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European Centre for River Restoration
September 9-13, 1996
Silkeborg, Denmark

River Restoration '96 - Plenary lectures

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 placed on this dimension of river quality in many parts of the world.

The scientific program and social events unfolded in the excellent physical framework provided by the Freshwater Centre, including the Freshwater Aquarium AQUA, which was one of the reasons that Silkeborg was chosen as host for the conference. Another was that Silkeborg lies in the center of a rich variety of freshwater sites, in the very hearth of Jutland. That made the logistics of the excursions simple: They just radiated in five different directions to a variety of freshwater sites in Jutland.

This publication contains the conference plenary lectures as well as a list of the oral and poster presentations and a list of the participants and the organizers.

The manuscripts of the oral and poster presentations will be published later, in the scientific journal Aquatic Conservation, or in the form of a conference proceedings. The editing work is in progress.

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

The editors

Introduction

Torben Moth Iversen and Bent Lauge Madsen

All over the world, there is growing concern for the state of environment and threats against nature. Valuable natural areas are disappearing at an alarming rate: rain forests, coral reefs and wetlands to name but a few. They are falling victim to human need and human greed.

It is happening in the developing world, where human need is greatest. And in the industrialised world, where human greed may exceed the need.

One of the greatest challenges facing us today is to end this wanton destruction of nature. In our quest for a solution, we must not consider technical measures alone. We must search for, and fight for, policies which meet the needs of the poor nations and curb the greed of the rich.

We have taken the first tentative steps. The 1992 Rio Conference has already made its mark. One of the most important things to emerge from that conference was the declaration to preserve our global biodiversity. This declaration now forms the framework for a great deal of international nature protection work.

As an example of more recent initiatives we could mention the Dobris Assessment published by the European Environment Agency 1995 (Stanners et al. 1995). It identified 12 major environmental issues to be addressed in Europe. Among these issues Denmark is particulary concerned with the management of freshwater ecosystems and the loss of biodiversity.

Denmark is a lowland country. For centuries, the soil has been a major national resource. The result is that agriculture has played a major role in shaping the Danish landscape.

In the past, Denmark had a crying need for more arable land. It supported our most important livelihood. It was regarded as an honourable challenge to reclaim land, even when the necessity for such action declined - when greed began to take over from need. Some 65% of Denmark is given over to agriculture.

Wetlands have been turned over into arable land by drainage. Most Danish rivers and streams have been straightened and deepened to make them more efficient in removing water from the fields.

It is very tempting to call it destruction. But we ought to look back on the activities of the past with a little more leniency. We should try to see it from the point of view of the people of that era. And use our experience to avoid similar mistakes in developing countries and poor regions in similar situations today.

A great Danish writer, Acton Friis, once wrote that "in no other country is it easier to subdue the land". He had land reclamation in mind. But fortunately, his statement can also be applied to the restoration of the destroyed wetlands - and we have already made considerable progress. So as Denmark may be the right place to study destroyed wetlands, it also is the place to study their re-establishment.

In 1995 the Danish Minister for Environment and Energy, Svend Auken, submitted a paper for discussion on the needs of strengthening nature restoration measures in Europe to the EU Council of Ministers (Møller, 1995). It was well received and our ministry, together with the Dutch Ministry of Agriculture, Nature Management and Fisheries, decided to arrange a seminar on the broader aspects of nature restoration in the EU.

Nature restoration is a significant measure in the struggle to improve the biodiversity of plants and mammals. However, one of the major conclusions of the seminar was that the restoration of wetlands to more natural state may well have implications that reach far beyond the protection of wildlife. The restoration of wetlands can safeguard the quality of our surface water and groundwater. When we restore the wetlands, we also restore the natural cleaning properties of natural wetlands. We have also learned, that if we re-establish the storage capacity of the wetlands in the upper stretches of rivers, we can also reduce the risk of serious flooding in the downstream stretches. We remove the domino effect - and that is most assuredly a better remedy than protective dykes.

Restoration of the natural properties of rivers and other wetlands is no longer the uphill struggle it was when arable land was at a premium. Current trends in EU agricultural policies are opening up unseen opportunities for nature restoration. The last areas of nature to be harnessed into agricultural use were the wet areas along the rivers and streams. Such areas have a limited lifetime as arable land. They are the first to be abandoned. They are important targets for nature restoration and numerous projects are under way throughout Denmark. Most of them are fortunately being conducted with considerable support from the local population.

It is important for the future of nature restoration in the EU that some of the financial subsidies in the agricultural sector be transferred from supporting agricultural production to supporting nature restoration in farmland. As the Danish Minister of Environment and Energy has put it: " EU taxpayers will demand more nature value for their money" (Møller, 1995). It is to be preferred instead of being forced to contribute, year after year, to the short-term set-aside schemes. There is a need for a subsidy model that links agricultural production to environmental measures.

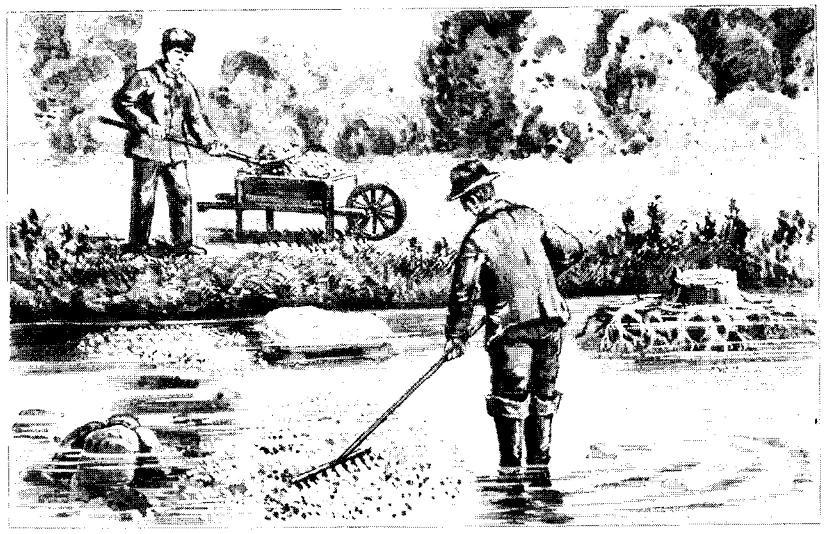
Another important aspect of nature restoration is the political attitude towards nature protection. In Denmark, it has generally been positive. For generations, our Watercourse Act was the benchmark by which we maintained our rivers and enchanced their ability to drain the fields. But now significant changes have been made: The rivers must still function as drainage channels but now they must also be good habitats for animals and plants.

The Danish Watercourse Act from 1982 has now regulations for river restoration.

Since then the river authorities in Denmark have acquired considerable expertise in river restoration. It is our hope that presentation of these experiences during lectures and excursions has given inspiration to be used in other countries.

The theme of River Restoration '96 is: "The physical dimension of stream restoration". In Denmark we have managed to solve many of the problems with the water quality in our streams (Danish EPA, 1995). The work to this end over the last 20-30 years has revealed previuously neglected problems: Our streams poor physical properties. The majority of our streams are straightened instead of having a natural course. The intimate relationship between the river and its valley has been broken. Furthermore, obstacles hinder fish migrations, there is a lack of suitable substrates for invertebrates and fish spawning, and a lack of hiding places for fish. All causing a loss in biodiversity.

We hope that this conference has provided inspiration for good solutions to the problem of poor physical conditions, in accordance with the motto: Let us examine the solutions rather than the well known problems.



Much wisdom is found in our past. This is river restoration a century ago (Walter, 1912).

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The Restoration of Freshwater Ecosystems - an Overview

Brian Moss

"Blessed are the meek:
for they shall inherit the Earth
Matthew 5,4

Introduction - the degradation of freshwater systems

Freshwater systems have suffered greatly in the last several decades. The damage may be structural - the drainage of wetlands, the engineering of rivers to straightened, deepened channels separated from the floodplain, the building of dams and other obstructions; chemical-acidification, eutrophication, organic or toxic pollution; or biological - the removal of species through overfishing or the introduction of exotic species. Often it is a combination of several of these.

The reasons why these systems are so vulnerable are not hard to discern. Freshwaters lie at the bottom of catchments and thus particulate and dissolved products of catchment activities inevitably gravitate to them; environmental legislation has rarely recognized the conceptual link between catchment use and the consequences for freshwater systems receiving their wastes ; agriculture and urban development have hitherto generally taken precedence over environmental conservation; and at least some systems, largely swampy wetlands have traditionally been regarded (Anderson & Moss, 1993) as hostile wastelands, to be reclaimed for profitable use. Prejudice against wetland areas is greater than that against other habitats and increases with age (Table 1). Streams, however, have a more favoured profile.

The damage is now so obvious that its consequences have been reflected in an increasing realization that functional, aesthetic and cultural values have been lost. Water is more difficult to treat for domestic supply; floods have become devastating downstream of where extensive reclamation has removed the storage capacity of wetlands; overfishing and engineering have led to collapse of fisheries; toxic algal blooms have prevented use of waters for recreation; landscapes and waterscapes have lost charm and interest; biodiversity has declined. The need for restoration of these values is now clear and there is widespread support among the general public for such initiatives.

Table 1. Perception of wetlands. Children in Liverpool primary schools were asked to choose adjectives from a mixed list of positive and negative qualities which they associated with particular habitats and animals. Results were examined by age (6-7 years and 10-11 years and gender) and are shown as percentages showing overall positive (+) or negative (-) perceptions of each category with probabilities of deviation from a 1:1 ratio of positives to negatives in each case (a, P<0.001; b, P<0.01; c, P<0.02; d,P<0.05; ns, not significant. Differences in perception by age or gender are shown as indicated with sign and probability. There were worsening perceptions with age of bogs and swamps as children acquired the prejudices of their elders.

Category		Boys	Girls	6/7 yrs	10/11yrs	Sig diff by age	Sig diff by gender
Crocodile	+	2	2	2	2		
	-	98a	98a	98a	98a	ns	ns
Hippopotamus	+	64	72	72	63		
	-	36b	28a	28a	37c	ns	ns
Dragonfly	+	73	61	65	64		
	-	27a	39a	35b	26b	ns	ns
Fish	+	99	96	99	97		
	-	1a	4a	1a	3a	ns	ns
Badger	+	82	80	82	81		
	-	18a	20a	18a	19a	ns	ns
Kitten	+	98	100	99	99		
	-	2a	0a	1a	1a	ns	ns
Wolf	+	8	1	5	5		
	-	92a	99a	95a	95a	ns	Boys+ <0.05
Bog	+	30	15	34	12		
	-	70a	85a	66a	88a	- <0.001	Boys+ <0.02
Swamp	+	10	14	22	1		
	-	90a	86a	78a	99a	- <0.001	ns
Brook	+	75	72	78	70		
	-	25a	28a	22a	30a	ns	ns
Stream	+	81	85	85	79		
	-	19a	15a	15a	21a	ns	ns
Desert	+	55	49	61	38		
	-	45ns	51ns	39d	62d	- <0.02	ns
Meadow	+	83	92	89	86		
	-	17a	8a	11a	14a	ns	ns
Woodland	+	77	91	82	95		
	-	23a	9a	18a	5a	+ <0.01	+Girls <0.01

Restoration

Restoration may mean simply cosmetic measures - the protection of eroded banks or treatment of symptoms (dumping of gravel for fish spawning in silted streams, liming of acidified catchments, use of algicides, fish stocking). More desirably it involves removal of the cause of the problems with consequent expectation that a more desirable biological community will naturally colonise. Such is the approach of reducing nutrient loads to deep, eutrophicated lakes, the installation of flue-gas desulphurizers to remove sulphur dioxide from power station chimneys, or the re-meandering and raising of the bed level of engineered streams. Ultimately, restoration may involve not only the removal of cause but also the manipulation of the biological community because a desirable one does not spontaneously emerge after the removal of cause alone. The restoration of macrophyte-dominated shallow lakes, discussed below, is a good example.

Whatever the approach used, it is wise to ask some questions before any restoration is attempted. Prime among these are "What features do we wish to restore? Should we attempt to return to some former, pristine state? What constituted such a state?; How do we determine it?" It is probably both impossible and undesirable to return to some particular state from the past but, on the other hand, knowledge of the former communities may be helpful as a general guide.

Targets

The important issue is that there should be a target for restoration, against which the project can be budgeted, the methods chosen, and the success of the work assessed. It is common, in terrestrial conservation ecology, to aim to restore particular arrays, usually of plant species, or to create suitable habitat for specific animals, often birds or mammals (Budiansky, 1995). This approach demands a knowledge of the ecology of the species concerned, and their interactions, that is usually not completely available. It also involves restoration of such specific conditions that continual management is required to guard against changes in the greater environment that might disrupt the specific needs of the chosen array. Such an approach, though understandable and desirable in remote and near pristine regions where particularly attractive species are concerned, is probably not a sensible one where there are large human populations, such as the developed lowlands. Here the aims must be to restore not a particular array but the functional values that may have been lost as ecosystems have been degraded. In general restoration of these values will also mean establishment of a biodiverse community of specific growth forms rather than of particular species.

This has generally been the approach taken by freshwater restoration ecologists, who have attempted to manipulate the driving environment and to allow the biological community to follow by largely natural colonization. Thus nutrient reduction in deep lakes allows the functional values of storage of cheaply purifiable water supply, maintenance of salmonid fisheries and tourist amenity to be restored. Raising of river bed levels, remeandering and re-establishment of flooding over the original flood plain allows values of flood storage and downstream protection, nitrate removal, fisheries, and enhancement of biodiversity for conservation to be restored. This emphasis in aquatic restoration does not reflect some prescient wisdom. It reflects three features of such systems.

First they are open systems controlled by events mostly outwith the aquatic system themselves. Secondly they are systems which naturally experience a great deal of unpredictability as a result of this and in which biological communities are, at any time, further from equilibrium than perhaps in some terrestrial habitats. Thirdly the behaviour of aquatic systems depends greatly on the nuances of chemical and microbial processes which are not as "visible" as those of competition and predation among the larger dominants of terrestrial systems. The trends of investigation in aquatic systems have thus been different from those in terrestrial systems and, in a sense, have been preadaptive to restoration techniques more appropriate to systems that will remain greatly human-impacted.

The inevitability of human impact

For that is the reality of the future. The degree of stress on natural systems is a product of human population, individual resource consumption and waste production and the impact of technology (Harrison, 1993). Though there is scope for reduction or stabilization in all three, the chances are that the effective product will nowhere decline greatly in the foreseeable future. Our aim as restoration ecologists must thus be to establish systems whose functional values can be sustained and in turn these must be set in sustainably managed catchments - where people will live and pastoral or arable agriculture will usually be pursued. But before a target can be set for a sustainable state in aquatic systems, sustainability needs to be defined for the catchment. The concept of meeting our own needs without compromising the ability of future generations to meet theirs is a worthy but only strategic definition. It must be translated into tactics.

I believe it must mean that the land-use in the catchment must reflect the natural climatic, topographic and geological features of the catchment (and not the possibilities made available by short term subsidies of cash or energy) and that any alien substances added (e.g. herbicides, pesticides) must be removed (degraded) at the same rate at which they are added. Native substances added in alien loadings (e.g. fertilizers) must also meet the same criterion.

Establishing the target for restoration

Restoration of some previous pristine state is unlikely ever to be possible, except in remote regions. It is, nonetheless, important to discover as much about past states of a degraded system as possible as a guide to what will be unreasonable as a restoration target rather than to what that target should be. There are now increasingly powerful tools for discovering the past, especially for water bodies which have accumulated sediment. Palaeolimnological analysis of sediment cores is moving from a generally qualitative endeavour to a quantitative one. It is possible, for example, from contemporary data on diatom species distribution in relation to variables such as pH or total phosphorus concentration, to reconstruct past values from the diatom arrays in the sediments.

The precision is greatest for variables, such as pH, with such great ranges in the environment that log functions are commonly used to express them. Many upland lakes in north and western Europe have become acidified and liming of lakes and catchments is a frequent symptom treatment for this. Liming has its own problems for it damages the previously moderately acid catchment vegetation and it may be overdone without guidance from reconstruction of past pH values. Thus, in a demonstration experiment at Loch Fleet, liming without such guidance overshot previous unperturbed pH values, later determined to have been around 5.6, by a whole pH unit (Brown et al. 1988).

Export coefficient models for nutrients can also be used to determine likely past concentrations of total phosphorus and total nitrogen if past land use is known, and for model situations where a particular land use is projected (Johnes, 1996, Johnes et al. 1996). The precision can be high, following proper calibration and validation of the models against contemporary measurements (Fig 1) and the technique allows nutrient concentration targets to be set for catchments brought into sustainable management. Anecdotal (oral tradition), the diaries and notes of past observers, old photographs (Fig 2) and postcards can all be used to determine former features, as can old maps. Political boundaries often followed meandering river channels which have subsequently been straightened.

The ultimate targets for restoration (or strictly, rehabilitation (Fig 3), because the past cannot be exactly restored) projects must be agreed through consultation with landowners, legislators and users of the systems concerned. The benefits that may collectively accrue to the community may not be so positive for individual interests and much negotiation may be necessary. The political climate which it will be necessary to create to restore present day degraded systems to functional sustainability is yet far removed from the present one which largely favours exploitation and individual gain. Nonetheless targets must eventually be set.

Techniques of restoration - the shallow lake example

The techniques of restoration are now many-fold and documented (Eiseltova, 1994; Madsen, 1995; Moss et al. 1996; Ryding & Rast, 1989). They have been gained through a combination of fundamental research, controlled management experiments, and often uncontrolled management trials. They are by no means perfect but understanding is increasing. The development of strategies for the restoration of shallow lakes from a turbid state dominated by suspended phytoplankton back to a clear water state dominated by submerged aquatic plants (Moss et al. 1996) is illustrative of the general process.

Deep lakes which have suffered eutrophication, the process of enrichment by increasing amounts of phosphorus and nitrogen compounds, are relatively easily restored, especially if the nutrients come from a relatively few point sources. Productivity of the plankton in such lakes is generally limited by phosphorus availability or such limitation can be induced by restricting the phosphorus sources. Thus sewage effluent may be diverted to the sea or phosphate may be chemically precipitated from the effluent before it is delivered to the

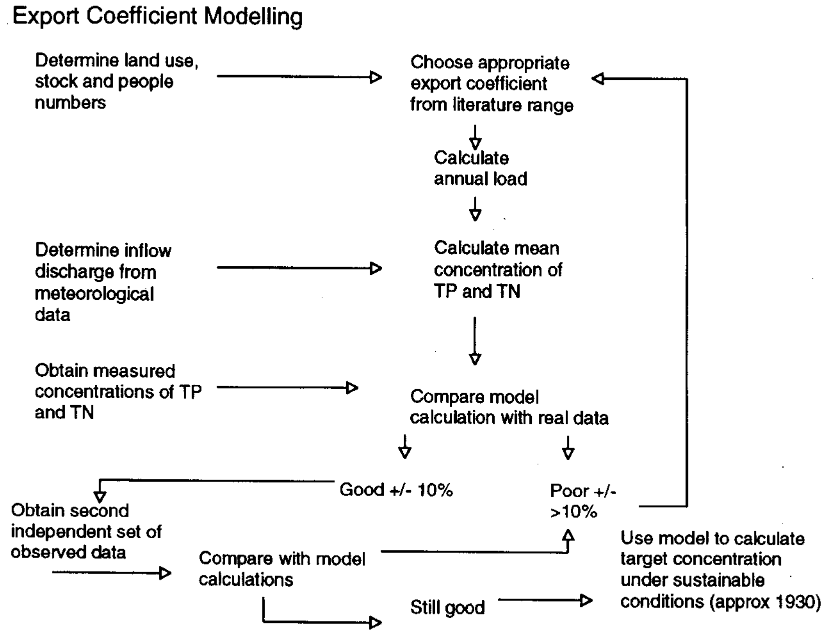

Figure 1. Flow diagram for a model for determining relationships between land use and animal populations and water quality in freshwater systems.

Figure 2. Old photographs such as this one taken by P.H. Emerson in the late 19th century give some indication of the former states of now degraded habitats.

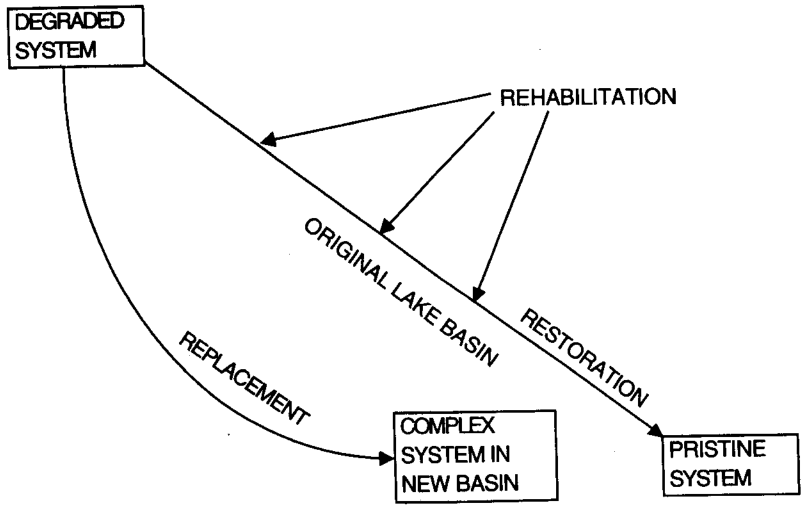

Figure 3. The relationships between restoration and rehabilitation in freshwater systems.

lake. Restriction of other, diffuse sources is more difficult but (in theory) interception (buffer) zones may be inserted between agricultural areas and the lake and stock wastes may be managed to minimise losses to watercourses. As point sources are controlled, more emphasis is being placed on control of diffuse sources.

Nutrient control, however, has proved largely ineffective in reducing algal growths in shallow lakes sufficiently to allow clearing of the water and submerged plants to grow. It was formerly thought that this was due to release of phosphorus from the sediments (internal loading) but, although this occurs, removal of sediments to control it has generally not led to much improvement in the state of the lake (Moss et al. 1996). A simple model in which increasing nutrient loading led directly to loss of clear water and aquatic plants, and in which restriction of nutrients would lead to restoration of vegetation has had to be discarded in favour of an alternative stable states model (Fig.4) in which either an algal-dominated or a plant-dominated state can exist over a very wide range of nutrient concentrations.

A unique clear water, plant dominated state probably exists below about 25μg l^{-1} total P (250μg l^{-1} total N) and could be restored with very severe nutrient reduction. This is probably impracticable in catchments with more than minimal agriculture. Over the range in which both types of state can persist (25μg l^{-1} total P to at least several milligrams of total P per liter), stabilizing (buffer) mechanisms preserve the extant state. This means that switching mechanisms must have caused the transition from plant dominance to plankton dominance and that other switches will be needed to restore plant-dominance in a degraded, algal dominated lake (Fig 4).

Buffers and switches

The buffer mechanisms that stabilize plant dominance in the face of increasing nutrient loads probably include (Fig 5): uptake and storage of nutrients by the plants; promotion of bacterial denitrification in the lower layers of the beds and the surface sediments, where sloughed off periphyton and plant material leads to deoxygenated conditions; and allelopathy, where the plants may secrete compounds inhibiting to algal growth. Perhaps more important is the harbouring by the plant beds of very large numbers of crustacean filter feeders, particularly *Daphnia*, which drift out to graze on any developing algae in the adjacent or overlying water. Such animals are particularly vulnerable

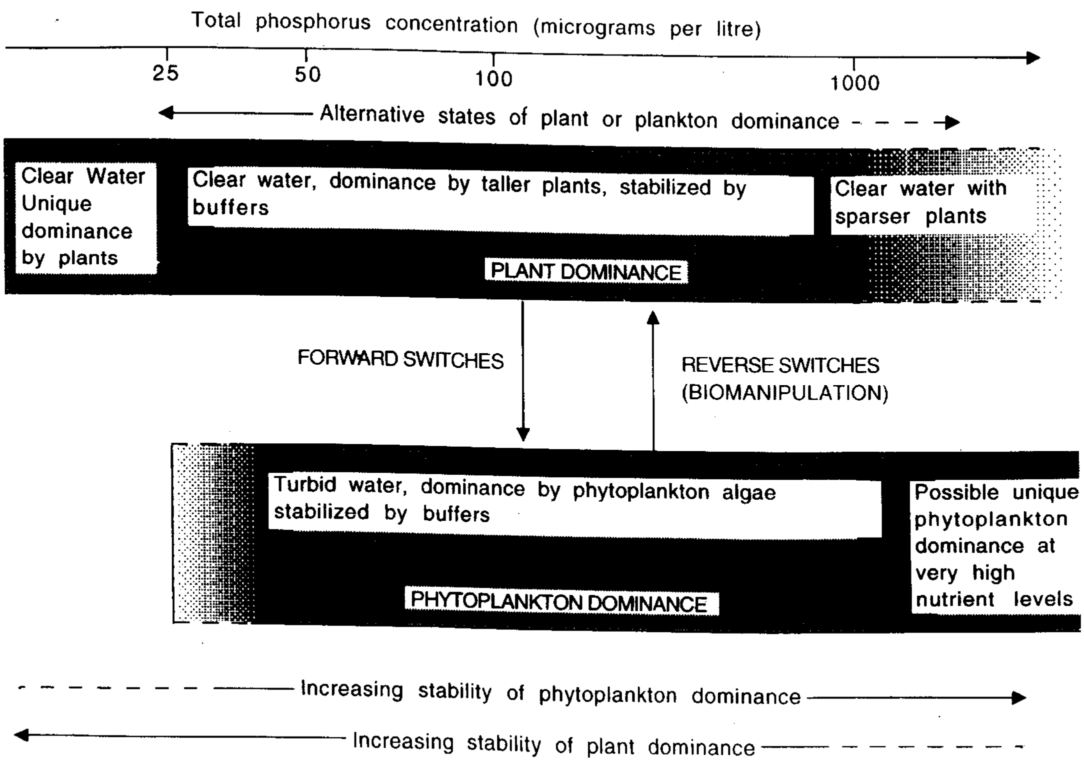

Figure 4. The alternative states model of relationships between plant-dominance, algal dominance and nutrients in shallow eutrophicated lakes.

to fish predation, but the refuges offered by the structure and darkness of the plant beds allow a coexistence of predator and prey.

In turn, in the structureless open water of the algal-dominated state, and the early growth of the algae may lead to competitive advantages for light and CO_2 over plants attempting to grow or geminate from fragments, turions or seeds on the bottom. But also (Fig 5), the habitat offers no refuge for large (and efficient) daphnids against fish predation and the zooplankton community is rapidly reduced to one of small rotifers, small cladocerans and copepods, which offer lower grazing potential, but through their small size or rapid movement can avoid predation by fish.

Switches that result in the loss of plants, once the appropriate threshold nutrient concentrations have been exceeded, include those that directly damage the plants (simple mechanical removal of large quantities, damage by boats, herbicides, or grazing by large concentrations of often exotic vertebrates, such as common carp (*Cyprinus carpio*) or geese and ducks). They also include agents that poison the daphnids (pesticides, increased salinity to over 5% sea water) or alter the intensity of fish predation on them through increases in the planktivore: piscivore ratio (selective winter fish kills under ice or in stagnant summer water). Such lists are not complete and there may, for example be many trace substances released in sewage and agricultural effluents that interfere with daphnid reproduction or survival. The waterproof paint I used on my concrete garden pond this year proved to be lethal to *Daphnia* even after drying and pre-leaching and a fishless pond that had been previously clear throughout the summer became turbid with algae from June until August.

Biomanipulation as a reverse switch and restoration mechanism
The switches that have been used to reverse the process and restore plant dominance are collectively called biomanipulation. All promote the husbandry of large *Daphnia* populations by reducing fish predation, though there may be other effects of removing fish. Biomanipulation may be by the stocking of additional piscivores, or the removal of zooplanktivores. The most effective technique is to take out as many fish as possible and then replace the piscivores during the restoration process. In theory, the aquatic plants and clear water can be restored without any nutrient control, but experience has shown that the system is more prone to switch back to a plant-dominated

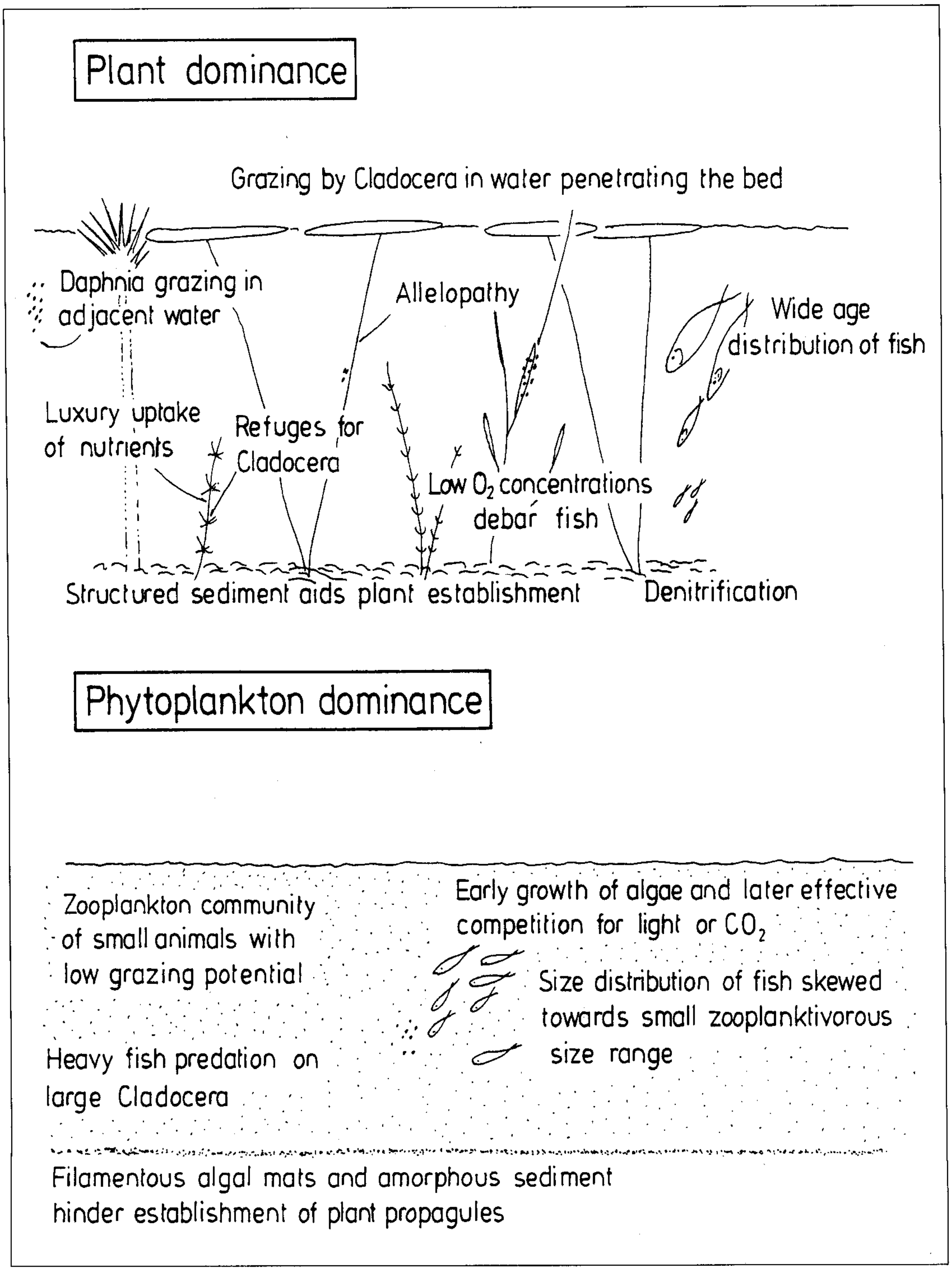

Figure 5. Buffer mechanisms operating to stabilise plant- or algal- dominance in shallow, freshwater lakes.

state, the higher the nutrient concentrations. The plant-dominated state is stabler at low nutrient concentrations and the plankton dominated state at high concentrations. Control of nutrients to the greatest degree possible is thus part of a successful strategy.

Restoration of shallow lakes by programmes that include biomanipulation has now been widely attempted in Scandinavia, and north-west Europe (Table 2). The results, taken collectively, allow a general strategy (Moss et al. 1996) for the guidance of future projects to be drawn up. Such a strategy includes eight steps: (1) Removal of existing or potential forward switches; (2) Establishment of practicable targets for nutrient reduction; (3) Nutrient reduction; (4) Biomanipulation; (5) Sediment removal or sealing; (6) Re-establishment of plants; (7) Replacement of the fish community; (8) Monitoring. This represents a composite of experience but an ideal which implies a logical progression not yet achieved in any individual project. At most stages, in a given project, there may be practical snags.

Practical problems

The removal of forward switches may be impossible and the project may go no further. Many shallow urban lakes have large flocks of hand-fed swans, geese and ducks which graze or trample any developing vegetation. Their removal may be opposed by those who enjoy feeding them! Control of pesticide or herbicide residues may also be impossible without alteration of the predominant agricultural systems of the catchment.

Setting of nutrient control targets is straightforward but achievement of them may not be. Some legislation may be helpful for control of point sources but diffuse sources are more difficult to identify and remove and may now be increasing as soils become saturated with phosphate fertilizers in some areas. These difficulties emphasise the need to work with larger and larger systems to ensure successful restoration (see below).

Biomanipulation itself is not conceptually difficult but removal of most fish may be practically impossible. Knowledge of their habits in a particular waterbody helps in the design of suitable netting techniques, and these may need to be repeated frequently. Ideally the stock should be reduced to 1 or 2 g fresh biomass per m^2 (10-20 kg ha^{-1}). Piscivore stocking is expensive as the fish may need to be cul-

Table 2. Summary of some restoration attempts on shallow lakes in Europe which have used Biomanipulation.

Site	Country	Area	Cause of problem		Target	Approach	Current degree of success
			Forward switch	Nutrient sources			
Cockshoot Broad	UK	3.3 ha	? Pesticides	Sewage effluent Agriculture (high)	Clear water Submerged plants	Isolation Sediment removal Biomanipulation	High
L. Væng	Denmark	15 ha	?	Sewage effluent (moderate)	Clear water Submerged plants	Biomanipulation (fish removal)	High
Zwemlust	Netherlands	1.5 ha	Herbicides	Sewage effluent (very severe)	Clearwater Submerged plants	Biomanipulation (fish removal & piscivore stocking)	High but deteriorating
L. Wolderwijd	Netherlands	2700 ha	? Salinity change	Sewage effluent Agriculture (moderate)	Clear water Submerged plants	Biomanipulation (fish removal & piscivore stocking)	Partial
Ormesby Broad	UK	54 ha	Plants initially present	Agriculture (moderate)	Charophytes	Biomanipulation (fish removal)	Moderate
L. Finjasjon	Sweden	1100 ha	?	Sewage effluent (severe)	Clear water Submerged plants	Effluent stripping Sediment removal Biomanipulation (fish removal) Wetlands & buffer zones	High

tured to obtain effective numbers. Following manipulation, it is of course necessary to prevent recolonization of fish from associated water bodies. This is a particular problem in lakes fed by rivers or channels in floodplains where the waterway needs to be kept open for navigation. One approach to prevention of recolonization is to create bubble curtains or electric stunning fields which allow boat passage but discourage fish. Alternatively, large exclosures can be built within the lake and fish removed from within them. Once plant beds have been established within the exclosure, and providing a sufficient area of beds (say >50% of the lake) has been covered, the exclosure walls can be removed and the buffering mechanisms left to cope. No project has yet reached this stage however.

If biomanipulation does not result in a clearing of the water for an extended period, removal of internal nutrient sources may be contemplated by sediment sealing or removal. The latter is to be preferred but is expensive. It has generally not resulted in effective control of internal loading and should only be contemplated where the lake has become very shallow and greater depth is needed for other purposes.

Biomanipulation is best carried out in winter or early spring before adult fish can breed and to minimise stress to the fish that would be caused at the reduced oxygen concentration of warm water. The lake should then be clear by early summer and plants may spontaneously grow from a seed bank left in the sediment, or from fragments that have persisted in the algal dominated state. If plants do not grow they may need to be introduced, again a costly procedure. Plantings and indeed naturally growing inocula may be attacked by birds such as coot and swan. Protective caging may be needed until healthy clumps have established.

Once plant beds are reasonably well established, fish removal operations can cease and a fish community be allowed to re-establish. It is usually impossible to remove all fish from a lake (unless it can be drained or poisons such as rotenone are used) and from the residual fish, the new community will be derived. Common carp should be deliberately excluded because of their damaging effects on plants and disturbance of sediment. Common bream (*Abramis brama*) can also disrupt sediment and cause turbidity problems. Piscivores should be stocked if they were previously absent. Table 3 gives some guidance as to the relative desirability of particular species.

Table 3. Summary of the characteristics of the most common fish species in lowland Britain in respect of their compatibility with shallow lakes restored to diverse plant communities. Br, Bream; Cp, Common carp; Cr, Crucian carp; Dc, Dace; El, Eel; Rc, Roach; Rd, Rudd; Pc, Perch; Pk, Pike; Tn, Tench; Bt, Brown trout.

	Br	Cp	Cr	Dc	El	Rc	Rd	Pc	Pk	Tn	Bt
Native/Introduced	N	I	N	N	N	N	N	N	N	N	N
Breeds prolifically	+	-	±	+	++	++	++	++	++	+	+
Disturbs bottom	++	++	+	-	-	-	-	-	-	++	-
Pelagial zoopl'vre[2]	++	+	±	-	-	++	+	++	-	-	-
Weed-bed zoopl'vre[2]	-	-	+	-	-	-	+	+	-	-	-
Piscivorous[2]	-	-	-	-	+	-	-	+	++	-	+
Intrusive angling	++	++	-	-	-	-	-	-	-	+	-
Usually abundant	+	++	±	±	++	++	+	++	++	+	±
Destroys plants	-	++	±	-	-	?+	-	-	-	?+[1]	-
Total score*	-7	-23	-2	+20	+28	-3	+1	+5	+25	-4	+33

[1] Because of predation on epiphyte eating snails. [2] Post-larval; pelagial means open water, middle of the lake.

* Scoring system: N = 5, (N) = 0, I = -5; for breeding, - = 5, ± = 3, + = 0, ++ = -5; for bottom disturbance, ++ = -5, + = 0, - = 5; for zooplanktivory, - = 5, ± = -1, + = -3, ++ = -5; for piscivory, ++ = 5, + = 3, - = -5; for angling intrusion, - = 5, + = -3, ++ = -5; for abundance, ± = 0, + = -3, ++ = -5; for plant destruction, - = 5, ± = -1,+ = -3, ++ = -5.

Most lowland European fish communities have been greatly altered by indiscriminate stocking in the past and so the concept of "designer" fish communities for restored sites should not cause problems.

Monitoring and the success of restoration projects

Monitoring is the final, and important stage in the strategy, for the results of many, if not all, restoration attempts on shall lakes have fallen short of hopes. Sometimes the system has switched back to phytoplankton dominance after a few years; usually the plant diversity is relatively low; stands may often be monospecific and of the most tolerant species such as *Ceratophyllum demersum* or *Potamogeton pectinatus*. Monitoring, if sufficiently detailed, helps illuminate the problems and contributes to future solutions.

The usual reason for disappointing, if still positive, results in shallow lakes is probably that nutrient levels have not been sufficiently reduced. Conventionally phosphorus levels are controlled rather than nitrogen, because of the difficulties of restricting supplies of the latter. However, substantial amounts of phosphate are released from sediments within plant beds and it is likely that in all but minimally impacted shallow lakes, phosphorus is never limiting to algal growth. On the other hand, vigorous plant beds are associated with very low available nitrogen concentrations. In restoration attempts it may then be more sensible to attempt nitrogen control, which may have the effects not only of leading to a more stable plant community, but also a more diverse one. We do not yet know whether parallel phosphorus control would also help in such cases.

A second reason for limited results may be that too small a project has been attempted and this leads us back to general issues of restoration. A classic case is Lake Zwemlust in the Netherlands, which is a small (1 ha) swimming lake. It had been plant-dominated until the, 1960s when herbicide was used to clear the plants so as to provide more swimming area. The lake then became dominated by algae, including blooms of the cyanophyte, *Microcystis aeruginosa*. In 1988 the lake was drained and all fish were removed. Some pike (*Esox lucius*) and rudd (*Scardinius erythrophthalmus*) were replaced after the lake re-filled by seepage from the nearby River Vecht. It became plant-dominated for several years but the plant communities attracted in flocks of coot (*Fulica atra*) which were responsible for severe grazing damage and the lake has recently reverted to algal dominance (van Donk & Gulati, 1995). The lake is the only water body with plants in an area that was once an extensive floodplain wetland; not surprisingly, coot from surrounding marginal habitat concentrated on the lake. Had it been possible to restore a group of lakes and surrounding wetland, this problem would probably not have occurred.

Small versus large systems

It is usually possible only to restore small, often isolated systems for several reasons. First, negotiations with landowners and users will be limited; secondly the costs will be relatively modest and thirdly the reasons for degradation may be more readily discernible and controllable. On the other hand, failure to control influences on a wider scale (e.g. diffuse nutrient loads, pesticide residues) may lead to only modest results. To obtain stable, diverse communities and to restore functional values of more than trivial extent requires restoration of large, complex systems - a substantial length of floodplain with a number of adjacent lakes and a natural flooding regime, for example. The costs of this are greater, and the larger the system to be restored, the more the ultimate reasons for environmental degradation need to be tackled. Such ultimate reasons emerge from the choices society makes concerning lifestyles and the intensity of resource use.

At present, in some European countries, only small projects are politically tenable. In others more ambitions schemes are being enacted. But in none is the scale of restoration sufficiently great to restore substantial function back to systems that could again contribute greatly to the well-being of a society less hell-bent on material consumption.

Only when a substantial reduction in the product of population, resource use and waste production and technological impact has been made will this be possible. In the "western" (industrialised) world, population is high and unlikely to decrease or decrease very much. The western world, however, consumes more and produces more waste per head than the rest of the world.

Such consumption is positively promoted under economic theories that consider only the internal costs of production that are borne by the industry but not those borne by society as a whole. Such theories are also underpinned by the valuing of those who grasp resources over those whose approach is to tread lightly. The western world also has been unable to control the extent to which its increasingly damaging technology is used and in this component of the equation there is scope for reducing environmental impact, but again the favoured economic theories encourage the unrestricted use of whatever technology becomes available. There is some inevitability in this. The nature of our evolution might predict, as with any other organism, that we are programmed to seek our own interests, and that those best able to grasp and manipulate will be best favoured.

Habitat restoration represents the antithesis of this. It counteracts the ultimate futility of destructive and consumptive behaviour. It is yet not a particularly pervasive or well funded activity but it must become so if we are really to develop sustainable societies.

"Only when we are straight in our own heads, and have structured societies that are able to override their own innate tendency to be overtaken by hawks and hawkishness, can we hope to create the kind of world that can be sustained, for only the meek can inherit the earth" Colin Tudge, 1994, "The Engineer in the Garden".

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Danish experiences on River Restoration I: Trends and Statistics

Torben Moth Iversen and Stig Per Andersen

Environmental background

Denmark is a lowland country with a total area of 43,000 km^2. Agriculture is by far the most important land use, accounting for approximately two thirds of the land area (Ministry of Agriculture, 1991). As a consequence the Danish landscape, including the many watercourses that permeate it, has been significantly affected.

A main issue for agriculture has been to avoid flooding of fields and to facilitate drainage. About half of all agricultural land is therefore drained (Ministry of Agriculture, 1991), and drainage and reclamation have turned previous meadows and wetlands into arable fields. To this end about 25,000 km ditches and canals have been constructed to supplement the 35,000 km of natural Danish watercourses. Between 80% (Markmann, 1990) and 98% (Brookes, 1984) of these natural watercourses have been channelized, and all watercourses, both natural and manmade, have been maintained through weed clearance and dredging.

During the last two centuries organic matter and phosphorus loading has been significantly reduced through sewage treatment. Nevertheless, about two thirds of all Danish watercourses do not meet ecological quality objectives established politically by the Danish county authorities (Danish Ministry of Environment and Energy, 1995), this being mainly attributable to poor physical conditions caused by channelization and hard handed maintenance.

Legislative background

The Danish Environmental Protection Act stems from 1973 and has the overall objective of securing a diverse flora and fauna. At that time the objective of the Watercourse Act was only to safeguard runoff and drainage, and this had a major impact on the way the authorities administered Danish watercourses.

In 1982 the Watercourse Act was revised and two major improvements introduced: The quality objectives of the Environmental Protection Act were now to be taken into account in the administration of the Water Course Act, and restoration became legally permissible.

Moreover, a number of specific restoration measures were stipulated in the Act, including the establishment of artificial overhanging banks, instream boulders, instream logs, current concentrators and spawning grounds, these being inspired by North American experience. The new Act also specified that landowners could claim compensation from the river authority and that the Danish Environmental Protection Agency could support projects financially.

A more detailed description of the Danish legislative background for watercourse management is to be found in Iversen et al. (1993).

Government supported projects

During the period 1984-95 the Danish EPA has supported 242 projects to a total of DKK 31.5 million (Table 1). In 1984-87, about 68% of the total costs were covered, the figure falling to about 32% in 1992-95. The remaining costs were met by the river authorities (mainly counties).

Table 1. Overview of the number and total costs of river restoration projects supported by the Danish EPA

	No. of projects	Danish EPA support mill. DKK	Total costs mill. DKK
1984-87	12	1.3	1.9
1988-91	74	13.0	29.6
1992-95	156	17.2	54.0
1984-95	242	31.5	85.5

The distribution of financial support varied widely between the 14 Danish counties (Table 2).Thus the five counties that each received over 10% of the support together accounted for about 75% of the total. This reflects differences in county size, as well as differences in political and administrative interests.

Table 2. Distribution of Danish EPA financial support for river restoration projects during the period 1984-95.

% of total support per county	No. of counties
>10	5
5-10	2
<5	7

Instream measures such as fish ladders, spawning grounds, replacing weirs and dams with riffles and bypasses account for about 65% of all projects (Table 3). The group "Other measures" compasses instream measures of the type specified in the 1982 Watercourse Act. Over the period 1984-95 the proportion of such projects decreased, while the proportion of projects comprising fish ladders and spawning grounds has remained stable. In contrast, the proportion of projects aimed at ensuring river continuity through the replacement of weirs and dams with riffles and the establishment of bypasses along dammed streams has increased.

Table 3. The distribution and trend in Danish EPA supported restoration projects during the period 1984-95.

	No. of projects	Trend
Fish ladders	39	→
Spawning grounds	17	→
Replacing weirs/dams with riffles	86	↑
Bypasses along dammed watercourses	15	↑
Opening culverted streams	16	→
Meanders	26	↑
Other measures	43	↓

In addition to the river restoration projects financially supported by the Danish EPA, an unknown number of mainly minor projects have been performed by the counties and municipalities, and in some cases also by non-governmental organizations.

Re-establishing river valley hydrology

The scope of Danish river restoration has to some extent changed since the early 1980s. Thus whereas many of the measures mentioned in the 1982 Watercourse Act aimed at improving the rivers as habitats for fish mainly trout and salmon, more recent river restoration projects such as those in the rivers Gels Å, Brede Å, Gudenå and Skjern Å have a wider scope, aiming not only at restoring the rivers, but also at restoring a significant part of the riparian areas and river valley. These projects are presented separately and underline the wisdom of H.B.N. Hynes, who stressed the importance of the interactions between the river and its valley (Hynes, 1975).

In the projects mentioned above, remeandering is an important element. Remeandering raises the groundwater level, increases the frequency of upstream floods, and restores a diverse physical environment in the watercourse and in the riparian areas.

The effects include reduced nutrient loading of downstream ecosystems. Phosphorus is removed during flooding and nitrate-nitrogen will be transformed to atmospheric nitrogen through denitrification in the wet riparian soils. Biodiversity increases in the river, as well as in the riparian areas. In addition, the increased water storage capacity reduces the risk of downstream floods. The need for this was clearly stressed by the 1995 floods in the Rhine, in Germany and the Netherlands and in the River Gudbrand in Norway.

The development of river restoration in Denmark thus stresses the need for integrated water management and the need to increase biodiversity, two of the main issues in the 5th Environmental Action Programme of the European Union: "Towards Sustainability".

Danish achievements in river restoration

Instream restoration measures such as the removal of weirs and other obstacles and the establishment bypasses around dams have rendered 5-10,000 km of watercourses accessible for upstream migration of fish and macroinvertebrates (Table 4), thus improving continuity in 15-30% of the physically disturbed watercourses. Moreover, meandering /remeandering has re-established about 200 km of physically varied watercourse, corresponding to about 0.6% of Danish watercourses of natural origin.

Table 4. Estimated Danish achievements in river restoration as of 1995.

Watercourses of natural origin	35,000 km
Physically disturbed	~31,000 km
Improved continuity	5-10,000 km
Meandering/remeandering	~200 km

As mentioned above, meandering/remeandering raises the groundwater level and re-establishes a natural hydrological regime in the riparian areas. Such restoration projects are rather new and a rough estimate is that about 20 km^2 of meadows have been re-established, corresponding to about 0.3% of the potential (Table 5).

Table 5. Estimated Danish achievements in re-establishing meadows through river restoration as of 1995

Danish land area	43,000 km^2
Agricultural area	28,000 km^2
Potential freshwater meadows	6,680 km^2
Freshwater meadows	458 km^2
Meadows re-established by meandering/remeandering	(20 km^2)

It can be concluded that the overall impact of hitherto river restoration and wet meadow re-establishment is still low. However, it should be noted that a century long period with loss of wet meadows and physical variation of watercourses has stopped, and tide has now turned. Hopefully, the demonstrative value of the relatively few projects so far undertaken will speed the process of restoration and other measures aimed at improving the environment of our watercourses, riparian areas and river valleys.

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Danish Experiences on River Restoration II: The Effort Beyond Restoration

Bent Lauge Madsen

The state of Danish streams as summarized in the plenary lecture by Torben Moth Iversen and Stig Per Andersen might superficially indicate that some of our results of stream restoration efforts, e.g. remeandering and reopening culverted streams, have been insignificant in comparison with the needs.

More significant seems the re-establishment of upstream-downstream continuity, which has made approximately 5,000-10,000 km of watercourse accessible for migrating fish. Since much of this work is made on the initiatives of local stream authorities - of which we have about 400 - we have as yet no exact statistics.

The majority of these stream reaches, as well as the remaining part of our approx. 35,000 km of streams of natural origin, have not only been impoverished by straightening and deepening, but also by hard-handed weed clearance and dredging.

It seems to be of little value to give fish access to stream reaches without a sufficient supply of hiding places, spawning banks and habitats for prey invertebrates.

A rich supply of potential spawning grounds have been established by the stream authorities. As an example, Silkeborg Municipality, has during the last few years placed about 1,200 m^3 of spawning gravel in small brooks, creating about 900-1,000 potential spawning grounds (Petersen, 1996). Making spawning grounds is considered by river keepers a simple task.

Usually they follow the general rule of spacing between riffles (Leopold, 1994) or just leave it to spates and trout to establish the spacing from a continuous layer of gravel. Thus within 3 years of a continuous carpet of spawning gravel being laid out in the small brook Dollerup Bæk near Thisted, spacing was observed that obeyed the riffle sequence (Eliasson, 1996).

Beyond restoration

Introducing spawning gravel into a stream is not the same as providing trout the opportunity to reproduce in the stream. To quote a century old book on fishery management (Bund, 1899) *"It is important, as Parliament has recognized, to give the fish free access to the spawning grounds; but the free access is useless if, when the fish have spawned, their ova are destroyed; yet, as the law now stands, there is absolutely no provision to guard against this danger, and Fishery Boards take no heed to it. It is illegal to disturb a spawning bed by moving the gravel; it is quite legal to ruin it by discharging matters into the stream, that cake together and kill every ovum in it".*

Migrating sand is the main threat to spawning grounds, natural or introduced (Larsen et al. 1992). For spawning to be successful, it is crucial to prevent loose sand from entering the stream. Our Watercourse Act provides river authorities with several tools to abate the sand problem: It is compulsory that farmers maintain a 2-metre wide cultivation-free border zone between the upper edge of the stream bank and their fields. To prevent cattle from trampling the banks, the stream authorities can order the farmers to erect fences along the streams and to establish watering places positioned a safe distance away from the stream grounds. Some watercourse authorities, e.g. Silkeborg Municipality, establish them on their own initiative (and expense) at streams where they have established new spawning grounds.

Many problems are still caused by migrating sand, especially that derived from field drainage systems, discharge spates caused by storm water from urban areas and roads, and weed clearance, which exposes the stream bank to erosion.

In many parts of the Jutland peninsula, leaching of ochre is a serious problem, not only for spawning grounds, but also for the entire biota. In Ribe County, 50% of the streams are affected by ochre, mainly caused by the water table in the surrounding fields being lowered by drainage. More than 25% of the streams are so infested with ochre that they are unfit habitats for fish (Ejbye-Ernst, 1993). As you have had the opportunity to study during the conference excursions to the western and southern parts of Jutland, endeavours to abate ochre pollution are widely undertaken by county authorities. The measures range from raising the water table by remeandering the streams to precipitating and eliminating the ochre by chemical and biological methods, all in the "lowtechnology" category. An annual mean reduction in ochre (total and soluble iron) in one of the projects of 85% (summer and autumn 98-99%) is convincing evidence of the success of these endeavours (Bolet et al. 1996).

The art of weed clearance

Weed clearance has always been an important activity in Danish streams, mainly in order to enhance their discharge capacity. The 1982 amendment of the Watercourse Act introduced a new concept to stream maintenance: When maintaining and enhancing stream discharge capacity, the stream's environmental requirements shall also be considered. Previously, all vegetation in the stream and on the banks was cut in a manner and according to deadlines stipulated in the Provisional Order governing each stream. This left a barren stream, with no shelter for fish or invertebrates. If riffles were not removed by former channelization, they became victims of maintenance dredging, as did any traces of undercut banks that the stream had managed to recreate. The river keeper's job was thus to destroy whatever repairs the stream had succeeded in making to the man-made canal. Quite literally, they had to maintain the stream in the form established by man.

The present Watercourse Act has provided river keepers with a tool to gradually create habitats for fish and invertebrates in the former barren channelized streams. In its most simple form, this just requires leaving some vegetation in place along the sides of the stream. Trout fry surfacing from the spawning grounds will benefit from such a practice, since they inhabit these marginal areas with low current velocity during their first 2-3 months of life (Bangsgaard, 1995).

In most Danish streams, the river keeper can leave some vegetation standing without coming into conflict with discharge capacity requirements. Although the Watercourse Act requires that he clears the weed to the extent stipulated in the Provisional Order, erosion due to previous hardhanded weed clearance and dredging has widened the cross section of many if not most streams far beyond their stipulated dimensions. Thus the river keeper has the freedom to exploit the "excess" cross-sectional area for environmental "purposes" (Figure 1).

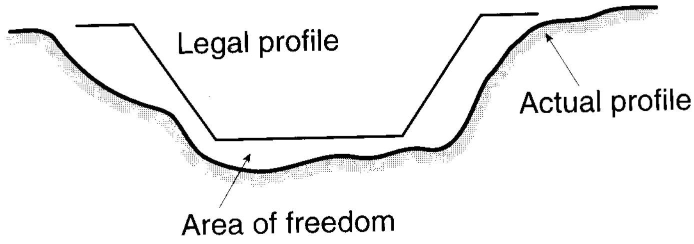

Figure 1. The actual profile of Danish streams are often larger than the legal. This gives freedom to leave weed and to introduce gravel and stones.

The weed clearance practice initially established during the first years of the new Watercourse Act was to leave vegetation borders along the sides of the streams. This practice gradually changed to clearance of a slightly meandering current channel in the centre of the stream. Such channels usually had a surprisingly good discharge capacity, and the

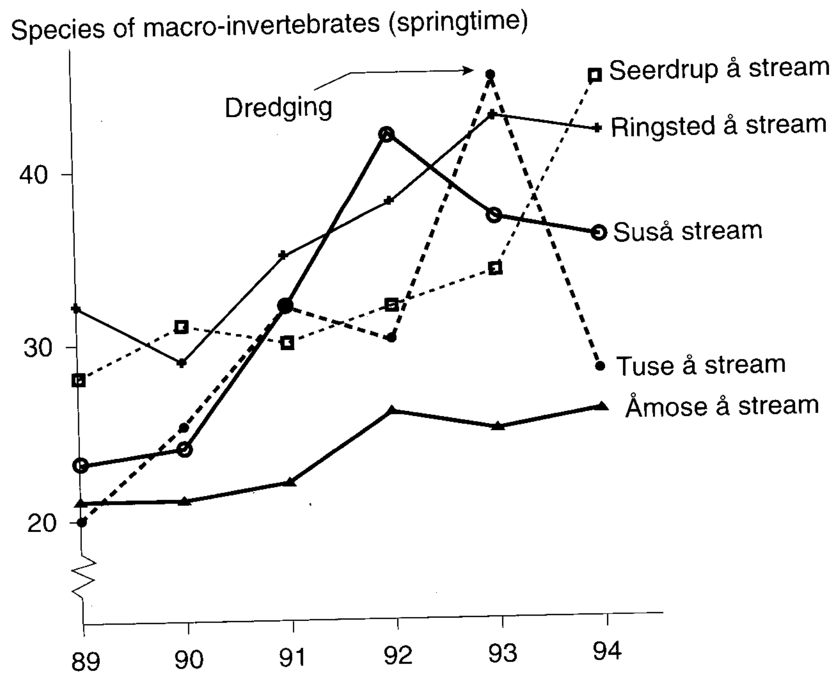

Figure 2. An increase in number of invertebrate taxa is observed in major streams in Vestsjællands county after the gentle weedcutting was introduced. Note the decrease in Tuse å following a dredging.

current kept the introduced gravel banks free of sand or even exposed the old gravel bottom. At the same time, the weeds prevented the current from eroding away at the banks and provided good habitats for invertebrates (Andersen, 1995), see figure 2, and fish such as trout (Wiberg-Larsen et al. 1994), see figure 3.

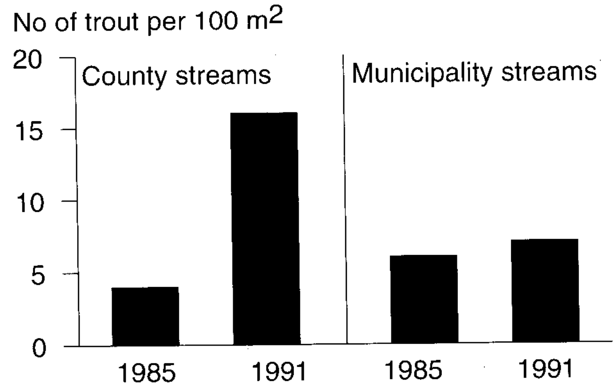

Figure 3: Median values of trout, no per 100 m² in Funen streams. The great increase in the county streams are attributed to the introduction of gentle weedcutting, a practice not yet much applied in Funen municipality streams. After Wiberg-Larsen et al., 1994.

A problem soon arose, however: The vegetation along the stream borders changed and sand and mud became trapped among the plants such that the borders gradually became part of the banks. As a result, the stream eventually narrowed to the profile stipulated in the Provisional Order. With that the river keeper's freedom also narrowed: To ensure the stipulated discharge capacity, he often had to clear the current channel of vegetation, thus reverting to the state in which he had started years earlier, i.e. a barren stream, albeit one that was narrower than the previous one.

The current advice to river keepers is thus to widen narrowed streams, if necessary using a mechanical excavator, so as to ensure sufficient room both for the water and for the vegetation, fish and invertebrates (Madsen, 1995), see figure 4.

This practice is not the final practice that river keepers should employ, however. We are still investigating the development of vegetation in the streams as a function of different weed clearance methods - or the absence of weed clearance. We are searching for management methods which can eliminate or inhibit plants such as the bur reed (Moeslund, 1995), which can severely obstruct water flow and which has very limited value as a habitat for stream invertebrates and fish.

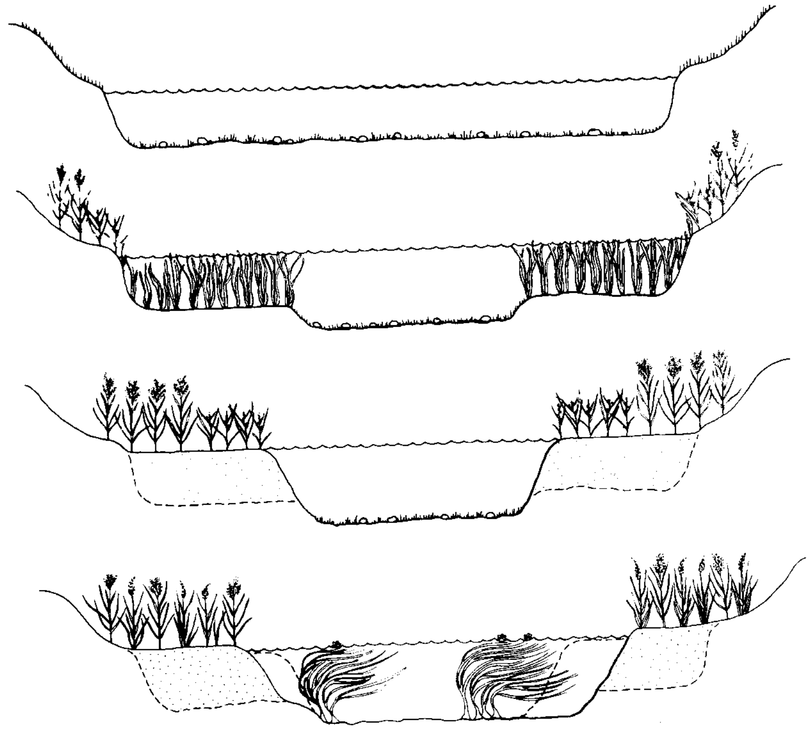

Figure 4: Steps in Danish stream maintenance, from total weedcutting (prior 1982) through single current channel to a "braided" pattern. From Madsen, 1995.

Weed clearance versus restoration

Restoration is the only means of making good many of the changes that former uses have imposed on Danish streams. If one wants to see new meanders in the foreseeable future, there may be few alternatives but to dig them as the natural forces are too weak (Brookes, 1984). But a combined action between deposition in the marginal areas and the "engineering" capabilities of certain plants, e.g. water celery, many small, former straightened streams have now been transformed into a shape approximating the meandering pattern.

There are few if any reliable alternatives to removing or bypassing the obstacles that prevent migratory fish from reaching their spawning grounds. With respect to spawning grounds, there is no alternative but to introduce gravel banks into the streams, albeit that current channels may sometimes re-expose buried spawning grounds.

There is an alternative to re-exposing culverted streams: Leave them to their own devices when the concrete culvert pipes break apart. We have some examples of this in Denmark, and these have given us the opportunity to follow how a small stream develops as it finds its way across a meadow when left to its own devices: Apparently it "dissolves" into a number of branches before disappearing into the wet ground.

There are few alternatives to weed clearance for maintaining and creating good habitats in streams, neither in restored streams. Prudent weed clearance helps keep gravel banks and stone beds free of sand and silt, and it creates "tailor-made" hiding places for the trout fry. If the current is too weak to cut substantial meanders, they can form by deposition in the stream margins.

Prudent weed clearance can have a considerable, beneficial influence on the fish population, as was the case in the county streams on Funen (Figure 3). Leaving the vegetation to its own devices can have great impact on the quality of the stream as a habitat for trout. A good example is from Idom A stream in Ringkjøbing County (Bisgaard et al. 1994). The trout population in a remeandered reach was compared with a naturally meandering and a straightened reach, where weed clearance had ceased. The trout population in the remeandered reach initially lagged behind the two other reaches, probably due to lack of plant cover for hiding. However, 3 years after remeandering the trout population in the new reach was comparable to that in the naturally meandering reach. It is evident, though, that there is also a very good trout population in the straightened reach too due to the good plant cover. It should be noted, however, that trout number is expressed per metre of stream length and that remeandering has more than doubled the length of the formerly straightened reach length, thereby providing extra habitats in addition to improving the quality of the habitats.

The real art of river keeping

The river keeper plays the key role in our endeavours to improve our streams. While his former work was very straightforward - just to remove all weed in time - it is now more complicated. According to personal accounts of river keepers, though, it is also more rewarding. It is the river keepers who add the qualities to the stream that sewage treatment cannot give alone: They are the creators and mediators of stream physical diversity, which is of utmost importance to the stream as a good habitat and a well-functioning ecosystem.

This is not their only task however, as they are also the messengers of the stream authorities and the contact to stream users. To explain to farmers that discharge capacity is but only one of the qualities of a stream is often a difficult task especially when the stream is flooding: To farmers who are used to seeing their streams cleared of vegetation, it is all too easy to view the vegetation now left standing and the narrowed stream as the culprit - and the river keeper as the scapegoat.

The education of river keepers - and the provision of information to farmers - are crucial elements in the new management of our streams. We thus give courses and lectures, make films, and publish books and leaflets, all with the sole purpose of easing the transition between the days when we worked against our streams, to the present, where we want to work with our streams.

As Bob Newbury taught us: "The art of stream restoration is to mimic the natural stream. But some mystery still remains".

From our experiences in Denmark we can add that a very important part of the art of prudent stream management is to create a positive political and phychological environment.

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Danish Experience on River Restoration III: From Idea to Completion

Mogens Bjørn Nielsen

A large number of restoration projects have been layed out in Denmark. In the following some of the more practically experiences from these works are presented. The process from idea to reality requires know-how on stream restoration itself. Other factors including the democratic process and involvement of landowners are also important.

Before one starts restoration it is necessary to "stop the accident". It is not possible for humans to restore the landscape to its original natural state. Once disturbed or destroyed habitats can never be completely recreated. It is, however, possible to rehabilitate features and habitats in a way that brings conservation benefits: a restored river with diversity of habitats is better than a channelised stream with little diversity. It is better still to protect habitats of existing value than to have the difficulties and expenses of attempting to recreate them once destroyed.

So much effort as possible should go to securing and protecting undisturbed streams and riparian zones. The lesson from Denmark and other countries is that the requirements of "agricultural and economic development" are no longer sufficient excuses for a modern society to disturb or damage streams and wetlands (Eiseltová et al. 1995).

Because the power in Denmark is decentralized the majority of the Danish projects are undertaken and financed by the Councils. The public elected County Counties have drawn up a policy and strategy in the environment and nature area. The Counties also administer the majority of the legislation on streams and the landscape. Approx. 1500 highly educated people are employed by the 14 Counties in the field of protection nature and the environment, e.g. biologists, geologists, engineers, hydrologists, geomorphologists, planners and surveyors. These professionals can secure a multidisciplinary approach including hydrology, biological conditions, the physical dimension, water quality, technical installations, legally aspects and cooperation with landowners.

In addition to the projects made by the counties also some of the municipalities make stream restoration projects in smaller streams. There are also a few examples of projects having been undertaken by private interests groups or the State.

Carrying out a restoration project is often a matter requiring patience. The main stages in a project is shown on table 1.

Table 1: Steps in a restoration project.

- Initial idea
- Pilot studies
- Contact to landowners and provisional acceptance
- Coupling of interests between landowners, the public and the authorities
- Drawing up of the project
- Approvals and processing by the authorities
- Clarification of financing
- Construction - the physical work
- Assessment and follow-up

In (Eiseltová et al. 1995) and (Nielsen, 1996a) a more detailed description is given on each of the above stages from idea to reality. A useful way of arranging a detailed description for a restoration project is presented in table 2.

Pilot studies

An outline project is made to obtain a first impression of whether an idea is scientifically defensible. Maps showing former course prior to channelization should be required. Biological conditions should be investigated, various measurements made and soil samples collected. Also information on discharge, larger sized technical structures in and alongside the stream should be checked, and possible legal constraints on the project be investigated.

Based on these informations an Assessment should be made of whether or not the project is technically realistic.

Table 2: Check list for the project description. (Nielsen, 1996b)

Check list for the project description

A useful way of arranging a detailed project description that complies with legal regulations and requirements regarding both regulation and restoration projects is as follows:

A. Introduction
- Origin of the idea and location of the area
- Purpose of the project
- Summary of the physical measures intended specifying exactly what is to be done.

B. Description of existing conditions
- General description of the locality (location, terrain, physical conditions, surveys)
- Preservation and regional planning constraints, i.e. the Preservation Scheme, preservation orders and constraints stipulated in the County Plan (raw material reserves, EU Bird Protection Areas, environmentally vulnerable agricultural land, etc.)
- Land use (cultivation, recreational or other uses)
- Fauna and flora (collation of existing knowledge/reports and new, supplementary investigations)
- Quality objectives and water quality (recipient quality plan, polutional state)
- Drainage and discharge conditions (water level, discharge, catchment size and character, groundwater conditions, drainage conditions and the provisions stipulated in the Provisional Order governing the watercourse)
- Soil conditions. Information on special conditions such as soft bed or potentially ochreous areas. Valuable information can often be obtained from existing studies in the area. In addition, one should be aware that it is sometimes necessary to undertake sediment analyses, typically for the heavy metals lead, cadmium, mercury and nickel. This has to be done if the excavated earth is to be dispersed on agricultural land. The county authorities have information on registered contaminated lands and ochreous areas

Continues

- Technical installations, e.g. various cables and pipes (water, sewage, telephone, gas and electricity), roads, footpaths and other crossings, masts, structures (weirs, dams, etc.), overflows, inlets, etc. Local utility companies and the Municipality's technical department have the relevant information
- Ownership (private, public, Land Registry entries, cadastral maps).

C. Planned measures

- Description of the planned construction work suitable for preparing the call for tenders
- Follow-up work, including re-establishment, sowing, planting, fencing, bridges and footpaths.

D. Results and consequences

- Expected future conditions, including water levels, discharge, groundwater conditions, water quality, and flora and fauna
- Consequences for land use
- Future ownersh ip
- Monitoring and impact assessment.

E. Necessary permits - summary

- Pursuant to the Watercourse Act
- Pursuant to the Nature Protection Act
- Pursuant to the Freshwater Fishery Act
- Pursuant to the Ochre Act
- From landowners. Review of the property's entry in the Land Registry to determine ownership, and to ensure that registered rights and easements are not violated. In addition, easements can reveal information on the location of technical installations, pipes and cables, road rights, etc. When clarifying ownership and agreements with landowners, one has also to take into account the possible rights of third parties. Such rights are not necessarily recorded in the Land Registry entry for the property, and in agricultural areas will often concern leasehold agreements. Ask the owner about such rights and enter into an agreement with the owner that clarifies who is to cover, for example, a leaseholder's crop losses caused by construction work.

Continues

F. Timetable

- Pilot project
- Preliminary discussions with landowners
- Political processing of the project application
- Possible public hearing
- Public phase
- Final clarification of financing
- Necessary approvals additional to those under the Watercourse Act, incl. appeal periods
- Final approval pursuant to the Watercourse Act, incl. appeal periods
- Construction phase
- Follow-up, including updating the Land Registry and deciding future division of maintenance obligations and responsibility.

G. Economic aspects

- A precise budget estimate and a summary of financing.

H. Annexes for a typical major project the following annexes will be relevant:

- Outline maps in scale 1:100,000 and 1 :25,000
- Old maps of the area
- Survey and survey maps
- Planning conditions
- Existing longitudinal and cross-sectional profiles
- Water discharge, water level, hydrographs
- Present ownership
- Present land use
- The measures planned in the project
- Coming longitudinal and cross-sectional profiles
- Miscellaneous detailed drawings
- Future ownership
- Future land use.

Involvement of landowners

Involving the landowners is often the most important phase of the project. This phase can be a major project killer if not handled carefully. It is advisable to go over the project idea with the landowners involved in an early stage e.g. before the project is mentioned in the press. The first contact should be made personally to each individual landowner. Also it is important that the material presented to them is clearly only a proposal. This ensures that it will be possible to incorporate local ideas and wishes.

Normally it is not all the wishes and comments that can be followed simultaneously, and the choice between possible solutions thus becomes a political decision. Hence it is normally a good idea that politicians from the responsible watercourse authority participate in a public meeting. The involvement of the politicians signals to the participants that there is more to the project that just some technicians´ idea. Moreover, one is more likely to accept political solutions when one has seen and heard the politicians in question.

Coupling of interests and drawing up the project

A restoration project can often take account of many different environmental and natural interests. The wider the proposal is, the more backing it will often be possible to obtain. On the other hand, though, it is not possible to take account of all interests at the same time and place. Priorities have therefore to be established.

A stream restoration project comprising restoring the stream to its original meandering path involves more than just restoring the course itself. Thus, riparian areas such as banks and meadows will often also be affected. In some cases, stream restoration involves raising the groundwater table and implementing ochre removal.

Better physical conditions in the stream, enhanced self-purification capacity in the stream and greater denitrification of nitrogen in the wet meadows are three major objectives for the water environment. Also for nature there are many advantages. A more varied landscape and a greater number of more varied habitats for threatened plant and animal species are achieved by integrated restoration projects.

Enrichment of outdoor life, including angling and hunting, also profits by the projects.

Various considerations will help to secure the greatest environmental and natural return of the investment in possible projects. The political dimension can help to get the greatest return of the investment in river rehabilitation. In river restoration one must ensure that the investments and changes in the stream are permanent, and that there are only few or no maintenance costs once the project has been completed. It is also necessary to aim for low costs for purchase and construction.

The link between know-how on restoration to the democratical process and to the practical world is essential. The art of restoration including professional know-how on biology and geology is absolutely necessary. But to go from a good project idea to implement it as a restoration project one must also take into account many other tasks and disciplines as shown on figure 1.

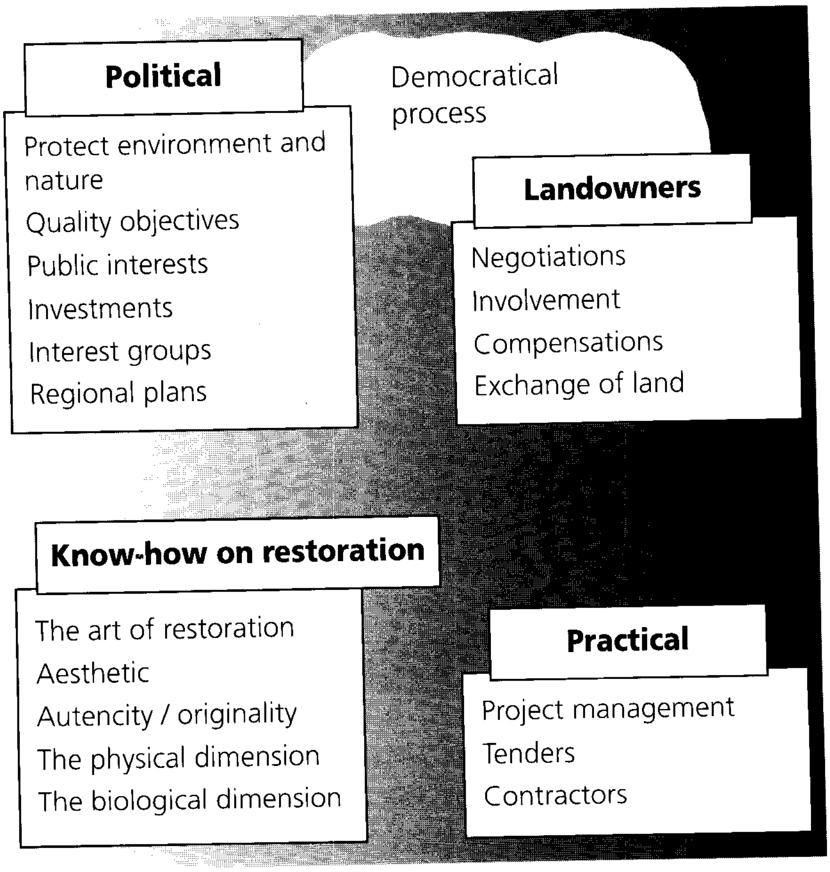

Figure 1: The links between know-how on restoration to the democratical process and to the practical world

Financing

Before the watercourse authority can issue final approval for a restoration project, financing has to be clarified. Many projects are in effect collaborative endavours, and financing often derives from a number of sources in the form of cash subsidies or labour. In some cases, labour undertaken by angling clubs or landowners is part of the financing. In other cases, land is provided free of charge or compensation.

Restoration sometimes help solving problems with the maintenance of a stream. Examples are reaches which continually silt up or where banks continually collapse. The relevant watercourse authority could profitably capitalize future maintenance costs and instead solve the problem by restoring the stream.

The most important sources of financing are county funds for restoration and State funds for restoration and ochre removal. Besides some funding are available from local municipalities, various funds, firms and in a few cases from EC e.g. three river restorations in Denmark have been funded by EU Life Programme.

Construction

If the watercourse authority decides that the project shall be undertaken by contractors, a call for tenders will have to be prepared. This is a normal procedure for any larger project. The call for tenders includes special descriptions of the work which, together with the detailed project, form the basis for the contractor to undertake the construction work.

An important task is to ensure effective supervision of the construction works. Among other things, this is important for future physical conditions in the stream and consequently for nature as well as for drainage from the individual landowner's property. In addition, supervision ensures that the funds expended on the work are used in a defensible and politically approved manner.

Evaluation and follow-up

Prior to each individual project one should assess how comprehensive the impact assessment studies should be. Projects with impact assessment studies demands that the monitoring is planned very early in the life of the project. Ideally it must be prior to the detailed design.

It is desirable to establish a reference or control reach upstream of the restored reach. This makes it possible to eliminate the effect of other influences such as climatic changes and the impacts of land use.

Evaluation of the effects of restoration on sediment and nutrient transport and on the hydrology of the floodplain requires that monitoring should start at least one year before construction (Nielsen, 1996b). Monitoring and sampling should be undertaken simultaneously in the reference and downstream reach. Changes in drainage conditions of the riparian zones should be monitored in selected transects along the stream.

The effect of restoration on changes in wildlife demands the use of standard methods and usually a minimum of two surveys - spring and autumn - before restoration starts and in the year after.

Recommendations for lowland stream restoration

The following recommendations are based on more than 10 years practical experiences with several hundreds of restoration projects in Denmark (Nielsen, 1996b).

An attempt should be made to include the whole stream valley in the project plan. Dimensions and discharge capacities should be recreated to secure a hydrological connection between the stream and its valley.

During project design, information on the old course of a stream, dimensions and information concerning existing physical conditions such as slope, discharges, hydrograph, sediment and services such as pipes must be obtained.

An aim should be to establish as many crossings as possible between the straight, regulated course and the new meandering, restored course, in order to secure rapid colonisation by aquatic plants.

Restoration projects involving excavation of the former floodplain must take into consideration existing vegetation niches worthy of preservation.

Restoration of streams by means of large-scale excavation should be programmed to start during periods of low discharge (in Denmark this period is July to September). The construction work should be finished before the spawning season for trout and salmon occurs later in autumn.

Restoration of streams by means of large-scale excavation should include a primitive sediment trap in the downstream end of the restored reach allowing deposition of some of the sediment transport created by the excavation.

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UK Experiences on River Restoration

Background to River Management, Degradation and Restoration in the UK

Nigel T. H. Holmes

Abstract

Determining an accurate picture of the extent of river and floodplain rehabilitation in the UK is difficult, with many organisations involved, and few with good records of what they have done.

No projects have approached comprehensive "restoration" to a pre-disturbed state, and therefore only "rehabilitation" has been achieved. Even the most ambitious projects have not combined channel rehabilitation with restored connectivity of the functional wetlands of their floodplain in more than 1 km of watercourse.

Rehabilitation of rivers has been undertaken most widely, and to the greatest degree of sophistication, in England and Wales. This reflects that more damage has been done to these rivers than in Scotland and N. Ireland, and the responsible authorities have had greater legal powers and responsibilities to undertake such work for more than a decade. Recently structural rehabilitation of two N. Ireland rivers has taken place, but none of any size have been completed in Scotland.

Greatest improvements in river environments have been achieved whilst undertaking management for other purposes. Primarily the greatest extent of benefit is achieved through modifying management practices undertaken for flood defence and land drainage benefits. High profile rehabilitations of small stretches of degraded river can be achieved where modifications are necessary as part of new developments, where the development pays for the improvements.

Increasingly the formation of river-based community projects is highlighting the value of river corridors for a wide range of interests. Such projects encourage partnerships where shared funding can achieve major improvements that single agencies cannot provide alone.

There are very grave limitation of funds available for river restoration, so few large projects are planned. It is suggested that the future

focus will be on more holistic rehabilitations, with catchment planning bringing changes to inappropriate and unsustainable land-use and less intensive use of river corridors.

Introduction

The focus for development of centres of human populations in Britain, and throughout the world, has often been rivers. Villages, towns and cities commonly developed on their banks, and as communities grew in size, the importance of, and pressure on, rivers and their floodplains became ever more intense. Urbanization and intensification of agricultural within such a small country with a growing and dense population resulted in major changes to rivers and floodplains leading to severe environmental degradations.

Brookes (1988) has identified that about 25% of rivers in England and Wales have been channelized, much more so than in Ireland or Scotland. The process began when the Romans took occupation but it is in the last few centuries that industrialization and agricultural intensification have demanded "control" of rivers through measures which divert, straighten, channelize, dam, or culvert them. This has led to the idea that engineering solutions can be found to protect buildings on floodplains and major drainage schemes could enable intensive cultivation virtually anywhere. From the time of the extensive drainage of the East Anglian fens in the time of Cromwell, to the early 1980s, a systematic programme of river improvements and land drainage in the lowlands of Britain occurred.

A more recent affliction to affect UK rivers and floodplains has been abstractions for water supply. Many rivers in Scotland have been grossly modified by water supply impoundments and dams which withhold all but the smallest of flows until large volumes are released for hydroelectric generation. Some reaches of rivers are depleted of all flows at some time due to historic rights (NRA, 1993) but greatest concern in the past twenty years has focused on groundwater abstractions which have resulted in many small chalk streams changing character totally, and wetlands drying out (RSNC, 1992; NRA,1993, 1994; Harding, 1993; EN, 1996).

Impacts of groundwater abstractions primarily affects lowlands, but recent intensification of grazing and afforestation in the uplands, both supported either by UK or EU money, has had a dramatic impact on rivers too. Severe loss of riparian vegetation (Gilvear et al. 1995) has led to instability and erosion problems leading in turn to channel widening and shallowing, and habitat loss within the river, riparian zone and on the floodplains. Research by HR Wallingford has shown that streams which retain riparian trees and other stabilizing vegetation are typically 30% narrower than those that have lost such vegetation. Many "Dales" rivers in Yorkshire have suffered from major erosion problems in four floods in the last 15 years; this has led to speculation that the 40% increase in the number of sheep, which have caused extensive riparian habitat destruction, may have a major influence (Sansom, 1996).

River "Restoration" means many different things to different people and interest groups in the UK and the terminology used to describe degrees of restoration are also many and varied. The most comprehensive reversal of previous degradations are termed Restoration - "the complete structural and functional return to a pre-disturbed state" (NRC, 1992; RRP, 1993). Rehabilitation is "the partial structural and functional return to a pre-disturbed state" (from Cairns, 1982). Enhancement (often referred to as Revitalization in mainland Europe) is "any improvement of a structural or functional attribute" (NRC, 1992) whilst Re-creation is the creation of a NEW ecosystem/habitats that previously existed but have been lost through previous activities.

In the UK, as elsewhere, "restoration" is the goal but this is rarely a viable option, and NO schemes are considered to have come close to achieving it. For many heavily engineered rivers which have lost all contact with the drained floodplain it is often an impossibility to restore the "natural state", and is not economically tenable at the present. "Rehabilitation", on the other hand, is a more viable, achievable and potentially sustainable option to promote, with wildlife, recreation, flood defence and other aspirations being integrated with catchment and population needs in the future. In the context of this paper, restoration of rivers diverted for roads or restored after mineral extraction are not considered.

Who manages and protects UK watercourses?

Knowledge of the organisations which have responsibilities for managing and protecting rivers is of great importance for promoting any river rehabilitation projects. Details of the main bodies with responsibilities for, or an interest in, UK rivers has been determined through an RRP sponsored study (RRP, 1994).

Responsibility for land drainage and flood defence rests with The Environment Agency in England and Wales, Departure of Agriculture (NI) in Northern Ireland and Regional Councils in Scotland. The Environment Agency has considerable responsibilities relating to environmental protection and enhancement, as well as conservation of water resources. Statutory responsibility for nature conservation and landscape is vested with English Nature (EA) and Countryside Commission (CoCo) in England, Countryside Council for Wales (CCW) in Wales, Scottish Natural Heritage (SNH) in Scotland and Department of Environment's Wildlife and Heritage Service (DoENIHS) in Northern Ireland.

The Environment Agency, formed in 1996, took over the responsibilities of the NRA that had operated since 1989. It has a remit covering the whole of England and Wales and has a wide range of "Functions", including flood defence, water quality and water resources. All must be carried out within a framework of a "Duty" to protect, enhance and promote the conservation of water, or water-related, habitats, flora and fauna.

Until April 1996 seven mainland River Purification Boards and three Island Councils had responsibility for maintaining (and improving where appropriate) the environmental quality of watercourses in Scotland. Main statutory responsibilities related to promoting clean rivers, monitoring pollution, consenting discharges and conserving water and they had no remit for promoting physical restoration of rivers. In 1992 the Government put forward proposals for a single Scottish Environment Protection Agency (SEPA) to combine several agencies with regulatory duties and it was established in April 1996 to deliver "well managed integrated environmental protection as a contribution to the Government's goal of sustainable development" (Macleod, 1996). However there is no remit, and little immediate opportunities, for active river rehabilitation or restoration.

There are a number of other organisations which have drainage responsibilities. Over 200 Internal Drainage Boards operate primarily in low-lying areas of England; they originally developed as consortia to coordinate improved drainage of agricultural land but now also have greater flood defence responsibilities for developing rural communities. Highway authorities and town, city, district, borough and county councils also undertake watercourse management. Individual landowners and companies have responsibility for their own ditches, dykes and small rivers which are not covered by any of the bodies mentioned above.

From this it can be seen that no single statutory organisation in the UK has comprehensive responsibility for river management, environmental protection or restoration. The situation is different for voluntary conservation organisations, with the Royal Society for the Protection of Birds (RSPB) being at the forefront of promoting better river management practices and being active in England, Wales, Scotland and Northern Ireland. The Wildlife Trust Partnership similarly operates in all four countries and has initiated many campaigns to bring greater awareness to those that manage and affect the water environment.

Recent changes

In common with many western European countries, a virtual revolution in management of rivers dramatically began in the early 1980s which had huge benefits for environmental interests of rivers. The scale of habitat degradation was beginning to be seen as unacceptable, and encouraged new legislation to provide improved protection for river, and associated, environments. Many guidelines for design of new river schemes and maintenance activities were produced (WSAC, 1984; Newbold, Purseglove & Holmes, 1983; RSPB/RSNC, 1984; MAFF/WOAD/DoE, 1982) which marked the start of river engineers and conservationists working together.

The formation of the National Rivers Authority (NRA) in 1989 brought one step further the notion that the river engineer's digger could, in the future, rehabilitate rivers and floodplains instead of being used to destroy them. More guidelines, supported by Government documents and financial incentive schemes to promote this, were produced (MAFF/DoE/WO, 1988, 1991; MAFF/EN/NRA, 1992; RSPB, NRA, RSNC, 1994; Newbold, Honner & Buckley, 1989; Holmes & Newbold, 1989). Ecological surveys of rivers and their corridors (NRA, 1992) also became the norm before major river works were planned so that any good river and floodplain habitats could be identified and subsequently protected; more significantly the surveys would highlight opportunities for rehabilitation as a core element of any proposed works.

Catchment management plans (Gardiner, 1990; Gardiner & Cole, 1992) provide a framework to consider together the disparate, and often conflicting, uses, interests and concerns within catchments and help shape future management strategies and land-use. The Environment Agency, with its wider environmental and regulatory remit, is now developing Local Environment Action Plans to provide the mechanism for more holistic approaches to solving existing catchment problems and developing sustainable land-use in the future. Only when sustainable changes to land-use and management occur in the many catchments which have inappropriate land-use and lack cost-effective management will the real benefits of such plans be realised.

Many Government-sponsored schemes now promote land-use change and these provide opportunities for river rehabilitation (Appleby, 1994; Swash, 1996). Such schemes target the rehabilitation of habitats which other Government-sponsored schemes of less than 15 years ago destroyed! There are many promising schemes, some of which already have proven worth, include River Valley ESAs, Water Fringe Habitat Improvement Schemes, Long-term Set Aside, Countryside Stewardship, Moorland schemes, Farm Habitat Improvement schemes, Woodland Premium schemes, Farm and Conservation Grant schemes, National Park grants, Urban Regeneration grants etc. A summary of funding sources that are available which might assist in river rehabilitation is given in RRP (1994). The need to prepare water-level management plans for all important wetland sites in England and Wales (MAFF/WO/ADA/EN/NRA, 1994) encourages improved future management and safeguards for many wetlands and provides a mechanism for rehabilitating degraded areas adjacent to remnants of extant interest.

Increasingly the importance of the hydrological link between functional floodplain wetlands and rivers (Newson, 1992) and fluvial geomorphological processes is being recognised in river rehabilitation (Kondolf, 1995; Kondolf & Larson, 1995). Sears (1994), Brookes (1995) and Brookes & Shields (1996) highlight that understanding fluvial geomorphology is of paramount importance in the success of sustainable river rehabilitations, and argue the need for geomorphological inputs at the design stage. Despite no geomorphological inputs being made to most previous engineering schemes, the Environment Agency is beginning to recognise its importance in long-term management and restoration of rivers by employing and contracting such specialists, and sponsoring research which links academic studies to the practical application of the discipline in rehabilitation works.

Impacts and justifications for restoration

All river engineering schemes have not brought the planned benefits, or many are now deemed to be inappropriate; however the legacy of their broad environmental impacts will be sustained until measures are taken to restore and rehabilitate them. Landscape and amenity value of rivers (NRA, 1993) have been severely impacted, but are difficult to quantify. Impacts that engineering works have had upon river and floodplain wildlife are well documented however.

Some obvious examples of ecological losses to marsh, fen, and reedbed wildlife have been attributed to river drainage schemes, with major declines in birds such as Snipe, Water Rail, Bittern and Marsh Warbler (NCC, 1984). Snipe are an example of a bird that breeds in floodplain wetlands. Marchant et al. (1990) confirms that the effects of drainage and pasture improvement are probably the major cause of the widespread decline of breeding snipe in lowland Britain, with the same causes identified by O'Brien & Self (1994) for Redshank and other waders. Williams & Bower (1987) identified the critical impact of over 7,500 km^2 of land being drained or re-drained between 1940 and 1980. Recent surveys (O'Brien & Smith, 1992) showed widespread declines from floodplain habitats in Ireland for Lapwing, Curlew, Redshank and Snipe, with the most extreme losses being along the Blackwater which had recently been the subject of a massive drainage scheme (Partridge, 1992; O'Brien & Self, 1994).

Lowland neutral grassland with herb-rich assemblages have declined by 97% due to agricultural intensification, the majority being in river floodplains and lost due to drainage schemes. Between 1637 and 1984 the reedbeds of East Anglia declined from 3,380 km^2 to just 10 km^2. The RSPB has identified that from an historical resource of over 1,200,000 ha of wet grassland in England, only 220,000 ha now remains with a mere 20,000 ha retaining high conservation value, and has expressed grave concern for losses and is promoting floodplain wet grassland restoration (RSPB, 1993).

Another example of major ecological losses associated with drainage is provide by Dony (1977). He compared the flora present in one small English county, Bedfordshire, in 1798 with that of 1976. In this 180 year period, 30% of the plant species of floodplain habitats became extinct.

However the strongest arguments for river and floodplain restoration are related to re-establishing the natural functions of the systems. Everard (1996), Gilvear et al. (1995) and many others identify that heavily modified rivers fail to perform efficient nutrient and sediment re-cycling, or hydraulic control, with the detriment to water quality, flooding and low-flow regimes as well as to a whole range of valued (both aesthetic and economic) environmental interests.

Extent of river restoration in the UK

In an attempt to determine how much river and adjacent floodplain restoration has being undertaken in the UK in the past decade a questionnaire was sent to all organisations which are most likely to have been involved in such work. The trawl for information included:

1. all statutory drainage authorities (which may or may not have much wider duties also) - *e.g.* all Regions of the Environment Agency, Association of Drainage Authorities, Scottish Office, DoENI Rivers Agency etc.,
2. all statutory conservation bodies - *e.g.* DoENIWHS, SNH, EN, CCW, Joint Nature Conservation Committee, CoCo etc.,
3. Parks Authorities with areas concentrated on river valleys - *e.g.* Lee Valley Park, Broads Authority
4. Environmental and Wildlife Trusts - *e.g.* RSPB, Wildfowl and Wetland Trust, World Wide Fund for Nature (WWF), Wildlife Partnerships etc.,
5. selected riparian owner associations, fisheries/angling Societies/Boards/Associations known for undertaking restoration, and the Game Conservancy.

The questionnaire was developed following consultation with colleagues in Denmark to ensure that information obtained could be accurately compared with data gathered from other countries by the European River Restoration Centre. Two proformas were sent out, the first (Table 1) requesting information on the numbers of times specific rehabilitation types had been achieved during the 1990s; a second form requested more information about individual schemes where large-scale rehabilitation was the aim. The consultees were specifically requested to focus on PHYSICAL WORKS leading to rehabilitations of river, riparian or connected floodplain habitats and NOT include examples of sympathetic management that minimise impacts or do not make a significant contribution to restoring lost habitats and features. To determine the mechanisms which give rise to rehabilitations, the scheme inventory required

Table 1 Proforma sent to UK organisations to determine extent of different types of river restoration carried out.

Form 1 INVENTORY OF WORK TYPES IN YOUR AREA/ORGANISATION			
Organisation..........Area Covered..........	A1	A2	A3
Contact Name (and Dept.)..........			
Address/Tel/Fax..........			
Type 1 Rehabilitation of Watercourse Reaches			
Reach Remeandered (>500m)			
Reach Remeandered (<500m)			
Culverted Reach re-opened (>100m)			
X-sectional habitat enhancement (>500m) -two-stage channel profiles etc.			
Long section habitat enhancement (>500m) - pool/riffle sequences etc restored			
River narrowing due to depleted flows or previous over-widening			
Backwaters and pools established/reconnected with water-course			
Bank reprofiling to restore lost habitat type and structure			
Boulders etc imported for habitat enhancement			
Gravel and other sediments imported for habitat enhancement			
Fish cover established by other means			
Current deflectors/concentrators to create habitat and flow diversity			
Sand, gravel and other sediment traps to benefit wildlife			
Tree/shrub planting along bankside (only if covers >500m of bank or >0.5ha)			
Artificial bed/bank removed and replaced by softer material (>100m)			
Establishment of Vegetation for structure/revetment (e.g. use of willows)			
Eradication of alien species			
Provision of habitat especially for individual species - otter, kingfisher etc			
other			
Type 2 Restoration of Free Passage between reaches - must benefit >1km upstream			
Obstructing structure replaced by riffle			
Obstructing structure replaced by meander			
Obstructing structure modified to enable fish migration			
Obstructing structure retained, but riffle/meander established alongside			
Culverted reach re-opened			
Obstructions within culvert (e.g. lack of depth, vertical falls) redressed			
Dried river reach has flow restored			
other measures undertaken to restore free animal passage			
others			
Type 3. River Floodplain restoration			
Watertable levels raised or increased flooding achieved by:			
*remeandering water-course			
*raising river bed level			
*Weirs established SPECIFICALLY to increase floodplain flooding/watertable			
*Termination of field drains to watercourse			
*Feeding floodplain with water (sluice feeds, watermeadow restoration)			
*narrowing water-course specifically to increase floodplain wetting			
*Lakes, ponds, wetlands established (may be flood storage areas)			
*Lakes, ponds, wetlands, old river channels restored/revitalized			
*Vegetation management in floodplain			
*Riparian zone removed from cultivation			
*Other			
Please list number of examples where above ELEMENTS achieved (NOT no of Project). For some elements acheived			
During maintenance the figures will be approximate: Indicate probable accuracy - 'a' >80%, 'b' = 50-80%, 'c' = <50%			
Please list no of egs with a,b,c in COLUMNS A1-3 where A1 = On back of other activity, A2 = Key Objective, A3 = Other.			
Table 1			

consultees to identify if the benefits were derived as a result of other works being undertaken on the rivers, or rehabilitation was the key objective. For the most significant restoration projects, organisations were asked to give more information regarding the primary objectives and identify individual elements of rehabilitation achieved; summaries of these are being prepared for the Environment Agency by the author.

Excluded from the trawl for information were wetland restorations not associated with rivers, and mitigation works which may improve the river, but are carried out because damage is done elsewhere. Examples also exclude any SMALL-SCALE enhancement works affecting less than 500m of river or 1ha of floodplain where local tree planting, channel and bank re-profiling, small ponds and wetlands are established in the river corridor, or limited use of trees and other vegetation are used for erosion control. These small river corridor and floodplain habitat enhancements are frequently achieved through creative and sensitive river management practices and designs, and are now considered to have become common practices (Holmes, 1992; Darby and Thorne, 1995). Many are featured in the RSPB/NRA/WT Handbook (1994) for the UK as they are for Denmark in Madsen (1995). Whilst not detailed in the information trawl, collectively such rehabilitations are making the most major contribution to improving river and floodplain environments than anything else. However they are dependent on the "need" to undertake management based on set standards of service; equal, or greater, benefits may be achieved in many rivers if they were allowed to re-adjust themselves in association with reduced pressure on their floodplains.

The trawl has confirmed that the eight Environment Agency regions (previously NRA) in ENGLAND and WALES have been most responsible for river rehabilitation in the UK to date. This partly reflects that they inherited flood defence responsibilities, and the legacy of environmental damage caused by past works, as well as duties to protect and promote conservation. Most has been achieved by allocating a proportion of its flood defence funding towards integrating environmental enhancements within its maintenance and capital works, and providing smaller sums where rehabilitation is the prime or sole objective. A duty to promote fisheries also provides funding for river rehabilitations which benefit the wider environment too. The extent to which rehabilitation works have been undertaken in the 1990s reflects a combination of the degree to which a Region's rivers have been impacted, the size of the flood defence budgets for maintenance and capital works, and opportunities for collaboration with others to utilize the small Government grant-in-aid they receive.

The trawl for information has so far failed to gain a truly representative picture of the extent of rehabilitation works undertaken. Most respondents report that the majority of rehabilitations depend on flood defence money being spent on more sensitive and restorative management. In this respect less routine dredging and capital schemes are being promoted, so the opportunities for rehabilitation are diminishing. Major schemes are generally dependent on either win-fall funds or as part of developments where river and floodplain enhancements are possible and the developer can fund such works as an integral part of an acceptable development. A common conclusion from most respondents is that major river restoration will not be achieved in the foreseeable future without collaboration with others.

Partly because of its large capital and maintenance flood defence budget, Thames Region has undertaken by far the most rehabilitation schemes. Despite this, only two re-alignment/re-meandering schemes affecting more than 1km of river have been undertaken. One was carried out on the Bear Brook as part of a flood alleviation scheme for the town of Aylesbury in 1993/4, and the other is the R Cole scheme which is a LIFE demonstration site (Holmes and Nielsen, 1997). Since 1991, between £500-800K annually has been spent by the Thames Region on river and floodplain habitat enhancements, with 48 enhancement schemes implemented in 1995/6 at a cost of £693K; a similar programme, funded from flood defence, is planned for 1996/7. None of the other seven regions have budgets similar to this, and where large schemes have been carried-out they have been primarily funded from external, or "windfall" sources.

Table 2 compares the proforma returns for two of the three Areas in Thames Region with two of the three Areas in N-West Region. The much greater extent of rehabilitation work undertaken in Thames Region is very clear, with N-West Region being more typical. In addition it shows that the types of rehabilitation vary markedly between the Regions, with gravel importation to the predominately low-energy systems of the Thames being a common theme whilst in the N-West eradication of alien invasive species is more common. The free-standing promotion of environmental enhancement works by Thames Region from its flood defence budget is clearly shown by the much higher proportion of schemes where the key objective is rehabilitation.

Tables 3 and 4 list the majority of the most significant river and floodplain rehabilitation projects to have been undertaken during the 1990s. Details of some of these, plus some earlier projects, are given in RRP (1994). The tables up-date those produced in Holmes (1996); despite a second trawl for information, some organisations have not responded, so this cannot be considered the limit of UK efforts in the past six years. From the tables it can be seen that it is rare for restoration to exceed more than 2 km if comprehensive works affect the river and/or floodplain.

Restoration of defined river floodplain wetlands, compared with extensive drained fens, generally affect very small areas indeed, covering little more than a few hectares. However with the pressure and landholdings of conservation bodies like the RSPB, there are several which have now been completed which cover several hundred hectares, and others are in the process of being planned or implemented. Case study examples are to be found in Bailey, Jose and Sherwood (1996). Examples of restoration which include both re-establishment of fluvial features and greater connectivity with wetter floodplains include the Till, Windrush, Thames at Oxford, Kennet and Severn. Consultation and feasibility studies are now underway for potentially major floodplain restoration projects, include enhancing extensive areas of the R. Severn floodplain, and restoration of large areas of the Somerset levels. The latter includes the Brue valley wetlands with education and tourism also in mind, and other areas of the Levels as Water Level Management Plans are prepared and implemented (MAFF/WO/ADA/EN/NRA, 1994).

Restoring meandering courses to previously straightened rivers in combination with raising floodplain water levels has rarely occurred in the UK. Most examples of rehabilitations shown in Table 3 cover only short stretches of river (<1 km), or when more extensive, do not incorporate restoration of both river and floodplain. The Brinkworth Brook Project resulted in the original meandering channel being restored, but the floodplain remains dry as the land drainage channel is retained to carry floodwater. In contrast the R. Cole in Solihull has remained in its straightened channel but removal of sheet-pile revetments and major channel, bank and floodplain re-moulding has created extensive habitat features, included numerous wetlands and backwaters.

Table 2 Numbers of times different types of river rehabilitation works achieved by two regions of the Environment Agency; for Thames Region the data from two of their three "Areas" are given separately. (SA = Southern Area; WA = Western Area)

	THAMES	THAMES	NW	NW
	SA	WA	A1	A2
Type 1 Rehabilitation of Watercourse Reaches				
Reach Remeandered (>500m)	1	1		3
Reach Remeandered (<500m)			1	2
Culverted Reach re-opened (>100m)			1	1
X-sectional habitat enhancement (>500m) -two-stage channel profiles etc.	2	3+5	6	1
Long section habitat enhancement (>500m) - pool/riffle sequences etc restored		5+4		2
River narrowing due to depleted flows or previous over-widening	1	3+13	3	3
Backwaters and pools established/reconnected with water-course		5+11	2	2
Bank reprofiling to restore lost habitat type and structure	1	5	9	2
Boulders etc imported for habitat enhancement		6	3	1
Gravel and other sediments imported for habitat enhancement		6+12		
Fish cover established by other means	3	2+2		
Current deflectors/concentrators to create habitat and flow diversity		5+7	2	1
Sand, gravel and other sediment traps to benefit wildlife			3	
Tree/shrub planting along bankside (only if covers >500m of bank or >0.5ha)	4	5+6		3
Artificial bed/bank removed and replaced by softer material (>100m)	2	3		
Establishment of Vegetation for structure/revetment (e.g. use of willows)	4+2	1	5	1
Eradication of alien species	2		6	3
Provision of habitat especially for individual species - otter, kingfisher etc	3	5+7	4	1
other				1
Type 2 Restoration of Free Passage between reaches - must benefit >1km upstream				
Obstructing structure replaced by riffle				
Obstructing structure replaced by meander		1		
Obstructing structure modified to enable fish migration	3+7		3	
Obstructing structure retained, but riffle/meander established alongside				
Culverted reach re-opened	1			
Obstructions within culvert (e.g. lack of depth, vertical falls) redressed			2	
Dried river reach has flow restored		2		
other measures undertaken to restore free animal passage	1	2		
others				
Type 3. River Floodplain restoration				
Watertable levels raised or increased flooding achieved by:				
*remeandering water-course				
*raising river bed level				
*Weirs established SPECIFICALLY to increase floodplain flooding/watertable		2		
*Termination of field drains to watercourse		2		
*Feeding floodplain with water (sluice feeds, watermeadow restoration)		1+3		2
*narrowing water-course specifically to increase floodplain wetting				
*Lakes, ponds, wetlands established (may be flood storage areas)	20?+2	20?+11	6	1
*Lakes, ponds, wetlands, old river channels restored/revitalized		2+6		
*Vegetation management in floodplain			1	2
*Riparian zone removed from cultivation				1
*Other				
A1 = Project on back of other activity, A2 = Rehabilitation Project Key Objective				
THAMES = Thames Region with Separate Data for West and Southern Areas				
NW = North-west Region combined data for South and Central Areas				
Table 2				

Table 3: List of major UK river rehabilitation schemes involving >500m of watercourse and at least some re-routing of the channel and/or bed raising to increase water-tables and flooding on adjacent land.

RIVER	LOCATION	KEY FEATURES	LENGTH/AREA	COST £K	YEAR
			>100m	350	1996
Chester Burn	Co Durham (NE)	Culvert re-opened	2km	500	1995
Skerne	Darlington (NE)	Re-meandering and river/floodplain enhancements (LIFE Demo Project)			1994
Nidd	Yorkshire (NE)	Extensive riparian planting and fencing to halt erosion and provide structure	30km	65	1994-5
Swale	Yorkshire (NE)	Extensive riparian planting and fencing to halt erosion and provide structure	2km (2.5ha)	180	1995
Whittle Brook	Warrington (NW)	Major channel rehabilitation inc. re-meandering, ox-bow , riparian mods	1.5km	100	1992-6
Padgate Brook	Warrington (NW)	Channel rehabilitation; pahse II on-going with corrider rehab. too	200m	240	1994-6
Alt	Merseyside (NW)	River released from culvert - meander, island, riffles, marginal zone etc.	>100m		
Maghill Brook	Mersyside (NW)	Culvert re-opened	7km	200+	1985-95
River Cole	Solihull (ST)	Instream, backwaters/ponds/major river corridor habitat creations	16km	?	1995-7
Idle	Nottinghamshire (ST)	Instream , margin and bank re-habilitation + reed other tree planting	1km		1995-6
Erewash	Nottinghamshire (ST)	Re-instating meanders and floodplain features	10km	?	1989-93
Avon	Watwickshire (ST)	Pool-riffle retoration, backwaters, wetland rehabilitation	c2km (26ha)	200	1994-8
Great/Long Eau	Tothill/Carlton (A)	Washland creation, floodbank re-alignment, channel enhancements	1.5km	5	1995
Wensum	Fakenham (A)	Restore natural river course	c1.0km (15.5ha)	15	1994
Little Ouse	Thetford (A)	Restore cut-off meander and improve adjacent wetland	3km	20	1995-6
Mardyke	Thurrock (A)	Comprehnsive channel, bank and corridor rehabilitation	0.5km	?	1994?
Ise	Desborough (A)	Tailby Meadow - river restored to old course; meadow made wetter	1km (8ha)	£100K	1993-4
Bear Brook	Aylesbury (T)	Re-meander river and extend wetland for flood storage	2km	250	1995-6
Cole	Swindon (T)	Re-meandering and river/floodplain enhancements (LIFE Demo Project)	>500m		1989-90
Ash	Staines (T)	Re-meandering and complete array of instream, margin and corrider features	>100m		1995?
Golf course stream	Sussex (S)	Culvert re-opened	>50km	?	1988-96
Medway	Kent (S)	Series of major and minor works as part of Medway River Project	>500m		1996
Cuckshot	Sussex (S)	Re-meandering	2km+ (100ha)	40?	1995
Fal	Cornwall (SW)	Raising bed levels to improve instream habitats and re-wet Goss Moor	3-4km	50	1992-5
Brinkworth Brook	Wiltshire (SW)	Restoring flow to large cut-off meander plus other works	15km	?	1996
Tamar system	Deven/Cornwall (SW)	part of Tamar 2000 project; fencing and riparian zone vegetation establishment	3.5km (0.5ha r-bed	44+	1994+
Bristol Frome	Bristol (SW)	Remeandering + wide variety of river enhancements + reedbed			
			500m	26	1994-5
Ballysally Blagh	N. Ireland	Channel and bank modifications	1km	40	1996
Tall	N. Ireland	Re-meandering, island creation and habitat enahncement	c30km	100	1994-96
Tweed	Scotland	Fencing, planting and stream rehabilitations by Tweed Foundation			
Table 3					

Table 4: List of many of the major UK river floodplain rehabilitations undertaken to benefit environment interests; wetland restorations not in direct contact with rivers have been excluded.

RIVER	LOCATION	KEY FEATURES	LENGTH/AREA	COST £K	YEAR
Till	Wooler (R)	7 dried cut-offs restored to open water (otters)		60	1990-95
Dearne	Rotherham	Reedbed, wet grassland, open lakes - former floodplain coal yard			
Soar	Leicester (R)	Re-wet drying SSSI-Valley bottom peat bog (Narborough)	0.5km (20ha)	8	1994
Windrush	Bourton-on-the-Water	Ancient water meadow restoration (10,000m of ditch)	1km (57ha)	120	1992-3
Atherton Brook	Wigan	Instream and major floodplain rehabiliation in flood storage area	.5km, (14ha)	80	1992-4
Thames	Oxford	Restore floodplain wetlands + experiment with habitat creation techniques	0.5km (2ha)	120	1990-92
Kennet	Hungerford	Restoration of water meadows, wetlands, ditches etc	4-5km		
Nene	Whittlesey	Raising water levels - re-establishing & enhancing grazing washlands	286ha		1985+
Yare	Gt Yarmouth	Low-intensity wet estuarine grazing marsh re-created	148ha		1987+
Yare	Norwich	Restoration of floodplain dykes, reedfen, grazing meadow/marsh/fen	c300ha		1975+
Hundred	Aldeburgh	Regenerate dried and scrubbed-over reedbed	23ha	c40	1993-96
Cam	Fowlmere	Arrest and reverse fen dessication - raised water levels	12ha		
Bourn	Comberton	Establishing extensive buffer zone	2km	zero	1991
Parrett	Langport	Wet grassland restoration - water-table manipulation and isolation	290ha		1979
Brue	Glastonbury	Major reedbed and open water creation (Ham Wall Project, EU LIFE)	140ha		1994+
Arun/Stour	Pulborough	Re-instate wet grassland following 1960s drainage	121ha	500	c1990
Severn	Dolydd Hafren	Extensive floodplain wetland creation (scrapes, meander/oxbow restoration)			1991+
		(Part of Severn Wetland Strategy - Collaborative)			
Cors y Bol	Llanerchymedd	Reedbed and wetland restoration (pumped drained V mire)	2km (2.5ha)	10	1994
Afon Crigyll	Rhosneigr	Reedbed Restoration/Swamp rejuvenation	20ha	17	1995
Afon Cedron	Porthmadoc	Former swamp re-flooded - reedbed and pastoral meadow	2km (300ha)	35	1993-6
Cors Geirch	Pwllmeli	Restoration of rich fen (commercial trade-off)	5km (183km)	zero	1992
Afon Erddreiniog	Lllangefni	Restoration of topogenous fen (NNR)	0.5km (50ha)	30	1994
Afon Cefni	Llangefni	Raise water table and create reedbed	150ha	30	1994
Afon Cefni	Llangefni	Protect, expand & enhance aquatic interest of Malltraeth Marsh SSSI	7km		1993
River Leri	Borth	Raise river levels to make Cors Fochno Raised Mire wetter			
		(Part of Dyfi Biosphere Reserve Strategy)			
Llyn		Llyn Fens initiative - lake and reedbed restoration			
Gwent Levels		Magor Marsh - raise ditch levels in tandem with wetland manipulation			
Table 4					

The most ambitious river restoration projects identified in the trawl have all cost in excess of £175K to plan, design and implement. Two urban schemes on the Alt and Whittle Brook were undertaken in N-W Region (Nolan and Guthrie, 1997) and were very different in nature. The latter, in urban public open space, resulted in about 2.5 km of river corridor being enhanced by creative movement of earth to form more natural river, bank and floodplain habitats. The former affected only about 200m of river, this being released from its culvert and reformed into a semi-natural channel again. The de-culverting of Chester Burn has also proven to be very expensive, as are virtually all urban schemes. Whilst more is generally achieved for wildlife conservation for much less money in rural rehabilitation schemes, urban schemes have the benefit of bringing much greater pleasure to more people. The true cost of the R.Cole re-habilitations in Solihull are difficult to assess as so much has been done in the partnership "Project Kingfisher", in addition to the river works. This has included employment of a ranger and other staff to develop the extensive floodplain as a living park. The other two major projects cited, the Skerne and Cole, were achieved through partnerships organised by the River Restoration Project (Holmes and Nielsen, 1997) and are the most comprehensively monitored scheme of its type in Britain (Biggs et al. 1997).

The trawl for information has indicated that in England and Wales there has been a large amount of small-scale enhancement associated with river engineering/management works, but few extensive lengths have had dedicated rehabilitation (RRP, 1993). The Swale (Table 3) has had one of the longest lengths of river dedicated to rehabilitation, but this has not involved any physical changes. Severe over-grazing and trampling of banks by sheep, and to some extent cattle, has led to complete loss of marginal and riparian vegetation, with resultant habitat loss for biota and erosion problems. The NRA/Environment Agency, with assistance from the River Swale Preservation Society, Farming and Wildlife Advisory Group and the Wildlife Trust sought landowner backing for the project. As a result a 30 km reach of river has had extensive tree planting and fencing carried out in 1994 and 1995. Already rates of erosion have declined in fenced and planted areas, with riparian habitat structure returning as planted trees and natural regeneration develops.

Combined river and floodplain restorations are extremely rare. Many partial restoration of floodplain wetlands have occurred successfully however, especially on large wetland reserves owned by conservation bodies (Everett, 1987; Everett, Cadbury & Dawson, 1988; Sills, 1988; Merritt, 1994; Mayled, 1996; Self & Jose, 1996; Callaway, 1996). Most rehabilitation as been on controlled wetlands with little natural connectivity with the rivers which once determined their interest. These schemes are therefore rehabilitations and definitely not restorations. However for practical purposes of re-establishing wetland habitats this can be an advantage because water regimes can be controlled more precisely than can the natural situation; habitats in most severe decline and with the potential for recovery can be targeted for precise restoration. Merritt (1994) and Bailey, Jose and Sherwood (1996) give details of considerable achievements in the UK in this area.

Rehabilitation of rivers in N. Ireland, other than for fisheries, had not been considered until very recently. The emphasis since the late 1980s is to minimise impacts to all aspects of the environment when undertaking capital or maintenance flood defence and drainage works. However over the past few years the agency responsible for flood defence (Department of Agriculture Northern Ireland, Rivers Agency (previously the Watercourse Management Division)) has begun to promote river rehabilitation. The first, and largest, was the rehabilitation of fishery habitats in the Blackwater, costing in the region of £1m.

Two pioneering rehabilitation schemes of much wider environmental interest, but costing much less, have been on the River Tall (Blackwater tributary) and Ballysally Blagh (Table 3). The former is considered to be the first river project in N. Ireland (cost £40,000) where the sole objectives are rehabilitation to improve conservation, landscape, recreational, water quality and fishery value. It was started in 1996 and includes creation of a new bifurcated channel to create an island, bank and marginal modifications to form wet ledges, wide pools, kingfisher cliffs and other habitat restorations to a previously trapezoidal channel. The latter has included installation of riffles and a degree of sinuosity to a previously straight channel, small embayments and bank re-profiling to a small stream flowing through the grounds of Coleraine University.

The two rehabilitation works have been carried out at a time when small-scale enhancements are being attempted when routine or capital works are carried out in N. Ireland. The prospect of river restoration has come late to the Province but literature has been produced by the Rivers Agency educating the public and landowners of the potential advantages of adopting a positive restoration programme. Whilst the Agency acknowledges there has been little enhancement to date, what has been done has highlighted achievable benefits for integrated catchment management. Thus in N. Ireland now, the prospects for Agency-led rehabilitations looks as promising as anywhere else in the UK.

There are several examples in N. Ireland of restoring free passage on major obstructions, but the fishery rehabilitation programme through habitat creation on the R. Blackwater is unprecedented in the UK. A major drainage scheme, only completed in the early 1990s, had such severe impacts on the valued salmonid fishery that over £1m has been spent on in-stream rehabilitation. Attention has focused on restoration of pool/riffle sequences, boulder and gravel imports for habitat enhancement, and deflectors and other structures to create diversity of flow and local areas of deep water and scour.

In Scotland the traditional importance of salmonid fisheries has led to an emphasis being placed on protection rather than restoration of rivers. Therefore on all good quality rivers with important fisheries, no barriers to migration have ever been allowed to be built. Some of the Regional Fisheries Boards have been involved with removing natural waterfall barriers to fish migration on relatively pristine rivers, enabling the headwaters to be used for spawning; many have considered this to be "rehabilitation works" as the populations of fish downstream have improved (e.g. on the R. Knaik in the Forth catchment). However in conservation terms this is viewed as a detrimental action.

In the more populated, industrial, or intensive agricultural areas some rivers were degraded centuries ago. In such cases the interests of development over-rode those of fisheries and some barriers to migration were built. With improved water quality in recent years, attention has begun to address barriers to movement and restoration of free passage has been carried out in a few locations. The Forth District Salmon Fishery Board has identified that within the Forth catchment there are c40 man-made obstructions which have a serious impact on salmon stocks. These range from major dams to simple culverts and it is the Board's intention to use new legislation to address the problem within five years. In flat lowland areas degradation of rivers has often been as great as in England, but the case for rehabilitation has only recently been considered and no schemes of repair are known.

The Tweed Foundation, a charitable Trust, has embarked upon a wide-ranging programme of rehabilitation in the tributaries streams where declines in salmon spawning and recruitment have been attributed to obstructions to migration and habitat degradation. Apart from easing passage, pilot habitat management is underway and extensive fencing is taking place to enable riparian vegetation to recover from the effects of over-grazing and trampling.

The World Wide Fund for Nature has recently taken a pro-active role in stimulating river rehabilitation in Scotland. Its initial prime objective is to raise awareness of the degradation of river systems that have hithertoo been considered wild and natural, and generate an educated debate on the scale of the problem and how it could be rectified. They launched the project in 1995, highlighting that many larger rivers have been greatly modified, and that their watercourses that flow through intensively farmed or urban areas are as artificial as many elsewhere in Europe. The project is based on the view that river controls and land-use have been too single-minded in the past and as a result floodplains and rivers have lost both interest and value. The alternative being promoted is that a more natural approach would be sustainable and more beneficial to a wider range of interests. The initiative aims to generate new riparian landscapes which incorporate lost historic features but takes full account of development needs. Six pilot demonstration sites are planned linked to an EU Life project.

Routes for promotion of river rehabilitation in the UK

The following routes (table 5) have been the most significant in promoting river rehabilitation in the UK. The order in which they are listed probably reflects the extent to which each has been directly responsible for rehabilitation being achieved. There is some arbitrary splitting, and the list is much more reflective of the numbers of schemes carried out than the comprehensiveness, quality or value of them. It would be misleading to consider that conservation bodies have not had a major role, but their involvement has been more in working to promote, develop and support partnerships for restoration and provide grants for others to undertake work. Agri-environment and other government fundings are not shown here either, but have, and will increasingly, feature in more holistic river rehabilitations.

Table 5: Routes for promotion of river rehabilitation in the UK.

1. - Statutory organisations with management responsibilities for flood defence and land drainage: - Environment Agency (NRA) - Maintenance, new capital works + restoration works - DoENI Rivers Agency - Maintenance, new capital works + restoration works - Local Councils (England and Wales) and Regional Councils (Scotland) - Internal Drainage Boards
2. - Statutory and voluntary fisheries and angling bodies: - Environment Agency in England and Wales and Fishery Boards in Scotland - Angling associations, preservation societies and "foundations" such as on the Tweed, - Game conservancy
3. - Local Authority Initiatives and Partnership Projects: Groundwork Trusts for Urban Regeneration River valley projects such as on the Medway and Project Kingfisher on the Cole in Birmingham
4. - Promotion via planning and development control
5. - Work on reserves and private landholdings,: Wildlife Trusts, RSPB and private reserves etc.
6. - Grant-aided schemes for river rehabilitation by Statutory Conservation agencies such as EN, CCW, CoCo and SNH
7. - One-off and/or demonstration major collaborative schemes supported by windfall funds, EU or "lottery" funding: (*e.g.* Cole and Skerne LIFE projects, Alt and Whittle Brook, WWF Wild Rivers Project)

Examples of several of the above categories have been identified earlier, but the examples of forming partnership for action may be the most important in the future. The Weaver River Valley Initiative, formed in 1994, is dedicated to enhancing and protecting the valley for people and wildlife in recognition of its valuable living resource. It was formed as a partnership between private, public and voluntary sectors. A small stream in the valley, Padgate Brook (Table 3), received rehabilitation works in 1992, but the support of the Initiative has been partly instrumental in gaining support and funds for the Environment Agency to undertake further major rehabilitations in 1996. A more established example is the River Medway Project. It was established in 1987/8 as a local community action for the countryside, and is funded by a variety of sources (primarily Environment Agency, the Kent County Council, Borough Councils (and the Countryside Commission with local industry often sponsoring specific initiatives).

Project aims include:
- manage and enhance the landscape and wildlife of the Medway;
- maintain and enhance the access and recreational use of the Medway;
- promote local community awareness of, and active involvement in, the enhancement of the Medway's environment;
- encourage landowners to take a positive role in enhancing the Medway and its surrounding countryside.

Many different tasks are coordinated by the project team. These include capital river projects (e.g. using willows and other soft engineering solutions for erosion control or habitat creation through establishing backwaters, bank reprofiling etc.) and involvement with maintenance activities, school party projects (floodplain pond restoration, tree planting or scrub/tree management), and other community activities such as litter collection and wardening. Few activities are carried out without involving volunteers or community groups. Since Its formation, volunteers from more than 75 community groups have been involved with more than 500 projects.

Conclusion

There is now a much greater awareness of the economic and social benefits of having more natural rivers and floodplains. Despite increasing evidence of its value, funds are very limited for free-standing restoration works, and therefore few comprehensive schemes have been done and little is planned for the future.

The Environment Agency confirms that fewer capital schemes are now undertaken and maintenance is reduced; whilst this means there is fewer opportunities for degradation, opportunities for rehabilitation as an integral part of other works has declined also. Most agree that rehabilitations are possible to incorporate into most capital flood alleviation schemes and some dredging works (Galloway, 1997). Where totally uniform rivers with earth floodbanks need repair, as occurred on the Torne (Table 3 - Holmes, 1992) and at the Wildfowl Trust at Slimbridge (Merritt, 1994) winning the material from the river banks or close by enables restoration of some marginal, riparian and floodplain wetland habitats. A step closer to "restoration" would be abandoning many floodbanks close to the rivers when they fail to provide an adequate flood defence service. This has yet to happen except on the most smallest scale. Total abandonment would not be reasonable if important assets required protection, and new banks would need to be built much further away from the river which would give rise to the opportunity for the restoration of floodplain habitats and attendant water quality, flood defence benefits etc. It is encouraging that the Environment Agency is considering this for the lower Trent in the future, where the present banks have shrunk and their repair to required standards is not considered sustainable for the future.

Other major opportunities arise through inputs to development control. The Environment Agency looks to obtain improved river environments if any rivers or wetlands are affected by developments. Such opportunities have been most associated with commercial developments, but some rehabilitations are being achieved from some road schemes.

General in-stream habitat improvements are likely to continue due to small-scale works for fisheries. Fishery interests will also lead to many barriers to migration being removed by the end of the century. Lack of capital engineering works, and relaxation of standards of service for intensively farmed areas, should lead to "natural rehabilitation" of many rivers through fluvial-geomorphological activity. However the most severe damage has occurred on low energy rivers, so recovery will be slow, and will not go very far without assistance. The few examples of major re-engineering, such as the LIFE demonstration project, will provide help in developing major restoration works in the future yet these are likely to be few and subject to major support from "lottery" or other similar funding.

As the importance of issues, such as health and peoples own demands for more pleasant open spaces for leisure, community river projects are likely to bring many interested parties together in rehabilitation projects in urban areas. The examples set by the Medway Project, Project Kingfisher and others has helped many more to be formed recently, and "save our river" campaigns are developing too. All indicate pooling of resources will lead to improvements in the future.

The lack of funding to undertake major physical restoration projects will result in the greatest future opportunities for rehabilitation of rural rivers being based upon helping nature restore the past scars. The potential arises from a re-alignment of the present intensive land-use associated with the many EU-driven schemes to a more extensive use. The proposals for Scotland by the Wild Rivers Campaign of the WWF and the those for the Tamar 2000 project in England provide a means for evaluating the economic implications of such changes and the extent of the environmental rehabilitation achieved by them.

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The Art of River Restoration

Constructing Riffles and Pools in Channelized Streams

Robert Newbury, Marc Gaboury and David Bates

Introduction

Urban and agricultural developments on floodplains, alluvial fans and deltas are often facilitated by relocating and channelizing (uniformly excavating) streams (Apmann and Otis, 1965; Bates et al. 1996; Corning, 1975; Emerson, 1971; Hogan, 1986; Keller, 1975). Two typical streams that have been channelized for agricultural and industrial developments are shown in Figures 1 and 2 (Mink Creek, Manitoba and Oulette Creek, British Columbia). In these uniform channels, the natural sequence of pools and riffles or swift and flat water features are eliminated. Regular flood flows may re-build the features but in many cases, the lack of suitable bed materials, changes in the flow regime, and long periods of recovery can eliminate suitable invertebrate and fish habitats for decades.

Aquatic organisms have evolved to exploit the spatial and temporal variations found in pools, riffles and meanders (Allan, 1995; Frissell et al. 1986; Higler and Mol, 1984; Sullivan et al. 1987). The replacement of this complexity with uniformly graded channels reduces or eliminates the sorting of substrates, vegetation and woody debris in pools, overhanging riparian vegetation, and a variety of flow structures and functions (Apmann and Otis, 1965; Corning, 1975; Emerson, 1971; Keller, 1975).

Meander, pool and riffle habitats

The repeated wave-form of naturally flowing waters that creates meanders, pools and riffles has been observed and measured by stream researchers and anglers. One of the earliest observers was Tohkichi Kani, a student of stream habitats in Japan. Kani (1981) found that the preferred habitats of benthic insects and fish could be related to the pattern of pools and riffles on the stream bed. In the 1930s, he proposed a classification system for a range of streams based on their pool and riffle patterns (Figure 3). The significance of pools and riffles to trout stream habitats was observed by Stuart in Scotland as well (1953). He

Figure 1: Mink Creek Walleye Spawning Restoration Project 1985, Central Manitoba. The channelized and unstable reach prior to the addition of rock riffles.

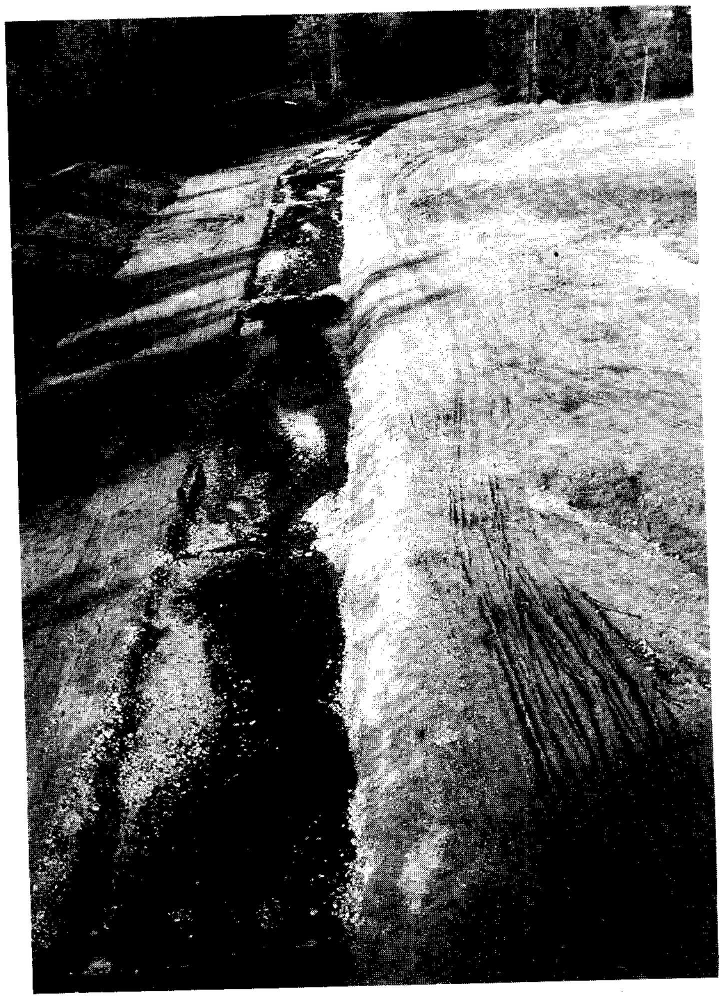
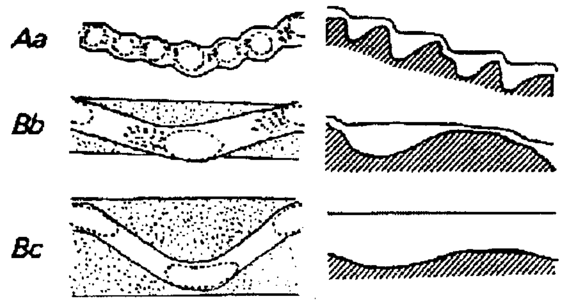


Figure 2: Oulette Creek 1978, Howe Sound, BC. In 1978, the lower reach was diverted and channelized to create a log sort yard on the alluvial fan. Single log and rock drop structures were constructed in the channel that subsequently failed.

Figure 3: The classification of pools, riffles and meanders for several Japanese streams (Kani (1944), 1981).



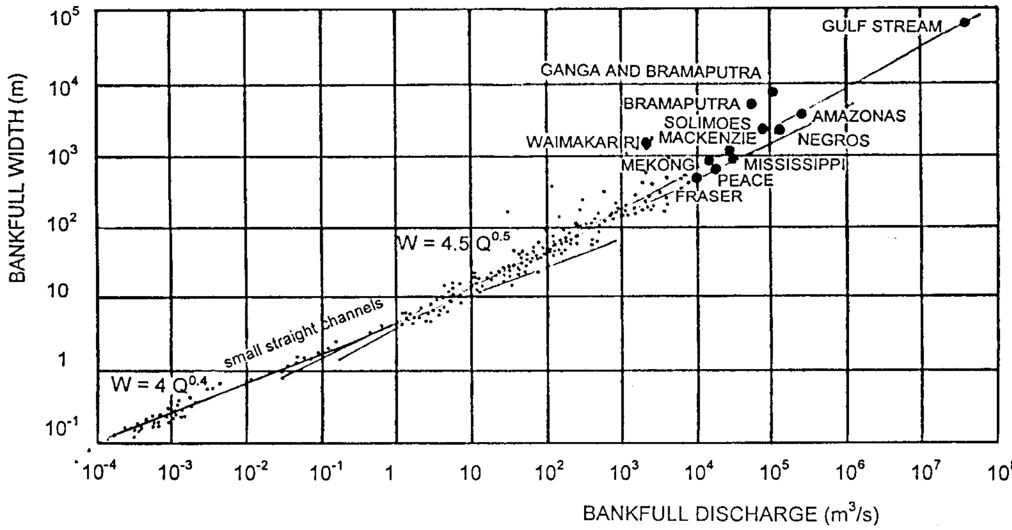


Figure 4: The relationship between bankfull width and discharge has been compiled for all ranges of river size by Kellerhals and Church (1989). For streams with bankfull discharges between 1 and 1000 m^3/sec, the relationship was estimated to be: Width = 4.5 × bankfull discharge$^{0.5}$.

was one of the first stream restorers to have naturally-spaced pools and riffles built on a channelized stream bed as described in Leopold, Wolman and Miller (1964):

Being concerned with the effect of diversion and re-alignment of certain gravel streams in Scotland on their ability to maintain trout, Stuart noted that new stream beds dredged by a dragline were, when just constructed, of uniform depth without pools and riffles. With the aim of producing the usual pool and riffle sequence, he directed the operator of the dragline to leave piles of gravel on the stream bed at intervals appropriate to riffles, that is, 5 to 7 (stream) widths apart. After a *few flood seasons, these piles had been smoothed out and presented to the eye a picture that in all respects appeared natural for a pool and riffle sequence. Moreover, the riffles so formed have been stable over a number of years of subsequent observation.*

The dimensions of pools and riffles and their relationship to river size was summarized by Leopold, Wolman and Miller in 1964 and Gregory and Walling in 1973. The natural width and corresponding flood discharge for channels that range in size from those of small streams to the Amazon River follow a surprisingly unified relationship (Figure 4, Kellerhals and Church, 1989). The average length of a pool and riffle reach was found to be 6 times the bankfull width of the river. For some combinations of discharge and slope, rivers were found to meander horizontally with the same wave form as well. The average meander wave length was found to be 12 times the bankfull width as it consists of two pool and riffle reaches. The average radius of curvature of the meander bends was 2.3 times the bankfull width.

These dimensions are important in understanding the structure and function of the habitats created in the water mass. For example, the outside bends of meanders in rivers with erodible banks are scoured and trimmed by regular bankfull flood flows (Figure 5 plan), often forming deeper pools with overhead cover that are preferred by trout. A fly cast into the centre of the riffle above the meander pool is carried to the outside of the bend under the overhanging bank and back

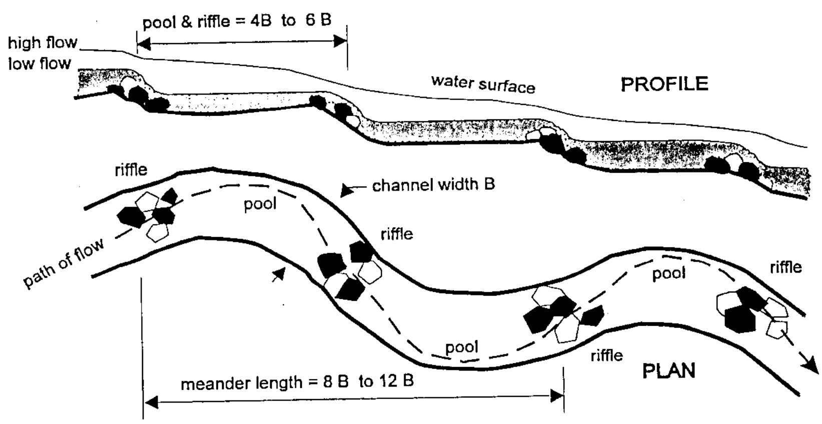


Figure 5: Pool and riffle profiles are formed in erodible channels with an average spacing of 6 times the bankfull width. In steeper streams, and where logs and tree roots are abundant, the spacing decreases.

across the lower edge of the pool by the curving helical flow that occurs as the stream changes direction. Surveys of trout habitat in mid-Canada have shown that the most preferred reaches occur in meanders with an average curvature of 2.3 river widths, suggesting that the fish may have adapted to the flow patterns and habitats created by the most frequently encountered meander curves in natural rivers.

At intermediate and lower discharges, water is stored in the pools impounded above the riffles or rapids (Figure 5, low flow profile). This maintains deeper fish habitats required for all life stages of the fish and provides water for passage up and down the river. In the riffles, the shallow flows are broken into chutes and waterfalls by cobble bars and boulders (Figure 6). Where the flow drops over an obstacle or is drawn through a narrow gap between boulders, it often reaches the critical state, a condition where the velocity is maximized for the total static and kinematic head of water that exists above the obstruction. If the water continues to accelerate over and past the obstruction, it attains super-critical velocities. Achieving this state of flow is important to maintaining the dissolved oxygen level in the river water. The super-critical flow sweeps air bubbles into the water and forms a hydraulic jump as it enters a deeper pocket or pool of sub-critical water downstream. The collapsing air bubbles rapidly re-aerate the flow. This is also the source of noise in the river as the breaking bubbles on the surface make the sounds of babbling brooks or roaring rapids. It may be an important acoustic signal for detecting spawning areas and passage opportunities (Stuart, 1953).

The shallow flows in riffles are efficient habitats for caddisflies, blackflies, and other benthic insects (Statzner et al. 1988). By locating on the tops and sides of boulders, they are able to expand their capture nets and cephalic fans to gather detritus from the flow as it converges to narrow passages over and around cobbles and boulders. The varied structure of the flow also creates chutes and local backeddies that allow fish to follow a deeper and staged path through the rapids.

Designing and Constructing Pools and Riffles

Properly designed rock riffles or rapids may be constructed in naturally uniform and channelized streams to re-establish some aspects of their lost habitats. A successfully constructed riffle and pool in a channelized reach of Chapman Creek (Sechelt Peninsula, BC) is shown in Figure 7. Other examples of pool and riffle restoration pro-

Figure 6: Varied natural flow states in a small rapids and upstream pool on the Pine River in central Manitoba.

Figure 7: Chapman Creek Restoration Project 1995, Strait of Georgia, BC. Coarse gravel bars have infilled in the upstream pool that are utilised by spawning salmon. The downstream slope and crest elevation were not changed by greater than bankfull flood flows.

jects and techniques are described in Brookes (1987), Gregory et al. (1994), Jungwirth et al. (1995), Madsen (1995), Muhar et al. (1995), Newbury and Gaboury (1993, 1994) and Shields et al. (1995). The projects have enhanced walleye *(Stizostedion vitreum)* spawning habitat and fry passage in uniformly excavated drainage channels, created year-round adult rainbow and brook trout *(Salvelinus fontinalis)* habitats in naturally uniform bedrock and boulder-dominated streams, and increased salmon spawning and over-wintering habitats in coastal streams.

Pool and riffle restoration projects are based on the pattern of channels and their natural dimensions in the catchment. The design

Table 1: Summary of steps in stream analysis and restoration projects (Newbury and Gaboury, 1994).

1) **Basins:** trace watershed lines on topographical and geological maps to identify the rehabilitation drainage basin and, if possible, nearby natural basins. Map the stream orders and measure a typical set of tributary drainage areas.

2) **Profiles:** sketch mainstem and tributary long profiles to identify discontinuities which may cause abrupt changes in stream characteristics (falls, former base levels, bedrock outcrops, etc.).

3) **Flow:** prepare a flow summary for the rehabilitation reaches using existing or nearby records if available (flood frequency, minimum flows, historical mass curve).

4) **Regional Channel Geometry Surveys:** select and survey sample reaches to establish the relationship between the channel geometry, drainage area, and bankfull discharge in the rehabilitation and nearby basins.

5) **Rehabilitation Reaches:** survey a plan and profile of the rehabilitation reaches in sufficient detail to prepare construction drawings and establish survey reference markers.

6) **Template Habitats:** prepare a summary of habitat factors for biologically preferred reaches using regional references and surveys. Where possible, undertake reach surveys in reference streams with proven populations to identify local flow forms, substrate, pool and riffle geometry, refugia, etc.

7) **Size Rehabilitation Works:** select potential schemes and structures that will be reinforced by the post-project stream discharges and geometry.

8) **Stability and Instream Flow Requirements:** test designs for minimum and maximum flows, set target flows for critical periods derived from historical mass curves in successful habitats and instream flow preferences.

9) **Supervise Construction:** arrange for on-site location and elevation surveys for enhancement works and provide ongoing advice for finishing details in the stream.

10) **Monitor and Adjust Design:** arrange for periodic surveys of the rehabilitated reach and reference reaches to improve the design as planting matures and the re-constructed channel ages.

process is summarized in Table 1. Constructed riffles should mimic natural rapids in form, materials, and function as closely as possible. Stability of the riffles is not absolute, but can be adjusted to the bankfull flow stage assuming that higher floods will utilize floodplains. In channels where floodplains are removed or constricted, higher than bankfull flows must be evaluated as well. If the riffle structures are eroded by extreme flows, the riffle will become a run. In these cases, riffle materials should be stockpiled nearby for post-flood repairs.

The design steps described below are presented as an iterative process, where the effects of an assumption made in one step must be re-checked for all steps. Additional background references and discussions related to natural channel designs are included in Heede (1985), Tripp (1986), Jungwirth et al. (1995), Lisle (1986), Muhar et al. (1995), Newbury (1995), Nunnally (1985) and OMNR (1993).

1) Location. At low flow, the pools and riffles distribute the fall in the reach in a series of steps. To establish a first approximation for the location of riffles, a template marked off in units of six bankfull widths can be placed on a large scale plot of the reach profile as shown in Figure 8. The locations can be adjusted so that they take advantage of existing pools, cross-over points in the flow between meander bends or other habitat features. In steeper slopes (5% or more) or where large woody debris is present, the riffle spacing may be decreased to as low as 4 times the bankfull width (Hogan, 1986). The locations can also be

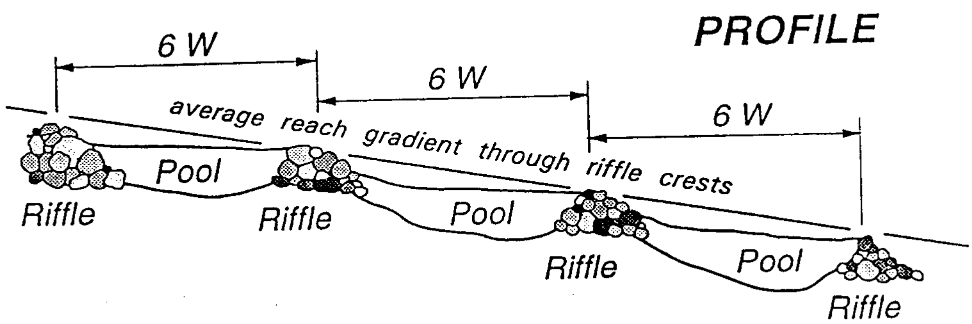


Figure 8: A design template based on average and observed pool and riffle spacing may be placed on the project reach profile to determine potential locations for constructing riffles. The riffle crest elevations are adjusted to follow the average reach gradient. The maximum height of the riffles above the stream bed is set to allow the bankfull discharge to be conducted over the riffle crest within the channel.

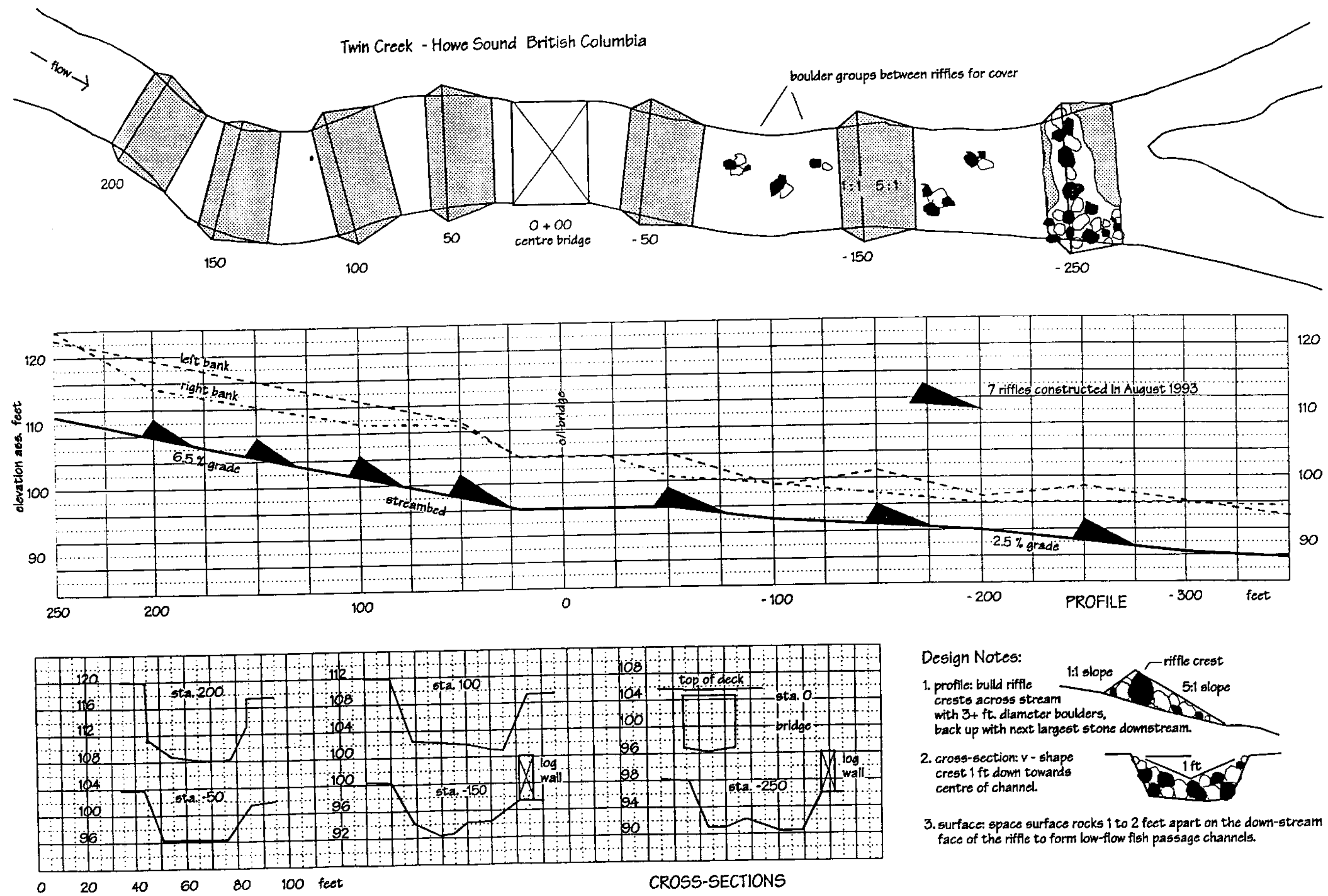


Figure 9: Twin Creek Restoration Project 1993, Howe Sound BC. Seven rock riffles were constructed on the lower channelized reach adjacent to a log sort yard. The upper riffles in the 6.5% gradient reach were spaced at 4 times the bankfull width. In the lower 2.5% gradient reach, the riffle spacing was increased to 6 times the bankfull width. In the first year, gravel and cobble bars were deposited in the upstream pools as the stream bed stabilized.

checked on aerial photographs of the reach but they must be confirmed in the field. In the Twin Creek design summary shown in Figure 9, the riffle spacing was decreased to 4 times the bankfull width of the channel in the steeper 6.5% slope upstream reach. A typical riffle constructed in the 2.5% slope reach downstream is shown in Figure 10.

2) Elevation and flood capacity. The height of riffle crests will depend on the local profile elevation, the slope of the stream and the desired depth of the low-flow pools. As a first approximation, the riffle location template (Figure 8) with a gradient equal to the average reach slope may be placed on the profile and adjusted to obtain the desired pool depths. The trial gradient may be adjusted to coincide with upstream and downstream conditions in the reach, or it may be varied at each end for a smooth transition to the adjacent reaches.

The elevation of the riffle crests is evaluated relative to the floodplain elevations to determine if there is sufficient local channel capacity to maintain the bankfull flows within the floodplains. The bankfull flow may be estimated from the reference channel surveys, regional flood frequency curves, or precipitation/catchment area relationships for the basin. The discharge capacity at the riffle site can be estimated by assuming that the flow is critical at the riffle crest for in-channel, non-backwater conditions. Typical bankfull flow conditions with critical flows occurring on the riffle crests in a constructed pool and riffle reach in Oulette Creek are shown in Figure 11. If more channel capacity is required, the proposed riffle crest gradient may be lowered relative to the floodplain, the floodplain elevation may be adjusted with fill, or the riffles may be re-located to sites with higher banks. After several iterations of the spacing and elevation template, sites are usually found that will allow the regular bankfull flows to be maintained at the natural level in the main channel. The channel banks at the riffle sites must be rip-rapped to conduct the locally accelerated flows over the riffle crests without scouring.

When flood flows are larger than the bankfull discharge, the channel and floodplain capacity must be assessed using open channel flow resistance formulas. Resistance values for the central channel should be chosen that are similar to those observed in pool and riffle rivers of similar dimensions. Visual and graphic references for small channels of all types are presented in "Roughness Characteristics of New Zealand Rivers" (Hicks and Mason, 1991). Complex channels with backwater conditions may require flood routing studies for higher than bankfull conditions.

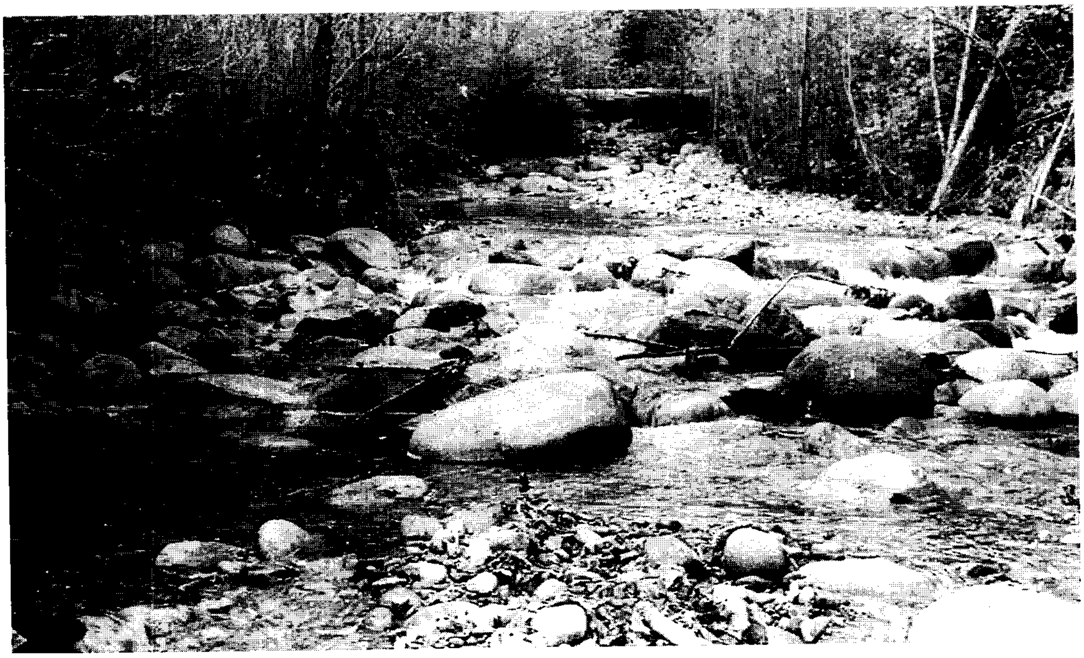


Figure 10: Twin Creek Restoration Project 1995, Howe Sound, BC. Upstream view from the toe of constructed riffle number 2 in the lower reach.

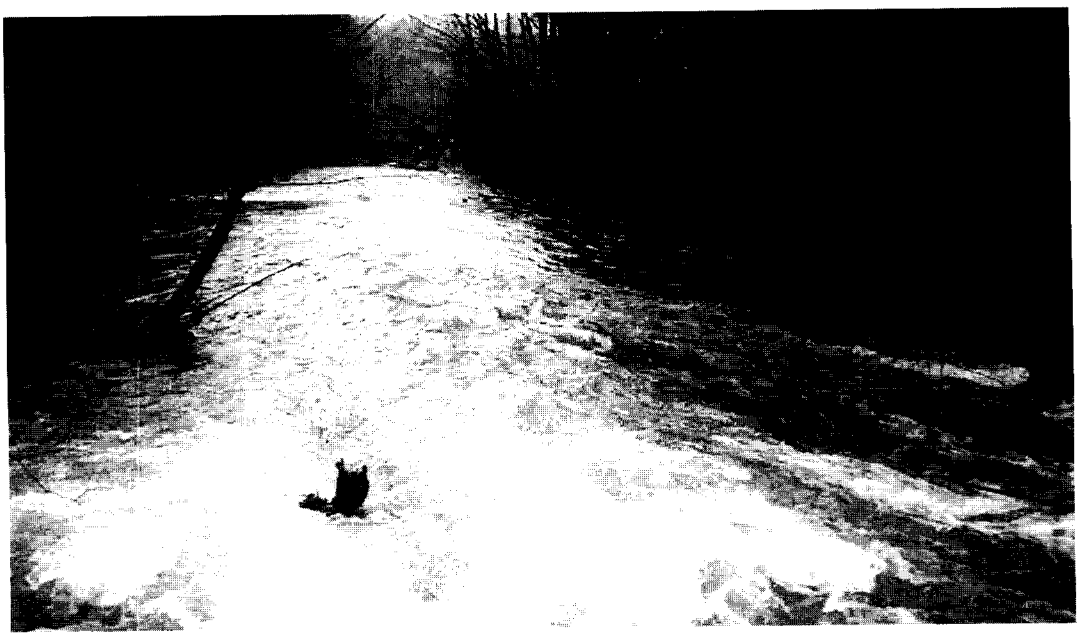


Figure 11: Oulette Çreek Restoration Project 1994, Howe Sound, BC. Downstream view overlooking constructed riffles at the bankfull flood discharge. The low flow pool and riffle steps are submerged as the average gradient of the water surface and stream bed become parallel. Critical flow occurs on the riffle crest.

3) Configuration. Surveys of natural rapids and riffles, including the collection of photographs, should be undertaken and used to develop riffle designs. The rapids shown in Figure 12 illustrate the diverse surface and flow conditions that occur in a rough and steep natural channel. A riffle constructed on Langdale Creek (Howe Sound, BC) that mimics these natural conditions is shown in Figure 13.

Most natural riffles have a downstream slope of less than 6 degrees (10:1 slope). This allows the water to enter the downstream pool at a shallow angle between the riffle face and the channel bed. Surveys of spawning rapids used by walleye were found to have downstream slopes of 20:1 (Newbury and Gaboury, 1993). Riffles surveyed in several BC coastal streams generally had downstream slopes of 10:1 with some as steep as 6:1 in boulder bed streams.

The riffle crest and downstream surface should be v-shaped in cross-section to direct the flow towards the centre of the downstream chan-

Figure 12: In a natural rapids, hydraulics jumps, pools, and chutes in various combinations dissipate energy and provide opportunities for fish to find navigable passages up the steep face. This diversity can be reproduced in man-made riffles with careful placement of large rocks on the downstream face.

Figure 13: Langdale Creek Restoration Project 1995, Howe Sound, BC. Diverse hydraulic conditions have been created by strategically placing large boulders on the downstream face of this constructed riffle. Note the well rip-rapped banks in the riffle zone adjacent to the re-constructed Sunshine Coast highway.

nel. This reduces bank scour at the riffle site and assists in maintaining a central pool depth downstream. At higher flows, the v-shape will form important back-eddies above and below the riffle that provide refuge for both adult and juvenile fish and promote coarse gravel accumulation on the sides of the channel.

4) Materials. The riffles are built with a range of rock sizes. The largest rocks are selected to be stable at the bankfull flood stage. They may tumble as smaller boulders are initially adjusted around them. The larger rocks placed on the surface of the riffle create chutes and small drops that assist fish passage at low flows. These rocks are the most vulnerable to movement and represent the upper range of rock size required for the riffle. An approximation of the maximum size required may be obtained by analyzing the tractive force (the average bed shear stress) on the face of the of the riffle. The tractive force T (kg/m^2) may be estimated as T = 1000 x flow depth (D in metres) x slope of the downstream face of the riffle (S) or: T = 1000 D S (Chow, 1959)

For bankfull design conditions, the tractive force may be based on depth of flow established by the height of the floodplains above the riffle crest and the slope of the downstream face of the riffle. Studies of stable channels summarized by Lane (1955) indicate that the relationship between the tractive force and bed material diameter at incipient motion for pebble-size and larger materials is T (kg/m^2) = diameter (cm). A safety factor of 1.5 is recommended (US Federal Highway Administration, 1988). With this safety factor, the estimated diameter of the stable rock size $\varnothing_S$ (cm) may be summarized in one relationship:

$$\varnothing_s = 1500\ D\ S$$

The volume of rock required at each riffle site is approximately equal to the riffle height x the riffle length x the bankfull channel width. This volume allows for extra rock to riprap the banks adjacent to the riffle site and to roughen the downstream slope of the riffle face. The rock sizes should cover the entire range observed in natural template riffles, with an adequate number of larger rocks to build the riffle

1. **PLAN: build riffle crest across the stream with large diameter boulders; back up with next largest stone downstream.**
2. **PROFILE: construct downstream face of riffle at a shallow re-entry slope that mimics local natural riffles (5:1 to 20:1).**
3. **SECTION: V-shape the crest and face downwards to the centre of the riffle (0.3 to 0.6 m).**
4. **SURFACE: place large rocks randomly on the downstream face 20 to 30cm apart to dissipate energy and create low flow fish passage channels.**
5. **BANKS: rip-rap both banks with embedded boulders and cobbles to the floodplain level.**

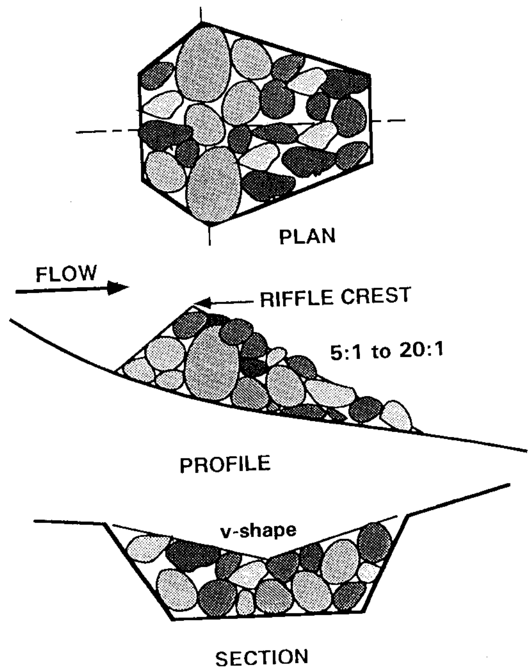


Figure 14: This schematic pool and riffle construction drawing may be augmented for machine operators with notes on the placement of construction survey stakes and photographs of natural and well-constructed riffles.

crest and armor the downstream slope. Any remaining rock may be stockpiled nearby for adjustments to the riffle and banks following the first few flood events.

5) Construction. The construction process is summarized in the notes accompanying Figure 14. This figure may be reproduced and supplemented with photographs of riffles and rapids as a guide for machine operators. To build a riffle with natural characteristics, large rock must be sorted and used with skill to create a stable crest and to form a properly roughened surface on the downstream face. A riffle under construction in the summer low-flow period on Twin Creek, Howe Sound, BC is shown in Figure 15.

Construction surveys at the riffle sites must be referenced to a benchmark established during the project reach profile survey. Construction stakes should be placed on either side of the channel at the upstream

Figure 15: Twin Creek Restoration Project 1993, Howe Sound, BC. Following the steps in the schematic construction drawing (Figure 14), the backhoe operator is sorting and placing the larger boulders along and below the riffle crest. The hydraulic thumb attached to the bucket allows boulders to be moved and placed individually.

toe, crest, and downstream toe of the riffle. The crest elevation at the banks and in the centre of the channel can be marked on the location stakes. These elevations will have to be checked as the construction proceeds. This can be done with a hand or surveyor's level and a reference elevation. Measurements may be made by the machine operator from a horizontal string line between points established on adjacent floodplains.

Natural riffle and pool habitat projects are designed to be adjusted by flood flows that will scour pools and deposit gravel bars. The adjustments often take place in the first 4 or 5 bankfull or greater flood events. After these events, the riffle configuration should be re-surveyed and assessed to see if additional rock is required to infill gaps or to improve the configuration of the flow on the riffle face.

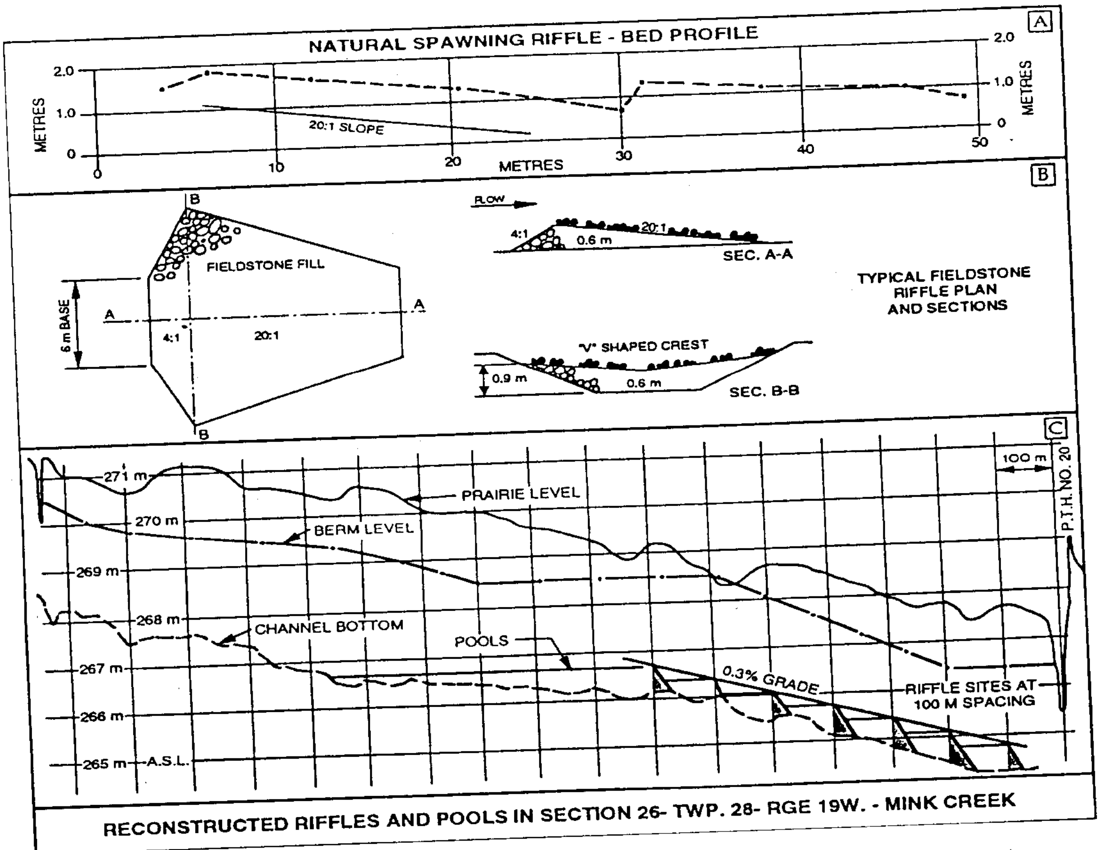


Figure 16: Mink Creek Walleye Spawning Restoration Project, Central Manitoba. A natural spawning riffle was surveyed to provide the design template (16A). Seven 1m high riffles (16B) were added to the easily eroded bed of the channelized stream (16C).

Two monitored pool and riffle projects

1) The Mink Creek Walleye Stream Restoration Project in Central Manitoba

Background: An extensive program of channelization to improve agricultural drainage and reduce Spring flooding occurred throughout the Dauphin Lake lowlands beginning in the early 1900s. The lower meandering reaches of Mink Creek were channelized in 1950 to improve the capacity of the channel to carry flood flows (Figure 1). The new channel streambed was steeper and had a more uniform grade than the natural channel. From 1950 to 1984, a repeated cycle of downcutting, bank slumping and channel widening occurred. The channel, constructed with a width to depth ratio of 7:1 had by 1984 re-established a more natural width to depth ratio of 12.5:1 (Newbury and Gaboury, 1993). The extensive erosion lowered the bed elevation by 1 m and created a 1 km^2 delta of eroded channel materials at the river mouth. Channelizing and re-grading eliminated many of the pools and riffles used by walleye as spawning and incubation habitats.

Restoration: In 1985, seven experimental riffle structures were constructed in Mink Creek with designs based on surveys of successful walleye spawning areas in the unchannelized Valley River nearby (Figure 16A). The size, spacing and distribution of boulders and cobbles on the downstream face of the natural riffles served as templates for the man-made riffles shown schematically in Figure 16B.

The Mink Creek riffles were spaced 100 m apart along the channelized reach (Figure 16C). The spacing of riffles was 6.5 times the natural bankfull width of the creek (Figure 17). Each riffle required 100 m^3 of fieldstone (donated) and cost approximately $1000 (CAN 1985) to construct.

Assessment: Walleye reproductive success was monitored by sampling the rehabilitated and unimproved riffle and pool sections during the spawning, incubation and larval drift periods. The assessment procedure was undertaken for six successive Spring spawning periods between 1986 and 1992. It consisted of five components:

1) pump/surber sampling to determine egg density and survival;
2) local hydraulic conditions at incubation sites (depth, velocity, slope, substrate);
3) drift net sampling of dislodged eggs;

Figure 17: Mink Creek Walleye Spawning Restoration Project 1988, Central Manitoba. The channelized reach 3 years after rock riffles were added. After several bankfull and greater flood events formed downstream pools, the channel has stabilized. The riffles and upstream pools are utilised by spawning walleye.

4) drift net sampling of walleye larvae;
5) mean daily discharge and water temperature.

The assessment techniques for each component are described in Newbury and Gaboury (1994).

Results: From the comparison between the rehabilitated section and isolated, shallow riffle-pool reaches in the channelized section, it was evident that the walleye utilized both reach types for spawning and incubation (Table 2). Viability of the eggs was similar with live eggs comprising 73% and 68% respectively, of the samples from all years. The number of larvae produced appeared to be similar from both sites as well. Egg scour and drift were positively correlated with discharge during the incubation period. The egg drift was greater from the channelized compared to the rehabilitated section, suggesting that although the built habitat was used with the same intensity, the added riffles provided more protection from scour and hence higher net survival rates.

Table 2: Summary of walleye spawning success information, Mink Creek restoration project (Newbury and Gaboury, 1994).

		Year					
Measurement	**Reach Type**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**
Mean egg density (catch/m²)	Single riffle rehab	0.73	1.27	19.73	0	29.22	0
	Double riffle rehab	-	4.18	7.01	0	40.52	0
	Existing channelized	3.22	8.41	4.65	0	65.53	0
Mean egg drift (catch/24h)	Single riffle rehab	19.38	0.33	163.00	0	567.00	0
	Double riffle rehab	-	0	233.00	0	1251.00	0
	Existing channelized	166.17	1.89	41.00	0	3701.00	0
Mean larval drift density (catch/h/100m³ water filtered)	Single riffle rehab	0.27	5.47	1.02	0	11.18	0
	Double riffle rehab	-	41.73	1.58	0	no data	0
	Existing channelized	0.78	16.13	0.26	0	no data	0
	Mean spawning flow (m³/s)	2.82	7.96	1.09	0.48	9.04	0.34
	Mean incubation flow (m³/s)	5.61	1.36	7.92	0.19	3.09	0.36
	Mean larval drift flow (m³/s)	2.43	0.27	1.00	0.10	6.07	0.92

Large floods, up to a 1 in 40 year event, were recorded in Mink Creek during the first five years after the riffles were constructed. A comparison of the 1986 and 1991 profile surveys indicates that the constructed riffles at the natural spacing of 6.5 times the bankfull width remained stable (Figure 18) with a minimal change in crest elevations (as Stuart found in 1953). Pool depths immediately upstream of the riffle structures have decreased since construction as a result of infilling but were maintained at a residual depth of 0.3-0.4 m immediately downstream. By 1991, the bankfull widths and depths of the pools had returned to an average ratio of 19:1, re-establishing the historic channel geometry. Increasing the cross-section of the flow in the pools decreased eroding velocities and allowed the streambanks to revegetate and stabilize. In contrast, erosion of the streambanks upstream from the rehabilitated reach has continued unabated. Consequently, restoring pool and riffle reaches has been adopted as a prerequisite to riparian restoration activities that are now being undertaken on all similarly channelized Dauphin Lake tributaries (Dauphin Lake Advisory Board, 1989).

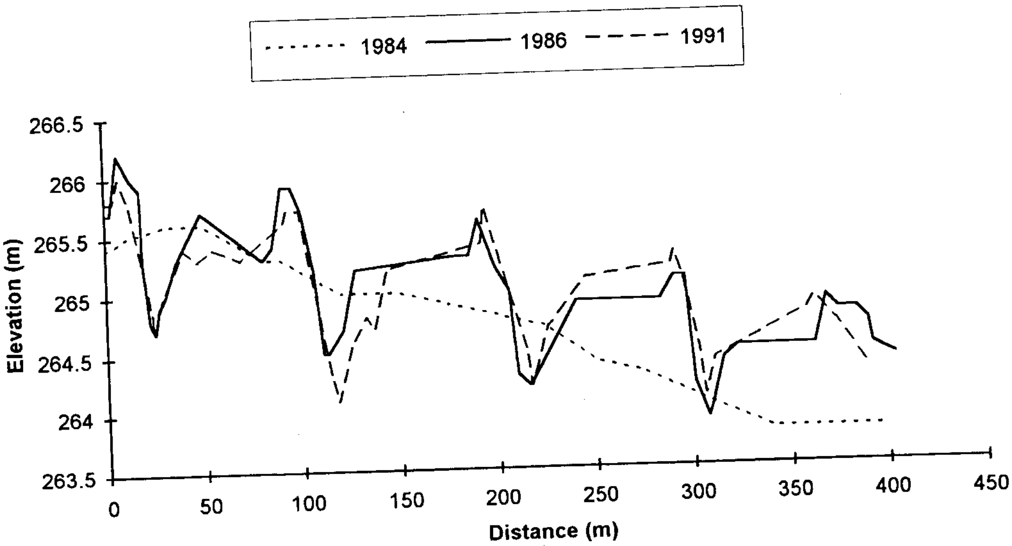


Figure 18: Mink Creek Walleye Spawning Restoration Project, Central Manitoba. Detailed profiles of the pool and riffle reach one year and six years after construction show that the pools that were scoured initially below the man-made riffles have maintained their depth and stability through several years of high-runoff events. The approximate profile of the pre-project channelized streambed is shown as a dotted line.

2) The Oulette Creek Salmonid Habitat Restoration Project, Howe Sound, Southern British Columbia

Background: In 1978, the steep (3% grade) lower 0.5 km reach of Oulette Creek was diverted to run on the western and northern edge of its alluvial fan in west Howe Sound (Figure 2). The fan surface was uniformly filled and graded for a sawmill and dry-land log sort with an offshore booming ground. Initially, restoration works were installed by dividing the diversion channel into 100 ft (30.5 m) steps with two alternating types of drop structure; a single log 0.75 m in diameter and a single row of 1 m diameter boulders. The logs were embedded in the stream banks to anchor them. Two years later, the drop structures were undercut or breached by flood flows as the new channel bed eroded (Figure 19). The downcutting was rapid in the unprotected bed below the logs and boulder drop structures where the energy of the flow was not dissipated on a sloping riffle face. Ten years later, the entire channel profile was approximately 0.7 m lower than the constructed elevation and a small delta of bed materials had accumulated in the mouth of the stream.

Figure 19: Oulette Creek 1982, Howe Sound, BC. In the first three years following channelization, the single log drop structures added to the uniform channel were undercut. Alternating single boulder drop structures were buried in deep scour holes formed immediately below the structure crests as there was no downstream riffle to convey the flows away from the structure.

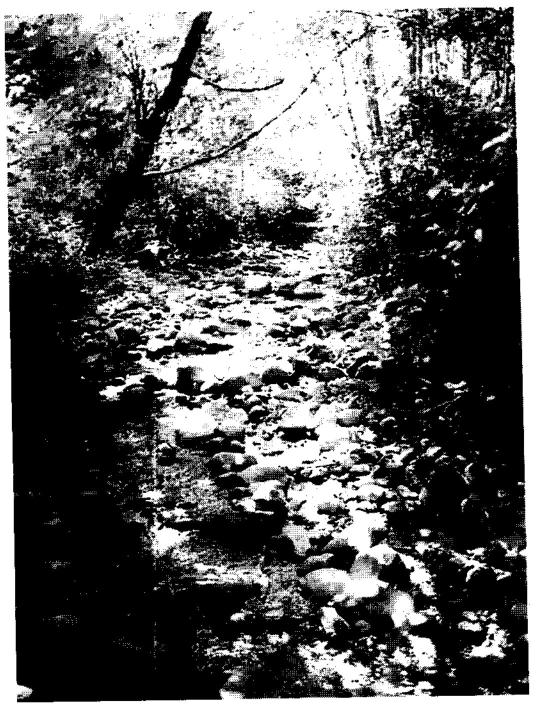


Figure 20: Oulette Creek 1994 (before), Howe Sound, BC. Prior to the addition of riffles (Figure 21) the channelized reach was a uniform run of cobbles and boulders.

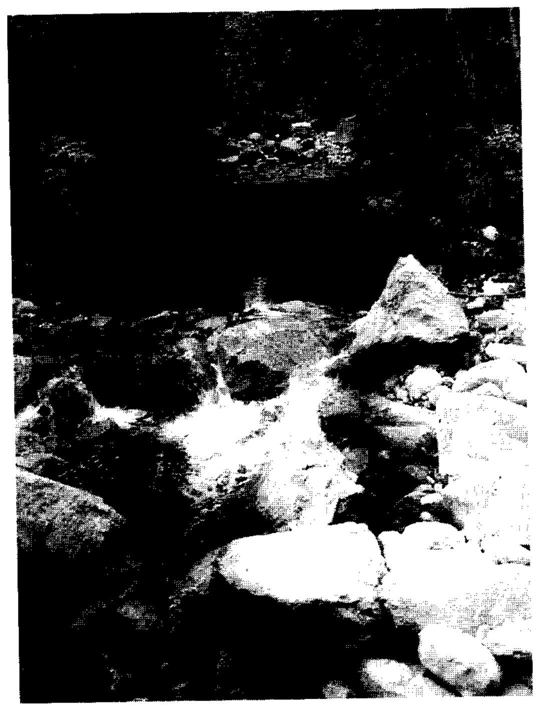


Figure 21: Oulette Creek 1994 (after), Howe Sound, BC. Rock riffles were added to the uniform reach at the former drop structure sites, creating a series of metre deep pools.

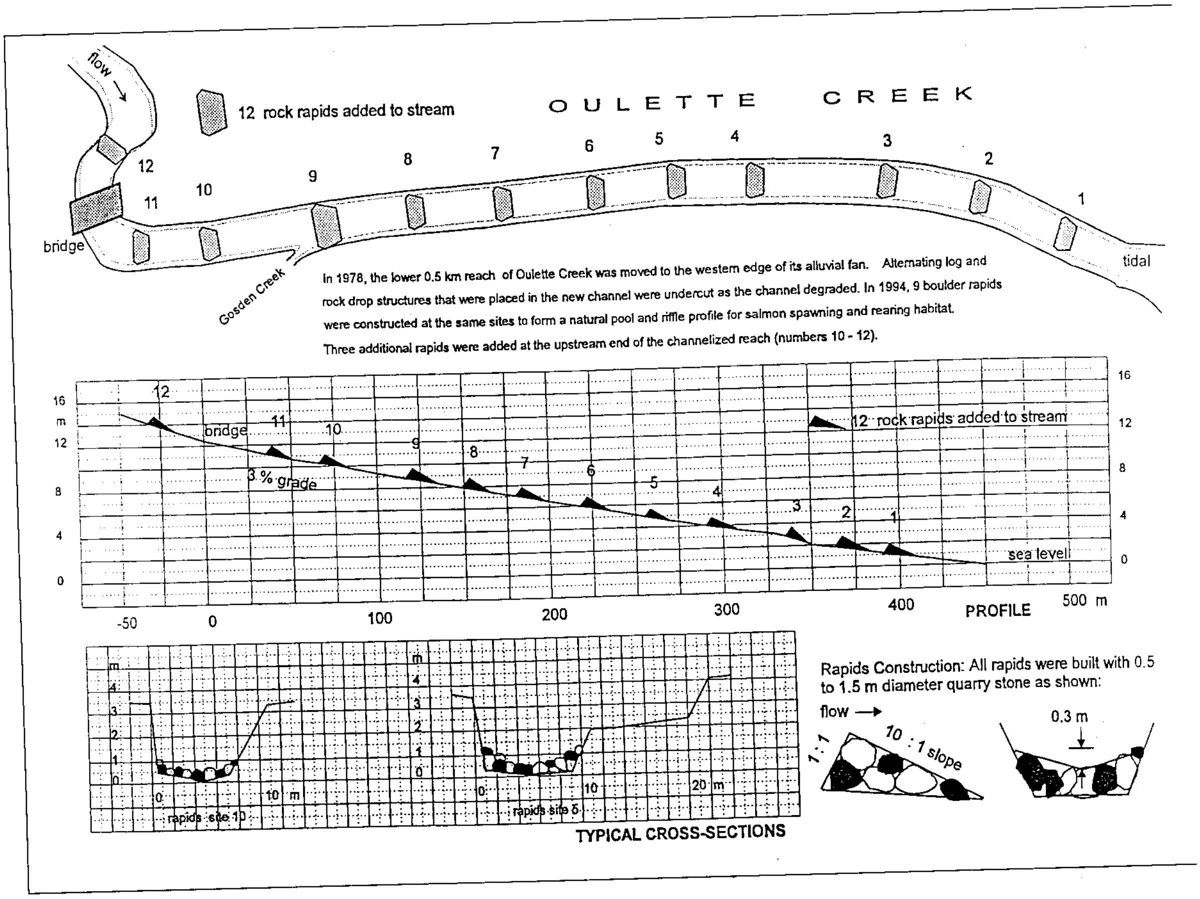


Figure 22: Oulette Creek 1994, Howe Sound BC. Condensed plan and profile drawings for the restoration project undertaken in 1994.

Restoration: In 1994, the Oulette Creek diversion was re-constructed by adding 12 boulder riffles to the channel, one at each of the old drop structure sites (Figure 20 before, Figure 21 after). Initially, the re-constructed steps in the channel profile formed 1 m deep pools above the riffles. The energy in the drop was dissipated on the 10:1 downstream sloping riffle face. The spacing of the pools and riffles is 30.5 m, approximately 4.3 times the natural stream width of 7 m measured above the diversion (Figure 22). Donated rock was hauled to the stream bank beside each riffle site from a nearby quarry prior to construction in the channel. The boulder sizes ranged from 0.5 m to 1.5 m in diameter. The total volume of rock used for 12 riffles was approximately 250 m^3 at a unit cost for hauling and placing of $35/$m^3$ ($730 CAN1994 per riffle).

Pools up to 1.5 m deep were formed by mid-winter bankfull flood flows in 1994/95 below the constructed riffles. After the flood peaks, gravel infilling occurred on the margins of the pools. In the summer of 1995, minor adjustments were made to the surface rocks in several riffles, boulder clusters were added to pools, and two floodplain ponds were excavated to augment winter rearing habitat.

Assessment: Fish population data were collected from representative sample sites for each habitat unit before and after restoration by electrofishing enclosed sample areas using a multiple pass and total removal method (Bates et al. 1996). The channelized reach was dominated by riffles and shallow glides which accounted for 83% and 90% of the available habitat in 1993 and 1994 (pre-restoration). Restoration shifted the pool-riffle ratio immediately with pools increasing to 70% of the existing habitat. In the ensuing year after several bankfull flood events, the habitat consisted of 51% pools and 49% riffles (Figure 23).

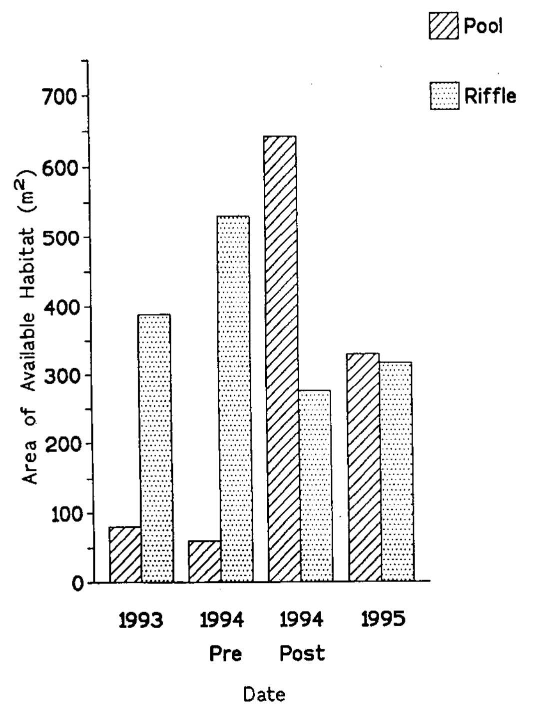


Figure 23: Available pool and riffle habitat before and after restoration of the channelized reach of Oulette Creek, Howe Sound, BC.

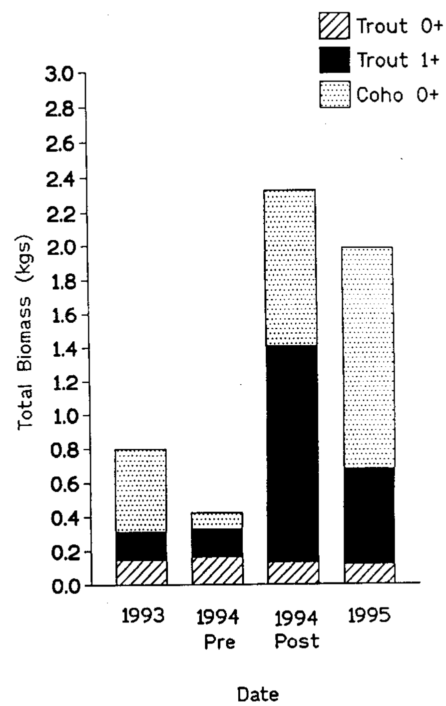


Figure 24: Total biomass before and after restoration of the channelized reach of Oulette Creek, Howe Sound, BC.

Calculated biomass per unit area (g/m^2) for all species increased after restoration suggesting immediate recruitment by fish to the new habitat from upstream reaches and a shift in species and/or age class structure. This increase resulted in a larger total biomass in the restored section (Figure 24). The most notable increase (540%) occurred in age 1+ steelhead and cutthroat trout. Density results show a decrease in the post-restoration stream for all species followed by an increase one year later. Although densities of fry decreased, actual fish numbers increased as the species and age class composition shifted.

Acknowledgements

The methods and projects reported were developed with the assistance and advice from many sources. In particular, Bernhard Statnzer and Bert Higler found the early work by Kani on Japanese streams, Gordon Wolman found the early reference to riffle construction on Scottish streams by Stuart, and Peter Newbury researched the early French physics journals dealing with open channel flow. The risk and expense of undertaking the first projects were borne by John Towle of the Dauphin Lake Advisory Board, Ken Sneddon of Sechelt Creek Contracting, Rob Liden of Terminal Forest Products and Grant McBain of the Department of Fisheries and Oceans.

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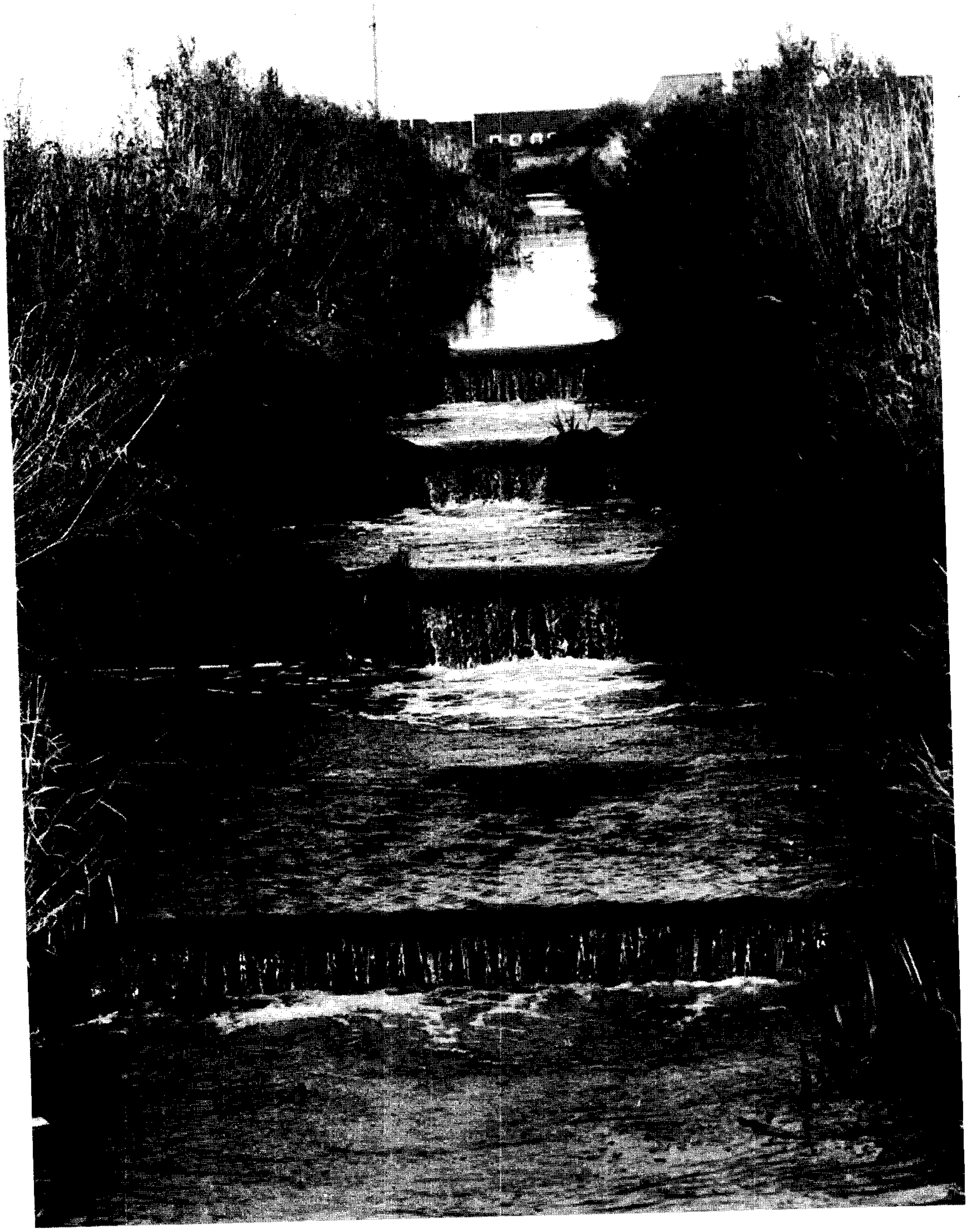

Trends and Dimensions in River Restoration: A Conference Summary

Philip J. Boon

Abstract

This paper attempts to provide a synthesis of the programme of papers and posters presented at River Restoration '96, and summarizes work on river restoration under a series of headings - described here as a five "dimensions".

The conceptual dimension addresses areas such as the motivation for restoration, and whether intervention by restoration should happen at all. It is concluded that river restoration projects are quite often motivated by particular sectoral interests (such as fisheries), and that there is a need (even in these cases) to carry out restoration work within a broader environmental framework.

The spatial dimension considers the lateral, longitudinal, and vertical connectivity within river systems, and the way in which restoration schemes must take full account of how rivers function spatially. There is a growing acceptance of the importance not only of connections between river channels and their adjacent floodplains, but also of the need to take adequate account of river processes operating at the catchment scale.

The temporal dimension describes both the importance of river history when attempting to reconstruct past river landscapes, and also the requirement for post-project appraisal once a scheme is completed. The distinction between programmes of "surveillance" and "monitoring" is discussed, and it is emphasized that systems of river classification and evaluation are essential for pre-project planning and for post-project appraisal.

River restoration is often focused on the technological dimension, and a wide array of engineering techniques are currently used both on river channels and the adjacent land. Analytical techniques such as mathematical modelling and GIS are now commonly applied to restoration projects, but it is important that sophisticated analysis is matched by a base of sound scientific data.

The presentational dimension plays a valuable role in river restoration, as restoration is unlikely to succeed without the support of a wide cross-section of society. River restoration projects must be presented to a wide audience, using appropriate educational materials developed within a multi-disciplinary framework. However, in attempting to demonstrate the wide range of benefits that river restoration can bring, it must never be portrayed as an alternative to maintaining high quality in undegraded rivers.

Introduction

This paper sets out a personal view of the programme of lectures and posters presented at River Restoration '96 held in Silkeborg in September 1996. The original title provided by the conference organizers for this summary talk was *Trends in River Restoration*. Attempts at identifying trends, however, should be treated with caution, especially when those trends are derived from the presentations at a conference. Nevertheless, the Silkeborg meeting did provide some indicators of where river restoration work is currently directed, and these are identified in this paper, together with some tentative recommendations for future work. Reference will be made throughout to some of the individual papers and posters, but inevitably this selection represents merely an illustrative cross-section of the full programme. A full list of authors and titles is given elsewhere in this publication.

A five-dimensional view of river restoration

In a previously published discussion on the case for river conservation, Boon (1992) suggested that conservation activities need to take account of five dimensions: three spatial dimensions recognizing the longitudinal, lateral, and vertical connections that rivers have with their immediate surroundings, a temporal dimension (rivers change with time), and a conceptual dimension in which the philosophical basis for river conservation can be determined. The presentations at this conference indicate that work on river restoration may be considered within an extended multi-dimensional framework comprising conceptual, spatial, temporal, technological, and presentational dimensions.

The Conceptual Dimension

Restoration or preservation?

River restoration has come a long way in a short time, yet much of what is termed "restoration" (and for convenience this word is predominantly used throughout the paper) might more accurately be described as "rehabilitation". It is debatable whether systems damaged or destroyed in the past can ever be fully restored; usually the best that can be hoped for is some re-creation of features or communities similar to those that once existed. Society must decide, therefore, how much emphasis to put on *restoration*, as opposed to *preservation* of high quality rivers that are still relatively intact (Boon, 1992). In practice, of course, only a small fraction of any nation's watercourses can be comprehensively protected, but where this does occur the contrast with unprotected rivers may be stark. This was well illustrated in a presentation by Newbury who compared the protection of natural river channels within a National Park in Manitoba with the channelization of the same rivers as soon as they crossed the Park's border.

Restoration or management?

The concept of river *restoration* is not the same as river *management*, although the two are closely linked. For example, Iversen et al. described the weed-cutting practices undertaken in many Danish streams, and Vought highlighted the importance of retaining coarse woody debris in Swedish stream channels, explaining its role in their ecological functioning. Neither example could be described as restoration *per se*, but rather as river maintenance activities which may represent important adjuncts to restoration.

Intervention or non-intervention?

When rivers have been damaged or degraded, should active restoration always be the preferred option? Several presentations discussed the relative merits of intervention compared with non-intervention. For example, a comparison of a restored reach of the River Gels Å in Denmark and a channelized but non-maintained reach, showed that rehabilitation of physical features usually takes place very slowly compared with the almost instant heterogeneity obtained through active restoration measures (Friberg et al.). A similar point was made by Tent on the rehabilitation of streams in northern Germany, who questioned whether waiting for perhaps 150 years for natural processes to bring about the desired changes could really be justified.

What motivates restoration?

When restoration is the agreed course of action, what provides the motivation? Several conference papers described projects motivated by restoring fish habitat which, in many cases, were driven by fishery (usually salmonid) interests rather than by wider concerns for species conservation (e.g. Azuma et al.: Nohgu River, Japan; Halbert: Skagit River Basin, Washington; Iversen et al.: Danish streams; bij der Vaate et al.: Rivers Rhine and Meuse, The Netherlands). Undoubtedly, some restoration projects would not happen at all were it not for the interests of fishery proprietors. However, when projects are motivated by single-interest goals, such as the restoration of individual species or groups of species, it is important that they are carried out with a view to their impact on the whole ecosystem. It is often said that the return of the salmon to a previously impoverished river indicates a healthy system. This may be a reasonable generality (salmon require good water quality and the presence of certain physical habitat features), but it is no guarantee that other ecosystem components, such as particular species of plants and invertebrates, will necessarily follow. The danger of single-interest restoration (perhaps especially for fisheries) is that schemes will be undertaken which appear to provide local improvements to habitat structure, but which prove to be unsustainable as they have taken insufficient account of processes operating at the catchment scale. That fishery-motivated restoration schemes can maintain a broad focus was demonstrated by Muotka et al. who described the results of experiments on leaf retention in Finnish streams, and subsequent processing of organic matter by invertebrates. In this case, a fundamental area of ecological functioning was seen as vital in pursuing the principal goal of improved salmon fisheries.

The recovery of other species or species groups apart from fish may also motivate river restoration projects. For example, Kozerski et al. pointed out that many proposals for lowland river restoration in Germany are the result of a perceived lack of habitats for zoobenthos. In The Netherlands a predictive approach has been developed by assessing the implications of different restoration options for the success of species such as beaver, snipe or barbel (Harms et al. Reijnen et al.). The so called "5-S model" of Mosterdijk et al. also focuses on the ecological and hydrological requirements of individual species, showing, for example, how the needs of the crayfish *Astacus astacus* could be catered for in tailor-made restoration projects.

Trends

- There seems to be a general trend towards intervention by restoration/rehabilitation, rather than by "letting nature take its course".

- Restoration projects are often motivated by the desire to meet the needs of particular species or species groups; fishery interests (especially for salmonids) often seem to dominate.

Recommendations
- Set clear goals for restoration projects.

- Give due consideration to channeling resources into protecting high quality rivers as well as restoring poor quality ones.

- Ensure that fisheries-led restoration projects take a comprehensive ecosystem approach.

The Spatial Dimension
Many riverine features have been the subject of restoration efforts, including the channel, banks, riparian zones, wet meadows, floodplain forests, oxbows, secondary channels, and marshy plains. This illustrates a growing awareness of important lateral connections which may need to be rebuilt between the main channel of a river and the adjacent land. Several presentations illustrated this point. For example, the poster by Ietswaart et al. described the role of side arms in the ecological functioning of the River Waal in the Netherlands, while van der Perk outlined an ambitious restoration project for the same river in which secondary channels, important for nature conservation, would be established across the floodplain.

The broader theme of re-establishing connectivity was an important thread running through many of the conference presentations, and formed the basis for the proposal by Hansen et al. that restoration projects should be divided into three broad categories - local improvement of shorter reaches, restoration of continuity between reaches, and restoration of whole river valleys. The importance of addressing connectivity was well illustrated by the work of Reijnen et al. who concluded that some of the species (e.g. black stork, night heron) which are the subject of restoration projects on the lower Rhine will only persist if habitat units are linked into a network.

Although many restoration projects do take account of the need to maintain or restore connections laterally (river/riparian zone/floodplain) and longitudinally (upstream/downstream), far less emphasis has been put on the vertical dimension. In her paper on south Swedish streams, Vought showed that hyporheic habitats deep within the river bed may also extend some distance outwards from the channel boundaries, and concluded that such areas made an important contribution to overall biodiversity. This may be a subject which merits further consideration in certain types of restoration scheme.

Perhaps the most important element of the spatial dimension is the relevance of the *catchment* as a unit in restoration schemes. The case is not for the restoration of whole catchments (which is rarely, if ever, possible and not usually necessary) but rather for local restoration projects to take account of river processes at the catchment level. This point was made in several ways during the conference. For example, the poster by Selig and Schlungbaum showed how sediment traps might be used to ameliorate the problem of eutrophication in the R. Warnow (Germany), but concluded that this would be worthwhile *only* in combination with other catchment restoration measures. The poster by Halbert on the Skagit River Basin in the USA described the varying effects of different land-use practices on erosional and depositional processes and thus on channel morphology, while Abernethy and Rutherfurd stressed the importance of recognizing different processes of erosion at different points within a catchment for re-vegetation to be effective in helping reduce bank erosion.

These examples illustrate the need for geomorphological work to be given a higher priority in river restoration schemes - a case that was argued persuasively by several of the participants at the conference. Kondolf suggested that geomorphology must be understood in the broader catchment context so that the factors causing channel adjustment can be accounted for in restoration design. Sear et al. pointed out that unless the geomorphological characteristics of restoration sites are properly investigated, there is no way of assessing which of the features expected to be present are missing, and thus what needs to be restored.

Above all, a catchment approach is essential if *sustainability* is to be ensured - the point central to Gardiner's paper and one that is recognized increasingly (as Holmes explained) by bodies such as the Environment Agency in England and Wales.

Perhaps one area not really addressed at the conference is the question of *scale*. It is not surprising that for many reasons most of the rivers discussed are little more than small streams, certainly in comparison with the truly large rivers of the world. As experience of river restoration grows, there will be a need to establish what can and what cannot be achieved in watercourses of different types, sizes, and locations, and to consider how transferable the experience gained of small-stream restoration is to larger rivers.

Trends

- There is a widespread recognition of the importance of lateral connectivity (river/riparian zone/floodplain) in river restoration.

- There is a growing acceptance of the need for river restoration to take adequate account of catchment processes.

- The key role of geomorphology in river restoration is beginning to be addressed, but there are many examples of restoration projects where this is not the case.

Recommendations

- Where necessary, hyporheic habitats should be considered when planning restoration projects, in recognition of the importance of the vertical as well as the longitudinal and lateral dimensions in the functioning of river ecosystems. (Boon, 1992; Ward, 1989)

- All river restoration projects should consider the case for incorporating geomorphology into project design.

The temporal dimension

Madsen, in a quote from Shakespeare, illustrated that human intervention in the structure of river channels has been going on for centuries, so it is perhaps not surprising that success in river restoration projects usually requires a sense of history. Historical maps are quite often used to reconstruct a river course that may have existed decades or even centuries earlier. For example, the poster by Bloesch and Frauenlob showed how maps 250 years old could help in restoring the River Inn, the largest tributary of the upper Danube. The importance of history, however, is not confined to the reconstruction of past landscapes. As Sear et al. (and other geomorphologists) pointed out, an appreciation of geomorphological history is crucial in understanding present processes, and in predicting future responses of river channels to restoration works.

The temporal dimension in river restoration implies not only a sense of history, but also a commitment to future monitoring. One of the common threads running through many of the conference presentations was the incorporation of "post-project appraisal" into the planning and costing of restoration schemes. In some cases (such as the UK/Danish LIFE project described by Biggs et al.) monitoring is extremely comprehensive and should provide the future planners of river restoration with a far better scientific basis for their work than is available at present.

Yet there is a more fundamental question which needs answering: What is monitoring really meant to achieve? The activity usually referred to as "monitoring" may often be better described as "surveillance". This distinction has been made by Hellawell (1978) who defines "surveillance" as *"a continued programme of surveys systematically undertaken to provide a series of observations in time"*, and "monitoring" as *"surveillance undertaken to ensure that formulated standards are being maintained."* The point here is not so much one of semantics (although greater clarity in terminology is certainly needed) but rather that more emphasis seems to be placed on surveillance and perhaps rather less on monitoring. Surveillance is undeniably important, as it is the only way in which the biological, physical, chemical, and geomorphological responses of river systems to restoration works can be assessed and documented. On the other hand, restoration schemes require not only that goals are clearly stated, but that at least some goals should be sufficiently prescriptive to enable their success to be monitored.

This raises two other issues. First, formulating and monitoring goals in river restoration depends upon a framework of river classification so that the biological and physical features which characterize rivers of a given type and location can be defined. This approach was well illustrated in the poster by Wolfert et al. which set out the use of the "River Ecotope System" in classifying 65 ecotopes found in the large alluvial rivers and floodplains of The Netherlands, and in defining river rehabilitation objectives. Second, river restoration requires schemes not only for river *classification*, but also for river *evaluation*, especially if some of the goals of restoration are difficult to define. If the intention, for instance, is to increase the "naturalness" of a river or its physical diversity, how are these attributes to be assessed? These problems have been addressed in different places and in different ways, most recently in a technique known as SERCON (System for

Evaluating Rivers for Conservation) (Boon et al. in press) which aims to provide a more rigorous and repeatable method for assessing river conservation value.

Trends

- There is a growing recognition of the importance of river history in restoration schemes.

- There is now widespread acceptance of the need for post-project appraisal, although this is not always as carefully targeted as it might be.

Recommendations

- Greater emphasis should be placed on historical channel analysis during the planning phase of river restoration schemes.

- The objectives of post-project appraisal should be stated clearly in every restoration scheme - whether for general surveillance, or for measuring the success of specific restoration goals.

- Within each country or region, systems should be developed for river classification and evaluation, as these are essential for pre-project planning and for post-project appraisal.

The Technological Dimension

Many of the conference presentations focused on the technology of river restoration, and referred to one or more of the wide range of techniques now applied to channels and their surroundings - reintroducing meanders, replacing weirs and dams with riffles, removing obstacles to fish migration, opening culverted streams, creating spawning beds, planting riparian vegetation, re-establishing river/floodplain connections, creating buffer strips, designing wetland areas adjacent to rivers for nutrient processing. The continuing growth in the range and complexity of restoration techniques suggests that there is a parallel need for a multi-disciplinary approach in which specialists in subjects such as geomorphology, botany, zoology, fisheries, hydrology, economics, landscape architecture, and sociology work together for a common purpose. Several examples of this approach were described at the conference, such as in Denmark (Madsen), on the River Rhône in France (Henry and Amoros), for the Sado River Basin (Saraiva) and on the River Mersey in the UK (Nolan).

One real trend that was apparent at the conference is the rapid advance in the use of technology for processing information on river restoration. For example, Mutz described a project on streams in eastern Germany in which well-established methods of aerial photography were combined with the rather newer development of Geographical Information Systems (GIS) to become a powerful tool in the hands of the restoration planner. Several presentations showed how GIS applications are now frequently coupled with mathematical modelling techniques, some of which may be described as "knowledge-based systems" directed towards areas such as the spatial dynamics of animal populations.

While the importance of new technological developments to river restoration should not be underestimated, the use of sophisticated techniques and their presentation can at times mask some serious flaws in the underlying data. The relationship between river restoration and the scientific understanding that supports it was not explored in any detail at the conference, yet in private discussion the question "to what extent at present does good science underpin river restoration work?" was raised more than once. There is certainly room for improvement, and many opportunities here for building bridges between basic and applied science. For example, as Henry and Amoros suggested, it is essential that recent ecological concepts in fields such as ecosystem dynamics are brought into the ambit of river restoration.

Trends

- Restoration projects are becoming more complex, and now rely on an increasing diversity of engineering techniques.

- Rapid advances are being made in applying mathematical models, knowledge-based (expert) systems, and GIS to restoration projects.

Recommendations

- New technology should be used as a tool in river restoration, but it must not become an end in itself.

- All river restoration must be underpinned by sound science in which the importance both of basic and applied elements is fully recognized.

The Presentational Dimension

This final section considers both the way that river restoration projects are presented to a wider audience, and the way in which the audience can become a participant (and not merely a spectator) in the whole process. There was relatively little discussion on this topic at the conference, yet such is the nature of restoration projects that they are unlikely to succeed without the support of a wide cross-section of society. There are indications that this cross-sectoral approach to river restoration is beginning to take root. For example, Scruton et al. outlined a restoration project on a Canadian stream developed as a partnership between a local conservation group, a private company, and the Canadian government. Other speakers (such as Nolan on the River Mersey, UK) showed the pivotal role that local communities can often play in restoration projects. As yet, the formal education sector appears to have little involvement with river restoration, and this area is perhaps one that could profit from greater attention. Nevertheless, the conference did learn of some educational initiatives, such as the innovative approach in Germany (described by Tent) where local school-children were encouraged to take part in a stream restoration project by helping with planting trees on the banks.

Although progress is being made, there are some key areas in this presentational dimension which need to be addressed. First, Holmes stated that there was often a misconception that river restoration is only concerned with nature conservation, and he proposed that the wider benefits to society, such as improved water quality or flood control, should be promoted. Second, there are many different audiences to whom river restoration must be introduced - primary and secondary school-children, university students, planners, politicians, research scientists, voluntary conservation workers, the lay public - each group requiring a different approach and appropriately targeted educational materials. Third, there is a danger that by promulgating river restoration schemes, a belief will emerge that causing damage to rivers is not really that serious a problem as things can always be put right later (Boon, 1996). In reality, river restoration is usually expensive and only possible at certain sites, so it can only be applied to relatively short lengths of watercourses. Moreover, repairing environmental damage is likely to be little more than a process of rehabilitation (by recreating conditions approximately similar to those that have been degraded) rather than replacing what has been lost. Surely the lessons that have been learnt from the experience of river restoration to date should be used to strengthen the arguments for carefully conserving those rivers that are still relatively undamaged.

Trends

- Partnership approaches to river restoration are beginning to develop.
- An awareness is growing that river restoration projects must be "sold" to a wide audience.

Recommendations

- More effort is required to demonstrate the wide range of benefits that river restoration can bring to society.
- Educational materials (leaflets, manuals, scientific papers, videos, etc.) aimed at describing and promoting river restoration schemes should be carefully targeted at particular audiences.
- River restoration should be seen more as a last resort and less as a panacea. Experience of restoration projects to date should be used to stress the importance of maintaining high quality in undegraded rivers.

Conclusions

Although the conference demonstrated that river restoration has made considerable progress, it still faces many formidable problems. One paper in particular (Berry et al.) discussed some of the barriers (other than scientific or technical) to implementing river restoration projects in Italy. Three principal categories of constraints were identified: legislative, institutional, and economic.

Legislative constraints include, for instance, laws that require river channels to be maintained to a particular cross-section in order to meet prescribed flood control standards (as described by Newbury). Complex institutional or bureaucratic structures may also prevent effective river restoration. For example, a poster by Decleer described how in Flanders 10 River Basin Boards were set up in 1993 with the responsibility for dealing with water quality and water quantity management on an ecological basis and from a catchment perspective. Yet after three years the Boards still lack a firm statutory foundation and have been reduced to mere voluntary discussion groups. Economic barriers received rather little attention at the conference. This area should be developed further, both by providing more facts and figures on the costs of restoration and by extending the rather limited work carried out so far on cost-benefit analysis of river restoration schemes.

There are, of course, many other constraints on river restoration activities, such as the issue of land ownership and the degree to which this dictates what can be achieved on the ground (e.g. alterations to channel structure or to river-floodplain linkages). Ultimately, much of the success of future river restoration projects will depend upon getting the balance right - the balance between what some perceive as competing interests (e.g. nature conservation *vs* recreation), the balance between delaying restoration work until comprehensive baseline data have been assembled *vs* hastening into a project with inadequate information, and the balance between the amount of money spent on feasibility studies or promotion *vs* carrying out the restoration work itself. No doubt future conferences such as this will be better placed to judge whether that balance has been successfully achieved.

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The titles of references from the RR '96 conference are given in the list of lectures and posters, page 143 and 149 respectively.

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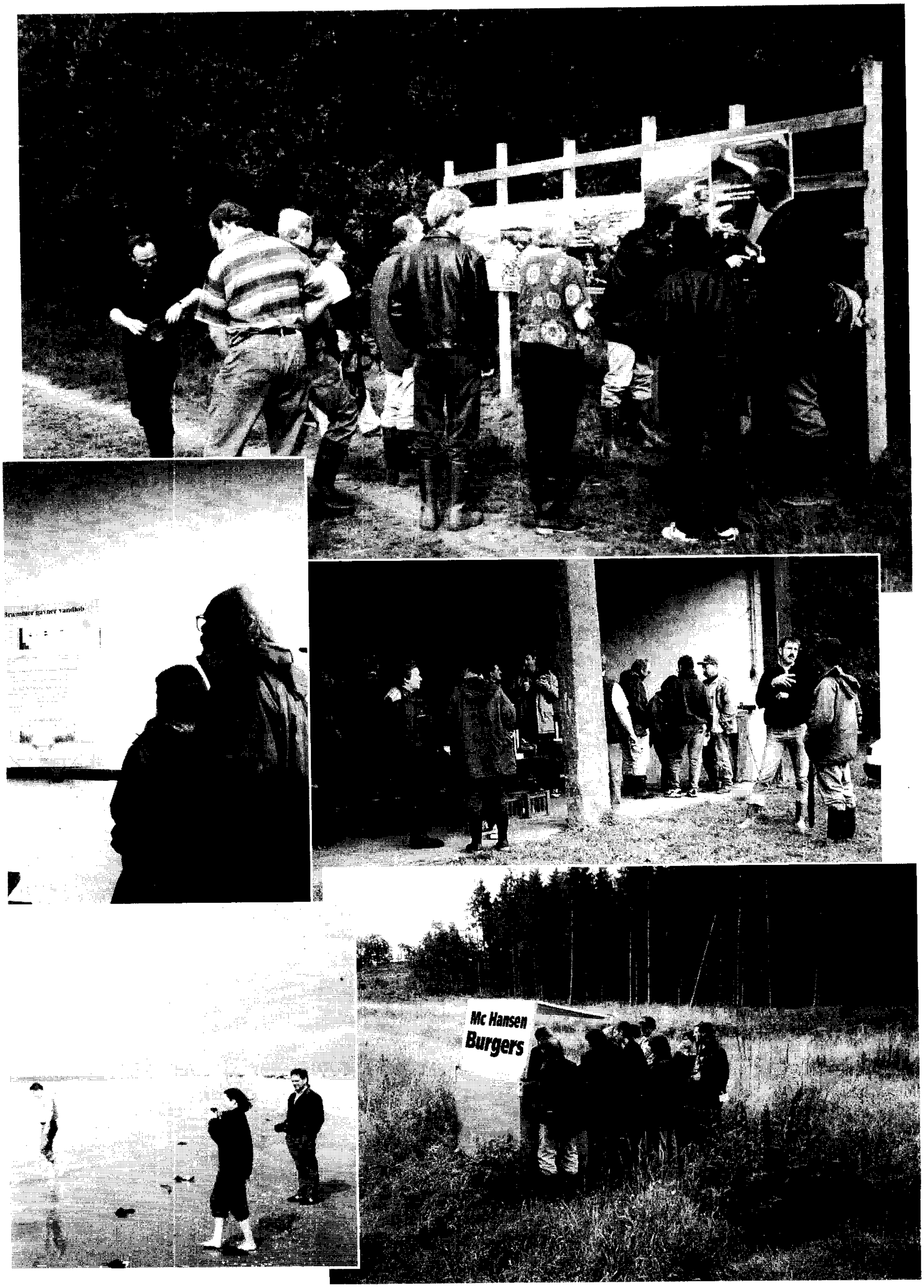
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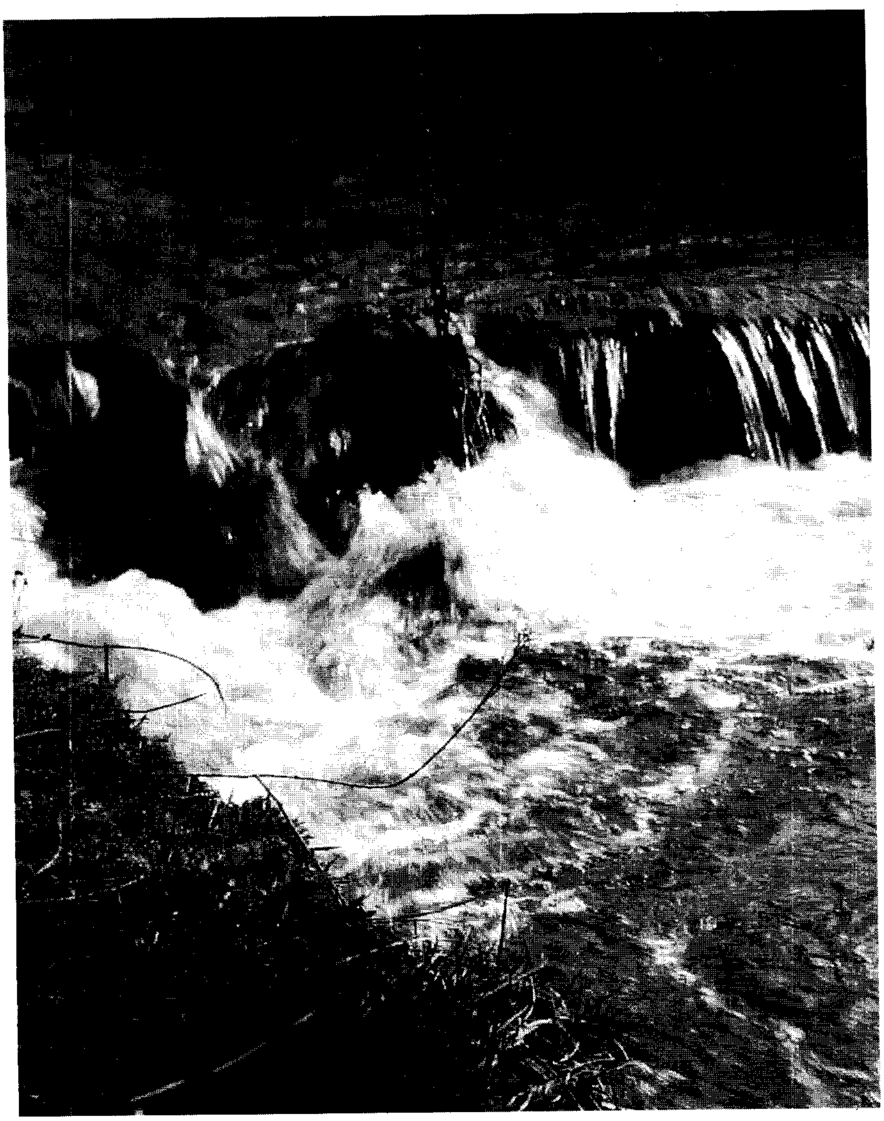

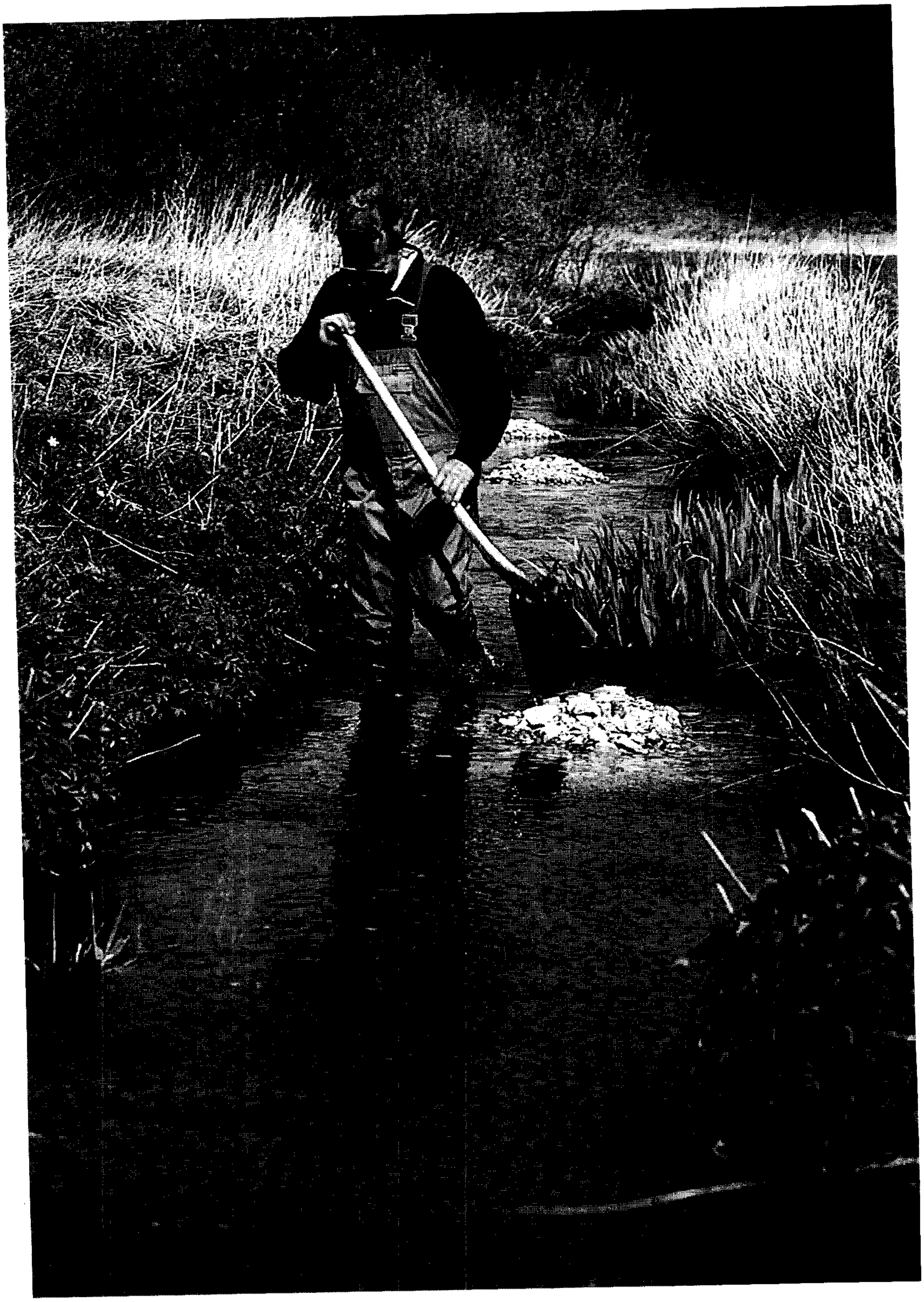

River Restoration '96

Session lecture titles

Abernethy **B.** *& I. Rutherfurd*
Scale analysis of bank stability: an approach to maximise the effect of riparian revegetation in stream restoration

Berry M.*, A. Agapito & M. Bacci*
Barriers to implementation af river restoration projects in Italy

Biggs J.*, H.O. Hansen, D. Walker, P.N. Grøn, M. Whitfield, P. Williams, T. Rich & A.Corfield*
Life - Brede/Cole/Skerne remeandering: The effects on the aquatic macroinvertebrate and plant communities of three contrasting restored river reaches

Boock P. *& J.A. Høybye*
Modelling open channel friction factor and river flow - i.e. as part of river-restoration

Brookes A.
Uncertainty and risk in river restoration: Some European experiences

Buijse A.D.*, M.J.R. Cals, R. Postma & J. den Held*
Ecological river restoration in The Netherlands: A cost-effective monitoring strategy for nature rehabilitation projects

Cals M.J.R.*, R. Postma & E.C.L. Marteijn*
Ecological river restoration in The Netherlands: State of the art and strategies for the future

Ciutti F.*, M. Siligardi, C. Cappelletti, M. Cerato, V. Fin & S. Cappelletti*
Rehabilitation of a lowland stream in alpine region (Trento - Italy)

Cooper C.M.*, F.D. Shields & S. Knight*
Channel rehabilitation in incised streams: Combining structures and ecology

Downs P.W. *& C.R. Thorne*
River channel rehabilitation for the River Idle, UK: Design practices and suitability testing for a channel with flood defence requirements

Driessen J.M.C. *& P.F.M. Verdonschot*
The 5-S-model, an integrated approach for stream rehabilitation in The Netherlands

Frandsen S.B. *& K. Rasmussen*
Presentation of different types of stream restoration in Vejle County - and their biological effects

Frank C.
Investigations for weed control in a karstic river

Friberg N.*, H.O. Hansen, B. Kronvang & L.M. Svendsen*
Long-term and habitat-specific respons of the macroinvertebrate community to the River Gels Å restoration

Fuglsang A.
Nutrient transformation in wet meadows

Gardiner J.
Sustainable management and erosion control at source

Gørtz P.
Effects of stream restoration on the macroinvertebrate community in River Esrom, Denmark

Gunkel G.
Development objectives and prediction for the natural construction of small running water

Hansen H.O.*, B. Kronvang & B.L. Madsen*
European Centre for River Restoration: Databases for river restorations

Harper D. *& M. Ebrahimnejad*
In-channel restoration: Defining the goals and measuring the success

Henry C.P. *& C. Amoros*
Concepts for former channels restoration applied to the Rhône River

Higler L.W.G.
How to assess a reference situation in lowland streams

Hoffmann C.C., *L.M. Svendsen, B. Kronvang, L. Øvig, P. Johnes & P. Walker*
Life - Brede/Cole/Skerne remeandering: Implications of river restoration on nutrient retention

Holmes N. *& M.B. Nielsen*
Life - Brede/Cole/Skerne project: Setting up and delivery of the project

Hyldegaard P. *& S. Petersen*
Revitalisation of the rivers in the County of Funen, Denmark

Katopodis C.
Stream restoration design philosophies

Kelly F.L. *& J.J. Bracken*
Fisheries enhancement of the Rye Water, a lowland river in Ireland

Kondolf G.M.
Lessons learned from restoration projects in California

Kronvang B., *A. Brookes, K. Fisher, B. Møller, M. Newson, O. Ottosen, D. Sear & L.M. Svendsen*
Life - Brede/Cole/Skerne river restoration: On river morphology, sediment transport and flood defence

Kronvang B., *L.M. Svendsen, P. Græsbøll, N. Friberg & H.O. Hansen*
Short and longer term adjustments of river channel morphology following remeandering

Muotka T., *P. Laasonen & A. Haapala*
CPOM retention and bentich community structure in channelized vs. rehabilitated streams

Mutz M.
Stream-system restoration in a strip-mining region, Eastern Germany: Dimension, problems, and first steps

Nolan P. A.
River rehabilitation in an urban environment: Examples from the Mersey Basin, NW England

Perala N.C.
Protocols for site assesment and design for bioengineering stream bank and floodplain revegetation

Petersen V.H.
"The River Odense in the Year 2000"

***Postma R.**, M.J.J. Kerkhofs, G.B.M. Pedroli & J.G.M. Rademakers*
A stream of nature. Outline of feasible nature in the rivers Rhine and Meuse, The Netherlands

Riber H.H.
Restoration of the Skjern River. Consequenses for flood hazards, sediments and nutrients

***Schrop M.** & C. Bakker*
Secondary channels as a basis for ecological rehabilitation

***Scruton D.A.**, T.C. Anderson & L.W. King*
Pamehac Brook: A case study of the restoration of a Newfoundland, Canada, river impacted by flow diversion for pulpwood transportation

***Sear D.A.**, A. Briggs & A. Brookes*
Geomorphological adjustments to river restoration in lowland rivers

Tent L.
Reconstruction versus ecological maintenance - improving lowland rivers in Hamburg and Lower Saxony

***Tockner K.**, F. Schiemer & J.V. Ward*
Conservation by restoration: The management scheme for a river-floodplain system on the Danube River in Austria

***Vaate A.bij de** & A.G. Klink*
Ecological river restoration in The Netherlands, effects on macroinvertebrate fauna

***Vivash R.**, O. Ottosen, M. Janes & H.V. Sørensen*
Life - Brede/Cole/Skerne remeandering: The restoration works and practical aspects of river restoration

Vought L.B.-M.
Difference between channelized and natural streams and its implication for stream restoration

***Wittler R.J.** & S. Keeney*
Rehabilitation of an incised sinuous stream in fine grained glacial soils with grade control and planform control structures

***Wolfert H.P.**, G.J. Maas & A.J.M. Koomen*
Monitoring geomorphological and ecological effects of lowland stream restoration measures

***Zalewski M.** & B. Bis*
The importance of riparian ecotone for restoration scenarios in sustainable river basin management

Zauner G.
Ecological evaluation of Danubian impoundments: Present circumstances and possibilities

International conference
European Centre for River Restoration
September 9-13, 1996
Silkeborg, Denmark

River Restoration '96

Poster titles

Azuma N.
Effect of habitat restoration on fish communities in a Japanese channelized stream

Bloesch J. *& G. Frauenlob*
Man made impacts and catchment development plan of the River Inn

Casas J.J.
Effects of the riparian canopy on the activity of hyphomycete fungi in leaf debris in a Mediterranean river with calcite incrustant waters

Dahl S.Ø. *& H.H. Riber*
Concepts in design techniques and consequences for the restoration of Skjern River

Fuglsang A.
Demonstration project about establishing wet meadows

Galloway L.
Partnerships in restoration: Promoting the concept of river restoration in Britain

Gardiner J. *& N.C. Perala*
Structural uses of vegetation in catchment management

Halbert C.L.
Historical analysis of the effects of changing land use on channel morphology in the Skagit River Basin, Washington (USA), with implications for salmon habitat

Hansen H.O., *B. Kronvang, P. Simonsen & M.B. Nielsen*
River Restoration in Denmark

Hansen H.O., *B. Kronvang, P.Simonsen, M.B. Nielsen & O. Ottosen*
Stream Restoration in Denmark

Harms W.B.*, W.C. Knol, J.R.-K. Lankhorst & H.P. Wolfert*
Nature rehabilitation and planning in the Gelderse Poort area

Hasholt B.
Monitoring effects of river restoration

Ietswaart T.*, P.A. Spaink & G.M. van Dijk*
Phytoplankton and zooplankton in a dead arm of the river Waal: A comparison with the main channel

Jonge J. de *& A.J. Hendriks*
Do contaminated sediments pose restrictions to ecosystem rehabilitation objectives?

Kapitzke I.P.
Stream rehabilitation and management in the wet tropics of North Queensland, Australia

Kierbyholm T. *& S. Bang*
Restoration of stream and adjacent valley

Koizumi N.
Quantitative assessment of fish habitat quality in urban streams in Tokyo, Japan

Mosterdijk H.G.*, P.F.M. Verdonschot & J.M.C. Driessen*
The 5-S-model in stream management practice

Obrdlik P.
Restoration of the floodplain forest horn 234 les on the lower Thaya River (Czech Republic)

Olesen K.W. *& H.H. Riber*
Restoration of the Skjern River. Consequences for flood hazards, sediments and nutrients

Perk J.C. Van der
The Afferdensche en Deetsche Waaden nature development project, situated along the river Waal

***Reijnen R.**, E.C.L. Marteijn, W.B. Harms, R.P.B. Foppen & H.P. Wolfert*
Rhine Econet: Ecological networks in river rehabilitation scenarios

Saraiva M.G
River corridor assessment and management in a Mediterranean Basin (Ribeira das Alcáçovas, SW Portugal)

***Selig U.** & G. Schlungbaum*
Inclusion of sediments in the restoration concept of a lowland river

***Svensson M.** & L. Vought*
Impact of restoration measures on the nutrient load to a small channelised lowland stream

Tropan L.
Lack af money - advantage or drawback

Verniers G.
Bank stabilization: Preservation of ecological and landscape roles

Wallsten M.
How to reach the goal of nutrient reduction in River Fyris

***Wolfert H.P.**, G.J. Maas & G.H.P. Dirkx*
Geographical variations in historical river meandering indicating potentials for rehabilitation of the River Vecht

***Wolfert H.P.**, E.C.L. Marteijn & J.G.M. Rademakers*
The River-Ecotope-System: A classification of riverine ecotopes