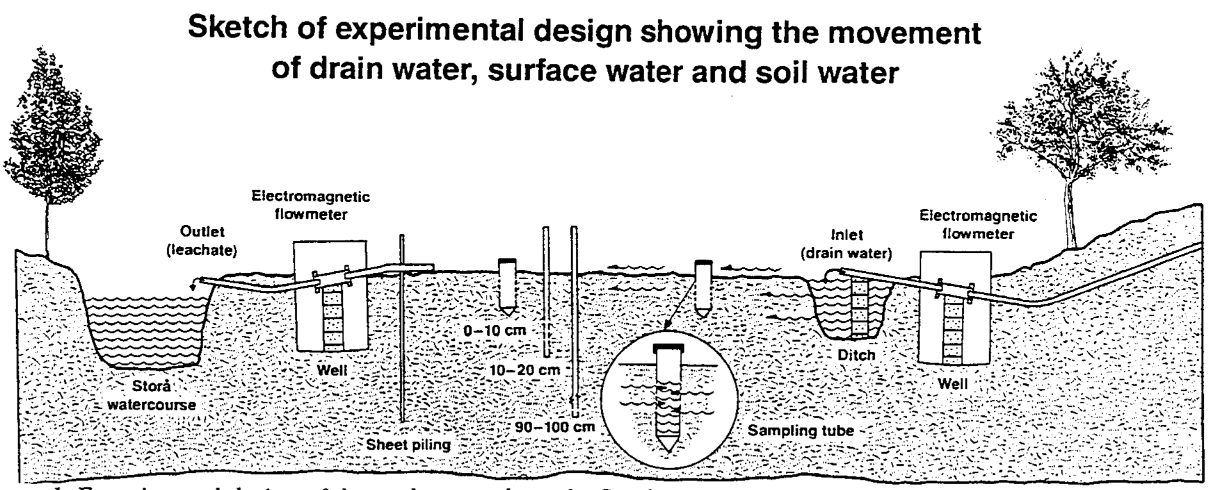

Figure 1. Experimental design of the study area along the Storå watercourse on Funen in Denmark.

In the study area water samples are collected from 18 stations in a depth of 0 to 10 cm. In addition, water samples are collected from a depth of 10 to 20 cm and 90 to 100 cm at 4 stations in deep well piezometers. Samples of the inlet and outlet are collected every two weeks from October 1991 and forward.
All samples are analysed for nitrogen fractions, phosphorus fractions, chloride, sulphate and acidity. Temperature and specific conductance are measured in the field. Twice a year all samples are also analysed for macro ions. Only results of nitrate are presented.

Results

Water balance

A water balance is calculated for the period from March 1991 to December 1994. The input to the study area is calculated on the inflow of water and the precipitation whereas the output is calculated on the outflow of water and the evapotranspiration.

The difference between the input and the output must correspond to the infiltration. The infiltration is almost at the same level in the winter periods. As an average the estimated infiltration is 1300 mm per year in the study area, which is predominantly clay soil with a secondary content of organic matter.

Nitrate transformation

The lowest nitrate transformation rates are measured during periods of high run-off and low temperatures and when nitrate inputs are low, typical in the summer. The highest nitrate transformation rates are measured during spring time. The nitrate load to the study area is high enough to ensure a maximum nitrate transformation. The nitrate transformation does not exceed a level about 120 kg nitrate per hectare per month. It is independent of nitrate load, when the load is high (Fig. 2).

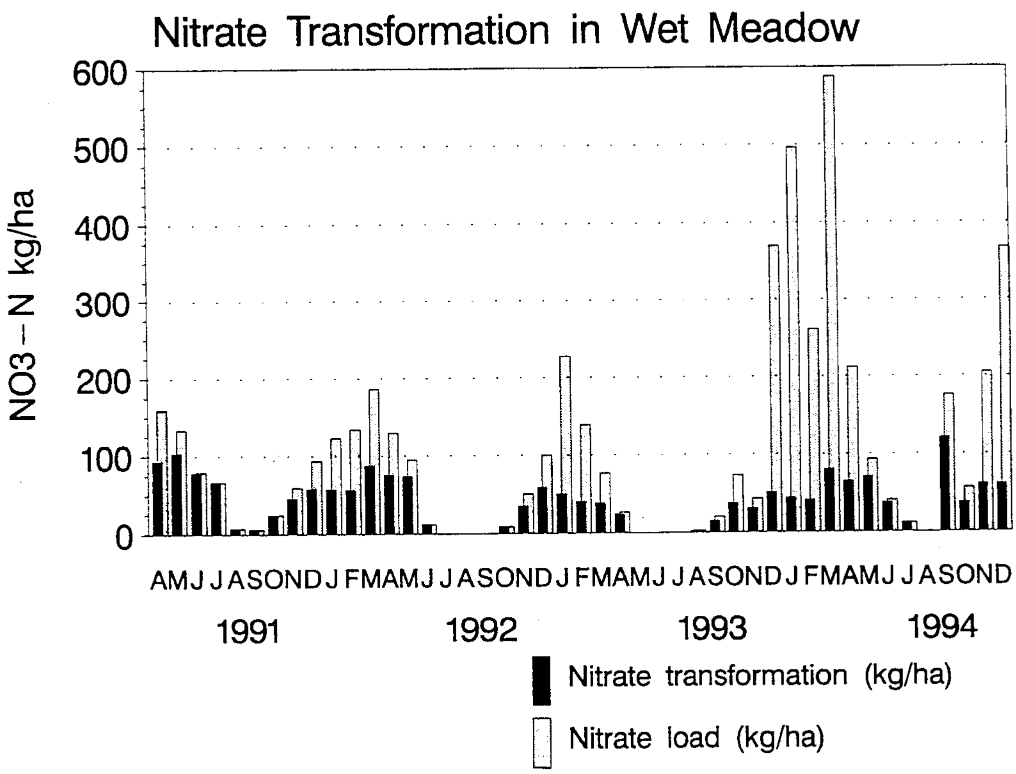

Figure 2. Nitrate transformation and nitrate load to the study area, 1991-94.

In the winter period (from November to March), when the temperature and the light intensity are low, the nitrate transformation is 50 kg N per hectare per month as an average corresponding to 40% of the nitrate inflow in the period 1991-92 and 20% of the nitrate inflow in the whole period 1991-94. In 1993-94 the discharges were extremely high, which caused a decrease in the transformation expressed in percentages of the load. In the period from April 1991 to December 1994 the amount of transformed nitrate varied from 0 to 120 kg N per hectare per month. 0 in periods without a nitrate input. It corresponds to a variation of 10% to 100% of the nitrate inflow (January 1994 and the summer periods). The annual rate of nitrate transformation has varied from approximately 290 to 640 kg nitrate-N per hectare per year with the highest rate in 1991 and 1994. Other investigations from Denmark show nitrate transformation rates approximately at the same level, although the transformation rates vary from site to site (2).

The plant biomass is not yet measured to calculate the plant up-take, but other investigations from Denmark show a plant up-take of approximately 5 to 7% of total nitrate input (3).

The infiltration of nitrate is approximately 3% of the total nitrate transformation and it corresponds to the deposition of nitrate on the study area. The deposition is not added to the amount of nitrate in the inlet, so these 2 amounts neutralize each other.

Vegetation
Investigations of the vegetation have been made in the period from 1991 to 1995. It is obvious that the study area is dominated by perennial plant species such as Creeping buttercup, Floating sweet-grass, Rough meadow-grass and Broadleaved duck. The variation of the cover degree of par example Creeping buttercup is from 35 % in 1991 to 50 % in 1994. But more or less the cover degrees vary within a certain range for each specie. As expected the 3 dominating species are all demanding high humidity.

Perspectives
Perspectives on Funen in Denmark
Results from the investigations on Funen show that wet meadows along watercourses, if properly selected and established, can be used as an important element, among others, to reduce the nitrogen leaching from intensively cultivated farm land.
Wet meadows, corresponding to an area of just 2% of the farm land on Funen, have a potential to reduce the nitrogen run-off from farm land to the Funen watercourses with 25%. These 2% of the farm land on Funen corresponds to less than half of the natural and extensively cultivated areas, which have been brought under cultivation since the 1950's (4)(5).
To re-establish wet meadows is very important in relation to reduce the nitrogen leaching to the surface water, but it does not solve problems about nitrate leaching to the ground water. These problems can be solved by measures on the cultivated fields, only.

Criteria for establishing effective wet meadows
Some of the most important criteria for establishing effective wet meadows are to have a distinct valley along the watercourse with draintiles carrying off adequate amounts of drainwater with adequate amounts of nitrate. Adequate amounts of organic matter in the soil of the meadow is also necessary, because organic matter functions as a carbon source in the denitrification process.
It is also important that there has been no load of sewage with a high content of phosphorus to the meadows previously. There can be a risk of phosphorus leaching if essential amounts of phosphorus are available in the soil.
Botanically valuable flora on existing grasslands, which is intolerant of nutrients, must be taken into account.

Preliminary investigations
The first limitation in relation to establish wet meadows is topography. If there is no distinct river valley with a certain width of the meadows, it is impossible to establish wet meadows without influencing the drainage of areas situated at the upslope part of the valley. A levelling of the terrain is especially useful if the river valley is not distinct at all parts.
It is very important to find out where the draintile systems are and the size of the catchment areas to these draintile systems. The size of the catchment areas to the draintile systems and the landuse within them can tell something about the amounts of drainwater and nutrients. Thereby it is possible to find the minimum size of the meadow in relation to avoid overload of the meadow.
Overload with water and nutrients can cause leaching of phosphorus depending on the content of par example organic matter and ferric oxides in the soil of the meadow. Therefore it is also very important to ensure that there has been no load of sewage or sludge containing great amounts of phosphorus to the meadow previously. Investigations of the soil composition can be a good guide to ensure an optimal nutrient transformation and to avoid leaching of par example phosphorus.
Funen County Council has measurements of phosphorus, too, showing a retention on an annual basis, but with great variations from month to month. In December, January and February with high discharges, a leaching of phosphorus appears. The sampling frequency has now been changed from every two weeks to continuously sampling to ensure samples from all discharge peaks.
To describe the botanical state of existing grasslands before flooding with nutrient rich drainage, is very important to avoid damage on botanically valuable flora.

From investigation to full scale
To find out how realistic it is to use wet meadows in nitrate control in a larger scale, the Funen County Council carries out a full scale demonstration project.

To go from investigations at 1 hectare to a full scale project at 50 hectares, often makes an incoherence between areas suitable for wet meadows and areas with interested farmers visible.
The vision of the full scale demonstration project is to make the river valley change from a situation with primarily cultivated fields along the river to a more sustainable situation with grasslands functioning as wet meadows with nutrient transformation. That will re-establish the river valley as a corridor, where watercourse and surroundings can function more as a whole in relation to environment, nature and landscape interests.
In Denmark a lot of money is spend on river maintaining. If the riparian zones are re-established as wet meadows, the maintaining of the watercourses can be stopped and the landowners can be compensated. In that way nutrient transformation, natural watercourses, more grasslands along the watercourses and satisfied landowners are possible effects in future.

Recommendations

- Be aware of the value of existing wet meadows as nutrient filters and protect them from getting drained and cultivated.
- Try to re-establish wet meadows, if they are already cultivated and drained, whether you can buy the land or pay the farmers some subsidies.
- Don't overload the meadows to use them as a sort of sewage treatment plants.

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Long term monitoring riverine suspended sediment and total phosphorus transport as a tool for evaluating the effects of river restoration

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Introduction

Many European rivers have been regulated by straightening, widening and deepening in order to facilitate rapid drainage of "excess" water to the sea. In addition, they have been modified by land drainage, floodplain urbanization and construction of agricultural and urban defence systems (1)(2)(3). These activities have resulted in reduced floodplain capacity to store and retain water, sediment and nutrients, alteration of water regimes and matter transport in streams, and, together with high organic pollution of anthropogenic origin, have damaged stream ecosystems (3)(4)(5).

In Denmark, less than 15% of the approximately 30,000 km of streams have retained their natural channel (6), while 98% have been physically changed to the extent that they have lost their natural physical properties (7). The river Skjern, which drains into Ringkjøbing Fjord, has the highest discharge of all Danish rivers (annual mean 39 $m^3 s^{-1}$, corresponding to 16 $l s^{-1} km^{-2}$).

From 1962 to 1968, the lowermost 25 km of the river and the lower part of some of its tributaries were channelized and dyked (8), thereby enabling reclamation of 4,000 hectares of former delta. High nutrient, organic matter, ochre and sulphate loading of Ringkjøbing Fjord was subsequently observed (9). The environmental condition of the fjord is currently characterized as poor (10) with an extremely high phytoplankton biomass (mean value for 1995: 1,674 $\mu g C l^{-1}$; summer mean: 2,482 $\mu g C l^{-1}$). Due to the consequent reduction in Secci depth, bottom vegetation is limited to depths of less than 0.80 m, as compared to 3.25 m in 1972. Moreover, oxygen concentrations below 4 mg l^{-1} are frequently observed.

In 1987 the Danish Parliament decided – in what is the hitherto largest river restoration project in Europe – to restore the lowermost 18 km of the Skjern river system, thereby re-establishing 2,100 ha of meadows, reed swamps, meandering watercourses, a lake and several ponds (8). The aims are to enhance the self-purification properties of the river system in order to improve environmental conditions in Ringkjøbing Fjord, and to improve habitat quality within the river and the riparian areas and to re-create recreational areas.

Experience from other Danish streams shows that remeandering leads to reduced sediment and nutrient transport as a result of reduced bank and bed erosion, as well as to a higher frequency of flooding, a higher retention capacity and a higher denitrification rate in adjoining riparian areas (11)(12)(13)(14)(15). Remeandering also leads to increased macrophyte and macro invertebrate species diversity and number (16)(17).

This study presents and discusses past, present and future transport of suspended sediment (SS) and total phosphorus (TP) in the lower part of the Skjern river system in relation to the planning, design and expected effects of the coming restoration project.

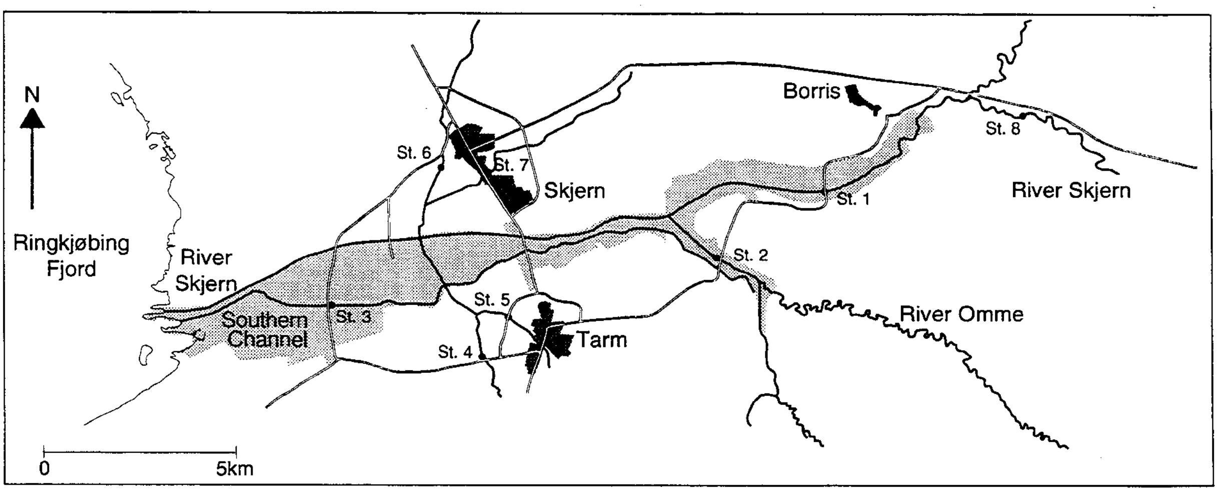

Figure 1. The project area in the Skjern river system (hatched) and location of monitoring stations. The four smaller tributaries in which stations 4, 5, 6 and 7 are located all drain into the Southern Channel.

Study area and methodology

Study area

The river Skjern watershed (2,490 km^2) is located in the western part of Jutland, Denmark (Fig. 1). The watershed has a gentle topography with elevation ranging from 0 to 138 m a.s.l. The soils of the upper parts of the watershed consist of sandy and loamy tills from the Sahle and Weichsel glaciations, while those of the stream valleys and the lower parts of the watershed are postglacial, alluvial sandy and loamy deposits. Of the total watershed area, 75% is cultivated, 13% forested, 7% is undisturbed countryside and the remainder is urbanized (18). The soils in the central restoration area (approx. 11 km^2) located between the river Skjern and the southern channel upstream of station 3 are peat soils and organic matter-rich alluvial loamy and sandy soils containing 5–6% pyrite (19). As a result of drainage and cultivation, the ground surface has settled by as much as 1.5 metres (20). Restoration will therefore transform part of this area into a shallow lake and the rest into reed swamps and periodically flooded meadows.

Methods

Field sampling at monitoring stations 1 to 8 was carried out between November 1993 and January 1996 (Fig. 1 and Table 1). At the discrete sampling sites (St. 3, 4, 5, 6 and 7) water samples (1,000 ml) were collected manually at approximately monthly intervals using a depth-integrating water sampler (21). At the continuous sampling sites (St. 1 and 2), water sub-samples (500 ml) were taken every four hours (2 sub-samples per bottle) using automatic ISCO samplers. These water samples were pooled as weekly samples except during storm flow events, when they were pooled as daily samples. At stations 1 and 2, additional water samples were collected manually every 2 weeks as traditional dip samples. The use of two different sampling strategies enabled evaluation of the accuracy of estimating SS and TP transport on the basis of discrete sampling and intensive monitoring.

Table 1. Catchment size (km^2) and sampling programme at each monitoring station: c = continuous measurement of water stage and intensive water sampling strategy; d = discrete, approximately monthly manual water sampling. Discharge was measured approximately monthly at each station.

	St. 1	St. 2	St. 3	St. 4	St. 5	St. 6	St. 7	St. 8
Catchment	1,554	612	250	45	35	80	44	1,055
Sampling programme	c	c	d	d	d	d	d	c*

* Only water stage measured, not SS and TP

Use of the continuous, automatic sampling method necessitates that the concentration measured at the intake to the automatic sampler is representative of the whole river cross section. Experiments were therefore performed to test that this criterion was fulfilled. Thus on eleven occasions distributed throughout the year in the river Omme and 10 occasions in the river Skjern, 2–7 depth-integrated samples were collected at various locations in the river cross section. In addition, a single point sample was collected approximately 20 cm below the water surface in the same profile as the intake to the automatic sampler.

The water samples were kept cold and dark until analysed in the laboratory for SS and TP. The SS concentration in the water was measured by filtering 500 ml samples through pre-combusted and pre-weighed 1.2 μm Whatmann GFC glass micro filters. The TP concentration was determined by converting TP to dissolved reactive phosphorus (DRP) by acid persulphate digestion in an autoclave as described by (22) and thereafter determining DRP colorimetrically using the method of Murphy and Riley (23). Particulate inorganic matter (PIM) was determined following combustion of SS at 550°C. Particulate organic matter (OM) was determined as SS–PIM.

Water stage was recorded continuously with data loggers at stations 1, 2 and 8. Discharge was measured approximately monthly at all stations. Daily discharge at the continuous monitoring stations was calculated by stage-discharge relationships adjusted for seasonal growth of macrophytes. Daily discharge at the discrete monitoring stations was calculated by discharge-discharge regression relations to station 8, for which continuous records on water stage and discharge are available back to 1921. The discharge time series for stations 1 and 2 were extended by regression to station 8, thereby enabling construction of a long time series for total discharge for the whole river system. Correlation coefficients (R^2) for the discharge-discharge relationships varied between 0.885 and 0.972 ($P<0.001$). SS and TP transport were calculated as the product of daily SS and TP concentrations and the corresponding discharge. Daily SS and TP concentrations from discrete sampling were obtained by linear interpolation between measured concentrations (24).

Since SS and TP transport measured at stations 4 to 7 is included in that measured at station 3 (Fig. 1), total transport to the restoration area is the sum of that calculated for stations 1, 2 and 3.

To assess inter-annual variability in SS and TP transport, the 2–year time series was extrapolated by establishing the regression between discharge and SS and TP concentrations and then estimating transport using the long discharge time series for station 8.

Results and discussion

Hydrology

Precipitation in the river Skjern watershed was record high in 1994, being 18% above the 31–year mean; in contrast, 1995 was a relatively dry year, precipitation being 9% below the 31–year mean (Table 2).
The discharge response to precipitation was quite similar at the two continuous sampling sites, there being m-arked seasonal variation with the bulk of discharge taking place during winter and early spring (Fig. 2).

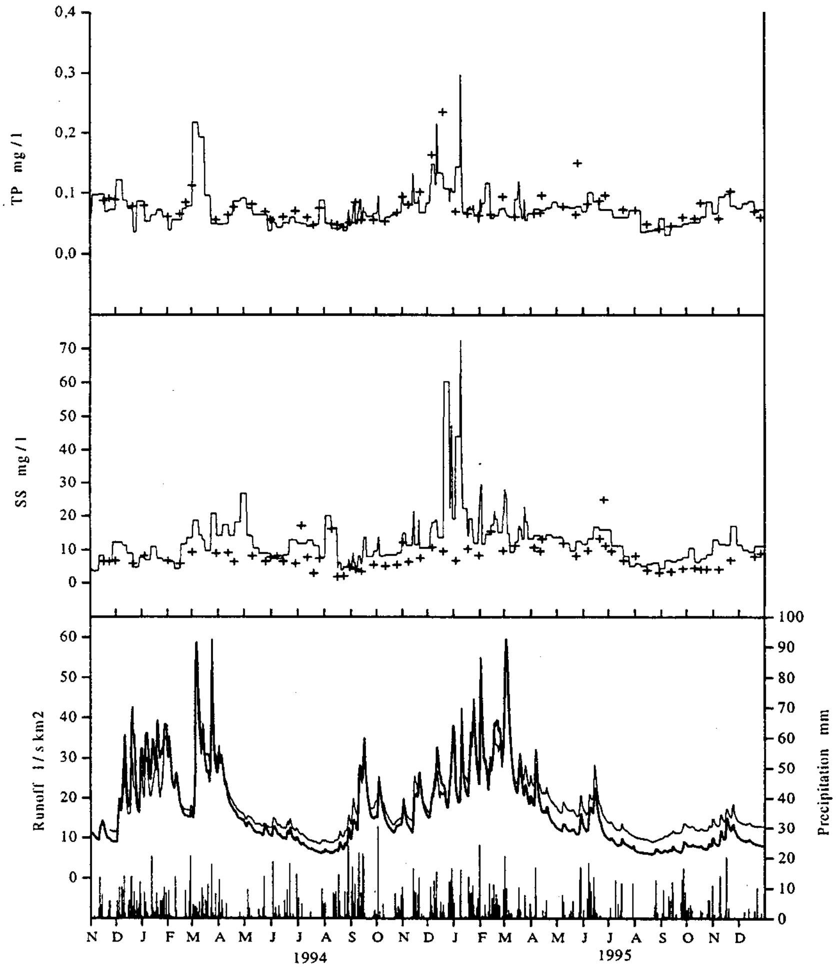

Figure 2. Daily mean discharge and precipitation at station 1 (thin line) and station 2 during the period 1993–95 shown together with SS (station 1) and TP (station 2) concentration determined by both discrete sampling (+) and intensive monitoring (—).

Even though precipitation was low in 1995, total discharge was above average (Table 2), thus indicating that most of the discharge derives from groundwater. The statistics in Table 2 are based solely on data from 1964 onwards because intensive drainage and channelization of the catchment in the early 1960s altered the precipitation-runoff characteristics at that time by reducing the response time (25).

Table 2. Calculated daily mean discharge at the outlet of the Skjern river system (catchment area 2,490 km²). Precipitation is the average for a 40x40 km grid covering the central part of the catchment.

Discharge $l\ s^{-1}\ km^{-2}$					Precipitation mm		
1994	1995	Mean (1965–95)	Min. (1965–95)	Max. (1965–95)	1994	1995	Mean (1961–90)
19.2	18.1	15.8	5.5	130	1,052	812	892

Sampling strategy

There was no statistically significant difference (tested as paired observations) between the concentration determined as the mean of a number of depth-integrated samples in a river cross section and those measured by point sampling in the same cross section at the intake to the automatic sampler (Table 3). Neither was there any systematic correlation between discharge and the concentration difference between the two methods (25). As the depth-integrating sampler samples down to a depth of 10 cm above the bottom, concentrations obtained by sampling at a distinct position in the cross section are representative of the whole cross section down to 10 cm above the bottom. Suspended bed material in the zone 0–10 cm above the bottom is allocated to the bed load, and is not dealt with further in this study.

Table 3. Corresponding values of SS, inorganic content in SS and TP in depth-integrated samples (d.i.) and point samples (p.) shown together with daily discharge for the river Skjern. Number of depth integrated samples taken in each river cross section and standard deviation are given in parentheses.

Date	Discharge ($l\ s^{-1}$)	Sampling method	SS ($mg\ l^{-1}$)	Inorganic SS ($mg\ l^{-1}$)	TP ($mg\ l^{-1}$)
940126	38,235	d.i. (7)	6.9 (0.37)	4.4 (0.44)	0.087 (0.055)
		p.	7.7	4.2	–
940209	35,552	d.i. (3)	4.9 (0.25)	3.1 (0.17)	0.055 (0.017)
		p.	5.2	3.3	0.056
940223	26,493	d.i. (3)	7.9 (0.53)	3.9 (0.53)	0.070 (0.0015)
		p.	7.5	3.9	0.074
940322	44,172	d.i. (7)	7.0 (0.59)	4.5 (0.70)	0.070 (0.0033)
		p.	6.5	4.2	0.064
940504	22,701	d.i. (7)	9.9 (0.36)	5.2 (0.56)	0.077 (0.0044)
		p.	9.7	4.7	0.075
940622	22,352	d.i. (2)	6.7 (0.14)	3.2 (0.28)	0.068 (0.024)
		p.	6.6	–	–
940804	13,986	d.i. (3)	3.1 (1.01)	1.5 (0.68)	0.051 (0.0038)
		p.	4.0	1.7	0.049
941005	38,049	d.i. (3)	5.4 (0.40)	3.2 (0.69)	0.073 (0.0012)
		p.	5.4	3.2	0.070
941207	33,093	d.i. (7)	11.6 (0.35)	7.1 (0.22)	0.099 (0.0023)
		p.	10.8	6.2	0.102
950202	85,574	d.i. (7)	15.2 (0.42)	9.7 (0.46)	0.130 (0.0042)
		p.	16.4	–	0.129

SS concentrations determined by discrete sampling (sampling interval 14 days) were generally lower than those determined by intensive sampling (Fig. 2). The high SS concentrations measured during the periods of high runoff at the end of 1994 with intensive sampling were not detected using the discrete sampling strategy. Annual SS transport determined by intensive sampling was 38–77% higher than that determined by discrete sampling (Table 4). Both sampling strategies yielded roughly the same annual TP transport, however.

Table 4. Annual SS and TP transport estimates at stations 1 and 2 based on both intensive monitoring (int.) and discrete sampling.

	SS (tonnes yr^{-1})				TP (tonnes yr^{-1})			
	St. 1 int.	St. 1 discrete	St. 2 int.	St. 2 discrete	St. 1 int.	St. 1 discrete	St. 2 int.	St. 2 discrete
1994	12,050	6,820	2,940	2,500	69.4	65.2	28.5	29.4
1995	13,190	8,260	2,570	1,470	78.6	72.1	23.8	21.5

The discrete sampling strategy entails the risk of failing to detect fluctuations in SS and TP concentrations (24). During periods of high discharge, SS transport will be extraordinarily high and particle size large (26). Large particles are generally low in phosphorus content as phosphorus is mainly associated with fine particulate solids (27)(28). In contrast to large particles, though, the concentration of fine particulate material is not determined by the transport capacity of the stream (29). The TP concentration will therefore vary less than the corresponding SS concentration, and the risk of underestimating transport when using discrete sampling will thus be higher for SS than for TP.

SS and TP transport in the Skjern river system in 1994 and 1995

Despite the fact that runoff was lowest in 1995, annual SS and TP transport was almost identical in both 1994 and 1995 (Tables 5 and 6). This is attributable to the relative importance of the high transport rates seen during the high discharge events in January to April 1995 (Fig. 2).

The area-specific TP losses for the whole system are comparable to those reported in the Danish Nationwide Aquatic Monitoring Programme (27) for catchments with low point-source pollution.

Table 5. Annual SS transport in the lower Skjern river system. Percentage organic matter (OM) is given in parentheses. Total transport from the river system as a whole is the sum of transport at stations 1, 2 and 3.

	1994		1995	
	tonnes yr^{-1}	kg ha^{-1} yr^{-1}	tonnes yr^{-1}	kg ha^{-1} yr^{-1}
St. 1	12,050	78 (47% OM)	13,190	85 (46% OM)
St. 2	2,980	49 (40% OM)	2,570	42 (45% OM)
St. 3	2,490	100	1,940	78
St. 4+5+6+7	750	37	710	35
Whole system	17,520	72	17,700	72

Table 6. Annual TP transport in the lower part of the Skjern river system. Percentage dissolved reactive P (DRP) is given in parentheses. Total transport from the river system as a whole is the sum of transport at stations 1, 2 and 3.

	1994		1995	
	tonnes yr^{-1}	kg P ha^{-1} yr^{-1}	tonnes yr^{-1}	kg P ha^{-1} yr^{-1}
St. 1	69	0.5 (22% DRP)	79	0.5 (16% DRP)
St. 2	29	0.5 (27% DRP)	24	0.4 (30% DRP)
St. 3	23	0.9	20	0.8
St. 4+5+6+7	9	0.4	8	0.4
Whole system	121	0.5	123	0.5

Organic matter accounted for 40–47% of the SS transport (Table 5). The DRP fraction of TP was somewhat higher at station 2 (27–30%) than at station 1 (16–22%), probably due to discharge from fish farms upstream of station 2 on the river Omme. Discharge of TP from fish farms thus accounted for 48% of TP transport at station 2 in 1995, while the corresponding figure for the Skjern river system as a whole was only 22% (30).

The station network enabled us to assess SS and TP losses from the central restoration area located just upstream of station 3, the assumption being made that specific SS and TP losses from the part of the catchment area of station 3 lying upstream of the central restoration area was the same as that actually measured at stations 4 to 7 (Tables 5 and 6). The specific SS and TP losses from this area were 939–1,391 kg SS ha^{-1} yr^{-1} and 9.2–10.5 kg P ha^{-1} yr^{-1}, respectively (Table 7), values which are extremely high for Denmark (27).

The high losses are attributable to decomposition and consequent land subsidence as a result of cultivation of the organic soils in the area in question followed by leaching of particulate organic matter, nutrients and iron compounds. The SS losses are thus believed to consist mainly of organic matter, although this has not been measured.

Table 7. Annual SS and TP losses from the central restoration area. Values are tonnes yr^{-1} with kg ha^{-1} yr^{-1} in parentheses.

	1994		1995	
	SS	TP	SS	TP
Sum St. 4+5+6+7: 204 km^2	750 (37)	9.0 (0.4)	710 (35)	7.9 (0.4)
Upscaled to 261 km^2 *)	960 (37)	11.5 (0.4)	907 (35)	10.1 (0.4)
St. 3: 272 km^2	2,490 (92)	23.0 (0.8)	1,940 (71)	20.2 (0.7)
Diff. = Central area 11 km^2	1,530 (1391)	11.5 (10.5)	1,033 (939)	10.1 (9.2)

*) 272 km^2 - 11 km^2 = 261 km^2

Establishment of a long time series for SS and TP transport

Transport of SS (and TP) is not a straightforward function of stream hydraulics e.g. discharge, but is partly determined by the availability of material for transport within the river channel and its watershed, the resultant relationship being hysteretic (28). During low flow situations, particulate matter deposits build up on the stream bed (e.g. in macrophyte patches and pools) and in the riparian zone. During the early stage of storm flow (on the rising limb of the hydrograph), SS (and TP) concentrations will therefore be higher than during later stages. Further, the accumulated pool of particulate matter becomes exhausted during autumn and winter (28). We found that the best possible model, which explained 27–74% of the variation in concentration, was one that included discharge, time of year (month) and information on whether or not the hydrograph was in the rising stage (the hydrograph was divided in base flow and storm flow using the base flow index method (31). The model for SS concentration in the river Skjern is given in [1]:

$$\log C_{SS} = -4.41 + 0.711 \log Q_{ij} + \alpha_i + \beta_j \quad r^2 = 0{,}485 \quad P<0.001 \qquad [1]$$

where i = month (1,2,.. ..,12), j = 0 (base flow) or 1 (storm flow), C_{SS} = concentration of SS, Q_{ij}= daily mean discharge, α_i denotes the effect of time of year and β_j denotes the effect of hydrograph slope.

The model was used to calculate SS and TP transport over the 31–year period 1965–95 based on the SS and TP concentration estimates. Similar equations have been compiled for bed load transport by Petersen and Hasholt (26) based on measurements of bed load during the period 1993–95.

Annual total transport (bed load and SS) was calculated to be 28,153 t, of which SS transport constitutes 12,220 tonnes or 43%. Annual TP transport was calculated to be 100 t. Yearly transport during the 31–year period ranged from 49% to 169% of mean annual SS transport and from 54% to 162% of mean annual TP transport (Table 8).

TP loading from the municipalities, industry and fish farms has been reduced 65% during the last decade corresponding to a 33% overall reduction in TP loading of the river system (18). The calculated TP estimates thus do not reflect the true TP transport during the 31–year period. However, the purpose of constructing the time series is to analyze naturally occurring inter-annual variation in order to predict future TP loading, and this is most convincingly done on the basis of recent data (1993–1995) since TP loading from point sources has reached a level from which a further marked reduction cannot be anticipated.

Table 8. Bed load (Petersen and Hasholt, 1995), SS and TP transport in the lower part of the Skjern river system during the period 1965–95. Standard error of the estimates is given in parentheses.

	Bed load tonnes yr^{-1}	SS tonnes yr^{-1}	TP tonnes yr^{-1}	Bed load kg ha^{-1} yr^{-1}	SS kg ha^{-1} yr^{-1}	TP kg ha^{-1} yr^{-1}
Min. (1976)	8,390	6,010	54	34	25	0.2
	(200)	(300)	(2)			
Max. (1981)	25,310	20,680	162	103	84	0.7
	(300)	(900)	(5)			
Mean (1965–95)	15,930	12,220	100	65	50	0.4
	(800)	(500)	(3)			

SS transport in the river Skjern system has been estimated twice previously based on short measurement periods and discrete sampling. Thus Christensen *et al.* (32) reported an annual SS transport of 24,000 tonnes while Hasholt and Jacobsen (33) reported an annual value of 14,300 t.

Effects of restoration on SS and TP transport

The planned restoration will create a shallow lake, wet meadows and a number of small ponds, and will allow frequent flooding of riparian areas thereby augmenting the retention capacity of the river system (34). The expected increase in active retention area as a result of restoration as estimated by the Danish Land Development Service and COWI Consult (19) is shown in Table 9 together with the area from which SS and nutrient loading will be reduced due to the change in land use.

Table 9. Expected increase in retention area and area of changed land use as a result of restoration shown together with estimated retention rates and resulting retention.

	Increase in area ha	SS Retention rate kg ha^{-1} yr^{-1}	TP Retention rate kg ha^{-1} yr^{-1}	SS Retention tonnes yr^{-1}	TP Retention tonnes yr^{-1}
Reed swamp, frequently flooded	290	1,000–15,000	2–20	290–4,350	0.6–5.8
Lake, ponds	605	150 x P_{ret}	0.07 x part.-P transp.	840	5.6
Cultivated land out of production[1)]	460	50	0.3 9.9	23	0.1
Central restoration area	1,100	1,150		1,300	10.8
Sum				2,450–6,500	17.1–22.3
Transport to Ringkjøbing Fjord from the river Skjern watershed				12,220	2100

[1)] That part of cultivated land not included in the central restoration area.

We have estimated retention rates for the different areas based on recent Danish studies (11, 15, 34) (Table 9). Relevant retention modes are: (a) Permanent retention by sedimentation of SS and particulate P in the shallow lake and on the flooded riparian areas; (b) Temporary retention within the river, which primarily occurs in the summer months, thereby having a positive effect on water quality of Ringkjøbing Fjord by limiting nutrient availability during the algal bloom season (15)(35).

The rate for P retention for frequently flooded areas is conservative, the reported values ranging from 15 to 94 kg P ha^{-1} yr^{-1}. However, these rates are measured on flooded areas having a width of approx. 100 metres, whereas the average width of the flooded areas of the river Skjern will be 500 metres. Sedimentation of particulate P has been shown to decrease exponentially with distance from the stream (36). P retention in the new shallow lake could not be estimated on data from similar Danish lakes, however, as most other Danish shallow lakes are characterized by internal P loading due to former point-source inputs (37). The internal P loading renders estimation of P retention by a mass balance approach impossible. The equation of Vollenweider (38) [2] was therefore used assuming a mean hydraulic retention time of 2 days (T_w = 2/365 year) (19), the equation previously having been shown to be applicable to Danish lakes (39).

$$P_{ret} = 1 - 1 / (1 + T_w^{1/2}) \qquad [2]$$

where P_{ret} denotes that fraction of particulate P transport that will be permanently retained in the lake.

The retention rate for SS in the shallow lake and ponds was calculated assuming that the SS:particulate-P ratio will be the same in the deposited material as in the wash load.

Taking cultivated land out of production and cessation of active drainage in the central restoration area will also reduce SS and TP losses. For cultivated land taken out of production, the SS and TP retention rates are the difference between the average catchment loss of SS and TP and typical rates for uncultivated areas (27). In the case of the central restoration area, present losses are expected to cease almost completely once pumping of drainage water ceases and the area is flooded. Retention rates for this area are given as mean values of the rates measured in 1994 and 1995.

The estimated total increase in SS and TP retention as a result of restoration corresponds to 37% and 20%, respectively, of mean transport during the 31-year period studied (Table 8). The reduction in SS and TP loads will be accompanied by a parallel reduction in ochre loading due to retention, as well as a significant reduction in nitrogen loading due to denitrification (11)(15)(34). The reduction in N load due to the restoration project (increase in denitrification and cessation of cultivation) has been estimated at 270–600 t N $year^{-1}$, corresponding to 5–12% of the annual riverine N load (18).

Based on bioassays, primary production of phytoplankton is reported to be N-limited in the northern part of Ringkjøbing Fjord and alternately N- and P-limited adjacent to the river Skjern outlet (40). Measurements of N and P concentrations reveals that primary production is potentially P-limited in the beginning and the end of the phytoplankton growing season (i.e. in April, May and October), whereas N is the limiting nutrient during late May to September (41)(42). The planned restoration leading to an additional reduction in nutrient loading will therefore improve water quality in the fjord. In addition, remeandering the river course and creating lakes and ponds will increase physical variation, thereby improving habitat quality and diversity within the river (16)(17). The study stresses the importance of considering streams and riparian areas as an entity when evaluating the effects of restoration activities.

Acknowledgments
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The importance of the riparian ecotone and hydraulics for stream restoration

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Abstract

The effect of riparian ecotone functional complexity and stream hydraulics on an upland river biota has been analysed. The amount of nutrients retained by bottom sediment was lowest on a sandy substrate, and the highest in wetland bays. A stream bed covered by *Berula erecta* had about 3 times higher retentive nutrient capacity than did a sandy substrate. The trophic potential of CPOM, measured as total protein, was significantly correlated with the amount of deposited CPOM, and depended on stream order. Both invertebrate and fish biomass in the upland river were significantly dependent on geological factors (calcium/bicarbonate system). The fish biomass, diversity and species richness were highest in pools, lower in riffles and the lowest in the run/transition zone. Biomass of macroinvertebrates was uppermost at an intermediate riparian ecotone complexity with adequate organic matter supply and light access. The fish biomass followed the same trend, being low in heavily shaded areas and in open channels without riparian vegetation, but highest in ecotones of intermediate complexity. The above results indicate that the riparian ecotone structure and the heterogeneity of the stream channel may regulate biodiversity, productivity and nutrient retention to a great extent in the fluvial corridor.

Introduction

The dynamics of a river ecosystem are expressed by nutrient spiralling and self-purification, mostly dependent on climate, geomorphology and biotic complexity. The first of these components is stochastic and cannot be regulated, so progress in river restoration should be based on understanding the role of the riparian/floodplain ecotone, hydraulics, and biotic interactions within the trophic spiral (1)(2)(3)(4).

River systems until recently have been regulated by engineering works without consideration of biotic processes (5). Approaches to restoration now focus upon such processes, such as enhancement of nutrient retention in the stream channel, control of light access to the stream by regulation of riparian canopy (6) and the well-presented Petersen *et al.* (7) idea, that in an uniform agricultural catchment, river valley engineering should be focused on reduction of diffuse pollution by the restoration of a riparian/floodplain zone.

River restoration, in order to be successful, needs to address the complexity of ecological interactions in a system characterised by a hierarchy of controls: from hydraulics through ecotonal to biological patches. This paper addresses the complexity through an examination of nutrient spiralling and the factors affecting it both temporally and spatially.

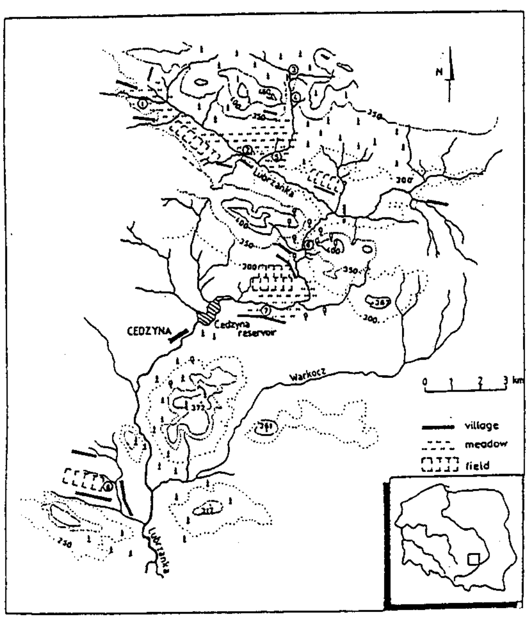

Figure 1. The study area: the Lubrzanka River (Central Poland).

Study area

The Lubrzanka River (Fig.1) is a tributary of the Nida River system (central Poland). The 8 study sites are situated in the upper part of the catchment, over a distance of 22 km from the source. The detailed characteristics of the river are provided by Zalewski et al. (3). Some data presented here (on phosphorus uptake) originate from another hardwater stream. This is the Tresta creek, a 1.3 km long 1st order stream, being the tributary to Sulejów Dam Reservoir on the Pilica River (central Poland).

Materials and methods

CPOM distribution and total protein contents

Bottom samples of coarse particulate organic matter (CPOM) were collected from November 1989 to May 1992 by means of Surber sampler (500 cm^2). At each station between 7 and 12 samples were collected. The major allochthonous components (leaves and woody debris) and autochthonous species of macrophytes were segregated and homogenised. Three subsamples from each component sample were analysed for total proteins using the method of Lowry *et al.* (8).

Experimental estimation of phosphate uptake

The uppermost sediment layers were collected from different riverine habitats by a bottom sampler. Known amounts of the suspension were placed in glass-stopered bottles (300 cm^3) filled with natural river water, with soluble reactive phosphorus (SRP) concentrations in range 20 - 40 $\mu g\ l^{-1}$, or the same water with initial P concentration increased to 200 $\mu g\ l^{-1}$ by adding Na_2HPO_4 solution. Bottles filled with water without added sediment served as blanks. The bottles have been exposed in the river channel, maintaining natural temperature and light conditions during exposition period (24 hours). SRP concentrations in filtered water after exposition were determined spectrophotometrically using the molybdenum blue - ascorbic acid method, according to (9).

Benthic fauna

Macrobenthos was collected by means of Surber sampler (500 cm^2), and a micromacrofauna shovel (150 cm^2) (10 over three years). Samples were taken to a sediment depth of 3 cm. At each station 10-15 samples were taken, every 10-12 weeks. All stations were mapped to record the various substrate types, aquatic and riparian vegetation, erosial or depositional areas, and the exact position of sampling sites. The animals were assigned to a particular functional feeding group according to the classification given by (11).

Fish.

For the analysis of fish distribution the Lubrzanka River channel was divided into several subsets - riffle, run and pool habitats, associated with different community types of riparian vegetation - grass, shrubs and trees. To determine each habitat type the Transect Line Intercept Method was used and detail bathymetric maps were prepared. Velocity measurements were made with electronic velocity meter. Light access to the habitats was measured along the transects (0.1 m above water surface) using the photometer ($\mu Ecm^{-2}s^{-1}$). Measurements were monitored for 96 habitats, seasonally, during 3 years. Habitats were electrofished using a pulsed DC apparatus. Fish density and biomass were estimated from regression between the percentage of fish captured during the first electrofishing and the logarithm of mean weight of individuals (12).

Results

Riparian ecotones and nutrient retentiveness in the stream channel

Phosphorus uptake by bottom sediments in a first order stream (Fig. 2), at elevated SRP concentration showed much more higher P-consumption abilities in pools and riparian (bog forest and meadow) ecotones, when compared to a sandy bottom of the channelized river bed. These data demonstrate the extent to which a diversified ecotone structure may prevent eutrophication of lower courses and reservoirs by reducing external biologically available phosphorus input from their upper reaches and catchments. It is noteworthy that the site-specific differences were more pronounced in spring or autumn than in summer.

Hydraulics as a factor controlling the autochthonous and allochthonous organic matter deposition in the stream channel

In the Lubrzanka River the average amount of allochthonous organic matter is about twice as much as the autochthonous. The amount of coarse particulate organic matter (CPOM) declines downstream. In the low order stream the amount of CPOM accumulated on the stream bed decrease inversely with the current velocity (Fig. 3). The total protein accumulation of organic matter deposited in the stream channel can be considered as an indicator of the importance of the microbial community in the nutrient transfer across the trophic spiral. Total protein amount has varied from 0.7 to 332 g m^{-2}.

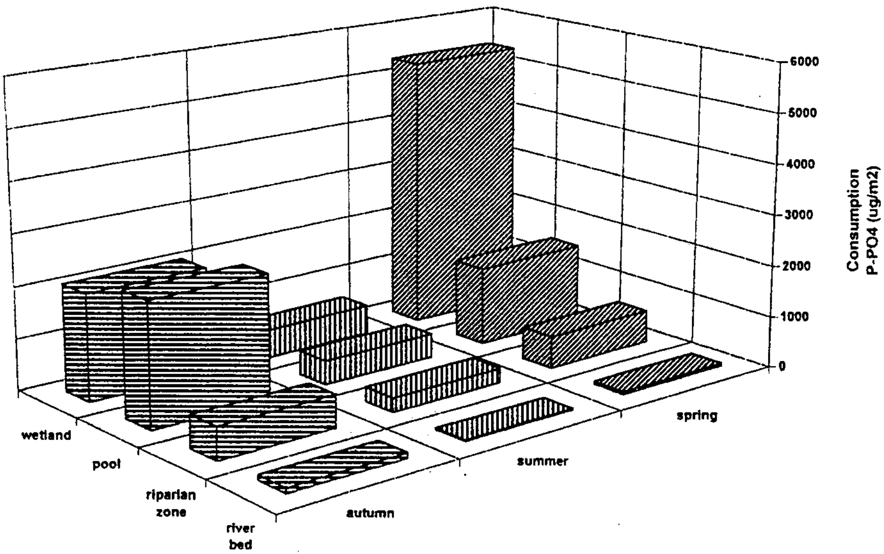

Figure 2. P-PO_4 consumption by bottom sediments in the various ecotone types.

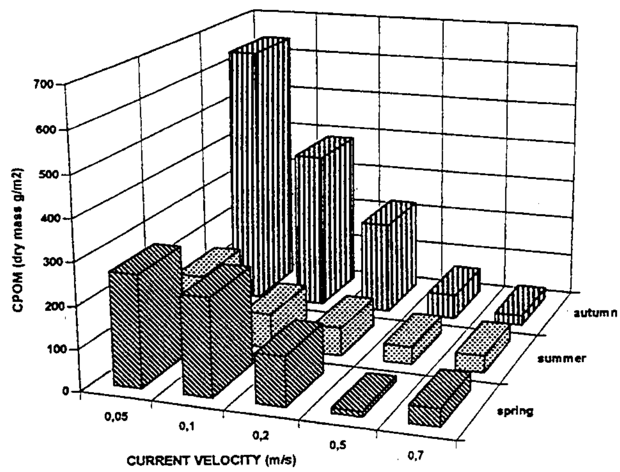

Figure 3. Changes of the amount of coarse particular organic matter (CPOM), related to the current velocity at st. 3.

The importance of woody debris accumulation and current velocity on the benthos community

The maximum amount of woody debris in the stream channel was about 350 g m^{-2}, but benthos density did not exceed 2000 ind. m^{-2} and no significant relation between retention of woody debris and benthos density was found. However, the results of principal component analysis (PCA) demonstrated strong correlations between various trophic components and functional feeding groups of benthic fauna e.g. a significant correlation between CPOM and shredders ($R=0.68$; $p<0.04$), as well as relationships among collector - gatherers, collector - filterers, scrapers, and either algal communities and FPOM (Fig. 4).

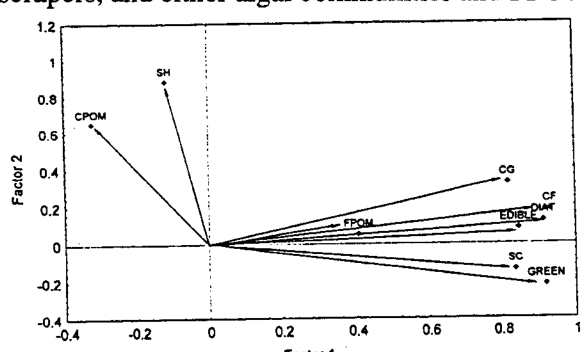

Figure 4. Principal component analysis - the relationships between functional feeding groups of benthic fauna and various sources of food in the forested section of the river (st.3,4,5).

Effect of hydraulics and channel morphology on fish distribution in the stream channel
The effect of current velocity and river channel morphology on the fish distribution pattern was tested at station 5. Fish biomass, species richness and diversity displayed a similar pattern in relation to habitat characteristics. All parameters were lowest in the runs, but biomass was highest in the pool. This suggests that habitat structure is important for large mature specimens and for the continuity of the population.

Light access to the stream channel as a factor limiting fish biomass and diversity
Input of solar energy to the river channel can be an important control of energy pathways in the stream through generation of autochthonous organic matter, and as a factor modifying the fish distribution by behavioural interactions connected with the availability of hiding places. There was a significant correlation between percentage of canopy cover and light access to the stream (R= 0.828; $p<0.0001$) (13). However, the relation between stream insolation and fish distribution, biomass and diversity was parabolic (Fig. 5). At optimal light, between 300 and 600 $\mu Ecm^{-2} s^{-1}$, average fish biomass was about 2 g m^{-2}, at several stations up to 4.5 g m^{-2}. In shaded sections, where light was below 300 $\mu Ecm^{-2} s^{-1}$ and at open sections, where light was above 600 $\mu Ecm^{-2} s^{-1}$ the fish biomass was approximately 1 g m^{-2}, nearly 2-3 times lower than at optimal light.

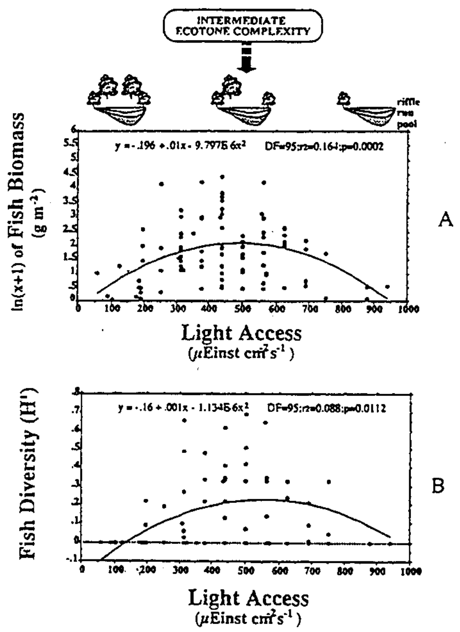

Fig. 5. The relationship between canopy cover and the light access to habitat, estimated for the Lubrzanka River.

The benthic invertebrates distribution pattern as a limiting factor for the fish community
The three-years data, from 8 stations in the Lubrzanaka River, have shown an distinctive phenomenon. At the stations with the highest primary productivity and fish biomass, the lowest summer benthos biomass was noticed (taking into account the peak emergence of adults). The comparison of data from all stations confirmed significant, negative correlations (R = 0.696; $p<0.04$) between an annual average fish biomass and summer changes of benthos density (percentage of change from the level of average annual benthos density) (Fig. 6).

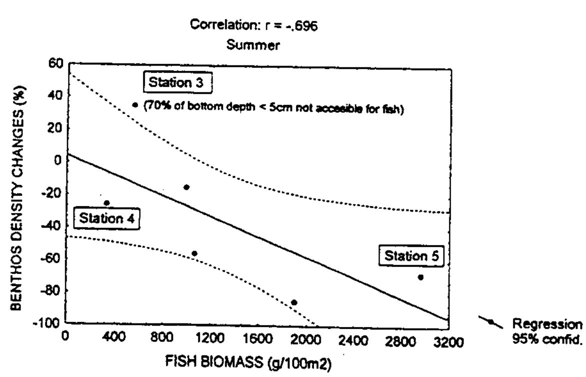

Figure 6. The correlation between annual average fish biomass (g $100m^{-2}$) and summer decline of benthos density (indiv. m^{-2}).

Only at station 3 with extended shallow habitats, which are not accessible for fish (70% of bottom surface below 5 cm depth), and with fish biomass about 40-60 kg h^{-1}, there was approximately 40% increase of benthos density in summer. But at the stations with the highest fish biomass (200-300 kg h^{-1}) a decline of benthos density between 60-80% was observed. These data imply a "cascading effect", whereby during summer, when the fish metabolic activity and consumption increased several times, a significant depletion of invertebrate density occurred.

The relations between calcium concentration and biomass of invertebrate and fish communities
In the Lubrzanka River, both fish and invertebrate density are significantly correlated with concentration of calcium/bicarbonate system (Fig. 7). The one of explanation might be the differences in general path of nutrient flow. In the Lubrzanaka River prevailing algal communities induce fast nutrient spiralling and calcium can be a factor determinating rate of phosphorous trapping.

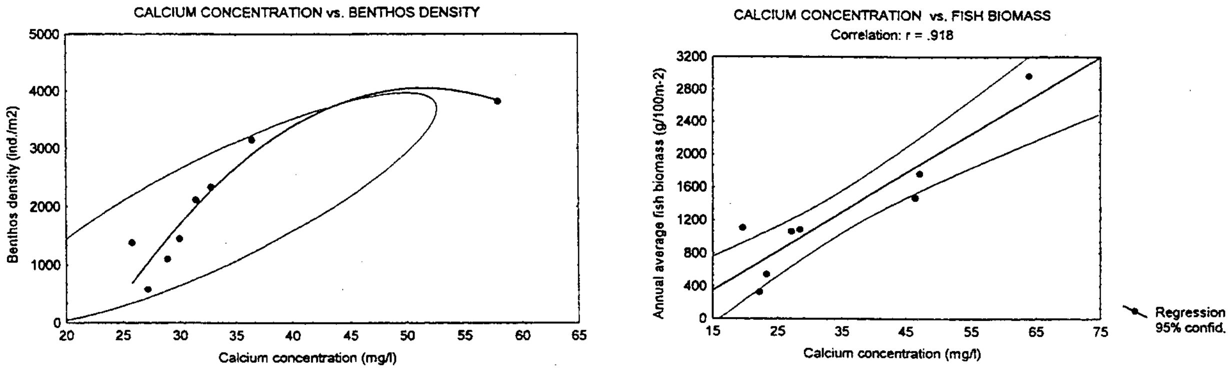

Fig. 7. The relationships between calcium concentration and the annual average benthos density (A), and the annual average fish biomass (B).

Discussion

River ecosystem quality (REQ), from the point of view of sustainable use of resources, can be measured by structure - density, biomass, spatial and temporal biodiversity; and function - nutrient transport, transformation and biotic production. All these parameters influence the carrying capacity, resistance and resilience of the ecosystem. The processes are dependent to a great extent on the form and intensity of catchment use, which influence water quality at any given stretch of the river continuum, but indirectly also the water quality in continually connected biota, e.g. reservoirs, lakes and coastal zones. On the other hand, the diverse structure of the river valley and water quality determine extremely intensive dynamics of nutrients and particulate organic matter, of both auto- and allochthonous origin. In consequence biodiversity of the system, and directly influence cultural and aesthetic values of the landscape, which in turn is the condition *sine qua non* of recreation. Most of those components are connected by multi-directional feedbacks, e.g. complexity of the riparian ecotone at the river valley positively influences water quality by intensification of deposition of organic matter and nutrients on the floodplain and reduction of non-point sources pollution (2). Riparian ecotones function as filters for nutrients, pollutants, and reduce the catchment erosion. Their filtering efficiency may reach values even above 80 %. However if discontinuity appear the effect of „bypassing" may diminish above positive process (14). When banks are unprotected, soil erosion increases turbidity and siltation through rapid run-off from agricultural areas (15). In such situations also pesticides are transferred directly from fields to the river and can be accumulated in food webs. The proper structure of a land-water buffer zone allows not only the retention of nutrients and pesticides transported to a river during rainy periods, but also through optimization of instream primary productivity, it may accelerate nutrient spiralling (sensu 16), and thus increase the self-purification ability of the river (6). The filtering capacity of riparian ecotones, together with their role in the enhancement of fish production by accelerating nutrient and energy transfer through food chains, reduces the amount of organic matter transported to reservoirs or estuaries, thus slowing down their eutrophication rate.

According to (17) the primary and secondary succession of stream/river biota is mostly determined by the pattern of organic matter supply from riparian/floodplain ecotones. Stable trophic enhancement appears as the effect of two processes, first the sequential allochthonous organic matter supply due to the differences in timing of leaves falling to the river channel, and the second determined by differences in decomposition rate of different leaves (e.g. alder vs. spruce). Thus, nutrient status of riparian vegetation, which depends on nutrient supply from the catchment, may seriously influence energy transfer through a stream's food web.

Insolated but diversified parts of the stream possess higher potential for trapping nutrients (18), as a result of their demand for biotic productivity, detritus accumulation and well-developed consumer communities. On open bottoms covered by water plants or epipelic algal communities, high intensity of light may increase their production and demand for phosphorous, and increase the depth of oxygenated sediments, which additionally reduce the release of phosphorous, but also the denitrification rates (19). However when a canopy does not exist complete blocking of the channel by macrophytes may occur and create flooding problems. Sometimes shaded stream sections may also exhibit high efficiency of phosphate uptake, when overgrown by a microbial - algal community connected with mucillaginous thalli of *Batrachospermum moniliforme* Roth. During its vegetation period, this community which cannot serve as a direct food source for invertebrates, reduce phosphorous availability for other, potentially edible algal communities (6). This does not allow for the production of higher tropic levels, decreasing finally their abundance, diversity, and the whole community resilience in cases of periodic disturbances.

Riparian ecotones influence the amount of food provided to fish both directly and indirectly. The quantity of terrestrial prey that enters the river depends directly on the ecotone structure, while the aquatic food resources depend indirectly on it, through both allochthonous organic matter supply and control of primary production through the light regime. According to (18), in a natural catchment the amount of phosphorus transferred by emerging insects can be approximately half that provided from the natural catchment to the stream. Terrestrial insects may provide the major portion of fish food in low order streams (21)(22). However it has been suggested by some authors that fish biomass and production in shaded stream is lower than in open ones e.g. (23)(24), these data indicate that even a rich supply of terrestrial insects from a dense riparian canopy cannot compensate for energy lost through a drastically reduced autochthonous food path. Our data confirm this conclusion indicating that at between 300 and 700 $\mu Ecm^{-2} s^{-1}$ fish biomass is 2-3 times higher than either at lower or maximal light inputs. A further explanation of the above phenomenon might be supported by our former studies on primary productivity (25) which showed that in shaded streams ($<$ 300 $\mu Ecm^{-2} s^{-1}$) primary productivity was very low, and the bottom algal community was dominated by non-edible Rhodophyta. This confirms the importance of the autotrophic food chain for fish populations even if allochthonous organic matter is provided to the stream (26). Also in shaded streams, low temperature and low levels of primary production inhibit biological processing activity, and so the amount of energy transferred through food webs, and thus available to fish, is low. In stream sections with light above 700 $\mu Ecm^{-2} s^{-1}$, the river channel does not provide enough instream structures and thus enhances terrestrial predators' activities (27).

Riparian ecotones of rivers affect the environment of fish by increasing habitat diversity. Undercut banks with tree-roots, overhanging branches, and logs modify depth, current velocity, and substrate coarseness, and create shelters for fish (28). In consequence, enhancement by riparian ecotones improves spatial segregation of fish thus reducing intra- and interspecific interactions (29).

Our results show that strong interactions between food chain components occur in both directions. The importance of the top-down effect in the trophic chain has been demonstrated by reduction of macro-invertebrate biomass by fish. A relatively low decline of the invertebrate community biomass compared to fish consumption might be explained by permanent migration of invertebrates from the ground-water of the stream bed to the stream channel (30), and by a high turnover ratio of invertebrates. The lowest utilization of the invertebrate production by fish at station 3 might have been a result of the specific hydraulic conditions at that stream section; most benthic invertebrates were not available to drift-feeding brown trout, as they were concentrated in very shallow stream margins, often not connected with the main current.

Comparison of the data concerning the role of stream hydraulics, geological influences (e.g. calcium/bicarbonate system), and riparian ecotones indicates that the best enhancement of diversity and activity (biomass retention and productivity) of the river biota by restoration can be obtained by creation of intermediate ecotones. Additionally, in streams where slope is higher than 3‰ and calcium concentration is low, addition of limestone rock to the stream may intensify biotic processes, increasing the self-purification rate of the river (31).

Every restoration strategy has to be based on two components if it is to be successful - elimination of threat and amplification of chances. If strategies are focused only on one of those, they will never lead to success. Up to now for example almost all effort has been focused on reduction of pollution, which means the elimination of threat. Now, there is increasing number of examples which show that, by shaping the biotic structure of the river corridor, it is possible to restore the aquatic ecosystem's integrity, enhancing its resistance and resilience against human stress e.g. (32)(33)(34). A strategy of river restoration based on understanding of biogeochemical processes should be considered as an amplification of the chances for sustainable use of freshwater resources.

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Protocols for soil bioengineering: Site assessment and monitoring for streambank and floodplain revegetation

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Keywords
Soil bioengineering, assessment, monitoring, streambank revegetation.

Abstract
This paper addresses bank and floodplain revegetation as a component of the interdisciplinary effort of river restoration. The use of physical, hydrologic and geomorphic parameters can form the basis for the integration of site assessment, project design and project monitoring, reducing costs and data losses. The focus of this paper is on the integration of assessment, design and monitoring using the same physical measurements from the field survey, related to project goals. A plea is issued to fund assessment and monitoring in river restoration, to progress the discipline technically, economically and in socio-political terms.

Relevance of soil bioengineering to river restoration

Riparian vegetation accords multiple benefits to the fluvial system and the water environment, including improved channel stability and water quality, buffer zones, wildlife habitat, landscape aesthetics and shade and food for fish, birds and animals. We now understand that these multiple benefits provide a strong rationale for the recovery of streambank and floodplain vegetation. However, the consequences of revegetating streambanks and floodplains are not as well understood, especially for fluvial geomorphic and hydraulic regimes, and concerns about possible changes, for example, in flood risk can make it difficult to implement plans to improve riverine water quality, ecology and aesthetics.

River restoration is a complex undertaking, and must rely on the expertise of an integrated team of several scientific disciplines (1). At a minimum, guidance is needed from hydrology, geomorphology and geology, engineering and plant ecology, and relevant disciplines may include water quality, land use planning, fisheries, wildlife ecology, forestry, landscape architecture and agronomy. Soil bioengineering is an unique contribution to this interdisciplinary team where project goals dictate that structural uses of vegetation will facilitate either streamside vegetation recovery, enhanced bank stability or both. The clearest documentation of the methods of soil bioengineering was written by Hugo Schiechtl in "Bioengineering for Land Reclamation and Conservation" (1982).

The lack of integration of stream restoration projects with criteria or methods for evaluating performance has been demonstrated by (2). They offer guidance on assessment and evaluation criteria. Without sound assessment methods and critical evaluation, the hybrid discipline of river rehabilitation cannot progress on scientific foundations. The means to develop clear decision-making criteria are available and relatively inexpensive, but do require some technical expertise, as does river management practice in general.

Much money has already been spent on modifying stream channels for environmental goals, but little effort has been devoted to post-project evaluation. Of nearly 100 river enhancement projects completed by 1991 in the UK, only five had been the subject of post project evaluation (3). In the subsequent five year interval, the percentage of projects receiving post-project evaluation seems not to have significantly improved. In the future, expenditure for assessment and monitoring should be included in construction budgets, so that the data which form the basis of project design are repeatable measures for monitoring project performance. Funding construction without assessment and monitoring is like performing heart surgery with no patient records or follow-up care.

Site assessment

Site assessment begins with identification of a problem; correctly identifying the causes of river degradation involves rigorous investigation. Project goals will reflect the desires of the workers and landowners involved, and the statement of goals has a profound influence on the outcome of the project, so care should be taken to articulate the goals at the outset.

One strategy being used in the USA is to begin with a river type assessment, to form a mental and quantitative picture of fluvial processes operating on a reach scale. The USDA Natural Resources Conservation Service has adopted the Rosgen classification system (4), and this method is now being used nation-wide, especially by government agencies, to type streams by hydraulic geometry, morphology and sedimentation processes. Care must be taken, however, not to reduce the value of a classification by extending this simplification into a "cook-book" approach to project design.

Another approach is to implement a range of assessments, from the catchment scale to the site, to relate the hydrologic regime to actual channel dimensions and the specific requirements of plants and animals within the reach of interest. This approach, articulated by Newbury and Gaboury, has been shown to be a effective basis for channel and floodplain design, both for hydraulics and revegetation. In some cases, especially in moist climates, when the channel condition becomes stable, streamside vegetation can regrow without the need to plant, but this response may still require a significant intervention. The "10 step design and construction process" relates the catchment and reach to hydrologic regime, and offers guidelines for the design, construction and monitoring processes (5).

Catchment or watershed scale assessment by topographic map is essential, to identify stream order and regional slope. Historic air photo interpretation has been well documented as a valuable tool for locating channel configuration and meander patterns (6). Integration of topographic and planform data into a simple GIS can be a valuable strategic framework for prioritising, analysing and documenting the rehabilitation process.

Geotechnical considerations of bank stability are often a motivating factor in choosing soil bioengineering or biotechnical slope protection methods. A good summary of the procedures involved in assessment of river bank erosion is available from the UK (former National Rivers Authority) Environmental Agency (7). Bank erosion problems must be placed into the larger catchment or watershed context (8), and the mechanisms of bank failure merit study before attempting to revegetate or otherwise stabilise banks, for many bank treatments may pass on destabilising forces in either the upstream or downstream direction, or both (9).

The site field assessment can be relatively simple, but must be repeatable. The field geomorphic survey depends on establishment of permanent benchmarks placed well outside the active channel (2). Survey cross-sections should be located at pools, riffles and intermediate sections, rather than at set intervals, to define morphological variability. Floodplain features and eroding banks should be included in surveys where ecological condition and/or bank stability may be a concern. The number of cross-sections needed to show river condition should span at least seven times the channel width to characterise the project area (10), and should include cross-sections upstream and downstream of the proposed project area.

Visual appraisal is also important, and permanent photopoints should show cross-sections, bank, channel and floodplain features. When choosing photopoints, one should keep in mind that riparian vegetation grows like weeds, and views should include some distant points so that when vegetation matures in a few years time, project features can still be identified (2).

Measures of reach slope and particle sizes by channel feature (e.g. Wolman pebble count) aid assessment of changes in roughness due to the growth of vegetation and associated scour and/or sedimentation. At least a few estimates of bed particle size give a measure of stream power, the force exerted against the bed and banks (2). These data assist in selecting a roughness value needed to assess channel discharge capacity.

Survey data provide the basis for a topographic map of the reach, and this map forms the basic data for the project design and construction. Controversy still exists on the newer technology of the total station theodolite against the traditional level and stadia rod. While use of the total station gives a large number of data points in three dimensions and the potential for computer graphing capability, these data cannot be reviewed in the field for accuracy. The cost of hardware and software, as well as the steep learning curve for total station technology make a solid place in river restoration for the dependable and inexpensive level and rod technology.

The level and rod are readily available to the farmer or landowner, and offer the means to acquire the basic data required for site assessment. Both cross-sections and long profile are needed; the long profile should include at least ten bankfull widths in length, encompassing areas both upstream and down of the proposed project site (Scott McBain, pers. comment).

Rainfall and storm discharge records should be obtained for the nearest gauging station, and if possible compared with other nearby stations. A summary of 20-30 years record should suffice to calculate the volume of the annual flood (11). Combined with the survey cross-section and water slope (or long profile) data, the hydrologic record allows the practitioner to calculate the volume of channel capacity needed to carry the base flow and the bankfull discharge. These data must be related to the project site for a design flood event, so that the revegetation project neither under-nor over-estimates the channel capacity needed. A channel reach sized in equilibrium with its hydrologic regime and upstream and downstream linkages will pass the water and sediment delivered to it, and maintain relatively stable bed and banks (12).

In arid regions, data on groundwater levels may be needed to determine the depths to which roots must grow to survive the first few years (13). If water quality improvement is a primary objective, background level data will be required. If fisheries or wildlife habitat objectives are motivation for streambank revegetation, then the ecology and geomorphic features of these habitats must be documented (14). Guidelines for assessment of biological values are extensive in the literature, and beyond the scope of this paper, but have often been the focus of river restoration projects to the exclusion of physically based parameters. The background data needed will reflect the original goals of the project, and when these are in place before design and construction are completed, monitoring becomes straight-forward.

Design based on assessment and objectives

Problem identification is always the first step in the design process. Although this sounds simple, problem identification can be surprisingly difficult to ascertain. A clear statement of the project goals is a valuable tool for prioritising funding guidelines and design procedures. The goal statement provides a framework for project design objectives. Specific revegetation design strategies will vary by region, and will differ greatly among the goals of fish habitat recovery, water quality improvement or stabilisation from bank retreat.

At this point in time, bioengineering technologies are just becoming known and are not well documented either in engineering or ecological terms. Much more work is needed, both in research and in practice, to develop methods for specific needs. For example, agricultural buffer zones are being developed in the USA to attenuate movement of nitrates, sediment and pesticides (15). Buffer zones have been designed as "grass", or "grass and trees", but have rarely used shrubs or specifically native plants, and have not yet shown good connectivity to the river corridor or multi-functional criteria (such as the integration of wildlife habitat with bank stability). However, this 'bufferzone' genre represents a valuable resource for integrating nutrient attenuation into riparian revegetation design for other criteria. (For more details, see the valuable bibliography from Dave Correll on the WorldWideWeb; Vegetated Stream Riparian Zones: Their Effects on Stream Nutrients, Sediments, and Toxic Substances, Sixth Edition, October, 1996 (WWW.SERC.SI.EDU).

Various aspects of the construction industry have developed geotextiles, geogrids and "hard" technical designs for stormwater pollution abatement from urban development, (for example, see the literature of the International Erosion Control Association). Pollution reduction from construction is greatly needed, and the most effective measures to remediate such begin in the form of legislation, in local authority rules to protect waterways from development and in various incentives to reduce soil disturbance. Geotechnical methods may offer assistance to the construction industry, yet could benefit from greater use of native vegetation as structural design elements (16). A note of caution however, for the expedient use of synthetic materials may have long-term unanticipated ecological and/or geomorphic negative consequences.

Methods to predict discharge in compound meandering channels have been researched in the UK (17). Based on flume data, there is much potential for improvement both of theoretical understanding of fluvial behaviour and experimental field research by incorporating such models into the river restoration design process. At the present time, it seems that channel design for natural rivers is as much art as science, and this may account for some of the inherent attractiveness of the subject.

This paper does not address the design process as such, but rather the need to relate design to the site field assessment, and to the monitoring programme to follow construction. Specific design guidance must vary be region, and new literature no doubt will emerge to guide the practitioner in the coming decade. For a sound review of channel design principles see (5), and the authoritative work on soil bioengineering remains Schiechtl's classic work (18). See also (16).

Project monitoring for design improvements - Success/Failure criteria

The monitoring program measures begin with the completion of construction, with photographs and an "as-built" map as a minimum. Ideally, the salient features of the project should be resurveyed after construction, to determine, for example, whether the channel widths, pool-riffle spacing, bank slopes or other features were correctly placed. This is important because the built project rarely follows the design in every detail, and departures from the plan can be significant.

Resurveys should be conducted after threshold flood events, which are specified in the design, to take account of adjustments to smaller flood flows, in order to identify potential shortcomings in project performance and make necessary corrections. Generally, resurveys should be conducted at year one, two, four, six and ten years after completion, and after large flood events (2). On average, a decade is long enough to witness multiple occurrences of the two-year or bankfull event, so that ten years is the minimum period needed for monitoring in a scientifically sound program.

The goals and objectives of the project define the criteria for quantitative evaluation of success or failure. Did channel widths return to the specified range? Were willow flycatcher nesting sites observed after construction and growth? Does bank vegetation provide shade and cover for brown trout? Was soluble nitrate reduced to less than 50 PPM?

To achieve project goals, objectives must be clearly stated at the beginning of the design process. The physical structure of the stream system must be well understood, and the project design should be based on these physical measures. Physical parameters, plus the necessary biological or chemical data, then provide the basis for the monitoring program, to determine whether the goals of the project were met.

Adaptive management and sustainable development

The real value of assessment and monitoring is in learning from experience, and by documenting that experience, many other workers can learn from one project. In progressing this young science, "failures" can often be more instructive than "successes", especially where quantitative documentation exists.

The benefit of documented "failures" lies in the potential for improving understanding of fluvial processes, river engineering and construction and maintenance schemes. Such lessons can only be incorporated into future design improvements when the lessons learned are passed on to others. This is the meaning of "adaptive management". and lies at the heart of long-term strategic success of any business enterprise. So-called "failures" are often far more instructive than "successes", and can be used to advance our knowledge if documented.

Documentation should include the decision-making process as well as the physical parameters discussed above. Of equal value are data on project costs, both expected and actual, as well as expenditures of time and labour. In many cases, obtaining landowner consents may be more time-consuming than the construction process, and the community and agency consultation processes are vital links in achieving co-ordination at the catchment or watershed level.

River restoration at a project scale can work toward connectivity in the river corridor when practitioners are able to include the upstream and downstream reaches, and to include ecological responses to site revegetation along the river continuum. The geophysical processes can be measured quantitatively, and equally important are the qualitative responses within the human community to "restored" streams and rivers. People often have strong opinions about their community, their river, and any changes made to these. An informed public is the best insurance against vandalism and for future improvements.

At the present time, there exist institutional and regulatory structures in every country poorly disposed to enhance environmental conditions. Changes in these institutions are needed at many levels in order to facilitate the multiple benefits to be achieved through restoration of the river environment. Perhaps the greatest challenge ahead is to demonstrate the economic links between such functions as improved fisheries and tourism, reduced flood hazard, improved water quality and increased land values.

Conclusions

Bank and floodplain revegetation should be seen as an essential component of the interdisciplinary effort of river restoration. Physical, hydrologic and geomorphic parameters, forming a firm foundation for the integration of site assessment, project design and project monitoring, will result in reduced costs and the increased ability to evaluate the performance of the project against defined success criteria. Multi-functional designs will receive greater emphasis (and funding) in the future of river restoration. Funding assessment and monitoring in river restoration is crucial to progress the discipline technically, economically and in socio-political terms.

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Rehabilitation of an incised stream in fine grained glacial soils with grade control and planform control structures

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Abstract

Muddy Creek near Vaughn, Montana, is an incising, sinuous stream. In the 1930's return flow from 32,375 ha of irrigated farm lands began to have an impact on Muddy Creek, increasing the annual volume of flow eight-fold above the pre-irrigation historical average. The fine-grained glacial soils of the Muddy Creek watershed are highly susceptible to erosion at the higher levels of flow and flow duration. Incision is roughly 6.7 m in the lower reaches, 4.9 m in the middle reaches, and 2.4 m in the upper reaches of the 64 km long watershed. The geotechnical properties of the soils result in sheer cliffs along the incised creek. The sediment transport rate from Muddy Creek is roughly 200,000 t year^{-1}. Sediment from the creek flows into the Sun River and subsequently the Missouri River at Great Falls, Montana, degrading water quality.

The deeply incised channel leaves very little room for creating a riparian area, especially an effective flood plain. The best solution to this problem is to halt the incision, constrain the lateral migration of the stream, and allow the system to adjust for several years. Grade control structures and planform control structures installed over the past two years are controlling the gradient, and constraining the lateral migration of the stream. Early monitoring indicates that wildlife are inhabiting the riparian corridor in increasing numbers, aquatic habitat is forming, vegetation is prospering, and water quality is improving. The creek appears to be adjusting to the artificial grade imposed by the grade control, and the planform control structures do not appear to be excessively constraining.

Introduction

Muddy Creek is an incising sinuous stream near the town of Vaughn, Montana, USA. Return and waste flow from irrigated farm lands increased the annual volume of flow eight-fold above the pre-irrigation historical average in Muddy Creek. The fine-grained glacial soils of the Muddy Creek watershed are highly susceptible to erosion at the higher levels of flow and flow duration. This paper describes rehabilitation efforts to stabilize the stream gradient and reduce erosion and sedimentation. Cooperators in the rehabilitation include the US Bureau of Reclamation (Reclamation), the US Natural Resources Conservation Service (NRCS), Greenfield Irrigation District (GID), all members of the Muddy Creek Task Force (MCTF). Since 1993 the Task Force has been demonstrating a new type of grade control and planform control on a 6.6 km reach of Muddy Creek.

The deeply incised channel leaves very little room for creating a riparian area, especially an effective flood plain. The solution to this problem is to halt the incision, constrain the lateral migration of the stream, and allow the system to adjust for several years. The erosion control scheme includes chevron weir rock ramps for grade control and barbs for planform control.

This paper has two objectives. The first is to describe the overall project philosophy and the approach that the Task Force took to rehabilitate the creek. The second is to describe the procedures for designing as well as siting the grade control structures that halt channel incision, and barbs that control the planform of the stream. Reclamation developed the technology for these controls in a demonstration reach of the creek.

Background

Fig. 1 shows the location of Muddy Creek, a tributary of the Sun River, in the Upper Missouri River Basin. The creek joins the Sun River 17 km upstream from the Sun-Missouri confluence at Great Falls, Montana. The Muddy Creek watershed is roughly 800 km^2 of agricultural lands. Muddy Creek is a sinuous stream augmented by irrigation return flows. The Sun River watershed is east of the continental divide and south of Glacier National Park in north-central Montana, USA. The Sun River starts in the Bob Marshall Wilderness area and meanders out of the mountains through rolling grass-covered foothills and farmland. Annual precipitation is about 30.5 cm per year, and the National Weather Service estimates annual class-A evaporation to be 145 cm. About 80% of the annual precipitation occurs between April and September. Snow melt commonly occurs before April, and rainstorms generally contribute significant percentages of the annual precipitation and cause intense runoff according to the NRCS (1).

Figure 1. Sun River and Muddy Creek watershed location in the United States.

Muddy Creek rehabilitation philosophy

Your first view of Muddy Creek quickly affirms the local moniker, the "Grand Canyon" of Montana. Though not so dramatic as the name implies, Muddy Creek is an eyesore and the major cause of water quality problems in the lower Sun River and the Missouri River below Great Falls. To the landowners along the banks of the Muddy, the creek is a deep gouge in their land, an impediment to crossing, and a reminder of unconsidered consequences of irrigated agriculture.

A superimposed hydrology has forever changed the character of the creek. In the largest sense the solution is two-fold: 1.) Adjust the channel to handle increased flow on a permanent basis including extreme event capability and 2.) Reduce return and waste flows. The ingrained irrigation practices of the region are difficult to change. Reclamation and GID are aggressively changing management practices leading the way to increased water conservation and reducing waste and return flows. Nevertheless, because of the geology of the area and the prevalence of flood irrigation, seepage and surface flow to Muddy Creek will continue at significant levels. This realization led to the conclusion that Muddy Creek should change from a steep ephemeral stream to a moderately sloped perennial stream. The soil and substrate types in the lower reaches of the Muddy Creek watershed are especially vulnerable to erosion. The rehabilitation of Muddy Creek therefore required installation of controls that reinforce the native materials.

A grade control structure is a hydraulic structure for dissipating excess head in the stream wise direction or maintaining the elevation of the existing stream bottom. A barb is a hydraulic structure that deflects current away from eroding banks. Barbs build stream banks and create riparian areas by trapping bed load and suspended sediments. A practicable solution is to form a series of shallow pools with grade control structures. In combination, barbs placed in the areas with the greatest lateral erosion rate will shore up the base of the incised banks, shelter caved bank material from currents, and build new riparian areas. Regulators expressed a strong desire to minimize the profile of the grade control structures and to avoid the use of engineered materials. The only choice left to the Task Force is grade control with hydraulic height less than 0.5 m using rock, earth, or woody debris. The magnitude of flow and the potential for vigorous ice jamming led to the choice of numerous, low-profile, robust rock grade control structures and barbs.

The next choice for the Task Force was the number and location of structures. Muddy Creek is more than 33 km in length. The available funding quickly led the Task Force to adopt a phased approach, with the use of a demonstration reach as the first phase. There were two reasons for this choice, economic and scientific. There was sufficient funding for 8-10 grade control structures, and at standard spacing that meant roughly a 6.6 km reach. Scientifically, rock grade control structures of this magnitude had not been widely tested. The demonstration reach gave the task force an opportunity to invest in a significant reach of the creek while proving the new technology. In addition, the contractor, Greenfield Irrigation District, had no experience with this type of construction. A controlled learning experience was best for all parties.

Grade Control -- Planform control philosophy
The philosophy of grade control and planform control in this incised stream is simple: Stop the incision, stop migration of the stream through steeply incised banks, and foster vegetative growth. As the banks cave into the creek, the dispersive nature of the soils causes quick suspension of the sediments for transport. Very little of the sediment load in Muddy Creek is bed-load. Reducing sediment transport requires two steps. First, shut off the source, that is the bank caving, and second, slow or stop the suspension of caved sediments.

Banks of this magnitude are almost impossible to stabilize. The Task Force focused on preventing erosion at the base of the banks and the subsequent caving. Planform control, as barbs, placed at the toe of the banks displaces the current and provides an area for bank material to cave. Caved material, when consolidated, becomes a bedding for vegetation and new riparian banks form. However, in an incising system, planform structures will fail as the stream incises, degrading the foundation for the barbs. Thus in concert with the barbs the Task Force knew halting incision with grade control was also necessary. The grade control would halt incision, the banks can get no higher, and the barbs will accelerate the formation of riparian banks and vegetation, immediately reducing sediment transport.

Concurrent to in-stream activities, water conservation activities are underway, reducing the source of the problem, that is return and waste flows. So, the Task Force is treating both the cause and the symptoms of the problem in the rehabilitation of Muddy Creek.

Demonstration stream restoration project
The demonstration project is an evaluation of low cost grade control and planform control designs on a 6.6 km reach of the stream where down cutting and bank erosion are most active Fig. 2 shows the topography surrounding the demonstration reach. The following sections describe the components of the structures, first the planform control, and then the grade control.

Figure 2. Topography surrounding roughly 6.6 km reach of demonstration project.

Summary of grade control and planform control structures
Wittler *et al.* (2) reported on the nine riprap grade control structures, or chevron weir rock ramps constructed in 1994 & 1995. Five grade control structures were constructed with a hydraulic height of 0.3 m, and four grade control structures were constructed with a hydraulic height of 0.6 m. A tenth structure, at the downstream border of the demonstration reach, is a riprap sill constructed by the US Army, Corps of Engineers (USACE). The USACE sill was originally constructed at grade, with zero hydraulic height. In addition, 33 riprap barbs were constructed to divert the flow away from the banks. In late 1995 two

additional grade control structures were installed just upstream of the demonstration reach. In 1996 more than 100 additional barbs were installed in the most unstable bank areas within the demonstration reach.

Plan form control

Barbs are rock jetties, triangular in plan, placed on the outside bends, displacing the thalweg away from the bank. Barbs build stream banks and create riparian areas by trapping bed load and suspended sediments. Other names of barbs include jetties, toe dikes, groins, habitat sills, and bendway weirs. Barbs slope from the bank to the stream and angle upstream to cause a weak back eddy next to the bank to create a protective flood plain. Barbs vary in size depending upon channel size, shape and flow levels. Typical barb construction uses rock whose size primarily depends on stream velocity. Barb elevation is near the normal high water elevation or the top-of-bank. The elevation of the point of a barb is usually the bed or low water elevation. Fig. 3 and Fig. 4 show a plan and section of a barb. This barb extends from the bank perpendicular into the flow. The only guidance, other than rule of thumb, for spacing the barbs, is in a Design Guidance from the US Army Corps of Engineers (3). The guidance uses the radius of the bend, the length of the bendway weir, or barb, and the width of the channel to specify the spacing between barbs. The demonstration project will soon issue additional guidance on spacing of barbs.

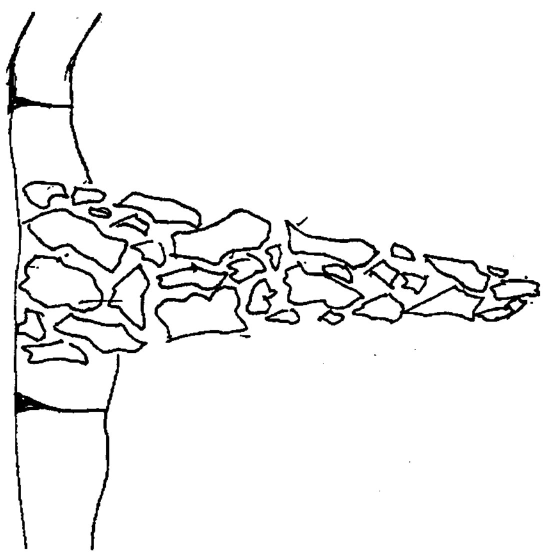

Figure 3. Plan of typical barb, perpendicular orientation.

Grade Control

Nonstructural, "soft engineering," or minimal disturbance methods of in-channel restoration have become standard practice. Regulatory agencies charged with protecting the environmental, biological, and aesthetic qualities of waterways are adopting these new methods as standards. The new standard severely decreases the likelihood of permitting of steel and concrete grade control structures. Additionally, financial realities require the development of a low cost alternative to traditional steel and concrete grade control structures. Within these regulatory constraints, Reclamation developed a Chevron Weir Rock Ramp for grade control.

Rock Ramp Weirs for Grade Control

As the name infers, the planform of the structure is in the shape of a chevron or arc. The weir crest angles or arcs with the vertex of the angle pointing upstream. The constituent material is angular rock, sized according to standard riprap sizing criteria. Recent research by Abt (5) and Wittler (6) provides the design guidance for using rock in these types of structures. Downstream of the rock weir crest is a ramp of rock, angling the flow towards the center of the structure at its toe. After four seasons in place, nine grade control structures with this design are performing within expectations. In late 1995 Reclamation installed two grade control structures using a second generation design based upon observations and performance of the original design.

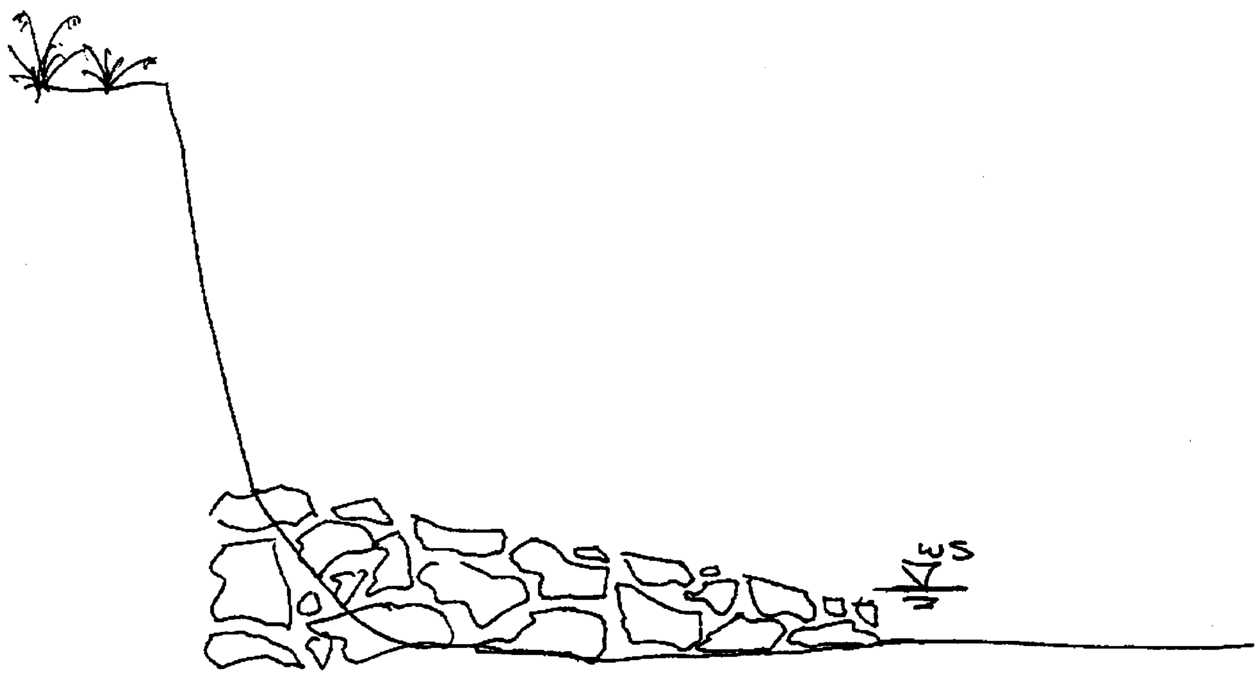

Figure 4. Section of typical barb.

Weir Configuration

The length of the ramp varies so that the final gradient of the ramp along the centerline is 10 percent. The target volume of rock was 6.5 t m^{-1} of width for a 0.3 m design hydraulic height. The target volume of rock was 9.8 t m^{-1} of width for a 0.6 m design hydraulic height. The difference in unit volume is evident in the length and thus the slope of the structures. The rock ramp thickness was one D_{100}, or 1.07 m. The bed materials of Muddy Creek are gravelly and sandy loams and light clays, laid down as reservoir sediments. Bedding for large rock on this bed material is a geofabric, Mirafi 1100™, a non-woven geofabric. The fabric is susceptible to UV degradation, however the rock and water should adequately shield the fabric. Choking the rock on the banks with soil protects the fabric and provides a base for vegetative growth. In the second generation design, an arch replaces the chevron at both the upstream weir and downstream toe. Excavation of the toe increased from 1.07 m to 1.74 m, increasing the volume of rock at the toe. Armoring provides erosion protection to a deeper elevation and there is sufficient rock volume to withstand migration into a developing scour hole and armor the upstream face of that scour hole. The same reasoning applies to a head cut that migrates into the toe of the structure. The adverse slope of the toe helps to confine a hydraulic jump, if present, on the ramp, preventing the flow from dissipating excess energy upon the bed of the stream. If the toe does collapse into a scour hole or head cut, the gradient of the ramp stands a high probability of remaining at or below the design gradient, preserving the function of the ramp and the design parameters. The radius of the arch is equal to the width of the channel bottom.

Rock Design

The rock design includes specifying the characteristic size and the maximum and minimum sizes. Two sources (4) and (5) specify characteristic sizes of rock for ramp applications. In addition, (5) provides criteria for defining the gradation of the rock mixture. In general the rock should be angular, durable, and resistant to hydraulic erosion or degradation. In cold climates freeze-thaw performance is also a major factor in the suitability of the rock. The rock should be suited to packing and interlocking. Therefore a mixture of sizes is preferable to uniform size. However, Wittler (6) demonstrates that a wide range of sizes reduces the stability compared with a moderately uniform size. Abt (5) recommends a uniformity coefficient, C_u, of 2.15. At Muddy Creek, the D_{100}, or maximum size rock is 1.07 m while the D_{10}, or practical minimum size rock, is 0.15 m.

Abt (5) and Chervet (6) include the same parameters in their formulae. Together they base the prediction of the maximum specific or unit discharge, q, upon a characteristic rock size and the slope of the ramp, J. Chervet defines the characteristic rock size as the D_{65}, that is 65 percent of the mixture is finer than this size.

Abt defines the characteristic rock size as the D_{50}, that is the median rock size, 50 percent of the mixture being either finer or coarser than this size. Equation [1] shows the Chervet (6) equation.

$$\frac{q}{\sqrt{gD_{65}^{3}(S_s - 1)}} \leq \frac{0.257}{J^{7/6}} \qquad [1]$$

q specific discharge over the ramp in $m^3\ s^{-1}\ m^{-1}$
D_{65} 65% of rock mixture is less than this size, in meters
S_s specific gravity of the blocks compared to that of the water (e.g., 2.65)
J ramp gradient in $m\ m^{-1}$
g acceleration due to gravity in $m\ s^{-2}$

Equation [2] shows the Abt (5) equation.

$$D_{50} \geq 0.503q^{0.56}J^{0.43}, \quad C_u = \frac{D_{60}}{D_{10}} \cong 2.15 \qquad [2]$$

D_{50} median rock diameter of the block in meters
q specific discharge over the ramp in $m^3\ s^{-1}\ m^{-1}$
J ramp gradient in $m\ m^{-1}$

Equation [1], with D_{65} equal to 0.838 m, yields a maximum specific discharge q, of 11.64 $m^3\ s^{-1}\ m^{-1}$. Equation [2], with D_{50} equal to 0.76 m, yields a maximum specific discharge, q, of 12.12 $m^3\ s^{-1}\ m^{-1}$. Typical widths on Muddy Creek are 7.6 to 12 m, yielding total discharge, Q, of roughly 91 to 144 $m^3\ s^{-1}$.

Conclusions and recommendations

After two years the first assessments of the success of the Muddy Creek Demonstration Stream Restoration project are positive. The grade control structures functioned as expected during an event with a five year return interval in the spring of 1995. Scour holes more than ten feet in depth formed below structures where backwater from the downstream structure fails to reach the toe of the upstream structure. Barbs are stabilizing the toe of thousands of lineal feet of unstable banks while providing a vegetative base. The public is responding favorably, even while erring in their estimate of the time scale for restoration of the stream corridor. Irrigation and range issues are progressing with the Irrigation District working to reduce return flows, and local landowners reducing grazing pressure in riparian zones. Overall, the Task Force believes that the project is successful and plans to expand the project.

Rock ramps, arched or chevron shaped, show potential for grade control as low-cost, low-profile structures. The combination of a chevron shape and a warped ramp concentrated the flow too much, resulting in adverse channel response below the grade control structure. Large riprap appears to be an adequate material for construction of grade control structures in concert with proper bedding or filters. Design formulae for riprap used in these designs appear to agree and yield reasonable rock sizes for this application.

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Quality objectives and goals for the restoration of small running waters.

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Abstract

The restoration of running waters was starting 20 years ago in Germany, but the scientific basis is still scare and not sufficient. The targets ('Leitbilder') of river restoration as well as the goals or quality objectives must be defined as a basis for the planning and construction of running waters. Targets for river restoration are a natural or potential natural river system, that means the realisable of a true to nature system. The targets of restoration must be co-ordinated with the use of waters. Quality objectives for restoration are given, and the state of 20 years' river restoration in Germany is presented.

The conception of a restoration project includes the prospective classification of the water system, beside the valuation of the restoration effect must be performed. This ecological valuation of a restored river is still a central problem, being very difficult and expensive. The use of target species is a new and simple method to describe and to evaluate an ecosystem. Target species can be applied for the outline as well as the valuation of restoration projects of running water; possible target species are given and discussed. Both concepts - development of objectives for restoration as well as of target species - must be used, and they lead to a better description of the goals and a higher effectiveness of restoration projects.

Introduction

The river consolidation had been a long-term process of river development, being called denaturalisation. This denaturalisation was starting in the Middle Ages with the construction of weirs for use of waterpower and for water retention. The denaturalisation of rivers had been done by several points of view: The main reasons were and still are use of water and of water power, cultivation of meadowland for agricultural use, protection against flooding, bank stabilisation, use of rivers for shipping and for water discharge and the input of waste water as a disposal of waste.

Today nearly all rivers in industrial countries are consolidated, straightened, canalised and the riparian area is used for agriculture. Unfortunately severe effects of the river consolidation are detectable. Today the ecological value of the consolidated rivers is reduced, and the many negative effects can be observed. Since about 20 years this denaturalisation process of rivers was returned by the river restoration as a 'natural construction' of waters and the use of biotechnology (1)(2)(3)(4)(5). A summarising of the state of river restoration is given by Osborne et al. (6), Gunkel (7) and Brookes & Shields (8).

Results

State of goals for river restoration

The restoration of streams and rivers should re-establish undisturbed running water ecosystems. Today rivers without any anthropogenic influence do not exist in industrial countries. That is why the target state, called 'Leitbild', was defined as a long-term and general goal for river restoration, being feasible and realisable (5)(7)(9)(10).

True to nature rivers are ecosystems with natural ecological functions, that means ecological processes like self purification, retention of nutrients by vegetation and sedimentation in flooded areas take place. Rivers too need a self dynamic development with bank erosion, sedimentation and formation of sand- or gravelbanks. This leads to a high-grade structure, and an increase of biotopes and of diversity occurs. The catchment area determines the output of nutrients and minerals by leaching or erosion; natural rivers need a landscape richness, a meadowland with regularly flooding, and a biodiversity of fauna and flora. This general description of a natural river leads to several goals or quality objectives for river restoration (7):

Physical heterogeneity: Straightened and canalised rivers are of low physical heterogeneity, being typical for consolidated rivers. In river restoration, many were done to re-establish a high geomorphological heterogeneity of the water course, bank and bottom development. Main processes are a hydraulic engineering true to nature, a re-meandering of the water course and a support of the self dynamic development of the river (11)(12)(13).

Water quality: A sufficient water quality is a basis for river restoration. The water quality is determined by direct or indirect input of nutrients, organic material and wastes as well as the output from the catchment area (and therefore by the use of the catchment area) as well as of the self purification of the river system.

Habitat diversity: The habitat diversity seems to be a better parameter than the physical heterogeneity, because it is of main interest to re-establish water wildlife and a high biodiversity. The habitat diversity is a simple parameter to describe a potential biocoenosis, but a valuation of the habitats must be done, too. River restoration must lead to a functional habitat development, that means, habitats must being settled by species and leading to an increase of biodiversity (8).

Biodiversity: The biodiversity is a main goal for river restoration, and the protection and re-settlement of water wildlife must be done. Many aquatic or semi-aquatic species are endangered or extinct, mainly due to the river consolidation (14)(15).

Stream quality: The stream quality is a not yet defined term, being determined by physical heterogeneity, water quality, habitat diversity and biodiversity. Some approaches for determination have been done, but the valuation of a running water is still a complex problem (7)(16)(17). Stream quality objectives are among else the salmonid and cyprinid water, that means reproductive populations of these fish (18).

Landscape richness: Landscape development has been pointed out as a goal of river restoration. But it is not possible to separate the landscape richness and the natural state of the catchment area from the stream quality. A river is a complex ecosystem, being build up by the water course, the sediments, the riparian zone and the catchment area. Landscape richness is part of a true to nature river, but landscape richness does not guarantee a good water quality. One aim of river restoration is an increase of water in the landscape and a start of the development of meadowland.

State of river restoration in Germany

In the last 20 years, more than 50 river restoration projects were carried out and published or well documented in Germany (7). The total length of restored river amounts more than 50 km. The river restoration done up to now was a very expensive action. In most projects the costs amounted among $ 150 to $ 1500 per meter, expensive restoration projects had costs up to $ 2,800 (basis: 57 projects in Germany in the years 1976 to 1995). These costs are calculated without any purchase of land, construction of bridges and roads.

The targets of river restoration were in most projects landscape development as well as the use of waters (use for water management, recreation or self purification). Only 25 % of the projects had the target 'reconstruction of biotopes' (Table 1).

Although we expend much money for river restoration, the effect on the ecosystem is very small. An investigation on the basis of 10 restored rivers in Germany showed only a small improvement of the fauna and flora, respectively no effect; only one project led to a significant improvement of the biocoenosis. A similar result was got for the ecological effects: the ecological effect was calculated as the difference between the restored river and a comparable natural river. Most of the 10 projects led to no or only a slight ecological effect (7 projects), and only one restoration project showed a significant ecological effect (19).

Several aspects can be emphasised leading to this bad valuation:

- Most restoration projects possess an insufficient length of the restored section: A restoration must be developed from the upper course to the lower course; it is necessary to restore complete river systems, not only a few meters like in many projects. 50 % of the restoration projects in Germany concerned sections of less than 1 kilometre! This leads to the development of island biotopes without ecological significance for the water wildlife.
- The meandering of the water course is a central problem of reconstruction a geomorphological heterogeneity, and in most projects only a slight bending or winding of the water course was realised. In these restored sections no elongation of the water course and no dynamic development with edge riffles and pools was established.
- In many restored sections no dynamic self development can occur - due to use of the riparian area and bank stabilisation or to a lack of high water and of flooding.
- In many restoration projects non-functional habitats are constructed, e. g. islands, gravel banks, water level deep under the ground level with drainage of the water/land biotope.
- A real problem is the riparian zone: woody plants are necessary for shading (regulation of the aquatic macrophytes) and input of leaves and wood (as a nutrient basis for the leave and wood consumers). In restored sections with new planted woods (e. g. *Alnus glutinosa, Salix* spp.) the young trees cannot result in a significant effect, it takes many years until the development of macrophytes will be regulated by shading and the development of leaves and wood consumer macrozoobenthon will be possible. Thus eutrophication effects and a little biodiversity occur.

Today the self development of a river seems to be a better concept to create natural river systems. In this case it is necessary to own or to bay the land on both sides of the river. Besides it is necessary to realise only a reduced and ecological maintenance to allow the river to development it's bed itself. Some disturbances of the river flow accelerate the process of self development, e.g. by interference stones of interference groyes. But the self development of a river bed is a process which takes nearly one hundred years or even more (11).

Table 1. Targets of river restoration projects carried out in Germany the last 20 years (summary of 57 projects).

Targets of river restoration	1976-1980	1981-1985	1986-1990	1991-1995
Landscape development				
Natural design of a river system		♦	♦♦♦♦♦♦♦	♦♦♦
Remove of a concrete bottom			♦	♦♦
Variation of the cross-section		♦	♦♦♦	♦
Remeandering		♦	♦♦	
Reconstruction of a piped stream		♦		♦
Water management				
Increase of the flowing off capacity		♦♦	♦♦♦♦	
Prevention of the bottom and bank erosion		♦♦♦	♦♦♦	♦
Retention of water				♦
Development of an ecological maintenance		♦		
Self purification				
Increase of the self purification		♦	♦♦♦♦	
Use for recreation				
Increase of the recreational value				♦
Reconstruction of biotopes				
Reconstruction of the permeability			♦♦	♦
Stimulation of the self-dynamic			♦	
Construction of creeks	♦			
Reconstruction of a backwater	♦		♦♦	
Reconstruction of a bog				♦
Reconstruction of a wetland				♦
Reconstruction of an *Astacus*-stream				♦
Reconstruction of a wet forest (*Alnus*)				♦
Improvement of the ecological situation		♦	♦	

Use of target species in river restoration

The valuation of a stream quality is still a problem, and many different approaches are used. Up to now three methods are common used in river restoration - the description of the physical heterogeneity, the habitat diversity and the biodiversity (see above). But the success is insufficient, because in restoration projects a potential state, not yet existing, must be described as a goal of a project.

A new concept being simple and practicable is the use of target species. A target species is an animal or a plant, which should be re-established by restoration. The qualifications for target species are species with:

- high popularity (e.g. by lobbyists or as useful species);
- high indication value (= characteristic for a segment of a running water respectively of a biotope);
- well known limiting factors;
- wide distribution (= supraregional use as target species);
- a high reproduction rate;
- high abundance in natural ecosystems;
- clear and easy determination.

Target species for the upper, middle and lower course of running waters are given in Table 2. These species need a defined habitat and have a high indication value. Using target species, there are quite simple steps in realisation of a restoration project: The goal or target state can be described by one or a few target species. A few years after finishing the restoration project, a valuation of the restored section must be done:

the parameter is the resettlement or population development of the target species. Following, a long-term monitoring of the stream quality must be done by the development of the target species.

Table 2a. Target species.

Habitat - The upper course of running water	**Target species**
Headwater area	
Extreme oligotrophic spring brooks with sandy bottom	Pearl Mussel *Margaritifera margaritifera* L.
Natural spring brooks	Water moss *Fontinalis antipyretica* L.
Summer-cold and fast-running spring brooks	Dragonfly *Cordulegaster bidentatus* Selys
Oligotrophic spring lakes (> 20 µg/l P)	Skunk Weed *Chara hispida* L.
Salmonide region	
Oligotrophic brooks with a gravelly bottom without any river consolidation and extension	Salmon *Salmo salar* L. Sturgeon *Acipenser sturio* L. River Lamprey *Lampetra fluviatilis* L.
Oligotrophic brooks with a bottom of sand and gravel	Brook Lamprey *Lampetra planeri* Bloch
Oligotrophic brooks with a sandy bottom	River mussel *Unio crassus* Phil.
Summer-cold, oxygen-rich and fast-running mountain brooks without any bank consolidation	Crayfish *Astacus torrentium* Schrank
Summer-cold, oxygen-rich and fast-running natural brooks	Dragonfly *Cordulegaster boltoni* Donovan Dragonfly *Calopteryx virgo* L. Crayfish *Astacus astacus* L. Trout *Salmo trutta* f. *fario* L. Grayling *Thymallus thymallus* L.

Habitat - The middle course of running water	**Target species**
Barbel region	
Natural brooks with a median water current	Water Cress *Nasturtium officinalis* R. Br. Water Crowfoot *Ranunculus fluitans* Lam. Freshwater Shrimps *Gammarus spp.* Barbel *Barbus barbus* L.
Gravel bottom with benthic diatoms, carbonate-rich water, (> 14 °C, O_2 > 8 mg/l)	Nerite *Theodoxus fluviatilis* L.
High oxygen concentration at bottom (> 5 mg/l O_2)	Caddis larvae *Hydropsyche contubernalis* McL.
Slightly eutrophicated natural rivers with dry valley slopes	Freshwater Turtle *Emys orbicularis* L.
Formerly steel banks of sand/poor clay	Kingfisher *Alcedo atthis* L.
Erosion banks of sand/poor clay	Sand Martin *Riparia riparia* L.
Water bodies in the meadowland *Marsilea quadrifolia* L.	Water ferns *Salvinia natans* Allioni, *Trapa natans* L.,
High-grade structured water bodies in the meadowland	Tree Toad *Hyla arborea* L.
High-grade structured water bodies in the meadowland, high ground-water level	Toad *Bombina bombina* L.
Wet grassland of meadowland	Mash Marigold *Calta palustris* L. Orchids *Dactylorhiza* spp., *Orchis* spp. White Stork *Ciconia ciconia* L. Redshank *Tringa totanus* L. Black-tailed Godwit *Limosa limosa* L.

Table 2 continued.

Habitat - The lower course of running water	**Target species**
Beam-region	
River with slow water current and high oxygen concentration at bottom, carbonate rich water	Mussel *Unio tumidus* Phil. Freshwater Shrimps *Gammarus* spp.
High oxygen concentration at bottom (> 5 mg/l O_2)	Caddis larvae *Hydropsyche contubernalis* McL.
River with slow water current and muddy bottom, carbonate rich water	Painters Mussel *Unio pictorum* L.
Slightly eutrophicated natural rivers with dry valley slopes	Freshwater Turtle *Emys orbicularis* L.
Formerly steel banks of sand/poor clay	Kingfisher *Alcedo atthis* L.
Erosion banks of sand/poor clay	Sand Martin *Riparia riparia* L.
Rooted plants with floating leaves	White Water-lilies *Nymphaea alba* L. Pondweed *Potamogeton* spp.
Reed	Great Reedmace *Typha* spp. Yellow Iris *Iris pseudacorus* L. Water Plantain *Alisma plantago-aquatica* L. Bur-reeds *Sparganium erectum* L. Great Reed Warbler *Acrocephalus schoenobaenus L.* Bittern *Botaurus stellaris* L.
Shallow and muddy waters without water current	Duck Mussel *Anodonta anatina* L. Swan Mussel *Anodonta cygnea* L.
Banks becoming periodically dry	Sedge *Cyperus fuscus* L.
Non eutrophicated river with flooding area	Pike *Esox lucius* L.
Wide natural river system	Otter *Lutra lutra* L.
Wide natural river systems with wet forests	Beaver *Castor fiber* L.
Wet grassland	Mash Marigold *Calta palustris* L. Orchids *Dactylorhiza* spp., *Orchis* spp. Toad *Bombina bombina* L. Frog *Rana arvalis* Nilsson White Stork *Ciconia ciconia* L. Redshank *Tringa totanus* L. Black-tailed Godwit *Limosa limosa* L.
Wet forest	Fern *Osmunda regalis* L. Bog Arum *Calla palustris* L. Water Avens *Geum rivale* L.
High-grade structured water bodies in the meadowland	Tree Toad *Hyla arborea* L.
High-grade structured water bodies in the meadowland, high ground-water level	Toad *Bombina bombina* L.

A restoration project must lead to an ecological improvement, that means a protection of water wildlife and an increase of biodiversity, mainly of sensitive species. Consequently a few target species can be selected to describe the potential river system as the goal of the restoration project. This goal has a good acceptance by the people due to the popularity of the target species.

Conclusions

The river restoration is a necessary development of consolidated rivers to natural conditions, and river restoration should re-establish ecosystems with high-grade ecological structure and with ecological functions (20)(21). In a few countries, river restoration is already done and the experiences are documented

(7)(9)(20)(22)(23)(24). Critical reviews of restoration projects, carried out in Germany, are given by (25) and (7), where many problems of river restoration are summarised. Up to now only a few other references are available with a critical valuation of restoration projects (9)(26)(27). This is mainly a consequence of a lack of a long-term monitoring of restored rivers as well as of missing goals for restoration projects.

For a successful river restoration, a better planing is needed, and the reference system, the target state (Leitbild) and the goals must be defined. The restoration of complete river systems is necessary to ensure an increase of biodiversity. The description of the restoration plan, a valuation and a long-term monitoring must be done, and target species can be used.

Up to now, there are only little experience with target species. One project is the resettlement of the salmon (*Salmo salar* L.) in the River Rhine, a program called 'Salmon 2000', being successful in a few years (28)(29). The next step in the River Rhine restoration may be the resettlement of the sturgeon (*Acipenser sturio* L.). Similar programs are developed for the River Elbe. The otter (*Luta luta* L.) is used as a target species for the restoration of the River Ise in North Germany (30). In many Danish and Canadian restoration projects, the trout is used as an exclusive target species (4). In the Netherlands, the concept of target species (e. g., Crayfish *Astacus astacus* L., Beaver *Castor fiber* L., Great Reed Warbler *Acrocephalus schoenobaenus* L., Bittern *Botaurus stellaris* L., Night Heron, *Nycticorax nycticorax* L.) is applied in a few cases (31).

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Planning for rehabilitation in a flood defence channel: the River Idle, UK.

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Abstract

The River Idle is a low gradient river flowing through north Nottinghamshire, UK. The river was comprehensively-channelised in the 1980's for flood defence and land drainage. The resulting channel has a low overall conservation value and is suitable for rehabilitation. However, the restoration design must tackle these deficiencies through improvements which do not compromise the other obligations of the managing authority. Designs for rehabilitation are based on geomorphological attributes by assessing the sources and pathways of sediment through the system and through geomorphological surveys which define conservation value and rehabilitation potential. The ideal of *prompted recovery* is central to the design of short-term objectives which do not compromise long-term geomorphological sustainability. The proposed measures were tested for positioning and their impacts on flow conveyance and flow levels using hydraulic models. As river restoration schemes extend to rivers with multi-functional management requirements, so catchment-level design principles and hydraulic testing become increasingly critical to justify suitable designs.

Introduction

In reaches where multi-functional river management requirements exist, full 'restoration' (1) of a river towards 'pre-disturbance' conditions, based solely on a conservation perspective, is not feasible. Instead, river rehabilitation strategies must employ a range of measures designed to initiate long-term improvements, as well as measures designed to bring shorter-term increases to the conservation value of the river, without significantly affecting existing functions such as flood defence and land drainage. This paper illustrates attempts made to achieve management goals while avoiding unacceptable adverse impacts on individual management functions for the River Idle, Nottinghamshire, UK. To be sustainable, it was essential that all proposals be appropriate to the catchment sediment context of the River Idle. On this basis, the overall objective of river rehabilitation may be summarised as to take to implementation 'proposals designed to provide a gradual and sustainable improvement to a severely degraded system within a multi-functional management framework, while taking care to avoid compromising existing or proposed future functions'.

Study Area

The River Idle is a mixed sand and gravel-bed river draining a 842 km^2 catchment of low relative relief (Fig. 1). Fifty percent of the catchment is below 150 m AOD and 25% is below 30m. Geology in the upper catchment consists largely of Sherwood sandstones, coal measures and magnesium limestone whereas Keuper Marls and alluvial sands and gravels predominate in the lower catchment. Catchment soils are amongst the most susceptible to aeolian erosion in the UK. The upper catchment has experienced considerable urban development and woodland clearance while the lower catchment has been developed for intensive arable cropping and, more recently, the extent of open-cast gravel workings is increasing.

The planform of the Idle itself has changed little over the past 200 years due to the low gradient, and the consequent low levels of bankfull mean stream power (0.6 - 2.2 Wm^{-2} (2)), make the river liable to sedimentation rather than erosion. The last severe flood, in 1977, prompted major flood defence and land drainage initiatives designed to augment piecemeal measures which had been installed since the 19th century. In the project reach, in 1982, channel capacity was increased by raising flood embankments and creating trapezoidal channel cross-sections (lowering the bed by an average of 0.7m) to provide flood protection to the 3-year (agricultural land) or 10-year standard (urban areas). Most of the natural planform sinuosity was, however, retained. Recent hydraulic tests downstream of the project reach suggest that the channel performs beyond its designated flood defence standard and this may also apply to the project reach, extending from Bawtry 23 km upstream to East Retford. The consequences are that rehabilitation measures might not compromise the intended level of protection, or capability for land drainage.

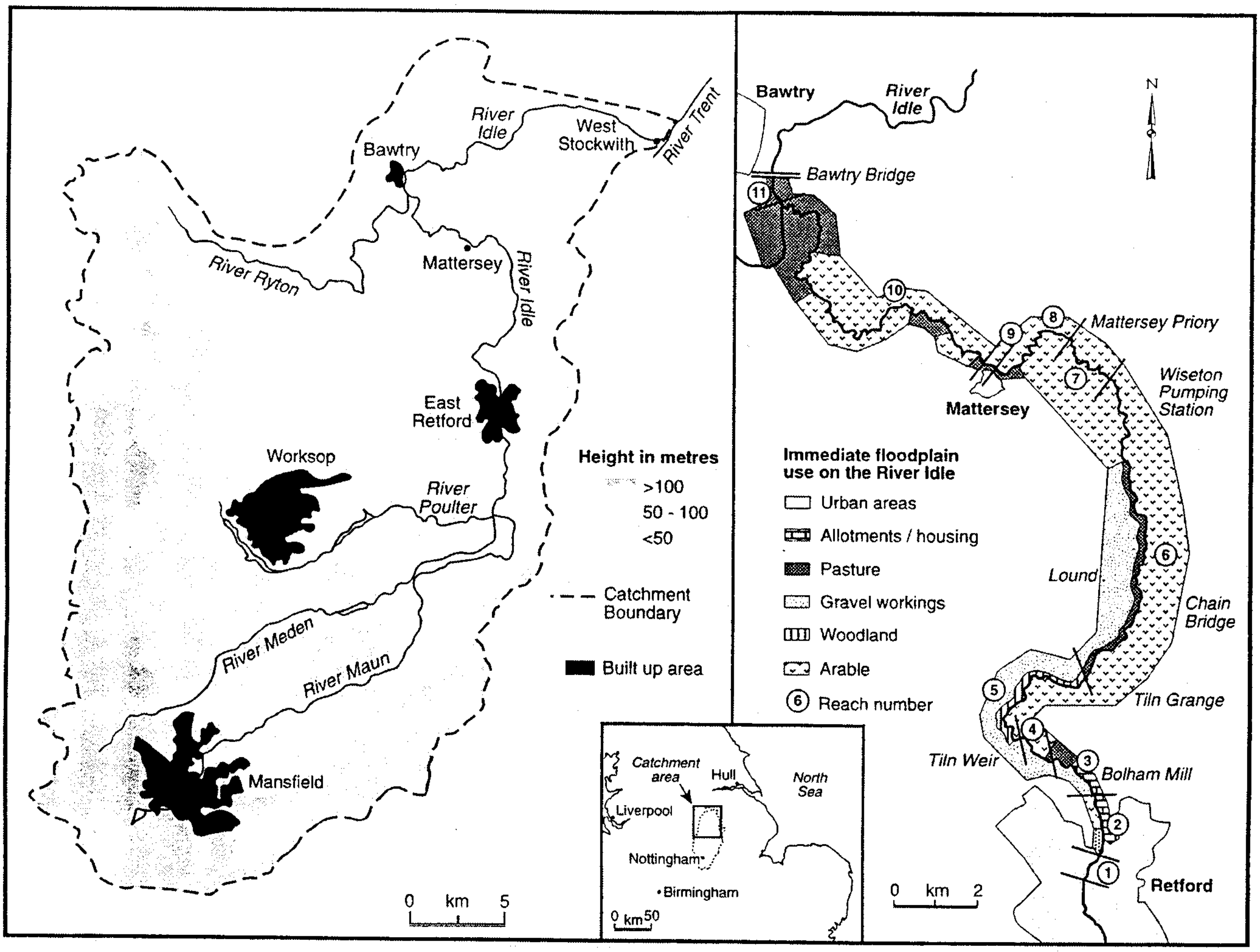

Figure 1. Location of the River Idle catchment within the UK, topography, settlement and river network, and details of the project reach (East Retford to Bawtry). Project reach shows bordering floodplain land uses and division of the reach into sub-reaches on the basis of geomorphological conservation value.

Assessment of Existing River Idle

The baseline environmental value of the current river was established using site visits and the results of previous thematic assessments of conservation value. This is a fundamental step in determining the objectives of a 'restoration' scheme, prioritising reaches for restoration, identifying the reference reach, and establishing the extent to which restoration can be achieved through *prompted recovery* (whereby morphological diversity is improved using geomorphological and hydraulic manipulation of natural processes) compared to the degree that sustainable environmental functioning will direct intervention to make the necessary morphological modifications.

Fluvial Geomorphology

Geomorphology was assessed using an approach developed for project appraisals (3) as a modified form of a 'catchment baseline survey' (4). In October 1994, a survey identified 11 sub-reaches which were in different ways geomorphologically homogeneous (Fig. 1). Bed material sampling indicated that the current River Idle had a gravel-bed which was exposed only intermittently at locations where local scour is sufficient to remove a blanket of silty-sand which otherwise smothers the bed. The impact of management on the project reach is that, overall, there is little geomorphological conservation value. Geomorphological rehabilitation potential correlates inversely with the geomorphological conservation value, but it is also affected by surrounding land use (see Fig. 1), which may restrict opportunities for improvement. In the study reach, rehabilitation potential is further constrained by arable agriculture on the floodplain, flood defence functions and land drainage.

River corridor flora
Ecological surveys carried out for the former NRA concluded that vegetation diversity was generally poor due to the engineered nature of the channel. Because the channel banks are mown frequently as part of operational maintenance, there was a poor diversity of habitat and a uniform species mix along the channel except where access for mechanical mowers was restricted. Unrestricted grazing by livestock produced similar outcomes. Many reaches had few or no trees or shrubs, resulting in a lack of shade and overhanging cover. Channel margin flora was generally restricted to short and narrow lengths of emergent reed bed or marsh species, and aquatic vegetation was restricted to pondweeds and algae. Protection of the bank toe against erosion by stoning restricts further the establishment of marginal vegetation.

Fisheries
NRA electro-fishing surveys (1989 and 1992) concluded that all sites except Mattersey Priory had the attributes of a poor fishery, both in total biomass and in fish species present. Subsequent research assessing fish habitat variation using parameters within the PHABSIM computer model concluded that that fishery potential is restricted by sand covering the gravel-bed, which restricts exposure of invertebrates living in the gravel interstices and on which the fish feed. Additionally, the steep, engineered banks and square-cut bank toe restricts the amount of shallow water habitat available for shelter during high flows, so that some species may be unable to remain in the reach through their entire life-cycle.

Public amenity
Recreational activity along the river in the project reach includes use by anglers, walkers and canoeists. Angling would undoubtedly benefit from increased fish stocking, but this unsustainable under the currently poor environmental conditions. The flood embankments provide excellent access for walking but there are no official riverside paths. A study of public perception of river environments along the Idle demonstrated a high degree of correspondence between favourable public opinion and the reaches of higher geomorphological and ecological value. On this basis, rehabilitation of the Idle appears to be consistent with preferences of the 'catchment community'.

Overall, the poor environmental values for the Idle may be explained primarily by the morphological monotony of the channel as constructed for flood defence. It follows that increased diversity in channel morphology would provide the basis for increased geomorphological diversity, to provide the range of habitats necessary to support a rich flora and fishery, to increase the amenity of the river and riparian zones for recreational use and to enhance public appreciation of the river as a useful landscape feature.

Design Approach For Geomorphological Sustainability

Prioritisation of site
After review of the Idle catchment network, reach 5 was selected as the reference reach due to its sinuous planform, gravel-bed materials and mature river corridor flora. It is the nature of all rehabilitation/restoration schemes that management of the river corridor, rather than just the channel itself, is necessary and, thus, land use constraints are important in determining rehabilitation potential. The 11 geomorphologically-defined reaches were set into four categories of rehabilitation priority. Reach 6 was chosen as the top priority as: it adjoins the reference reach (reach 5), it retains some natural sinuosity, it has set back embankments which provide a defined (narrow) river corridor, the development of gravel workings along its left bank reduces the economic consequences of flooding, angling club interests within it mean that short-term recreational as well as ecological improvements can be attempted, and the small Nature Reserve on its left bank forms a focus for river corridor improvements.

Geomorphological context
Specific objectives for rehabilitation must be compatible with the geomorphological context of the catchment to ensure their sustainability. The low stream power of the downstream reaches of the River Idle mitigate against serious erosion, but it promotes a depositional environment. The requirement to maintain flood capacity and to preserve the low elevation of base flow water levels required for land drainage under gravity means that sedimentation has long been seen as a problem which necessitates frequent desilting. Concerns about sedimentation since implementation of the 1982 flood defence and drainage schemes led to

a catchment-based sediment transport report (2) which focused on the *rate* and *cause* of sedimentation. The report questions whether the current desilting frequency of between 1 in 5 and 1 in 10 years might not be relaxed to a 15-25 year cycle (2). In relation to rehabilitation, it is possible that such a sedimentation rate can be dealt with through 'prompted recovery', whereby fluvial processes are manipulated to create improved conditions for silt transport and storage, rather than relying on mechanical removal.

The earlier study estimated that the time taken for sediment to travel through the project reach would be nearly a year under continuous flood flow conditions, or over 25 years under low flows. Therefore, siltation in the Idle must be driven by local sediment sources rather than a remote upstream sediment supply. As there is little bank erosion, much of the sediment deposited must originate from floodplain soil erosion. This is reasonable because of the high percentage of Very High erosion risk soils in the Idle basin (32.4% compared with a national average of 1.5%, 2) and farming practices which involve ploughing to leave exposed soil in winter, associated with sugarbeet, maize and winter wheat. That these practices maximise the potential for soil erosion is illustrated by the need for annual de-silting of many field drains and the 2 -3 year maintenance regime of larger drains. Eroded sediment arrives in the channel either directly via aeolian transport, or indirectly via drainage ditches. Other significant sediment sources may derive from sewage treatment works and/or spoil heaps from disused collieries.

It is clear that sustainable rehabilitation measures will require an approach that is sensitive to the catchment sediment context. Therefore, design suggestions were formulated to support sustained habitat recovery at three spatial scales: catchment, corridor, and in-channel. The catchment-scale proposals necessarily require management initiatives and co-operation that the river authority (in this case the Environment Agency) can only tackle within the context of wider catchment planning.

Catchment-scale measures

Catchment-scale proposals are designed to control to generation of the sediment responsible for siltation *at source* and are vital to making any rehabilitation sustainable. The following three goals are, therefore, necessary long-term objectives:

- Reduce fine sediment being transported into the reach from upstream: sources of fine sediment may include overflows from urban sewers and releases from the Mansfield Sewage Treatment Plant (STP).
- Reduce the contribution of wind-blown sediments which enter the Idle directly by using a barrier of trees and shrubs along the floodbanks to shelter the river and filter out sediment.
- Reduce the contribution of eroded sediments which enter the Idle via the drainage ditches using set-back embayments at the junction of drains with the main channel to intercept channel-bound sediments.

Corridor measures

Effective river management must deal with land and water issues together. In practice, this can be achieved in part by management based upon a river corridor which encompasses a strip of land on either side of the channel. The existing flood embankments on the Idle already define a narrow corridor within which four river corridor measures are suggested:

- Provision of tree barriers on the outside of flood embankments: for ecological and aesthetic improvement and to provide a physical barrier to delivery of aeolian sediments to the channel (see previous section).
- Planting of low-maintenance, low productivity grass and indigenous wild flower mixes on ungrazed embankments to improve wildlife habitat and reduce the requirement for maintenance grass cutting.
- Planting of small stands of trees and shrubs to increase habitat connectivity in zones which are not critical to the conveyance of flood flows, that is, on the outer bank margin of the flood corridor in sinuous channels as overbank flood flows are focused across the inner bank.
- Planting of tree species alongside the river channel, especially on the southern bank, to provide wildlife cover and shade for fish. The trees help to create stable habitats in terms of light, shelter and temperature, provide links to other terrestrial habitats and shade out aquatic weed growth. To minimise their impacts on flood flows, trees should be planted parallel to the flow and opposite the side of the maximum velocity filament in high flows.

In-channel measures

In-channel measures should focus on using natural flow processes to improve habitat diversity while also dealing with the potential of siltation to reduce channel flood capacity and reduce maintenance costs. Siltation in the Idle occurs through some combination of:

- insufficient stream power to transport sediments through the reach,
- insufficient morphological diversity to allow the orderly patterns of silt deposition characteristic of natural rivers,
- flood embankments severing the ability for sediment deposition overbank during flood events.

The latter two factors can be attributed to river management for flood defence. However, it should be possible to create morphological diversity in-channel which allows patterned sediment deposition while maintaining a coarse-bedded, self-scouring, low-flow channel. A combination of measures is proposed and these are summarised in Fig. 2 (with the proposed locations of fringing trees).

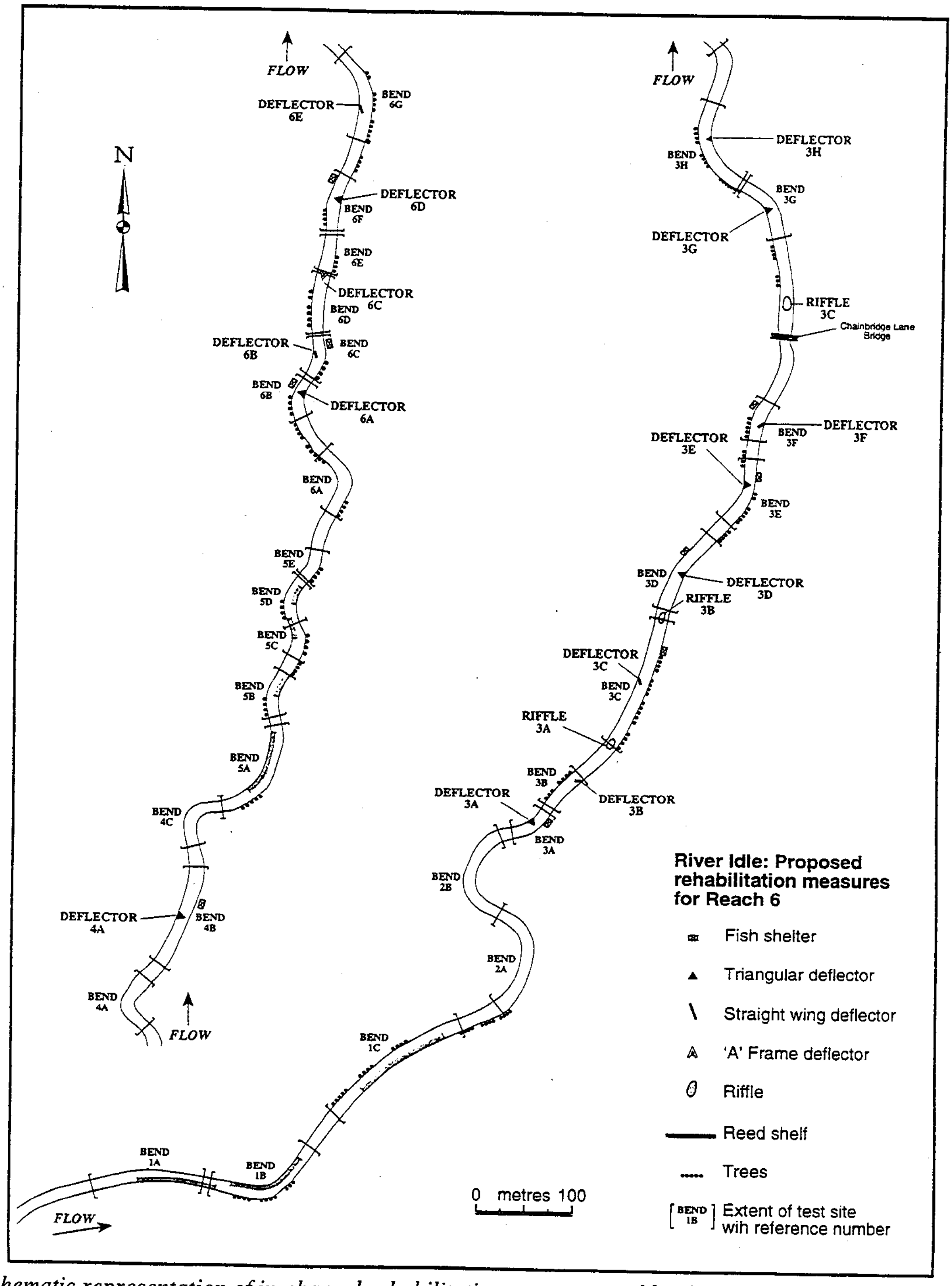

Figure 2. Schematic representation of in-channel rehabilitation measures and bankside tree planting proposed for Reach 6. Test sites for checking deflector locations via BENDFLOW are indicated.

- Deflectors to alter the spatial pattern of river currents to increase in-stream habitat diversity especially in straightened reaches where the reinstatement of meanders is not possible due to limitations of land availability. Low flow sinuosity can be induced by deflecting flows with a periodicity related to the appropriate natural half-meander wavelength. The deflectors create localised scouring that desilts the bed and creates or maintains pools by accelerating flow through a constricted section while, in the slack water zones, sedimentation causes bar formation and allows vegetative recolonisation.
- Riffle installation to provide gravel habitat. As no incoming gravels can be expected to replace transported sediments, the installed gravels must be stable for the majority of discharges. Sediment mobility calculations indicate that riffles formed from medium gravels should be stable in the Idle but the threat of burial by sand deposition is of real concern.
- Reed planting to enhance habitat value by providing fish shelter, shading and nutrients. Planting should be in naturally slow flowing zones at the inside of bends in sinuous reaches where reeds can be used to narrow the low-flow channel and locally to increase low flow velocities and trap sediment. For the River Idle, reed growth is restricted currently by the square-cut bank toe which reduces the amount of shallow, slow-flowing water required for rooting. Where reed planting is planned, the vertical bank at the edge of the low bench must be reprofiled prior to planting so that it shelves into the water.
- Bank reprofiling to provide river cliff and point bar habitats which have been precluded by the uniformity of the bank morphology and flow processes on the River Idle. In naturally meandering rivers, river cliffs provide nesting locations for a range of birds and small mammals while point bars provide a habitat for a variety of invertebrates. Selected meander bends should be re-profiled with the outer bank cut vertically to form a river cliff and the inner bank re-graded to a 1:2 or 1:3 slope, with the toe of the re-profiled inner bank protruding into the channel and locally reducing low-flow channel width. Low stream power means that significant retreat of the river cliff is unlikely.
- Fish shelters to provide short-term shelter (albeit, artificially) until a more varied morphology develops natural shelters. Shelters are installed opposite deflectors so that an adequate water depth exists through scouring effects.

Performance Testing

Siting of proposed measures and assessment of erosion risk
Appropriate siting of the proposed measures, so that they are consistent with the natural tendencies and periodicities of the river while avoiding significant impacts on channel flood flow conveyance, requires consideration of the pattern of existing flow at each site, with particular regard to the positions of the thalweg and the filament of high velocity at various discharges. A theoretical comparison between the observed thalweg (1994 NRA survey) and the filament of maximum velocity at both low and high discharges was performed using the BENDFLOW mathematical model to predict the distributions of depth-averaged flow velocities and depths in non-circular bends (simplified example shown in Fig. 3). BENDFLOW was also used to test the impact of meander bend reprofiling in four bends proposed for alteration. Maximum scour depths were predicted to increase between 0.02m and 0.15m in high flows which should have little impact on channel stability.

Impacts of proposals on flood capacity
The impact of the proposed rehabilitation measures on flood capacity was studied using HMODEL2, a recently developed hydraulic model designed to predict stage-discharge curves in two-stage channels with vegetated flood banks and, in sections where cross-sectional geometry will change (i.e. deflector sites), the FCFA method which is designed specifically for discharge calculation in compound channels. The two methods were applied to test various widths of reed shelf creation, varying tree spacing scenarios, the impact of the deflectors and overall impact of the planned combination of measures. At flows near to 'embankment full' level, overall conveyance losses range from 5.6% to 10.1% in reaches with combinations of reeds and trees, and from 5.7 to 11.0% in reaches with deflectors. Where reeds and tree planting are proposed, the majority of the impact is from reed bed creation, whereas the impact of the trees is calculated to be minimal (but see (5)).

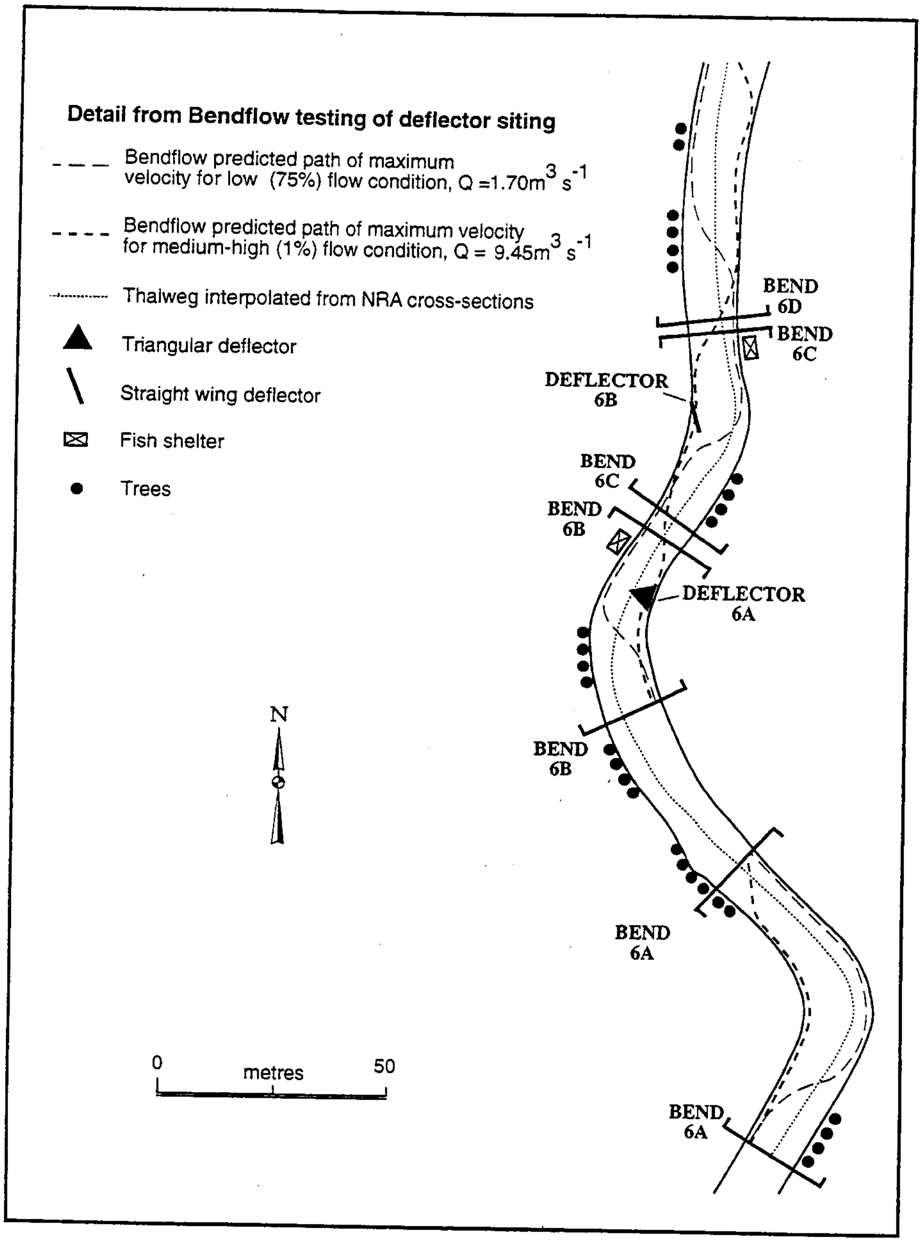

Figure 3. Detail from testing deflector locations using BENDFLOW in bends 6A-6D.

Impacts of proposals on flood levels

The Environment Agency has the step-backwater hydraulic model HECRAS operational through the proposed rehabilitation zone. This model was used to test the potential impact of the rehabilitation proposals on flood stages. The model was run for four discharges, 8.50 m^3s^{-1}, 22.48 m^3s^{-1}, 29.36 m^3s^{-1} and 36.71 m^3s^{-1}, of which the upper three flows correspond to return period flows of about 15, 50 and 100 years, respectively. The results suggest that the maximum water level rise under the three high flows would be only 0.05m for the 15 year flood, or 0.12m if maintenance is neglected or significantly reduced.

Overall, testing confirmed that while some local conveyance capacity is lost, the proposed measures have no regional impact on flood defence and are unlikely to increase the threat of channel instability (further details in (5)). In light of the over-servicing for flood defence noted earlier, the rehabilitation designs appear compatible with statutory flood defence requirements.

Discussion

The River Idle is, in many ways, a typical lowland UK catchment. Overall, it may be described as severely degraded and a river in need of restoration (cf. (6)). However, as the human causes of degradation are unlikely to disappear, true restoration is impossible and *rehabilitation* is necessary. To be sustainable, rehabilitation must have due regard to the catchment geomorphological system (i.e. recreating form *with* function) whilst acknowledging the constraints to design (and assessment) existing in a multi-functional river management environment. Experience on the Idle has highlighted three core planning issues. First, the appraisal process is critical in assessing the existing conservation value of the river, the management performance requirements and the objectives of the planned restoration. A range of baseline surveys is required at appropriate timings and frequency (see (7)) because restoration designs are often hampered by a lack of baseline data. The amount of existing background data for the Idle (exceptional for a UK river in our experience) was critical in providing a cost-effective basis for achieving a rehabilitation design within a reasonable timespan. Second, the design approach used a catchment perspective whereby sustainability and the suitability of context were focused on the correct level of dynamic geomorphological activity and the sources and pathways of sediment transport (see (8)). For this river, important factors include the low energy nature of restoration zone, the enlarged upstream urban area and intensification of agriculture in the floodplain surrounding the project area. These factors required catchment-, corridor- and in-channel-measures to counteract the dominant trend for sedimentation using *prompted* recovery with small-scale structures to re-create riverine functioning and so to re-establish morphological diversity. Third, performance testing of the designs was critical in this flood defence channel, even though modelling of river flow and morphology is still subject to large uncertainties. Future improvements to restoration designs will continue to be highly dependent on experience gained from post-project monitoring and appraisal must be adequately funded as an integral part of the rehabilitation process.

Rehabilitation of the River Idle has concentrated on pragmatic approaches to a wide range of the best practice criteria suggested in the river restoration literature. In management terms, it is apparent that pre-existing baseline surveys provide considerable time savings and enable a rounded appreciation by the project team of the entire 'design environment'; they should, therefore, be funded as part of an on-going strategic commitment to river management. It is apparent also that, to reduce the risk of failure, planning for rehabilitation requires a commitment to funding which extends across financial years, even when baseline surveys exist, and that the commitment must extend also to post-project appraisal and monitoring. Installation of the measures recommended in this paper occurred during 1996 and early 1997; channel surveys were taken prior to installation and post-construction monitoring at regular intervals is on-going.

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Artificial riffles in river rehabilitation

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Introduction

The papers in this volume testify to the upsurge in interest and practice of river restoration and rehabilitation in western Europe; similar work is in progress in Eastern Europe (1). Despite this interest, perhaps because it is relatively recent, there are several problems with the practice of restoration in the UK, which have not, to date, been effectively addressed. These problems are:

1. Inadequate budgets, so that most projects are small rehabilitation works which fail to address the main causes of degradation (e.g the planting of trees on the bank top of a degraded, straightened channel).
2. An inadequate scientific basis, in which the link between hydrology, through geomorphology, to ecology has not been clearly understood and goals not clearly defined. As a result, some restoration schemes have been short-term successes and longer-term failures (e.g. inappropriate placement of current deflectors which initially work but soon become silted).
3. Inadequate human lines of communication, which may mean that examples such as 2 above were correctly planned but incorrectly implemented.
4. Inadequate or absent post-project appraisal, so that the any problems arising from rehabilitation above are not fully appreciated or their lessons learned. Equally, successes have gone unrecognised.

A rapid method has been developed to address these problems in lowland alluvial rivers in eastern England, where numerous small rehabilitation projects have been implemented in the last five years (e.g. (2)(3)). The basis was the identification of a suite of habitats, termed 'functional habitats', which together provided distinct habitats for the invertebrate biodiversity of the river channel (4). The formation of functional habitats is dependent upon the hydrology of the river and so they act as a link between hydrology and ecology.

The effectiveness of riffle replacement in a 2-kilometre stretch of severely canalised river was evaluated, three years after the works were implemented. The evaluation had three phases: i) geomorphological measurements, ii) functional habitat measurement, and iii) quantification of the macroinvertebrate community development. In this way the effectiveness of the functional habitat assessment, a rapid procedure, could be compared with more detailed geomorphological and ecological assessments.

Site Description, Materials and Methods

The stream studied was The Harper's Brook, a lowland third-order tributary of the river Nene, a clay catchment draining lowland arable and pasture agriculture in eastern England. In the study stretch, where the Brook runs along the edge of the wider floodplain of the Nene just before their confluence, gravel extraction over the past five decades has progressively created a series of lakes (many now nature reserves). Approximately thirty years ago, the channel of the Brook was re-aligned to carry it around a large gravel working. In the process, the existing river was straightened and deepened above the new channel (Fig. 1). The channel thus created has had to be continuously dredged since that time, because the river is moderately enriched by the effluent from several upstream village sewage treatment plants, and low flows in the over-large channel result in sedimentation and dense growths of emergent macrophytes dominated by *Sparganium erectum* each summer. Fish densities were poor. The logistics of the scheme including details of the riffle construction were described by (5).

Geomorphological assessment of the riffle rehabilitation was made in the following ways:

1. Measurement of the existing riffle spacing from mid-point to mid-point (by 30 m measuring tapes along the banktop) and comparison with the spacing predicted from calculations based upon bankfull discharge and that calculated from the relationship with mean annual discharge (a gauging station is located 1 km upstream with no intervening tributaries) using the regression published for the river Welland by (3).
2. Measurement of riffle lengths, from top to tail (by 30 m measuring tapes along the banktop) and comparison with original lengths of the riffles by measurement of length of fencing installed on one bank to prevent sheep crossing by the riffles.
3. Measurement of the substrate proportions by visual estimation of the percentage frequency of cobble, stones, gravel, sand and silt, using the methods described in (6) and comparison with those of the construction materials.
4. Measurement of riffle depths (by steel rule) and velocities (by 'Ott' current meter) over the riffle surface, in five mid-channel points on each riffle from head to tail.

5. Measurement of the maximum depth, and distance from riffle mid-point to the point of maximum depth, of pools, and comparison with maximum depths recorded from adjacent runs assumed to be free from the influence of riffles.

Functional habitat assessment of the riffles was achieved by recording the presence/absence of functional habitats in ten riffles of varying depths, and ten randomly selected similar-length stretches of run (representative of the river channel before rehabilitation). The list of sixteen functional habitats used is from (7).

Biological assessment of the majority of the riffles was achieved by replicate sampling of the invertebrates in sixteen riffles, chosen from an original 26 placed in the stream to give the widest range of depth and average velocities over them, and to include examples from the most upstream and the most downstream to take account of any possible influence of backup from the river Nene confluence. Two samples were taken by timed kick sample with a handnet of 500μ mesh from each riffle, at head and at tail, and analysed to genus on return to the laboratory, excluding the chironomidae. The results of these samples were analysed using Canonical Correspondence Analysis (8)(9), to show the influence of physical factors upon invertebrate abundance.

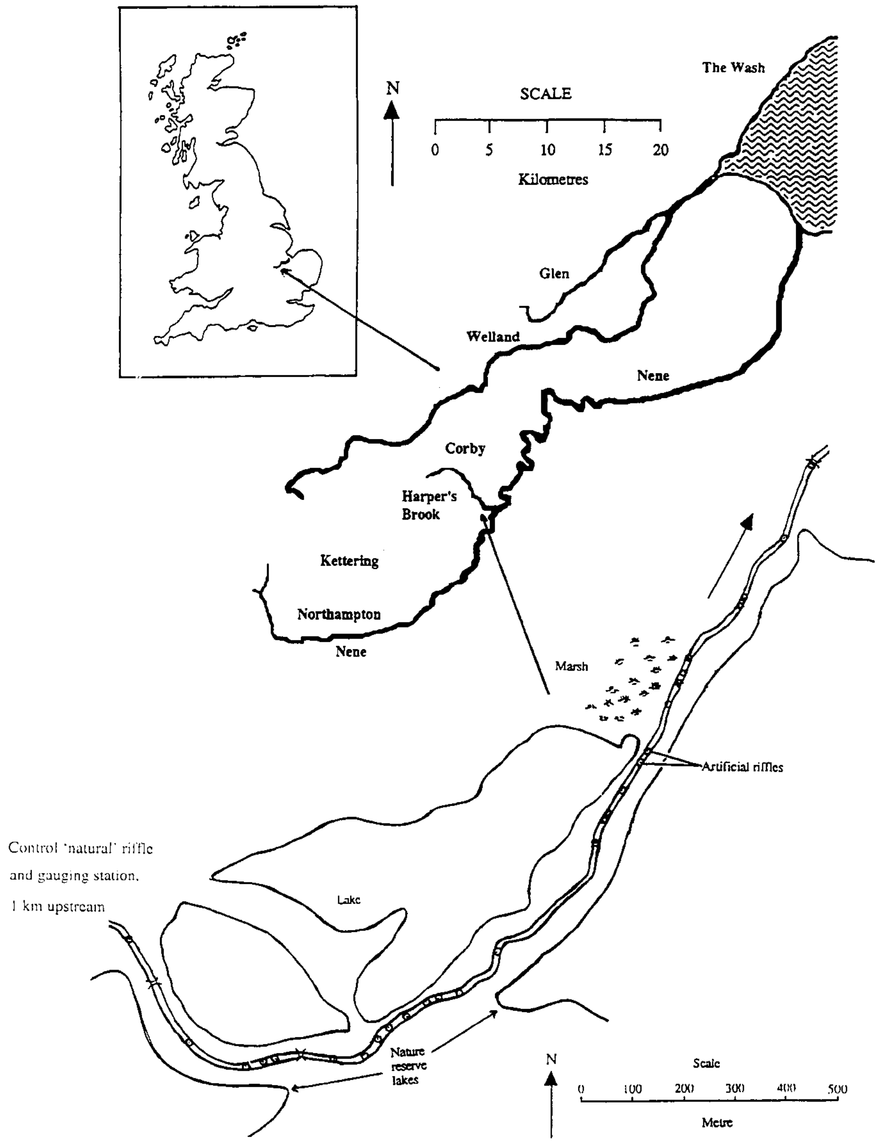

Figure 1. Location of the rehabilitation stretch of the Harpers' Brook in Eastern England

Results

The theoretical spacing, calculated from the relationship for riffles measured in the adjacent river Welland was:

$$y = 18.134+17.39x$$

where x = ÷(mean annual discharge in $m^3\ yr^{-1}$)/1000) and y = mean riffle spacing in metres (3).

Mean annual discharge, for the upstream gauging station over the eleven years 1983-1994, was 13 x 10^6 m^3 (NRA unpublished data), giving riffle spacing (y) of 44.6 m.
Using the average relationship of 5-7 times bankfull width (6), the mean bank full width was measured as 8.6 m for 13 locations selected at random in the study stretch, and riffle spacing should thus be between 43 - 60 m. Measured mean spacing between the 26 installed riffles was 84 m. A great deal of variation existed about this mean, with a range between 355 and 25 m. It was clear however that two sections of the study reach contained more regular riffle spacing – between riffles 7-12 and 16-22. Their mean inter-riffle distances were 39.3^{+}/-10.2 and 56.1^{+}/-22.6 respectively. The positions of the riffles (and their original location as marked by fencing) suggest that initial placing was incomplete for unknown technical or financial reasons.

The initial riffle dimensions were estimated by measuring the banktop lengths of fencing installed in 1992 along each riffle. They were a constant length, each between 7-8 metres. The theoretical lengths were calculated from the assumption that riffles occupy around 25% of stream channel (measured on the adjacent river Welland (3)). If inter-riffle distance is assumed to be around 50 m, then individual riffle length should be 9.5 m. Direct measurements (n=25, one riffle could not be adequately distinguished) showed mean length to be 7.6^{+}/- 4.2. The mean implied that there had been little change since establishment, but this hid the fact that one riffle had effectively disappeared and its length could not be measured, and one had grown dramatically; the range was 5.2 - 21 m, indicating little overall loss of material, more a re-distribution within the stretch.

There is no information available about the intended depths of riffles or about initial depths after construction. Depths and velocities were measured during a low flow period in late summer 1995. Mean depth was 26.5^{+}/-8.7 cm, mean velocity 42^{+}/-18 cm sec^{-1} There was a clear relationship, just significant (r^2 =0.51), but there were three groups of riffles; a shallow, fast flowing group of three-four, with depth < 20 cm and velocity >100 cm sec^{-1}, a deep sluggish group of four with depth > 40 cm and velocity < 25 cm sec^{-1}, and an intermediate group.

On installation in 1992, riffles were constructed from a cobble support plus 150mm gravel from the 'rejects' of an extraction company within the floodplain (NRA pers. comm.). Three years later, twenty riffles were still clearly dominated by cobbles and gravel, whilst 2 were overlain by sand and four by silt. The four silt-dominated riffles were the deeper ones. As would have been expected, deeper riffles with more sluggish current speeds have become dominated by finer particles deposited during low flow periods.

There is no information about the existence of pools prior to riffle re-instatement, so we can only assume that the deepest parts of the long runs in between groups of riffles are typical of the depths of the whole stretch prior to riffle construction. The mean depth of the runs measured on one day during a low flow period in 1995 was 46^{+}/-11 cm compared with the mean depth of the deepest points found below each riffle of 111^{+}/-45 cm. This suggests that, in the three years since their creation, the artificial riffles have been effective in creating pools during high flow events. Those riffles that are more correctly spaced have been more effective than those which are not; the mean pool depth of the fourteen riffles of the two more regular spaced groups is 126 cm. The mean distance of the pools from the riffles was 760^{+}/-172 cm, which is considerably shorter than the 2500 cm which would be expected from the predicted riffle spacing (even the riffles in the two groups spaced according to predictions did not form pools any further downstream than the other riffles).

The relationship between riffles and the original river bed was specified as 'a 300 mm head' (NRA pers. comm.). In a sequence of closely-spaced riffles the difference is nearer to 500 mm (although the riffles are closer together than predicted spacing would suggest appropriate).

Functional Habitat development

There were no surveys conducted before the riffle reconstruction, and so we assume that the functional habitats present in the river before 1992 were the same as those found in the runs in 1995. These were five: sand, silt, broad-leaved submerged plants, emergent plants, filamentous algae. Clearly, the riffle reconstruction added pebble/cobble and gravel. In 1995 we found additionally on the riffles fine-leaved submerged (only *Ranunculus sp* and *Potamogeton crispus*), moss (only *Fontinalis antipyretica*), marginal plants (several spp.) and leafy debris (as leaf packs in cobble spaces in slack water).

The ten riffles which were surveyed for the appearence of functional habitats showed that shallower riffles contained the highest habitat richness (Fig. 2). This was due to the shallow riffles being kept clear of silt by the higher current speeds, which also were the only areas in which fine-leaved submerged macrophytes and mosses grew. The shallow edges of riffles were the only suitable location for marginal plants and accumulations of leafy debris among the interstices of the cobbles, as elsewhere had smooth, steep-sided edges (the constucted berm was an exception, this was excluded from the comparison).

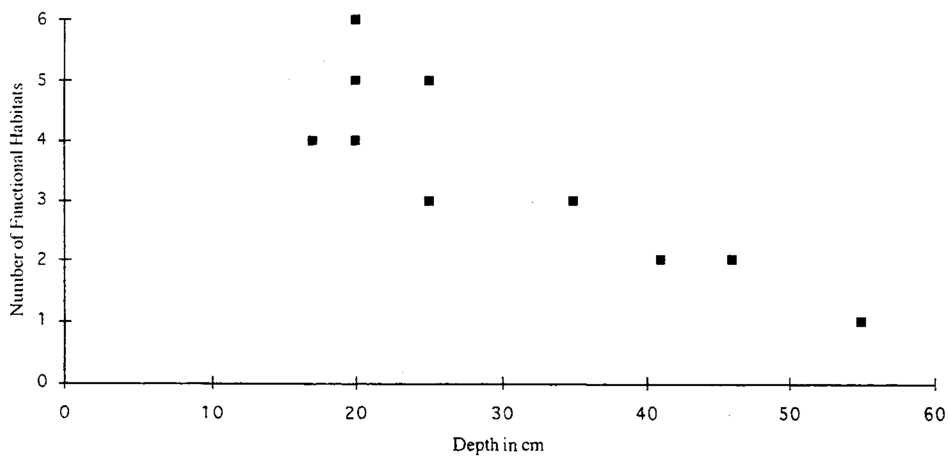

Figure 2. The occurrence of functional habitats in ten artificial riffles in relation to mean depth.

Biological colonisation

In the sixteen riffles sampled, thirty genera were identified. These were 3 mayflies, 2 caddis flies, 4 beetles, 5 gastropod molluscs, 3 bivalve molluscs, 5 leeches, 2 bugs and 5 dipterans. Numerically dominant were the gastropod *Hydrobia*, the dipteran *Simulium*, and the bivalve *Sphaerium*. Fourteen genera were present in numbers high enough for the CANOCO ordination to explain more than 25% of their variation (Fig. 3).The correlation between species and environmental variables recodred at the time of sampling was high in both axes ($r = 0.97$ and 0.86 respectively); in total 37.6% of the species variation is explained (27.9% by the first axis and 9.7% by the second).The first axis is dominated mainly by depth ($r = 0.91$) and silt ($r = 0.88$) with cobbles, current speed and fine-leaved macrophytes; while the second is dominated more by gravel ($r = 0.59$) and moss ($r = -0.52$) with sand. Nine of the fourteen genera are associated with the shallow coarse habitats, five with the deeper, sluggish, fine-particle habitats. The strongest indicators were mainly those of the latter habitats, the molluscs *Planorbis*, *Pisidium* and *Sphaerium*.

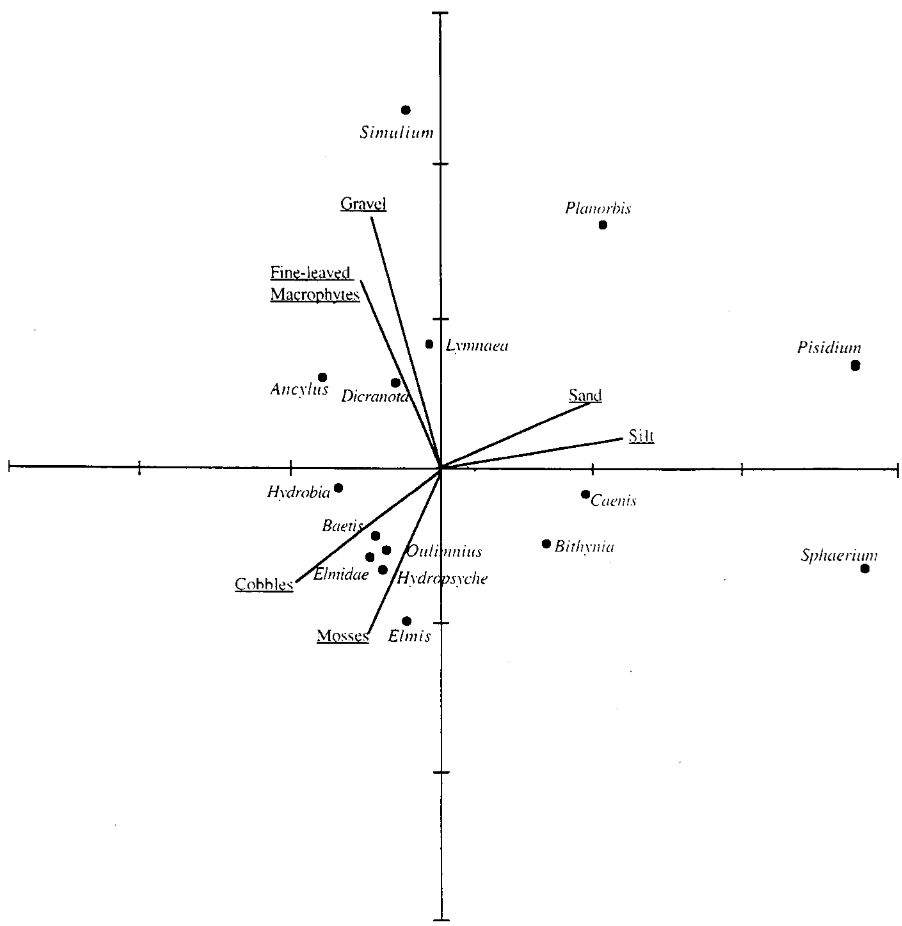

Figure 3. CANOCO analysis of genera (excluding chironomids) on 16 of the artificial riffles.

Discussion

Rehabilitaton works at this site were only undertaken in 1992, so an examination of their effectiveness three years later does not give a final conclusion: nevertheless it does provide some clear pointers, which can be compared to their installation costs (5) and to riffle reconstruction as part of more comprehensive restoration schemes. There appear to have been two failures, albeit modest, to this reconstruction project. The first was the inability, either through limitations of cost, time and manpower or through inadequate preparatory planning, to reconstruct riffles throughout the full length of the project stretch. Those riffles that were in a sequence approximating to the predicted sequence for a river of this size have more clearly scoured pools. The second was the 'loss' of six riffles to siltation, either because they are constructed in the wrong place and have lost material or their original construction was too deep (it is not possible to be conclusive about this but the presently deep riffles are all solitary or close to only one other). Such deep, silted riffles have developed a community characteristic of fine sediments and little different from the runs that they replaced. On the other hand, shallow riffles have developed a community new to the 2 km rehabilitation stretch (although characteristic of riffles elsewhere in the river). At least, 20 riffles, or 77% of the original, have remained in place and those which are most shallow have diversified their physical environment sufficiently to begin to scour pools and create new functional habitats within the new shallow environment.

Rapid assessment of this process by measuring the number of functional habitats on riffles confirms the importance of shallow depth in creating fast currents in mid-stream leading to micro-environmental changes, and illustrates the ability of a simple technique linking geomorphology with ecology which can profitably be used more widely in post-project appraisal.

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A joint Danish and British EU-Life demonstration project: Life - Brede, Cole and Skerne river restoration, I - Setting up and delivery of the project

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Abstract

1. In recent years there has been considerable interest in the benefits of, and the mechanisms for, comprehensive river restoration schemes.
2. In 1994 work began on a collaborative project in Denmark and the UK to restore three lengths of degraded rivers, supported by EU LIFE funds and the country's statutory bodies responsible for river management and environmental protection.
3. The restoration project is a demonstration exercise, incorporating unprecedented environmental monitoring to determine the extent of benefit.
4. The pioneering nature of the partnership project provides many lessons which should be of great benefit to future promoters of river restoration schemes.
5. This paper described how to develop large multi-disciplinary partnership, indicating the need for visionary plans, sound designs, professional project management and legal agreements which assure partners of their responsibilities and provide safeguards for sites in the future.
6. Investment in professional planning and project development has been a main factor in attracted further funding to benefit both the UK and Danish restoration sites.

Introduction

Many rivers and streams in N. Europe and in most developed parts of the world have been markedly modified for centuries. Engineering works for flood defence and land drainage have been commonplace as has urbanization of floodplains. A result of this has been extensive loss of river ecosystems and a marked reduction in the capacity of floodplains to store water and sediments and reduce nutrient levels within rivers.

For more than a decade, due to the influences of the EU Common Agricultural Policy in intensifying food production, and then it's set-aside policies for agricultural land, there has been increasing awareness of the value of river and watershed restorations for integrated catchment management. This is now leading to the view that re-instatement of naturally functioning river-floodplain systems may bring benefits to holistic catchment management by increasing nutrient retention, aiding improved summer low flows, increasing floodwater storage and therefore reducing flood risk downstream, minimising maintenance costs and provide improved fishery, recreation, landscape and ecological value.

The failure of many past engineering works to achieve objectives without many dis-benefits, and especially the public's alarm at such a rapid decline in environmental value of rivers and floodplains that had previously been taken for granted, has led to many *ad hoc* enhancements, rehabilitation and restoration works on rivers (e.g. (1)(2)(3)(4)(5)(6)(7)(8)).

In several countries in Northern Europe rehabilitation has become common practice as part of routine management activities (9)(10)(11). In several European countries major restoration projects involving floodplain restoration and/or re-meandering of rivers have taken place in the past decade. Examples come from Germany (e.g. (6)), Austria (e.g. (12)), Switzerland (e.g. (13)), Netherlands (e.g.(14)(15)(16)) and Denmark (e.g. (17)(18)). In the UK the River Restoration Project (RRP) was formed in 1993 to help promote projects to restore rivers and disseminate information on techniques and benefits.

At the same time the EU began directing some attention to river and catchment restoration through its LIFE, and other, programmes. These aim to improved understanding of river catchment functions and ecosystem bio-diversity and the effects on these of engineered and restored rivers. In March a successful application to support a collaborative project on river restoration in Denmark and UK. The key aims were:

1. establish a European Demonstration Project applying new and state of the art techniques to the restoration of damaged rivers and floodplains;
2. demonstrate the benefits of river restoration for Integrated Catchment Management *viz.* water quality, river hydrology, flood prevention, nature conservation and amenity etc. through a detailed monitoring programme;
3. involve, motivate and train those who influence, or undertake, river management;

4. illustrate how to put partnerships together to facilitate achievement of common goals that cannot be achieved by single agencies alone;
5. determine the cost-and-benefit of restoration schemes; provide a framework for determining the public's perception of river restoration works; disseminate information about river restoration.

The project led to restoring three previously deepened, widened and straightened river reaches, each exceeding 2 km long: River Brede in Denmark, and the River Cole and River Skerne in the UK. The sites were chosen as typical examples to illustrate the range of degradations commonly seen on small lowland rivers in Europe. The objectives went beyond the need to restore semi-naturalness to these three lengths of river and floodplain, since the project also aimed to help more efficient implementation of similar schemes in the future.

This paper gives information relating to developing the project from the 'idea' stage to the production of detailed plans ready for implementation. Information regarding the practical deliverance of restoration works on the ground, effects on river and floodplain nutrient budgets, river geomorphology/sediment transport/flood defence and the extensive environmental monitoring programme are outlined by (19) and (20).

To determine the scale of the project, the combined budget for the three sites was initially c£2 million (£1m from the EU), funding the restoration of 9 km of river and floodplain, and supporting a comprehensive monitoring programme to determine benefits. During the project period additional funding, especially in Denmark, resulted in more than 10 km of the River Brede being re-meandered, with associated floodplain restoration.

The UK budget was initially set at £850,000, but following increased interest and support the total sum approached almost £1m. In the region of £350,000 of the budget was spent on construction contracts resulting in changes to the rivers and floodplains, £200,000 on the pre- and post-monitoring studies, £190,000 on management, promotion, compensations and administration, and almost the same amount on survey, design, contract documentation and site supervision. These figures reflect the importance attached in this project to developing model partnerships and agreements, and monitoring the changes that result from the works undertaken.

Developing the demonstration project

Once EU funding had been confirmed in late 1993, many tasks had to be concurrently undertaken for the UK part of the partnership. The most critical activities were: obtaining assurances from signatory organisations that they would provide their promised matching funding, and confirming which two sites should be selected to ensure objectives would be realised to the full. The application to the EU had been made with the National Rivers Authority (NRA - now The Environment Agency) and English Nature (EN - the statutory conservation body) as the main collaborative funders.

The project went through a period of uncertainty since the NRA would not confirm support until arrangements for project management, project board structures, site selection, adequate financial inputs from other partners, and legal agreements regarding liabilities had been substantially completed. This was in marked contrast to the situation in Denmark where all such issues had been resolved prior to the application to the EU. Here the R. Brede had already been selected, matching funding was secured, project management was in place, plans for construction works had been prepared, and monitoring was underway.

The contrasting situations provide good examples of two routes to take in developing river restoration projects. The Danish example is the simplest, being a project promoted and led by the authority with most responsibility for managing/monitoring the river for flood defence, land drainage, water quality, water resources and wider environmental interests. To increase the range of expertise available, and set up the European Centre for River Restoration, the regional council in south Jutland (Sønderjyllands Amt) entered into partnership with the National Environmental Research Institute (NERI) with support from the Danish Environmental Protection Agency (EPA). Since the authority itself matched the EU-LIFE contributions, work on the ground could begin very soon after the latter's funds were confirmed.

The UK experience is very relevant for potential major schemes which are being promoted in the hope of receiving financial support from lotteries, millennium funds, national government schemes or EU funds. Bids often have to be made which are based on best available information, supported by indicative matching funds by other organisations with common interests. In the case of the LIFE project, all partners at the time of the application were fully supportive of the project, but when it came to making guarantees on their financial commitments, a much more detailed business case and options assessment was demanded. Early activities of RRP (21) identified that no single organisation existed within the UK for managing and protecting rivers, and so national projects of this kind would be unlikely unless promoted by an independent body, with support from key statutory bodies.

The contrasting 'state of readiness' in the two countries is reflected by work on re-meandering the R. Brede beginning in summer 1994, only six months after the confirmation of the EU funds. In contrast site selection on the UK sites was still on-going in early 1995. When confirmed, six months of hectic activity commenced, with the two selected sites subjected to detailed surveys prior to developing detailed designs and contract documentation being drawn together. Whilst this was going on, matching funds had to be secured and Memoranda of Understanding, Project Plans and Legal Agreements drawn-up.

Work to restore the Skerne and Cole did not begin until July 1995, more than 18months after the formal start date of the project. Because the project involves not only the construction and monitoring works on the three sites, but also promotion of river restoration and dissemination of results, a Project Plan was necessary to ensure full integration of the varied elements on all three sites. This was produced at an early stage, the summary is shown in Fig. 1. More detailed Project Plans were also produced for the individual sites.

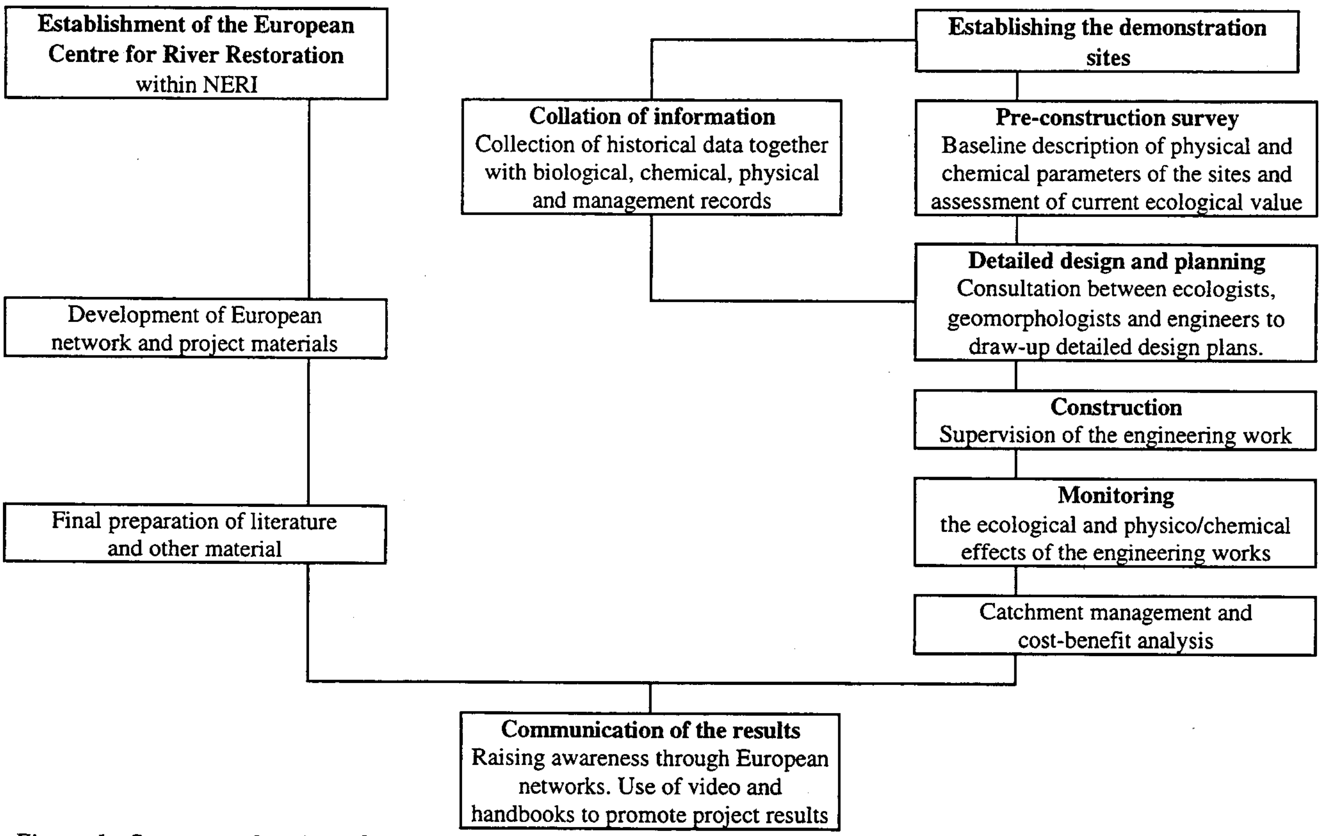

Figure 1. Summary of project plan.

Site selection

The Site in Denmark, the R. Brede, was already determined before the LIFE application was made. It was selected because internal funding was already assured for this site, and the reach was located down-stream of a successful previous restoration scheme, and upstream of an even more extensive reach planned for further restoration. The work was also very important strategically, since the catchment of increased flood storage were required to obviate the need for a major flood defence scheme in the lower reaches of the river.

The two main UK co-funders determined that their support for the project would be conditional on:

1. all potentially suitable sites should be appraised to ensure they meet ALL the objectives, have a good chance of being carried out without unacceptable risks, and represent best value for money;
2. further funding would be forthcoming from other organisations;
3. there would be no deterioration in either assets or standards for which they had statutory responsibilities;
4. projects would be promoted through rigorous project management control, accountable and detailed engineering design procedures would be followed, and supervision of construction would be undertaken by professionals with appropriate experience;
5. legal and other agreements would be in place before structural modifications were undertaken.

To meet the first requirement a short-list of more than 20 river reaches was considered as LIFE demonstration restoration sites by the RRP. These were selected following a trawl for recommended sites which might have the potential to benefit from the type of rehabilitation works being proposed. The selection procedure involved site inspections, appraisal of available information, and reporting upon these within a consistent framework. The reports for each river site were then appraised in the selection process against pre-determined criteria, allocating numeric scores for each.

The six key criteria by which candidate demonstrations sites were assessed are listed below (22):

1. *Aims:* sites must offer great potential to achieve the aims of river channel and floodplain restoration where wildlife, landscape, recreation, water quality, fisheries, amenity and other local interests would benefit without detriment to flood defence or other needs.
2. *Technical:* each site must provide the opportunity to illustrate a wide variety of reversible degradations which can be promoted with confidence in the future. Such reversal must be measurable and sustainable.
3. *Funding:* the site-specific project must be adequately funded through partnerships which secure long and short-term economic viability, with some supporting funds likely to be derived because of the selection of the site.
4. *Ownership:* owners and occupiers must be fully committed to ensure full achievement of objects with minimal negotiations.
5. *Promotional:* the site-specific project must serve to support the wider aims of being a catalyst for promoting river rehabilitation elsewhere, and advancing knowledge and understanding of restoration techniques.
6. *Risks:* as far as is possible, risk of failure must be minimal. Sites should be chosen where there is low risk of future serious pollution incidents, land slips or other catastrophic events to undo the restoration work.

The scoring system was developed, together with the site selection itself, through a panel which involved personnel from the partner organisations. The River Cole was selected as the rural site because it offered a greater range of reversible degradations than other candidate sites, scoring well for all aspects, especially land ownership and perception of minimal risk. The River Skerne was the first choice urban site for several reasons, most notably because of additional partnerships with Darlington Borough Council and Northumbrian Water. The risk of failure, and costs of worthwhile restoration works, were considerably less than for the original candidate site submitted in the application to the EU.

Project management

The overall management of the project was the responsibility of the Danish Project Leader. He had responsibilities for integration of all activities on the three sites to ensure individual elements complemented each other and there was minimum overlap. Fig. 2 shows the summary structure used. Development and management of the UK sites was delegated to the RRP.

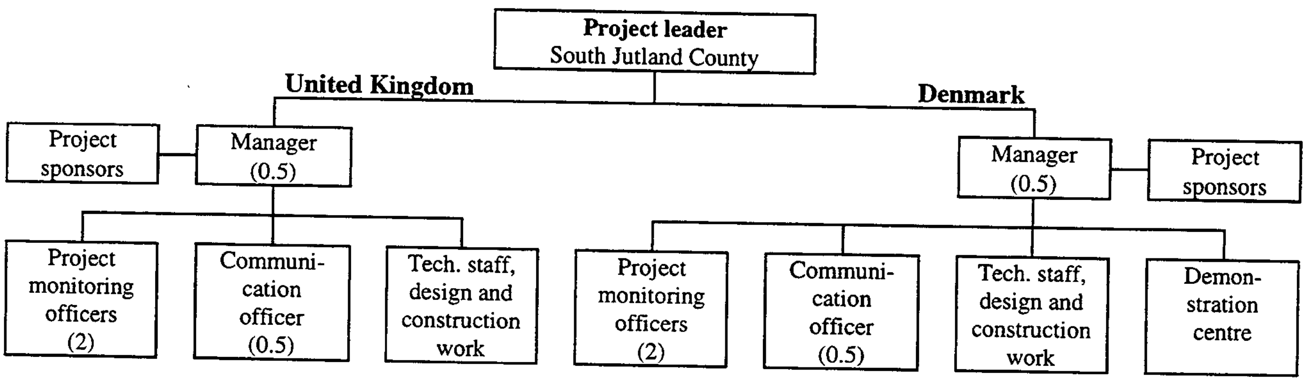

Figure 2. Project management structure.

In Denmark the project was administered by South Jutland County Council, following the same structure and procedures used in previous restoration schemes. The Council is one of 14 which cover the whole country, with responsibilities for water, environmental protection and nature conservation. County Council policy-making, administration and environmental protection is supported by more than 1,500 employed biologists, geologists, geomorphologists, hydrologists, engineers, planners and surveyors. Regional plans, determined by the county councils, set quality objectives for rivers, lakes and coastal waters; these form the basis for investments in wastewater disposal, discharges and restoration schemes. To execute the R. Brede project a multi-disciplinary team of specialists was assembled from the County's Stream Department, supported by specialist expertise from NERI and the EPA.

The Organisational Structure for the UK sites is outlined in Fig. 3. It was more elaborate than that used in Denmark, because overall management was the responsibility of RRP, an independent organisation with no statutory responsibilities for managing rivers. It is outlined because it may serve as a useful example for others promoting river restoration where they too do not have statutory responsibilities for river management. It is a proven example of how issues such as overall management, funding, pre-and post-monitoring studies, concept developments, vision plans, designs, and construction can be efficiently handled when many different organisations are involved. The figure shows how design options were developed through separate WORKING GROUPS of specialists who reported to the PROJECT BOARDS. The former was made up of technical specialists which undertook site investigations, designs and developed options and vision plans for the sites; the latter comprised of senior representatives of the funding/landowner partners who determined what options to adopt and allocated funds accordingly.

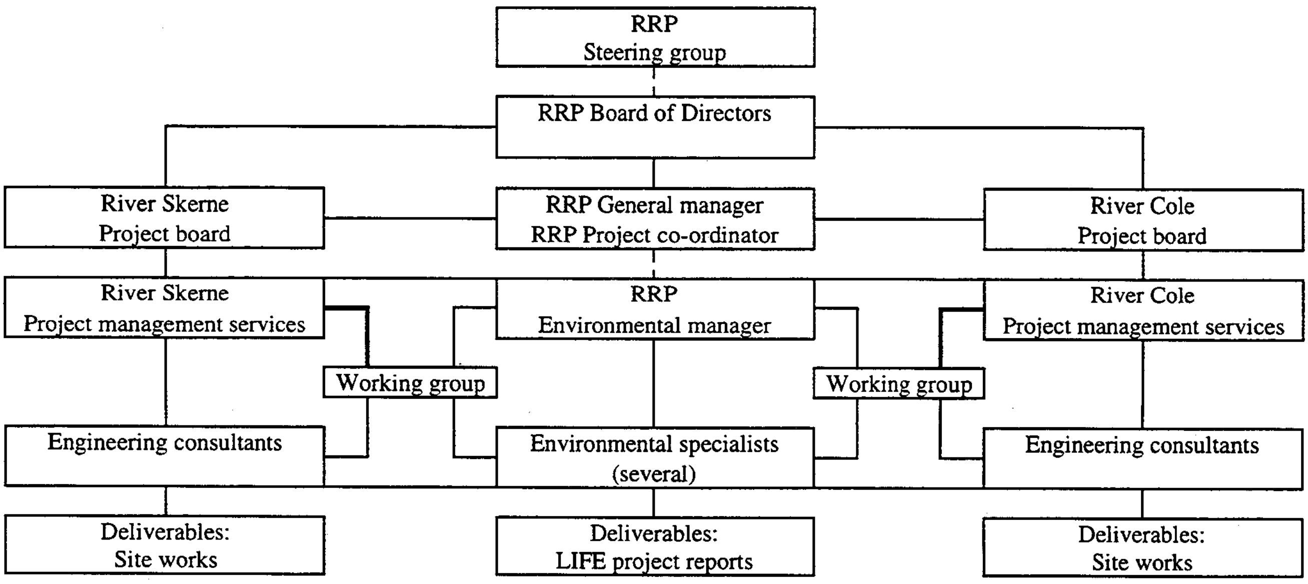

Figure 3. UK Life demonstration project: Organisation structure.

The separate Project Board met together to initiated the process in September 1994, and met again in June 1995 to finalise and approve the scheme designs, appointment of contractors, site supervision arrangements and construction budgets. In the interim period the separate Working Groups and Project Boards had met frequently to progress site surveys and initiate the huge environmental monitoring programme in tandem with public consultation. Fig. 4 summarizes the activities undertaken at each of the two sites. For more details of the development of 'vision plans', monitoring and implementation, see (19) and (23).

Whilst river restoration aims to improve river environments for the future, achieving long-term benefits may result in some impacts. For all sites, several potential adverse effects were identified in the development stages, those resulting from construction works being considered the most significant. These were considered to be short-term in duration and more than out-weighed by the benefits. For the R Cole the independent Environmental Impact Assessment (EIA) of the restoration scheme concluded that some productive farmland would be lost but the 'works will result in improved river and floodplain habitats'.... 'the extent of these environmental benefits both on site and within the wider catchment are unclear and will be assessed through the monitoring programme'.

Memorandum of understanding and legal agreements

In the UK many different organisations may have interests associated with the management of rivers. Land drainage and flood protection is sometimes the responsibility of Internal Drainage Boards but the vast majority of rivers in England and Wales come under the jurisdiction of The Environment Agency (previously the NRA). For any rehabilitation works to be sustained, the goals must be recognised in future management strategies, and prior agreements and consents obtained during the project development. Organisations such as the Environment Agency are not the only bodies with whom agreements are a pre-requisite for successful implementation of restoration schemes. Landowners and occupiers are also critical.

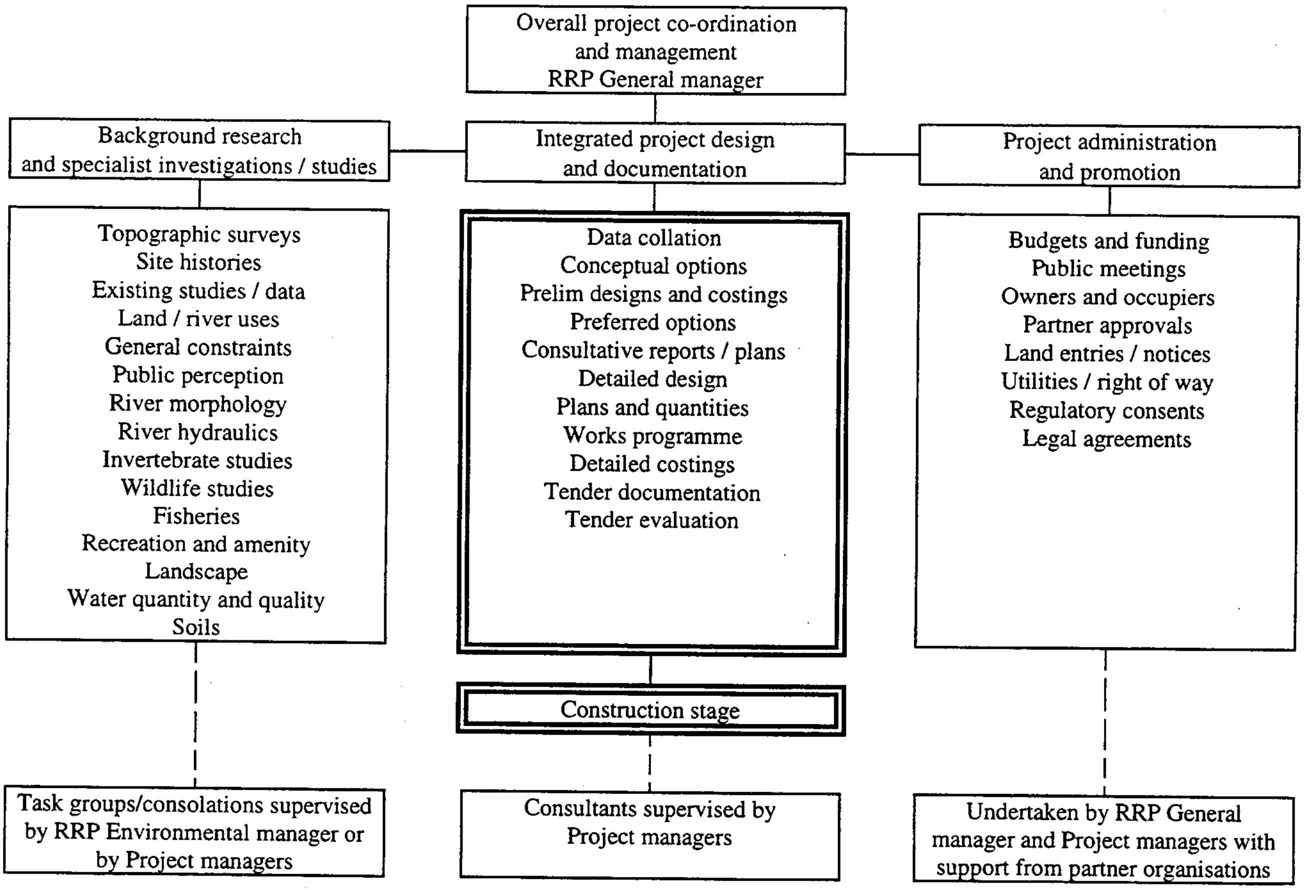

Figure 4. Design activities chart.

They need to be aware of what will change, and what is expected of them in the future; failure to gain agreement on future management and responsibilities is likely to result in many of the long-term objectives of a project not being realised, or even undone due to inappropriate land management.

Promotion of the LIFE project in Denmark and the UK has indicated that many key administrative tasks must be undertaken to secure a firm basis for collaborative work, and assurances for the future. Two different agreements were signed by the partners to show their commitments to bring into the partnership the full powers of their statutory responsibilities or professional indemnity. A Memorandum of Understanding between all UK participants was signed, each one agreeing to work together to resolve any unforeseen problems, and 'bringing both their agreed funding responsibilities and relevant statutory powers as far as they are able to the project'. There was a single document for each site, identifying commitments to budget contributions, outputs, project management and decision-making responsibilities. Indemnity Agreements were more numerous covering such aspects as liabilities of consultants and contractors, to the responsibilities of organisation involved with land and river management in the future, long after the restoration works are completed.

Examples of legal agreements signed prior to completion of the demonstration river restoration project included:

1. landowners at all three sites (approx 40);
2. consultants engaged in the design works;
3. contractors undertaking construction works;
4. consultants engaged in the monitoring programme;
5. Northumbrian Water, responsible for sewerage in Darlington on the Skerne;
6. the Municipality of Loegumkloster on the R. Brede;
7. the Environment Agency (responsible for river management in England and Wales);
8. permissions from South Jutland County (responsible for river management in the region of the R. Brede.

The development of the Memorandum of Understanding and Legal Agreements took considerable time and effort, but if used by templates by others, are expected to be of major benefit to future river restoration projects promoted in partnerships.

Discussion

The experiences of this demonstration project in putting together funding from a wide variety of sources, developing Memoranda of Understanding, Legal Agreements and Project Management structures for delivering such a partnership project, should assist others seeking to promote such schemes in the future. A key point to stress is that these take patience, money and time, all of which must be accounted for in developing a project. Construction works did not begin on the two UK river sites until half way through the project. The experience suggests that rigorous site selection, adequate pre-scheme investigations, design, contract drawings, tendering and production of the necessary memoranda and legal agreements take at least 18 months to undertake if projects are not promoted by the key organisation with statutory responsibilities for river management.

The final documentation to the EU and partner bodies will identify how accurately budgets needed for such restoration projects can be forecast. The experience of this project identified under-estimates in the areas of:

- promotion and management,
- surveys, design and tendering, and
- site supervision.

Promotion and management increased due to unforeseen expenditure associated with planning permissions and compensation. Such payments were intended to be avoided since both set undesirable precedents, but special circumstances prevailed. The depth and scope of pre-works investigations and designs were greater than originally envisaged, and costly hydraulic modelling of the UK sites was necessary to ensure increased flood risks to properties would not result from improved use of the floodplain for storage; much of this breached new ground, and has been a key aspect of the learning experience. The construction contracts were awarded under full civil engineering conditions and a full presence on both sites has proved essential to deliver the complex works.

For the UK sites the production of a standard EIA (when not legally required) was considered essential, and is recommended as an integral part for all major restoration projects. These should be independent and comprehensive. The former ensures that pre-conceptions of benefit, or oversights on impact assessment, are minimised. The latter is also important because it decreases the risk of achieving benefits in one area at the expense of impacts to other interests; it also should help in undertaking projects that are appropriate for the catchment as a whole, and link with other catchment or regional rehabilitation initiatives. Restoration on the Danish site followed the normal process adopted for most such schemes in the country. They follow a regional priority plan but work in very close contact with local interests within an effective procedure to enable efficient promotion.

The attention to detail on project management and structure, and the production of the memoranda and legal agreements, has been an essential element of building confidence in the partnership for restoration. There were no reluctant participants, but many were wary at the start because they were entering into 'new territories', and there were genuine concerns about the risks they might be taking and potential threat to their assets. Future partnerships will be able to benefit from the successful implementation of the schemes which have delivered what was promised.

All three sites in Denmark and the UK have attracted further funding during the project, partly because of the success of works on the ground, but also due to the existence of a 'Vision plan' and a professional management and assessment team. Extremely high value for money can be achieved in such cases as the majority of new funds can go directly to increasing the extent of works on site as concepts and outline design are incorporated into the long-term vision. Additional funds have been forthcoming on the Cole for an experimental floodplain reed-bed to improve water quality in a small agricultural tributary. An even larger grant has been made from the Heritage Lottery Fund to support extending the ecological, visual, recreation and amenity value of the Skerne site. This is particularly important as the benefits of an Integrated Catchment Management project can be seen and enjoyed by a large number of people. In Denmark additional funds were also granted by the Danish EPA and south Jutland Council because of the immediate benefits which were apparent on the R Brede site.

Acknowledgements
The County Council of south Jutland is indebted to its project partners, the Danish EPA for funding, and acknowledges with particular thanks EU LIFE for providing the majority of the initial funding to enable a collaborative project to be undertaken. The project in the UK could not have been undertaken without funding and general support from the Environment Agency (NRA), English Nature, Scottish Natural Heritage, Countryside Commission, Department of Agriculture Northern, National Trust, Darlington Borough Council and Northumbrian Water. Constant guidance from our Danish partners was given to RRP who are also grateful to all its contractors and the many individuals and organisations that have undertaken work on the project at their own expense.

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A joint Danish and British EU-Life demonstration project: Life - Brede, Cole and Skerne river restoration, II - Benefits for integrated catchment management: The river restoration works and related practical aspects

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Abstract
This paper presents practical experiences and achievements on the restoration of the three river sites within the LIFE Demonstration Project. These are the River Brede in Denmark and the Rivers Cole and Skerne in the UK; two are in rural locations and one urban, comprising 7.4 km of river in total.

When the decision to restore a degraded river has been taken, the practical tasks of designing and implementing the restoration works must be undertaken to fulfil the stated aims of the project. The process of design and implementation is explained covering the key tasks of survey, formulating design targets and constraints, actual design, consultation, construction and budget management. The resultant costs of design and implementation are discussed.

Whilst the emphasis was firmly on restoring as many natural river characteristics as possible, the impact of functional constraints proved to be a significant factor in determining the final scheme(s) of works.

The restoration works involved many specialist disciplines and detailed consultation with landowners and river users. The overriding achievement of the project has been to deliver strikingly different river and flood-plain environments, in a form that has successfully integrated all interests, leading to evident approval within the local communities and by participating organisations.

Introduction
Three river reaches selected for restoration had each been straightened, deepened and widened for various functional reasons, such as flood defence, land drainage, land reclamation or milling. A common requirement for each reach was to 're-engineer' the channel to restore sinuosity to the plan form, with commensurate variations in cross section, against a background of appropriate, sustainable, use of the floodplain lands adjacent. The development and implementation of the project through the design and construction stages is described together with costs. Effectiveness of engineering, and management techniques utilised is reviewed

The three restoration sites
After a systematic process of site selection (1)(2) the following rivers were considered to afford the best overall opportunity to introduce, and to monitor, river restoration techniques of sufficient scope and variation to demonstrate the potential for applicability to other lowland European sites.

The River Brede, near Tønder, Southern Jutland, Denmark:
A 3.2 km reach within a rural sand/peat based catchment with good water quality, realigned to a ruler straight course to control flood frequency and groundwater levels, primarily in support of intensive grassland agriculture. The site is part of a contiguous 13 km reach identified by the County as part of a river restoration strategy which commenced in 1991 and is on-going (Fig. 1, Plate 1).

The River Cole at Coleshill, near Swindon, Wiltshire, UK:
A 2 km reach within a rural clay based catchment with good water quality, straightened and impounded in the 17th century to enable the operation of a water mill located in the middle. In the 1970s the downstream (tailwater) channel had been further deepened and widened to alleviate flooding in support of arable farming in the flood-plain (Fig. 1, Plate 2).

The River Skerne on the north eastern side of Darlington, County Durham, UK:
A 2 km reach with moderate water quality in an urban environment, straightened to enable waste from iron based industries to be tipped on the flood-plain at great depth, creating a deeply incised, and wholly artificial 'ravine' over the lower half of the reach. On the upper half, sufficient flood-plain had survived to support a heavily mown public open space overlooked by housing. The public open space was divided by a straightened and enlarged R. Skerne designed to protect the housing and infrastructure from flooding. Utility services, including numerous surface water outfall structures were evident throughout the reach (Fig. 1, Plate 3).

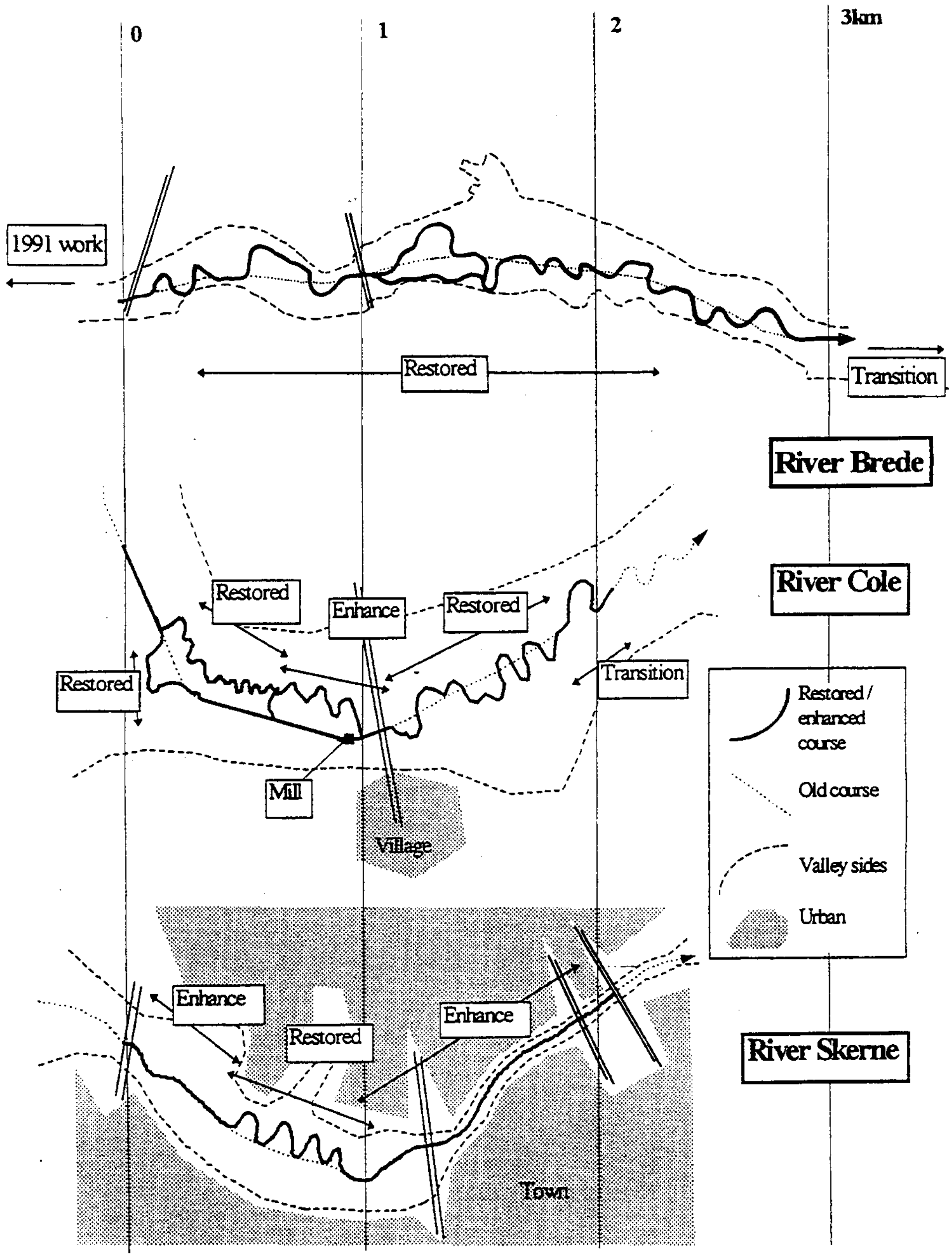

Figure 1. LIFE Demonstration Project - Simplified site plans

Survey and background information

At the outset of the project it was realised that accurate and comprehensive information would be needed on a wide range of parameters to support the process of designing for change. This information was utilised to gain a thorough understanding of the prevailing system as a basis upon which to formulate and develop proposals for change through river restoration. Much of the information also served as a basis for monitoring the effects of change through the project's comprehensive Monitoring Programme (3)(4).

Design targets and constraints

It was important to recognise that the ultimate goal of river restoration, a river in a wholly natural state, was not achievable at any of the three sites. It was necessary to define a range of functional parameters within which river restoration works would have to be contained to meet river and land use criteria, whilst ensuring that functional constraints did not prevent the aims of the project from being achieved. It was necessary to be clear what the project, as a minimum, should encompass.

Prior to the commencement of detailed design, a matrix of design targets and constraints was developed for each site in order that this work could be well focused. A few simplified examples are listed below:

- Flood levels and frequencies affecting people and property to be reduced.
- Flood frequencies affecting agricultural land to be increased, low intensity farming still viable.

- Channel sinuosity to be restored, surviving riparian trees, etc., to be retained.
- Channel widths and depths to be reduced, gradients consistent with the natural valley bottoms.
- At the River Cole, restoration of the ancient mill to remain viable.
- At the River Skerne, no disturbance of trunk sewers, gas mains, or industrial tips. Surface water outfalls to be re-constructed in a less intrusive form.
- Opportunities for raising groundwater levels, creating off river wetland habitats to be exploited
- Safe access to the riverside for people, livestock and wildlife to be intrinsic to the design.
- Financial budgets for works not to be regarded as a primary constraint in developing overall plan of works.



Plate 1(left). River Brede, LIFE Demonstration Project. 1995 restoration work. (Flow top right to bottom left.)
Plate 2 (middle). River Cole, LIFE Demonstration Project.
Plate 3 (right). River Skerne, LIFE Demonstration Project. Remeandered reach - restored 1995.

Design of the works
Definition of the 'design' role proved to be a complex issue since it involved a wide range of environmental and other specialisation (hydraulic modelling, geomorphology, landscape architecture, fisheries, terrestrial, riparian and aquatic ecology, soil science) that needed to be brought together to develop a creative package of works for each site.

Given that the final product of the design process was to be engineering drawings, contract specifications and Bills of Quantities, the overall brief to bring the project to this stage was assigned to dedicated civil engineering teams, required to assimilate specialist inputs to the extent that the design would be environmentally led but co-ordinated and delivered as an engineering product.

Overall responsibility for co-ordinating design was assigned to the Project Manager for each site (1).

Vision Plans
The first output of the design process were conceptual 'Vision Plans' depicting, in easy to understand terms, the ideal extent and nature of river restoration works for each site. The plans were based on a balance of preliminary hydraulic information, and informed judgement on what was environmentally desirable and technically and economically feasible. They formed the basis of discussions with owners and occupiers, public information brochures and consultation, etc., such that consults views could be brought into the developing design process.

The achievement of all that the Vision Plans provided for would clearly be constrained by the availability of confirmed funding, so elements of works were subjected to preliminary costing and prioritisation. This exercise structured the detailed design towards elements that were achievable within the project budgets.

Detailed design

The outputs of detailed design fix and prescribe all of the many elements of works forming part of the eventual construction contract; ranging from new river alignments to the sizes of nuts and bolts in structures. The approach to key aspects is described.

New river courses

In some circumstances it proved sensible to select a meandering course that was known to exist immediately prior to regulation works and this was achieved on parts of the restoration upstream of Coleshill Mill on the River Cole. Generally, this simple approach was not feasible.

At the River Brede, the old course had been infilled with sandy material which had not shrunk to the same extent as much of the flood-plain land had done, because of its peaty nature. The difference was as much as 0.5 m suggesting that the new course should favour the lowest elevations. This was in keeping with the farmers wishes and considerably reduced the quantity and cost of earthworks.

Downstream of the mill, at the River Cole, mature trees existed along the river bank and the flood-plain was largely situated on the north side of its course. By establishing a meander course either side of the existing, it was possible to retain trees on the new river bank as well as enabling the river to continue to serve as a 'natural' boundary between sloping arable fields on one side and open flood-plain on the other side.

The River Skerne posed a typically urban problem as the presence of a high pressure gas main on the north side restricted re-meandering options to the south side. Since space available on this side was limited by industrial tipping, a course that occupied the available flood-plain became the obvious choice. The line was further defined by the presence of two surviving willow trees and an electricity crossing which were not to be disturbed.

Within these types of practical constraints, geomorphological principles were applied to finalise the course supported by knowledge of soil types and the nature of surviving channel sinuosity in the catchment.

River sections

Fig. 2 provides a simplified example of the cross-sections adopted at each site, as well as that of the existing straight channel for comparison.

The common theme was to determine a mean symmetrical cross-section as well as an extreme 'offset' section applicable at the meanders. The geometry between these two 'fixed' profiles was to vary to provide smooth transitions. This simple concept required a great deal of skill during excavation to create the continuously variable changes in bank slopes, bed slopes and plan form that were required.

Various refinements to the simple 'straight line' sections depicted in Fig. 2 were made to more closely anticipate the 'natural' profiles that would be achieved through the subsequent fluvio-geomorphological processes. This was particularly necessary where clays were evident, but much less so in the granular material that occupies much of the River Brede flood-plain. The strategy adopted was to observe channel form adjustments during the first winter after construction, and to intervene only where it was self evident that natural profiles would not be readily achieved by leaving it to the river.

Longitudinal profiles were important on the Cole and Skerne sites, particularly within the meander 'corridor'. This corridor proved to be important to the conveyance/storage of floodwaters necessary to achieve flood protection standards. Some careful detailing was required to cater for flood flows straight across meanders. This involved ensuring that submergence began on the downstream side prior to a general overbank flow, to reduce erosion potential.

On the Skerne site, the land between meanders was also profiled to minimise the risk of people being suddenly isolated by overbank flows. Flooding will occur from the river channel in an 'upwards and outwards' fashion to achieve this.

Revetments

The strengthening of river banks by revetments has generally been avoided, however some notable exceptions were made. On the River Brede, light revetments were specified where appropriate, e.g., compacted clay over indigenous sand, sometimes reinforced with small stone. On the River Skerne, the close proximity of a large diameter high pressure gas main meant that no risk could be accepted and revetment was speci-

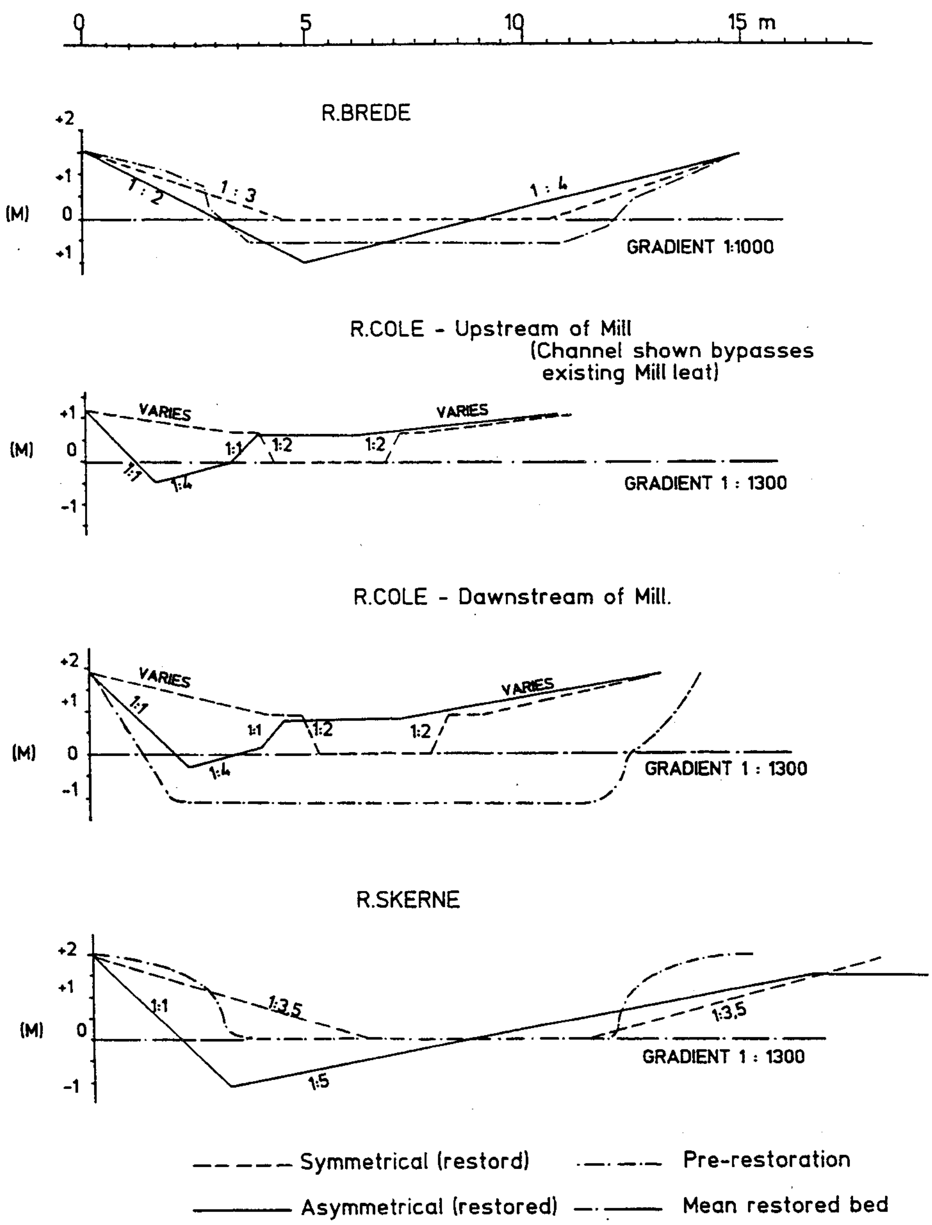

Figure 2. LIFE Demonstration Project - Channel cross-sections

fied. The opportunity was taken to introduce a range of 'soft' revetment techniques utilising willow and reed in combination with geotextiles and underwater stone. This aspect was developed as part of the project's demonstration role.

Surface water outfalls
The River Skerne site displayed a significant number of concrete headwalls discharging, what appeared to be, partially contaminated surface water sewage. This led to a comprehensive 'survey and correct' exercise undertaken by the private water utility responsible. The utility also undertook the design of interceptor chambers to replace and reduce the system of headwalls; each chamber discharging underwater within the restoration reach backwater features. These works were integrated into the overall LIFE Project and funded by the utility.

Enhancement of reaches not subject to re-meandering works
The majority of the River Skerne restoration reach could not be re-meandered due to physical constraints (above). It was, however, possible to specify some instream enhancements of the existing, straight channel which became a priority area for additional funding and follow up contracts.

Spoil disposal
At all three sites this presented a potential difficulty since spreading on the floodplain adjacent to the point of excavation was considered to be contrary to river restoration objectives. Hauling off site would prove to be prohibitively expensive. A common policy of designing landform areas (re-contouring the lower slopes of the adjacent valley sides) was adopted. This policy was particularly suited to the Skerne site where the adverse impact of ancient tip faces was considerably ameliorated in landscape terms.

A multitude of detail supported the broad concepts explained, but the drawings necessary to account for the majority of works were remarkably few. Only drawings detailing structures were comprehensively prepared and these related mainly to the River Cole where some water level/flow regulation was required. The development of earthworks detail was generally considered to be more appropriately undertaken at site level as works progressed. This was less so on the Skerne site where the proximity of services and industrial waste demanded more rigid design.

Consultation and consent process
None of the works proposed could be implemented without the support of the individuals and organisations that have an on-going interest in the river and/or its floodplain. Owners and occupiers of the land and fisheries affected by works are the direct beneficiaries who must have confidence in the design, and commitment to the project aims, if it is to succeed. They must be compensated if it proves to be impossible to avoid individual financial loss in pursuit of the overall benefits.

Consultation, leading to consent, was therefore a critical aspect of the project and was approached as:

- Consultation commenced at the very beginning of the project when aims and objectives were explained.
- Precise descriptions of proposals, and their consequences, were set out as the design developed; often at an individual level.
- Time was allowed to keep people informed of progress, and to win their confidence and trust.
- Consultation was meaningful; detailed proposals were seen to be influenced by consultees.
- There was equal consideration given to all interests.

The County of Southern Jutland were able, if necessary, to promote and implement the River Brede works using permissive statutory powers but, nevertheless, voluntary consents from the numerous landowners involved was gained.

At the River Cole, the only landowner directly involved (The National Trust) maintained a direct and active involvement in design, implementation and consultation. The owner secured the consent of its three tenant farmers who were compensated for loss of crop, and also secured annual subsidy payments through UK government's Countryside Stewardship scheme. Consultation also involved the local village community.

The principal landowner of the River Skerne site was the local authority (Darlington Borough Council). Structured consultation at individual level was undertaken as a part of the project's monitoring programme and was supported by public meetings. The appointment of a full time locally based Community Liaison Officer to build and maintain on-going links with interested individuals, schools and special interest groups was central to the consultation strategy of keeping in touch with the beneficiaries. Regular progress bulletins were published and information boards maintained on site.

The activities described were all integrated with the design activities such that final scheme documentation was fully in accordance with negotiated consents, both voluntary and regulatory, such that contracts for works could confidently be awarded without a break in the project's momentum.

Construction contracts and supervision arrangements
These were tendered for and awarded in accordance with public sector practice adopting, as far as possible, standard civil engineering conditions and methodology.

Supervision of the contractors was close and continuous to cater for the many on-site decisions that were needed to ensure that channel works, in particular, were fully appreciative of the nature of the soils and other physical considerations that were encountered as works progressed. At each site, a positive relationship between contractor and client was developed to the extent that both contributed to the process of arriving at the best solution to the many challenges that the imposition of radical and extensive change to the river regimes presented.

At the River Cole site an 'Environmental' supervisor was employed to work with the client engineer and the contractor to assist in decisions on how to construct a 'natural' river and its associated habitats.

Budgets and cost control

Budgets for design and construction activities were allocated from the overall budget on a 'cash ceiling' basis. Individual Project Managers for each site were responsible for working within these budgets, which were constantly reviewed in the context of the whole, so that adjustments could be made if it was clear that these were beneficial to the whole.

Because of the uncertainties that are intrinsic to the nature of the contracts awarded, and thereby to the final contract costs, a contingency was withheld until after substantial completion. This enabled sufficient flexibility to be maintained during the execution of contracts in the knowledge that a buffer against the unexpected was retained.

The costs arising from design and implementation of the works are summarised in Table 1. These include the costs of consultation, compensation and consents directly related to works and described above.

Timescales

Design and construction were undertaken within a two year timescale at each site. Planning, design and tendering took one year followed by a construction period of about 4½ months during the late summer/autumn to achieve substantial completion. After a winter suspension period, works were finalised during early summer of the second year. The River Brede works were substantially completed in the autumn of 1994 and work on the River Cole and River Skerne in the autumn of 1995.

Achievements

- The project has demonstrated on a significant scale, a wide range of techniques appropriate to the restoration of degraded lowland rivers. The sites are strikingly different from pre-scheme conditions as result.
- Each site presented unique challenges that were successfully addressed to the extent that knowledge and experience had been significantly advanced within the teams involved. Thus, it is possible to disseminate this knowledge for the benefit of others, which is one of the LIFE Project objectives.
- The restored river environments have each been well received within the local communities and by those participating. The beneficiaries have, on the whole, demonstrated a willingness to reassure others who may be considering river restoration elsewhere.
- The organisational frameworks within which design and construction progressed worked well; a high degree of job satisfaction was achieved and enthusiasm for the job in hand generated as a lasting asset.
- The changes in river regime introduced all performed satisfactorily during the first year (two on the Brede) after substantial completion. Few unforeseen difficulties have arisen; in most cases the works performance has exceeded expectations.
- The restoration works were achieved within programmed timescales and budgets.
- The restoration works are expected to demonstrate sufficient changes in the scientific and ecological conditions at each site, to render the project's monitoring programme effective in quantifying and analysing the results of change over time.

Discussion and review

Table 1 shows the costs of restoration works on the scale undertaken to be significant; particularly the non-works element which were in the range of 32% to 53% of available funding. Experience in the UK suggests that pre-works costs would not have been significantly higher had the length of river restoration been longer. Thus the percentage 'on costs' for pre-works activities is sensitive to the length of the reach being restored; the longer the better. Experience in Denmark bears out this observation; pre-works costs are lower than in the UK when expressed as a percentage of the (longer) length restored. Another significant difference that affected pre-works costs is considered to be the experience, and thereby the confidence, of the teams and participant organisations involved. In Denmark, experience and confidence was at a high level because of previous works successfully completed over several years, largely within the same catchment. This contrasts with the position in UK where participants were embarking on what was a largely 'first time' experience.

Table 1. LIFE Demonstration Project - Project costs

1) COSTS

		R. Brede	%		R. Cole	%		R. Skerne	%
Project management, PR, etc.		12000	3		14000	5		16000	5
Compensation and consents		45000	13		26000	9		1000	0
Site survey and design		47000	13		77000	26		47000	16
Construction works		242000	68		140000	47		190000	64
Site supervision		11000	3		41000	14		45000	15
TOTALS	£	357,000	100	£	298,000	100	£	299,000	100

2) ANALYSIS OF COSTS

		R. Brede		R. Cole		R. Skerne
Length of contract works		3.2 km		1.5 km		1.0 km
Construction works cost **per km**	£	76,000	£	93,000	£	190,000
Total project length		3.2 km		2.1 km		2.1 km
Total project cost **per km**	£	111,562	£	141,904	£	142,380

All participants feel that experience of river restoration will progressively lead to increased confidence and reduced pre-scheme costs, particularly if restoration is promoted over geomorphologically coherent reaches as practised in Denmark, e.g., 13 km of the River Brede (plus 5 km planned).

It is difficult to make meaningful comment on the costs of construction at the three restoration sites. The tendering process ensured that they fairly reflected market rates but nevertheless they vary widely when expressed as a cost per km of reach restored. Costs of between £76K and £190K are recorded in Table 1. Considerable differences in the quantity and nature of works undertaken suggest that this aspect is extremely site specific which, by implication, suggests that site specific requirements must be assessed if budgeting for restoration works in general.

It is worth noting that Vision Plans identified scope for additional expenditure towards ultimate river restoration goals. In practice, expenditure was curtailed to available funding suggesting that an evaluation of 'worthwhile' expenditure is an important measure before embarking on any commitment to restoration.

Channel design and construction

The effectiveness of the policy of simplifying the specification of river cross-sections (above) became evident after the first winter floods. At all three sites river form adjustments were recorded (5)(6). The key aspect of this observation in the context of design is the need, or otherwise, to undertake detailed adjustments to channel form as soils are exposed during construction. Generally speaking, granular soils adjusted readily whereas clays did less so.

Experience on the River Cole is perhaps most useful, since a wide variation in soils was experienced - more so than could be foreseen at the design stage. Clay 'cliffs' were excavated, as a post-works exercise, where they had not formed naturally following flooding. This suggests that best practice is to keep the question of channel form under review during construction and to confirm final details with the contractor as works progress.

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A joint Danish and British EU-Life demonstration project: Life - Brede, Cole and Skerne river restoration, III - Channel morphology, hydrodynamics and transport of sediment and nutrients

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Abstract

1. A comprehensive monitoring programme was initiated at the Brede, Cole and Skerne river restoration projects in order to elucidate the impact of remeandering on flood levels, floodplain inundation, adjustment of river morphology, sediment transport and overbank sediment deposition.
2. Reducing the bankfull capacity, raising the bed level and lowering the bank level allowed an increase in flooding frequency and in the amount of water passing onto the floodplain at all three rivers. In the river Brede, restoration of the natural hydrological contact between the river and its floodplain resulted in high deposition of sediment (189 tonnes per year) and sediment-associated phosphorus (770 kg P per year).
3. Construction work caused excessive downstream loss of sediment and phosphorus as documented from sediment mass-balances for the R.Brede and R.Cole. Short term adjustments in river morphology were recorded in the river Cole based on the fluvial auditing procedure. Post-restoration morphology changed compared to that prior to restoration in terms of both total diversity and the type of features recorded.

Introduction

Human impact on river-floodplain ecosystems has significantly reduced the capacity of floodplains to attenuate floods and retain water, thereby reducing water transit time and changing river hydrographs by inducing higher peak discharges (1). Moreover, the sediment and nutrient retention capacity of rivers and adjacent floodplains have decreased considerably, and decoupling of the land/water interactions by the destruction of marginal wetlands and buffer zones through tile and ditch drainage has altered abiotic and biotic processes in this important ecotone (2)(3)(4).

Since river and floodplain corridors form a very important part of our ecosystems, their restoration should be given high priority. Very few large-scale restoration projects of rivers and adjacent floodplains have as yet been conducted, however, and scientific documentation of their ecological benefits are therefore scarce. The short-term physical and ecological impact of remeandering formerly straightened river channels has seldom been investigated (5) (6)(7). As a consequence, the ecological benefits of restoring formerly straightened rivers and drained floodplains to more naturally-functioning ecosystems have yet to be documented. In this respect, knowledge of the short-term adjustments of channel morphology, the excess sediment transport and the implications for macrophyte and invertebrate immigration is crucial, as is knowledge of the potential downstream impacts. Moreover, the longer-term ecological benefits following the establishment of steady-state morphological and hydrodynamic conditions in a restored river channel are important measures for future research on demonstration sites.

This paper presents details of baseline and key environmental studies carried out in three restored rivers – the Brede, the Cole and the Skerne. The impact of river channel restoration on river channel morphology is described for all three rivers. In addition, the immediate adjustments in river channel morphology are described based on the river Cole key study, while changes in sediment and nutrient transport are described based on the river Brede key study. The hydraulic consequences of restoration are also presented, the focus being on the consequences for floodwater storage. Finally, a key study is presented of overbank deposition of sediment and phosphorus in the river Brede.

Hydrological and drainage conditions

A detailed description of background information and restoration design is presented for the rivers in (8)(9)

Mean annual discharge in the river Brede is 3.51 $m^3 s^{-1}$. The river has a relatively high baseflow and moderate response to rainfall due to the catchment being underlined by sandy deposits. The mean annual peak discharge is 14.3 $m^3 s^{-1}$ based on a 72–year record from the gauging station at Brede bridge, 7 km downstream of the restoration site. The 1-in-100 year flood discharge is predicted to be 28 $m^3 s^{-1}$ at Brede bridge.

Mean annual discharge in the river Cole is 1.18 $m^3 s^{-1}$. The river originates in a chalk basin which sustains a modest base-flow throughout the year. The river has a high response to rainfall because more than 55% of the catchment is underlined by clay. The mean annual flood discharge based on the 18-year record from the gauging station at Inglesham, the downstream limit of the catchment, is 15.5 $m^3 s^{-1}$, rising to 26.3 $m^3 s^{-1}$ during the highest recorded flood in December 1979. The 1-in-100 year flood discharge is predicted to be 57 $m^3 s^{-1}$ at Inglesham weir and approx. 60 $m^3 s^{-1}$ at Coleshill Bridge.

Prior to 1950, the floodplain of the river Cole was only partially drained and much of it was operated as a wet meadow system which encouraged inundation. Downstream of Coleshill Bridge, the floodplain was regularly flooded and land use was dominated by permanent pasture. The Land Drainage report of 1935 describes much of the floodplain as waterlogged and prone to frequent flooding. Overall, the hydrology of the catchment has been altered by urbanization, large-scale underdrainage (in the 19th century and more recently) and arterial drainage systems, eventually culminating in the 1974 Cole Stage 1 works which effectively eliminated inundation of the floodplain downstream of Coleshill Bridge.

Mean annual discharge in the river Skerne is 1.61 $m^3 s^{-1}$. Mean annual peak flood discharge is 23 $m^3 s^{-1}$. The predicted 1-in-100 year flood discharge is 55 $m^3 s^{-1}$. The most recent extreme flood event on the river Skerne was in 1979, when flood levels slightly exceeded the 1-in-100 year event. The flood corridor of the river Skerne through the restoration reach is very narrow.

Monitoring and survey programmes and methods

A basic monitoring programme was established at the three demonstration sites in order to document the environmental benefits of restoration, in particular nature conservation benefits resulting from changes in river channel morphology. Monitoring and surveys conducted also provide information on catchment benefits from water quality improvement and increased flood storage capacity. Key environmental areas were subject to more detailed studies in some of the rivers.

Hydrometric, sediment and nutrient monitoring

Continuous measurements of water level were attained by means of mechanical data logging equipment at four stations in the river Brede located a) immediately upstream and b) downstream of the restored reach, c) in the restored reach and d) at Brede bridge, approx. 7 km downstream. Discharge was measured synchronously every fortnight at all four stations in order to establish a water balance. Water samples were collected by use of simple dip sampling and automatic sampling equipment at an up- and downstream monitoring station in order to establish a mass-balance. Daily mean and instantaneous discharge were calculated using normal stage-discharge relationships. Water samples were retained and filtered using standard procedures to determine the suspended sediment concentration (10). Total phosphorus and total iron concentrations were determined using standard laboratory procedures (11).

Sedimentation on the river Brede floodplain during flooding was measured by means of cylindrical sediment traps each having a sampling area of 40.7 cm^2. The sediment traps were installed in three transects of the floodplain representing the upstream, central and downstream parts of the restored reach. Twelve to fifteen traps were installed in each transect with their openings just above ground level. In dry periods the traps were covered by floating balls which raised when the floodplain became inundated. The average deposition of sediment per square meter in each transect was calculated by interpolation between each sampling site.

Geomorphological and habitat surveys

Surveys of river channel cross-sections in the river Brede were conducted every 100 m along the restored reach prior to restoration (November 1993) and immediately following the construction phase (November-December 1994). In addition, a detailed survey of channel cross-sections was conducted every 10 m along two 200 m sub-reaches. Geomorphological monitoring in the river Cole initially focused on detailed surveys of river cross-sections and long-profiles made at 3-6 month intervals. In addition, morphological mapping was conducted using procedures developed for the Environment Agency (12). Whilst the surveys provide scaling and rates of channel adjustment, the mapping studies seek to record the location and frequency of geomorphological features within a framework of the channel sediment system (13).

A relatively unique approach was taken to the morphological evaluation of the river Cole and river Skerne prior to and following restoration. This involved mapping the morphological units and physical habitats (14). A study of the habitat hydraulics in the river Cole and river Skerne provided information on velocity, depth and substrate at 15 transects, point measurements being made at the surface, at a depth of 0.2, 0.6 and 0.8 m, and near the bed. All transects were classified as "glide" using a system adopted by the Environment Agency for river habitat surveys in England and Wales based on field observation of flow type (in this case "smooth boundary turbulent" flow).

River channel hydraulics and flooding

A hydrodynamic model, MIKE 11 (15), was set up and calibrated for the river Brede to investigate the existing and planned river channel morphology and hydraulics. For both the Cole and the Skerne, numerical models were built to investigate the existing and planned flooding regime using the SALMON-F package. The results are based on the statistical 1–in–2 up to 1–in–100 year flood conditions and the model predictions are currently (1996) being validated with field data. The flood hydrographs were determined using a flood routing model, RIBAMAN.

Results

Restoring channel morphology

The pre- and post-restoration channel characteristics of the river Brede are summarized in Table 1. Channel sinuosity has increased markedly at all three sub-reaches. Channel width at bankfull discharge also increased, although there was more variation than in the pre-restoration channel (Table 1), and channel depth at bankfull discharge has decreased. Together with an overall decrease in channel slope, this has markedly decreased bankfull discharge, thereby increasing flooding frequency and floodplain inundation. Stream power (Ω) has consequently decreased, especially in the upstream parts of the restored reach.

Table 1. Changes in river channel form, channel slope, channel dimensions and hydraulics in the upstream, central and downstream parts of the river Brede.

	N	P	S	W_{bf} (m)	D_{bf} (m)	Q_{bf} ($m^3 s^{-1}$)	Ω ($W m^{-2}$)
Upstream							
Pre-restoration	5	1.01	0.00102	13.0±0.4	2.4±0.3	25.3±4.6	19.1±4.6
Post-restoration	12	1.55	0.00036	13.6±1.4	1.9±0.2	10.4±3.0	2.7±0.7
Central							
Pre-restoration	5	1.01	0.00050	12.2±1.0	2.7±0.3	17.9±2.7	7.2±0.6
Post-restoration	13	1.59	0.00038	14.0±1.6	1.7±0.5	9.8±3.8	2.5±1.0
Downstream							
Pre-restoration	5	1.01	0.00039	13.0±1.8	2.4±0.4	15.3±3.4	4.5±0.6
Post-restoration	10	1.44	0.00042	15.3±1.7	1.7±0.5	10.9±5.6	2.8±1.3

N = number of cross-sections; P = sinuosity; S = channel bed slope; W_{bf} = width at bankfull; D_{bf} = depth at bankfull; Q_{bf} = bankfull discharge; Ω = stream power;

Channel characteristics in the river Cole are summarized in Table 2. Channel sinuosity has increased following restoration, there now being 21 new bends in two reaches. Discharge in the upstream sub-reach is currently divided between the original channel, which feeds a mill, and the new restored river. In addition, the upstream restored channel is designed to spill over onto the adjacent floodplain more frequently. As in the river Brede, stream power has consequently decreased in the upstream part of the restored reach, but has essentially remained unchanged in the downstream part.

Changes in physical biotopes were mapped at both the river Cole and river Skerne. Considerable change in the post-restoration physical biotopes was detected in the river Cole (Table 3). The 'glide' biotope dominated the pre-restoration channel of both the Cole and the Skerne (Table 3). Following restoration, major changes took place in the physical biotopes of the river Cole and minor albeit measurable changes in the river Skerne (Table 3). Thus, the abundance of runs, riffles and deadwater biotopes increased greatly in the Cole, while the main change in the Skerne was an increase in the deadwater biotope.

Table 2. Changes in river channel form, channel slope, channel dimensions and hydraulics in the upstream and downstream parts of the river Cole.

	P	S	W_{bf} (m)	D_{bf} (m)	Q_{bf} ($m^3 s^{-1}$)	Ω ($W m^{-2}$)
Upstream						
Pre-restoration	1.05	0.00069	13.6	2.0	15.0-22.0	7.5-10.9
Post-restoration	1.27	0.00071	3.5	1.5	1.5-4.0	3.5-7.9
Downstream						
Pre-restoration	1.06	0.00052	15.5	3.0	23.0-34.0	7.6-11.2
Post-restoration	1.41	0.00110	11.0	2.0	12.0	11.6
Impact reach	1.61	0.00055	15.5	3.2	23.0-34.0	7.9-11.8

P = sinuosity; S = channel bed slope; W_{bf} = width at bankfull; D_{bf} = depth at bankfull; Q_{bf} = bankfull discharge; Ω = stream power;

Table 3. Pre-restoration and post-restoration distribution of physical habitats in the rivers Cole and Skerne

	Cole		Skerne	
Biotope	Pre-restoration	Post-restoration	Pre-restoration	Post-restoration
Glide	91%	65 %	90.9 %	88 %
Deadwater	0.2 %	7 %	0 %	9 %
Pool	4.5 %	0 %	-	-
Run	3.7 %	12 %	6 %	3 %
Riffle	0 %	12 %	3 %	0 %
Mixed (Boil/rapid)	0.6 %	4 %	0.1 %	0 %

Restoring flood water storage

The bankfull discharge capacity stipulated in the prevailing Provisional Order governing the river Brede was much lower (average = 7.9 $m^3 s^{-1}$) than pre-restoration discharge conditions (average = 20.0 $m^3 s^{-1}$). Bankfull discharge was reached on several occasions the first very wet winter following completion of the restoration (Table 4). Following restoration, floods were much more pronounced in the upstream part than in the central and downstream part of the restored reach, and flooding and inundation of the valley generally increased.

Post-restoration bankfull flow in the river Cole is approximately 13 $m^3 s^{-1}$ as compared to 22 $m^3 s^{-1}$ prior to restoration at the Coleshill Bridge (which is a strategic position in terms of flood defence along the river). With lowered banks, the water passes onto the floodplain at this position approximately 10 hours earlier than it would have done prior to restoration. Furthermore, in a typical 1–in–100 year flood the water remains on the floodplain for approx. 32 h as compared to 19 h prior to restoration. The increase in the volume of water on the floodplain for the whole area considered for restoration during a typical 1–in–100 year flood event is predicted to be 1.6 Mm^3, representing a 70% increase over the predicted 1–in–100 year pre-restoration floodplain volume of 2.3 Mm^3.

Table 4. Pre-restoration and post-restoration flood duration in three sub-reaches of the upstream, central and downstream parts of the restored reach of the river Brede from November 1994 to March 1995.

	November	December	January	February	March
Upstream					
Pre-restoration	0	0	0	0	0
Post-restoration	22 h	118 h	287 h	260 h	101 h
Central					
Pre-restoration	0	0	0	0	0
Post-restoration	0	0	0	24 h	0
Downstream					
Pre-restoration	0	0	24 h	24 h	0
Post-restoration	0	12 h	51 h	34 h	0

Table 5 shows the predicted bankfull flow and estimated duration of flooding in a 1-year period at several locations along the river Cole prior to and following restoration. Bankfull flow on the mill channel downstream of the bifurcation should be reduced from 15 $m^3 s^{-1}$ to 5 $m^3 s^{-1}$ which corresponds to the banks being flooded an average of 6 days a year compared with an average of less than one day per year prior to restoration. The situation is similar at the football pitch, where the bankfull flow should be reduced from 4 $m^3 s^{-1}$ to 2.7 $m^3 s^{-1}$, and the average number of flood days per year should increase from 1 to 5. At the fritillary field on the right bank downstream of Coleshill Bridge, the bankfull flow should be reduced by 50% as the channel bed level has been raised by over 1 m. At this site the duration of flooding over a year should have increased from a few hours per year prior to restoration to one day per year thereafter.

Table 5. Bankfull flow and flood duration in the river Cole. D/S = downstream; U/S = Upstream.

Location	U/S of bifurcation	D/S of bifurcation on main channel	New channel just D/S of bifurcation	New channel	Foot-ball pitch	D/S of Coleshill Bridge	Fritil-lary Field
Pre-restoration							
Bankfull discharge ($m^3 s^{-1}$)	22	15	-	-	4	34	23
Duration of out of bank flow in 1 yr (h)	4	8	-	-	24	1	2
Post-restoration							
Bankfull discharge ($m^3 s^{-1}$)	22	5	4	1.5	2.7	15.6	12
Duration of out of bank flow in 1 yr (h)	4	144	24	408	100	5	24

The river Skerne flood hydrographs are relatively unchanged as the alterations to the river have mainly influenced the planform of the river by introducing meanders. The banks and floodplains have been re-profiled. A design stipulation was that flood frequency on adjacent property should not change. This has been achieved effectively by means of a compound channel, regrading of banks, etc. The bank level within the meanders has been reduced by 0.3 m and the predicted, bankfull discharge has decreased by 3.5 $m^3 s^{-1}$ to 8.5 $m^3 s^{-1}$, a 23% reduction. This allows more water onto the floodplain, thereby giving a predicted increase in the flood water volume on the floodplain in a 1–in–100 year flood of almost 1 Mm^3 from approx. 3.7 Mm^3 prior to restoration, i.e. an increase of more than 25%.

The pre-restoration frequency of flooding in the restoration area of the river Skerne is shown in Table 6 based on daily average flow excedence curves. The greatest frequency of flooding is predicted to occur around Rockwell Nature Reserve, where there will be on average 4.5 days of flooding per year, 4.0 days of which should occur in the winter months (October to March).

Table 6. Bankfull discharge and flood duration in the river Skerne for the whole year and the periods October to March and April to September

Location	Footbridge	Meanders	Rockwell	Downstream of Five Arches Bridge
Bankfull Discharge ($m^3 s^{-1}$)	21	12	10	14
Flood duration (h) (all year)	15	79	108	42
Frequency of flooding (h) (October-March)	14	66	96	36
Frequency of flooding (h) (April-September)	1	8	12	6

Restoring sediment sinks - the river Brede key study

Deposition of sediment and phosphorus during overbank flooding was measured during five periods in the winter of 1994/95. Measurements were also conducted in the winter of 1995/96 but inundation of the floodplain did not take place in this 1–in–100 year drought. The average deposition of fine particulate matter (<250 μm) differed from period to period and from transect to transect (Table 7).

The average sedimentation rates during each of the five sampled flooding periods correlated to the flooding frequency at the upstream part of the restored reach, but not to that at the central or the downstream parts. The explanation of the latter is partly that the northern side-branch of the reach with multiple channels functioned as a bed-load trap during the winter following construction work as a result of problems in finishing restoration work due to extreme weather and runoff conditions.

Table 7. Flood duration and average sedimentation in the upstream, central and downstream parts (transects) of the river Brede floodplain during the first winter following completion of the restoration work.

	Upstream (Transect 1)		Central (Transect 2)		Downstream (Transect 3)	
Period	Flood duration (h)	Sediment deposition (g DW m^{-2})	Flood duration (1h)	Sediment deposition (g DW m^{-2})	Flood duration (h)	Sediment deposition (g DW m^{-2})
24.10.94 - 06.12.94	22	4	0	51	0	0
07.12.94 - 20.12.94	50	771	0	9	0	25
21.12.94 - 01.02.95	373	2,282	0	30	63	4,414
02.02.95 - 08.03.95	371	1,240	36	3,538	34	3,696
09.03.95 - 05.05.95	0	138	0	1,262	0	230

A crude estimation of the total deposition of sediment on the floodplain was made using an average sedimentation rate for each of the five periods shown in Table 7 and extrapolating these values to half of the floodplain area (31.7 ha). Gross sedimentation during the first winter following completion of the construction work was estimated at 189 tonnes sediment. The concentration of total phosphorus in the deposited sediment measured for each period and each transect averaged 0.21–0.69%. Crude estimation of phosphorus retention on the floodplain revealed that 770 kg P was retained. Sediment and phosphorus retention on the floodplain corresponded to 9.1% and 4.4%, respectively, of total suspended sediment and particulate phosphorus transport during the sampling period.

Sediment and phosphorus transport - the river Brede key study

A mass balance for water, suspended sediment (SS), particulate phosphorus (PP) and total iron (TI) was established for the restored reach. SS, PP and TI loss is shown in Figure 1 for an upstream control catchment and the restored reach catchment during a pre-restoration period, the construction period and a post-restoration period. Loss of SS, PP and TI from the restored reach was much higher than that from the control catchment during the construction period (Fig. 1).

Estimates of excess loss or retention of SS, PP and TI from the restored reach during the four- month construction period and the post-restoration period were based on the average export coefficient restored:control ratios during the monitored pre-restoration period. Excess mobilization and export of SS, PP and TI amounted to 620 tonnes, 3.6 tonnes and 51 tonnes, respectively. Mobilization expressed per square metre of restored channel was 10,200 g m^{-2} SS, 58.7 g P m^{-2} PP and 843 g m^{-2} TI.

SS, PP and TI loss from the control and restored catchments varied greatly during the post-restoration period (Fig. 1). Retention of SS, PP and TI occurred during the early spring of 1995, when the river valley was temporarily flooded, and retention of PP and TI occurred during several other months with low or decreasing discharge conditions. The estimated excess mobilization of SS from the restored catchment amounted to 135 t during the 19 month monitoring period. Net retention of PP and TI amounted 73 kg and 14,9 t, respectively.

Morphological adjustments - the river Cole key study

Table 8 records morphological diversity of the Cole restoration site in terms of key geomorphological components of the sediment system standardised per unit river length. Post-restoration morphology is different both in terms of total diversity and the type of features recorded. Sediment storage features dominate in all cases, although it should be remembered that the scale of individual features is not represented. Thus one mid-channel bar, though recorded as a single component, may only represent a small storage volume. Prior to restoration, R. Cole was characterized by a relatively impoverished morphology of fine sediment benches within an overwidened and deepened land drainage channel with little interaction with the floodplain. Sediments were stored in berms and pools. The main channel was often heavily vegetated, with debris dams often extending across the channel. These features, together with low gradients, serve to drown out bed topography.

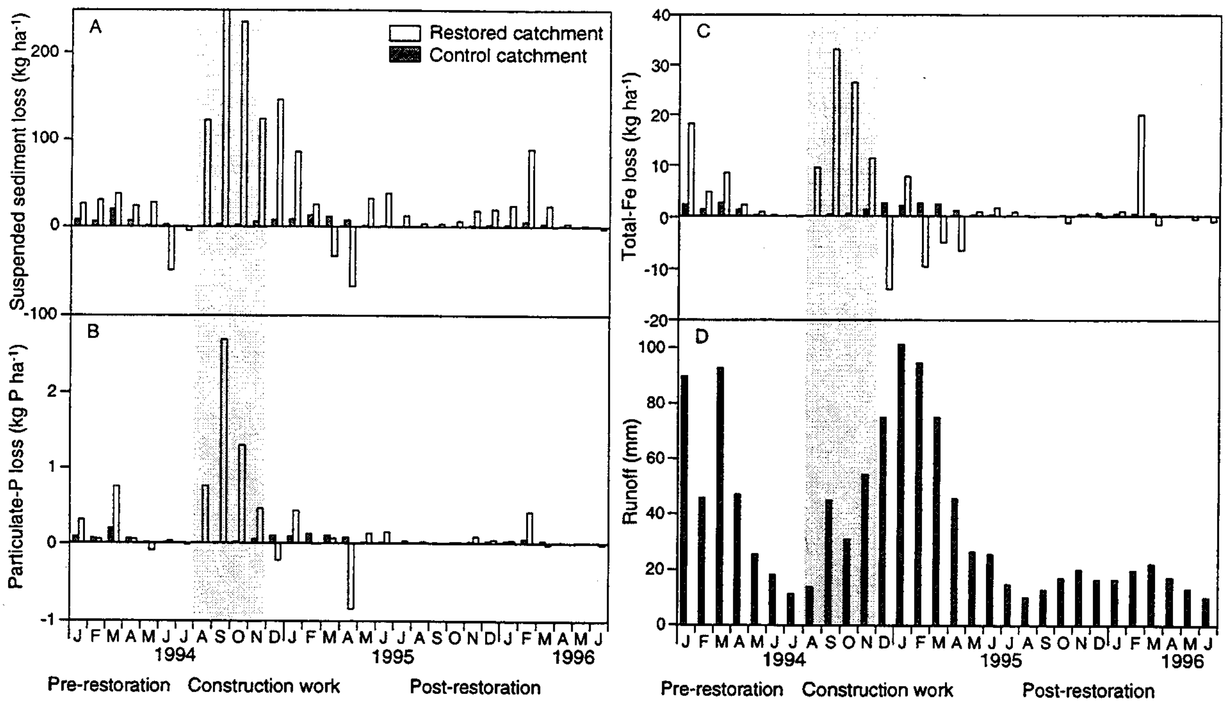

Figure 1. Monthly losses of suspended sediment (A), particulate phosphorus (B), total iron (C), and runoff (D) from an upstream control catchment and the restored reach of the river Brede, Denmark.

Following restoration and a bankfull flood that occurred soon after completion of the project on 20th December 1995, erosional features increased in frequency. Moreover, as a result of the consequent release of sediment, riffles and bars continue to evolve. The upstream part of the restored reach accounted for only one riffle and one point bar of exposed riverine sediment out of those recorded in Table 8. The location of depositional features comprised of coarse sediment such as mid-channel bars, riffles and point-bars, all correspond with local outcrops of gravelly material in the river bank usually – though not exclusively – located downstream of eroding meander apices. The importance of sediment availability for construction of robust geomorphological features (sensu 16) underlies the need for site evaluation prior to and during restoration work. Restoring coarse sediment features in the downstream part of the restored reach required initiation, whilst the upstream part required creation, the former being more sustainable and less cost intensive since the river is encouraged to do the work.

The change in erosional (supply) and depositional (storage) features illustrates how the channel has simultaneously eroded and accumulated sediments (Table 8). Morphological diversity of the downstream channel has increased through sediment accumulation, creating new point bars and pools as the coarse sediment slug passes. The downstream reach is currently characterized by a slug of construction sediment extending 200 m or more beyond a weir at the end of the restoration channel. The sediment slug exhibits downstream fining, which influences the evolving bed morphology. Point-bar and riffle construction has occurred where coarse sediments have accumulated immediately downstream of the restored channel. Further downstream, fine sediment has filled in benches. Progression of this sediment wave is currently being monitored.

Discussion and conclusion

By means of hydrological monitoring and hydraulic models, it has been shown that flood frequency and river valley inundation have increased in the three restored river reaches (Tables 4, 5 and 6), thereby reducing downstream peak water levels. Active river restoration can thus restore the attenuating effect of the water flowing onto the floodplain, thereby counteracting the change in runoff characteristics caused by increased drainage of rural catchments and the expansion of towns and buildings on the floodplain (e.g. (17)).

Another important effect of river restoration is to restore the natural buffer capacity of the river and floodplain for sediment and phosphorus deposition and removal of nitrate through denitrification (4)(18)(19) (20). The *in situ* measurements of overbank deposition of sediment and particulate phosphorus in the river Brede revealed gross deposition amounting to 189 tonnes sediment and 770 kg phosphorus, corresponding to 9.1 and 4.4% of the total export of suspended sediment and particulate phosphorus during the winter period. This

Table 8. Fluvial audit of pre-restoration and post-restoration (+4 and 5 months) channel geomorphological features in the river Cole for an upstream control reach, the restored reach and a downstream impact reach

Geomorphological feature	Control	Restored Pre-rest.	Restored +4 m	Restored +5 m	Impact Pre-Rest	Impact +5 m
Riffle	0.00	0.25	0.17	0.58	0.19	0.37
Pool	0.28	0.38	0.75	0.75	0.56	0.93
Run	0.00	0.00	0.25	0.33	0.00	0.00
Berm	0.84	0.76	0.08	0.00	2.62	2.43
Point-bar (ERS)	0.00	0.00	0.17	0.25	0.00	0.19
Mid-channel bar (ERS)	0.00	0.00	0.08	0.08	0.00	0.00
Actively eroding bank	0.28	0.51	0.83	0.83	0.19	0.37
Debris dam	0.56	0.00	0.00	0.00	0.37	0.37
Overbank deposit	0.00	0.00	2.08	2.08	0.00	0.00
Total Storage Features	1.69	1.15	3.17	3.17	3.55	3.95
Total Supply Features	0.28	0.51	0.83	0.83	0.19	0.37
TOTAL	1.97	1.91	4.42	4.92	3.93	4.67

All values in No./100 m of channel

was corroborated by the mass-balances for suspended sediment established for the restored reach of the river Brede, where there was a large decrease in net loss of suspended sediment, even changing to net retention during the four months with flooding (Fig. 1). The average sedimentation rates measured in the three transects of the restored reach, i.e. 4,435 g DW m^{-2} in the upstream part, 4,890 g DW m^{-2} in the central part and 8,365 g DW m^{-2} in the downstream part are of the same order of magnitude as the 3,000 g DW $m^{-2}y^{-1}$ long-term (ca. 100 y) deposition rate documented for a frequently flooded UK river/floodplain system (20).

Stream power was greatly reduced for the entire length of the restored R. Brede and the upstream reach of R. Cole, and was less than the threshold value identified by (21) as separating channels with erosional or depositional adjustment tendencies, suggesting that newly created channels will largely recover through aggradation

The fluvial audit of channel geomorphological features in the river Cole revealed a major increase in storage features such as pools, berms, point bars and overbank deposits in the restored channel as compared to the pre-restoration channel. Moreover, the mass-balances for suspended sediment clearly demonstrated that construction work at the river Brede had a short-term impact on downstream water quality due to excessive mobilization of sediment and sediment-associated nutrients. However, the fluvial audit of geomorphological features on a downstream impact reach in the river Cole revealed an increase in morphological diversity due to the import of sediment from the restored reach and the creation of new point bars and pools. These short-term adjustments of river morphology illustrate that restoration of isolated reaches can result in complex responses within the restored channel and downstream impact reaches. Following restoration, overloose sediments and bare surfaces increase sediment supply to the restored and downstream reaches, thereby driving morphological development. These levels fall off as coarse bed material armours, and surfaces become colonized by vegetation.

While downstream aggradation may result in a loss of flood conveyance, it provides morphological diversity for habitat creation over and above that designed in the restoration reach. Following the initial phase of downstream aggradation, declining sediment loads from the upstream restored reach may cause a phase of incision and a delayed increase in post-restoration sediment yield. Construction sediments can be rapidly evacuated following flooding, leaving a bare surface susceptible to erosional processes. Future sediment loads from the restoration reach will represent a balance between the rate of vegetation colonization and the weakening of exposed surfaces by weathering.

The three restoration projects in the Brede, Cole and Skerne rivers have clearly demonstrated that restoration can restore contact between a river and its floodplain. By restoring sections of rivers, floodwater discharge can be attenuated as in more natural river/floodplain systems thereby benefiting water storage, water quality and the ecology of riparian areas. Surveys of channel geomorphology, geomorphological features and physical habitats proved to be promising monitoring tools in quantifying the effects of restoration. The results presented in this paper mainly concern short-term responses to restoration. It would be useful to also evaluate the longer-term morphological and sedimentological effects over a period of several years at both sites.

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A joint Danish and British EU-Life demonstration project: Life - Brede, Cole and Skerne river restoration, IV - Implications for nitrate and iron transformation

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Introduction

The drainage of riparian areas in Denmark has caused a general reduction in hydrological contact between streams and their adjacent floodplains and consequently reduced their water and nutrient retention capacity significantly (1)(2)(3). At the same time, increasingly intensive agricultural production has resulted in an increased leaching of nutrients to the groundwater and surface waters, threatening drinking water supplies and contributing to the eutrophication of freshwater and coastal marine waters (4)(5). Diffuse losses of nitrogen to the Danish aquatic environment currently account for more than 80% of the total land based losses (6). Attention is therefore focused on the abatement of diffuse nitrogen pollution of surface waters, especially in relation to agriculture.

Restoration of streams and adjacent floodplain ecosystems is one of the means used in Denmark to combat diffuse nutrient pollution and increase biodiversity (2)(3)(7). Restoration of formerly straightened, deeply incised and overwide stream channels to new meandering channels with semi-natural channel dimensions reinstates natural hydrological contact between streams and their floodplains. Stream-land interactions increase, as does the groundwater level and the extension of the riparian wetlands and wet meadows (2).

Riparian wetlands and wet meadows have an anaerobic environment which facilitates denitrification (8)(9)(10). Several Danish studies in small natural wet meadows receiving groundwater from agricultural areas indicate typical nitrate removal rates of about 400 kg N ha^{-1} yr^{-1} (2). The rise in groundwater levels and the increased flooding of riparian areas, that accompanies the remeandering of streams and the associated decrease in bankfull capacity, reduces non-point nutrient pollution of the aquatic environment by enhancing important natural nutrient retention and transformation processes.

Experience from large-scale demonstration projects is still sparse however, and river and floodplain restoration projects therefore provide a platform for improving our knowledge about processes concerning nutrient removal and exchange across this type of ecotone.

The aim of this paper is to assess the ecological benefits of remeandering a 3.2 km reach of a larger Danish river, the River Brede. This part of the study focuses on description and quantification of the complex hydrological and biogeochemical processes coupled to nitrogen and iron in the restored floodplain.

Study site

The study was undertaken on a 4.5 km remeandered reach of the River Brede (Fig. 1). The river valley is dominated by peat deposits. A belt of gley soil dominates along the southern slope of the valley, while alluvial deposits are found along the original meandering river course. In the middle of the restored section there is an area on the northern side with a special hard pan soil type, classified as ferric soil. Iron has probably played a significant biogeochemical role in the river valley for thousands of years, Iron Age settlements and bog iron having been found in the area.

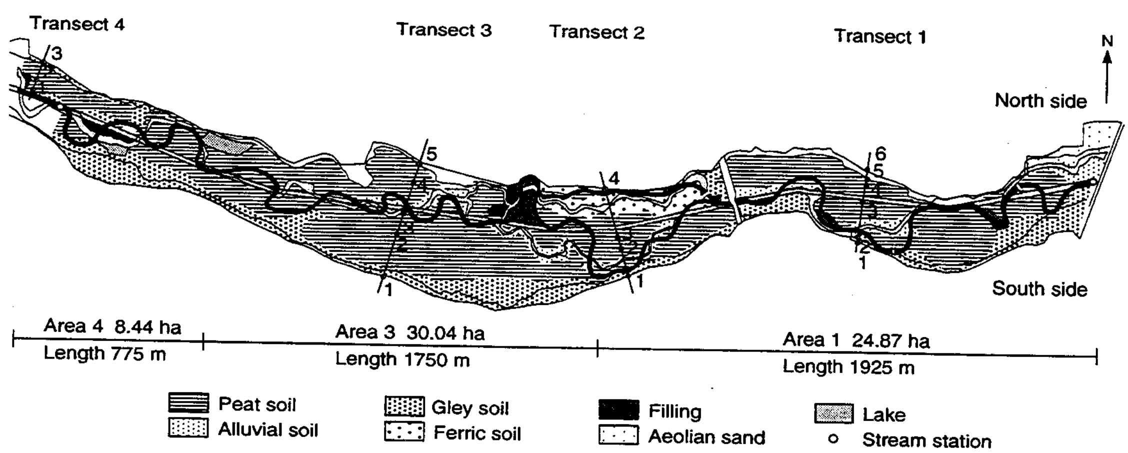


Figure 1. The restored reach of the river Brede. The former straightened channel (white), the old meandering reach (grey) and the new meandering reach (black) are shown together with the dominant soil types and the four transects used in the study.

Methods

Field and laboratory investigations

Two river monitoring stations were established immediately upstream and downstream of the restored reach of the River Brede to enable determination of the water and nitrogen balance for the reach.

Four transects were established across the river valley as indicated in Fig. 1. Transects 1, 2 and 3 covered the valley from hillslope to hillslope, while transect 4 only covered one side. Piezometers were positioned in the soil along the transects at one or two depths. The exact location and size of the screens varied according to soil profile, i.e. screens were not placed in impermeable soil layers such as strongly humified peat and gyttja. In order to record flooding events, piezometers with screens from 10-60 cm were positioned at 1 m, 3 m, and 10 m from the river. The groundwater table was measured at each piezometer once a week.

The soil was characterized and classified using USDA soil taxonomy guidelines (11). A 100 x 100 m grid was laid out in the river valley. In addition, the soil profile was described at each piezometer station..

Ammonia and nitrate were analysed on a flow injection analyser. Chloride and sulphate were analysed according to Danish standards DS 239 and DS 286 (12)(13), respectively. Phosphate concentrations (measured three times) were at the detection limit and phosphate will not be mentioned further. Ferrous iron was measured by the biphyridyl method (14). Total iron was measured as ferrous iron after addition of hydroxylamine to the sample.

Data Analysis and Calculations

The water balance for the river valley at the restored reach was calculated using the one-dimensional Darcy expression (1):

$$q = k \frac{dp}{L} \quad (1)$$

where: q = discharge per metre river reach; k = hydraulic conductivity; dp = hydraulic head; L = distance between measuring points.

For transects 1, 3 and 4, the mean hydraulic heads between neighbouring stations were used in the calculations. This was a useful approximation, as the coefficient of variance only ranged from 34 to 57% (Table 1). No field measurements of hydraulic conductivities were performed, values for the hydraulic conductivity of the different soil layers instead being taken from the literature (15) based on the very detailed soil profile descriptions made during installation of the piezometers. Calibration of the inter-station water flux was done by finetuning of the hydraulic conductivities. In order to calculate the water balances it was assumed that the hydrologically active part of the soil at all piezometer nests was one metre wide and five metres deep, measuring from the highest groundwater table downwards. This gives a total of five square metres of vertically active area at each transect.

Table 1. Mean hydraulic heads between adjacent piezometer stations at transects 1, 3 and 4. N: North side; S: South side; n: observations; CV: coefficient of variance; dp/L: hydraulic head divided by distance.

Transect (piezometer)	*n*	Mean head	Lower 95%	Upper 95%	CV %	dp/L
Tr. 1 (6-5) N	75	0.117	0.105	0.129	44.6	0.0039
Tr. 1 (5-4) N	75	0.053	0.046	0.059	57.1	0.0032
Tr. 1 (4-3) N	75	0.165	0.152	0.178	34.0	0.0033
Tr. 1 (1-2) S	75	0.003	-0.004	0.010	987.9	0.0002
Tr. 3 (1-2) S	51	0.258	0.229	0.288	40.1	0.0020
Tr. 3 (2-3) S	51	0.107	0.091	0.124	55.7	0.0018
Tr. 3 (5-4) N	51	0.291	0.263	0.320	35.0	0.0055
Tr. 4 (3-1) N	20	0.508	0.380	0.635	53.6	0.0060

The river valley was divided into three areas: 1, 3 and 4 based on transects 1, 3 and 4. Area 3 was further subdivided into a north and south section (Fig. 1). At transect 1 the flow from the left side of the river valley proved to be insignificant due to the extremely small hydraulic head between station 1 and 2 (mean = 0.003 m, min = -0.090 m, max. = 0.065 m; see also Fig. 3 and Table 1) and between station 2 and the water table in the river. Transect 2 was not used to calculate the water balance because the presence of the island and division of the river into two channels leaves only one station between the valley and the hillslopes. The water flux from each area was calculated by multiplying the discharge per metre river with the total length of the area in question (Fig. 1). The water flux from area 4, i.e. data from transect 4, was assumed to be equally divided between the two bank sides. The total water balance for the restored reach was calculated by summing up the fluxes for the three areas.

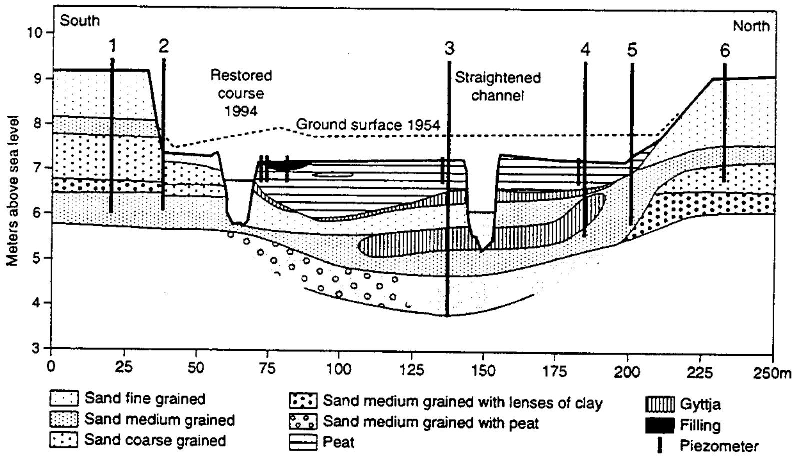


Figure 2. Cross section of the river Brede valley at transect 1. Location and depth of deep and shallow piezometers shown to scale. Soil profile constructed and drawn from ten borings

Results

Soil types

A representative soil profile of a cross section of the river valley is shown in Fig. 2.

Since 1954, the mean ground surface has subsided 0.7 m, ranging from 0.2 m in alluvial deposits to 1.0 m in the peaty parts of the valley. In the central part of the valley, peat deposits dominate the upper 1.0-1.5 m of the profile, but elsewhere in the river valley peat deposits can be up to 3.5 m thick. At all four transects gyttja layers are present at depths 0.6-1.3 m and 2.0-2.5 m. The thickness of the gyttja layers, generally varies from 0.1 to 0.5 m, but may reach 1 m. The hillslopes and the southern bank consist of sandy deposits. Sandy deposits are also found below the peat and gyttja layers.

Hydrology - Hydraulic heads and potentials

The groundwater recharge period in Denmark is from October to March. Precipitation during the 1995-96 recharge period was very low, being only 193 mm as compared to the normal level of 411 mm. As a result, only a limited amount of water was available for percolation in 1995-96. The prolonged period of low recharge to the groundwater aquifer affected runoff in the River Brede at the end of the study period. In contrast to 1995-96, precipitation during the 1994-95 recharge period was much higher than normal, amounting to 628 mm. Recharge was therefore considerable (577 mm).

Except for the southern bank in transect 1 all hydraulic potentials measured showed the same pattern. The highest hydraulic potentials were found at the hillslope piezometers. The hydraulic potentials gradually decreased with decreasing distance to the river, thus indicating that groundwater was recharged at the hillslope and discharged to the river (Fig. 3). The concentration of chloride in groundwater also confirm the horisontal movement of water from hillslope to river. Statistical analysis of the chloride concentrations at the piezometers in each of the transects and for each bank side could not demonstrate any difference between stations nor transects. Mean chloride concentrations at the north bank side were 43.5, 38.0 and 38.1 mg l^{-1} for transect 1, 3 and 4 respectively. Ernstsen (16), reported that the chloride concentrations varied between 30 and 40 mg l^{-1} at nine piezometers in transect 2 (including piezometers in the upland)

The hydraulic heads were very constant in all three transects throughout the study period, indicated by the coefficients of variance (Table 1 and Fig. 3). The mean hydraulic heads were therefore used in the calculations. The hydraulic heads decreased during flooding of the river valley. During the winter 1994-95, the river valley was flooded for 32 days at transect 1 and for 4 days at transect 3. During the remainder of the study period the hydraulic heads were constant at all three transects due to the very stable hydrological conditions (low precipitation input) during 1995 and especially 1996. The hydraulic potentials have been recessive since the winter flood in 1994-95, the trend only being broken by a minor flood during spring 1996.

Subsurface runoff from the southern bank in transect 1 was insignificant or non-existent due to very low hydraulic heads (Fig. 3 and Table 1). The term dp/L, i.e. mean hydraulic head of adjacent stations divided by the distance between them, was constant along transect 1, as was also the case for the southern bank at transect 3 (Table 2). In contrast, dp/L on the northern bank at transects 3 and 4 was significantly greater than that on both banks at transect 1 and the southern bank at transect 3 (Table 1). The soil profiles indicate that the hydraulic conductivities should be of the same order of magnitude on both banks (17), the differences in dp/L thus imply that the groundwater discharge is 2-3 times greater on the northern bank at transects 3 and 4, than on the south side.

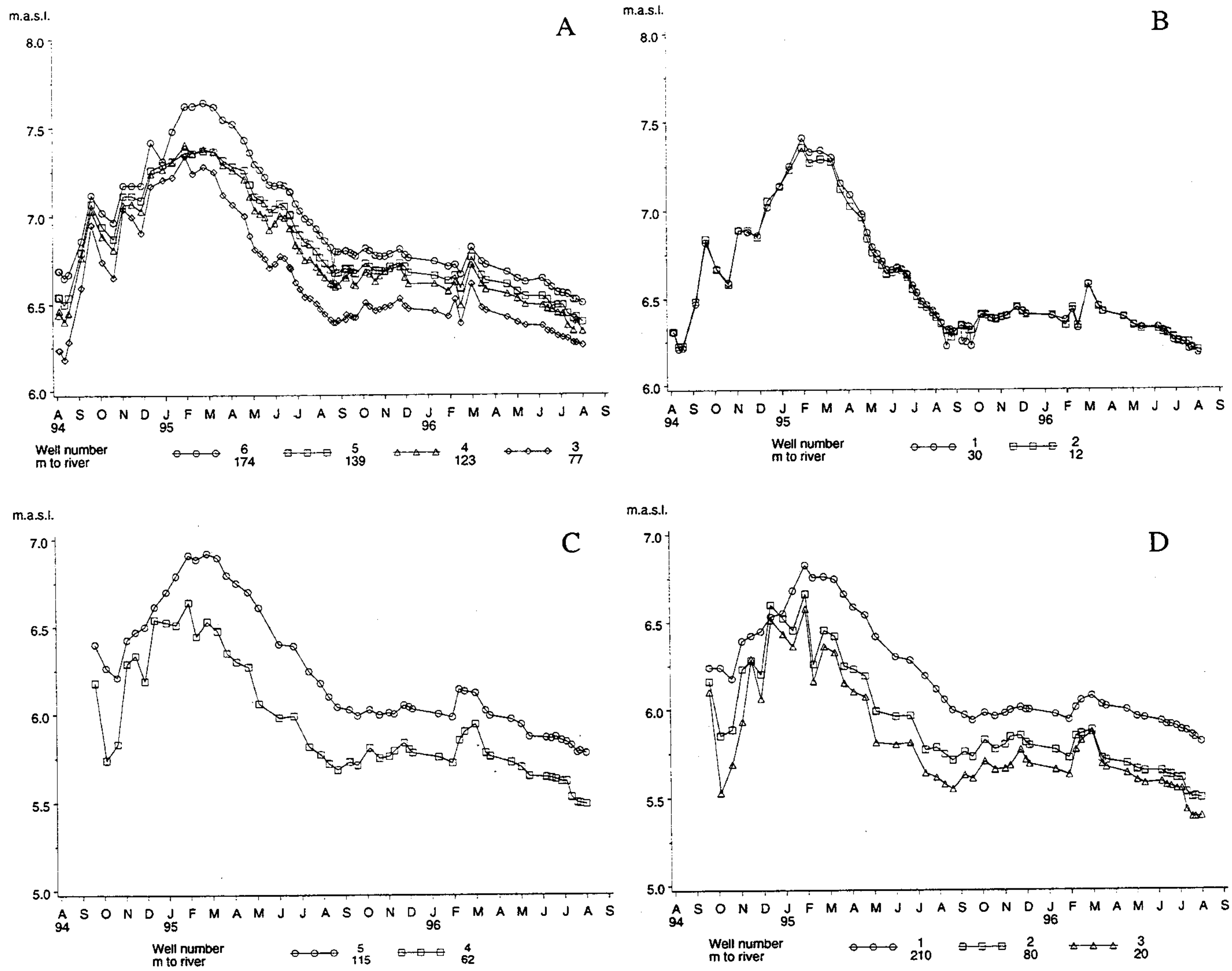


Figure 3. Hydraulic potentials in piezometers measured at transect 1 north bank (A) and south bank (B), respectively. Also shown hydraulic potentials in piezometers at north bank (C) and south bank (D) of transect 3. Potentials measured in metres above sea level (m.a.s.l.). For well locations refer to Fig. 1.

Table 2. Total groundwater discharge to river Brede. Calculations made for each transect and bank side per metre river bank per day (Q_{day}) and per year for the whole riparian area (Q_{year}) covered by the transect in question (Fig. 1).

Transect	Q_{day} ($m^3\ m^{-1}\ d^{-1}$)	Q_{year} ($m^3\ year^{-1}$)
1 (6-3) north	0.571	408,888
3 (5-4) north	1.020	664,020
3 (1-3) south	0.224	145,824
4 (3-1) north	0.668	194,868
Total, $Q_{RIPARIAN}$	0.882	1,413,600

Water balances

There is a considerable variation in groundwater discharge to the river along the restored reach. Highest groundwater discharge is at the northern bank with maximum at transect 3, 1.020 $m^3\ m^{-1}\ d^{-1}$ (Table 3). At the southern bank groundwater only discharges at transect 3, 0.224 $m^3\ m^{-1}\ d^{-1}$. Yearly groundwater discharge, $Q_{RIPARIAN}$, to the river from the restored reach was 1.41 x 10^6 $m^3\ y^{-1}$ or 1.18 x 10^5 m^3 monthly (Table 2 and 3).

The water balance estimated from the two river monitoring stations located immediately upstream and downstream of the restored reach, Q_{RIVER}, was on average 6.43 x 10^5 m^3 $month^{-1}$ or 7.72 x 10^6 $m^3\ y^{-1}$. Minimum runoff was 2.51 in august 1996 and maximum runoff 17.94 x 10^5 m^3 $month^{-1}$ in January 1995 (Table 3). The monitoring period consisted of 5 high flow months (November 94 to March 95) with monthly runoff varying between 10.49 and 17.94 x 10^5 m^3 $month^{-1}$, while 15 out of 23 months had a runoff below 6 x 10^5 m^3 $month^{-1}$. Therefore, the median runoff value 4.39 x 10^5 m^3 $month^{-1}$ is more informative than the mean value (Table 3). Nevertheless, there is a distinct difference between the calculated groundwater discharge,

*Table 3. The runoff, Q_{RIVER}, calculated for a minimum, median, mean and maximum month together with the calculated horizontal groundwater discharge, $Q_{RIPARIAN}$, and the calculated vertical groundwater discharge from the Ribe Formation, $Q_{R.F.}$. The difference, dQ, between Q_{RIVER} on the one hand and $Q_{RIPARIAN} + Q_{R.F.}$ on the other hand is calculated for a minimum, mean, and maximum discharge month during the study period. The calculation further includes the Q_{RIVER} median value. * Median value of $Q_{R.F.}$ is assumed equal to the mean value. $Q_{RIPARIAN}$ was found to be constant (see text and Table 2).*

	Minimum m^3 $month^{-1}$	Median* m^3 $month^{-1}$	Mean m^3 $month^{-1}$	Maximum m^3 $month^{-1}$
Q_{RIVER}	2.51	4.39	6.43	17.94
$Q_{RIPARIAN}$	1.18	1.18	1.18	1.18
$Q_{R.F.}$	2.03	2.64	2.64	3.25
$dQ=Q_{RIVER} - (Q_{RIPARIAN} + Q_{R.F.})$	-0.70 (-28%)	0.57 (13%)	2.61 (41%)	13.47 (75%)

$Q_{RIPARIAN}$, and the water balance figures obtained from the river monitoring stations (Q_{RIVER}).

There are two possible explanations to the deficit between $Q_{RIPARIAN}$ and Q_{RIVER}. A deep-lying regional aquifer, the so-called Ribe Formation, discharges to the river and the valley at some points along the restored channel (18)(19). A possible contribution from the Ribe Formation is not included in the calculated groundwater discharge, $Q_{RIPARIAN}$. The calculation only consider horizontal transport. Most likely the leakage occur in the area around transect 2 where a particular soil type (ferric soil) containing a ferrous hard pan is located, thus indicating that ferrous iron rich groundwater recharges the river valley. Subsurface springs have also been observed in this area (Øvig, pers. observation).

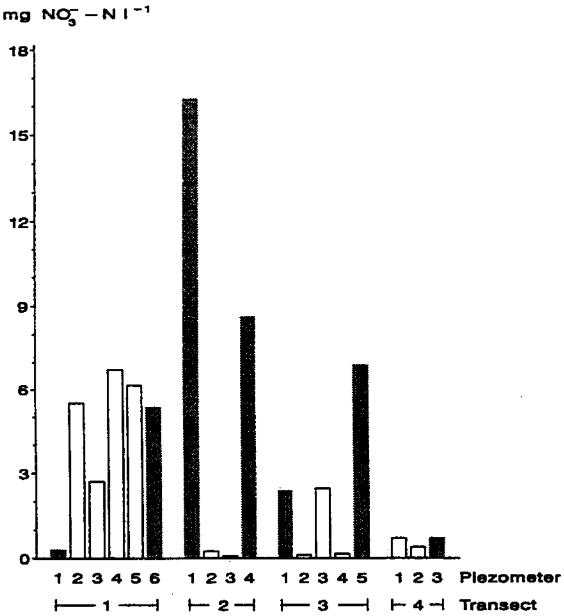
The groundwater discharge to the River Brede from the Ribe Formation can be estimated using the Darcy equation (Eq. 1, assuming $k = 45$ m d^{-1}), together with data from Friborg and Thomsen (19), according to whom the hydraulic potential in the Ribe Formation covering the restored area varies from 12 to 15 m above Danish Zero Level (DZL, i.e. metre above sea level). The vertical distance from the Ribe Formation to the River Brede is approximately 150 m. The mean water level in River Brede is 7 m above DZL. The water balance for the restored reach including the groundwater discharge from the Ribe Formation, $Q_{R.F.}$, revealed that the minimum and median deficit, dQ, between Q_{RIVER} on the one hand and $Q_{RIPARIAN} + Q_{R.F.}$ on the other hand was small (Table 3). However, in January 95 (the maximum runoff month) the deficit, dQ, between Q_{RIVER} and $Q_{RIPARIAN} + Q_{R.F.}$ is very high (Table 3). The difference must be a combination of surface runoff and interflow as well as a higher uncertainty in the water balance obtained from the two river monitoring stations due to flooding of the river valley and hence difficulties in measuring runoff.

Another possible explanation for the deficit between $Q_{RIPARIAN}$ and Q_{RIVER} is that the horizontal groundwater discharge through the riparian areas was calculated assuming 5 m depth of saturated flow, but the depth of saturated flow might be deeper in some parts of the river valley.

Nitrate and iron concentrations

All elements showed marked variation, both between transects and between piezometers (well locations). Although not significant in all cases, some of the concentration patterns were conspicuous. Nitrate concentration in the deep piezometers was generally highest at those located at the hillslope and lower at those in the valley, thus indicating that nitrate disappeared during passage of the valley (Fig. 4). The difference was significant for transects 2 and 3 on both sides of the river. At transect 1 the nitrate concentration only decreased on the north side (station 6 to station 3), albeit that the difference was not statistically significant (95% level). As mentioned above, there was practically no discharge to the river at all from the south side in the area around transect 1, implying that no nitrate leached to the river despite the relative high nitrate concentration of 5.5 mg NO_3^--N at piezometer station 2 (Fig. 4). The data on nitrate concentration in the topsoil (10-60 cm) only includes 33 observations due to the prolonged dry period in 1996. Mean nitrate and ferrous iron concentrations for transects 1, 2, and 3 (no measurements from transect 4) are shown in Table 4. Low nitrate concentration seemed to coincide with high ferrous iron concentration, and the statistical analysis showed that the nitrate concentration depended on the ferrous iron concentration and the transect. The model $\log_{10} NO_3^- =$ Transect, Fe^{++}, $n = 29$, three outliers and one influential observation excluded, explained 79% of the variation (Table 4).

The total-iron (Fe-tot) concentration varied in a pattern opposite to that for nitrate. Fig. 5 shows the mean of Fe-tot at each deep piezometer in all four transects. The overall picture was that Fe-tot concentration was highest in the valley, and lowest at the hillslope. As with nitrate, however, the pattern for transect 1 was somewhat vague, with no significant differences between piezometers, albeit that there was a trend towards a higher concentration at the hillslope on both sides of the valley (piezometers 1 and 6). At transects 2 and 3, the Fe-tot concentration was significantly higher at the valley piezometers than at the hillslope piezometers. The statistical analysis revealed that Fe-tot concentration was dependent on an interaction between



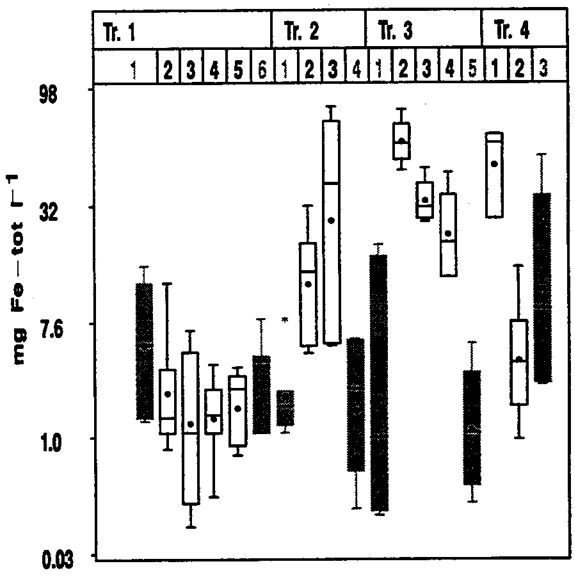


Figure 4. Observed mean nitrate-N concentrations measured in the deep piezometers in each transect. Hill slope piezometers are shown shaded.

Figure 5. Box-and-Whisker plot showing total iron concentration in the deep piezometers at each of the four transects. Mean = dot; median = horizontal bar; 25% and 75% quartiles = lower and upper edges of the box; the endpoints of the whiskers extend to values that lie within 1.5 interquartile ranges of the box and asterisk represents values outside this range. Hill slope piezometers are shown shaded

Table 4. Observed mean nitrate and ferrous iron concentrations in the top soil (left). Shown together with model redicted nitrate concentrations (right) for transects 1, 2 and 3, n = 29.

Transect	Observed means		Predicted	
	NO_3^--N mg l^{-1}	Fe^{++} mg l^{-1}	NO_3^--N mg l^{-1}	95 % C.L.
1	2.22	5.35	8.81	4.27 : 18.18
2	0.30	82.16	1.14	0.44 : 2.95
3	9.98	0.27	13.04	5.63 : 30.21

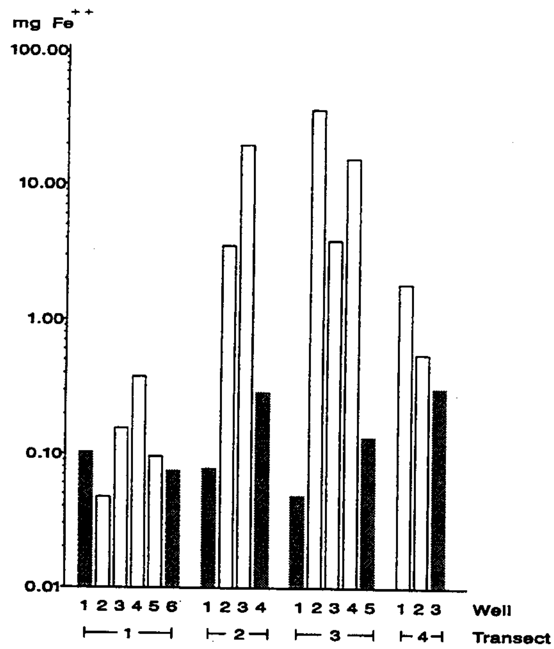
transect and piezometer. The statistical model Fe-tot$^{0.2}$ = Tr x piezometer, n = 105, explained 61% of the variation.

The concentration pattern for ferrous iron (Fe^{++}) in the deep piezometers very much resembled that for Fe-tot, the concentrations being lowest on the hillslopes (Fig. 6). The concentration of Fe^{++} was dependent on an interaction between transect and piezometer, albeit that nitrate also appeared to have an influence. Although nitrate concentration varied to some extent at the hillslope piezometers, the concentration was usually higher than in the corresponding valley piezometers (Fig. 4), a pattern opposite to that of the Fe^{++} concentration. The model $\log_{10} Fe^{++} = NO_3$, Tr x piezometer , n = 122, explained 60% of the variation.

In the topsoil the Fe^{++} concentration varied considerably (Fig. 7), being low in the piezometers closest (1, 3, 10 metres) to the river. Only the piezometer 61 m from the river at transect 2 was significantly different from these piezometers, however the differences in Fe^{++} concentration between the other piezometers was not significant (95% level).

Based on $Q_{RIPARIAN}$ data the mass balances for the river valley as a whole are tabulated in Table 5. The calculations for areas 1 and 3 are based on data from eleven sampling dates, while only five dates are available for area 4.

Neither Fe^{++} nor Fe-tot were retained in the restored reach as a whole, although the area represented by transect 1 retained both ferrous iron and Fe-tot. The river valley generally acted as a source of iron. While only 11% of the total iron input from the upland was Fe^{++}, 69% of the Fe-tot discharged to the river was Fe^{++}. Area 3 seemed to be the major source of Fe^{++}. In this area more than 84% of the Fe-tot discharge to the river took place as Fe^{++}, but only 7% of the upland input entered the river valley as Fe^{++}. This means that 68 kg Fe^{3+} ha^{-1} y^{-1} (total 2053 kg) entered the river valley at the hillslope and additionally 108 kg ha^{-1} y^{-1} (total 3263 kg) was liberated from the valley soil resulting in a total discharge of 176 kg Fe^{3+} ha^{-1} y^{-1} to the river. In area



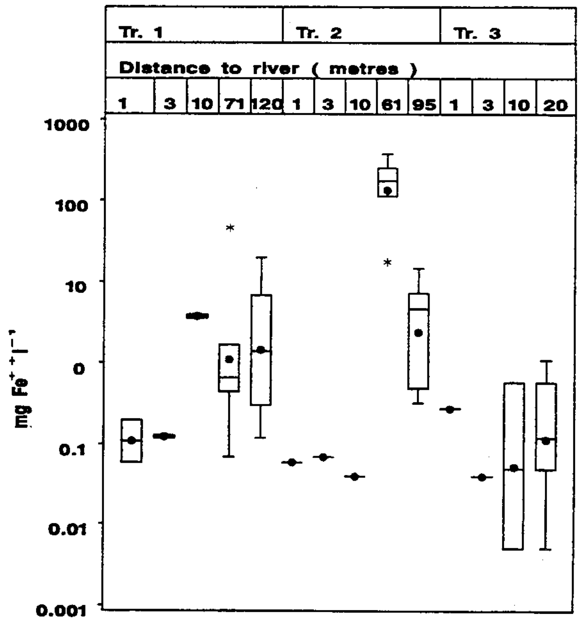


Figure 6. Observed mean ferrous iron concentrations in the deep piezometers in each of the transects. Hill slope piezometers are shown shaded

Figure 7. Box-and-Whisker plot showing ferrous iron concentration in the top soil measured at transect 1, 2 and 3 at different distances from the river. See Fig. 5 for explanation of symbols.

Table 5. Mass balances for the river valley at the restored reach. Retention figures shown with " 95% confidence limits.

Transect and area (ha)	Input (kg y^{-1})	Total retention (kg y^{-1})	Retention (kg ha^{-1} y^{-1})	Retention (%)
Fe^{++}				
1 (24.9)	97	27 ± 46	1 ± 2	28
3 (30.1)	156	-17386 ± 1357	-578 ± 45	-11263
4 (8.4)	614	-149 ± 60	-18 ± 7	-24
∑ (63.4)	866	-17508 ± 4943	-276 ± 78	-2022
Fe-total				
1 (24.9)	1435	490 ± 378	20 ± 15	34
3 (30.1)	2209	-20649 ± 4052	-686 ± 135	-935
4 (8.4)	4212	-5249 ± 970	-625 ± 115	-125
∑ (63.4)	7856	-25408 ± 9394	-400 ± 148	-323
Nitrate-N				
1 (24.9)	2236	1087 ± 707	44 ± 28	49
3 (30.1)	5793	4812 ± 794	160 ± 26	83
4 (8.4)	243	-51 ± 31	-6 ± 4	-21
∑ (63.4)	8272	5847 ± 2327	92 ± 37	71
Ammonia-N				
1 (24.9)	21	-208 ± 28	-8.4 ± 1.1	-974
3 (30.1)	23	-138 ± 32	-4.6 ± 1.1	-601
4 (8.4)	123	18 ± 15	2.1 ± 1.7	15
∑ (63.4)	167	-364 ± 110	-5.8 ± 1.7	-197
Sulphate				
1 (24.9)	19086	-14235± 6145	-575 ± 247	-75
3 (30.1)	29843	-32789±10567	-1092 ± 351	-110
4 (8.4)	11166	2947± 1112	349 ± 132	26
∑ (63.4)	60095	-44077±26952	-696 ± 425	-73

4, 15% of Fe-tot entering at the hillslope was ferrous iron whereas only 3% of that discharged to the river was ferrous iron. There was, nevertheless, a net loss of 18 kg Fe^{++} ha^{-1} y^{-1}. The loss of ferric iron was considerable, however, as 428 kg Fe^{3+} ha^{-1} y^{-1} entered the river valley, but more than twice that amount (1035 kg Fe^{3+} ha^{-1} y^{-1}) was discharged to the river (net retention = -607 kg Fe^{3+} ha^{-1} y^{-1}).

In areas 1 and 3 nitrate disappeared during passage through the river valley, net loss being 44 and 160 kg NO_3^- -N ha^{-1} y^{-1}, respectively. In area 4 nitrate leached to the river, although in small amounts (6 kg NO_3^- -N ha^{-1} y^{-1}). In contrast, ammonium was retained in area 4 (2.1 kg NH_4^+ -N ha^{-1} y^{-1}), which was also the area in which the load was highest, 225 kg NH_4^+ -N y^{-1} or 26.8 kg NH_4^+ -N ha^{-1} y^{-1}.

The river valley seemed to retain sulphate in area 4 (349 kg SO_4^{2-} ha^{-1} y^{-1}). However, as only five sampling dates were available and the sulphate concentration varied considerably, the uncertainty was bigger than it appeared. In the other two areas discharge of sulphate to the river was substantial, and total sulphate loss from the river valley thus amounted to 696 kg SO_4^{2-} ha^{-1} y^{-1}.

In order to test if the increased flooding of the riparian areas might have caused any changes in riverine nitrate-N concentrations the study period was divided into three comparable sub-periods representing the pre-restoration period (I: January - June 1994) and the post-restoration periods (II: January - June 1995 and III: January - June 1996). Student's t-test on the differences in the log-transformed nitrate-N concentrations during the three monitoring periods (I-III) showed that there was no significant differences in nitrate-N concentrations between periods I and II ($t = 1.09$; $p = 0.29$) or periods I and III ($t = -0.22$; $p = 0.82$).

Discussion and conclusion

A comprehensive soil survey revealed the geology of the floodplain to be extremely complex (19), thus underlining the difficulties in measuring and quantifying geochemical and hydrological processes in such river floodplains.

LaBaugh (20) and Carter (21) have both stressed that it is important to measure all water balance parameters in order to make reliable calculations of groundwater discharge, etc. In this study we focused on groundwater storage because the Brede river valley is a discharge area for groundwater, thus implying that groundwater storage is quantitatively the most important hydrological compartment. Nevertheless, hillslope groundwater discharging (Eq. 1) to the river cannot explain the runoff measured in the restored reach, and excess precipitation and input from the regional aquifer, the Ribe Formation, need also to be taken into account.

It was expected that restoration of the river and floodplain would induce a detectable change in floodplain hydrology and geochemistry. That no changes were actually observed is probably due to the extremely dry period starting shortly after completion of restoration work, the hydrological year 1995-96 being the driest this century in Denmark (6). The prolonged dry period in 1996 resulted in gradual lowering of the groundwater table but only caused minor changes in hydraulic heads.

The results suggest that ferrous iron and nitrate concentrations are significantly linked ($p < 0.001$) in both the topsoil and deeper soil layers, possibly as a result of nitrate reduction through oxidation of pyrite. According to Kölle *et al.* (22, 23) the following reactions take place:

$$5\,FeS_2 + 14\,NO_3^- + 4\,H^+ \rightarrow 7\,N_2 + 10\,SO_4^{=} + 5\,Fe^{++} + 2\,H_2O \qquad (2)$$

$$5\,Fe^{++} + NO_3^- + 7\,H_2O + \rightarrow 5FeOOH + 0.5\,N_2 + 9\,H^+ \qquad (3)$$

The reduction of nitrate by pyrite oxidation, i.e. autotrophic denitrification, has previously been reported to occur in the redox zone of a sandy aquifer in Jutland, Denmark (24).

Indications for leakage of ferrous iron and consequent reduction of nitrate and production of sulphate were found at transect 3 (area 3). On a weight basis the ratios NO_3^--N / Fe^{++} and NO_3^--N /SO_4^{2-} are 0.7 and 0.2, respectively, thus indicating that the described reaction in equation 2 is likely to take place in this part of the river valley (Table 6). In view of the prolonged dry period in 1996, pyrite was probably also oxidized with oxygen as an electron acceptor. Also heterotrophic denitrification (i.e. organic matter as e-donor) is likely to take place in the river valley, as area 1 seems to reduce nitrate and retain iron at the same time. The apparently contradictory finding of sulphate retention and nitrate and Fe-tot (ferric iron) loss in area 4 is probably due to the scarcity of data for this area.

Nitrate removal in the River Brede floodplain was estimated to be 92 kg N ha^{-1} y^{-1}, which is somewhat higher than previously reported for forested wetlands on mineral soils (25)(26)(27). In an organic riparian soil Cooper (28), found the average areal removal rate of nitrate to vary between 26 and 184 kg N ha^{-1} y^{-1}. In a Danish wet meadow Hoffmann *et al.* (29) found a net removal of 60 kg N ha^{-1} y^{-1}. However, the extreme winter and summer drought in 1995-96 makes it difficult to draw conclusions as to whether restoration of the River Brede and the adjacent floodplain have enhanced nitrogen removal.

The present study revealed that ongoing biogeochemical processes in the restored River Brede floodplain remove nitrate by pyrite oxidation. The climatic conditions during the study period prevented the precise effects of the restoration project from being elucidated. Determination of the effects of such river and floodplain restoration projects on nutrient retention and hence of whether they are likely to be a successful catchment management tool for combating diffuse nutrient pollution, necessitates a longer period of study.

Acknowledgements

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A joint Danish and British EU-Life demonstration project: Life - Brede, Cole and Skerne river restoration, V - The effects on the aquatic macroinvertebrate and plant communities of two contrasting restored river reaches.

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Key words
River, habitat restoration, aquatic macroinvertebrates, macrophytes, downstream impact, colonisation, species richness, rarity.

Abstract
This paper describes the short term effects of river restoration on the wetland macrophyte and aquatic macroinvertebrate assemblages of two rivers, the R. Brede in Denmark and the R. Cole in the UK. The effects of the restoration work were assessed in terms of changes in species richness, rarity and abundance on (i) the restored sections and (ii) potentially impacted sections downstream of the restoration works.

In the restored areas of both rivers the species richness of wetland macrophyte assemblages recovered to at least pre-restoration levels one to two years after restoration. Macroinvertebrate species richness recovery was more variable. The abundance of invertebrates and wetland macrophytes generally recovered less rapidly than species richness. For wetland macrophytes, the recovery process was enhanced by the presence of refugia.

Uncommon invertebrates were slower to re-colonise the restored sections in the year after restoration (monitored on the R. Cole only). The number of uncommon wetland macrophyte species recorded was similar throughout the restoration and recovery period.

Potentially impacted sections of the river up to 1.2 km downstream of the restored area showed a relative decline in invertebrate species richness one to two months after the physical works were completed, but little difference from pre-restoration levels after one year. Plant surveys downstream of the restored area showed no evidence of a significant change in species richness. Neither was there evidence that uncommon plant or invertebrate species were affected by downstream impacts (sediment or nutrient release) due to restoration.

Introduction
River channelisation affects many thousands of kilometres of river channel and floodplain habitat throughout Europe. The process of channelisation is acknowledged to bring with it a wide range of adverse environmental impacts (1)(2). Not least of these is a reduction in the quality of biotic assemblages associated with riparian and channel habitats (3)(4)(5).

In recent years there has been considerable interest in the potential for river restoration to ameliorate some of the environmental damage caused by channelisation. Small-scale measures such as local bank reprofiling, removal of weirs and introduction of gravel have been undertaken fairly extensively in some channelised rivers to increase channel diversity (6)(7)(8). Increasingly, larger scale schemes, involving remeandering of straightened river channels and restoration of floodplain areas are also being undertaken in an attempt to more fully reverse the original channelisation process (9)(10)(11).

This paper describes the short term (1-2 year) effects of restoration on the conservation value of both macrophyte and invertebrate assemblages in two rivers with newly restored sections; the R. Brede in Denmark and the R. Cole in the UK. These were the two rivers for which ecology was a special study area in the EU-LIFE demonstration project, an overview of which is given in (11). The third site in this project, the R. Skerne, was also monitored but in less detail and the results are not presented here.

The present paper is an abridged version of (12).

The study areas and restoration works
The R. Brede is a low energy, sand and gravel bed river located in rural southern Jutland, Denmark. In terms of biological water quality the site has a good water quality. Channelisation of the R. Brede was originally undertaken in the 1950s; restoration of the river in 1994 involved remeandering a 3.2 km section of the river, increasing its length to 4.5 km, with river bed levels raised by approximately 0.5 m.

The R. Cole is a low energy clay-bed river located in a predominantly rural catchment in southern England. In terms of biological water quality the site is considered to represent rivers which are 'unstressed' (13). Channelisation of the R. Cole occurred in stages since 1650. Restoration of the river was undertaken in 1995. Restoration involved both new channel creation and reshaping of existing channels over a distance of 2 km. During this process channel width was considerably reduced from a mean of 14.9 m to 9.4 m, and channel length was increased by about 8%. Mean gradient in the restored section was about 1:1300. Bankfull capacity was reduced by raising bed levels relative to ground level by about 1.0 m. On both rivers, wetland vegetation was allowed to re-colonise naturally.

Methods

General survey protocol

The methods used to assess the effects of restoration on the two rivers were designed to be complementary and/or compatible where possible. On both rivers, the study employed a BACI design (Before, After, Control, Impact) (14). Control survey sites were located 2 km (R. Cole) and 5 km (R. Brede) upstream of the restored areas (Fig. 1) to provide information on background trends in biotic assemblages outside of the restored areas. On the R. Cole survey sites were also established in downstream, potentially impacted, sections of the river. Within the sections of the river designated as restoration, control or impact sections, 50 m channel lengths were identified for invertebrate sampling (both rivers), and 500 m (R. Cole) and 100 m (R. Brede) lengths for wetland macrophyte survey. On both rivers, biotic assemblages were initially described in the year prior to restoration, with further surveys during the restoration period itself. Post-restoration, macroinvertebrate data was available up to one year after restoration and vegetation data two years after restoration.

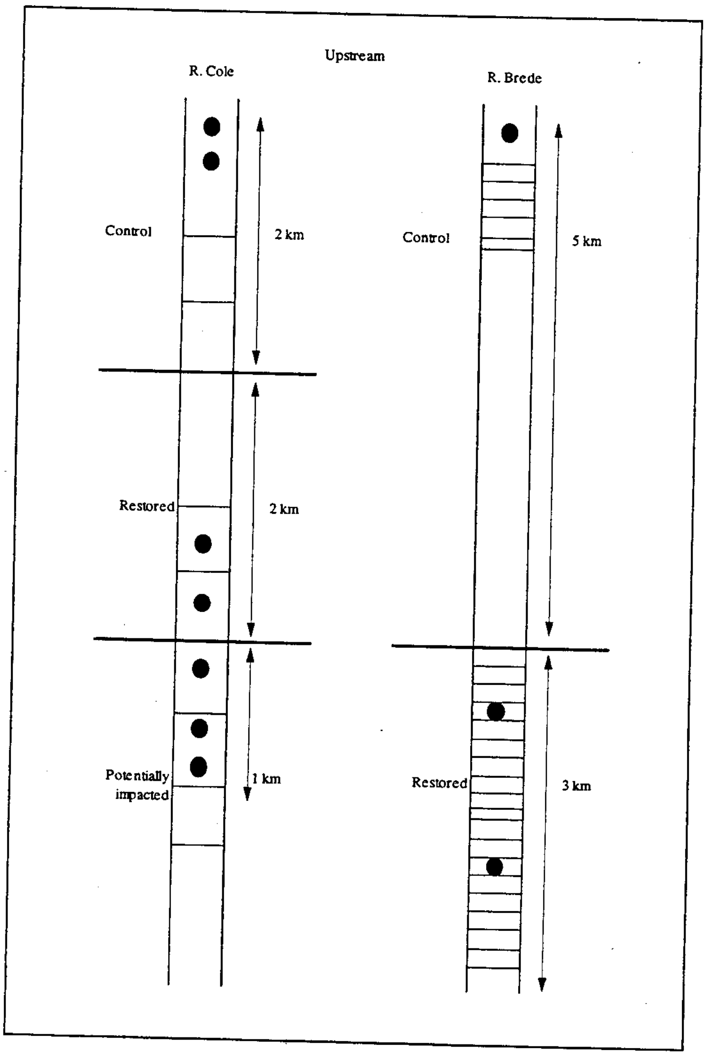

Figure 1. Schematic representation of the River Cole (UK) and R. Brede (Denmark) showing location of control, restoration and potentially impacted sections and survey sites. Approximate positions of macroinvertebrate sampling sites and wetland macrophyte survey lengths are shown by filled circles and light horizontal bars, respectively.

Aquatic macroinvertebrate survey methods

Aquatic macroinvertebrate surveys were undertaken quantitatively on the R. Brede and semi-quantitatively on the R. Cole. Samples were collected three times annually in the R. Brede (May, July, November) and twice in the R. Cole (June, November).

On the R. Cole invertebrates were collected using a standard 1 mm mesh pond net. At each survey site, 12 x 15 s spatial replicate samples were collected by a combination of kick and sweep sampling. Three samples were collected from bank habitats and nine from channel habitats. Samples were collected from discrete locations within the survey site, each sample being collected from an area which could be sampled comfortably in 15 s. Macroinvertebrate taxa were identified to species level in the groups for which reliable UK distribution data and Red Data Book information are available. These were: Tricladida, Hirudinea, Mollusca, Malacostraca, Ephemeroptera, Odonata, Plecoptera, Heteroptera, Coleoptera, Megaloptera and Trichoptera.

On the R. Brede quantitative sampling of aquatic invertebrates was undertaken using Kayak core samplers. Core samples were collected at random locations on nine transects within the survey site and between 22 and 29 samples were collected at each site on each survey date. In addition to the taxa recorded in the R. Cole, Hydrozoa, Nematomorpha, Nematoda, Ostracoda, Copepoda, Cladocera and Diptera taxa were also included in analyses of 'species' richness and abundance.

Wetland macrophyte survey methods

Plant species richness and total plant cover on the R. Brede were recorded in thirty 100 m survey lengths on the restoration site, with five 100 m survey lengths upstream used as controls. On the R. Cole wetland plants species richness was assessed using seven 500 m survey lengths (two upstream control lengths, two lengths in the restored area and three downstream).

Data analysis

Data analysis focused on comparison of the conservation value of river plant and invertebrate assemblages before and after restoration. Conservation value was assessed in terms of (i) species richness, (ii) abundance/cover and (iii) species rarity (data available for the UK only).

Species richness was measured as the number of species, or distinctive taxa, recorded per unit area or unit time. In the R. Brede invertebrate species richness was expressed as numbers of individuals per 21 cm^2 core sample. Vegetation abundance was assessed as percentage cover and invertebrate abundance as number of individuals 0.01 m^{-2}. For the purposes of analysis, species richness and cover data for wetland macrophytes were divided into emergent plants (i.e. tall emergents and wetland herbs) and aquatic plants (i.e. floating and submerged taxa). Wetland macrophyte categories were defined using a standard plant recording sheet (15).

Comparisons of species rarity were made using a Species Rarity Index (SRI) similar to the original Species Quality Index developed by Foster and colleagues in the 1980's (16) and described in more detail in (17). SRIs were only calculated for plant and invertebrate assemblages on the R. Cole since appropriate Red Data Book and other distribution data were not readily available for Danish freshwater plants and invertebrates. The SRIs data were placed into one of four conservation value categories: low (<1.00), moderate (1.01-1.19), high (1.20-1.49) or very high (>1.50) conservation value.

Trends evident in the restored reaches were interpreted in the context of natural variation evident in the upstream control sections. For macroinvertebrate species richness and abundance a three factor ANOVA was used to test for differences between location (control vs. restored), time (before vs. after restoration) and season. To maintain orthogonality of analyses, only 1994 and 1996 data were used in ANOVAs of R. Cole data and only spring and summer data for the R. Brede. On the R. Cole the control, restored and impact survey sites were treated as if they were randomly selected locations as there was little evidence of consistent site effects. On the R. Brede the single control site was compared with each of the two restored survey sites. Again, it is assumed that the locations were representative of the river as there was little evidence of consistent site effects. Note that for both the R. Cole and R. Brede, figures in the results section include additional data from other years and seasons.

For wetland macrophyte species richness and abundance on the R. Brede, two factor ANOVA was used to test for differences between location (control vs. restoration) and year. On the R. Cole, wetland macrophyte data comprised species lists for two 500 m survey lengths in the control and restored sections and three 500 m lengths in the potentially impacted section. As measures of species richness from the 500 m lengths were effectively absolute values, statistical significance tests were not applied. For SRI values, Mann-Witney *U*-

tests, undertaken pairwise, were used to test for differences between location (control vs. restored) and time (before vs. after restoration).

Results

The impact of restoration in the restored reaches

Variability of the control sites

Data from the upstream control sites indicate that both the R. Brede and the R. Cole showed marked seasonal and between-year variation in invertebrate species richness and abundance (Figs. 2a,b, 3a). These trends were internally consistent between sites for each river. Macroinvertebrate SRI values in the control sites on the R. Cole, although varying slightly, remained in the "moderate" conservation value category throughout the study (Fig. 3b).

Wetland macrophytes in the control lengths of the R. Cole showed no trends in species richness or SRI during the study period (Fig. 4a,b). In the R. Brede, however, trends were apparent in the control lengths, with wetland macrophyte species richness increasing through the survey period, due to an increase in emergent plant species richness (Fig. 5a; two-way ANOVA: $p<0.0001$, $F = 16.45$, $df = 2, 24$). Channel vegetation cover in the R. Brede control section did not change significantly (Fig. 5b).

Invertebrate assemblages colonising the restoration sites

On both rivers, remeandering on the restoration sites eliminated most of the original river channel. Colonisation therefore began in channels with no pre-existing invertebrate assemblages.

Aquatic macroinvertebrates recolonisation was rapid in both rivers and, after one year, species richness was only slightly below pre-restoration values (Figs. 2a, 3a). On the R. Brede, species richness in the restored sites was not significantly different to that on the control site (Fig. 2a; three-way ANOVA, $p>0.2$ in both cases). On the R. Cole there was a significant time (before vs. after) x location (control vs. restored) interaction indicating that species richness in the restored channel had not fully recovered to pre-restoration levels (Fig. 3a; three-way ANOVA, $p=0.001$, $F = 49.93$, $df = 1.8$).

The average species rarity of macroinvertebrates colonising the restored R. Cole section was significantly lower than in the pre-existing channel (Fig. 3b; Mann-Witney *U*-test, $p<0.05$ for both restored sites), although by August 1996 four local or Nationally Scarce species had colonised the new channel. Before the creation of the new channel began, thirteen local or Nationally Scarce species had been recorded in the restoration section, with a mean SRI of 1.05 (moderate). After restoration mean SRI dropped to 1.01 (moderate). There were no significant changes before and after restoration in either the control or downstream section SRIs.

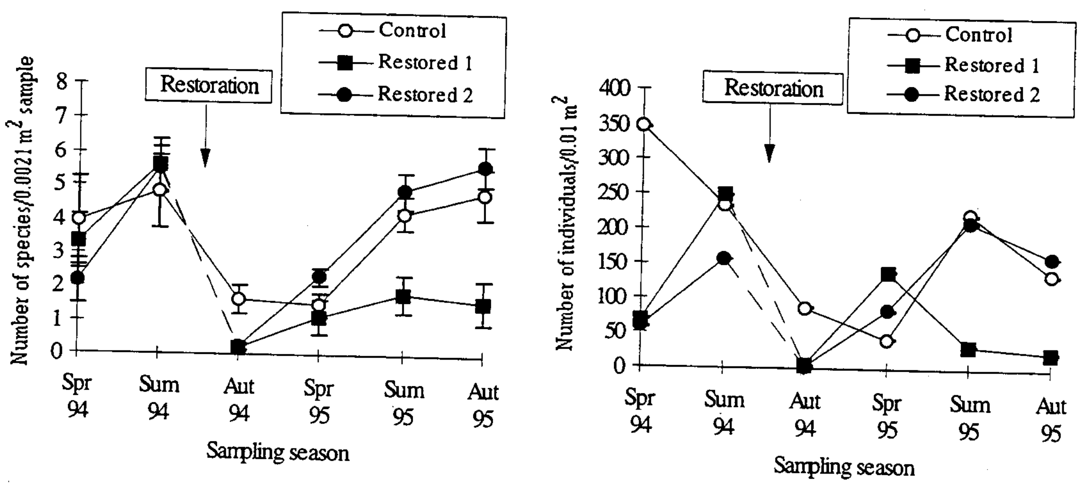

Figure 2. Invertebrate species richness and abundance in the R. Brede, before and after restoration: a (left): species richness (mean number of species per 21cm^2 sample); b (right): abundance (no. individuals per 0.01 m^2).

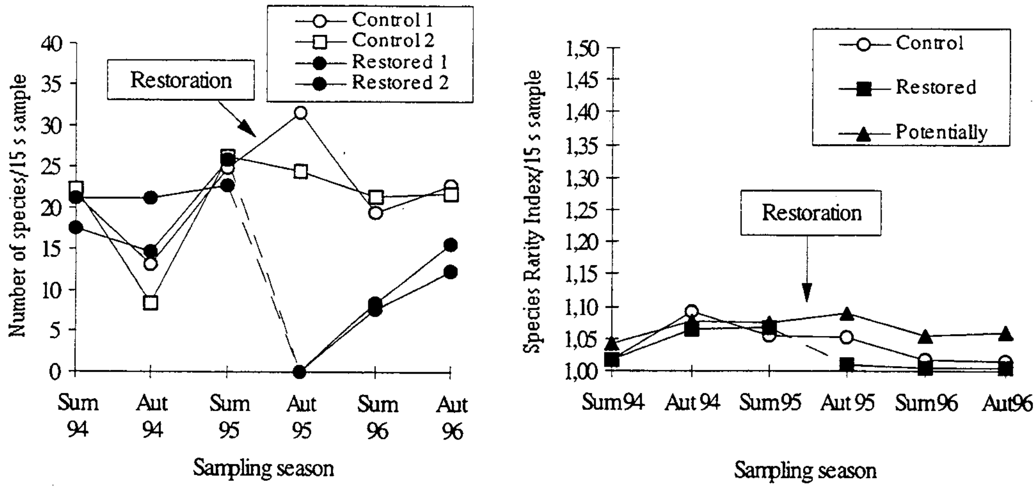

Figure 3. Macroinvertebrate species richness and species rarity in the R. Cole, before and after restoration: a (left): species richness (mean number of species per 15 s sample); b (right): species rarity (mean SRI per 15 s sample).

Plants assemblages colonising the restored channels

Species richness

Wetland macrophyte species richness (aquatic and emergent plants combined) in the new channels of the R. Brede and R. Cole quickly reached pre-restoration levels, relative to the control sections (Figs. 4a and 5a). However there were differences in the responses of the emergent and aquatic plants to the restoration work. Emergent plant species richness in both rivers remained the same, or increased, after restoration (Figs. 4a and 5a). In the R. Cole emergent plant species richness remained virtually constant in 500 m survey lengths before (autumn 1994) and within a month after restoration (autumn 1995) (Fig. 4a). However, one year after restoration, the mean emergent plant species richness increased from 27 to 38 species per 500 m survey length. In the R. Brede, following a small decline in species richness one year after restoration, the number of emergent plant species recorded returned to pre-restoration levels (adjusted for increases in the control lengths). Consequently, there was a highly significant increase in species richness between years but no interaction between location (control vs. restored) and year (Fig. 5a; difference between years: two-way ANOVA, $p<0.0001$, $F = 16.45$, df = 2,24; interaction between location and year: $p=0.09$).

The number of aquatic plant species recorded from the R. Cole was little affected by restoration (mean no. of species per 500 m: 7.5 pre-restoration, 7.0 within a month of restoration, 8.0 one year after restora-tion) (Fig. 4a). On the R. Brede aquatic plant species richness was significantly lower in the year after resto-ration (Fig. 5a; two-way ANOVA, $p<0.001$, $F = 9.72$, df = 2, 24). In the second year the number of aquatic species returned to pre-restoration levels. On R. Cole, wetland plant SRIs indicated similar average rarity values for the assemblages before, during and after restoration (Fig. 4b). SRIs could not be calculated for R. Brede.

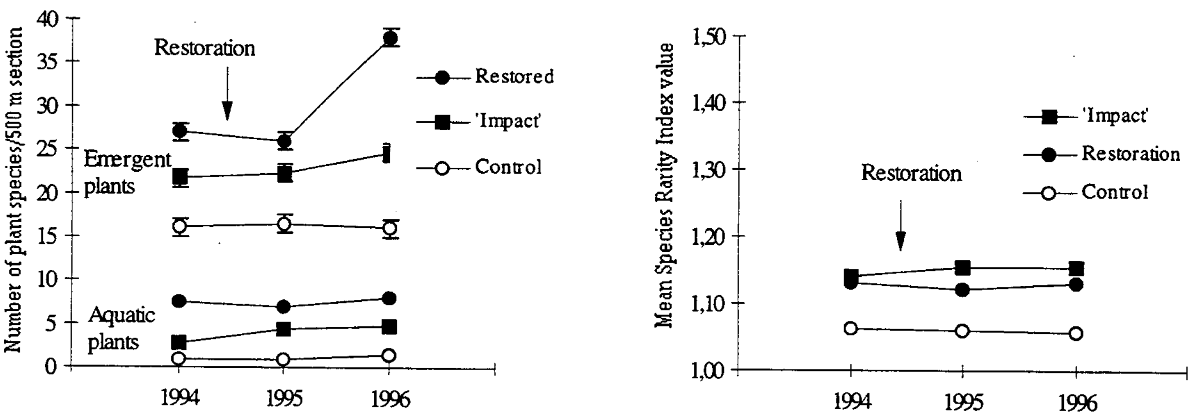

Figure 4. Wetland plant species richness and species rarity on the R: Cole for control, restored and potentially impacted sections: (a) species richness (mean number of plant species/500 m section (n = 2 samples per year in control and restored sections); (b) species rarity (mean SRI/500 m section). For clarity, error bars are only shown for SE > 0.5.

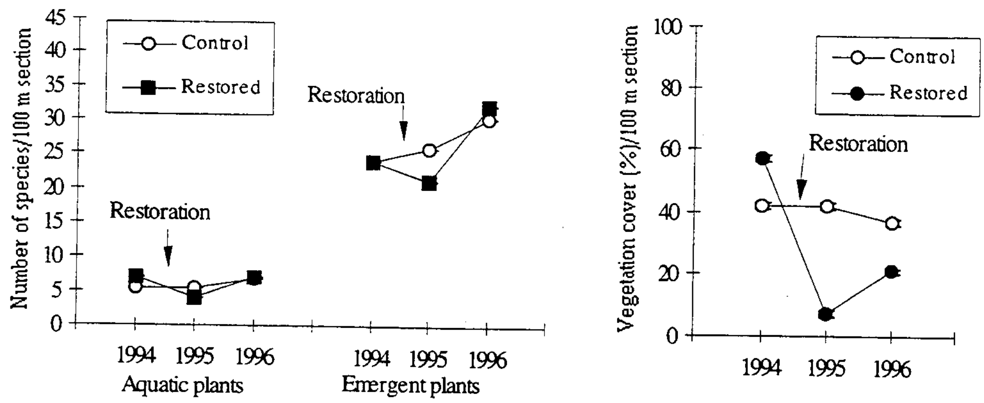

Figure 5. Wetland plant species richness and cover in the R. Brede: a (left): species richness (number of species per 100 m section; mean ± 1 SE); b (right): abundance of channel vegetation (vegetation cover (%) per 100 m section; mean ± 1 SE). For clarity, error bars are only shown for SE > 2.0.

Vegetation abundance

Total wetland macrophyte *cover* in the R. Brede was lower in the year after restoration, and then began to recover, with a highly significant location (control vs. restored) x time (before vs. after) interaction (Fig. 5b; two way ANOVA, p<0.0001, F = 23.67, df = 1, 24). Channel vegetation cover was 10.4% one year after restoration and 22.7% in the second year after restoration, compared to about 60% before restoration. Since control length cover fell slightly in 1996, this suggests that cover had returned to about half its pre-restoration level after two years. Vegetation cover was not measured in the R. Cole 500 m lengths.

Impacts downstream of the restoration site

Impacts on invertebrate assemblages

The impact of restoration works on the downstream invertebrate assemblages was assessed on the R. Cole at sites 300 m, 750 m and 1200 m downstream of the restoration section (Fig. 1).

In the pre-restoration phase (summer 1994 to summer 1995) all three sites located downstream of the works showed similar trends in species richness to the upstream control sites. The control sections therefore appear to provide a good model for assemblage species richness trends in the downstream sections. In both control sections species richness increased immediately post restoration (i.e. in autumn 1995 vs. autumn 1994) with species richness more than doubling. However, in all three sections downstream of the works, species richness increased only slightly between autumn 1994 and 1995 (note that the comparison is with the same season, not the previous season). This suggests that invertebrate richness underwent a moderate decline in all three sections downstream of the works in the autumn one to two months after the restoration was completed. This was evidenced by a highly significant interaction between time (before vs. after) and season (summer vs. autumn) (three-way ANOVA, p=0.0001, F = 29.44, df = 1.12).

Comparable assessments made during summer and autumn 1996 (up to one year after the main works) are more equivocal with no significant interaction between time and season.

SRI values for the downstream sites (Fig. 3b) suggest little difference before and after restoration. Overall, therefore, whereas species richness may have shown a relative decline below the works, there was no evidence that uncommon species were at particular risk.

Downstream impacts on macrophyte assemblages

Plant survey data from the potentially impacted section of the R. Cole showed no evidence of a significant change in conservation value as a result of the works. Comparisons of species richness, abundance and SRI data before and after the works show very little change (Fig. 4a,b). There was particular concern that sediments released from the works could shade-out submerged aquatic plant assemblages downstream but, in practice, there was no evidence of such damage.

Discussion

Species richness and rarity

Plant and aquatic invertebrate assemblages showed a rapid recovery of species richness in restored sections of the R. Brede and R. Cole after channel reconstruction. The rate of recovery of invertebrate richness (approaching pre-restoration levels after one year) concurs well with the results of studies from other rivers where potential colonists from upstream have been available (see (10)) and reviews by (18)(19).

Wetland macrophyte species richness also recovered to pre-disturbance levels rapidly and on a time similar scale to the macroinvertebrate assemblages. In both rivers the rich macrophyte assemblage was largely achieved through rapid colonisation of new muddy banks by wetland ruderals (e.g. *Veronica catenata* and *Ranunculus sceleratus*). In addition, field observations showed that species totals were increased by the retention of a number of more slowly colonising competitor species (*sensu* (20)) in backwaters which functioned as refuges. These were small sections of the old channel (on the R. Cole there were two backwaters of c. 30 m in length, and on the R. Brede two of 50 m and 100 m length) which remained attached to the new channel and were included within the relevant survey sections. Plants retained in this way included *Carex riparia*, *Solanum dulcamara* and *Nuphar lutea*.

Within the macrophyte assemblages, both rivers showed a tendency for aquatic plant species richness to recover more slowly from channel reconstruction than emergent plants. In the R. Brede this may in part have reflected the predominance of unconsolidated sandy bottom substrates which provide a poor substrate for colonisation by rooted macrophytes. However, it may also reflect the different colonisation strategies which predominate in the two wetland plant groups. A high proportion of emergent plant species are ruderals producing abundant wind-borne seeds, with a persistent seed bank and an affinity for bare substrates (20). Amongst the aquatics, vascular species are more likely to be competitors than ruderals, reproducing either mainly vegetatively (e.g. *Ranunculus pennicilatus*, *Elodea canadensis*) or through production of few, large water-borne seeds (e.g. *Nuphar lutea*). Both strategies facilitate colonisation of downstream river sites. The number of individual plants initially colonising any given stretch will, however, have a tendency to be lower amongst aquatic species than in the ruderal marginal species which produce abundant wind-dispersed seeds.

Abundance

The abundance of invertebrates colonising the new river channel was of particular interest because of the role of macroinvertebrates as food for fish and other vertebrates. On the R. Brede, the total abundance of species recovered rapidly, as might be expected considering the tolerance of river channel faunas to natural disturbance events such as floods (Fig. 2b) (21).

Vegetation abundance in the new river sections was of interest in the study because of the role played by wetland macrophytes as a major habitat for aquatic macroinvertebrates and fish, and also because channel vegetation can locally increase flooding of adjacent areas (which may in turn reduce flood peaks, increase water storage, enhance sediment deposition etc.). In terms of total in-channel cover, recovery to pre-restoration levels was slow compared to the recovery of species richness. In the R. Brede, aquatic species were significantly less abundant following restoration and had not recovered to pre-restoration levels after two years.

Downstream impacts

There is little information available about the impact of river engineering works on downstream habitats, despite the frequency of such operations. In the R. Cole, where this impact was investigated, the detrimental effects appeared to be restricted to the macroinvertebrate assemblage and were greatest immediately after completion of the works. One year after the restoration work, downstream invertebrate species richness was not significantly different from that in control sections.

Conclusions

The short-term impacts of large-scale river restoration are potentially negative. Complete re-excavation of a new channel will inevitably eliminate most existing assemblages present in that section. In addition the disturbance caused has the potential to generate downstream impacts, particularly through the release of sediments and nutrients. It is implicit within the concepts of river restoration (a) that any damage caused to the restored areas or to downstream sections should be either minimal or relatively short term and (b) that the channel re-engineering will lead to eventual improvements that not only outweigh initial damage, but facilitate improvements in the quality of channel and riparian assemblages above and beyond their original state.

For most assessed quality parameters, this study provides little evidence to refute the contention that adverse impacts from river restoration engineering works are likely to be relatively minor or short term. However, the study has also shown little evidence of net benefits in the short term. On the R. Brede and R. Cole, macrophyte and invertebrate species richness recovered quickly by natural recolonisation, and after about one year approached pre-restoration values. Only on the R. Cole was there clear evidence of a short-term increase in wetland macrophyte species richness. Wetland macrophyte and invertebrate abundance, and invertebrate rarity, generally recovered more slowly, but sequential surveys indicated that both were approaching pre-restoration levels. Plant species rarity values appeared to be unaffected by restoration.

Although evidence of downstream impacts were observed (in the R. Cole), adverse effects were most evident in the short term, one to two months after the works, and appeared only to affect invertebrate assemblages. One year after channel construction the effect on downstream assemblage species richness was equivocal. Uncommon invertebrate species did not appear to be especially at risk in the potentially impacted downstream areas.

Clearly, a longer period of study is required to determine the ultimate effects of river restoration on the biota of the R. Cole and R. Brede. The critical test of the success of the restoration works, whether they bring net benefits in the medium and long term, has yet to be proved.

Acknowledgements
We thank the project partners of the EU-LIFE project "River restoration: benefits for integrated catchment management" who part funded the work reported here. Bob Clarke of Plymouth Marine Lab. gave us valuable advice on the analysis of BACI design field studies, whilst Mike Furse (Inst. of Freshwater Ecology) gave very helpful comments on the text.

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Stream restoration in Vejle County, Denmark - and their biological effects

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As one of 14 regional nature and environmental authorities Vejle County Council is responsible for setting up environmental quality objectives for the watercourses. In order to improve conditions for fish and other river life we are carrying out stream restoration projects. Over the past 10 years we have carried out 120 projects. Most of these have consisted in making a free passage for fish and invertebrates. The biological effect of the projects has been documented, primarily through fish investigations. One of the results is that by-pass streams and riffles besides giving free passage also provide good habitats for trout fry. We have produced a video film with excerpts from different types of restoration of streams in Vejle County.

Vejle County Council is one of 14 regional nature and environmental authorities in Denmark. One of the many tasks facing us in the environmental field is the setting up of quality objectives for lakes and watercourses. The overall objective is to ensure a natural and varied plant and animal life. In Vejle County there are 1510 km of watercourses which have quality objectives. Of these about 90 % are defined as habitats for either salmonides or cyprinids.

As far as watercourses are concerned we are attempting to improve water quality by bringing about a reduction in the discharge of sewage and other pollutants. In order to improve the physical conditions for fish and invertebrates we are also carrying out stream restoration projects. From 1986 to 1996 we have carried out 120 projects. Most of these projects are made in order to allow a free passage for fish and invertebrates: fish ladders, by-pass streams and riffles. (Fig.1). In 1986 we registered approximately 360 serious obstructions in our watercourses. Mainly at hydroelectric power stations, water mills, fishfarms and at culverts under roads.

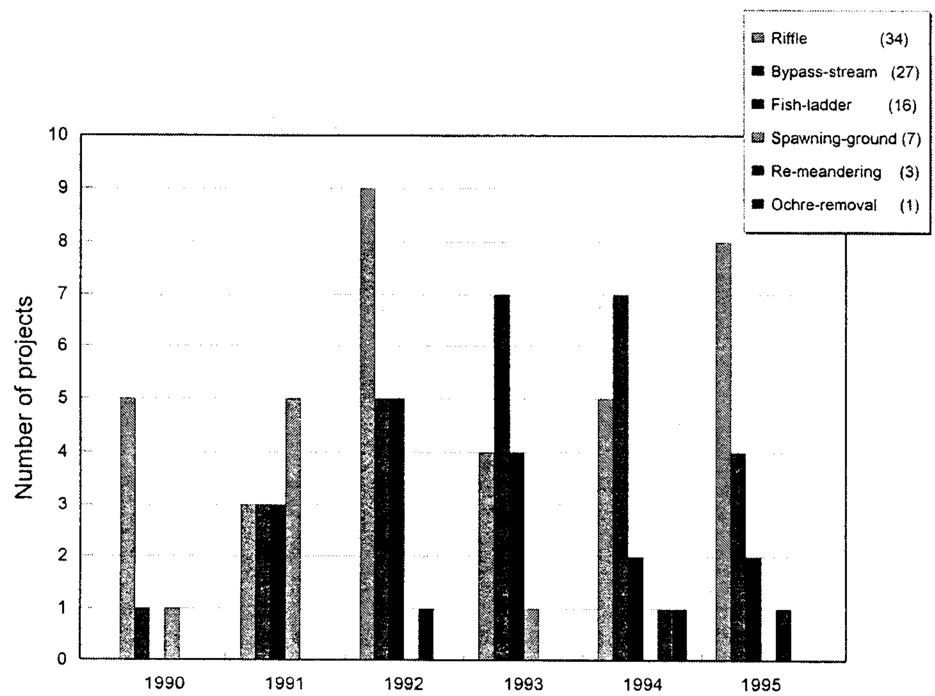

Figure 1. Different types of restoration projects carried out in Vejle County from 1990 to 1995. As fish pass we are making more and more by-passes and less fish ladders.

The total investments in stream restoration projects in Vejle County in the period from 1989 to 1995 was 20.3 million DKK (= 3.5 million USD). The financial support was about 8 million DKK, mainly given by the Danish Environmental Protection Agency (Fig. 2).

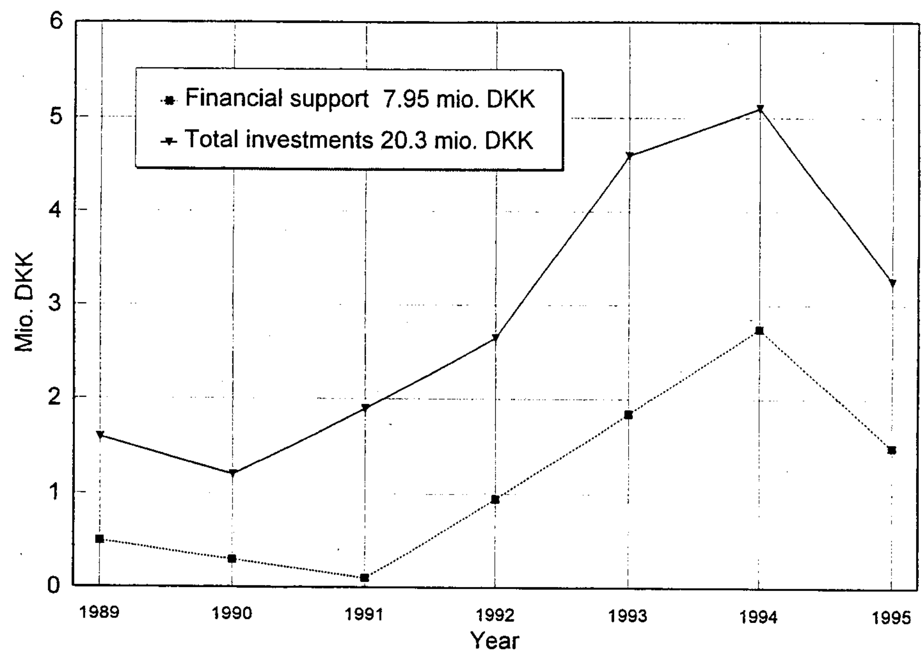

Figure 2. Investments in stream restoration carried out by Vejle County.

By making fish ladders, by-pass streams and riffles 314 km of streams has been re-opened for fish migration in the period from 1989 to 1995 (Fig. 3).

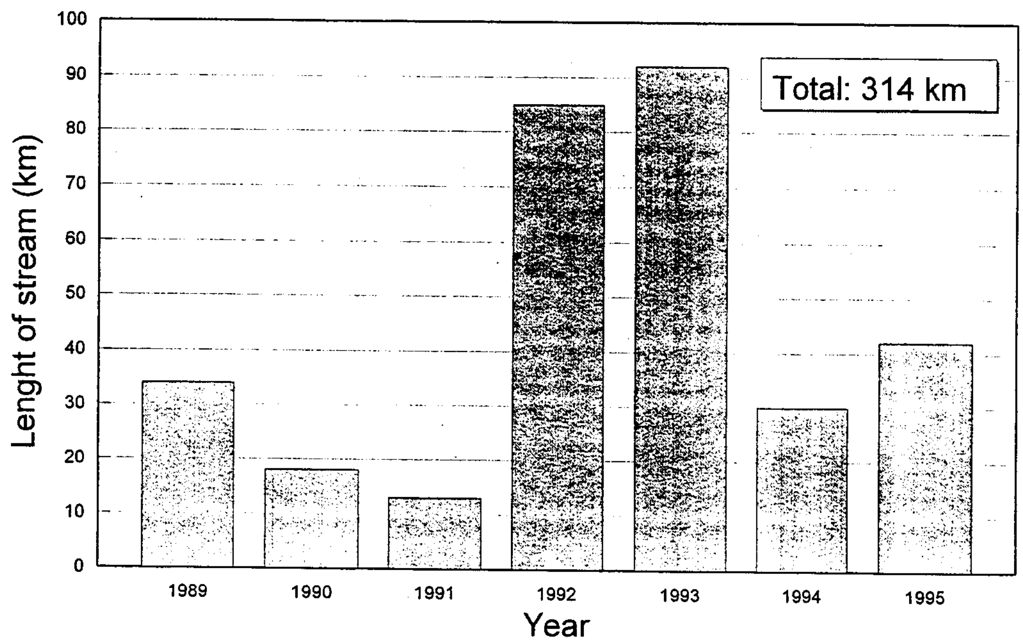

Figure 3. As a result of restoration in Vejle County 314 km of streams has been re-opened for upstream fish migration.

Almost all the projects that we have carried out have been followed by investigations, both before and after the restoration. In nearly all cases we have witnessed a positive effect upon the fish populations. An example of the biological effect of a restoration project is given at the river Klokkedal Å at the water mill at Boller where a fish ladder of the pool type was constructed in 1990 (Fig. 4). Now the spawning running sea trout are able to use the upper reach of the stream for spawning. This has led to a vast increase in the number of trout fry at the upper reach. We have recorded densities of troutfry up to 132 per 100 square meter of stream bed. And this will result in an increase in the number of downstream migrating smolts.
In the 1980´s and early 1990´s we constructed fish ladders of the Denil type at some weirs and dams. This type of fish ladder, though, is far from perfect. Frequent cleaning is necessary - branches and leaves have to be removed. Fish that are weak swimmers such as the roach find it difficult to climb the ladders. Fish may also have difficulty in finding the ladder entrance (1).

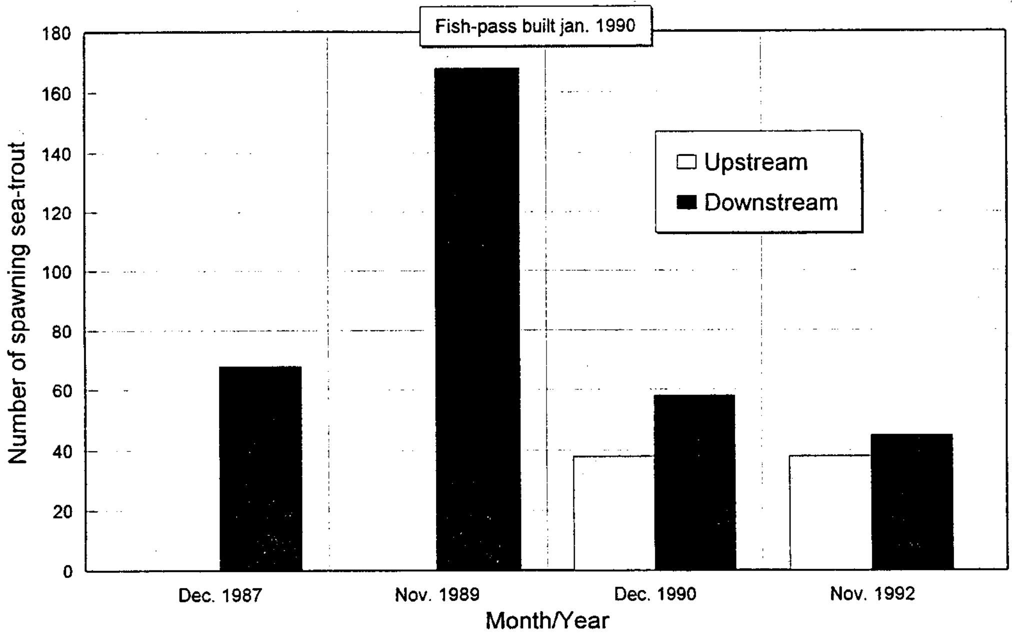

Figure 4. Before 1990 spawning sea trout was not able pass the weir at Boller Water Mill in the river Klokkedal Å. Now they are passing the pool-type fish ladder and they are spawning in the whole length of the river.

In Vejle County we have found that by-pass streams provide a good solution. From 1990 to 1995 we have constructed 27 by-pass streams at dams and weirs. The by-passes have been constructed with gradients up to 35 ‰. The gravel bed and the quick flowing water provide excellent living conditions for fish and invertebrates. In many cases we have registered high densities of trout in the by-pass streams. The densities in the by-passes are often higher than in the watercourses themselves (Fig. 5) (2).

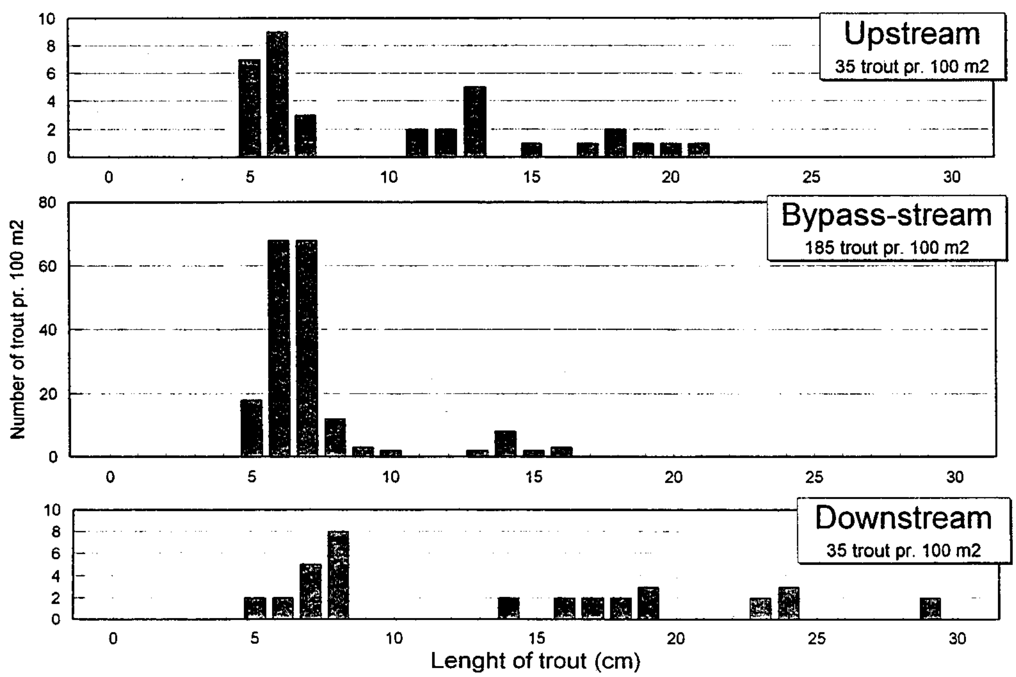

Figure 5. Trout density in the by-pass stream in the brook Kvak Møllebæk compared with the densities in the brook up- and down stream the by-pass.

By-pass streams also allow a free passage of other fish species than strong swimmers as the trout. A long term study at the by-pass stream at the Vestbirk Hydroelectric Power Station (River Gudenå) showed that almost all species that were present in the river system used the by-pass, which is 330 m long and with an average gradient of 13 ‰ (3).

At smaller weirs, which were often constructed in relation to the channelization of many watercourses, long stone riffles can be made to offset the fall. From 1990 to 1995 we have made 34 riffles. Riffles provide a free passage. Furthermore they often provide very good habitats for trout fry. An example is given at an artificial riffle at the river Højen Å where a trout density at 390 per 100 square meter stream bed has been recorded (Fig. 6) (2)

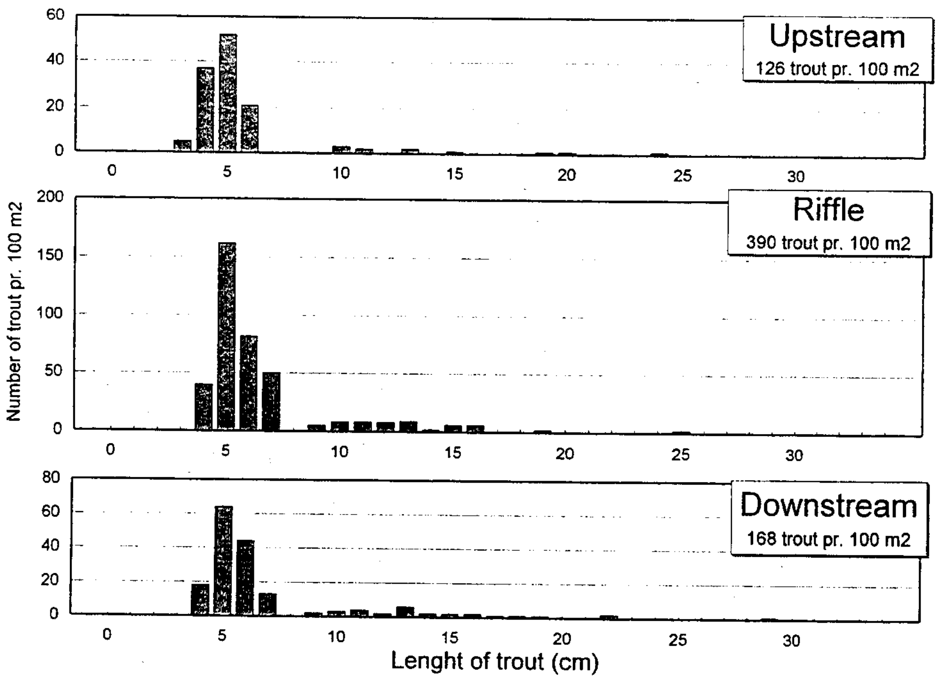

Figure 6. The man made riffle at the river Højen Å at Stokbro provides a very good habitat for trout fry.

In the 1980's and early 1990's the municipal sewage treatment plants were greatly improved. Liquid manure from local farms no longer runs directly into the streams. This has led to a vast improvement in water quality over the past few years.

Today's main concern is that many watercourses are in a poor physical condition because of dredging and channelization. They lack physical diversity.

In the years to come we will focus more attention on making restoration projects that will improve the physical conditions on longer reaches.

We have produced a video film showing examples of some of the projects that we have carried out. The title is "Restoration of Watercourses in Vejle County".

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Long-term, habitat-specific response of a macroinvertebrate community to river restoration

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Key words
Restoration, channelization, weed clearance, macroinvertebrate community.

Abstract

1. In 1989 a 1.3 km channelized reach of the river Gelså was restored to a new 1.9 km meandering course. The restored reach was subsequently (1989-95) monitored for changes in physical and biological features compared with an upstream channelized reach.
2. By 1993 the restored reach had already stabilised, both physically and with respect to diversity and density of the macroinvertebrate community.
3. The upstream reach gradually improved physically during the study period, but remained less heterogeneous than the restored reach, with only a very limited amount of stony substratum. Stone dwelling macroinvertebrate species were consequently still scarce in 1995, while overall diversity and density of the macroinvertebrate community was similar to that in the restored reach.
4. Our results indicate that natural rehabilitation of physical features is a rather fast process, but in some ways cannot match the almost instantaneous heterogeneity obtained by active restoration measures.

Introduction

The natural physical characteristics and the biota of streams and riparian areas in Denmark and elsewhere have been strongly altered and in many cases lost due to human manipulation and impact on the landscape (1)(2). The primary reason for the deterioration of streams and riparian areas in Denmark has been the change in land use from forested land to intensively cultivated land; 63% of Denmark presently being arable farmland and only 12% forest. Cultivation of farmland has resulted in extensive straightening and culverting of streams and drainage of riparian wetlands, and in the process more than 90% of the 35,000 km of natural Danish streams have been physically modified (e.g. (3)). The physical impact that straightening and channelization have had on Danish streams was perpetuated by traditional annually maintenance of streams and banks with the removal of all higher vegetation and regular dredging of the stream channel (e.g. (4)). In addition, excessive organic matter, nutrient and other contaminant pollution of streams by sewage effluent from urban areas and runoff from farms reduced water quality in the majority of Danish streams (e.g. (5)).

The water quality of most Danish streams has improved markedly during the last two decades (e.g. (6)(7)). However, this has not been matched by an overall improvement in stream quality due to the poor physical condition of many streams (3). One way of improving physical stream quality is by restoration, and many projects has already been undertaken in Denmark (3)(8)(9). Another important measure taken to improve stream physical conditions is a change in stream maintenance practice towards more environmentally sound measures rather than just focusing on discharge capacity of the stream channel (3)(4).

Active remeandering of stream channels results in a immediate restoration of natural stream channel morphology, whereas changed stream maintenance, e.g. cessation of weed clearance and dredging, leads to a gradual change in stream channel morphology towards a more natural state. Moreover, active remeandering is costly and energy consuming, whereas changed maintenance often saves energy and money. It is therefore of vital importance to assess whether active restoration measures result in physical and ecological benefits which cannot be achieved by simply changing or ceasing stream maintenance work.

As yet there have been very few studies documenting the effects of stream restoration on stream biota, albeit that the number is increasing (e.g. (7)(10)(11). With respect to the long-term effects of stream restoration, however, there is a total lack of knowledge, primarily because restoration projects are still somewhat novel and hence have a relatively short history.

We have previously described the short-term effects on the macroinvertebrate community of active remeandering of a reach of the Danish river the Gelså (11). The purpose of the present paper is to describe the longer term effects on the macroinvertebrate community of the remeandering project and to compare them with the effects of changed maintenance practice.

Material and methods

Study site

The study site has previously been described along with the background for the restoration project (11) and only key information will be presented here. In summer 1989 (July to September), a 1.3 km straightened and channelized reach of the river Gelså at Bevtoft in southern Jutland, Denmark was restored to a 1.9 km meandering coarse. 1,000 m^3 of stone was used to create rip-rap structures in the new meanders and 740 m^3 of gravel was laid out as new spawning grounds. The main physical properties of the reach prior to and following restoration are shown in Table 1. Creation of sixteen new meanders changed the stream channel morphology, decreasing channel width by 3-4 m and reducing discharge capacity by almost 50% (from 6.6 $m^3 s^{-1}$ to 3.5 $m^3 s^{-1}$). Prior to restoration of the Bevtoft reach a 0.5 km upstream reach with very similar physical, chemical and biological characteristics was selected for comparison. This upstream reach remained channelized. Because of the rigorous maintenance practice (dredging and mechanical weed clearance) employed at both reaches prior to 1989, the dimensions and hydraulic capacity of the stream channel at both reaches were much greater than stipulated in the local authority regulations governing the watercourse. However, in 1990 the only maintenance practice employed was weed clearance by scythe, and since 1991 no maintenance work of any kind has been undertaken at either reach. The upstream reach therefore represents an alternative means of river rehabilitation compared to active restoration, namely natural restoration without human intervention.

Table 1. Main physical properties of the restored reach of the river Gelså before and after restoration.

	Before restoration	After restoration
Catchment area	113 km^2	113 km^2
Annual mean discharge	12.8 $l\,s^{-1}\,km^{-2}$	12.8 $l\,s^{-1}\,km^{-2}$
Stream length	1,340 m	1,850 m
Stream slope	0.65 ‰	0.8 ‰
Bankfull discharge	6.6 $m^3 s^{-1}$	3.5 $m^3 s^{-1}$
Number of meanders	0	16
Spawning grounds	Few	18 (3,500 m^2)

Sampling strategy:

Kick-samples were collected in 1989, before the restoration and in 1990; 1991; 1993 and 1995. Sampling was each year undertaken in May. The samples were collected at two sites in the restored reach and two in the upstream reach. Each site was divided into three transects approximately 10 m apart and 5 kick-samples collected along each transect using a 0.5 mm mesh hand net. Each kick sample was taken in a standardised manner by placing the foot in front of the handnet and kicking backwards about 40 cm twice (12). In the period 1989-91, samples from each site were pooled (11) while each kick were kept separate in 1993 and 1995, giving a total of 30 samples per reach per year. All samples were preserved in 70% ethanol in the field. Macroinvertebrate samples were sorted in the laboratory and identified. Samples from the period 1989-91 were identified to species level, while this was only the case for the majority of invertebrates collected in 1993 and 1995, exceptions being most dipterans (which were identified to family or subfamily level) and some Oligochaeta and Coleopterans. However, all samples were prior to analysis corrected to the same taxonomic identification level (the 1993/1995 level) to enable comparison.

Channel substrate composition at each kick-sample site was visually assessed by an experienced geomorphologist and the water depth measured. Fourteen sediment samples were collected in 1995 at selected kick-sampling sites to ensure that all possible substrate types were represented. Sampling was conducted with a Kajak corer (diameter 54 mm) by pushing it 5 cm down in the bed sediment. Larger stones at the sampling sites were collected before coring by means of hand sampling. Nine of the core samples were collected on the restored reach and 5 on the upstream reach. The uneven number of samples reflected the larger substrate variation in the restored reach than in the upstream reach. On return to the laboratory the 14 sediment samples were dried and the organic matter content removed by treatment with 6% hydrogen peroxide at 60 °C. The sediment samples were thereafter wet sieved using the Udden-Wenthworth grades (64 mm to 0.0625 mm). Descriptive statistical measures of grain size composition (median grain size: D_{50}; sorting coefficient: S_o) were estimated according to (13). Median grain size, sorting coefficient and organic matter content of the 14 sediment samples were used in a cluster analysis (14) in order to group the river bed sediment into dominant classes. The visual assessment of substrate types at the 60 kick-sampling sites used in 1993 and 1995 was thereafter calibrated on the basis of the results of the cluster analysis.

In addition to kick-samples, ten fist-sized stones were collected randomly at the same water depth (approx. 0.5 m) in the restored and upstream reaches. The stones were lifted into a small submerged hand-net (0.2 mm mesh) into which loosened material and macroinvertebrates were swept. These samples were treated the same way as the kick-samples (see above). The projected surface area of the stones were measured in the laboratory, and average density of macroinvertebrates calculated. Data from stones collected in 1993 has been reported previously (11).

To remove the influence of inter-reach variation in substrate type, 6 artificial substrates were placed in each reach in May 1995 and attempts made to retrieve them again after 6 months in December 1995. Only 3 of the artificial substrates were recovered in the restored reach and 4 in the upstream reach. Each consisted of 10 similar sized stones bound together with coarse stainless steel netting (15 mm mesh size). The total projected area of the substrates ranged from 650-775 cm^2. Macroinvertebrate on artificial substrates were treated in the same way as the kick-samples (see above).

Results

Changes in macroinvertebrate density and composition following remeandering

Prior to the restoration in 1989, at which time weed clearance was still undertaken, total benthic macroinvertebrate number was about 2,500 individuals (sum of all samples) in both reaches (Fig. 1A). In 1990, benthic number increased in both reaches to about 6,000 individuals. In the restored reach benthic number peaked in 1991 at 11,000 individuals, subsequently decreasing to the 1990-level in 1993 and 1995. In the upstream reach benthic invertebrate number remained relatively constant from 1990 to 1995.

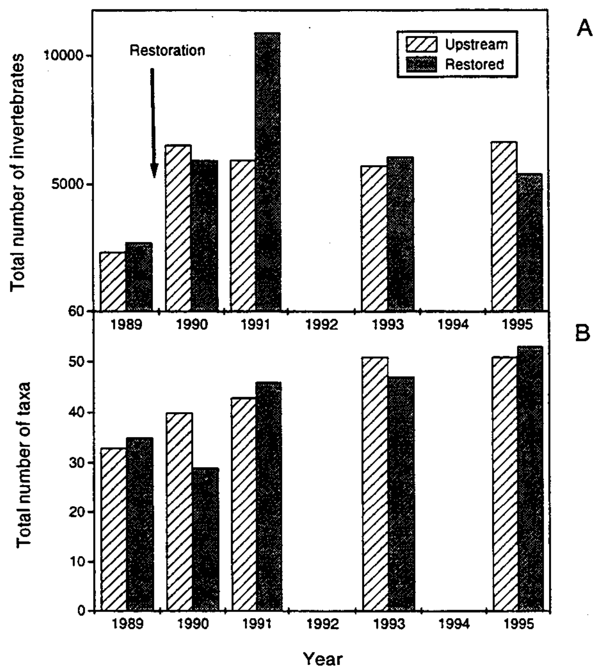

Figure 1. Total number of individuals (A) and taxa (B) of macroinvertebrates found in kick-samples from the upstream and restored reaches of the river Gelså prior to (1989) and following restoration (1990-95). No sampling was undertaken in 1992 or 1994.

In general, the number of taxa in both reaches increased markedly during the study period (Fig. 1B). The number of taxa in the restored reach only fell in 1990, the first year following completion of restoration. This was also the year in which the inter-reach difference in taxa number was greatest (29 *vs* 40), the number of taxa found in the two reaches in the other years being very similar.

In 1991 several species associated with coarse substrata and stones were only found in the restored reach, e.g. the mayfly *Heptagenia sulphurea* and the caseless caddisfly *Hydropsyche siltalai*. Species with poor dispersal abilities such as the leech *Glossiphonia complanata* and the beetle *Limnius volckmari* were still absent from the restored reach in 1991, but were present in the upstream reach. However, these species were all present in both reaches in 1993 and/or 1995, indicating that no macroinvertebrate species appear to be restricted to only one of the two reaches.

Quantitative composition of the macroinvertebrate community

Gammarus pulex was the most abundant species in the restored reach in 1993, constituting 50% of the total macroinvertebrate fauna, as well as in both reaches in 1995 (Fig. 2). The number of *G. pulex* was significantly higher in the restored reach than in the upstream reach ($p < 0.01$, t-test on log transformed data), whereas there was no significant difference in 1995. Species such as *Heptagenia* spp. and *Elmis aenea* Ph. Müll. were clearly more abundant in the restored reach than in the upstream reach in both years, which was not the case for other stone dwelling species such as *Ancylus fluviatilis* and *Oredyctes sanmarkii*. The latter species became very frequent in the upstream reach in 1995. In both years, species that prefer soft sediments were most abundant in the upstream reach, total abundance of Oligochaeta, Tanytarsini and Chironomini being significantly higher than in the restored reach in both years ($p < 0.02$, t-test on log transformed data). However, there was a clear tendency towards a decrease in total abundance of soft sediment dwellers in the upstream reach from 1993 to 1995.

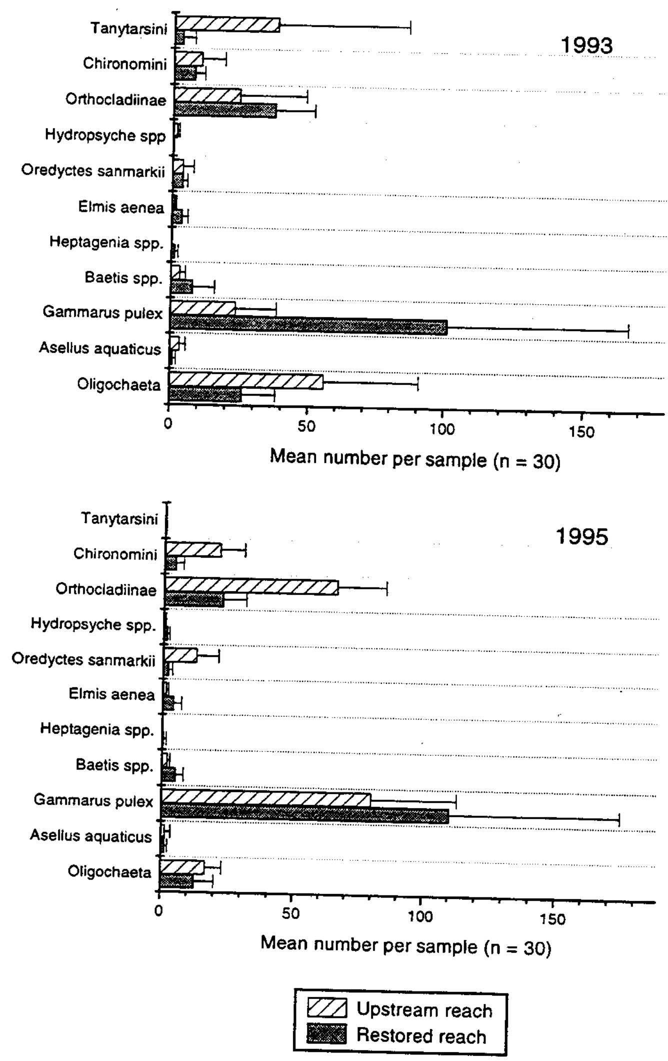

Figure 2. Mean number per kick-sample (n = 30) of the most abundant macroinvertebrate taxa found in the river Gelså in 1993 and 1995. Error bars denote the 95% C.L.

River channel substrate composition and classes

Cluster analysis revealed that the 14 sediment samples could be grouped into 6 substrate classes (Table 2). Substrate class 1 was very coarse gravel, as reflected by the high median grain size diameter (D_{50}). The substrate was poorly sorted (i.e. large heterogeneity in grain size) and low in organic matter content. At the other end of the spectrum substrate class 6 comprised well sorted, medium-sized sand high in organic content matter content.

The median diameter and sorting coefficient of river substrate provide some clues as to the environmental conditions under which they were deposited, the former reflecting the strength of the current that transported the material and the latter the range of hydraulic conditions present at the site. The environmental extremes are thus represented by substrate classes 1-2, indicative of an environment with high flow velocity (erosional), and substrate class 6, indicative of an environment with low flow velocity (depositional). However, substrate class 1 is also indicative of an environment of alternating hydraulic conditions due to poor sorting, while substrate class 2 is indicative of a more steady high flow velocity regime. The three intermediate substrate classes are indicative of different transitional states between the above mentioned classes, the main differences being in grain size and sorting, organic matter content only increasing slightly from substrate class 1 to 5.

Table 2. The six substrate classes identified on the basis of the cluster analysis of 14 sediment samples. (See text for additional information).

Class	Substrate	D_{50}	Sorting	S_0	Organic matter content
1	Very coarse gravel	55 mm	Poor	4.1	0.27%
2	Medium gravel	15 mm	Moderate	3.0	0.35%
3	Fine gravel	4.5 mm	Poor	4.2	0.26%
4	Coarse sand	0.59 mm	Poor	5.2	0.40%
5	Coarse sand	0.60 mm	Well	1.6	0.48%
6	Medium sand	0.50 mm	Well	2.4	1.41%

Changes in substrate composition

In 1991 we estimated that about 25% of the substrate consisted of gravel and stones in the restored reach but less than 6% in the upstream reach (11). The main difference between the two reaches in both 1993 and 1995 was that the coarse substrate class 1 was totally absent from the upstream reach (Fig. 3).

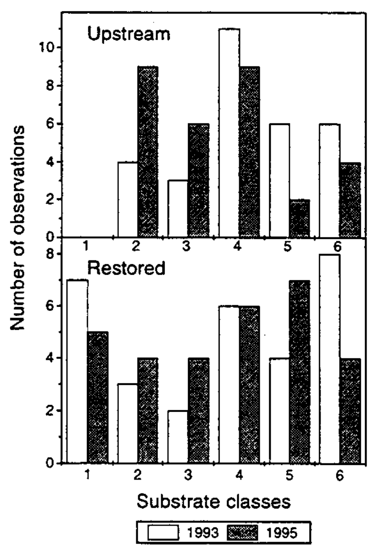

Figure 3. Substrate class distribution at the sampling sites in the upstream and restored reaches of the river Gelså in 1993 and 1995.

The distribution of substrate classes tended to differ between the restored and the upstream reach in both years (Chi-square test, $0.05 < p < 0.10$). However, there was a clear shift from mainly fine grained substrata to more coarse substrata from 1993 to 1995 in the upstream reach, whereas there were only minor changes in substrate classes in the restored reach.

Relationship between macroinvertebrates and substratum
Ordination analysis (DECORANA (15) revealed that macroinvertebrate samples taken on the poorly to moderately sorted substrates (class 1-4) could be separated from samples taken on the well sorted substrate classes 5 and 6 (Fig. 4). Samples taken from the two reaches (restored and upstream) did not separate clearly, however, indicating that substrate composition (sorting) was a more important determinant of invertebrate composition than the location of the sampling reach.

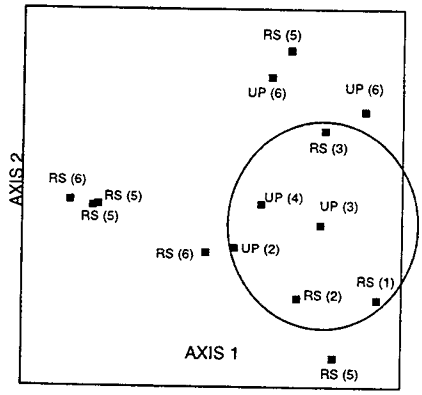

Figure 4. DECORANA ordination analysis of 14 macroinvertebrate kick-samples taken in the upstream reach (UP; n = 5) and in the restored reach (RS; n = 9) of the river Gelså in 1995. The substrate class present at each kick sampling site is given in parentheses.

Macroinvertebrates on natural and artificial stony substrata
Analysis of the macroinvertebrates found on stony substrata in 1995 revealed clear inter-reach differences in species density (Table 3). *Elmis aenea* ($p < 0.05$) and *Heptagenia sulphurea* ($p < 0.01$) were significantly more abundant on stones from the restored reach than from the upstream reach (t-test on log transformed data). The opposite was the case for *Rhyacophila* sp., which was significantly more abundant in the upstream reach ($p < 0.05$, t-test on log transformed data). Furthermore, there was a tendency for the total invertebrate density to be higher on natural stony substrata in the upstream reach than in the restored reach.

Table 3. Macroinvertebrate species density on stones in 1995 (No. m^{-2}).

Species	Upstream reach	Restored reach
Ancylus fluviatilis	0	56 ±68
Gammarus pulex	2,316 ±1,487	3,575 ±2,906
Baetis sp.	143 ±139	83 ±77
Heptagenia sulphurea	15 ±33	204 ±122*
Elmis aenea	717 ±590	3,548 ±3,059*
Oredyctes sanmarkii	466 ±415	134 ±194
Rhyacophila spp.	540 ±300*	198 ±219
Hydropsyche spp.	175 ±134	366 ±245
Other invertebrates	19,095 ±3,680	8,446 ±3,591

*Mean ±95% C.L. * denotes significant (p <0.05) differences between reaches.*

The relatively low recovery rate of the artificial substrata limits the possibility for statistical analysis. Nevertheless, analysis of macroinvertebrates on the artificial substrates revealed clear differences in colonisation pattern between the restored and upstream reaches, there being substantially more stone dwelling invertebrates and *Gammarus pulex* on the substrates from the restored reach than from the upstream reach (Fig. 5). The difference was only significant for *Heptagenia sulphurea*, though ($p < 0.05$, Mann-Whitney U-test). Despite sampling having been undertaken at different times of the year, there was good overall agreement between the inter-reach differences in macroinvertebrate density on natural stones and the artificial substrates.

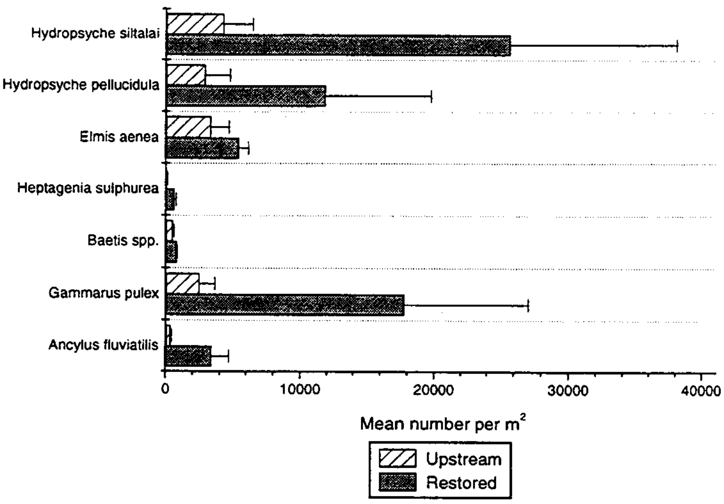

Figure 5. Macroinvertebrate densities (No. m^{-2}) on the artificial substrates in the upstream and restored reaches of the river Gelså in 1995. Mean ±1 SE.

Discussion

Our results indicate that the restored reach of the river Gelså had stabilised physically by 1993, no major changes in channel morphology and substrate composition having taken place from 1993 to 1995. The macroinvertebrate community also appears to have stabilised by 1993, no major changes in density, diversity or species composition having occurred thereafter. Remeandering of a reach of the river Gelså thus seems to have rapidly (<3 years) created a physically stable environment with an improved (in terms of density and diversity) macroinvertebrate community.

We also found that the upstream reach has undergone a remarkable recovery during the study period, but that in contrast to the restored reach, physical conditions were still improving in 1995. This finding lends further support to the notion that traditional maintenance practice prevents streams recovering their natural riffle and pool sequence and hence substrate variability in reaches where their would otherwise have been sufficient stream power for this to occur (16). When not cleared, the aquatic macrophytes serve as "ecological-engineers" (17), improving the physical heterogeneity of the stream channel by increasing the variation in flow conditions. The increased water velocity between macrophyte patches creates a coarser and less sorted substratum, as we found in the river Gelså. In addition, substrate stability increases, thereby benefiting the macroinvertebrate community (18)(19), and the macrophytes serve as refugia and habitats for a large number of macroinvertebrate species (e.g. (20)). In the upstream reach of the river Gelså following cessation of maintenance the macroinvertebrate community recovered rapidly, with density and diversity being similar to that in the restored reach in both 1993 and 1995. Macroinvertebrate community composition in the upstream reach differed from that in the restored reach until 1995, however, reflecting the almost complete absence of stony and very coarse (class 1, Table 2) substrata. This habitat type appears to be too limited in extent to sustain large populations of macroinvertebrate species that prefer very coarse, stony substrata. This contention support the findings of (21) that diversity of mayfly species increased with the area of implemented artificial substrates.

We have tried to incorporate our site-specific results from the river Gelså into a conceptual figure (Fig. 6) predicting the effect of two kinds of river rehabilitation - remeandering and cessation of maintenance - on the invertebrate community as compared with a channelized and traditionally maintained stream reach.

1) In channelized streams in which rigorous maintenance practice are employed, diversity and density are both low due to the high level of disturbance. Macrophyte habitats are cleared several times during the year, resulting in uniform stream flow patterns and unstable substrate conditions with high levels of

sediment transport (22)(23). This was the situation in both reaches of the river Gelså prior to the restoration (i.e. in 1989). Macroinvertebrate diversity and density will fluctuate considerably over the year due to the physical perturbation, whereas there will be no overall changes in community structure over a longer time scale (24). The number of species preferring a stony habitat will be low as this habitat type will be almost absent.

2) In restored streams macroinvertebrate diversity and density will both decrease for a short period following creation of new meanders, reflecting the mechanical disturbance and excess sediment transport associated with the construction work (9)(25) (Fig. 6). However, the macroinvertebrate community will recover rapidly (within ~ 1-2 years) reflecting its high resilience (e.g. (26)(27)) and in agreement with the findings of (10) in other restored streams. However, the recovery process could be prolonged in cases where upstream colonising sources are very distant or totally absent (28). Moreover, within approximately 2 years both diversity and density will probably be higher than prior to restoration, reflecting the creation of more habitats (e.g. (29)). Shortly thereafter there may be a peak in macroinvertebrate abundance in accordance with our findings in the river Gelså, reflecting a depositional regime (9) which appears to favour species such as *Gammarus pulex* (11), probably by providing an excess of food.

3) Three to four years after restoration the macroinvertebrate community will have stabilised, although there will be a slow increase in community diversity due to immigration of species with low dispersal abilities (28). Seasonal fluctuations in both density and diversity are predicted to be much less pronounced than in traditionally maintained streams because the environment is more stable (30) and the only disturbances are natural. Species preferring stony habitats and very coarse substrata will be a prominent feature in the restored reach from the moment the negative effects of the construction work have ceased as the stones and gravel introduced as part of the restoration immediately create habitats for colonisation by stone dwellers.

4) In stream reaches in which maintenance has ceased, there is no abrupt change in the macroinvertebrate community. Instead there is a steady increase in both diversity and density to a seasonally fluctuating level similar to that in the restored reach within 3-4 years. Compared to the restored reach, the major differences is that species composition reflects the fact that stony and very coarse substrata habitats are too limited in extent to sustain large populations of some stone dwelling species. Natural recovery of a stony and coarse substratum will depend on the availability of coarse material in the stream bed and banks, the stream power and the maintenance history (i.e. if stones have been removed)

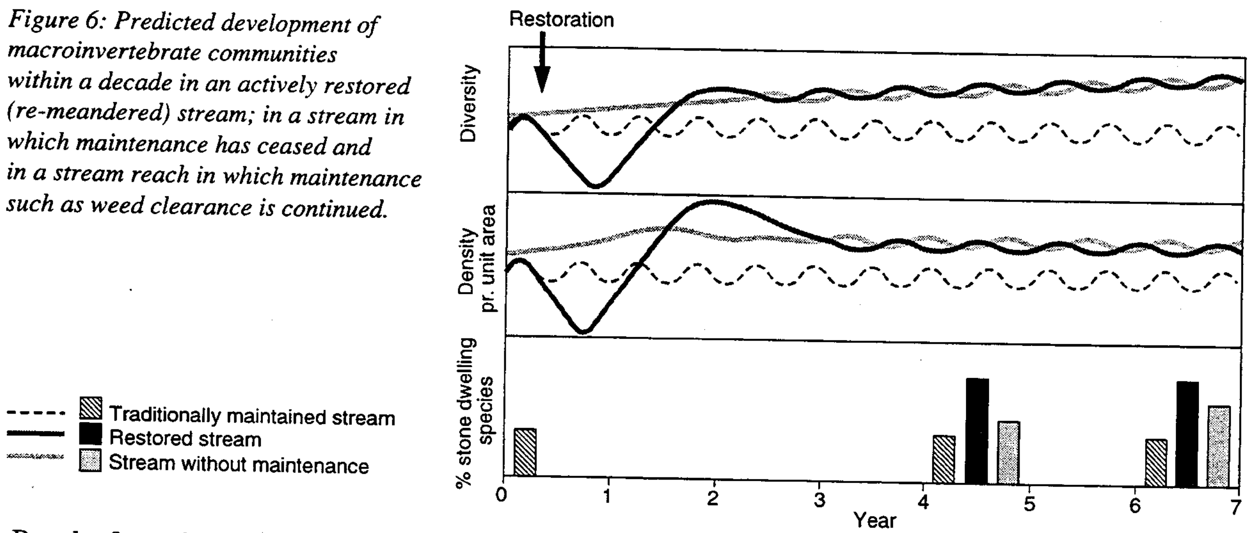

Figure 6: Predicted development of macroinvertebrate communities within a decade in an actively restored (re-meandered) stream; in a stream in which maintenance has ceased and in a stream reach in which maintenance such as weed clearance is continued.

Results from the present study indicate that cessation of stream maintenance practices alone can be beneficial for the stream environment after a relatively short period of time, although our results suggest that the addition of coarse substrata and stones to the stream bed further improve the stream biota. Cessation of maintenance saves money and energy, which could instead be used to add stones to the stream channel, thereby rendering the rehabilitation effort cost-neutral. Our results suggest that this might eventually yield the same benefits as active remeandering of stream reaches, but at a much lower cost.

However, remeandering offers other immediate environmental benefits: higher aesthetic value, a larger stream area over the same direct distance, increased flood-storage capacity and nutrient retention, etc. These various considerations need to be balanced before selecting the appropriate means of rehabilitating a stream.

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The River Odense in the year 2000

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Abstract

'The River Odense in the Year 2000' is a plan for revitalization of the River Odense in the County of Funen, Denmark. The catchment area is 600 km^2 and the length of the watercourse is 54 km. Environmental quality objectives for the watercourse are set forth in the County of Funen's Regional Plan. The watercourse has good water quality because of good sewage treatment in the cities in the catchment. The goal is to improve the physical quality of the watercourse and the interplay between the riparian areas and the waterway. The first step is to create free passage for the sea trout in the watercourse. Twelve millions DKK are already invested in this part of the project. Next step is to establish new spawning grounds and remeandering the watercourse. As the watercourse leads the water into the shallow waters of Odense Fjord an important part of the project is nitrogen removal in wet meadows bordering the watercourse. This part of the project is investigated further in the LIFE-project: 'Economic efficiency control of water protection action in the EC'. 'The River Odense in the Year 2000' is an integrated part of the 'The Funen Sea Trout' and is mainly financed by this project. 'The Funen Sea Trout' is a development project for the environment and tourism. It consists of three main elements: - release of large quantities of sea trouts, - building up of top class angling tourism and - enhancement of sea trout's living conditions in the watercourses. The tourist organizations have estimated that income from angling tourism has increased 80-100 millions DKK annually due to the Funen Sea trout project.

Introduction

The plan for the River Odense in the year 2000 is a part of the Funen sea trout project. The Funen sea trout project is a development project for the environment and tourism. It combines the need for commercial development with the desire to preserve and strengthen the environments in Funen. It consists of three main elements: - release of large quantities of sea trout, - building-up of top class, - angling tourism, and - enhancement of sea trout's living conditions in the watercourses of Funen. The tourist organizations have estimated that income from angling tourism has increased 80-100 millions DKK annually due to the Funen Sea trout project.

River Odense is the major river in the county. The catchment area is 600 km^2 and the length is 54 km. The mean discharge is 4.8 $m^3 s^{-1}$. According to the watercourse act and the environmental protection act the county has an obligation to fulfil the environmental quality objectives for the river Odense. The political adopted environmental quality objectives for the river Odense are that it has to be suitable as spawning and breeding grounds for salmonids. The quality objectives are set forward in the Region Plan for the county of Funen. To fulfil the quality objectives it is necessary to look on three things: - the amount of water in the river, - the water quality and - the physical environment in the river. The plan for the River Odense in the year 2000 deals with the physical environment.

Amount of water and water quality

In the catchment area to the River Odense great importance is attached to water supply from ground water to the city of Odense and intake of freshwater directly from the river for irrigation especially in market gardens. In the region plan for the county of Funen is set forward guidelines for the administration of use of groundwater and surface water. The water quality of the river has not always been able to fulfil the quality objectives for the river. For example has the content of BOD_5 and $(NH_3 + NH_4)$-N exceeded the recommended values. Investments of about 100 mill DKK in improved sewage treatment have created a better water quality in the river. The discharge limits for the major sewage treatment plant in the catchment area- Ejby Mølle - is now $BOD_5 < 10$ mg l^{-1}. (NH_3+NH_4)-N < 2 mg l^{-1} (summer) and 4 mg l^{-1} (winter), Tot-N < 8 mg l^{-1} (6 mg l^{-1} summer) and Tot P < 0.5 mg l^{-1}.

Physical revitalization

The county has elaborated the plan for the river Odense in the year 2000 as the last step to fulfil the quality objectives for the watercourse.

The main elements in the plan are to:

- create effective passage for fish and fauna
- recreate spawning grounds
- remeander the river
- improve the interplay between the river and the river valley
- investigate economic effective water protection actions in the catchment

In the year of 1175 the first water mill was built by the monks in the city of Odense. Since then it has been difficult for the sea trouts to reach the spawning grounds. In the past ten years the county has created effective fauna passage at lots of the minor obstructions. Three of the four major obstructions are rebuilt into a so called 'sweep'. Twelve millions DKK is invested in this part of the project.

To investigate the possibilities to recreate spawning grounds and remeandering the river to scenarios for the future river is considered. The first scenery is a total remeandering of the channelized parts of the river. The second scenery is to use the water depth created by erosion of the watercourse itself in the period from 1960 just after the channelization of the river and until 1990. This water depth is used to create new spawning grounds and remeandering parts of the river. The work with scenarios is not finished yet.

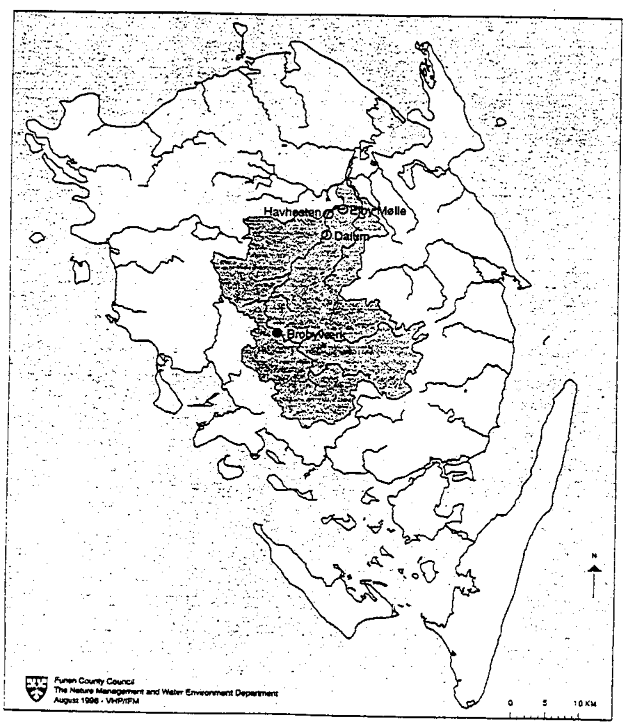
The possibility of improvement of the interplay between the river and the river valley is investigated with the economic efficiency of different water protection actions in the catchment area in the LIFE project 'Economic Efficiency control of Water protection Actions in the European Community'. The LIFE-project is of greater interest as the stream discharges into the shallow waters of Odense Fjord where improved nitrogen removal is necessary. The water protection actions investigated is use of wet meadows in the river valley to remove nitrate, reduction in the use of N-fertilizer in the catchment, buffer zones along the river and further sewage treatment in rural areas. There is potential for re-establish wet meadows in the catchment area. In 1895 there was 10.000 ha of meadows and moors in the catchment. Nowadays there is only 3000 ha.

Decision process

The first part of a decision process is to form the basis for the decision. The county has to report the history of the river and the biological impacts of mills and the channelization.

Realization of the plan involves many interests. First the landowners affected by the plan and their organizations. Also the municipalities in the catchment, the society of nature conservation, the angling society and other interested parts are to be involved in the decision. The final decision is taken by the county council but can be complaint to the Danish Environmental Protection Agency. A major part of the plans of creating effective fish passages has been carried out according to the possibilities of financing the separate projects. One might say that this is a good combination of planning and realization.

Catchment Area River Odense



A database for river restoration projects

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Keywords
River restoration, classification of projects, database.

Abstract
In order to obtain a useful overview of the river restoration projects undertaken it is important to compile statistics on the projects and undertake continuous systematic collection of information. A precondition for being able to compile such statistics, however, is the availability of an unambiguous classification system for the different types of restoration projects and methods.

This paper presents a proposal from the European Centre for River Restoration for a classification system and database on river restoration projects. The proposed classification system already form part of a database on river restoration projects previously and currently being undertaken in Denmark. It is hoped that the proposed system in the future will also form the basis for project databases throughout Europe. The databases could subsequently be compiled and updated under the auspices of the European Centre for River Restoration.

In the classification system the river restoration projects are subdivided in three types according to the overall objectives of the project:

- Type 1: Restoration of watercourse reaches;
- Type 2: Restoration of continuity between watercourse reaches;
- Type 3: Restoration of river valleys.

Each 'type' encompasses the 'methods' that have been used to achieve the objective of the project.

Introduction
During the course of this century numerous watercourses have been channelized or otherwise manipulated throughout Europe. As a result there are now only few watercourses that live up to our present-day ideas of a natural watercourse.

In Denmark we realise that if we want to save whatever is left of the environment connected to the streams and their riparian areas new legislation has to come into force. For 15 years it has been legally permissible to improve the physical conditions of Danish watercourses, named restoration. This possibility has been widely exploited, and over the years numerous restoration projects have been carried out - ranging from the laying out of spawning gravel to major projects aiming at remeandering watercourses and improving the interplay between the streams and their river valleys. More than 1000 small and larger-scale river restoration projects have so far been undertaken primarily by the Danish counties and municipalities. As a consequence considerable experience and know-how regarding watercourse and river valley management and restoration have been accumulated in the Danish regional and national authorities during the last decade, both with respect to legislation, conservation and to practical experience.

Interest in restoring watercourses and river valley ecosystems for the benefit of wildlife has also increased in other European countries since the first international conference on river restoration held in Lund, Sweden in 1991.

Many river restoration projects have already been undertaken achieving wide environmental benefits. Today, biodiversity is given high priority on the political agenda and restoration of rivers and their adjacent areas has been identified as one of the measures to maintain or even improve European biodiversity. At the same time there is increasing awareness that reinstating naturally functioning river-floodplain systems may bring catchment management benefits, particularly by increasing flood-storage capacity, giving increased nutrient retention and ameliorating low flows. Sustainable management and restoration of river and floodplain ecosystems may also reduce river maintenance costs and provide better facilities for amenity and recreation. In Europe as a whole several million ECU are spent each year on river restoration.

Exchange of knowledge
However, the exchange of information and experience nationally and not least internationally is inadequate. At the national level central points of contacts for information on national achievements, proposals and

dissemination for technical information to practitioners have recently been established in a few countries (Denmark and UK), but at European level such an institution has so far not existed.

As a consequence the European Union's Life Programme in 1993 granted funds to establish three major European remeandering demonstration projects in Denmark and the United Kingdom. As part of this the European Centre for River Restoration (ECRR) was established in 1995. The Centre is described elsewhere in these proceedings (1).

The overall objective of the Centre is to support the development of river restoration as an integral part of sustainable water management in European countries and to increase cost efficiency in river restoration. One of the measures to achieve this will be by compiling informations on European river restoration projects in databases.

Compilation of river restoration projects

Until now no clear statistics have been compiled of European restoration projects, and no clear overview has been available of what and how many restoration projects have been carried out. Such an overview is essential in order to be able to steer future restoration projects in the right direction, and to achieve such an overview it is important to compile statistics on the projects and undertake continuos systematic collection of information.

A precondition for being able to compile such statistics, however, is the availability of an unambiguous classification system for the different types of restoration projects and methods. Without such clear definitions, one cannot expect questions and answers to be interpreted in the same way from one person to another. Therefore a classification system for restoration projects has been developed by the Danish National Environmental Research Institute for the European Centre for River Restoration.

The classification system was initially presented at a meeting in 1995 with the Danish counties and EPA as participants. They received the idea of establishing a classification system and a database in a very positive spirit (2), and have since then been very intensively involved in the further development. The system has also been discussed and further developed in co-operation with the British River Restoration Project group and Dr. Nigel Holmes from Alconbury Environmental Consultants.

Even though considerable efforts have been made to design the classification system as unambiguously as possible, it is inevitable that there will be some obscurities and overlapping. Nevertheless it is our hope that the proposed system will form the basis for databases on restoration projects being undertaken throughout Europe.

The various national databases should subsequently be compiled and updated under the auspices of the European Centre for River Restoration, and the informations should eventually be made accessible for interested parties on the Internet and GIS (Geographical Information System). This will give interested parties the possibility to study the database and retrieve specific information for their own use directly to their own computers.

The river restoration database

The database is founded on a classification system which differentiates between **'Types'** and **'Methods'**. Each restoration project are subdivided in one of three **types** according to the overall objectives of the project. This subdivision is based on the extent of rehabilitation within the watercourse system as shown schematically in Fig. 1.

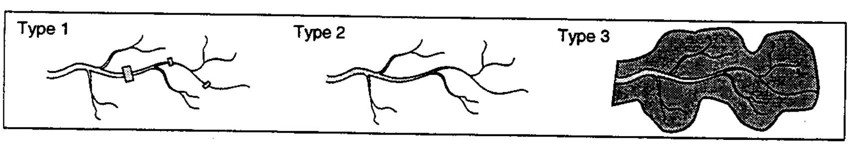

Figure 1. Schematic definition of the three types of rehabilitation project describing the primary objective of the restoration project.

- **Type 1: Rehabilitation of watercourse reaches**, encompasses projects whose objective is local improvement of shorter reaches. The methods used under type 1 will typically result in *better habitats* locally, both in the watercourse and in the 2 meter cultivation-free border zone.
- **Type 2: Restoration of continuity between watercourse reaches**, encompasses projects aimed at ensuring free passage along watercourse systems. The methods employed under type 2 are those that reconnect reaches and restore *free passage* and continuity between a watercourse's component reaches and between the watercourse and its immediate surroundings.

- **Type 3: Rehabilitation of river valleys**, encompasses projects affecting both the watercourse and its whole river valley. The methods employed under type 3 are those that ensure that the watercourse and river valley function as an *ecological and hydrological entity*. Their impact reaches across the watercourse and its surroundings.

Each type always has one **Primary Method** and might have a number of **Secondary methods** that have been used to achieve the objective of the restoration project (Table 1). The classification system and database is further described and explained in (3).

Table1. Watercourse rehabilitation - types and methods.

Type 1: Rehabilitation of watercourse reaches
51 Reach remeandered
52 Culverted reach opened to create better habitats
53 Two-step cross-sectional profile created
55 Lakes established/re-established in connection with the watercourse
56 Ochre sedimentation basin established in connection with the watercourse
57 Single measures (see below)
• Stones laid out
• Gravel laid out
• Artificial fish hiding places established
• Other solid objects laid out
• Current concentrators established
• Sand traps constructed
• Artificial bed and/or bank established (fascines, concrete, paving slabs, etc.)
• Artificial bed and/or bank removed (fascines, concrete, paving slabs, etc.)
Type 2: Restoration of continuity between watercourse reaches
26 Obstruction replaced by riffle
27 Obstruction replaced by meanders
28 Bypass riffle established at preserved obstruction
29 Riffle established at preserved obstruction
30 Culverted reach opened to create free passage
31 Culvert falls evened out (drop manhole removed, etc.)
32 Greater water depth and/or current breakers in underpass culverts
33 Falls evened out at culvert outlet/bridge
34 Fish ladder/fish sluice established
35 Fish ladder/fish sluice removed
36 Formerly periodically 'dried-up' stream reach completely/partly restored
38 Water pumped into watercourse to maintain flow in periodically 'dried-up' reach
39 Otter pass established
40 Free passage established for other vertebrates
42 Fish ladder/fish sluice improved
48 Obstruction removed
Type 3: Rehabilitation of river valleys
1-6 Water table and flooding frequency increased by:
1 - remeandering the watercourse
2 - raising the bed
3 - terminating drains in meadows
4 - establishing a dam
5 - meadow trickling
6 - narrowing the watercourse
• Lakes/ponds/wetlands etc. established/re-established in the river valley
• Vegetation management in the river valley

The Danish river restoration database

The classification system has been used in creating a database on Danish river restoration projects. Up to and including 1996 a total of 930 river restoration projects have been carried out in the Danish counties. Of those projects were 174 rehabilitation of watercourse reaches (type 1), 740 restored the continuity between watercourse reaches (type 2), and 16 included rehabilitation of the adjacent river valleys (type 3) (Table 2).

In addition to the 930 projects carried out by the counties comes a substantial number of restoration projects carried out by the Danish municipalities and private organisations.

Table 2. Number of projects carried out in the Danish counties up to and including 1996 split up in types and primary methods (see Table 1).

Total no. projects	930																					
Type no.	3			2														1				
No. projects in each type	16			740														174				
Primary method no.	1	2	4	26	27	28	29	30	31	32	33	34	36	38	39	42	48	51	52	53	56	57
No. projects in each primary method	7	7	2	348	4	84	36	25	6	5	57	104	5	2	12	14	38	18	5	3	34	114

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Reconstruction versus ecological maintenance - improving lowland rivers in Hamburg and Lower Saxony

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Abstract

The general improvement of water quality in North Germany's lowland brooks and rivers in the last decades is not generally reflected in a similar increase of species richness and/or biomass of sensitive species. Although there have been changes e.g. to a more natural fish species composition in the Elbe river after 1989 with the decline of toxic waste emissions other water courses esp. the smaller ones, do not show convincing biota in comparison to quality of the water body. Investigations revealed that in many cases poor structure of the bottom or overall morphology of a brook seems to be the "minimum factor" hindering characteristic evertebrates of flowing waters to flourish - with "Allerweltsarten" (ubiquists) colonizing the river bed. Maintenance of the running waters often is the most important cause for this.

To enhance structure diversity (e.g. depth and width variance) different measures have been undertaken, in urban brooks of Hamburg as well as in rural areas of Lower Saxony. The activities range from construction works of professionals, expensive measures financed partially by building owners enforced by nature conservation laws (compensation) over selective initiatives of laymen with collected field stones and gravel to simply reduction or even stop of maintenance work watching the watercourses develop by own forces. To all this examples are given with pros and cons including remarks to costs.

Characteristics

The investigated brooks are situated in the Federal States of Hamburg and Lower Saxony, Germany, respectively (Fig. 1). They flow through an area that has been shaped by the glacial ages, with moranes characterized by sand, gravel and pebbles up to erratic blocks. Besides these dunes and peat areas are often found. - The brooks are summer cold, the water flow ranges from less than 100 l s^{-1} up to several m^3 s^{-1}. Before joining the river Elbe they extend up to about 50 km in length. Their natural potential in the upper courses is shown by turbulent flow induced by high amounts of dead wood, a stable stony bottom washed free over long periods of time, shaded banks with alder dominated deciduous woods, salmonid fish (esp. brown and sea trout, grayling) and accompanying fauna and flora (1)(2).

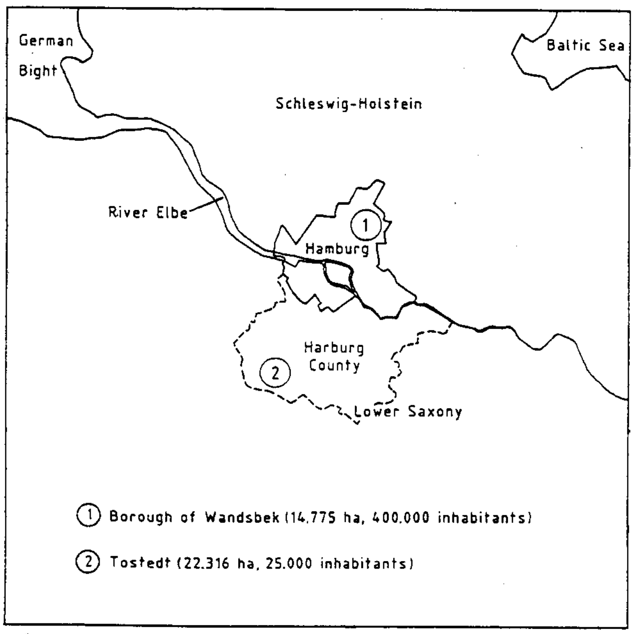

Figure 1. The brooks are situated in the REK area (Regionales Entwicklungskonzept für die Metropolregion Hamburg).

Problems

For centuries brooks and rivers have been straightened with intensifying this up to the sources in the last decades. Even during the time of water quality improvements in the seventies and eighties which resulted e.g. in better migrating and spawning results for sea trout in North Germany (3)(4) construction works, piping of small brooks in rural regions and consecutive destruction of these biota by maintenance works hindered the redevelopment of aquatic and amphibic habitats (5). The ongoing dredging practices, the removal of every piece of dead wood - no matter if done by machine or by hand - maintain poor physical dimensions. V-shaped, extremely deepened cross sections, overwide channels with resulting sand and mud deposits (Fig. 2) and minimized numbers of hiding places for big individuals up to now led to untypical, small species numbers and less than one tenth of potential production. - The observation of this nowadays situation misleads the public, but also limnologists and other scientists to talk about sand brooks although e.g. a look to drilling profiles from housing investigations clearly reveals the presence of coarse materials - not to talk about masses of visible stones on ploughed land like potato fields (soil degradation led to the word „the stones grow out of the earth").

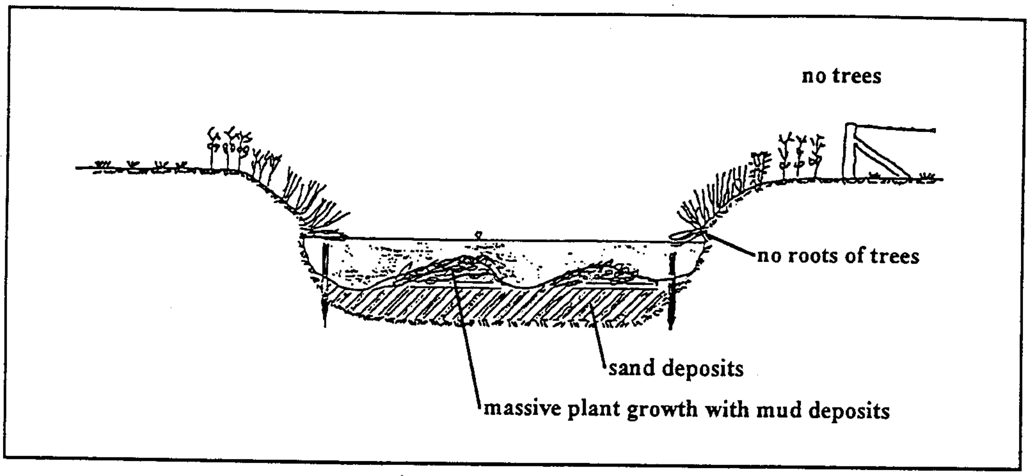

Figure 2. Nowadays main problem of lowland brooks: overwide channel with deposits which hinder running waters' organisms to thrive.

Measures for improvements

There has been a lot of attempts to improve the riverine habitats. The eighties saw many dredging activities to restore old meanders - so-called "renaturalisation". Most of these brooks, however, show no convincing return of rheophilic species because the works created the same situation as before: instead of short, straight channels elongated stretches with bends (Fig. 3) were the result. So again overwide cross sections lead to massive sedimentation, in most cases the current's forces do not suffice for the creation of sustainable salmonid habitats as structure inducing materials are not allowed to remain in the river bed. Especially the loss of stony particles over centuries can only be overcome by reintroduction.

The general objective to obtain the river continuum was not everywhere to be achieved, especially in urban areas where permanently flooded rainwater retention basins divide brooks into sections without chance for bypasses. An example is given in Fig. 4: to improve the general ecological situation the technical channel has been reconstructed to a delta entering the retention basin. The brook Seebek now is able to establish it's

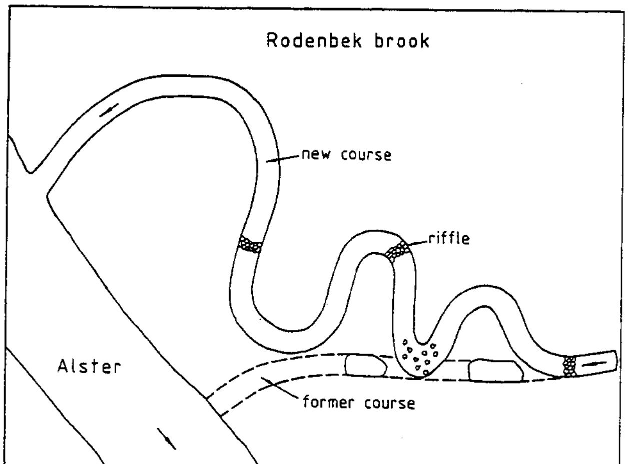

Figure 3. Remeandering of the first stage (the overwide channel is back again).

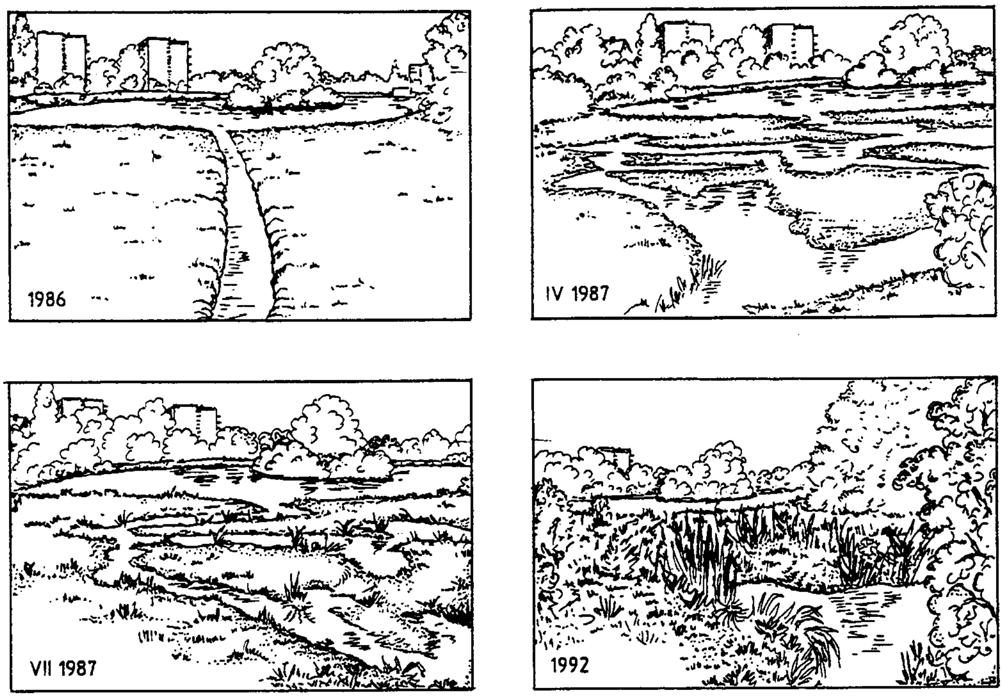

Figure 4. The Seebek experience - "The jungle enters the city".

own course depending on water flow situations. Mowing of grass has been minimized so not only the delta but also the surroundings give place for lots of wildlife reinvading the City of Hamburg. New experience with their park - like smells from oxbows in hot summer periods - had to be discussed with the public, but the aesthetical and ecological improvements are clearly to be seen for everybody. This is but one example for the trend being obvious from avifaunistic investigations: species numbers and individuals per urban area surmount rural numbers in the last decade.

Independent of success or failure of such remeandering the costs amount to 150-1000 DM m^{-1} watercourse. Table 1 gives a rough impression what this means for different locations in Germany looking for improvements all over the country (sums only for the small brooks and rivers as have been defined above). In times of decreasing budgets this method will not lead to an overall increased habitat quality in the short term.

Learning from these experiments the 'new' way of river restoration discussed in Germany lives from the waters' forces (6). The idea is to buy riparian land and to let the river create its own characteristic shape. The time span talked about is 100-150 years. Critics fear that masses of species will be lost by this attempt because 'nature's healing forces' could be much slower than destruction of short term events happening in the meantime.

Improvements to be watched by take advantage of nature observation and add action to the above mentioned concept. The cheapest measure to improve water courses is to reduce maintenance works. Trying to reflect on the necessity of different activities led to nearly the total stop of mowing the banks in the Borough of Wandsbek. By this 300 000 DM per year could be saved with about 30 000 to be spent for really necessary cleaning activities. The result of this is shown in Fig. 5. Depth and width variance is plainly

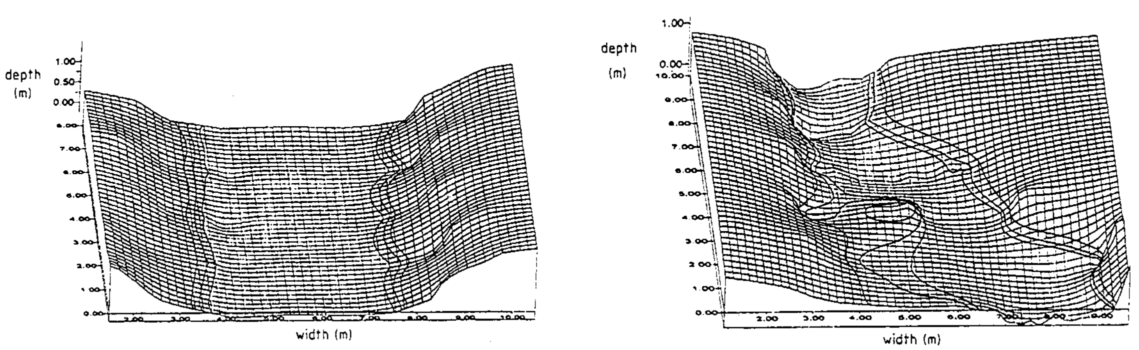

Figure 5. The Berner Au experience - ceased maintenance - restructured brook.

increased. The biological data have to be evaluated and to be published elsewhere but rough electrofishing revealed the improvements by elevated species numbers and an increase of age classes present in the now diversified stretch. Future maintenance work in this area will be restricted to punctual activities like mowing of a narrow meandering course and to the introduction of coarse material to enhance the improvement of biological structure.

Table 1. Rough impression on future costs, some questions and a personal opinion

Finance/Costs all calculated with 1,000 DM per m running water, 100 DM per m results 'only' in one tenth of the sums.

	area	costs
Borough of Wandsbek (400.000 inhabitants, compare to Tostedt: 23.000 inhabitants)		
300 km running waters	14,775 ha	300 million DM
Free and Hanseatic City of Hamburg	74,753 ha	1.5 billion DM
Lower Saxony	4.73 mio ha	96 billion DM
Germany	35.7 mio ha	720 billion DM

Questions
- Who shall pay for it?
- Who will pay for it?
- Where to start (downriver upstream? Spring regions first?)
- How many km to be restored/improved in a given time?
- What is the time table?

My personal opinions
- There is enough knowledge. Start in your own place. START.
- Don't wait for "global" programs.
- Don't hinder action in respect to awaited research.
- Nonsense has to be stopped: especially maintenance practices have to be altered dramatically or wherever possible maintenance has to be stopped.

In many cases the brooks show us what to do, published e.g. in (7). Fig. 6 gives such an example: From an in former times and in upstream reaches still 0.5 m wide brook this stretch by continuing dredging activities has been devastated up to a 2 m deep incised rectangular profile with a width of 2-3 m. Inside this cross section the brook meanders showing us its natural demands. - With the help of interested people, possibly collecting necessary money by themselves in-stream measures like narrowing the low water cross section to induce running waters' characteristics, planting alders and establishing gravel banks result in the typical pool-riffle structure of most running waters. Groups of citizens working for a better urban environment, so-called "Bachpatenschaften" (brook sponsorship schemes (8)), are able to conduct such works, including monitoring and removal of refuse, measuring biological and chemical situations, report bad and good situations including PR-activities in local newspapers etc. No matter of age or profession - every person is able to engage: The „Bachpatenschaften" at the moment are dominated by pupils' groups, NGO activists and neighbourhood alliances. These groups should be supported effectively to give the urban population an impression of the worth of nature in their neighbourhood and to encourage them for further activities.

Figure 6. Open your eyes - the brook shows us its needs.

Outlook

Reconstruction of brooks and rivers to a more natural shape and to diverse and productive biota will be restricted to but a few pilot stretches: the necessary capital stock will not be available for all water courses. Publications of good results will show the positive example but possibly obscure the view for the overall needs.

Maintenance as the threat and the chance for the waters will play the most important role in the next decades. For improvements ecological information (9) has to be integrated into the daily practice. With towns and villages as the responsibles for maintenance the brooks will benefit from the nowadays' lack of money. - Federal States like Lower Saxony with maintenance boards dominated by farmers and technical advisers (understanding themselves as drainage boards although water laws demand for ecological responsible action) at the moment try to elaborate „Gewässerentwicklungspläne“ (water development plans) in which among others shortcomings of the waters' physical state and measures for improvements are mentioned. As long as these necessary activities, however, are not financed by the boards' budgets although many of them result from former maintenance work but are assigned to the taxpayer's money there will be no sustainable success to come in the short term. - For sustainable improvements in all running waters legal action, the novellation of the water laws, is needed. Up to that date waters' biota will mainly depend on voluntary activities like described above.

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Fisheries enhancement of the Rye water, a lowland river in Ireland.

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Abstract

1. The Rye Water is the major salmon spawning tributary of the River Liffey. It is an example of a lowland river which lost much of its productivity as a salmonid river following an arterial drainage scheme which extended over two years (1955-1957). The scheme introduced a series of hydraulically uniform continuous glides of abnormal length and a reduction in the diversity of the natural riverine habitats.
2. To rectify this a fisheries enhancement programme was initiated in 1994 on a 2.4 km stretch of the river.
3. The aims of the programme were to optimize the capacity of the channel to function as a brown trout (*Salmo trutta* L.) fishery and to ensure that its role as a salmon (*Salmo salar* L.) spawning and nursery area would be enhanced.
4. The enhancement project was designed to narrow and deepen the channel, create meanders, pools, cover and to stabilize eroding stream banks. Habitat improvement structures included deflectors, riprap and boulder placements. Work was carried out by the Office of Public Works in conjunction with the Central Fisheries Board and the Zoology Department, University College Dublin, Ireland.
5. Detailed monitoring of physical characteristics is ongoing. Salmonid populations have been monitored by electrofishing pre- and post-enhancement at control (unaltered areas) and experimental sections. Initial results (i.e. one year post-works) indicate that salmon densities have significantly increased. Brown trout, on the other hand, were slower to recover.

Introduction

The quality and quantity of habitat available to wild salmonid stocks has diminished because of diverse and steadily increasing use of land-based resources such as, agricultural development, channelization, afforestation, and impoundment (1). Today, most rivers throughout the developed world are regulated, many are hydraulically optimal but ecologically poor (2). However, the use of habitat restoration/rehabilitation/enhancement schemes to mitigate the effects of this work is now worldwide (3).

Arterial drainage (channelization) programmes have been carried out in many of Ireland's riverine catchments over the last century (4). Channelization frequently involves straightening and shortening natural riverine contours, destruction of riffle-pool sequences and the removal of accumulated debris. Elimination of such habitat diversity typically results in reduced species diversity and population densities (5). Arterial drainage was carried out on the Rye Water and its tributary, the Lyreen, over a two year period from 1955 to 1957, to alleviate persistent flooding in Leixlip village. This work led to, hydraulically uniform, continuous, glides of abnormal length with little bankside and overhead cover, providing few resting areas for salmonids, shallow pools, extensive siltation and macrophyte growth, gravel compaction, bank erosion and a reduction in the diversity of the natural riverine habitats.

Since the 1980's fisheries enhancement/rehabilitation programmes have been undertaken in Ireland to improve fishery losses due to arterial drainage. The combined efforts of the Office of Public Works and the Central Fisheries Board were united to carry out enhancement/rehabilitation programmes in a number of important catchments in Ireland. Where possible pilot experimental/control zones have first been established in these catchments and monitored for two to three years post-works to assess the relative success of particular instream strategies, before embarking on major programmes over longer sections of channel (24). In Irish rivers the relative success or failure of such schemes have become evident, in most cases, within one year following completion of the physical works (4). Investigations into the success of these programmes are still ongoing in Ireland.

A fisheries enhancement programme was carried out on a 2.4km stretch of the lower reaches of the Rye Water during a six week period in July and August 1994. Work involved major physical alterations to river bed sections to optimize the salmonid carrying capacity and the placement of habitat improvement structures such as current deflectors, boulders and riprap. These devices recreate the natural riverine features, such as the pool-riffle pattern and channel meandering and can increase the overall level of habitat diversity (3). Initial results of the monitoring programme are outlined in this paper. The aims of the enhancement programme were to optimize the capacity of the channel to function as a brown trout fishery and improve the angling value of the river and to ensure that it's role as a salmon spawning and nursery area is enhanced. The objective of the study was to compile baseline data (physical and biological) and determine the limiting factors effecting the biological community, during the initial two years (pre-enhancement work) and use this to determine whether enhancement work had a significant effect on the biological community, particularly on the salmonid populations.

Description of study area

The Rye Water is a major spawning tributary of the river Liffey, in the east of Ireland. The catchment area is approximately 100 km^2. The geology of the catchment is Lower Carboniferous limestone.

The fish population is dominated by brown trout (*Salmo trutta*) and salmon (*Salmo salar*), but stoneloach (*Neomacheilus barbatulus*), eel (*Anguilla anguilla*), pike (*Esox lucius*), 3-spined stickleback (*Gasterosteus aculeatus*), minnow (*Phoxinus phoxinus*) and lamprey (*Lampetra fluviatilis*) are also present.

Materials and methods

The project was designed to narrow and deepen the channel, create meanders, pools and cover and stabilize eroding stream banks. Gravels were tossed throughout the stretch. A total of 840 tonnes of imported material was used in the stretch. Thirty two new pools were created, eight existing pools were enlarged and many pools were lined with riprap.

Three paired sites, control sites (S1C, S2C and S3C) where little or no enhancement work was carried out and experimental sites (S1E, S2E1, S2E2, S3E1, S3E2 and S3E3), which were treated in a predetermined manner, were chosen, to analyse the effects of changes in channel morphology and the effects of these on the fish populations (Fig. 1).

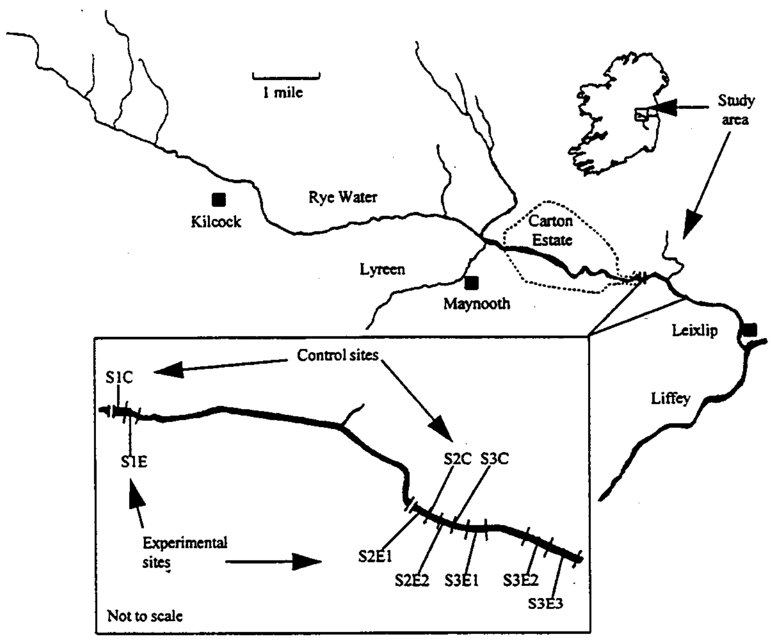

Figure 1. Location map of the Rye Water indicating sampling sites.

In each case every attempt was made to ensure that paired sites were as similar as possible in physical and ecological terms. No instream structures were placed in control sections, however instream macrophytes were removed from S1C (this site was treated as a typical channelized stretch). Deflectors of varying types were constructed in each experimental stretch. New pools were created, boulders were placed in the pools to provide additional resting areas. Riprap was used to protect the eroding edge of pools and meanders.

Each site was stop-netted, at either end, prior to the commencement of electrofishing. Pulsed D.C. (250V) electrofishing equipment was used. Typically two or three successive catches were employed for each stretch, depending on the success of previous catches (6). The removal method (7) was applied to the data. Captured fish were measured to the nearest mm (fork length) and weighed to the nearest gram (except 0+ fish). Scales for age determination were collected. All fish were held in a fyke net after processing until they had fully recovered. Particular care was taken to ensure that the fish were returned to the same sections of river. Population estimates for sections with three removals were calculated separately for 0+ fish and fish older than 0+ (8). In some circumstances only two catches were considered necessary and the two catch estimate (6) was employed. The biomass (standing crop) of each section electrofished was calculated by multiplying the mean weight of fish in each section with the population estimate obtained.

Permanent channel cross-sections were used to assess the effects on stream channel morphology and fish habitat suitability (9). Transects were spaced at ten metre intervals in the control and experimental stretches. The habitat variables, measured along each transect, included, mean wetted width, mean depth, maximum depth, mean velocity, discharge, wetted perimeter, cross-sectional area, surface area, substrate composition, gradient and percentage macrophyte cover.

Results

There was little change in the overall mean brown trout density (all ages excluding 0+) and standing crop in the enhancement section. There was a mean decrease in density of 18% in the control sections compared to a mean increase of 21% in the experimental sections and a mean increase in biomass of 11% in control sections and an increase of 23% in experimental sections. This mean increase in density and biomass in the enhancement sections was due to an increase in the number of 2+ and 3+ brown trout and a decrease in 1+ fish. An outline of the percentage change in brown trout density at individual sites is shown in Fig. 2.

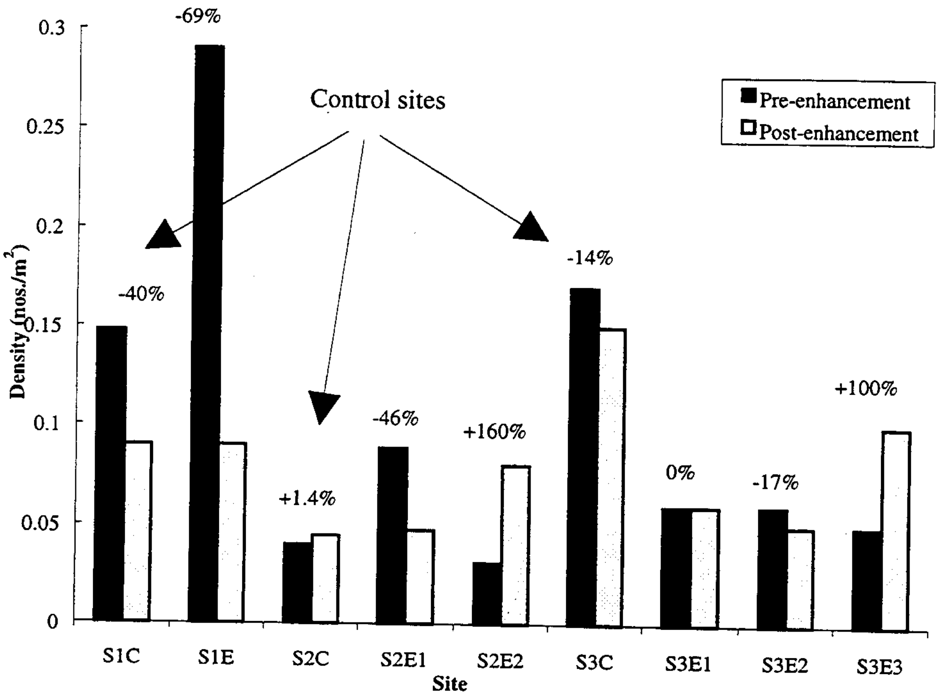

Figure 2. Density (nos./m²) of brown trout on the Rye Water (pre- and post-enhancement). Percentage change in density is included.

By comparison, the salmon populations changed dramatically. There was an overall mean increase of 152% in salmon density (p<0.5*, Mann-Whitney U-test) in the experimental sections compared to a mean increase of 36% in the control sections. Percentage increase in salmon density ranged from 25% at S1E to 300% at S3E3 (Fig. 3). Salmon biomass also increased significantly (P<0.1**, Mann-Whitney U-test). An overall mean increase of 219% in biomass in the experimental sections was recorded in comparison to an increase of 88% in the control sections. Increase in biomass in the experimental sites ranged from 75% to 390%.

Table 1 gives a summary of the mean physical variables at nine sections in the Rye Water pre- and post-enhancement. Mean physical data were compared using the non-parametric Mann-Whitney U-test. Many physical variables were lower post-works due to severe drought conditions which effected water levels in many rivers in Ireland between April and October 1995. Mean water depths were lower at seven sites post-works. However, results indicate that the channel became deeper at six of the nine sites post-works due to the increase in the number of pools. Velocity and discharge values were lower at all cross-sections. Maximum depth increased at all sites post-works. Pre-works highest velocity values were seen in open channel areas, i.e. those free of emergent macrophytes, zero values were frequently recorded in weeded areas. Removal of instream vegetation and creation of deflectors caused a redistribution of velocities. A

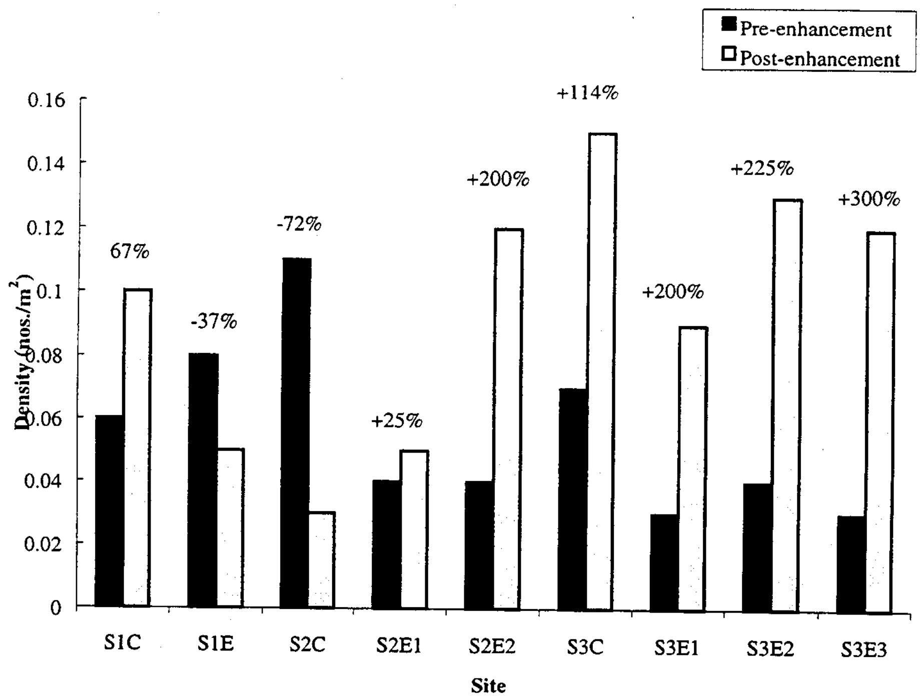

Figure 3. Density (nos./m^2) of salmon on the Rye Water (pre- and post-enhancement). Precentage change in density is included.

Table 1. Comparison of mean (and standard error) physical habitat variables (River width (RW); Wetted perimeter (WP); Depth; Velocity (V); Discharge (Q); Cross-sectional area (CSA)) in control and experimental section pre- and post-enhancement work (P<0.5, p<0.1**, Mann-Whitney U-test).*

Site	Date	RW (m)	WP (m)	Depth (cm)	Max Depth (cm)	Height (cm)	V (m/s)	CSA (m^2)	Q (m^3/s)
S1C	Pre	15.4 (0.92)	16.5 (0.97)	31.3 (2.99)	53	81.0 (4.4)	0.10 (0.02)	4.79 (0.59)	0.57 (0.12)
	Post	13.88 (0.68)	-	23.1 (2.80)	56	84.7 (2.53)	0.06 (0.01)	3.15 (0.32)*	0.17 (0.02)
S1E	Pre	11.4 (0.85)	13.2 (0.54)	32.6 (2.09)	62	77.5 (3.52)	0.17 (0.02)	3.77 (0.43)	0.63 (0.08)
	Post	9.97 (0.39)	12.7 (0.27)	19.7 (4.19)*	100	67.1(5.94)	0.12 (0.04)	4.3 (1.26)	0.16 (0.04)*
S2C	Pre	9.0 (0.16)	9.6 (0.25)	20.9 (2.79)	36	61.0 (3.86)	0.13 (0.02)	1.88 (0.26)	0.21 (0.02)
	Post	8.4 (0.33)	8.45 (0.34)**	18.1 (2.56)	40	64.6 (4.21)	0.09 (0.01)	1.56 (0.26)	0.14 (0.02)*
S2E1	Pre	9.2 (0.25)	10.5 (0.50)	31.3 (4.72)	64	96.4 (16.3)	0.10 (0.03)	2.89 (0.42)	0.41 (0.20)
	Post	8.1 (0.43)*	9.2 (0.41)	24.0 (3.74)	50	91.7 (12.1)	0.05 (0.02)	1.98 (0.35)	0.12 (0.02)
S2E2	Pre	7.7 (0.32)	8.2 (0.36)	23.7 (1.77)	34	63.8 (3.96)	0.17 (0.02)	1.83 (0.12)	0.34 (0.02)
	Post	8.4 (0.40)	10.2 (0.16)**	24.7 (4.60)	60	66.3 (4.91)	0.07 (0.02)	2.11 (0.45)	0.30 (0.01)*
S3C	Pre	9.6 (0.48)	11.15 (0.33)	33.2 (4.45)	60	72.25 (9.64)	0.28 (0.06)	3.16 (0.43)	0.79 (0.07)
	Post	8.7 (0.24)	7.53 (1.04)*	28.3 (8.76)	80	80.53 (6.98)	0.16 (0.09)	2.48 (0.78)	0.28 (0.08)*
S3E1	Pre	8.7 (0.82)	8.6 (0.96)	37.5 (1.91)	60	82.72 (2.87)	0.26 (0.03)	3.31 (0.35)	0.78 (0.18)
	Post	8.2 (0.73)	8.6 (0.85)	25.1 (4.85)	104	82.86 (5.66)	0.14 (0.05)*	2.20 (0.54)	0.18 (0.03)**
S3E2	Pre	6.5 (0.45)	7.7 (0.54)	25.1 (2.11)	43	87.4 (2.71)	0.28 (0.02)	1.62 (0.17)	0.34 (0.08)
	Post	7.5 (0.41)	9.3 (0.62)	29.0 (8.45)	61	106.3 (6.27)*	0.11 (0.06)*	3.15 (0.79)	0.43 (0.33)
S3E3	Pre	7.4 (0.24)	8.8 (0.29)	42.7 (1.65)	60	83.6 (3.43)	0.16 (0.02)	3.12 (0.26)	0.44 (0.02)
	Post	7.7 (0.16)	9.0 (0.22)	36.3 (9.95)	82	92.14 (8.25)	0.08 (0.04)	2.87 (0.83)	0.15 (0.01)*

number of negative velocity values were also recorded post-works, this was caused by the creation of eddy currents behind some of the deflectors.

The relationship between salmonid densities and standing crop and a range of habitat variables were investigated using correlation coefficients (Spearmans Correlation Coefficient in SPSS). All 1+ and older brown trout data were combined from all sections. Both density and biomass were significantly correlated with mean river width, cross-sectional area and maximum depth (r_s=0.59**, 0.51*, 0.66**, 0.61**;0.52*, 0.72*** respectively). The relationship between individual age groups (1+, 2+ and 3+) and habitat variables was also investigated. Biomass and density of 1+ brown trout were positively correlated with river width (r_s=0.67** and 0.62** respectively). Density and standing crop of 2+ brown trout were positively correlated with river width, cross-sectional area, depth, maximum depth and gradient. 3+ brown trout were positively correlated with cover and surface area. Density of 1+ salmon were negatively correlated with cover, velocity and discharge (r_s=-0.66**, -0.5* and -0.5*).

Discussion

Since the 1930's numerous studies have shown that stream improvement will result in increases in both numbers and biomass of trout (10)(11)(12)(13)(14)(15).These studies have shown that the quality of habitat is an important determinant of salmonid biomass and production (16). Changes in trout carrying capacity, in many studies are primarily attributed to increased pool area, increased depth and the provision of more resting areas and cover (11)(12)(17)(18). Post-enhancement there was an increase in abundance of 3-year old brown trout (from 1.4 to 16%). Kennedy and Strange (19) found that older fish, i.e. two and three year olds were restricted to deep areas (>30cm). One aim of the enhancement work was to deepen and narrow the channel to provide more resting areas for brown trout and therefore to increase the carrying capacity of the channel for brown trout. According to Hunt (20) these changes primarily benefit older trout a fact borne out and confirmed by the present results. Pools are the more favoured habitat of salmonids, either for the shelter they provide, or because of low flows permitting a lower expenditure of energy (21). Evidence of the importance of habitat quality to salmonid abundance has come from correlation analyses of trout abundance in relation to specific habitat characteristics (16). Wesche (22) showed that cover, in some form, was the habitat characteristic most closely associated with abundance of brook trout and brown trout. Eklöv (23) found that river width was an important physical variable in determining salmonid distribution in a stream. According to (24) the major factors regulating density are gradient, mean summer discharge value and substrate type. Results from the Rye Water agree with these comments. It was found that maximum depth, cross-sectional area, river width, gradient, percentage macrophyte cover and overhead cover were the major factors regulating the density and standing crop of the brown trout population.

It is clear from the results that the enhancement programme initiated in the Rye water has been successful in increasing the salmon population in the river and increasing the brown trout carrying capacity one year post-works. However, the results do not allow for a prediction of long-term effects on trout and salmon population dynamics and productivity. According to Cowx (25) there is a paucity of follow-up information on the success or failure of fishery enhancement projects. Hunt (11) examined the effectiveness of a brook trout (*Salvelinus fontinalis*) habitat development work over a six year period and found that the optimum carrying capacity was not reached until the fifth and sixth years post-development. Therefore, it is recommended that the salmonid population be monitored on a continuing basis over the coming years.

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Rehabilitation of a lowland stream in the Alpine region of Trento, Italy

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Abstract

The main aim of this study is to rehabilitate the lowland streams in Valsuguna (an alpine valley) situated north east of Trento. The Brenta brook selected for the project originates in valley springs and runs for about 3.5 kms through corn and strawberry fields before joining the main Brenta river. Blocking and flooding every year due to a badly constructed discharge pipeline was the rootcause of disrupting the hydrological safety of the area. A four phase restoration programme was chalked out and water quality and retention was measured using the EBI method. Aesthetic and landscape management was immediately improved and restoration also led to an increased number of the Benthos taxa.

Introduction

In the past few years a new approach to water course management has emerged that aims to maintain ecological functionality of riverine ecosystems. This approach is in contrast to the traditional engineering where water courses usually 'subjugate' human requirements. As a matter of fact, quite often water management projects resulted in provoking destruction of aquatic environments and reduction of biological quality and animal populations such as insects, molluscs, fish, etc. thus favouring proliferation of bacterial populations and other ubiquitous species.

Following the floods of October 1992 in the province of Trento a special research programme was introduced to look into hydrological safety. The first of this ambitious project began in 1995 on the Romito Brook or locally known as 'Brenta Vecchio'. This paper reports the preliminary results observed in Brenta vecchio. The main objective of this research is to improve ecological quality of the aquatic environments. The Brenta Vecchio is a small brook originating from valley springs. It is a meandering channel which flows through cultivated lands and is separated by patches of riparian vegetation along its banks. The mean gradient of the brook falls between 1% and 4%. The velocity of the current varies according to the slope of the riverbed and as a result the sediments change from gravel to mud. The catchment area is uniformly covered by forests with a surface of ca. 2.8 km^2. The brook is approximately 2 km long and is elongated rectangular in shape. The present course is more steeper than the previous course. The former old inflow into the Brenta River was a partially obstructed pipe buried under the embankment crossing the riverside works. This old discharge tube gets blocked frequently thus flooding the neighbouring area and eventually depositing the material carried by the water system.

Restoration and site descriptions

The restoration of the above mentioned discharge of the Romito brook was performed with an excavator. The excavated material was deposited on the banks where it was uniformly distributed and subsequently milled to obtain good topsoil for the growth of vegetation. Crops indeed soon developed after its application. Excavation was carried out to obtain maximum morphological and biological diversity of the watercourses. This was obtained by creating a sinusoid route.

In some sections where this method could not be applied, some artificial diverted-shelters for fish were introduced. Made of water resistance chestnut wood they provide shelter sites for fish in open and non-shaded areas, and divert water flow direction to change current velocity. The depth and the width of the bed were modified to influence the discharge conditions. Thomas & Walker (1) and Rutherfurd (2) demonstrated that flow regulation can cause channel changes. Enlargements where the flow was very slow were alternated with narrower segments. Great care was devoted to the management of riparian vegetation as this is fundamental for the ecological equilibrium of the water course. Vegetation provides energy to all forms of aquatic life and influences the physical and chemical conditions of the water. However, its excessive proliferation can have undesirable hydraulic consequences. The other way round can also be true. The decline of the riparian vegetation of the river Murray in Australia was accelerated by river regulation and was largely dependent on flooding (3).

Thinning of tree vegetation was aimed at (4) releasing the section of water flow which was obstructed by (parts of) plants leaning into the brook; (5) protecting banks by disentangling the plants which had the best location for that purpose; and (6) to maintain, as far as possible, shading on lentic water subjects to warming effect. Also, a complete colonisation of the channel by Phragmites was avoided by maintaining a certain level of vegetation cover. In general, the highest variability of light intensity was sought to enhance the ecological potentials of the watercourse. In autumn the Phragmites grove located along the whole course of the brook was completely cut down and burnt to eliminate excess organic matter which, if left in the water would decompose and foster eutrophication.

Two small ponds were created over an area of approximately 500 m^2 in two nearby untilled areas next to the brook. The ponds are fed by some springs where excavation work was carried out. The excavated material was heaped on the banks and the water was channelled into the main course through a canal reinforced by sills made of small boulders. Downstream a flooded area was formed to favour an efficient spiralling of organic matter and was fenced for safety reasons. These two interventions (ponds and the flooded area) were aimed at providing the greatest bio-ecological and morphological variability, consistent with the space available.

To ensure a hydraulically safe discharge of the brook into the Brenta River and to eliminate obstacles to the biological continuity of the water course (in particular to allow fish migration) a small bridge was built.

The bridge replaces the old pipe area which has been removed and where the discharge water runs into the river directly. As a result the once straight tube has become inclined around 8%. This steep gradient has been reduced by creating step-pool channels of 15 cm. A morphological diversity was created by alternating runs to riffle and pools. All interventions were carried out to favour the upstream migration of fish to suitable sites for spawning.

Biological monitoring

The water course presents three different types of substantially homogeneous sections:

- the first section is a lentic headwater with a soft bed mainly of mud with high discharge and 200 m long;
- the second section of 1600 m has a slight incline and low speed; the substrate is mainly composed of pebbles, gravel and sand;
- the third section is approximately 200 m long, located before the mouth of the discharge tube, characterised with a steep gradient (8%), coarse bed sediment prevalently with pebbles and gravel, and fast current.

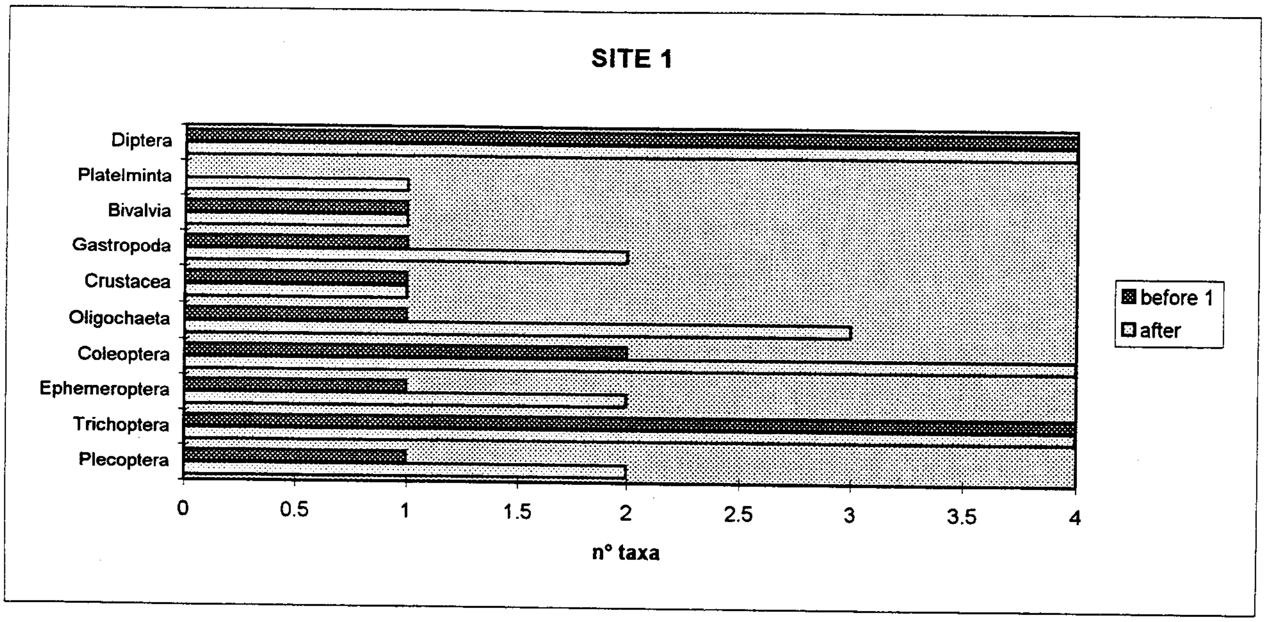
To survey the biological features of the brook, three sites were selected in each of the three sections.

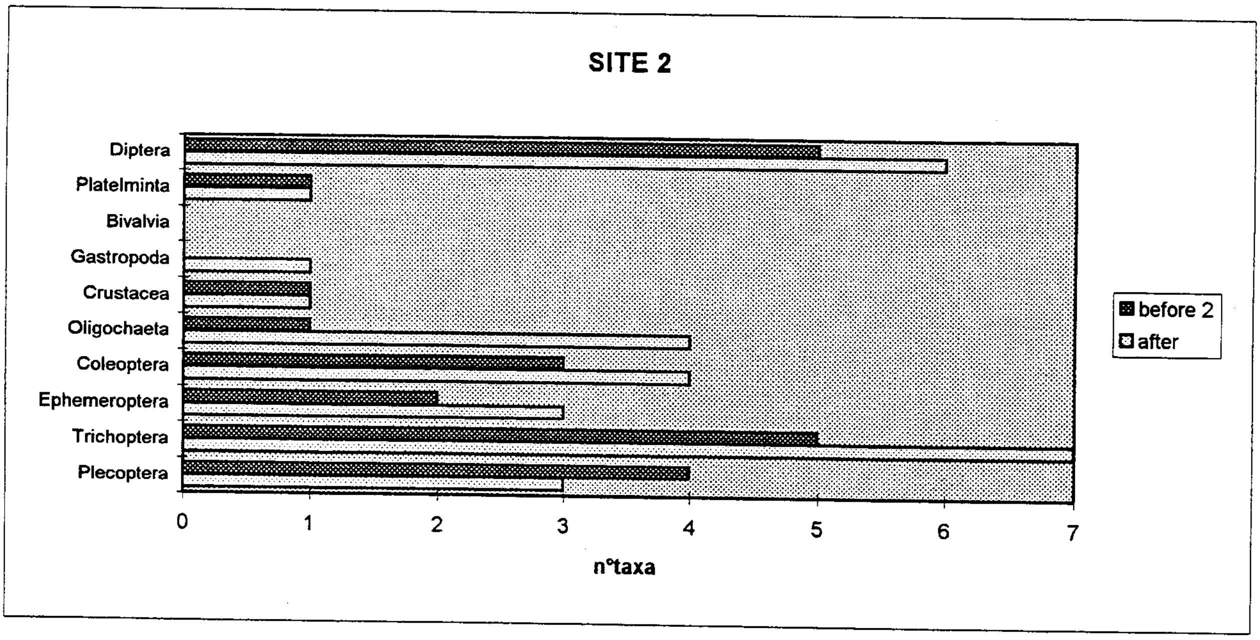
The quality of benthic community was evaluated according to the EBI method (Extended Biotic Index) modified by Ghetti before and after various interventions. Results are reported below and describe the three sites and indicate the presence of macrobenthos.

Site 1, a lentic environment, registered a high number of gastropods and bivalves. Sites 2 and 3 were dominated by individuals that are typical in a lotic environment (i.e. *Plecoptera*). It is observed that restoration caused a remarkable increase in the number of taxa. Benthos were classified according to their feeding habits and it is worth noting that in 1996, after the intervention, the number of systematic units (taxa) were remarkably higher than in the previous sampling periods (Graph 1). However, a survey was conducted on the algae present on the periphyton in the slow flowing-stagnant areas (Table 1). The population diversity resulted high and diatoms were prevalent.

Vegetation of Brenta Vecchio

The riparian vegetation belt is not very wide as the whole area bordering the water course is agricultural land with some areas almost reaching the edge of the riverbank. Near the untilled land, rich spots of vegetation can be found that consist of poplars and black alders, purple willows and osiers, willows, blackberry elders, cornel trees, alder buckthorns and blackthorns. Furthermore, there are some rows of high trees of the above mentioned species located in patches along the riverside.


SITE 1
Diptera
Platelminta
Bivalvia
Gastropoda
Crustacea
Oligochaeta
Coleoptera
Ephemeroptera
Trichoptera
Plecoptera
0
0.5
1
1.5
2
2.5
3
3.5
4
n° taxa
before 1
after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Gastropoda
Crustacea
Oligochaeta
Coleoptera
Ephemeroptera
Trichoptera
Plecoptera
0
1
2
3
4
5
6
7
n°taxa
before 2
after

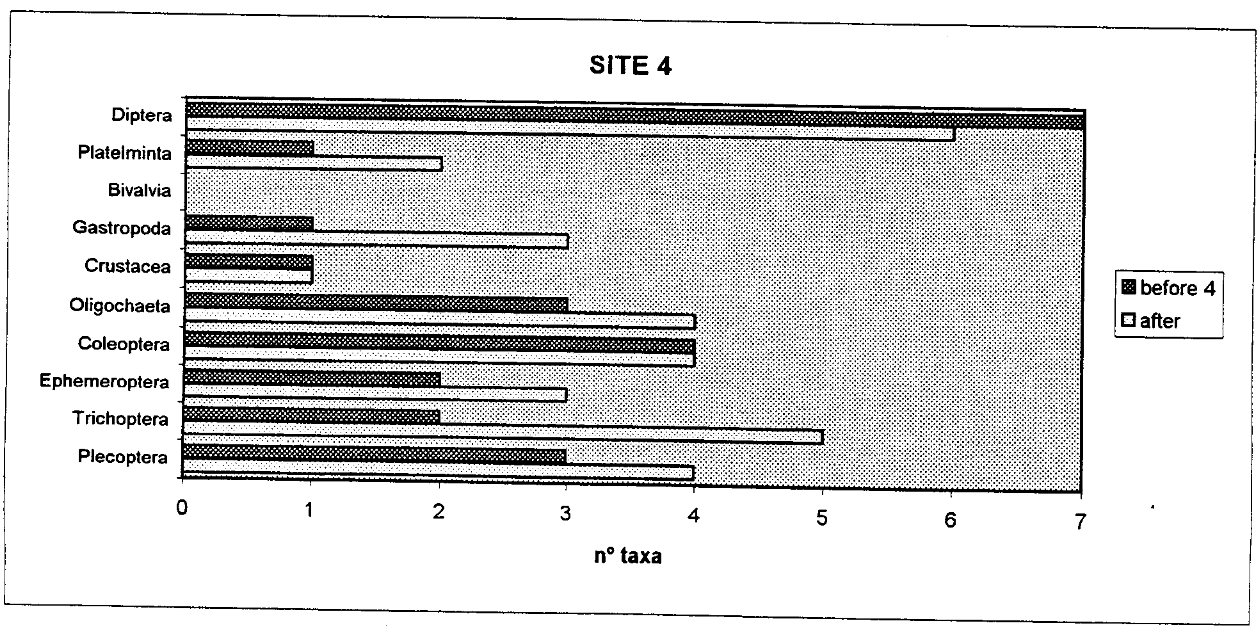
SITE 4
Diptera
Platelminta
Bivalvia
Gastropoda
Crustacea
Oligochaeta
Coleoptera
Ephemeroptera
Trichoptera
Plecoptera
0
1
2
3
4
5
6
7
n° taxa
before 4
after

Table 1: Periphyton in the slow flowing - stagnant areas.

CYANOPHYTA
Oscillatoria sp.
Anabaena sp.
CHRYSOPHYTA
Bacillariophyceae
Melosira sp.
Diatoma sp.
Diatoma hiemale (Lyngbye) Heiberg
Diatoma elongatum C.A.Agardh
Fragilaria crotonensis Kitton
Fragilaria capucina Desmazieres
*Synedra ulna (*Nitzsch) Ehrenberg
Achnantes sp.
Cocconeis placentula Ehrenberg
Cocconeis pediculus Ehrenberg
Navicula spp.
Pinnularia sp.
Gyrosygma sp.
Amphora ovalis Kuetzing
Cymbella ventricosa Kuetzing
Cymbella sp.
Gomphonema constrictum Ehrenberger
Gomphonema sp.
Nitzchia acicularis (Kuetzing) Wm. Smith
Nitzchia linearis (Agardh) Wm.Smith
CHLOROPHYTA
Bryopsidophyceae
Cladophora glomerata (Limnaeus) Kuetzing
Cladophora sp.
Conjugatophyceae
Closterium sp.
Closterium ehrenbergii Meneghini
Spirogyra spp.
Mougeotia sp.

Near the ponds there is a coppice hazel nut grove which has been partially thinned following excavation work to provide easier access to the area.

The aquatic vegetation of the Brenta Vecchio is characterised with narrow watercourses located near the base of mountain slopes fed by springs and karst springs. They are generally of limited flow and have small beds. Water is clean and clear with almost no suspended or solute materials.

Water flow is relatively constant so there is no substantial lowering of the water level and no erosion of the bed. The banks are gentle and the current speed is not uniform thus favouring the rooting of macrophytes. Running water species and border species alternate forming a basic linkage between the two types of vegetation. Typical species of stagnant waters were also found such as duckweed, indicating that the environment is rich in nutrients and is eutrophic as well.

Another factor that influenced the growth of macrophytes is the presence of a dense tree cover, implying a good degree of shading with a consequent decrease in the presence of aquatic vegetation. A systematic sampling of the aquatic vegetation in the Brenta Vecchio along the entire watercourse was not conducted, as only the most characteristic sections of the bed were sampled. The aquatic vegetation can be divided in two main groups of species depending on the dominant location. The first being mainly located in the bed and the second along the banks of the watercourse (Table 2). *Phragmites* had practically colonized the whole section of the bed where the current was slow and without trees exposed to sun-light. During the operation of enlarging the banks care was taken to work alternatively on the two banks of the brook to preserve spots of riverside vegetation which was essential for a fast recolonisation of the sections affected during the operation.

Due to increased heterogeneity found on the bed, the banks and the creation of new micro-environments, such as the small pools and new bends, an increase in aquatic vegetation diversity is expected with the arrival of new plant species typical of lake areas such as waterlilies, water-milfoils, and species of running waters such as buttercups.

Table 2. List of species found on the bed and along the banks of Brenta Vecchio.

Species found on the bed	Species found along the banks
Mentha aquatica	*Mentha longifolia*
Cardamine amara	*Phalaris arundinacea*
Phragmites australis	*Solidago canadiensis*
Berula erecta	*Lisymachia vulgaris*
Carex rostrata	*Eracleumm sfondilium*
Carex acutiformis	*Lithrum salicaria*
Lemna minor	
Nasturtium officinale	
Sparganum erectum	
Veronica anagallis aquatica	

Conclusions

The restoration project of the Brenta Vecchio Brook is intended as an example of water course management where hydraulic and environmental needs are equally considered guaranteeing good management and enhancing ecological features of the lowland aquatic environment.

Besides the first and immediate aesthetic and landscape improvements which were readily obtained and easily appreciated, the full impact of the improved environmental quality achieved during this study will become evident in the years to come by monitoring the evolution of environmental factors.

This project is a part of a management plan to restore the Valsugana Valley, which is being administered and organised by the Department of Civil and Environmental Engineering of the University of Trento and the Autonomous Province of Trento. This accompanies proposals to enhance the enjoyable natural environment in the framework of a teaching project related to the cycle-track along the lowlands.

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Initial geomorphological adjustments to river restoration in a lowland river

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Introduction

In a recent report to the Environment Agency of England & Wales, it was shown that out of 1500 river reaches randomly sampled on a 10km grid, only 23% could in any way classed as semi-natural on the basis of their geomorphology (1). In a European context, the recent Dobris Assessment of the European Environment specifically draws attention to the extent of channelization in (particular) western European lowland countries; although within this distribution some regions have higher proportions of natural and semi-natural channels. Some 96% of lowland river channels in southeast England have been modified and in Denmark the value is nearer to 98% (2). As the scale of restoration schemes increases from the isolated, opportunistic habitat enhancement to the multi-kilometre restoration of channel morphology there is a growing need for information on river dynamics and the impacts of such modifications on rates of channel adjustment (3). In an increasingly integrated management arena, conflicting needs of river users necessitates clearer guidance on the impacts of restoration; in particular the production, transmission and storage of sediments.

River restoration: Geomorphological models of channel adjustment

The prediction of river channel adjustment is rendered difficult by the level of indeterminacy in the solution of the theoretical equations governing causal links between external (independent) factors such as discharge regime (Q), sediment load (Qs) and internal controls such as boundary materials (Dx), flow velocity (U), frictional resistance (f), and the dependant variables governing river morphology for example Slope (S), depth (d), width (w), bedform (z) and planform geometry (P). Assumptions may be made about the relative rates of adjustment of the independent variables, but in practice one cannot sensibly predict the location, rates and style of adjustment in alluvial rivers with any degree of certainty. Geomorphological guidance though in some cases qualitative, is increasingly able to make predictions about some of these causal links, based on field and laboratory measurements of channel morphology and adjustments to environmental change over sensible timescales (4)(5). A conceptual model of lowland river response to restoration is presented in Fig. 1. This model hypothesises that the main sediment system impacts of restoration come about during construction, when the newly created river becomes a net exporter of sediments. This results from the exposure of bare surfaces to fluvial and sub-aerial erosion, the severity of which will be dependant on bed and bank materials and the geotechnical stability of the river banks. Although the output may attain equilibrium, the processes of sediment generation may be altered thus giving the river channel a different sensitivity to changes in water and sediment discharge.

Using the general model shown in Fig. 1 together with the qualitative predictors in Table 1, it is possible to suggest the likely channel response to restoration and the impact on downstream reaches. During the construction phase, channel morphology is created and the subsequent release of sediments modifies the form, largely through increases in width, reductions in depth through aggradation, and a decrease in particle size. It should be noted that in the restored reach, sediment load will increase downstream through the reach as the area of disturbed channel increases, so adjustments will be at a maximum in the downstream reaches. As the bare surfaces stabilise, gravel areas of the river bed and notably emerging (or created) riffles begin to armour whilst construction related deposits incise to produce a narrower, sinuous channel, bounded by berms or point bars depending to some extent on the channel planform. Slope is predicted to locally increase, although the aggradation in the downstream river, may control this process. Once the channel has filled the available storage sediments loads will stabilise. possibly at rates lower than the previous channel, due to greater residence times in complex storage units (point-bars, deadwaters etc.). Morphological changes will then reflect in-coming sediment loads. The downstream channel responds in a similar manner, aggrading and widening to pass construction sediments accompanied by a fining of the bed material. Subsequent reductions in sediment load trigger incision of these sediments accompanied by a narrowing, deepening and increased sinuosity of the channel before attaining a dynamic equilibrium form. A test of this model is presented below using evidence from the River Restoration Project site at Coleshill.

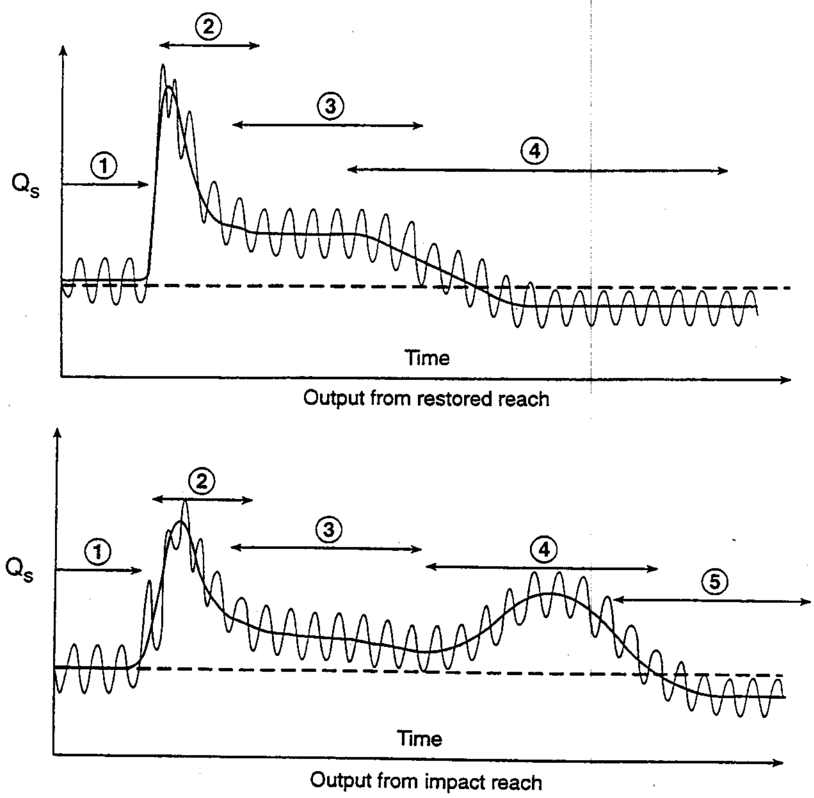

Figure 1. Model of sediment yields resulting from river restoration. 1: Pre-restoration - Dynamic equilibrium/aggradation; 2: Construction and aftermath - Erosion; 3: Colonisation and adjustment - Stabilization; 4: Overbank conveyance - Floodplain accretion.

Table 1. Qualitative predictions of geomorphological response to river restoration).

Phase	Relative system response	Restoration reach morphological scenarios	Impact reach morphological scenarios
Phase 2 - Construction	Qs^{++}, $Q^{-/=}$	W^{+}, D^{-}, S^{+}, d_{50}^{-}, P^{-},	W^{+}, D^{-}, S^{+}, d_{50}^{-}, P^{-},
Phase 3 - Colonisation	Qs^{-}, $Q^{=}$	W^{-}, $D^{+/-}$, S^{*}, d_{50}^{+}, P^{+}	W^{-}, $D^{+/-}$, S^{*}, d_{50}^{+}, P^{+}
Phase 4 - Storage/Incision	Qs^{-}, $Q^{=}$	W^{-}, D^{+}, S^{-}, d_{50}^{+}, p^{+}	W^{-}, D^{+}, S^{-}, d_{50}+, P^{+}
Phase 5 - Storage Filling	$Qs^{=}$,$Q^{=}$	$W^{=}$, $D^{=}$, $S^{=}$, $d_{50}^{=}$, $P^{=}$	$W^{=}$, $D^{=}$, $S^{=}$, $d_{50}^{=}$, $P^{=}$

Field site and methodology

The River Cole restoration is part of the RRP LIFE Project. The River is typical of many lowland clay-vale streams in southern and eastern England having a sinuous planform and relatively low width:depth ratio (Fig 2). Further details are to be found in (6). Restoration increased channel sinuosity, with the creation of 21 new bends in two reaches. Discharge in the upstream section is currently split between the original channel, feeding a mill, and the new restored river. In addition, the upstream restored channel is designed to spill more frequently into the adjacent floodplain with the aim of restoring floodplain connectivity for water and sediment storage. Stream power (Ω), in the upstream reach is consequently reduced whilst values are essentially maintained in the downstream reach Table 2. The values of stream power fall below the threshold value of $35Wm^{-2}$ identified as separating channels with erosional or depositional adjustment tendencies suggesting that the newly created channel will recover largely through aggradation.

During the restoration period, water levels and suspended solids were monitored at the sites located in Fig. 2 using continuously logged pressure transducers, and automatic pump samplers. Samples were retained and filtered using standard procedures to determine concentrations. Morphological mapping was conducted using standard procedures developed for the Environment Agency (7) and termed 'fluvial auditing'. The aim of this process is to account for the sources and storage's of sediments in a river reach with particular reference to channel morphology. Although not mentioned in this paper, detailed cross section surveys were made to provide scaling of those features recorded by fluvial auditing as well as information on the rates of channel adjustment.

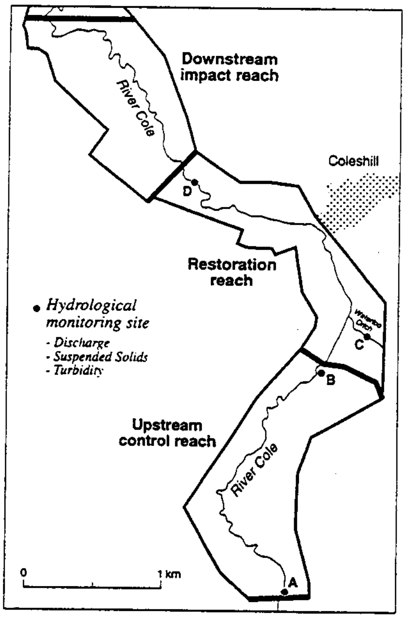

Figure 2. River Cole restoration site and sampling stations.

Table 2 Hydrogeomorphological characteristics of the river Cole restoration project

Reach	Q_{bf} (m^3)	S	W_{bf} (m)	D_{bf} (m)	Ω (Wm^{-2})	P
U/s Pre-Restoration	15.0-22.0	0.00069	13.6	2.0	7.5 - 10.9	1.05
U/s Post-Restoration	1.5-4.0	0.00071	3.5	1.5	3.5 - 7.9	1.27
D/s Pre Restoration	23.0-34.0	0.00052	15.5	3.0	7.6 - 11.2	1.06
D/s Post Restoration	12.0	0.00110	11.0	2.0	11.6	1.41
D/s Impact Reach	23.0-34.0	0.00055	15.5	3.2	7.9 - 11.8	1.61

Figures derived from land surveys and hydraulic model (6).

Results

Fig. 3a documents the mean daily discharge and suspended solids loads over the period immediately prior to construction, during the construction phase, and over the first period of adjustment until April 1996 for a site located 650 m downstream of the lower restored section. During construction, small events were experienced, but none of significant magnitude to account for the concentrations of sediment recorded at this station. Indeed during this period, sediment inputs to the reach from upstream were an order of magnitude lower (Fig 3b).

A flood of design bankfull flow (11 m^3) occurred soon after completion of the project on 20th December 1995, which was associated with sediment concentrations of 246 mg l^{-1} and 346 mg l^{-1} at the input and output stations. Exhaustion of fine sediments occurs at both sites during this event, and although subsequent high flows in early January produce peaks, it is notable that floods of upto 6.2 m^3 produce little suspended sediment response at the output station. This latter point suggests that the main storm and subsequent smaller events, cleaned out most of the construction sediments from the restoration reach.

A sediment budget for the reach was constructed using mean daily flow and sediment records and extrapolating these over the period of record shown for Fig. 3 using duration curve methods. The absolute values obtained are tentative, and thus proportional values are given for comparison (Table 3).

The sediment budget for suspended sediments (typically less than 250 microns) clearly shows the net export of material from the restored reach resulting from construction and exposure of bare soil surfaces. The budget also reveals the effects of flow ponding from the mill weir in the reach immediately upstream of the restoration site which is a focus for sediment storage.

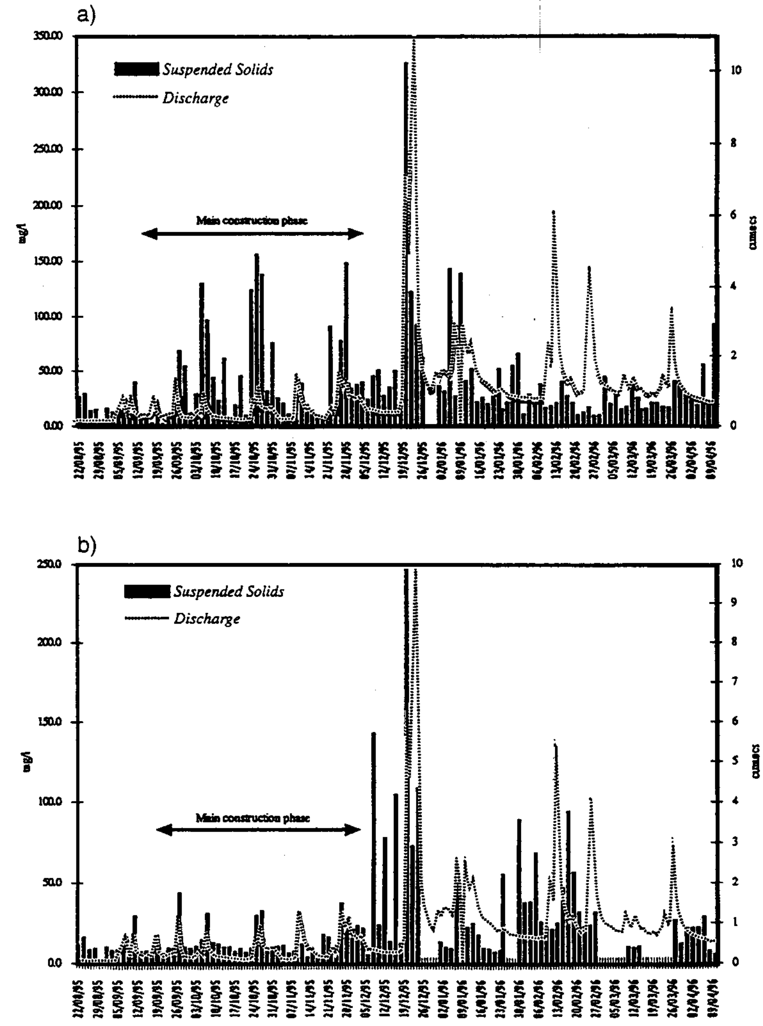

Figure 3. Suspended solids loads and discharge in the a: downstream output reach showing effects of construction; and b: upstream input reach.

Table 3 Tentative suspended sediment budget for the river Cole during and immediately after construction.

Reach	**Load (Tonnes) 21/8/95 - 27/3/96**	**Proportion of input %**
Upstream input A	606	100
Upstream input B	289	48
Waterloo Ditch C	239	39
Output D	802	133 (152)

Figure in brackets refers to proportion of site B+C (total input to restored reach)

The geomorphological changes associated with the export of sediments from the restoration reach, and in particular during the flood of December 20th 1995, are recorded in Table 4, based on the fluvial auditing procedure. Fluvial scour of meander bends has been particularly effective in the downstream section, where sands and gravels are exposed in the banks, outcropping on the channel floor for 150m upstream of the impact reach. Analysis of the bank features revealed that much of the undercutting resulted from the composite nature of the bank material. Gravel lenses in the underlying clay were picked out by fluvial scour, resulting in crescentic slumps in the bank line, sometimes on the inner bank of the meander. Local erosion attained 1.2 m of bank retreat, during the December 20th flood.

The balance of erosional and depositional features illustrates how the channel has eroded, and accumulated sediments simultaneously in the restored channel. In the downstream reach of restored channel, morphological diversity has increased by sediment accumulation, creating new point bars and riffles. Currently, this downstream reach is characterised by a slug of sediment that extends 200m+ beyond the limit of restoration. This slug of construction sediments exhibits downstream fining, which influences the

Channel rehabilitation in incised streams: a review of the Demonstration Erosion Control Project

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Abstract

1. Channel incision, particularly serious in watersheds with no bed controls, separates a stream from its floodplain, destroys arable land, and degrades environmental resources.
2. A demonstration project dealing with channel erosion was begun in 1984 in the loess hill lands of northwestern Mississippi, USA. The project objective centered on developing stabilization/rehabilitation technology in 15 watersheds (1 to 1,590 km^2) characterized by erosion and sedimentation associated with channel incision.
3. Stream channels were typically straight due to past) channelization, enlarged by erosion, and had little woody debris, pool habitat, or stable substrate. Suspended sediment yields averaged about 1000 t km^2 yr^{-2}.
4. Structural measures were selected on the basis of specific site needs within the scope of total watershed planning and were designed on the basis ofgeotechnical and hydraulic parameters. Common measures included field-scale grade control pipes, stream grade controls, bank protection, and floodwater-retarding reservoirs. Channel clean out and levees were less common.
5. Aquatic habitat studies at >100 sites showed that major needs included greater water depth and improved habitat stability. Based on water depth and increases in number of species andbiomass, grade control structure energy-dissipation pools, stone spur dikes, and V-shaped weirs improved in-stream habitat. Field-scale grade controls and sediment retention ponds created wetland and open water habitats for all classes of vertebrates. Success of woody vegetation plantings (primarily native willow) varied with site.

Introduction

Stream restoration is particularly challenging in incised streams. Initial incision from several possible causes, including lowering of downstream flood stages and channelization, separates a stream from its floodplain and is often followed by rapid channel enlargement. Channel cross-sections increased by as much as 1000% during this erosional phase (1). Because of watershed and channel processes,instream suspended sediments and bedload materials are, by volume, the largest pollutants in theU.S. (2). Additionally, common stream restoration techniques may not work in incised streams because of increased shear stress at high flows. Accelerated soil and channel erosion have presented problems in northwestern Mississippi since European settlement (beginning ca. 1835) and have resulted in deforestation, land cultivation and greatly accelerated valley sedimentation (3). The landscape in this region is particularlyerodible because topsoil is a fine loess underlain by sand and clay; furthermore, streams have no permanent bed controls. As a result of clearing the land for agriculture, soil rapidly eroded from hilltops andsideslopes and filled valleys with over a meter of new sediment. Stream channelization to "improve" drainage exacerbated stream instability. As a result of the landscape scale erosion, theU.S. Congress declared the region a national disaster and passed the Flood Control Act of 1954 which established a massive flood prevention program. This program stabilized much of the local landscape with tree planting and reservoirs but did little to reverse channel erosion processes. Knickpoint migration is the most common method ofdowncutting in these unstable streams (3)(4). Knickpoint movement in Johnson Creek averaged 160 m yr^{-1} from 1940 through 1975 (4). Channel incision was followed in many streams by explosive channel widening. A reconnaissance study showed that 25,000 km of 142,000 km of bank in the immediate drainage of the lower Mississippi valley was eroding and in need for repair (5).

A long-term federally funded project began in 1984 and established a series of 15 demonstration watersheds to address critical erosion problems on land and in stream channels of hill and piedmont lands. The project (the Demonstration Erosion Control Project in theYazoo Basin (DEC Project)) provides development and testing of systematic watershed soil conservation, channel stability, and flood control technologies. This paper describes evaluation of stream stabilization measures used in the project and how they have performed in habitat enhancement.

Materials and methods

Study sites

Fifteen watersheds located in the East Gulf Coastal PlainPhysiographic Province along thebluffline of the Mississippi River Valley were selected for the Demonstration Erosion Control project (Fig. 1) These loess morphological diversity index permits the classification of restoration schemes as well as providing a benchmark against which to assess the subsequent development of restored rivers.

Conclusion

The results of simple geomorphological modelling and partial confirmation from a recent restoration project illustrate that the restoration of isolated reaches can result in complex responses within the restored channel and downstream. Post-restoration, overloose sediments and bare surface increase sediment supply to the restored and downstream reaches which drive morphological development. These levels fall off as coarse bed material armours, and surfaces become colonised by vegetation. Nevertheless, vertical bank faces may remain a focus for subaerial and fluvial erosion particularly where the bank materials are geotechnically unstable. Downstream aggradation may result in a loss of flood conveyance but will provide morphological diversity for habitat creation over and above that designed in the restoration reach. Following the initial phase of downstream aggradation, declining sediment loads from upstream may cause a phase of incision and a lagged increase in sediment yield post-restoration. Construction sediments can be rapidly evacuated following flooding, leaving a bare surface susceptible to sub-aerial processes. Future sediment loads from the restoration reach will represent a balance between the rate of vegetation colonisation and the weakening of exposed surfaces by weathering.

Pragmatically the lessons from the river Cole show the need for detailed ground surveys of floodplain sediments and their stratigraphy so that locations of gravels and weak sediments may be mapped either to provide sources of sediment for morphological development, or to avoid instability and higher sediment loads. Ground penetrating radar could prove a useful tool in achieving this objective. The study also raises the issue of restoration upstream of sensitive river channels which suggests that assessments of restoration schemes should include attention to the downstream responsiveness of river channels to increased sediment loads. The study has also revealed the importance of determining what constitutes natural morphological diversity both as an aid to the design of restoration schemes, but also as a means of assessing their success and trajectory of development.

Acknowledgements

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cumulative effects of watershed treatments, testing specific practices furnished specific performance information which may be used to predict applicability in other watersheds or sub-watersheds.

Habitat

Habitat data collection and analysis were based on standard methods (10) modified to describe conditions in the channelized, eroding channels of northern Mississippi. Reach-scale measurements were measured at baseflows and included current speed, water depth, water surface width, and bed type (classified as clay, sand, gravel, riprap, vegetation, debris, or other [e.g., man-made items]). These data were collected at each of about 100 points located at nodes of a grid established along 100 m reaches. Top bank width, channel depth, and bank vegetation were visually estimated. The presence and number of beaver dams and man-made structures (e.g., weirs, revetments, jacks, etc.) within or immediately downstream from each reach were noted, and the area of large woody debris formations in the plane of the water surface was visually estimated.

Water quality

Temperature, conductivity, dissolved oxygen, and pH were measured in-situ weekly. Total solids, suspended solids, dissolved solids, nutrients and coliforms were analyzed by standard methods (11). Pesticide and contaminant metal samples from storm flows were analyzed by gas chromatography and atomic absorption spectrophotometry (9). Storm runoff was sampled seasonally.

Biological sampling

Fish were collected from all major habitat types: pools, riffles, debris piles, dikes, and grade control structure pools. Sampling methods varied by habitat type and local conditions. Seines, fish traps, fish toxicants (rotenone), and boat and backpack mounted electroshocking equipment were used. Taxa richness, diversity, catch per unit of effort and numbers per unit of effort were calculated for each site. Macroinvertebrates were collected from all major habitat types according to procedures described for Rapid Bioassessment Protocol (9).

Results

Structural measures to control channel incision and lateral channel migration have included bank stabilization, field and stream scale grade control (drop) structures, small reservoirs, levees, channel modifications, debris dams, and land treatment. As of 1995, bank stabilization was the most common construction activity in the demonstration watersheds (143,000+ m). Its major forms included full-bank revetment, toe protection, and spur dikes composed of stone rip-rap. Comparison of fisheries catch per unit of effort showed spur dikes to be comparable with natural bank habitat in degraded streams while lateral stone paving was inferior to spurs and natural bank (12).

Knickpoint migration, a major cause for channel incision, has been controlled by field-scale (drop pipes) and stream-scale (low drop or high drop) grade control structures. By transferring water from field level to stream level and dissipating flowing water energy, field scale grade control pipes eliminate lateral downcutting into incised stream beds. Assessment of incidental habitat conditions associated with both field and stream ends of pipe and natural gully sites and their plant and animal inhabitants is currently underway. As of 1996, 100 species of vertebrates have been identified in created habitat. Twenty-three in-stream grade control devices have been planned or constructed in the project.

Fish populations in energy-dissipation pools associated with in-stream low drop structures were compared with naturally-occurring pools in incised streams (13). Comparison showed similar total weight to volume of pool (0.06 kg m^{-3}), but plunge pools supported larger fish (0.025 kg m^{-3}) than natural pools (0.001 kg m^{-3}) Inhabitants were more indicative of pool dwelling-fishes rather than opportunists and year classes also exhibited greater stability (13).

Rock weirs were constructed with the point of a vee upstream so as to focus overtopping flows to the center of the channel and thus create and maintain a scour hole. Weirs have formed deep (~1.3 m) pools necessary to maintain harvestable fish populations. In one case, a series of 0.6 m high weirs produced changes in mean width, depth, and velocity sufficient to increase the stream area classified as pool habitat from 25% before construction to 74%. Furthermore, fish species composition shifted from one dominated by small cyprinids to one dominated by larger, pool-dwelling centrarchids.

Floodwater retarding structures are relatively small impoundments (pool areas of 0.06 to 0.4 km^2) constructed near tributary headwaters to moderate amount and velocity of floodwater and serve as sediment traps. Dendy and Cooper (14) found that a small impoundment (1.1 ha) trapped an average of 77 percent of fine sediment and up to 100 percent of sand. Eight floodwater retarding reservoirs have been constructed to hill watersheds were chosen based on their history of disturbances, geographic locations and intensive agricultural history. When Grissinger and Murphey (6) measured cross-sections in a 4.7 km length of Goodwin Creek, Mississippi, they found that eroded channel bank materials averaged 1900 $m^3 km^{-1}$ per year. Bed materials aggraded over 3000 m^3 for the reach during the 10 years of record. Mean suspended sediment yields from eight gaging sites representative of incising channels in northwestern Mississippi averaged 1,111 t $km^2 yr^{-1}$ (7). Channel incision lowers base level of all tributaries and also initiates lateral knickpoints into fields which drain directly into a stream, destabilizing the entire landscape.

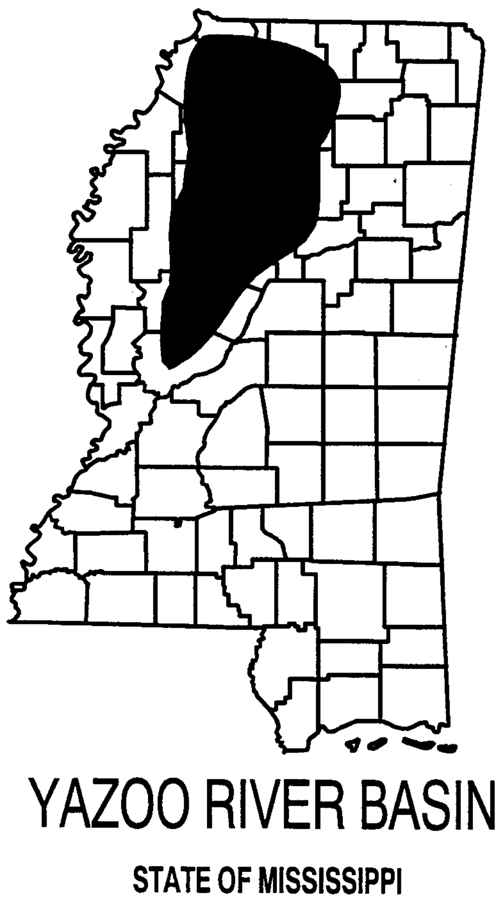


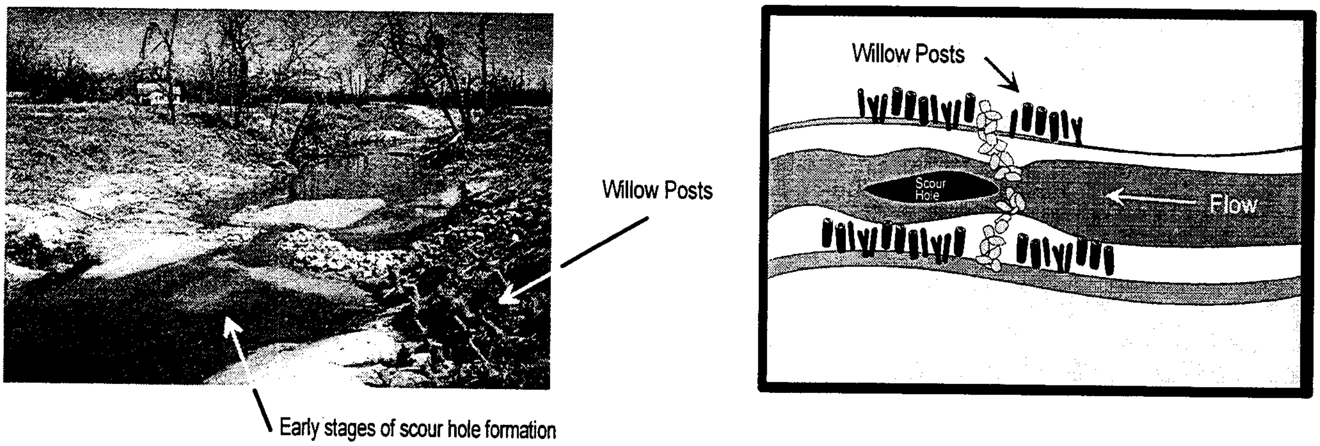
Figure 1. Map showing the range of the Demonstration Erosion Control Project.

Rehabilitation design

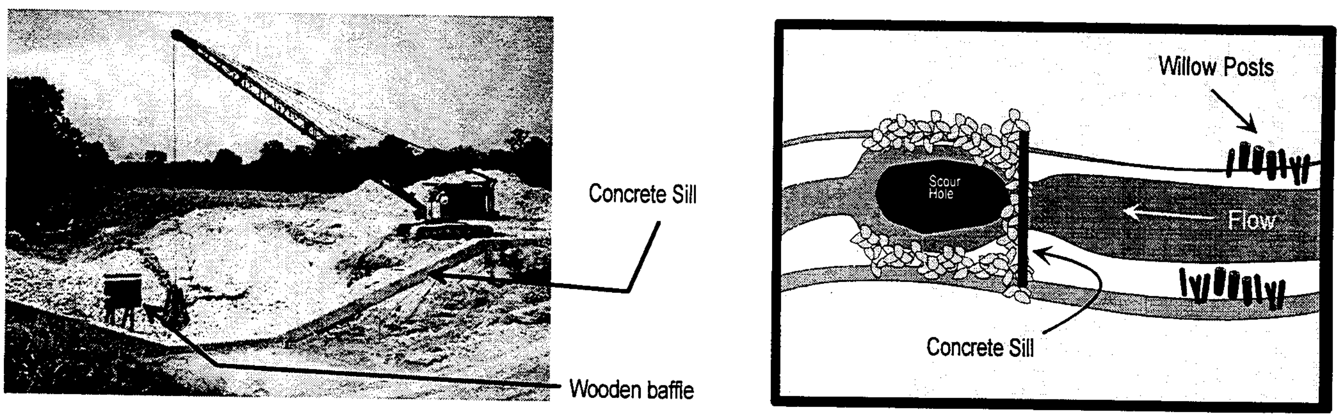
Project design in the Demonstration Erosion Control Project is based on the concept of managing the entire watershed. Biedenharn *et al.* (8) described design procedures, and a general overview is provided by (7). Procedures have evolved since project conception and particular measures are designed as part of a larger plan necessary to stabilize incised channels and eroding drainage nets. Conceptual models of incised channel evolution are used to project future states of watershed systems and strategic siting of stabilization structures. Watershed drainage networks are segmented into reaches 1-10 km long for study and data set construction. Data assemblage combines historical data with current data sets and allows the use of stable reaches to develop design criteria for unstable reaches. Design criteria include upper limits for mean thalweg slope, critical shear stress at channel-forming discharge, and bank heights and angles.

Environmental assessment

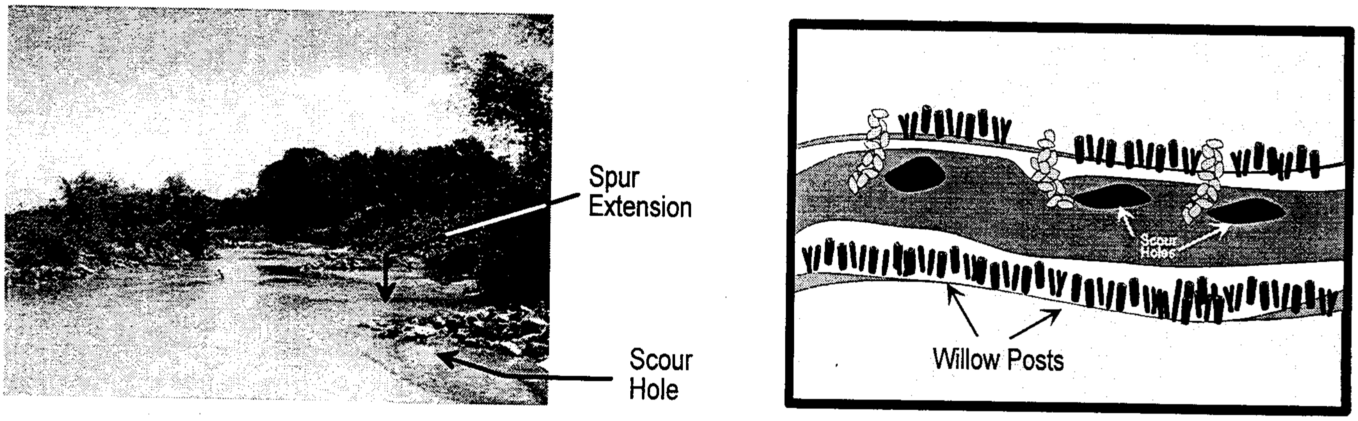
Environmental assessment strategy included long term water quality, habitat and biological monitoring of project catchments by sub-watershed at 80 sites and testing of specific management practices or structures at 44 sites (9). Monitoring sub-watershed changes provided focused information on performance of management techniques. Sub-watershed sampling also provided the opportunity to detect problems at the level needed for initial decision making. While sampling sub-watersheds provided a broad view of



Weirs were angled up-stream and notched in the center to create stable, self-cleaning pools.



Grade control structures consist of a concrete or steel sheet piling sill and a rock lined basin. A wooden baffle is installed in the stilling basin to dissipate energy.



Wings were extended by adding 10% more stone. Each wing was alternately angled to enhance the scouring effect and provide habitat heterogeneity. Willows were planted along each bank.

Fig. 2 Typical erosion control structural measures used in the Demonstration Erosion Control Project that provide habitat benefits.

dampen hydrograph peaks, especially where downstream overbank flooding has been a concern.

Large woody debris removal has been necessary on 6,545 meters of channel where debris density and aggradation caused flooding problems. Over 9,000 meters of levees have been constructed or repaired in alluvial areas. On Abiaca Creek, setback levees have been designed to allow for construction of a bottomland hardwood riparian zone which will also serve to trap sediment.

Discussion and conclusions

The extensive rock placement necessary to control lateral migration allowed for assessment of different measures including bank paving, longitudinal stone toe protection and spur dikes. Zevenbergen *et al.* (15) calculated that longitudinal stone toe protection was the most cost-effective rock placement; it was followed closely by spur dikes. Fisheries data, especially year class information, showed that overall shallowness of water and the lack of permanent pools adversely affected fish communities except for opportunistic spawners. We found that longitudinal stone toe was helpful in revegetation of raw banks (16) but provided little fish habitat (12). Conversely, spur dikes created additional mesocosms of habitat which were comparable to incised natural bank habitat by producing scours along their tips (12). Spur dikes with extensions (Fig. 2) coupled with woody vegetation planted on adjacent banks and sand bars may be used instead of lateral stone paving since they create stable pools and provide shade and carbon (17). Subsidence of spur extensions placed on a sand bed has reduced effectiveness at one location.

Three scales of grade control structures have been used in DEC to control knickpoint erosion. Field-scale grade control pipes are the most commonly constructed structures (750 pipes). These structures, commonly called riser or drop pipes, stop lateral knickpoints from overbank flow, stabilize gullies, and provide additional streamside habitat for a variety of animals. Low-drop (< 1.8 m) grade control structures (Fig. 2) are used for vertical stabilization where head cuts or knickpoints are migrating upstream. In addition, more-costly high-drop (> 1.8 m) grade control structures have been constructed occasionally because of the magnitude and severity of knickpoints in some areas. In several instances road and bridge stabilization and installation of box culverts have been used to stabilize knickpoints and improve local road infrastructure.

The fish fauna in naturally-formed pools was compared with that from grade control plunge pools. Grade control-associated pools (Fig. 2) were self-maintaining, but the natural pools were ephemeral due to episodic scour and deposition. Thus, grade control pools provided the opportunity for more extensive food web formation. Limestone rocks used to line pools added substrate for benthos and refugia for small fish and larger invertebrates. The plunge pools supported larger fish which were more indicative of pool dwelling-fishes rather than opportunists and year classes also exhibited greater stability (13).

Stone weirs (Fig. 2) have been constructed to serve as grade controls and to rehabilitate stream habitats. They create and maintain a scour hole and have a narrow channel width at their central notch, forming a stable riffle/pool sequence and stimulate bar formation for colonization by vegetation.

Dormant willow (*Salix spp.*) posts were planted on sand bars and stream banks to promote accumulation of fine sediments and to provide a source of carbon, canopy, and woody debris. Plantings are especially helpful because incised streams are isolated from their former floodplains. Two site specific problems exist in the demonstration watersheds: competition from the introduced exotic vine, kudzu (*Pueraria lobata*), and dense, impermeable soils. Accordingly, success of willow planting has varied from site to site (Table 1). In some cases, significant bankline revegetation has occurred even though survival ratios based on individual posts are low. Bankline revegetation has been most successful where posts have been planted on sandbars in reaches experiencing bed aggradation following episodes of incision and channel enlargement.

Table 1. Experience with dormant willow post plantings along DEC streams.

	Length of treated bank (m)	Post diameter (m)	Post length (m)	Individual survival (%)	No. of growing seasons observed	Source
Hotophia	1,500	2 - 25	1.5 - 1.8	30	2	(18)
Goodwin	200	8 - 30	1.5	53	2	(16)
Goodwin	500	8 - 30	1.5	20	1	(19)
Martin Dale	500	8 - 30	1.5	~11	1	(16)
Harland	2,250	2.5 - 16.3	3	41	2	(20)

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Incised channels receive elevated sediment loads originating from the lateral down-cutting of runoff from directly bordering subwatersheds. Field scale grade control pipes transfer water from field level to stream level and also dissipate flowing water energy. These "drop pipes" provide an added benefit by creation of small islands of habitat. Field level habitats range from small terrestrial habitats to permanent wetlands, while stream level habitats are small backwater pools associated with pipe outlets. Assessment of field level habitats showed that they support populations of all major vertebrate classes. he highest number of captures occurred in intermittent riverine wetlands, followed in declining order by scrub-shrub wetlands, saturated emergent wetlands, gully erosion sites, and upland meadows.

The Demonstration Erosion Control project has provided an opportunity to test the combination of erosion control and stream stability measures in incised channels where standard stream rehabilitation concepts may not work. Stability design is necessarily done at a watershed scale. Thus, large and small habitat improvement/creation can benefit stream corridor ecosystems generally rather than focusing on a particular favored species or stream size. Additionally, by combining erosion/stability and rehabilitation efforts, the larger ecological system comprising the entire stream corridor can be considered. Off-channel habitats are important both as providers ofallochthonous energy and from a larger ecosystem level perspective. Demonstration Erosion Control construction activities have shown that environmental enhancement can accompany stream stabilization without the sacrifice of project objectives.

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much more difficult to restore than surface connectivity), (b) only minor engineering work will be necessary to considerably enhance hydrological connectivity, (c) an empirical database, including the main functional processes and habitat requirements of the biota, is available, (d) the area is large enough to identify limnological processes which are representative for the whole river-floodplain system and (e) the land is in the public domain (National Forest Authority) or is held in trust by WWF-Austria.

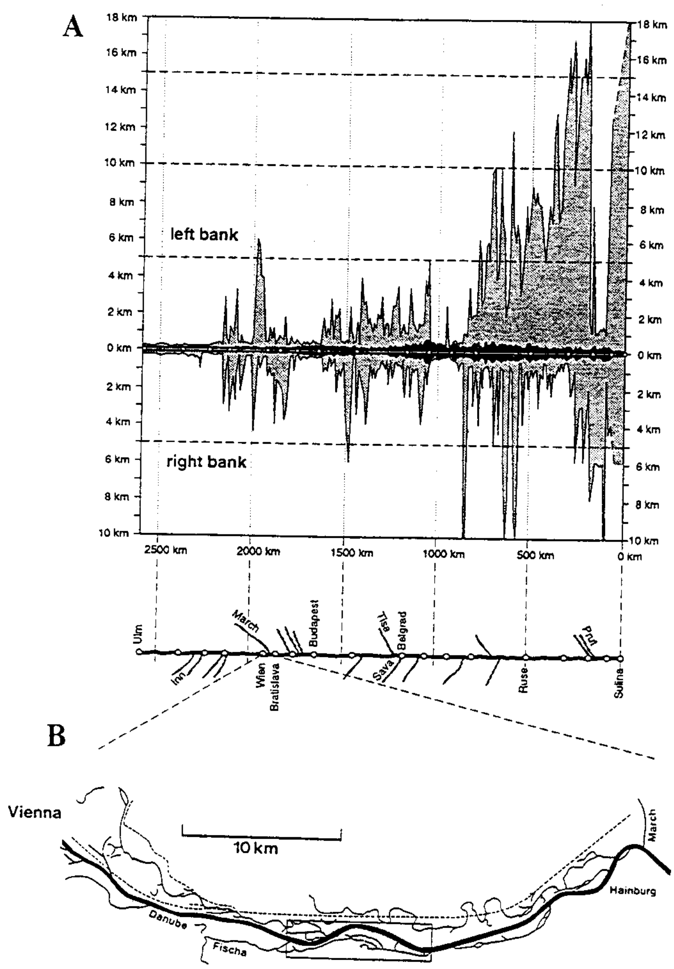

Figure 1. A.) Extent of former inundation areas along the Danube River (between the mouth area and Ulm (Germany)). Black line marks the average width of the main river channel. B.) Location of the remaining free flowing section between Vienna and the Slovakian frontier and the restoration site (rectangle). Modified after (5)

The backwater system is dominated by a former river channel that was cut off from the Danube at its upstream end more than 100 years ago (Fig. 1B). At present, long stagnant periods are interrupted by short-term flood pulses (average duration: less than four days per event) that typically occur one to three times per year. These are caused by upstream connections at high water levels (> 4,100 $m^3 s^{-1}$) via former inflow areas in the streamside embankments (6).

Water quality

In this area of the Danube nutrient concentrations are close (nitrogen) or well above (phosphorous) desired values of 0.15 mg l^{-1} P and 2.2 mg l^{-1} N (7), with a tendency toward slightly higher concentrations in the last decade. Water quality may influence the success of the restoration scheme. The high nutrient load constrains hydrological restoration to side arms close to the main river channel. The negative ecological effects of enhanced eutrophication (e.g., impoverishment of benthic communities), can be somewhat ameliorated by a simultaneous reduction of the water retention time within this side arm system.

Bed degradation

Averaged over the past 45 years, the annual decrease of the mean water level is about 2 cm per year for the free-flowing section east of Vienna (8). Bed degradation leads to a decrease of the groundwater table, and reduces the frequency of floodplain inundation and the duration of flooding.

The Restoration Concept for a River-Floodplain System on the Danube River in Austria

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Abstract

One of the last remnants of a functional alluvial landscape on the Danube River extends from Vienna to the Slovakian frontier ("Alluvial Zone National Park"). However, connectivity has been reduced and floodplain habitats have been fragmented. A successful conservation strategy for this floodplain area requires a management scheme based on a solid conceptual foundation and of the key processes in river-floodplain ecosystems. Re-establishing hydrological dynamics is recognised as the most vital step, because most other processes are influenced by the flow regime and resulting connectivity. Therefore, a large-scale pilot project has been developed for a segment of the Danube to gradually restore the hydrological connectivity between the river and its floodplain. The side arm system will be reconnected to the main channel by lowering parts of the riverside embankments. To improve the rate of the discharge through side arms, the check dams crossing them will be removed. After implementation, the side arm system will be integrated with the flow regime of the river for more than half of an average year (at present: < 8 days/year).

Introduction

The Danube River, once famous for its large inundation areas (Fig. 1A), has undergone a fate similar to that of large rivers in temperate Europe and North America.

The Danube has been channelized, confined by levees, impounded, and polluted (1). The last remnants of semi-natural alluvial landscapes on the Danube are located between Vienna and the Slovakian border (2)(3). However, conservation of this river-floodplain system requires effective ecosystem management. Restoration *sensu stricto* - a repairing of the floodplain ecosystem to the diversity and dynamics of its indigenous status - is no longer possible and therefore is not a realistic restoration goal. Nevertheless, ecosystem management must be based on a solid conceptual foundation and on an understanding of the principal structures and processes of river-floodplain ecosystems (4). One of the first concerns of river-floodplain rehabilitation projects must be the integrity of the hydrograph.

General characteristics

The riverine landscape of the Danube has been severely impacted by large-scale flood control measures and regulation work for navigation purposes and land reclamation since the second half of the 19th century. After World War II, the Danube River (upstream of Bratislava) had been transformed into an almost uninterrupted chain of impoundments. The last remnant of a semi-natural alluvial landscape - one of the largest in Europe - extends from Vienna to the Slovakian frontier (Fig. 1B). This free-flowing section still exerts its major functional attributes associated with the dynamics of water level fluctuations and bed-load transport, despite being highly influenced by former river regulation work. Therefore, this section has been designated as a National Park ("Alluvial National Park"). However, a successful conservation strategy for this floodplain area as a sustainable ecosystem must include measures to (a) reduce bed degradation in the main river channel, (b) to improve water quality and habitat heterogeneity, and (c) increase hydrological connectivity between the river and its floodplain area. Within these required management strategies, the restoration of hydrological connectivity is recognised as the most vital step, going well beyond species and habitat preservation. This concept of restoring hydrological connectivity has been developed in strong co-operation with the Federal Waterway Agency (Wasserstrassendirektion Wien, WSD) and the Committee of the National Park, and both scientists and engineers assume responsibility for this project.

Restoration area: present status and trends

The study area designated for the large-scale pilot programme on flood plain restoration is located 25 km downstream of Vienna on the orographically right bank of the River Danube (Fig. 1B). This area has been selected on the basis of the following considerations: (a) floodplain water bodies and the Danube channel are still dynamically interconnected via groundwater flow (we suspect that groundwater dynamics would be connected water bodies, while macrophytes are species rich in semi-isolated water bodies. Most fish species are recorded for the river channel. However, high biodiversity in the Danube floodplains must be considered as a transitional phenomena, because without natural flood disturbances, the floodplain system tends towards geographical and temporal uniformity, with a resulting reduction in the variety of plant and animal species (9)(10).

Table 1. Species numbers (with relative proportion of endangered species, %) of selected groups identified for the river-floodplain area between Vienna and the Slovakian border (9).

Taxon	Number of species	(Endangered)
Riparian vascular plants	623	(16 %)
Aquatic macrophytes	57	(50 %)
Mollusca (aquatic/semiaquatic)	79	(86 %)
Odonata (dragonflies)	49	(43 %)
Trichoptera (caddisflies)	53	(17 %)
Coleoptera (aquatic beetles)	34	?
Amphibia	12	(100 %)
Reptilia	7	(100 %)
Fish	54	(48 %)
Aves (incl. migratory birds)	164	-
Aves (breeding birds)	94	(29 %)

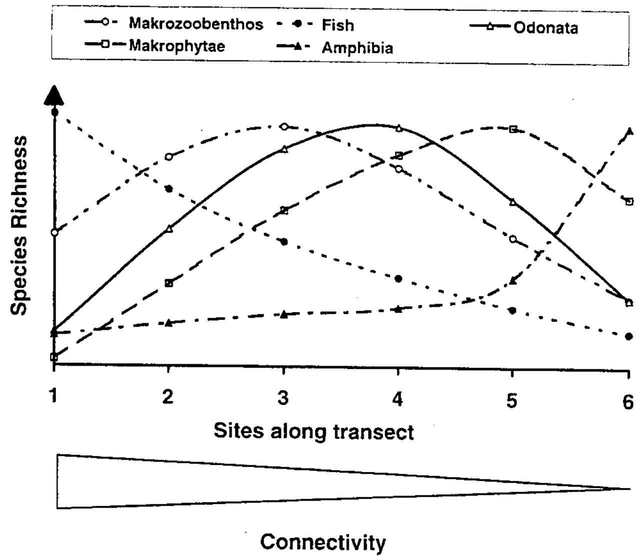

Figure 3. Species diversity (richness) for different groups across a lateral Danube (site 1) - floodplain (sites 2 - 6) transect (9).

Restoration scheme, operational work and monitoring programme

Here we briefly describe the restoration of hydrological connectivity between the Danube River and its floodplain, which is recognised as the most vital step of a 'master plan' for the whole area. Other main schemes include improvement of the water quality, instream habitat enhancement and attempts to reduce bed degradation processes. Attempts to re-establish river-floodplain integrity involve highly complex systems which are temporally and spatially very dynamic. Different species have different requirements and attempts to optimise management for particular groups can become controversial and contentious (Fig.3) (9)(10)(11).

Therefore, restoration requires (a) careful planning, (b) considering the whole area of the alluvial landscape (the river and the floodplain), (c) restoring hydrological connectivity step by step, and (d) including a wide range of functional and structural parameters for monitoring. Based on the concept of "degree of reversibility" (12), we believe that the restoration area has a high recovery capacity, likely the highest in this section of the Danube. Therefore, re-establishment of ecosystem "self organisation" in this section is realistic and will facilitate restoration of other reaches of the Danube.

Habitat heterogeneity, landscape fragmentation and ecological connectivity
A major consequence of channelization and the construction of embankments is the reduction of habitat heterogeneity in the river channel. Less than 15 % of inshore areas in the main river channel are adequate habitats for the recruitment of riverine fish (1). The river-floodplain system is artificially fragmented. This fragmentation disrupts landscape connectivity at different scales: (a) the whole stretch is isolated from its upstream and downstream stretches by dams (b) lateral surface connectivity between the river and its floodplain is confined mainly to extreme flood events, and (c) floodplain waters are isolated from one another, especially during low water conditions. Fragmentation in the river-floodplain complex is characterised by the distributional pattern of different geomorphological types of water bodies (9). The main river channel (Eupotamon) covers an area of 72 %. Isolated floodplain waters (Palaeopotamon) are numerically dominant (> 50 % of floodplain water bodies), yet represent a small total area (200 ha, 10 % of the total water surface). Laterally, well defined spatio-temporal boundaries exist between the main river channel and floodplain water bodies. Strong separation of side channels from the main stem is clearly illustrated by the distribution pattern of macrobenthic communities, e.g. chironomids (Diptera, Insecta), across a river-floodplain transect. Relative faunal similarity between the river channel and individual side arms is less than 5 %, although sediment characteristics (grain size distribution) show no significant differences between the river channel (site 1) and the main side arm (site 2). Within the floodplain area chironomid assemblages change gradually from the main side arm towards isolated waters (Fig. 2). Annual short-termed flood events are still able to flush accumulations of fine sediments from large parts of the backwater system, but they are too short to allow the establishment of riverine communities (6)(9).

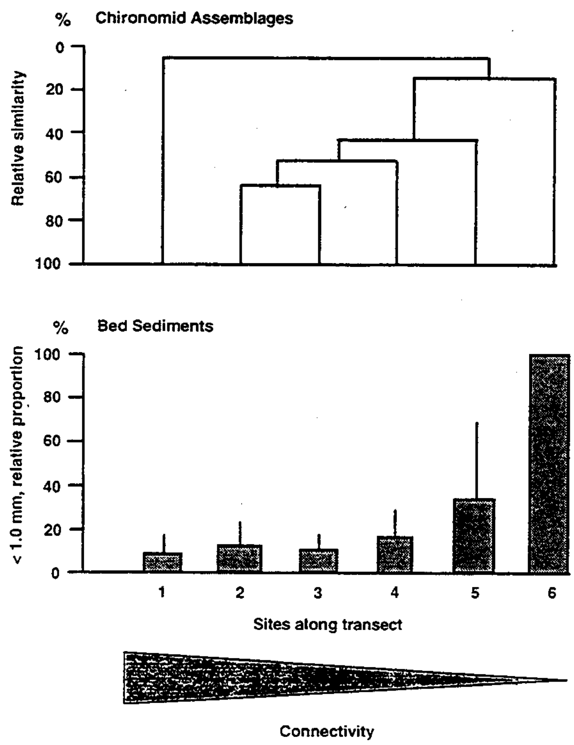

Figure 2. Relative similarity (%) of benthic chironomid assemblages and composition of bed sediments (relative proportion of the grain size < 1.0 mm) across a Danube-floodplain transect. Site 1: Danube, sites 2 - 6: floodplain water bodies, arranged according to their hydrological connectivity (1).

Species diversity patterns
Despite the regulated status, the river-floodplain complex downstream of Vienna is colonised by a diverse fauna and flora. The free-flowing area is still a suitable habitat for more than 80 % of the fish species occurring in Austria, and for two-thirds of all dragonflies and about one third of the caddisflies (9). A high proportion of the species is endangered (Tab. 1). By focusing on species distribution in relation to the spatial location, we are able to demonstrate that the high overall species diversity is mainly a result of the remaining spatial heterogeneity (spatial array of floodplain waters of different age across the whole river-floodplain complex, Fig. 3). Amphibians are restricted in their occurrence to isolated and astatic water bodies, free of fish. Macrobenthic invertebrates are species rich in the main side channel. Odonates dominate intermediate

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The side arm system will be reconnected to the Danube by lowering parts of the riverside embankment (length at each site: 30 m) and by the creation of artificial openings (Fig. 4). Embankments will be lowered at one site down to mean water level (MW), at the two other sites down to MW + 0.5 m. Some surface connections via artificial openings will occur at lower levels (MW - 0.5 m, Fig. 4). After implementation, the side arm system will be re-integrated in the flow regime of the river for more than half of an average year. To improve the rate of discharge through side arms, existing dams crossing side-arms and dividing them into single sections (9)(10) will be completely removed and additional outlets will be created.

Three major hydrological effects are expected after reopening of former inflow areas: first, a gradual increase in floodplain water discharge, secondly, an increase in the frequency and duration of lotic conditions in the side arm system, and finally a rise of the water level, leading to an expansion of shallow waters in the floodplain. The river channel itself will benefit from restoring connectivity. It will be supplied more frequently by non-refractory organic matter from the ATTZ (aquatic-terrestrial transition zones) or by phytoplankton biomass; and riverine communities may utilise main side channels frequently, in particular during the lotic conditions.

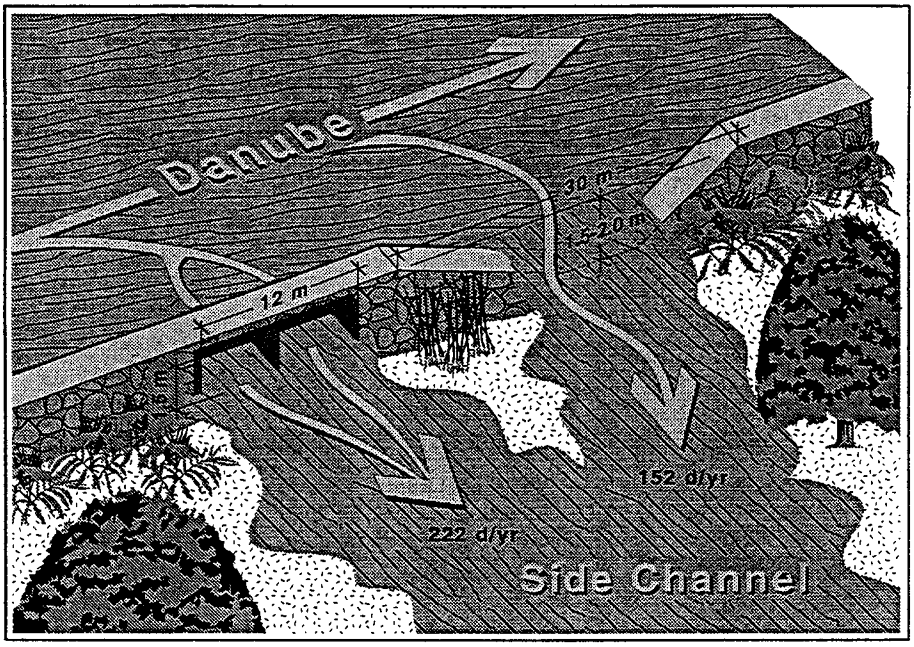

Figure 4. Measures to reconnect side channels by lowering of riverside embankments and creation of openings to reconnect former inflow channels (side channel) with the Danube channel (numbers indicate the duration of surface connectivity, days per year (9)).

Large-scale restoration work began in autumn 1996, and completion of the first stage (between river-km 1895 and river-km 1901.5, Fig. 1) is slated for winter 1997. Before starting with the next stage of connectivity restoration, time for impact evaluation will be permitted (9).

A key challenge in the evaluation of the effects of restoration will be the development and testing of an appropriate monitoring scheme. This has to combine physiographic and biotic parameters (11)(13). The main abiotic parameters evaluated are hydrography, geomorphology, flow, water retention, sediment structure and sediment transport. Our biotic describers include the distribution pattern of macrophytic vegetation, macrozoobenthos, adult and larval fish and amphibians. Functional limnological properties of the waterbodies are assessed by measurements of phytoplankton, primary production, bacterial production and nutrient regeneration. A detailed, intensified programme was conducted from 1995 to the end of 1996 in order to supplement previous investigations and to derive a comprehensive pre-restoration understanding of the system. The post-restoration sampling programme will remain consistent and last over a longer period (up to ten years), so that various stages of recovery are documented.

The designation of the alluvial landscape as a National Park offers an exceptional opportunity to develop large-scale rehabilitation programmes. In this section, at least eight additional sites have been pre-selected as potential areas for future restoration of hydrological connectivity. After completion of the first step, this restored area may serve as an important "stepping stone" for a future rehabilitation of the whole floodplain area downstream of Vienna.

flow regimen after restoration. The existing diversion dyke across Pamehac Brook was then removed in August 1990 and natural flows were restored to the middle and lower portions of Pamehac Brook. The re-watered stream bed of Pamehac Brook was surveyed for obstructions and a number of abandoned beaver dams, fallen trees and points of pulpwood accumulation were removed.

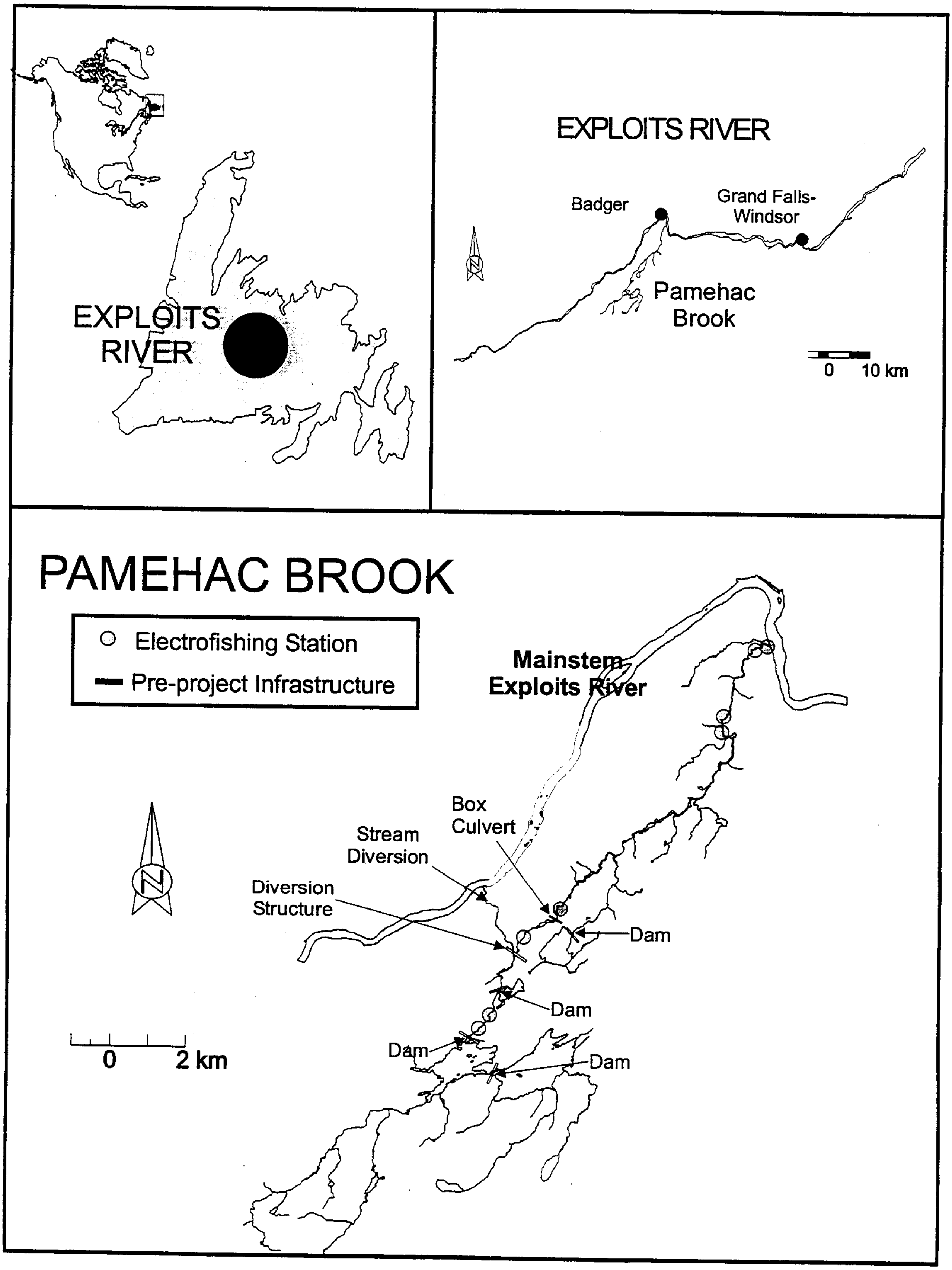

Figure 1. The location of Pamehac Brook, Exploits River, in central Newfoundland showing the location of storage dams, the diversion channel, and electrofishing stations.

Pamehac Brook: Restoration of a river impacted by flow diversion for pulpwood transportation

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Abstract
In the early 1970's, dams were constructed in the upper reaches of Pamehac Brook, Newfoundland, Canada, and the headwaters of the system was diverted into the main stem of the Exploits River to facilitate water borne transport of logs to a pulp and paper mill. This de-watered 12 km of high quality brook trout (*Salvelinus fontinalis*) and Atlantic salmon (*Salmo salar*) rearing and spawning habitat. The restoration of Pamehac Brook was undertaken in August 1990 and included replacement of control dams with bridges and culverts and removal of a diversion dyke to re-water the stream. Surveys conducted before and after the project indicated a gain in fluvial habitat of 450 units (1 unit = 100 m^2), a 62% increase, through re-watering of the stream channel. Improved access was provided to 175 habitat units in the headwaters. Population estimates of juvenile fish suggested limited response by fish populations in the initial 2 years after restoration. In 1996, a dramatic increase in biomass of larger juvenile salmon and trout (>0+) was indicated and attributed to increased habitat area and altered microhabitat conditions, in part, related to creation of standing water areas from beaver dams. Population estimates in 1996 indicated a production potential of juvenile fish of 330 kg, a 18 fold increase from pre-project estimates.

Introduction
The forestry sector has been a major industry in central Newfoundland for over one hundred years and harvesting activities have been extensive. Forest harvesting since the early 1900's provided raw material for the pulp and paper mill at the town of Grand Falls-Windsor (Fig. 1). In the early years of operation, prior to the widespread construction of forest access roads, pulpwood cutting was concentrated along the main stem and tributaries of the Exploits River. Log transport to the mill was traditionally by water and, to facilitate this, dams to control water flow were constructed both on the main stem and tributaries of the Exploits River. Pulpwood was contained behind storage dams on various tributaries before logs were driven downstream during high flow periods. This practice was widespread throughout Newfoundland and the infrastructure associated with this practice remains intact, in various states of disrepair. The removal of these storage dams, concurrent with activities to remedy the effects of historical log driving activities, has provided an abundance of habitat restoration opportunities (1). The Pamehac Brook Restoration Project is a case study in large scale stream rehabilitation to remedy the effects of historical log driving and dam construction.

Study area
Pamehac Brook is a small tributary (100 km^2) of the Exploits River which is the largest river in insular Newfoundland with a drainage area of over 11,000 km^2. In the early 1970's, logging dams were constructed at Pamehac Lake and Five Mile Lake and Pamehac Brook itself was diverted into the mainstem of the Exploits River (Fig. 1). The lower section of Pamehac Brook consisted of good trout and salmon habitat, while the constructed diversion channel contributed 1.5 km of high gradient, poor quality replacement stream. The resulted in the lower 12 km of Pamehac Brook being subject to varying degrees of flow reduction including total de-watering from the diversion channel to the first inflow tributary. At the mouth of Pamehac Brook, flows were approximately 36 % of the pre-diversion levels owing to runoff contributions from tributaries in the lower drainage basin. Log driving activities ceased in the early 1980's, however, the infrastructure remained in place and presented many residual problems. The dams impeded migrating salmonids while a series of falls and rapids on the diversion canal prevented migrating fish from entering the upper watershed of Pamehac Brook from the Exploits River. Long sections of the natural river from the upstream lakes to the diversion canal had been channelised.

Materials and methods
The initial phase of river restoration entailed remedying the infrastructure related to historical log driving activities. A collapsed box culvert on the mainstem of the river was replaced with new, properly sized cylindrical culverts while two control dams (at the outlets of Pamehac and Five Mile Lakes) were replaced with new bridges. This removed migration barriers and provided capability of accommodating the increased

units of pool (4 % increase). There was also an increase in mean width (from 9.5 m to 13.7 m, 44 % increase) and mean depth (from 18.7 cm to 26.0 cm, 39 % increase). In terms of substrate composition, there was an increase in coarse substrates (bedrock, large boulders, small boulders) and a corresponding decrease in the smaller materials (rubble, cobble, gravels), likely related to increased discharge and re-watering of coarser materials along the stream margins.

Fish populations

Population estimates for Pamehac Brook were determined prior to restoration (1990) and after restoration (1991, 1992, 1996) at stations above and below the diversion. Mean and standard deviations for stations above and below the diversion for density and biomass are presented in Figures 2 and 3, respectively.

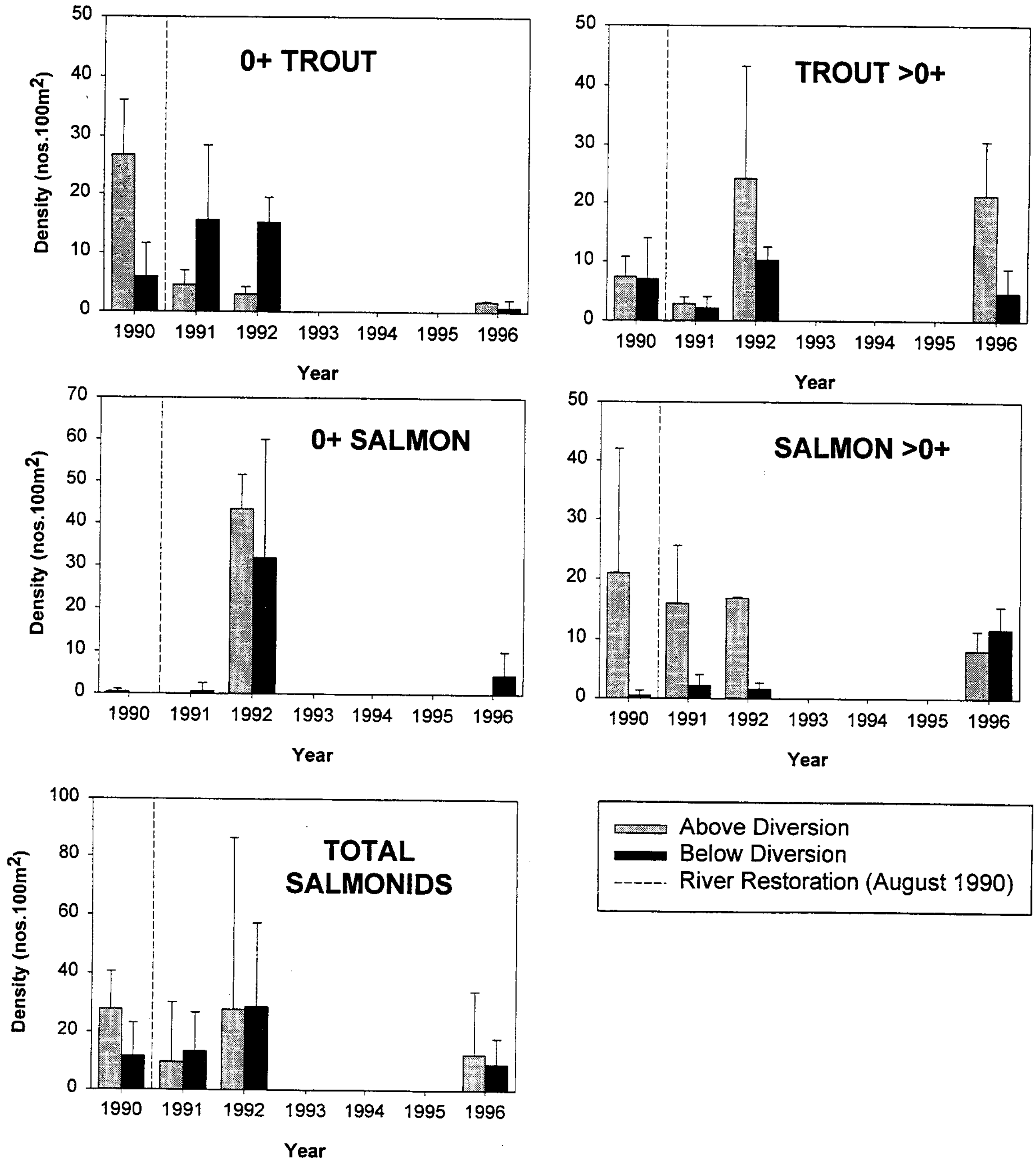

Figure 2. Fish population densities (mean ± 1 standard deviation), by age/size class, for electrofishing stations above and below the diversion channel on Pamehac Brook before (1990) and after (1991, 1992, 1996) restoration. Salmonid age/size classes are as follows: 0+ TROUT (brook trout fry), TROUT >0+ (brook trout 1+ and greater in age), 0+ SALMON (Atlantic salmon fry), SALMON >0+ (Atlantic salmon 1+ and greater in age), and TOTAL SALMONIDS (total of all juvenile salmonids).

Detailed habitat surveys were conducted in 1990, prior to restoration, and again in 1992, after restoration following methods described in (2). Surveys were conducted from the river mouth (confluence with the Exploits River) in 200 m long sections, or at other reach lengths as determined by changes in habitat type. For each section the following attributes were evaluated: habitat type, channel and wetted width, depth profiles, substrate composition, cover types, riparian vegetation, ice scour/flood debris height, stream bank conditions, presence and measurement of pools, and description and measurement of obstructions to migration. Large areas of steady type habitat were not surveyed as conditions in this habitat type were not expected to change significantly after restoration.
Fish populations were sampled by electrofishing in 1990 (pre-restoration) and in 1991, 1992, and 1996 (after restoration) at a total of 8 stations, 2 above the diversion and 6 below the diversion (Fig. 1). Results are partially confounded by stocking of 42,000 unfed salmon fry at 2 locations in Pamehac Brook in June 1992. As it was desirable to assess natural recolonisation of the restored stream stocking was not repeated. Population estimates were determined by electrofishing using the fixed effort (successive) removal method (3). Fish were identified to species, measured for fork length and weight, and scale samples collected (fish greater than 1+ in age). Scales were subsequently aged using a Bausch & Lomb microprojector. Abundance estimates (both density and biomass) were obtained using the Microfish 3.0 program using a maximum likelihood (ML) estimator (4). Estimates were derived separately for: (i) all salmonids, (ii) separately for brook trout and Atlantic salmon and (iii) separately for young-of-the-year (0+) and older (> 0+) age classes of each species. Statistical comparison of estimates between years was completed using the Mann-Whitney Rank Sum Test in the Windows-based software program SigmaStat. Statistical significance was determined as follows: not significant (NS; $p>0.05$), significant (S; $p<0.05$) or highly significant (HS; $p<0.01$). Habitat gain associated with this project was determined from total habitat area (before and after the project) multiplied by the average biomass (for 1990, 1992 and 1996) to estimate fluvial 'habitat productive capacity' for juvenile fish.

Results

Fluvial habitat

Habitat survey results conducted prior to the restoration project (1990), both above and below the diversion, and after restoration (re-watering) of Pamehac Brook (1992) are provided in Table 1.

Table 1. A comparison of habitat quantities and attributes for Pamehac Brook as surveyed in 1990 (pre-restoration) and in 1992 (after restoration). The 1992 survey includes sections that were not surveyed in 1990 (as they were completely de-watered) and also reflects habitat changes related to remedial activities (dam replacement with bridges/culverts).

	1990 (Pre-Restoration)			1992	
	Above Diversion	Below Diversion	Total	(After Restoration)	% Change
Total Stream Length (km)	1.99	4.52	6.51	7.30	+ 12 %
Total Habitat Area (100 m^2 units)	175	547	723	1172.3	+ 62 %
Mean Wetted Width (m)	8.9	9.8	9.5	13.7	+ 44 %
Mean Depth (cm)	29.1	15.4	18.7	26.0	+ 39 %
Habitat Area by Type (units, %)					
Riffle	118.1 (67.5 %)	519.2 (94.9 %)	637.3 (88.2 %)	942.0	+ 48 %
Pool	0 (0 %)	2.2 (0.4 %)	2.2 (0.3 %)	2.3	+ 4 %
Steady	29.2 (16.7 %)	6.0 (1.1 %)	35.2 (4.9 %)	87.6	+ 148 %
Run	14.9 (8.5 %)	0 (0 %)	14.9 (2.1 %)	29.9	+ 100 %
Rapids/Other	6.1 (3.5 %)	19.7 (3.6 %)	25.8 (3.6 %)	110.5	+ 289 %
Substrate Composition (%)					
Large Boulder	9.7	2.1	3.9	6.6	+ 69 %
Small Boulder	13.1	15.6	15.0	24.1	+ 60 %
Rubble	37.2	42.9	41.5	26.9	- 54 %
Cobble	21.7	27.8	26.3	21.1	- 24 %
Gravel	18.3	8.6	10.9	2.1	- 419 %
Bedrock	-	3.0	2.3	8.0	+ 247 %

After restoration, there was a total of 449.3 units (1 unit = 100 m^2) more habitat area, related primarily to re-watering of 0.79 km of river that had been completely de-watered and increased wetted width of fluvial habitat in lower reaches that had been partially de-watered. By habitat type, there was a gain of 304.7 units of riffle (48 % increase), 52.4 units of steady (148 % increase), 15.0 units of run (100 % increase), and 0.1

highly significantly lower in 1996 than in 1992. The 1996 densities could be considered more indicative of natural fry production levels in comparison to 1992 densities, which were confounded by stocking activities (Fig. 2). The 1996 results suggested a shift in population structure to larger, older salmonids.

Table 2. Statistical comparison of mean density and biomass for brook trout 0+ parr and trout greater than 0+, Atlantic salmon 0+ parr and salmon greater than 0+, and total salmonids between years. Statistical significance is denoted as not significant (NS; p>0.05), significant (S; p<0.05) or highly significant (HS; p<0.01). The direction of change (+, increase; -, decrease) is also indicated.

Species/Age Group	1990 vs 1991	1991 vs 1992	1992 vs 1996
Density			
0+ Trout	NS	NS	HS (0.001) (-)
Trout >0+	NS	S (0.012) (+)	NS
0+ Salmon	NS	HS (0.002) (+)	HS (0.003) (-)
Salmon >0+	NS	NS	S (0.029) (+)
Total Salmonids	NS	HS (0.002) (+)	HS (0.001) (-)
Biomass			
0+ Trout	NS	NS	NS
Trout >0+	NS	NS	S (0.014) (+)
0+ Salmon	NS	NS	NS
Salmon >0+	NS	NS	HS (0.001) (+)
Total Salmonids	NS	NS	HS (0.001) (+)

Estimates of production potential

Pre-project (1990) estimates of productive capacity indicated a production potential for salmonid juveniles of 18.0 kg for fluvial habitat in the watershed (Table 3). In 1992, increased average salmonid biomass and increased accessible habitat suggested a production potential of 52 kg for the watershed, a 2.9 fold increase. In 1996, with the substantial increase in salmonid biomass, the estimated production potential was 330 kg, an 18.3 fold increase from the pre-project estimate of habitat productive capacity.

Table 3.Estimates of habitat productive capacity for juvenile salmonids in fluvail habitats of Pamehac Brook, before and after the restoration project.

Units (100 m^2) of Habitat	Average Biomass per Unit	Potential Production	Increase
Pre-Project 1990			
(Above) 175 units	68.4 g	11.4 kg	
(Below) 542 units	12.2 g	6.6 kg	
		Total 18.0 kg	N.A.
Post-Project 1992	43.9 g	52 kg	2.9 fold
Post-Project 1996	281.3 g	330 kg	18.3 fold

Discussion

Flow diversion usually modifies the spatial and temporal characteristics of the natural flow regimen which in turn alters the composition and stability of habitat (5). Reduction of a naturally uneven flow regime can leads to decreased flood peaks, decreased sediment supply from upstream reaches, and a reduction or elimination of the ability of the water course to move bed materials (6). Loss in stream power may lead to reduced channel capacity, aggradation of silt and debris, encroachment of vegetation; which can result in reduced habitat quantity and as well as effects on habitat quality until the stream channel has 're-balanced' to the reduced flow.

For salmonid fishes in northern climates, there are two key periods in their freshwater life cycle that regulate juvenile populations: the low water, hot period in the summer affecting growth and survival; and the low water, cold over-wintering period affecting egg incubation success, hatching and juvenile survival (7)(8). In Newfoundland, critical periods for resident salmonids in small streams are the low flow period in the warm part of the summer and overwintering periods. Consequently, habitat restoration initiatives that provide and improve habitat refugia during these limiting periods are very beneficial (9). The effect of flow reductions on lower Pamehac Brook may have been particularly detrimental during these 'habitat bottlenecks', especially the overwintering period. Chapman (10) has suggested that habitat (space) is the principal regulator of stream dwelling salmonids in winter. Under reduced flow conditions, ice accumulation, both on

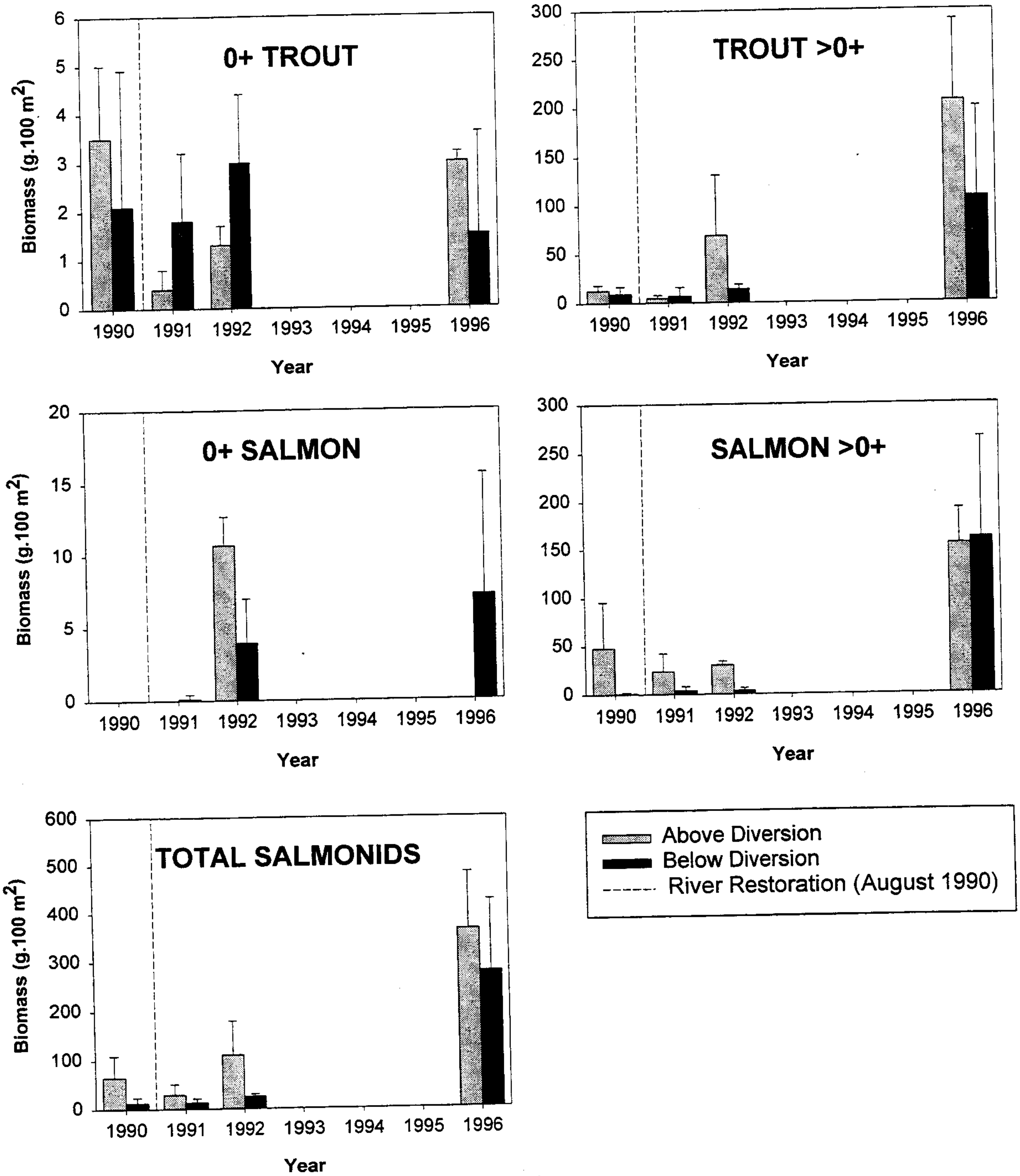

Figure 3. Fish population biomass (mean ± 1 standard deviation), by age/size class, for electrofishing stations above and below the diversion channel on Pamehac Brook before (1990) and after (1991, 1992, 1996) restoration. Salmonid age/size classes are as follows: 0+ TROUT (brook trout fry), TROUT >0+ (brook trout 1+ and greater in age), 0+ SALMON (Atlantic salmon fry), SALMON >0+ (Atlantic salmon 1+ and greater in age), and TOTAL SALMONIDS (total of all juvenile salmonids).

Statistical significance of between year comparison of density and biomass are provided in Table 2. The most relevant comparison of fish populations would be between the pre-restoration (1990) and initial post-restoration (1991) estimates and data collected in 1996. Estimates from 1992 are confounded by introductions of salmon fry. Fry stocked in 1992 would have left the system as salmon smolt by 1996. Generally, salmonid densities and biomass in the first 2 years after restoration were not significantly different from pre-restoration levels, with the following exception. Highly significant differences in 0+ salmon and total salmonid densities were apparent in 1992 and were attributable to fry stocking efforts (which were subsequently discontinued). In 1996, there was a dramatic increase in biomass of large salmon and trout resulting in a similar increase in total salmonid biomass (Fig. 3). Only trout >0+ demonstrated a significant increase in density in 1996. Trout and salmon fry densities, and total salmonid density were

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the surface and the formation of anchor ice, would have significantly reduced available space in the water column and substrate (11). Post-restoration surveys indicated both an increase in wetted width (44% increase) and water depth (39 % increase) which would have been important in providing additional overwintering habitat space.

Flow reduction may have caused gradual siltation of habitats downstream of the project, in particular spawning substrates. Siltation could result from dampened high discharge periods with concurrent reduction in competency to transport and remove sediments (12). Reduced flows during incubation may also expose eggs to increased likelihood of freezing and reduction in oxygen (13) and the presence of sediment may facilitate the process (14). Pre-restoration densities of salmon fry were extremely low in sites below the diversion, being zero at some, possibly providing evidence of poor spawning conditions.

Reduction of peaks in the hydrograph will also affect fluvial dynamics and maintenance of the riparian habitat. Peak flows often regulate substrate size and distribution, distribution of habitat types, and stream bank and cover conditions (15). Considerable vegetation encroachment in the riparian areas and complete invasion of terrestrial vegetation in the fully de-watered stretch were apparent prior to restoration. Initial post-restoration (1991, 1992) response simply involved flooding of riparian vegetation. In 1996, anecdotal evidence suggested a more natural riparian environment had established with more clearly defined aquatic-terrestrial boundaries.

Pre-restoration habitat in Pamehac Brook was dominated by riffles, however, flow reductions would have altered velocity and depth conditions thereby reducing quality of these habitats for older salmon parr. This is reflected in low density and biomass of older salmon, and to a lesser degree trout, prior to restoration (1990). The shift in size/age structure of the salmonid community in 1996 is consistent with changes in fluvial microhabitat conditions and age/size class specific habitat preferences. Habitat use varies with fish size/age (16) and, in general, as young salmon grow they select progressively faster, deeper water over coarser substrates (8). Salmon fry prefer pebble/cobble dominated substrates in shallow, slow water areas (8). Brook trout seek out deeper, slower waters as they grow and are often associated with the stream margins and riparian cover (17). Anecdotal evidence in 1996 indicated the presence of a number of beaver dams providing large standing water areas in Pamehac Brook, which were not present in 1992. These beaver dams may provide a benefit in terms of increased rearing habitat for older juveniles, however, these dams may, or in the future, constitute partial or complete barriers to migration.

The project has also resulted in restoring full access to the watershed for migrating fishes, in particular anadromous Atlantic salmon. Prior to restoration, habitat above the diversion was obstructed from the lower reaches of Pamehac Brook and the Exploits River and consequently was utilised by resident species only. After restoration, the entire watershed was accessible from the Exploits and hence available for colonisation. Consequently, population levels in Pamehac Brook after restoration would reflect both redistribution and colonisation by resident species as well as colonisation from residual populations of anadromous salmon.

The post-restoration habitat productive capacity would be reflective of the increased flows and wetted width as well as changes in microhabitat features. It may have taken several hydrological cycles to re-establish channel thalweg and scour any sediments and vegetation that would have been in the expanded stream channel. It would also have taken time for the fish to redistribute and colonise the available habitat at or near the restored carrying capacity. This may explain, in part, why the appreciable increase in salmonid biomass was only apparent in 1996, 6 years after restoration. Evaluation of habitat restoration projects must consider the time required for habitat features to stabilise and the additional time for fish populations to respond to these conditions (18). Evaluation and monitoring of habitat projects must consider this temporal aspect and design assessments accordingly (19).

Estimates of the 'habitat gain' and increase in productive capacity were determined to assess the overall success of the project. The pre-restoration estimate of production potential for juvenile salmonids in fluvial habitats was 18 kg. The initial post-restoration (1992) estimate of potential habitat production was 51 kg, a 2.9 fold increase. Recent estimates (1996) now indicate a potential production of 330 kg, a substantial 18.3 fold increase from pre-project conditions. This assessment indicates the project has been successful in achieving a substantial habitat gain and fish populations have, in recent years, responded to the increased habitat area and improved conditions in the re-watered fluvial habitats.

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DFO staff involved in this project included R. Goosney, C. Bourgeois, K. Houston, L. Cole, J. O'Brien, J. Murray, and a variety of summer students. Similarly, staff of the Environmental Resources Management Association participating in this project included F. Parsons, J. Pollett and a variety of additional staff.

Many non-geomorphologists have designed stream restoration projects based on a stream classification system (3), utilising a table which specifies bed and bank structures suitable for each 'stream type' (4). Such a 'cookbook' approach to restoration design does not get at the fundamental issues of how the river functions geomorphologically and ecologically, and what are the underlying causes of the current (degraded) river condition. Nonetheless, this approach has exerted a strong attraction upon many non-geomorphologists, many of whom understand that geomorphology is important but have been frustrated by its complexity. Once the alpha-numeric codes have been mastered, the classification scheme may provide the illusion of understanding the specific river. It is perhaps a human trait that while we understand and appreciate the complexities in our own fields, we are often drawn to believe that another field can be reduced to a set of principles that we can easily apply. It is easy to mistake the simplifications of the classification system for an understanding of the often complex geomorphology of the river.

Many such classification-based projects have failed in California, undermining public support for stream restoration in at least one case.

3. Coastal California rivers have high seasonal and inter-annual variability, so traditional concepts of equilibrium channels may apply poorly to some California rivers. With its Mediterranean climate, virtually all precipitation in the winter. Runoff is likewise concentrated in winter in rainfall-fed rivers at lower elevations, but rivers draining high elevations derive most flow from snowmelt, with most flows delayed until later spring or early summer. In addition, there is a large year-to-year variability. Concepts of bankfull discharge and its common return period of 1.5-2 years (5) are derived mostly from studies in humid regions or on snowmelt rivers. In more arid climates, less frequent events are more geomorphologically effective (6). In rivers of the southern and central California Coast Ranges, the channel may widen during floods, only to progressively narrow during years with lower discharge as vegetation is able to re-establish along the channel.

4. The frequency of large floods has been reduced by extensive dam construction in California. Floods are periodic disturbances in the aquatic and riparian ecosystem is whose important role is increasingly recognised (7). In many rivers, reduction or elimination of flooding downstream of reservoirs has resulted in reduced rates of channel migration and reduced connectivity between floodplain and channel, resulting in less diversity of riparian and aquatic habitat (8). In California, fish communities in reaches downstream of dams are more often dominated by exotic species than unregulated reaches (9), evidently because the elimination of flood disturbance allows the exotic species to thrive. Channel adjustments to reduced floods (and to reduced sediment supply) can be expected on alluvial rivers (10). In California, channel narrowing is the most common adjustment, due to factors such as reduced sediment supply, incision, establishment of vegetation in the active channel, or deposition.

The altered hydrology and sediment supply below reservoirs has implications for restoration channel design and minimum instream flow requirements. Flow requirements are often set based on the distribution of water depths and velocities in the channel, assuming fixed channel boundaries. However, if the channel is adjusting to changed conditions (such as the dam), the relation between flow and hydraulic conditions is likely to change. These changes must be understood in setting instream flows and designing (and evaluating) restoration projects (11).

In California, most rivers are dammed: 1400 dams over 7.5 m in height and 60,000 m^3 in reservoir capacity (and many smaller ones) impound over 60 percent of the state's runoff (12). Thus, restoration projects are likely to be located below dams, but the implications of the altered hydrology and sediment supply have not always been appreciated by project designers. The case study describes the basis for setting flushing flows for Rush Creek.

5. Changes in sediment supply must be understood for restoration design. Many channels in California are sediment-starved because rates of sediment supply have been reduced by upstream dams, extraction of sand and gravel from the channel, bank protection works, and other influences. Other rivers have experienced increased sediment supply as a result of land-use effects. In the Trinity River, California, the supply of coarse sediment has been reduced by upstream dams, while the supply of fine sediment from tributary catchments has increased due to timber harvest and road construction. The delivery of fine sediment to the channel below the dam, combined with reduction in flood flows capable of transporting the sediment downstream, resulted in extensive deposition of fine sediment over gravel and cobble substrates important for salmon spawning and invertebrate production. High-flow releases have been proposed to flush fine

River restoration projects in California: lessons learned

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Abstract

As river and stream restoration projects have grown in popularity (and funding) in California, many practitioners have been drawn to the field, some with little training in geomorphology and ecology. Many projects have been unnecessary, ineffective, or deleterious to aquatic and riparian resources. Restoration projects should be planned and designed based on an understanding of geomorphological and ecological *processes*, rather than simply mimicry of *form*, as in blind application of a classification scheme.

California is a tectonically active region with a Mediterranean climate, resulting in extreme spatial and temporal variability in river channel conditions. Restoration approaches that work in one part of the state may not succeed elsewhere. Most rivers in California have been dammed, resulting in changed flow and sediment transport conditions downstream. If these changes are not recognised, restoration designs are likely to be ineffective or inappropriate.

Introduction

River and stream 'restoration' projects have been undertaken in California for a wide variety of objectives. These objectives range from full restoration, in which riparian and aquatic habitats lost due to past human action are recreated, to projects that are motivated by flood defence or similar purpose, but which may involve enhancement of environmental values (1).

In a region with relatively uniform geology, topography, and channel characteristics such as Denmark, a restoration technique successful at one site is more likely to be successful in others. California, however, is a tectonically-active region, with a wide range of rock types, elevations, erosion rates, and strong orographic controls on precipitation. Elevations range from below sea level to over 4300 m, and annual precipitation ranges from under 100 mm to over 3 m. Moreover, there are extreme seasonal and inter-annual variations in precipitation. As a result, stream power and sediment transport vary enormously spatially and temporally. Thus, techniques successful in one locality may not work in another. Also, flows are so variable that a designer's intuition about likely future flows at the project site (based on his experience over the previous several years) may be a poor guide to actual flows in the future. To forecast the performance of a restoration technique at a particular site requires that the geomorphology of the site (and catchment influences) be understood and that the stream power experienced at the site in the future be forecast from analysis of the hydrologic regime.

The recently increased popularity of river restoration projects in California has drawn many practitioners into the field, some of whom lack background in fluvial geomorphology and ecology but nonetheless design projects involving large manipulations of channel form. Despite the designers' good intentions, many projects have been unnecessary, unsuccessful, or actually detrimental to aquatic habitat. Most restoration projects have not been subject to objective post-project evaluation, so the actual rates of success are unknown, and lessons cannot be learned to improve the performance of future projects. One source of evaluations has been the research undertaken by graduate students at the University of California at Berkeley, upon which this paper is largely based.

Lessons Learned

1. Objectives should be clearly stated and based on an understanding of geomorphological and ecological processes. It is only in the context of actual geomorphological and ecological processes that restoration goals can be sensibly formulated and evaluated. While social and institutional factors are clearly important, they do not guarantee that the physical modifications undertaken are necessarily beneficial to the physical and biological processes in the channel.

2. Geomorphology is needed to plan and design restoration projects. A competent geomorphological analysis can shed light on the fluvial processes and controls at a catchment scale, and an historical analysis can document the evolution of the channel and catchment, providing the manager with insight into the underlying causes of the channel's current condition (2).

floods. Lack of upstream sediment supply below dams, and the channel's competence to move artificially added sediment, must be considered in design of restoration projects below dams.

Perhaps most importantly, each restoration project is potentially an opportunity to learn more about the behaviour of these rivers and the effect of various treatments upon them. Thus, objective post-project evaluation is badly needed to permit the field to advance.

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sediment from the gravels and maintain a more dynamic channel regime (13) in conjunction with a program of physical alterations to river banks and pools (14).

To mitigate for the effects of upstream dams in reducing the supply of gravel, spawning riffle restoration projects have been undertaken in at least fifteen rivers and streams in California. These projects have involved artificial importation of spawning-sized gravel to the channel, either placed in constructed riffles or dumped below dams for redistribution by the currents. Some of these riffle restoration projects have been undertaken without an appreciation for the sediment transport regime downstream of dams. Riffle restoration projects on the Merced, Stanislaus, and Tuolumne Rivers have washed out in flows with return periods as low as 1.5 years (15).

6. Restoration should be based on understanding of process, not simply mimicry of form. Many of the problems described above can be viewed through a distinction between *process* and *form*. A restoration project is more likely to be successful if its design is based on an understanding of geomorphological and ecological processes, rather than an imitation of channel forms believed to be suitable or prescribed by adherence to a classification scheme. Commonly, runoff and sediment load in the catchment have been altered (e.g., by land use changes or dam construction) such that historical channel forms or channel forms from nearby 'reference reaches' (reaches believed to reflect pre-disturbance conditions at the project site) may not be in equilibrium with current, changed conditions.

7. Post-project performance evaluation is needed to avoid repeating mistakes and to develop an understanding of how rivers respond to restoration actions. It is often *assumed* that restoration projects are beneficial, but many well-intentioned projects are actually ineffective or detrimental (16) (17). River geomorphology and ecology are complex, and we cannot predict precisely how the river will respond to a given treatment. Our restoration efforts are best viewed as experiments, from which we can learn valuable lessons to improve future project design. Post-project evaluation can entail repeat ground and/or aerial photography, cross section surveys, bed material size sampling, vegetation surveys, and sampling of invertebrate, bird, and fish populations (18).

Unfortunately, objective post-project evaluation is rarely undertaken by agencies constructing or funding restoration, perhaps because it is felt that limited funds should be used to 'do something' rather than for 'more studies'. For example, the guidelines for a grant program funding local projects to improve fish habitat conditions explicitly states that funds are for "implementation" only, not for "studies", evidently precluding funding for post-project evaluation to the grantee (19). However, the agency itself does not conduct objective evaluation of the performance of the projects it funds.

Even when an agency constructing a project seeks to conduct objective evaluation, a lack of in-house expertise may lead to an ineffective evaluation study design. One costly and well-publicised restoration project in northern California (20) included enormous effort (mostly by high school students) to measure channel habitat conditions and sample invertebrates. Unfortunately, it was subsequently impossible to determine if the project objectives had been achieved because the pre-project baseline data collected were not appropriate for evaluation of performance (21).

Conclusion

The physical settings and objectives vary widely among river restoration projects in California, but some lessons emerge from experience and observations of many restoration projects. Clear objectives, consistent with geomorphological and ecological processes, are a prerequisite to effective restoration, and to avoid constructing projects that are ineffective or actually harmful to aquatic and riparian resources. A real understanding of geomorphological and ecological processes (based on adequate study of the channel history, catchment-level influences for the site, and analysis of flow records) is needed, rather than application of 'cookbook' approaches based on mimicry of form. This is especially important given the wide range of conditions encountered in California streams. It is essential that the overall objectives for river management and restoration be clearly thought out to ensure that all restoration objectives are compatible and that proposed projects are consistent with the overall objectives for the channel.

Other important features of geomorphological processes in California are the extreme seasonal and inter-annual variability in flow, and the influence of infrequent large floods on channel form. Because most California rivers have been dammed, many channel reaches proposed for restoration are undergoing adjustments to reduced flood magnitudes and reduced supply of sand and gravel. Thus, many restoration programs now include explicit requirements for periodic flushing flows to simulate some effects of natural

Methods

Laboratory measurements of nutrients according to (2). Data from the year 1987 were selected from (3). Radiation data were obtained from the University of Hohenheim, Stuttgart, discharge data from the governmental water authorities. Selected transects from the karstic spring to the last 42 kilometres were mapped for their vegetation and species composition by R. Reinboth.

An experimental section for the biomass measurements, with five subsections with different management was installed in 1992, it lays around station 11 of the nutrient measurements.

Section I was a shaded area (light reduction during the vegetation period up to 80 %); Section II was managed as usual (no light reduction); Section III was only cut in early May (no light reduction); Section IV was only cut during flowering (no light reduction); and Section V was the control (no light reduction).

All sections were 250 m long, about 10 m wide, 0.5 - 1.2 m in depth, current velocity 0.3 - 0.8 m s^{-1}, flow direction South-East.

Biomass was estimated by means of Scuba-divers according to (4).

Results

Major nutrients, species composition and weed biomass were determined during the vegetation period. The results of the years 1987 -1995 characterise the river as high productive due to high nutrient levels (Fig. 2).

The investigated river could be divided into three parts by the distribution of the major nutrients, from the source to sampling station 6 before the main settlement area, station 7 to 9 within the settlement area and a major sewage plant effluent and the stretch below station 10.

All nutrients showed an increase during the river course. Phosphorus and ammonia decreased during the investigation period due to improvements at the sewage plants, but nitrate is still increasing due to farming practice, not only by the nitrification process.

The river is well oxygenated, the water temperature winterwarm and summercold as expected for a karstic, spring fed river. The water quality index (2) is II, moderate polluted, only downstream of two sewage plants the index is II-III, critical polluted (5).

The plant species composition remained constant in the upper reaches with less influences of sewage. With increasing nutrient levels the species composition changes and the biomass increases. During the investigation period *Ranunculus trichophyllus* became dominant (Table 1).

Table 1. Makrophyte species in the Brenz.

Species	Reach 1		Reach 2		Reach 3	
	B1-B6		B7-B9	B10-B13		
	1987	1995	1987	1995	1987	1995
Hippuris vulgaris	d	d	-	-	-	-
Groenlandia densa	a	d	-	-	-	-
Ranunculus gluckii	d	a	-	a	-	-
Myriophyllum spicatum	-	-	+	a	+	a
Potamogeton crispus	+	+	+	+	+	a
Rannunculus trichophyllus	a	+	a	a	a	d
Zanichellia palustris	a	+	d	d	a	a
Callitriche obtusangula	a	a	d	a	d	a
Berula erecta	a	a	a	+	d	a
Fontinalis antipyretica	a	a	a	a	a	a
Elodea canadensis	a	+	+	+	a	+
Sparganium emersum	a	+	-	+	d	a

d = dominating species; a = abundant species; + = few individuals; - = missing.

Investigations for weed control in a karstic river

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Introduction

Mass development of aquatic weeds in the karstic river Brenz , a tributary of the river Danube in South-West Germany (Fig. 1), results in high management costs each year (< 250,000 DM). Statutory regulations for flood control management were the background for weed control. It is necessary to maintain a certain discharge capacity to prevent housing areas from flooding.

A research and investigation programme was implanted by the Ministry of environment Baden-Württemberg to reduce these costs. Part of the programme was a literature study (1). Main goal of the investigations was the impact of reduced weed cutting on the river characteristics, e.g. changes in species composition, biomass, and hydrological regime.

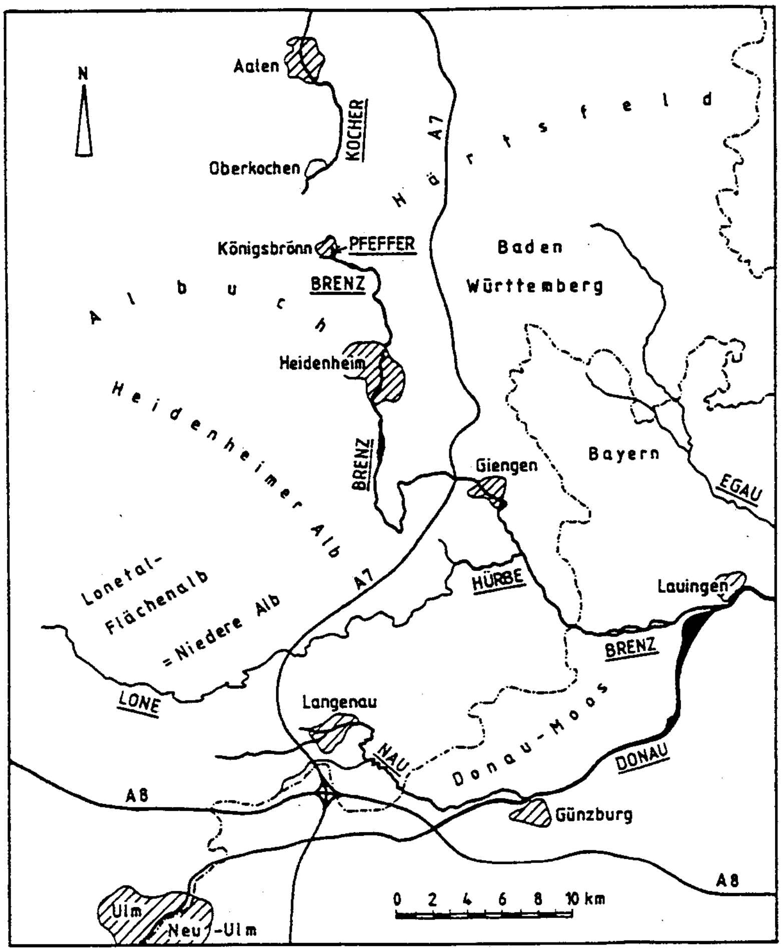

Figure 1. Location of river Brenz (from (3)).

The river valley was influenced by human activities since the Romans settled in this region. During maintenance and consolidation of farmland in the 1960's the river has been straightened and enlarged to keep a discharge of 35 $m^3 s^{-1}$. The river is know 52 km long, 42 kilometres belong to Baden-Württemberg. 23 weirs cut the slope to an average of 0.56 ‰. It is fed by a karstic spring with a mean discharge of 1.25 $m^3 s^{-1}$. The addition of tributaries and other springs (B7) increases the mean discharge up to 8.2 $m^3 s^{-1}$. After thunderstorms in the summer the discharge can reach values as high as 26 $m^3 s^{-1}$.

Programme

From 1991 to 1996 the programme worked on three major aims:

- Changes in nutrients and other water quality parameters;
- Changes in species composition;
- Changes in biomass production by different management practice.

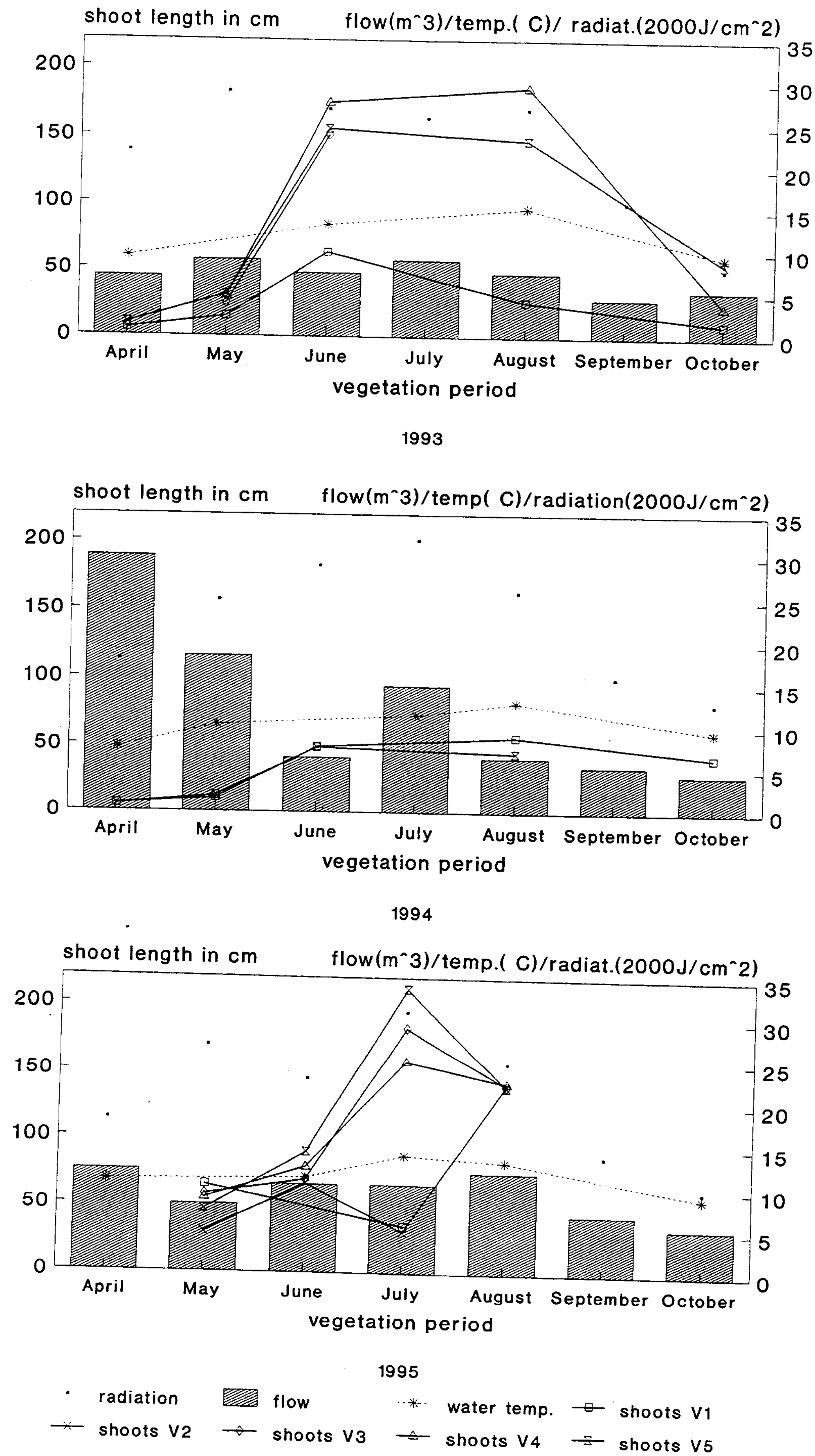

Figure 3. Radiation, discharge, water temperature and weed growth of Ranunculus trichophyllus. (n = 20) in A) 1993; B) 1994; C) 1995.

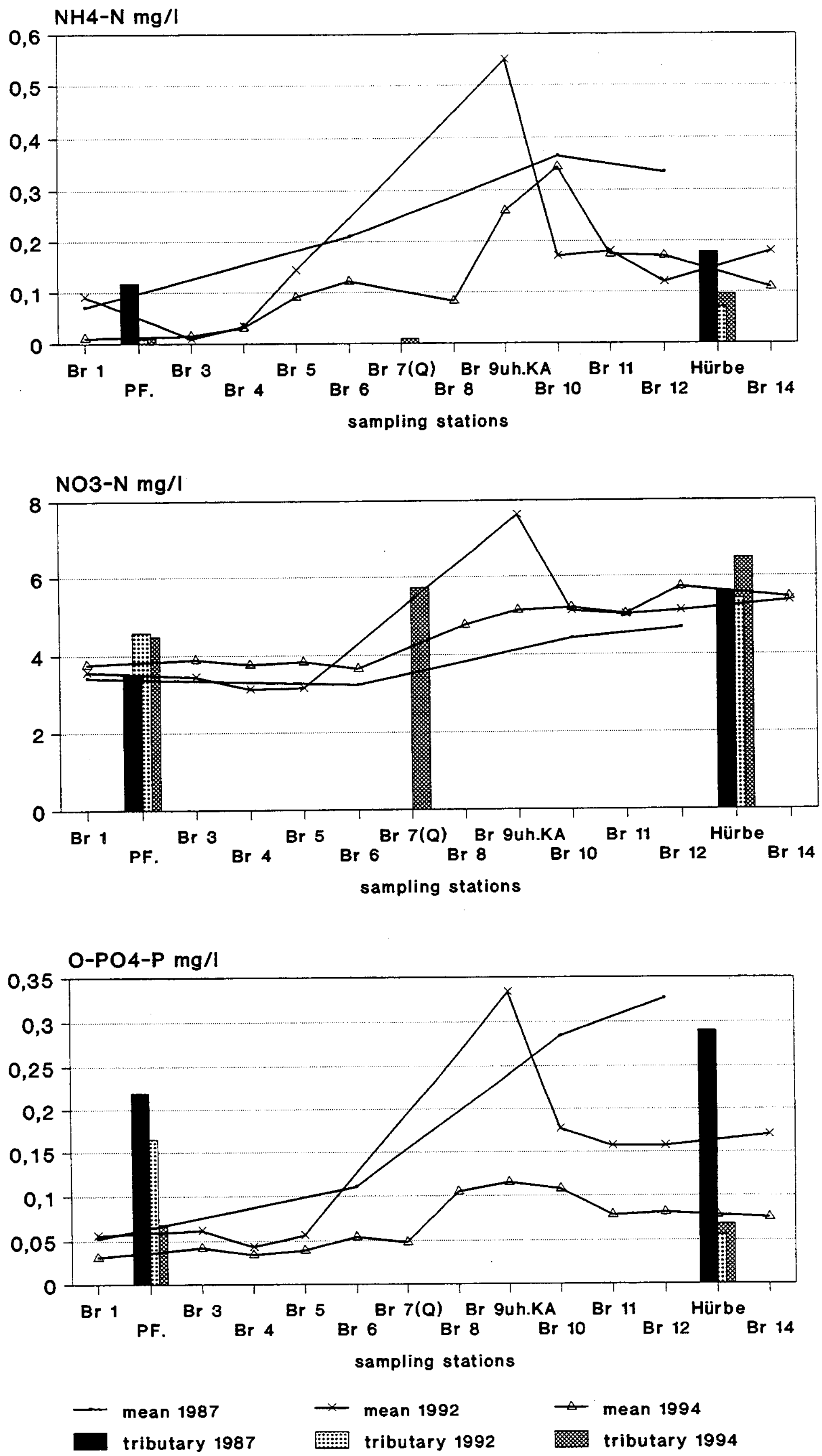

Figure 2. Major nutrients at the sampling stations of the river Brenz, A) ammonium B) nitrate C) phosphor mean (n = 3-5). Sampling stations: Br = River Brenz; PF = Stream Pfeffer; Hürbe = Stream Hürbe.

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In 1993 all sections of the river showed good growth of weeds, 1994 was characterised by weak weed growth during spring and summer, 1995 good growth in some sections in spring, but the vegetation cover was very variable. Therefore the length of shoots was used for comparison of the experimental sections (Fig. 3). Mass development of weeds started in May, reached a maximum in June and remained constant till August, decreased in September and October. Weedcutting in June and July stimulated fast weed growth, which resulted in further weed cuttings during the main growing season.
Biomass in the experimental sections ranged between 16-26 kg w.w. m^{-2}. Shaded control sections showed biomass between 0-1.5 kg w.w. m^{-2} (Fig.4). Experimental sections without management showed less weed production than sections with weed control twice a year.

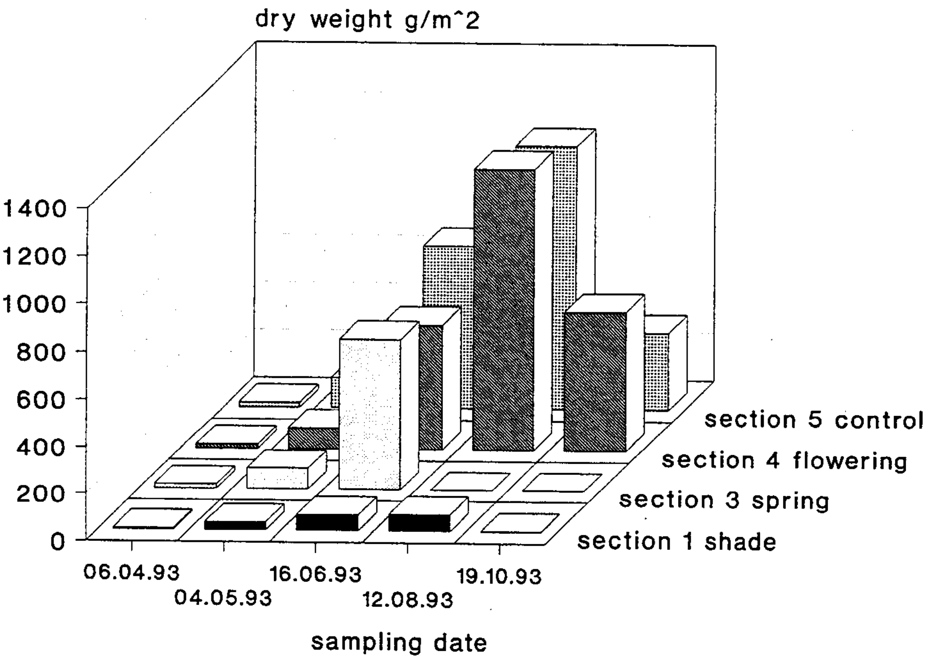

Figure 4. Biomass development in the experimental section 1993.

Discussion

Different plant growth during the investigation years as well as differences in the management practice by the river keepers resulted in only weak arguments for different management practice, e.g. cutting in spring. We compared the management effort in autumn and the following spring for 14 years. The correlation was low, $r = 0.313$, radiation was computed for the same years with the management intensity , $r = 0.36$ also a low correlation, high discharge and management effort showed a very low correlation, which means that other variables have a high influence on the management intensity or management is mostly done as usual.

The major effect on weed depression has shading of the river bed. As pointed out by a country wide monitoring of the natural status of streams and rivers in Baden-Württemberg (6) the river Brenz is fairly far away from being a natural watercourse. The banks are well cut grasslands, only a few sections with natural vegetation or trees. Therefore the improvement of shade by planting trees and scrubs will have a major effect on the growth of weeds. Because of the statutory regulations for discharge control and the interference by riparian vegetation an investigation on the hydraulic influence of the riparian vegetation (7) is in preparation.

As pointed out by many other authors management (weed cutting) should be adapted to the needs of the river, done only when necessary, reduced to a small meandering channel in the river and done by ecological trained river keepers.

Acknowledgement

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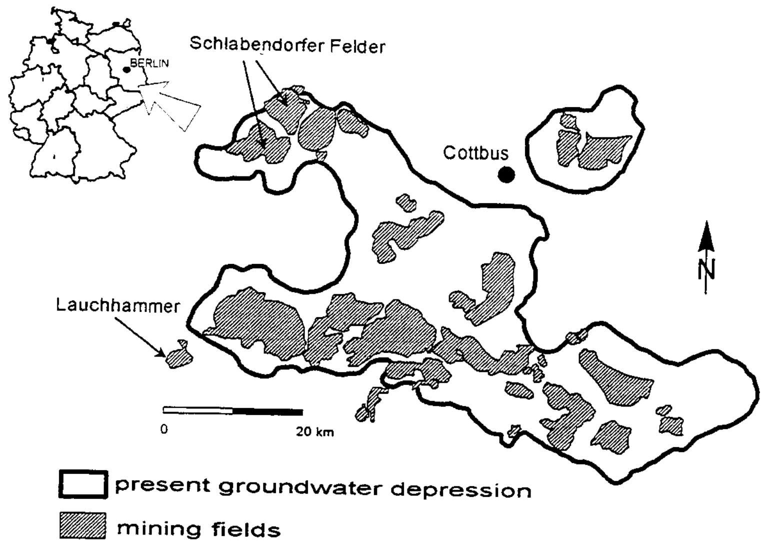

Figure 1. Outline of the 23 large open-cast mines in the Lower Lausitia and the extention of the coherent groundwater depression in 1992 (after Lausitia Brown Coal Agency , modified).

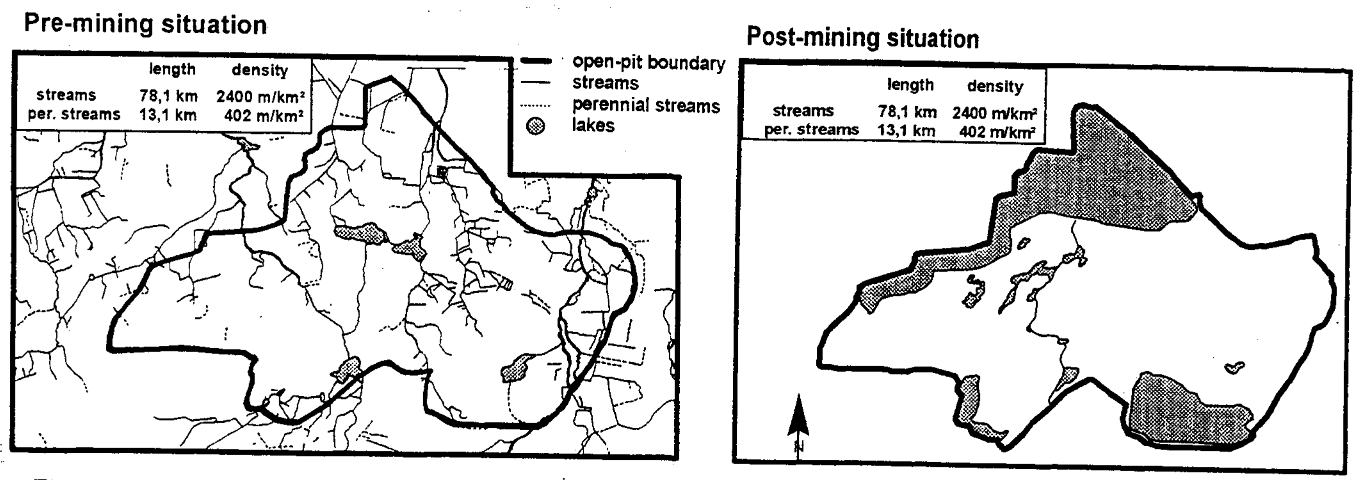

Figure 2. Change of stream systems in the mining area of Schlabendorf Shd. The post-mining situation shows only the streams within the former open-pit boundary.

Water quality of the streams

Through redeposition of the Tertiary overburden, sands showing sulphur contents of about 4 to 5% with little acid neutralizing capacity have been exposed at the surface. Subsoils show high contents of marcasite and pyrite, resulting in a severe potential for acidification of the percolating water. As a consequence, residual lakes and streams fed by such groundwater suffer from considerable acidification with pH-values below 3 and intensive ochre deposition. This impact on the water quality is influencing streams far beyond the actual mining areas. Due to the great extent of overburden displacement, active restoration measures such as liming of soils or water will not be successful in most cases. The present strategy for dealing with the acidification problem is to achieve water quantity management, for example by diluting the acid water within the stream systems and residual lakes and by restricting the problem to parts of the surface-water systems, which are generally not considered for human use. Active flooding of the residual open-cuts with river water rich in nutrients is intended, to control flow of groundwater and speed up natural recovery of acidified waterbodies by biological processes (1). Nevertheless large areas will have to deal with acidified waters for several decades, especially the natural recovery areas.

Hydrology of the streams

Pre-mining hydrology of the mining areas was largely dependent on the complexity of the ground in the end moraine areas of the Lausitia. Patchy layering of aquifers and water obstructions occurred and led to locally high groundwater, resulting in wetlands, springs, and exfiltration of groundwater in running waters. Through

Stream system restoration in a strip-mining region, Eastern Germany: Dimension, problems, and first steps

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Abstract

Excessive open-cast mining of lignite in the Lower Lausitia, eastern Germany, caused a new dimension in the field of stream system restoration. 740 km^2 of landscape have been destroyed by 1990, including topography and stream systems. Loss of streams is also reaching far beyond the actual open-pit boundaries due to the coherent groundwater depression covering 2100 km^2. Stream system restoration takes place in a man made landscape with at least in parts lasting unnatural conditions. A conceptual framework for specifying long term restoration goals in the man made environment is established, adapted to the complexity of comprehensive landscape restoration. This includes extensive surveys of stream structures and assessment of ecological functions in the post-mining areas. Standards to evaluate possible scenarios of development must be explicit and adapted to the specific constraints of the post-mining landscape.

Introduction

One of the most important German coal deposits is in the Lower Lausitia region in the eastern part of the country. Intensive extraction of brown coal (lignite) has been going on since the beginning of this century. Energy politics of the former German Democratic Republic, enforcing heavy exploitation of inland energy resources, resulted in a production peak of 200 million tons of coal per year in 1989. This excessive use of the geological resources in conjunction with the sudden economic changes in Germany after reunification, led to a new dimension in the task of restoration. Substantial reduction of lignite haulage caused a break down of the mining-based economy of the area. The restoration of the landscape is now a base for the necessary socioeconomic transition of the region and must be achieved as soon as possible. Concepts for the recultivation of the landscape and the recovery of the disturbed water balance are in progress. The regeneration of natural groundwater and surface-water systems are the main objectives of this task. This involves the fields of stream hydrology, water quality, and in particular the physical framework of the watercourses.

The goal of the paper is to give an insight into the complexity, specific constraints and problems of the ongoing and forthcoming stream system restoration. A conceptual framework for stream system restoration in the post-mining landscape under the specific conditions of the Lausitia is presented and considerations regarding the goals of stream system restoration in man made landscapes are given.

Dimensions of the restoration task

Consumption of landscape and running waters

Due to the shallow depth and the thinness of embedded coal seams, lignite was extracted by open-cast mining. Prior to coal conveyance, overburden of up to 80 m height had to be removed and redeposited, mostly by use of the bridge type conveyor technique. With this very productive technique high rates of advance could be achieved and strip-mining in the Lower Lausitia had covered an area of 740 km^2 by 1990, destroying all the elements of the earthsurface such as soils, topography and surface-waters (Fig. 1). Before 1990 only approximately 52% of this area had been recultivated and 350 km^2 remained as devastated landscape, which has to be reshaped by man. In these open-pit mining areas, restoration of running waters is part of a comprehensive restoration of landscape, creating new topography and soils in the catchments and stream corridors. The task is to create new watercourses as elements of the man made environment.

Surface-water systems of the post-mining landscape will be dominated by large and deep standing waters, the residual open-cuts. Main constraints for stream creation are valley topography, often shaped under the aspect of minimal mass displacement, high hydrological conductivity of ground (see below) and future groundwater level, in general predicted to be much lower than in the pre-mining situation. Under these conditions only a small percentage of the pre-mining watercourses can be created inside the former open-pit boundaries (Fig. 2). In planning, the future stream corridors often run through so called natural recovery areas, where regeneration of nature is not restricted by human activities. Here the topography of the streambed and the stream corridor should be shaped to create optimal support for natural self-regeneration and self-regulation. Asserting explicit physical parameters as a basis for stream creation causes considerable problems because of uncertainties in future hydrology and water quality.

predictions for the future ecological conditions are still changing as shown above. Therefore this evaluation has to be done constantly, leading step by step to a complete picture of the future framework for the streams under restoration.

- Second, reference streams are analyzed to determine quasi-natural properties. Since the basic target of the creation and restoration of the watercourses in the post-mining areas is the physical framework, stream morphology is the main emphasis of this analysis. Selection of reference streams is done according to the ongoing specification of post-mining conditions. Historical information derived from old topographic maps and data presently assessed by field surveys of the few remaining quasi-natural streams in the region are combined.
- Third, detailed information on site-specific potential and limits of stream restoration is collected and the impact of different types of mining on streams is specified. Survey of two representative mining fields is undertaken (Fig. 1): The 'Lauchhammer area', where coal-extraction commenced 1815 and the last of 22 smaller open-cast mines was shut down in 1966, and the 'Schlabendorfer Felder', where two large open-cast mines were operated by bridge conveyor technique from 1959 to 1991. The centre of interest of the survey is stream morphology, but evaluation of waterchemistry, aquatic and riparian vegetation, and macrozoobenthos are also included.
- Fourth, the magnitude of ecosystem processes and self-regeneration potential under post-mining conditions is estimated. This is done by interpretation of the survey data of the abandoned Lauchhammer mines and an assessment of selected ecological processes in different types of stream reaches in Lauchhammer. Processes assessed are primary production, community respiration, leaf-litter decomposition and formation of sediments.

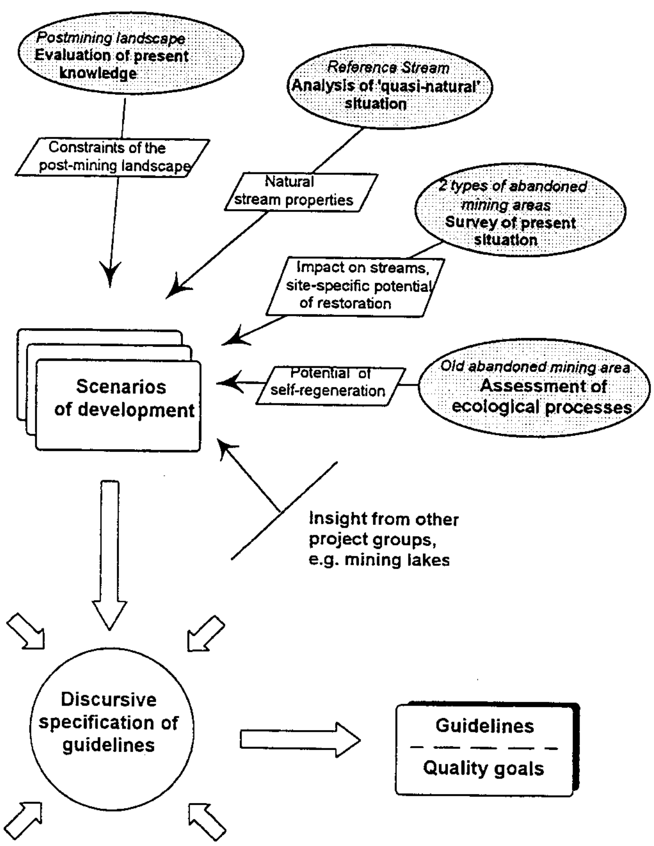

Figure 3. Conceptual framework to develop guidelines for streams in the post-mining landscape.

The information is completed with the insight provided by other parts of the project, in particular by the group working on residual lakes, which will be the sources of many post-mining streams. There will be a set of scenarios of stream development according to different post-mining conditions. The elaboration of this potential for development is a constant evolutionary process, starting with rather crude outlines and specification of the missing information and knowledge. Discursive interaction with other parts of the project guarantee that the different ideas concerning the ecological potential of interdependent objects of nature, such as lakes and streams, will fit together and form a holistic view of the post-mining landscape.

the mining technique of depositing the overburden by conveyor bridges, this patchy layering of cohesive material can not be reconstructed and largely uncohesive sulphureous virgin soils dominate hydrological conductivity (2). In addition changes in future landuse, also a consequence of low quality arable soils, which are deposited on the surface, will cause unpredictable changes in evapotranspiration, quantity of run-off and the level of the phreatic surface. Therefore concepts for stream system restoration must deal with these high uncertainties of basic parameters. In some cases stream corridor and streambed of headwaters, physically shaped during recultivation, could remain dry forever due to unpredictable high phreatic groundwater discharge.

Water balance of the Lower Lausitia

In addition to causing changes in the future water balance within the open-pit boundaries, mining also caused severe changes to the present water-balance of the Lausitia. For strip mining to take place, the water table of the mining areas had to be lowered below the depth of the workable coal-seams. Therefore intensive pumping and diverting of groundwater was done, reaching its maximum in 1989 with a quantity of 1220 million m^3 a^{-1}. The resulting coherent groundwater depression covers an area of 2100 km^2 (Fig. 1). The present water-deficit of the Lausitia compared to natural conditions is 13 billion m^3, with 9 billion for static groundwater and 4 billion m^3 for filling the worked-out open-cuts, future residual lakes resulting from mass-extraction (3). As a consequence of the man made water balance the springs have been depleted and almost all small streams have run dry or show only periodical discharge. The main watercourses have been developed as drainage systems for the rapid discharge of pump water. This includes the deepening, widening and canalization of the streambed. Only a few streams are fed with pump water to supply protected wetlands and woods or to fulfill basic demands for human use such as disposal of sewage. In all cases, no natural hydrological regime remains. The recovery of water balance is basic to stream system restoration and governs the timescale of restoration and the regeneration potential. Even rapid recovery of the water balance by active flooding of the area with water from the rivers Spree, Schwarze Elster and Neisse, will take approximately 20 to 30 years (1).

Although future hydrology and water quality, which will largely determine the potential for stream restoration, can at present not be exactly predicted, ideas about the stream restoration have to be developed as quickly as possible, because physical restoration of landscape and thereby creation of future watercourses is already beeing undertaken. Present guidelines for these restorations are based on traditional engineering approaches, which are unacceptable in natural recovery areas. The need for the ongoing very costly and far reaching restoration of an entire region must be seen as a chance to develop and accomplish long term goals for comprehensive ecological enhancement.

First steps to stream system restoration in the Lower Lausitia

Specifying the goal

In Germany and Austria, based on experiences in the field of nature conservation and the discussion on assessment of stream value, the so called guiding view-concept ('Leitbildkonzept') is established, which specifies the goals of stream development (4)(5). The guiding views represent the natural potential (6) and give guidelines to type-specific restoration measures. To develop such guidelines for the entire post-mining landscape in the Lower Lausitia, the interdisciplinary research project 'Guidelines for Natural Recovery Areas of the Post-mining Landscape' (LENAB) is now in progress. One task of this comprehensive cooperative project is to formulate scenarios of possible stream development as a basis for the discursive finding of guidelines (7). In general, guidelines are based on the analysis of present or historic pristine situations, where natural properties can be determined (4),(5). In Europe, and in particular in lowland regions, the 'natural' properties reflect a quasi-natural state of a historic situation of the streams in the cultivated landscape. So this acting implies the acceptance of the historical quasi-natural state as primary standard. In case of the Lausitian post-mining landscape specifying these properties of the quasi-natural situation is only one part of the task. Due to the irreversible changes of the framework for streams caused by mining, pre-mining streamtypes will be of limited use as a base for guidelines. In addition the limitations and possibilities resulting from the very specific post-mining conditions have to be ascertained and their effect on the potential of the stream's self-development must be considered. This is done by formulating scenarios of self-development based on the results of the following four activities (Fig. 3).

- First, the present knowledge of the conditions of the Lausitian post-mining landscape is evaluated to specify constraints for streamsystem restoration. This basic knowledge to stream restoration is very dynamic and actually quite difficult to assess, because different ecological processes and various socioeconomic ideas interact in a complex manner. The concepts of the future use of the post-mining landscape as well as the

River rehabilitation in an urban environment: Examples from the Mersey Basin, NW England

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Abstract

This paper looks at steps taken by the UK Environment Agency (and previously the National Rivers Authority NRA), to improve sections of two physically degraded watercourses in the Mersey Basin in NW England. It sets out the historical context for such heavily engineered watercourses and explains the rationale behind their rehabilitation. Whittle Brook, a small lowland watercourse, was unusual in that the highly engineered and managed stream ran through an area of landscaped "greenspace" in a modern housing development. The physical structures of the stream and its riparian zone have been restored as an integral feature of its local landscape. The River Alt is a medium-sized lowland watercourse that has been heavily 'channelised' in the past. As part of a community-driven catchment plan called "Alt 2000", a section of the river has been taken out of culvert and restored as an open river corridor designed to create a range of riparian habitats with associated landscaping. It is concluded that the involvement of multi-functional teams with the local community is the key to success.

Introduction

The Mersey Basin is a large, mainly urban/industrial catchment, where the rivers and riverine habitats have been grossly modified by human activity associated with agricultural, industrial and residential development (1). These factors have adversely affected the rivers' ecology, physical characteristics and visual appearance. The River Mersey is one of the most polluted and heavily engineered watercourses in Europe, described in 1982 as "An affront to the standards a civilised society should demand of its environment" by Michael Heseltine, the then Secretary of State for the Environment. However, recent improvements in water quality have led to the re-establishment of fish populations in parts of the lower Mersey Basin. Further improvements in water quality are planned (2).

The North West region of the UK Environment Agency (the Agency) is building on these water quality improvements by improving the physical structure of watercourses and their corridors as part of catchment-wide community-driven initiatives and has established a programme of river rehabilitation.

Our main objectives for these rehabilitation schemes are to:

- restore and create habitats for wildlife in river corridors
- involve local people and schools in decision-making and provide educational benefits
- improve the amenity and recreation value of the site, and therefore raise public awareness
- create a more natural watercourse and encourage the rivers self maintaining potential
- seek long-term improvements to water quality
- monitor effectiveness through post project appraisal

Other benefits include seeking improvements in water quality, pollution detection, and benefits for flood defence through increased flood storage capacity and a requirement for less intensive river maintenance.

The sites

Whittle Brook (Bk) and the River (R) Alt, are located in urban areas of the Mersey Basin and have suffered from poor water quality. This affected what could be done in terms of design and construction of the rehabilitation schemes. The impracticalities of restoring rivers to their original or pre-disturbance conditions in such locations are highlighted by (3) amongst others.

Whittle Bk, a small lowland watercourse in Warrington, was unusual in that part of the highly engineered and managed stream ran through an area of landscaped 'green space' in a modern housing development. The scheme area was 1.7 km in length. The ecological value of the brook was limited. Biological surveys of macroinvertebrate samples had indicated that water quality was 'fair' to 'poor'. Fisheries surveys in autumn 1994 found small numbers of eels (*Anguilla anguilla*), flounders (*Platichthys flesus*) and goby (*Pomatoschistus microps*). Agricultural improvements and recent development pressure were key factors in the shaping of the brook's character and corridor. Water quality problems were caused by enrichment from upstream agricultural improvements, organic pollution from contaminated surface water outfalls including domestic discharges e.g. washing machines wrongly connected to the surface water drainage system ("wrong connections").

The problem of evaluation

Although the primary goal of the project is to outline scenarios of stream development, the rating of these scenarios from the viewpoint of ecologists has to be done, because it is a necessary input into the discursive social process of finding the definite guideline (7). The rating is closely related to the problem of specifying stream-value. Fortunately, in the field of river or stream conservation many different criteria have been developed to evaluate streams. This includes parameter-systems for quantitative assessment of structural properties, which indicate the physical state of streams. Establishing the appropriate standards for evaluation is still critical. As mentioned before, in Germany and Austria 'naturalness' is implicitly the main standard in running water evaluation, as well as in water legislation. The specification of the quasi-natural properties and definition of the most favorable state of the streams is one and the same. In areas where the quasi-natural framework of streams can not be established e.g. in urban areas and at least in some parts of the post-mining landscape, explicit standards, other than naturalness must be found. In the Lausitian post-mining landscape three site-specific cases are identified regarding standards for evaluation:

1. Only a few parameters of the stream's framework have been changed, but the stream development can lead to the quasi-natural situation of the pre-mining landscape (e.g. a man made v-shaped valley only determines unnatural sinuosity of a stream reach). Naturalness can still be used as primary standard for the evaluation of development scenarios.
2. Basic parameters of the stream's framework have been changed. The resulting post-mining streamtypes have not been present in the quasi-natural pre-mining situation of the Lausitia, but stream development can lead to a situation, which is quasi-natural in an other area showing comparable climatic and geological features (e.g. streams with large deep lakes as sources). In this case the standard for evaluation will also be naturalness but refering to the quasi-natural properties of this other area.
3. Basic parameters of the stream's framework have been changed to unnatural conditions, which are not present in any landscape with comparable climatic and geologic features. Stream development can not result a in quasi-natural situation (e.g. the streams water showing pH < 3). In this case I suggest as primary standards the dynamic of abiotic processes - in particular the dynamic of discharge and streambed morphology - and the undirected biological sucsession. This choice is based on the limitations, but also on the possibilities of these sites, where space and time is available to allow free self-development in a wide stream corridor over a period of 100 - 200 years. It also implies the acceptance of situations, which are not part of our present or historic cultivated landscape. Using these standards in developing guidelines for stream restoration, will foremost result in the creation of streambeds with a high potential for morphological dynamics (e.g. high frequency of bankfull discharge).

The selection of the final set of standards will be the result of an interdisciplinary discussion. This discussion has to involve experts of different fields as well as social and political groups to guarantee stability and acceptance of the guidelines developed, as it is necessary for successful long term restoration. It will be based on the information collected during the project and the above presented standards for evaluation.

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Site selection, feasibility, design and construction

The two schemes were managed independently of each other by project teams. The teams were similar in composition, with a core of representatives from flood defence, ecology, pollution control and landscape sections. Inputs from other sections e.g. hydrometry, water quality planning and fisheries were also provided as required. The R Alt scheme was designed and executed by its in-house project team. Whittle Bk scheme was designed by a external, multi-disciplinary group of consultants working with the project team. These included engineers, geomorphologists, ecologists, landscape architects and planners. Both schemes were constructed using external contractors. For the Whittle Bk scheme, the consultants produced detailed designs and provided the resident engineer supervising the contractors for the construction works. The contractors did both the detailed design and built the R Alt scheme, with site supervision provided by the NRA.

Potential sites were identified through area consultation and local knowledge and evaluated and ranked using criteria based on the methodology described in River Restoration Project (4)(5). Sites in the South Area were from a number of different catchments and rivers. In the Central Area, attention was focused on the R Alt catchment. This was to take advantage of planned water quality improvements and the existence of the "Alt 2000" project; this is a community-driven catchment plan and river valley initiative which aims to raise awareness of and identify opportunities for environmental improvement. The schemes presented here emerged as the top scoring projects in each area.

Due to the conditions attached to the funding (source NRA), the selection, feasibility, design and substantial construction work had to be completed within the 1994/95 financial year (1 April - 31 March). This tight timescale imposed limitations on the design period and the scope of the designs that could be considered. The flood defence function of the watercourses had to be maintained. Physical constraints included the close proximity of housing, existing bridges, service pipelines and spoil disposal. Other constraints were the protection of the existing buildings, public safety, public access during construction works, future development potential of surrounding land and the existing culvert on the R Alt. Residents adjacent to the R Alt site were also extremely concerned about security issues.

Detailed appraisal studies were undertaken to develop the optimal river rehabilitation solution under present conditions and constraints. Consultation with the local authority and various interested groups were important parts of this stage. The responses were used to guide development of the design.

On Whittle Bk the optimal solution focused on restoring sinuosity and connecting the stream to the floodplain where possible. Extensive consultations with the local authority and local community then took place and included exhibitions, talks and meetings. The costs of the feasibility and design works for this scheme were approximately £183,000, with construction costs estimated at £127,000. Whittle Bk Scheme included a geomorphological assessment as an important part of the feasibility and development of the final design. The value of this assessment was to confirm the rehabilitation potential of the site and recommend sustainable environmental improvements.

There was no geomorphological input on the River Alt Scheme. Old maps and drawings were consulted in order to try to establish the historical course of the River Alt. The earliest map that could be found (1845) indicated an artificial, straight channel. With the lack of evidence for what might have been a natural channel for the river, a 'naturalistic' channel was designed by the NRA project team. The profile and section of the channel on the R Alt scheme were primarily designed using engineering criteria, but also with landscape and wildlife features in mind (for examples see (6)). The engineering drawings were produced first with landscaping features added afterwards. Further consultation with the local authority and local residents' groups took place.The costs of the feasibility and design works for this scheme were approximately £25,000 with construction costs at £200,000.

The timing of the construction phase brought several problems. Wet weather during the first six weeks of the contract period delayed works, increasing construction costs on Whittle Bk to over £200,000, and created problems for machines and haul routes. The region then had the driest summer for many years which helped the earthworks but led to problems with germination of the pre-seeded geotextile ('grassmat') used to cover the newly excavated banks on Whittle Bk. The drought conditions experienced in NW England during 1995 and 1996 also affected planting work, particularly tree planting in the Alt scheme with failure rates of 35% overall and 60% in some parts of the site.

The planned winter working period led to some elements of over-design in the Whittle Bk scheme, particularly in bank stabilisation techniques used. The low-level berms were protected using coir matting which worked well. However, the use of 'grassmat' to protect the upper berms and banks and provide a seed

The R Alt is a medium-sized, lowland watercourse which drains half of the area of Liverpool. From its source in Huyton, it flows for 15 km through intensively developed urban areas. For the remainder of its 28 km length, it drains a productive agricultural area, before discharging into the estuary via a pumping station. The scheme presented here was 200m long and was located near the top of the catchment in open space between two housing developments. The river had been culverted in the early 1970s with the intention of building further housing on the land. The water quality was poor, with only the occasional stickleback (*Gasterostus aculeatus*) found and pollution-tolerant fauna. Water quality problems in this stretch were associated with inadequately treated sewage discharges from wastewater treatment works, discharges from combined sewer overflows and 'wrong connections'. A summary of both schemes' catchment characteristics are given in Table 1.

Table 1: Catchment Characteristics summaries for Whittle Bk and R Alt (adapted from (14)(15)).

Characteristic	**Whittle Brook**	**River Alt**
Catchment Area	20.7 km^2	230 km^2 (9.5 km^2 for study area)
Mainstream length	7.5 km Study reach: 1.7 km	28 km Study reach: 0.2 km
Slope	0.0067 $m\ m^{-1}$	0.00125 $m\ m^{-1}$
Geology (Solid)	Drift is underlain by Triassic Pebble Beds in west and by Wilmslow Sandstone to the east.	Drift is underlain by Mercia Mudstones in lower catchment and Sherwood Sandstones in upper catchment. Study site lies on Carboniferous Coal Measures.
Geology (Drift)	Deposits of alluvium with glacial boulder clay at upstream end, with cover of alluvium and blown sand in the downstream end of the site	Upper catchment glacial boulder clay and wind-blown sands. Lower catchment contains large areas of peat and alluvium. Study area is on boulder clay.
Soils	Soil Type 4 (FSR) Low Winter Rainfall Acceptance Potential (WRAP) class. Stagnogley soils. Non- calcareous loamy, clayey in associated drift deposits in low permeable subsoil. Made ground with shallow (0.1 -0.4 m) topsoil.	Non calcareous clayey loam with lenses of sand. considerable deposited fill and rubble found on study area.
Landuse	Residential in the downstream catchment 22% urbanised, with arable and small woodland upstream. Urbanisation is predicted to increase to c40%. Former mining in upper catchment. High level of landscaping and maintenance.	Residential and industrial in upper catchment, 80% urbanised. Lower catchment intensive arable land.
Width/Depth Ratio	3 - 4 (Width is 3 to 4 times the depth)	
Planform	Sinuous (low sinuosity with straight and wide bends)	straightened in the study area and upper catchment. No direct evidence of previous form in study area (pre 1894 map). Sinuous in lower catchment.
Stability	Formerly with high sinuosity, now modified trapezoidal channel with accumulation of silty berms, part of lower section gabioned.	Unknown
Sinuosity (P)	Old channel (1928) 1.254, new channelised section (1992) 1.045	In straight culvert
Power	31 Wm-2	2 $W\ m^{-2}$
Sediment sources	Fines from bank erosion is limited, urban runoff, outfall and culvert runoff	Fines from bank erosion limited due to culvert, upstream urban runoff, culvert and outfall runoff.
Floodplain	Parkland and gardens, made ground and landscaped, right bank steep and flat on left bank (looking downstream)	Houses and gardens, some open space and school playing fields.
Conservation value	Present value lies in the low silty berms that have been formed in the reprofiled channel and which are now vegetated with tall herb and rough grass, and occasional willow	Present value low. Study area is rank, unmanaged grassland used for informal recreation, some habitat for small rodents and associated predators.
Principal tributary streams	One major culverted input, not flowing at time of survey	None
Constraints	Natural features, projected development and flood defence requirements	Existing culvert, flood defence requirements, access requirements.

Figure 1. Stretch of River Alt after rehabilitation scheme.

Figure 2. Stretch of Whittle Brook after rehabilitation scheme.

mat appeared over-extensive, covered large areas of the re-profiled banks, and looked like carpet underlay; however, it has helped in the control of pernicious weeds on the site.

It proved very difficult to implement some designs as planned. The design of the small ox-bow pond and remote floodbanks, for the Whittle Bk scheme, looked quite natural on paper but during construction the restrictions imposed by the need to maintain machine access to the floodbanks led to a very 'engineered' end result. There was an unplanned change in the design on the Alt scheme after breaking out the culvert when it was discovered that upstream channel bed levels were going to be some 200 mm lower than expected. A proposed riffle area was lost and the wetland 'backwater' was stranded above normal water level!

Local residents in both scheme areas were leafleted prior to any construction works commencing. However, the close proximity of the works to houses caused some concerns, such as noise and disturbance to footpaths and access routes. Safety on site was a prime concern, particularly when breaking out the culvert on the R Alt scheme, as the area was popular with local children. Vandalism was a common problem during construction works for both schemes, mainly the grassmat and fencing on Whittle Bk, and fixtures and fittings such as benches and stone cladding on bridges and headwalls on the R Alt.

Initial results and observations

The results achieved by both schemes, approximately one year after completion of major construction works, have been assessed against the original objectives set by the Agency for river rehabilitation (Table 2). The assessment shows a general success in achieving most of the original objectives.

There was little experience in river rehabilitation schemes amongst UK civil engineering contractors. The machine operatives wanted to create uniform banks with hard edges and little variety in profile, as was the requirement on most civil engineering schemes. Skill and time were needed in directing the contractor to give the works a 'natural' feel. The engineered-led appearance was particularly apparent on the R Alt scheme (Fig. 1). On Whittle Bk, the use of a multi-disciplined consultancy team with close site supervision appeared to have led to a more 'natural' design with variety in form and profile (Fig. 2).

Table 2: Assessment of scheme results against original criteria set.

	Objective achieved? Whittle Brook	**Objective achieved? River Alt**
Restore and create habitats	Yes	Yes
Improve amenity and recreation value	Yes	Yes but limited public access to the site at present
Create more natural watercourse	Yes Too early to assess self-maintaining potential	Yes Too early to assess self-maintaining potential
Increase awareness and apprecition of water environment	Awareness raised but appreciation difficult to measure - litter and vandalism still a problem	Awareness raised but not all residents have responded positively to presence of river. Litter and vandalism still a problem.
Involve local people & schools in decision making and provide educational benefits	Local people and schools involved at all stages. Local schools and Ranger Service make use of the site for projects. Nature area for school created as part of scheme.	Local people involved at all stages. Little interest by schools to date.
Implement work on the ground using integrated approach at all stages	Yes and scheme has adopted integrated approach at all stages	Yes and scheme has adopted integrated approach at early stages of feasibility and design
Monitor effectiveness through post project appraisal	Quarterly PPA for first year by consultants - report still awaited. Agency will monitor in future.	PPA being carried out by the Agency - no results available as yet.
Water quality improvements	Little evidence as yet (Biological monitoring of aquatic invertebrates in 1996 has recorded BMWP scores of 18-41 with ASPTs of 3-4.1; in 1994 BMWP of 22-27 & ASPTs of 3.4-4) but has influenced North West Water move forward its planned programme of improvements to sewerage system	Too early to say - water quality improvements planned throughout Alt catchment. Some evidence of improvement in aquatic invertebrate community in study area (BMWP score increased to 24 in 1996; in 1994 BMWP of 15 with ASPT of 3).

BMWP - Biological Monitoring Working Party ASPT - Average Score Per Taxon

Conclusions

In an urban environment it is really only possible to undertake river rehabilitation rather than total restoration of the river with its floodplain, due to the many constraints operating in such an environment. However, the value of such schemes in an urban environment are still very important. The authors believe that it is vital that river rehabilitation schemes adopt a multi-functional approach at all stages of the process, but the cost implications of such large teams have to be taken into account. It is equally important that all sectors of the community are involved and as early as possible in discussions on potential rehabilitation schemes. Finally, the importance of focusing on catchments to plan and drive such projects is stressed. Whittle Bk and the R Alt have only recently been constructed and it is important that lessons learned at all stages of these schemes, particularly monitoring against objectives, are incorporated into future projects by the Agency.

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There were clear differences between the outcomes of the two schemes. The differences were partly due to the different nature of the two sites, but also due to differences in approach to the design, the nature of the designs themselves and the way in which work was carried out on the ground. Whittle Bk involved the use of consultants as well as an NRA project team. The value of having a multi-functional project team involved at all stages in an integrated design approach, is advocated by (7), particularly on "engineered waterway corridors prevalent in urban corridors" such as those in the Mersey Basin. The Whittle Bk scheme benefited from the wealth of professional expertise used but this increased the overall costs. However, costs were offset in that the same consultants also undertook detailed appraisals of three other potential river rehabilitation schemes in the south area, which may be developed in the future should funding become available. The R Alt scheme had the benefit of cheaper design costs, but the engineering-led approach was reflected in the final design. The use of civil engineering contractors to construct both schemes created problems in constructing 'natural' features; this was particularly apparent on the R Alt scheme where the contract was 'design and build'.

The value of employing geomorphologists in a river rehabilitation project team is also reflected in the design of the Whittle Brook scheme when compared with that of the R Alt. The geomorphologists understand river dimensions and behaviour but they also understand ecology. The use of geomorphology is vital if there is to be an understanding of the nature of the catchment sediment system and the most appropriate channel morphology for the contemporary catchment processes. Such a view has been highlighted by (3)(8)(9) amongst others. However more information is needed on the morphological performance of restored river channels before their success can be confirmed geomorphologically (3)(8). Geomorphological assessment is part of the PPA of the Whittle Bk scheme.

A more 'natural' watercourse has been created in the Whittle Bk scheme, and one which is more in keeping with the local landscaping. The characteristics of the channel are now more in keeping with its former, unrestrained character. However, it will never be totally restored due to the various constraints imposed by its urban location and catchment characteristics. Full restoration of rivers, more common in countries such as Germany as described by (10), is not really feasible in highly urbanised catchments such as the Mersey Basin with limited available width in the river corridors. However, real and positive improvements in river landscape, amenity and ecology can be made. This has been particularly apparent in the case of the river Alt, where a "lost" river has been "restored to light".

Public reaction on Whittle Bk has been generally good after the initial concerns raised during the construction phase. On the R Alt more work is needed to persuade local residents to allow open access to the river. Local communities were involved in both schemes, but seem to have responded more positively to the aims of river rehabilitation on Whittle Bk than on the R Alt, which may be due to the more extensive public consultations undertaken on the former scheme. Much research on public perception of rivers has been carried out (11)(12) and people have clear views on what they consider to be 'attractive' or 'polluted' rivers. In the case of the R Alt, the authors believe that the perceptions of the river to the residents were minor when compared with their over-riding concerns about security issues in the area.

The success of these projects has created a snowball effect. The success of the "Alt 2000" Project in particular has spawned the development of a number of River Valley Initiatives (RVI) in the Mersey Basin. These are working partnerships between the public, private and voluntary bodies. Their main aims are to raise awareness of and identify opportunities for development and environmental improvement along a river and its corridor. Coupled with the integrated local management plans based on river catchment areas, these will highlight potential sites for future river rehabilitation. Experience with the "Alt 2000" initiative and the interest generated by the Whittle Brook scheme indicates that involvement by all sectors of the community is vital and that the best way forward is through the support of existing RVIs and the promotion of new ones. Such a view is supported by (13) when he highlights the success of community participation in the Medway River Project. Whittle Brook is part of the "Sankey Now" RVI and the perceived success of the scheme has encouraged the Initiative to explore other tributaries within the catchment for potential rehabilitation schemes. The local authority has responded very favourably and is keen to see other schemes in their area. Rehabilitation work is planned on a stretch of another tributary in Warrington and on another stretch of the river Alt in autumn 1996.

kessleri, and a number of species in the family of Percidae). Dependant on the species and life stage, the land/water ecotone also play an important role (2). Shallow water zones along the river banks, which offer varying flow velocities and food during fluctuating water levels, constitute valuable reproduction and breeding areas.

Within the group of rheophilic fish, whose total life cycle takes place in the main channel, some species (striped ruffe *Gymnocephalus schrätzer*, Rußnase *Vimba vimba*, and the white eye *Abramis sapa*) prefer more moderately flowing stretches. Optimal habitats for these species are mainly found in side channels where finer sediment fractions and lower flow velocities prevail. These secondary channels are subject to strong seasonal changes in respect to discharge and flow velocity. In addition to main-channel rheophilic species, other rheophilic species require open, interconnected oxbows to complete specific stages of their life cycle. These oxbows are subject to strong hydrological dynamics due to their frequent connection to the main channel. These dynamics result in the sparse growth of macrophytes. Dense macrophytic cover is characteristic for oxbows which are only rarely connected with, or flooded by, the main channel. These waters are subject to falling dry, and are also different from open oxbow systems in that limnophilic species dominant the fish assemblage. Only limnophilic species can tolerate, or to some degree require, these ephemeral conditions characterised by swamp land vegetation. There are only a few such species in the Austrian Danube (e.g. mud loaches *Missgurnus fossilis* and the Giebel *Carassius auratus gibelio*). In addition to rheophilic and limnophilic species, there are also a number of generalist species found in the Danube which are somewhat indifferent to specific flow-velocity conditions.

While today, along free-flowing stretches of the Danube, one can find a high number of lentic backwaters which are only rarely flooded due to the regulation of the main channel, open oxbows and side channels are comparatively scarce. The original braided channel system was characterised by tremendous heterogeneity guaranteeing a mosaic distribution of the full variety of secondary channel habitats. In comparison, in the impounded stretches, no original habitat types can be found. The goal of ecological improvement of Danube impoundments is to promote the development of environmental conditions which fulfil, to the extent possible the ecological function of original habitats.

Hydrological conditions in a Danube impoundment

While in remaining free-flowing stretches, more or less similar hydrological profiles exist throughout, impounded areas reveal a common pattern of longitudinal zonation. Therefore, the possibility of using specific restorative measures depends strongly on the location within an impoundment. Flow conditions at the head of an impoundment are most similar to unimpounded areas. There are high fluctuations in the water level, moderate flow velocities, and the dominant substrate within the channel profile is gravel. Downstream of this area, the increasing depths and decreasing flow velocity result in the increasing deposition of fine sediments along the banks. Fluctuations in the water level are as well minimised and, at some point towards the middle of the impoundment, a point of zero water-level fluctuation (maintained by either releasing or withholding the fluctuating discharge of the river at the dam) referred to as the *Kippegel*, is reached. Downstream from the *Kippegel*, the prevailing conditions do not reveal any elements typical of a river. The extreme reduction in flow velocity with increasing water depth also results in the deposition of fine sediments several meters thick. At high discharges, the water level below the *Kippegel* can be actually lowered by several meters due to surplus releases at the dam. This potential situation is an important and severely limiting factor in attempting restorative measures in this area of the impoundment.

Technical possibilities for the ecological improvement of Danube impoundments:

Dependent on technical, topographical and hydrological considerations, there are five groups of revitalisation measures which could be realised within an impounded stretch. These measures do not aim for the impossible, that is to reconstruct natural ecosystems in their entirety, but strive to improve those portions of the riverine landscape which have already been strongly altered by man (3).

These measures can be described shortly as follows:

- Broadening the now linearly constructed reach of the impoundment head in order to bifurcate or braid the river channel;
- Creating characteristic river structures (gravel bars, islands, etc.) in the head of the impoundment;
- Moving back the flood control dams from the banks in order to enlarge the inundation zones;
- Re-establishing flow into previously cut-off side-channels and ditches by constructing numerous flow structures with the help of overflow stretches;
- Creating bank structures in the central impoundment area to increase the heterogeneity of the bank line.

1) Recommendations in the floodplain the impoundment head

Dependent on site-specific hydrological conditions, it is possible to implement restoration measures in the head of an impoundment which, at best, nearly restore elements of the original Danube.

In most cases, the head of an impoundment is isolated from the riparian area due to the dredging of the river bed in the course of the hydropower plant construction. This isolation prevents the development of the typical bottom land vegetation which would be positive for both ecological and economic reasons. By broadening the flood plain in the impoundment head, a braided channel reach could be recreated. This would expose old oxbows, side channels, and ditches to river flow, create new side channels, and result in

Ecological evaluation of Danubian impoundments: Present circumstances and possibilities

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Introduction

Natural riverine habitats and their accompanying landscapes are decimated to the degree that they can often not fulfil a variety of important ecological functions. Various competing interests and uses have lead to radical changes in the sum total of natural characteristics along the Danube river. Development and rehabilitation measures, currently offered to improve upon, or at least consider the deficit of natural habitats, have rarely considered the varying ecological ramifications.

Present situation

The Danube River, with a length of 2,888 km and a drainage area of 817,000 km^2, is the second largest river of Europe; only the Volga is larger. Of the 351 river kilometres contained in Austria, 280 will be regulated by impoundments following the completion of the hydropower plant Wien-Freudenau, near the city limits of Vienna (Fig. 1).

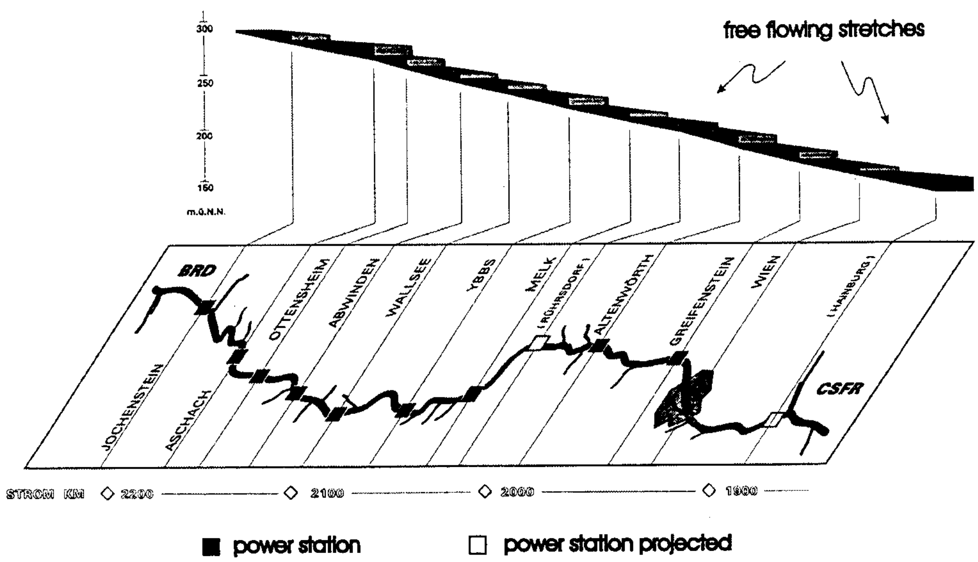

Figure 1. Eighty percent of the Austrian Danube is presently regulated by impoundments.

In addition to hydropower production, several other human activities have a negative influence on the ecological functions of various riverine habitats; these include shipping traffic, agricultural and forestry practices, gravel extraction, fisheries, and other leisure-time pursuits.

Although the river channel in the unimpounded stretches is straightened, and is also to a degree rip-rapped, it nevertheless provides a variety of habitats which meet the needs of the local aquatic fauna. In contrast, the impounded reaches are characterised by continuous and monotonous rip-rapped banks.

In the case of the Danube, habitat heterogeneity is one of the more important characteristics responsible for the occurrence of a high number of fish species. The lack of natural habitats in impounded river stretches is likewise reflected in a loss of typical Danube fish assemblages (1). Therefore, typical riverine elements and conditions are a necessary precondition to preserve and develop the indigenous fish fauna. These environmental conditions were mosaically distributed within the braided channel patterns of the original riverine landscape. Even today, such elements, although fragmented and scarce, are to be found in the regulated but free-flowing stretches of the Austrian Danube. These physical characteristics serve as a model to guide various restoration measures which can be carried out in the different areas of impoundments.

Habitat types of the Danube

The most important habitat types and their importance to the fish assemblage will be briefly presented as follows:

A large portion of the Danubian fish fauna can be classified as rheophilic. The life cycle of many of these species is carried out in the main channel (nase *Chondrostoma nasus*, barbel B*arbus barbus*, Frauennerfling *Rutilus pigus virgo,* long whiskered gudgeon *Gobio uranoscopus,* Dnestr long-whiskered gudgeon *Gobio*

Ecological assessment
Depending on the limiting abiotic preconditions, the ecological worth of various measures must be assessed differently. The more a restoration measure succeeds in providing the conditions of the former braided channel system, the more likely these newly created habitats will promote typical and sometimes endemic species of the Danube.

Recommendations group 1:
Broadening the river corridor to create a braided channel system results in characteristics that closely match our model of the former river system. Only the lower fluctuations of the water level caused by the impoundment, and the lack of, or reduced bed-load, limit this measure's power to restore the ecological integrity of the system. In addition to ecological improvements there are also both aesthetic and socio-economic gains.

Recommendation group 2:
Creating structures typical for riverine environments also promotes the local rheophilic fauna. These species are among the most endangered since their habitats are rare. Even if these measures, in most cases, are limited to the upper quarter of an impoundment, ecologically desirable effects can be gained for the whole impounded area.

Recommendation group 3:
Because the abiotic conditions just downstream from the impoundment head begin to deviate widely from the original conditions, it is difficult for any restoration measures to restore the ecological integrity of the river system. Despite the potential large-scale gain in aquatic and semi-aquatic habitat when flood protection dams and dikes are moved further back from the river, the stabile water level and low current velocities found in these areas typically promote ubiquitous ecological generalists, and not the species most in need of protection. More specialised, or endemic species, only profit from these measures to a small degree.

Recommendation group 4:
The construction of flow structures for former, or presently isolated, riparian wetlands, is generally accompanied by ecological improvements for the entire river system. The variety of aquatic and semi-aquatic environments maintained by such measures, provide ecological niches to a host of species which, at least partially, can compensate for the loss of original habitats. But even if migration corridors between the lower and upper areas of the impoundment are created, the lateral connectivity of the river and its riparian wetlands, so important for sustaining the successional dynamics of these normally dynamic environments, is usually still lacking.

Recommendation group 5:
If an evaluation of the success of a particular restoration measure is based on promoting former abiotic or biotic elements of the Danube, or those species most endangered by the loss of riverine habitat, the limited measures available in the central and lower impoundment would be considered unfavourable. This is despite the fact that these habitats are characterised by high species numbers and densities.

Summary
Eighty percent of the Austrian Danube is presently regulated by impoundments. Resulting from the largely monotonous and technically oriented engineering of the river channel, and the subsequent massive changes of both hydrologic and topographic conditions, the resulting habitats are unfavourable in promoting the indigenous aquatic fauna. The promotion and perhaps preservation of these species can accomplished with the ecological rehabilitation of these impoundments. The corresponding restoration measures available however, will to some degree, have very different results toward achieving this goal. Priority should be given to those measures which can realistically bring back the heterogeneous habitats of the original braided channel system. The ability of particular measures, in particular areas of the impoundment, to result in positive ecological effects, correlates strongly with the presently limiting abiotic conditions. Due to its similarity with former riverine conditions, the head of the impoundment holds the highest potential for ecologically beneficial improvements. It must however be clearly understood, that none of the rehabilitation measures discussed can hope to restore the natural ecosystem, but rather provide some improvement to a landscape which has already been drastically altered by man. With this perspective, the preservation of the few remaining free-flowing river stretches in Austria should be paramount.

an increase in the total area of riparian habitats. Gained as well are the former dynamic processes like flooding, erosion, sedimentation, and groundwater fluctuations, which contribute to the maintenance of the various successional stages of both aquatic and terrestrial communities.

The feasibility of realising such restorative measures on a large scale (> 100 ha) is aided by the fact that the excavated gravel can be sold to help finance the operation (4). Additionally, at higher discharges, water levels at these impoundment heads will be lower than at present, increasing the head of upstream hydropower power plants. And last but not least, the recreational value of the riverine landscape is increased through the improvement of both ecological and aesthetic conditions.

2) Within-channel recommendations in the impoundment head

River engineering measures on the Danube led to a drastic decrease in structural elements like gravel bars and islands. In impoundments, such riverine structures, can again, only be created or maintained in the impoundment head. Especially in the Danube, the reproductive and rearing phases of rheophilic species can only be fulfilled within the habitats created by gravel bars and islands. Thus, the creation of such structure promotes and strengthens that portion of the fish fauna which is most affected by impoundments. By building up presently inundated gravel bars, in hydrological suitable areas, these vital habitats can be realistically restored. Due to the lower amplitude of water level fluctuations, the height of these structures is an important technical consideration. The maintenance of suitable depths in the shallow water zones surrounding these structures, during the spawning season of various rheophilic species, is especially important. The feasibility of realising these restoration measures in the Danube is dependant on minimising potential socio-political and economic conflicts as well as both planning and building expenses.

Several projects completed by the water transit authority provide some background data and experience to help guide future projects involving these measures. Zauner et al. (5) provides some data on the succession of sedimentary and morphological processes of newly created gravel structures in the head of the impoundment behind the power plant Aschach.

3) Recommendations in the floodplain downstream of the impoundment head

Below the impoundment head, broadening the flood plain can as well promote some elements of the original riverine environment. By setting flood-control dams further back from their present location, shallow water zones can be created in which additional structures can also be placed. The inclusion of riverine wetlands in the dynamics of the discharge regime, can guarantee the regeneration and maintenance of ecologically valuable habitats; examples of these measures can be seen along the impoundments of the lower Inn River (6)(7). Due to both hydrological and topographical conditions these measures are probably useful only as far downstream as the *Kippegel.*

4) Recommendations in the floodplain the central and lower impoundment head

While the large, channel regulation measures in the Danube were the primary cause of the loss of free-flowing side channels in favour of large cut-off oxbows, the impoundments also cut existing side channels off the main channel, inhibited more frequent flooding of the bottom land forest, and accelerated the sedimentation of seasonally inundated backwaters. To meet the model of a braided channel system, flow must necessarily be restored to these relic side channels. The restoration of hydrodynamic processes in the riparian zones of the central and lower impoundment are at least partially feasible using the surplus river flows that occur during floods, which in any case, are not used for hydropower production. These surplus flows can help recharge an array of aquatic habitats including not only side channels but small ponds, swamp land, and groundwater reservoirs. The realisation of these measures however can not be simply met through flooding, but must include reshaping, opening, and where necessary, creating the proper side channel and riparian characteristics. Existing alterations and artificially constructed channels have to be modified to conform to the landscape, and be efficiently incorporated into a network of flow structures that optimises surplus river flows in creating aquatic and semi-aquatic environments. Ideally, the initial connection or input of main-channel flow into the riparian area should occur as high up in the impoundment head as possible. Outlet flows from the riparian wetlands into the lower end of the impoundment may allow for the immigration and emigration of aquatic fauna throughout the system.

5) Within-channel recommendations in the central and lower impoundment

In the central areas of the impoundment the possibilities for ecological improvement are considerably limited due to a range of technical demands of the power plant authorities. Therefore, recommended measures focus only on improving and naturalising the structure and heterogeneity of the bank where the floodplain has been unnaturally widened, or along existing point bars of the impoundment. The aggradation of fine sediments or deposits of dredged material can provide the materials for restructuring the bank line. In this area, stable water levels can allow for the evolution of spawning and rearing habitats for both stagnophilic and generalist fish species. Unfortunately, the potential of these habitats to function as high water refugia is greatly diminished by the expectation of sudden drops in water level during surplus flow releases.

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Poster proceedings

The brook of Hvidøre is planned to be restored by separating the sewage and stormwater from the rain- and drainage water. The sewage will still be pumped to the treatment plant in Copenhagen. The restoration of the Brook of Hvidøre consists of 4 main-purposes:

- improving the possibilities of natural and historical/ cultural experiences to the public in this town-near recreational area;
- improving habitats for flora and fauna;
- to ensure that clean surface waters are led to the Sound instead of being led to the sewer-system;
- improving water quality in streams and wetlands along the Brook of Hvidøre and its catchment-area.

The project is planned to start out in 1997 and the total costs of project are believed to be 13 mio. DKK. The main costs are mainly connected to the renewal plans of the sewer system.

Example of Stream Restoration - the Brook of Hvidøre

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Project-area

In the northern part of the Municipality of Gentofte north of Copenhagen it is planned to restore a stream of approximately 4 km - the Enghaverende (Fig. 1). The restoration is a municipal project planned in close co-operation with the Jægersborg Forest District and RAMBØLL as the consultant for the Municipality.

The Enghaverenden used to be a natural stream flowing from the Lake of Gentofte to Øresund through a sub-glacial stream trench. As the municipality developed, the stream was piped and the surface water was led to the sewage-system instead. During the period of the project it has been decided to rename the brook with its original name: the brook of Hvidøre

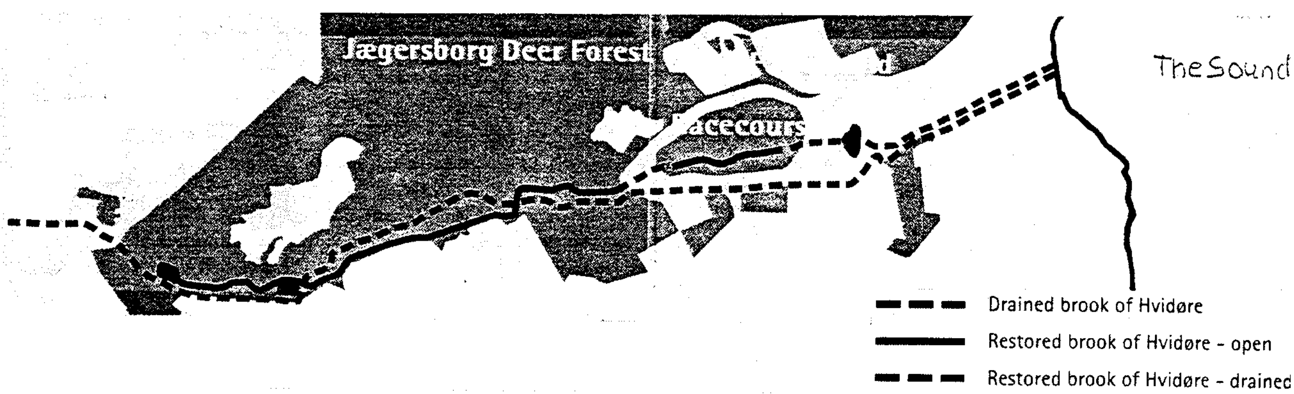

Figure 1. Situation plan of the project-area

Restoration of the stream and modelling the future flow

The brook of Hvidøre is being restored by leading drainage, surface water and rainwater-run-off into the stream. A groundwater-surface water model has been developed to estimate the future flow of the stream

The restoration of the brook of Hvidøre will be a dynamic process, where the future configuration of the brook primarily will be created by the stream itself.

Monitoring the future water-quality, flora and fauna

The restoration of the brook of Hvidøre is planned to be followed up by various biological studies in order to evaluate nature improvements. Also the quality of surface waters and groundwater will be controlled by setting up a monitoring program.

Landscape and recreational aspects

A comprehensive landscape solution for the entire area is aimed at. Existing wood, wetlands, (i.e. meadows, ponds and ditches) and lakes are integrated in the project. Also, recreational interests in this area so close to Copenhagen are taken into consideration. The restoration of the brook of Hvidøre adds yet another element of nature to the this recreational area so close to Copenhagen.

The overall purpose and costs of the project

The restoration of the Brook of Hvidøre is due to a systematic review of the sewer system with a view to reducing the discharge of stormwater and sewage to the Sound. The discharge to the Sound takes place in continuation of the piped brook of Hvidøre at a very popular beach. Reduction of this discharge has been given very high priority in the rehabilitation plan of the municipality of Gentofte in order to improve the beach as well as the sewer system.

Besides these rehabilitation plans it is important to know, that the project area also has cultural and historical interests due the rather complicated installations for fortification. By damming it was possible, at wartime's, to flood the entire area, in order to prevent attacks on Copenhagen. The installations for fortification will still be visible after the restoration of the stream.

barbel zone has been changed into the grayling zone, while in the lower stretches the barbel zone has been transferred into the bream zone. In these two lower zones 69% and 39%, respectively, of the fish species have been lost due to technical impacts and pollution. Further, the natural spawning has been lost to a great extent, as longitudinal connectivity has been disrupted and spawning habitats have been destroyed by hydropeaking and channelization. In consequence, the ecological functionality of the river system is drastically diminished. While the micro- and macrofauna may still feature natural reproduction, the life cycle of fish is interrupted. Stocking could only partially improve this deterioration, as also exotic species such as rainbow trout (*Oncorhynchus mykiss*), competing with brown trout, have been introduced. Usually, fish species which are not commercially used, such as Minnow (*Phoxinus phoxinus*) and Bullhead (*Cottus gobio*), are strongly endangered. Other species, especially those migrating from the Black Sea into the Danube River system, are extinct (13).

Data on benthic communities along the 510 km of river are scarce. Generally, the rhithral community, dominated by chironomids, stoneflies and mayflies, is changing, along the longitudinal gradient, into a community dominated by caddisflies, molluscs and oligochaetes. Bauer (11) found 182 taxa at the mouth of the major tributary, River Salzach, including 25 species from the red list in Bavaria. A general picture of benthic community structure shows 27% deposit feeders in the epirhithral zone of the Engadine, 38% in the metarhithral zone near Innsbruck, and 54% in the metapotamal zone, 50 km above Passau. Despite of severe regulation, this is in accordance with the river continuum concept of Vannote et al. (14). The ratio between producers and consumers changes along the variable geomorphological, hydrological, physical and chemical gradients (9). In the lower stretches, shredders, especially *Gammarus roeseli*, are abundant. In the secondary braided lowland floodplains (see below), Reichholf (15) has found a drastic decrease of benthic biomass from 2,000 g m^{-2} in 1970 to 5-10 g m^{-2} in 1994. He hypothesized that the establishment of waste water treatment plants and a subsequent general decrease in particulate organic matter (POM) input from upper river stretches have caused this dramatic change, which further has a great effect of the fish and bird fauna, both lacking food.

Along the longitudinal gradient, the riparian vegetation has been diminished to a great extent (H. Zoller, pers. comm.). Only three near natural stretches of braided floodplains and corresponding vegetation remain in the upper reaches in Switzerland. In the Austrian part, a floodplain forest area of 1,627 hectares in 1855 had been diminished to 211 hectares by 1986. The primary floodplains in the lowermost Bavarian stretches were first disconnected in 1890 by channelization, then backflooded by a new impoundment in 1922. The wetlands filled up with sediments, allowing a partial restructuring of the forested areas into secondary floodplains with high diversity of plants, benthos, amphibians, fish and birds (15)(16).

Suggestions for maintaining the ecological functionality and a sustainable development

Ecological functionality may be defined according to OENORM M6232 (9) as: 'Potential for maintaining the complex network between habitats in both water and riparian zones, and their organisms - according to the natural feature of the respective type of water'. Our literature review revealed the actual condition of the River Inn: There is doubt that the ecological functionality nowadays is maintained along the total length of 510 km. However, despite considerable human impacts, the River Inn system retains ecological functionality in some single stretches. These refuges show the potential for river conservation and restoration.

Our knowledge of large river systems such as the Inn is limited, especially with regard to the role of waste water treatment plants, the basic energetic and chemical processes, the ecological function of the floodplain vegetation, the structural changes in benthic communities (*sensu* Moog (9), and according to the serial discontinuity concept of Ward & Stanford (2)) along gradients of e.g. impoundments, and the overall fish migration, life strategies, and habitat structures.

The River Inn should be considered as an important sub-ecosystem of its recipient, the River Danube, and therefore is of European importance. It is obvious that achieving ecological functionality is the ultimate goal from the point of view of water protection and corresponding legislation. This needs to be balanced with the use of water and adjacent land, i.e. to be focused on sustainable development of the catchment. We are aware of the fact that this cannot be precisely defined. However, we can define some vectors along which further development and use should be directed ("Leitbild", in German, see (17)):

1. Remaining near-natural stretches should be conserved and interconnected, as they act as breeding sources and refugial space for benthos and fish.
2. Deteriorated stretches need to be gradually restored, wherever possible, according to established restoration procedures, and ensuring high flow protection including a gradual risk management.

Ecological functionality of the River Inn in view of man made impacts: Proposals for a sustainable development of the Inn catchment (extended abstract of a literature study)

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Abstract
For centuries, the River Inn and its tributaries have been gradually altered by man through pollution, channelization, impoundments, and water diversion. Human pressure is still increasing, especially through hydropower and gravel exploitation. In this respect, the question arises, whether the development in the Inn catchment is sustainable or not. The aim of our literature study was to compile the present knowledge of the Inn degradation, to demonstrate the need for restoration projects and conservation of remaining near-natural stretches, and to outline strategies for further research and sustainable development. The full paper is published in German (1); the full list of 294 references on the River Inn is available on diskette or as booklet.

Abiotic characteristics of the River Inn fluvial system: Then and now
The fluvial system of the River Inn is 510 km long and includes a catchment area of 26,000 km^2 and four countries (Switzerland, Italy, Austria, Germany). The Inn includes the whole spectrum from pristine alpine headwaters to lowland meanders. Accordingly, the benthos, fish and riparian vegetation cover a wide range of altitudinal and geomorphological zonation. The high diversity and natural ecological functionality of such large river landscapes are based on high variations in habitat structures and large temporal changes (2).

The Inn is a mountain river with a glacial to nivo-glacial regime, peaking typically in summer (3), with a mean discharge of 740 $m^3 s^{-1}$ at the confluence, in Passau, with the Danube River. Hydropower generation with reservoirs and water diversion has modified the seasonal pattern of discharge and temperatures. Moreover, hydropeaking exerts a major direct impact on both benthos and fish (4)(5). The transportation of suspended matter is considerable, with about 3 million tons per year near the border between Austria and Germany (6). Flow higher than 135 $m^3 s^{-1}$ cause the bed sediments to move (3). Gravel exploitation drastically diminishes the natural sediment transport, which strengthened the trend of vertical stream bed erosion.

The highly dynamic character of the Inn River discharge created a highly variable morphology, in general dependent on the geological structure and the steepness of the valley. Of greatest ecological importance are the braided floodplains, interconnected with the main channel, and the still-water floodplains and meanders. These natural structures were gradually degraded by man since the middle age, and already in 1904 the main regulations were completed (7). In the Tyrolian Inn not a single free-flowing stretch of water remains (8). In the lowermost 217 km the establishment of 16 impoundments have decreased the steepness from 0.7-1.0 per mille to 0.08 per mille, thus decreasing water current and sediment transport tremendously. Such impoundments are a threat to lotic river systems, since longitudinal connectivity is disrupted, and bed sediments are clogged by fine detritus (colmation). Regulated rivers are subject to longitudinal upstream and downstream shifts in temperature, chemical parameters and biological phenomena (2)(9).

The load of nutrients in the Inn is moderate and increases along the longitudinal gradient, but ammonium and nitrate have increased also in time, indicating the human activities in the catchment. Organic pollution of the Inn is only moderate, as saprobic indices show class II (beta-mesosaprobic) in the upper Tyrolian part, and class II to III (beta- to alpha-mesosaprobic) in the lower Tyrolian part (10)(11). The establishment of waste water treatment plants resulted in a slight improvement of water quality, especially in the lowermost Inn stretches. Heavy metals (e.g. Pb) in water and sediments were a severe problem in the 1950's (12), but contamination with Pb concentrations <41 $\mu g\ l^{-1}$ is acceptable nowadays (H. Pehofer, pers. comm.).

Biotic characteristics of the River Inn fluvial system: Then and Now
According to the traditional zonation scheme, the natural Inn was divided into the epirhithral or trout (*Salmo trutta fario*) zone, the metarhithral or grayling (*Thymallus thymallus*) zone, and the hyporhithral or barbel (*Barbus barbus*) zone. Naturally, the potamal or bream (*Abramis brama*) zone did not exist in the River Inn system, as it occurred further downstream in the Danube. It is important to note that near Innsbruck the

Towards an effective policy for river restoration in Flanders (Belgium). Easier said than done.

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Abstract

A state of the art is presented of the river conservation and restoration policy in Flanders. Successful and/or large-scale nature rehabilitation is precluded by the poor water quality in the majority of the Flemish river systems and a lack of public support. Only three large-scale river restoration projects are under implementation at this moment : the river Dijle and the streams Scheldt and Meuse. Ecological engineering techniques aimed at wider scale mitigation or used in small-scale projects are slowly making their appearance at more and more places. Meanwhile, efforts are made to improve the water quality and to stimulate integrated water management.

Introduction

In Belgium nature conservation and river management are the responsibility of the three regions : Flanders (Dutch language group), Wallonia (French language group) and Brussels. The Flemish region (13,512 km²) is one of the most densely populated areas of Europe (430 inhabitants per square km). There is a high degree of industrialization, a small-scaled, but very intensive agriculture (with a lot of bio-industry) and a dense network of motorways, railways and canals. Hence, the natural landscape is highly fragmented and the environmental quality is under a lot of anthropogenic pressure.

Altitudes in the largest part of Flanders range from 0 to 50 m a.s.l. Only in a few areas in the south and the extreme east altitudes go up to around 100-150 m and additionally in one particular region heights occur between 150-288 m. Consequently most of the nearly 16,000 km of Flemish watercourses can be categorized under lowland streams, rivers and brooks. A general picture of the different types is presented in Table 1.

Table 1. Presence (in km) of the different types of watercourses in Flanders.

Type	Length in km
Spring rivulets	155
Small brooks (< ± 5 m wide)	10,767
Large brooks (5-10 m wide)	989
Small rivers (10-20 m wide)	185
Large rivers (> 20 m wide)	327
Tidal river (fresh)	185
Tidal river (brackish)	39
Artificial watercourses	
Canals	670
Large polder ditches	2,865
Total	**15,958**

For a small area like Flanders, the organization of physical river management is still amazingly old fashioned and complex. Different administrations are responsible according to (a) the size of the catchment area in a particular section of the river and (b) the presence of navigation. Navigable rivers and river sections with a catchment area of more than 5,000 ha are the responsibility of the Flemish government. The provincial authorities are responsible for the management of the river sections with a catchment area between 100 and 5,000 ha, while rivers and watercourses with smaller catchment areas are managed by the municipalities. Moreover, lowlying areas with a dense network of ditches and brooks (such as sea polders and river valleys) are often managed by so-called "polder authorities". Their existence often goes back to historical times and, due to their very old legislative basis, they can operate almost sovereignly within their jurisdiction. Traditionally their interest is mainly orientated towards the maintenance or the improvement of a maximal water drainage capacity. 304,835 ha are actually still managed by 110 of such polder authorities (1). It is clear that the large fragmentation of responsibilities in Flanders makes it very difficult to realize a common water management policy. Because of the absence of any interest in the ecological functions of river systems in the past, river habitat structure characteristics show heavy degradation due to regulation, channelization, presence of concrete embankments or an intensive maintenance management. The poor condition of most of the Flemish rivers with respect to habitat structure is summarized per water catchment

3. The ecological functionality of secondary wetlands, established now as bird sanctuaries of international reputation, needs to be further elucidated and conserved by thorough studies of nutrients cycling and energy transfer.
4. Gravel exploitation needs to be reduced, so as to maintain sustainability of the morphological structures of the river bed: The amount exploited must not allow for vertical erosion, i.e. the sediment transport capacity and accumulation of the river need to be balanced.
5. Present hydropower generation must be linked with minimum residual water discharge, minimizing hydropeaking and establishing fish passes. Further hydropower use needs to be integrated in a general discussion about energy production and consumption, and developing other types of alternative energy sources.
6. Human population growth in the catchment needs to be stabilized; land and tourist development need to be controlled; natural resort areas and potential flooding areas need to be selected. Local communities need to plan the catchment space into regions of landscape and stream protection, and various forms of water use and human activities.

We are convinced that a supraregional effort to stop further degradation and to improve the overall ecological functionality of the River Inn catchment is necessary and with good prospects, when scientists, politicians and residents are co-operating.

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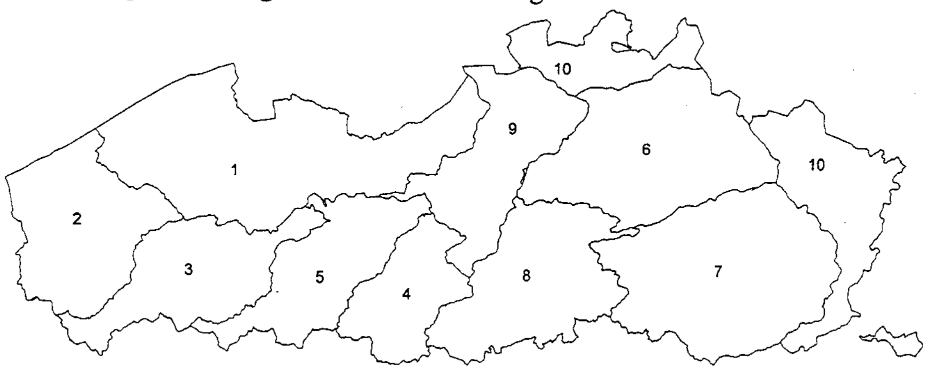
- Since 1991 amelioration of the water quality in Flanders is considered as an environmental issue with top priority. Between 1991 and 1995 37,300 million BF were invested to accelerate the construction of mains sewage and sewage treatment plants (5). The target is that by the year 2003 at least 74% of the Flemish population will be connected to a sewage treatment plant. A private company with government holding, called "Aquafin", was established to execute the ambitious plans. The financial means are mainly supplied by a special fund ("MINA-fonds") which is mainly generated by levy taxes on the production of domestic and industrial waste and wastewater. In 1995 the levy taxes for wastewater amounted to 5,310 million BF and for waste to 3,780 million BF (5).
- The principles of "integrated water management" are increasingly being promoted. In 1993 Flanders was divided in 10 hydrographical zones where "Catchment Area Boards" were to be installed (Fig. 3). The purpose was to initiate a fundamental change in the complex organization of river management in its widest sense. These boards are responsible for the coordination of the ecological, the water quality and the water quantity management of the complete catchment area. Different administrations, local authorities, nature conservation organizations and experts take part in these boards and their working groups on ecology, water quality and water quantity. Here, often for the first time, the different parties involved can exchange knowledge and have to work together.



1 Polders & Gentse Kanalen
2 IJzer
3 Leie
4 Dender
5 Boven-Schelde
6 Nete
7 Demer
8 Dijle
9 Beneden-Schelde
10 Maas

Figure 3. Division of Flanders in 10 hydrographical zones where >Catchment Area Boards are installed or will be installed in the future.*

- Basic, policy supporting ecological research has been executed with a view to river restoration in Flanders. A classification and evaluation survey of all the watercourses was done (2). In a global ecological policy plan for river ecosystem restoration, priorities were put forward (6)(7). Fig. 4 shows the priority zones for river restoration and conservation in Flanders. A general method was drafted to set up integrated river ecosystem management schemes (8). The Flemish Government also commissioned a methodological study on the inventory, the ecological effects and the rehabilitation of river sediments in order to develop a classification method for contaminated fresh water sediments (9).

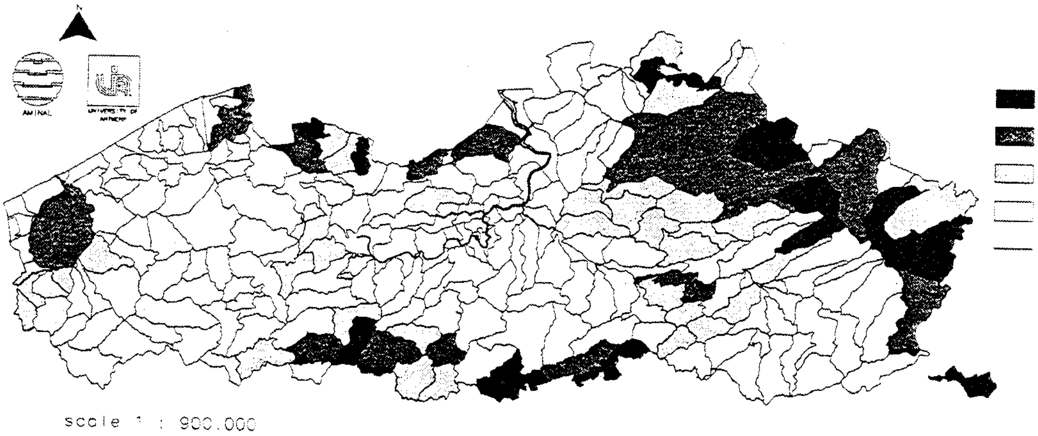


Figure 4. Priority level of the different catchment areas in Flanders for river restoration and conservation. Black: Priority 1 (highest priority); Dark: Priority 2; Grey: Priority 3; White: No priority; —: watercourse with priority 2.

unit in Fig. 1 (2). Flanders is probably (still) one of the most polluted areas of Europe. Fig. 2 shows that river catchment areas with a good water quality are actually very scarce in Flanders (2).

Considering the poor water quality and the massive loss of natural habitat structures along watercourses it is not surprising that during the last decades aquatic biodiversity has reached an all-time low in Flanders. For instance, most of the native waterplant species showed a large-scale decrease in abundance compared to several decades ago and as a result 52 species (64%) of them are at present on the Flemish Red List (3). Provisional data from Coeck (4) showed that 35% of the native fresh water fish fauna is extinct or near to extinction, while 21% is considered to have the status 'vulnerable'.

Figure 1. Evaluation of the water quality per catchment area in Flanders. White: no data available; Very light grey: Class 1 (very poor); Light grey: Class 2; Grey: Class 3; Dark grey: Class 4; Dark: Class 5; Black: Class 6 (very good)

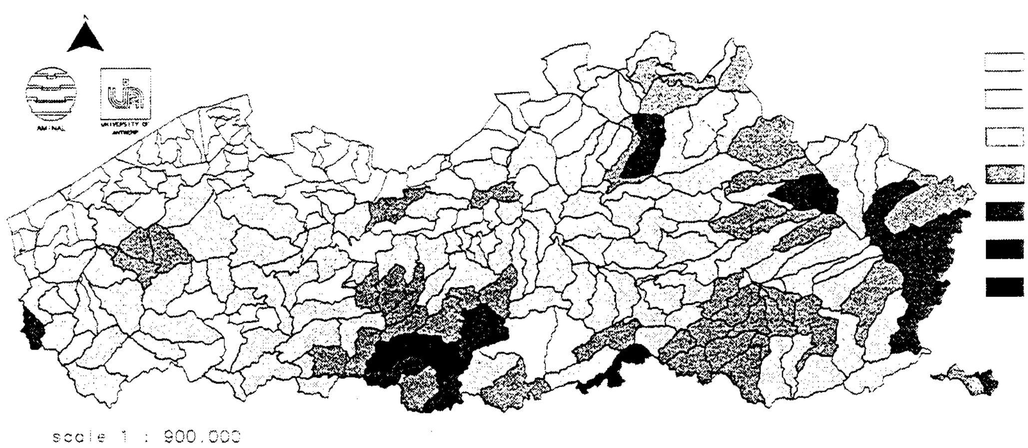


Figure 2. Evaluation of the watercourse structure per catchment area in Flanders. White: only man-made watercourses (polders); Very light grey: Class 1 (very poor); Light grey: Class 2; Grey: Class 3; Dark grey: Class 4; Dark: Class 5; Black: Class 6 (very good)

New incentives by the Flemish Government

- In accordance with the EC-Directives 75/440/EEC, 76/160/EEC, 78/659/EEC and 79/923/EEC the Flemish Government passed a law in 1987 to indicate water quality standards for all surface waters in Flanders and adjusted water quality standards for drinking water, swimming water, fish water and shell water. These water quality standards were to be reached before 1/7/1995.
- The environmental permit legislation in Flanders has been modernized in the late eighties. It provides a basis to impose severe exploitation conditions and penalties to the industry with respect to, for example, emission standards or the compulsory use of particular techniques. Disconnection from the household sewage-pipe system is encouraged.
- After long and difficult negotiations legal standards for manure deposition on agricultural land were finally laid down in 1995. The actual standards are very complex and considered as a compromise but future tightening of the regulations is probable. One of the interesting innovations is the ban on fertilization in a zone five metres wide along watercourses.

River restoration and sustainable rural development planning

The river restoration priority plan (6) has to be incorporated in the forthcoming "Structure Plan of Flanders", an updated and much needed instrument for rural development planning in Flanders. Unfortunately, the future for the long awaited "Structure Plan", appears to be uncertain as a result of recent political decisions. The incorporation of the river restoration priority plan therefore remains in doubt.

Rivers and their valleys are an important part of the ecological network of any area. A new nature conservation law has been drafted for the future realization of such a consistent network, which is to be implemented in the "Structure Plan" as well. Unfortunately, the extent of the priority areas for an ecological network will be limited to 125,000 ha. Additionally, the indication of 150,000 ha will be possible where management agreements with farmers will be encouraged.

River restoration and public support

After three years the Catchment Area Boards still lack a firm legislative basis. They continue to function on a voluntary basis. Meanwhile the outdated water management administrations in Flanders still operate in isolation. This situation causes a lot of confusion and sometimes conflicting decisions are made. As a consequence the boards are more or less reduced to discussion groups. Their strength and usefulness largely depend on the composition of the delegates and their individual expertise and attitude.

Nature development and nature restoration still face a lot of problems in Flanders (12). For several years there has been a difference in interests between nature conservation and agriculture. Many areas which are indicated on the existing physical planning maps as areas with a primary ecological function are still intensively managed by agriculture. Moreover, some ecologically valuable areas lack the appropriate protection. Management agreements with farmers are not yet possible on a legislative basis in Flanders. Especially the western and northern regions, with strong agricultural pressure groups, face a lot of difficulties to convince people for the needs of integrated water management. To allow or re-allow natural inundation of river valleys is perceived as a curse. In most parts the traditional, intensive and nature-hostile management of watercourses is still continued, especially in the river reaches controlled by the provinces, the municipalities or the polder authorities. Everything must be fully controlled by man. Drainage for agricultural purposes remains the first and very often the only priority.

Slowly, however, there are a few signs of change. Fish have great public appeal. The construction of spawning zones, fish traps and eel pipes are becoming more popular in Flanders and are generally rather easily accepted by the community. There is also an increased interest for ecological contributions in the creation of artificial water retention areas, sediment traps, submerged berms and reed-bed purification treatments. But, since in most cases there is a need for sequestration of agricultural land, there is much more heated debate about this item.

River restoration and nature conservation benefits

Spawning zones, fish traps, eel pipes, artificial water retention areas, concrete sediment traps and submerged reed berms threaten to become synonymous with "river restoration". Although these local and small-scale measures have their importance, such opportunities must be considered as mitigation measures or "ecological engineering" rather than restoration measures. True nature rehabilitation along watercourses is only possible when large areas are involved and where natural processes such as water and vegetation dynamics can be tolerated and stimulated. An ecological perception on the relations between the river and the surrounding valley grounds is therefore indispensable.

In densely populated Flanders true nature restoration of rivers and watercourses will often be difficult or impossible due to domestic needs of navigation, flood protection or agricultural drainage which are imposed. The best opportunities may be found in the few large areas which are protected as nature reserves or where agricultural practices are absent or marginal. Minimal human intervention in combination with low density grazing of large herbivores may well be the easiest and certainly the cheapest way to achieve the ecological targets, as becomes obvious in the case of the lowland river Dijle in the central-southern part of Flanders (De Becker, pers. comm.). Over a length of 1.5 km mechanical cleaning of this still freely meandering river (approximately 10-20 m wide) has ceased for the past 6 years and trees have been allowed to fall into the water and are not removed. The ecological and hydrological results are being monitored as a model project and, even after such a short period, these look very promising. Large parts of the valley are already managed by private or governmental nature conservation bodies and more land will be acquired in the future. Actually the government is expropriating buffer zones along the river over a length of 15 km, which apparently is a much cheaper operation than the continuation of intensive mechanical cleaning to

- A manual for engineers and administrations has been published to encourage the use of more environmentally friendly techniques in river management and to provide useful ecological background information on nature conservation and nature rehabilitation along watercourses (10).
- Interest in restoration and nature rehabilitation projects along Flemish watercourses has increased, especially within the framework of large public maintenance works along big rivers and canals which fall under the responsibility of the Flemish government. Examples are the streams Scheldt, Meuse and Yzer. Good opportunities for the rehabilitation of more natural conditions are provided here by the "Dike Decree" which enables the expropriation of land to enlarge the water retaining capacity along embanked rivers.

Evaluation of the new incentives

Water quality

The statutory water quality standards for surface waters in Flanders, put forward in 1987, were not nearly reached in 1995. Only 16% of the approximately 1000 water quality monitoring points met the basic standards at that time, while 31% are still heavily polluted, 45% are polluted and 8% are slightly polluted (11). Nevertheless, all the efforts paid off in a slight overall improvement of the water quality during the period 1990-1995. Based on data of the Environmental Agency for oxygen availability (Prati-index) in 40% of the sampling points the water quality clearly improved, 8% of the points however showed a quality decrease, while in 52% of the cases there was more or less a status quo. Water quality records of extremely heavy pollution dropped from 20% to 5%. The relative contribution of households, industry and agriculture to current water pollution were calculated by the Flemish Environmental Agency (unpublished), based on data from 1994 (Table 2).

The improvements are attributed to a decrease in industrial pollution and the increase of wastewater treatment plants. The high levy taxes make the investment by industry in less environmentally damaging technology and practices cost effective. As a result the figures of especially suspended matter and heavy metals have dropped in the period 1992-1995. Although 81% of the Flemish population drains on a sewer-pipe system, only 35% is connected to a wastewater treatment plant (Flemish Environmental Agency, unpublished).

Table 2. Proportional contribution of different sectors to water pollution in Flanders in 1994 (unpublished estimations in percentage by the Flemish Environmental Agency). "Pollution" is differentiated in oxygen absorbing matter (B.O.D. and C.O.D.), total Nitrogen and total Phosphorous.

		BOD	COD	N	P
Households	- with treatment	5	21	9	12
	- without treatment	55	33	23	35
Industry	- with treatment	4	15	5	10
	- without treatment	36	31	14	26
Agriculture		-	-	49	17

Unfortunately, in most cases there is no separation between wastewater and rainwater removal and, according to the Environmental Agency, the average treatment efficiency of the operational plants for nutrients are rather low (40% for nitrogen and 47% for total phosphorous in 1994). It is estimated that another 142,000 million BF are needed to complete the necessary sewage treatment infrastructure (5). There is also an urgent need for investments in small-scaled wastewater treatment for the more isolated houses or industries. Until now no legislative incentives have been taken in this direction by the Flemish government (for example to make subsidies available). It is estimated that 6,5% of the population (approximately 150,000 houses) will never be connected to a sewage treatment plant.

There is no change yet in the input rate of nutrients and pollutants from the agricultural sector. High phosphorous and nitrate levels are responsible for the poor condition of aquatic life in the rural areas. The high levels of nitrate in catchment areas used for drinking water production also remain a cause for concern. Provisional data supplied by the Flemish Environmental Agency indicate that there is a high input of pesticides into the watercourses as well (for example atrazine, simazine, dimethoate).

It is obvious of course that there is still a long way to go before ecological water quality standards will be reached at most places. For the international rivers there is also evidence that a lot of pollution still originates in France, Wallonia or Brussels. Cross-border initiates and agreements are urgently needed.

Stream rehabilitation in the Netherlands: Present status and future developments

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Keywords:
Stream rehabilitation, monitoring, controlling factors, 5-S-model

Abstract
In 1993 a total of 159 former and current stream rehabilitation projects in The Netherlands were evaluated. It concerns about 300 km of stream length. Ecological criteria are used to assess stream rehabilitation in the Netherlands in historical perspective. In most projects goals are defined only in general terms. Until 1985, background studies are not available, but there is a considerable increase in use of background studies since. Most measures planned or taken focus on morphological features of the stream. Though a slight increase can be observed, only few hydrological and water quality measures are applied.

A second survey was conducted in 1995 to obtain more information on monitoring schemes. In about 51% of the projects monitoring procedures are mentioned. Monitoring and evaluation procedures of these projects are analysed more in detail. Often monitoring and evaluation do not directly fit with the measures taken. Still a large number of abiotic and biotic parameters is measured. Sampling is mostly restricted to a few commonly used sampling techniques. Sampling frequency differs between regions and covers a period of maximal 10 years. Usually, more "classical" biological water quality assessment systems are used to evaluate stream development. A direct assessment related to predefined target communities lacks. From all results guidelines for future stream rehabilitation are given in terms of the 5-S-model, to facilitate and stimulate a true ecological approach.

Introduction

After decades of adapting streams to agricultural, domestic and industrial needs, one became aware of the damages these alterations caused to the natural stream ecosystem. In the Netherlands, only about 4% of the streams still has a natural morphology and a (more or less) natural hydrology. In comparison to Denmark, where even only 2% is more or less natural (1). Environmental awareness, concern for the loss of stream habitat and reduction in water quality provided the (political) route for stream rehabilitation.

In 1993, a survey to evaluate the state of stream rehabilitation projects in the Netherlands over the last three decades is conducted among water management authorities.

Since stream rehabilitation can be viewed as being in its infancy (2) it is important to evaluate the success or failure of stream rehabilitation projects. In 1995, a second survey was conducted in order to obtain more detailed information about post-project monitoring.

In this article the results of both surveys are presented and discussed, resulting in guidelines for future stream rehabilitation.

Methods

Survey 1: Stream rehabilitation projects

In 1990/91, the Agricultural University of Wageningen conducted an evaluation of technical stream rehabilitation (3). In 1993 an additional survey updated these data, and especially added ecological criteria (4). This evaluation focused on general information of the project, whether background studies were conducted and which rehabilitation measures were taken. The authorities consulted concern national and provincial governments, regional water authorities and nature conservation institutions. In total, 85 organizations are interviewed, resulting in 159 projects over the time period 1960-1995.

Survey 2: Monitoring schemes

Monitoring of stream rehabilitation projects in the Netherlands is usually performed by regional water authorities. Aquatic ecologists, employed by regional water authorities, are consulted to collect information about monitoring schemes on stream rehabilitation projects . This survey collected general information, information on the monitoring techniques used and on the evaluation of monitoring programs. The results are presented in number of projects per region. In total nine regions in the Netherlands are distinguished.

keep the river in a fixed course. The valley is already flooding more frequently and acts as a buffer for the protection of the city of Leuven downstream. The bottle-neck preventing wider implementation of large-scale riverine habitat restoration in Flanders is that there are very few large valleys which are managed by nature conservation organizations and that many valleys have been fragmented by the building of houses. Another problem is a lack of money to finance restoration projects when expensive re-meandering measures are clearly the most desirable.

The cases of the streams Scheldt and Meuse in Flanders illustrate that there are some good possibilities for large-scale nature restoration projects when socio-economic interests of navigation and flood protection are involved and public money becomes available more easily. In these projects physical measures include the removal or realignment of flood walls in combination with a less intensive land use or the creation of nature reserves between the flood walls. The Scheldt project is of special ecological interest because it aims at the conservation, restoration and creation of large fresh water tidal marshes which are extremely rare in Western Europe. Areas of brackish tidal marsh are involved as well (13). Unfortunately the water quality is still very poor and the river sediment is polluted with heavy metals. The Meuse project on the border between Belgium and the Netherlands is planned in close cross-border co-operation and aims at large-scale nature rehabilitation of a broad gravel bed stream with islands and gravel banks over an unregulated reach of 40 km. The project also deals with a less intensive use of the floodplains and nature reclamation of former gravel mines (14). Both the Scheldt and the Meuse project are predominantly still in the planning phase.

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Table 3. Average reach length restored per project

Period	Number of projects	Average reach length restored (km)
1985-1989	13	2.7
1990-1992	28	3.8
1993-1995	41	3.9

Background studies

Because stream rehabilitation is a rather young discipline in ecological water management, much has to be interpreted from background studies of the respective streams and basic ecological knowledge . One has to understand the functioning and interactions of the controlling factors in stream ecosystems in general as well as in the stream under study. Four main groups of controlling factors are distinguished: hydrology, morphology, water quality and biology.

The availability of background studies on these factors is evaluated. Information on (one of) these factors is available for 65 of the 159 projects. Fig. 2 shows the percentage distribution of background studies used over the period 1985-1995. Rehabilitation projects before 1985 did not contain the required information. There is a considerable increase in use of background studies, on all the subjects, since 1985.

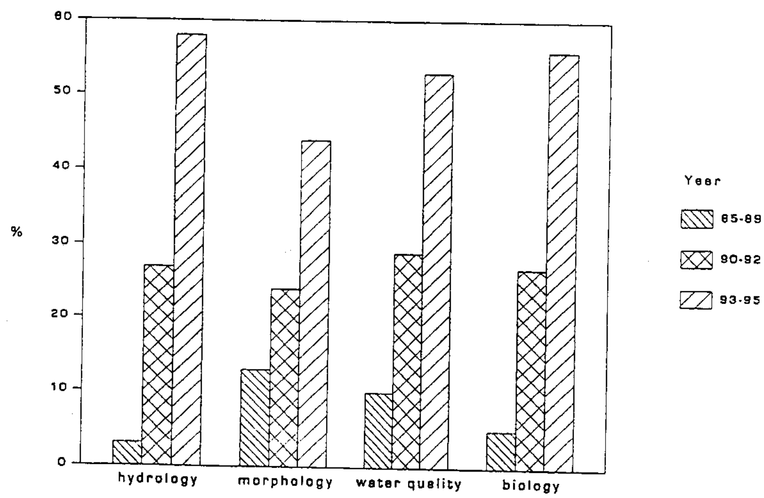

Figure 2. Percentage of available background studies on respectively hydrology, morphology, water quality and biology per time period over the years 1985-1995.

Rehabilitation measures

One of the most important features in stream rehabilitation concerns the measures taken. Like the survey on background studies, the distinction is made between groups of hydrological, morphological, water quality and biological measures (Fig. 3). As could be expected, in all 159 projects measures are indicated.

Striking is the lack of hydrological and water quality measures until 1985 and the slight increase since. Measures on morphology and biology were already popular in the sixties. They show an increase as well. The increase of percentage of measures per time period implicates an increase on average of the number of measures taken per project.

Table 4 gives an overview of the measures distinguished per category. Considering these measures, the hydrological measures, respectively, 'increasing (ground)-water level' and '(ground)-water supply' in the catchment area, are equally applied. The morphological measure, 'creating riparian zones and river banks', is most frequently conducted, followed by 'meandering'. The water quality measure 'direct reduction of input of substances' is far more used than 'creating bufferzones' (indirect reduction). From the biological measures, 'adjustment of stream maintenance' (in favour of flora and fauna), is most often applied. 'Species directed management' (habitat adjustment) and 'planting bank vegetation' are equally applied, whereas 'introduction of species' is hardly used. Considering all measures taken, 'creating riparian zones and river banks' is most frequently conducted, followed by 'adjustment of stream maintenance'.

Results

Survey 1: Stream rehabilitation projects

<u>General information</u>

The number of projects increases over the period 1960-1995 (Fig. 1).

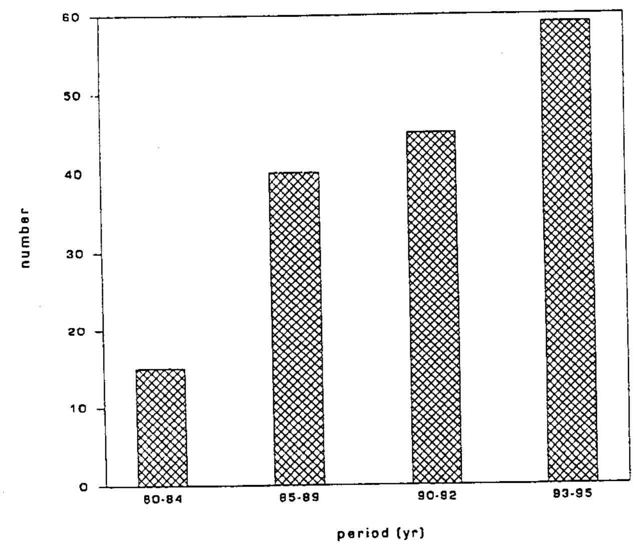

Figure 1. Number of stream rehabilitation projects per time period over the years 1960 until 1995

More than 65% of the projects date from 1990 and on. For 102 projects the financial contributors are registered. Both national government and regional water authorities contribute in more than 70% of the projects (Table 1).

In 71 of the 159 projects the costs are roughly indicated. The average costs per project increase during the period 1985-1995, up to 1 million dollars per project (Table 2). In 82 projects, the length of the stream reach restored is indicated (Table 3). A slight increase is observed since 1985.

Table 1. Financial contributors in stream rehabilitation projects (n=102)

Contributor	%
National Government	75
Regional Government	32
Regional Water Authorities	70
Nature Conservation	11
Others	11

Table 2. Average costs of a stream rehabilitation project

Period	Number of projects	NLG per project	$ per project
1985-1989	12	494,250	290,735
1990-1992	26	1,536,538	903,846
1993-1995	33	1,754,484	1,032,049

Table 5. Monitoring techniques:parameters measured, number of regions where the respective parameter is used and sample frequency of measurement.

	Parameter	Number of regions	Sample frequency * (and reference)
Hydrology	Ground water level	3	2x/mth (2), 2x/yr (1)
	Water level	4	1x/wk (1), cont.. (2) n.i. (1)
	Discharge	3	cont. (2), n.i. (1)
	Current velocity	5	6x/yr (1), 2x/yr (2), cont. (1), incid. (1)
Morphology	Llongitudinal profile	4	1x/yr (2), 3x/yr (1), n.i. (1)
	Transversal profile	5	1x/yr (2), 3x/yr (1), n.i. (1), incid. (1)
	Substrate mosaics	3	2x/yr (2), 3x/yr
Water quality	Oxygen	9	12x/yr (5), 9x/yr (1), 6x/yr (2), 4x/yr (1)
	Nutrients	9	12x/yr (5), 9x/yr (1), 6x/yr (2), 4x/yr (1)
	Major ions	7	12x/yr (1), 7x/yr (1), 4x/yr (3), 2x/yr (1), 1x/yr (1)
	Toxicants	4	4x/yr (2), 2x/yr (1), 1x/yr (1)
Biology	Riparian vegetation	8	1x/yr (5), 2x/yr (3)
	Water vegetation	8	1x/yr (5), 2x/yr (3)
	Diatoms	1	2x/yr (1)
	Macro-invertebrates	9	2x/yr (6), 1x/yr (2)
	Fish	6	2x/yr (1), 1x/yr (5)
	Others	6	not relevant

** sample frequency: 2x/yr = 2 times per year, 2x/mth = 2 times per month, 2x/wk = 2 times per week, cont. = continuous, n.i. = not indicated, incid. = incidental , (x) = number of regions*

Table 6.Sampling techniques, identification level and method of assessment per group of organisms used in monitoring schemes. (x) = number of regions

	Sampling techniques	Identification level	Method of assessment*
Riparian vegetation	Tansley (7), Braun Blanquet (1), target species(1)	Species (8)	ind. species (8)
Water vegetation	Tansley (7), Braun Blanquet (1), target species (1)	Species (8)	ind. species (8)
Diatoms	Scraping (1)	Species (8)	ind. species, vDam (1)
Macro-invertebrates	Pond net (8), corer (1)	Species (8)	ind. species ((8), biot. ind. (2), sapr. ind. (2), ecol. ass. (6)
Fish	Electrofishing (5), net or fish-trap (2)	Species (8)	ind. species (4), div. (1), hab. suit. (1)

** method of assessment: ind. species = indicator species; vDam = Van Dam index (18); ecol. ass. = ecological assessment method; biot. ind. = biotic index; sapr. ind. = saprobic index; div. = diversity; hab. suit. = habitat suitability index.*

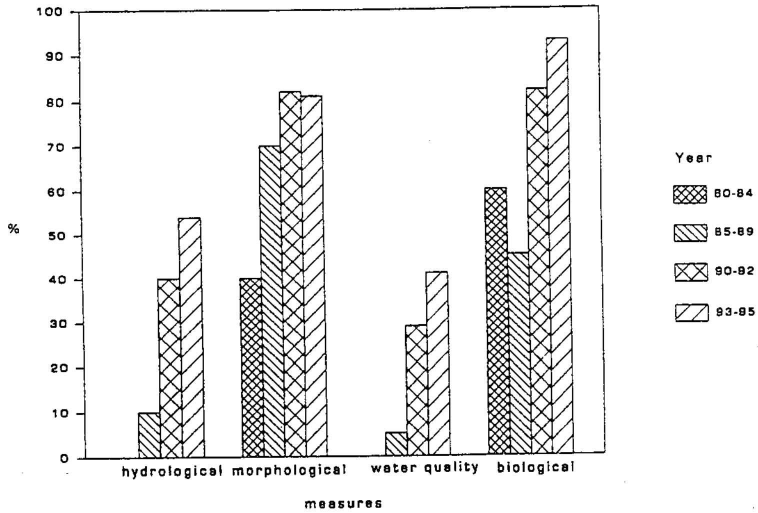

Figure 3. Percentage of groups of hydrological, morphological, water quality and biological measures taken per time period over the years 1960-1995.

Table 4. Percentage of measures taken, categorized in measures on hydrology, morphology, water quality and biology. (n= 810)

Hydrology	%	Morphology	%	Water quality	%	Biology	%
Increasing (ground)-water level	4	Removal of embankments and dams	6	Direct reduction of input of substances	7	Planting bank vegetation	11
Increasing (ground)-water supply	3	Meandering	7	Creating buffer zones	3	Adjustment of stream maintenance	16
		Creating riparian zones and river banks	25	Removing water sediment	1	Introduction of species	2
		In-channel features like pools and riffles	5			Species directed management	10
Total	**7**		**43**		**11**		**39**

Survey 2: Monitoring schemes

General information

In total, 91 rehabilitation projects are studied. Only 51% (46 projects), actually, provided a monitoring or evaluation program, though some of the projects were in an early stage and thus monitoring programmes are not yet available. This evaluation is based on these 46 projects containing a monitoring program.

Monitoring techniques

In all regions the initial condition is described in order to be able to compare with post project data.

The abiotic and biotic data collected per region are given in Table 5. Thereby, the frequency of data collection is indicated, though these do not concern yearly recurring schemes. It is obvious that water quality and biological parameters are more often measured than hydrological and morphological ones. The sample frequencies vary strongly between the regions. The length of the period of monitoring differs from minimal 2 years to about 10 years. Most regions indicate that 10 years of monitoring will be taken into account.

Collecting techniques, identification levels and assessment methods for biological data per region are given in Table 6. Between the regions, a great similarity in monitoring methods is observed.

For vegetation research, mostly the Tansley method is used. Diatoms are collected by scraping of vegetation or other substrates. Macro-invertebrates are mostly collected by using a pond net and fish is collected by electrofishing or nets. All organisms are identified to species level. For evaluation of monitoring results, the available knowledge on the autecology of individual species is most frequently used. For macro-invertebrates several biological assessment methods support the interpretation.

catchment. Stream hydrology comprises the controlling factors related to water quantity. Structures concern the morphological characteristics in catchment, stream corridor and stream. Substances compose water quality gradients from catchment boundary to stream and from source to mouth. All three components, stream hydrology, structures and substances, act at an intermediate spatial and temporal scale . Finally, the fifth 'S' of Species (communities) concerns the biological response to the four abiotic groups of factors described, and acts at a low spatial and temporal level. Each of these groups is described more in detail in mutual related dominant factors. The 5-S-model is fully explained by Verdonschot *et al.* in these proceedings (17).

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Evaluation
Until now, the results of monitoring schemes and techniques are hardly evaluated. Although monitoring schemes are often adjusted as they progress in time, it is difficult to obtain the reasons for these adjustments. Possible causes for these adjustments concern finances, available manpower or adjustment of objectives.

Discussion
A total of 159 rehabilitation projects, concerning 300 km of stream length, illustrates the great interest in stream rehabilitation in the Netherlands. Since stream rehabilitation requires more and more a multidisciplinary approach (5)(6), the involvement of so many organizations is regarded as a positive development.

Although stream rehabilitation should focus on the whole catchment area (2)(4)(7) most projects are restricted to short stream reaches. Hopefully, the slight increase of the average reach length restored indicates a growing awareness of the importance of a whole system approach (8)(9).

The necessity of using knowledge on the factors hydrology, morphology, water quality as well as biology is recognized. Recently, more and more information is gathered in rehabilitation projects. Within the scope of this evaluation it is difficult to tell whether this knowledge is correctly and adequately used in order to make the proper choices in stream rehabilitation measures.

From the major factors acting on a stream, hydrology primarily defines the functioning (10). Therefore, rehabilitation measures are most effective when they focus on stream hydrology (11). Thereby, measures to improve the water quality will strongly benefit to the stream ecosystem (12).

Unfortunately most measures taken, concern morphological and biological aspects. Although there is a slight increase in the number of hydrological and water quality measures taken, they still compose the smallest part of the total number of measures taken. Most projects focus on rehabilitation of (segments of) the stream channel and a small adjacent riparian zone. In only few projects, measures intended, consider the catchment area or the whole stream, like in case of an 'increase of (ground)-water level and supply'. These measures demand a lot of space and/or need large adjustments in land use. In an overpopulated country like the Netherlands, with a lack of space and many demands of society, other than ecological ones, large scale measures are difficult to accomplish. Especially, when those measures include a reduction of economic benefit.

The costs of stream rehabilitation are relatively high and are still increasing, because recent rehabilitation programmes comprise, respectively, more ecological aspects, more background studies, more (expensive) measures and (slightly) longer stream reaches.

The survey of stream rehabilitation projects showed, quite often, a limited approach to the problems. Due to local circumstances, specific personal interest and limited knowledge and space, rehabilitation often focuses on only parts of the stream ecosystem.

The awareness of the necessity to monitor and evaluate stream rehabilitation projects is indeed growing (13). However, monitoring techniques and evaluation methods need a lot of improvement (1). Until now, monitoring programmes still reflect the traditional, standard water quality sampling and assessment methods, which were used by water management authorities already for decennia. This explains the resemblance in all regions in methods of sampling, identification and assessment. The rehabilitation goals should be defined in terms of qualitative and quantitative, abiotic and biotic parameters. To describe these goals, knowledge of the major controlling factors is inevitable. With this knowledge, monitoring schemes and methods can be appropriately planned, executed and evaluated (14).

Monitoring should focus on the goals (14), should embrace the recovery time (of the stream) in relation to the measures taken (15) and should be efficient (minimized) in effort and costs (16). Already, water management authorities in the Netherlands point out the enormous increase of time and money spend on monitoring activities.

Ecological stream rehabilitation calls for a whole stream ecosystem approach. In such system approach, conditions of the catchments hydrology, morphology, water quality and biotic components play an important part, as already described before. Thus, to facilitate practical stream rehabilitation one needs a check-list which guides the water manager through all the major factors controlling the stream and its catchment.

This check-list is developed in terms of the 5-S-model. The 5-S-model is a simplified but complete arrangement of major controlling factors in a stream ecosystem. Both spatial and temporal scale levels as well as the hierarchy in factors and processes is included.

In short, the 5-S-model is composed out of five main groups of controlling factors. System conditions correspond to the ultimate controlling factors and act at a high spatial and temporal scale level in the

Criteria for establishing effective wet meadows

Some of the most important criteria for establishing effective wet meadows are to have a distinct valley along the watercourse with draintiles carrying off adequate amounts of drainwater with adequate amounts of nitrate. Adequate amounts of organic matter in the soil of the meadow is also necessary, because organic matter functions as a carbon source in the denitrification process.

It is also important that there has been no load of sewage with a high content of phosphorus to the meadows previously. There can be a risk of phosphorus leaching if essential amounts of phosphorus are available in the soil. Botanically valuable flora on existing grasslands, which is intolerant of nutrients, will be taken into account.

Objectives of the full scale demonstration project

The objectives of the full scale demonstration project are to carry out concrete measures to reduce the diffuse leaching from agriculture, in respect to fulfil the National goal of 50% nitrogen reduction, and to show possible elements for a sustainable agriculture in the future, where far-reaching regards to the recipient and nature interests are taken.

Practical initiatives

The full scale demonstration project has to be a catchment scale project where many aspects are taken into account. Flooding of meadows with drainage water from adjacent cultivated areas, thus restoring the function of these meadows as filters for nitrates is the most important element of this project. The over-burdening of the waterways, and consequently the sea, with nitrates will thus be reduced. The water quality will be improved.

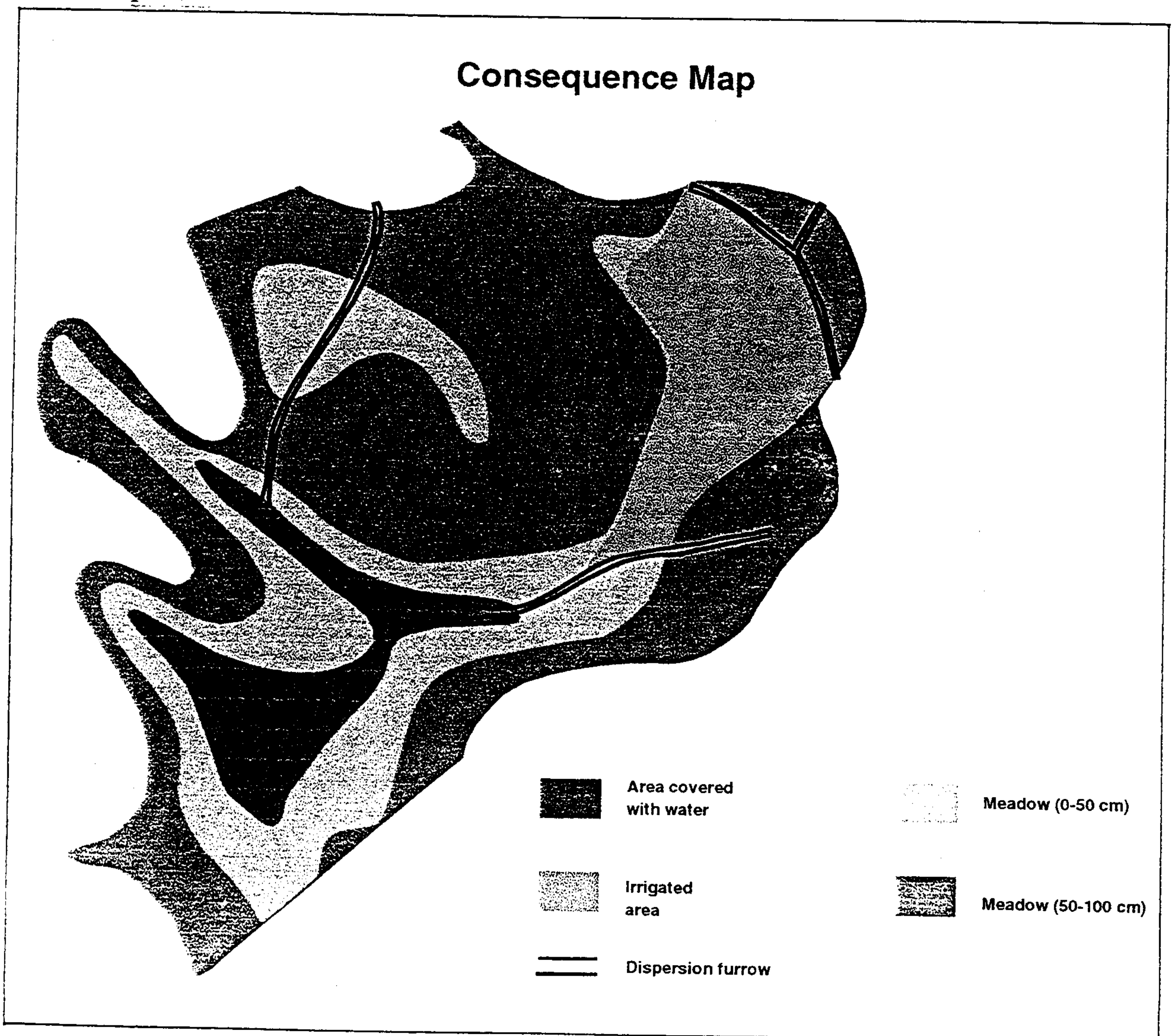

Figure 1. Practical design of a wet meadow and the consequences for the land use of the meadow.

Demonstration project about establishing wet meadows

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Introduction

This paper is a very short presentation of a full scale demonstration project about establishing wet meadows along a whole watercourse. The full scale demonstration project is carried out along the watercourse named Hundstrup River situated on the island Funen in Denmark. The full scale demonstration project continues for at least 5 years (1996-2001).

The Funen County Council in Denmark has through a long period of investigations for many years found out that there are great perspectives in nitrate transformation in wet meadows. Wet meadows, corresponding to an area of just 2% of the farm land on Funen, have a potential to reduce the nitrogen run-off from farm land to the Funen watercourses with 25% (1).

It demands that the wet meadows are correctly established as uncultivated meadows flooded by drainage water from cultivated fields. And - it is only realistic to establish wet meadows along watercourses with a distinct valley, where the consequences for the drainage of the upland fields can be avoided.

To re-establish wet meadows is very important in relation to reduce the nitrogen leaching to the surface water, but it does not solve problems about nitrate leaching to the ground water. These problems can be solved by measures on the cultivated fields only.

To find out how realistic it is to use wet meadows in nitrate control for surface water in a larger scale, the Funen County Council carries out a full scale demonstration project.

Background

In 1989 the Funen County Council has started an investigation project. The objective of the investigation project is to investigate the capacity of wet meadows along watercourses to reduce nutrient leaching from cultivated farm land.

The study area which is 0.8 ha was cultivated until the summer of 1989. In autumn 1989 the study area was flooded by drain water from cultivated fields so that nitrate from the drain water could be transformed to gaseous nitrogen. Previously the drain water ran directly into the watercourse.

The highest nitrate transformation rates are measured during spring time when the biological activity is high. The lowest nitrate transformation rates are measured during periods of high run-off and low temperatures and when nitrate inputs are low, typical in the summer.

The nitrate load to the study area is high enough to ensure a maximum nitrate transformation. The nitrate transformation does not exceed a level about 120 kg nitrate per hectare per month. It is independent of nitrate load, when the load is high.

In the winter period (from November to March) the nitrate transformation is 50 kg N per hectare per month as an average corresponding to 40% of the nitrate inflow in the period 1991-92 and 20% of the nitrate inflow in the period 1991-94. In 1993-94 the discharges were extremely high, which caused a decrease in the transformation expressed in percentages of the load.

The annual rate of nitrate transformation has varied from approximately 290 to 640 kg nitrate-N per hectare per year with the highest rate in 1991 and 1994 (1).

Results from the investigations on Funen show that wet meadows along watercourses, if properly selected and established, can be used as an important element, among others, to reduce the nitrogen leaching from intensively cultivated farm land.

Wet meadows, corresponding to an area of just 2% of the farm land on Funen, have a potential to reduce the nitrogen run-off from farm land to the Funen watercourses with 25%. These 2% of the farm land on Funen corresponds to less than half of the natural and extensively cultivated areas, which have been brought under cultivation since the 1950's.

To re-establish wet meadows is very important in relation to reduce the nitrogen leaching to the surface water, but it does not solve problems about nitrate leaching to the ground water. These problems can be solved by measures on the cultivated fields, only.

Partnerships in Restoration

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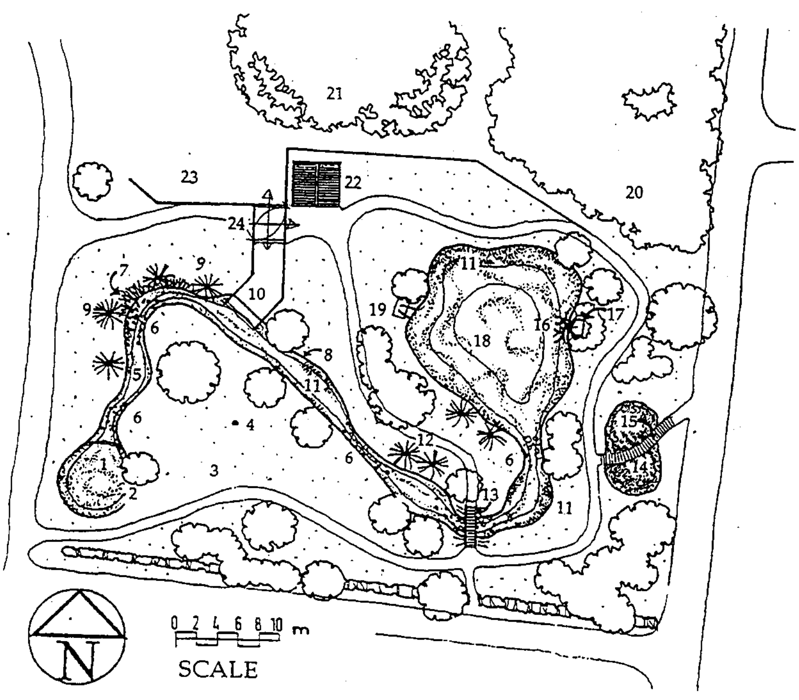
This paper considers the importance of and potential for partnerships in the implementation of river restoration projects in Britain with special reference to dissemination of the river restoration philosophy by the Environment Agency, Midlands Region.

One significant way of reducing conflict and ensuring that restoration is viewed as a worthwhile objective, is to gain widespread support for the philosophy. It will facilitate the business of searching for partnerships, and encourage landowners to participate.

In order to interest as wide an audience as possible in the concept of restoration, the former National Rivers Authority joined a group of agencies to set up the Farming and Countryside practical display area at the Royal Showground at Stoneleigh in Warwickshire. The Royal Show attracts an attendance of some 200,000 visitors from Britain and abroad every year and many of these visitors are the riparian owners and farmers who live and work close to our rivers. The possibility of demonstrating realistic river restoration ideas to landowners, advisory and regulatory organisations, and to the public was recognised as a significant opportunity. It was necessary to excavate and construct a totally artificial river system, (Fig.1), both lined with an impervious membrane and also puddled with clay, moulding a natural shape for the channel. The water flow is maintained by a recirculating pump system and flows by gravity down the system over a number of pebbly riffles which are in reality weirs, containing the water in ponded sections. This ensures that the aquatic and marginal habitats are not deprived of water at times when the pump is switched off. The site was visited by HRH Prince Charles in 1995, as well as government ministers and other dignitaries; it also attracted very favourable press comment.

The potential of such a demonstration area is considerable, fulfilling the public's current expectation of interactive displays, making it particularly appealing. The vitality of the achievement provides a practical vision to landowners who are not sure how or where to start on rehabilitation. It delights and interests people and inspires them to try such ideas, but it also provides a forum where technical issues and concerns can be discussed and advice can be given. It is an educational opportunity and allows the Agency to communicate with all ages and interests.



KEY

1 Boom to contain floating surface pollution
2 Simple outfall structure
3 Unimproved meadow with wild flowers
4 Flag pole
5 Urban litter demonstration
6 Weirs forming gravelly riffles
7 Willow spiling: traditional bioengineering technique
8 Low level "berm" at edge of channel
9 Pollarded willows: traditional management technique
10 Fenced cattle drinking place on river bank
11 Biologically rich marginal planting
12 Traditional coppicing of willows
13 Simple pedestrian footbridge for small river or stream
14 Conservation reedbed habitat creation
15 Boardwalk
16 Willow sculpture; dead timber forms excellent habitat
17 Pump suspended on pole to deter vandalism
18 Pool: typical of small conservation pool
19 Artificial otter holt to encourage colonisation by native otters
20 Copse/woodland planting
21 Existing mature oak trees
22 Timber cabin
23 Paddock for cattle
24 Stock crossing place for access to river

Figure 1. Demonstration river and pool at the Royal Agricultural Society of England Showground, Stoneleigh, Warwickshire

Flooding the meadows with water from the watercourse by avoiding or decreasing the maintenance of the watercourse is another element with the same objectives as flooding with drain water. Furthermore improvement and protection of the interaction between waterways and neighbouring environment will appear. It has not yet been possible to use this measure along the Hundstrup River, because it demands that all areas/landowners along the watercourse will be included within the project.

A natural consequence of flooding the meadows is more extensive cultivation methods/laying fallow of areas bordering waterways (meadows). The surface leaching to the appropriate waterways will thereby be limited, especially from the cultivated fields. The use of fertilisers and pesticides close to waterways will be avoided and the re-established meadows will be potential for new nature. Existing grasslands will only be flooded with drainage water, if fertilizer has been used previously and if they are not habitats for botanically valuable flora with intolerance of nutrients. An example of the practical design of a wet meadow and the consequences for the land use on the meadow is shown in Fig. 1.

Management proposals will be individually assessed for each separate area along the watercourse. Varied types of habitats, including areas under grass advantageous to wild flora and fauna, can thereby be provided. Management of the meadows consider especially to nature and landscape interests. Although a removal of plant biomass will also result in a removal of nutrients from the system. By removal of plant biomass it has to be ensured that the amount of organic matter in the meadow is sustained or regenerated.

The re-established meadows will be managed by grazing or mowing where possible. Generally 1 Livestock Unit per hectare will graze the areas.

Follow-up studies

To demonstrate that the changes of the land use along waterways have an effect on the diffuse leaching of nutrients from agriculture to the waterways the Funen County Council has chosen a watercourse system (a catchment area of approximately 80 km^2) with an existing water quality monitoring station for this full scale demonstration project. Measurements from the next years can be compared with previous measurements and thereby it can be demonstrated whether the nutrient removal objectives for the project are reached or not.

A registration of the land use in the catchment of the Hundstrup River is carried out to ensure that essential changes in land use in excess of the establishment of the wet meadows are registered and can be used in relation to the total assessment of the water quality data.

Collaboration with farming organisations and landowners

Funen County Council has collaborated with farming organisations through the whole progress of the project. In connection with establishing contact with landowners in the areas bordering the selected watercourse the farming organisations have participated in meetings, calculation of economic compensation etc. Close collaboration is set up with about 15 landowners, who are interested in making an agreement with the Funen County Council about establishing wet meadows.

Facts from the full scale demonstration project

Going from investigations at 1 hectare to a full scale project at about 50 hectares it gets obvious that there is not always coincidence between areas suitable for wet meadows and areas with interested farmers.

The catchment area to the monitoring station in the watercourse is 7.500 hectares. 5% of the catchment area corresponds to the river valley, 1% corresponds to areas suitable for wet meadows and 0.6% corresponds to areas with interested farmers. About 15 farmers out of 28 are interested, but anyway it will only be possible to make agreements for about half of the areas suitable for wet meadows, even if the farmers does not loose anything economically.

References

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The support of policy and strategy documents at national and regional level is also of great help in promoting river restoration philosophy. The opportunity exists to identify substandard reaches of rivers and to state measures, which may include survey work such as River Landscape Appraisal/River Habitat Survey, needed to plan their restoration to a satisfactory standard. For The Environment Agency, such policy can be written into Local Environment Agency Plans (formerly Catchment Management Plans). Furthermore, such policy can be co-ordinated with the Planning Authority's Structure and Local Plans and with other policy documents such as the Countryside Commission's Countryside Character Framework which includes management objectives for the future.

There are clearly many ways in which river restoration work can be planned and implemented, even though there is no evidence of any funding dedicated to restoration as such. Therefore, the implementation of restoration is likely to depend heavily on the interest, enthusiasm and perseverance of practitioners who are in key co-ordinating roles. They need, not only to see and understand the opportunities for restoration, but also to know who can be interested in collaborating and how a project can be developed. Co-ordination of the many elements of a restoration project will need ingenuity and determination, as well as skill, in the real world!

Funding and implementation:
As well as the practical guidance, the implementation of restoration must be viable financially. There must be funding available which will support and implement projects. The Ministry of Agriculture, Fisheries and Food has a number of support grants which enable farmers to take land out of production and to improve wetland habitat adjacent to rivers. A significant step in ensuring the final implementation of the philosophy, is the ability to inform landowners of the funding available and to discuss with them, ways in which such mechanisms can be improved. From 1996, the Countryside Stewardship Grants for taking land out of agricultural production have been focused even more closely on the need to restore and re-create river and water-related habitat. For example, parts of the River Avon and its tributaries are targeted for the restoration of wet grasslands, wetland habitat for wading birds, reedbeds, ponds, scrapes and ditches, appropriate marginal and flood plain trees. This type of incentive will encourage farmers to play their part.

A significant responsibility for the future of river restoration in Britain will lie with The Environment Agency. This will only be achieved by demonstration and information through the media of exhibitions, press, television and radio and by willingness to advise in conjunction with other interested organisations such as the Ministry of Agriculture, Fisheries and Food. Project funding may be available by application for Government funding, either as Grant in Aid or from sources such as the Millennium Fund resourced by the National Lottery. Private or charitable Organisations may also be approached, but it is unlikely that any of these will provide reliable support for restoration on any scale. The Environment Agency will be able to promote restoration in all its operational works by employing best practices in maintenance and management strategy and by pro-actively involving other organisations to promote the philosophy. There is often considerable scope to do this in larger capital works.

The River Chelt is a 15km length of main river running from upstream of the spa town of Cheltenham to its confluence with the River Severn. Much of its course is urban and often culverted; where rural, it has been extensively drained in places and denuded of vegetation by agricultural practices and past river maintenance techniques. The feasibility of carrying out a Flood Alleviation Scheme is currently being examined and the opportunities for restoration and collaborative enhancements is very considerable. This has only been identified by the process of early environmental assessment which is a routine part of the Agency's Capital Works Programme. Wide consultation at the scoping stage has highlighted many issues, concerns and opportunities. It has been possible to take account of many of these in the choice of engineering options. Furthermore, river restoration proposals have been drawn up for the whole river corridor and these will go to consultation shortly as proposals to mitigate the impacts of the works. Fig. 2 illustrates the proposal for one such length; there are 20 in total, many of them requiring urban design solutions.

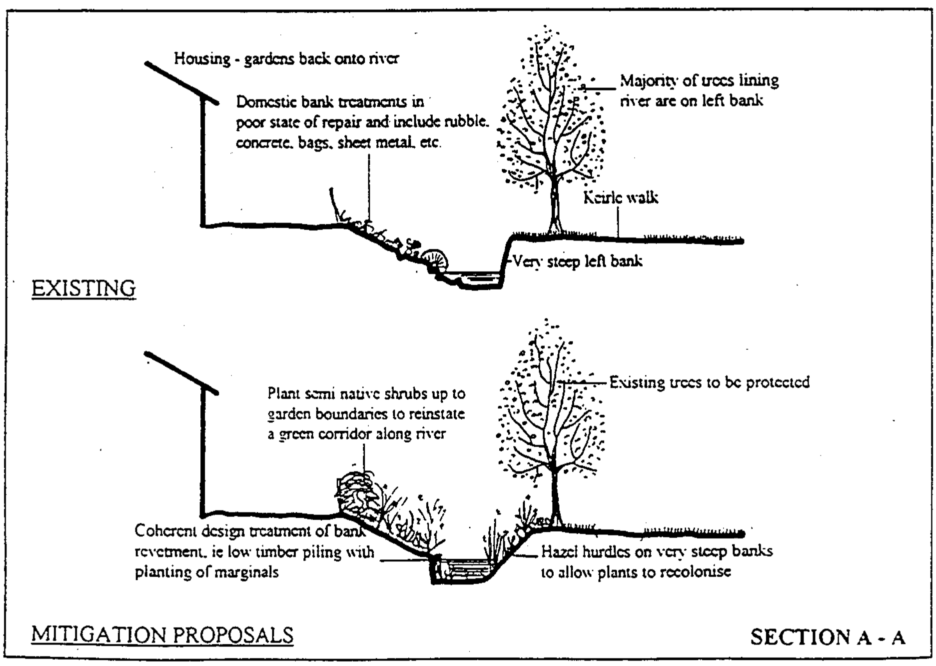

Figure 2. Mitigation proposals for the River Chelt flood alleviation scheme. Prepared for the Environment Agency by Branch Landscape Associates

areas analysed lie in the lower catchment area of the tributary watersheds. The size of the tributary study areas range from 2.6 km^2 in Day Creek to 17.0 km^2 in Finney Creek whereas the size of the entire tributary watersheds range from 10.4 km^2 in Muddy Creek to 168 km^2 in Finney Creek. The tributary study areas are characterised by a very similar geology and climate as compared to the rest of the basin while the river channel in this part of the basin lies in alluvium and is therefore unconstrained and able to adjust to significant changes in discharge or sediment supply.

A historical land use and channel morphology database was created within a Geographical Information System (ATLAS GIS) with the use of aerial photos from the Skagit River Basin in 1937 and 1992 with a photo scale of 1:12,000 and 1:24,000 respectively. In general, the best overlaps between the historical land use digitised from the 1937 and 1992 aerial photos allowed for an analysis of land use between 2-5 km perpendicular to the mainstem. Analysis was confined to areas defined by the eight tributary watersheds.

The landscape in the aerial photos was classified into the following land use variables: agriculture, bare (permanently unvegetated), forested, harvested (timber), residential, urban, railroads, and surfaced and unsurfaced road areas. A Zoom Transfer Scope was used to transcribe the various land use categories from the aerial photo onto a piece of mylar (see-through plastic) which overlaid a base map from which geo-referenced control points were taken. The mylar was then subsequently digitised into the GIS. The area (km^2) or length (km) for each land-use variable was then determined from the GIS in both the 1937 and 1992 layers. The area for each land use was divided by the total study area for each individual tributary to obtain a relative land use area percentage (km^2). This reduced any potential bias due to the unequal sizes of the study areas for each tributary. In an analogous manner, all length measurements for land-use variables (e.g., roads, railroads) were also divided by the total study area to obtain density (km km^{-2}) measurements. The percent area or density change was then calculated by subtracting the 1992 number from the 1937 number.

Land use was analysed at three landscape scales within each tributary study area:

- land use within the aerial photo coverage, hereafter referred to as the photo scale;
- land use within the 100-year floodplain within the aerial photo coverage, hereafter referred to as the floodplain scale;
- land use within 90 meters of the tributary creek within the aerial photo coverage, hereafter referred to as the tributary riparian scale.

Channel morphology measurements were made in the mainstem area only, since the scale of the aerial photos and obscuration by riparian coverage prevented the ability to make these measurements in the tributaries. Mainstem channel changes were measured between the junctions of the tributary watershed boundaries onto the mainstem. The intersection of the tributaries drainage area onto the mainstem Skagit River channel defined the upstream and downstream reach for each tributary study area. The change in the channel morphology variables was measured as a direct percent change (i.e., it was not standardised to the study area) by calculating the ratio of the measurements taken in 1937 to 1992.

The channel morphology variables measured from the features digitised into the GIS included channel area, wetted area at low and high flows, bank length, sinuosity, bankfull width, wetted width, and exposed gravel bar area at different locations. Channel area was defined as the river area between the right and left banks at the upstream and downstream tributary study reach area. Right and left bank length was simply the length of the river bank between the upstream and downstream tributary study reach area. Sinuosity was measured by dividing the bank length by the straight-line length in a reach area. Bankfull (bank to bank) widths included any exposed gravel bars that may have occurred between the banks. Wetted widths were based on the active channel area and differentiated into low and high flows by assuming that unvegetated gravel bars would be submerged at high flows and including this area in width measurements at high flow. Wetted area at low flow was calculated by subtracting the total exposed gravel bar area from the channel area. Wetted area at high flow was calculated by subtracting the exposed vegetated only gravel bar area from the channel area. As with wetted widths, the assumption is that all unvegetated exposed gravel bars are submerged at high flow. Gravel bars were divided into channel bars (those associated with the right or left bank) and mid-channel bars (those surrounded by water on all sides).

In order to determine if the land use variables varied consistently in the same direction between 1937 and 1992 across all eight tributaries, each tributary was treated as an independent statistical unit and a non parametric Wilcoxon paired-sample t-test was applied to the data for each scale (i.e., photo, floodplain, tributary riparian). In an analogous manner, a non parametric Wilcoxon paired-sample t-test was applied to determine if channel morphology attributes varied consistently in the same direction between 1937 and 1992 across all eight tributaries. The data were corrected for small sample size. Spearman rank correlation analyses were conducted to see if a systematic relationship could be determined between the percent area

Landscape scale and the effects of land use on channel morphology: implications for salmon habitat restoration

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Landscape scale, Skagit River, land use, channel morphology, GIS, salmon habitat, river restoration

Abstract
This study measured the historical changes in land use and river channel morphology from a vector based historical Geographical Information System (GIS) database created from aerial photos in 1937 and 1992 from the Skagit River Basin (Washington State, USA). The primary objective was to determine if relationships (i.e., correlations) could be detected between historical changes in land use and mainstem river channel morphology features with the use of aerial photos as the primary data source. A secondary objective was to determine whether the relationships detected are a function of landscape scale. Therefore, the data were analysed at three landscape scales (aerial photo, 100 year floodplain, and 90 meter tributary riparian). This study determined that a systematic relationship could be determined between a particular land us and a particular channel morphology variable. The most general trends observed indicate that land uses classified as agriculture, bare (permanently unvegetated), and railroad were associated with eroding processes (presumably due to increased sediment supply to the river channel), whereas forestry, residential, urban and road areas were associated with non-erosive (or depositional) processes (presumably due to decreased sediment supply to the river channel). In several instances, however, the data indicate that the actual relationships (i.e., positive or negative correlations) between historical changes in land use and channel morphology may in fact be dependent on season (i.e., high and low flows) as well as landscape scale. This study demonstrates that the mechanisms governing landscape changes, such as the impact of land use on channel morphology, appears to vary not only according to the land use in question, but also according to the season, and landscape scale observed. Implications for salmon habitat restoration are discussed.

Introduction
Habitat restoration efforts require a greater understanding of how land use impacts stream habitat. Understanding the impact of human activity on the landscape is, however, challenging since humans are part of the landscape (1), and because ecosystems and landscapes themselves are not defined by static or equilibrium conditions (2). Moreover, the observed changes in the landscape are highly dependent on the temporal and spatial scale at which one views them (3). Thus, the challenge to researchers and managers is to identify how anthropogenic activities have perturbed ecosystems beyond natural variation (4).

The first step in meeting this challenge is to assess the changes on the landscape. In this study, the best available historical data that could be interpreted consistently over space and time was that delineated from aerial photos. The primary objective was to determine if relationships (i.e., correlations) could be detected between historical changes in land use and mainstem river channel morphology features with the use of aerial photos as the primary data source. A secondary objective was to determine whether the relationships detected are a function of landscape scale. Therefore, the data were analysed at three landscape scales (aerial photo, 100 year floodplain, and 90 meter tributary riparian).

Methods
The Skagit River Basin, of which the majority lies in the North Cascades Mountains in Washington state, was chosen for this study because multiple land uses (e.g., agriculture, forestry, and urbanisation) occur within its basin. The Skagit River, with its numerous tributary streams, also has a great variety of aquatic environments, virtually all of which are suitable for use by some anadromous and/or resident fish species. For these reasons, it is an ideal system in which to study the impacts of various land uses on channel morphology with implications for salmon habitat.

Eight tributaries within the Skagit River Basin were selected for analysis: Wiseman, Jones, Day, Red Cabin, Muddy, Alder, Grandy and Finney Creeks. Due to the availability of aerial photo coverage, the study variable to which other aspects of channel form adjust. Channel widening or aggradation occurs because the load-discharge ratio is increased as excess sediment load is deposited. The load-discharge ratio is altered when a reduction in stream gradient reduces the capacity of the stream to transport sediment. Excess sediment results from accelerated slope and tributary valley erosion. Although increased sediment supply may have several origins, it is generally considered to result from an increase in erosion rates caused by human activities such as agriculture, timber harvesting, and urbanisation (8).

Virtually all of the changes in channel morphology indicate that sediment supply to the mainstem Skagit River channel decreased within the study area between 1937 and 1992. In particular, channel area, wetted area at high flow, various channel width and exposed gravel bar area measurements decreased across all eight tributary reaches

In addition, right bank length and right bank sinuosity increased. Area is analogous to width, which is predicted to decrease with a decrease in sediment supply, and sinuosity (which is related to bank length) is predicted to increase. Gravel bars, which store bedload material, are assumed to be an indicator of sediment supply to the channel. Thus, a decrease in exposed gravel bars, and an increase in sinuosity is consistent with an observed decrease in channel area and width.

Several other historical observations support a decreased sediment supply to the mainstem Skagit River channel between 1937 and 1992. As noted above, timber harvested areas decreased and residential and urban areas increased in all tributaries at all three landscape scales. Since deforested areas have been shown to increase water discharge and sediment supply after timber removal, subsequent reforestation would be expected to reduce sediment supply to the channel resulting in decreased channel width (9). Bank vegetation exerts a strong control over bank stability, and erosion rates are diminished with an increase in root strength resulting from revegetation. In addition, although urbanisation temporarily increases sediment supply, particularly during the construction phase, in the long run, due to an increase in impermeable surfaces, sediment supply actually decreases below natural levels once urban development is complete (10). The areas that were harvested in the early part of the century were generally either reforested or converted to other land uses such as agricultural and residential areas. These observations thus support the conclusion of a decreased sediment supply to the mainstem channel.

Relationships between historical changes in land use and channel morphology

Overall, the data indicate that there are inferred differences in how particular land uses may affect various channel morphology characteristics. Although the trends in various channel morphology dimensions are not expected to behave in a uniform manner, in general, the direction of change can be associated with eroding or depositional processes. The most general trends observed indicate that land uses classified as agriculture, bare (permanently unvegetated), and railroad were associated with eroding processes, whereas forestry, residential, urban and road areas were associated with non-erosive (or depositional) processes. For example, agriculture, bare (permanently unvegetated) and railroad areas were associated with increases in various channel width and area measurements, whereas forested, residential, urban and road areas were associated with decreases for these same variables.

At first glance, it may seem surprising that residential, urban and road areas have a similar impact on channel morphology as forested areas. As noted earlier, however, other studies have clearly shown that over time, urbanization activities in fact decrease sediment supply to the channel owing to the increase in impermeable surfaces associated with these land uses. The decrease in sediment supply as a result of increased impermeable surfaces would thus have a similar effect to vegetative cover that stabilises or decreases erosion processes. Moreover, the relative amount of land area within a catchment that is classified as urban has a significant effect on alterations to water discharge patterns and sediment supply. At all three landscape scales analysed, the relative percent of rural and urban areas combined did not exceed 7.5%, with a mean of 3.3%. This level is below that noted in other studies in which a 10-12% level of urbanisation resulted in increases in peak discharge and flood frequency.

Although urban areas are associated with decreased sediment supply as a result of increased impervious surfaces, these same surfaces reduce infiltration resulting in a higher percentage of rainfall becoming runoff which increases water discharge. Thus, the impact that a particular land use has on increasing or decreasing sediment and discharge could be predicted to vary with season. For example, the impervious surfaces associated with urbanisation, which generally reduce sediment supply (during low summer precipitation), could be expected to increase sediment supply during winter when high rainfall results in increased runoff and faster overland flow velocities.

change in a particular land use with the direct percent change in a particular channel morphology variable. The results were analysed at three landscape scales (photo, floodplain, tributary riparian area).

Results and discussion

Land use changes

This study assessed changes on the landscape in the Skagit River Basin in order to determine if historical changes in land use impacted river channel morphology. Due to limited space availability, the reader is referred to a complete and detailed tabular presentation of the statistical results in (5). The general results that were statistically significant and their implications are discussed here.

The results of the Wilcoxon paired-sample t-test for land use changes between 1937 and 1992 indicate that the land uses that changed consistently across all 8 tributaries at various landscape scales include harvested (timber), residential, urban, railroad and unsurfaced road areas. Harvested areas decreased at all three landscape scales due to the fact that within the study area, timber harvest peaked in the 1920s (6). Initial cutting was conducted in low elevation areas along the mainstem river and tributaries, which could be used to transport logs and shingle bolts. As the areas next to waterways became depleted, logging moved upslope into higher elevations. The subsequent logging operations in higher elevations is not reflected in the data presented, as the aerial photo coverage analysed is limited to 2-5 kilometers away from the mainstem. Residential and urban areas increased in all eight tributaries at all three landscape scales which is not surprising given the corresponding trend in increased population growth within Skagit County. Railroads decreased at the photo and tributary riparian scale most likely as a result of converting from railroad logging to truck logging in the mid-1950s. Unsurfaced roads increased consistently across all eight tributaries only at the photo scale. No consistent trend was noted at the floodplain and tributary riparian scale because the construction of unsurfaced roads decreased in some areas as they were converted to surfaced roads.

Those land uses that did not change consistently across all eight tributaries at any landscape scale include agriculture, bare (permanently unvegetated), forested and surfaced roads. This is because agriculture increased in some tributaries, and decreased in others. The same is true for forested areas. In fact, in every tributary watershed in which agriculture increased, forested areas decreased, and vice-versa, suggesting a direct trade-off between these two land-uses. No significant change in bare (permanently unvegetated) areas was detected due to low sample size. Surfaced roads did not change consistently across all eight tributaries because surfaced roads decreased in the four most downstream tributaries, whereas they increased in the four most upstream tributaries. This is because the majority of roads were established in the lower portion of the basin by 1937 whereas subsequent road building increased in the upper portion of the basin as settlement patterns moved up the basin over time.

The results of the Wilcoxon paired-sample test discussed above evaluated whether there was a consistent difference in the same direction across all eight tributaries between 1937 and 1992. Statistical non-significance in this case is not an indicator that the magnitude of change was insignificant in any particular study area, but rather that the direction of change varied inconsistently across all of the tributary study areas. This is in fact desirable in attempting to assess whether land use has an impact on channel morphology. In other words, it is preferable to have varying land uses in the different tributaries and to assess if these differences vary in a systematic way (i.e., as one variable increases the other increases, or vice-versa). For this reason, Spearman rank correlation analyses were conducted to see if a systematic relationship could be determined between the percent area change in a particular land use with the direct percent change in a particular channel morphology variable.

Channel morphology changes

The two major processes affecting channel morphology are water discharge and sediment supply In drainage basins which have had relatively little human impact, and in which equilibrium conditions prevail, the stream system itself tends to be morphologically stable, transporting the water and sediment loads imposed from within the watershed without enlarging or aggrading the channel. The way the stream system responds may be altered when the watershed has been greatly disturbed by natural disturbances or human activities. In particular, any significant change in vegetation is likely to increase sediment discharge proportionately more than water discharge. Major changes in vegetation as a result of changes in land cover due to agriculture, deforestation, and urbanisation have been documented to have the most extensive and crucial impacts on streams (7).

Although several parameters can be used to define river channel morphology (e.g., mean depth, channel capacity, meander, riffle-pool wavelengths, etc.), channel width is considered a primary morphological the quality and quantity of physical habitat influences the abundance of salmon populations (11). Moreover, the evolution of river channel morphology and salmonid habitat are linked processes (12).

Although there is no consensus as to the factors causing salmon declines, there is, however, a great deal of interest in protecting and restoring these animals. Habitat restoration efforts, which are by necessity and practicality limited to the freshwater habitat in which salmon live, is one step in this direction. Focusing restoration efforts on freshwater habitat requires an assessment of historic land use and channel conditions in order to understand the geomorphological processes affecting a channel reach. The impact of human activities (e.g., deforestation and dam construction) on geomorphological processes such as flow regime and sediment load needs to be understood if restoration efforts are to be successful (13). Since the result of sediment storage is cause a lag time between a change in the supply of sediment to the system and the adjustment of the channel morphology, any investigation must start by examining historical changes in land use, hydrology and river morphology so that the present channel behaviour and morphology can be put into context (14).

This historical context can be used to develop criteria upon which success should be evaluated, as well as form the basis from which to evaluate the results. Used in conjunction with adaptive management techniques, in which there is an explicit link between science and management and management itself is treated as an experiment, it can provide a means by which to learn from the past (15). For the purposes of establishing connections between geomorphic and biologic evaluation techniques, two approaches to define success have been suggested. The first defines success as the creation of physical habitat features, (e.g., pools, riffles, or riparian nesting areas), whereas, the second defines success as increases in populations of organisms in the project reach as a result of restoration (16).

Since the intent of this study was to determine the historical impact of land use on channel morphology, the best available historical data that could be interpreted consistently over space and time was that delineated from aerial photos. By necessity then, the inference on salmon habitat was limited to mainstem channel morphology measurements that could be made from aerial photos. Since channel geomorphology is the framework upon which ecological systems are developed, any changes in channel morphology beyond natural variation are likely to have negative consequences for salmon habitat and populations.

The historical analysis in this study showed that certain land uses, particularly, agriculture, bare (permanently unvegetated), and railroad areas, could be characterised as having erosional effects on river channel morphology. However, the data also indicate that the overall sediment supply to the Skagit River system appears to have declined between 1937 and 1992. Evidence includes a general narrowing of several mainstem channel dimensions, a decrease in exposed gravel bars and timber harvested areas, and an increase in forested areas within the tributary riparian areas. This could be interpreted as improved salmon habitat health since many of the results support predicted fluvial relationships as a consequence of human alterations in the watershed. Improvement in health, however, needs to be looked at on a continuum. In this basin, most of the historical evidence indicates that the majority of negative impacts to the river system had already occurred by 1937, the date of the first set of aerial photos utilised in this study. From this perspective, it is not surprising that mainstem channel habitat health has improved. It is difficult, however, to interpret the significance of this improvement. Is it a minor or major improvement in comparison to a previous state of habitat health and against what point should habitat health be measured?

The conclusions drawn here, as in any historical study, are contingent on events that have taken place previously within the watershed. Moreover, it is the preponderance of information that must be considered since any one item is unlikely to provide conclusive proof. It is important to keep in mind that although many of the results in this study support predicted fluvial relationships, these relationships are based on equilibrium conditions, which may or may not apply. Furthermore, inherent in these fluvial relationships is the notion that they are continuous without thresholds. The system may in fact be more aptly characterised by threshold values, at which point the processes may reverse themselves. This appears to be particularly true for activities associated with urbanisation and road-building. Up to a certain threshold value they do not appear to have negative impacts on channel morphology, but beyond a certain threshold value (i.e., percent drainage coverage or density) negative impacts begin to appear. Their effects, however, are likely to be complicated by spatial location (e.g., presence/absence in tributary riparian area, elevation) and season as indicated previously. In addition, any changes in the watershed should be viewed on a continuum. Channel narrowing and decreased sediment supply may indicate an improvement of habitat conditions up to a certain point. Beyond a certain point, channel narrowing may in fact indicate degradation of habitat and loss of riverine habitat and complexity.

Several observations in this study indeed indicate that there appears to be a seasonal component to how land use affects channel morphology. For example, when wetted width measurements were differentiated into low and high flows (high flow measurements were obtained by assuming that unvegetated exposed gravel bars would be submerged at high flow), the expected correlations for both agricultural and forested areas held at low flow, while they were reversed at high flow. This did not, however, hold true for unsurfaced roads, which did not show different patterns between high and low flows at any particular landscape scale.

Somewhat surprisingly, unsurfaced roads did not affect channel morphology in a different manner than surfaced roads (i.e., they were negatively correlated with nearly all channel morphology features). The exceptions appear at the tributary riparian scale where positive correlations were noted with unsurfaced roads and wetted width measurements. This may indicate that the tributary riparian area is most susceptible to increased sediment supply from unsurfaced roads. Improved road-building techniques may explain why unsurfaced roads affected channel morphology in an analogous manner as surfaced roads at the photo and floodplain scales. Moreover, it should be emphasised that the impact of roads is most likely related to their density and location. Because of the difficulty in detecting roads in heavily forested areas on the aerial photos, this study underestimated actual road density although the method utilised was sufficient to detect trends over time (i.e., increase or decrease). In addition, the negative impacts generally associated with road construction are likely to be more severe at higher elevations, which are not represented in the study area.

As noted previously, exposed gravel bars clearly declined in all tributary reaches between 1937 and 1992. When exposed gravel bars were subdivided into channel (those directly associated with the right or left bank) and mid-channel bars (those surrounded by water on all sides), distinctly different patterns emerged. Most notably, for any particular land use, the trend observed for channel bars was always opposite of that observed for mid-channel bars. For example, at the photo scale, total exposed channel gravel bars were negatively correlated with bare areas and positively correlated with residential, urban, and road areas, while the exact opposite was true for total exposed mid-channel gravel bars. This may indicate that channel bars are more likely than mid-channel gravel bars to reflect sediment supply from land use in the adjacent tributary watershed. Mid-channel bars may be differentially incorporating more of the effects of upstream sediment supply and, therefore, may not reflect adjacent land use.

Spatially dependent observations between changes in land use and channel morphology

Several observations indicate that some trends vary according to the scale of the land use analysed (i.e., photo, floodplain, or tributary riparian).

The most notable trends between land use and channel morphology that appear to be dependent on landscape scale are those for timber harvested areas. As would be expected, harvested areas have the same impact on channel morphology features as agricultural areas at the tributary riparian scale. Both of these land uses can be expected to increase sediment supply to the channel. Surprisingly, harvested areas act opposite to agriculture and bare areas, and the same as forested areas for some channel morphology features at the photo scale. For example, bankfull width at the centre of the reach area was negatively correlated for both harvested and forested areas while positively correlated with agricultural areas. In an analogous manner, channel area was negatively correlated with harvested areas while positively correlated with bare areas. This indicates that increased sediment supply from harvested areas has the greatest impact on channel morphology at the tributary riparian scale, but not at the larger photo scale. Furthermore, it substantiates the idea that the tributary itself appears to be the primary mover of sediment supply to the mainstem river channel as a result of land use in the adjacent tributary watershed.

Additional observations that appear to substantiate the conclusion that certain land uses are dependent on landscape scale were found between roaded areas and wetted widths. At the photo and floodplain scale, virtually every correlation between roads (both surfaced and unsurfaced) and channel morphology was negative. At the tributary riparian scale, however, several positive correlations were noted for roads with wetted widths. This may indicate that roads have a greater negative impact on channel morphology at the tributary riparian scale than at the other landscape scales.

Implications for salmon habitat restoration

The preceding discussion has been limited to how changes in land use may affect river channel dimensions from a geomorphological perspective. The physical parameters describing channel geomorphology constitute the physical framework supporting riparian and aquatic ecosystems and it may be assumed that

River restoration in Denmark

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Introduction

Prior to 1983, the Danish legislation on streams gave priority to agricultural drainage of water. This resulted in the straightening and channelization of most of the approximately 35,000 km of natural Danish streams. By the revision of the Danish Watercourse Act in 1982 a balanced priority was given to drainage of water and environmental quality, bringing ecologically more appropriate maintenance practise into focus. At the same time special provisions were given for stream restoration activities. Since then, several hundred measures have been undertaken throughout Denmark to improve the quality of the streams. Restoration of continuity between watercourse reaches has been carried out most frequently.

River restoration measures in Denmark

To gain an overview of the number of different river restoration projects carried out by the Danish counties the European Centre for River Restoration have developed a database. The database is further described and explained in (1) and (2). In the database the projects have been divided into three restoration types. Up to and including 1996, a total of 930 river restoration projects have been carried out by the Danish counties (Table 1).

The database is linked up to GIS via the UTM grid-net enabling the plotting of the restoration site positions on maps (Fig.1).

In addition to the 930 projects carried out by the counties comes a substantial number of restoration projects carried out by the municipalities and private organisations.

Table 1. Number of projects carried out by the Danish counties up to and including 1996

Type no.	Type description	Number of projects
Type 1	Rehabilitation of watercourse reaches	174
Type 2	Restoration of the continuity between watercourse reaches	740
Type 3	Rehabilitation of river valleys	16
Total		**930**

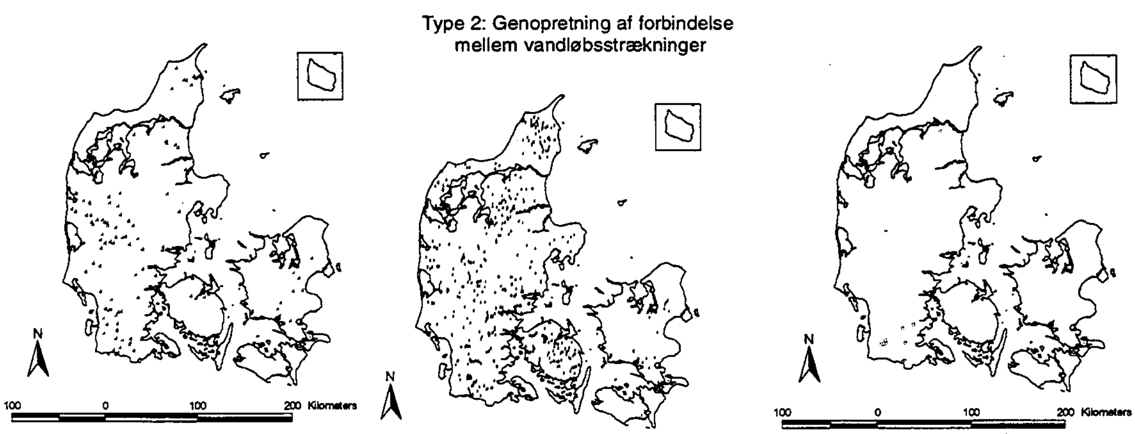

Figure 1. Positions of restoration projects carried out by the Danish counties up to and including 1996: Left: Type 1 (Rehabilitation of watercourse reaches); Middle: Type 2 (Restoration of the continuity between watercourse reaches); Right: Type 3 (Rehabilitation of river valleys). Please note that a number of projects are missing on the maps as no UTM co-ordinates have been given.

Conclusion

In conclusion, this study determined that a systematic relationship could be determined between a particular land use and a particular river channel morphology variable from an historical vector based GIS database created with aerial photos. Moreover, it was shown that the mechanisms governing landscape change, such as the impact of land use on channel morphology, appears to vary not only according to the land use in question, but also according to the season, and landscape scale observed.

The advantage of aerial photos is that they allow the creation of a high quality database that is temporally and spatially compatible. One drawback is that they often do not exist for periods before extensive water-shed alteration have occurred. In addition, the obscuration of riparian coverage and the scale of the aerial photos often do not allow an assessment of channel morphology within the tributary creek itself. However, the ability to create a uniform and consistent database across time and space in order to solve the problems of either non-existent data, or the problem of comparing "apples and oranges" of data collected in varying ways at different times and places is perhaps the greatest virtue in utilising GIS to create an historical data-base. This uniform and consistent database is necessary in order to determine the relationships of historical changes in land use to channel morphology. In addition, GIS allows for the testing effects of land-scape scale from the database. The importance of understanding the differential impact that landscape scale has on how land use impacts stream habitat is crucial for improving management practices leading to sustainability.

The interactions governing watershed processes are complex. Moreover, understanding ecosystem properties is often a question of temporal and spatial scale. Here, the inference is made that changes in channel form may be an indicator of salmon habitat quality which in turn may affect the health of salmon populations. Further studies are needed to more clearly determine if channel morphology characteristics can adequately be used as an indicator of salmon habitat quality. This is particularly important because channel morphology measurements are often the only viable historical data that can be obtained from aerial photos at a watershed scale in order to determine the impact of historical land use on salmon habitat.

Historical reconstructions is an underutilised approach which may aid in the understanding of ecosystem properties in time and space. Although observed changes and correlations do not functionally define cause and effect, these observations may facilitate the identification of which factors may be of most significance in understanding the underlying mechanisms of how land use may affect salmon habitat and/or salmon populations. The success of restoration efforts is likely to depend on this type of understanding.

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Quantitative Assessment of Fish Habitat Quality in Urban Streams in Tokyo Prefecture, Japan

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Key words: Fish Habitat Quality, Urban Stream, Generalised Linear Model

Abstract

In order to assess quantitatively fish habitat quality, we statistically examined the relationship between fish population indexes and fish habitat factors related to human activities on 24 streams passing through urban areas in Tokyo Prefecture, Japan. For statistical analysis, we used the Generalised Linear Model (GLM), composed of each of the six fish population indexes as response variables, and five quantitative and three qualitative fish habitat factors as explanatory variables.

The index of biotic integrity, the number of individuals of Japanese pale chub and the total number of the four fish species as the fish population indexes estimated from GLM were significant at the 1% level, and the coefficients of determination (0.725, 0.553 and 0.488) were also higher than those of the other fish population indexes. The signs of coefficients for fish habitat factors selected using GLM indicated that a high biochemical oxygen demand, the presence of odour and the absence of running water particularly are not desirable factors for fish habitat quality.

Introduction

Fish habitats in streams passing through urban areas in Japan are affected by many human activities such as stream channelisation, water pollution, reclamation etc. (1). Fish populations in such streams have a tendency to decrease and become dominated by a few species. Urban citizens expect restoration of streams that can sustain both a large fish population and also a high species diversity as well as being comfortable for themselves.

The purpose of this paper is to investigate quantitatively fish habitat quality in 24 streams passing through urban areas in Tokyo Prefecture, Japan. We have statistically examined the relationship between fish population indexes and quantitative and qualitative fish habitat factors related to human activities by means of the GLM (2).

Materials and Methods

We selected 30 sites on 24 streams in Tokyo Prefecture (Fig. 1). Data sets of the fish population indexes and fish habitat factors for each site are summarised in Tab. 1. Scores of the Index of Biotic Integrity (IBI) (3), number of individuals of Japanese pale chub *Zacco platypus*, Japanese dace *Leusiscus hakonensis*, Cyprinidae *Cyprinus carpio* and *Carassius* spp. and ayu *Plecoglossus altivelis* and the total number of the above four species were adopted as the fish population indexes. Urbanisation ratio, country ratio and forest ratio for the land use in the riparian area, revetment ratio for the stream channelisation, Biochemical Oxygen Demand (BOD), odour intensity and transparency for the water quality, and current for running water condition were used as the quantitative and qualitative fish habitat factors related to human activities (Tab. 1). Details of the fish population indexes and fish habitat factors are given in (1)(3).

We examined quantitatively the relationship between each of the six fish population indexes and the five quantitative and three qualitative fish habitat factors by means of GLM using the multiple regression type analysis (2).

$$Y = \theta_1 x_1 + \theta_2 x_2 + \theta_3 x_3 + \theta_4 x_4 + \theta_5 x_5 + \alpha_1 z_{6,1} + \alpha_2 z_{6,2} + \alpha_3 z_{6,3} + \alpha_4 z_{6,4} + \beta_1 z_{7,1} + \beta_2 z_{7,2} + \gamma_1 z_{8,1} + \gamma_2 z_{8,2} + C + \epsilon.$$

Where Y the response variable is the fish population index. $x_1,\dots, x_5$ the quantitative explanatory variables are the urbanisation ratio, the country ratio, the forest ratio, the revetment ratio and the BOD, respectively. $z_{6,1},\dots, z_{6,4}$, $z_{7,1}$ and $z_{7,2}$ and $z_{8,1}$ and $z_{8,2}$ are the categories of the qualitative explanatory variables as none, slight, mild or marked odour intensity, clear or muddy for the transparency and suitable or none for the current, respectively. These categories are the dummy variables, which are expressed by one or zero. C is a constant, and ϵ is an error factor with a normal distribution, N $(0, \sigma^2)$.

$\theta_1,\dots,\theta_5$, $\alpha_1,\dots,\alpha_4$, β_1, β_2, γ_1, γ_2 and C in the equation were estimated by the iterative weighted least squares method of the maximum likelihood method (2). Fitness propriety of GLM was decided by a step wise method using Akaike Information Criterion.

Remeandering in Denmark

Large-scale projects such as remeandering of formerly straightened streams (type 3 in the database) are the most conspicuous to the public. Until recently such large-scale projects have often been restricted by local resistance from the farmers.

However, new EU-legislation has made it unprofitable to cultivate drained areas and has thus reversed the resistance into a generally positive understanding thereby making it possible to recreate many of the earlier floodplains and to remeander a selection of Danish streams in especially important nature areas.

Remeandering has been undertaken in about 10 larger Danish streams. Several projects are planned for the coming years, including the remeandering of 18 km of the largest river in Denmark, the River Skjernå. This project will be the largest river remeandering project in the World to date.

In order to monitor the biological, chemical and physical effects of river and flood-plain restoration the Danish National Environmental Research Institute has in several cases implemented a monitoring programme in co-operation with local authorities, and a standardised national monitoring programme to be used in connection with restoration projects is now being developed.

Two EU-LIFE demonstration projects in Denmark

In connection with the development of the monitoring programmes the EU Life-programme has granted funds to two river restoration demonstration projects in the rivers Gudenå and Bredeå. The rivers have been remeandered and their adjacent flood-plains restored. The River Gudenå represents the small headwaters of a stream whereas the River Bredeå represents the middle-sized Danish river. In both projects the biological, chemical and physical effects of the restorations were followed intensively.

The remeandering project in the River Gudenå was undertaken in the uppermost 2.7 km of the river starting from its source. The river was remeandered in 1995 from a straight and channelized reach into a new 3.5 km meandering course.

The River Bredeå was remeandered in 1994 from a 2.8 km straight stream into a 4.3 km meandering course. Subsequently, the county continued the remeandering of the River Bredeå upstream and downstream in the following years resulting in a total restoration of more than 22 km stream with meanders and wetter adjacent meadows - the largest remeandering project in Denmark at present.

The remeandering of the River Skjernå will commence in 1999. Being the largest river in Denmark the remeandering will gain valuable knowledge on large sized river restoration and supplement the experiences from the restoration of the small headwater stream and the middle-sized river represented by the Gudenå and the Bredeå projects.

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Table 2 shows the relationship between the fish population indexes and the fish habitat factors analysed by GLM. All of GLM were significant, in particular GLM for IBI, Japanese pale chub and the total of the four fish species were significant at the 1% level, and had relatively high coefficients of determination (0.725, 0.553 and 0.488).

The BOD was frequently selected as a significant variables in GLM, the sign of the coefficient for the BOD mainly had a minus. The odour intensity and current were also selected significantly in some GLM. Both the sign of the coefficient for zero odour intensity (none) and the presence of current were plus. Generally the water quality factors such as BOD and odour intensity had a stronger relation to the fish population indexes than the land use factors such as the urbanisation ratio, country ratio and forest ratio. The signs of the coefficients of the fish habitat factors indicated mainly that a high BOD, the presence of odour and the absence of running water are not desirable factors for fish habitat quality. To increase fish populations in urban streams in Tokyo Prefecture, we must firstly improve the present water quality management in consideration of the results of this analysis.

Table 2. Relationship between fish population indexes and fish habitat factors using the GLM multiple regression type analysis.

		Fish population index (response variables)					
Fish habitat factors (explanatory variables)		IBI	Japanese pale chub	Japanese dace	Cyprinidae and *Carassius* spp.	Ayo	Total species
Urbanization ratio (θ_1)			-0.735			-0.055	
Country ratio (θ_2)		-0.177		-1.345		-0.083	
Forest ratio (θ_3)				0.914		0.067	
Revetment ratio (θ_4)			0.349 **				0.411
BOD (θ_5)		- 1.155 **		-1.570	3.105 *	-0.140 *	-3.253 *
Odor intensity	None (α_1)	-8.482	16.503		43.861		
	Slight (α_2)	-6.978 *	-7.560 **		10.301 *		
	Mild (α_3)	10.644	-2.856		-29.310		
	Narked (α_4)	4.815	-6.088		-24.852		
Transparency	Clear (β_1)		6.111				
	Muddy (β_2)		-6.111				
Current	Suitable (γ_1)	6.698 **		11.530			37.524 **
	None (γ_2)	-6.698		-11.530			-37.524
	Constant (C)	37.592	-16.484	25.830	-32.333	2.535	31.936
	R^2	0.725	0.553	0.308	0.308	0.355	0.488
	Equation	**	**	*	*	*	**

GLM with maximum coefficient of determination (R2) are shown for each of the fish population indexes. Numerals indicate coefficients of the explanatory variables selected using the step wise method with AIC. Significance of explanatory variables and equations are shown with asterisks. **, significant at 1% level; *, significant at 5% level. $\theta_1,\ldots,\theta_5$, $\alpha_1,\ldots,\alpha_4$, β_1, β_2, γ_1, γ_2 correspond to parameters of the equation in the text.

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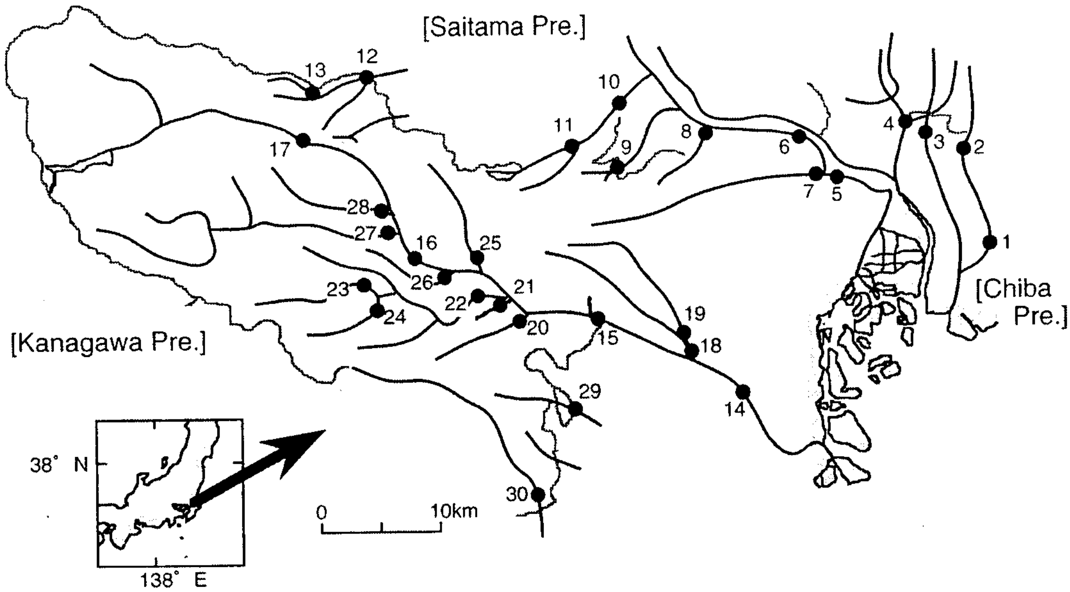

Figure 1: Locations of the 30 sites on 24 streams in Tokyo Prefecture. 1, Ex-Edo; 2, Edo; 3, Naka; 4, Ayase; 5, Sumida; 6, Sinkawagishi; 7, Ishikamii; 8, Shirako; 9, Ochiai; 10, Yanase; 11, Karabori; 12, Kurosawa; 13, Naruki; 14, 15, 16 and 17, Tama; 18, No; 19, Sen; 20, Ohkuri; 21, Hodokubo; 22 and 23, Asa; 24, Minamiasa; 25, Nokobori; 26, Yachi; 27, Aki; 28, Hirai, 29, Tsurumi; and 30, Sakai. •œ, site of fish sampling and environmental survey.

Table 1. List of attributes for the fish population indexes (response variables) and fish habitat factors (explanatory variables). [1]Mean on site from 1985 to 1993; [2]No. of data is one from 1990 to 1993; [3]Mode on site from 1985 to 1993.

Variable		Unit (category)	Analyzed statistic	Attribute	Data citation
Fish population index					
IBI, Indeks of Biotoic Integrity		Score	Mean[1)]	Quantitative	Report of fish samplint and environmental survey published by Tokyo Prefecture
Fish species	Japanese pale chub	Individuals	Mean	Quantitative	
	Japanse dace	Individuals	Mean	Quantitative	
	Cyprinidae and *Carassius* spp.	Individuals	Mean	Quantitative	
	Ayu	Individuals	Mean	Quantitative	
	Total of the four fish species	Individuals	Mean	Quantitative	
Fish habitat factor					
Urbanization ratio		%	No treatment[2)]	Quantitative	Topographical map on a scale of 1 to 25,000
Country ratio		%	No treatment	Quantitative	
Forest ratio		%	No treatment	Quantitative	
Revetment ration		%	No treatment	Quantitative	
BOD, Biochemical Oxugen Demand		mg l^{-1}	Mean	Quantitative	Report of fish sampling and environmental survey published by Tokyo Prefecture
Odor intensity		None; slight; mild; marked	Mode[3)]	Qualitative	
Transparency		Clear; muddy	Mode	Qualitative	
Current		Suitable; none	Mode	Qualitative	

Results and Discussions

There were several correlations between the fish population indexes and the quantitative fish habitat factors. IBI and ayu indicated a positive correlation with the forest ratio ($r=0.364$ and 0.385, $p<0.05$) and a negative correlation with the BOD ($r=-0.522$, $p<0.01$ and -0.416, $p<0.05$). There were many significant differences between the fish population indexes and the qualitative fish habitat factors. The fish population indexes, except for Japanese dace and Cyprinidae and Carassius spp., to clear waters were significantly higher than those of muddy waters. Also all of the correlations of fish population indexes to current were significantly higher than for those where no current occurred.

the intercalated lakes (2). The former meanders are to a great extent still present as 70 backwaters, which form an extensive potential for the restoration of the original river morphology by remeandering. The investigations were carried out at two sections (Fig. 1): First at the "Krumme Spree", a 23 km section of the river about 100 km upstream of Berlin, in a cross section 600 m upstream of the weir at the village of Kossenblatt. The second section was a 400 m long segment of the "Müggelspree" near the village of Freienbrink, about 11 km upstream of Berlin.

Zoobenthos samples were taken in cross sections each meter with a VAN-VEEN-grab, sampling an area of 600 ± 50 cm^2. Funnel and box traps have been used in order to determine emergence rates in seven habitats. Dry weight was estimated, using length - weight regression equations. These power regressions were established using specimen from the Spree. Sediment composition was determined by dry sieving of the uppermost 5 cm of sediment cores obtained with a 5 cm ID corer. Current velocity was measured using a propeller (SEBA Instruments inc.) near Kossenblatt at mean discharge conditions on 31/8/1994.

Results

The cross-section near Kossenblatt shows, like most of the other sites, a relatively symmetric, artificial trapezium shape. Current velocities were therefore quite uniform across the river bed, except for the first 6 m near the river banks. In the central zone of the river channel (6 to 24 m from the left bank), maximum velocities within each vertical profile ranged from 0.24 to 0.36 m s^{-1}. Velocities near the river bottom did not deviate much from 0.15 ms^{-1}. River bed sediments were dominated by medium sand (0.5 - 1.0 mm) in the central zone, with an increasing share of coarse sand towards the left bank. The medium sand fraction does not form a compact sediment layer, but is loosely deposited forming moving ripples. In the sublittoral zone, sediments were constituted mostly by fine sand, except for the coarse gravel of the rip-raps (Fig. 2).

Macrozoobenthos abundance and diversity showed clear peaks in the sublittoral zones (Fig. 2). Highest abundances were recorded in samples that included major shares of coarse sand or gravel. Invertebrate assemblages were dominated by mussels (*Unio tumidus, Unio pictorum, Anodonta anatina, Dreissena polymorpha*), gastropods (*Viviparus viviparus, Bithynia tentaculata*), dragonfly larvae (Odonata), and sponges. In contrast, the central zone was colonized nearly exclusively by Chironomini (Chironomidae, Diptera) in low density.

Mussels of the above-mentioned species were found in a density of c. 1400 individuals per meter of river length, with a dry mass (without shells) of c. 1 kg. Based on data for specific filtration rates for these species (J. Siefert, pers. comm., for *Unio* and *Anodonta,* (3) for *Dreissena*), a portion of about 20 % of the daily water discharge could be estimated, which is filtrated by the whole mussel community of the "Krumme Spree" at mean discharge conditions (c. 20 m^3 s^{-1}). Filtration efficiency is supposed to be correspondingly higher during periods of low flow rate in summer.

At the river segment near Freienbrink a very similar situation was found. The central areas were covered by moving sand, too, which was extremely sparsely colonised. The zoobenthos community of fine sandy bottoms populated with macrophytes was clearly dominated by bivalves (*Unio tumidus, Anodonta anatina, Unio pictorum). Simulium erythrocephalum.* was abundant on macrophytes. Larvae and exuviae of three species of Gomphidae (*Gomphus vulgatissimu, Stylurus flavipes, Ophiogomphus serpentinus*) and adult Sphaeriidae (Bivalvia, e.g. *Sphaerium rivicola*) were found on uncovered fine sand sites.

The zoobenthos community of rip-raps was dominated by epilithic grazers (e.g. *Viviparus viviparus*) and some neozoic crustaceans (e.g. *Orconectes limosus, Chaetogammarus ischnus, Corophium curvispinum*). However, some endangered potamobiontic insects (*Heptagenia flava, Heptagenia sulphurea*) also showed clear preferences even for rip-raps. These rheophilic taxa, typical for the epipotamalic section of this lowland river, have adopted the rip-raps as 'secondary habitat'. Probably these hard-bottom dwelling taxa had preferred submerged woody debris before the river morphology had been altered (4).

Average annual emergence rate was about 2.0 g d.w. · m^{-2} · a^{-1} for a stream bed strip extending up to 3 m distance from the river bank. Chironomidae and Trichoptera emergence dominated on rip-raps and on fine sand. The highest emergence was estimated for the fine sands that are the habitat of the Gomphidae. The zoobenthos of the lower River Spree includes at least 200 species, among them about 150 insects. The list can be completed with at least 100 stagnophilous species of the backwater fauna.

Proposals for the restoration of River Spree (Germany) based on assessments of zoobenthos habitats.

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Abstract

1. The lowland River Spree (North-East Germany, upstream of Berlin) has been engineered and partly depleted in natural habitats during the past 200 years.
2. Based on an inventory of the bottom sediments and physical investigations of characteristic sections, the most important five habitats of zoobenthos were assessed and the major deficiencies were determined.
3. The importance of benthic invertebrates for self-purification is outlined.
4. This results in a proposal for the restoration of the river, which should include re-meandering, the removal of rip-raps and a change of cross section morphometry.

Introduction

The restoration of a complex system like a river demands complex views, which take into consideration all compartments and relations within the system and all important links to the environment. Here we contribute criteria for restoration concepts based on assessments of zoobenthos habitats, which integrate many demands of the entire ecological and geomorphological system. Zoobenthos is important as a nutritional basis for fishes and as an active element for self-purification and matter retention processes in the river. It also links the aquatic ecosystem and the riparian zone, as the terrestrial stages of benthic insects play a major role in the terrestrial food web.

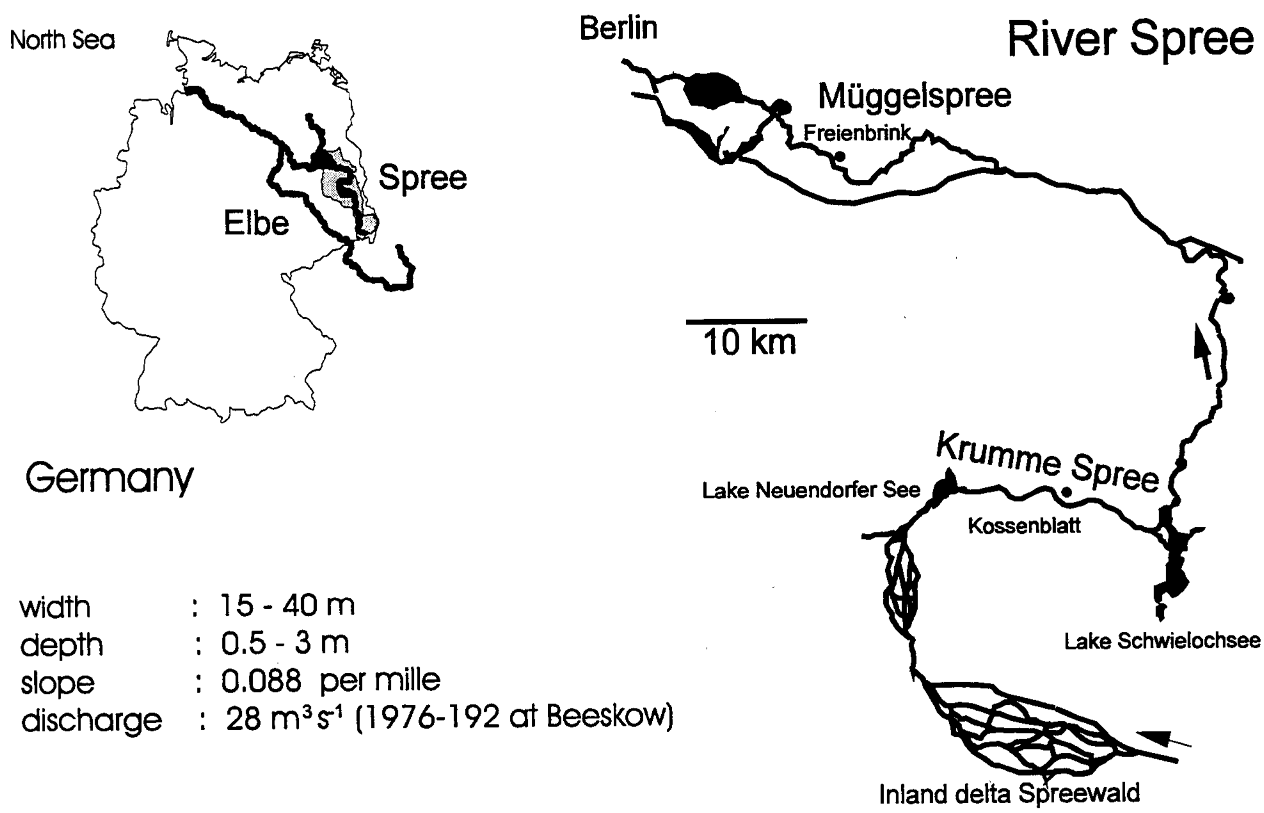

Figure 1. Location of the investigated river sections

Sampling sites and methods

River Spree is a typical lowland river flowing through unconsolidated sandy postglacial deposits with a mean gradient of only 0.088 ‰. It flows through a reservoir and some shallow lakes (1). During the past 200 years, the river has been straightened, deepened and the banks have been fixed by rip-raps. Some positive economical effects due to flood control and navigation have been accompanied by serious problems concerning sediment erosion followed by self-deepening, drop of groundwater up to 1.3 m, and siltation of

Discussion

Our investigations demonstrate that the composition of river-bed sediments is influenced by human impacts on both the river bed and the hydraulics. The natural armouring of the river bed with glacial gravel deposits and woody debris was removed. Due to increased and uniformed current velocities, the straightening of the river resulted in large areas covered with moving sands. Obviously, these areas can hardly be colonised by aquatic macrophytes, which would reduce flow velocity and retain sediments.

The colonisation of running water sediments by benthic invertebrates is largely determined by sediment composition, current velocity, and food supply (5)(6). Therefore, the reduction of spatio-temporal hydrological variation or morphological diversity by channelization resulted in a significant decrease of invertebrate density and diversity (c.f. (7)). This is particularly true for mussels which have significant purification effects. As the Spree represents the main water supply for the city of Berlin, and considering the highly eutrophic status of the river (1), the purification activity of the mussels may have important economic significance.

It is hypothesised that in a river section with restored channel morphology invertebrate abundance and diversity is increased, since natural river morphology offers a wider array of possible habitats with unique combinations of controlling environmental factors, as sediment particle size, current velocity, and nutrient supply e. g. by macrophyte stands. This should hold true both for soft-bottom dwellers on the inner sides of river bends, but also for unionid mussels in compact fine sands, and for hard-bottom dwellers on exposed parts of dead wood. By widening the stream bed, hydraulic roughness is increased and probably the areal extension of uniformly shifting sand is reduced.

In summary, five major habitats have been identified:

1. The rip-raps, which occupy a strip of 2 - 4 m, are densely colonised by invertebrates. However, most of the taxa are neozoa not typical for the zoobenthos assemblages of this lowland river. Thus these rip-raps should be stepwise reduced, following the progress of creation of new habitats for hard bottom-dwelling invertebrates.
2. Bars of fine sand are habitats for a typical potamobiontic community. The protection of this endangered community, which was typical for central European lowland rivers, is a target of the regional conservation policy. Significant sand transport is needed for the conservation of existing bars. New ones can be created by increasing the number of bends due to remeandering. The new inner border of the bends must be maintained unmolested by human activities as natural deposits of fine sand.
3. Fine sand with macrophyte stands are exquisite habitats for filtrating mussels. Prerequisites for these habitats are light for macrophyte growth, and weakened hydraulic traction forces at the stream margin. These habitats could be expanded by widening of the river channel, protection of bars from excavating, and logging of trees that had been planted to fix the river banks.
4. Muddy deposits on fine sand near the bank are scarcely colonised and should be reduced. The management practice of the hydrological regime should be changed to allow natural flood events. These must be strong enough to wash away the mud from dead zones and redistribute it on the floodplain.
5. Uniformly structured medium sand covers large areas of the river bed and is nearly uncolonised by invertebrates and macrophytes. Its share of bottom area must be drastically reduced. Extensive sediment transport is caused by untypically high current velocity. Therefore, the average slope of the river should be be diminished either by a prolongation of the river channel due to remeandering. Meanders minimise netto sediment transport rates by a slope reduction and by accumulation of sand at the inner sides of the bends.

Remeandering of the River Spree (Fig. 3) covers most of the necessities and should be the basis of a complex habitat restoration. River Spree has a large potential for remeandering, if the existing backwaters are activated. A "Leitbild" (model) for remeandering can be derived from oldest maps and colour infrared pictures, which reveal old meander structures in the flood plain. As listed above, remeandering does not meet all requirements and must be accompanied by:

- a partial widening of cross sections;
- allowing floods more frequently;
- reducing stream maintenance actions;
- removing rip-raps, and logging of bank trees.

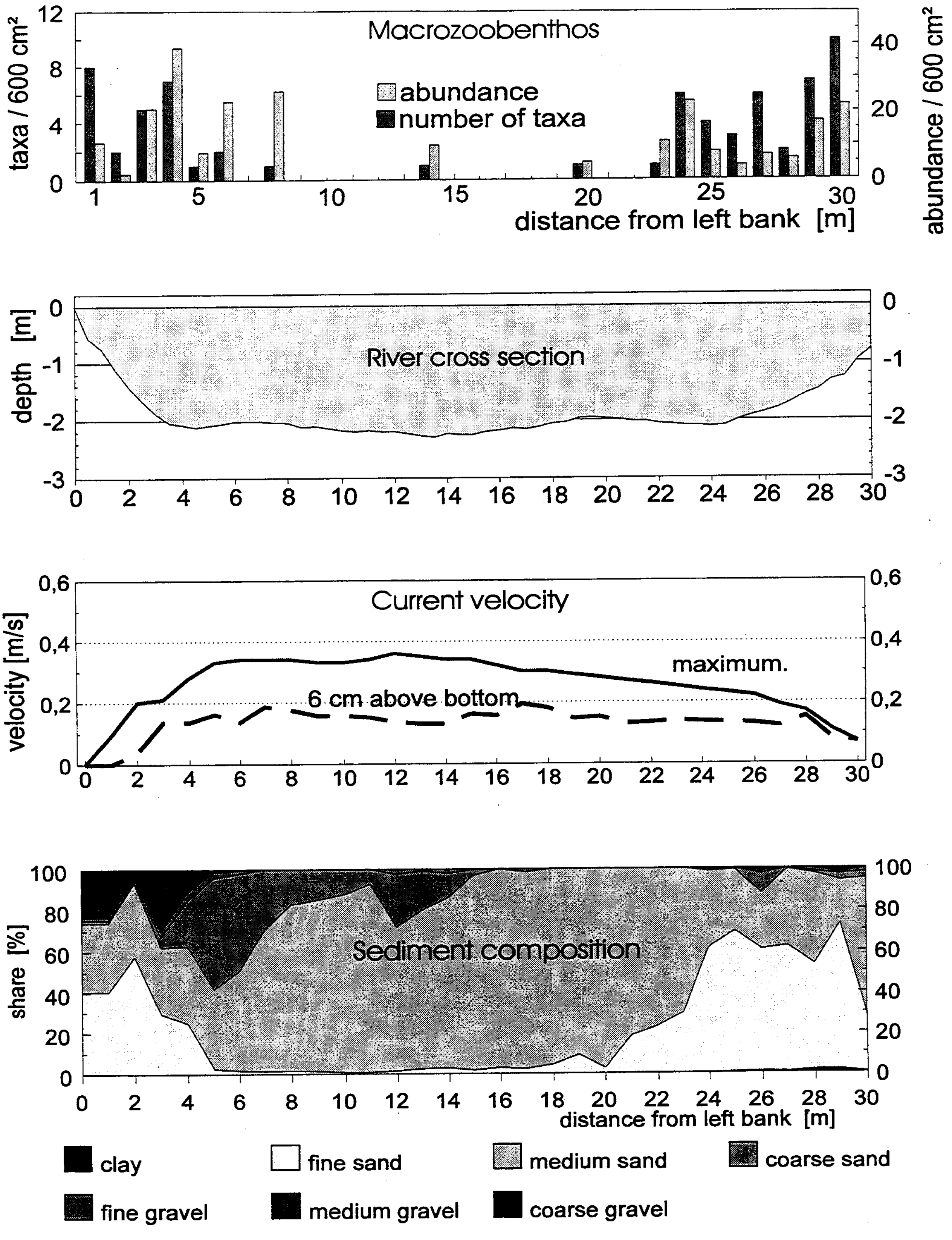

Figure 2 Zoobenthos, current velocity, and sediment composition in a cross section of River Spree near Kossenblatt demonstrating a great share of sandy and low populated habitats.

Kråkebäcken - a case study

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Abstract

Channelizing and underground drainage systems has reduced the self cleaning capacity in many agricultural lowland streams. This has lead to increased nutrient load to the streams and further to the sea, with eutrophication as consequence. Kråkebäcken is a small channelized lowland stream in the southern part of Sweden. As the main restoration measure, a 5-10 m wide vegetated buffer zone was established along most of the stream in 1991 and has since then been left undisturbed. In addition, one pond and 7 small wetlands have been built in connection to some of the drainage pipes. During a 6 year period there has been no clear decrease in phosphorus or nitrogen load as expected. The year to year changes can mainly be explained by climatic factors, phosphorus saturation in soil etc. The buffer strips are mainly expected to reduce phosphorus input through surface runoff. One reason for the lack of reduction is a phosphorus build up in the soil around the stream. Soil core experiments have shown a leakage of phosphorus suggesting the soil to be saturated.

Introduction

For decades lowland streams has been used as nutrient transport systems. They have been channelized and lost their self cleaning capacity at the same time as the anthropogenic nutrient load has increased, mainly by an increase in agricultural activity. Watercourses that function as ecosystems have a natural ability to retain and process nutrients and thereby decrease the load on our lakes and the sea. To regain that capacity watercourse restoration is necessary. A concept of measures have been designed by Petersen *et al.*, (1), called "The Building Block Model". Some of the measures have been used in this project, bufferzone ,"horseshoe wetlands" and sedimentation pond, with emphasis on retention studies of the bufferzone and the "horseshoe wetlands". Bufferzones have been shown to work better in reducing phosphorus than nitrogen in experiments conducted in natural bufferzones by (2)(3) and for this reason we wanted to study bufferzones in a longer perspective. The nutrient retention is dependent on a combination of biological, chemical and physical processes (i.e. plant uptake, denitrification and sedimentation). The mechanism for phosphorus retention is adsorption to the soil particles and sedimentation. It is determined by content of clay minerals, aluminium- and iron oxides, organic matter and calcium carbonates (4). Nitrogen retention is partly explained by plant uptake but the main mechanism is denitrification (5). This process is dependent on availability of nitrate and organic matter together with anaerobic conditions (6). Temperature and pH are other important factors. This project has studied the impact of the restoration measures, bufferzone and "horseshoe wetlands", on the nutrient load. It has two goals:

1. calculate the yearly nutrient load for three sampling points in the stream and evaluate if the buffer zone has had any impact on the load in a long term perspective, relative to a reference point with no buffer zone or "horseshoe wetland";
2. study the nutrient retention in the buffer zone, the "horseshoe wetlands" and the sedimentation pond by measuring denitrification and phosphorus uptake.

Materials and methods

Site description

Kråkebäcken is a small channelized lowland stream in an agricultural area in the southern part of Sweden. The surrounding soils are mainly clay or sandy clay soils. Eightyfive percent of the 7 km^2 catchment is cultivated. The stream is 7 km long and additional 7 km runs in culverts. In 1991 a 5-10 meter wide buffer zone was established along 85% of its reach. The vegetation consists of grass and herbs (75%), bushes and trees.

Longterm nutrient budget

Water samples is taken monthly at three sampling points along the stream; Station 1, at the beginning of the stream; station 2, halfway downstream and; station 3, just before the stream flows out into a bigger stream. The samples are analysed for NO_2^-, NO_3^-, NH_4^+, total nitrogen, PO_4^{2-}, total phosphorus and Cl^- according to Swedish standards. Total nitrogen and total phosphorus are used in the calculation of the load. Field analysis are done according to Swedish standards. The flow is measured with a Nixon Streamflo 422.

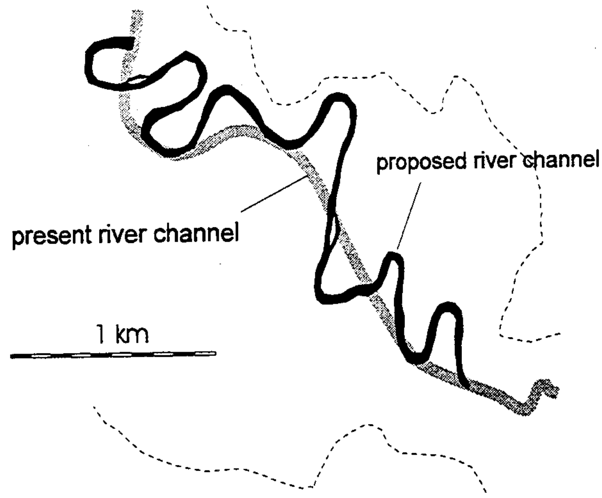

Figure 3. Possibility for re-meandering a section of River Spree

For River Spree, the termination of the self-deepening process and the re-elevation of the groundwater level in the floodplain are prior restoration aims. Remeandering is a key method also in this respect. It can be shown that the changes in river morphology, the increase of bed material supply (8), and the addition of woody debris in order to stabilise sediments and enlarge the different habitats are needed. Additionally, the reinforcements of the river banks should be removed. The combination of these measures will restore the original degrees of freedom that enables self development of the river's morphological and ecological diversity.

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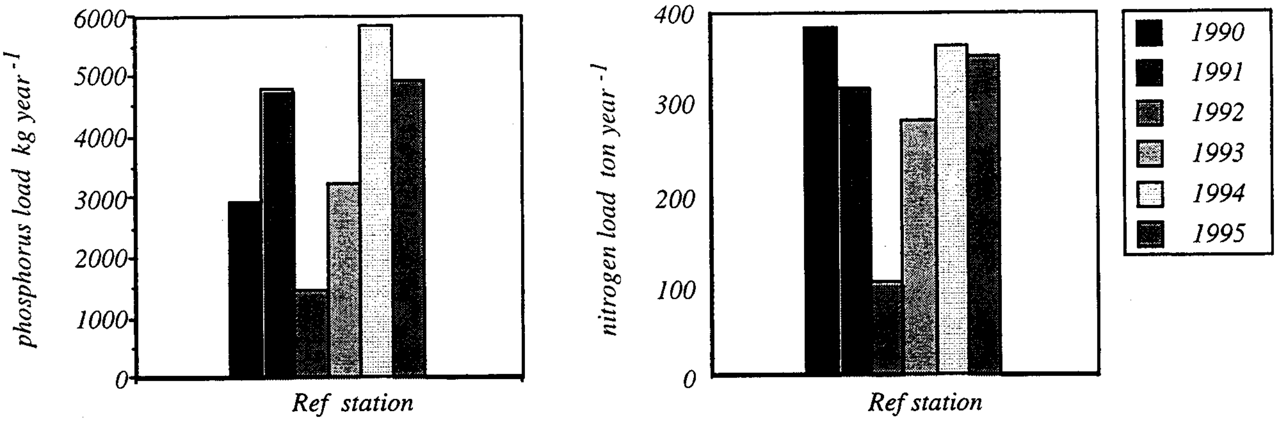

Figure 2. The yearly phosphorus and nitrogen load at the reference station, 1990-1995.

phosphorus (Fig. 4). One additional reason why the results varies is that part of the drainage water is still running through drainage pipes and are not undergoing any self cleaning process as it would filtering through the soil of the bufferzone. Osborne & Koviac (10), suggest that bufferzones are less efficient if drainage pipes are still in use.

Denitrification

To be able to estimate the potential denitrification and the nitrogen retention in stream and wetland sediment and bufferzone soil, denitrification rates were measured during 1995-96. Denitrification was high during summer and autumn and more efficient in the bufferzone and the actual stream channel than in the pond and the "horseshoe wetlands". The bufferzones seem to be less efficient retaining nitrogen than phosphorus (2)(3). One probable reason is that the soil is aerobic and does not provide good conditions for microbial processes. However, the results from the denitrification studies in Kråkebäcken shows high activity in the bufferzone during summer and autumn (Fig. 3). This can be explained by nitrification increasing the contents of nitrogen at high temperatures (pers. comm. T. Davidsson).

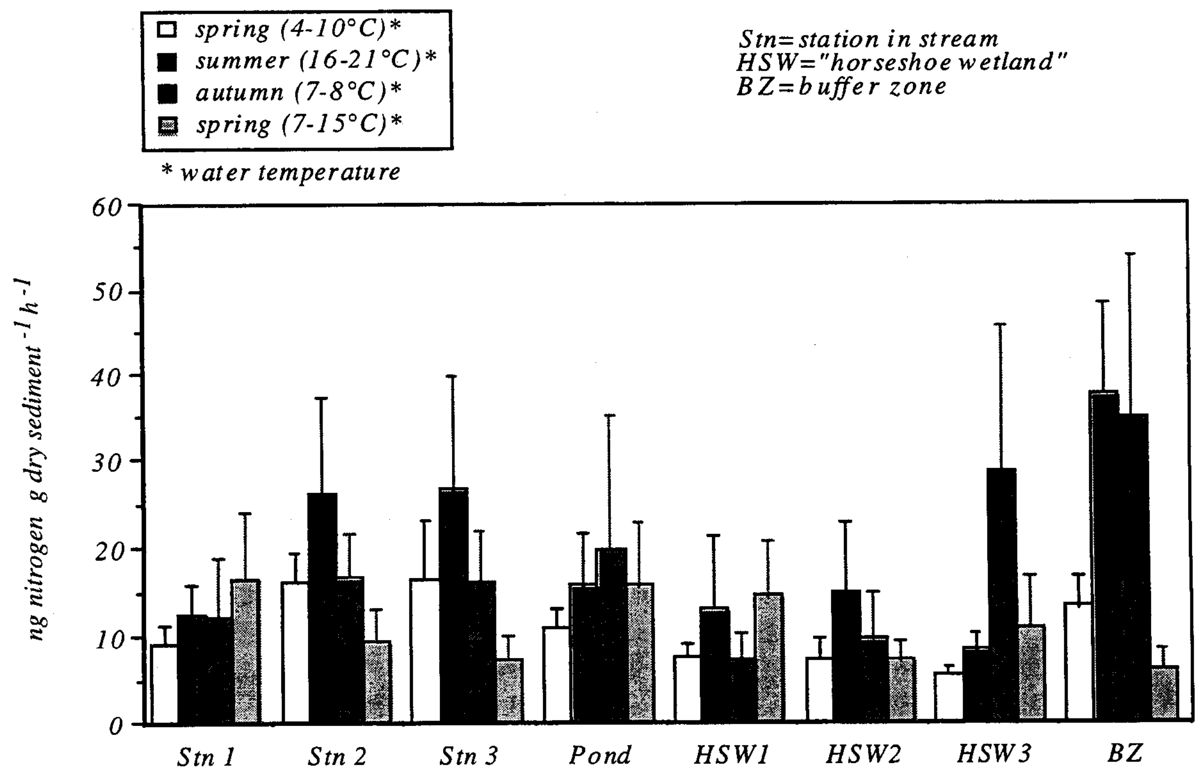

Figure 3. Denitrification during spring, summer, autumn 1995 and spring 1996 in the Kråkebäcken channel (station 1, 2 and 3), the "horseshoe wetlands" (HSW 1, 2 and 3), the pond and in the bufferzone at station 2 (BZ). Mean values (n=9).

Denitrification
During April (spring), August (summer), November (autumn) 1995 and April (spring) 1996, soil- and sediment samples (9/site) were taken in the stream, the pond, three of the "horseshoe wetlands" and the buffer zone. Denitrification analysis were performed according to the acetylene inhibition method (7). The soil samples were taken with Plexiglass tubes (Ø 26 mm, length 50 mm) and were placed in glass jars with a rubber septa. In the laboratory, 50 ml of stream water was added to the aquatic samples. Ten ml of acetylene gas was added. The samples were shaken and incubated at 10_C for 4 hours. The dinitrogen oxide was sampled in vacuum glass tubes, Vacutainers, and analysed with a Varian 3400 Gas Chromatograph.

Phosphorus uptake experiment
At four sites along the stream soil samples were taken (5/site) in the buffer zone and 15 meters away from the edge of the stream in cultivated field. The samples were taken with Plexiglass tubes (Ø 26 mm, length 50 mm). In the laboratory the samples were mixed with water containing 500 µg PO_4-P/l and left standing for one hour. The samples were filtered through GF/C-filters and PO_4-P was analysed according to Swedish standards.

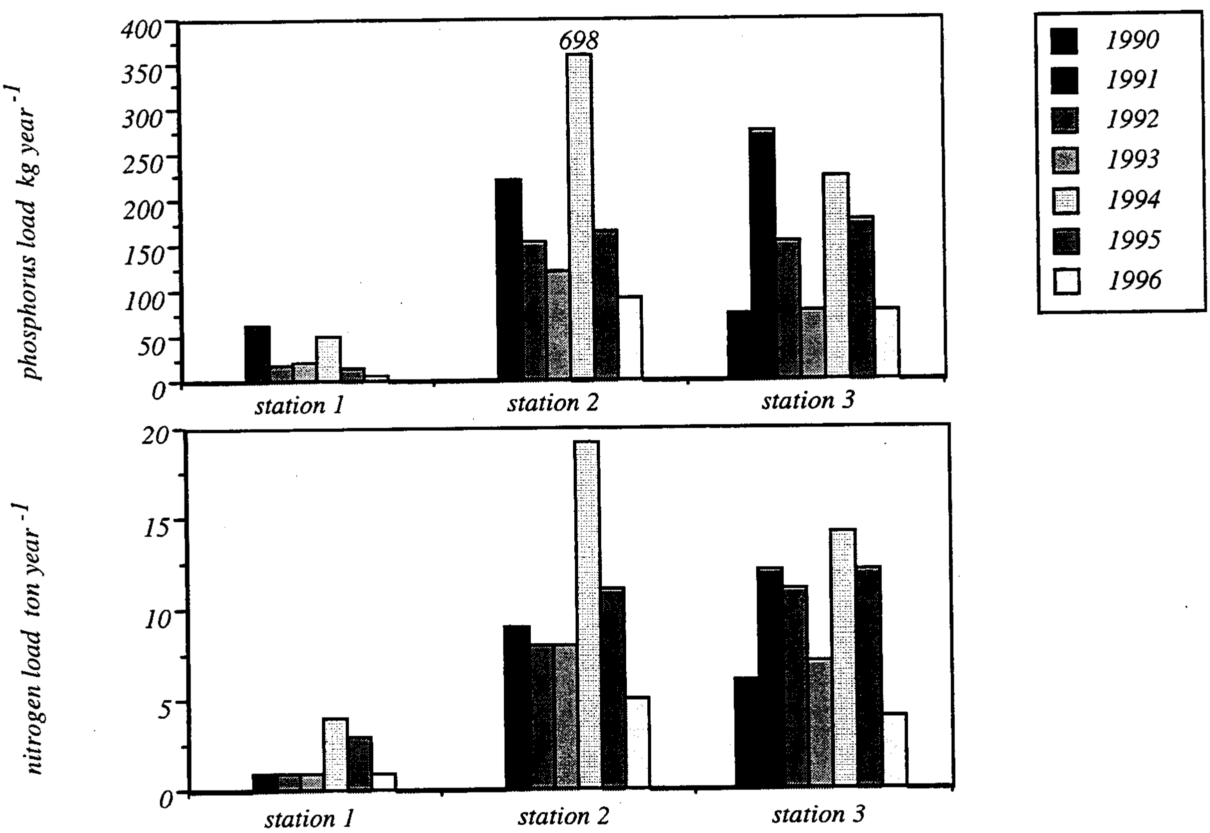

Figure 1. The yearly phosphorus and nitrogen load at station 1, 2 and 3, 1990-1996. The 1996 results are based on calculated values.

Results and discussion

Longterm nutrient budget
In experiments with grass and shrub bufferzone types (3), 66% of the added phosphorus was retained after a distance of 8 meters. After additional 8 meters as much as 95% was retained. The results for nitrogen was 20 and 50%. Other experiments has shown similar results (8)(9). Because of influence by climatic factors (amount of rain, rainfall intensity, temperature etc.), phosphorus saturation etc., the studies of Kråkebäcken do not show the same clear-cut results but varies from year to year. No up- or downward trend can be defined, which also is recognized in the results from the reference point (Fig. 2). Generally going downstream there is a natural nutrient load increase. In Kråkebäcken however there is a decrease of both nitrogen and phosphorus load at station 3 from year 1993 and on. The mean value for the measuring period also shows a decrease at station 3. This indicates that the buffer zone has an impact on the nutrient load. A probable reason why we do not find the same reduction at station 2 is that the soil being saturated is leaking

Lack of money - advantage or drawback?

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Abstract

The poster shows the few examples how the lack of the funds (money) for regulating the natural watercourses and their maintenance in projected relations can influence their restoration. That is the positive effect of being short of money. The example of the hydroamelioration drainage system, which is very poorly maintained shows how the negative effects are formed because the basic function of the system can not be achieved.

The solution is the use of the holistic approach and looking for the balanced solutions (for new operations and for renewal of already existing regulated watercourses) which take into account quantity, quality and ecological conditions of the watercourses.

Foreword

The level of development of water management facilities is dependent on the amount of money available to a given society in a given moment, but also on the kind of relation between the professional (idea promoters) and politicians (decision makers). The facilities are constructed, and later on maintained, in dependence on the type and quality of such relations. The growth of the number and size of such facilities results in the growing demand for financial resources for their maintenance. For regulated watercourses this means technical and biological works (repair of stone and concrete woks, clearing of vegetation, mowing of grass and weed, etc.).

In former socialist countries the organisational level of the society and the economic power were inadequate to ensure successful maintenance of water management facilities/systems. These circumstances in gradual returning of regulated watercourses to the natural state.

Example 1

The interceptor canal along the motorway Zagreb - Karlovac, of 11.85 km was constructed in 1972. It is parallel to the motorway, crossing all torrential watercourses flowing into the Kupa river valley from the slopes of Plješivica and Žumberak. In the canal there are 9 sills and the water intake for the supply of the fishpond Crna Mlaka (special bird reservation). As in the period from the canal construction to 1990 the funds for the maintenance were insufficient, the results were as follows:

- growth of trees and bushes (autochthonous species),
- appearance of meanders and islands in the watercourse,
- crumbling of sills, etc.

The above processes were still intensified during the war. The canal can still perform its principal function. However, in future, with respect to the complex development of the catchment area, the interceptor canal will have to be repaired in a modern way.

Example 2

Črnec Polje is a hydroamelioration drainage system east from Zagreb, covering the area of 61.000 hectares, out of which 45,000 hectares of arable land. The system was completed in 1986.

The system consists of:

• drainage canals	7,738 km
• subsoil pipe drainage	6,300 km
• protection dikes	350 km
• pumping stations	12

Since the completion (1986), the investors financial responsibilities towards the World Bank for loan repayment have exceeded the level of revenues from the water management compensation which is used for regular maintenance of the watercourses and the hydroamelioration system. Therefore, the works have not been properly and regularly maintained.

Phosphorus uptake experiment
For a bufferzone to be efficient, it has to be able to retain phosphorus. Experiments with the soil surrounding Kråkebäcken showed that soil from the cultivated field leaked phosphorus at station 3 and the bufferzone soil as well as the cultivated field leaked phosphorus at station 2 (Fig. 4). This and the fact that phosphorus are released from the ironcomplex into solution when the soil becomes anaerobic at water saturation (e.g. at high rainfall) (11) can explain the high load at station 2.

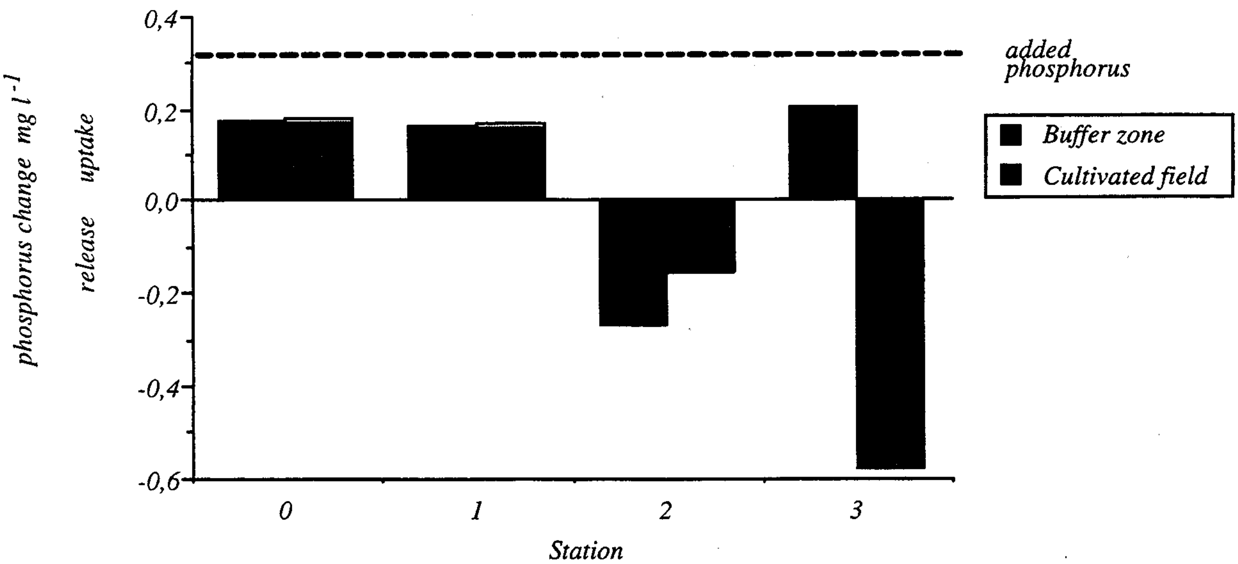

Fig. 4 Phosphorus uptake at four points along the Kråkebäcken in the bufferzone and the cultivated field.

Acknowledgement
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Bank stabilization: Preservation of landscape role

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Abstract
The banks of our rivers have endured several modifications of their natural state. These modifications are linked either to the abandon of ancient maintenance practices, or to the occupation of the river banks by habitat, cultures, roads or railways. The document is, mainly, to identify the essential landscape role played by natural river banks and to bring forward the necessity of modifying or improving the techniques used for stabilization.

Introduction

The present evolution in the concept of stream management directs itself in an ever increasing manner towards a vision of the river as a living environment and also as a place where human activities are concentrated.

This new approach corresponds to a social demand, as well as an evolution in land management policies. It thus appeared necessary to set up a methodology comprising a number of tools that make it possible to define the guidelines for valorizing landscapes.

It is within that broad framework that the GIREA is carrying out a study of landscapes along 2 streams (Saulx and Ornain, two tributaries of the River Marne), following a request formulated by the Agence de l'Eau Seine-Normandie (France).

The riverine landscape

The riverine landscape is fragile because it is located at the convergence of both lines of force of the valley. The interface soil/water (border zone particularly diversified biologically) is sensitive to development since it is under constant pressure by human communities due to the attraction it exerts upon man.

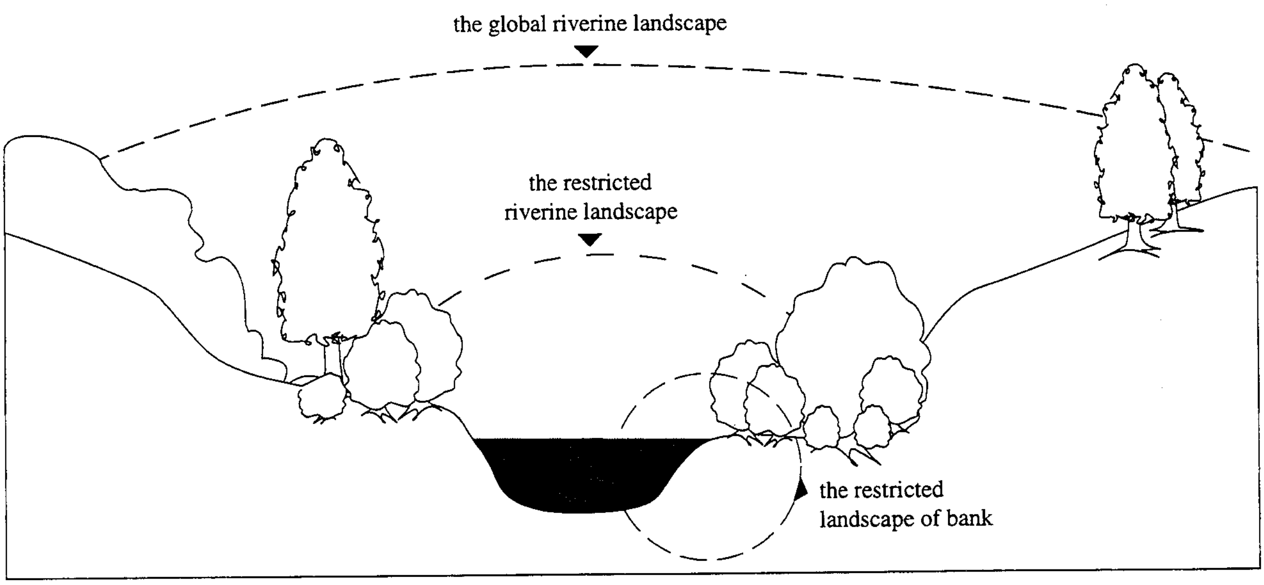

Figure 1. The riverine landscape.

The mechanisms involved in perceiving a landscape, and methodological considerations (1), have led us to consider the riverine landscape under three levels (Fig. 1) :

- the global riverine landscape is the landscape perceived as far as the vision of the observant can. The stream plays a role that is of variable importance depending on the ratio between the length of the river and its floodplain, and the width of the valley.
- the restricted riverine landscape is the environment immediately perceived by the observant who stands alongside the river. Various parameters enable to characterize it : visual quality of the river water, width, presence of valorizing (monuments, rock assemblages, islands,Y) and devalorizing (dams, campings, roads, factories,...) elements (2).
- the restricted landscape of the bank: on its configuration will depend the accessibility to the water and the type of visual relationship that can be established with the water by someone standing alongside the river.

Thus, the drainage tertiary and quaternary canals are now covered by thick tree and bush vegetation, and cannot perform their function to drain the excess water from the Črnec Polje area. The extent of the damage is impossible to assess without systematic measurements.

Conclusion

I can see the solution in the application of the holistic approach and looking for balances solutions (for new operations and for the renewal of the already existing regulated watercourses), taking into account quantity, quality and ecological conditions of the watercourses.

- artificial banks made of cobble-layers mixed with vegetation,
- rubble-stone walls associated with vegetation.

- the types of banks of very low landscape quality are :
  - natural eroded and bald banks,
  - totally artificial mineral banks,
  - concrete walls associated with vegetation,

The landscape quality is dependant, for a great part, upon the degrees of "naturality" and attractivity of the bank.

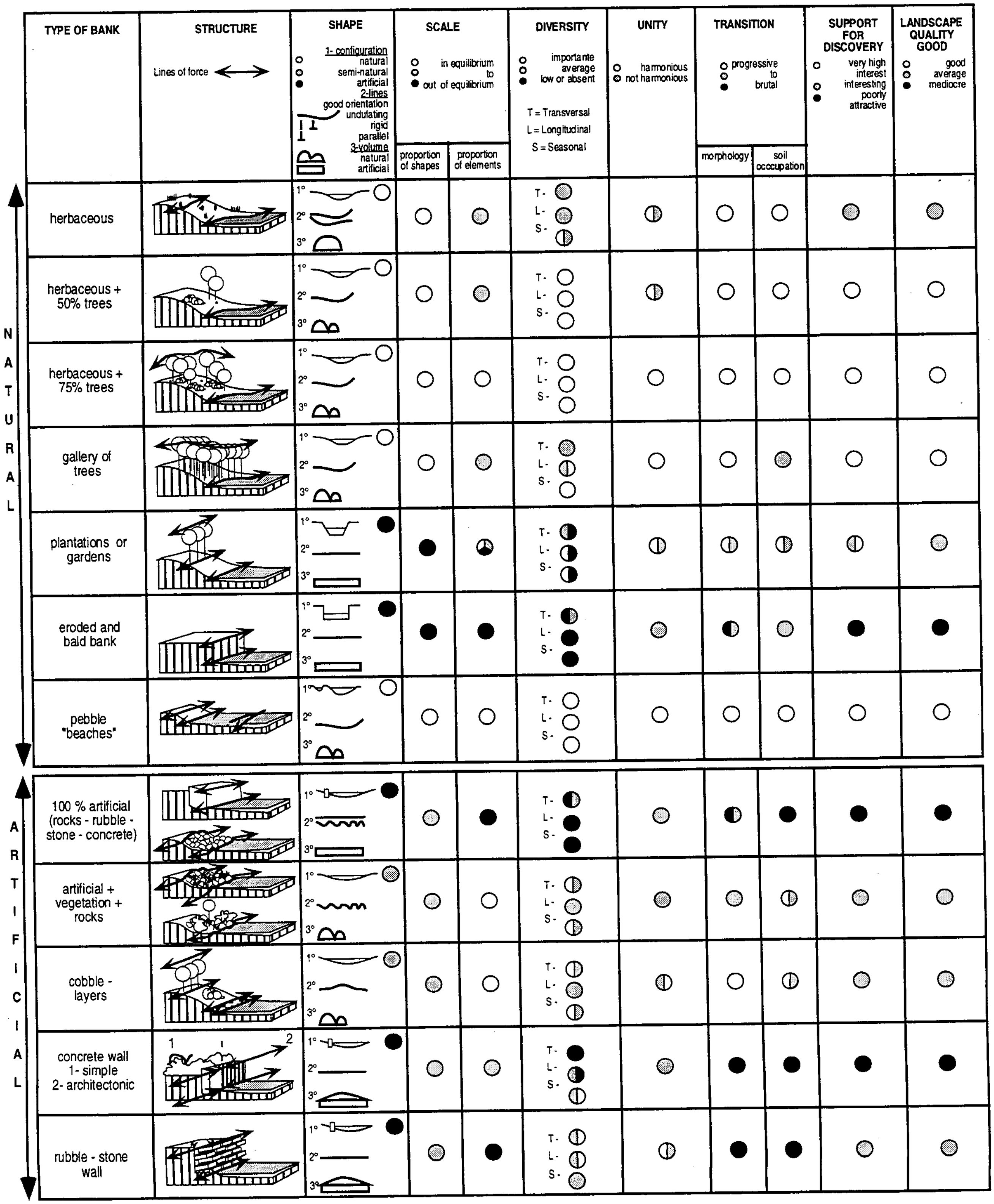

Figure 2. Synthesis of landscape characteristics of the various bank types (extract).

The role of banks in landscapes

The diversity of bank types (natural or artificial, in equilibrium or in a process of erosion or sedimentation, planted or not, in rural or urban locations,...) is such that there cannot be an "ideal" type of bank, but that banks can be optimized for every particular situation, taking into account all the factors that act upon them when conceiving them.

The bank, a transition zone, plays 2 roles in the landscape, which are not necessarily compatible (3) :

- it is part of the factors that enable to characterize and identify the riverine landscape,
- it is the place from which strollers can, in a privilegiate manner, discover the landscape and best observe its multiple features.

The landscape characteristics selected as representative of the landscape value of the bank, as quantifiable by simple parameters, and as integrable in their conception are :

- the apparent height of the bank (for a waterbody of average size),
- the slope of the bank,
- the degree of artificialization of the materials used, and their organization,
- the type of laying-out of the embankment,
- the type of laying-out at the foot of the bank,
- the longitudinal diversity,
- the vegetation covering.

Example of a study along the River Saulx

In order to improve our knowledge of the landscape and ecological value of the banks of the River Saulx; we have carried out a typological mapping based on 2 approaçhes (3):

- a macroscopical analysis, in the laboratory, on the basis of aerial photographs, leading to a census of the broad categories of bank vegetation (Table 1).
  In the valley of the Saulx, wooded banks occupy 62.4 %, whereas the remaining 27.6 % are characterized by herbaceous vegetation. Some alignments of poplar trees can also be observed (4.1 %). These figures only reflect the extent of the vegetal colonization, but not the nature of the banks.
- more detailed observations, on the field, focusing on 15 bank types chosen as representative (morphology, vegetal associations, landscape characteristics).

Table 1. River Saulx in France.

Broad categories of bank vegetation	Saulx (%)
Herbaceous vegetation	18.0
Herbaceous vegetation + isolated trees	9.6
25% trees and shrubs	12.7
50% trees and shrubs	17.4
75% trees and shrubs	19.2
Gallery of trees	13.1
Poplars	4.1
Gardens - parks	2.0
Bank without vegetation	2.8
Underground river	0.3
Unspecified	0.5

The confrontation of the landscape characteristics and the vegetal associations of each bank type, of their degree of transition, and their value as a support for discovering the river, illustrated with the help of the comparative table (Fig. 2) shows that :

- the types of banks that exhibit a high landscape value are :
  - natural herbaceous banks + 25 % trees,
  - natural herbaceous banks + 50 % trees,
  - natural herbaceous banks + 75 % trees,
  - natural banks covered with a gallery of trees,
  - natural banks that are prolonged by pebble "beaches".
- the types of banks of average landscape quality are :
  - natural banks used as plantations or gardens,
  - artificial banks made of rocks associated with vegetation,

Management prescriptions

Globally, this river is well managed and looked after, whereas the ways to access the riverside are far from being numerous.

The main problems we encountered for managing its banks are the following :

- lack of buffer zones between cultivated areas and the river (Fig. 3) ➔ creation of an unoccupied riverine "strip" (possibility for a natural stabilization of the slope, easy to maintain, improvement of water quality, possibility of outflooding, presence of a floodplain, access for strollers and anglers);
- numerous sites where erosion of the banks is in progress following the cutting-down of their vegetation ➔ envisage the plantation of adequately chosen indigenous species (alder's, willows,...);
- damaged caused by cattle ➔ create watering places;
- inadequate intervention of some riverside residents and choice and placement of bank stabilization techniques ➔ communicate the knowledge of, and experiment, the stabilization techniques using vegetations and based the role of root systems (4) ➔ re-constitute a littoral zone alongside artificial banks making it possible for aquatic and semi-aquatic vegetation to establish itself.

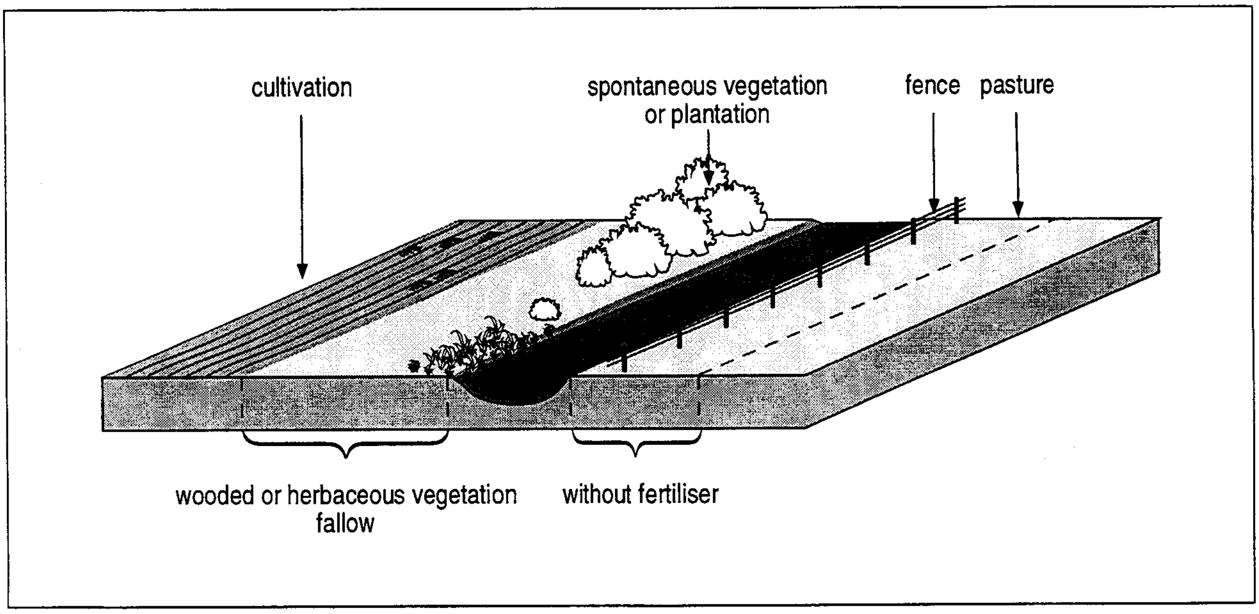

Figure 3. Buffer zone.

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