4

Hans Ole Hansen
Brian Kronvang
Bent Lauge Madsen

Classification system for watercourse rehabilitation

Proposal for a classification system

Denmark is currently well to the forefront in the watercourse area, both with respect to legislation, administration, rehabilitation, and protection. Unfortunately, though, no clear statistics have been compiled of Danish restoration projects, and no clear overview is available of the number and type of projects undertaken in Denmark.

In order to obtain a useful overview of the projects undertaken and in order to be better able to steer future rehabilitation projects in the right direction, it is important to compile statistics on the projects and undertake continuous systematic collection of information.

A precondition for being able to compile such statistics, however, is the availability of an unambiguous classification system for the different types of restoration project and methods. Without clear definitions, one cannot expect that the questions and answers will be interpreted in the same way from person to person.

In the present chapter, we therefore put forward a proposal for a classification system for watercourse rehabilitation projects (Appendix A). The classification system only concerns rehabilitation projects that benefit the environment, though, and rehabilitation projects solely undertaken to improve drainage are not included.

Even though considerable efforts have been made to design the classification system as unambiguously as possible, it is inevitable that there will be some obscurities and overlap. It is nevertheless hoped that the proposed system can form the basis for a database on the rehabilitation projects previously or currently being undertaken in Denmark. In addition, it is hoped that further development of the proposed classification system will lead other European countries to establish similar databases.

The various national databases could subsequently be compiled and updated under the auspices of the European Centre for River Restoration. The information compiled could eventually be made available on the Internet and GIS (Geographical Information System). This will give interested parties the possibility to study the database and retrieve specific information for their own use directly to their own computers. In addition, it would eventually enable registration of projects to be decentralized.

Proposed classification system

The classification differentiates between “Type” and “Method”. The rehabilitation projects are subdivided in three types according to the overall objectives of the project. Subdivision of rehabilitation projects by type is based on the extent of rehabilitation within the watercourse system, as shown schematically in Figure 4.1. Each type encompasses the methods that can be used to achieve the objective. Rehabilitation project types and methods are summarized in Table 4.1. The list is open, though, and may be expanded.

Type 1: Rehabilitation of watercourse reaches, encompasses projects whose objective is local improvement of shorter reaches. The methods used under type 1 will typically result in *better habitats* locally, both in the watercourse and in the 2 metre cultivation-free border zone.

Type 2: Restoration of continuity between watercourse reaches, encompasses projects aimed at ensuring free passage along watercourse systems. The methods employed under type 2 are those that reconnect reaches and restore *free passage* and continuity between a watercourse’s component reaches and between the watercourse and its immediate surroundings.

Type 3: Rehabilitation of river valleys, encompasses projects affecting both the watercourse and its whole river valley. The methods employed under type 3 are those that ensure that the watercourse and river valley function as an *ecological and hydrological entity*. Their impact reaches across the watercourse and its surroundings.

With this basic classification system as a foundation, the next phase is to develop a system that can be employed in questionnaires and databases. There has to be room for rehabilitation types and methods to be combined, though, in as

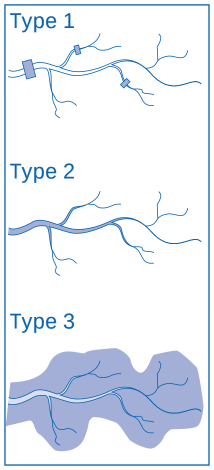


Figure 4.1. Schematic definition of the three types of rehabilitation project.

Table 4.1. Watercourse rehabilitation – types and methods.

Type 1: Rehabilitation of watercourse reaches

Reach remeandered
Culverted reach opened to create better habitats
Two-step cross-sectional profile created
Lakes established/re-established in connection with the watercourse
Ochre sedimentation basin established in connection with the watercourse
Stones laid out
Gravel laid out
Artificial fish hiding places established
Other solid objects laid out
Current concentrators established
Sand traps constructed
Trees and bushes planted within the 2 metre cultivation-free border zone
Trees and bushes removed within the 2 metre cultivation-free border zone
Artificial bed and/or bank established (fascines, concrete, paving slabs, etc.)
Artificial bed and/or bank removed (fascines, concrete, paving slabs, etc.)
Other methods: fences, watering places, etc.
Other

Type 2: Restoration of continuity between watercourse reaches

Obstruction replaced by riffle
Obstruction replaced by meanders
Bypass riffle established at preserved obstruction
Riffle established at preserved obstruction
Culverted reach opened to create free passage
Culvert falls evened out (drop manhole removed, etc.)
Greater water depth and/or current breakers in underpass culverts
Falls evened out at culvert outlet/bridge
Fish ladder/fish sluice established/removed
Formerly periodically “dried-up” stream reach completely restored
Formerly periodically “dried-up” stream reach partly restored
Water pumped into stream to maintain flow in periodically “dried-up” reach
Otter pass established
Other

Type 3: Rehabilitation of river valleys

Water table and flooding frequency increased by
– remeandering the watercourse
– raising the bed
– terminating drains in meadows
– establishing a dam
– meadow trickling
– narrowing the watercourse
Lakes/ponds/wetlands etc. re-established/established in the river valley
Vegetation management in the river valley
Other

unambiguous a manner as possible. Our proposal for a coming questionnaire is given in Appendix A.

Examples of methods

The methods encompassed by each type are those used to achieve the objective of that restoration project type. Examples of the individual methods are illustrated in Figures 4.2 to 4.19.

Type 1 encompasses methods used for making local improvements in watercourse reaches and the 2 metre cultivation-free border zones along their banks so as to provide better habitats for animals and plants (Figures 4.2 to 4.9).

Figure 4.2. *Remeandering of watercourse reaches* can serve several purposes, and is therefore included under all three rehabilitation project types. Under type 1, remeandering creates more varied habitats in the watercourse, among other things because of the resultant alternation between deep and shallow parts and weak and strong current. In addition, the current in meandering watercourses hinders sanding over of the gravel and stones.

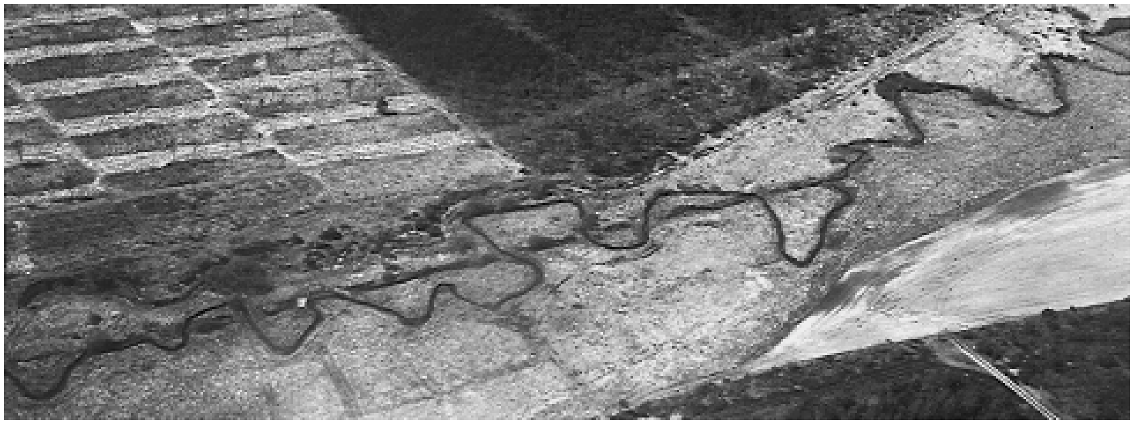


Figure 4.3. A *two-step cross-sectional profile* ensures an adequate water depth and current in dry periods.

Figure 4.4. *Stones* provide hiding places for fish and habitats for stream macroinvertebrates. They also improve habitat conditions by causing currents such that the water becomes oxygenated.

Figure 4.5. *Gravel banks* serve as spawning grounds for fish and as a habitat for stream macroinvertebrates.

Figure 4.6. Setting up *artificial hiding places for fish* was one of the original rehabilitation methods allowed under the Danish Watercourse Act, but is seldom used nowadays.

Figure 4.8. *Sand traps* reduce the transport of sand in watercourses.

Figure 4.7. *Current concentrators* – made, for example, by placing mounds of coarse gravel on alternate sides of the watercourse – ensure that the current is strong enough to keep the gravel banks free of sand.

Figure 4.9. *Trees and bushes planted within the 2 metre cultivation-free border zone* can stabilize the banks and create hiding places for fish. In other places, it can be an advantage to remove trees and bushes.

Type 2 encompasses the methods that restore free passage between watercourse reaches, thereby enabling the fauna to move freely between the different parts ofthe watercourse and between the watercourse and its immediate surroundings (Figures 4.10 to 4.16).

Figure 4.10. *Obstruction replaced by a riffle.*

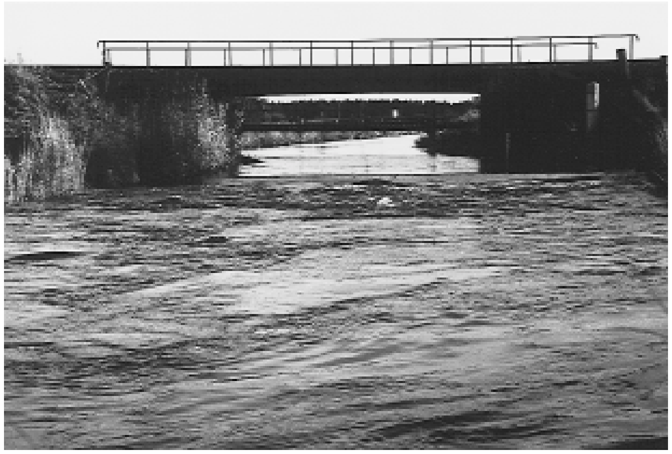


Figure 4.11. *Bypass riffle established at preserved obstruction.* In cases where one wants to preserve an obstruction, e.g. a hydroelectric power station or a historical water mill, but at the same time ensure free passage to the fauna, a solution can be a bypass riffle.

Figure 4.12. *Culverted reach opened*. If the primary objective is to restore free passage between two reaches, the method comes under type 2. However, if the primary objective is to create better habitats in the formerly culverted reach, then the project is classified as a type 1 project – even if it also restores free passage between two reaches. Thus one must always bear in mind the primary objective. If one is in doubt, one has to make a decision.

Figure 4.13. *Current breakers in underpass culverts.* In order to enable fish to pass through a culvert one can raise the stream water level and insert current breakers.

Figure 4.14. *Falls evened out at culvert outlet.* In cases where the outlet of a culvert, e.g. at a road underpass, is higher than the stream water level (left), one can establish a short riffle or lower the culvert to the level of the stream (right).

Figure 4.15. *Fish ladders* were one of the first Danish rehabilitation measures undertaken, but are now only used in cases of need, for example if there is insufficient space to establish a bypass reach. A watercourse reach can also be improved by removing a fish ladder and replacing it with a riffle or a bypass reach.

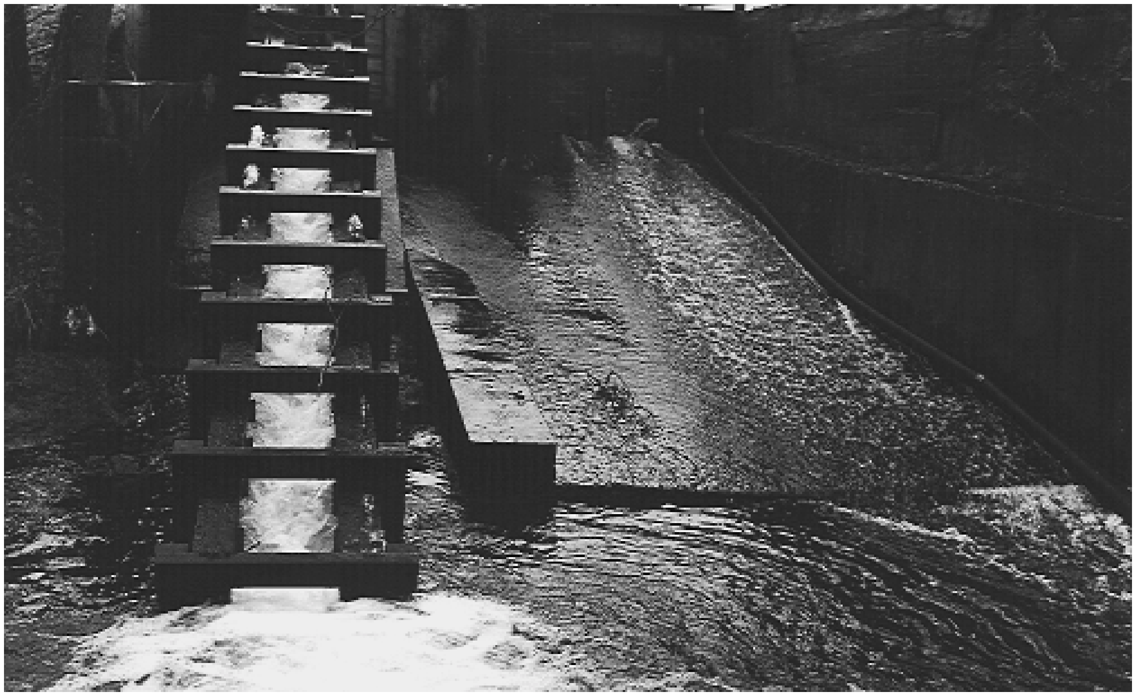


Figure 4.16. *Otter pass*. This is a type 2 rehabilitation method that helps otters to pass under bridges. Many otters are killed by vehicles in Denmark when trying to cross roads over streams.

Type 3 encompasses methods aimed at improving contact between the watercourse and its river valley through raising the water table in the meadows and ensuring that the watercourse can flood over into the meadows when the water level is high. A higher water table and more frequent flooding can be desirable, for example if one wants to reduce sediment transport or the stream water nitrogen or ochre content. The methods are generally the opposite of those used to drain the meadows in the past (Figures 4.17 to 4.19).

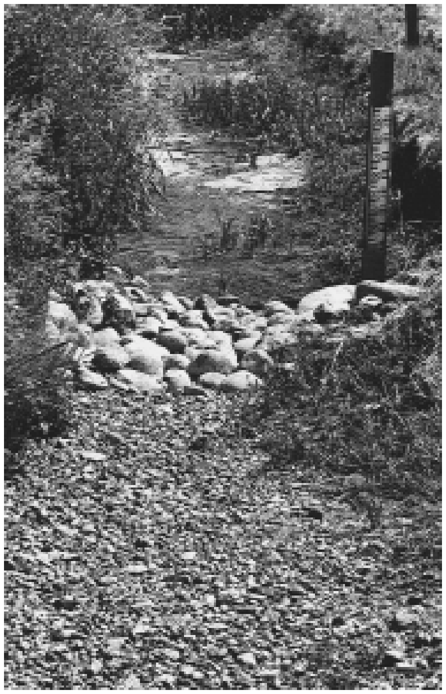


Figure 4.17. *Water table and flooding frequency increased by raising the bed*. One can also raise the water table and increase the frequency of flooding by raising the watercourse bed, for example by establishing high riffles (shown here during a dry summer).

Figure 4.18. *Water table and flooding frequency increased by remeandering the watercourse.* One can raise the water table and increase the frequency of flooding by remeandering the watercourse.

Figure 4.19. *Lakes, ponds and wetlands* can be established or re-established in the river valley, for example by excavation or by damming the watercourse.

5

Hans Ole Hansen
Brian Kronvang
Bent Lauge Madsen

Environmental impact of watercourse rehabilitation

In order to be able to assess whether the objective of a watercourse rehabilitation project has been attained, one has to investigate the project's impact on the watercourse and its immediate surroundings. The impact studies have to be designed according to both the project type and the objective. If the main objective of the rehabilitation project is to remove an obstruction between two watercourse reaches to restore free passage for fish and stream macroinvertebrates, one has to focus on investigating the impact of restoration on the upstream populations of migratory fish (e.g. trout) and macroinvertebrates. If the main objective of the project is to restore the riparian areas to their original condition, then one has to focus more generally on the impact on plants, animals and birds, as well as on retention and/or turnover of water, nutrients and organic matter in the riparian areas.

In connection with watercourse rehabilitation, one has also to bear in mind that aesthetic considerations and user interests are nearly always involved. Impact studies can therefore also involve user opinions as to the watercourse's appearance and utility value after rehabilitation.

To date, only few actual impact assessment studies have been undertaken as follow-ups to rehabilitation projects in Denmark. Some of these have been carried out as part of already existing watercourse pollution monitoring programmes, while others have been planned and carried out as direct follow-ups of the rehabilitation projects.

While the biological impact of rehabilitation of watercourse reaches often first becomes apparent after some time, the physical effects are normally easily demonstrable, for example in the form of a removed obstruction, new spawning grounds or a new meandering course with all its natural characteristics such as meander bends, riffles and periodically flooded riparian areas.

This section presents a small selection of each of the three main types of watercourse rehabilitation project described in Chapter 4. Although the selection focuses on the positive effects that rehabilitation can have on watercourse quality, the impact studies should naturally also encompass possible negative effects. Moreover, it is essential that one pays close attention to assessment criteria. For example, flooding can be assessed as positive from the viewpoint of water quality, but negative from the viewpoint of cultivation of the flooded fields. In the following, the impact of rehabilitation is mainly examined from the viewpoint of its impact on nature and the environment.

Type 1: Rehabilitation of watercourse reaches

Form and shape

The physical changes that have been made to Danish watercourses have had many negative effects on watercourse quality. Channelization, deepening and the lack of cultivation-free border zones alongside the watercourses have enhanced sediment input and led to the loss of the natural stone and gravel bed. This impoverishment of physical conditions has resulted in the loss of habitats, thereby critically affecting the survival of many plant and animal species. The path to recreation of the lost habitats in our watercourses is rehabilitation and a switch to more environmentally sound maintenance practices.

The amount of sediment input to our channelized watercourses in many cases exceeds the watercourse's capacity to transport the sediment away. This raises the watercourse bed, resulting in a uniform bed of migratory sand. In contrast, naturally meandering watercourses with dimensions appropriate to the volume of water draining from the catchment area are in dynamic equilibrium with respect to sediment input and transport. In addition, the watercourse will be much better able to adapt to a change in sediment input since both the pools and the periodically flooded riparian areas function as buffers in the form of sedimentation areas.

Rehabilitation in the form of remeandering of watercourse reaches and introduction of environmentally sound watercourse maintenance helps to recreate natural variation in watercourse form and shape. It endows the watercourse with varied current conditions and creates pools and riffles. The current will be slow in the shallow areas that form near the banks on the outer side of the meander bends, but rapid on the inner side of the meander bends and at the shallow riffles that form between them. Such physical variation is a characteristic of naturally meandering lowland watercourses. Thus instead of a watercourse with a roughly uniform depth and width, remeandering gives one with great physical variation. Among other places in Denmark, this has been documented for Gelså stream (1) (Figure 5.1 and Table 5.1). The project recreated a longer course, several meanders, riffles and spawning grounds, and increased the ecologically important area of the riparian zone subject to periodical flooding.

Existing experience with the monitoring of watercourse remeandering projects in Denmark indicates that considerable erosion takes place in the watercourse during the actual construction phase, as well as during a subsequent period of adjustment (Figure 5.2). However, much of the transported sand can be caught using a temporary sand trap established immediately downstream of the remeandered reach. In contrast, though, the fine particulate matter will more easily escape from the reach, thereby augmenting sediment transport in the water for a shorter or longer period. Experience with the remeandering of Gelså stream has thus shown that following a period of considerable erosion during the first winter, the watercourse entered a phase of net deposition, primarily near the banks and on the flooded riparian areas. Thus

	Before remeandering	After remeandering
Watercourse length	1,340 m	1,850 m
Discharge capacity	6.6 $m^3 s^{-1}$	3.5 $m^3 s^{-1}$
No. of meander bends	0	16
No. of spawning grounds	Few	18 (3,500 m^2)
Periodically wet riparian areas	0	approx. 2,000 m^2

Table 5.1. Physical conditions at Gelså stream before and after remeandering in 1989 (1).

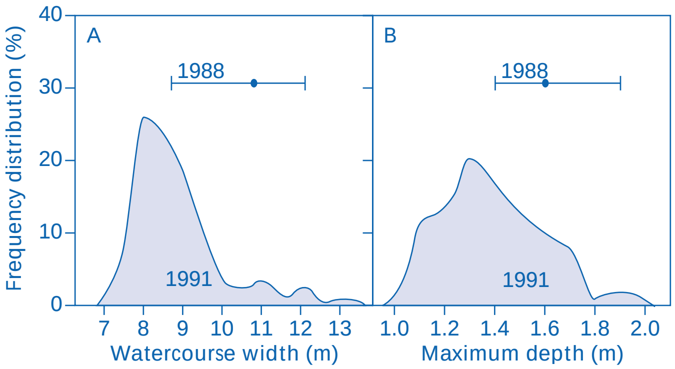


Figure 5.1. Variation in the width (A) and maximum depth (B) of Gelså stream before (1988) and after (1991) remeandering. Stream width varied from 9–12 metres in 1988, and from 7–14 metres in 1991. Stream maximum depth varied from 1.4–1.9 metres in 1988, and from 1–2 metres in 1991. Thus on average, the watercourse has become narrower and more shallow after remeandering, thereby increasing the possibility of flooding.

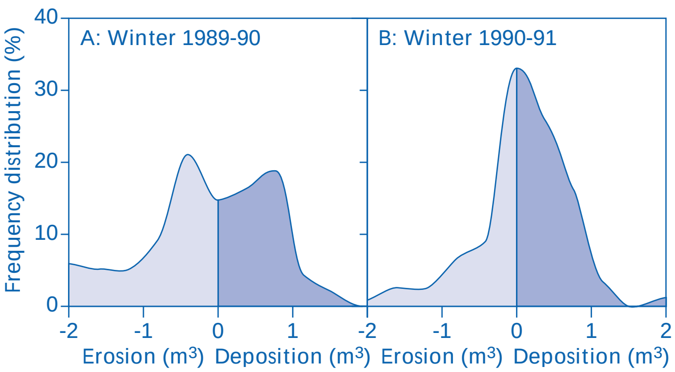


Figure 5.2. Erosion and deposition of bed material in Gelså stream during the first (A) and second (B) winter after remeandering. The figure is based on precision surveyance of 120 cross-sectional profiles.

two years after remeandering, dynamic equilibrium had not been reached (1).

Spawning possibilities for trout

Establishment of new spawning grounds for trout is one of the most common forms of rehabilitation in Danish watercourses. The grounds are often established simply by laying out gravel mixed with stones at regular intervals along watercourses.

In order to investigate the utility of new spawning grounds, it is not sufficient just to investigate whether trout spawn in them or whether they contain eggs in the spawning season. One has also to investigate how many fry hatch from the gravel the following year. In many cases, the majority of the eggs die before hatching because the gaps between the gravel particles silt up with sand, mud or ochre. Silting-up of spawning grounds can present a major problem in Danish watercourses. An example of this was seen in an experimental project in 1987, where spawning grounds were established in ten watercourses (2). Electrofishery the following spring revealed the presence of trout at only four of the spawning grounds, and after the first winter period, the majority of the new spawning grounds contained 5–20% more fine material (<2 mm) than when they were laid out the preceding autumn.

Larsen and Henriksen (3) have developed a method able to assess the condition of the eggs and the early stages of trout in spawning grounds. The eggs are placed in a net cage filled with gravel which is then buried in the spawning ground. Aftersome weeks or months, the cages are retrieved. Before retrieval, though, the cages are enclosed in a plastic “sock” to prevent material from being washed out. Experiments undertaken with the cages in watercourses revealed that the presence of very small amounts of fine material was sufficient to block the gaps between the gravel particles so much that a large part of the

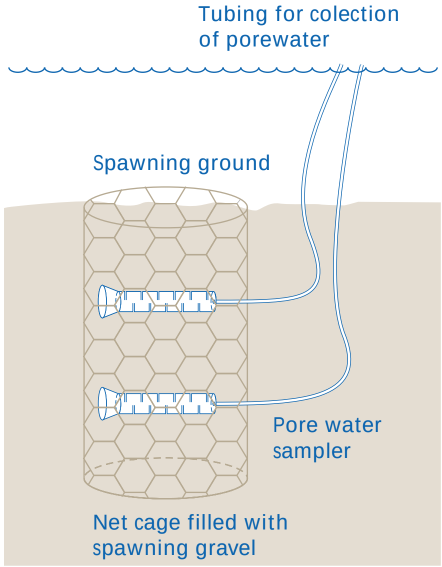


Figure 5.3. Diagram of the net cage placed in the spawning ground. Pore water samples are collected at a depth of 10 and 20 cm using porewater sampling probes connected to the surface by tubing.

eggs died of oxygen deficiency. It is therefore insufficient just to ensure a good current over the spawning ground since this will only keep the surface clean – material can still be forced down into the gaps in the gravel. Thus the transport of sand and other fine material over the spawning grounds has to be sufficiently low if spawning is to be successful.

Sivebæk and Bangsgaard (4) modified the “egg cage” by fitting it with two probes for the collection of porewater for the measurement of the oxygen concentration in the spawning gravel (Figure 5.3). They too found that the eggs died when the amount of fine particles exceeded a certain low level. Moreover, they found that a strong current did not help with the

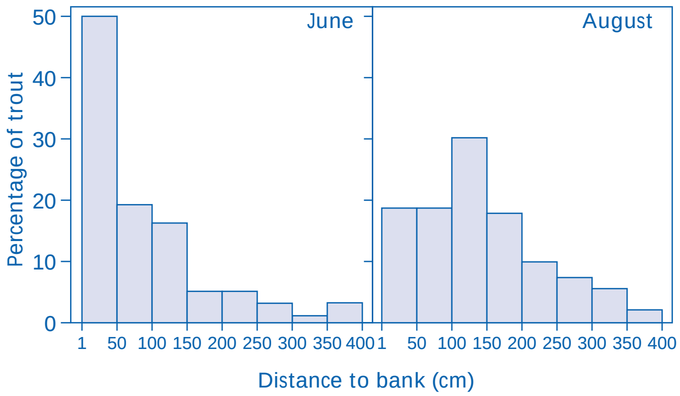


Figure 5.4. At first, the trout fry keep to the shallow water and weeds close to the bank (5).

problem as a current exceeding 80 cm s^{-1} can wash the eggs out of the spawning ground.

On the basis of these impact studies, it can be concluded that for spawning grounds to be able to function, transport of fine material has to be low. Thus in sediment-plagued watercourses, one has to take measures to deal with the source of the problem, as well as measures to reduce sediment transport. Examples include establishing paved watering places in parts of the watercourse where cattle trample down the banks, enforcing regulations concerning the Danish 2 metre cultivation-free border zone along watercourses, and switching to a weed clearance practice that protects the banks against erosion by the current. One can also reduce sediment transport over spawning grounds by establishing a sand trap. Sivebæk and Bangsgaard (4) have shown that trout eggs survive best in spawning grounds protected by a sand trap located immediately upstream.

Habitats for trout fry

Spawning grounds are not the only precondition for maintaining a satisfactory trout population. Suitable habitats have also to be available for the fry that hatch from the gravel. Mortality at this stage is very great. Numerous studies from Denmark and abroad show that the number of hiding places (in particular weed) and an appropriate low water depth and current are decisive determinants of the survival rate of the young trout (5). The best way to ensure good conditions for newly hatched fry is therefore to ensure that the watercourse fulfils these conditions (Figure 5.4).

The final proof of successful spawning is the development of a satisfactory population of salmonids in those watercourses where stocking is not undertaken. In Ribe County, the watercourse quality objective salmonid spawning and nursery waters is being fulfilled by an increasing number of watercourses (Figure 5.5) (6).

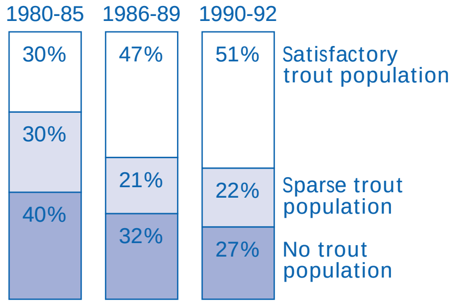


Figure 5.5. Trout abundance in watercourses designated as salmonid spawning and nursery waters in Ribe County (6).

Much remains to be achieved before all watercourses fulfil the quality objectives, though.

Habitats for trout

Bypass riffles around preserved obstructions not only permit free passage for fish and stream macroinvertebrates, but may also provide good habitats for trout. Investigations of the trout population in newly established riffles and bypass reaches in Vejle County show that there is often a markedly larger population in riffles and bypass reaches than in the upstream and downstream reaches (7). The reason is probably better physical conditions in the form of hiding places and current breakers, as well as the fact that the stones laid out ensure a good food resource with a rich population of macroinvertebrates.

When Idom stream was remeandered (see Chapter 3.5) the trout population in the remeandered reach three years after remeandering was just as large as in an unregulated downstream reference reach, which already had a satisfactory trout population. However, remeandering *per se* does not necessarily mean the sudden availability of better habitats for trout compared with those in a channelized reach. Good habitats can also be created in the channelized reach by switching to more environmentally sound maintenance practice. Thus during the same period, the trout population of an upstream still channelized reach of Idom stream also increased markedly, and in the first years was actually greater than in the newly remeandered reach. The reason for this is that good habitats rapidly developed in the regulated reach as a result of the cessation of weed clearance, while in the newly excavated remeandered reach, the weeds first needed time to become established.

When assessing the impact of remeandering, one has to take into account the fact that the remeandered reach is longer that the channelized reach it replaced. There is therefore actually room for many more habitats, and hence a greater number of trout. In the case of Idom stream, the new reach was twice as long as the former channelized reach.

Habitats for stream macroinvertebrates

The laying out of stones and gravel in watercourses not only benefits the fish, but also provides new habitats for the macroinvertebrates that inhabit such a substratum. In Aarhus County, a marked increase has been registered in the so-called “stone fauna” in watercourses where stones and gravel have been laid out. The same has been seen in cases where changed weed clearance practice keeps the bed free of mud and sand.

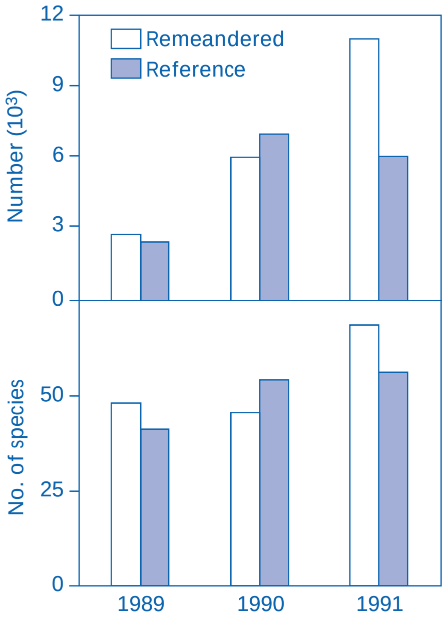


Figure 5.6. Macroinvertebrate abundance and species number in the remeandered and reference reaches of Gelså stream (1).

In the period before and after the remeandering of Gelså stream in 1989, the macroinvertebrate fauna was monitored in both the remeandered reach and in an upstream still channelized reach (1). The year following remeandering, the macroinvertebrate fauna was impoverished in the remeandered reach compared with the reference reach (Figure 5.6). This was probably because of the unstablemorphological conditions discussed above. By 1991, however, both macroinvertebrate density and species number had increased considerably in the remeandered reach as compared with the reference reach.

Remeandering watercourses enhances the variation in current and water depth and increases bank area. This creates habitats for a more varied and abundant macroinvertebrate fauna. Thus while the number of macroinvertebrate species in the two reaches of Gelså stream was almost equal prior to remeandering, there were 30% more species in the remeandered reach after two years (1).

The population of stone fauna such as *Heptagenia sulphurea* also increased markedly in the remeandered reach of Gelså stream relative to the more unstable and sandy reference reach (8). Moreover, a marked increase in the number of macroinvertebrates inhabiting stable beds was also seen within a year of remeandering a reach of the river Brede.

The increased abundance of macroinvertebrates in Gelså stream and the river Brede following remeandering is also partly attributable to a change in the composition of the vegetation. Thus species such as the bur reed (*Sparganium emersum*), which thrive on a soft bed with a weak current, are being replaced by species such as the water starwort (*Callitriche* sp.) and water crowfoot (*Batrachium* sp.). The latter species provide good habitats for many different macroinvertebrates, whereas the filamentous leaves of the bur reed almost only provide a suitable habitat for the buffalo gnat.

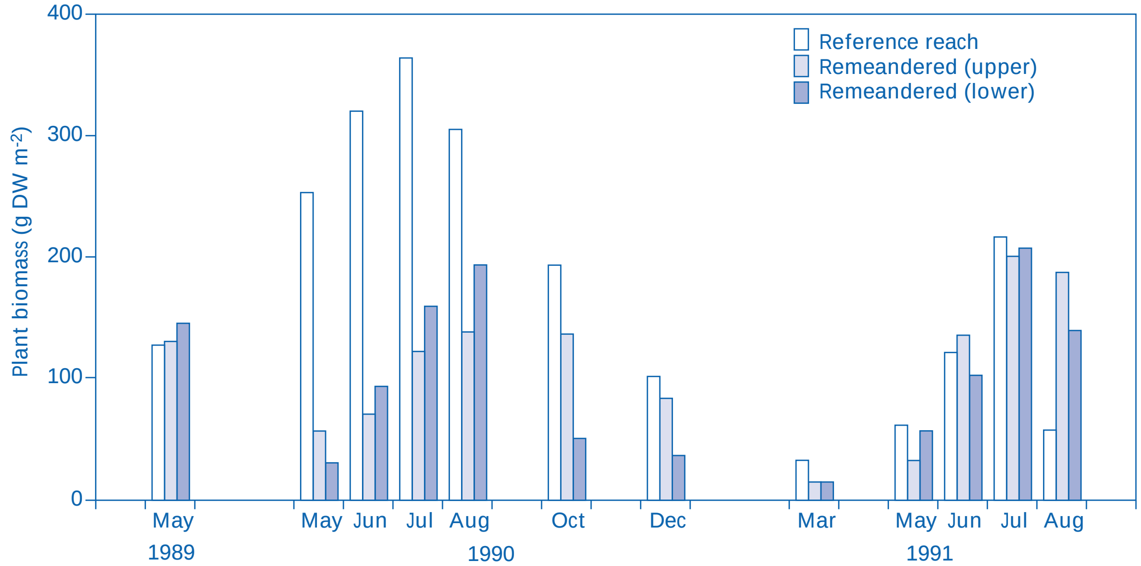


Figure 5.7. Aquatic macrophyte biomass in the reference reach and the lower and upper parts of the remeandered reach of Gelså stream (1).

Effects on the plant community

After a watercourse has been remeandered, it takes some time before the new vegetation in the watercourse achieves the same coverage as prior to remeandering. In Gelså stream, it took two years for aquatic macrophyte biomass to reach the level in the reference reach (Figure 5.7). In Idom stream, it took up to three years before vegetation coverage reached a level corresponding to that in the reaches that were not remeandered.

Monitoring of Gelså stream following remeandering in 1989 also shows that after two years, a more diverse plant community had developed in the remeandered reach that was comprised of 30 species, as compared with 22 species in the upstream channelized reference reach (1). The increase in species diversity is primarily attributable to species of terrestrial vegetation and species known to be frequent in the seed bank, and which easily germinate on the temporarily vegetation-free banks, e.g. *Juncus articulatus*, *J. bufonius*, *Rumex obtusifolius*, *Ranunculus sceleratus* and *Carex pseudocyperus*.

Compared with conditions in the stream prior to rehabilitation and those in the reference reach, the plant community on the riparian areas changed from one dominated by herbaceous plants to one dominated by grasses. The latter benefit from the new riparian areas that flood during the winter and the slower current in the newly created zones near the banks. Because of Gelså stream's new meanders with the great variation in current conditions, habitats have become available both for species that prefer flowing water, and as for marsh plants as well as for species that normally grow in more dry areas.

Type 2: Restoration of continuity between watercourse reaches

Passage for migratory fish

The investigations undertaken by Vejle County of the fish populations in newly established riffles and bypass reaches have shown that fish are even able to pass steep riffles of up to 20–30‰, provided that they are able to find shelter from the current behind stones and the suchlike (7). Moreover, it is not just strong swimmers such as trout that are able to pass, but also weaker swimmers such as theroach. In order to be on the safe side, however, such bypass riffles should not slope more than 10‰. This provides the best conditions for passage and the relatively flat riffle provides better habitats and possibilities for spawning. That many other fish than trout are able to pass a correctly constructed bypass riffle is demonstrated by investigations of the river Storå bypass riffle at Holstebro, which has an average slope of 10‰ (9) (Table 5.2).

On the other hand, investigations have shown that it is usually only the strongest swimmers such as salmon and trout that are able to pass through fish ladders, whereas weak swimmers such as the salmonid fish the lavaret are not quite able to do so. The selective effect of fish ladders with respect to various fish species is one of the reasons why we in Denmark prefer to establish riffles and bypass reaches rather than fish ladders. Another reason is that fish ladders require considerable supervision and maintenance as they can easily be blocked by branches,

Table 5.2. Number of fish that passed the bypass riffle in the river Storå at Holstebro over a 90-day period during the second half of 1991 (9).

Species	No.
Bream	536
Dace	146
Eel	63
Flounder	28
Grayling	21
Gudgeon	8
Lavaret	4,695
Perch	108
Pike	41
Rainbow trout	2
River lamprey	3
Roach	436
Ruffe	63
Salmon	8
Sea lamprey	5
Sea trout	3
Tench	2
Trout	4
Total	6,174

etc. On the other hand, though, it can still be necessary to establish fish ladders if there is insufficient space to establish a riffle or a bypass reach.

Culverts often act as an obstruction to migratory fish. However, there is an example from Vejle County of trout being able to pass a culvert providing the current is not too great (10). The investigation was carried out in Truds stream, where the stream runs through a 68 metre long culvert under a motorway. The slope in the culvert was so great and the current so strong that sea trout migrating upstream to spawn were stopped at the culvert outlet. They were unable to swim through the culvert and had therefore to lay their eggs downstream of the culvert. As a result, the spawning grounds became so overfull of eggs that only a small percentage survived. The reach downstream of the culvert thus had insufficient carrying capacity for all the trout that migrated up to spawn. The County solved the problem by damming up the water in the culvert by means of a simple dam that could easily be passed by the trout. This changed the current conditions so much that the trout were once again able to swim through the culvert. In the subsequent spawning season, the spawning grounds upstream of the culvert were also utilized, and over-utilization of the downstream spawning grounds ceased. As a result, considerably more eggs and fry survived, the carrying capacity of the stream having been better utilized (Figure 5.8).

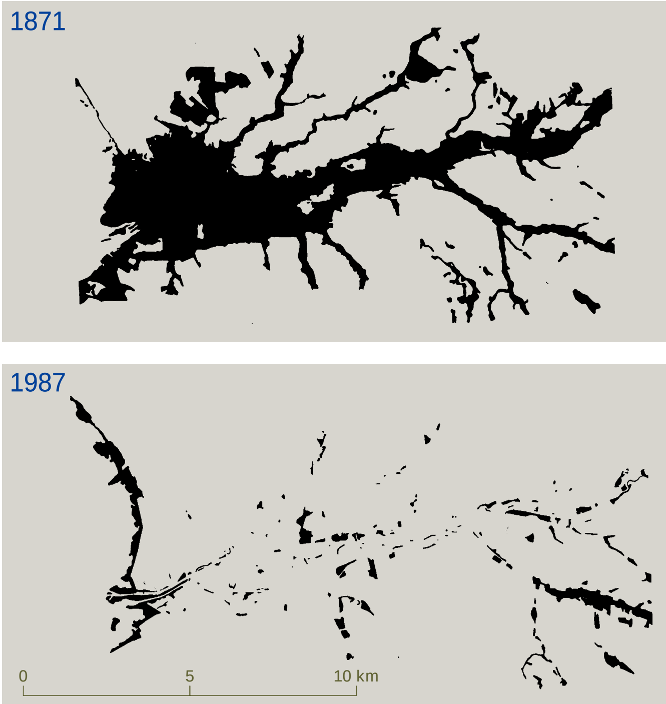


Figure 5.9. Meadows and marshland in the lower part of the Skjern river system in 1871 and 1987. Major drainage in the 1960s transformed approx. 4,000 ha of meadow and marshland to arable land.

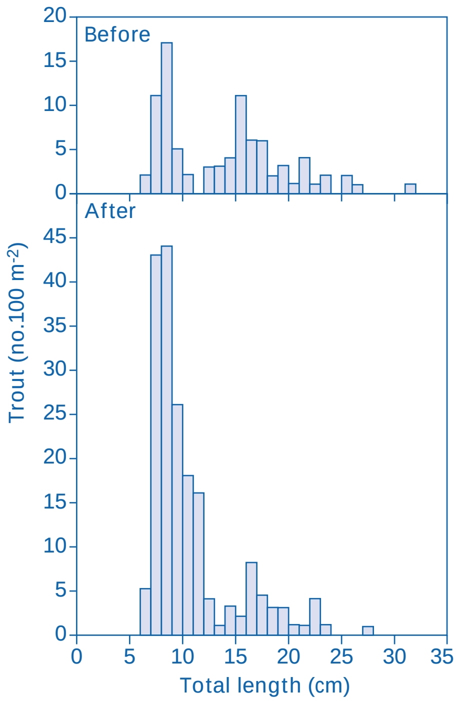


Figure 5.8. Number and size distribution of trout in Truds stream before and after passage was opened to additional upstream spawning grounds (10).

Type 3: Rehabilitation of river valleys

The objective of former channelization of watercourses was to lower the water table in the riparian areas in order that they could be cultivated. In addition to Denmark having lost much of its wetlands (Figure 5.9), channelization has also had a negative effect on the quality of the water and its content of nitrogen and iron compounds. We now know that riparian areas posses a natural potential for removing nitrate-nitrogen by denitrification (11). This removal capacity is lost or reduced when the meadows are no longer flooded, and instead the nitrogen is transported by the watercourse directly to lakes and the sea. Moreover, in cases where lowering the water table exposes iron-rich soils to the air, ochre loading will increase.

As a consequence of the lower groundwater table in riparian areas following watercourse channelization and deepening, the organic matter deposited as peat becomes exposed to air and starts to decompose. Over the years, this has led the ground level to sink in many riparian areas with peaty soil. Extreme cases have been recorded where the ground level has fallen 1–2 metres during a relatively short period of 20–30 years.

Decomposition of the peat results in the release of large amounts of nitrogen and phosphorus. Moreover, in areas with pyrite deposits large amounts of dissolved iron are also released which precipitates out in the watercourses as ochre.

When one rehabilitates the watercourse by raising the water table again and enabling the watercourse to flood its meadows, one to a greater or lesser extent recreates the original conditions. Close contact is then restored between the watercourse and its river valley.

Effects on nutrient and organic matter turnover and retention

Greater hydrological contact between a watercourse and its river valley leads to improvements in biological conditions and watercourse quality, but also plays animportant role with regard to the capacity of the system to even out water and sediment input, especially under conditions of extreme precipitation and runoff. Better hydrological contact with the possibility to flood the riparian areas during periods of high discharge can increase the retention time of the water, thereby limiting extreme discharge events. This helps reduce the risk of flooding further downstream, where the riparian areas are often lower-lying. In addition, flooding results in considerable retention and deposition of sediment in the river valley (Table 5.3) (12).

Rehabilitation projects involving raising the water level in the watercourse and increasing the frequency of flooding reduce the nitrogen loading problem because of the natural capacity of wet riparian areas to remove nitrate-nitrogen by denitrification (11) (Table 5.4). Such rehabilitation projects also raise the groundwater table in the adjacent riparian areas, as was the case when Gelså stream in southern Jutland was remeandered. Raising the watercourse bed and reducing its cross-sectional area increased the water depth in the stream and the groundwater table in the adjacent riparian areas, thereby restoring the anoxic conditions necessary for denitrification in the peat layer. This was expected to eventually reduce diffuse nitrate loading of the stream. During excavation work in summer 1989, though, nitrate loading of the rehabilitated reach exceeded that of the upstream channelized reaches. However, measurements made the following two summers gave the opposite result, annual nitrogen loading having fallen by approx. 80 kg nitrate-nitrogen per hectare wetland in the river valley. The expected reduction in nitrate loading of the remeandered reach thus materialized.

River valley and wetland type:	Turnover of nitrate-N ($kg\ ha^{-1}\ yr^{-1}$)
Stevns stream (wet meadow)	57
Rabis brook (wet meadow)	98
Voldby brook (meadow)	140
Voldby brook (bog)	875
Søbyvad stream (wet meadow)	590
Gjern stream (wet meadow)	42

Table 5.4. Turnover of nitrate-nitrogen in wet and water-logged meadows and bogs alongside selected Danish watercourses (11).

Table 5.3. Mean accumulation rate of sediment and total phosphorus at approx. 5,000 m^2 of temporarily flooded meadow land in the lower part of Gjern stream during three flooding events in winter 1992-93 (12).

Period	No. of days	Accumulated sediment ($kg\ m^{-2}$)	Accumulated phosphorus ($g\ P\ m^{-2}$)
24 Nov - 2 Dec 1992	8	0.26	1.18
11 Jan - 20 Jan 1993	9	1.21	3.78
21 Jan - 9 Feb 1993	19	3.02	6.54

Rehabilitation projects that lead to more frequent flooding of riparian areas also have other positive effects. Thus large amounts of phosphorus can sediment out on the riparian areas together with fine particulate matter during flooding. This has been demonstrated in the Gjern river valley, where up to 50 kg phosphorus sedimented out on 0.5 ha flooded meadow over a winter period encompassing 6–7 flood events.

In connection with the remeandering of Rind stream, Ringkjøbing County showed that effective ochre removal could be obtained by letting the stream water flow over the meadow during the winter period (see Chapter 3.6). The stream has been dimensioned such that the surrounding meadows flood at the normal winter discharge in the stream. It is also at this time that leaching of ochre from the catchment is greatest. A number of shallow basins with a grass bed have been made on the meadow. The dissolved and particulate iron in the stream water precipitates out in the basins such that the water leaving the meadow is considerably cleaner than that entering the meadow.

There are also risks associated with restoring former cultivated riparian areas to wetlands, however. Thus in cases where the amount of nitrate-nitrogen that has to be denitrified in the riparian areas exceeds the natural production of organic matter, there is the risk that phosphorus and dissolved iron will be released from the former arable soil when anoxic conditions are restored.

Effects on the river valley flora

A higher water table can be demonstrated by, among other things, investigating the plant community in the river valley. When the Gelså river valley was mapped out prior to remeandering in 1989, eight areas were found with *Glyceria maxima*, which is one of the plant species indicative of areas where groundwater seeps to the surface. In 1992, *Glyceria maxima* was found in 10 areas and in larger quantities than in 1989. Its growing presence thus indicates a general rise in the groundwater table in the river valley.

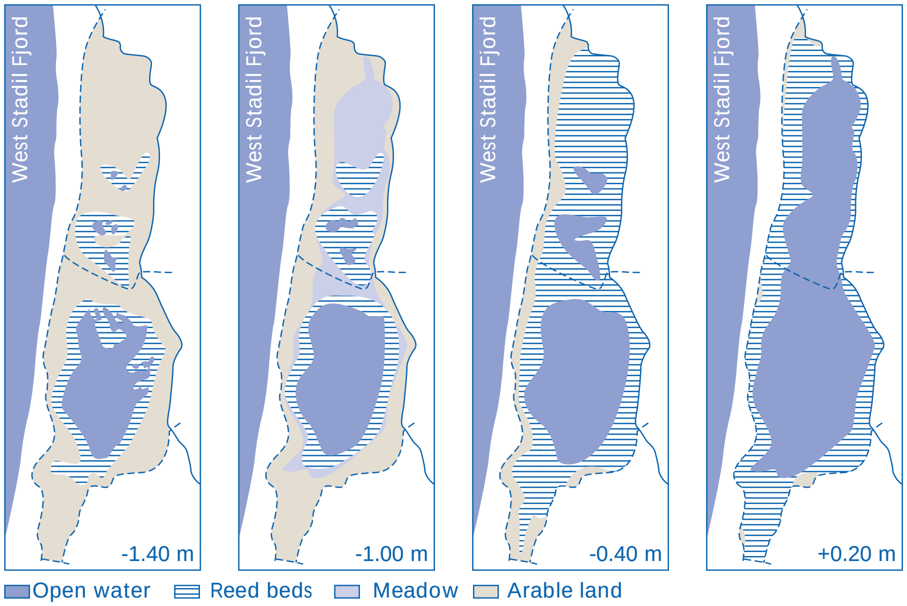
Already before fixing the new path in watercourse remeandering projects, one needs to decide whether or not the former path of the watercourse should be followed exactly. During the time that the watercourse has been channelized, valuable new habitats might have arisen that have potential as future dispersal areas. One therefore needs to assess whether it is possible to preserve them, or whether they can be re-established in the river valley following completion of excavation work. The removal of important habitats cannot always be avoided, however. When Gelså stream was remeandered, the new course followed many of the former meanders. The majority of these were inhabited by more plant species than was average for the river valley, especially wetland species (1). Nevertheless, despite the removal of several wetland communities a more characteristic wetland vegetation had established itself in the river valley already within two years of remeandering.

Effects on the river valley fauna

When a dry meadow is transformed to a wetland, conditions for the fauna will change. Which species will dominate depends on how the area develops. This can be illustrated by an example from West Stadil Fjord (14), a partly reclaimed low-lying wetland area adjacent to Stadil Fjord. Even though it is not a watercourse, the example illustrates the general possibilities for changing habitat conditions for fauna.

The expected impact on this drained wetland ecosystem of four alternative water table levels is illustrated in Figure 5.10. In the first alternative, the water table is unchanged relative to the current drained level, and is nearly 1.5 metre below sea level. This provides good possibilities for agriculture and good conditions for the many thousand geese that rest here each spring and autumn. In the second alternative with a higher water table, many of the fields will be too wet to be cultivated. The geese will still be able to thrive and conditions will improve for ducks and wading birds. In the third alternative with an even higher water table, reed beds will spread and the agricultural areas and the meadows will almost disappear. Wading birds and geese will loose their feeding grounds but on the other hand, good habitats will arise for bitterns and other birds that inhabit reed beds. All three alternatives require continued pumping of water out of the area. In the final alternative, in which pumping is ceased completely, the water table is 0.2 metre above sea level and a lake forms surrounded by reed beds. The area's most important function is as a stopover for birds on the open surface of the water.

Figure 5.10. Distribution of ecosystem types in West Stadil Fjord at four different water levels relative to sea level: Unchanged - 1.4 m, -1.0 m, -0.4 m and +0.2 m (corresponding to the level in Stadil Fjord) (14).



The need for impact assessment studies

With most types of rehabilitation project, it is necessary to undertake a certain minimum amount of monitoring as a form of documentation to the general public and to benefit the planning of future projects. Such a basic programme will usually make use of the existing environmental monitoring programme, perhaps with additional supplementary measurements. Surveys of the benthic macroinvertebrate and/or fish fauna will in most cases be sufficient to provide the necessary documentation.

The examples of impact assessment studies that are presented in this book are from several points of view insufficient to allow evaluation of the value to nature and the environment of the rehabilitation projects undertaken in Denmark. On the other hand, there are also many results that unambiguously indicate that the types of rehabilitation project currently being undertaken live up to expectations.

Our knowledge of the impact of type 1 projects i.e. those designed to rehabilitate watercourse reaches by remeandering, constructing a two-step cross-sectional profile, opening culverted reaches, establishing spawning grounds for salmonids, etc., is in some respects insufficient. While there is no doubt that we are now able to establish good spawning grounds that are in fact utilized by trout, they often become silted over with sand or finer material because of excessive sediment input to the watercourse from the surroundings. Establishment of spawning grounds should therefore be followed up by investigations of whether the eggs survive, hatch and produce adult trout.

With regard to major changes to the path or form of watercourses, considerable knowledge has been accumulated in Denmark through integrated physical, chemical and biological investigations in selected projects. We thus know that projects of this type create greater physical and hence biological diversity. Our knowledge is nevertheless still insufficient because the investigations have usually only been undertaken over a short period after completion of rehabilitation. Thus the impact assessment studies are usually undertaken during the period when the watercourse is still being colonized by flora and fauna, and when physical adjustments are still taking place in the direction of dynamic equilibrium. Ideally, one should therefore repeat the studies after a couple of years.

The results of the studies undertaken at Idom stream indicate that an optimal trout population can become established within three years of a reach being remeandered (see Chapter 3.5). With regard to macroinvertebrates, there are other examples of the very rapid establish-

Rehabilitation project effects	Physical effects	Chemical effects	Fish	Macroinverte-brates/insects	Plants	Birds	Other animals	Recreative uses
Type 1: Rehabilitation of watercourse reaches	+	++	+	+	+	0	0	++
Type 2: Restoration of continuity between watercourse reaches	0	0	+	+	0	0	+	++
Type 3: Rehabilitation of river valleys	++	+++	-	+++	++	++	+++	+++

0: No effect likely.
+: Knowledge exists or is forthcoming, but the element should be included in basic impact monitoring studies.
++: Only partial knowledge is available, and the element should be included in new impact monitoring studies.
+++: No knowledge is available, and the element should be included in selected projects.

Table 5.5. Areas and topics for which knowledge of the impact of the various types of rehabilitation project in Denmark is lacking.

ment of a fauna appropriate to the habitat conditions pertaining. Thus if stones are laid out, they will be rapidly colonized by macroinvertebrates that prefer stony substrata. A precondition, though, is that there is a population nearby. This occurs most rapidly when the macroinvertebrates are present in upstream or downstream reaches, although stream insects can also fly in from other watercourses.

The type of rehabilitation projects about which we know most are the type 2 projects, which aim to restore free passage between watercourse reaches. An example is modern fish passes, which are constructed in the form of riffles or bypass reaches. In this case, impact assessment studies have shown that fish really can pass them. However, even if fish and macroinvertebrates can pass the former obstructions, the biological objective of removing the obstruction is not fulfilled if upstream habitat conditions are unsuitable for them, or if they are unable to wander freely in the upstream reaches.

The type 3 rehabilitation projects, which aim to rehabilitate the riparian areas (the river valley), are those about which we know least. At the same time, they are often the projects whose impact is most difficult and costly to assess. Moreover, it can take many years for such projects to take effect fully. Some impact assessment projects have been initiated in Denmark in connection with the rehabilitation of riparian areas. Examples are the remeandering of the river Brede in southern Jutland and the remeandering of the upper reach of the river Gudenå (15). The results of these studies will first be available in the coming years.

In the future, there is a particular need to collect experiences from suitable rehabilitation projects that can supplement already existing knowledge – not only from Denmark, but also from the rest of Europe. This applies both to methods and to geographical conditions.

With respect to the Danish projects aimed at rehabilitating riparian areas, experience is in most cases lacking as to both the hydrological effects and the effects on the turnover, retention and possible release of nutrients, iron, sulphate, etc. In addition, studies of their impact on animals and plants are also lacking, as are studies of the utility value of the projects. In the coming years, it is therefore necessary to establish further large-scale demonstration projects encompassing integrated monitoring.

When planning impact assessment studies, one has to differentiate between areas where knowledge is presently insufficient, and areas where it is considered that sufficient information is available to be able to assess the value and possible risks of rehabilitation projects. Where knowledge is lacking or inadequate, detailed studies of the topic should be undertaken in connection with general monitoring in a few specially selected projects. In the case of areas wheresufficient knowledge is already available, a basic monitoring programme can be undertaken as a natural part of normal watercourse supervision. In Table 5.5, we have attempted to summarize the areas and topics where Denmark currently lacks knowledge of the impact of the various types of rehabilitation project.

References to Chapter 5

1 *Kronvang, B., Græsbøll, P., Svendsen, L.M., Friberg, N., Hald, B., Kjellson, G., Nielsen, M.B., Petersen, B.D. & Ottosen, O. (1994):* Restoration of Gelså stream at Bevtoft – Environmental impact on the watercourse and riparian areas (in Danish). – Technical Report No. 110, National Environmental Research Institute. 87 pp.

2 *Græsbøll, P., Aub-Robinson, C. & Kronvang, B. (1988):* Establishment of spawning grounds in watercourses (in Danish). – Technical Report No. 22, Freshwater Laboratory, Danish Environmental Protection Agency. 75 pp.

3 *Larsen, K.H. & Henriksen, P.W. (1992):* Sand migration destroys trout eggs (in Danish). – Vand & Miljø **6**: 188-192.

4 *Sivebæk, F. & Bangsgaard, L. (1995):* Sediment on trout spawning grounds (in Danish). – Vand & Jord **6**: 258-261.

5 *Bangsgaard, L. & Sivebæk, F. (1996):* What habitats do trout fry prefer? (in Danish) – Vand & Jord **1**.

6 *Ejbye-Ernst, M. (1993):* Watercourse fish populations (in Danish). – Ribe County, Technical and Environmental Department. 39 pp.

7 *Bangsgaard, L. (1993):* Fish density in 14 riffles and bypasses in Vejle County (in Danish). – Vejle County Council. 41 pp.

8 *Friberg, N., Kronvang, B., Svendsen, L.M., Hansen, H.O. & Nielsen, M.B. (1994):* Restoration of a channelized reach of Gelså stream, Denmark: effects on the macro-invertebrate community. – Aquatic Conservation: Marine and Freshwater Ecosystems **4**: 289-296.

9 *Jørgensen, J. (1993):* Fish passage at Holstebro hydroelectric power station (in Danish). – Vand & Miljø **1**: 13- 17.

10 *Kristiansen, H.R. (1994):* Free passage for trout restored in Truds stream (in Danish). – Vand & Jord **2**: 77-79.

11 *Kronvang, B., Hoffmann, C.C., Iversen, T.M., Jensen, J.J., Larsen, S.E., Platou, S.W. & Skop, E. (1994):* Nitrogen loading of Limfjorden fjord (in Danish). – Tema-rapport No. 1, National Environmental Research Institute. 16 pp.

12 *Aub-Robinson, C., Falkum, Ø., Hansen, C.D., Svendsen, L.M. & Kronvang, B. (1996):* Retention of particulate matter and associated nutrients in aquatic macrophytes and on flooded riparian areas. – In: Kronvang, B., Sibbesen, E. & Svendsen, L.M. (eds.): Erosion and delivery, transport and fate of sediments and sediment-associated nutrients in watersheds. – Proceedings of a workshop, 9-12 October 1995, Silkeborg, Denmark. National Environmental Research Institute.

13 *Madsen, B.L. (1995): Danish Watercourses – Ten years with the new Watercourse Act:* Collected examples of maintenance and restoration. – Environmental News No. 11, Danish Environmental Protection Agency. 206 pp.

14 *Degn, H.J. (1990): We choose our nature ourselves (in Danish). – Vand & Miljø **4**:* 134-136.

15 *Hansen, H.O. (in press):* Remeandering of a Danish headwater stream: The river Gudenå demonstration project. – Internat. Verein. Limnol.

Appendix A

Suggestions for a questionnaire

When filling out the questionnaire, one should always bear in mind the primary objective of the rehabilitation project. Four levels need be considered:

- The first level describes the project **type**. Only one of the three types may be selected. Each type has its own questionnaire (Forms A.1, A.2 and A.3 are examples of how to fill out the questionnaires).
- The second level describes the **primary method**. Only one primary method shall be selected under each project type.
- The third level describes the **secondary methods**. Several secondary methods may be selected, but they should not be assigned any order of priority. Note that in some cases there are no secondary methods, but only a primary method.
- The fourth level describes the **elements** used in the rehabilitation project. Several elements may be selected, but they should not be assigned any order of priority. Note that in some cases there are elements but no secondary methods.

In the case of type 2 rehabilitation projects – **Restoration of continuity between watercourse reaches** – the project has to create free passage to at least 1 km of upstream watercourse to be considered a project. Thus if there are, for example, five obstructions over a 1 km reach, removal of one of the obstructions is not considered a rehabilitation project that should be included in the statistics until all five obstructions have been removed, and then only as one single project. In the above example, the project is not considered to have been completed until all the obstructions have been removed, not even if there is a delay of several years between the removal of the first and last falls. Similarly, the reopening of culverted reaches does not count as a rehabilitation project unless it creates free passage to at least 1 km of upstream watercourse.

In the following, three examples are given of how the questionnaire should be filled out. Note that we have not yet completed the final design of the questionnaires and the database.

Type 1 example (Form A.1): A reach of a watercourse passing through a forest is culverted. Prior to being culverted, the reach was inhabited by three rare species of caddis flies. It is wanted to recreate habitats for these three species by reopening the culverted reach. At the same time, the reach is to be remeandered along its original course. In addition, the fir trees that were planted along the watercourse after it had been culverted are to be removed and replaced with the natural vegetation of elm trees.

The rehabilitation project falls in under type 1 – Rehabilitation of watercourse reaches – since the main objective is to create habitats locally in the watercourse. Despite the fact that removal of the culvert also creates free passage between the downstream and upstream reaches that is not the main objective, and the project cannot be classified as a type 2 rehabilitation project.

As the main objective is to open the culvert, the primary method is therefore 52 – Culverted reach opened to create better habitats. Although remeandering of the reach is part of the project, it will not be undertaken without removal of the culvert and 51 – Reach remeandered is therefore a secondary method.

In addition, the project includes element 83 – Trees and bushes removed within the 2 metre cultivation-free border zone and element 82 – Trees and bushes planted within the 2 metre cultivation-free border zone.

In the database, the rehabilitation project is therefore recorded as 1/52/51/82–83, or as follows:

Project type	Primary method	Secondary methods	Elements
1	52	51	82
			83

Type 2 example (Form A.2): A reach of a watercourse is culverted. It is wanted to open the reach to enable trout to migrate to upstream spawning grounds. The reach is remeandered with a two-step cross-sectional profile. Stones and gravel beds are laid out and trees are planted along the banks.

As the main objective is to restore free passage, the project falls in under type 2 Restoration of continuity between watercourse reaches.

The primary method is 30 – Culverted reach opened to create free passage, while the secondary methods are 51 – Reach remeandered and 53 – Two-step cross-sectional profile created. The elements used in the project are 76 – Stones laid out, 77 – Gravel laid out and 82 – Trees and bushes planted within the 2 metre cultivation-free border zone.

In the database the rehabilitation project is therefore recorded as 2/30/51–53/76–77–82, or as follows:

Project type	Primary method	Secondary methods	Elements
2	30	51	76
		53	77
			82

Type 3 example (Form A.3): It is wanted to enable a watercourse to flood adjacent meadows in the hope of reducing the nitrogen content of the water. This is achieved by narrowing the watercourse and terminating the drains in the meadow rather than in the watercourse. In addition, a culverted reach of the watercourse is to be opened and a two metre high falls is to be replaced by a riffle of stones. Finally, a pond is to be established in the meadow and the water is to be led through an ochre sedimentation basin.

The main objective in this example is to enable the watercourse to flood the meadows, and the project thus involves the whole river valley. The rehabilitation project therefore falls in under type 3 – Rehabilitation of river valleys. That free passage is created between two watercourse reaches by reopening the culvert is a side benefit of the rehabilitation project.

The primary method is 6 – Water table and flooding frequency increased by narrowing the watercourse, while the secondary methods are 3 – Water table and flooding frequency increased by terminating drains in meadows, 8 – Lakes/ponds/wetlands etc. established in the river valley, 26 – Obstruction replaced by riffle, 30 – Culverted reach opened to create free passage and 56 – Ochre sedimentation basin established in connection with the watercourse. As the riffle was made of stones, the project involved element 76 – Stones laid out.

In the database, the rehabilitation project is therefore recorded as 3/6/3–8–26–30–56/76, or as follows:

Project type	Primary method	Secondary methods	Elements
3	6	3	76
		8	
		26	
		30	
		56	

Form A–1. Example of a type 1 rehabilitation project (see “Suggestions for a questionnaire” above).

Type 1: Rehabilitation of watercourse reaches

Watercourse:		Vridsted brook
Location (town/district):		Vridsted
Watercourse system:		River Karup
County/Municipality (code):		07/105
Coordinates:		56° 27´ N 9° 02´ E
Rehabilitation completed (year):		1995
Total cost (excl. VAT):		DKK 350,000
Length of rehabilitated reach (m):		750
Upstream catchment area (km^2):		21
Discharge in the rehabilitated reach (l/s):	Mean:	10
	Max:	16
	Min:	5

Primary method One cross	Secondary methods Several crosses	Elements Several crosses	No.	Description
			51	Reach remeandered
x			52	Culverted reach opened to create better habitats
			53	Two-step cross-sectional profile created
			54	Designated as a maintenance-free natural watercourse
			55	Lakes established/re-established in connection with the watercourse
			56	Ochre sedimentation basin established in connection with the watercourse
			57	Single measures
			58	
	x		51	Reach remeandered
			52	Culverted reach opened to create better habitats
			53	Two-step cross-sectional profile created
			54	Designated as a maintenance-free natural watercourse
			55	Lakes established/re-established in connection with the watercourse
			56	Ochre sedimentation basin established in connection with the watercourse
			57	---
			58	
			76	Stones laid out
			77	Gravel laid out
			78	Artificial fish hiding places established
			79	Other solid objects laid out
			80	Current concentrators established
			81	Sand trap constructed
		x	82	Trees and bushes planted within the 2 metre cultivation-free border zone
		x	83	Trees and bushes removed within the 2 metre cultivation-free border zone
			84	Artificial bed and/or bank established (fascines, concrete, paving slabs, etc.)
			85	Artificial bed and/or bank removed (fascines, concrete, paving slabs, etc.)
			86	

Form A–2. Example of a type 2 rehabilitation project (see "Suggestions for a questionnaire" above).

Type 2: Restoration of continuity between watercourse reaches

Watercourse:		Vester Bybæk brook
Location (town/district):		Slagelse
Watercourse system:		Tude stream
County/Municipality (code):		04/189
Coordinates:		55° 24´ N 11° 23´ E
Rehabilitation completed (year):		1995
Total cost (excl. VAT):		DKK 350,000
Length of rehabilitated reach (m):		325
Upstream catchment area (km²):		102
Discharge in the rehabilitated reach (l/s)	Mean:	35
	Max.:	70
	Min.:	19

Primary method One cross	Secondary methods Several crosses	Elements Several crosses	No.	
			26	Obstruction replaced by riffle
			27	Obstruction replaced by meanders
			28	Bypass riffle established at preserved obstruction
			29	Riffle established at preserved obstruction
x			30	Culverted reach opened to create free passage
			31	Culvert falls evened out (drop manhole removed, etc.)
			32	Greater water depth and/or current breakers in underpass culverts
			33	Falls evened out at culvert outlet/bridge
			34	Fish ladder/fish sluice established
			35	---
			36	Formerly periodically "dried-up" stream reach completely restored
			37	Formerly periodically "dried-up" stream reach partly restored
			38	Water pumped into watercourse to keep open "dried-up" reach
			39	---
			40	---
			41	

Primary method	Secondary methods	Elements	No.	
			26	Obstruction replaced by riffle
			27	Obstruction replaced by meanders
			28	Bypass riffle established at preserved obstruction
			29	Riffle established at preserved obstruction
			30	Culverted reach opened to create free passage
			31	Culvert falls evened out (drop manhole removed, etc.)
			32	Greater water depth and/or current breakers in underpass culverts
			33	Falls evened out at culvert outlet/bridge
			34	Fish ladder/fish sluice established
			35	Fish ladder/fish sluice removed
			36	Formerly periodically "dried-up" stream reach completely restored
			37	Formerly periodically "dried-up" stream reach partly restored

Type 2 – continued

Primary method One cross	Secondary methods Several crosses	Elements Several crosses	No.	Description
			38	Water pumped into watercourse to keep open “dried-up” reach
			39	Otter pass established
			40	Free passage established for other vertebrates
			41	
	x		51	Reach remeandered
			52	Culverted reach opened to create better habitats
	x		53	Two-step cross-sectional profile created
			54	Designated as a maintenance-free natural watercourse
			55	Lakes established/re-established in connection with the watercourse
			56	Ochre sedimentation basin established in connection with the watercourse
			57	---
			58	
			59	
		x	76	Stones laid out
		x	77	Gravel laid out
			78	Artificial fish hiding places established
			79	Other solid objects laid out
			80	Current concentrators established
			81	Sand trap constructed
		x	82	Trees and bushes planted within the 2 metre cultivation-free border zone
			83	Trees and bushes removed within the 2 metre cultivation-free border zone
			84	Artificial bed and/or bank established (fascines, concrete, paving slabs, etc.)
			85	Artificial bed and/or bank removed (fascines, concrete, paving slabs, etc.)
			86	
			87	

Form A–3. Example of a type 3 rehabilitation project (see “Suggestions for a questionnaire” above).

Type 3: Rehabilitation of river valleys

Watercourse:		Egebæk brook
Location (town/district):		Ringe
Watercourse system:		River Odense
County/Municipality (code):		02/094
Coordinates:		55° 14´ N 10° 30´ E
Rehabilitation completed (year):		1995
Total cost (excl. VAT):		DKK 350,000
Length of rehabilitated reach (m):		2500
Upstream catchment area (km^2):		135
Discharge in the rehabilitated reach (l/s)	Mean:	75
	Max:	105
	Min:	50

Primary method One cross	Secondary methods Several crosses	Elements Several crosses		
			1	Water table and flooding frequency increased by remeandering the watercourse
			2	Water table and flooding frequency increased by raising the bed
			3	Water table and flooding frequency increased by terminating drains in meadows
			4	Water table and flooding frequency increased by establishing a dam
			5	Water table and flooding frequency increased by meadow trickling
x			6	Water table and flooding frequency increased by narrowing the watercourse
			7	---
			8	---
			9	---
			10	
			11	
			1	Water table and flooding frequency increased by remeandering the waterurse
			2	Water table and flooding frequency increased by raising the bed
	x		3	Water table and flooding frequency increased by terminating drains in meadows
			4	Water table and flooding frequency increased by establishing a dam
			5	Water table and flooding frequency increased by meadow trickling
			6	Water table and flooding frequency increased by narrowing the watercourse
			7	Lakes/ponds/wetlands etc. re-established in the river valley
	x		8	Lakes/ponds/wetlands etc. established in the river valley
			9	Vegetation management in the river valley
			10	
			11	

Type 3 – continued

Primary method One cross	Secondary methods Several crosses	Elements Several crosses	No.	Description
	x		26	Obstruction replaced by riffle
			27	Obstruction replaced by meanders
			28	Bypass riffle established at preserved obstruction
			29	Riffle established at preserved obstruction
	x		30	Culverted reach opened to create free passage
			31	Culvert falls evened out (drop manhole removed, etc.)
			32	Greater water depth and/or current breakers in underpass culverts
			33	Falls evened out at culvert outlet/bridge
			34	---
			35	Fish ladder/fish sluice removed
			36	Formerly periodically "dried-up" stream reach completely restored
			37	Formerly periodically "dried-up" stream reach partly restored
			38	Water pumped into watercourse to keep open "dried-up" reach
			39	Otter pass established
			40	Free passage established for other vertebrates
			41	
			42	
			51	Reach remeandered
			52	Culverted reach opened to create better habitats
			53	Two-step cross-sectional profile created
			54	Designated as a maintenance-free natural watercourse
			55	Lakes established/re-established in connection with the watercourse
	x		56	Ochre sedimentation basin established in connection with the watercourse
			57	---
			58	
			59	
		x	76	Stones laid out
			77	Gravel laid out
			78	Artificial fish hiding places established
			79	Other solid objects laid out
			80	Current concentrators established
			81	Sand trap constructed
			82	Trees and bushes planted within the 2 metre cultivation-free border zone
			83	Trees and bushes removed within the 2 metre cultivation-free border zone
			84	Artificial bed and/or bank established (fascines, concrete, paving slabs, etc.)
			85	Artificial bed and/or bank removed (fascines, concrete, paving slabs, etc.)
			86	
			87	

References

Ansbæk, J., Jensen, F., Schultz, K.E. & Aagaard, P. (1981): The societal significance of watercourses (in Danish). – Freshwater Laboratory, Danish Environmental Protection Agency.

Aub-Robinson, C., Falkum, Ø., Hansen, C.D., Svendsen, L.M. & Kronvang, B. (1996): Retention of particulate matter and associated nutrients in aquatic macrophytes and on flooded riparian areas. – In: Kronvang, B., Sibbesen, E. & Svendsen, L.M. (eds.): Erosion and delivery, transport and fate of sediments and sediment-associated nutrients in watersheds. – Proceedings of a workshop, 9-12 October 1995, Silkeborg, Denmark. National Environmental Research Institute.

Bangsgaard, L. (1993): Fish density in 14 riffles and bypasses in Vejle County (in Danish). – Vejle County. 41 pp.

Bangsgaard, L. & Sivebæk, F. (1996): What habitats do trout fry prefer? (in Danish) – Vand & Jord **1**.

Brookes, A. (1984): Recommendations bearing on the sinuosity of Danish stream channels. – Technical Report No. 6, Freshwater Laboratory, Danish Environmental Protection Agency. 130 pp.

Degn, H.J. (1990): We choose our nature ourselves (in Danish). – Vand & Miljø **4**: 134-136.

Ejbye-Ernst, M. (1993): Watercourse fish populations (in Danish). – Ribe County, Technical and Environmental Department. 39 pp.

Friberg, N., Græsbøll, P. & Larsen, S.E. (in press): Causes of the generally poor state of smaller Danish watercourses (in Danish). – Environmental Project, Danish Environmental Protection Agency.

Friberg, N., Kronvang, B., Svendsen, L.M., Hansen, H.O. & Nielsen, M.B. (1994): Restoration of a channelized reach of Gelså stream, Denmark: effects on the macroinvertebrate community. – Aquatic Conservation: Marine and Freshwater Ecosystems **4**: 289-296.

Græsbøll, P., Aub-Robinson, C. & Kronvang, B. (1988): Establishment of spawning grounds in watercourses (in Danish). – Technical Report No. 22, Freshwater Laboratory, Danish Environmental Protection Agency. 75 pp.

Hansen, H.O. (in press): Remeandering of a Danish headwater stream: The river Gudenå demonstration project. – Internat. Verein. Limnol.

Hunt, R.L. (1992): Evaluation of trout habitat improvement structures in three high-gradient streams in Wisconsin. – Technical Bulletin No. 179, Department of Natural Resources, Madison. 210 pp.

Jørgensen, J. (1993): Fish passage at Holstebro hydroelectric power station (in Danish). – Vand & Miljø **1**: 13- 17.

Kristiansen, H.R. (1994): Free passage for trout restored in Truds stream (in Danish). – Vand & Jord **2**: 77-79.

Kronvang, B., Hoffmann, C.C., Iversen, T.M., Jensen, J.J., Larsen, S.E., Platou, S.W. & Skop, E. (1994): Nitrogen loading of Limfjorden fjord (in Danish). – Tema-rapport No. 1, National Environmental Research Institute. 16 pp.

Kronvang, B., Græsbøll, P., Svendsen, L.M., Friberg, N., Hald, B., Kjellson, G., Nielsen, M.B., Petersen, B.D. & Ottosen, O. (1994): Restoration of Gelså stream at Bevtoft – Environmental impact on the watercourse and riparian areas (in Danish). – Technical Report No. 110, National Environmental Research Institute. 87 pp.

Larsen, K.H. & Henriksen, P.W. (1992): Sand migration destroys trout eggs (in Danish). – Vand & Miljø **6**: 188-192.

Madsen, B.L. (1995): Danish Watercourses – Ten years with the new Watercourse Act: Collected examples of maintenance and restoration. – Environmental News No. 11, Danish Environmental Protection Agency. 206 pp.

Nielsen, J. (1994): Fish passage at obstructions in Danish streams. – Vejle County. 9 pp.

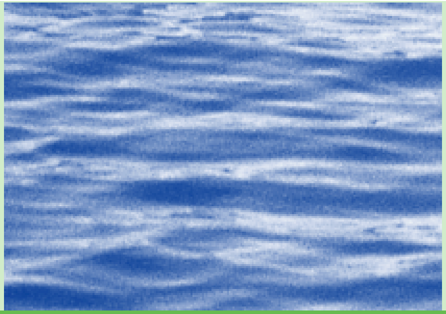
Nielsen, J. (1995): Fish requirements as to watercourse physical condition – A selection of existing knowledge (in Danish with English summary). – Environmental Project No. 293, Danish Environmental Protection Agency. 129 pp.

Osborne, L.L., Bayley, P.B. & Higler, L.W. (eds.) (1993): Lowland stream restoration: Theory and practice. – Freshwater Biology (special issue) **2**: 187-342.

Sivebæk, F. & Bangsgaard, L. (1995): Sediment on trout spawning grounds (in Danish). – Vand & Jord **6**: 258-261.

Thienemann, A. (1950): Die Verbreitungsgeschichte der Süsswassertierwelt Europas (in German). – Die Binnengewässer Band XVIII, Stuttgart.

Wiberg-Larsen, P., Petersen, S., Rugaard, T. & Geertz-Hansen, P. (1994): Better watercourse maintenance increases the number of fish (in Danish). – Vand & Jord **6**: 263-265.



Restoration of watercourses is currently attracting increasing attention throughout Europe, and considerable experience and know-how has been accumulated in Denmark over the last decade.

To benefit from this experience, the European Centre for River Restoration (ECRR) has recently been established at the National Environmental Research Institute in Silkeborg, Denmark.

The ECRR will eventually grow to encompass a network of relevant European institutions working with river restoration.

This handbook is the ECRR's first, and aims to provide an insight into Danish experience with watercourse and river valley management and restoration.

River Restoration – Danish experience and examples

Ministry of Environment and Energy

National Environmental Research Institute